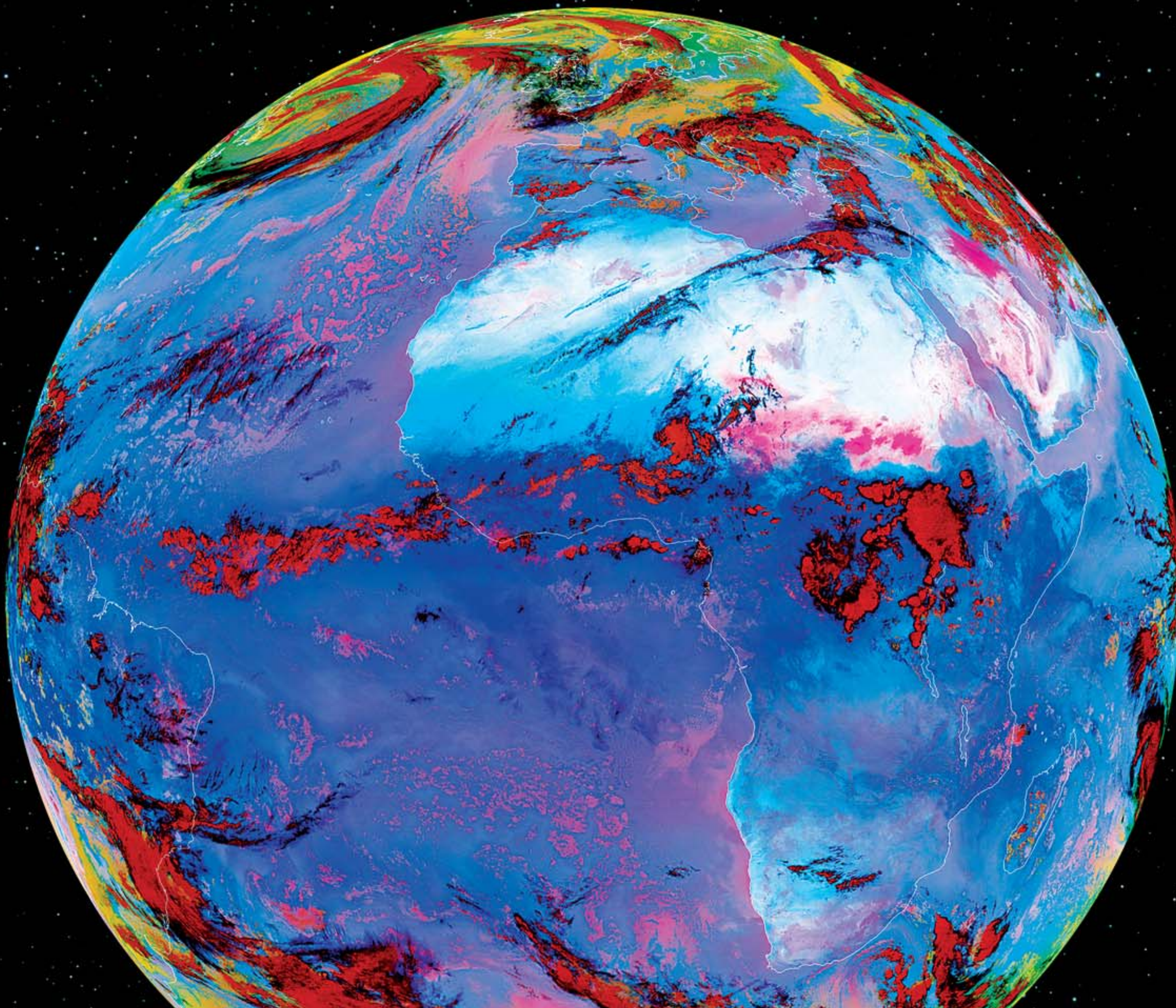
Climate Sense



World
Meteorological
Organization
Weather • Climate • Water

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WCC-3 - Climate sense
ISBN 978-92-63-11043-5

Tudor Rose

Published by Tudor Rose
www.tudor-rose.co.uk

Acknowledgements

Consulting Editor: Ghassem R. Asrar
Editorial Team: James Dodd, Rebecca Lambert, Adam Lawrence and Sean Townsend
Designed by Paul Robinson and Bruce Graham
Project Manager: Stuart Fairbrother

Cover design: Leigh Trowbridge
Cover image: Cover image shows large dust storms over Sudan, Lybia and the Middle East.

With thanks to all the authors listed in the contents section for their support in making *Climate Sense* possible.

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Foreword

MICHEL JARRAUD, SECRETARY-GENERAL, WMO
KOÏCHIRO MATSUURA, DIRECTOR-GENERAL, UNESCO

Over the past 30 years, significant progress has been made in observing, understanding and to some extent predicting the variability and changes in Earth's climate system. This progress was made possible by a remarkable international cooperation. Climate variability and change pose many major challenges, and the debate surrounding climate issues illustrates the difficulty of transforming knowledge into appropriate actions transcending beyond any single nation, as required to respond effectively to these challenges.

There is now an overwhelming consensus that human activities have been affecting the composition of Earth's atmosphere, significantly altering our environment. These changes, together with the natural variability of the climate system, are affecting every socioeconomic sector. Furthermore, it is anticipated that the frequency and intensity of a number of extreme events such as floods, droughts and heat waves are very likely to increase in the next decades. These changes and their effects will be felt at the global, regional and local levels, and they will impact water resources, global agriculture and food security, energy and transport systems, marine and terrestrial ecosystems and the services we derive from them — to give just a few examples.

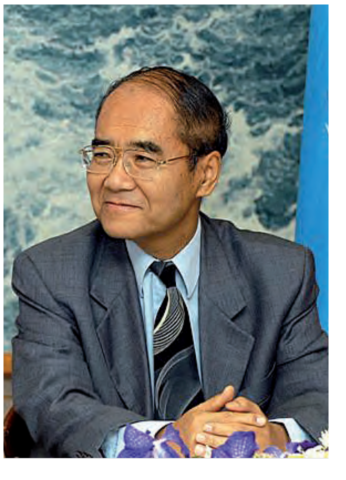
By bringing together perspectives from the various stakeholders, from fundamental science to customized services, at the international, regional, national and local levels, *Climate Sense* provides an invaluable view of the progress and challenges for responding to climate variability and change. The World Meteorological Organization (WMO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) are pleased to co-lead this collaborative effort to advance the climate observations, research and assessments necessary for informed decision- and policy-making by public authorities and civil society — and in this way improve world security and sustainability.

To translate the scientific understanding of climate system for policy-makers, nations have together established global observing and information systems, mandating their National Meteorological and Hydrological Services, as well as their marine and ocean institutions, to play a critical role in collecting relevant data and making this basic information available worldwide. As a result of such efforts climate research programmes like the WMO/UNESCO/International Council for Science (ICSU) co-sponsored World Climate Research Programme (WCRP), as well as intergovernmental bodies such as the Intergovernmental Panel on Climate Change (IPCC) — which was awarded the Nobel Peace Prize in 2007 — have come into existence. As part of the UN-wide effort to unify delivery on climate change, UNESCO and WMO have been given the responsibility to lead in the cross-cutting area of climate knowledge. These efforts have provided policy- and decision-makers with an up-to-date scientific understanding of climate variability and change.

The personal statements and papers presented in this publication, *Climate Sense*, convey the richness, the level of commitment, and the good will and cooperation that exist today to take on this multi-generational challenge and to respond to it most effectively.

The publishing of this unique book on the occasion of World Climate Conference-3 (WCC-3), from 31 August to 4 September 2009, serves as a reminder of the importance of climate adaptation as a necessary strategy to cope with climate variability and change. Organized by WMO, WCC-3 will create a global framework for climate services, providing society with the information and the tools for managing risks and seizing opportunities generated by the climate. Through its sharing of best practices across a variety of disciplines and sectors, *Climate Sense* is a unique resource for advancing the framework.

We thank Tudor Rose for publishing *Climate Sense*, and appreciate the work of all those who contributed to this publication.



Michel Jarraud, Secretary-General, WMO
Koïchiro Matsuura, Director-General, UNESCO

Preface

ALEXANDER BEDRITSKY, PRESIDENT OF WMO

Climate variability and change are posing unprecedented challenges to society. Every day, scientists are making discoveries that shed insight into the many and varied ways climate affects the Earth system and how that impacts people and economies.

Over the last three decades, the World Meteorological Organization (WMO) has mobilized the international community around the climate issue. It was WMO that in 1976 issued the first authoritative statement on the accumulation of carbon dioxide in the atmosphere and the potential impacts on Earth's climate. Since then, WMO and the National Meteorological and Hydrological Services (NMHSs) of its 188 Member States and Territories have built a foundation of observations, research and scientific assessment to understand climate variability and change.

There is now an urgent need to organize the global community to develop and disseminate the best-available climate information needed by the regions and sectors, globally. WMO and its Members are rising to this challenge, developing climate research and services to help policy-makers and decision-makers everywhere prepare for changes in climate and respond with actions informed by the best available science. Climate predictions at the seasonal to multi-decadal scale enable key socioeconomic sectors to plan ahead in the light of anticipated natural hazards and other weather-, water- and climate-driven phenomena. The ultimate goal is to strengthen interactions between climate information providers and users to develop climate services that advance socioeconomic development while ensuring hydrometeorological and environmental security around the world.

A climate information system is required to aid decision-makers in policy, infrastructure development and investment decisions. Such a system would be based on: reliable climate predictions over timescales of seasons to decades; tailored forecasts for regions and localities; integration of atmospheric, oceanic, terrestrial and social data into a comprehensive Earth System prediction; and decision-support interfaces that can be adjusted to provide user-specified scenarios.

The common goal of the global community for the new decade should be to have in place such a system that enables regional assessments that are well organized and based on the best scientific understanding and knowledge available at the time. Furthermore, the global community should aim to deliver the needed information to the network of regional and local experts, especially for the developing regions of the world. Such a system must build on the solid foundation of Earth observations, research and prediction, as well as the assessment capabilities that the global community has put in place during the past 30 years, but it must also be responsive to the needs of global and regional decision-makers.

Investing in a climate information system is the best way to ensure that our generation and future generations have the ability to manage the risks and realize the opportunities associated with climate variability and change. WMO continues to facilitate the exchange of climate knowledge not only among NMHSs but also with the broad international community as the UN System's leader in the field.

We thank Tudor Rose for providing an opportunity to highlight how WMO and its Members are working with decision-makers and experts across all disciplines to enhance climate services for protecting people's lives and livelihoods, and for improving the well-being of all.

Alexander Bedritsky, President of WMO

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SPECIAL MESSAGE FROM BAN KI-MOON, SECRETARY-GENERAL OF THE UNITED NATIONS

Climate change is one of the most serious challenges that humankind has ever faced. It affects every aspect of society, from the health of the global economy to the health of our children, from food security to international peace and security. We must act quickly, equitably and decisively to protect people and the planet. Without delay, we must reduce global greenhouse gas emissions and set our economy on a cleaner, more sustainable, low-carbon path.

Governments from around the world are working to address the climate challenge. Any agreements they reach must meet the 'scientific bottom line' — that is, what the world's scientists are telling us is necessary to avert catastrophe. They must be fair and effective in mitigating emissions. And they must increase assistance to vulnerable populations as they adapt to the inevitable impacts of a changing climate. Such help will be crucial in strengthening our ability to fight poverty and achieve the Millennium Development Goals.

Climate change is a global problem that requires global solutions and collaborative efforts that span disciplines and borders. By showcasing knowledge and promoting informed decision-making, *Climate Sense* makes a timely contribution to the efforts of the United Nations system and its partners to 'deliver as one' in meeting the climate challenge.

Ban Ki-moon
Secretary-General of the United Nations

STATEMENT BY ÓLAFUR RAGNAR GRÍMSSON, PRESIDENT OF ICELAND

At the dawn of the 21st century, Iceland is at the centre of climate change. Our glaciers, the largest in Europe, are receding rapidly and so increasing the likelihood of dramatic volcanic eruptions. The ocean currents, transformed by the melting of the neighbouring Arctic ice cap, could alter their movements so as to affect every continent on earth. Iceland's entire water systems, wildlife, patterns of soil and land alterations are no longer as they used to be.

These changes present extraordinary democratic and moral challenges to our scientists and policymakers, to civil society and political institutions. The key to addressing such challenges will invariably be knowledge.

Icelandic scientists have studied the glaciers and mapped the weather patterns for decades in all regions of the country, often assisted by enlightened citizens and an actively engaged public. Early on, research on the oceans and soil preservation became the pride of the nation and represented an important contribution to global understanding.

We can now draw on this wealth of wisdom to enable other countries to gain a new perspective on the changes in their part of the world. But Iceland has more to offer.

In the second half of the 20th century Iceland decided to transform its entire national energy system from primary dependence on fossil fuels to become a global leader in the area of clean and sustainable energy.

Our experience proves that it is possible to combat climate change if the necessary energy policies are put into action, and if citizens and governments alike take up such initiatives in earnest.

Iceland thus represents both a warning and a vision to the world. It demonstrates the alarming rate of climate change, but also how it can be averted.

Ólafur Ragnar Grímsson
President of Iceland

STATEMENT BY DR DANILO TÜRK, PRESIDENT OF THE REPUBLIC OF SLOVENIA

Slovenia is by no means immune to the problems of climate change, despite its favourable geographical location between the Alps, Mediterranean and Pannonian Basin. During the last three decades global warming has brought us frequent droughts and heat waves. In the autumn of 2007 Slovenia suffered severe flash floods, while in the summer of 2008 we were hit by devastating storms. Unfortunately, we can expect similar events during 2009.

Agriculture is particularly affected by these increasingly frequent, extreme climate events. Therefore our primary focus in the climate change adaptation process is to prepare an adaptation strategy for agriculture. Indeed, Slovenia took an active role to this by accepting responsibility for the Drought Management Centre for Southeastern Europe.

The climate is changing much faster than the habits of the people that live on this planet, and as such we need to fundamentally shift our attitude towards the environment. To do this, first of all, we have to truly appreciate that the environment cannot be taken for granted.

I believe that if the world takes the necessary steps in a prompt fashion — with the richer countries taking responsibility and leading the way — we can tackle climate change successfully. Although it is not an easy task, I am convinced that if we unify our collective strengths and resources we can achieve the common goal of ensuring that our planet is a decent place to live — not only for ourselves, but also for our children. The EU countries have to lead the way, but it is crucial that everybody participates — our responsibilities are differentiated, but at the same time shared.

Dr Danilo Türk
President of the Republic of Slovenia

STATEMENT BY ANGELA MERKEL, CHANCELLOR, FEDERAL REPUBLIC OF GERMANY

Climate protection is one of the biggest challenges facing us in the 21st century. The scientific facts are clear: the pace of climate change is accelerating; it is endangering our security and economic development. The impact will be dramatic and the risks uncontrollable, if we do not take resolute action right now.

It therefore makes complete ecological and economic sense for the world to agree at the Conference of the Parties in Copenhagen at the end of this year on an ambitious, effective and comprehensive climate convention for the period after 2012. With this new convention we must pave the way for reduced global emissions. If we succeed in cutting emissions by at least 50 per cent from 1990 levels by 2050, we will be able to keep the global rise in temperature below the critical two degrees Celsius mark.

At the same time we must intensify our efforts to adapt to climate change. So the Copenhagen Convention should also provide an appropriate framework for the development and implementation of adaptation strategies. The precondition for this is the systematic analysis and evaluation of the effects of climate change on infrastructure, environment and nature. Attention should be given to particularly hard-hit regions, such as coasts and mountain ranges, and to economic sectors, above all agriculture and tourism, as well as to health-related aspects.

I therefore welcome the goal of the World Meteorological Organization and the World Climate Conference-3 — namely, to improve the international community's ability to predict key climate trends and risks. The planned new information network can play a decisive role in allowing climate information and predictions to be used more effectively to plan adaptation strategies. Only on the basis of reliable and scientifically sound information can effective action plans be drawn up and implemented.

With this admirable initiative the World Meteorological Organization is building a bridge between established climate data on the one hand and the application of climate information by decision-makers on the other. It is thereby making a valuable contribution to the endeavours to counter the impact of climate change on the world's population.

Angela Merkel
Chancellor, Federal Republic of Germany

STATEMENT BY JOSÉ LUIS RODRIGUEZ ZAPATERO, PRESIDENT OF THE GOVERNMENT OF SPAIN

I appreciate the invitation of the World Meteorological Organization to contribute, as President of the Government of Spain, to this publication commemorating the World Climate Conference-3. I believe that this conference, as well as this publication, will contribute in a significant way to a better acknowledgement of the vulnerability of society to climate evolution, as well as to the necessity for long-term political and economical actions to assure the sustainable progress and development of humankind.

As indicated by the last Intergovernmental Panel on Climate Change report, the Iberian Peninsula is a highly vulnerable region with regards to the climate change process, and some of the first effects are already evident in our natural, economical and social environment. As such, the development of adaptation and mitigation policies is a high priority for my government, as is contributing to joint global efforts to prevent humankind from being seriously affected by climate change. Indeed, this aim should serve as a foundation for the development of a new ecological conscience, as well as for a model of economical development compatible with this.

I reiterate my appreciation to the United Nations for its efforts — made through the World Meteorological Organization — and I fully support its efforts to maintain and reinforce activities that are critical to the future of our planet.

José Luis Rodriguez Zapatero
President of the Government of Spain

STATEMENT BY LARS LØKKE RASMUSSEN, PRIME MINISTER, DENMARK

The World Meteorological Organization has chosen to publish this book at a crucial hour. Once again we are presented with clear and unambiguous evidence of the severity of climate change. The scientific community is playing a crucial role in keeping the facts on the table, both in terms of identifying the problems and pointing to the solutions. The more we are confronted with those facts the greater is the probability that we will conclude an ambitious agreement in Copenhagen, in December this year.

Climate change affects our way of life and all the environments around the world. This book contributes to promoting the application of climate information and predictions to societal problems. It explores how to enable adaptation to climate variability and change in areas such as agriculture and food security, water, health, energy and wildlife. All these aspects are important and must be dealt with on international, regional, national, municipal and local levels.

COP15 in Copenhagen may be one of the most important meetings of this new millennium — a meeting where we cannot afford to fail. I expect the world to deliver particularly on three elements. First of all we have to reverse the trend of CO_2 emissions; secondly we have to agree on a pathway towards achieving our targets; and thirdly we have to set in motion the policies and measures to sustain this process.

It is my sincere hope that in 10-15 years, when we look back at 2009, we will see it as the year where world leaders finally stopped ignoring the strong evidence evinced by the scientific community. The year where we realized the potential of low-carbon transition. The year where we made the necessary decisions. We still need science to stay engaged, and we will draw upon the scientific community's advice in the search for solutions compatible with political and economic realities. The world must find a way — and I remain confident that we will find it.

Lars Løkke Rasmussen
Prime Minister, Denmark

STATEMENT BY MORITZ LEUENBERGER, MINISTER OF THE ENVIRONMENT, TRANSPORT, ENERGY AND COMMUNICATIONS AND FORMER PRESIDENT OF THE SWISS CONFEDERATION

The face of the world is changing. From our planet's alpine peaks to its ocean depths, from its verdant plains to its arid steppes, climate change affects our daily life, our environment and our economies.

No nation is spared from making far-reaching decisions. Must an area be evacuated due to flood risk? Are the necessary precautions in place to prevent famine caused by drought, or epidemic outbreaks from persistent humidity? What investments are required in ski resorts to counter the rising snow line? Knowing the answers to these questions is vital: our ability to adapt depends entirely upon our understanding of how the world will change. This is what climate information is all about.

We should not forget that this need to adapt has arisen from our emissions of greenhouse gases, which science tells us are the cause of global warming. Fortunately, it is possible to mitigate climate change. But, to reach this goal, we must set ambitious reduction targets for the next decade, at Copenhagen in December 2009.

Nevertheless, adjusting to the unavoidable effects of climate change remains a necessity, and helping the most vulnerable to do so is an obligation. Climate information lies at the heart of this. But developing countries need financial support as well to implement these adaptation measures. That is why Switzerland has proposed a global CO_2 levy based on the 'polluter pays' principle. Its implementation would allow financial resources to flow to those communities least responsible for climate change, but most vulnerable to its impact, and help prevent deep rifts opening up in our societies.

I would like to thank the World Meteorological Organization and its UN and other partners for convening the World Climate Conference-3. They call on us all to work together across different regions and sectors to address the challenges of climate change, so as to enhance mankind's adaptive capacity, and achieve major benefits to society as a whole. I am particularly proud to welcome the World Climate Conference to Geneva, and this for the third time.

Moritz Leuenberger
Minister of the Environment, Transport, Energy and
Communications and former President of the Swiss Confederation

STATEMENT BY ANDREAS CARLGREN, MINISTER OF THE ENVIRONMENT, SWEDEN

World Climate Conference-3 is a very timely event, happening only three months before United Nations Climate Change Conference 2009 (COP15) in Copenhagen. Climate change is an issue of great significance to Sweden, as we lead the European Union during the half year when international negotiations for a new comprehensive climate agreement reach their conclusion. Adaptation is one of the most important areas in this context, as whatever we do now to limit global warming, we will still have to cope with the unavoidable effects of climate change.

The International Commission on Climate Change and Development, a Swedish initiative, has recently released its final report. An important conclusion of the report is that adaptation to climate change must be driven at a local level, particularly within those societies most vulnerable and exposed to the impacts of climate change. Adaptation must be integrated into development planning and substantial resources devoted immediately to strengthening resilience and supporting adaptation actions.

An essential tool in these efforts is the availability of accurate, relevant and accessible information and data on climate change. Improved climate observations, monitoring and data provision from climate models detailed enough for regional and local community action, must form the backbone of such information. It is my absolute belief that World Climate Conference-3 will provide an essential stepping-stone to achieving this improvement in data quality, applicability and availability.

WMO has the competence and resources to continue channelling essential support and contributions as the lead agency in the UN system.

Andreas Carlgren
Minister of the Environment, Sweden

STATEMENT BY DR JANE LUBCHENCO, UNDER SECRETARY OF COMMERCE FOR OCEANS AND ATMOSPHERE AND NOAA ADMINISTRATOR

The demand for clear, authoritative and useful information about climate change is growing. More broadly, increased understanding is needed about how atmosphere, ocean, and land systems, social and economic systems, human health, and infrastructure will be affected by climate change and variability in the context of other stresses.

To meet this increasing demand for climate information in the United States, the National Oceanic and Atmospheric Administration (NOAA) is working to further integrate its already considerable capabilities in climate observations, research, modelling, assessments, predictions, and projections to deliver relevant and timely climate products and services. We also recognize this demand for climate information extends beyond our nation's borders and support enhanced international partnerships.

The exemplary tradition among member states of the World Meteorological Organization to exchange observations, research results, and best practices for the common good must now be extended to ensure that information about climate variability and change is shared for the benefit of all peoples and economies. NOAA stands ready to bring its expertise to a broader global framework for climate services that will build upon the existing observational, research, and modelling pillars of climate services and, in collaboration with user communities, will establish improved mechanisms to deliver relevant climate information and predictions.

Dr Jane Lubchenco
Under Secretary of Commerce for Oceans
and Atmosphere and NOAA Administrator

STATEMENT BY RICARDO LAGOS, FORMER PRESIDENT OF CHILE, UN SPECIAL ENVOY FOR CLIMATE CHANGE

Climate change and global warming are undeniable facts and are affecting every single one of us. Far-reaching decisions and decisive concrete actions are urgently needed from high level policy-makers across the globe. The wellbeing of future generations depends on us making a crucial choice: either taking steps to nurture economic growth and find sustainable solutions to our ever-growing population, or allowing unrestricted unsustainable growth. By choosing the latter, quite simply our civilization will end.

Climate change is a global problem that requires global solutions, where all nations act and agree in a mutually cooperative way. The basic principles for such an agreement are clear, and depend on international equity, historical responsibilities, national capacity building and an overall willingness by all of us to reduce greenhouse gas emissions. All of us have common but differentiated responsibilities. Furthermore, we will share scientific and technological knowledge and adopt relevant adaptation measurements for the world's most vulnerable communities. The challenge of facing climate change is a universal responsibility that stretches from ethical changes in our own personal behaviour, to international agreements and governmental commitments to change. We must make a difference now, whilst the light of human civilization still burns brightly.

Ricardo Lagos
Former President of Chile
UN Special Envoy for Climate Change

STATEMENT BY DR HAMADOUN TOURE,
SECRETARY GENERAL, INTERNATIONAL TELECOMMUNICATION UNION

The science of climate monitoring has benefited greatly from the parallel development of information and communication technologies (ICTs). Today ICTs play a critical role in global, long-range climate monitoring. For example, the World Meteorological Organization (WMO)'s Global Climate Observation System (GCOS) uses ICTs in a plethora of ways. Radio-based remote sensors placed on satellites and aircraft relay data to environment control centres. Telecommunication networks are used in the real-time exchange of large volumes of data between meteorological centres. More generally, thousands of interconnected mini-, micro- and supercomputers are used to process the enormous volumes of data used in weather prediction.

The International Telecommunication Union (ITU) helped to establish the technical basis for the use of ICTs in GCOS by providing the necessary radio frequency spectrum for the meteorological aids radiocommunication service, as well as the satellite orbit resources for sensors used on the meteorological and earth-exploration satellites. ITU also published the radio regulations and voluntary international standards for telecommunications used by GCOS. Finally, ITU provided guidance on the use of ICTs in environmental monitoring, as well as in the prediction and mitigation of the negative effects of disasters linked to climate change.

WMO and ITU have collaborated for over 135 years. WMO formulates needs for environmental information and the corresponding radio spectrum required. In response, ITU — through World Radiocommunication Conferences — considers these requests and ensures the availability and protection of the necessary frequency bands.

WMO and ITU are working together to raise awareness of the use of telecommunications and ICTs in climate monitoring. A recent example is the ITU/WMO handbook: *Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction*.

Dr Hamadoun Toure
Secretary General, International Telecommunication Union

STATEMENT BY TALEB RIFAI, SECRETARY-GENERAL A.I., THE WORLD TOURISM ORGANIZATION

Responding to climate change is a major challenge for our society in light of its social, economic and environmental impacts. It is a global problem that demands global engagement. Tourism is especially sensitive to climate variability and change. Rising sea levels, beach erosion, desertification, deforestation, declining snow cover, receding glaciers and loss of biodiversity caused by global warming are harming the tourism sector and the millions of people whose livelihoods depend on it. Today, tourism is a major economic activity and is often the most valuable resource of developing countries and small islands. The threat posed to it by climate change must therefore be urgently addressed.

The World Tourism Organization (UNWTO), a specialized agency of the United Nations, is engaged in supporting the adaptation of tourism destinations to climate change and its effects. It is committed to helping the sector move towards more efficient use of energy, while simultaneously reducing its contribution to global warming. The 'Davos Process' it initiated at the International Conference on Climate Change and Tourism in 2007 has enhanced awareness regarding this issue among all tourism stakeholders including travellers themselves. It provides a framework for a coordinated response to climate change that does not jeopardize the important role tourism plays as a tool for poverty alleviation.

Climate information is essential for decision makers in the tourism sector. In particular, they require access to reliable seasonal and long-term climate predictions. This is vital because of the high degree of future uncertainty deriving from climate change, as well as the limited relevance of past observations. In this regard, the World Climate Conference-3 has the important goal of bridging the gap between the providers and users of climate information.

UNWTO has actively supported the WCC-3 initiative from the beginning, as it represents an important step in the joint effort to adapt to the risks of climate change.

Taleb Rifai
Secretary-General, a.i, the World Tourism Organization

STATEMENT BY MARGARETA WAHLSTROM, ASSISTANT SECRETARY-GENERAL FOR DISASTER RISK REDUCTION, UNITED NATIONS INTERNATIONAL STRATEGY FOR DISASTER REDUCTION

Most of us have occasionally experienced severe weather, such as gale force winds or flooding rains, and maybe have also witnessed the devastating impacts of long-term drought. Even in an age of sturdy architecture, public flood protection works and early warning systems we can still be shaken by the fearful power of nature and the threat it can represent to our safety and well-being.

However, for many millions of people around the world, such events are not occasional, nor are they mere disruptions to the daily routine. They occur frequently and threaten life itself through drowning, collapse of dwellings, injury and ill health, as well as by destroying assets, livelihoods and food supplies.

We know that climate change will make matters worse, and that this will be the case most immediately for the poor. Many communities face not only greater extremes of weather and raised sea levels, but also depleted water resources and food production, which weakens their capacities to resist even the current levels of stress.

Clearly, we must prepare. Reducing greenhouse gas emissions is a fundamental requirement. But we must also act to reduce disaster risks, by applying well known methods such as risk assessments, land use management, building codes, early warning systems and public education. Disaster risk reduction methods must become a foundation stone of climate change policy.

This World Climate Conference provides the perfect opportunity to emphasise the need for risk-reducing adaptation action, underpinned by sound monitoring systems, databases, analysis centres and research programmes. It should show practical ways forward, to make the world a safer place.

Margareta Wahlstrom
Assistant Secretary-General for Disaster Risk Reduction,
United Nations International Strategy for Disaster Reduction

STATEMENT BY ACHIM STEINER, UN UNDER-SECRETARY GENERAL AND EXECUTIVE DIRECTOR, UN ENVIRONMENT PROGRAMME

Improving weather predictions is going to become ever more important in a climate constrained world if society is to assist vulnerable communities to adapt and to climate-proof their economies.

Their quality will, for example, determine the usefulness of smart micro-insurance mechanisms that pay out to farmers on continents such as Africa before they are down to their last stick of maize and facing hunger.

Improved forecasts can also reduce the impact of extreme weather events on lives and livelihoods by improving warnings and disaster planning.

Historical weather patterns are unlikely to be guides to future ones. Governments planning infrastructure projects such as dams or roads need to know whether they are likely to be filled or washed away in a climate-altered world, in advance of a multi-million dollar investment.

Developers of wind farms to big agricultural schemes need to know that future wind speeds will prevail in a chosen location and that certain crops can still flourish under a climate-altered world.

Thus an improved predictive capacity, that builds and more finely focuses the existing global and regional predictions of the Intergovernmental Panel on Climate Change, is urgently needed — particularly at the national level.

Climate Sense, published to coincide with World Climate Conference-3, syntheses some of the best scientific knowledge in this key field, in order to catalyse an international response to these current and future challenges.

Its publication comes some three months before the crucial UN climate convention meeting in Copenhagen where investment in improved weather, climate and water service management, and forecasting needs to be part of a transformative deal.

Achim Steiner
UN Under-Secretary General and
Executive Director, UN Environment Programme

STATEMENT BY ANNA K TIBAIJUKA, UNDER-SECRETARY-GENERAL AND EXECUTIVE DIRECTOR, UN-HABITAT

The United Nations Human Settlements Programme (UN-HABITAT) is the lead UN agency for cities. Its primary focus is on affordable housing and sustainable urban development. The single biggest group of people that are suffering the effects of climate change are the urban poor. Lack of access to decent housing and basic urban services means that they are the most at risk of losing life, property and livelihoods from rising sea levels and other extreme weather patterns. At the same time, cities consume over 65 per cent of the world's energy and constitute the biggest source of greenhouse gas emissions.

UN-HABITAT helps cities and communities to devise integrated approaches to implementing climate change mitigation and adaptation strategies. For the majority of the world's rapidly growing cities, mitigation and adaptation require very similar solutions. These are: more rational land-use planning; more robust infrastructure; and smarter and greener urban services that are equally accessible by all.

Scientific knowledge is critical to understanding the causes and effects of climate change, especially at the local level. This understanding, in turn, allows us to develop practical tools that can help cities and their communities address climate change. For this reason, UN-HABITAT has launched the World Urban Campaign including a Cities and Climate Change Initiative to spearhead the coordinated approach by all stakeholder groups — and by the UN family — in the documentation and dissemination of best practice, tested tools and methodologies, and model legislation in areas of sustainable urban development.

We count on the World Climate Conference-3 outcome to further advance knowledge of climate change and to strengthen mechanisms to deliver climate information. This will help all stakeholders to apply that knowledge to their respective adaptation and mitigation strategies at the local level.

Anna K Tibaijuka
Under-Secretary-General and Executive Director, UN-HABITAT

STATEMENT BY JANEZ POTOČNIK, EUROPEAN COMMISSIONER FOR SCIENCE AND RESEARCH

Impressive progress in climate science, reflected notably in the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) and in the results from EU funded research projects, provided robust findings on the causes of climate change and its impacts over the next decades. Limiting climate change to a temperature increase of 2°C above pre-industrial levels as proposed by the European Union requires urgent and ambitious global action. The EU is therefore working towards a comprehensive agreement at the Copenhagen Climate Change Conference in December.

We now know that even within this limit of global average temperature increase there will be serious climate change impacts requiring adaptation at global and regional levels. However, recognising the need to adapt is not sufficient. We need to know where, when and how to adapt. This is of paramount importance for policy-makers. Thus, we need science-based climate information and prediction tools to enable risk management and adaptation to climate change.

The Third World Climate Conference occurs at a critical moment to stimulate action and increased public awareness on those issues. Therefore, I strongly support the initiative of the WCC-3 to establish means for the provision of climate services. These new services will need to inform on the expected consequences of climate change at time and geographical scales corresponding to society and people's needs. Achieving this will require a leap forward in further understanding climate change and sustained efforts in climate research and observation. We need sound and close international cooperation, extensive combined use of climate data and models and the development of relevant services for information provision. The European Commission has been contributing to these endeavours actively with the Framework Programme for research and will continue to do so.

Janez Potočnik
European Commissioner for Science and Research

STATEMENT BY BEKELE GELETA, SECRETARY GENERAL, INTERNATIONAL FEDERATION OF RED CROSS AND RED CRESCENT SOCIETIES

All over the world, people — including Red Cross Red Crescent staff and volunteers — face the impacts of a changing climate. We see changing hazards combined with rising vulnerabilities due to population growth, urbanization, poverty and environmental degradation. In particular, we are responding to a substantial rise in smaller climate-related emergencies — a real change in the typology of disasters.

Through our unrivalled community-based volunteer network, we are well placed to respond to these localized disaster events, which often go unnoticed by the international media.

Instead of waiting for emergencies to happen, we work to prevent disasters and reduce their impact through enhanced disaster preparedness. We monitor vulnerability, hazards and risks — working in partnership with governments and civil society, and with local communities worldwide to increase their resilience through improved contingency planning and public awareness. Climate information is a key ingredient in these efforts, helping to anticipate threats days, weeks, months, even years and decades before they become disasters.

However, experience shows that climate information by itself is not enough. The people who use it — particularly the most vulnerable — must understand and trust it, and be able to act upon it. That last mile, getting from scientific early warning to early action on the ground, is often the crucial missing link. The International Federation of Red Cross and Red Crescent Societies can bridge this gap and stands ready to do its part.

Bekele Geleta
Secretary General, International Federation of Red Cross and Red Crescent Societies

STATEMENT BY EDWIN CARRINGTON, SECRETARY GENERAL, CARICOM

On behalf of the the Caribbean Community (CARICOM) I wish to congratulate the World Meteorological Organization for this timely meeting, which comes on the eve of the UN Copenhagen Climate Change Conference (COP-15), in December 2009. As the global community is aware, adapting to and mitigating the impacts of climate change are critical to the survival of the Caribbean.

Recently, the region has experienced extensive environmental and socioeconomic impacts from storms and hurricanes that have significantly slowed development activities in several countries. This, coupled with the conclusions of the Fourth Assessment Report of the Inter-Governmental Panel on Climate Change and regional studies that indicate that climate change will lead to a future with higher sea levels, hotter climates and more extreme weather events, justifies our fears about the impacts of climate change on our already vulnerable climate-based economies, ecological systems and way of life.

In 2009 the World Bank noted that by approximately 2080 the cumulative annual impact of future climate change on all CARICOM Member and Associate Member States will be around 11.3 per cent of the projected cumulative gross domestic product. This ratio is too large and will slow future sustainable development in the region.

With the assistance of the international community, the region is aggressively pursuing climate change mitigation and adaptation strategies through existing, as well as new institutions, such as the Caribbean Community Climate Change Centre and through collective regional policies. The region believes, however, that the global architecture on climate change should be restructured and will assertively raise its concerns in international fora such as COP-15.

Edwin Carrington
Secretary General, CARICOM

I

THE IMPACTS AND IMPLICATIONS OF CLIMATE CHANGE AND VARIABILITY

Economic and social implications of climate change and variability: new challenges for climate services

Thomas R. Karl, Lead, NOAA Climate Services; Chester J. Koblinsky, Director, NOAA Climate Program Office; Richard D. Rosen, Senior Advisor for Climate Research, NOAA Climate Program Office

Concern about climate variability and change is now part of the public consciousness and dialogue. This new awareness of the global environment and humanity's place in it can be attributed to at least two factors. First, through the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a scientific consensus has emerged that 'warming of the climate system is unequivocal' and, moreover, that 'most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations'. Second, the world is experiencing profound environmental changes, many linked to, or consistent with, those which climate models predict on a warmer planet. Notably: reductions in snow and sea ice extent, rising sea levels, changes in ocean acidity, extended droughts, increased frequency of heavy and extreme precipitation events, stronger tropical storms, and unusually warm night-time temperatures.

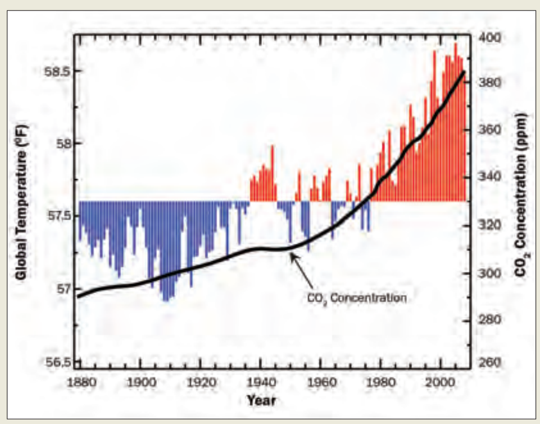
Under these circumstances, it is not surprising to find a growing demand for climate information across a broad spectrum of sectors and regions. Fishermen and fishery managers want to know the impacts of a warming and more acidic ocean on their stocks; city planners, the possible range of future weather and climate extremes to inform infrastructure design for their growing populations; public health officials, the potential for a new climate regime more favourable for environments that support pathogens and agents of infectious disease; coastal emergency management officials, what to expect about extreme events and rising sea levels associated with inundation and flooding; Arctic populations, how warming will continue to be amplified in polar regions, affecting their culture and livelihoods — the list goes on.

This demand coincides with advances in climate science that make the possibility of providing useful answers feasible. Global observing networks made possible the first IPCC conclusion, and international climate modelling capabilities enabled the second. New high-performance computing capacity and increased understanding of the climate system offer the potential to predict climate evolution over the next several decades at spatial resolutions relevant to decision and policy makers. While such advances hold exciting promise, observation and modelling systems remain fragile, too often lacking sustained oversight and commitment. An 'end-to-end' approach that recognizes the interdependencies of climate-related physical, chemical, and biological processes with human and natural systems remains underdeveloped. This is required to properly conduct climate vulnerability assessments and risk management to support climate resilient communities. Internationally, recognition of these gaps has led to the call for a Global Framework for Climate Services at World Climate Conference-3. Nationally, within the United States (US), this recognition is at the heart of discussions on forming a National Climate Service (NCS).

An agenda for climate services

Sustaining climate observations and state-of-the-art modelling capabilities are but elements of a broader

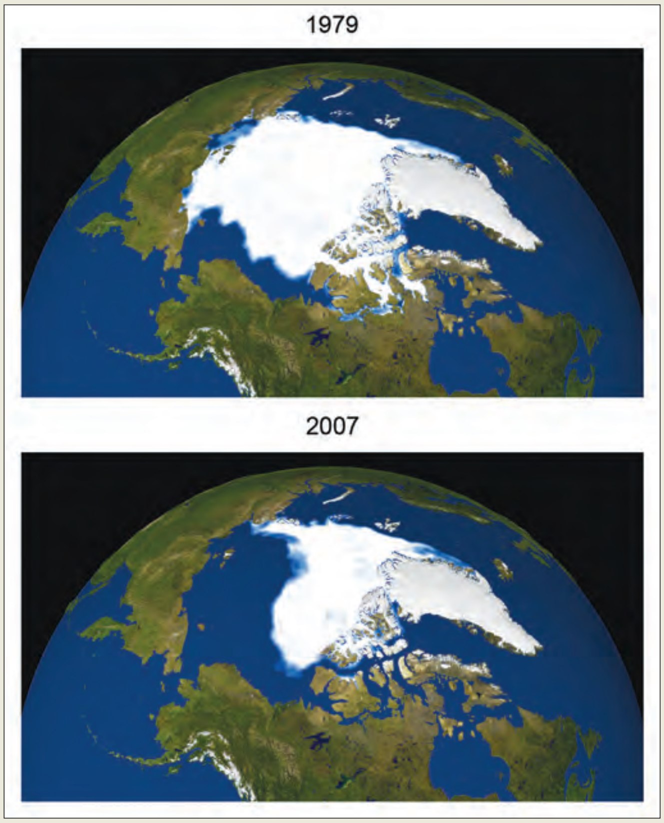
Global annual average temperature



Red bars indicate temperatures above and blue bars indicate temperatures below the average temperature for the period 1901-2000. The black line shows atmospheric CO_2 concentration in parts per million (ppm). While there is a clear long-term global warming trend, each individual year does not show a temperature increase relative to the previous, and some show greater changes than others. These fluctuations in temperature are due to natural processes, like the effects of El Niños and the eruption of large volcanoes

Source: Karl et al. (2009)

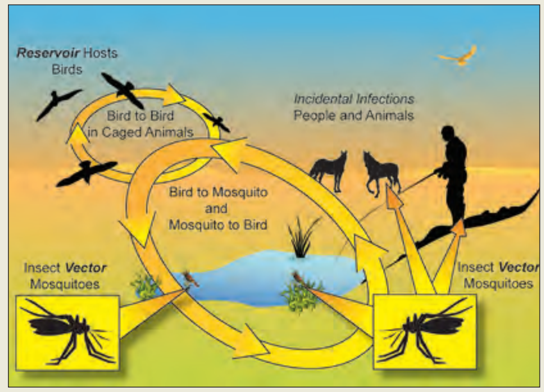
Arctic sea ice annual minimum



Arctic sea ice reaches its annual minimum in September. The satellite images show September Arctic sea ice in 1979, the first year these data were available, and 2007

Source: *Sea Ice Yearly Minimum 1979-2007*, NASA/Goddard Space Flight Center Scientific Visualization Studio (GSFC)

West Nile virus transmission cycle



While migratory birds were the primary mode of the West Nile virus spread in the United States after the first outbreak occurred in 1999, epicentres of the disease were linked to locations with either drought or above average temperatures during the epidemic summers of 2002-2004. Analyses of a more virulent strain that emerged in 2002 indicate this strain responds strongly to higher temperatures, suggesting that greater risks from the disease may result from increases in the frequency of heat waves

Source: Karl et al. (2009)

'agenda for climate impacts science' described in a state-of-knowledge report entitled Global Climate Change Impacts in the United States published by the US Global Change Research Program.[1] It recognizes that advances in scientific understanding have already contributed greatly to decision making. Further advances are required, however, to better understand and project changes in rainfall, storm tracks, storm intensity, heat waves, and sea-level rise. With respect to advancing knowledge specifically about the impacts of climate variability and change and the processes responsible, the report makes six recommendations that would better ensure the information provided by climate services is of use to decision makers:

Expand understanding of climate impacts — Increased knowledge is needed about how ecosystems, economic systems, human health, and the built environment will be affected by climate variability and change in the context of multiple stresses. This will be derived from sustained observations, field experiments, model development, and integrated impact assessments performed through collaborations among researchers, practitioners and stakeholders.

Refine the ability to project climate variability and change at local scales — Decisions on adaptation will be made largely at local and regional scales. Although progress is being made at these scales, significant uncertainties remain. Higher resolution models, improved downscaling approaches, additional observations at relevant scales, and better methods for quantifying uncertainties are all required to provide useful information about the potential for, and impacts of, extreme events. It is important to recognize, however, that aspects of uncertainty at fine scales will remain irreducible.

Expand capacity to provide relevant climate information to decision makers and the public — Through interactions between information providers and users, monitoring systems, distribution networks, and information tools can all be developed and refined. Monitoring efforts need to adhere to principles that ensure the quality of observations, and improved access to data archives will facilitate society's ability to respond to change. Credible climate services must provide reliable, well documented, and easily used information. While implementation is most important at a national scale, many decisions and policies addressing impacts take place regionally. Experience has demonstrated that the practice of climate services requires sustained, ongoing regionally-based interactions with users.

Improve understanding of thresholds for abrupt climate changes — Climate has shifted regimes relatively quickly in the past, suggesting it is capable of doing so again in the future. More needs to be learned, however, about the tipping points that can trigger such changes. The sensitivity of major ice sheets to sustained warming is of concern in this regard, requiring improved observations, analysis, and modelling of ice sheets and their interactions with surrounding oceans. Thresholds in biological systems also need to be better understood.

Improve understanding of most effective approaches to mitigation — Different paths to reducing concentrations of greenhouse gases exist, and a mixture of mitigation

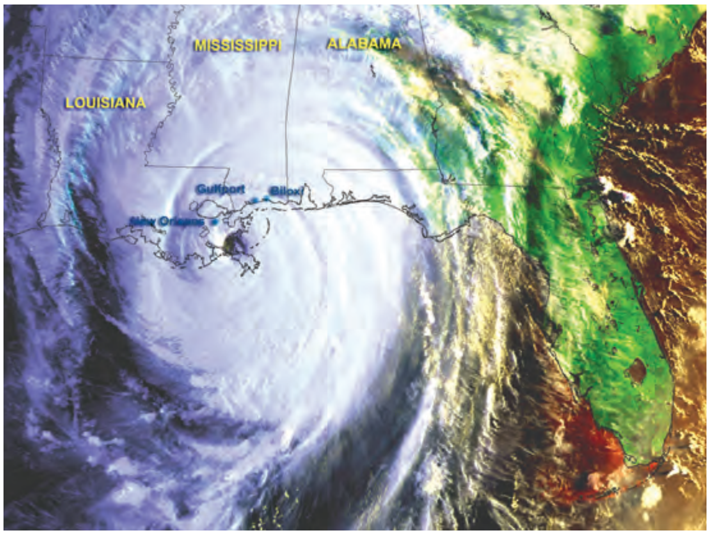


Image: NOAA

Hurricane Katrina, August 29, 2005

Image: Karl et al. (2009)

Global Climate Change Impacts in the United States: a state-of-knowledge report published by the US Global Change Research Program

options will likely emerge as the best way forward. Decisions about what that mixture might be, however, will need to be supported by additional research. This research will also need to consider the potential for unintended consequences of different mitigation options (for example, widespread adoption of biofuels), so those options with the largest negative impacts can be identified, and decision makers can make informed choices about the inherent costs and benefits of different strategies.

Enhance understanding of how society can adapt — Given the large climate forcing already produced by humanity, the need to adapt to variability and change is inevitable regardless of mitigation efforts. The ability of communities, regions, and sectors to adapt, however, is not well understood. This gap is not surprising considering the complex interplay among environmental, political, social, and economic considerations involved, but interdisciplinary research on adaptation decision making is needed to better understand the effectiveness of proposed options. Gaps need to be filled between climate information currently available and the development of new guidelines for infrastructure, and regular assessments of adaptation measures taken need to be made.

Potential benefits of climate services

Assuming the above agenda is widely adopted, including by an NCS in the US, we envision benefits accruing across a broad spectrum of sectors:

Living marine resources — Incorporating climate information into the management of US fisheries would help support a USD60 billion per year fishing industry. Similarly, the management of endangered and protected marine species would benefit from relevant climate research and model projections.

Energy — Climate information will allow energy producers to operate more efficiently, for example in the operation of reservoirs that are sensitive to seasonal climate events. Investments in renewable energy sources like wind or solar will be better informed.

Transportation — Insights into future climate variability and change will provide a scientific foundation for long-term investments in infrastructure.

Human health — Climate observations and predictions can be used to anticipate adverse health outcomes associated with future heat waves, vector-borne diseases, and food or water-borne bacteria and viruses.

Water resources — Projected changes in patterns of precipitation and related factors will be important considerations in a variety of investments and, ultimately, in ensuring sustainable populations and ecosystems. This information will enable sounder long-term investments and help anticipate acute shortages.

Population and demography — In response to food and water shortages, large population shifts can occur and lead to political instability in many regions of the world. Climate information will allow the US and other developed nations to prepare to assist with such potential upheavals.

Decision support for water resources: NIDIS as a model for climate services

Sectors associated with water resources deserve additional mention. The potential impact of climate variability and change on the quality and quantity of fresh water is so profound that steps to deal with it in the US began even before an NCS is formally established. Those steps, beginning with the signing into law of the National Integrated Drought Information System (NIDIS) Act of 2006, provide a good example of how a full service might function. As a comprehensive early warning information system for drought, NIDIS is being developed to consolidate hydrological and socioeconomic data; develop a suite of usable drought decision support and simulation tools focused on criti-

Image: Don Becker, USGS

Historic flooding in Cedar Rapids, Iowa, USA, 2008

cal management indicators and triggers; and engage and enable planning by those affected.

NIDIS is overseen by an interagency Executive Council, with execution responsibility in the hands of its Program Implementation Team, composed of representatives from over 40 federal and state agencies, academic institutions, and tribal and private entities. At the regional level, the implementation team convenes multi-agency teams focusing on: communication and developing an awareness of drought and drought impacts; integrating information from monitoring and forecasting networks; interdisciplinary research to develop socioeconomic impact assessments and tools to generate impacts scenarios; engaging preparedness communities to ensure the needed indicators and management triggers are developed and usable; and the development of national and regionally-specific web-based drought portals that act as clearinghouses for information at different scales.

In addition to coordination, a key NIDIS activity is the conduct of ongoing gap assessments for feedback to the Executive Council, to improve interagency collaboration and guidance where needed. It also focuses on the transfer and adaptation of successful innovations identified in one region to others in need. NIDIS draws on the personnel, experience, and networks of other relevant institutions and alliances to integrate basic and applied research into an adaptive decision support environment.

Drought risk management provides an important prototype for testing knowledge management and use across the full spectrum of climate timescales. Research has shown that effecting cross-scale climate risk management is most readily accomplished when leadership and the public are engaged, and an authoritative basis for integrating monitoring, research and management is established. NIDIS offers the US a prototype to achieve these service requirements. Some of its tools have already been extended across US borders. For example, the US, Canada and Mexico jointly produce a monthly drought monitoring product that provides scientifically-based information about the status of ongoing drought across North America.

Concluding thoughts

The US has yet to establish an NCS, although active consideration of its responsibilities and structure is being given by both executive and legislative branches. It is easy to imagine, however, that if a service is to succeed it must be grounded on a set of principles that include: a commitment to a service-centric approach, in which user requirements will be identified collaboratively through ongoing dialogue with decision makers, the research community, the service, and its partners; a balance between present and future information needs that recognizes both user requirements and the readiness of science to address those requirements; encouraging public-private partnerships, in which respective roles are defined and respected and value-added climate products by the private sector are welcomed; and ensuring robust products are based on sound science, developed through sustained collaborations with partners across the federal government and in academia, effectively communicated to a broad spectrum of users.

Climate impacts on the society and economy of Croatia

Ivan Čačić and Krešo Pandžić, Meteorological and Hydrological Service, Croatia; Sandra Vlašić and Seth Landau, United Nations Development Programme

This review is based on the United Nations Development Programme (UNDP) 2008 Human Development Report for Croatia relating to the most prominent challenge of our time — climate change and its impact on our society and economy. It is a breakthrough report for Croatia and the first of its kind following the new analysis released by the International Panel on Climate Change (IPCC). In coming years more reports from other nations are expected to highlight the vulnerability of individual countries and the issues that the south and central European region face because of climate change. Climate change brings significant risks, but it may even present some opportunities for our future. We have a responsibility to act, to manage that risk and to mitigate the damage in the most effective way.

It is a scientifically proven fact — recognized by a Nobel Prize in 2007 — that climate is significantly changing due to human activities. It is obvious that the consequences of that change and reflected variability are already being felt all over the world. Croatia is no exception. In this report, we provide an assessment of impacts as well as quantifying the damage to several sectors of the Croatian economy over past years as a result of climate change and variability. The analysed sectors — including agriculture, fisheries, health, hydropower, tourism and the coastal zone — represent 25 per cent of the Croatian economy, employ almost half the working population and represent total annual gross domestic product (GDP) of EUR9 billion.

Both the government and citizens are concerned by, and interested in, climate change. The government is already pursuing several strategies to reduce greenhouse gas (GHG) emissions, thus allowing the Human Development Report to focus on identifying key gaps and to provide specific recommendations on 'climate-proofing' human and economic development strategies. The 'climate for change' that currently exists in Croatia will provide the motivation needed for the country to continue to develop and to address the challenges adequately.

Image: Damir Sencar, HINA

Severe bora at Senj

Current and future climate

When examining Croatia's vulnerability to climate change we must have a basic understanding of the current climatic conditions within the country, as well as predictions for the future under various scenarios.

Over the last century, emissions of GHGs caused by human activity have already had an impact on the climate system. Three direct characteristics of the climate, and changes to those characteristics, can have an impact on human development:

- Temperatures, which appear to be increasing in Croatia
- Precipitation, which appears to be decreasing – especially during certain seasons
- Extreme weather events, such as wind storms, heat waves and droughts, which are already having significant impacts on human development.

In Croatia during the 20th Century, most regions saw a fall in precipitation and an increase in temperature in almost every season. It has not been possible to distinguish how much of this is due to natural climate fluctuations or to human influence without climate models for Croatia that undoubtedly point to significant future changes in climatic conditions especially if emissions are not cut dramatically.

Image: www.blueflag.org

Beach in Split

Image: www.images.google.hr

The Krka river in Croatia

In the future, Croatia is expected to be hotter and drier, especially in summer. Increased temperatures are expected to have considerable impacts such as: increase of temperature in both sea and inland bodies of water, soil temperature increase, groundwater temperature increase, which may lead to higher rates of evaporation and a decrease in the groundwater table, a fall in lake and river levels, decreases in soil moisture leading to droughts, more heat waves affecting health, and numerous other impacts.

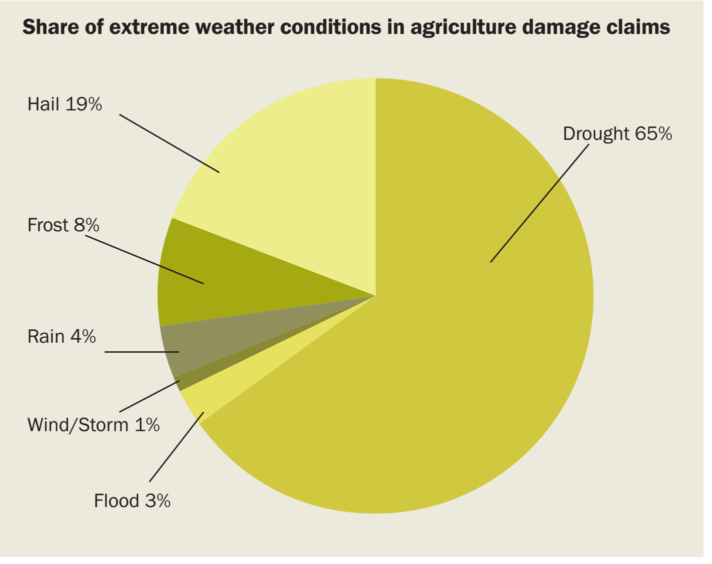
What would climate change affect in Croatia?

Tourism has long been important in Croatia. In 2007, tourists stayed for a total of 56 million days and spent EUR6.7 billion. Tourism generates about 20 per cent of GDP and 28.7 per cent of total employment (336,000 jobs). By 2018, it is expected to account for one third of total employment. In addition to those directly working in the tourist industry, there are many people employed in related industries that are directly impacted. Tens of thousands of families rely on tourism income in the grey economy by supplementing their incomes through tourism (unregistered apartment rentals, unregistered sales of agricultural, aquaculture or fishery products). The value of unregistered accommodation alone is equal to almost one per cent of the entire country's GDP. Most projections of tourism in the EU show that by the end of the century, because of climate change, hotter daytime temperatures along the Adriatic coast will cause many beach tourists to avoid these destinations in summer in favour of cooler locations further north. Conversely, the conditions for tourism along the coastline are expected to improve in the spring and, to a lesser extent, in the autumn. Overlooking these facts could have serious adverse consequences on many local communities and, given the important role of beach tourism, to the national economy. Hotter, drier summers with more extreme weather events and a rising sea level may put human and economic development gains at risk.

The basic options available for coping with sea-level rise, predicted to be between 9-88 centimetres by the year 2100, are to protect vulnerable areas or to retreat from them. Estimates of the expected rates of sea-level rise are very uncertain. That, coupled with the fact that it will probably occur very gradually means that there is still time to develop the best methods for coping with the problem, locality by locality. A mixture of near and long-term strategies involving both protection and retreat measures could be the best approach.

Events such as heat waves, which are likely to increase in frequency, have had a health impact on Croatians. The 2003 heat wave caused an estimated 185 additional deaths in Croatia — a 4.3 per cent increase in mortality. Therefore, it is very likely that climate change will have an impact on human health in Croatia. These risks are not fully understood, however, they are likely to include cardiovascular risks from heat waves, increases in allergic reactions resulting from changing pollen counts and changes in the distribution periods of plants and pollens and increased frequencies of heatstroke and other acute impacts from hot daytime temperatures.

Water is a critical natural resource. It is used for drinking, agriculture, wetlands services, and the production of hydroelectric energy, among other things. Croatia has abundant freshwater resources, and therefore water resources are not considered a limiting factor for development. However, while there is no shortage of water per se, problems do exist. First, a large amount of pumped water is wasted, which leads to lost revenue of up to EUR286 million (0.9 per cent of GDP) per year and increased GHG emissions resulting from the additional use of electricity for pumping.



Source: UNEP, 2008

Soil drought conditions in northern Croatia

Second, farmers often face water shortages at certain critical times during the growing season and, in general, the soil lacks moisture. Croatia uses only a small fraction of its available water resources (about 1 per cent). However, climate change may stress some of the systems that depend upon fresh water. The Croatian energy sector is potentially vulnerable if climate change results in reduced river flows — which is likely given the predictions of climate models simulating a drier country. During 2000-2007, 50 per cent of Croatian electricity production came from hydropower. In draught seasons in 2003 and 2007, significant losses in production resulted in increased costs for electricity production. A likely scenario for the future is a direct loss of between EUR16-82 million annually, with multiplier effects throughout the economy.

The impact on agriculture is expected to be significant because of its vulnerability to climate conditions in general. Precipitation, temperature, weather extremes and evaporation rates have separate and joined impacts on agricultural production. Agriculture is important to the economy due to its value, its impact on food security and vulnerable populations, and the employment it generates. In 2001, 92 per cent of Croatia was classified as rural, with 48 per cent of the population living in rural areas. Generally, rural households are more vulnerable due to poorer access to basic infrastructure and poorer housing conditions than those in urban areas. Existing climate variability already has a significant impact on agriculture. Extreme weather events have resulted in average losses of EUR176 million per year during 2000-2007. This represents 0.6 per cent of national GDP, or 9.3 per cent of the national Gross Value Added (GVA) generated by the agricultural, forestry and fisheries sector. Looking at the future effect on maize alone, the lost revenue due to climate change is about EUR6-16 million in 2050 and EUR31-43 million in 2100. This corresponds to 0.8-5.7 per cent of all revenue from arable crop sales in 2005. Most of this damage is due to water shortages during critical times, as well as flooding and hailstorms. Particular years, such as 2003 and 2007, suffered huge economic damage that it is difficult to recover from. While some Government-supported insurance programmes and a new irrigation programme exist, current vulnerability to climate variability remains — particularly with regards to drought.

Croatia has a long history of fishing and mariculture and a coastline well suited for developing a modern industry in these areas. The fishery and mariculture sector in Croatia accounts for a small portion of the GVA — an average of 0.25 per cent or around EUR56 million in 2003 and 2004 — but it plays an important role in the socioeconomic status of a large number of people. Climate change and increasing temperatures may result in important impacts in the near future that will challenge this industry.

Though climate change is a global problem, it will not affect all people equally. Just as global climate-related impacts are distributed unequally and disproportionately among the poor, impacts at the national level mirror this trend. Vulnerability to climate change depends greatly on the geographic, sectoral and social context. Poor communities can be especially vulnerable to climate change — especially those concentrated in higher-risk areas. Poorer communities tend to have more limited adaptive capacities and are more dependent on climate-sensitive recourses. Similarly, the elderly – who are disproportionately poor — are likely to face more severe consequences related to health impacts in addition to economic impacts.

Croatia is already seeing the impact of climate change and will inevitably continue to do so. UNDP's 2008 Human Development Report for Croatia showed climate change is happening and that actions must be taken to reduce its impacts and reduce the extent of that change. These impacts are expected to lead to a myriad of problems that affect human development. Negative impacts may include damages from more frequent natural disasters and sea-level rise, strains on food production, harm to human health, and many others. If not addressed, climate change in Croatia could restrict people's choices, slow down and undermine development gains and have a long-term negative impact on human development in general.

Climate change and food security

Richard A. Betts, Pete D. Falloon, Jemma Gornall, Neil Kaye and Andrew Wiltshire, Met Office Hadley Centre; Timothy R. Wheeler, Walker Institute for Climate Systems Research, Department of Agriculture, University of Reading, UK

Food security has been defined as 'a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'.[1] Although the production of food is clearly fundamental, the concept of food security goes beyond production and considers the entire system. It therefore encompasses other aspects of food availability such as distribution and exchange, and wider issues of access and utilization.[2]

Global food systems are inherently linked to climate in a large number of complex ways. The productivity of food crops, livestock and fisheries is highly dependent on climatic conditions and other environmental factors linked to climate, such as atmospheric composition. There is a tradition in agriculture of coping with year-to-year changes in climate. Nevertheless, human-induced change is expected to push these managed ecosystems beyond their natural boundaries, requiring greater adaptation. Climate change and its drivers are therefore likely to impact on the production aspect of food security. Moreover, since social and economic systems as a whole are influenced by climate, food security is also likely to be impacted by climate change through its wider effects on infrastructure and economies.

Impacts of climate change on food production

Climate change is likely to directly impact on food production across the globe. At higher latitudes where production is currently limited by temperature, producers may benefit from longer growing seasons for moderate warming, although higher levels would be expected to counter these benefits. Even moderate levels may not necessarily confer benefits without adaptation by producers, as an increase in the mean seasonal temperature can bring forward the harvest time of current varieties of many crops and hence reduce final yield, in the absence of any adaptation to a longer growing season.[3] In areas where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately.[4] In seasonal arid environments higher temperatures may also be more immediately detrimental by increasing heat stress on crops and water loss by evaporation.

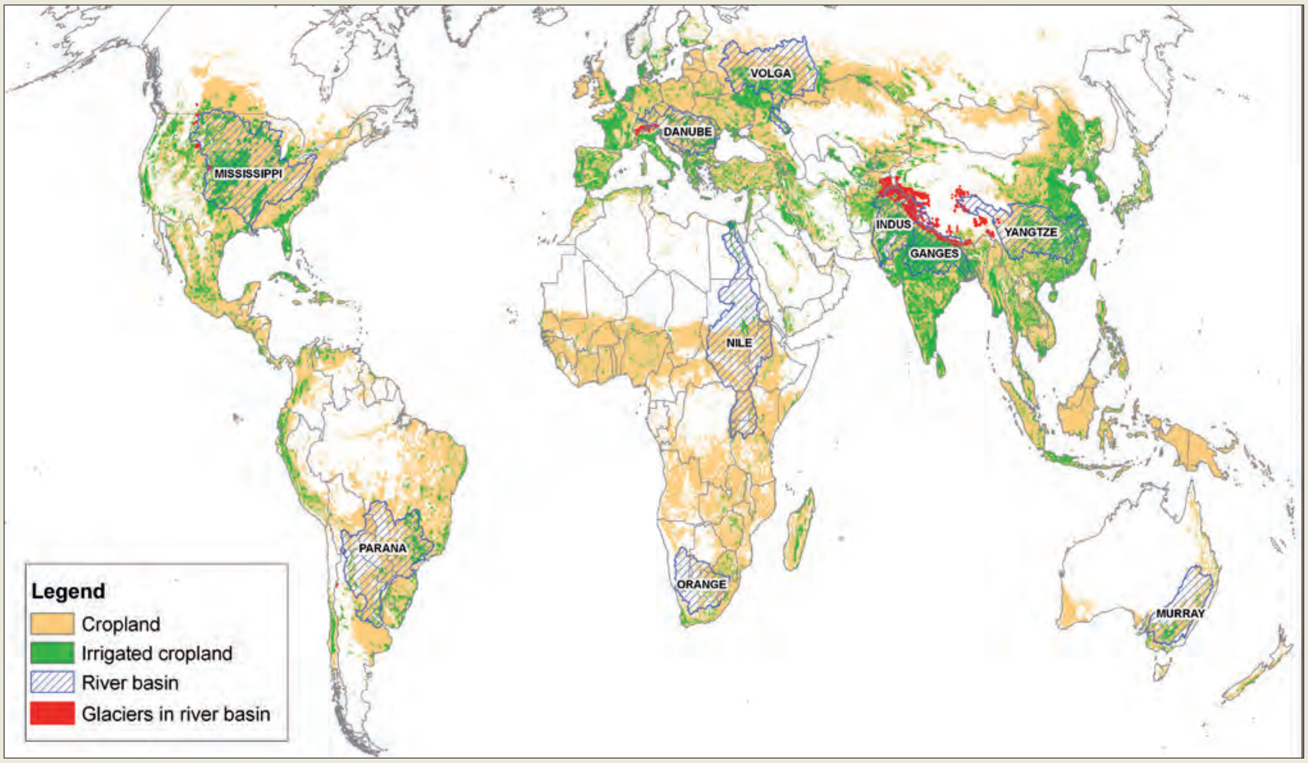
Changes in short-term temperature extremes can be critical, especially if these coincide with key stages of crop development. Only a few days of extreme temperature (greater than 32°C) at the flowering point of many crops can drastically reduce yield.[5] Temperature extremes also increase the risk of heat stress to livestock. Changes in the water cycle will be vital to production, whether by a decrease in the availability of fresh water or increasing damage caused by an excess. More frequent heat waves and droughts are expected,[6] causing yields of food crops and fodder for livestock to be more variable from year to year,[7] decreasing overall.[8] Further development of crop cultivars that are more tolerant to extreme weather is needed. Other impacts of drought may be reduced pasture productivity, increased livestock deaths, soil erosion via wind and land degradation.

Food production can also be impacted by too much water. Heavy rainfall events leading to flooding can wipe out crops and drown livestock over wide areas, and since an increase in the intensity of extreme rainfall is expected in a warmer world,[9] damaging flooding events may become more frequent.[10] Flooding aside, direct negative impacts of excess water include soil water-logging, anaerobicity and reduced plant growth. Indirect impacts include delayed farming operations or implementation when they could cause compaction damage, as in livestock treading and 'poaching'.[11] Agricultural machinery may simply not be adapted to wet soil conditions. Extreme wind events such as intense storms and hurricanes can also cause widespread damage across cropland areas.

Changes remote from production areas may also be critical. Irrigated agricultural land comprises less than one fifth of all cropped area but produces 40-45 per cent of the world's food,[12] and water for irrigation is often extracted from rivers which depend on distant climatic conditions. Some key rivers are fed by mountain glaciers, with approximately one-sixth of the world's population currently living in glacier-fed river basins. Populations are projected to rise significantly in major glacier-fed basins such as the Indo-Gangetic plain and other major irrigated areas such as those near the Yangtze and Nile. As such, changes in remote rainfall and the magnitude and seasonality of glacial meltwaters could impact food production for many people.

Sea-level rise is another potential indirect influence. In low-lying coastal areas, rising seas will inundate agricultural lands and salinize groundwater. Short-lived storm surges can also cause great devastation, even if land is not permanently lost. These impacts will challenge the livelihoods of many millions of people who live near the world's mega deltas. Both marine and freshwater fisheries may also be impacted by change. Positive and negative impacts of warming on fish have been reported.[13] Marine fisheries may be affected by general poleward shifts in ranges determined by temperature, and shifts in the ranges of pathogens and changes in nutrient supply due to altered oceanic circulation. Freshwater fisheries may benefit from increased

The importance of distant water sources for crop production



Areas of cropland and irrigation, with selected major river basins and mountain glacier regions supplying water from distant sources. Future crop production may be influenced by changes in climate both in the immediate vicinity and in other regions, in some cases up to thousands of kilometres away

Source: Met Office, British Crown Copyright

flooding events, or be threatened by declining low flows in drought affected regions.

Further indirect effects on production arise from other biological and ecological impacts. A substantial proportion of potential crop yield is lost due to weeds, pests and pathogens. Averaged over the major world crops, losses have been estimated as 34 per cent from weeds and 18 and 16 per cent from animal pests and pathogens, respectively.[14] The distribution of many pests, diseases and disease vectors is closely linked with climate, particularly temperature. Changes in climate and pest and disease management practices will likely lead to challenges in managing agricultural contaminants (pesticides, veterinary medicines) to avoid negative human health impacts.[15]

Drivers of climate change through alterations in atmospheric composition can also influence food production directly, particularly by impacts on plant physiology. Increasing concentration of carbon dioxide (CO_2) in the atmosphere will enhance the productivity of all major food crops except those using the C4 photosynthetic pathway (for example, maize, millet, sorghum and sugar cane). Many hundreds of crop experiments suggest that a doubling of CO_2 from current levels would lead to increases in yield of approximately one third, on average — although recent studies in field conditions indicate that this may be an overestimate.[16]

Physiological damage to crops by increased ground-level concentrations of ozone (O_3) is also a risk. O_3 concentrations are projected to rise significantly as a consequence of anthropogenic pollution,[17] and reduced yields of key crops have resulted when grown under higher O_3 concentrations.[18] Atmospheric pollution may also impact plant productivity by changing the nature of incoming solar radiation. Increased concentrations of aerosol particles increase the proportion of diffuse solar radiation, which enhances photosynthesis in comparison with direct sunlight. It is suggested[19] that this has increased vegetation productivity in Europe, North America, Africa, India and China by up to $30 gCm^{-2}y^{-1}$.

Impact of climate change on other components of the food system

Food distribution and other post-production aspects of the food system depend largely on a functioning socio-economic system, with transportation, storage and purchasing of food all being key components of the process between production and consumption. Climate change is expected to affect the price of food — for example, cereal crop prices are expected to increase with high levels of global warming due to reductions in productivity, although it is less clear whether lower levels of global warming will increase or decrease prices. Many components of the food system, such as transport and infrastructure, are likely to be more vulnerable to changes in extremes rather than shifts in the mean climate. River and coastal flooding and extreme wind events cause damage to infrastructure, affecting transport and sale of food. Although extreme weather events can directly cost lives through the immediate impacts, such as drowning or serious physical injury, wider humanitarian impacts often occur through the indirect effects of the event acting via a breakdown in the means to distribute food through normal channels.

Food safety can also be threatened by climate change. Higher temperatures increase the need for careful storage, and extreme events pose a threat through increased risk of contamination by water-borne disease during flooding or an increase in crop storage pests and diseases. Moreover, if human livelihoods and incomes are affected through a major extreme weather event, this could impact on food affordability and therefore security.

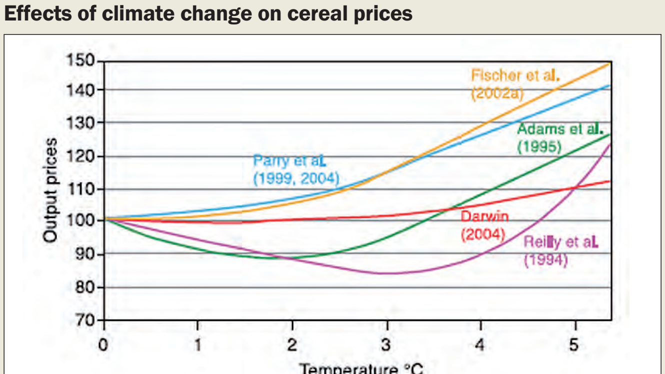
Challenges in forecasting climate change impacts on food security

Past increases in greenhouse gas concentrations have caused detectable warming which has yet to be fully realized, so further warming can confidently be predicted irrespective of whether emissions are cut significantly in the next few years. Global mean temperatures are expected to rise by between approximately 0.5 to 2.0°C by 2050, with regional land temperatures rising more rapidly in most areas. Working Group 2 of the Intergovernmental Panel on Climate Change concluded that global crop production will be threatened by +1°C of warming and begin to decline at +3°C.[20]

Direct consequences of warming, such as increased heat stress and increases in mean sea level are therefore inevitable, although the rates of such changes and local impacts are less certain. While warming is also expected to increase global average precipitation, long-term precipitation changes at regional scales are far more difficult to confidently predict, especially in the next few years to decades when year-to-year variability remains an important factor, before being overridden by major human-induced climate change. Some level of skill in model forecasts of decadal climate change has been demonstrated at the global scale,[21] and at smaller scales in some regions, especially the tropics, but considerable improvements in climate modelling are required before long-term plans can be confidently supported.

The complex interactions between different impacts of climate change also increase the difficulty of forecasting, with much agricultural productivity depending not only on local change but also other areas via factors such as glacier melt, river flows and sea-level rise. The extent to which these changes may be counteracted or magnified by other influences such as CO_2 fertilization, O_3 damage and changes in pests and diseases is also not yet predictable with confidence. Identification of the key drivers of major impacts will be important. An ability to assess changes in the risk of extreme events will be key. The influence of ongoing trends in average conditions may be overridden by a single major extreme event that affects distribution of food across a wide area. Considerable work is currently underway to improve regional-scale monthly to decadal forecasting, especially of the likelihood of extreme events.[22]

Effects of climate change on cereal prices



Projected cereal prices (per cent of baseline) versus global mean temperature change. Prices interpolated from point estimates of temperature effects

Source: Easterling et al. (2007). Copyright IPCC

Adapting food systems to climate change

The main issues will be the rapidity of change and consequent lag in adaptation (human and technological), together with the vulnerability of food crops to extremes. With severe limitations on the ability to forecast many aspects of climate change impacts at the scales required, adaptation measures in the short- to medium-term will need to focus on reducing vulnerability. This can be achieved using a number of approaches, including increasing productivity and improving distribution.[23]

Increased crop productivity may be achieved through the selection of cultivars with traits that facilitate greater resilience, such as more efficient water use, and greater tolerance to temperature extremes, pests and diseases. Changes in management tools and techniques such as irrigation may also assist with adaptation to shifting mean climate states. Implementation of such adaptation will require that climatic changes be discernible enough to prompt action but gradual enough to give adequate response time, or forward planning on the basis of future risk assessment.

Reducing the vulnerability of individual farms' productivity to extreme events may be particularly challenging — for example, it has been suggested[24] that small farmers in Amazonia often lack the long-term knowledge and information on climatic extremes to cope with unusual events such as the 2005 drought. Improved food security may therefore require intervention by local or national government. Adaptation of post-production aspects of food systems may be needed, such as improving the resilience of food distribution infrastructure and communications.

In part this will require adaptation to climate change, but given that resilience is already poor in many areas, improving the ability to cope with existing climate variability is also needed. Some extreme events are relatively localized, so food security can be enhanced by improving distribution networks to ensure that impacts on local productivity are mitigated by access to production elsewhere. This development must take account of potential change, to ensure improved resilience is maintained.

While regional-scale decadal forecasting is still very much in its infancy, seasonal forecasts in some regions such as Ghana and northeast Brazil are already demonstrating predictive skill due to improved understanding and modelling of links between regional weather and sea surface temperatures. There is therefore some scope for the use of seasonal climate forecasting as an adaptation tool, facilitating early warnings of impacts on food production. While there are still many improvements to be made in the scientific capability of seasonal and decadal forecasting, there is also considerable scope for improved pull-through of such forecasts to a wider range of actions on the ground.

Corals and climate change

Angelique Brathwaite, Coastal Zone Management Unit

Corals are the proverbial 'canaries in the coal mine' with respect to climate change, existing within very narrow environmental confines and so responding to even relatively small changes in the environment. Corals are restricted to essentially warm and clean waters with temperatures between 18-36°C (but with an optimal range of 26-28°C), salinity between 3.3-3.6 per cent, moderate wave energy, low nutrients and low sediment loading.

While seemingly fragile, both in terms of their structure and inability to exist under broad environmental parameters, coral reefs have existed on this planet well before humans and have adjusted to suit their changing environment in major ways over geological time. Reefs have formed, even if in different assemblages since at least 37–24 million years ago.[1] In contrast, our present day coral reefs have been existing for a mere 10,000 years and are distinctly different from those that thrived during the Oligocene and the Pliocene times.

With respect to our changing climate, there are four major areas of concern for coral reefs, and the primarily Small Island Developing States (SIDS) that they protect:

- Increased temperatures
- Ocean acidification
- Sea-level rise
- Increased intensity of storms and hurricanes.

Image: Coastal Zone Management Unit

Erosion along the west coast of Barbados, 2009

These are all serious issues for small tropical islands especially since there is no realistic expectation that the major producers of greenhouse gases will change their modus operandi in the near future.[2]

The predictions from the Intergovernmental Panel on Climate Change (IPCC) with respect to these elements are dire, and it is probable that we will continue to lose the enormous benefits of our coral reef ecosystems, such as protection from high energy waves, nutrition from their flora and fauna, medicines, tourism revenues and their stunning, natural beauty if they come to fruition, without major coastal infrastructural works. Of course, one would also hope that the major global emitters of greenhouse gases would change their practices, and reduce their emissions.

Increasing temperatures

Coral bleaching, which occurs when sea surface temperatures exceed the normal summer maximum by 1°C or 2°C for at least four weeks[3] has already had a catastrophic impact globally on coral reef ecosystems. The phenomena occur when the coral animal is stressed and expels its algal symbiont (zooxanthellae), which also produces much of the nutritional requirements the animal needs for growth. The IPCC reports that if all factors remain as they are, the warming trend will continue at a rate of about 0.1°C per decade, due to the slow response time of the ocean. It has also been suggested that as a result of increasing greenhouse gas emissions, temperatures over the tropical oceans will be 2°C and 3°C higher than the 1990 baseline by the 2050s and 2080s respectively.[4] In addition current projections suggest that the situation will only get worse with a prediction that bleaching could become an annual event within the next 30-50 years, with the highest incidence in the Caribbean.[5]

All predictions will have dire consequences for corals as most of them exist quite close to their upper thermal limits, and are already displaying adverse reactions to the increase in temperature. It is expected that coral bleaching will continue and coral diseases will flourish, while the ranges of many species will change and fisheries will be harmed.

Major bleaching events occurred in 1997-98, where 50 per cent of tropical corals were bleached and just about 16 per cent of the world's coral reefs were destroyed. In 2005, the bleaching affected primarily the Caribbean region. In Barbados, 90 per cent of all coral were affected and mortality due to bleaching was estimated at around 20 per cent.[6]

The bleaching phenomenon is an extremely serious matter for all tropical islands like Barbados especially since it doesn't seem that there will be a reversal of the global warming trend, even under the most optimistic future climate scenarios.[7]

Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in pH of 0.1 units.[8] By the end of the century, acidification might be occurring at a rate one hundred times faster, and three times greater than has occurred on our planet during the last 21 million years.[9] This is expected to lead to a reduction in the rates of calcification of reef-building corals by between 14-30 per cent by 2050. If corals are unable to build, rates of bioerosion will exceed that of growth and their infrastructure could essentially crumble.

Sea-level rise

According to the IPCC, sea level rose around 6-7 inches during the twentieth century, which was ten times faster that the rate during the last 3,000 years. They have additionally predicted a 7-23 inch rise in the global average sea level by the 2090s, however many scientists are concerned that the rate will actually be higher, since some recent studies have been showing that the ice sheets of parts of Antarctica and Greenland are melting much faster than previously anticipated.

Coral reefs are expected to respond to sea-level rise in a number of ways, based on their ability to accrete calcium carbonate and the pace of the rise. If reef structure is compromised as a result, then secondary impacts such as beach erosion are likely to follow. Coral reefs are in constant motion, continually accreting and pushing themselves upwards, as well as being bioeroded. According to Neumann and Macintyre corals will respond to sea-level rise in three ways. They will either keep up, catch up or give up. If the rates of accretion can keep pace with the rise in sea level, the reefs will keep up. These are primarily shallow water corals, which maintain their presence in shallow water as the sea-level rises.

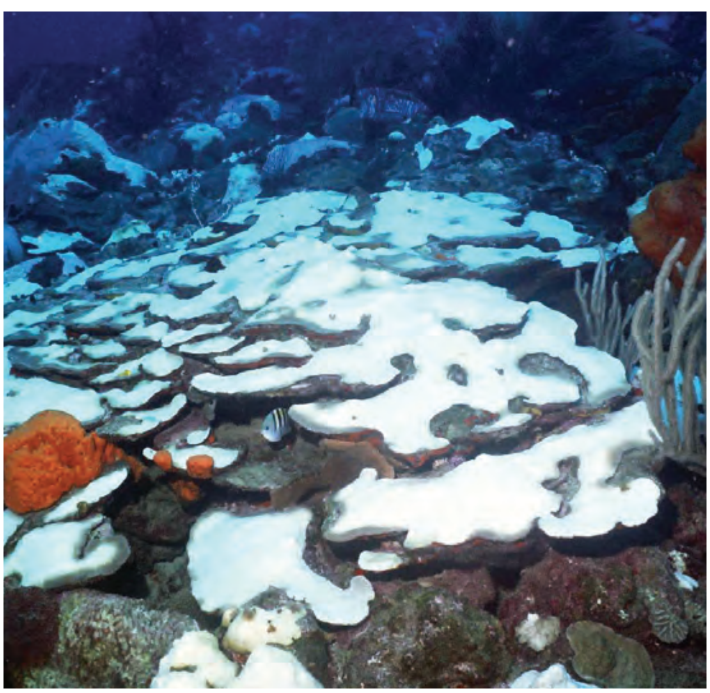


Image: CERMES, University of the West Indies

Bleached colony of *Montastrea faveolata* on Maycocks Reef during the 2005 event

The 'catch up' reefs are those which were initially found in deeper water, but caught up after sea-level rise slowed down. On this type of reef are found younger, shallow water corals growing on top of older deep water corals. The 'give up' reefs are those that have stopped accreting, usually the deeper water corals.

Barbados, unlike many of its neighbours is a relatively flat island and therefore extremely susceptible to inundation from sea-level rise. Most of our critical infrastructure, such as the major hospital, and central police headquarters, lies within a kilometre of the coast, and will be lost if IPCC's prediction comes true, without major preventative works. The island is already experiencing serious levels of coastal erosion and has undertaken major coastal restorative works to protect beaches. On the optimistic side, Barbados appears to be undergoing tectonic uplift, and seems to be keeping pace with sea-level rise. However, if this situation does not last, our 'keep up' and 'catch up' reefs might be experiencing difficulties in the future.

Increased intensity of storms and hurricanes

The IPCC predicts that hurricanes and other extreme weather events will become more severe. Intense wave action generated by such events has already resulted in physical damage to the reef structure as well as sediment smothering, due to runoff resulting from increased rainfall. Moderate storms were thought to have a beneficial effect on reefs by removing the old, sick and otherwise compromised corals, thus clearing the way for new corals to settle. However, present day coral reefs are already impacted by such a plethora of negative factors, that knocking them down at this stage has only resulted in dead corals being overgrown by algae which further limits coral recruitment. Recovery times (from storm damage) have been estimated at around 50 years for Caribbean reefs, however this period will most likely have to be extended due to the prevalence of other impacts such as bleaching, disease and over growth by algae.[10]

Coral reefs have already experienced sea level changes, ice ages and other extreme climatic conditions. It is as yet unclear, if the climate induced stresses being exerted on present day coral reefs are merely a part of the global boom or bust cycle as described by Hubbard[11] or if they are experiencing unprecedented new stresses, which together could result in the annihilation of our coral reef ecosystems. That question remains unanswered as we continue to tackle the issue of reducing atmospheric carbon dioxide as well as other anthropogenic impacts such as nutrient and sediment loading, physical damage and overfishing on coral reefs.

What is clear, however is that coral reefs as we know them will cease to exist, along with their accompanying ecosystem services, unless serious measures are taken now to reduce levels of carbon dioxide. According to Wilkinson and Souter[12], warming from past greenhouse gas emissions has already committed us to more bleaching events by the 2030s. However, if the greenhouse gases are dramatically reduced within the next 20 years, and with careful management of the coral reef resources that exist presently, we might be able to preserve some of this important ecosystem.

Climate change and tourism: facing the challenges

Luigi Cabrini, Director, Department of Sustainable Development of Tourism, World Tourism Organization

Compelling evidence indicates that the global climate has changed considerably since the pre-industrial era.[1] According to the Intergovernmental Panel on Climate Change (IPCC): "Warming of the climate system is unequivocal".[2] Furthermore, the climate is anticipated to continue changing over the 21st century and beyond. The IPCC projected that the pace of climate change has a greater than 90 per cent probability of accelerating if greenhouse gas (GHG) emissions continue at or above the current rates. As a consequence of this change, the frequency and intensity of extreme events — such as heat waves, tropical cyclones or heavy precipitations — is also very likely to increase. Even if atmospheric concentrations of GHGs were stabilized at current levels, the Earth would continue to warm as a result of past GHG emissions and the thermal inertia of the oceans.[3]

Due to its close connections with the environment the tourism industry and tourist destinations are clearly sensitive to climate variability and change.[4] The climate defines the length and quality of tourism seasons as well as playing a major role in destination choice and levels of tourist spending. As such, climate changes will unmistakably affect the tourism sector. Indeed, the necessity for awareness and preparedness at a local level — through systematic capacity building and strategies for disaster risk — has already been highlighted by numerous tourism destinations.

Image: Becken, S

Coastal erosion and sea wall protection on a beach in Fiji

Tourism in the era of global climate change

The tourism community's concern regarding the challenge of climate change has visibly increased over the last few years. The World Tourism Organization (UNWTO) and several partner organizations convened the First International Conference on Climate Change and Tourism in Djerba, Tunisia in 2003. The Djerba Declaration recognized the complex inter-linkages between the tourism sector and climate change, and established a framework for future research and policy making on adaptation and mitigation. Climate affects a wide range of the environmental resources that are critical attractions for tourism, such as snow conditions, wildlife productivity and biodiversity, as well as water levels and quality. Climate also has an important influence on environmental conditions that can deter tourists, including infectious disease, wildfires, insect or water-borne pests (such as jellyfish and algae blooms), and extreme events such as tropical cyclones.

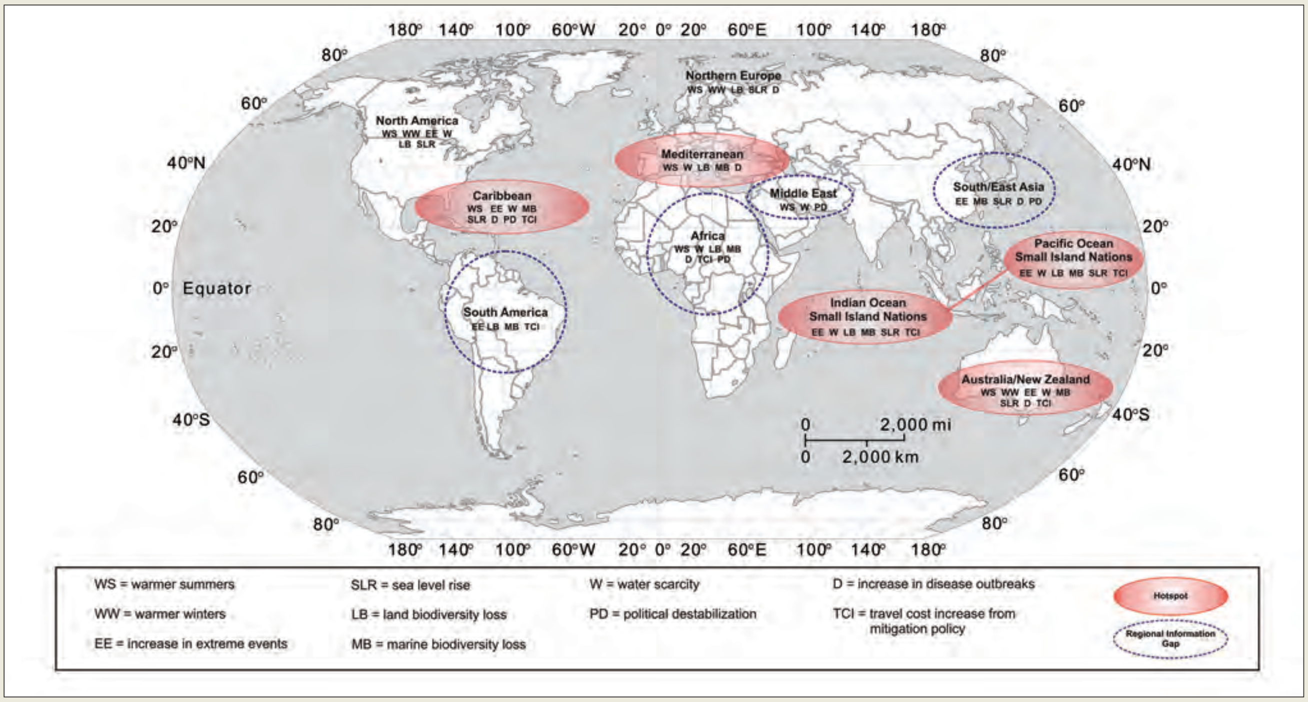
There are four broad categories of climate impacts that will affect tourism destinations, their competitiveness and sustainability:[5]

Direct climatic impacts — Climate codetermines the suitability of locations for a wide range of tourist activities, is a principal driver of global seasonality in tourism demand, and has an important influence on operating costs, such as heating/cooling, snow-making, irrigation, food and water supply, and insurance costs. Thus, changes in the length and quality of climate-dependent tourism seasons ('sun and sea' or winter sports holidays) could have considerable implications for the competitive relationships between destinations, and therefore the profitability of tourism enterprises on the whole.

Indirect environmental change impacts — A wide range of climate induced environmental changes have profound effects on tourism at the destination and regional level. Changes in water availability, biodiversity loss, reduced landscape aesthetic, altered agricultural production, increased natural hazards, coastal erosion and inundation, damage to infrastructure and the increasing incidence of vector-borne diseases will all impact tourism to varying degrees.

Impacts of mitigation policies on tourist mobility — While seeking to reduce GHG emissions, national and international mitigation policies are likely to have an impact on 'tourist flows'. They could lead to an increase in transport

Geographic distribution of major climate change impacts affecting tourism destinations



A summary assessment of the most at-risk tourism destinations for the mid to late 21st century. Due to the very limited information available on the potential impacts of climate change in some tourism regions, this qualitative assessment must be considered with caution

Source: UNWTO, UNEP and WMO (2008)

costs and may foster environmental attitudes that lead tourists to change their travel patterns (for example, shift transport mode or destination choices). There has been substantial recent media coverage on this topic, specifically as it relates to air travel. Long-haul destinations can be particularly affected and officials in Southeast Asia, Australia, New Zealand and the Caribbean have expressed concern that mitigation policies could adversely impact their national tourism economy.[6]

Indirect societal change impacts — Climate change is thought to pose a risk to future economic growth and to the political stability of some nations.[7] According to the Stern report on the economics of climate change, although a global warming of only 1°C might benefit worldwide gross domestic product (GDP), greater climate change would eventually damage economic global growth. Furthermore, unmitigated climate change could cause a reduction in consumption per capita of 20 per cent later in the 21st century or early 22nd century. Any such reduction of global GDP due to climate change would reduce the discretionary wealth available to consumers for tourism and have negative implications for anticipated future growth in tourism. However, there has been no in-depth interpretation of the Stern report[8] with regards to the tourism sector.

The integrated effects of climate change will have far-reaching consequences for tourism businesses and destinations. Changes in temperature and other important features of climate will manifest themselves differently across the regions of the world, generating both negative and positive impacts on the tourism sector. These impacts will vary substantially by market segment and geographic region. The implications of climate change for any tourism business or destination will also partially depend on the impacts on its competitors. A negative impact in one part of the tourism system may constitute an opportunity elsewhere. Consequently, there will be 'winners and losers' at the business, destination and national level.

Contribution of tourism to climate change

The tourism industry uses energy in several activities such as transportation and accommodation. As in many other economic sectors, most energy use in tourism is based on fossil fuels. Climate change is caused by GHG emitted into the atmosphere — primarily through the burning of fossil fuels. As such, the tourism sector is not exempt from contributing to the process of global warming.

Carbon dioxide (CO_2) is the greenhouse gas that contributes the most to climate change, accounting for an estimated 60 per cent of the warming caused by GHG emissions.[9] The reported volume of CO_2 emissions attributed to tourism varies considerably depending on, among other factors, the definition of what constitutes 'tourism'. According to UNWTO's, tourism refers to: "The activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited."[10]

Given this definition, emissions from tourism, including three main sub-sectors — transportation, accommodation and activities — are estimated to represent close to 5 per cent of global CO_2 emissions in 2005. From the total CO_2 emissions contributed by tourism in that year,

Image: Scott, D

Electric vehicle fleet for tourists in Werfenweng, Austria

transport generated around 75 per cent, with approximately 40 per cent being caused by air transport alone. CO_2 is not the only cause of climate change, with other GHGs and the 'radiative effect' also making significant contributions to global warming. There are however wide discrepancies in calculations of their impact on climate change.

Estimated emissions from global tourism in 2005, including international and domestic tourist trips, as well as same-day visitors

	CO_2 (Mt)
Air transport	515
Car	420
Other transport	45
Accommodation	274
Activities	48
TOTAL	1,302
Total world	26,400
Share (%)	4.9

Colours represent the degree of certainty with respect to the data and underlying assumptions. Green represents a degree of uncertainty of +/-10 per cent, blue +/-25 per cent and red +100 per cent/-50 per cent. 'Total world' indicates annual fossil carbon dioxide emissions (including those from cement production), according to IPCC, The Physical Science Basis

Source: UNWTO, UNEP and WMO (2008)

Mitigation policies and measures

Continued growth of tourism-related emissions is projected under 'business-as-usual' conditions, so mitigation policies are vital for the industry. Such policies need to consider several dimensions including: the need to stabilize the global climate; people's right to rest, recovery and leisure; and the United Nations Millennium Development Goals.

Climate change mitigation relates to technological, economic and socio-cultural changes that can lead to reductions in GHG emissions. As the reductions required from tourism to contribute meaningfully to the broader emission reduction targets of the international community are substantial, mitigation should ideally combine various strategies — such as voluntary, economic and regulatory instruments. These can be targeted at different stakeholder groups including: tourists; tour operators; accommodation managers; airlines; manufacturers of cars and aircraft; and destination managers. Instruments could also be applied with different emphasis in different countries, so as not to jeopardize the opportunity to reduce poverty offered by tourism in developing countries.

It is possible to distinguish four major mitigation strategies for addressing GHG emissions from tourism:

Reducing energy use — One of the most essential aspects of mitigation. It can be achieved by changing destination development and management practices, as well as altering transport mode (for example, more use of public transport, or shifting from car and aircraft to rail and coach). Tour operators can play a key role in this process, as they bundle products and can have considerable influence on demand for less carbon intensive journeys by creating attractive products that meet tourists' needs and desires. UNWTO hosts the secretariat of the Tour Operators' Initiative for Sustainable Tourism Development, which seeks, among other objectives, to encourage initiatives and efforts to achieve sustainable development across all sectors of the tourism industry.

Improving energy efficiency — The use of new and innovative technology can significantly reduce emissions and energy demand.

Increasing the use of renewable energy — The substitution of fossil fuels with renewable energy sources is particularly important for island destinations, where energy supply based on fossil fuels is expensive and at risk of supply interruption.

Sequestering CO_2 through carbon sinks — Within the tourism industry this is currently practiced through carbon compensation or carbon offsetting, which means that an amount of GHG emissions equal to that caused by a certain activity will be reduced elsewhere (for example, through reforestation).[11]

In order to estimate how emission pathways in the global tourism sector might develop in the future, a team of experts has developed several scenarios considering different mitigation options. The 'business-as-usual' scenario (which takes into account the UNWTO's Tourism 2020 Vision forecast of an average 4 per cent annual growth of international tourist arrivals up to 2020) predicted that CO_2 emissions in the global tourism sector will experience a growth of 161 per cent by 2035. If the maximum possible technological efficiencies were achieved for all transport modes, accommodations and activities 38 per cent lower emissions would be generated. In the case of reducing energy use by a combination of transport modal shifts, shifts to shorter haul destinations and increasing average length of stay emissions could be reduced by 44 per cent. Under the most effective mitigation projection, using a combination of technological efficiencies and energy reduction, the 'business-as-usual' scenario emissions of 2035 could be reduced by 68 per cent.[12]

Mitigating the contribution of tourism to climate change is a pervasive issue that is addressed by many of the programmes and initiatives supported by the UNWTO. For instance, UNWTO coordinates the Hotel Energy Solutions project (former EETI). The programme seeks to deliver training, information and technical support to help small and medium size hotels across the 27 UE countries increase their energy efficiency and use of renewable energy. The project aims to increase energy efficiency by 20 per cent and use of renewable energy by 10 per cent.

Adaptation in the tourism sector

In order to minimize the risk and to capitalize upon the opportunities offered by climate change, all tourism businesses and destinations will need to adapt in an economically, socially and environmentally sustainable manner. At the Second International Conference on Climate Change and Tourism in Davos, Switzerland in 2007, special sessions were dedicated to climate change adaptation in different types of vulnerable destinations including: coasts, islands, mountain regions and nature-based destinations. The Davos Declaration acknowledges the need to adapt to changing climate conditions and calls for specific actions by different tourism stakeholders.

Although the capacity of the tourism sector to adapt to climate change is relatively high due to its dynamic nature, adaptive capacity varies substantially both within and between stakeholder groups — depending on financial resources, technical knowledge and capacity to move. Due to their relative freedom to avoid destinations impacted by climate change, or to shift the timing of travel to avoid unfavourable climate conditions, tourists have the greatest adaptive capacity. Large tour operators, who do not own the infrastructure, are in a better position to adapt to changes at destinations because they can respond to clients demand and provide information to influence clients' travel choices. Suppliers of tourism services and tourism operators at specific destinations have less adaptive capacity. On the other hand, destination communities and tourism operators with large investments in immobile capital assets have the least adaptive capacity.

The most vulnerable destinations will require assistance to adapt. UNWTO particularly supports the Least Developed Countries and Small Island Developing States (SIDS) schemes. In these locations persistent poverty and environmental needs are expected to exacerbate the adverse consequences of climate change, and adaptive capacity is relatively low due to limited financial resources and technical knowledge. Unfortunately, such areas are also often highly dependent on tourism. In order to implement adaptation measures and disseminate good practices, UNWTO is assisting the integration of tourism as a means of economic diversification into national adaptation strategies through a series of pilot projects. The pilot projects are expected to deliver replicable outputs, as SIDS and other coastal destinations have similar climate and tourism challenges — such us shoreline and beach erosion, reduced water availability, interrupted supply chain, coral bleaching and physical damage to property due to extreme climatic events. The aim is to enhance the resilience of the tourism sector to climate change by demonstrating adaptation initiatives — initiatives that will enhance the ability of operators and tourism dependent communities to respond to these challenges.

Image: Great Barrier Reef Marine Park Authorities

Coral bleaching in the Great Barrier Reef

Overview of the relationship between climate and tourism

Our lifestyles, economies, health and social well-being are all affected by climate change — and all nations and economic sectors will have to face the challenges it represents. Tourism is no exception, indeed, it is a highly climate-sensitive economic sector due to its close connections to the environment and climate itself. However, tourism not only suffers the effects of climate change, but also contributes to it through the emission of greenhouse gases — mainly CO_2 — to the atmosphere. This demands adaptation and mitigation strategies aimed at preventing and adapting tourism destinations to climate change consequences, as well as at reducing the contribution of the tourism sector to this phenomenon. Using a broad range of technological, educational and managerial measures the tourism sector has been adapting its operations to climate zones worldwide — however, much more needs still to be done.

The importance of identifying measures to address climate change should not however jeopardize the tourism sector's role in contributing to the achievement of the United Nations' Millennium Development Goals, especially poverty alleviation.[13] A meaningful and effective response to the challenge of climate change must be integrated within the broader agenda of sustainable development.

These are the main principles inspiring the 'Davos Declaration Process' promoted by UNWTO and aimed at actively involving tourism stakeholders in the identification and application of adequate responses to the challenges of climate change.

Managing climate related health risks

S.J. Connor, International Research Institute for Climate and Society

Good health status is one of the primary aspirations of human social development. Consequently, health indicators are key components of human development indices — for example, the Millennium Development Goals (MDGs), by which we measure progress toward sustainable development.[1] Certain diseases and ill health are associated with particular environmental, seasonal and climatic conditions. This was recognized by the ancient writers of Vedic literature, and by Hippocrates, but largely overlooked during the development of modern medicine. However, community and public health services are showing increased awareness of these associations, and climate and health interactions are the focus of considerable research today. During 2008, many high-level policy recommendations were made on the importance of climate and environmental change and its potential impacts on health. Climate and health was the topic of World Health Day and a special resolution on climate and health was passed by the 61st World Health Assembly.[2]

Climate impacts on health through a number of mechanisms. This may be directly, through cold or heat stress, or indirectly through its impact on communicable and non-communicable disease. Climate and weather extremes cause hazards, drought, food insecurity, social disruption and population displacement — leading to greater exposure to malnutrition, diseases or accidental death. The World Health Organization (WHO) recently identified 14 climate sensitive communicable diseases, including malaria, meningitis, cholera and dengue. WHO describes these diseases as being candidates for the development of climate informed early warning systems. WHO also acknowledges that many non-communicable coronary and respiratory diseases are climate sensitive.[3] Using research evidence to guide the creation of effective health policy has been strongly promoted in recent years through, for example, the Cochrane systematic reviews.[4]

Before using climate information in routine decision making, health policy advisors and decision makers should ask for evidence of the impact of climate variability on their specific outcome of interest. They should also investigate whether using climate information is a cost-effective and practical means to improve health outcomes.

This demand asserts the importance of evidence in effective policy making while placing climate in a broader context as one amongst several imperatives. If evidence is to have a greater impact on policy and practice, four key requirements are necessary:

- Agreement on the nature of acceptable evidence
- A strategic approach to evidence creation, together with the development of a cumulative knowledge base
- Effective dissemination and access to knowledge
- Initiatives to increase the uptake of evidence in both policy and practice.

Improving routine health surveillance is clearly one essential component of this strategic approach, but more effective partnerships need to be developed to integrate the climate factor effectively. The following examples, both from the more developed and less developed countries, illustrate this.

Respiratory disease and heat stress in the temperate zones

There are numerous studies linking atmospheric air quality and airborne particulate matter (airborne PM: particulate matter less than 10 micrometres in size) to aggravated cardiac and respiratory diseases (such as asthma, bronchitis and emphysema) and various forms of heart disease. A strong correlation exists between high levels of airborne PM and increases in emergency room visits, hospital admissions and fatalities. Children, the elderly and people with respiratory disorders are particularly susceptible. Meteorological services are able to provide routine information to help mitigate this problem.

For example, the Canadian Meteorological Service produces a daily air quality forecast. Air quality is expressed using an Air Quality Index. Air Quality Advisories are issued when the air pollution levels exceed national standards. They are issued in partnership with provincial and municipal environment and health authorities, and contain advice on action that can be taken to protect health and the environment. A cornerstone of this process is the development of relevant and timely health messages that allow Canadians to safeguard their own health, as well as the health of those in their care, and to motivate change in improving air quality in their communities over the medium- to longer-term. Similar activities are taking place across the border in the United States, as well as in Europe.

The European heat wave during the summer of 2003 was associated with an estimated 45,000 excess deaths, with more than 15,000 of these occurring in France alone. Following this event, the European Office of WHO, with funding from the European Union (via Euro-Heat), joined research institutions, health care providers and many of the National Meteorological Services in studies to establish the factors and mechanisms responsible. This information was then used to set up early warning systems to increase public awareness and to reduce vulnerability and associated risk.[5]

The socioeconomic factors related to heightened risk and vulnerability are complex but include age, existing medical conditions, poor levels of physical fitness, urban residence, air quality and poor ventilation. The climatic factors involved focus largely on the stability and persistence of elevated temperatures, relative humidity and cloud cover — where these create a high local heat stress index. Météo France, a Euro-Heat partner, declared July 2006 as the warmest on record. Yet figures suggest that heat related deaths in France numbered only a few hundred, and for Europe a few thousand. While this was extremely good news, and suggests that early warning systems might be contributing to this reduction, the importance of socioeconomic factors with regards to climatic factors is yet to be clearly understood. While heat early warning systems offer benefits in the immediate-term more should be done to encourage greater promotion of insulation, ventilation and improved home design by urban planners and buildings regulators. By managing current climate risk and lowering vulnerability public health and allied services provide examples of adaptation to a changing climate.

Epidemic disease in the tropics

Malaria and dengue are vector-borne diseases associated with tropical regions — however, their persistence in the tropics is strongly related to poverty and under-development. Malaria was rife in Europe and North America prior to its eradication between 1940 and the 1950s. It is now widely recognized that malaria is a major constraint to both socioeconomic development and the MDGs in Africa, where an estimated 90 per cent of all malaria deaths, and immeasurable sickness occurs. Approximately 500 million Africans live in regions endemic to malaria. Endemic malaria is highly correlated with climate in terms of its spatial distribution and its seasonality. A further 125 million Africans live in regions prone to epidemic malaria, which is again highly correlated with climate, but in this case, with climate anomalies. Significant resources are now being made available to control malaria in African countries through the Global Fund for AIDS, TB and Malaria. It is considered that climate information could be used to help focus these resources more effectively.

While significant gaps have been identified between climate services and end-users in Africa, a number of African countries seek to use climate information as part of integrated epidemic early warning and response systems. The most advanced example can be found in Botswana where the National Malaria Control Program uses tailored seasonal climate forecasts and weather scale information received through the National Meteorological Services as part of an effective Malaria Early Warning System. State-of-the-art seasonal forecasts derived from the EU's Framework 5 and Framework 6 DEMETER and ENSEMBLES project have been produced at the Southern African Development Community's Drought Monitoring Centre and made available to the Ministry of Health and the WHO Intercountry Team for Malaria Control in Southern Africa. The forecasts, which have shown predictability of high (and low) malaria years with five months lead-time,[6] are followed with rainfall routine monitoring products, which add confirmation of risk and more geographical focus, with high predictability at one to two months lead-time.[7]

Botswana's example has been promoted by WHO to encourage other African countries to follow suit and there are clear signs of improved management of epidemic malaria in the region.[8] This has been managed to some large extent through the Malaria Outlook Forums with their special focus on providing appropriate climate information to the national malaria control programmes in Southern Africa.[9] Preliminary economic studies also show strong potential for cost advantage of using climate information to guide the extent of malaria control activities in this region.[10]

However, if such initiatives are to perform at the scale required, including the densely populated highland fringe epidemic settings where the interplay between rainfall, temperature and humidity is more complex, then significant interdisciplinary research and collaboration is essential. Appropriate training must be provided, and mechanisms developed across disciplines, to address socioeconomic vulnerability to severe disease outcomes. Recent initiatives in a number of African countries (Ethiopia, Kenya and Madagascar) have centred on the establishment of Climate-Health Working Groups (CHWGs). The CHWGs are multi-agency partnerships — in each case chaired by the Ministry of Health and co-chaired by the National Meteorological Services — with members drawn from supporting agencies (UN agencies, and governmental and non-governmental organizations) providing broad support to the health sector.[11] These multi-agency initiatives offer a good opportunity to elicit broad needs for climate risk management and stimulate demand for the development of appropriate training and services.

Concerns over climate change have heightened the urgency of achieving significant advances in disease reduction and health care delivery. Increasing urbanization has led to the situation where more than half of the world's population are living (formally and informally) in cities and their margins. Dengue is emerging as a major threat to urban and peri-urban populations in Asia and Latin America. Uncertainty in understanding the impact of a warming climate on regional rainfall distributions has major implications for rain-fed agriculture, water resources, food security and malnutrition among the rural poor; each of these poses its own unique set of challenges regarding climate-health policy recommendations and guidelines for practice in improving and maintaining health outcomes.[12]

While there are promising examples demonstrating the basis of climate risk management in the health sector, much more needs to be done in building research capacity and developing appropriate educational curricula. Currently there are few boundary institutions able to provide the level of training required at this interface, and this requires significant investment if we are to have new generations of appropriately trained professionals ready and able to tackle the risks of a constantly changing climate.

Image: James Gathany/2004

Anopheles freeborni takes blood from a human host

Climate change migration from low-lying small island communities

David King, Director of the Centre for Disaster Studies, and Scott Smithers, Associate Professor in the School of Earth & Environmental Sciences, James Cook University

Climate change research has recorded increases in surface temperatures and evidence of sea-level rise.[1] While there is great debate about climate change projections, problems of sea level inundation have already been experienced in low-lying small islands in the Indian and Pacific oceans. Sea flooding in these communities has initially occurred as storm surges from hurricanes, cyclones and distant storms accompanied by high tides, producing episodes of intense inundation and erosion. It has taken the momentum of evidence during this decade to move governments and institutions to acknowledge the need for adaptive action, although much of the human population probably remains largely unaware. Making people aware of the changing environment and climate requires a number of complex processes. As F. Duerden comments: "Personal experience takes place in a limited timeframe, making it difficult to separate long-term change from aberrations."[2]

Those remote and rural communities that are dependant on local resources face adaptation, which may make them especially vulnerable. Handmer et al[3] make the point that globally, adaptation is effective, but that at the local level vulnerability is extremely unequal. Some populations simply will not survive in their current locations. This introduces migration as an adaptive strategy — certainly not part of emergency management thinking, which is focused on relatively static local communities. Low-lying islands and coastal areas, particularly atoll groups in the Indian and Pacific oceans, are the first environments to face the threat of inundation from rising sea levels. Some communities already face the prospect of migration away from their homelands. These are either spontaneous individual or household decisions, or planned relocations by communities or government institutions.

Image: Scott Smithers

High tides and storms cause flooding at Takuu in the Mortlock Islands, Papua New Guinea, December 2008

What physical processes are taking place in low elevation small island communities?

Low-lying reef islands are dynamic landforms that are especially sensitive to the changes in wind, waves and water level that occur normally from season to season and within the natural variability of local climate conditions.[4] They are also sensitive to changes in shoreline processes and sediment movement to and around their shores. This includes islands associated with both traditional and engineered shoreline protection or reclamation activities. The recent experience of many island communities is one of marked shoreline change, coastal erosion and loss of island area into the sea. The impacts of these changes are often compounded by two factors. First, is the breach of a higher natural berm that typically encircles the lower central parts of many reef islands, allowing the sea to flood into the island core during higher tides and storms. Second, population growth on many islands means that settlements may now occupy island areas long known to be vulnerable to periodic flooding.[5]

Whether recent erosion and inundation is driven by climate change impacts is a moot point, although it is known that many island communities fear that recent changes are the beginning of a trajectory of decline and that submergence is, ultimately, inevitable. Wave inundation associated with extreme high tides, elevated sea levels associated with a strong La Niña, and two large storms in the region affected broad areas of the western Pacific in December 2008, eroding shorelines, washing away houses and infrastructure, flooding food gardens and contaminating water supplies. This event can be explained by the unlucky coincidence of three factors that may be unrelated to climate change — although it may be argued that they have become more intense and frequent as a consequence of it. Indeed, washover events have been experienced before — one recent occurrence has been associated with the Chilean tsunami. However, this event appears to have been viewed differently by many island communities — a prelude of what is to come — and clearly something that they do not want to face again.

Image: Jeffrey Holdaway

Small atoll communities are particularly vulnerable to flooding

Migration and resettlement schemes

Pacific and Indian Ocean island countries such as the Maldives, Tuvalu and Kiribati are especially vulnerable to sea-level rise and have already experienced its impacts. The media has, in the past, made reference to climate change refugees and the disappearance of these three nations as their limited land area is engulfed by the sea. Equally vulnerable are small atoll communities that are part of larger island states such as Papua New Guinea, Solomon Islands and Fiji. While small nations like Tuvalu contemplate not only the loss of their homeland, but their independence and sovereignty if they are forced to relocate, the consequences are no less dire for remote communities such as the Carteret, Mortlock and Tasman islands in Papua New Guinea, whose populations have maintained strong cultural autonomy in the absence of much outside support.

In the face of increased erosion and inundation, individuals, households and communities face the prospect of emigrating from their homelands. Although, Pacific islanders have been migrating to larger centres for decades to seek opportunities and services that they are unable to access at home.[6] Many island governments including Tuvalu have encouraged migration, as absentees remit earnings to support their family at home and provide a cultural and socioeconomic base for subsequent migrants.

Outmigration in the Pacific, therefore, is not a new phenomenon related to climate change. Factors such as the lack of development coupled with population increase, pressure on resources and consequent degradation of soil, land and vegetation has all contributed to immigration. Alongside spontaneous internal and international migration, government schemes have also been working to resettle populations within countries. Both the Maldive and Papua New Guinean governments practise population resettlement, which has recently been identified as 'climate change migration'.[7]

The Republic of Maldives government allocates populated islands to tourist resorts, transferring responsibility for infrastructure and service provision to tourism companies. At the same time, action has been taken to separate resorts from the indigenous population with the aim of protecting culture. More recently,

The Carteret Village at Kuveria Atolls Resettlement Scheme, Bougainville in 1987

the Maldives has initiated a regional planning policy of consolidation of government services. Instead of providing a range of services on all inhabited islands, a wider range of services is provided on a smaller number of more highly populated islands in order to reduce government costs. People on more remote and sparsely populated islands will be accommodated on the destination islands, where the increased number and density of people makes services more economically viable. Forced relocation was never a part of this plan.[8] As the Indian Ocean tsunami occurred during this planning process, it also became necessary to identify safe islands that were less vulnerable to surges and destructive waves. Thus, anticipation of climate change and rising sea levels has influenced a planning process that was initially concerned with a more efficient provision of government services, in a country with limited resources.

The Tulun (Carteret) islanders in Papua New Guinea have been labelled by the media as the world's first climate change refugees, but it must be acknowledged that their own non-governmental organization leader has also used the issue to publicise their plight. Throughout 2009, families started relocating to resettlement sites on the mainland of Bougainville. This is a resettlement that began many decades ago. Colonial government officers first identified a population and resource crisis in the Carteret Islands during the 1960s.[9] By the early 1980s, the government of the North Solomons province, which contains Bougainville and the Carterets, drew up a policy paper identifying problems including storms, erosion, population pressure, and food shortage affecting the Carteret, Mortlock, Tasman and Nissan islands. In response to this, a resettlement site was designed and built at Kuveria in Bougainville. Carteret islanders first started relocating in 1984, because their population and resource crises were the most extreme. This scheme continued until 1987, when civil war broke out on Bougainville. However, Tulun families had already by that time begun to drift back to their original homeland.[10] The civil war and loss of all services sealed their desire to return home. The population and land crises in the Carterets did not change, and as peace returned to Bougainville a new resettlement scheme was developed. Adaptation to this new site will prove just as dramatic this decade, and provincial government funding is much less generous than it was in the 1980s. Thus, the experience of the Carteret islanders constitutes a lengthy environmental crisis that began with population pressure and has been exacerbated by the more general erosion of the very small low-lying islands.[11]

Migration can be interpreted as a response of individuals and communities to the negative impacts of climate change, but it takes place within the complex dynamics of social change, population increase, raised expectations and environmental degradation. Where survival is seriously compromised, as in the Carteret islands, a formal resettlement scheme will assist the population to retain its identity and culture, albeit in a transformed state. It is important that such group migrations are well supported and closely monitored, as the social impacts need to be clearly understood if much larger populations have to be relocated in the future. In the meantime, it is important to recognise that communities face a complex range of hazards and environmental and economic issues in which climate change is one of many factors.

Climate in the Pacific: building capacity for climate services

Janita Pahalad and William Wright, Bureau of Meteorology, Australia

Pacific Island Countries (PICs) are largely dependent on the natural environment and natural resources for their socioeconomic sustenance. Agriculture, fisheries, tourism, mining — and forestry in some of the larger more elevated islands — are the main economic sectors for most PICs, and subsistence lifestyles dominate the activities of many rural communities. Both subsistence economies and commercial activities are dependent on the natural resources of the land and the sea. The transport sector is important and is affected directly by severe weather events and persistent climatic abnormalities. Reliable sea and air transport is essential to the well-being and development of the region, due to the vast distances between island producers and both their internal and export markets, and to bring tourists to the islands.

The poor and highly permeable soils of many islands and all island landscape processes are sensitive to weather and climate fluctuations. Effectively used, weather and climate information provided by National Meteorological and Hydrological Services can contribute significantly to the success of almost all PIC national activities, especially economic activities aimed at reducing poverty. Timely and accurate seasonal climate prediction services, in particular, can contribute substantially to social well-being and economic development.

The climate of the Pacific is strongly influenced by the El Niño-Southern Oscillation (ENSO) phenomenon, which leads to significant interannual variability in the frequency of many extreme weather types in the region, such as tropical cyclones, floods and droughts. ENSO can also cause significant fluctuations in sea level affecting island coastal zones and especially the very many coral atolls, which have little or no elevation. Today, climate models can simulate some key aspects of interannual and interdecadal variability in climate variables when forced by historical SSTs (sea surface temperatures). Management of the risks associated with seasonal and interannual fluctuations, and the likely even greater impacts of climate change, would benefit from the development of a within-country capacity to generate seasonal predictions, and its application to the many challenges in adapting to climate change.

Pacific Island communities are already being challenged by economic and demographic changes taking place throughout the world. Climate change too is already being observed throughout the region and its effects, including sea-level rise, will very likely influence the frequency and intensity of extremes in the region. The superimposition of these multiple external influences will have profound consequences on the region unless they are dealt with systematically and comprehensively through in-country actions reinforced by well-targeted donor support programmes.

Pacific Island Climate Prediction Project

Acknowledging that seasonal to interannual climate variability has important practical, planning and policy implications for PICs, in 2003 the Government of Australia commenced the Pacific Island Climate Prediction Project (PI-CPP). The aim of the project, managed and implemented by the Australian Bureau of Meteorology, has been to expand and enhance the prudent use of information derived from SCOPIC,[1] a climate prediction software package introduced by the project into the meteorological services of ten PICs.[2] The incorporation of objectively derived climate information — including predictions — into decision-making processes within client/stakeholder agencies of the participating PICs has been a major focus of the project. The value of climate prediction information has been demonstrated through a number of pilot schemes that have involved in-country training of both meteorological personnel and stakeholders receiving and applying the information.

One such pilot scheme involved the application of climate forecasts for improved management of drought and crop production (sweet potato) in Papua New Guinea (PNG). Throughout the Pacific and in Pacific rim countries, including PNG and eastern Australia, the teleconnections of climate anomalies associated with El Niño and La Niña events are sufficiently strong and reliable for decision making in activities and industries sensitive to climate variability. Individuals, communities and governments can all develop and apply appropriate seasonal response strategies to mitigate the harmful impacts, or enhance potential benefits arising from, periods of climate extremes. The long-term goal of this pilot project is to identify the underlying environmental, economic and social impacts of drought (and floods) on local agriculture and, with the aid of seasonal forecasting, develop strategies that will reduce vulnerability to expected harmful climatic periods, or enhance productivity when climatic outcomes are expected to beneficial.

Another pilot scheme explored the relationship between ENSO and incidence of malaria in the Solomon Islands. In the Solomon Islands malaria is one of the leading causes of morbidity; *Plasmodium falciparum*, the most severe and life-threatening form of the disease, accounts for approximately 60-70 per cent of all confirmed cases. Since the late 1990s reports of malaria have risen sharply in several prov-

Climate data rescue efforts in the South Pacific started with the physical sorting and archiving of the paper-based records and storing them in acid free boxes to minimize further deterioration

inces, particularly in 2003 and 2004. Malaria is now also being reported at higher altitudes. This pilot project aims to determine whether malaria epidemics in the Solomon Islands are related to rainfall and other hydro-climatic variables during particular phases of ENSO, and then to determine whether or not such relationships can be used to develop an early warning system for predicting heightened risk of a malarial epidemic, and therefore assist in implementing targeted control strategies.

A third pilot scheme looked at sugarcane in Fiji: The sugar industry in Fiji is totally rain fed (which is to say totally unirrigated); consequently seasonal to interannual climate variability has a major impact on sugar production and hence on the economy of the nation. To maximize yields, it is therefore essential to understand how different climatic patterns affect sugarcane growth and sugar yields, and to develop management options that take into account the likely climatic effects of an upcoming season. Fiji's sugarcane productivity is especially vulnerable to extreme events such as droughts and tropical cyclones, and the need to adapt to climate change has added another challenge to the industry. This pilot project aims to devise an effective mechanism for disseminating climate information directly to the farmers in a format that will be easily understood and can be applied in making decisions relating to planting, replanting and harvesting.

Communication and trust

The project has also conducted in-country workshops on improving the communication skills of meteorological personnel in dealing with the media, in conducting public awareness campaigns and in working with government agencies and industry groups that utilize the climate information products.

Building effective dialogue between Meteorological Services and the users of their information throughout the various climate sensitive sectors has been recognized as critically important to the overall success of the project. Reaching out to the grassroots level is especially challenging, as there is also a need to link climate information with traditional knowledge and indicators.

Fostering trust between provider and user can be encouraged in several ways; regular face to face contact instils a sense that the user is a valued client and not just one of a collective and anonymous group; personalized emails or phone calls are particularly effective as well. Trust also depends on honesty, for example by communicating the uncertainties and limitations of seasonal forecasts. Users are generally willing to accept climate information in spite of the limitations, providing it is communicated properly and transparently.

Importance of data

One cannot stress too highly the importance of measurements and data to the success of building indigenous capability in seasonal prediction and adaptive capacity to climate change. The availability of adequate climate data is fundamental: time-series of key climate variables that are relatively long (at

Image: Rod Hutchinson

Early climate data were invariably recorded in paper-based formats. In tropical regions such records can be subjected to harsh environmental conditions if not properly stored, which can lead to the deterioration of the media and possible loss of the data

Image: Rod Hutchinson

The utility of climate data can only be fully realized when the data are keyed into a digital database. ClimSoft is a database ideally suited to meet the needs of small island developing states of the South Pacific

least 30 years), reasonably complete, reliable, and accessible. Unfortunately, while historical climate observations are mostly available, their accessibility has been hampered by a lack of skills and facilities within nearly all countries in the Pacific Region to adequately secure and manage the data. This deficiency impedes the development of effective information systems for managing climate variability and change. For both scientific and practical reasons, there is a compelling case for improving the capacity of Pacific Island Meteorological Services to preserve and manage their respective nation's climatological data and information, and to make them more easily accessible.

For these reasons the Australian Bureau of Meteorology, backed by funding from the Australian Government, has been active over recent years in data rescue and data management-related capacity-building activities within the PICs. The work, which commenced in 2005, initiated data rescue activities in six countries (Solomon Islands, Kiribati, Vanuatu, Papua New Guinea, Fiji and Samoa).

The aims of this project have been: to immediately secure data at risk of loss or damage through a combination of moist tropical air, vermin and insecure storage; to establish and train staff in sound records management processes; and to recommend further actions to preserve and improve access to the data.

While preserving original records is critical it is only the first step in making the data available for practical applications. However well-stored paper records may be, the data remain difficult to access and put to good use unless they are subsequently digitized into a computer compatible form. In 2006 a project commenced (funded initially by the then Australian Greenhouse Office, and subsequently by the Australian Agency for International Development), to install Climate Data Management System (CDMS) software in Pacific Island countries, to encourage digitization of data from paper records, and the migration of data from older, outmoded computerized systems. The CDMS system used was ClimSoft,[3] a software package specifically designed to accommodate the skills and resourcing levels of developing and least-developed countries. The software was installed and associated training conducted in ten PICs during 2006-07.

This work initiated under PI-CPP is set to continue under the Pacific Climate Change Science Project, which is part of the Australian Government funded International Climate Change Adaptation Initiative. The new effort aims to support adaptation to climate change, and improve climate change monitoring in the climatically important Pacific Region for the benefit of the global community. The project will also contribute to the World Meteorological Organization initiative to extend and improve existing CDMS functionality to developing and least developed countries in all parts of the world — notably Africa, the Pacific and the Caribbean.

Combating climate change: how prepared are poor fishing communities in South Asia?

Yugraj Yadava, Director, Bay of Bengal Programme Inter-Governmental Organisation

Climate change is a critical global challenge of recent times. Several events during the last two or three decades have dramatized our growing vulnerability to the phenomenon. Research shows that climate change may impact agriculture and endanger food security; trigger sea-level rise; accelerate the erosion of coastal zones; aggravate natural disasters; and quicken species extinction and the spread of vector-borne diseases.

Fish exemplify global biodiversity. The world's oceans, lakes and rivers harbour at least 27,000 known species. Some 140 million metric tonnes of fish are captured or raised each year, with humans eating more than 75 per cent of this catch. Worldwide, marine and freshwater fisheries generate over USD130 billion annually, employ at least 200 million people, and feed billions of people who rely on fish as their primary source of protein.

Image: S Jayaraj

Too many fishing boats chasing too few fish: the overcrowded fishing harbour in Cox's Bazaar, Bangladesh

The global warming of seas, rivers and lakes threatens fish stocks, which are already under pressure from overfishing, pollution and habitat loss. Such a decline in fish catch could devastate human populations, particularly in poorer countries that rely on fish for protein.

The impact of climate change on climatic and oceanographic parameters in the South Asian seas

The Intergovernmental Panel on Climate Change (IPCC) has projected that the global annual seawater temperature and sea level will rise by 0.8 to 2.5ºC and 8 to 25 centimetres respectively by 2050.[1]

In India, the sea-level rise for Cochin on the southwest coast during the past century has been estimated at two centimetres.[2] Future decades may see the rate of increase go up to five millimetres per year.

The data set on sea surface temperature (SST), obtained from various sources, clearly shows sea surface warming along the entire Indian coast.[3] During the 45 year period from 1961 to 2005, SST has increased by 0.2ºC along the northwest, southwest and northeast coasts, and by 0.3ºC along the southeast coast. In neighbouring Sri Lanka too, the surface temperature record clearly indicates sea surface warming.[4]

Fish, fisheries and global warming

Sea warming and sea-level rise may strongly impact coastal fisheries in South Asia, aggravating the poverty of coastal communities. Countries in the region can't prevent climate change, but can adopt mitigation/preparedness strategies.

In relation to this, studies have been carried out in India, Bangladesh, Maldives and Sri Lanka — all are members of the Bay of Bengal Programme Intergovernmental Organisation (BOBP-IGO) — on the impact of climate change on fisheries and on mitigation/preparedness strategies to counter such impact.

India

Marine capture fisheries are vital for food supply, food security and income generation in India. Some one million people in this sector produce three million tonnes of fish annually. The value of fish production

Over-exploited coastal resources and the adverse impacts of global warming are making life difficult for traditional fishers in Tamil Nadu, India

from a fleet of 59,000 mechanized craft, 76,000 motorized craft and 105,000 non-motorized craft is about USD2.8 billion. Recent scientific studies described below show that some commercially viable maritime fish species in India are adapting to climate change.

Small pelagics, especially the oil sardine, were at one time confined to the Malabar upwelling zone along the southwest coast of India, the area between latitude 8ºN and 14ºN and longitude 75ºE and 77ºE, where the annual average SST ranges from 27 to 29ºC. Until 1985, almost the entire catch was from this area. In the last two decades, however, the catches from latitude 14ºN to 20ºN are increasing, indicating a positive correlation between the oil sardine catch and SST.[5] Catches from this area contribute to about 15 per cent of India's entire oil sardine catch during 2006.

The Indian mackerel, *Rastrelliger kanagurta*, is also showing signs of changing its habits. During the last two decades this species, which normally occupies surface and sub-surface waters, has not only moved north but has descended into deeper waters.[6] During 1985 to 1989, only two per cent of mackerel catch was from bottom trawlers, pelagic gear such as drift gillnet accounted for the rest of the catch. But from 2003 to 2007, bottom trawlers captured an estimated 15 per cent of the mackerel catch.

The threadfin breams *Nemipterus japonicus* and *N mesoprion* are distributed along the entire Indian coast at depths ranging from 10 to 100 metres. Data on the number of female spawners collected every month off Chennai on the southeast coast of India from 1981 to 2004 indicate wide monthly fluctuations. The spawning season used to occur in the warmer months from April to September, when mean SST ranges from 29.0ºC to 29.5ºC. It now occurs in relatively cooler months — October to March, when mean SST is 27.5ºC to 28ºC.[7]

False trevally, *Lactarius lactarius*, is an economically and culturally important fish in India. It ranks as one of the most preferred, high-quality fish in the Gulf of Mannar region. Higher water temperatures and lower rainfall because of global warming, however, have led to a drastic decline in the numbers of this fish over the last few years.

In the Indian seas, coral reefs are found in the Gulf of Mannar, Gulf of Kutch, Palk Bay, Andaman Sea and Lakshadweep Sea. Indian coral reefs have experienced 29 bleaching events since 1989. Intense bleaching occurred in 1998 and 2002 when SST was higher than the usual summer maxima.

Given the warning that reefs will not be able to sustain catastrophic events more than three times a decade, reef-building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040. Reefs are likely to become remnants between 2030 and 2040 in the Lakshadweep Sea and between 2050 and 2060 in other regions in the Indian seas.[8]

On 30 June 2008, India released its first National Action Plan on Climate Change outlining current and future policies on climate mitigation and adaptation. The plan identifies eight core 'national missions' running through 2017. The plan identifies measures that promote development objectives and reap the benefits of combating climate change.

Bangladesh

For Bangladesh, climate change may cause even more of the floods, cyclones, storm surges and droughts that have devastated it in the past. In September 2008, the government developed the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), a ten-year programme to build the capacity and resilience of the country to meet the challenge of climate change over the next 20 to 25 years.

BCCSAP claims that climate change will damage freshwater and marine fisheries in many ways — the spawning of freshwater species will be impaired; water temperatures in ponds and inland fisheries will go up; the ingress of saline water inland further south will affect the aquatic ecosystem and hit fish production; and turbulent weather will impact on fishing livelihoods. It is critical, therefore, that all potential impacts are identified and measures are put in place to conduct the research and development of management strategies.

Maldives

The Maldives is also particularly vulnerable to climate change and the many scientific and technical assessments of the region, which have taken place since 1987, have stressed the need for long-term adaptation to climate change.

Fishing is at the heart of the Maldivian economy. More than 20 per cent of the population depends on it. It is a dominant employer with more than 15,000 fisher-

Image: Y S Yadava

Skipjack tuna forms the mainstay of fisheries in Maldives. Global warming will have adverse impact on pelagic species such as tuna

Image: Y S Yadava

Declining fish resources are making life difficult for fishermen in Bangladesh — Chittagong Fishing Harbour, Bangladesh

men, and contributes to 7 per cent of the country's gross domestic product output. In addition, fish is the primary source of protein for the population — tuna is served daily at every meal.[8]

Climate change has the potential to devastate the fishing industry. Tuna is very sensitive to biophysical conditions of the pelagic environment, particularly changes in SST, and pole-and-line tuna fishery is highly dependent on live bait, making it particularly vulnerable to climate change. In addition, the Marine Research Centre in Malé, Maldives, has determined that rising temperature is a key factor in the health and growth of coral reefs.

In 2006, the Maldives adopted the National Adaptation Programme of Action (NAPA). Its goal is to enhance the resilience of natural, human, and social systems and their sustainability in the face of predicted climate hazards. NAPA strives for synergy with Vision 2020, the Seventh National Development Plan and the Millennium Development Goals.

Sri Lanka

The coastline of Sri Lanka measures approximately 1,760 kilometres, the third longest in South Asia. Some 4.6 million people (about one quarter of the population) live along the coast. The coastline is geographically very diverse, with more than 1,337 fishing villages and 131,000 households.

A study by the National Aquatic Resources Research and Development Agency discusses the impact of climate change on coastal resources. It says that the most sensitive habitats in the country suffer different degrees of degradation owing to a combination of human activity and climatic change. It recommends a slew of projects to battle climate change including: culture of seaweed; oyster farming; crab fattening; artificial production of marine ornamental fish; value addition to agriculture and fisheries products; and use of fish aggregating devices.

Going forward

A general understanding of the impact of temperature rise on fish populations is limited at present because of a lack of long-term research. However, with coastal fishery resources already under pressure because of overfishing, the possible impact of climate change is a serious worry.

BOBP-IGO has already initiated some sensitization activities in member-countries with an aim to collect and compile scientific information and share it within the regional and global community. Capacity building programmes are also being taken up to create a cadre of fishery personnel that are aware of the impacts of climate change and are capable of communicating related issues to all stakeholders, including of course the fishers.

Since the fishery sector alone can't prevent climate change, BOBP-IGO will strive to study precautionary measures undertaken elsewhere and adapt them to the region. The result will be a regional status document on the impact of climate change on fisheries and a regional action plan for South Asia.

Sustaining fish supplies for food security in a changing climate

Edward H. Allison, The WorldFish Center, Penang, Malaysia; Manuel Barange, Plymouth Marine Laboratory, UK; Nicholas K. Dulvy, Simon Fraser University, Department of Biological Sciences, Canada

When we think of food security, we tend to think of subsistence agriculture. Can a smallholder farming family grow enough maize, rice, millet or wheat to feed itself? Of course, food security is more complicated and in a market economy even smallholder farmers in remote areas buy some of their food by selling their surplus crops. Being food secure also means more than just ingesting enough calories. Nutritional balance and food quality are also important to children's development and to healthy adulthood.

Health advice in developed countries is to eat more fish and less red meat. Fish is even more important to the food security of citizens of developing countries, both as a source of income and as a component of healthy diets. Currently, one-third of the world's six billion people rely on fish and other aquatic products for at least one-fifth of their annual protein intake. In addition, catches by subsistence and artisanal fisheries make up more than half of the essential protein and mineral intake for over 400 million people in the poorest countries in Africa and south Asia.[1] Fisheries and aquaculture directly employ over 36 million people worldwide, 98 per cent of them in developing countries. Overall, there are approximately 520 million people whose lives depend on sustaining fisheries and aquaculture. The sector also supports global trade worth over USD78 billion in 2008.[2]

Sustaining these benefits is a critical challenge, as over half the fish we eat is still caught in the wild. The other half comes from fish farming, or aquaculture. A large proportion of wild-caught fish not directly eaten is turned into fish oil and meal, which goes into feeding farmed fish and livestock. These supplies, as of 2006 totalling 92 million tonnes from capture fisheries and 52 million tonnes from aquaculture, are threatened by overfishing, pollution and now, by climate change.[3]

The potential impacts of climate change on fishing communities and fish supplies

Climate change is accelerating and is already affecting marine ecosystems and services. Both models and observations indicate that the world's oceans are warming and patterns in atmospheric variability are changing — resulting in changes in currents, sea ice distribution and light supply to the surface ocean. Biological responses to these changes are visible, but variable. Some waters may become more productive, while others will fail to sustain fisheries at historical levels.[4] Always unpredictable, fishing may increasingly become a lottery as migration routes and spawning and feeding grounds change from those that fishers have learnt to harvest. More certain are the impacts of rising sea temperatures on 'bleaching' of coral reefs — a phenomenon which results in coral death, erosion of reefs and reduction of their capacity to support fish populations, as well as damaging one of our natural defences against storm waves.[5]

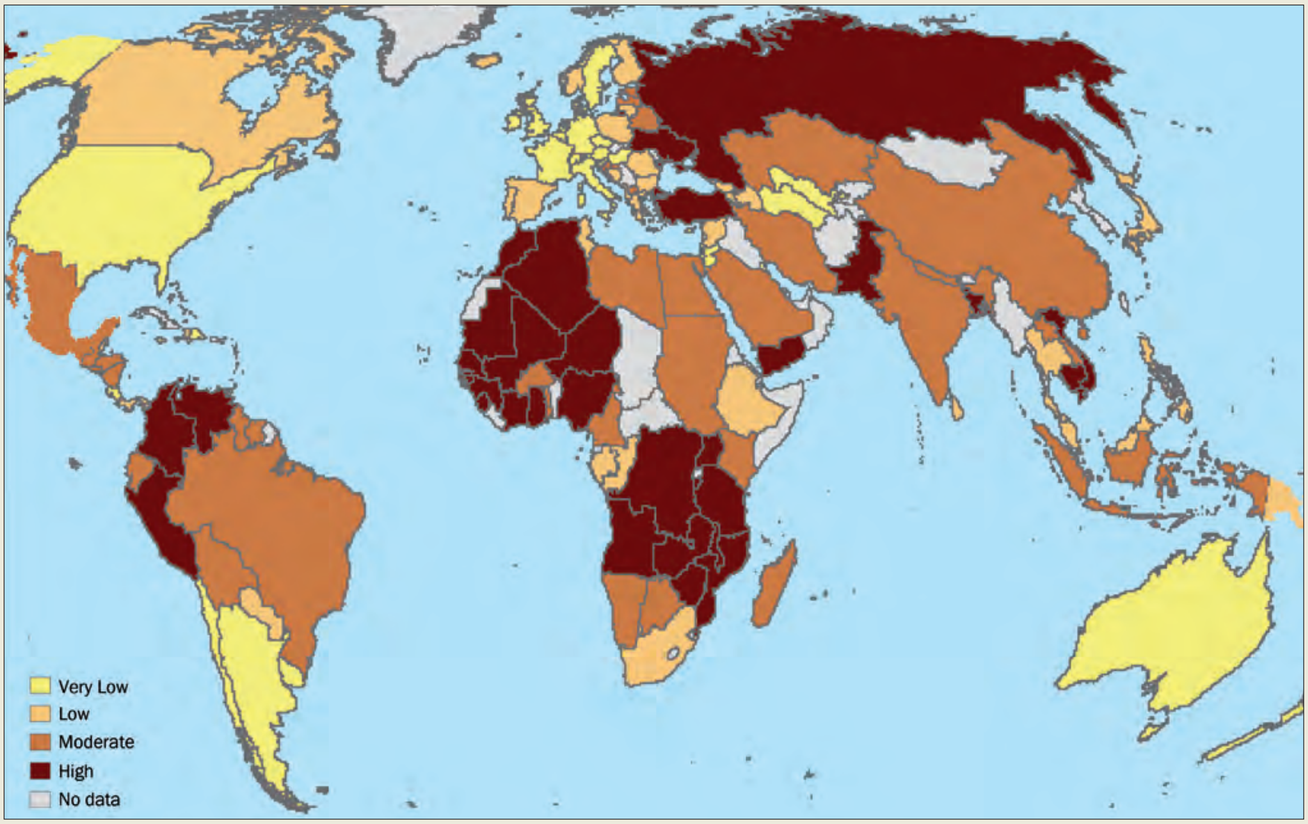
Climate change also directly impacts on fishing and the lives of fisherfolk. Predictions for increased frequency and severity of extreme climate events – storms, floods, droughts — coupled with rising sea levels and melting glaciers at the headwaters of major rivers, will leave fishing communities, along both rivers and coasts, increasingly vulnerable to disasters that damage infrastructure and threaten human lives and health.[6]

Climate change may thus profoundly affect fisheries and aquaculture and their contribution to local livelihoods, national economies and global trade-flows. The future consequences for global fish supplies are uncertain and subject to ongoing analysis. But what is certain is that there will be winners and losers, and that the losers will be those who don't have much already. Every major report on climate change published recently indicates that the poorest people, living in climate change sensitive areas such as floodplains and low-lying coastal areas, will be the most adversely affected and least able to adapt.[7]

This observation pertains to the fishery sector too. In a recent analysis it was demonstrated that African and southeast Asian countries are the most economically vulnerable to climate change impacts on fisheries and aquaculture sectors.[8] This arises from a relatively high reliance on fisheries combined with low levels of societal capacity to adapt to anticipated temperature increases. Of the 33 nations identified as being most vulnerable, 19 are among the world's least developed countries, whose inhabitants are twice as reliant on fisheries for food as those of more developed nations. Not only are the most vulnerable countries highly dependent on fish for protein, they also rely on fishery products as a source of income, producing around 20 per cent of the total tonnage of global exports, worth about USD6.2 billion.

African and southeast Asian nations face the double jeopardy of high vulnerability to climate effects on both their fisheries and agriculture sectors. By 2050, global yield of rain-fed maize is forecast to decline by 17 per cent and irrigated rice by a fifth as a result of climate change, with sub-Saharan Africa and south Asia the worst hit.[9]

Unequal vulnerability



The vulnerability of national economies to potential climate change impacts on fisheries was calculated on the basis of exposure, sensitivity and adaptive capacity, assuming slowly increasing global emissions (scenario B2 of the IPCC). Colours represent quartiles, with dark brown for the upper quartile (highest vulnerability), yellow for the lowest quartile and grey where no data were available

Source: Originally published in 'Vulnerability of national economies to potential impacts of climate change on fisheries', Fish & Fisheries

Three countries in particular have both the highest national vulnerability to climate impacts on fisheries and 'extremely alarming' global hunger indices: Sierra Leone, Niger and the Democratic Republic of the Congo.[10] These nations deserve the greatest support for adaptation and development to face these challenges.

Strengthening science to inform adaptation needs and mitigation options

The quantification of direct climate impacts on fish resources at the global scale, and the resulting economic risks and societal vulnerabilities, is hampered by a variety of factors: difficulties of downscaling Global Climate Models to the scales of biological relevance; lack of global ecosystem models capable of capturing biological processes at the right scale and resolution; uncertainties over future global aquatic net primary production and the transfer of this production through the food chain; difficulties in separating the multiple additional stressors affecting fish production, including differential geographical and temporal exploitation patterns and policies; and, inadequate methodology to estimate human vulnerabilities to these changes at all scales.

Quest-Fish, a research consortium between leading UK and international institutions, is addressing some of these challenges through an innovative multi-scale, multi-disciplinary approach focused on estimating the added impacts that climate change is likely to cause, and the subsequent additional risks and vulnerabilities to human societies.[11] The project, led by Manuel Barange, is anchored on outputs from global climate models and coupled physical/biological ecosystem dynamic models to predict ecosystem functioning in pre-industrial (1850), present (2005), near future (2050) and distant future (2100) scenarios. For each time period, the project is estimating plankton production in 20 large marine ecosystem units around the world.

Primary production will be linked to fish production with models based on macro-ecological theory, thus bypassing much of the species-based complexity of marine food webs to express fish production by groups of fish of different body size. These estimates are used in the context of scenario building exercises conducted with fisheries and development specialists — including fisherfolk themselves, who are the real experts. Scenario exercises are used to assess vulnerability of fisheries to future climate change, in the context of other drivers. Specifically, the consequences of climate change impacts on the markets for major fish-based global commodities, such as fishmeal and oil. The results should provide a new framework to study fluctuations in natural resources subject to climate and

Image: Minkoh, for FAO

Fish — both marine and freshwater — are an essential part of a healthy diet for millions of people in developing countries

market impacts, providing new insight into the complex interactions between humans and nature.

Putting knowledge into policy and practice

Although better predictions of the magnitude and distribution of climate change impacts are urgently needed, we cannot wait for better knowledge before taking action. There are three key areas where adaptation actions could potentially be taken.[12]

It is important that existing efforts to manage fisheries are improved. Currently, a quarter of the world's fisheries are either over exploited or recovering, while half are at their limits of productivity. Fisheries tend to target abundant species that dominate the ecosystem in which they live. A fish stock which is depleted is more susceptible to any negative impacts of climate change on that ecosystem, and the combined effects of climate change and fishing pressure may lead to collapse, causing the ecosystem to 'flip' into a different state. Some scientists argue that this is what happened to the Newfoundland cod fishery, which collapsed in the early 1990s and has not recovered despite a moratorium on fishing.[13]

There is a need for adaptation approaches that involve managing an integrated portfolio of natural resource sectors such as water, forestry, farming, aquaculture and capture fisheries. Fisheries are affected by adaptation initiatives in some of these sectors — for example building dams for water storage will affect downstream fisheries. Also, many fisherfolk in developing economies have diverse livelihood strategies, combining fishing with other occupations to maintain income and food security when fisheries are adversely affected by weather and climate. One novel cross-sectoral scheme in the Solomon Islands is assessing the potential for carbon sequestration by mangrove forests — ecosystems threatened by unsustainable aquaculture — which could then be eligible as a source of carbon credits under the United Nations' (UN) programme Reducing Emissions from Degradation and Deforestation. Researchers are examining how this approach might be used to promote conservation, mitigate climate change and help alleviate poverty among people dependent on the mangroves and adjacent marine ecosystems.

Finally, thought should be given to mainstreaming fisheries in wider development processes. Climate change is not the only stress facing fishing communities. Many are poorly served by infrastructure, markets and social services, and are thus economically, socially and politically marginalized. Building adaptive capacity to address these multiple stressors will require cross-sectoral approaches implemented through newly decentralized governance. The world's least developed countries are among those eligible for UN funding to engage in long-term planning through the National Adaptation Programmes of Action. In countries where fisheries are important, sector-specific needs should be planned and budgeted for in this process. Of course, governments and international finance institutions need to then deliver on their promises to fund adaptation — something they have, so far, substantially failed to do.

Collaboration for climate change adaptation

The scale and importance of impacts on fisheries are beyond the capabilities of any one organization or

Image: E.Allison

The future of fish is in the hands of government negotiators in the UNFCCC process. Failure to keep CO_2 emissions below 450 ppm is likely to signal the end of reef-dependent fish species and fisheries

group to address. Responding to the threat requires coordinated action, both at the community scale, and in representing the sector at the global level. The last year has seen the emergence of networks that are aiming to do just this — and to bring justice in climate change adaption to fisherfolk.

Much activity has focused on getting the needs of the sector recognized in the current round of talks leading up to the 15th Committee of the Parties of the UN Framework Convention on Climate Change (UNFCCC). One such collaborative effort is that of the UN Food and Agriculture Organization, the World Bank's Profish programme — an initiative to tackle unsustainable fishing practices — and international non-profit research group the WorldFish Center in Penang, Malaysia. These organizations aim to share the task of achieving representation for the sector in high-level climate policy dialogues by joining forces with other agencies such as the UN Environment Programme, regional intergovernmental organizations such as the Secretariat of the Pacific Community, and representatives of fisherfolk organizations worldwide.[14]

Image: WorldFish

Sea-level rise and increased frequency and severity of floods and storms will make some low-lying coastal areas uninhabitable

Such alliances can be used to highlight vulnerability, adaptation needs and mitigation opportunities. Together with the Global Forum on Oceans, Coasts and Islands and supporting the Indonesian Government's leadership in promoting an Oceans Agenda in the UNFCCC process, this partnership has helped to ensure that fishery issues are represented in the draft negotiating text for UNFCCC.[15] These high-level efforts must be complemented by action where it matters to people currently dependent on fisheries and aquaculture — at the level of national sectors and communities. Our work — which draws on climate science and predictions, policy scenarios, and understanding of the dynamics of change at local level — aims to ensure that the contribution of fisheries to food security receives recognition and support in these times of climate change.

Climate change, land degradation, and forced migration

Andreas Rechkemmer, Special Advisor, Executive Direction and Management, United Nations Convention to Combat Desertification

Growing evidence on the linkages between climate change, land degradation, the reduction of drylands, ecosystem services, poverty, and migratory movements has raised the awareness of scholars and policy makers alike. These linkages were traditionally understood as the interplay between physical patterns of change and human activities. Recent research efforts, however, have shown that both climate change and desertification must be understood as social phenomena largely driven by human activities. Hence migration triggered by climate change and land degradation can be perceived as socially constructed phenomena in an age of global change.

Environmentally triggered migration and environmental refugees

When the Convention Relating to the Status of Refugees was adopted in Geneva in 1951, environmental degradation and natural hazards were not considered by the negotiators when they defined refugees as people suffering the 'well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group or political opinion'.[1] In 1972, with the Stockholm Conference on the Environment, world opinion turned to global environmental issues and led to the establishment of the United Nations Environment Programme (UNEP) in 1973. However, the problem of worsening environmental degradation leading to environmentally triggered migration remained unnoticed until the 1980s when El-Hinnawi[2] formulated the concept of environmental refugees.[3]

Environmental refugees are a dramatically growing group, mostly migrating from rural areas to cities. They are not yet officially mentioned in United Nations High Commissioner for Refugees statistics, as they do not fulfil the criteria of the Geneva Convention. They are not mentioned in the statistics of the UN Populations Division[4] or in the annual US World Refugee Survey.[5] As they are not officially counted, only approximate estimates exist. And yet, they may have surpassed all other types of refugees in numbers, and could become the largest group of migrants this century, particularly due to rapid global climate change.

There have always been people migrating due to natural and environmental changes, hazards or disasters, and several civilizations — such as the Maya — collapsed due to environmental change. Since then, the degradation of natural resources has dramatically increased. In the late 1980s the ecological footprint of humankind finally exceeded Earth's capacity, marking the first time in history when humankind managed its ecosphere in an unsustainable way — not only locally or regionally, but globally.[6] During recent decades, increasing scarcity and overexploitation of natural resources, such as soil and freshwater, has become a severe problem due to an unprecedented rate of expansion. These circumstances have evoked a new type of migratory movement of people — the environmentally induced migration. The causes of this migration are mostly anthropogenic: transformations such as degradation of soil or vegetation, fresh water and fresh air, and global climate change.

The most severe of all environmental push factors is global climate change. Norman Myers[7] argues that: "when global warming takes hold there could be as many as 200 million people displaced by disruptions of monsoon systems and other rainfall regimes, by droughts of unprecedented severity and duration, and by sea-level rise and coastal flooding". This projection refers to the year 2050, and means that based on an estimated world population of nine billion, one in every 45 people will become a forced migrant due to climate change and its epiphenomena. Oli Brown[8] says: "We know that climate change will redraw our coastlines, alter where and when we can find water, and expose us to fiercer storms or more severe droughts. We know that on current predictions the 'carrying capacity' of large parts of the world — the ability of different ecosystems to provide food, water and shelter for human populations — will be compromised by climate change".

The case of land degradation and desertification

As far as land degradation and desertification are concerned, there are four groups of countries with different causes but comparable results:

- Heterogeneous developing countries with their fast overexploitation of land because of growing populations, high vulnerability to climate change-induced droughts, floods and precipitation changes, worsening ecosystem services and international trade patterns without real chances for coping mechanisms
- Industrializing countries in Asia and South America with their strong extension of food production and population growth, foremost in urban areas

- Fuel exporting countries with their own kind of overexploitation and desertification phenomena
- Eastern European countries with their chemically and agriculturally induced land degradation.

They all have to face similar results of loss of ground, desertification and its impacts. The tropics suffer most from these events. The Living Planet Index of tropical grasslands, savannahs and deserts dropped by 80 per cent since 1970, while temperate areas remained quite stable. The sharp drop does not equate to a total loss of existing species, but a loss of 80 per cent of the former existing individual animals, which is the highest number of all observed ecosystems.[9]

In the early 21st century, 'drylands occupy 41 per cent of the Earth's land areas and are home to more than two billion people. Some 10-20 per cent of drylands are already degraded. About 1-6 per cent of the dryland people live in desertified areas, while a much larger number is under threat from further desertification'.[10] Another synthesis of the state of Earth's deserts was published by UNEP.[11]

Traditional approaches to assessing and combating land degradation distinguished between 'the meteorological and ecological dimensions of desertification (the biophysical factors) and the human dimensions of desertification (the socioeconomic factors). Previous failures to recognize and include the interdependencies of these dimensions in decision-making have slowed progress toward the synthetic approaches needed to tackle the enormous problem of dryland degradation'.[12]

In the past this has hindered the scientific community in its approach to present a comprehensive understanding of the 'causes and progression of desertification'.[13] Therefore, 'synthesis of dryland degradation studies continues to be plagued by definitional and conceptual disagreements, and by major gaps in global coverage'.[14] Even the Millennium Ecosystem Assessment (MA) with its broad research agenda had to acknowledge wide gaps in the scientific understanding of desertification processes, as well as their underlying causal factors.[15]

Nevertheless, with the concept of 'ecosystem services',[16] the MA used an important and widely underestimated link between environmental degradation and human well-being, partially putting together ecological and human dimensions of desertification, and offering an important answer to the question on how desertification leads to migration: through poverty. Already, dryland populations are being left behind by the rest of the world, given the fact that they rank very low in terms of human well-being and relevant development indicators.[17]

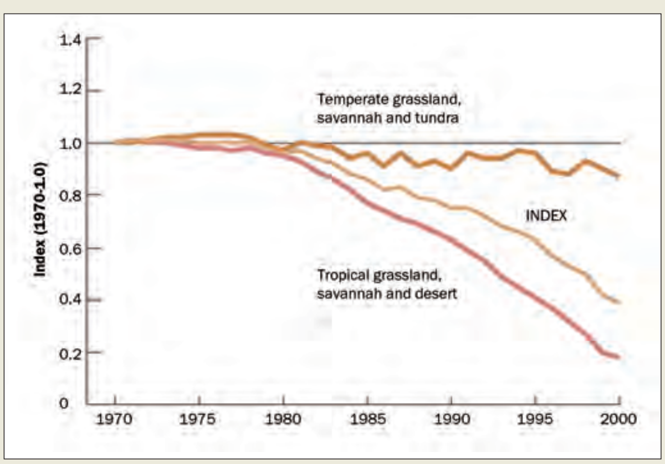
The effects of poverty are also considered by Reuveny[18] who developed a new theory, arguing that people are able to adapt to environmental changes in only two ways: they can resist the changes, or leave the affected area. Which option they choose depends on the severity of environmental degradation and on the society's technical capabilities. In extreme situations, land degradation can remove the economic foundation of a community or society. Experience from recent decades can be interpreted as showing that land degradation and desertification have been a major driving force behind the displacement of people.

Myers[19] quotes a figure of at least ten million people who have become environmental refugees in semi-arid lands with a far greater number expected to come, as one billion people are at risk, and their population growth rate is as high as three per cent per year. Desertification reduces the land's resilience to climatic variations and thus undermines food production, contributes to famine and affects local socioeconomic conditions. It thereby triggers a vicious circle of poverty, ecological degradation, migration and conflict. Desertification-induced migration and urbanization may worsen living conditions in destination countries by overcrowding, unemployment, environmental pollution and overstressing of natural and infrastructural resources. It could also cause social tension and conflicts, as well as increase problems such as crime and prostitution.

Considering incomes and human well-being, the 'worst situations can be found in the drylands of Asia and Africa; these regions lag well behind drylands in the rest of the world'.[20] The situation regarding the present and prospective availability of key ecosystem services appears to be similar, 'the greatest vulnerability is ascribed to sub-Saharan and Central Asian drylands'.

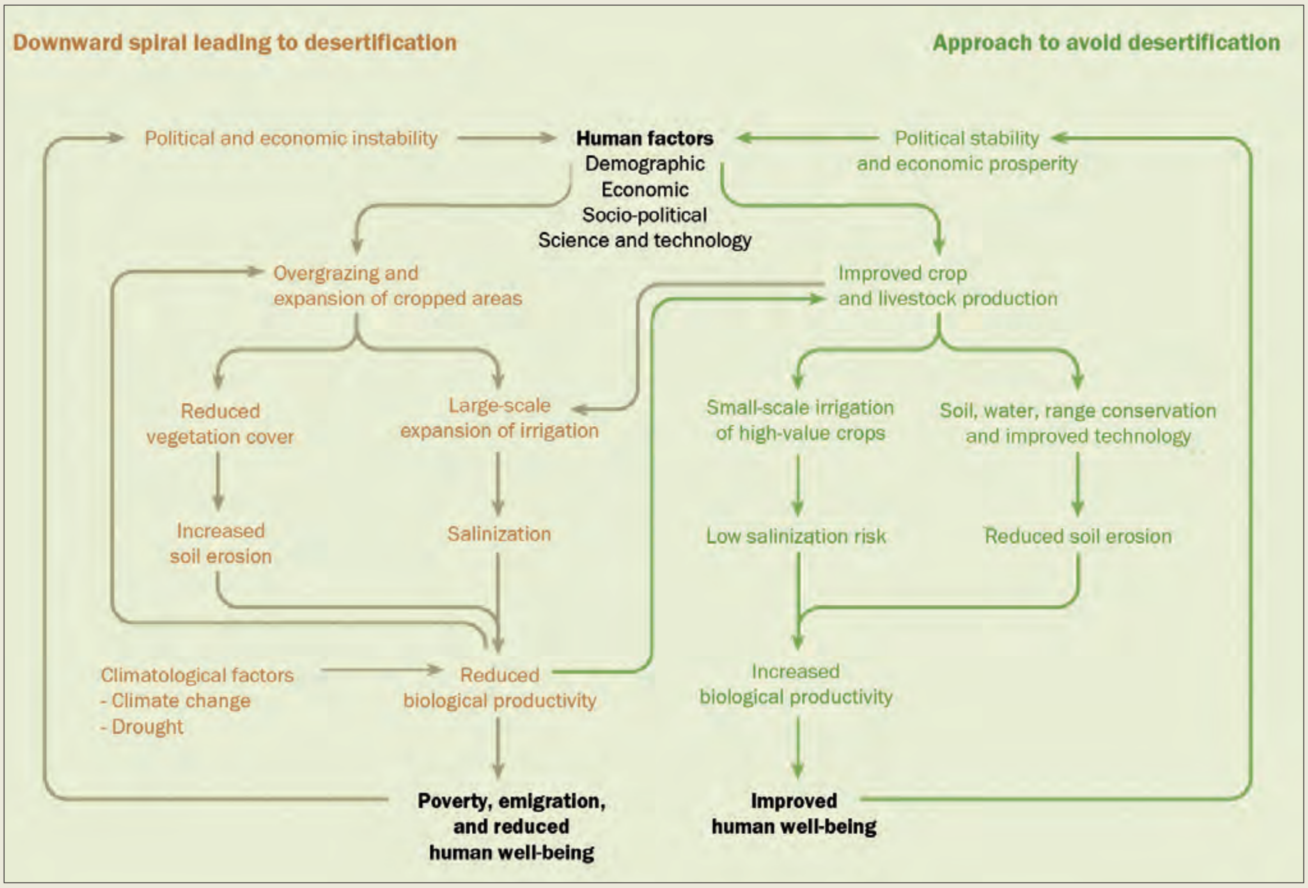
The synchronous appearance of conflict, migration and desertification does not happen by chance. Their links are clearly visible. 'Conflicts and environmental degradation further aggravated the pressure for migration from poorer to relatively prosperous regions, within and outside the West African sub-region. In the Sahel, in particular, desertification and cyclical famines have triggered waves of environmentally-displaced persons across national frontiers within the sub-region'.[21] These environmental events are expected to appear more often and more severely with ongoing and exacerbated global warming,[22] especially when sustainable agriculture practices are not being quickly and resolutely implemented.

Living Planet Index



Source: WWF (4: 2004)

Schematic description of development pathways in drylands



Source: Millennium Ecosystem Assessment (2005)

Coping strategies

The United Nations University (UNU) estimates that in 2010 there will be up to 50 million environmental refugees. Therefore, former UN Under-Secretary-General and UNU Rector Hans van Ginkel has called for the recognition of environmental refugees within international frameworks, while realizing that limited resources already restrain the relevant global organizations' capabilities to deal with conventional refugees.[23] This is also reflected in a proposal by the German Advisory Council on Global Change for managing migration through cooperation and further developing international law.[24]

In relation to dryland development there are two partially competing, scientific approaches — the 'desertification paradigm' and the 'counter-paradigm'.[25] The older, indeed fatal, desertification paradigm states that drylands are basically stable ecosystems which collapse when human influence exceeds certain levels, and, most important, that few, if any, measures exist to prevent this downward spiral. In the more recent and scientifically supported counter-paradigm, this is only one of two possible outcomes. It first states that deserts are by themselves unstable and therefore highly vulnerable areas. This does not neglect human influence in land degradation — and its sometimes disastrous outcomes — but puts it into the broader picture of natural droughts and anomalies, which are still far from being fully understood.

Following this counter-paradigm, it is also possible, but dependent on social developments and political decisions, to mitigate climate induced land degradation by using sustainable farming practices or integrated water system management. Indeed, research has been undertaken since 2001 in a series of international workshops on: the role of freshwater resources and other possible rehabilitation of drylands; sustainable management of marginal drylands; and on prevention of land degradation through traditional knowledge and modern technology.[26]

Climate change and desertification, with all the underlying factors and manifold consequences, will not be defeated easily. There are, though, ways to respond, mitigate and adapt effectively. In addition, we no longer lack the ability to end poverty, one of the main human drivers as well as impacts of desertification.[27] But we seem to lack the political will to combat it effectively. It is certain that we do still lack scientific understanding of soils, their degradation and the human dimensions of desertification. Therefore, we should prepare for growing numbers of environmental refugees, both nationally and globally, to prevent further political destabilization in developing countries.[28]

II

GOVERNANCE AND POLICY

Assessment of climate change and adaptation in India

Ajit Tyagi, India Meteorological Department, New Delhi;
and B. N. Goswami, Indian Institute of Tropical Meteorology, Pune

The vulnerability of society to rising temperatures, changing precipitation patterns and increasing climatic extremes has become one of the most discussed issues in the global economic, social, scientific and political fora. Global and regional models have been used to produce climate change scenarios focusing on the frequency and intensity of extreme events such as heat waves, cold spells, severe thunderstorms, tropical cyclones, storm surges, severe storms and drought. Extensive observational data from the past is required for any such assessment. It is widely acknowledged that better forecasting capability is central to an effective adaptation strategy, particularly in the Indian context where livelihoods are strongly tied to the physical environment. Therefore, India has taken steps to develop capabilities in regional climate modelling and impact assessment, as well as to evolve sector-specific impact minimization and adoption strategies.

Status of climate change in India

India has maintained a well disributed network of about 200 meteorological observatories across the country for more than a century and about 500 observatories since 1947. Findings derived from the data, and its subsequent analysis, have helped in climate monitoring and climate change studies.

Mean annual surface air temperature over India rose by 0.52°C during 1901-2008 and has been above normal since 1990 over a base period of 1961-1990. This warming is primarily due to a rise in maximum temperature across the country. However, since 1990 the minimum temperature has steadily risen at a slightly higher rate than the maximum value.[1]

Upper air temperatures have increased in the lower troposphere, with the trend significant at 850 hectopascals, while a small decreasing trend was observed in the upper troposphere.[2] The spatial pattern of trends in the mean annual temperature shows significant positive (increasing) trends over most of the country, except over parts of Rajasthan, Gujarat and Bihar, where significant negative (decreasing) trends were observed.

During the last century the Indian summer monsoon season rainfall (June to September) has shown no significant trend. However, three subdivisions — Jharkhand, Chattisgarh and Kerala — have shown a significant decreasing trend, while eight subdivisions — Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka — have shown a significant increasing trend during the same period.[3]

A significant increasing trend has been observed in the frequency of heavy rainfall events over the west coast.[4] Many extreme rainfall indices have shown significant positive trends over the west coast and north western parts of the Indian Peninsula with the exception of Mahabaleshwar, which shows a decreasing trend in some of the extreme rainfall indices.[5]

Long-term linear results from the frequency of tropical cyclones over the north Indian Ocean, the Bay of Bengal and the Arabian Sea for different seasons and years, generally show a significant decreasing trend.[6] In addition, a sharp decrease in the frequency of cyclones during the monsoon season was observed.[7] However, an increasing trend in the frequency of tropical cyclones over the Bay of Bengal in the months of May and November was also observed.

Prediction of climate over India

South Asian summer monsoon (SASM) rainfall and its potential for change were evaluated under the World Climate Research Program Coupled Model Inter-comparison Project data set. The response of SASM rainfall to a transient increase in anthropogenic radiative forcing was investigated for two time-slices — 2031-2050 and 2081-2100 — in the non-mitigated Special Report on Emission Scenarios B1, A1B and A2. Only 10 out of 25 models are able to simulate the annual cycle and the space-time characteristics of SASM precipitation reasonably well.

Almost all models show an increase in precipitation and weakening of monsoon circulation for future projections.[8] A substantial increase in precipitation was observed over the western equatorial Indian Ocean and southern parts of India when using ten selected models.[9] However, the monsoon circulation weakens under all the three climate change experiments. While global atmosphere-ocean coupled models can provide a good representation of the planetary-scale features, their application to regional studies is limited by their coarse resolution (around 300 kilometres).

The regional climate modelling system Providing Regional Climates for Impacts Studies (PRECIS), developed by the Hadley Centre for Climate Prediction and Research, has been applied in India to develop high resolution climate change scenarios. The model has a resolution of approximately 50 kilometres and is forced at its lateral boundaries by a high resolution (around

150 kilometres) atmosphere-only general circulation model called HadAM3H. This model is in turn forced by the sea surface temperatures generated by a coupled atmosphere-ocean General Circulation Model called HadCM3.

PRECIS estimates a 20 per cent rise in all Indian summer monsoon rainfall for future scenarios. Simulation for 2071-2100 indicates an overall warming of the Indian subcontinent associated with increasing greenhouse gas (GHG) concentrations. The predicted annual mean surface air temperature rise by the end of the century is 3 to 5ºC under the A2 scenario, and 2.5 to 4ºC under the B2 scenario. It is predicted that the warming will be more pronounced over the northern parts of India.[10]

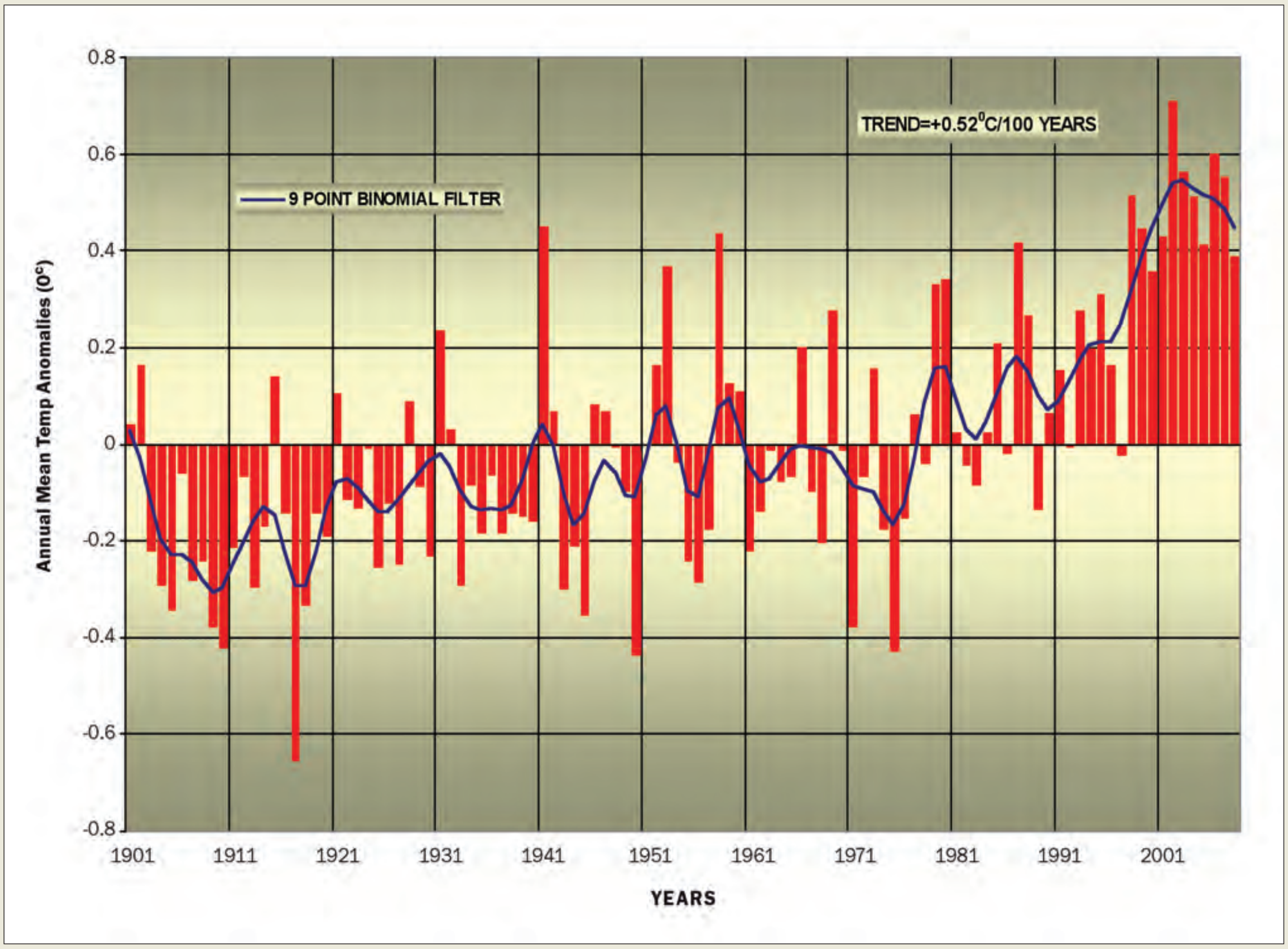
Climate change adaptation strategies for agriculture

IMD established the Agrometeorological Advisory Service to help Indian farmers mitigate the impacts of climate variability and extreme weather events through agricultural planning and management in rhythm with nature. The service provides district level weather forecasts of up to five days for seven weather parameters: rainfall, maximum and minimum temperature, wind speed and direction, relative humidity and cloudiness. It also provides a weekly cumulative rainfall forecast using the multi-model ensemble technique. Extended-range weather forecasts and seasonal climate forecasts are also being investigated for inclusion in the advisory bulletins.

Acting together, IMD and regional Meteorological Centres add value to the above range of services by providing a twice-weekly advisory bulletin to 130 AMFUs. This bulletin is called the Agromet Advisory Service and provides specific advice on crops, as well as livestock. The bulletin is usually disseminated to the farmers through channels including the mass media and the internet. A mechanism has also been developed to obtain feedback from the farmers on the quality and relevance of the forecast content, as well as the effectiveness of the dissemination system.

Via the Agromet Advisory Service, the scientific community develops different adaptation strategies suitable for different agroclimatic regions of the country to counter the negative effects of climate change and extreme weather events. These adaptation strategies include educating farmers about weather forecasts,

Assessment of climate change and adaptation in India



India's annual mean temperature anomalies for the period 1901-2008 (based on 1961-1990 average)

Source: India Meteorological Department

Image: IIT Bombay

Climate change and societal response: afforestation

Image: Anand Agricultural University, Anand

Climate change and societal response: capacity building for community base adaptation to climate change

current climate risks and soil and moisture conservation, as well as helping to develop traditional water resources in the village. The service also helps in the development of pasture land and other capacity building programmes related to mitigation. All this is done in partnership with the district authorities and non-governmental organizations through a participatory programme including both villagers and farmers.

Indian initiatives focus particularly on development-oriented drought mitigation and water management, as well as animal husbandry programmes. It is also concerned with strengthening research for enhancing adaptive capacity and mitigation potential. In addition, it promotes the government-run Agriculture Insurance Company, which protects farmers from the vagaries of the weather.

Societal response

The most effective way to address climate change is to adopt a sustainable development pathway. This can be achieved by shifting to environmentally sustainable technologies and by promoting concepts such as energy efficiency, renewable energy, forest conservation, reforestation and water conservation. The main issue for developing countries is reducing the vulnerability of their natural and socioeconomic systems to the projected effects of climate change.

India is already expending over two per cent of its GDP on programmes that address climate adaptation. The Government of India has made many policy decisions aimed at reducing risks and enhancing the adaptive capacity of the most vulnerable sectors and groups in the country. The ultimate target of such efforts is to secure livelihoods and alleviate poverty. Adaptation schemes currently in progress include: 6 on disaster management; 19 on health improvement and prevention of disease; 22 on crop improvement and research; 19 on drought proofing and flood control; 6 on risk financing; 12 on forest conservation; and 30 on poverty alleviation and livelihood preservation.

Specific programmes fall under all sectors and include: the National Rural Employment Guarantee Act; the National Agricultural Insurance Scheme; formulation of the coastal regulation zones; and the Participatory Forest Management Programme.

Adaptation and mitigation mechanism

The Government of India is in the process of setting up a National Action Plan on Climate Change, which contains eight aims focused on energy efficiency. The Action Plan is a response to India's current vulnerability to climate change, and represents its strong commitment to sustainable development though energy efficiency and the conservation of natural resources. Two factors form the basis of this promise: India's heritage of an environmentally-friendly culture and recognition of its international responsibility as a developing country. These actions will enable India to engage constructively with global efforts to preserve and protect the environment through practical solutions, for the benefit of all humankind.

A state-level advisory council — incorporating experts from various organizations including IMD — conveys specific advice on adaptation issues, providing uniformity in policy making across the country. India's meteorological services and the observing systems which support them are strengthened as frequently as technological advancements allow to ensure maximum economic, social and environmental benefits. India is not obliged to cut emissions under the Kyoto Protocol, nevertheless it has a range of actions in place to reduce GHG emissions and improve energy efficiency including: setting up a Bureau of Energy Efficiency; reforming its power sector; initiating afforestation and conservation projects; and using cleaner and less carbon-intensive fuel for transport.[11]

Climate change: challenges and opportunities for development in Kuwait

A. Ramadan, Kuwait Institute for Scientific Research

Whether we believe it is mainly natural phenomena, or mainly the result of human beings, there are few who would still deny that there has been a significant change in the Earth's climate. This is most obvious in the global rise in mean temperatures, which is widely accepted to be attributed to the increasing anthropogenic emissions of greenhouse gases, water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and CFCs — an implicit result of population growth. This argument is strong, although direct warming due to waste heat, which is typically 60 per cent of that released by burning fuel, should not be underestimated.

According to projections reported by the Intergovernmental Panel on Climate Change (IPCC), the average global surface temperature is likely to rise by 1.1-6.4°C during the 21st century.[1]

The melting of the polar ice caps is a direct result of climate change. Other results of climate change are the variation in pattern and amount of precipitation, the extinction of rare species and the increased intensity of extreme weather events. Hurricane Gonu, which wrecked the coastline of Oman in June 2007, serves as a good example of the extreme weather conditions affecting the Arabian Gulf region.

Kuwait and other Arabian Gulf countries have a huge proportion of the earth's fossil fuel reserves. Other, cleaner, sources of power also abound in the region, including solar energy. The fact that most of the load on electricity comes from air conditioning units during the summer season (March-November) ties well with availability of solar energy.

Locations of weather stations in Kuwait

Source: Ashraf Ramadan

Kuwait has a network of 34 weather stations. Nine belong to the Kuwait National Meteorological Network (KNMN), while the rest are operated by the Directorate General of Civil Aviation.

Long-term observation of ambient temperature

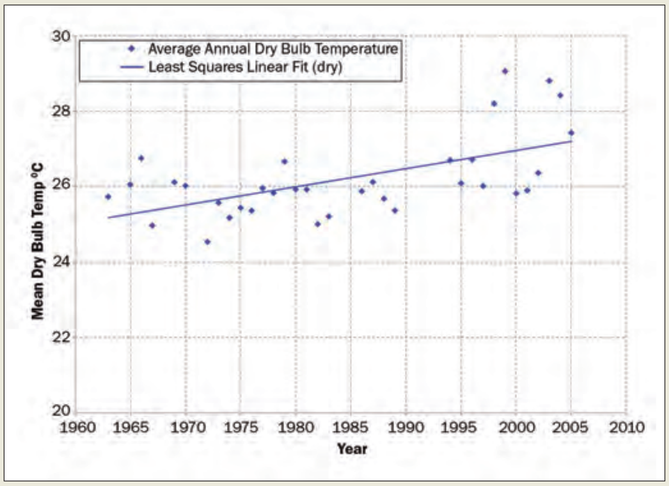
Historic ambient temperature data covering over 40 years sheds some light on climate change in Kuwait. Using the linear least squares fitting technique through the yearly average dry bulb temperature data reveals a positive gradient ranging between 1.1ºC/century in July to 9.4ºC/century in December, with an overall average of 4.7ºC/century.

The overall trend for extreme maximum temperatures over 40 years is positive with the rate of change being 3.1ºC/century. When it comes to minimums, the rate of change is higher, 6.1ºC/century.

Considering that minimums occur at night and maximums during the day, this asymmetry is understandable. Based on four decades of surface thermometrics in the US, the former Soviet Union and China, Karl et al. concluded most of the warming in these countries was due to an increase of mean minimum temperatures with the mean maximum temperatures displaying a smaller increase.[2] Such a phenomenon leads to a decrease of the mean (and extreme) temperature range, which is an important climate change variable.[3] Increased Diurnal Temperature Range (DTR) in summers and reduced DTR in winters suggests increasing cloud cover and increasing soil moisture may play a direct role (increase in cloudiness suppresses warming during daytime, which results in reduced maximum and higher minimum temperatures — hence reducing the magnitude of DTR).[4, 5]

This reduction in DTR cannot be solely attributed to the changes in aerosols, ozone or water vapour and this is in alignment with the conclusion of Watterton that such reduction is not fully accounted for by many climate models.[6] According to him, there are great errors in the way these models treat clouds. The extreme temperatures in Kuwait are in accord with these findings. For the dry bulb temperatures, the increase in the maximum (daytime) value over the past forty years is 6.3ºC/century compared to the 14.4ºC/century increase in minimum (night-time) tempera-

Annual average temperatures in Kuwait (1963-2005)



Source: Ashraf Ramadan

tures. A general reduction in the global solar radiation measured in Kuwait for that period is attributed to the increased cloud cover during the daytime, and this ties well with the conclusions made based on ambient temperature.[7]

Challenges and opportunities for development

The hot and humid climate of Kuwait requires extensive use of indoor air conditioning running on cheap, subsidized power. Also, the lack of precipitation and scarcity of water dictate high desalination capacity. Sixty per cent of the world desalination capacity is in the Arab countries, particularly in the Gulf Cooperation Council (GCC) countries.[8] In the GCC countries about 58 per cent of energy consumption is attributed to air conditioning and water desalination.[9]

These conditions can only lead to high rates of electricity consumption. The energy sector, dominated by huge thermal electric power plants with complete reliance on fossil fuels, is a primary driver of both economic development and environmental degradation; a balance between the two has yet to be achieved in Kuwait, and globally.

Kuwait has witnessed a sharp rise in energy consumption with peak power demand increasing 6-8 per cent annually in the 2000s.[10] In 2006, energy consumption per capita in Kuwait was 16.311 kilowatts per hour compared to 2.751 kilowatts per hour worldwide.[11] CO_2 emissions are largely a by-product of energy production. Accordingly, annual CO_2 emissions per capita in Kuwait were 36.9 tonnes in 2005, well above the world average of 4.5 tonnes.[11]

Kuwait has also gone through a rapid cycle of development in oil exploration, exploitation and refining. This encouraged the government to embark on major programmes for industrialization, establishing plans for new construction and rapid expansion of petrochemical complexes, fertilizer plants, refineries, chemical plants, iron and aluminium smelters and other energy-intensive industries. This has led to an increase in pollutants, including CO_2.

Flaring of gases (which usually accompanies oil production and refining) results in high CO_2 emissions. According to the World Bank's Global Gas Flaring Reduction partnership, at least 150 billion cubic metres of gas is flared or wasted every year, adding about 400 million tons of greenhouse gases. This is equivalent to almost all the potential yearly emission reductions from projects currently submitted under the Kyoto mechanisms.[12] Out of the 150 billion cubic metres flared annually, about 50 billion comes from the Middle East and North Africa. Each cubic metre of gas flared generates two kilograms of CO_2 and Kuwait is among the top 20 major flaring countries in the world.[12]

Another source of air pollution is vehicular emissions. This is exacerbated by Kuwait's complete reliance on fossil fuels and the fact that the number of vehicles per thousand of people is nearly triple the world average.[13]

Rapid economic and population growth — at 2.4 per cent, double the world average — has put Kuwait's environment under severe stress, especially with respect to air quality.[11]

Adaptation strategies

Adaptation strategy is a broad and multi-dimensional endeavour. Many of the issues related to adaptation must be taken on a global rather than national scale. It is important that each country endeavours to reach a set of goals, but the activities concerned will work best if they are coordinated with social and economic development.

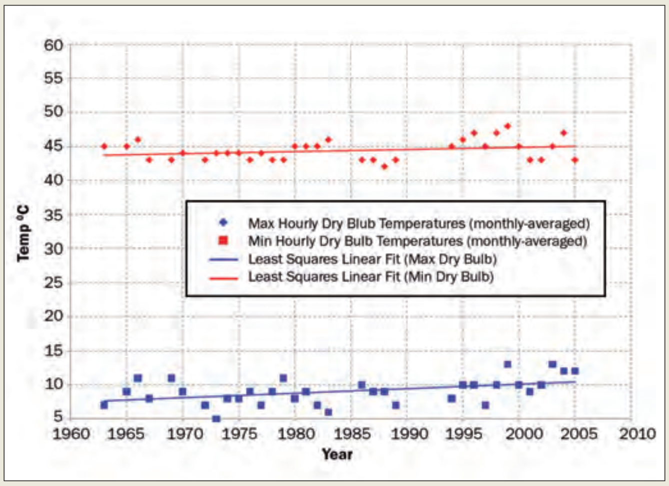
It is widely accepted global warming can be beaten if political will exists. The available technologies and measures are able, if implemented seriously, to achieve a broad range of atmospheric CO_2 stabilization levels over 100 years, but implementation will require socio-economic and institutional changes. Switching to solar and wind power is one of the many ways to do this. According to the IPCC's Working Group Three, following its conference in Accra, Ghana, the cost of reducing greenhouse gas emissions is lower than imagined: half of these potential emissions reductions may be achieved by 2020 with direct benefits exceeding direct costs, operating and maintenance costs.[14]

Kuwait ratified the United Nations Framework Convention on Climate Change and the Kyoto protocol in 1994 and 2005 and activities are under way on greenhouse gas inventories and climate change action plans, including efforts to create integrated waste management programmes and monitoring and imposing legislation on air pollution. Below are some success stories.

Ministry of Electricity and Water

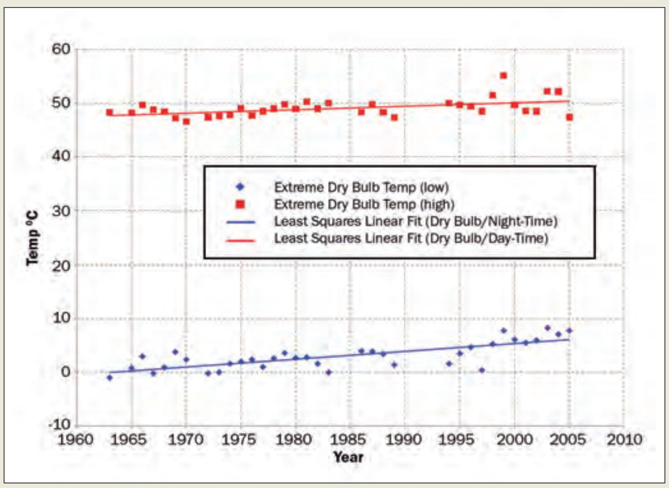
Based on the recommendations of several pieces of research, the Ministry of Electricty and Water (MEW) has revised power plant expansion plans.[10,15,16,17] At Az-Zour Power Station (AZPS), MEW is introducing a more efficient co-generation (power and water) plant containing Combined Cycle Gas Turbine (CCGT) power plant and Multi-Stage Firing/Reverse Osmosis type distillation units instead of conventional thermal plants. Also, the existing Siemens and Alstom Open Cycle Gas Turbines at AZPS will be converted to CCGT to increase thermal efficiency and reduce fuel consumption. In general MEW has started installing low NOx burners in all new facilities, demanding supply of cleaner fuels (natural gas and gas oil) instead of crude oil and heavy fuel oil for power generation and optimiz-

Monthly averaged maximum and minimum hourly temperatures in Kuwait for 1963-2005



Source: Ashraf Ramadan

Extreme hourly dry bulb temperatures in Kuwait for 1963-2005



Source: Ashraf Ramadan

ing the load cycle — in order not to violate Kuwait Environment Public Authority air quality standards.

Kuwait National Petroleum Company

The growth of the petroleum and petrochemical industry in Kuwait need not be a source of alarm if the concepts (efficiency and reduction of emission and waste generation at the source) adopted by the Council of Arab Ministers Responsible for Environment are adhered to. It is feasible to increase industrial output two to threefold without increasing emissions. A precedent has already been set by the refinery industry: the Government of Kuwait has pledged to reduce sulphur content in petroleum products, gas flaring and other hydrocarbon releases by building a large modern refinery to produce environmental friendly fuel to cope with the demands for the power plants of MEW.[10, 16]

In 2007, the company started executing front-end engineering and design for its Clean Fuel Project-2020, which involves modification, upgrade and installation of new facilities including new flaring systems at its three refineries. Mina Abdullah (MAB) and Mina Al Ahmadi (MAA) will be upgraded to give increased capacity and conversion of low sulphur fuel oil to higher end products through 'Bottom of Barrel' processing using ARDS/COKER/HC technologies. Shuaiba will become a tank farm, gasoline blending and shipping/logistics centre with potential integration of some offsite facilities with MAA/MAB operations.[18] According to satellite data released by the United States National Oceanic and Atmospheric Agency in 2007, Kuwaiti flared volume decreased from 2.5 tonnes in 2006 to 2.1 tonnes in 2007.[12]

Kuwait Oil Company

Kuwait seeks to increase its use of natural gas in electricity generation, water desalination, and petrochemicals to reduce the impact on the environment and free up as much as 100,000 barrels per day of oil for export. Kuwait hopes to accomplish this through increased drilling for natural gas, and tying together gathering centres.

Public Authority for Agriculture and Fisheries

The work to establish green belts in Kuwait is well under way, to combat sand encroachment and develop carbon sinks through tree planting and afforestation.

Despite the above, more work is still required. An emission inventory should be conducted for all air pollution sources including industries, power plants, traffic and domestic sources to assess the status emission loads. District cooling is more economical and environmentally friendly than small air conditioning units. When residential areas are close to the coast (as in Kuwait), the benefits are far greater.

Another important aspect is renewable energy. Kuwait is a hot spot for solar power generation, with potential for wind energy. The government of Kuwait represented by the Amir (Sheikh Sabah Al-Ahmad Al-Jabir Al-Sabah) is giving serious consideration to the use of renewable energy, especially solar and wind.[19]

Incentives should be given for energy-efficient buildings. Solar water heating should also be encouraged, and environment-oriented non-governmental organizations must be empowered to advance sustainable development and strengthen environmental legislations. The implementation of carbon capture and storage technologies is also important.

Historic records of temperature in Kuwait show clear signs of climate change, at a rate of 4.7-6.6°C per century. The data shows asymmetry in the increase of temperature during day and night, with the increase in the latter being greater. Solar radiation data supports these findings.

The overall picture can be interpreted differently based on the background against which the picture is held. Considering the current challenges, along with pollution levels and the rate at which they have increased, the future can still be considered murky. However, when one takes into account the serious strides taken by Kuwait through adaptation strategies and implementation of new technologies one can be assured the years to come will witness an improvement in local air quality.

Adapting to changes and fluctuations in climate: a Russian perspective

Dr Alexander Bedritsky, Head, Roshydromet

One of the biggest public requests the scientific community receives is for forecasts on the probability of extreme climate events with significant socioeconomic and ecological consequences including heat waves, droughts, floods and hurricanes. While the problem of the predictability of extreme events, and of the climate system as a whole, remains highly relevant for timescales ranging from several decades to several centuries, today the most urgent need is for lead time forecasts of one season to one decade. It is obvious that the potential for predictability within the above mentioned timescale varies according to different climatic characteristics (as well as to different regions of the planet) and may often be quite limited, especially for Russian territory.

As we are looking at timescales in which, as a rule, the changeability of both the climate system itself — as well as its individual components — significantly exceeds input from external (anthropogenic) influences, the task of forecasting for one season to one decade poses considerable difficulties. Research in this sphere should probably be devoted to more clearly delineating the theoretical borders of the impossible, rather than to promising a progressive increase in forecast accuracy and lead time. Hopes for higher precision in evaluating future changes in climate extremes on Russian territory, which are of great practical interest, are connected with advances

Image: International Polar Foundation

Climate change could improve conditions for cargo transport in the Arctic seas in computer technologies that would allow for the possibility of carrying out complex calculations with high resolution climatic models. This will allow changes in the probability of the spread of climatic characteristics to be evaluated more accurately — in particular, for changes in the recurrence and intensity of hazardous events.

An Assessment Report on climate change and its consequences for the territory of the Russian Federation (RF) was prepared by the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) in collaboration with the Russian Academy of Science and published in 2008. This report presents the results of up-to-date research into many years of hydrometeorological observations on Russian territory, and also examines the results of climate modelling.

According to the Roshydromet Report, a significant part of the territory of the RF is located within the region of maximum climatic change, both observed and predicted.

The consequences of climate change vary for different regions of Russia and can impact differently on diverse groups of the population, sectors of the economy and natural phenomena within the confines of any given region. Therefore, when working out a national strategy for the RF, it is vital to take into account the whole spectrum of losses and gains connected with change.

Among the consequences of the expected climate change which would be positive for the RF and are connected to significant potential for the effective development of sector-specific and regional economies are, in particular: northward displacement of the northern boundary of the comfortable habitation zone as a result of mitigating climatic conditions; reduction in energy expenditure on heating during the cold season; improvement in ice conditions and consequently in conditions for cargo transport in the arctic seas, easing access to the Arctic Shelves and their reclamation; improvement in the structure and expansion of plant husbandry as well as an increase in the productivity of animal husbandry (providing certain additional conditions are met and certain measures taken); increase in the productivity of boreal forests; increase in water resources (for the country as a whole, notwithstanding the appearance of some regional deficits) and improvement in conditions for the development of hydro-electric power.

Among negative consequences of expected climate change are: an increase in the recurrence, intensity and duration of droughts in some regions, and in others a rise in extreme precipitation, floods, and cases of soil humidity reaching agriculturally dangerous levels; increased fire risk in forested landscapes; degradation of permafrost with damage to buildings and infrastructure in northern regions; disruption of the ecological equilibrium, displacement of one biological species by others; increase

Image: International Polar Foundation

Scientists gather important data about the climate from research in polar regions in energy expenditure for air conditioning in the summer season for a considerable proportion of settlements.

Among the advantages enjoyed by the RF in comparison to many other countries are:

- An overall higher adaptation potential which can provide for large portions of the territory
- The presence of considerable water resources
- The relatively low proportion of the population living on territories especially vulnerable to climate change.

Social groups, natural phenomena, economic infrastructures, and elements of the state structure of the RF differ as regards the nature and degree of their vulnerability to the unfavourable consequences of climate change. Moreover, not all types of possible damage can be evaluated today in monetary terms, and the evaluations of possible losses may themselves contain significant uncertainties. The existence of such uncertainties should not become an obstacle for providing an acceptable level of protection, as a measure of reasonable precaution, for the more vulnerable territories, aspects and social sectors. Particular attention should be paid to this while evaluating vulnerability, developing and realizing lead time measures for preventing and neutralizing unfavourable consequences of climate change.

On the other hand, in a situation of uncertainty, it becomes especially important to provide decision makers not only with objective information about current and predicted climate changes but also with a proper interpretation of these, as well as with clear indications of measures to be taken — adaptation, risk management and others.

The Roshydromet Report — which is in essence the first Russian National Assessment Report — made a significant contribution to scientific argument underlying an important political document: the Russian Federation's Climate Doctrine. This was also prepared by Roshydromet and approved by the session of the Presidium of the Russian Government. With the long-term perspective in mind, the Climate Doctrine project pays special attention to the development and planning of measures for adapting to the consequences of climate change. Adaptation is the only possible answer to many of these consequences. One of the top priorities for RF climate policy is anticipatory adaptation with the goal of minimizing losses and maximizing gains connected with future climate changes, especially those which are unavoidable in the near future.

Taking into account the dimensions of Russia's territory, its geographical location, the exceptional variety of climatic conditions, economic structure, demographic peculiarities and a range of other factors — the spectrum of tasks relating to climate change adaptation on the country's territory is extremely broad. As such, alongside a variety of projects, the RF's national strategy must include the development of observation (above all, observing extreme events), prediction and early warning systems. Without these components, no adaptation project can be effective. For example, probability forecasts for drought and precipitation form the basis for adaptation projects in the sphere of land use. Here, the most important role, besides developing predictive models, is played by climate observations, and improving these — including improved organization in cases where additional observations are necessary — is an essential factor for successful adaptation measures.

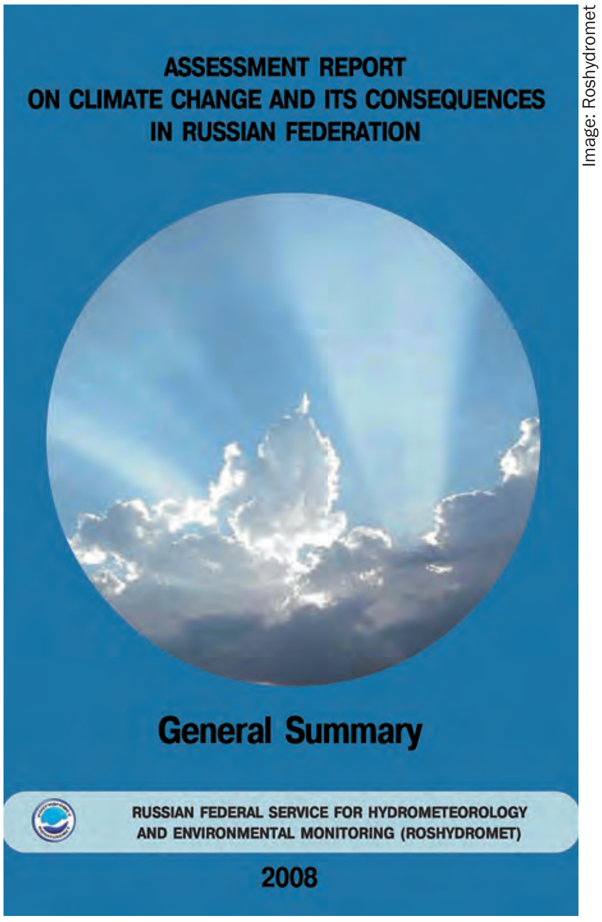


Image: Roshydromet

The Roshydromet Report is a significant contribution to scientific argument

Measures for climate change adaptation, including those relating to RF collaboration with the international community, are regulated by government decisions. The planning, organization and implementation of adaptation measures, including proactive adaptation, are carried out within the framework of the RF's state socioeconomic policy in the sphere of climate. They take into account sector-specific, regional and local peculiarities, as well as the long-term nature of these measures, their scope, and how deeply they impact on different aspects of the life of society, the economy and the state.

The most important components in developing and planning adaptation measures are evaluations of: vulnerability to unfavourable consequences of climate change and the associated risks of losses; possibilities of benefiting from favourable consequences of climate change; cost effectiveness and practicality of relevant adaptation measures; and adaptation potential, taking into account economic, social and other factors which would impact on the state, economic sectors and social groups.

Roshydromet takes an active role in undertaking and clarifying the above mentioned evaluations, and in delivering them to decision makers.

Challenges for the climate services in Switzerland

C. Appenzeller, A. P. Weigel, M. Begert, S. C. Scherrer, M. Croci-Maspoli, G. Seiz, N. Foppa, A. Rubli, Climate Division, Swiss Federal Office of Meteorology and Climatology MeteoSwiss

Growing concern about global climate change has increased awareness of the importance of providing accurate climate information for the past, present and future. The current state of the Swiss climate has become an active element in public debate. Reports on the warmest month or season on record, or articles on the impact of once-in-a-hundred-years precipitation events, are headlines in the daily news. Historically, climatology at the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss) has primarily focused on the observation of weather elements, data quality control, homogenization and data archiving, and subsequently calculating and reporting basic statistical quantities such as monthly temperature and precipitation summaries. In retrospect, this work was fundamental in triggering the development of national climate monitoring infrastructures. Without them, we would not know how much the climate has changed in recent years.

The growing importance of issues related to climate change has increased the demand for new climate services and poses a wide range of challenges to MeteoSwiss. Switzerland, due to its mountainous topography, seems to be particularly exposed to climate change. Indeed, over the period 1971 to 2008 Switzerland has experienced a temperature rise of 1.75°C, which is twice the globally averaged land surface trend. Climate projections suggest that this warming will continue and by the middle of this century affect tourism, biodiversity, water resources, hydropower generation and many other sectors of socioeconomic and ecological relevance. A specific example is Swiss winter tourism. Many ski resorts are located at an elevation of 1,000 to 1,500 metres above sea level. One of our research projects revealed that the 0°C line in winter is projected to rise from roughly 900 metres today to 1,250 metres above sea level in the next 50 years. This means that by 2050 dozens of ski resorts may not have enough snow in winter to continue to exist. Information of this kind is crucial for those in charge of regional planning as well as for investors in holiday resorts.

Image: Ruedi Wyss

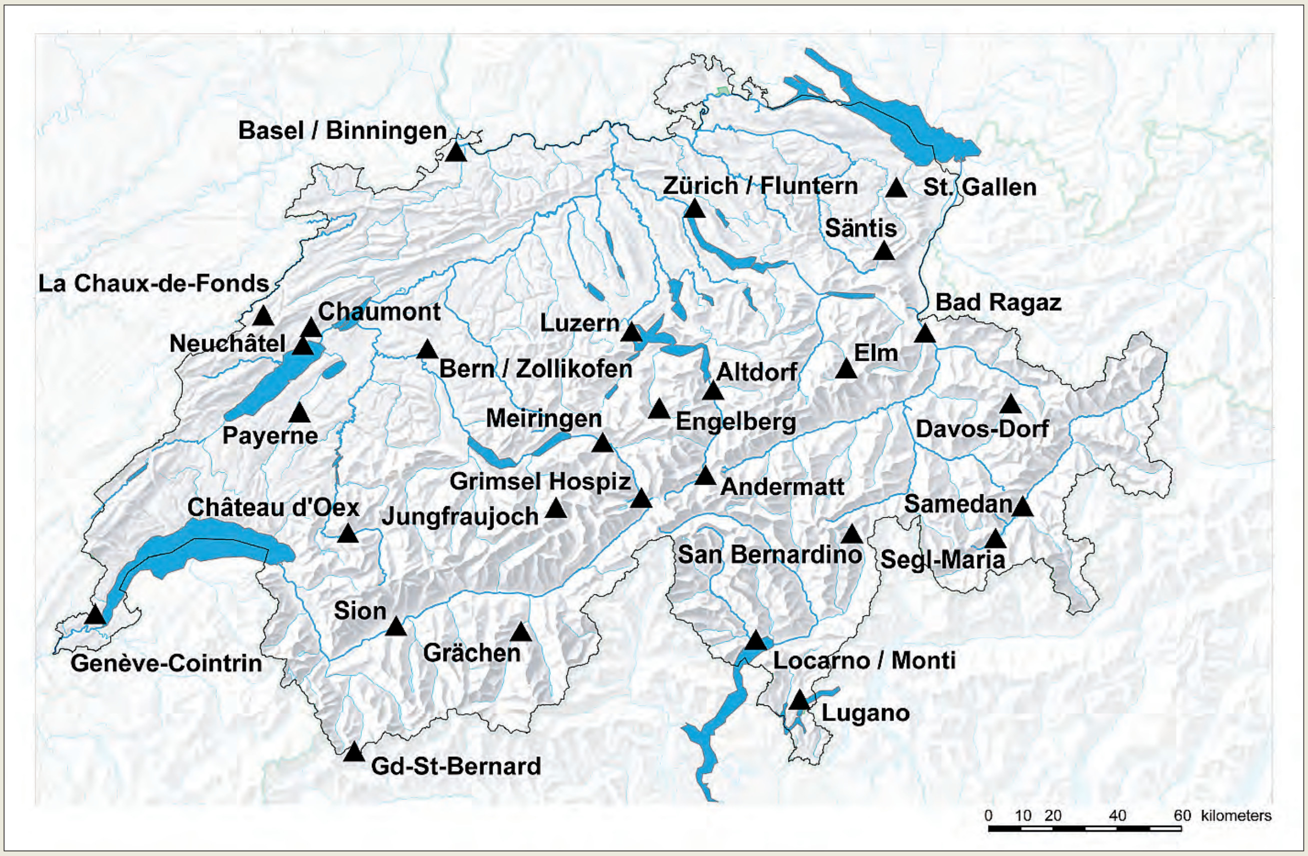
Monitoring the high alpine climate of Jungfraujoch at 3,580 metres

This example illustrates that, although the problem of climate change is a global one, its effective consequences can be highly localized and site-specific. In the ideal case, climate services would therefore be custom-tailored to the demands of each region in Switzerland. This not only refers to future climate projections, but also to observations of the present day climate, given that any climate change signal can only be detected and quantified if high quality observations are available. It is therefore a key focus of our service to ensure that climate monitoring is secured in sufficient spatial resolution and on a high quality level.

Climate observation and monitoring

Switzerland has a long tradition of climate observation. Some temperature series date back to the middle of the 18th century. Since 1864 a dense network of meteorological surface stations has been maintained and meteorological measurements have been recorded systematically all over the country. Many of these stations are still in operation today. They are part of our official meteorological surface station network, SwissMetNet. The most valuable climatological stations within SwissMetNet are pooled together in the Swiss National Basic Climatological Network (Swiss NBCN). Research is under way to digitize and homogenize most

The Swiss National Basic Climatological Network (Swiss NBCN)



Source: Federal Office of Topography swisstopo/Federal Office of Meteorology and Climatology MeteoSwiss

available NBCN data in order to provide high quality data series and to address climate change and climate variability issues. Swiss NBCN also ensures long-term continuity of measurements in the future.

Systematic long-term measurements also make a significant contribution to the Global Climate Observing System (GCOS) — a programme jointly sponsored by the World Meteorological Organization, the Intergovernmental Oceanographic Commission of the United Nations Educational Scientific and Cultural Organization, the United Nations Environment Programme and the International Council for Science. The Swiss GCOS Office, established at MeteoSwiss in 2006, coordinates all climate-relevant measurements in Switzerland. As a basis for a legal and sustainable strategy of the national climate observing system, GCOS Switzerland, a comprehensive inventory report was compiled in 2007.[1] Based on this report, the Swiss Federal Council decided in June 2008 to ensure the long-term continuation of at risk climate measurement series and international data centres in Switzerland.

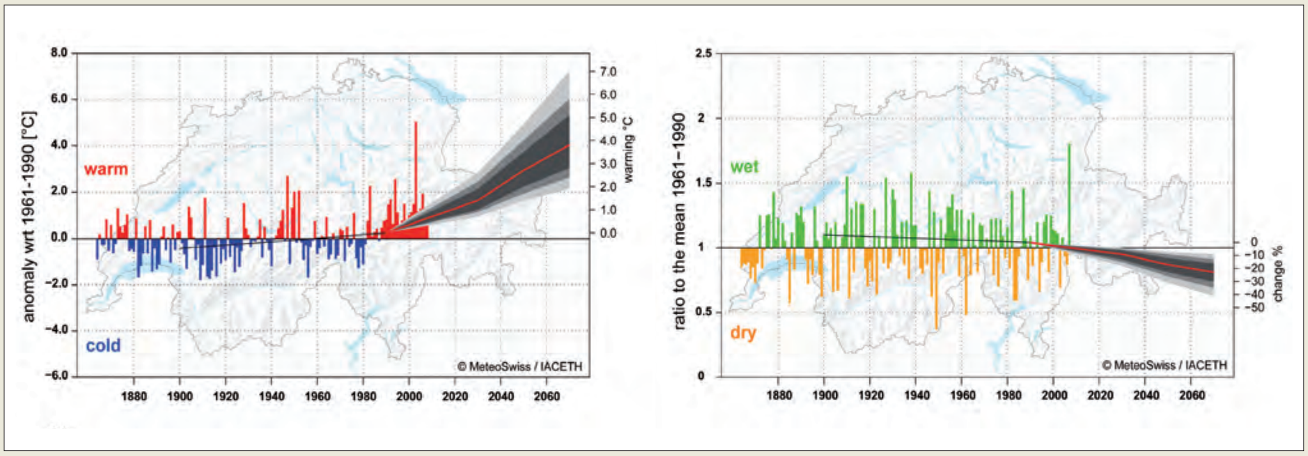
Apart from their fundamental role in climate monitoring, meteorological and climatological observations are relevant for many other purposes. For example, the data are used as inputs for defining the initial state of the atmosphere in numerical weather prediction models, as well as being indispensable for the verification and calibration of climate models.

Climate prediction and scenarios

Climate models are the backbone for providing information about future climate in the form of climate scenarios. This information has become indispensable for many stakeholders and decision makers in the public and private sectors, where climate risks need to be quantified and managed. The relevant timescales range from short-term — defined as monthly to seasonal climate fluctuations — up to multi-decadal climate change. There is a growing demand for integrated information on all these timescales, a demand which is also shaping the climate services provided by MeteoSwiss.

Scientific research has led to a substantial improvement in understanding and predicting short-term climate variability in many regions of the world. MeteoSwiss has started to make use of this knowledge and provides both public and private clients with probabilistic climate forecasts for the upcoming weeks and months. Although such forecasts still have comparatively little skill in Switzerland and Europe, they are nevertheless valuable for a wide range of specific applications, such as the pricing of weather derivatives or the estimation of developments in the energy market. To strengthen the link between forecast providers and forecast users and to get deeper insight into user demands, several joint projects have been set up with leading international Zurich based reinsurance companies. These projects showed that for applications in climate risk management it is

Climate projection for northern Switzerland



Observed (1864-2008) and projected (1990-2070) summer temperature (left, in °C) and precipitation anomalies (right, in per cent) for northern Switzerland with respect to 1961-1990. The grey areas show the uncertainty range of the projection (5-95 per cent confidence), assuming that no quick measures are implemented to reduce greenhouse gas emissions

Source: Federal Office of Meteorology and Climatology MeteoSwiss/Institute for Atmospheric and Climate Science ETH

essential that the forecasts are reliable and that the underlying uncertainties are appropriately quantified. This is a non-trivial task which involves a series of post-processing steps and has become a research focus of our climate service.

Concerning longer timescales, our observations clearly show that the climate has changed over the last decades. At the same time, climate model predictions as summarized, for example by the Intergovernmental Panel on Climate Change, indicate that the climate will continue to warm. While the magnitude of climate change depends on the future development of the global economy, technological innovation and policies, local and regional adaptation strategies can only be formulated if sound climate information is available, which in turn requires an involvement of the national climate services. For example, regional observations and projections of summer mean temperatures and precipitation for northern Switzerland have been determined under the lead of the Swiss national advisory board on climate change (OcCC, 2007).[2] However, most stakeholders require information that is even more specific, and we have to answer questions such as: Will there be a stronger temperature change at higher altitudes? How does the precipitation pattern change in a region or at a specific site? For example, the canton of Valais or the city of Geneva. What about changes in the frequency of extreme weather? Will there be more strong storms such as those in December 1999, floods like in August 2005 or heat waves as in 2003? And again — how certain are these projections?

An answer to these complex questions requires close collaboration with the Swiss and international climate research community. Since 2001, our office has been an active partner in the National Centre of Competence in Research on Climate, a scientific network bringing together more than 100 researchers from national partner institutions with the aim of better understanding the climate system by carrying out interdisciplinary research on its variability and interactions. At the same time, MeteoSwiss has participated in international research projects such as EU FP6 ENSEMBLES — a largescale European research initiative to provide objective probabilistic estimates of uncertainty in future climate on the basis of a large ensemble of global- and regional-scale climate model simulations.

While the duration of such programmes and initiatives is usually limited, the user demand for high quality climate information is continuously growing and requires the establishment of a more permanent framework to guarantee this kind of service. An integral component of such a framework could be provided by the Center for Climate Systems Modeling (C2SM) located at the Swiss Federal Institute of Technology in Zurich, which was established in autumn 2008 by Zurich based institutions, including MeteoSwiss. The C2SM has the potential to act as a long-term interface between climate research on the one hand and end-user oriented climate services on the other, and may form an integral part in the development of a national adaptation strategy.

Maintaining a reliable, high resolution measurement network that provides high quality local and regional climate information as well as climate change projections is among the most challenging tasks of our climate service. Together with our partners from research, the economy and public sector we can help to give answers to many climate related questions. However, we also need to improve dialogue between our service and stakeholders. Switzerland started with the development of a national adaptation strategy. Climate information will be the backbone of this strategy. A constructive dialogue will help to set the focus of our services. However, users must know the potential and limitations of our products if they want to achieve optimal benefits. The quantification and communication of prediction uncertainty is one of the key challenges in this context.

Danish alliances with the developing world on climate change and adaptation

Dr Wilhelm May, Senior Scientist, Danish Meteorological Institute

The Danish Ministry of Climate and Energy was established in 2007 as a part of the government's increased efforts to promote a greener and more sustainable society. One of its main tasks is the preparation of the United Nations COP15 climate conference in Copenhagen in December 2009. The ministry consists of several agencies conducting climate research projects in developing countries in close partnership with both Danish and local agencies in the target nations. The following examples are centred around the experiences of the Danish Meteorological Institute (DMI).

From 2009 to 2012, DMI will collaborate with the Sokone University of Agriculture in Tanzania and the Tanzania Meteorological Agency in a research project on the availability of water resources for agriculture under future climate conditions in northern Tanzania. The aim of connecting these three institutions is to give Tanzania the ability to prepare for future climate change.

During the same period DMI will be part of a 'twinning-project' with the Zambia Meteorological Department (ZMD). The aim of this project, which has been initiated by the Royal Danish Embassy in Lusaka, is to improve ZMD's capacity in climate monitoring and modelling as well as in the dissemination of weather and climate products. As a result, ZMD will be better prepared for providing weather and climate-related information and services to the public, as well as to various stakeholders, both governmental and private.

In particular, ZMD will be better qualified to provide important information and advice to governmental bodies on the issue of climate change in Zambia. It is envisaged, for example, that ZMD will be more able to provide detailed data on both present-day Zambian climate variability and future climate conditions, which is the basis for the National Adaptation Programme of Action on Climate Change (NAPA), formulated by the Ministry of Tourism, Environment and Natural Resources. Moreover, it is envisaged that ZMD will be better positioned

Image: John Cappelen

Meteorological station, Lusaka International Airport, Zambia to provide timely short-, medium-, and long-range forecasts to various stakeholders in the areas of aviation, agriculture and food security, hydropower and energy security, as well as warning of weather and climate-related disasters such as drought and flooding. Through this process, ZMD will also be a more valuable collaborator for international organizations operating in Zambia, such as the United Nations Development Programme.

ZMD is well aware of the need to improve its capability in weather and climate monitoring and in the dissemination of the resulting information, and has identified three major components that need to be addressed in the near future:

- Strengthen the capacity of existing meteorological stations by increasing the number of weather parameters monitored and increasing the equipment base
- Expand the station network to cover all 72 districts of Zambia
- Strengthen the interpretation and dissemination of weather and climate information for national early warning in order to enhance community and government awareness.

In addition, ZMD's capacity in addressing the issue of climate change needs to be upgraded, in particular the aspects of climate modelling and downscaling global climate projections.

A variety of activities will be undertaken in the twinning project between DMI and ZMD, to improve ZMD's capacity in the areas mentioned above. It should be emphasized that capacity building is considered an essential part in all of them. Several are related to properly monitoring and describing the weather and climate in Zambia. To achieve this, the existing meteorological station network must be improved and possibilities for expanding the existing meteorological station network need to be assessed. At present, the 38 principal meteorological stations are located in less than 25 Zambian districts, from a total of 72. The expansion of the station network would lead to better spatial coverage in many parts of the country.

Moreover, the management of existing meteorological data at ZMD needs to be streamlined, and some basic data analysis techniques introduced. In particular, the introduction of spatial gridding techniques is needed for creating maps that properly describe the state of the climate and its variability over the entire country. Such maps are not only an important basis for assessing present day climate variability and future climate change, but also for preparing for climate variations — such as extended periods of drought or rainfall — and for developing strategies to adapt to the consequences of projected long-term climate change, as stated in the NAPA report.

DMI will also assist in producing regional climate simulations for Zambia by downscaling global climate projections. Through this process, information on the future climate can be obtained at a regional level, which is necessary for developing measures to adapt to the regional consequences of climate change. To achieve this, DMI will perform simulations with the HIRHAM Regional Climate Model for Zambia, both for present day and future climate conditions. In order to assess the quality of these climate simulations and possibly to improve them, observational data on both daily and monthly timescales monitored and processed by ZMD are of crucial importance. It is envisaged that ZMD will be supplied with the data from these climate simulations as far as is possible, so that it can give various stakeholders information on potential future climate changes, or provide data originating from these simulations to local research-

Image: John Cappelen

Cup counter and wind vane at meteorological station, Zambia Meteorological Department, Lusaka, Zambia

Image: John Cappelen

Victoria Falls and Victoria Bridge seen from helicopter

ers with an interest in issues related to climate variability and change, such as the University of Zambia.

Also important is the dissemination of weather and climate information at a regional level, for example, in the Southern Province. The Southern Province is of particular interest because, on one hand, it is the breadbasket of Zambia and, on the other, it is the region that is most vulnerable to the adverse effects of drought and occasional flooding. Local weather and climate information, such as the existing 10-day Crop Bulletin, is essential for agricultural planning purposes. A website for weather and climate information at a regional level will be set up as a pilot project, and is expected to markedly increase the level of information dissemination, especially if it can also provide translations into local languages and information about farming practices suitable for the forecasted weather conditions.

In addition to these current programmes, from 1997 to 2000 DMI was part of the Danish International Development Agency project: Water Resources Information Systems (WRIS) in Ghana, in collaboration with the country's Meteorological Services Department (MSD). The aim of the WRIS project was to rehabilitate the hydrometeorological and other meteorological information produced by MSD. In addition to the station network and data handling, the project also focused on public relations. The latter improved awareness of MSD and its services in Ghana.

In the period 2006-2007, DMI took part in a research project called Sustainable Resource Use or Imminent Collapse? Livelihood and Production in the Southwest Pacific (CLIP). The goal of CLIP, which was coordinated by the University of Copenhagen and supported by several private funds, was to investigate how small isolated societies in developing countries such as the Solomon Islands cope with the modern problems of globalization and global change. The issue of climate change was considered in the project, since the Solomon Islands are likely to be increasingly vulnerable to changes in climate and related impacts, such as increasing sea level, the acidification of the ocean and changes in severe weather and climate events.

All of the above projects have capacity building as a common goal and give developing countries the best possible knowledge of future climate problems and possibilities through scientific cooperation and alliances.

Increasing preparedness for climate change in Hungary

István Láng, Hungarian Academy of Sciences; László Csete, 'CLIMA-21' Brochures, Budapest; Tibor Faragó, Ministry of Environment and Water, Budapest; Márton Jolánkai, Szent István University, Gödöllö; János Mika, Hungarian Meteorological Service and Eszterházy Károly College, Eger

In 2003 the Hungarian Ministry of Environment and Water (HMEW), and the Hungarian Academy of Sciences (HAS) launched a joint research project called 'Global climate change, its impacts in Hungary and responses'. The project is commonly referred to as VAHAVA, from the abbreviated Hungarian for 'Change, Impact, Response'. Since the National Environmental Program of Hungary was already dealing with the national task of controlling emissions of greenhouse gases, VAHAVA focused primarily on vulnerability and adaptation in relation to the anticipated impacts of climate change.

It formulated two strategic objectives: preparing the Hungarian people and economy for likely increased extreme weather and hydrometeorological events, thus enabling them to cope with warmer and drier conditions; and developing the organizational, technical and financial infrastructure needed for a timely response.

VAHAVA's major methodological aim was the synthesis of large systems. Representatives of various scientific disciplines were invited to take part in this complex project. No new research programmes were launched, but knowledge, data and experience gained in past decades was synthesized — creating new intellectual products.

Image: Hungarian Meteorological Service, Budapest

Heavy snowfall limits even the railway transport. Though the event becomes less frequent with global warming in Hungary, the ability to cope with it should be sustained

Climate and extremes in Hungary

The Hungarian climate is affected by influences from three directions: continental effects from the east, Atlantic from the west and Mediterranean from the south. As a result the meteorological events from year-to-year and season-to-season are highly variable.[1] The countrywide average temperature follows global changes, but shows somewhat higher warming than the global rate. These changes occur mostly in summer.

The disadvantageous impacts of extreme meteorological events include: floods; excess inland water inundations; droughts; deluvian rainstorms; hail; heat waves; increasing UV radiation; early and late frosts; heavy snow drifts; wind storms; forest and bush fires; and the appearance of new pathogens and pests. The more serious impacts are also affected by human activities — for example, inappropriate land use and the lack of maintenance of levees in flood-prone areas.

The working hypotheses of the project were that warming will be stronger than the expected global average in the Carpathian Basin, that we should expect decreasing annual average precipitation, and that the number and intensity of extreme meteorological events will increase.

Basic results and recommendations of the project

A large number of measures and regulatory considerations were formulated in the wake of the project. A selection of findings and recommendations follows.

VAHAVA concentrated its activities on increasing the general awareness of interested stakeholders on climate change hazards, impacts and necessary responses. Different layers of society, individuals, elements of the natural environment, landscape and sectors of the national economy all react differently to climate changes. Their vulnerability and resilience are also different. An extremely important result was that it successfully drew the public's attention to changing climate and the need for increasing preparedness. There is an urgent need for raising awareness, in which education, training, professional advice and popular-scientific publications should play equally important roles. A wide range of professionals became acquainted with new terms (‘climate policy’, ‘mitigation’, ‘adaptation’) and knowledge of the general features of climate and weather.

Responses to impacts and their solutions can be achieved in sequence, taking the interdependencies of mitigation and adaptation into consideration. The order is: preparation; prevention of damage; defence (rapid, professional and effective reaction, the mobilization of reserves and disaster prevention forces); and remedial action (rapid elimination of damage, especially that affecting health and infrastructure, and the establishment of relevant insurance systems, financial and other reserves). A major proposal is that a Preventive Climate Strategy for Public Health Protection should be developed. In a critical situation the availability of food, drinking water, medicine and other reserves determines the length of an emergency situation and how many lives are saved.

Great importance is attributed to the role of forests in reducing damage, and of vegetation cover in general, with special regard to their absorption and storage of CO_2. An ever increasing stress is the reduction of freshwater resources and deteriorating water quality, along with rising water prices. The project intends to reduce flooding and protect subsurface drinking water as well as thermal, medicinal and mineral water resources.

Proposals related to the field of energy production and consumption, which play a deterministic role in global warming, are concentrated on mitigation. Strategies include improving the efficiency of power generation, using energy saving technologies to decrease power dependency and reduce costs, and expanding alternative power resources. A special response package was created for transportation, aimed at reducing emissions.

Experience gained during the project

Efforts were made to involve the widest possible professional and social groups in debating partial results. This also drew the attention of decision makers to the problem area. The project involved very active communication and dissemination work. Between 2003 and 2006 more than 200 articles were published in newspapers and journals and about 150 radio and TV interviews were broadcast on the topic of climate change. A majority of these mentioned VAHAVA. Among its publications and conferences are various books, proceedings and CD-ROMs, totaling around 4,000 pages.

To summarize, some organizational experiences that could be useful to other countries facing similar circumstances include:

- In such a large and synthesizing project it is extremely important to gain the support of leading politicians, government officials and scientists
- Guarantees of financial support should be obtained. In this case the leaders of the Ministry for the Environment and Water Management and HAS made an agreement
- The existing but underused research results of around 300 experts were built into this synthesizing work, secured by personal motivation and interest
- Active and constructive working relationships were developed with the leading green non-governmental organizations. A good relationship with the media was established.

National climate change strategy

After the publication of the proposals, the Hungarian Government decided on preparation of a National Climate Change Strategy (NCCS), coordinated by HMEW and taking into account the results and recommendations of VAHAVA. Parliament unanimously adopted NCCS on 17 March 2008. The resolution was

Image: VITUKI, Budapest

The record flooding in Budapest during August 2002. Public transport was unusable along the riverbank, but the second dyke defended the downtown

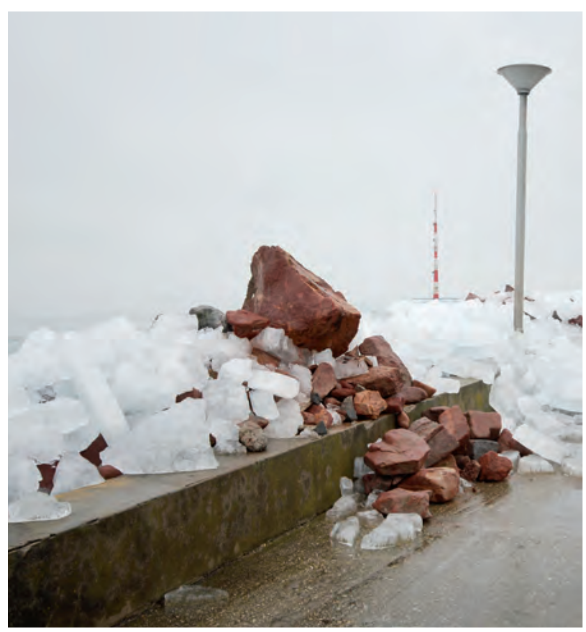


Image: Hungarian Meteorological Service, Budapest

Ice drifted onto the pier by the stormy temperate latitude cyclone, Kyrill Lake Balaton, Hungary, 19 January 2007. As well as the strong wind, the high water level also contributed to the event

Image: Mariann Darányi, Hungarian Meteorological Service

A painted sign for tourists is split by strong winds. The nearby meteorological station registered wind gusts of up to 36.8 m/s (Bánkút, Hungary, 30 October 2008)

compiled in order to determine objectives, instruments, priorities, and tasks connected to: climate change research; adaptation to domestic impacts; reduction of domestic greenhouse gas emissions; and the preparation of instruments for achieving these objectives. The Climate Strategy began in 2008 and is scheduled to run until 2025 in accordance with international commitments. The government will review it in 2010 and subsequently every five years.

Based on previous scientific research synthesized by VAHAVA, NCCS outlined the effects of climate change on specific sectors. These are: nature conservation; human environment and health issues; water management; agriculture; regional development, including development of settlements and the built environment. NCCS will widen its scope to cover other sectors including tourism, security policy and urban planning.

Follow up activities related to impact research

VAHAVA was pursued within the framework of the national research project Preparation for Climate Change: Environment — Risk — Society.[2] The range of the research areas were varied. Climate change expectations were based on the Prudence Project for Hungary, among other sources.

Climate change as input variables for impact and adaptation studies was investigated on two levels: as a continuous linear slow change of mean temperature and precipitation; and as a non-linear change with more frequent and serious anomalies.

Considering the first type of change, crop development is accelerated by higher temperature — assuming no nutrient and water stress — although much higher than optimal temperature can endanger crop growth. High temperatures increase evapotranspiration which can rapidly dry the soil, although increasing CO_2 concentration has a positive effect on biomass accumulation. Water use in agriculture is expected to become much more expensive and thus more strictly limited because of increasing private and industrial water use. Soil productivity is also expected to change because organic matter breaks down more intensively at high temperatures. Warming has a positive effect on the reproduction rate of pests, which increases the occurrence of infestation and makes pest control more expensive. Research suggests that ecological zones can shift north at a rate of 150-250 kilometres if global warming equals 1ºC. For Hungary this means that a temperature increase of 2ºC would involve great changes in climate conditions, in turn requiring totally different land use.

We can establish that anomalies make production uncertain, and extreme events can cause catastrophes, which have serious social and economic effects. But since the global and moderately resolved regional models could not provide full details of the changes in frequency and peak intensity of these extremes, no specific conclusion could be made.

Regional climate modelling

Climate dynamics and modelling in Hungary date back to 2004, with the primary aim of adapting, validating and developing regional climate models for the Carpathian Basin. There are four recent regional models available for the simulation and projection of climate. These are: ALADIN-Climate, PRECIS, RegCM and REMO.

The following predictions can be made for the period 2021–2050, on the basis of model experiments. All models agree that warming above global mean change is anticipated for Hungary. The precise extent of the increase varies between models, however the signal is statistically significant. Uncertainties exist for change in precipitation. Although the annual amount is not expected to alter considerably, annual distribution is likely to completely change. Decreased summer precipitation is marked in each model, however changes in other seasons are very uncertain. Projected precipitation tendencies are not significant for any of the models. Regarding extreme climate characteristics, 'warm' extremes and severe precipitation events will increase, while 'cold' extremes will decrease to a lesser extent. For temperature related extremes the changes are significant, while results for precipitation should be interpreted with extreme care, since they might represent natural climate variability.

In summary, the most important aspect of climate modelling in Hungary is the fact that regional models are available and can be successfully used for the Carpathian Basin. It is essential that projections contain information about their reliability and probability. Outputs of the regional climate models should be used as primary inputs for climate impact assessments in the future, including the implementation of NCCS and other adaptation-related efforts in Hungary.

The project has effects on Hungary's position in international negotiations, as well as its participation within the framework of EU level cooperation. It is especially valid for setting, assessing and formulating impact policies and measures.

Sustainability in climate change mitigation and adaptation: a Spanish perspective

Domingo Jiménez Beltrán, Adviser to the Spanish Observatory on Sustainability and Former Executive Director of the European Environment Agency

Climate change obliges humankind to alter its unsustainable development patterns at all levels and in particular in relation to energy. Developed countries must begin a process of reducing resource use, while uniting in efforts to share said resources with the developing world.

This process of rethinking the whole climate change approach to account for sustainability will require mass global cooperation. Existing knowledge in the fields of meteorology and climate sciences will need to be shared as much as possible and efforts must be renewed to develop joint research and development programmes aimed at extending the use of science beyond its immediate scope to the planning and decision making process. This, in turn, will hopefully allow us to build up more sustainable medium- and long-term scenarios.

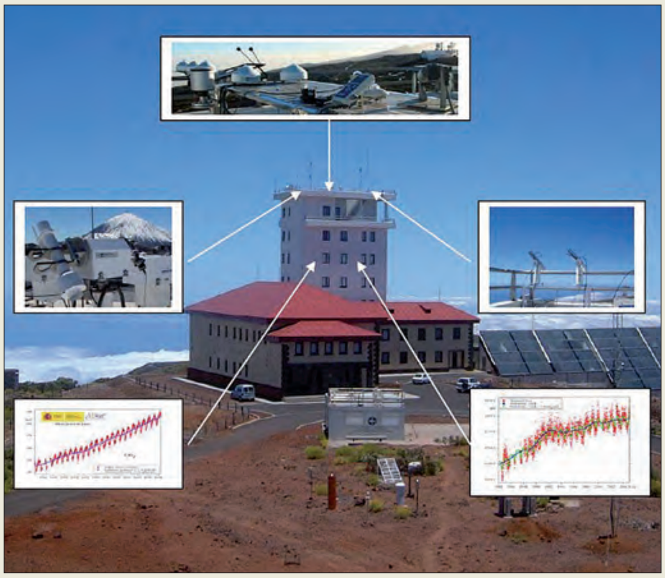
Spain has introduced research and development programmes on climate change adaptation and mitigation as a priority, as well as having developed advanced networks to survey trends in climate change and in background atmospheric composition at national, regional and global levels — particularly in the Mediterranean area. These programmes could and should be used for extended knowledge sharing and development cooperation efforts, especially considering Spain lacks a high level of application for meteorological and climate sciences.

The observable effects of climate change clearly signify that humankind must reorient its approach to development to place a greater emphasis on sustainability. The developed world must reduce its use of

Image: E. Viñuales. CENEAM-O.A.P.N.-MARM- Spain

Retreat of glaciers in the Pyrenees Mountains is one of the most important signs of climatic change in Spain

Izaña Atmospheric Research Center



Source: AEMET

resources. This does not mean it must become 'less developed' or with a lower quality of life, but rather that it should approach development in a different, more efficient manner. The world must also unite in helping the developing countries to embrace the sustainable use of resources while improving substantially the quality of life to converge with the developed world.

The question is — why not transform this reactive attitude to environmental challenges into a more proactive one, and thereby transform this global challenge into a real opportunity? In doing so we could transform it from climate change to a 'climax for change' and genuinely hope to face the urgent call for a sustainable solution to the impending environmental and economic crisis.

It is evident that we must 'rethink everything' by applying a new and different logic akin to Einstein's idea that: "We can't solve problems by using the same kind of thinking we used when we created them." As such, the UN Conferences of Rio and Johannesburg (at a global level) and the Lisbon Treaty, the Socioeconomic Agenda and the Sustainable Development Strategy (at a European level) have demonstrated that the only logical approach to providing simultaneously for economic wealth, improved social cohesion and welfare, and enhanced natural resources is one of sustainability.

The good news is that we have the means to make the processes of development and globalization more sustainable. The bad news is, that the purpose to do so is lacking. This fact is manifest in the current lack of development of the necessary conditions for change, including the sharing of access to the best available knowledge.

We must make greater efforts to share knowledge of meteorology and climate sciences by extending cooperation and networking, as well as by demonstrating the best ways to use such knowledge in the planning and decision-making processes — as ultimately sustainable development is a 'development based on knowledge'. Currently unsustainable projects continue to put knowledge aside in favour of short-term and in most cases abusive and speculative economic interests. This attitude transfers significant costs to the rest of the society now and in the future. This is particularly the case of many land development and urban planning processes, where the most elemental knowledge is ignored or misused.

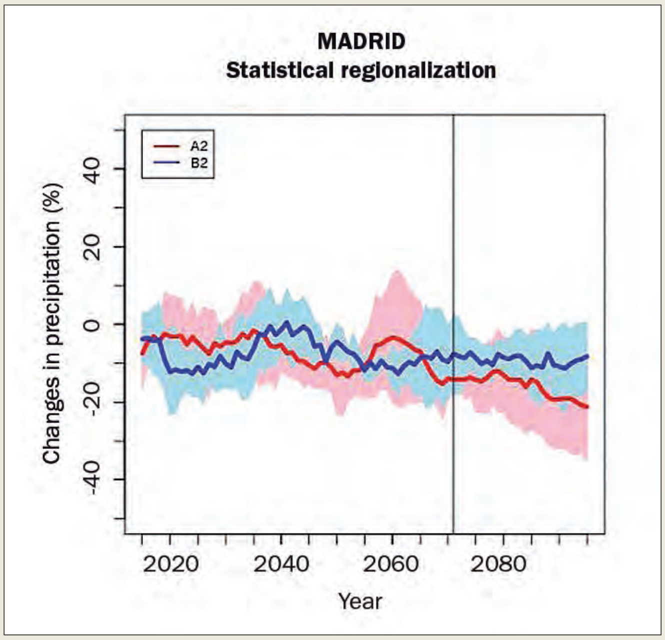
The scientific community must coordinate its efforts to improve knowledge of the climate and its evolution, as well as formulate very specific aims to improve the numerical models and statistical techniques used in prospective analysis. This, in turn, will result in more accurate projections, a reduction of uncertainty in results, and — more generally — optimized decision-making and planning processes that are more sustainable, more harmonious with nature and adapted to the changing climatology, as well as to the related availability and vulnerability of natural resources. This will enable humankind to face the climate change challenge more efficiently; with improved and specific strategies, as well as plans for the mitigation of and adaptation to the impacts of climate change. Furthermore, an even bigger effort must be made to apply and share these improvements at the global level.

Because of its geographical location in the Mediterranean, Spain is particularly vulnerable to climate change. As such, it is actively participating in a broad range of international climate change-related initiatives including the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC). In the European context, Spain has cooperated with other Western European countries — via their meteorological services — in initiatives such as the creation of the European Climate Support Network in 1992, which later on became a EUMETNET programme. One of the first tangible results of such activities was the first report on European climate, which was presented in Berlin during the first Conference of the Parties to the UNFCCC.

Spanish concerns are also reflected in the country's administrative efforts to provide capacity for the analysis of the potential socioeconomic implications of climate change, as well as to develop and coordinate policies of mitigation and adaptation to minimize its negative impacts. In 1992 the National Commission for Climate Change was established, with the different departments of the General Administration represented, as well various social organizations at the national level. Its main goal was to advise the government on the best policies and strategies to face climate change. In particular it sought to facilitate the development – following the recommendations of the World Meteorological Organization — of a National Programme on Climate, integrating all government actions related to climate and climate change.

One of the first actions of the commission was to establish a focus on climate as part of the national research and development plan for the years 1996-1999. The aim was to improve knowledge of the climate and its future evolution in order to reduce existing incertitude regarding how, when and to what extent climate change will affect Spain. Such programmes have piqued the national scientific community's interest in different

Regionalized scenarios for climate change



Source: AEMET

climate change research areas, from variability studies to regional modelling. This has resulted in a significant increase in the number of research groups dedicated to climate change, as well as of related articles and publications in international reviews and magazines.

This commission was replaced in 2001 by the larger National Council on Climate, which includes representatives from the autonomous regions, the Spanish Federation of Municipalities and Provinces, the Federación Española de Municipios y Provincias, universities, social agents and non-governmental organizations.

Spain has carried forward a focus on climate change to its national research and development plan for 2008-2011, including topics on observation, adaptation and mitigation. Of specific importance is research exploring the development of energy from renewable sources that have potential in the Mediterranean region — especially since water resources will become increasingly scarce in the area, as will the energy derived from such sources. These efforts represent an experience that could easily be transferred to other countries (especially Mediterranean ones) through cooperation programmes.

One Spanish research effort of particular interest at regional and global levels is the continued survey of the background composition of the atmosphere. This activity is overseen by Spain's meteorology agency Agencia Estatal de Meteorología (AEMET). To this end, AEMET has a Global Atmosphere Watch station located at the Izaña Atmospheric Research Center on the Island of Tenerife. At this location it measures parameters including concentration of greenhouse gases, aerosols and ozone. AEMET also has 13 stations measuring background air quality distributed all over the nation — as well as another group of stations located in three national parks – that monitor ongoing environmental, social and economic changes resulting from climate change.

Because of its vulnerability to climate change, identifying potential adaptation strategies is of significant interest to Spain. In addition, this insight and experience can be shared with the entire Mediterranean area, which shares similar climatological and socioeconomic conditions and thus has similar vulnerabilities. In line with keeping climate change a priority, in 2006 Spain established The National Plan for Adaptation to climate change (PNACC) with the goal of incorporating adaptation strategies into the planning and management of natural ecosystems and economical activities dependent on climate variability.

The PNACC set out to generate regionalized scenarios for climate change in Spain with a further focus on evaluating its impact on water resources, coastal zones and biodiversity. AEMET is responsible for generating regionalized climate change scenarios at the Spanish level, and as such, it has established a two-phase project. The first phase has been finalized and will provide package projections for Spain and each of the autonomous regions up to the end of the 21st century. These packages will be based on information resulting from numerous Spanish research projects, the third assessment report from the IPCC, and from AEMET itself.

During the next four years the second phase will be developed to generate new regionalized scenarios based on global-level information used in the fourth assessment report and using new regionalization models with the support of national research groups working in the field. The results of the three other priority actions concerning the specific impacts of climate change will be available in 2010.

Spain is clearly not lacking in the knowledge required to improve the policies, plans, programmes and projects relating to sustainable development and the climate change challenge. Rather, it is lacking the correct application of its knowledge assets, and in doing so is failing to optimize its actions towards the mitigation of and adaptation to climate change. This is the real challenge for Spain.

2010 will be a key year for Spain, as it will assume the Presidency of the EU just after the December 2009 Copenhagen Climate Summit — hopefully on time to halt the increasing loss of biodiversity and put the UN Commission for Sustainability on the right track.

2010 represents a good opportunity for Spain to reinforce climate change and its related issues as an EU priority. But it also gives it the chance to prove its purpose to apply newly available knowledge on climate change scenarios to policy making and planning — particularly with regards to economy and land planning — as many ongoing national research projects will have delivered results by then. Therefore, it will be possible to demonstrate the proper application of such knowledge by sharing it — particularly within the Mediterranean area. This should be considered not just as a responsibility, but also as an opportunity to turn climate change into a 'climax for change'. With its vulnerability to climate change and expertise on energy from renewable resources Spain should be considered a leading country in this effort.

Earth observation and global environmental research for adaptation to climate change — a Japanese perspective

Hiroshi Ono, Director, Research and Information Office, Global Environment Bureau, Ministry of the Environment, Japan

As climate change becomes a real threat, there has been increasing emphasis placed on earth observation and global environmental research to help understand and assess the potential vulnerabilities and impacts it heralds, as well as to enable informed policy-making on mitigation and adaptation. At its third session the Earth Observation Summit, held in Brussels in February 2005, adopted a Global Earth Observation System of Systems Ten-Year Implementation Plan. The Ten-Year Implementation plan made it clear that understanding the earth system — including its weather, climate, oceans, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards — is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, reducing disaster losses, and achieving sustainable development. The observation of the earth system constitutes a critical input for advancing this understanding.

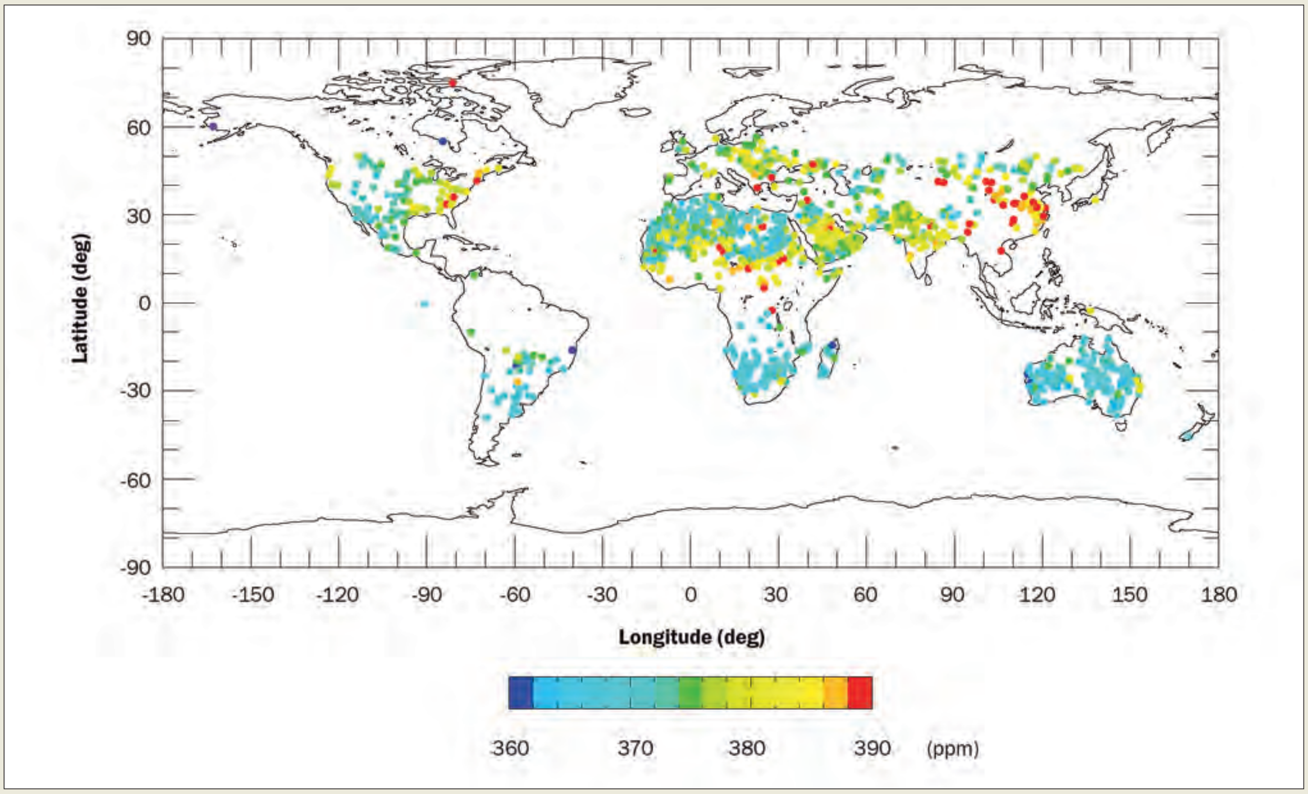
In Japan, the government's Earth Observation Promotion Strategy recommended the establishment of a national earth observation alliance to enhance cooperation among organizations, ministries and institutions. As such a Japanese Alliance for Climate Change Observation (JACCO) was launched in April 2006, co-chaired by the Ministry of the Environment, Japan (MOEJ) and the Japan Meteorological Agency (JMA). In March 2008, JACCO delivered its first assessment report on the needs and priorities of climate change observations. It also functions as an inter-agency node to facilitate the accessibility and comparability of observation data, as well as the coordinated use of observational platforms by relevant organizations.

One of the most innovative initiatives relating to climate change observation recently reached fruition, when the world's first satellite dedicated to the observation of greenhouse gases (GHGs) was successfully launched on 23 January 2009 from the Tanegashima Space Center in Japan. The Greenhouse gases Observing SATellite (GOSAT) — or IBUKI[1] as it is nicknamed in Japanese — measures the global distributions of carbon dioxide (CO_2) and methane (CH_4) concentrations with 56,000 measurement points, and produces the geographical distribution and seasonal and interannual variations in the emissions and removals of GHGs. The GOSAT mission is a joint effort involving MOEJ, the National Institute for Environmental Studies (NIES) and the Japan Aerospace Exploration Agency. The analytical results will bring a breakthrough in the scientific understanding of the global carbon cycle in relation to the atmosphere, land ecosystem and ocean, thus providing climate modelers with key information for significantly reducing uncertainties in climate change prediction.

In May 2009 the initial analysis of CO_2 and CH_4 concentrations was released, though still in the process of calibration and validation. The global distribution of average column concentrations analysed by NIES using a nine-day data set showed higher CO_2 and CH_4 concentrations in the northern hemisphere compared with those in the southern hemisphere, which is largely compatible with the existing ground measurement results. Although any decisive interpretation of individual data could not be derived from this initial analysis — since data calibration and validation was incomplete — the result positively demonstrated that there are no mechanical issues or unexpected problems in the measurement and data retrieval system. In the future, compiled data sets will be provided first for researchers contributing to calibration and validation, with a calibrated and validated data set expected to be released to all users in the next five to eight months.

Global environmental research is another important element of helping those in power make scientifically informed, sound decisions on mitigation and adaptation to climate change. In recognition of this, MOEJ operates a competitive grant scheme for global environmental research contributing to formulating and implementing global environmental policies. The scheme was initiated in 1990 and is called the Global Environmental Research Fund (GERF). Since then the GERF has played a unique and leading role as a core fund in Japan for promoting, global environmental research related to the interdisciplinary integration of natural, social and political sciences. Impacts, vulnerabilities and adaptation relating to climate change are identified as high-priority research areas in relation to policy-making. A current GERF flagship project involves the identification of risks and vulnerabilities relating to, as well as the quantitative assessment of, climate change impacts on key sectors in Japan. The project focuses on water resources, human health, agriculture,

Initial analysis of CO_2 concentrations measured by GOSAT



Column averaged dry air mole fraction derived from uncalibrated nine-day data

Source: JAXA/NIES/MOEJ

forest ecosystems, coastal zones and disaster prevention. The latest outcomes include the monetization of incremental damages in selected sectors toward the end of the 21st century under different stabilization scenarios including: 450 ppm-CO_2eq, 550 ppm-CO_2eq and BAU. The results are expected to contribute to the formulation of national and local adaptation strategies and plans.

The impacts of climate change are especially severe in highly vulnerable developing countries. Various impacts are predicted in the Asia-Pacific region including: increased floods caused by glacier melts; increased risk of food shortage; increased floods affecting coastal mega-cities; and decreased land area of small islands due to sea-level rise. In order to address these impacts, Japan is facilitating support for and cooperation with developing countries. One such initiative includes international research cooperation on global environmental change in the Asia-Pacific region to enhance developing countries' research capacity. To this end, MOEJ took the lead in establishing an Asia-Pacific Network for Global Change Research (APN)[3] in 1996, which now has the participation of 21 countries, including 15 developing countries. MOEJ, together with Hyogo Prefectural Government, is committed to the further development of the APN. By increased support for enhancing scientific capacity through the APN, Japan is ready to take a leading role to facilitate regional climate change assessments and local adaptation actions.

A big challenge ahead of us is how we can formulate and implement effective adaptation strategies and measures based on scientific data and information obtained via earth observation and global environmental research. Following are some of the highlights of MOEJ activities to this end, on both a domestic and international scale.

Scientific guidance on adaptation framework

Even in developed countries, observational data and research results clearly show that various phenomena are rapidly emerging as a result of climate change. Because of this, public awareness of the necessity of adaptation is growing rapidly. With this background, MOEJ published a study report entitled Wise Adaptation to Climate Change in June 2008.[4] This report assessed climate change impacts in Japan and presented basic principles for developing adaptation strategies. The study proposes a series of scientifically-informed precautionary actions including: the maximum use of state-of-the-art regional vulnerability assessments; the combining of various local adaptation options; and the incorporation of future changes in temperature, rainfall and sea level into designing adaptation measures in advance.

Integrated scientific information for adaptation

The IPCC's Fourth Assessment Report provides a global and regional perspective of climate change and its impacts to various sectors. However, specific information at a national level is essential to examine the necessity and extent of concrete adaptation measures

Image: APN

Fourteenth session of the Inter-governmental Meeting of Asia Pacific Network held in March 2009 (Kuala Lumpur, Malaysia)

Image: JAXA

GOSAT image

that need to be taken. MOEJ, together with JMA and the Ministry of Education, Culture, Sports, Science and Technology, has established a scientific panel to develop an assessment report for integrating scientific knowledge of GHG monitoring, climate prediction, and vulnerability and impact assessment for Japan. The latest scientific knowledge — including the results of high-resolution climate model simulation using the Earth Simulator, and detailed impact and damage estimations — will be assembled in the report. The report is expected to be published by October 2009 and will be made available to those considering adaptation strategies and plans both at national and local levels.

International cooperation to share adaptation knowledge

The United Nations Environment Programme (UNEP) — in collaboration with key UN and other international organizations — has proposed the development of a Global Climate Change Adaptation Network (the Network). The Network aims to enhance the adaptive capacity of developing countries by mobilizing knowledge and technologies to help build the climate resilience of vulnerable human systems, ecosystems and economies. To initiate the Network development process, UNEP convened an International Consultation Meeting on 30-31 October 2008 in Changwon, South Korea. The outcomes of the meeting were welcomed by many parties of the UNFCCC on the occasion of its SBSTA 29, and on other occasions including the Conference of Parties (COP) 14. To further elaborate the Network activities in a regional context, the Asia-Pacific regional consultation meeting was held on 2-3 February 2009 in Tokyo, hosted by MOEJ. The meeting reaffirmed the urgent necessity of a knowledge network to help developing countries in addressing the impacts of climate change. It established an Interim Steering Committee chaired by Prof. Masataka Watanabe of Keio University, and identified step-wise actions toward the establishment of the Asia-Pacific Network including the development of an implementation plan for the initial phase (2009-2010) with institutional arrangements, priority areas and activities, and a detailed timetable. MOEJ will fully engage in the establishment and implementation of the Asia-Pacific Network and hopes that tangible progress will be reported by the time COP15 is convened.

Seasonal climate forecasts and satellite information: improving decisions in the Uruguayan agricultural sector

Walter E. Baethgen, International Research Institute for Climate and Society, The Earth Institute at Columbia University; and Agustín Giménez, GRAS, National Institute of Agricultural Research, Uruguay

Uruguay's economy is largely dependent — directly or indirectly — on agriculture including crops, livestock and forests. The country's agricultural production is centred on the highly-fertile soils of the Pampas, an ecosystem in which temperate and subtropical grasslands are used for livestock production, or have been converted to improved pastures and croplands. Large interannual and interseasonal climatic fluctuations in Uruguay result in high variability in crop and pasture production, as well as having a potentially severe effect on the economy.

Southeast South America has an established El Niño-Southern Oscillation (ENSO) signal and, therefore, it has reasonable climate predictability — especially during the austral spring and early summer months.[1] Precipitation in this region tends to be above or below normal during years with warm or cold ENSO events, respectively. In addition, some research results suggest that the impacts of La Niña are stronger and/or less variable — in both rainfall and crop yields — than the impacts of El Niño.[2] Regarding the impact of ENSO phases on temperature, the very few studies conducted in Uruguay suggest that the temperature amplitude in northern Uruguay is reduced in El Niño years. The studies also suggest that mean temperatures in the whole country tend to be lower in La Niña years in all months, with a few exceptions during the summer.[3]

Recent La Niña-related droughts in Uruguay

Two La Niña episodes, during 1988-1989 and 1999-2000, had strong negative impacts on the Uruguayan economy. Both episodes were characterized by extended periods with reduced rainfall that strongly affected the agricultural sector.

One of the most critical rainfall periods for agriculture in Uruguay is late spring and summer (October-February). Average rainfall conditions during the summer months, 90-130 millimetres a month depending on location, are typically insufficient to compensate for evapotranspiration losses. Therefore, pasture and crop growth greatly depends on the soil's ability to store water. Natural grasslands in Uruguay occupy more than 70 per cent of the total land area and are mostly located in the northern and central regions of the country. Soils in these regions are frequently shallow (less than 30 centimetres in depth), and therefore possess low water storing capacity. Pasture production in these regions is thus highly dependent on the rainfall that comes during the late spring and summer months.

On the other hand, annual summer crops (for example maize, sorghum, sunflower and soybeans) require adequate rainfall during the critical flowering growth stage. Maize in Uruguay is grown in deep soils with relatively large water holding capacity. However, the amount of stored water in these soils is typically insufficient to satisfy the crop water demand, and yields of non-irrigated crops strongly depend on rainfall during the flowering months of late December and January.[4]

In summary, good years in Uruguay for natural grasslands in shallow soils and for annual summer crops in deeper soils are characterized by larger than normal rainfall during late spring and summer. In the two most recent La Niña episodes (1988-1989 and 1999-2000), rainfall during these critical periods was considerably below average.

Although the total land area of Uruguay is relatively small (approximately 190,000 square kilometres), large spatial variability is typically found in the spring and summer rainfall across the country's regions. For example, in both 1988-89 and 1999-2000 rainfall in spring and summer was much lower in the northwest than in the southwest or central regions. Also, the negative rainfall anomalies in 1999-2000 started earlier and lasted longer than in the 1988-89 period.

Responses in the agricultural sector to the 1988-1989 and 1999-2000 droughts

In 1988 Uruguay had no institutional structures, special policies or programmes in place to respond to droughts. At that time droughts were viewed as very low frequency phenomena that did not justify the development of special structures or programmes. As such, governments had typically reacted to previous droughts with crisis management responses such as special aid programmes for affected regions.

Research on teleconnections and impacts of ENSO on climate in Uruguay was incipient. Ropelewski and Halpert had just published the first article showing the correlation between ENSO anomalies and rainfall patterns in southeastern South America.[5] Climate scientists from the University of Uruguay and the National Weather Service were only just starting the first research studies on ENSO impacts.

The 1988-89 drought found Uruguay with no institutional structures, with no capabilities to assess or monitor water availability and with incipient research on the ENSO impacts on rainfall. Consequently, the government and the private sector could only respond to the drought with a crisis management approach. In the livestock sector the direct losses attributed to the drought due to animal death equalled USD300 million. However, the actual losses were much larger, since the reduction in the population of breeding animals was felt for several years after 1989.

Several changes had occurred in Uruguay by the time of the 1999-2000 droughts. Firstly, the government had created two institutions, the National Emergency System (NES) and the National Commission for Drought (NCD). The NES is appointed directly by the office of the President of Uruguay, and had played a key role in crisis management activities during the 1997-98 El Niño floods. The NCD was created under the leadership of the Ministry of Agriculture and included representatives of the research community, a few governmental offices and several organizations from the private sector.

Also, the National Institute for Agricultural Research (INIA) had formed a Climate, Environment and Satellite Agriculture interdisciplinary team (GRAS), which started collaborative research with staff of the International Research Institute for Climate and Society (IRI). The INIA-IRI collaboration included research projects in the following areas:

- Applications of seasonal climate forecasts in the agricultural sector (with the University of Uruguay)
- Development of an information and decision support system (IDSS) for the agricultural sector of Uruguay (with NASA's Goddard Institute for Space Studies, the Soils Department of Uruguay and the National Agricultural Research Institute of Argentina).

These research projects became active during the period when the first negative impacts of the 1999-2000 drought were being felt in Uruguayan agriculture, and proved to have major impacts on the government response. The INIA-IRI collaborative projects included the creation of a Technical Working Group (TWG) for improving the dissemination and applications of seasonal climate forecasts. The TWG was composed of agricultural and climatic researchers, as well as by representatives of the major farmer organizations, agribusiness and governmental offices. The TWG met every three months immediately after the southeast South America Regional Climate Outlook Fora (RCOF). During the TWG meetings the climate scientists presented the regional outlook produced in the RCOF, as well as the results of their own climate research conducted at the national level. The agricultural scientists presented advances on the tools to apply climate information, while the stakeholders from the public and private sector discussed the results and limitations of the information they received. In addition to creating the adequate environment to improve the applications of climate information, these meetings were crucial for the dissemination of the climate outlooks to the agricultural sector.

Furthermore, the INIA/IRI project for developing the IDSS included two activities that were also used extensively by the public and private sectors responding to the 1999-2000 drought. Firstly, the IDSS included calibrated and tested crop simulation models that were used to identify agronomic practices better adapted to the drought conditions. Also, the INIA/IRI research group included two types of satellite data: AVHRR and Landsat images. The AVHRR images (1 kilometre) were used to monitor the vegetation status (NDVI) throughout the season for the entire country. Maximum monthly NDVI values were expressed in absolute terms and as deviations from long-term mean values.

All the information produced in these collaborative projects was published on the GRAS-INIA web page (www.inia.org.uy/GRAS) where it is available to farmers, agribusiness representatives, agronomists and government officers. In addition, IRI and GRAS-INIA staff gave several live presentations and teleconferences in collaboration with the Extension Service of the Ministry of Agriculture and Fisheries, which reached all the major regions of the country. Researchers also appeared on several TV and radio programmes and prepared numerous articles for the major newspapers. Via these sundry communications, the researchers presented the results of the latest climate forecasts, the evolution of the monitored vegetation status, and the results of the crop and pasture simulation models.

This continuous communication between researchers and the public and private agricultural sectors provided stakeholders with the most updated, objective and sound information on the status and evolution of the drought. Emergency situations are often characterized by the existence of an overflow of information from many different sources, and with varying levels of objectivity and scientific soundness. This information overflow often causes confusion and hampers private and public sector stakeholders taking effective responsive actions. In such scenarios identifying trustworthy sources of understandable, relevant and actionable information is crucial for making decisions at any level.

Insights derived from the comparative drought study include:

- Moving from 'crisis management' to 'risk management' requires climate-related information and products that are relevant, trusted, timely and actionable
- Climate related information and products need to be communicated to stakeholders in formats that are understandable and directly connected to sectoral information upon which they can act
- Information and products can only be effectively applied to inform and improve decisions if adequate institutional arrangements and policies are in place.

Image: ©iStockphoto.com/ KevinDyer

View across the Argentine pampas in summer, with cattle drinking water from a pond fed by a windmill water pump

Beyond the tropical archipelago: the provision of climate services in Indonesia

Sri Woro B. Harijono and Edvin Aldrian, Meteorological Climatological and Geophysical Agency, Indonesia

The maritime continent of Indonesia is one of the few regions in the world that covers a vast tropical archipelago. Located between two large oceans and continents that create a considerable amount of evaporation and rainfall, Indonesia has a humid tropical climate and is one of the most vulnerable areas to the impacts of climate change. Severe weather and climate extremes are set to become more frequent and intense as the direct impact of climate change hits. Proximity to the ocean governs most climate phenomena in the region, although for many years scientists have found that picking up on changing ocean characteristics is useful for predicting seasonal climate change. Despite this, the use of climate information in this region is still poor. A recent feature of escalating extremes in climate includes the strengthening and more frequent occurrence of El Niño-Southern Oscillation (ENSO), leading to longer periods of drought. When ENSO last occurred, the drought period was followed by forest fires in Sumatera and the Borneo islands, causing transboundary smoke-haze pollution. With a common expectation that events like this will occur more often in the future, Indonesia must make use of its climate information to become more prepared.

Historical background

Indonesia's provision of weather and climate information services can be traced back to the Dutch colonial era of the 19th century when information was used by plantation companies all over the archipelago. Since gaining independence, climate services in the country have focused on characterizing annual monsoon cycles, and wet and dry seasons for the agricultural sector and the management of water resources. It has long been recognized, however, that at present these services are not yet adequate enough to provide information for the entire population.

As the need for sectoral adaptation strategies has grown with the realisation of the severity of the impacts of climate change, the role of the Meteorological Climatological and Geophysical Agency (BMKG) has evolved. Until mid 2007, the function of the climate service division was purely to act as a supplement to the country's weather services. Now, this division has been elevated to one of the pillars of the institution and the term 'climatology' has been introduced into the institution's name following a presidential decree in mid 2008. Currently, there are two kinds of climate information service provided by BMKG: a climate variability service and climate change service.

Image: BMKG

Forest fire usually follows the long drought caused by severe El Niño conditions. Climate information services to predict the dry condition far in advance will help mitigate the devastating impact of the forest fire

Servicing climate variability information

The Center for Climate, Agroclimate and Marine Climatology at BMKG provides climate services and information for the agriculture, water resource and marine sectors — including seasonal climate predictions for flooding, climate information for crop suitability and marine climate information.

BMKG has a long history in providing climate information for the agricultural industry. Recently, several districts in Indonesia have piloted agriculture extension activity projects with the aim of getting local farmers accustomed to using climate information that relates directly to their livelihoods. The result of this has been very positive, most notably in Indramayu — the 'rice bowl' district in West Java — where economic and welfare conditions have improved significantly because of the intensification of agricultural activity. The success of this programme relies on BMKG's ability to translate scientific language into a language the farmer can easily understand. This is a task carried out by people working for the project.

Sustaining water resources

Another key function of the climate service at BMKG is to provide information for the management of Indonesia's water resources. The water authority in West Java in

Image: BMKG

Flood occurrence has become more frequent in recent years. Heavier rainfall intensity related to the several regional phenomena such as active Madden-Julian Oscillation phases, cold surge and divergent disturbances can lead to severe flooding in the Jakarta metropolitan area

particular benefits from such information. It controls the cascading hydro dam, which serves the capital city Jakarta, the 'rice bowl' of several districts along the north coast of West Java, and provides power for the national electrical company. As well as this, a coordination meeting involving the water resource authority, all related stakeholders and BMKG is held on a routine basis. At each meeting presentations are given regarding current monitoring and evaluation of ongoing water management activities. Possible water management options include discharge control, electricity power management, water holding and weather modification. The weather modification option is currently considered to be a last resort for when water availability in the cascading dam is scarce. So far, climate information services for the water management authority in the region have been extremely successful in maintaining the activities of the most fertile region in the country and providing a good water supply to the Jakarta area.

The national food policy

At a national level there is a committee for dealing with climate variability and its impacts on agriculture. In particular it deals with issues relating to ENSO and its affect on the national food policy. The committee holds a meeting twice a year before the dry season and wet season. Although some consider the dry season meeting to be too early (it is usually held at the end of April), the information provided at it is key to deciding the national food policy, especially regarding rice, the nation's staple food. Decisions made at the meeting have a significant impact on many of the country's forthcoming activities. In recent years, wetter climate conditions have meant that there has been no need to import rice. When ENSO causes long droughts in the country, the government will need to take necessary actions to sustain food and water resources. This may involve importing rice and adjusting its policies towards agriculture, and the distribution, enhancement and storage of water.

Air quality information

The Center for Climate Change and Air Quality is a new BMKG centre that deals with providing services and information about climate change and air quality. One of its core purposes is to measure the ambient carbon dioxide concentration across Indonesia, which it then compares to measurements taken by the Global Atmospheric Watch — the worldwide system established by the World Meteorological Organization to monitor trends in the Earth's atmosphere. So far, carbon dioxide levels measured in Indonesia are much lower than the global average. The Center for Climate Change and Air Quality is also conducting research into Indonesia's paleoclimate, using records from tree rings and ice sheets.

The national adaptation and mitigation policy

Following the presidential decree in 2008 to set up the National Council on Climate Change, nine development sectors for a climate change adaptation focus strategy have been set up. Based on the national action plan and referring to the United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, BMKG will provide a comprehensive range of products to help such sectors as agriculture, energy, health and fishing plan for and put into practice climate change adaptation strategies. For the agricultural industry, the adaptation programme provides seeds as well as

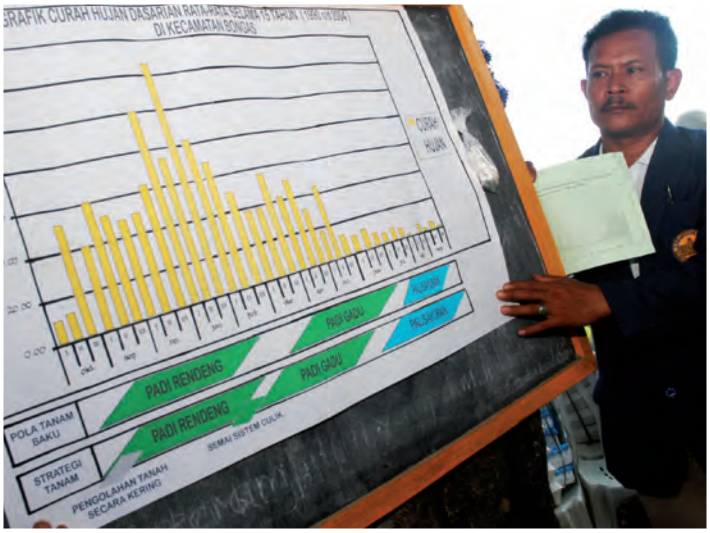


Image: BMKG

Climate field schools use climate information to help farmers optimize their plantation period and increase agricultural produce

information about crop plantation seasons and crop variety. For the energy sector, the aim is for Indonesia to become self-sufficient and look at using wind and solar energy. For the infrastructure sector, the aim is to develop Indonesia's water resources, have roads with proper drainage, and build water reservoirs below roads. For coastal zone infrastructure, the adaptation programme is looking to set up wave barriers, sand dune protection and buffer pools as sea levels rise. For tourism, the adaptation strategy is to adequately support the planning and design of facilities and tourist attractions. For the forestry sector, such programmes as the Reduced Emission from Degradation and Deforestation programme and the National Forest Rehabilitation programme have been set up. Efforts are also underway to mitigate the occurrence and severity of forest fires. Finally, for the water resource sector, the adaptation programme is dealing with the operational improvement of dams.

Guided by the National Action Plan on Climate Change, the IPCC assessment report and outcomes of United Nations Framework Convention on Climate Change (UNFCCC), each sector has developed these action plans to meet the Indonesian government's midterm (five years) government policy strategy to restructure according to climate change. This government policy is derived from long-term climate scenario projections and BMKG is playing a major role in this, by providing all the climate information required. In 2009, the government also set up a new legislative act on meteorology, climatology and geophysics. This new act will endorse the strong participation from all community levels, as well as weather, climate and geophysics information services. The act will also put more pressure on relevant stakeholders to strengthen weather and climate data systems for the use of the nation.

International roles

The Indonesian government has been particularly active in participating in international climate debate and policy making. The 2007 Bali Action Plan, a result of the UNFCCC Conference of the Parties (COP) 13, was a momentous event for climate change policy under the UN framework. This action plan has set Copenhagen COP15 up to replace the aging Kyoto Protocol with a new regime. Other international level climate events have been equally successful. The Manado World Ocean Conference in Indonesia, for example, which focused primarily on the effects of climate change on the ocean, led to the May 2009 Manado Ocean Declaration.

Further highlighting its commitment to dealing with the scientific issues of the climate change, Indonesia will host the 31st Intergovernmental Panel on Climate Change session in October 2009. It is also playing an active role in the preparation for the World Climate Conference-3 in 2009.

At a regional level, BMKG is actively involved as a subcommittee on meteorology and geophysics research. It is engaged in several activities including regional training on climate modelling and the training of regional meteorological service officers in agroclimatology.

What is still left to do?

Despite Indonesia's ongoing efforts to deal with climate change, it is still suffering from inadequate climate information services. Besides its lack of facilities, the country is still limited in its knowledge of climate issues and lacks a basic understanding of how climate change really occurs and how it will impact in the long-term. Knowledge of events related to climate phenomena such as monsoons, for example, is also weak. This is largely because basic climate information is still derived from statistical analyses rather than from dynamical analyses and decisions are made based on indirect output from other regional climate centres. There is a need, therefore, to have better tools for climate analysis and to promote enhanced cooperation between established climate centres across the country to improve the provision of information.

Considering the vastness of Indonesia, there is a vital need to develop a regional analysis and data assimilation technique. Future climate prediction must also incorporate ocean climate models. At the moment, information about the region's surrounding marine climatology is not well developed and establishing even a basic knowledge of the ocean around the region requires considerable effort. For all of these reasons, BMKG is advancing its research and development division to overcome these problems. BMKG must also look to improve its performance by providing better climate data with an integrated system. In the future, BMKG will develop a national meteorological climatological early warning system to detect climate extremes.

Finally, making the public aware of the importance of climate information is essential. Although most are already inherently aware of climate — since it affects their day-to-day activities — a lack of true knowledge, combined with the perception that extra information is unnecessary means that general public climate awareness is still low. Even in business and economic activities, climate factors are rarely included in decision-making policies and climate is still not considered enough when it comes to taking out insurance. These issues are something BMKG needs to work on in the near future in order to better provide for the region.

Delivering climate services in Australia

Michael Coughlan, Bureau of Meteorology, Australia

Arguably no other branch of the earth sciences has relied more heavily on extensive, systematic long-term observations than meteorology. The complex thermodynamical nature of the atmosphere and the non-linearity of the interactions between the various forces at play, render meteorology a difficult topic for study using the formal equations of motion and the laws of thermodynamics. Using the most powerful computers available, the generation of weather and longer-term predictions relies on a vast and continuous influx of observational data — not only from the atmosphere, but also increasingly from the other earth system domains. Forecasts, while more accurate and precise than ever, retain levels of uncertainty that will never be entirely eliminated and increase with the length of the forecast period.

Defining the climate

The sub-discipline of climatology, which is the study of the nature of the statistical outcomes of weather over a period of time and the underlying earth system forces, is also rooted in the practice of taking systematic observations. Indeed, the original purpose for collecting meteorological data was the need to understand the nature of climate at a given

Image: Michael Coughlan

Australia has one of the most variable climates in the world and drought is common throughout much of the land. However, desiccated scenes can turn around very rapidly with just one season of good rainfall locality. Responding to the general characteristics of weather conditions at different times of the year is a fundamental rhythm in all living systems, and human societies have always sought to understand and use knowledge of the seasonal cycle to their advantage. The increasing rigour in the application of scientific method throughout Europe and elsewhere following the Enlightenment, saw the beginning of systematic recordings of meteorological variables such as rainfall, wind and temperature. In addition, a wide range of phenological data relating to climatic events — such as the first and last dates of frost, the thawing of rivers and the migratory habits of birds — began to accumulate in Europe and in other advanced civilizations.

All this collecting of data resulted in the conception of 'the climate', which once defined would provide a strong guide on what it was feasible to do and when it could be done, across a wide range of human activities sensitive to the prevailing weather. The early history of climatology saw the development of systematic characterizations of climate in terms of the natural vegetation that it supported. The first comprehensive attempt to classify world climate along these lines was that of a Russian climatologist, Wladimir Köppen at the beginning of the 20th century, with later modifications by the German climatologist Rudolf Geiger. An American climatologist, Charles Thornthwaite, with access to an increasing body of archived meteorological data, was able in 1948 to incorporate factors such as evapotranspiration rates to help delineate different climatic zones.

Climate is variable

Once devised, these climatic classifications were essentially static, underpinned by the notion that climate could be reliably defined by around 30 years of data — the period over which climatic 'normals' were derived. As the data collections grew over time it became clear that there could be significant differences between the climatic statistics of consecutive 30-year normals for any location, and hence there was potential for changes in the vegetation and broader ecosystems that could be supported. The notion that climate significantly varied only on glacial/interglacial timescales had to be well and truly set aside.

The inherent variability of climate across all timescales was no more evident in reality than in Australia. Since the arrival of the first settlers at the end of the 18th century, the norms of European agriculture were time and again confounded by recurrent and crippling periods of drought. Indeed the history of Australian agriculture has been one of good years and not so good years, punctuated every so often by multiple years of drought with catastrophic crop failures.

Establishing a climate service

In 2008 the Australian Bureau of Meteorology celebrated its 100th year of existence, having been formed shortly after the federation as the national agency for: 'taking and recording meteorological observations'. One of the most significant outcomes of this transfer of responsibility to a single national authority was the standardization of how meteorological observations should be made. Hitherto there was a wide variation between the Australian State authorities in the way meteorological instruments were exposed and how recordings were made. Ensuring that meteorological records truly reflect the prevailing weather and climate and are not contaminated by local effects — such as growth in nearby vegetation or the erection of an adjacent building — remains an ongoing challenge. Through careful archiving and analysis, however, Australia now has sufficient data to represent, with a fair degree of accuracy and on at least a daily basis, the variations of weather and climate across the breadth of the land for the past 100 years.

In 1967 drawing on more than 60 years of monthly rainfall records from around 6,000 locations around Australia, W.J. Gibbs and J.V. Maher of the Australian Bureau of Meteorology developed a method of using rainfall deciles as drought indicators. For any location or region where the aggregated rainfall over a period of three calendar months or more was below the first decile (lowest 10 per cent of all historical rainfalls for that period), the rainfall was considered to be seriously deficient. Interestingly, in the announcements that followed the delineation of extended areas of seriously (or severely) deficient rainfall, the term 'drought' was not used. There was recognition that lack of rainfall alone might not be adequate for determining that agriculture was being stressed to the point where government assistance was required. Nonetheless, the Australian Drought Watch Service, which continues to operate on the same basic principles, represents one of the first examples of a routine systematic community service based on the rigorous use of climatological data.

A lesson learnt

The management of Australia's water data was not centralized following the federation and remained the responsibility of individual states and territories, devolving down in fact to more than 200 individual agencies and authorities across the nation, with a consequential set of disparate standards for recording and reporting on water resources. In its centenary year, following an extended period of rainfall decline across the southern Murray-Darling Basin — Australia's major agriculturally productive region — the Water Act 2008 was passed, which gave responsibility for the development of national water accounts and water resource assessments to the Bureau of Meteorology. The actual recording and primary collection of water data remains a devolved responsibility, but the standards and regulations for carrying out these functions are set and maintained by the Bureau of Meteorology, which is now archiving the data in a central repository called the Australian Water Resources Information System.

Synoptic climatology

Another critical outcome of the systematic collection of meteorological and related data (including from oceanic regions) was the ability to study the nature and ultimately the causes of Australia's highly variable climate. While it had been thought by some that external forces such as sunspot activity and even periodic meteorite showers were a possible cause of recurrent drought over Australia, it was the linking of the atmosphere-based Southern Oscillation to the

Depleted Corin Reservoir near Canberra. Australia has developed a number of very large reservoirs that are used to supply water for irrigation and its major cities during periods of erratic rainfall or longer intervals of drought. The prolonged drought that occurred over the 10-15 year period across much of southeastern Australia leading up to 2009 led to a massive depletion in these reserves, which will likely take many years of better than average rain to replenish

recurring ocean-based El Niño phenomenon in the eastern Pacific that revealed the true nature of Australia's highly variable climate. Recent research on somewhat more subtle variations in atmosphere/ocean interactions of the tropical India Ocean suggests a further layer of complexity.

The continuous flow of observations from the atmosphere and the oceans together with adequate computing capacity now enable climate to be treated synoptically, with analyses of rainfall, temperature and other variables routinely available within a few hours of the end of an averaging period (typically a calendar month). Using base climates, derived from the more than one hundred years of historical data, it is now possible to determine with a high degree of precision a wide range of anomaly and extreme value statistics for a month or a season just completed. It is estimated that users of the Australian Bureau of Meteorology's website have virtually instant access to several thousand different forms of analyses on the nature of the climate for any given month across the breadth of the country, or for specified regions.

Predicting climate – the future

As for weather, establishing the current state of the climate system through synoptic analysis is only part of the challenge. Since the mid 1980s, seasonal forecasts of expected rainfall and temperature anomalies have been issued by the Bureau of Meteorology for Australia using the Pacific Ocean (El Niño-Southern Oscillation) and Indian Ocean relationships. The modest skill of these statistical forecasts, while real and useful, is inconsistent throughout the year and varies from region to region. Strong trends in rainfall and temperature over the past few decades for large areas of Australia have further brought into question the reliability of the forecasts. A major research effort is now underway in Australia and elsewhere to develop dynamical, computer-based models of the coupled earth system, that can be used to predict the variability in climate from weeks through seasons to periods of a decade or more. While predictions from these experimental models have yet to attain sufficient skill for them to be used operationally for rainfall and temperature outlooks, they are coming tantalisingly close to achieving this goal and will very likely do so within the next five to ten years.

International training programme on climate change — mitigation and adaptation — a Swedish experience

Sten Bergström, Swedish Meteorological and Hydrological Institute

Commissioned by the Swedish International Development Cooperation Agency, the Swedish Meteorological and Hydrological Institute (SMHI), along with its partners SWECO AB and the Stockholm Environment Institute (SEI), organizes advanced International Training Programmes under the title 'Climate Change — Mitigation and Adaptation'. These programmes consist of a four-week training course in Sweden, followed by six to eight months of work on an individual project, as well as a follow up seminar in Asia, Latin America or Africa.

The overall objective is to transfer and increase knowledge and capacity related to climate change and its consequences. A further aim is to develop and spread methods for identification of vulnerable sectors in society — from both a national and international perspective. Mitigation, society's adjustment to the future climate and the development of action plans are other important aspects covered in the training programme. Individual projects are carried out as part of the programme, but at the participant's home organization location.

Image: Gordon Carlson, SMHI

Participants waiting for the tram in winter weather in Norrköping, Sweden, March 2009

The International Training Programme is designed for individuals active in reform processes of strategic importance at various different levels, as well those who have management — or other key positions — in organizations related to national, regional or local community planning. In addition would-be participants are expected to be well acquainted with climate change issues from a society adaptation perspective, as well as having a technical, scientific or social science degree at university level (or equivalent). From a long-term perspective it is hoped that the programmes will contribute to the strengthening of institutions and capacity building in the participants' home countries. In summary, the programme is designed for participants from ministries, authorities (local, regional or national), environmental institutes and research organizations, non-governmental organizations, consulting firms and industries.

Three of the weeks in Sweden are hosted by SMHI in Norrköping, with the one remaining week hosted by SWECO in Stockholm. Lecturers come from the host organizations or from other institutes or universities in Sweden and abroad.

Programme outline

The training programme has four main components: preparation in home country; training programme in Sweden; project work in home country; and regional seminars.

The selection of participants is based on a formal application process. It consists of a brief presentation from the applicant, including an outline of his or her role in the home country, as well as a description of the individual project work that he or she would like to carry out as a part of the programme.

Participants are selected and confirmed by the programme organisers and immediately afterwards develop a detailed plan for their individual projects. This includes preparation of a brief verbal presentation to be given and discussed during the stay in Sweden. The participants are also assigned a facilitator in Sweden, who acts as supervisor and provides support for the participants during project work.

During the four weeks of training in Sweden the following topics are addressed:

- The greenhouse effect and impacts of climate change
- Strategic planning to counteract the causes of climate change
- Impacts on water resources and coastal zones
- Impacts on agriculture and forestry and the need for preventive action
- Community planning, vulnerable sectors, interdisciplinary planning and cost benefit analysis
- Strategic planning pertaining to potential positive consequences of climate change
- Information, education and public participation.

The training is based on lectures, demonstrations, group discussions, exercises and study visits to relevant industries and institutions. The participants are divided into 'theme groups' where individuals with similar interests are more likely to meet and interact. There is also time for developing individual projects through discussions with other participants and the assigned facilitators. These group exercises provide the participants with both theoretical knowledge and practical experience, as well as bringing different nationalities closer together. Thus they are an essential aspect of the programme. It is also significant that the training programme provides a forum for discussions and an exchange of experience between participants, lecturers and specialists.

During a period of six to eight months after the Sweden visit, the participants continue with their individual projects according to the plan developed during their stay. The Swedish facilitator is available, mostly via e-mail, to discuss and help draft the report. The participants are also encouraged to present their project results to colleagues in their home organization and together with them define complementary work to be done during this phase. Finally, a written report on the outcome of the individual project and a verbal presentation are prepared for the regional seminar.

There are two regional seminars held six to eight months after the course in Sweden involving lectures on specific climate related topics provided by regional experts. Each participant attends one of these, depending on their geographical location. The main focus of the regional seminars is the presentation and discussion of individual projects, with each participant acting as an 'opponent' to one of the other individual project presentations. The regional seminars also have open sessions with contributions by local lecturers from the region. These seminars constitute the formal ending of the International Training Programme on Climate Change — Mitigation and Adaptation.

During 2009 seminars have been held in Namibia and in Senegal and are planned in Tanzania and in Vietnam.

Experience so far

The advanced International Training Programme on Climate Change — Mitigation and Adaptation has so far been carried out five times, which has involved a total number of approximately 125 participants — coming mostly from Africa, Asia, Latin America and the Middle East.

SMHI has previously organized International Training Programmes in the fields of air quality and

Image: Gordon Carlson, SMHI

Group discussion at SMHI, March 2009

Image: SMHI

The participants of the regional seminar in Hanoi, Vietnam, October 2008

Image: SMHI

Excursion in the Thukela catchment — an agrarian area close to Pietermaritzburg — during the regional seminar in South Africa November 2007

water resources, so is far from inexperienced in the process. However, the organization of this particular training programme has been something of a challenge due to the strong interdisciplinary factor. Never the less, the overall experience has proven very positive and it is obvious that this type of training programme fulfils a need for many institutions in developing countries. In Sweden it has meant new contacts and has also provided valuable new perspectives on the country's own climate concerns. Notably, in contrast to the challenges that poorer countries are facing in relation to climate change, those of rich Nordic countries seem really quite manageable. The programme has also resulted in a network forming between the participants and host organizations, which will hopefully prove fruitful with regards to future cooperation.

The concept of utilising individual projects and regional seminars has created continuity and brought realism into the whole process. It demands long-term engagement from the participants, as well as commitments from their home organizations. It is also very stimulating for SMHI staff to observe and learn from local climate situations to gain an understanding of the conditions for mitigation and adaptation in the participant countries. The individual projects have covered a wide range of topics from local educational programmes and local climate adaptation problems to long-term planning of mitigation and adaptation strategies. The input from individual projects to the course has contributed to its continuous development and improvement, as it has given the host organizations realistic and practical examples based on the local conditions in participating countries.

Hosting some 30 people from mostly warm climate zones in Sweden during four dark and cold winter weeks has perhaps been the biggest challenge for SMHI. However, in general, this social challenge has been addressed superbly, with participants and the SMHI staff engaging in various social activities, including ice skating. Participants have also been invited to the homes of staff members to experience the everyday routines of Swedish living. This has brought a new dimension into the lives of the participants, as well as of the SMHI staff.

Making stream flow monitoring work for biodiversity and social justice

Nicky Allsopp, South African Environmental Observation Network

How does a long-term programme monitoring flow rates from afforested mountain catchments result in a ground-breaking poverty relief programme? The Working for Water programme of the South African Government uses scientific evidence to justify the removal of invasive alien plants on the basis of their detrimental economic impact, whilst providing employment for unemployed people. This evidence derives from a monitoring programme started several decades earlier with quite different objectives.

In 1935, at the fourth Empire Forestry Conference, hosted in South Africa, concerns of farmers' associations that plantation forestry was drying up rivers were debated. Swift action followed with the establishment of a forestry research station that year at Jonkershoek, near Cape Town. The first stream flow gauging weirs, based on the paired catchment principle, began monitoring water runoff in 1937. Following the Second World War a network of gauging weirs was set up in mountain catchments around the country in different climatic regions, with different vegetation. The Jonkershoek data represent some of the oldest stream flow monitoring records in the world. Monitoring stream flow is important in South Africa as surface runoff accounts for 77 per cent of the country's current water usage.

The resulting stream flow catchment monitoring data confirmed that plantations of exotic trees used more water than indigenous vegetation. These data were used to regularize the forestry industry and, as a consequence, practices adopted to ameliorate water use by plantations enabled the forestry industry to recently attain Sustainable Forestry Certification.

In South Africa, most of the invasive alien plant species are woody plants, many of which have spread from plantations. They have invaded all important terrestrial biomes, cover about 10 per cent of the land surface and most riparian systems, and threaten much of the unique biodiversity of the country.[1] It is recognized that invasive alien vegetation impacts ecological functioning and ecosystem services, invades otherwise productive land and intensifies the impacts of fire, floods and soil erosion.

Data from the experimental catchments were used to show that almost 7 per cent of water resources were being lost to invasive plants in the catchments and along rivers, and in cities like Cape Town, 30 per cent of available water was lost to these plants.[2] Furthermore, clearing invasive trees could be done at a fraction of the cost of building new water

Image: Tessa Oliver

Fynbos vegetation in South Africa (foreground) being invaded by pines escaping from plantations (background)

Image: Nicky Allsopp

Run off from mountain catchments has been measured since 1937 with continuously-recording stream flow gauges such as this one at Jonkershoek, South Africa

supply infrastructure. If invasive plants are not kept in check it is likely that they will double their stream flow reduction impacts in 15 years.

But could evidence that invasive plants used more water than indigenous vegetation be sufficient to muster the kind of resources needed to eradicate them? For several decades environmental volunteers and conservation agents had been clearing invasives with limited resources and not much hope of making an impact.

In 1994, South Africa had its first democratic elections and with these came hope that some intransigent problems could be solved. It took a group of scientists convinced of the need for action based on the stream flow evidence, a far-sighted government minister and a big dose of serendipity to create a solution. If poverty alleviation could be linked to invasive alien plant control then funding could be attained for clearing. From this, the Working for Water programme was born in 1995.[3]

Poverty, exacerbated by widespread lack of skills training, is recognized as one of the biggest problems facing South Africa. Large sectors of communities, including rural communities, face the prospect of almost permanent unemployment. Those hardest hit by this are women and young people, who with low education and no skills struggle to enter employment.

Working for Water engages otherwise unemployed people to clear invasive alien plants using an integrated approach of physical clearing, chemical treatments and biocontrol to tackle the problem. From 30 projects in 1995, there are now 300 clearing projects. Almost 20,000 previously unemployed people are employed a year. Programme managers aiming to meet targets to engage women, young people and disabled people ensure that 53 per cent of those employed are women, 22 per cent are young people and 0.6 per cent are disabled. Social development programmes run parallel to the clearing programme. These are operated in partnership with other organizations and include establishing childcare facilities for communities where Working for Water is active, HIV and AIDS education programmes, and a programme to reintegrate ex-offenders into the workplace, as well as training in clearing, restoration and workplace health and safety issues. Training is also given in business skills to develop contractors from disadvantaged communities who then manage the clearing teams and, it is hoped, will be able to take up private clearing contracts.[4]

Although the winning point for this programme is its ability to provide employment, many other indirect consequences of the programme improve people's general standard of living. South Africa's targets to provide most of the population with potable water and sanitation are reliant on sufficient water resources. This is a challenge in a largely arid country. Water that otherwise would be lost is now available for agriculture, urban and industrial use. Clearly, water saved from alien plants can contribute to ensuring a better future for the people of South Africa.

Ironically, just as Working for Water was being conceived, the monitoring that justified it was being shut down in the early 1990s by the government forestry division, who could see no further use in quantifying water-use by plantations. Only the original weirs at Jonkershoek continued to be monitored by the Council for Scientific and Industrial Research. These faced closure in 2007 when government funding ceased. The newly created South African Environmental Observation Network, or SAEON, stepped in to secure the monitoring whilst negotiations were underfoot. Fortunately, a change of perspective in decision-making circles has made the future of catchment monitoring more secure. It has been recognized that flow data is relevant far beyond commercial forestry, particularly in understanding the relationships between rainfall and runoff in a changing climate. In addition it is recognized that if we are to understand the direction and nature of climate change in a country where climate is naturally highly variable, long-term records are essential. If we are to ensure that water continues to play its social, economic and ecological roles from source to its eventual sink in our oceans, then an integrated monitoring and research approach — moving away from narrow sectoral interest — is needed. Adaptation to altered water delivery is also highly dependent on understanding what happens to water as it enters the cycle.

In international literature on public works the multiple objectives of the South African Working for Water programme have been described as being without precedent. In biodiversity circles it is lauded as the largest environmental management programme in Africa. Among many policy decision-making processes which impact people as well as the environment, Working for Water stands out as one where scientific evidence is evaluated, progress is monitored and assessed in both the biodiversity and social spheres and new research is commissioned to ensure that decisions are underpinned by as sound evidence as is available.[5] Yet in the 1930s when the catchment monitoring programme was launched, these outcomes could not have been foreseen. This suggests that whilst monitoring programmes need to be based on sound scientific reasoning, we should be open to unintended results. We should also protect environmental monitoring programmes from the vagaries of narrow and sectoral interests that may threaten their continued existence. The challenges we face need interdisciplinary approaches and, it can be argued that, support for environmental monitoring programmes will be strengthened, and their results be more broadly useful, if they are initiated in partnership with people from different sectors.

Adapting to climate change and variability

Jorge F. Carrasco, Dirección Meteorológica de Chile, Dirección General de Aeronáutica Civil

The Chilean continental territory is located on the western side of South America between 17°30' and 56°30' S. It has a total surface area of 756,096 kilometres squared, which spans 4,300 kilometres from north to south and is limited to the west by the Southern Pacific Ocean and to the east by the Andes mountains. With this geographical location, Chile is characterized by a large variety of climates: being home to one of the driest places in the world (the Atacama Desert) as well as the cold and snowy Patagonian ice fields. From an atmospheric viewpoint, the climate is determined by the presence of the permanent Southern Pacific high-pressure centre, the westerly circulation and the summer monsoon type circulation in the southern Amazon basin. The annual cycles in temperature and precipitation, as well as other meteorological variables, are related to the seasonal variation of these features and their interannual variability is mainly associated with El Niño Southern Oscillation and the Antarctic Annular Mode. Interdecadal changes can be related to the Pacific Decadal Oscillation (PDO) and secular long-term tendencies can be attributed to the greenhouse effect.

The IPCC Fourth Assessment Report indicates an overall warming, ranging from 0.2 to 1.1ºC in the northern, central and southernmost parts of Chile, while it revealed a cooling of -0.2 to -0.5ºC in the region between 38 and 43ºS during the 1901-2005 period. However, an overall cooling of -0.2ºC per decade has occurred in the northern and central coast of Chile (17º-37ºS) along with a warming of +0.25ºC per decade in the inland and Andes sectors during the period 1979-2006. This coastal behaviour is associated with the PDO, which showed a phase change during 1976-77.

The secular precipitation behaviour during the 1950-2006 period shows no statistically significant tendency for the central (30-38ºS) and southernmost parts of Chile (south of 52ºS), while a decrease in precipitation does occur in the southern part between 38° to 46ºS, which is statistically significant in some locations. Although the scarce precipitation records in the northern Altiplano allow only a limited examination of the precipitation trends, the long-trend behaviour at Visviri, which can be considered a reference station in the region, reveals a slight overall increase (not statistically significant) of between 10 and 14 millimetres per decade during the full 1962-2003 period, although a non-significant negative trend is observed since the mid-1980s.

In terms of interannual climate variability, El Niño Southern Oscillation is the main natural mechanism that strongly influences the precipitation regime in the northern Altiplano and the central parts of the country. Most wet years in central Chile are related to El Niño, and dry years with La Niña, while in the Altiplano the wet summers are mostly associated with La Niña and dry summers with El Niño. Seasonal sea surface temperature forecasts have significantly improved during recent decades, allowing for predictions of the development and future stages of El Niño Southern Oscillation. This has made possible the development and implementation of the statistical seasonal forecast (three months in advance) for precipitation and temperature in the Chilean National Weather Service. The climate variability and the climate seasonal prediction are priority issues because of the immediate impact that precipitation has on many sectors. For this reason, these forecasts are issued every month and are publicly available on the institutional webpage. They are also sent to the Secretary of Agriculture, National Emergency Office, Water Resources Office and Secretary of Energy — among other organizations — for specified purposes.

The Intergovernmental Panel on Climate Change (IPCC) global climate model projections for different scenarios for the end the 21st century show an overall warming of at least +2 to +4°C with respect to present conditions (1961-1990 period). This prediction is for the entire country, with the

Image: Janette Calderon

Future decrease in precipitation in central and southern Chile will have a strong impact on water resources (Rapel Dam) higher increases being in northern Chile and along the Andes mountains. Regarding precipitation, all model simulations predict a decrease in rainfall in the central and southern parts of Chile, while an increase is expected in the southernmost region of the country during the winter season. The observed and projected climate changes will not only have consequences in the natural environment, but also in all societal sectors.

The above-mentioned changes and projections imply a strong impact on water resources. Chile is highly dependent on hydrological power generation for its energy supply, and on water for mine operations, industries, forest and agriculture sectors and human consumption. Also, continental Chile has a long coast facing the Pacific Ocean with many low zones that can be affected by rising sea levels. The country has arid and semi-arid areas that can increase in a warmer and drier climate, as well as susceptible areas for deforestation, erosion and desertification. In addition, changes in the ocean will affect the fishery industries, aquiculture and marine biodiversity. Chile, therefore, is highly vulnerable to climate change and action needs to be taken to manage its: geographical spatial and natural resources in urban and non-urban developments; exposed coastal areas; water resources; and the potential impacts of extreme weather events.

To this end the Commission for National Environment, or Comisión Nacional del Medio Ambiente (CONAMA), developed, with the approval of all state secretaries, a National Action Plan for Climate Change: 2008-2012. The plan involves three defined priorities: adaptation to climate change impacts; mitigation of greenhouse gas emissions; and development of capacity building.

The plan pursues the development of adaptation measurements that will protect the population's well-being, hydrological resources, food provision, urban and coastal infrastructure and energy supply. To do this, the Chilean government encourages and supports actions that will permit the definition of future climate scenarios of vulnerability to climate change in all sectors, with the purpose of evaluating the impacts on the environment as well as the socioeconomic costs related to adaptation measurements.

Image: Janette Calderon

Water resources for agriculture and hydropower generation are vital for Chile's development. More dams will be needed for reserving and managing water resources in a warmer and drier climate (Dam El Yeso)

A first step was taken with the generation of climate scenario simulations using the Providing Regional Climates for Impacts Studies (PRECIS) regional model, developed by the Hadley Centre at the UK Met Office. Simulations were performed by the meteorology group at the University of Chile and were carried out for A2, B2 and the baseline (1961-1990 period) scenarios with a resolution of 25 kilometres.[1]

The agriculture sector in particular will be affected by climate change, and will benefit from using the simulation results. A warmer climate will affect the precipitation system, the amount of winter snow on the Andes Mountains, the terrestrial flora and fauna and the spread of diseases. To minimize, or at least manage the impacts of temperature increase, the simulations can be used to determine when, for example, chemical substances may be used to counteract effects of a rise in temperature. Some of the most vulnerable agriculture systems are those in dry land prairie in central Chile, where exotic forest species like pine and eucalypt grow. Also, the warmer environment and the decrease in water availability will impose hydro-stress on plants with consequences on their growth and even survival. As the forestry and agriculture sectors are crucial to the country's development, it is necessary to evaluate future scenarios for adaptation. CONAMA took action on this and requested a study that was developed by the Centre of Agriculture and Environment of the University of Chile.[2]

Using PRECIS outputs for A2 and B2 scenarios alongside a model that simulates plant productivity, an overall displacement was found of the current distribution of ecosystems toward southern and upslope locations in response to climate change. Among other findings, the study indicates that most sowing times will change in annual farming, and this may overcome in part the adverse climate situation. In central Chile, irrigated wheat will accelerate its lifecycle in response to a warmer environment, yet it will also be highly affected by the rise in droughts. Wheat production in southern Chile and upslope locations, on the other hand, will increase. Corn production is set to significantly increase with warmer climates. And while potato production will suffer in central and southern Chile, an increase is expected in coastal and mountainous areas. Overall, the impact of climate change on the forest and agriculture sector varies according to the specie and the region; it can be negative or positive. Adverse responses are mainly related to a reduction in the availability of water, which will require improved management and prepared infrastructure to store excess water. To face this and other related issues, the Minister of Agriculture created the Agriculture Climate Change Council, a governmental body in charge of guiding and establishing priorities in an adaptation programme. Some actions already undertaken include the ongoing study *Determination of the current and potential erosion in the Chilean territory*, as well as initiatives for studying the genetic improvement of vegetation and the determination of the carbon footprint for exporting products.

Water resources for agriculture and hydropower are vital to Chile's development. The IPCC and PRECIS projections indicate less precipitation and snow accu-

Image: Gualterio Hugo

Irrigation technology will be needed to improve current practices

mulation than at present, as well as greater hydrological volatility associated with El Niño and La Niña events. The hydrological cycle is expected to change, in some cases the maximum run-off will suffer a month's displacement, whereas in others it will be uniformly distributed. To overcome such scenarios, dams are needed to reserve and manage water resources in a warmer and drier climate. In response to this, the National Action Plan includes priority guidelines for evaluating the impact of climate change on the hydrological cycle, water availability in future scenarios, improvement of irrigation technology, and glacier studies and monitoring.

Energy plays an essential role in socioeconomic activities in all countries. Chile, as a developing country, is aiming to improve the well-being of its population and the role of energy is vital for its sustainable economic development.[3] The challenge is how to grow without increasing greenhouse gas emissions and without substantially increasing energy production. From a global viewpoint, Chile only contributes around 0.2 per cent to total emissions, but it must be recognized that in order for it to continue its development, the country will need to increase its energy production. With this in mind the government, through the National Energy Commission, established a new energy policy with the purpose of articulating a public policy for long-term development and key guidelines for energy development based on sufficiency, efficiency, equity, security and sustainability, as well as to respond to requirements imposed by climate change and related national and international policies and agreements for environment protection.[4] In summary, the strategic guidelines are: institutional strengthening by creating the Minister of Energy; promotion and encouragement of energy efficiency; optimization of the energy matrix by the inclusion of non-conventional sources; ensuring that produced energy is compatible with sustainable development; and to support the fair use of energy.

The government already has support projects in place that use renewable, non-conventional energy sources. In 2001, the first three wind tower energy generators were installed in southern Chile, producing two megawatts to supply about 9,000 houses with electricity. Since then, more wind farms have been deployed and others are set to be installed in the future. Alongside this, two solar energy centres will be installed in northern Chile with a capacity of ten megawatts. These initiatives reveal the government's decision to increase the energy matrix using non-conventional sources, proving its commitment to mitigating the greenhouse effect, as well as adapting to a drier climate with new energy sources not dependent on water.

Other initiatives included in the National Action Plan are to evaluate the possible distribution of marine species and the impacts of future climate scenarios on inshore and industrial fishing. The plan also takes into account the impact and adaptation measurements needed in relation to low coastal zones. In the health sector, evaluations are needed on the new infrastructure and health personnel required to face new and increased numbers of diseases, as a consequence of climate change. Also, vulnerable zones and exposed populations need to be identified, and an environmental variables monitoring system needs to be enforced so that information can be given on the effect of climate change to health.

According to the Institute of Research Resources for Sustainable Development, the main strengths Chile should leverage in developing its adaptation policies are threefold. Firstly, its geographical location — distinguished latitudinal climate characteristics along the country, as well as altitudinal west-east variation with a north-south central valley, the coastal mountain chain and the Andes.[5] This situation gives a large range of possibilities for adaptation. Secondly, Chile's economic factors are related to international agreements for importing and exporting goods, and it has an economically and politically stable environment. And lastly, Chile has a basic building capacity and a good public/private relationship that will facilitate future initiatives for adaptation. An example of this from the private sector is the Agroclimate System Information (www.agroclima.cl) established by the Fruit Development Foundation (Fundación de Desarrollo Frutícola). A good public sector example is the National Weather Service and the Agriculture Research Institute (Instituto de Investigaciones Agropecuarias). Working together, these three organizations aim to promote and develop scientific and technological research that contributes to improving the overall quality and productivity of the agriculture sector.

The role of the state is essential in developing public policies and taking measures to protect the most vulnerable sectors of society. But, in order for these measures to work, integration of the private sector, parliament, research centres and universities, and social organizations is crucial. The National Action Plan for Climate Change is a synergetic plan; many organizations have different roles and responsibilities. They need to be able to provide information and answers for policy-makers, so that in turn they can best deal with risk by adaptation and mitigation and work towards minimizing the residual impact.

Information and communication technologies and climate change

Dr Hamadoun I Touré, Secretary-General of the International Telecommunication Union

The digital revolution and proliferation of information and communication technologies (ICTs) has changed people's lives dramatically and boosted economic growth. ICTs are now embedded in almost every part of the world economy and society.

At the same time, ICTs have also had a negative impact on the environment and contribute about 2.5 per cent of greenhouse gas (GHG) emissions.[1] This comes from a number of sources, including:

- The proliferation of ICT users. The number of mobile phone users rose from 145 million in 1996 to 4 billion in 2008. There are more than 1.5 billion TVs and about 2.5 billion radio receivers
- An increasing number of data centres, which represent one of the main ICT sources of GHG emissions, at 0.8 per cent
- The increasing number of devices used by individuals. Many users own multiple devices such as a mobile phone, TV, radio, DVD player, computer and set-top box
- Rising processing and transmission power. For example, 3G mobile phones operate at higher frequencies and need more power than 2G phones
- A trend towards 'always-on' usage and 'stand-by' modes, as well as a tendency to store rather than delete older material.

However, ICTs have the potential to assist the rest of the global economy in combating climate change. The International Telecommunications Union (ITU), as the specialized UN agency responsible for telecommunications/ICTs, initiated a new programme called *ICTs and climate change*,[2] which focuses on the use of ICTs for preventing and averting climate change. Its main goals are to provide governments and the private sector with methods for the use of ICTs as a very important component in climate monitoring, climate change mitigation and adaptation to climate change.

Image: ITU/C. Zavazava

Taman Wisata Alam, Bandung, West Java, Indonesia

ICTs and climate monitoring

The science of climate monitoring has benefited greatly from the parallel development of ICTs. At present, the Global Climate Observing System (GCOS) is based on the use of ICTs in general and remote sensors (both in situ and space-based) in particular. These radio-based applications provide the main source of information about the Earth's atmosphere and surface. In turn, this information is used for climate, weather and water monitoring, natural disaster prediction, warnings, and risk reduction, as well as in support of disaster relief operations. It is also used for planning preventive measures for adapting to and mitigating the negative effects of climate change.

The ITU framework regarding the role of ICTs in direct monitoring was initially envisioned in 1947 at the International Radio Conference in Atlantic City, where ITU member states included Meteorological Aids Service (MetAids) in the radio regulations, and allocated radio frequency spectrum for MetAids applications employed for environment and climate monitoring.

ITU creates the technical basis for the use of ICTs in GCOS by providing necessary radio frequency spectrum and satellite orbit resources for sensors employed by the organization. It also develops treaty status (Radio Regulations) and voluntary (ITU Recommendations) international standards for telecommunications used by GCOS. Remote Sensing Series is an example of a voluntary standard. Guidance is provided on: the use of ICTs for environment monitoring; and the prediction and mitigation of the negative effects of disasters initiated by climate change.

ITU cooperates with many international and national organizations and agencies involved in climate monitoring activities. However, special attention is paid to proposals from the World Meteorological Organization (WMO). WMO assesses the need for environmental information and the corresponding radio spectrum allocation. ITU World Radiocommunication Conferences explore these needs and ensure the availability and protection of frequency bands for observations. A recent example of this collaboration is the ITU/WMO handbook *Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction*,[3] which is approved by the Secretaries General of two UN agencies. An electronic version of this handbook is available free of charge.

ICTs and climate change mitigation

The main carbon abatement opportunities offered by ICTs are: reduction of ICTs carbon dioxide footprint, reduction of GHG emissions in other sectors of the economy, and the replacement of 'atoms' by 'bits.' This is the process of 'dematerialization' — online access to books, documents and films instead of publishing them with print media or on disc copies. ICTs already provide the relevant media and tools for the application of methods such as electronic paperless publications and distributing multimedia via Internet TV. Radiocommunications even 'dematerialize' the connective wire with the spread of wireless technology.

Current technological development allows significantly reduced ICT energy consumption by using new components, algorithms, protocols, software and telecommunications system structure. It is one of the

Image: ITU/C. Zavazava

Phuket after the December 2004 Tsunami

Image: ITU/C. Zavazava

Destroyed building in Banda Aceh, Indonesia

major focuses of ITU's work. For instance, in the last few years ITU Recommendations have approved standards for the development of next-generation networks[4] that will reduce energy consumption by 40 per cent compared to the present public switched telephone network. Another recommendation, to switch from analogue to digital broadcasting, may reduce the energy consumption of powerful broadcasting transmitters by 10 times. As there are hundreds of thousands of broadcasting transmitters, some with power up to 100-150 kilowatts, the GHG emission reduction could be very significant.

ICTs can play a vital role in the reduction of GHG emissions in other industries. Forecasts estimate that they could help cut emissions by 15 to 40 per cent, by reducing or substituting business travel by audio- and video-conferencing and remote collaboration, providing means for remote working, enabling intelligent transport systems, improving supply chain management and using 'smart' building technologies.

ITU develops international standards, guidelines and other documents facilitating the introduction of environment-friendly ICT equipment and networks in telecommunications and other industries. Businesses around the world could unlock global energy efficiency savings of over EUR500 billion by systematically using ICTs.

ICTs and adaptation to climate change

According to the United Nations Framework Convention on Climate Change: "Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making appropriate adjustments and changes."

There are many measures that are necessary to respond to climate change. One is the establishment of an environment observation system that predicts, identifies and measures the extent of the problem, while also providing data for the development of effective response strategies. This needs to be combined with an early warning and emergency telecommunication system, which takes information obtained by the observation system and uses it for the generation and distribution of warning signals and for planning relief operations.

ICTs are the main components of both systems. Wireless communications were used for the first time in saving the lives of hundreds of sailors aboard the battleship General-Admiral Apraksin at the end of the 19th century. Since that time the importance of emergency telecommunications has increased significantly. Early warning and emergency telecommunications, both wired and wireless, have saved hundreds of thousands of lives during recent decades.

The development of regulations and standards for early warning and emergency telecommunication systems has been one of the key activities of ITU since its inception. Standards such as recommendations on signaling protocols and Common Alerting Protocol on the use of radiocommunications serve as the technical basis for these systems.

International spectrum management functions, fulfilled by the ITU secretariat, assist in the development and effective operation of space and terrestrial radiocommunication networks. These are particularly important in disaster relief activities when wired communications are damaged or completely destroyed.

ITU and climate change

The use of ICTs for combating climate change is among the most important items on the agenda of ITU conferences and assemblies. ITU has adopted several

Image: ITU/Actualités Suisse

Forest fire in South Africa. High-tech navigation, communication and satellite tracking systems enable water bombers to combat effectively the threat of wildfire

Image: ITU/Actualités Suisse

Forest fire in Corsica. ICT-based solutions substantially mitigate the impact of natural disasters

resolutions requesting its sectors conduct research and develop international regulations and standards containing more tolerant climatic range specifications. The ITU focus group on ICTs and Climate Change recently developed methodologies to measure the impact of ICTs on climate change, both in direct and indirect terms.

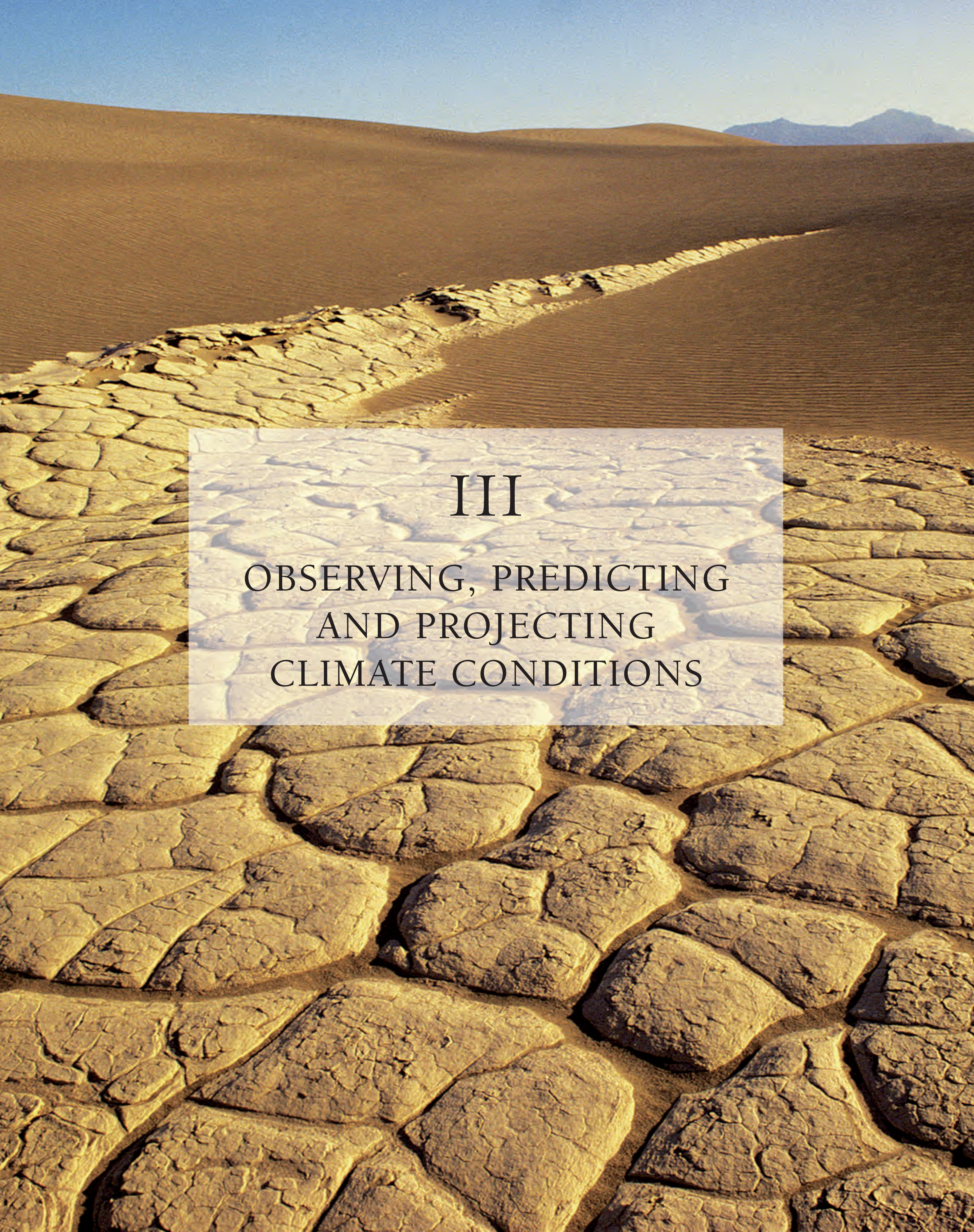
ITU has developed an integrated approach to address the range of technological, scientific, policy, organizational, economic and social issues initiated by climate change in its fields of competence. Its main activities in developing responses to climate change are:

- Providing the necessary radio frequency spectrum, orbit resources and developing technical standards for environment monitoring, early warning and emergency telecommunication systems, both wired and wireless
- Developing regulatory and technical standards limiting and reducing GHG emissions and promoting the use of more energy efficient devices and networks
- Assisting Member States and other industries to take full advantage of ICT applications for environmental management and sustainable development and to use telecommunication/ICTs to adapt to, and mitigate the effects of, climate change
- Cooperating with other organizations in combating climate change
- Continuing to develop an integrated approach to examining the relationship between ICTs and climate change, focusing on technology, climate data collection, adaptation and mitigation
- Joining the UN commitment to lead by example through achieving climate-neutral status within three years, through paperless meetings and virtual conferencing
- Continuing to promote the use of ICTs to strengthen and develop scientific and industrial tools in all areas to combat climate change.

ITU has already established and strengthened strategic partnerships with other United Nations agencies, international and national organizations, NGOs and the private sector involved in monitoring, mitigation and adaption to climate change.

The ITU together with the United Nations Environment Programme supports an initiative of ICT service providers and suppliers called the Global e-Sustainability Initiative. The initiative will provide direct assistance to countries on policies and strategies for the harmonized co-existence of human interaction with the environment through the use of ICTs.

> “Climate change is the moral challenge of our generation. ITU is one of the most important stakeholders in terms of climate change in bringing the benefits of ICTs to meet the challenge of climate change”
>
> Ban Ki-moon, UN Secretary-General



III

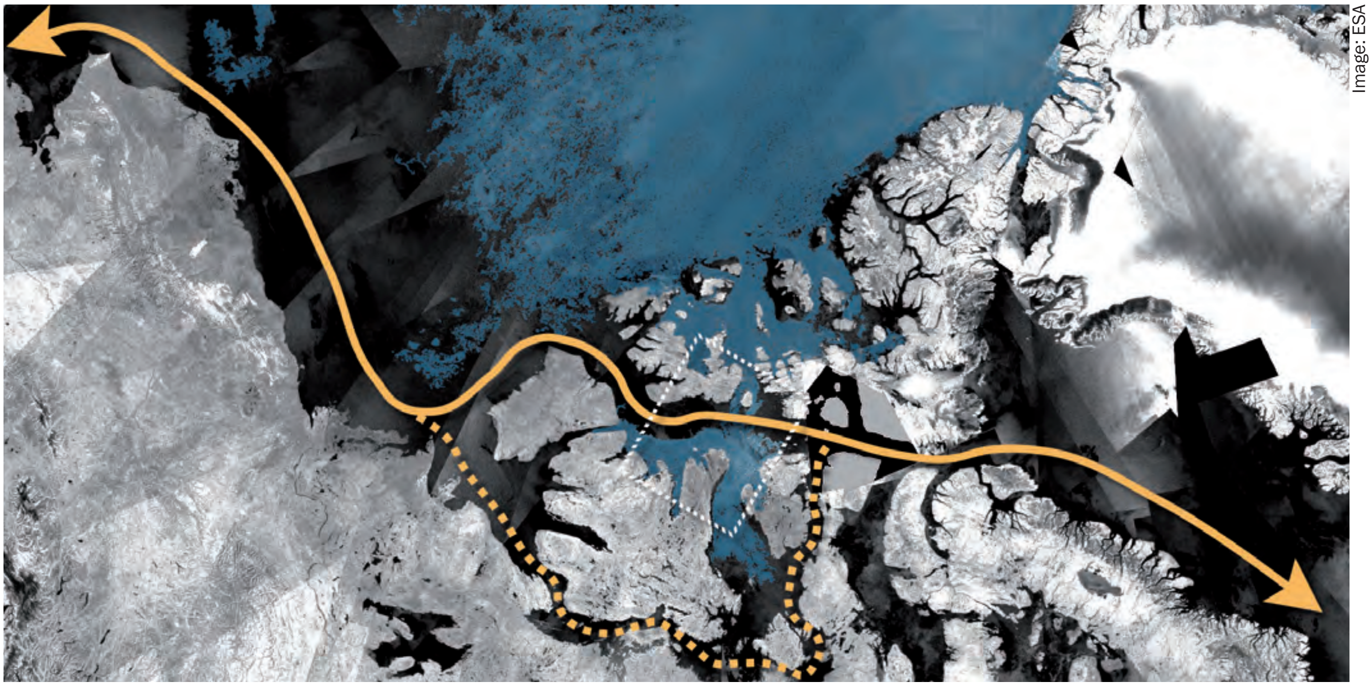
OBSERVING, PREDICTING AND PROJECTING CLIMATE CONDITIONS

The ESA Climate Change Initiative: foundations, objectives and benefits

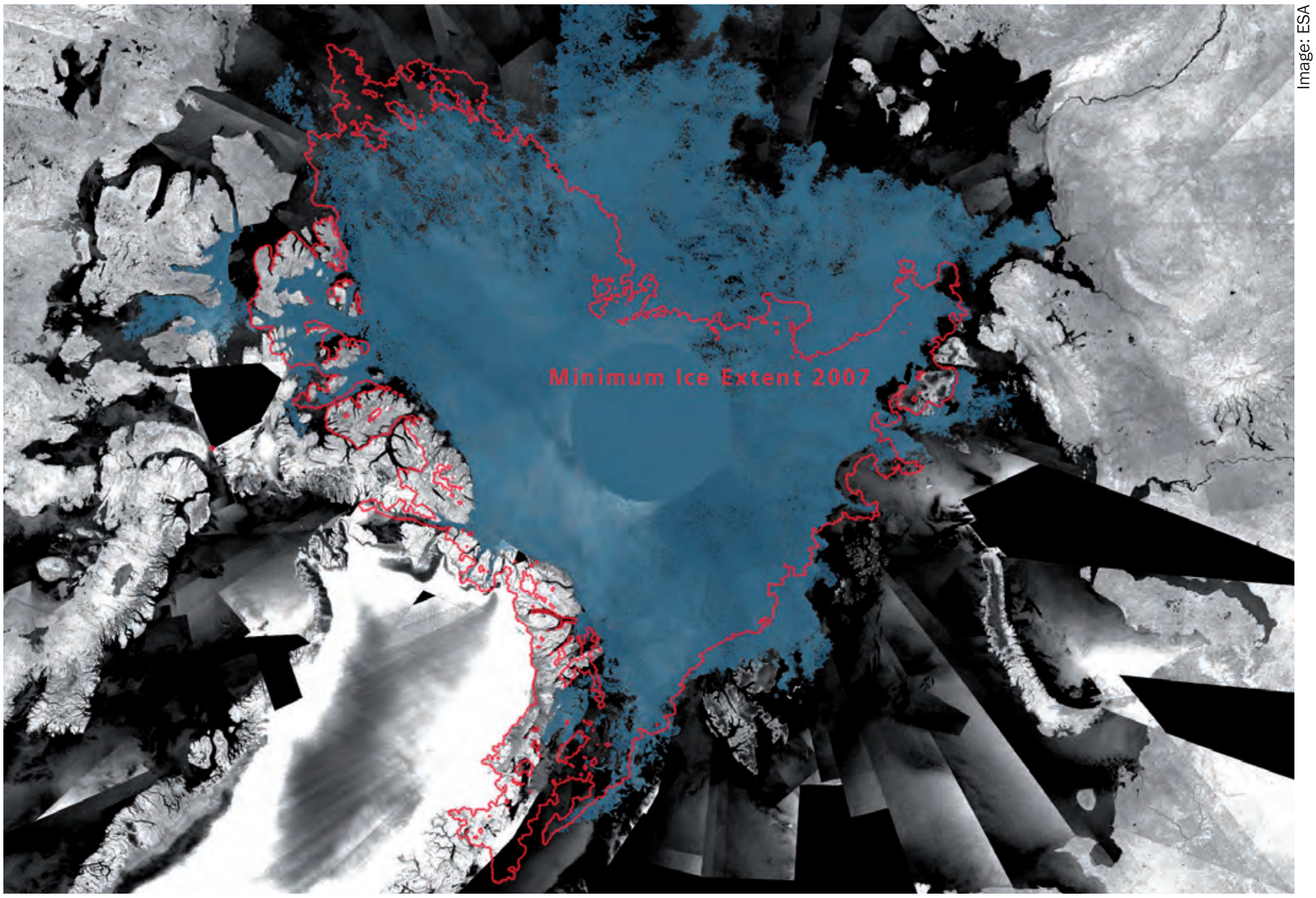
Dr Volker Liebig, Director, Earth Observation Programmes, European Space Agency

Climate — including the atmosphere, the hydrosphere, the cryosphere, land masses, and anthropogenic influences — has, since the beginning of space-based Earth observation, been a central observational target. The first satellites launched by the European Space Agency (ESA) at the end of the 1970s were meteorological missions. This Meteosat series opened a wide range of applications, as well as laying the foundation for over 30 years of operational weather monitoring and forecasting. Today we continue with the second generation of Meteosat missions, even while the third generation is under development and looking to deploy from 2015 onwards. These early European efforts have created long-term records of meteorological and climate observations and have led to the creation of a specialized agency — European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). ESA and EUMETSAT provide a stable basis for European meteorological observations.

Since the advent of multi-purpose ESA Earth observation missions with the launch of ERS-1 in 1991, followed by ERS-2 in 1995 (still functional today) and Envisat in 2002, climate-related data have been increasingly obtained and analysed for scientific purposes. A better understanding of the functions and interactions of the various spheres of the Earth, as well as the role humans play therein has ever since been a central part of both data gathering and scientific analysis. Such new quasi polar-orbiting missions allowed for different kinds of observations, as well as serving as precursors to an operational polar-orbiting, climate monitoring system. The latter was realized with the launch of the first MetOp satellite in 2006. The ESA Earth Explorer missions — specialized satellites focusing on themes of scientific interest and urgency — perfectly complement the organization's efforts to better understand climate development, climate change and the anthropogenic element therein. The first of these satellites — the Gravity field and steady-state Ocean Circulation Explorer, a mission to map the Earth's gravity field in unprecedented accuracy — was successfully launched in March 2009. Two more missions — the Soil Moisture and Ocean Salinity mission (SMOS) and ESA's ice mission CryoSat — are also



Envisat ASAR mosaic from mid-August 2008 showing an almost ice-free Northwest Passage. The direct route through the Northwest Passage is highlighted in the picture by an orange line



Envisat ASAR data mosaic showing sea-ice coverage as of mid-August 2008. The red line indicates the all-time minimum Arctic sea ice coverage in September 2007

ready to be launched during 2009. Another four Explorers are currently in the development stage. The missions are selected and developed in close cooperation with the scientific community, which allows science needs to be directly translated into the space-based instruments.

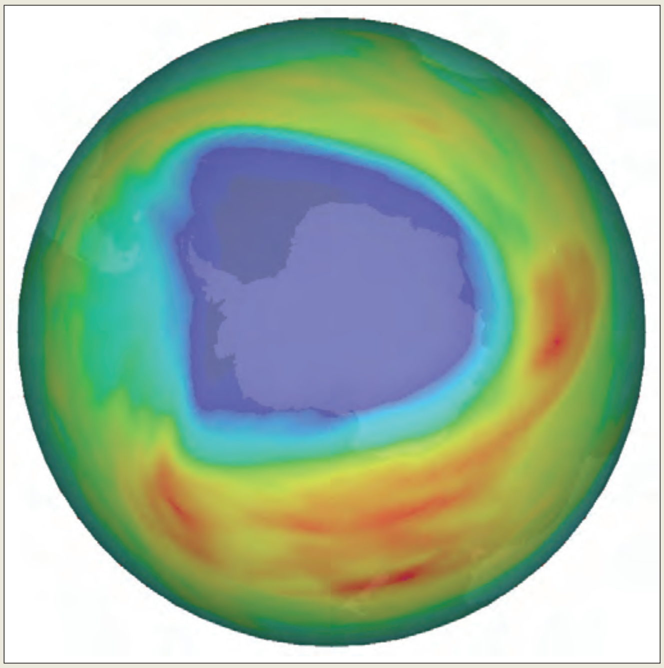
The quest to aid scientists in better understanding the Earth's climate continues with the European Union's (EU) preparation of the Global Monitoring for Environment and Security initiative. ESA has taken up the responsibility of implementing and coordinating the space component of this initiative. Dedicated satellites, called Sentinels, will provide the operational continuity needed to support European policies on environment and security issues. Climate constitutes a large part of this; not only is it a fundamental factor in our environment, but climate change and the human reaction to it also has a large social and security impact. Land, ocean and atmospheric chemistry monitoring, climate quality observations and many more factors are therefore key in preparing for and adapting to future challenges. The partnership with the EU (representing user interests) aims to provide the necessary basis for sustainability.

The importance of global observation for understanding climate change has also triggered action on the international scene — a fact long recognized by the United Nations Framework Convention on Climate Change (UNFCCC). As a result, the Global Climate Observing System (GCOS) was established in 1992 by the World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission, United Nations Environment Programme and International Council for Science to ensure that the high-quality observations needed to address climate-related issues are obtained and made available to all users. The focus was on better understanding the climate system for better decision-making. To meet this goal GCOS defined a set of approximately 44 essential climate variables (ECVs) that should be systematically monitored in order to quantify the state of our climate in an objective and effective way.

Over the last decade GCOS has published a series of adequacy reports assessing the gaps in the existing climate observation system, as well as an implementation plan to deliver high-quality reliable climate data sets of the ECVs. The international community recognizes the vital role played by Earth observation satellites in globally monitoring the climate system, as well as in delivering consistent and homogeneous long-term climate data records. GCOS articulates the data needs for a subset of about 25 ECV products in terms of the 'Fundamental Climate Data Records', which relate ECVs to the observables measured by space-borne sensors.

In 2006, the Committee of Earth Observation Satellites (CEOS) — being the primary international forum for coordination of space-based Earth observation missions — provided a coordinated response by space agencies to the data needs expressed through GCOS, identifying more than 50 actions to be performed by space agencies all over the world. In this context, ESA took on the commitment to contribute to GCOS's implemen-

Ozone hole during 7 October 2008



Ozone hole during 7 October 2008 as measured by the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) atmospheric sensor onboard ESA's Envisat

Source: ESA

tation plan. ESA's response took the form of a proposal for a new programme, referred to as the ESA Climate Change Initiative, which aims to: "Systematically generate, preserve and give access to long-term data sets of the ECVs required to meet the needs of the parties to the UNFCCC". The programme was submitted to the ESA Ministerial Council in November 2008 and accepted by ESA Member States with a level of funding equalling EUR75 million over six years.

The programme also provided ESA with a unique opportunity to capitalize on the huge European investment in the space sector that has taken place over the last thirty years, and in particular to realize the full potential of the long-term Earth observation archives established in Europe. For example, the 15-year homogeneous record of high precision altimetric data from ERS, Envisat, TOPEX/Poseidon and Jason-1 established by ESA and the European member states provides a significant contribution to the ECV oceanic record. Such high-quality data records have radically transformed our view of the ocean, not only providing considerable insight into new and often unexpected oceanic processes, but also by revealing the global rise of sea-level within the astonishing accuracy of a few millimetres.

Likewise, rapid changes have been observed in the cryosphere – the Earth's ice and snow masses. This comprises not only the Arctic sea ice — which is dramatically shrinking, as observed by the Envisat mission — but also measurements of the changes in the Greenland glaciers. Tandem campaigns flown by the ESA flagship missions ERS-2 and Envisat in 2008 and 2009 collected interferometry data over the Arctic and Antarctica. They obtained important data including measurements suggesting that the polar glaciers are moving faster than previously anticipated. Another topic of importance is the measurement of global deforestation rates. This supports the implementation of the UNFCCC/REDD initiative, as such measurements will be undertaken by the ESA Sentinel-2 mission, which is currently under development.

The ESA Climate Change Initiative aims to provide the necessary climate records by ensuring that the full capital is derived from data obtained from ongoing and planned missions in Europe. In particular, it is worth noting that the SMOS mission will provide a significant contribution to the GCOS implementation plan as it addresses two of the highest priority ECVs: soil moisture and ocean surface salinity.

Regarding direct activity, the Climate Change Initiative aims to implement a coherent and continuous suite of actions encompassing all the steps necessary for the systematic generation of relevant ECVs, including recalibration, periodic reprocessing of the long-term records, algorithm development, product generation and validation, and quality assessment of climate records in the context of climate models. The need for long-term data preservation poses specific challenges. ESA has already observed an exponential growth of its EO data archives, with a total of some 3,300 terabytes of data archived since 1986. It is necessary to constantly update archiving technology, with ESA still attempting to address the issue of establishing long-term funding for this process. ESA plans to make a proposal to its Member States for long-term archive maintenance at the 2011 ESA Ministerial Conference.

Another interesting aspect of the Climate Change Initiative lies in the set-up of a 'feedback loop' mechanism, whereby new user feedback and the latest scientific knowledge can be easily integrated within each re-processing phase. This ensures regular updating of the climate records on timescales corresponding to the increasingly urgent needs of the international climate change community.

The Climate Change Initiative is being implemented by ESA in partnership with key users (including GCOS and UNFCCC), space agencies and CEOS, relevant players in the field of climate change research (including European Commission and the National Climate Programme) and monitoring (including WMO, the National Oceanic and Atmospheric Administration and EUMETSAT), as well as in full coordination with existing activities, such as the WMO Space Programme GSICS. A scientific advisory group, involving world-leading scientists representing key stakeholder organizations, has also been set up to provide scientific guidance for the programme.

Through its Earth observation missions — in conjunction with the Climate Change Initiative — ESA is developing quality climate observation systems, providing free access to the worldwide science community, and working with its partners to ensure long-term observations of fundamental climate data records and the resulting ECVs. The particular value of the Climate Change Initiative is that it enables timely action from decision makers, as well as providing a framework that will strengthen the dialogue between Earth observation data research communities and the climate science and modelling community.

EUMETSAT: responding to climate monitoring challenges

EUMETSAT

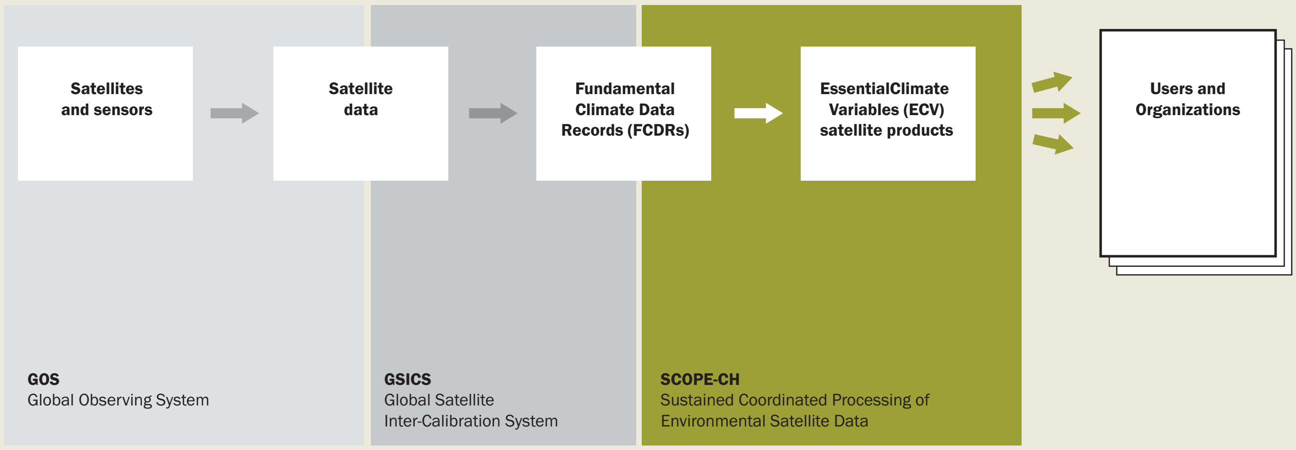
EUMETSAT will continue its all-important and well-established mission delivering operational satellite data, products and services in support of meteorology while at the same time addressing the two greatest challenges facing humankind in the 21st century. The first is global warming and the climate change associated with it. The second challenge faces EUMETSAT alone; namely how to strategically and tactically align its tremendous capabilities, ranging from space systems to end users, to address the urgent requirements needed to understand, mitigate and adapt to the potential devastation caused by global change. It is clear that EUMETSAT's mandate embraces both challenges. EUMETSAT's vision is to be the leading operational satellite agency for European Earth observation programmes that are consistent with its objectives. Its primary objective is to establish, maintain and exploit operational European meteorological satellite systems, taking into account as far as possible the recommendations of the World Meteorological Organization (WMO).

A further objective of EUMETSAT is to contribute to the operational monitoring of the climate and the detection of global climatic changes. Being 'operational' is key and means EUMETSAT must maintain continuing series of satellites with a guaranteed replacement policy. This distinguishes EUMETSAT from its other European space

Image: EUMETSAT

The negative impacts of climate change are manifold

Global solutions through networks



The need for information on climate change means that steps have to be taken to harmonize and integrate the various observing systems

Source: EUMETSAT

partner, the European Space Agency (ESA), whose primary objective in Earth observation is research and development. Whereas ESA develops new capabilities for monitoring global climatic changes, EUMETSAT hones that new potential into continuing series of data. These data respond directly to the requirements of the WMO's co-sponsored Global Climate Observing System (GCOS). GCOS has articulated requirements for Essential Climate Variables (ECVs) in terms of long-term data records, called Climate Data Records (CDRs). Since its existence EUMETSAT has responded with dedication and vigour in providing data for CDRs.

The availability of accurate climate information collected over decades will benefit mankind at all levels and in a wide range of areas, including:

- Assistance to policymakers when considering the need for, and the effects of, actions to mitigate climate change, such as the Kyoto Protocol
- Monitoring compliance with international obligations related to climate change
- Assistance to regional and national planners to better assess the potential impacts of climate change and to thereby select the most appropriate options for their infrastructure planning
- Supporting initiatives such as Global Monitoring for Environment and Security (GMES) in its provision of accurate information for policy-making
- Assistance to the science community in its quest to better understand the mechanisms of climate change and its potential impacts
- Support for a better understanding of climate physics, resulting in better climate projections
- Management of human health risks associated with climate change, such as the spread of vector-borne diseases and heat stress
- Identification of flood-prone areas and requirements for coastal protection
- Management of agriculture, fisheries, food production, freshwater resources and land use
- Risk identification for biodiversity
- Providing the industrial and service sectors with the information they need to respond efficiently to the challenges of climate change
- Providing the material to educate people about climate change and the contribution attributed to human activities, thereby enabling individuals to better understand the impact of their decisions.

In supporting the development of ECVs, EUMETSAT has striven to place long-term data sets into the hands of the ultimate user communities. This paper describes the end-to-end process that will enable EUMETSAT to best achieve its vision and meet the challenges. It provides a brief description of each component — space, ground and end-user segments — for EUMETSAT's integrated and coordinated approach to tackling climate monitoring challenges from an operational agency's perspective.

Space segment

The Meteosat programme is the well-established European contribution to the ring of operational geostationary satellites. The first Meteosat satellite was launched by ESA in 1977. In 1995, EUMETSAT took over the operation of the Meteosat satellites. EUMETSAT currently operates two Meteosat satellites of the first generation (Meteosat-6 and -7) over the Indian Ocean and two second generation satellites (Meteosat-8 and -9) over the prime meridian, clearly demonstrating Europe's ability to build long-lasting systems that strongly contribute to fundamental climate data records.

Second generation satellites have much higher capabilities in terms of temporal repeat cycles (15 minutes compared to 30 minutes for the first generation) and twelve spectral bands, as compared to only three spectral bands for the first generation Meteosats. The larger number of spectral bands enables a better observation of important climate variables, especially those undergoing diurnal cycles. An additional advancement of vital importance to climate observations is the improved on-board calibration of the thermal infrared channels of the Meteosat Second Generation (MSG) satellites.

Images of the Ocean Surface Topography Mission/Jason 2 satellite (left) and the Metop-A, which was launched in October 2006

EUMETSAT has already made good progress in a programme for the third generation of operational geostationary satellites. The unique nature of geostationary measurements and their high temporal frequency provide the capability to observe sub-synoptic atmospheric and surface events — particularly precipitating cloud systems — and to characterize the diurnal cycles of the atmospheric-surface system. Characterization of the annual, as well as diurnal cycles, is crucial for an understanding of the physical processes determining the status of the climate system and its potential changes.

Since the launch of Metop-A in October 2006, EUMETSAT has been operating a polar orbiting satellite system, called the EUMETSAT Polar System (EPS), with a long-term operational and global perspective. Through its innovative payload, the Metop satellite can provide information on a large number of key climate variables over at least 14 years of operational service on a global scale.

The hyper spectral Infrared Atmospheric Sounding Interferometer (IASI) allows the retrieval of temperature and moisture profiles with high accuracy (1 Kelvin, 15 per cent, respectively) over one-kilometre layers. IASI also allows the observation of trace gases relevant to the greenhouse effect and for atmospheric chemistry. The Global Ozone Monitoring Experiment-2 (GOME-2) continues to measure ozone profiles and related trace gases with high accuracy. The Global Navigation Satellite System Radio-occultation Atmospheric Sounder (GRAS) also provides information on temperature and humidity profiles, with the advantage that no adaption of calibration between subsequent satellites is required for the creation of long-term data sets. The observations are absolute, based on time. From the other instruments on Metop — the Advanced Very High Resolution Radiometer (AVHRR), Advanced TIROS Operational Vertical Sounder (ATOVS) and Advanced Scatterometer (ASCAT) — long-term climate records can be derived, especially with regard to AVHRR and ATOVS, which provide continuity of climate records from US National Oceanic and Atmospheric Administration (NOAA) satellites dating back to the 1970s. The continued contribution to ECVs with satellite data benefits from observations from operational meteorological satellites in a polar orbit, because such satellites provide the required continuity in time and global coverage. The post-EPS satellite series planned after EPS/Metop will provide the necessary continuity for atmospheric ECVs, as well as for terrestrial and oceanic ECVs.

The Ocean Surface Topography Mission (OSTM/Jason-2) provides essential observational data on mean sea level ECVs. Intergovernmental Panel on Climate Change reports on the acceleration of global mean sea-level rise beyond 1993 are essentially based on satellite altimetry. Low-inclination orbiting satellite altimetry missions are unique instruments for addressing the spatial requirements on mean sea level observations. A particular goal of OSTM/Jason-2 is to extend the existing mean sea level ECV data set beyond Topex/Poseidon and Jason-1 to complete the first two decades of high-precision altimetry observations.

EUMETSAT will also play a pivotal role in the space segment of the European GMES programme, in which it will operate the Sentinel-3 series of oceanographic satellites. Sentinel-4 and -5 instruments for monitoring atmospheric composition constituents from geostationary and polar-orbiting platforms are planned to be included on related follow-on EUMETSAT missions. The future is bright when considering EUMETSAT follow-on missions; it will further increase its capabilities with Meteosat Third Generation and Post-EPS by carefully assessing climate monitoring requirements within these two new programmes.

Ground segment

EUMETSAT's application ground segment, which consists of the central facility in Darmstadt as well as the distributed network of Satellite Application Facilities (SAFs), is used for processing climate data records from its satellite data at various levels.

Reprocessing of archived data is currently ongoing, targeting Meteosat First Generation calibration and the generation of surface radiation products and atmospheric motion vector (wind) products.

EUMETSAT's network of SAFs consists of eight facilities, some of which are using data from meteorological satellites both in geostationary and polar orbit. EUMETSAT's nowcasting and very short range forecasting, numerical weather prediction, land surface analysis, ocean and sea ice, hydrology and water management, ozone and atmospheric chemistry monitoring and — of course — climate monitoring SAFs provide products and services on an operational basis that are extremely relevant to climate monitoring, in addition to the dedicated climate-related activities of the GRAS SAF.

On an international level, EUMETSAT currently supports two activities relevant to the production of information in support of climate monitoring: the WMO Global Space-Based Inter-Calibration System (GSICS) and the Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM).

SCOPE-CM, led by WMO and strongly supported by EUMETSAT, as secretariat, addresses GCOS requirements in a cost-effective and coordinated manner, capitalizing on existing expertise and infrastructures. Its overall objective is the continuous and sustained provision of high-quality satellite products for the derivation of ECVs on a global scale. Efforts are made with other satellite operators worldwide.

GSICS was established by leading satellite operating agencies with the overall goal of creating an operational system that monitors and evaluates the calibration of the global meteorological satellite observing system in a coherent and systematic manner. EUMETSAT is one of the founding members of GSICS and very actively pursues the realization of such an operational system. Implementation plans are reviewed and updated by the GSICS executive panel and the implementation activities are now underway.

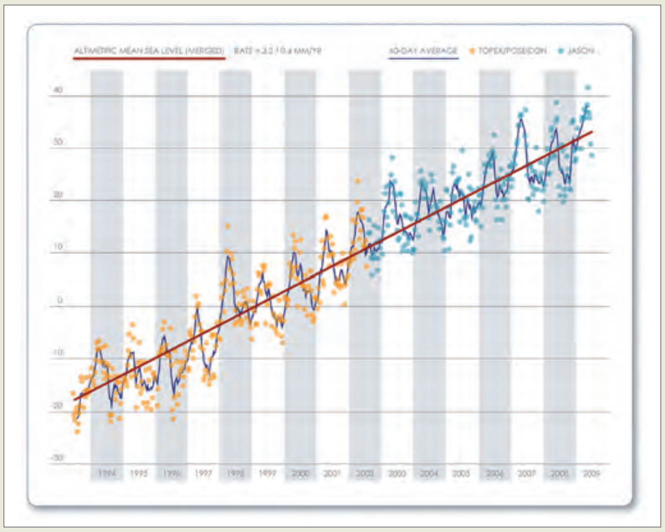
Operational EUMETSAT inter-calibration activities have concentrated on the instruments of geostationary satellites: Meteosat Visible and Infrared Imager and MSG's Spinning Enhanced Visible and Infrared Imager. So far, this has been based on inter-calibration with the High Resolution Infrared Radiation Sounder instruments on NOAA satellites. A major recent step was the inter-calibration with the IASI instrument on Metop; IASI is considered an in-orbit reference for thermal infrared calibration because of its excellent on-board performance. It is also noteworthy that a longer-term comparison with Meteosat First Generation (Meteosat-7) has been done, which is important for the recalibration of first generation Meteosat satellites; which is in turn important for reprocessing in support of reanalysis activities at numerical weather prediction centres. EUMETSAT has already reprocessed more than 30 years of Meteosat First Generation data. Additionally, since the beginning of Metop, EUMETSAT has been reprocessing ASCAT and GOME-2 data.

Engaging the climate community

EUMETSAT's strength emanates from its primary focus on the end users. The organisation maintains a close dialogue with the Member States' National Meteorological Services (NMSs), its foremost customers. This close dialogue helps to understand the evolving requirements of the meteorological user community and to translate these into facilities capable of providing relevant data, products and services. This strong focus on maintaining user dialogues is now being extended to the wider climate monitoring user community with similar successful results.

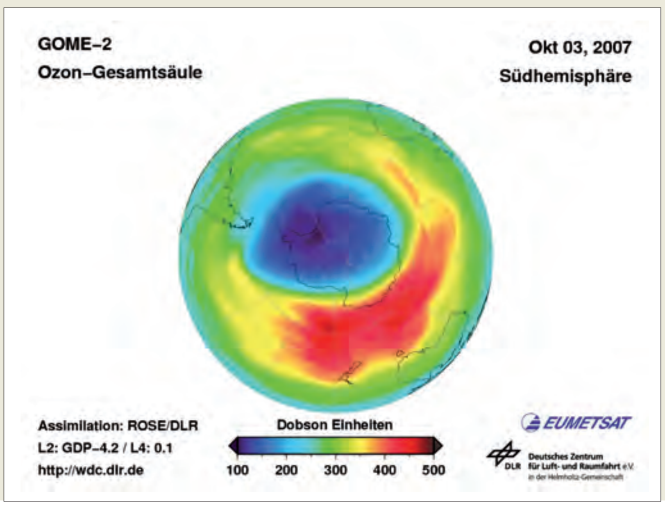
Through the dialogue with the NMSs and international collaboration, EUMETSAT is now establishing itself as an operational satellite agency providing sustained observations that deliver the satellite data necessary for climate change monitoring. Those needs are incorporated in the requirements for current and future operational satellite missions. Furthermore, the value of the long-term satellite data records delivered by EUMETSAT is enhanced through continuous reprocessing activities, ensuring the generation of consistent climate-relevant satellite data records.

Global mean sea level derived from TOPEX/Poseidon and Jason-1 and -2 data shows an average rise of 3.2mm a year



Source: University of Colorado, LEGOS/CNES

Total ozone in the Southern Hemisphere measured by GOME-2



Source: DLR and EUMETSAT

The data sets from the EUMETSAT reprocessing activities are already used in climate-related studies, like the European Centre of Medium-Range Weather Forecasts' reanalysis activities (www.ecmwf.int/research/era/do/get/Reanalysis_ECMWF). These activities provide a consistent long-term analysis of the atmosphere as reported at the 15th Session of the GCOS/World Climate Research Programme Atmospheric Observation Panel for Climate meeting in April 2009. Furthermore, the reprocessed data sets will enable the derivation of consistent thematic climate data records from EUMETSAT satellite data, like total ozone currently generated with data from the GOME-2 instrument that will benefit activities like the WMO/UN Environment Programme Scientific Assessment of Ozone Depletion.

International partnerships: global solutions through networks

The nature of climate change is such that no individual organization — or country — has the capability and resources to fully respond to its challenges independently. In particular, the need for global information on key indicators of climate change means that steps have to be taken to harmonize and integrate the various observation systems in order to be able to provide the required consistency of information. EUMETSAT has responded to this call through strong space agency collaboration within the Committee for Earth Observation Satellites (CEOS) and for even longer in the Coordination Group for Meteorological Satellites (CGMS) — in which it serves as the permanent secretariat. CGMS members include all the operational meteorological satellite operators. The CGMS link is especially beneficial for long-term continuity of data records due to its members' global contingency plans for both geostationary and polar-orbiting satellites. CEOS has played a vital role in preparing a space agency-wide response to the GCOS implementation plan, with recurring updates reported to the United Nations Framework Convention on Climate Change, as well as to the Group on Earth Observations initiative to establish a Global Earth Observing System of Systems.

Within Europe, EUMETSAT participates as a member of the European Meteorological Infrastructure that includes member state operational meteorological organizations, the European Centre for Medium-Range Weather Forecasts and the European Meteorological Network. Within the context of climate monitoring, EUMETSAT has the potential to serve as a cornerstone in the emerging European Climate Infrastructure as it is developed under the leadership of the European Commission.

EUMETSAT's activities in support of climate monitoring

EUMETSAT's mission is to deliver cost-efficient operational satellite data, products and services that satisfy the meteorological and the climate monitoring data requirements of its member states.

For climate monitoring, EUMETSAT will provide and maintain satellite-based climate data records over decades and with the highest possible level of accuracy, homogeneity, reliability and stability.

As a first priority, EUMETSAT, at its central facility and through its climate monitoring SAF, will generate Fundamental Climate Data Records.

As a second priority, EUMETSAT will generate Thematic Climate Data Records, making best use of the expertise available in the EUMETSAT SAFs.

In conducting these activities, EUMETSAT will rely on GCOS guidance and extensively build on international cooperation schemes, such as the WMO GSICS and SCOPE-CM activities.

The Caribbean Drought and Precipitation Monitoring Network: the concept and its progress

Adrian Trotman, Anthony Moore and Shontelle Stoute, Caribbean Institute for Meteorology and Hydrology

Rainfall in the Caribbean islands is characterized by a wet and a dry season in each year. The wet season normally begins during May to June and finishes during November to December. At least 70 to over 80 per cent of the rainfall occurs, on average, during the wet season.[1] In the case of Guyana, in particular the northern portion, the influence of the Inter Tropical Convergence Zone is responsible for the two wet and two dry seasons per year. The seasons show much variability in commencement, duration and rainfall quantities. Also, it is not unusual to experience significant dry spells during the wet season or very wet spells in the dry season.[2] Cycles of 50 to 60 years[3] suggest phases of high and low rainfall, with significant interdecadal variability. During the low phases, water shortages will be more frequent, whilst flooding will be more common during the high phases. Droughts and floods impact heavily on economic sectors, such as agriculture, water resources and tourism.

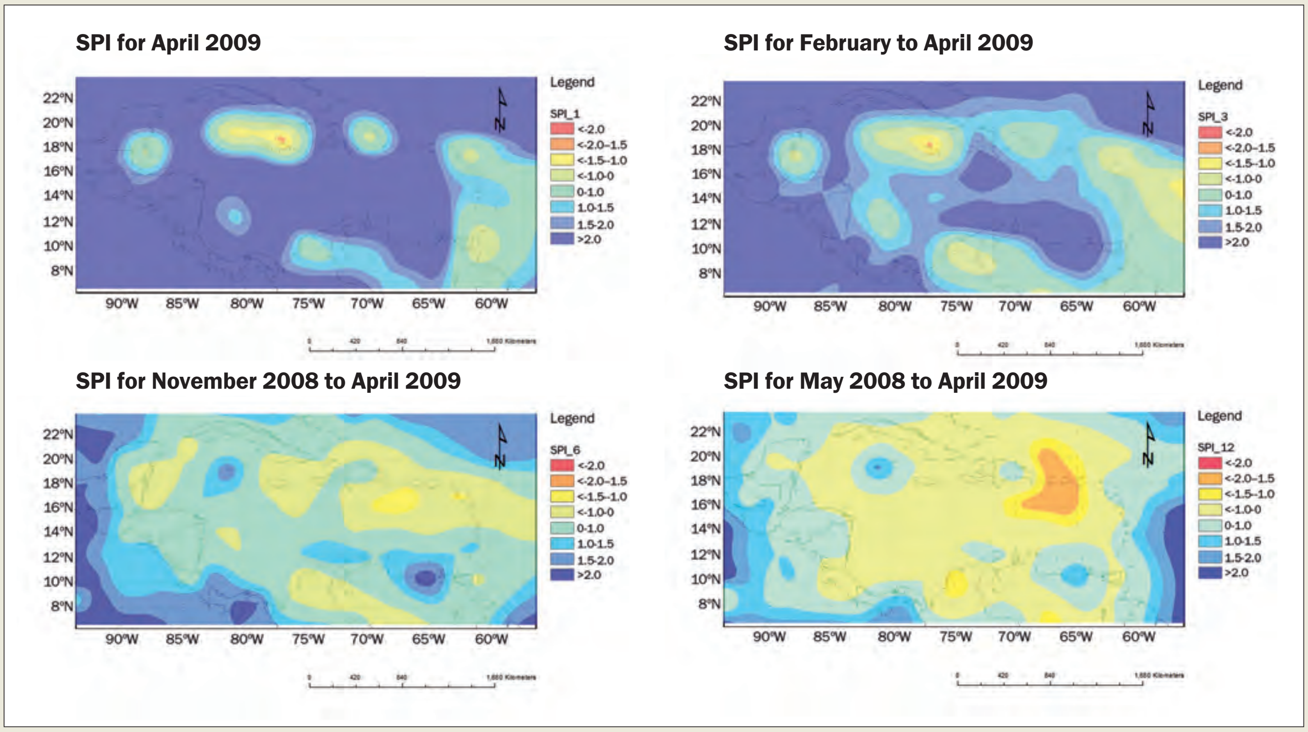
Drought can be defined in a variety of ways. Typically, it is viewed as abnormally low water availability, often due to abnormally low precipitation. It is a slow, creeping disaster that may only be recognized when it is already upon us — then it might be too late. Droughts range in intensity, duration (weeks to years) and spatial extent, which is normally greater than for other climate hazards. Drought impacts are normally cumulative and the effects are magnified when occurring from one season to the next.[4] There is, therefore, the need to closely monitor precipitation for such occurrences. If we interpret drought as a 'water shortage', the distribution of water during dry seasons in the Caribbean region makes life extremely difficult for water resources managers, agriculturists and ecosystem managers. The region's booming tourist industry is no less vulnerable as the dry season, which coincides with the boreal winter season, realizes the heaviest influx of visitors and places a greater strain on water supplies. Drought severely magnifies this lack of water during the dry season. Sub-normal precipitation during wet seasons is commonplace and can have great impacts on agro-ecosystems and biodiversity.

In 1998, Guyana experienced water rationing, cessation of logging and river transport in some places and the loss of livestock due to drought associated with El Niño conditions.[5] Rice farmers were forced to leave 35 per cent of their rice fields uncultivated and more than 1,500 Amerindian families in southern Guyana reliant on agriculture were affected by this event.[6] Jamaica experienced below normal rainfall from December 1996 into 1998 with the greatest damage occurring in the agricultural sector. Losses in the sugar sector prompted the Jamaican government to offer the sector a USD100 million assistance package late in 1997.[7] Later, between October 1999 and March 2000, when rainfall was less than 25 per cent of the average in some places, Jamaican authorities reported crop losses of approximately USD6 million.[8] One of the islands making up Grenada, Carriacou, experiences less rainfall than the main island. It also accounts for 30 per cent of the nation's livestock production, and experienced losses of 20 and 40 per cent due to drought in 1984 and 1992 respectively.[9]

Flooding is the most frequent natural disaster in the Caribbean. Flooding in Guyana from late December 2004 to February 2005 severely affected 37 per cent of the population, was blamed for the deaths of 34 people and caused about USD465 million in total damage. Of this, approximately USD250 million was lost in the housing sector and USD55 million in damage to the agricultural sector, which in 2004 accounted for 35.4 per cent of Guyana's gross domestic product.[10] The following year, a similar, but smaller-scale event resulted in losses to the agriculture sector of USD22.5 million in the major affected regions.[11] In January 2001, flooding associated with the passage of a cold front resulted in losses of more than USD3 million in Jamaica.[12] It has also been reported that in Trinidad, estimated damage from flood events in 1993, 2002 and 2006 was USD580,000, USD3.3 million and USD2.5 million respectively.[13]

With limited peer-reviewed information for the Caribbean, the Intergovernmental Panel on Climate Change projects in its Fourth Assessment Report[14] that there is a 90 per cent chance that temperatures will rise across the Caribbean. An average of 21 models suggests the increase in the annual temperature could be in the range of 2°C to 2.5°C.[15] There is, however, greater uncertainty in the rainfall projections for the region, particularly in the Lesser Antilles. Nonetheless, it is projected with 66 per cent certainty that rainfall is likely to decrease in the

SPI maps for the Caribbean basin



Rainfall readings taken in 1, 3, 6 and 12 month intervals ending April 2009. The drought information can be found at www.cimh.edu.bb/precipindex.html

Source: CIMH

Greater Antilles during the months from June to August. Most models predict a decrease in annual precipitation in the region of 5 to 15 per cent.[16] It is therefore anticipated that droughts will become more frequent in the future. On the other hand, there are indications of more intense rainfall events occurring in the region since 1950,[17] and this trend is likely to continue with anthropogenic climate change.

Basic approach of drought and precipitation monitoring

With concerns over drought and excessive precipitation, it was thought necessary to develop a system that can monitor and forecast such events and thereby allow for the mitigation of their impacts and provide some means for adaptation in the future.

The Caribbean Drought and Precipitation Monitoring Network (CDPMN) was launched in January 2009 under the project The Caribbean Water Initiative (CARIWIN).[18] The goal of CARIWIN is to increase the capacity of Caribbean countries to deliver equitable and sustainable Integrated Water resources Management (IWRM). It sets out to achieve this by improving the capacity of the Caribbean Institute for Meteorology and Hydrology (CIMH) to meet the water management needs of their member states in a multi-stakeholder environment, in collaboration with regional and national networks, selected national governments and community water users. The mission of CIMH is to build national capacities in meteorology and hydrology. By integrating the IWRM approach into CIMH training and capacity development initiatives, the project will have a significant multiplier effect throughout the Caribbean. CARIWIN, launched in February of 2007, was jointly implemented by the Brace Centre for Water Resources Management of McGill University, CIMH, and the partner countries of Grenada, Guyana and Jamaica. This six-year project is funded by the Canadian International Development Agency.

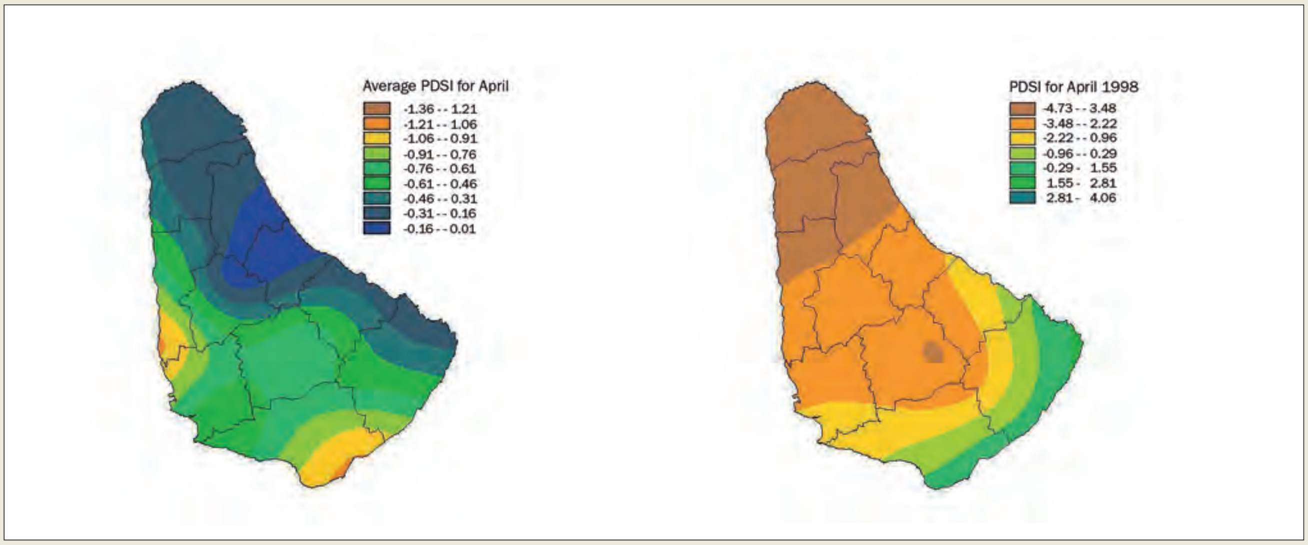
Drought and the general precipitation status will be monitored on two scales: regional, encompassing the entire Caribbean basin, and national using a number of indices and indicators. Indices such as the Standardized Precipitation Index (SPI),[19] and deciles[20] will act as indicators of normal or abnormal rainfall. Other indices can provide information on normal or abnormal soil moisture (Palmer Drought Severity index (PDSI), developed by Palmer in 1965;[21] and Crop Moisture Index (CMI) developed by Palmer in 1968[22]), as well as the status of vegetation (Normalised Difference Vegetation Index). Other indicators can provide information on stream and river flow, lake and reservoir levels and ground water quantities.

The final drought and precipitation status of the region/country will be determined — by consensus — by a network of persons from different sectors, institutions, communities and backgrounds embracing the diversity in definitions and impacts of drought and utilizing the spectrum of indices and indicators.

Caribbean Basin monitoring

The Caribbean Basin monitoring has been the first area of focus. It constitutes mainly sea surface, but

Mean PDSI maps for Barbados

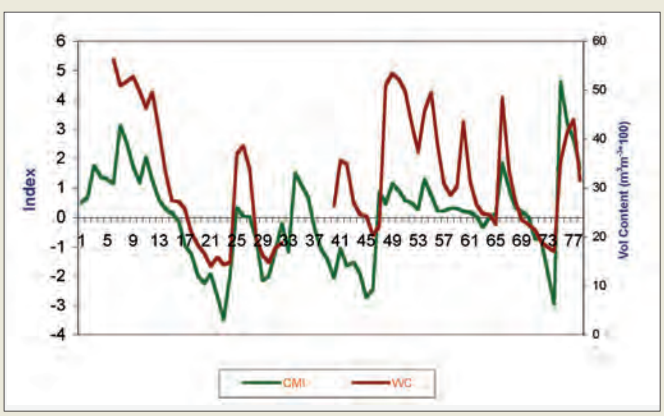


Mean PDSI map for April (left), and PDSI for April 1998 (right), an El Niño year, which was also drier than normal in Barbados. Note the more negative (drier) values in April 1998

Source: Shontelle Stoute

also includes some islands forming an archipelago, as well as coastal South and Central America. The only indices/indicators of drought that would merit use on the regional scale would therefore have to be related to rainfall — as water flows, water levels and soil moisture would not apply. SPI maps are currently produced, with the intention of adding deciles to the monitoring. The first regional maps were produced on 7 April 2009, which provided the precipitation status as of the end of March on four timescales, reflecting the reality that different types of drought manifest themselves after different times lengths of exposure (for example, agricultural drought is expressed much sooner than hydrological drought).

Crop Moisture Index (CMI) and measured soil moisture



Time series of CMI, and measured soil water content (using Sutron's 5600-0089 Soil Moisture/Temperature Sensor) at 10 cm depth at CIMH. The correlation between CMI and measured soil moisture was 0.74

Source: Shontelle Stoute

As many land stations as possible are being sought for the production of these maps. Over the sea and in areas where land data is not currently provided, NCEP/NCAR[23] reanalysis data is used. Currently 14 countries, particularly in the Eastern Caribbean, contribute monthly data to this endeavour. With time more countries in the archipelago are anticipated to contribute data, restricting the use of reanalysis data to over the sea. It is also important that there is some investigation into the relationship between the reanalysis data and actual station data. This task will also be performed. Using the reanalysis and land station data, SPI maps for 1, 3, 6 and 12 month intervals are being produced in under seven days after the end of each month.

National monitoring

National monitoring will occur in the three CARIWIN partner countries of Jamaica, Guyana and Grenada. Another collaboration between CIMH and The Institute of Earth Sciences, University of Applied Sciences of Southern Switzerland would allow for two other islands (Barbados and Trinidad) to be included in the monitoring. It has to be determined which indices and indicators will be used to monitor drought in these countries. Unlike Caribbean Basin monitoring, indices and indicators utilizing data other than precipitation can also be engaged. Possible data sets that can be made available are currently being investigated; for example soil moisture, soil available water capacity, evapotranspiration, vegetation indicators, streamflow and reservoir levels. The usefulness of PDSI and CMI has already been investigated in Barbados in a preliminary way. In Jamaica, investigations are taking place into the use of the Soil and Water Assessment Tool of the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA to estimate soil moisture and stream flow. These would be related to SPI and Normalised Difference Vegetation Index data, and implies that rainfall indices will also be prime foci of the national monitors.

Projection of rainfall indices

CIMH currently produces a precipitation outlook for the Caribbean from Guyana in the south, across the island chain to Belize in the West. The information comes in the form of probabilities of normal, above normal and below normal rainfall with a lead time of three months. The forecasts will be used in combination with the monitoring output to provide projections of precipitation index values with the same lead times.

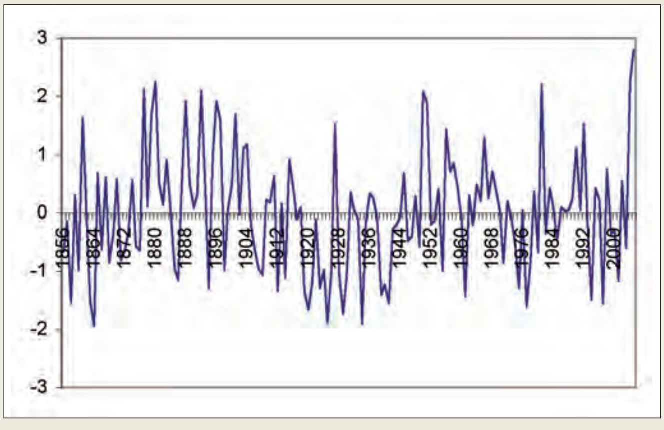
A number of model outputs are used to produce the final outlook maps. Rainfall projections from the European Centre for Medium Range Forecasting, the International Research Institute for Climate Prediction and the United Kingdom Meteorological Office are combined with some subjective climatological experience. The intention is to produce at least two projections; one using the combined final outlook, and at least one using a lone model output. Model validation would be performed to determine the model that best represents the region.

Outcomes and benefits expected from CDPMN

The network is expected to improve the management of water resources, and aid in planning and adaptation to drought and heavy precipitation, which are real and increasing threats. It will fulfil four main functions:

- Monitor the status of rainfall via climatological, hydrological, and other indicators
- Undertake projections with lead times of up to three months by coupling seasonal forecasts with drought monitoring
- Post warnings on CIMH website and disseminate to key agencies, governments and media in partner countries
- Enable the development of adaptation and response strategies to drought and excessive rainfall by creating a network of researchers working with stakeholders, including all levels of government from the local to national.

Edgecumbe SPI Jul-Dec (6 months)



Historical SPI values for Edgecumbe, St. Philip, Barbados from 1856

Source: CIMH

Measuring river levels in St. Cuthbert Mission, Guyana

Discussion so far has concentrated on the first three functions. A key aspect of the fourth function is an awareness of the impacts of the different severity classes of indices and indicators. For example, how did the peaks and troughs of the historical SPI for Edgecumbe, Barbados, impact on vital sectors of the economy such as agriculture and water resources? Research will pay some attention to relating the indices and indicators with impacts in the relevant sectors, and would be an important activity at both the local/community and national levels.

In addition to monitoring trends, implementing early warning systems and networking, the CDPMN will define knowledge gaps and uncover the need to address extreme events and coping mechanisms. The network will be valuable for decision makers to be able to target their efforts on the most vulnerable regions and communities.

Through the CDPMN, which is expected to be fully operational by 2010, researchers and decision makers will gain access to a community of professionals working on drought and flooding/excess precipitation issues. They will partake in workshops and training sessions on impacts of extremes and how to adapt. They will be invited to share experiences and be involved in identifying and shaping the research priorities related to water resources, climate and climate change.

Long-term observations of global climate change

Kazuo Umezawa, Keiji Imaoka, Kazuhiro Tanaka, Yoshihiko Okamura, Japan Aerospace Exploration Agency

Global warming has developed into a problem which if ignored will see significant and detrimental changes to the global environment. The fourth assessment report of the Intergovernmental Panel on Climate Change states unequivocally that the climate is becoming warmer, citing observed increases in global average air and ocean temperatures, as well as widespread melting of snow and ice.

Observing climate change has its complexities. While some symptoms of global warming are explicit the majority are more discreet. In addition, such signals are affected by natural variability and thus do not appear in a uniformed guise worldwide. As such, any observational system for climate variability should be thoroughly consistent, of an extensive duration and have global coverage.

Japan Aerospace Exploration Agency (JAXA) is developing the Global Change Observation Mission (GCOM) in response to these requirements. GCOM will involve two medium-sized, polar orbiting satellite series. The series will stretch over multiple generations, with one-year overlaps between consecutive generations for inter-calibration. Two instruments were selected to cover the wide range of geophysical parameters required: the Advanced Microwave Scanning Radiometer-2 (AMSR2) for GCOM-W and the Second-Generation Global Imager (SGLI) for GCOM-C. AMSR2 will cover observations relating to the global water and energy cycle, while SGLI will cover the surface and atmospheric measurements related to the carbon cycle and radiation budget.

Image: JAXA

Overview of the GCOM-W1 satellite

GCOM-W

GCOM-W will focus on long-term observations related to global water and energy circulation, including the monitoring of polar areas. To achieve the desired results multichannel microwave radiometers will be used, which are capable of capturing quantitative data with the required frequency and at a global scale. More specifically, the radiometers will be used to gather quantitative measurements of given surface parameters through non-precipitating and – in some cases – light precipitating clouds. In addition, they will capture vertically integrated layer information via the interaction of microwave radiation with intercepting media, such as rain drops or snow grain.

Leveraging the capabilities of AMSR2, GCOM-W will observe various changes in the cryosphere including variability in: sea ice, ice sheets and snow cover. Such measurements are considered an excellent indication of the potential extent and timing of global warming. Changes in sea surface temperature, precipitation, cloud water and water vapour will also be monitored in association with air-sea interactions, such as the El Niño-Southern Oscillation. Finally, surface soil moisture will be observed to help quantitatively determine the water and energy balance between the land and atmosphere.

The first generation GCOM-W (GCOM-W1) satellite will be a medium-sized platform, smaller than the ADEOS and ADEOS-II satellites. This is to reduce the risk associated with large platforms that feature multiple, valuable observing instruments. Also, since the ADEOS-II problem was related to the solar paddle, recent Japanese satellites almost always have dual solar paddles. One concern relating to the dual-paddle design was a possible influence on the Cold Sky Mirror (CSM) field of view, introducing cosmic background temperatures to the feed horns. We have assessed the direct effects solar paddles have on the CSM by simulating observed brightness temperatures and it was confirmed that the direct effect was negligible. To avoid the shading of the solar paddles by large AMSR2 antennas and the effect to CSM mentioned above, the paddles were designed to have longer booms. The local time of the ascending node will be 13.30 to remain consistent with the Aqua/AMSR-E observations.

The system Preliminary Design Review of the GCOM-W1 satellite was completed in March 2008 and the AMSR2 system critical design review (CDR) was finished in November 2008. In designing the instruments and interface for the spacecraft, the main goal

Major characteristics of the GCOM-W1 satellite

Instrument	Advanced Microwave Scanning Radiometer-2
Orbit	Sun-synchronous orbit Altitude: 699.6km (over the equator) Inclination: 98.186 degrees; Local time of descending node: 13:30
Size	5.1m (X) * 17.6m (Y) * 5.0m (Z) (on-orbit)
Mass	1940kg
Power	Over 4050W
Launch	JFY2011 (beginning of CY2012)
Design Life	5 years
Status	Phase-C study started in JFY2008

Source: JAXA

was to improve the reliability and extend the lifespan of the units from three to five years. As a result, a redundant momentum wheel and an interface board for two signal processor circuits were added.

The basic concept of AMSR2 is almost identical to that of the AMSR-E: conical scanning system with large offset parabolic antenna, feed horn cluster to realize multi-frequency observation, external calibration with two temperature standards and total-power radiometer systems. The 2-metre diameter of the antenna, which is larger than that of AMSR-E, provides a better spatial resolution under the same orbit altitude of around 700 kilometres. There is also an allowance for slight underlaps in the 89 gigahertz scans, due to the narrower beam size of AMSR2 with the same sampling interval of AMSR-E. The C-band receiver uses additional 7.3 gigahertz channels to mitigate potential radio frequency interference. An incidence angle of 55 degrees (over the equator) was selected to keep consistency with AMSR-E. The observational swath width of 1,450 kilometres, combined with the selected satellite orbit, will provide almost complete coverage of the entire Earth's surface within two days, independently for ascending and descending observations.

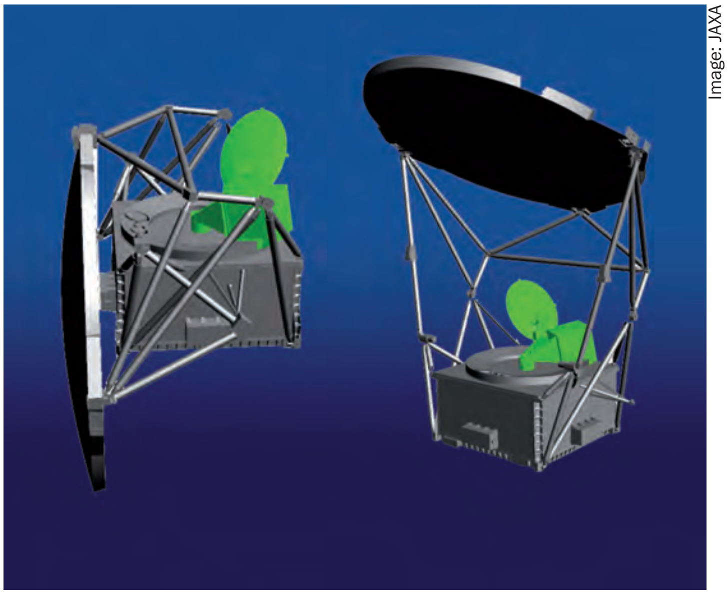


Image: JAXA

Overview of the AMSR2 sensor unit

GCOM-W data products will include brightness temperatures (Tb) and geophysical parameters in swath form. In addition, spatially and temporally averaged global grid products will be generated. Since the Tb values are fed into retrieval algorithms to derive all the geophysical parameters and are directly used in the numerical data assimilation scheme, well-calibrated and stable Tb data is necessary. Eight geophysical parameters will be retrieved and processed as standard products.

GCOM-C

For this series the four primary parameters will be atmosphere, ocean, land and cryosphere to best reflect the human contribution to climate change. In the atmosphere category measurements will centre on aerosol and cloud. In order to observe aerosol over land, three observation methods will be employed, namely: an ordinary split window method, a near-UV method and a polarimetry method.

In order to monitor the ocean, low polarization sensitivity for precise ocean colour observations and a 250 metre resolution near coastal areas is needed, because primary productivity depends largely on the coastal environment. For the land, a 250 metre resolution, as well as multi-angle observation are planned so that it is possible to precisely evaluate vegetation and land use change, including primary production and deforestation. The cryosphere also requires a 250 metre resolution to more accurately estimate loss of ice sheet, as well as snow physical characteristics. The aerosol effect on snow is a particularly important issue that needs to be monitored.

The total number of observation channels has been reduced compared to the previous GLI sensor by optimizing the objectives in each area. The signal to noise ratio at standard radiance is over 200 for the visible and near-infrared channels, while the noise equivalent temperature difference is lower than 0.2 Kelvin for thermal infrared (TIR) channels.

To optimize broad spectral range requirements the system is split into two sensors. For visible and near-infrared a push-bloom type sensor called the Visible and Near Infrared Radiometer (VNR) was selected to attain multi-angle polarimetry and non-polarimetry observation. To successfully achieve this with a whisk-bloom type sensor is difficult, as it requires a tilt mechanism and low polarization sensitivity, which are difficult to incorporate because of the sensor's size and catoptric character. For non-polarimetry observation, the system has three telescopes to cover a wide area, and for polarimetry observation the system has two telescopes. For shortwave infrared and thermal infrared, the system has a whisk-bloom type sensor called, simply, Infrared Scanner (IRS) to take over from the GLI system. Each VNR and IRS has an on-board calibrator to manage change.

The SGLI/VNR will cover a relatively large area for a push-bloom type sensor. Because of this, the obser-

Frequency channels and resolutions of AMSR2

Centre frequency [GHz]	Band width [MHz]	Polarization	Beam width [deg.] (Ground resolution [km])	Sampling interval [km]
6.925 / 7.3	350		1.8 (35 x 62)	
10.65	100		1.2 (24 x 42)	
18.7	200	V and H	0.65 (14 x 22)	10
23.8	400		0.75 (15 x 26)	
36.5	1000		0.35 (7 x 12)	
89.0	3000		0.15 (3 x 5)	5

Source: JAXA

SGLI channel specifications

Channel	Centre wavelength	Band width	Standard Radiance	Maximum Radiance	Ground resolution
	VN,P,SW: nm T: μm		VN, P: W/m²/sr/μm T: Kelvin		m
VN1	380	10	60	210	250
VN2	412	10	75	250	250
VN3	443	10	64	400	250
VN4	490	10	53	120	250
VN5	530	20	41	350	250
VN6	565	20	33	90	250
VN7	673.5	20	23	62	250
VN8	673.5	20	25	210	250
VN9	763	12	40	350	1000
VN10	868.5	20	8	30	250
VN11	868.5	20	30	300	250
P1 *1	673.5	20	25	250	1000
P2 *1	868.5	20	30	300	1000
SW1	1050	20	57	248	1000
SW2	1380	20	8	103	1000
SW3	1630	200	3	50	250
SW4	2210	50	1.9	20	1000
T1	10.8	0.74	300	180~340	500
T2	12.0	0.74	300	180~340	500

**1 Polarization channels should have capability to observe at three polarization direction (0,60,120 deg.) and NADIR / Tilt view at +-45 deg*

Source: JAXA

vation orbit and swath design are crucial for the sensor system to work. A sun-synchronous orbit with an approximate height of 800 kilometres and a 34 day revisit period was selected. Considering the observation frequency requirement, the sensor swath should be wider than 1,100 kilometres for every two-day observation at mid-latitude. Because we are using a push-bloom type sensor for VNR, swath is an important parameter. The detector array size and total volume of optics depends largely on this parameter. The preferred local time at descending node is 10.30, taking into account the amount of cloud over the land.

VNR consists of a non-polarimetry part, a polarimetry part, an on-board calibrator and an electrical component. For the non-polarimetry part, which has 11 channels, there are three telescopes to cover a wide swath. To separate channels, we decided not to use a dichroic filter to minimise polarization sensitivities by optics. So, instead of using filters we decided to use along-track direction for spectral channels, though it has some parallax. Keeping a low inci-

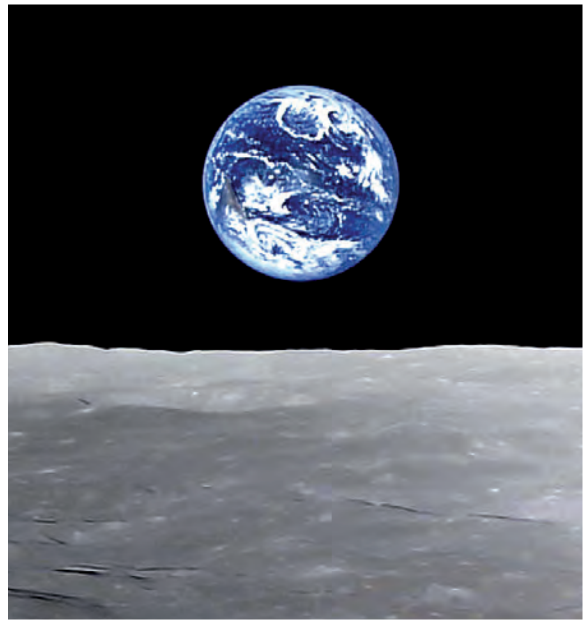


Image: JJAXA/NHK

"Full Earth-rise" taken by HDTV on JAXA's Kaguya (SELENE) Spacecraft

dent angle in optical design, this sensor has very low polarization sensitivities — lower than two per cent.

For the polarimetry part, which has two channels, two telescopes with two wavelengths were employed. Because the polarimetry part is designed for tilt observation, the swath can be covered with one telescope. Two telescopes are used to minimize parallax between the three polarization direction sub-channels, and in each telescope there are three polarization direction sub-channels. With three polarization direction observations at 0, 60 and 120 degrees, it is possible to determine storks vectors (I, O, U) of observed light, where element V of the storks vector is negligible in natural light. Tilt observation geometry is required for the poralimetry part. The signal from aerosol is optimal in a forward scattering direction, therefore the observation direction must be forward tilted in the northern hemisphere, and backward tilted in the southern. In one orbit, the sensor tilts forwards and backwards once each. The scatter angle of aerosols to be measured is between 60 and 120 degrees.

For both non-polarimetry and polarimetry about 6,000 element CCDs were used to cover a 1,150 kilometre swath. To divide channels spectrally there is a striped colour filter on each detector array. For polarimetry, a striped polarizer is added. Then, the observed signal is digitized with a 12bit analogue-to-digital converter. When the satellite is not over land or coastal areas, the 250-metre resolution data will be integrated and averaged on board into 1-kilometre resolution data. The daily total data download rate will be about 70 gigabyte, including both VNR and IRS data.

For on-board calibration, the satellite is equipped with a solar diffuser, as well as an internal light. An attempt will also be made to use the Moon as a stable natural light source. Other observation modes for cali-

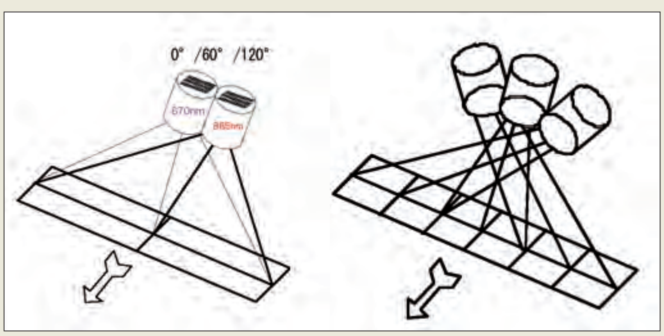

Image: JAXA

Overview of the GCOM-C1 satellite

bration are also under study, such as the satellite 90-degree yaw manoeuvre.

The total system design of IRS comes from the previous GLI on ADEOS-2, as well as the Ocean Colour and Temperature Scanner on ADEOS. IRS is a full catroptic optical system with a compact conical scanner to avoid any colour aberration. The detector range is covered by PV-MCT type detectors for TIR channels, while indium gallium arsenide detectors were selected for shortwave infrared (SWIR) to attain higher sensitivity and lower noise than on the GLI. For the cryo-cooler of the TIR focal plane assembly, a staring cycle cooler system is used. The required thermal environment for infrared detectors is about 55 Kelvin. For SWIR calibration we will also use solar and internal light, the same as VNR. For TIR, an ambient black body will be used as a high level input source. A deep space view is used for both SWIR and TIR at zero level. For TIR band the resolution is set at 500 metres, whereas the SWIR channel is set at 1 kilometre except for one 250-metre channel.

Polarimetry and non-polarimetry observation



Non-polarimetry part using three telescopes (left); Polarimetry part using two telescopes (right)

Source: JAXA

International cooperation

GCOM-W will play a role in the global precipitation measurement (GPM), a joint mission between NASA and Japan. GPM consists of a core satellite carrying a dual-frequency precipitation radar, a microwave radiometer and contributing satellites carrying microwave radiometers. GPM will enable frequent global observation of precipitation and water-related quantities.

GCOM has also started cooperating with the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NPOESS and GCOM will support the operational and research needs of the meteorological, oceanographic, environmental and climatic remote sensing programmes as well as provide global environmental support. Data from these satellites will also be made available to meteorological and environmental organizations to support their weather forecasting and climate prediction capabilities. The USA and Japan will jointly operate these two major satellite systems; sharing data and conducting joint calibration, validation and science activities.

The GCOM satellite series in overview

The GCOM-W satellite series will globally observe water-related quantities in the atmosphere, ocean and on land. Data measured by AMSR-2 will be used to derive: water vapour content, cloud water content and precipitable water in the atmosphere; surface temperature, surface wind and ice in the ocean; and soil water content and snowfall on the land. This data will be used for societal benefits such as describing and forecasting phenomena such as El Niño and La Niña, monitoring sea-ice variations, monitoring and forecasting typhoons and providing a meteorological data service to daily weather forecasting facilities. Close collaboration mechanisms for the data use have already been established with national and international operational organizations for meteorology, maritime operations and fishery information services.

The GCOM-C satellite series will observe vegetation on the land, phytoplankton (ocean colour) in the coastal region and sea-surface temperature with a horizontal resolution of 250 metres. Highly variable aerosols in the atmosphere and snow, as well as ice parameters will be observed. Data can be practically applied to benefit society in collaboration with meteorological and fishery information services. National and international environment research institutes will analyse the global changes in vegetation and sea-surface temperature.

The GCOM programme is Japan's first attempt at 13 years of continuous satellite observation with three series of satellites, each with a five-year lifespan, and one-year overlap. This mission was implemented because it is necessary to reveal the relationship between climate and the effects of human activity, namely to exclude the influences of solar activity, which change on an 11-year cycle, and natural variability on shorter cycles, to improve the accuracy of predicting climate change.

Observing and understanding the ocean

Dr P. Bernal, Executive Secretary, The Intergovernmental Oceanographic Commission, and Assistant Director-General, United Nations Educational, Scientific and Cultural Organization

The ocean plays a key role in regulating the climate system: capturing, transporting and releasing vast quantities of heat, the ocean serves as the memory of climate, influencing patterns of drought and flood over land. The ocean is inexorably rising, expanding in volume as it warms, and from the landlocked ice that melts into it.

Permanently absorbing nearly two billion tons of human-generated carbon from the atmosphere every year — and therefore reducing the speed of change — the ocean has already spared us from catastrophic climate change. Eventually the ocean will absorb most of the additional carbon civilization produces. However this is happening at the expense of the health of the ocean. A direct consequence is the growing acidity of the ocean, and the impact this has on ocean life and ecosystems.

The ecological services the ocean provides are fundamental to the maintenance of life on Earth. This makes the ocean the ultimate global commons, because all humankind has a stake in preserving a healthy, functioning ocean.

But many questions remain unanswered:

- How will the ocean capacity to absorb carbon evolve?
- What will the impact be on marine ecosystems?
- Are there tipping points in ocean circulation that by locking the climate system in a different equilibrium could lead to sudden changes in patterns of drought and rainfall over land?
- How are human stresses on the marine environment exacerbated by climate change?

In the past decade, we have started to systematically observe the ocean for the first time in history. In May 2009, 8,132 automated platforms collected data from the ocean. The Argo Project has seeded the ocean with more than 3,000 robotic floats evenly distributed across the globe. These floats park at a depth of 2,000 metres, rising once every ten days to the surface, measuring physical properties on their way up and transmitting their data by satellite once at the surface.

Today satellites measure the surface of the ocean with great precision. They record changes in temperature that set the atmosphere in motion, measure the height and shape of the sea surface which reveals the speed and direction of the currents below, and derive the strength of the wind on its surface from observing and quantifying the waves it whips up. Around the world tide gauges record changes in sea level with high precision for climate monitoring, and with high speed for tsunami alerts. The data are used for climate monitoring, research and forecasting, but also to support weather and ocean forecasts, as well as hazard warnings. Without ocean information it is impossible to predict seasonal rainfall anomalies, the appearance of El Niño, or the extent of local sea-level rise. We would have difficulty predicting the amount of carbon in the atmosphere, and how fisheries will evolve under the effects of climate change.

The Intergovernmental Oceanographic Commission (IOC) recently reported to the state parties of the United Nations Framework Convention on Climate Change that this success in expanding ocean observations rests on tenuous ground. While many nations contribute to sea level measurements along their coasts, only a limited number of nations contribute much to the satellite and in situ observing systems. On the satellite side, many of the ocean observing devices are launched as part of ‘research missions’, and the transition from these ad hoc missions to a long-term sustained monitoring effort has been extremely difficult to achieve. The European Union has made good strides into making commitments to sustaining essential ocean climate observations from space. But too many of these observations rely on research-based voluntary support structures that were never meant to sustain an observation and information system over the long-term. Until now following a policy of ‘business as usual’, nations of the world are not rising to the challenge of building perennial structures to monitor the ocean, a key part of the climate and life support system of the Earth.

These observations have been crucial in improving the scientific understanding and our ability to better predict the global climate system. In 2007 the Fourth Assessment Report of the Intergovernmental Panel on Climate Change categorically stated that climate change was ‘unequivocal’, based in part on the assessment of nearly 300 scientific papers written by oceanographers drawing on these new ocean observations. They noted evidence that the average temperature of the global oceans has increased, and that the ocean has been absorbing more than 80 per cent of the heat added to the climate system.

We also know that many centuries of change in the climate are already in the pipeline and will take place based solely on past emissions from human activities thus far since the beginning of the industrial age. So even if strong controls on emissions are negotiated, human populations, and particularly those in the developing world, will have to adjust to a changing climate, with different patterns of rainfall and drought and rising sea levels. It seems obvious that to underpin these diffi-

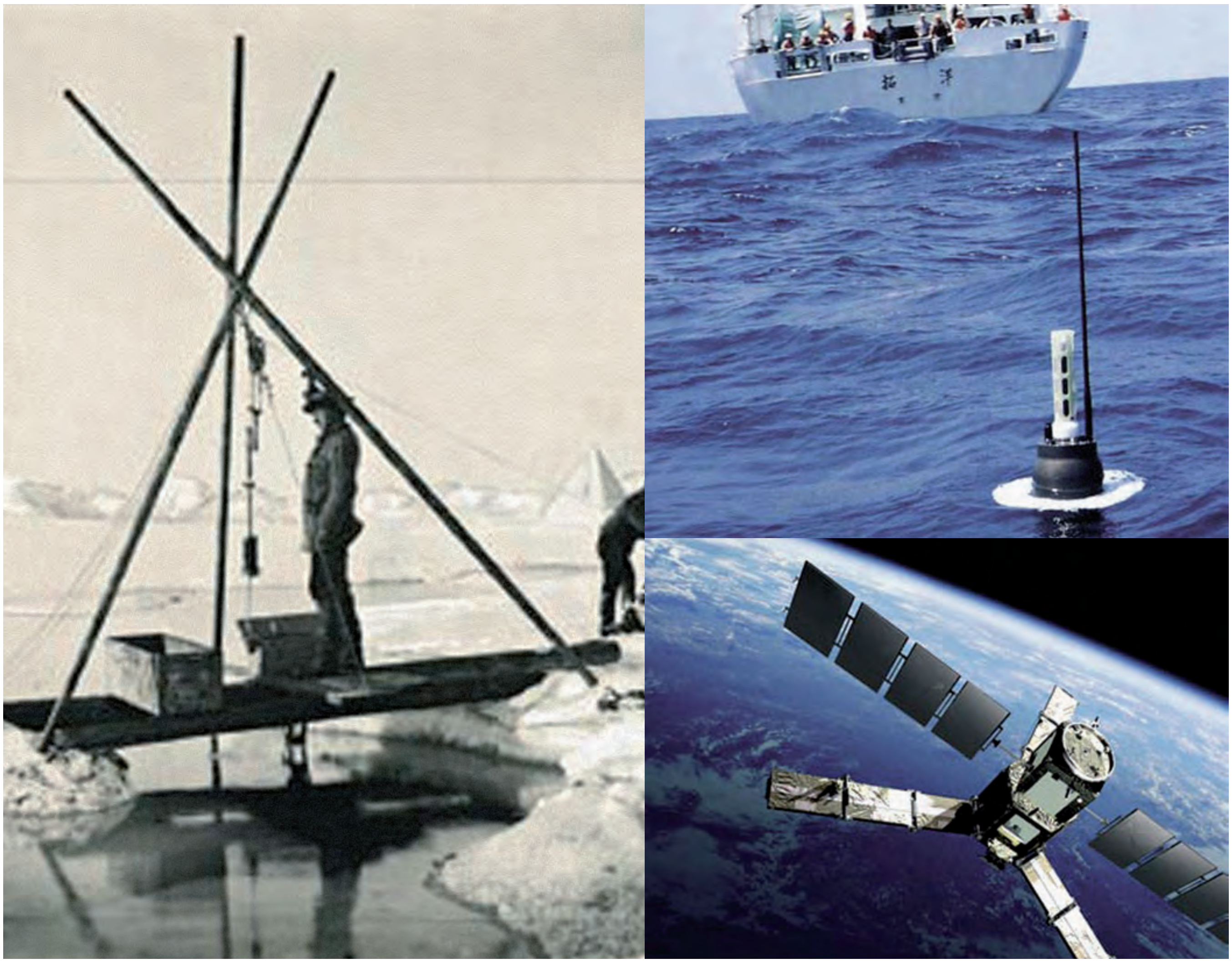


Image: IOC UNESCO

The evolution of ocean observations: from Fridtjof Nansen's 19th century arctic expeditions to today's sophisticated satellite technology

cult and expensive decisions to adapt societies to climate change, scientific knowledge is more important than ever.

From studying the geological past we know that sea level can dramatically shift up or down, by up to 120 metres. This has shaped the coastlines of the world, as seen in the coastal plains carved by the different sea levels of the past. Evidence of these changes can also be found in coral reefs. For the organisms living then, this was a major challenge to which they had to adapt. Many perished in the process, but many successfully adapted to the change. Today it is not only nature that will have to adapt to these changes but our whole civilization. But we have built our civilization, with the entire infrastructure that supports it, on a given geological configuration that we take as immutable. Climate change confronts us with unavoidable change. For example, we have built mega cities on the existing coastline — cities that now need to adapt to sea-level rise and solve the problem of relocating large populations inland

To do this, understanding and prediction of the physical system will have to be scaled down to focus on local problems. Coming changes are far less known for a particular region than for the globe as a whole, likewise they are less known for the coming few decades than over the next century as a whole. To improve our knowledge of both, which is key for making decisions on adaptation, we must improve our observations of the oceans and the numerical models with which we predict change.

To succeed in generating a global framework, developing specialized institutions that will turn the available and new knowledge into useful information for decisions is critical. The impacts on ecosystems, and the key role that human and social vulnerability plays in designing the right adaptation strategies, need to be better understood.

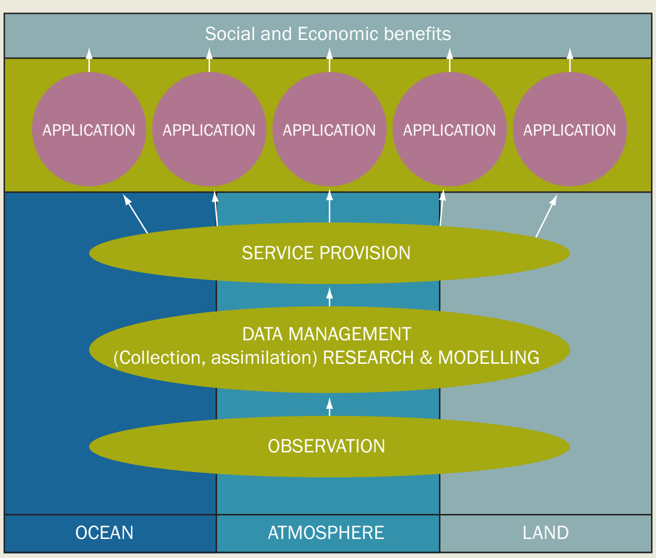
The overriding ethical concerns associated with climate change need to inform the decisions, not only of the international community, but also the critical decisions affecting citizens at the national, regional and local level. Local communities need to be empowered to participate in this dialogue. This is not only a challenge to the hardcore physical and natural sciences, but also to the social and human sciences. For this reason, UNESCO and its IOC are fully committed to the goals of the WCC-3, and ready to contribute to the development of the tools and institutions that will help us to overcome this civilization challenge.

The Global Climate Observing System as the observational foundation for climate services

John W. Zillman, Chairman, Global Climate Observing System Steering Committee

For more than 100 years, international cooperation in the collection of meteorological observations has enabled National Meteorological Services (NMSs) around the world to keep their local communities informed on the changing patterns of weather and climate. Increasingly integrated observation of the atmospheric, oceanic, and terrestrial domains of the global climate system since the establishment of the World Climate Programme (WCP) in the wake of the First World Climate Conference in 1979 has underpinned the past 30 years of remarkable progress towards the understanding, modelling and prediction of climate on global, regional and national scales. The Global Climate Observing System (GCOS), which was established — following the Second World Climate Conference (WCC-2) in 1990 — by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU), will provide the essential observational foundation for the new world climate services system that is expected to emerge from World Climate Conference-3.

An integrated climate observation and service system



The end-to-end operation of an integrated climate observation, research and service system, which delivers social and economic benefits by informing decision making in a range of climate sensitive application sectors

The basic concept of operation for an NMS providing weather and climate services at the national level has been well understood for a long time.[1] In addition the end-to-end service provision architecture from observations through data collection, processing, modelling, prediction and service delivery and application was well reflected at the international level in the 1960s and 1970s by the WMO World Weather Watch.[2]

The same overall end-to-end architecture of the traditional NMS and the World Weather Watch is equally valid for the provision of the much wider range of climate services now becoming both possible, as a result of integrated observation and modelling of the climate system, and necessary, as a result of the increasing worldwide focus on climate risk management and adaptation to climate change.

The WCP was established in 1979 with four components:

- World Climate Data Programme (WCDP)
- World Climate Applications Programme (WCAP)
- World Climate Research Programme (WCRP)
- World Climate Impacts Programme (WCIP).[3]

The first two of these were strongly service and applications focused, with the third aimed at providing the scientific basis for climate prediction in support of, among other things, the eventual introduction of climate prediction services at the national level in WMO Member countries. By the time of the WCC-2 in 1990, however, it had become clear that the observational foundation to support the WCRP, and especially the increasingly wide range of climate information, monitoring and prediction services, was severely inadequate and deteriorating and that there was an urgent need for a greatly strengthened global climate observing system.

In the light of the conclusions of the WCC-2, WMO and three of its WCP cosponsoring partners

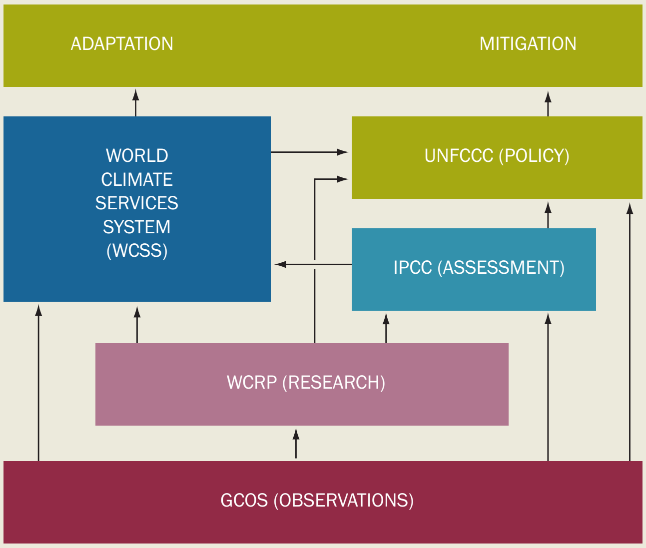
(UNEP, IOC and ICSU) took the initiative to establish GCOS as a 'system of systems' built on their existing global observing networks. Especially important components were the WMO Global Observing System (GOS) and Global Atmosphere Watch (GAW), and the emerging Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS). The aim was to underpin the increasingly important climate monitoring and service needs of countries. This was reflected in the renaming of the WCDP as the World Climate Data and Monitoring Programme (WCDMP), and the WCAP as the World Climate Applications and Services Programme (WCASP).

The objectives of GCOS were identified as providing the observational information needed for:

- Climate system monitoring
- Climate change detection and attribution
- Research to improve understanding, modelling and prediction of the climate system
- Operational climate prediction on seasonal to interannual timescales
- Assessment of the impact of, and vulnerability and adaptation to, natural climate variability and human induced climate change
- Applications and services for sustainable economic development
- Requirements of the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC) and other international conventions and agreements.

It was not intended that, even as an integrated system of systems, GCOS should meet these end-user needs itself. Rather, GCOS was designed to support the various components of the World Climate Programme and related international programmes which would serve its end-user objectives.

A new Global Framework for Climate Services (GFCS)



The Global Climate Observing System (GCOS), providing the observational foundation for the World Climate Research Programme (WCRP) and development of a user focused world climate services system as part of a new Global Framework for Climate Services, which will complement the climate change assessment role of the IPCC and the policy role of the UNFCCC

The planning and implementation of GCOS over the 19 years since WCC-2 has been guided by a GCOS Steering Committee (originally entitled Joint Scientific and Technical Committee) supported by a small WMO-based Secretariat. The role of the Steering Committee has been to advise GCOS sponsors, and those responsible for their observing systems, on how to ensure those systems most effectively meet the total global needs for climate and climate related observations.

The foundation for GCOS from the beginning has been the GOS of the World Weather Watch, maintained by the NMSs of the now 188 WMO Member countries, along with the much more comprehensive networks operated by NMSs for national weather forecasting and climate purposes. This has been strongly reinforced by the completion, in recent years, of one of the most important components of GOOS, the network of Argo floats. These provide temperature and salinity profiles of the upper 1,500 metres of the ocean, the key layer for coupled atmosphere-ocean modelling on seasonal to interannual timescales.

During the late 1990s, GCOS implementation shifted from its initial emphasis on support of climate research and services to support of the UNFCCC, with a major 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC' completed in 2004 and a recent progress report revealing significant progress over the past five years.[4]

Another important development of the past decade was the establishment of the Global Earth Observation System of Systems (GEOSS) as an even broader system of systems serving nine identified Societal Benefits Areas (SBAs) with the objectives of the climate SBA essentially identical with those of GCOS.[5] With the establishment of GEOSS, and the recent shift in emphasis under the UNFCCC to adaptation to climate variability and change, the focus of GCOS is again returning to support for climate services in aid of the full range of applications at the national level.

This shift is particularly timely in the context of World Climate Conference-3, with its focus on climate information and prediction for decision-making, and the proposed new Global Framework for Climate Services. It is clear that any such framework must include, in addition to effective operational service provision systems and user applications (essentially a user oriented world climate services system), the fundamentally important underpinning role of observations through GCOS and research through WCRP. Such an observation and research-based world climate services system, when implemented, will parallel and complement the role of the WMO-UNEP IPCC and UNFCCC, in supporting the mitigation end of the adaptation-mitigation spectrum of actions for addressing the challenges of climate variability and change.

GEOSS: the backbone of decision making on climate

José Achache, Director, Secretariat of the Group on Earth Observations

Since 2005, the Group on Earth Observations (GEO) has enabled 130 governments and international organizations to collaborate on linking together their space, aerial, ocean and land-based systems for environmental observation, prediction and information. The resulting Global Earth Observation System of Systems (GEOSS) provides decision-support capabilities and end-to-end services that support science-based decision making on major global challenges such as climate change and climate variability.

When Governments adopted the 'GEOSS 10-Year Implementation Plan' for 2005 through 2015, they agreed that GEOSS should contribute to international efforts to understand, assess, predict, mitigate, and adapt to climate variability and change. The need for GEOSS to provide better information on climate was reiterated by the leaders of the G8 when they met in Hokkaido, Japan in July 2008. "To respond to the growing demand for Earth observation data," they declared, "we will accelerate efforts within the GEOSS, which builds on the work of UN specialized agencies and programmes in priority areas, inter alia, climate change and water resources management, by strengthening observation, prediction and data sharing."

A cross-cutting issue par excellence, climate both affects and is affected by changes in the atmosphere, oceans, water cycle and biosphere, as well as land-use patterns, energy use, natural disasters, socioeconomic conditions and many other variables. Because GEOSS addresses eight other major societal benefit areas in addition to climate, it captures and integrates a broad range of observations and analyses that are relevant to all aspects of the climate challenge.

GEO member governments and participating organizations are coordinating the construction of GEOSS through an agreed work plan containing over 100 activities. This article will highlight four important activities that illustrate the different kinds of climate services and monitoring systems that are currently being developed.

End-to-end climate services

The GEO task to provide 'environmental information for decision-making, risk management and adaptation' addresses decision makers' needs by integrating relevant climate and environmental risk management activities. The aim is to coordinate and drive the development of tailored climate products and services, encourage the use of this information by decision makers at all levels, and initiate user-oriented activities to increase the demand and foster the supply of climate and environmental services. This development also provides an illustration of how governments and organizations are implementing GEOSS as a collaborative effort through the coordination framework provided by GEO.

The Australian Bureau of Meteorology, the World Meteorological Organization (WMO), the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme are leading an effort to enhance climate, weather, water and environmental prediction and to deliver new and improved services. Key activities relate to: seamless weather, climate and Earth system prediction; multi-scale organization of tropical convection and interaction with the global circulation; data assimilation for coupled models as a prediction and validation tool for weather and climate research; and information to assess the risks and benefits of climate and weather predictions for society and the global economy.

Complementing this effort, WCRP and the Global Climate Observing System (GCOS) are coordinating the work of organizations and agencies committed to strengthening climate information for decision making, risk management and adaptation. In particular, they are promoting the funding and implementation of the Climate for Development in Africa Programme. This programme aims to improve the availability, exchange and use of climate information and services at national, local and regional levels in support of economic growth and the Millennium Development Goals. African partners include the African Union, the UN Economic Commission for Africa, the African Development Bank, and African National Meteorological and Hydrological Services.

Similarly, GCOS, WCRP and other GEO member governments and participating organizations are supporting the programme 'Climate Observations and Regional Modeling in Support of Climate Risk Management and Sustainable Development', which seeks to assist the developing and least-developed countries of Eastern Africa to undertake and use climate projections in adaptation planning.

Global carbon monitoring

Another partnership is implementing a set of activities aimed at establishing a global carbon monitoring system as part of GEOSS. This system will include a forest carbon monitoring service that is being coordinated by the governments of Australia, Japan and Norway, plus the Committee on Earth Observation Satellites (CEOS), the Food and Agriculture Organization and the Global

The Global Earth Observation System of Systems

The Global Earth Observation System of Systems provides decision-support capabilities and end-to-end services that support science-based decision making on major global challenges

Terrestrial Observing System's Global Observation of Forest and Land Cover Dynamics.

This programme is building a rigorous forest carbon monitoring, reporting and verification capacity by integrating data from various optical and radar Earth observation satellites. It uses agreed methodologies and models for estimating carbon content. The methodology is validated by in situ observations of the carbon content of forests and soils.

Combining data from different radar frequencies makes it possible to map the forest canopy and thus the biomass and carbon it contains. This sophisticated radar imagery can then be overlaid with optical imagery to provide the most complete remote representation of the forest possible.

The tools developed for this project could be mixed and matched to suit the particulars of any given forest while enabling forest managers and investors to demonstrate or confirm the accuracy and comparability of the carbon measurements. This service has the potential to support the emerging carbon markets while contributing to efforts to track whether particular forests are net carbon emitters or net carbon sinks.

Meanwhile, the Japan Aerospace Exploration Agency, the US National Aeronautics and Space Agency, the European Space Agency and others are fostering the use of space-based greenhouse gas (GHG) observations. They are consolidating data requirements for the next generation of GHG monitoring satellite missions and establishing an international group in close cooperation with the CEOS Atmospheric Composition virtual constellation and the GEO Community of Practice (an informal grouping of organizations sharing an interest in a particular societal issue) on the carbon cycle. They are initially focusing on the end-to-end use of space-based GHG data, particularly those of Japan's Greenhouse Gases Observing Satellite, which was launched in early 2009. These efforts are being coordinated with ground-based systems for validation and they will build, as appropriate, upon existing observations and products from satellites, aircraft, and surface-based instruments.

Strengthening observing systems

The GEO membership is working to maintain and expand the terrestrial, oceanic and atmospheric observing systems, both in-situ and space-based, underpinning scientific efforts to understand the climate. These systems are also central to the construction of GEOSS and to advances in other societal benefit areas.

The Global Terrestrial Observing System (GTOS) and others are developing the intergovernmental mechanisms for coordinating the terrestrial observations needed for climate studies and forecasting. In addition, GTOS is supporting the preparation of guidance materials, standards and reporting guidelines for terrestrial observing systems. It is also promoting work on the associated data, metadata and products that are needed to expand the comprehensiveness of current networks and to facilitate the exchange of data.

The Global Ocean Observing System, the Partnership for Observation of the Global Oceans and the Institute of Electrical and Electronic Engineers, supported by another GEO Community of Practice (on coastal zones), are enhancing the coordination of coastal and open-ocean observations and modelling initiatives. Related activities include: improving the global coverage and data accuracy of coastal and open-ocean observing systems, as well as the management

Source: www.geoportal.org

Source: www.geoportal.org

The GEOportal provides an entry point to access remote sensing, geospatial static and in situ data, information and services

and archiving of the resulting data and information; contributing to the implementation of global coastal and open-ocean observing networks by sustaining and extending the global array of Argo ocean monitoring buoys; and developing a globally coordinated information and data system for monitoring the deep ocean and the dynamics of ocean processes throughout the ocean water column.

The WMO is leading efforts to build a complete and stable Global Observing System. The surface-based component is to include in situ, airborne, land and possibly ocean measurements; high priority will be given to ensuring a stable and, as far as possible, automated World Weather Watch Upper Air Network and to further developing the Aircraft Meteorological Data Relay programme. The space-based module is to include operational geostationary and polar components.

Finally, WCRP and yet another GEO Community of Practice (addressing the cryosphere) are collaborating on ensuring that the Legacy of the International Polar Year (IPY) 2007-08 enhances the use of Earth observations in all appropriate realms including, but not limited to, sea and land ice, permafrost, coastal erosion, physical and chemical polar ocean changes, marine and terrestrial ecosystem change, biodiversity monitoring and impacts of increased resource exploitation and marine transport. The long-term goals are to ensure an appropriate legacy for IPY projects and to advocate the continuation of relevant efforts beyond the duration of the IPY.

A climate record for assessing variability and change

A fourth major effort is the GEO community's work on extending and improving the quality of past climate records through advanced data reanalysis and reconstruction of the atmosphere, ocean, land and sea ice domains. The aim is to generate high-quality, temporally homogeneous estimates of the past climate to support current analyses of climate variability and change.

The activities under this effort include: reprocessing and reanalysing climate data to ensure consistency in historical records; extending the record of climate variability at the global scale in order to ensure a global coverage of high-resolution, well-dated reconstructions of past climate parameters in the ocean and on land; and securing key climate data from satellite systems. These activities are led by many of the GEO member governments and participating organizations already mentioned.

A framework for collaboration

These four examples, all related to the field of climate, are excellent illustrations of how governments and organizations are working together through GEO on a voluntary and best-efforts basis to construct GEOSS for the benefit of scientists, managers, decision makers and, ultimately, the global general public. By building on existing programmes, initiating new investments to fill gaps, and emphasizing synergies and partnerships, this collective endeavour demonstrates the old adage about how the whole can be greater than the sum of the parts.

To continually improve GEOSS, GEO is assessing user needs, developing technical standards to make data interoperable, improving information dissemination, and identifying gaps in current observing and information systems. GEO consistently pursues new opportunities for generating integrated data sets, information products and analyses in near real-time, as well as combining data from a wide variety of fields and sources and presenting them in user-friendly formats.

It is no accident that the construction of GEOSS has been initiated at this time. Until now, a critical mass of instruments, technologies, databases, models and decision-support services had not been realized. Similarly, the sense that 'we are all in this together', and that nations must collaborate on addressing our shared global problems, has only emerged in recent years. Both the supply side and the demand side of Earth observations have recently started to mature.

This non-binding and cooperative approach advocated by GEO may not be easy to understand at first, but it is the right model for global collaboration in the 21st century. GEO gets the incentive structure right by ensuring that contributors to GEOSS continue to manage and receive credit for their contributed components. At the same time, by collaborating with others, these contributors leverage their own investments in Earth observations through better access to information, analyses and other collective resources. The end result is a stronger capacity for effective economic and societal decision making on an increasingly complex and interconnected planet.

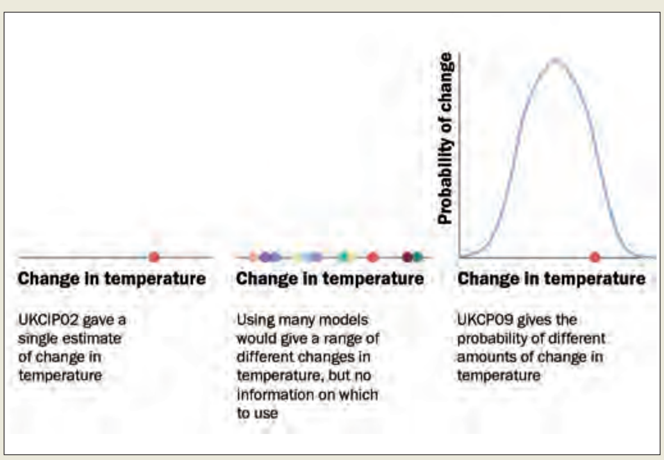
The UK Climate Projections — Met Office science and headline results

Vicky Pope, James Murphy, David Sexton, Geoff Jenkins, Daniel Williams, Julia Slingo, Met Office, United Kingdom

Our climate is changing faster than it has done for hundreds of thousands of years, driven by the greenhouse gases produced from human activities. Some changes have already occurred and, because of the greenhouse gases already in the atmosphere, we are guaranteed further changes in the coming years and decades. This will have significant effects on the UK — posing many potential threats and opportunities. It is essential to understand these issues so that we can start adapting now for the changes ahead.

The UK Climate Projections 2009 (UKCP09) — commissioned by the UK Department of Environment, Food and Rural Affairs — are a major step forward in addressing this need. UKCP09 involved the Met Office Hadley Centre producing an ambitious and comprehensive analysis of regional climate change. The projections provide probabilistic information on how the UK's climate will change in the 21st century based on state of the art climate models, observations and statistical analysis, combined with expert knowledge. The projections are a key part of a programme of measures from the UK Government to both encourage and support action to prepare for the impacts of our changing climate. The UK Climate Impacts Programme (UKCIP) provides the first point of contact to help stakeholders use UKCP09. The projections are designed to inform planners and decision makers about the risks associated with different levels of climate change in their efforts to tackle future challenges.

A schematic diagram showing the progression from UKCIP02 to UKCP09, using temperature as an example



Source: Met Office UK

How the projections were made

Scenarios of UK climate change were published in 1991, 1996, 1998 and 2002. These projections have formed the basis for many climate adaptation schemes already in progress. UKCP09 provides a step change in the information available, by using the latest science and advanced computing power to produce the most comprehensive information to date.

The projections have been generated using the Met Office Hadley Centre climate model — recognized as one of the best in the world. This has been updated to take into account improved understanding of the climate system — such as recognition of how changes in the carbon cycle can exacerbate climate change.

There are still inherent uncertainties in climate modelling, however. These focus around an incomplete understanding of the complex processes of the atmosphere ocean and land surface combined with natural varaibility. There is also uncertainty as to how manmade greenhouse gas emissions will change over the projection period.

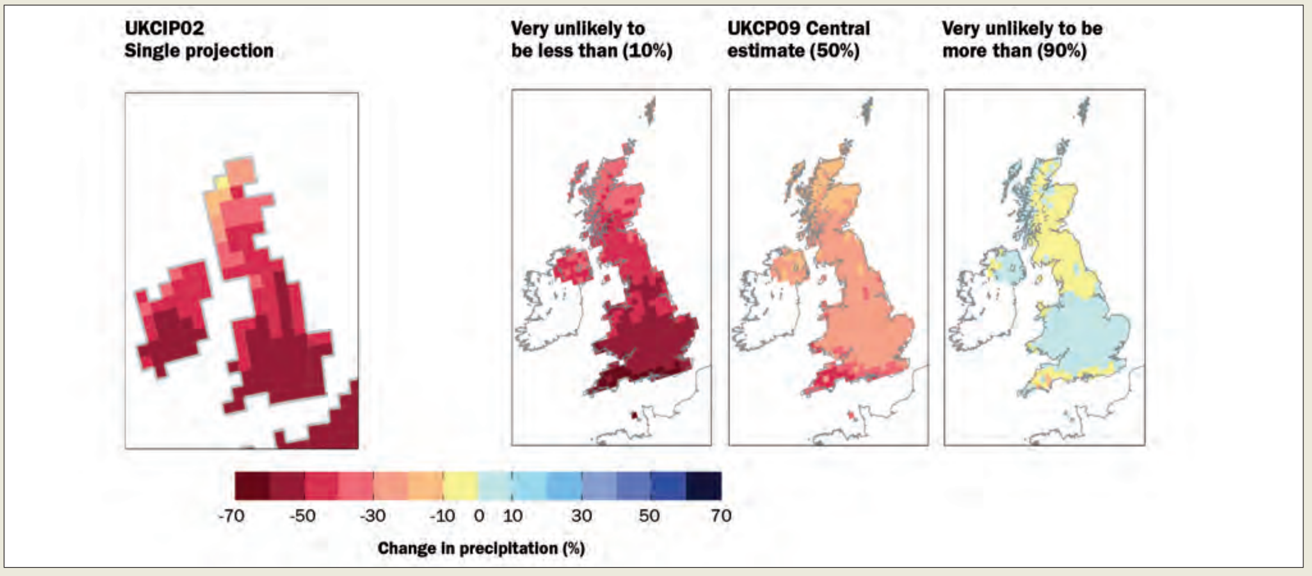
UKCP09 tackles these uncertainties by using a range of projections generated by running its model hundreds of times using a range of different values for key parameters. This means many nuances in the understanding of atmospheric science are taken into account. To ensure an even wider spread of the possibilities is considered, 12 of the world's other leading models have also been used to create projections. For the more local projections (at 25 kilometres resolution), more detailed climate models were run to include local factors that are known to affect regional climate, such as mountains and coastline.

The Met Office uses climate science, observations and expert judgement to attach levels of confidence to each of the projections. The level of probability given can be seen as the relative degree to which each climate outcome is supported by current evidence.

The probabilistic approach, used at a regional level for the first time, allows UKCP09 users to get a clear picture of the likelihood attached to each projection. This enables an informed approach to risk — a highly important assessment when making vital decisions on levels of adaptation.

The benefits of this approach are illustrated by comparing results from UKCIP02 with those from UKCP09. The UKCIP02 projections for changes in summer average rainfall are shown to be very unlikely in the new UKCP09

Comparison of changes in summer average rainfall by the 2080s under high emissions scenarios, from the UKCIP02 report and as projected in UKCP09

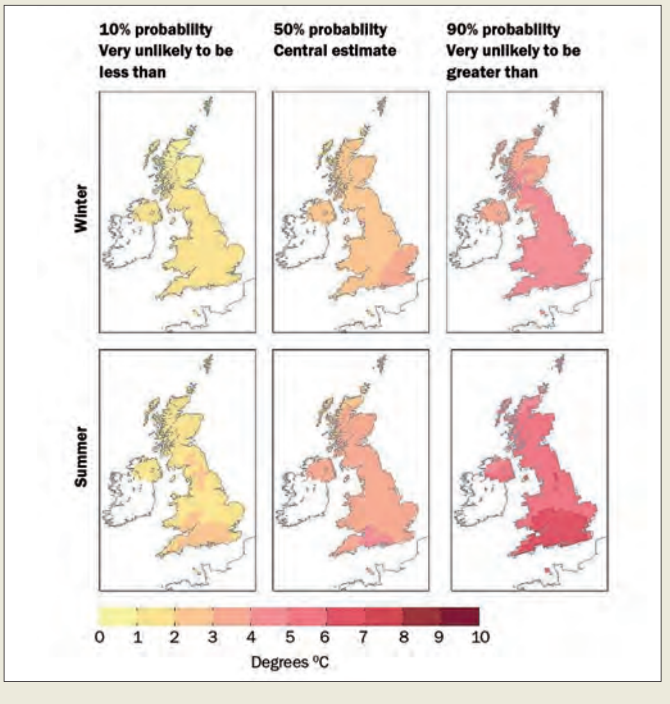


The 50 per cent probability level (where the evidence for being above or below this level is equally strong) gives a useful central estimate. The 10 per cent and 90 per cent probability levels give a useful range of possible outcomes

Source: Met Office UK

projections. UKCIP02 overestimated the reductions in rainfall because its model (HadCM3) has a tendency to dry out compared to other models. The new projections better encompass the true range of our knowledge of the science. In most other fields the UKCIP02 results fall close to the central estimate in the UKCP09 projections.

Maps of winter and summer temperature change for 2080s medium emissions compared with 1961-90



Source: Met Office UK

How the projections are delivered

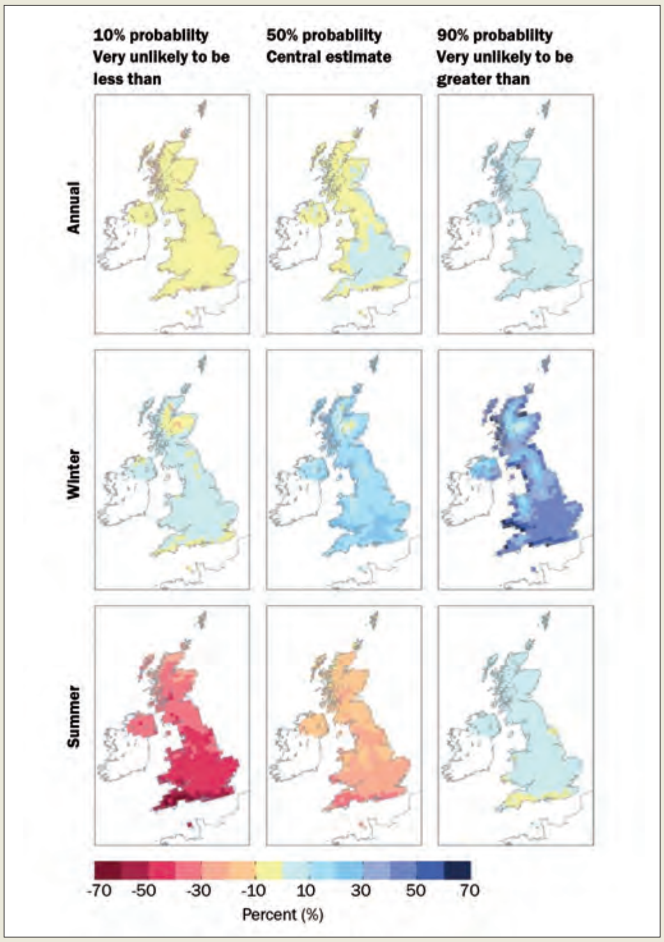
Probabilistic projections are given at a resolution of 25 kilometres, but are also presented as averages over larger land and marine regions. They are delivered over seven overlapping 30-year periods and for three future emissions scenarios. Variables covered include temperature, precipitation, relative humidity, cloud cover, heat radiation and mean sea level pressure. Monthly, seasonal and annual averaged data are also provided.

There is a range of confidence within the climate projections. There is very high confidence in global warming due to manmade greenhouse gas emissions, while only moderate confidence in projections at a continental scale. Information at a resolution of 25 kilometres is based on the continental scale, but includes the influence of local conditions such as mountains and coastline. However, adding regional detail also adds uncertainty. Confidence is also affected by the variable under discussion. For example, no probability information is given for regional or local wind changes.

What the projections tell us

The projections give a measure of the strength of evidence for the UK climate changing in a particular way—a projected level of precipitation or temperature rise, for instance. The probability depends on the weight of scientific evidence behind the projections. It's important to understand these probabilities reflect how sure we are that a change will happen, rather than the 'percentage chance' of it occurring.

Maps of annual average winter and summer rainfall change for the 2080s medium emissions compared with 1961-90



Source: Met Office UK

As a snapshot, the 50 per cent probability level (where the evidence for being above or below this level is equally strong) gives a useful central estimate. Looking at the spread of projections at different probabilities will give a clearer picture, however.

Expected changes in climate

Temperatures will increase across the UK, more in summer than in winter. All areas will see increased winter rainfall and decreased summer rainfall, with little overall change in the annual average (for the central estimate).

If the world economy and population continue to grow, but we move away from fossil fuels to a more balanced energy mix and adopt new energy saving technologies, this would constitute a medium emissions scenario. Under such a scenario the summer average daily maximum temperature rise in the south east of the UK by the 2080s is likely to be above 2°C and below 6.4°C. The central estimate is 4°C. Hence, by the 2080s typical summers will be around 2°C warmer than the warmest summers in the recent past (2003 and 2006).

The impacts on the warmest day of summer could be even more dramatic. Although the central estimate of increases in the warmest day is only 3°C the range is bigger than for average temperature. So there is a 10 per cent chance that increases could be as much as 10°C in some parts of the UK. As such, the hottest day of summer could be 33°C, compared with 30°C today. In a high emissions scenario, it is possible that temperatures in London could reach a peak of 41°C. The highest temperature recorded in the UK was 38.5 °C on 10 August 2003 in Faversham, Kent.

If we look only 40 years ahead to the 2050s we can still expect dramatic changes in climate, regardless of what we do to decrease emissions in the interim. We are locked in a climate trajectory for the next 30 years that reflects our historic emissions. So under all scenarios, average summer daily maximum temperatures will rise by around 2-3°C to 23.5-24.5°C, making a typical summer as hot as the current warmest years on record. The 2003 and 2006 summer daily maximum temperatures were 23°C and even the record-breaking summer of 1976 only reached an average of 24.1°C.

With the same scenario for the 2080s, average summer rainfall for the south east is unlikely to decrease by more than 47 per cent, or increase by more than 7 per cent. The central estimate is for a decrease of 22 per cent. In contrast, during the winter, rainfall could increase significantly. In the north west, for example, it is very unlikely to increase by more than 35 per cent or by less than 3 per cent. The central estimate is for rainfall to increase by 16 per cent. It is, however, worth bearing in mind that there are large natural variations in rainfall. As summer rainfall decreases, on average we will see more dry records broken and fewer wet ones, but variations will still be large.

Regional differences are predicted as small, except in summer. Rainfall decreases more in the south and west than in the north and east. For example the central estimate of summer rainfall ranges from decreases of 10-20 per cent in Scotland to 30-40 per cent in Devon and Cornwall.

Rainfall changes in the 2050s is likely to be a bit smaller with summer rainfall in the south east falling by 18 per cent and winter rainfall in the north west increasing by 13 per cent, or from 349 to 396 millimetres (where all these figures are central estimates). Similarly the wettest day of the winter will be wetter — on average increasing from 26 millimetres today to 29 millimetres in 2050.

Adding value to the UK Climate Projections

UKCP09 represents a wealth of information that can add real value to decisions on adaptation. However, the projections are complex and need to be carefully interpreted, making full use of online documentation — such as the user guidance available on the UKCP09 website. Additional guidance can be provided by Defra funded work at UKCIP.[1] In addition, the Met Office can add value to UKCP09 by generating information and solutions tailored to the exact needs of users. This includes adding more detail to projections by focusing on specific locations, variables or scenarios, updating projections with the very latest science or taking user-specific situations into account. For example Extreme Value Analysis can be applied to UKCP09 to assess how the severity and frequency of extreme weather may change in the future. This information can be used when planning future infrastructure — for example ensuring adequate drainage on roads or future proofing public buildings to withstand increased hot spells.

Bioclimatic modelling: linking biodiversity and climate science

Dr Ahmed Djoghlaf, Executive Secretary; Jaime Webbe, Programme Officer; Annie Cung, Programme Assistant, Convention on Biological Diversity

Biodiversity is the term given to the variety of life on Earth – plants, animals and microrganisms. Biodiversity also includes genetic differences within each species and the variety of ecosystems such as deserts, forests, wetlands, mountains and agricultural landscapes. In each ecosystem living creatures, including humans, form a community, interacting with one another and with the air, water and soil around them. We depend on biodiversity to live. Indeed, ecosystem services provide us with food, clean air, drinking water, raw materials, medicines and many other benefits.

Many human activities threaten biodiversity. According to the Millennium Ecosystem Assessment, the main drivers of biodiversity loss include habitat change, climate change, invasive alien species, overexploitation and pollution.[1] Moreover, these drivers are either steady, show no evidence of declining over time, or are increasing in intensity. Therefore, changes in biodiversity are projected to continue, or accelerate.

Observed changes in climate have already had significant impacts on biodiversity and ecosystems, including changes in species distributions, population sizes and timing of reproduction or migration events.

Image: Mathieu Rossier

Ho Chi Minh City, Vietnam. Changes in the climate impact biodiversity and thereby affect the ability of ecosystems to deliver goods and services for human well-being

Observed impacts include coral bleaching, wetland salinization, expansion of arid and semi-arid lands at the expense of grasslands and acacia, poleward and upward shifts in habitats, replacement of tropical forests with savanna in the Amazon Basin and Mexico, and shifting desert dunes — particularly in Northern and Southern Africa.

By the end of the 21st century, climate change and its impacts could become the dominant direct driver of biodiversity loss. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC),[2] approximately 20 to 30 per cent of plant and animal species assessed so far are likely to be at a higher risk of extinction if increases in global average temperature exceed 2ºC to 3ºC above pre-industrial levels.[3] For example, a 51 to 65 per cent loss in the area of the Fynbos biome of South Africa is projected by 2050.[4]

To assess the impacts that the predicted changes in climate will have, scientists turn to a variety of modelling approaches. Due to the complexity of natural systems, predictive modelling is limited. Moreover, different modelling approaches have a varying degree of accuracy and yield a range of conclusions. The types of models used in a study can have important effects on the predicted impacts on biodiversity. However, such models can provide a good first approximation of the potential impacts of climate change. Nevertheless, model results should not be interpreted without due consideration of their limitations.

Bioclimatic models: linking science and policy

Attributing changes in biodiversity to climate change is complex because a number of non-climatic influences also affect it. However, recent studies analysing more than 1,700 species show that recent biodiversity trends match climate change predictions, including range shifts towards the poles and advancement of spring events.[5]

Modelling strategies for predicting the potential impacts of climate change on biodiversity often focus on the identification of a species' bioclimatic envelope. This can be determined by correlating current species distributions with climate variables, or through an understanding of species' physiological responses to climate changes. After having identified a species' bioclimatic envelope, scenarios of future climate change can be applied to assess the envelope redistribution.[6] A recent analysis using bird species' observed range shifts and climate change scenarios provided validation of such models, and also demonstrated that uncertainty can be reduced by selecting the most consensual projections. This method can provide good range projections of species for the purposes of conservation planning and biodiversity management.[7]

Due to the complexity of natural systems, predictive errors are inevitable. However, for certain species and at certain scales, the bioclimatic envelope approach can provide a first approximation of the potential impact of climate change on species distributions. Nevertheless, bioclimatic models should only be applied and interpreted with a thorough understanding of the limitations involved. In particular, it should be noted that these models assume no barriers to movement which, in the case of highly fragmented ecosystems, may deliver a significant underestimation of the scale and scope of climate change impacts.

Change in biome[8] area simulated by coupled Global Circulation Models and Global Vegetation Models may be used to estimate changes in species richness, if the assumption is made that the biome's climatic definition is to be used as a proxy for the climatic envelope of multiple resident species.[9] These types of models may not be well suited to estimate changes in biodiversity, since they usually assume that ecosystems or biomes simply shift location while maintaining their current composition and structure.[10]

Policies related to the conservation of biodiversity and climate change need to be informed by the best possible recent scientific findings. However, these findings depend on the accuracy of modelling techniques and confidence in projections of future climate change and its impacts. Policy formulation and decision making is therefore often based on a certain degree of scientific uncertainty. It is important that policy makers are well informed of this uncertainty.

For IPCC experts, assessing the extent to which recent observed changes in biodiversity were caused by climate change was a very difficult task. These difficulties were partly due to the differences in approach between biologists and other disciplines, and in perspectives of what constitutes an important factor of change. Moreover, field biologists often have a difficult time convincing policy-makers of the climate change impacts they observe in the field.[11] The IPCC, in its fourth assessment report, concluded with 'very high confidence'[12] that climate change is already affecting living systems.

The Ad Hoc Technical Expert Group (AHTEG) on biodiversity and climate change was convened in response to a decision from the Conference of the Parties to the Convention on Biological Diversity (CBD). AHTEG was established to provide biodiversity related information to the United Nations Framework Convention on Climate Change (UNFCCC) through the provision of scientific and technical advice on the integration of the conservation and sustainable use of biodiversity into climate change mitigation and adaptation activities. One of the tasks of the group was to identify relevant tools and methodologies for assessing the impacts on, and vulnerabilities of, biodiversity as a result of climate change. Results from AHTEG revealed that key uncertainties limit our ability to project climate change impacts on ecosystems, but that despite their limitations, bioclimatic models provide a useful first assessment of the vulnerability of biodiversity.

Identifying climate data needs within the biodiversity community

There are a number of research needs and gaps with regards to assessing the impacts of climate change on biodiversity. Some of these have been filled, but many remain. For example, there is still a lack of extensive, readily available quantitative information on many species globally.[13] A review of relevant literature conducted in 2006 revealed a continuing terrestrial bias and identified additional gaps with regards to geographic distribution.[14] In particular,

Image: Toan Cung

Mendenhall Glacier: the melting of glaciers is accelerating rapidly in Alaska. Animals that dwell on or near glaciers may be affected by the disappearance of their habitats

Image: Camellia Ibrahim

Kea, an alpine parrot endemic to New Zealand's alpine areas. The Kea is considered an endangered species. Potential threats for this species include the effects of climate change on alpine areas

Image: Sonia Gautreau

Red-eyed Tree Frog, *Agalychnis callidryas*, Gandoca Costa Rica. Since frogs rely on water to breed, any reduction or change in rainfall could reduce frog reproduction. Moreover, rising temperatures are closely linked to outbreaks of a fungal disease that contributes to the decline of amphibian populations, especially frogs in Latin America

the review revealed that, of the 866 peer-reviewed papers considered, most impact studies were based in North America, northern Europe and Russia. There were very few studies on impacts in South America, and even fewer from Africa (mostly South Africa) and Asia (mostly Japan).

Other uncertainties with regards to the impacts of climate change on biodiversity can be drawn from the impacts of interactions between climate change and other drivers of global environmental change in ecosystems. Indeed, models often separate the impacts of climate change from other human activities. For example, human land and water use patterns are available for many parts of the world, but are not widely integrated into the typical models used for looking at biodiversity impacts.[15]

Moreover, ecosystems are complex, and therefore responses to climate change are rarely linear. Changes may take place in the form of sudden shifts, whose timing and location are difficult to predict. Such responses may include thresholds beyond which adaptation may be impossible.[16] This uncertainty is exacerbated by the fact that downscaling of climate data is particularly poor for precipitation and extreme events.

However, despite uncertainties, conserving biodiversity can be an important safeguard. Diverse ecosystems may to some extent buffer against moderate changes in climate. In particular, the diversity of species and interactions amongst them, as well as landscape-scale habitat heterogeneity, may provide a range of natural adaptive capacity in the face of a certain level of change.[17]

Partnerships and alliances

To improve information sharing and collaboration between the climate and biodiversity communities, strategic partnerships and alliances are crucial. A great amount of knowledge in both fields currently exists, but there is often little communication and sharing of data and information. Furthermore, while current projections of climate change impacts are based on both observational data and modelling, there is a need to ensure further collaboration between scientists generating each type of data. Climate change is a multifaceted issue and therefore addressing it requires a multidisciplinary and multilevel approach.

Convention on Biological Diversity (CBD) contributes to relevant processes under the World Meteorological Organization (WMO) and benefits enormously from the contribution of WMO to the development of scientific information on climate and climate change. With regards to World Climate Conference-3, this collaboration will allow the climate community to provide more user-oriented information and predictions, and will in turn improve access and use by CBD of climate information and prediction.

In addition, the secretariats of the CBD and UNFCCC collaborate on a number of issues ranging from the provision of inputs and views, to participation in respective processes, to ensure that activities are mutually supportive. The work by the secretariats is also supported by a number of official processes such as AHTEG, convened under the CBD. In fact this AHTEG has issued an action pledge under the Nairobi work programme on impacts, vulnerability and adaptation to climate change on improving bioclimatic modelling.

When running models, the availability of data is often a limiting factor. The Global Biodiversity Information Facility (GBIF) and the CBD secretariat signed a Memorandum of Cooperation in July 2003. The goals of this agreement include facilitating the development and implementation of technologies and best practices that will be necessary to access, share and disseminate biodiversity data via the Internet. On the issue of climate change, GBIF is contributing to the construction of the Global Earth Observation System of Systems (GEOSS) in order to link biodiversity data with climate data. GEOSS links together existing and planned observing systems around the world, combining the thousands of different instruments into coherent data sets.[18]

Conclusion

Despite their limitations, bioclimatic models allow a useful and often accurate first assessment of changes in biodiversity, especially when informed by observational data. Policies must be formulated taking into account the likely impacts from a range of climate change scenarios and projections.

Although uncertainty in models is unavoidable given the complexity of climate-biodiversity interactions and the impacts of other drivers of change, this uncertainty should not become a reason for inaction. Perhaps biodiversity and climate change policy should best be considered as risk avoidance and minimization in order to balance the probability of certain events with the costs of addressing them.

As both the climate and the natural environment are highly complex systems, the exact replication of their functioning will never be achieved, despite advances in modelling techniques. Therefore, one must make the best use possible of existing knowledge and techniques, which is made possible through effective collaboration and partnerships.

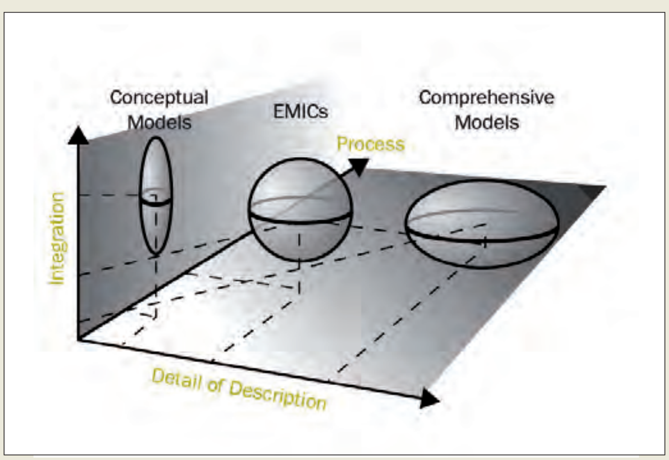
Modelling in earth system science

Michio Kawamiya and Tatsushi Tokioka, Research Institute for Global Change, Japan Agency for Marine-earth Science and Technology

Changes in the natural environment due to human activities are becoming visible. While one of the most evident examples is global warming, the problem goes well beyond the single issue and includes ocean acidification, perturbations of the global nitrogen cycle due to industrial fixation and others. These issues are mutually related, and none of them can be solved without interdisciplinary collaboration among scientific fields such as meteorology, oceanography, geochemistry, biology and even social sciences. Recognizing the situation, scientists have been arguing the necessity of an 'earth system science' (ESS), where the global environment is recognized as a system composed of its interacting subsystems: atmosphere, ocean, biosphere, cryosphere and society.

Among early advocates of the concept of ESS were the Russian scientist V. Vernadskii, who established the biosphere concept in the 1920s, and J. Lovelock and L. Margulis, the founders of the Gaia hypothesis, who provoked a lot of dispute in the 1970s by claiming that the biosphere plays an active role in maintaining the global environment. Based on these preceding ideas, a report by NASA Advisory Council in 1988 first used the term 'earth system science' explicitly and provided a clear definition of ESS as used today. It sets the goal of ESS as: 'to obtain a scientific understanding of the entire earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all timescales'. The Advisory Council also points out that accomplishing this goal would require various research schemes such as numerical modelling, global observing systems and information networks that enable efficient dissemination of observed data and research outputs. The predictive statement was surprisingly accurate taking into consideration that, around that time, internet usage was limited to certain advanced institutes and there were very few attempts to incorporate biogeochemical processes into general circulation models.

Categorization of earth system models



Model types categorized according to the degree of complexity and integration. Models in the category 'conceptual models' have the lowest level of complexity

Source: Claussen et al. (2002), Clim. Dyn. 18, 579-586

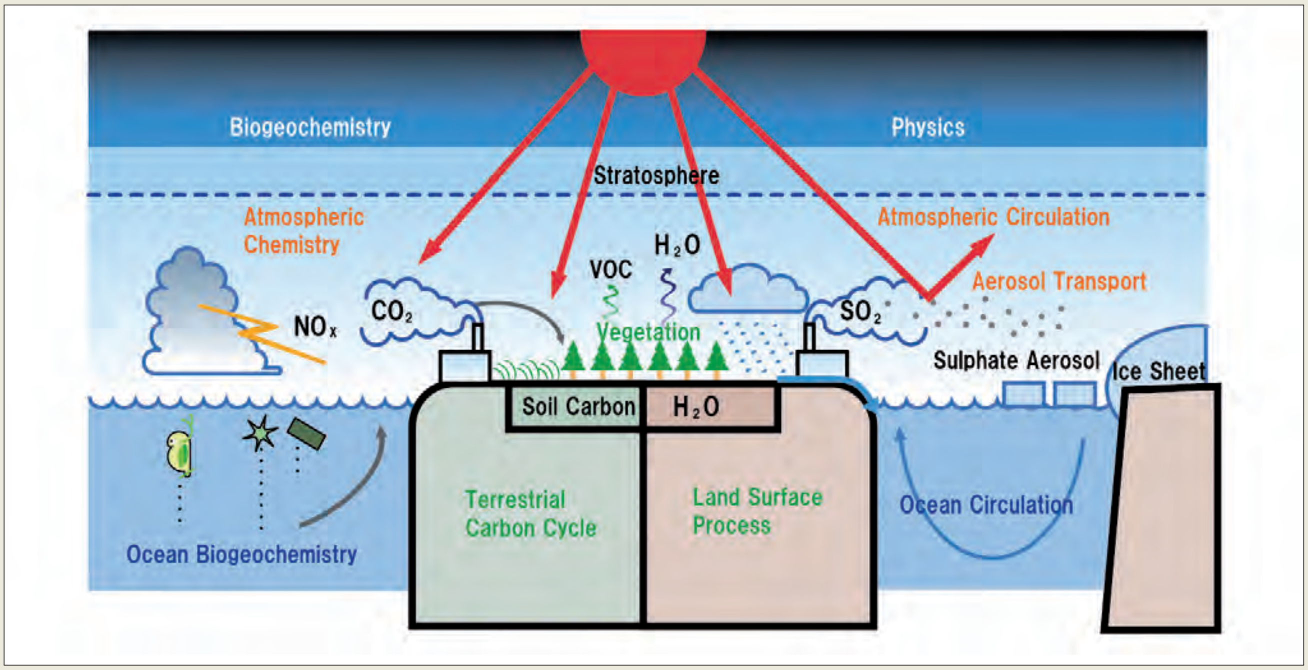
Models used in ESS, and conceptual models

As the NASA report emphasized, modelling can be a powerful tool for investigating the dynamics of the earth system. Models that have been developed and applied for this purpose can be categorized according to the degree of complexity and integration. Models in the category 'conceptual models' with the lowest level of complexity consist of several simple equations mimicking certain aspects of the complicated behaviours of the earth system. The simplest example is the model for calculating the radiative equilibrium temperature of the earth, which a meteorology student will find in the first chapter of their textbook. During the late 1960s and the 1970s, authors including M. I. Budyko and W. Sellers proposed models of this category for discussing multiple equilibriums inherently possessed by the earth system due to interactions between the cryosphere and atmosphere. These conceptual models can often be analytically manipulated yet remain instructive, allowing us to grasp the mechanism of interactions and feedback operating in the earth system. The degree of abstraction is, however, extremely high for this type of model and the correspondence between their equations and processes in nature is not readily conceivable, which leads to a fundamental difficulty in estimating model parameter values. Models of this category are, therefore, mainly applied as educational tools or as supporting material to construct a theoretical framework, and rarely used for a projective purpose.

Earth system models with intermediate complexity

At the other extreme, atmospheric and oceanic general circulation models (GCMs) have been applied to projections of El Niño-Southern Oscillation events and global warming. GCM-based earth system models have the drawback that they are computationally expensive.

Components in MIROC-ESM, a GCM-based earth system model



Increasingly elaborate earth system models are being developed for global warming projection by coupling biogeochemical modules with general circulation models

Source: JAMSTEC

In order to fill the gap between conceptual models and GCMs, earth system models with intermediate complexity (EMICs) are now being vigorously developed. EMICs greatly simplify equations of motion for the atmosphere and ocean and radiation processes, retaining the minimal ability to reproduce realistic properties such as geographical temperature distribution and deep water formation. EMICs require fewer computer resources, and can be integrated without supercomputers.

Using the advantage of computational efficiency, EMICs have often been applied to paleoclimate studies, in which model integration of tens of thousands of years is common. Embedding vegetation dynamics and carbon cycle processes in EMICs is an active field. Indeed, four EMICs with the carbon cycle made a significant contribution to the IPCC Fourth Assessment Report (AR4) by participating in the Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP) together with seven GCMs. EMICs are also suitable for tackling problems addressed in the coming Paleo Carbon Modelling Intercomparison Project.

General circulation models

EMICs constitute, with carefully designed experiments, an important element for future projection and interpretation of past events with timescales longer than a few hundred years. However, they have the same drawback of a high degree of abstraction as pointed out for conceptual models, although to a lesser extent. It is desirable to make a parallel use of GCM-based earth system models (ESMs) and EMICs in a complementary manner within the allowance of computer resources. Many of the institutes involved in global warming projection are developing elaborate ESMs by coupling biogeochemical modules (vegetation dynamics, carbon cycle and others) with GCMs.

A good example is the structure and results of MIROC-ESM, the GCM-based ESM developed by Japan Agency for Marine-earth Science and Technology (JAMSTEC), under collaboration with Center for Climate System Research, University of Tokyo, and National Institute for Environmental Studies.

The target resolution for the model development is 280 kilometres with 80 vertical levels for the atmosphere and 50-140 kilometres (spatially variable) with 44 levels for the ocean. The resolution is rather coarse, particularly considering the fact that JAMSTEC runs the Earth Simulator, once the world's fastest computer and still one of the fastest available for earth scientists. Coupling many components with a GCM is itself a challenging task for model developers. Furthermore, some of the component modules are quite expensive in terms of computer resources. Plunging into a high-resolution ESM from the start is not a wise choice. A unique aspect of MIROC-ESM is its sophisticated treatment of the stratosphere, leading to reproduction of self-sustained Quasi-Biennial Oscillation and realistic distributions of chemical particles such as ozone.

MIROC-ESM was involved in a coordinated experiment under C4MIP, in which interactions between climate and carbon cycle were examined. Results showed that, when interactions are taken into account, the estimated CO_2 concentration for 2100 has to be elevated by 120ppm compared to the case where no interactions are considered. The main mechanisms are enhancement of microbial degradation of soil carbon, and lower uptake of excess CO_2 by oceans due to lower solubility of CO_2, both of which

Image: JAMSTEC

Theoretical performance of the new Earth Simulator, upgraded in April 2009, is three times as high as that of the former

are associated with higher temperature. The 120ppm elevation of CO_2 corresponds approximately to 1ºC. This is clearly significant for global warming projection where a typical range of temperature rise is 2-4ºC. Namely, there is a feedback loop between climate and carbon cycle, in which warming raises CO_2 concentration and vice versa, meaning that the feedback is positive.

One of the difficulties in developing ESMs exists in the shortages of available data to verify them. Interactive processes between climate and carbon cycles in ESMs need to be verified against observations as soon as possible. A recent preliminary experiment with a new version of MIROC-ESM — where a spatially explicit and individual based dynamical global vegetation model is included — shows a possibility of considerably reduced feedback compared to the previous C4MIP case (under the same anthropogenic CO_2 emission scenario A2) through growth of new types of vegetation under changing climate. Uncertainty in the intensity of climate-carbon cycle feedback will be one of the central themes for the next assessment report of IPCC. Geographical distributions of monthly mean CO_2 and methane, which will be available from the satellite GOSAT, are expected to contribute with respect to verifying short-term processes in the carbon cycle and reducing associated uncertainties.

The climate-carbon cycle feedback has implications for the design of a long-term mitigation plan against global warming. IPCC AR4 for Working Group 2 discusses CO_2 stabilization targets and emission pathways to achieve them, often without considering the feedback. By appropriately adopting ESMs, it is possible to evaluate its impact on emission pathways. Such experiments have been indeed performed by some of the existing GCM-based ESMs. Results from MIROC-ESM show that the permissible emission to accomplish CO_2 stabilization is reduced by around 20 per cent when climate and carbon cycle are allowed to interact. In order to provide a scientific basis for mitigation planning in the Fifth Assessment Report of IPCC, due in 2013, international coordination is underway to organize experiments for evaluating permissible emissions with GCM-based ESMs.

Outlook

The concept of ESS has existed for a relatively long time, but realization of the urgent need for it has only been appropriately recognized over the last decade. This is perhaps why scientists are still hesitant to acknowledge this new field as a discipline. Another reason may be that, while other new scientific fields have often defined themselves by restricting subjects and methods, ESS has in its nature an inclination toward widening of subjects and integration of exiting paradigms.

ESS should be regarded as a framework of thought rather than an established discipline. This interpretation is perhaps more readily acceptable to most scientists, but raises another question, as to whether ESS is really a 'specialty' worth dedicating a considerable portion of a scientific career to. However, under the current situation where responding to global change is a pressing mission for earth science as a whole, the necessity of a 'bridge' is obvious for connecting ever-deepening traditional disciplines. It would be an invaluable work if earth-system scientists could create and develop a common mindset that commands a bird's-eye view of relevant fields of earth science and possibly social science. Modelling will continue to contribute to a cooperative growth of diversifying disciplines and expanding ESS.

Seasonal to decadal prediction: improving accessibility and widening applications

*Richard Graham, Adam Scaife, Anca Brookshaw and Mike Davey, Met Office, UK;
Rowan Sutton, National Centre for Atmospheric Science, UK*

The potential benefits of reliable seasonal to decadal climate prediction are enormous, and evident in both the impacts that could be avoided as a result, and the forecast applications developed by various centres. Users of these predictions are often most interested in extremes such as drought, flooding or heat waves. Studies show it is when natural and anthropogenic climate change combine that extremes become more frequent and more intense, so prediction systems need to include both sources of variability. This understanding has led to a growing need for initialized predictions to provide advance warning of impending extremes, and to respond and adapt to climate change. State-of-the-art seasonal to decadal predictions are best placed to predict these events because they are initialized with the current state of the climate system while also including expected changes in anthropogenic forcing. This has accelerated the requirement for seasonal to decadal predictions to be incorporated into the operational output of National Meteorological and Hydrological Services (NMHSs).

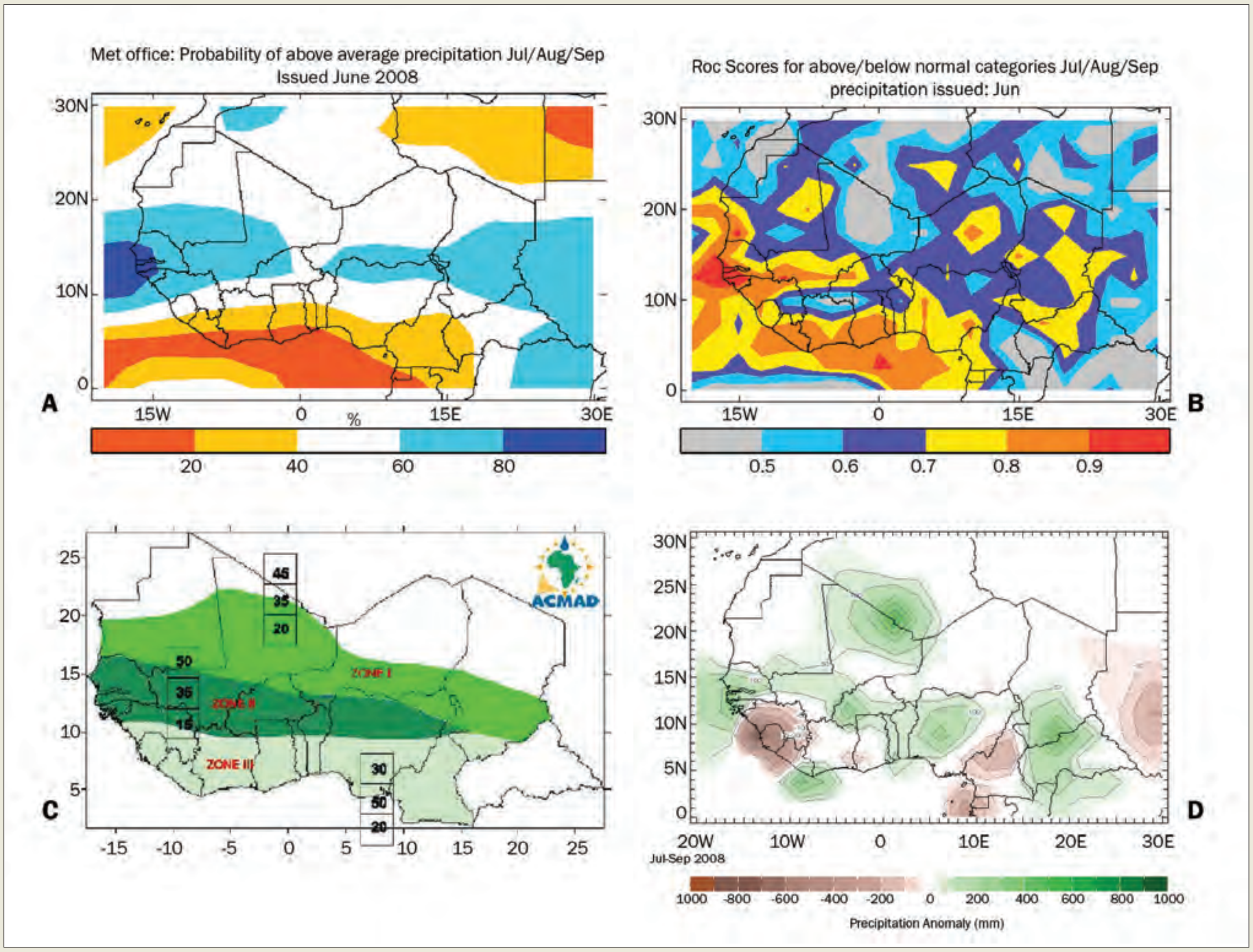
The Met Office makes routine predictions across seasonal to multi-decadal timescales. Relatively detailed predictions are made in some regions, mainly in the tropics, where skill levels are highest. Decadal predictions offer the possibility of additional extratropical predictability, due in part to the growing anthropogenic climate change signal and in part to low-frequency Atlantic variability. The main forecasting tools are dynamical prediction systems which use coupled ocean-atmosphere general circulation models to develop ensemble predictions, allowing assessment of uncertainties in the forecast. Below are some examples of long-range forecast applications, covering a range of (tropical and extratropical) locations, timescales, customers and impacts, and illustrating international collaborations.

Regional Climate Outlook Forums (RCOFs) are currently convened for regions with strong rainfall seasonality (such as the West African monsoon, and the East African wet seasons). Their main objective is to develop a consensus broad-scale outlook, which may be elaborated to national scales by the respective NMHSs, and disseminated to sectors including agriculture, water resources, energy, health and media. The forums also provide opportunities to form alliances between forecast users and producers, for users to feed back requirements to producers and for institutional capacity building. The consensus outlooks are developed using statistical and dynamical forecasts, blended where discrepancies occur using interpretation from regional experts. An example of dynamical model input to RCOFs is the rainfall prediction over West Africa for July-September 2008 from the Met Office coupled ocean-atmosphere seasonal prediction system (GloSea). The prediction formed one input to an update forecast for the region, developed following the West Africa RCOF (PRESAO 11) and issued by the African Centre of Meteorological Applications for Development on 27 June 2008. Forecast statements highlighted enhanced risk of wet conditions and advised a strengthening of local weather watches. In response to the forecast a number of flood mitigation procedures were implemented by the International Federation of Red Cross and Red Crescent Societies, including pre-positioning of emergency stocks. In the event, heavy rain and flooding affected many West African countries in July 2008.

The relatively good seasonal prediction skill for West Africa has also led to the development of a number of applications for river basin and reservoir management in the region. The Met Office has developed a system to predict water volume inflow into Lake Volta, to assist management of the 1,000-megawatt hydro-electric power plant near Akosombo, at the lake's southern end. Inflow peaks in September, with around 95 per cent occurring between June and November. Predictions for total inflow over this period are made from May, with updates issued each month. The predictions are derived using observed preceding rainfall and river flow in the catchment, global sea surface temperature patterns and GloSea-predicted rainfall spanning the target period. On average, over a 20-year period, these predictions are more accurate than predictions using only catchment observations.

Hindcast skill of dynamical models over much of Europe is currently marginal, especially for precipitation. However, there is the potential for predictions in individual years to be informative. The Met Office has adopted a process for generating seasonal predictions for Europe by combining dynamical-model output with data from several other sources. This approach was first used for the winter 2005-2006, exploiting connections between sea-surface temper-

Predictions and observations for the 2008 wet season in West Africa



a) GloSea-predicted probability for rainfall above the 1987-2001 average, for JAS08 b) Prediction skill based on hindcasts for 1987-2001, scores greater than 0.5 indicate forecasts are better than guesswork and perfect forecasts would attain a score of 1.0 c) PRESAO 11 consensus update forecast showing predicted probabilities of (top to bottom) above-average, average, below-average rainfall for each geographical zone indicated by the colour shading. d) observed JAS08 rainfall anomalies relative to 1979-2000

Source: a) and b) Met Office Hadley Centre, c) African Centre for Meteorological Applications for Development, d) International Research Institute for Climate and Society

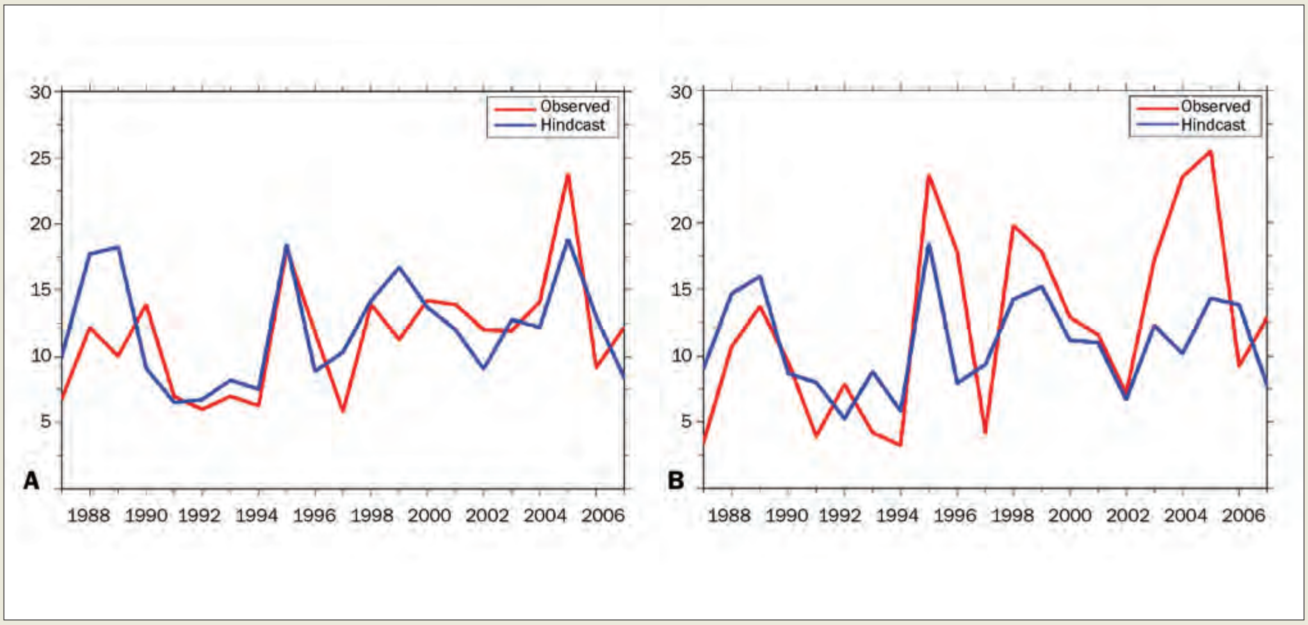
atures in the North Atlantic and northern European winter climate, and later for the summers of 2007 and 2008, when teleconnections between Europe and the tropical Pacific (in La Niña phase) were invoked. In all these cases the 'consolidated' forecast provided generally accurate guidance.

The cost of tropical storm damage represents one of the largest risks covered by the insurance sector, and consequently there is considerable interest in its long-lead prediction. Recent research has shown that the skill of dynamical systems, such as GloSea, for predicting the numbers of North Atlantic tropical storms is comparable to that of statistical prediction methods, which have traditionally formed the basis of most published predictions. Based on research initiated at ECMWF and using GloSea, the Met Office issues predictions of tropical storm numbers and the accumulated cyclone energy (ACE) index (a measure of the collective intensity and duration of storms) during July-November.

In hindcasts, the method predicts well the interannual variability of storm numbers and ACE index. Real-time forecasts since 2007 have also been successful: 12 storms occurred in 2007 when the best estimate prediction was ten, and 15 storms in 2008 when the best estimate prediction was 15.

Currently applications in the health sector are probably best developed for malaria prediction in Africa. In malaria-prone regions incidence of the disease is positively correlated with seasonal rainfall totals. Research has demonstrated the potential of using dynamical seasonal predictions to predict malaria incidence in southern Africa. Ensemble-mean November-February rainfall anomalies from dynamical models of three centres participating in the EU project DEMETER (Met Office, ECMWF and Météo-France) show spatial distributions that are similar to observed distributions when composited for years with

Verification of predictions for tropical storm numbers and ACE in the North Atlantic



Ensemble-mean hindcasts (blue) from June and observations (red) of A) tropical storm numbers and B) ACE index (divided by 10) for July-November periods, 1987-2007. In both cases, the correlation of hindcasts and observations is ~0.6; observations from HURDAT (Jarvinen et al. 1984)

Source: Met Office Hadley Centre

highest and lowest malaria incidence. Multi-model output from these centres has since been used as input to Malaria Outlook Forums in Botswana.

Applications of decadal predictions are at a more experimental stage than seasonal forecast applications. Using a decadal prediction system (DePreSys) which includes present day observations, the Met Office has developed updated long-term temperature averages, used for planning in many sectors. Because of warming trends, averages based on the standard period 1971-2000 are more representative of the 1980s than of present-day climate. To account for climate change, decadal predictions are used to extend the observed historical temperature record into the future. The long-term temperature averages for particular years are then calculated using a mix of observations and predictions. The method has been tested for the UK, using hindcasts from the early 1980s, and has been found to provide more accurate estimates than multi-decadal climatologies based only on past observations.

Accessibility to seasonal forecast information for use by Regional Climate Centres (RCCs), RCOFs and NMHSs has improved considerably in recent years following WMO designation of 11 Global Producing Centres of long-range forecasts (GPCs). In order to promote coordination in both forecast and validation outputs GPCs must adhere to minimum criteria for products. Additional long-range forecast products are also available from other centres, currently not designated as WMO GPCs. A significant boost to international cooperation occurred in 2009 with WMO designation of a Lead Centre for Long-range Forecast Multi-Model Ensembles, jointly hosted by the Korean Meteorological Agency and the NOAA National Centres for Environmental Prediction. The centre has a range of functions, with two central themes:

- To provide a single portal from which users (RCCs, RCOFs, NMSs and GPCs) can access GPC forecast output in common formats
- To promote research and generate multi-model products from the GPC forecasts.

The Met Office continues to work towards improving dynamical prediction models, including their resolution and initialization, to produce more accurate simulations of climate variability and improve forecasts. There remain many processes, with global teleconnections, which are currently poorly modelled, yet offer great potential for improving seasonal to decadal forecasts. This suggests a permanent role for semi-empirical forecast methods as a benchmark in development of seasonal to decadal forecasts, as these methods can sometimes represent a sizeable portion of regional climate variability with just a few predictable factors.

Even with model development and improved initialization, seasonal to decadal forecasts will always be subject to uncertainties. Forecasts need to include likely ranges of uncertainty and this represents a barrier to many users, including the public. Another barrier to wider use is in transforming the forecast output into user-relevant quantities. There is a great need to couple with more application-based models to represent downstream impacts such as health, crops and water availability. The climate prediction community needs to face up to the challenge of simplifying the format and language of forecasts, and working with a broad range of users to tailor forecasts to their needs.

Strategic planning in the Caribbean: the role of seasonal forecasts

Kim Whitehall, Margarette Mayers-Als and David A. Farrell, Caribbean Institute for Meteorology & Hydrology

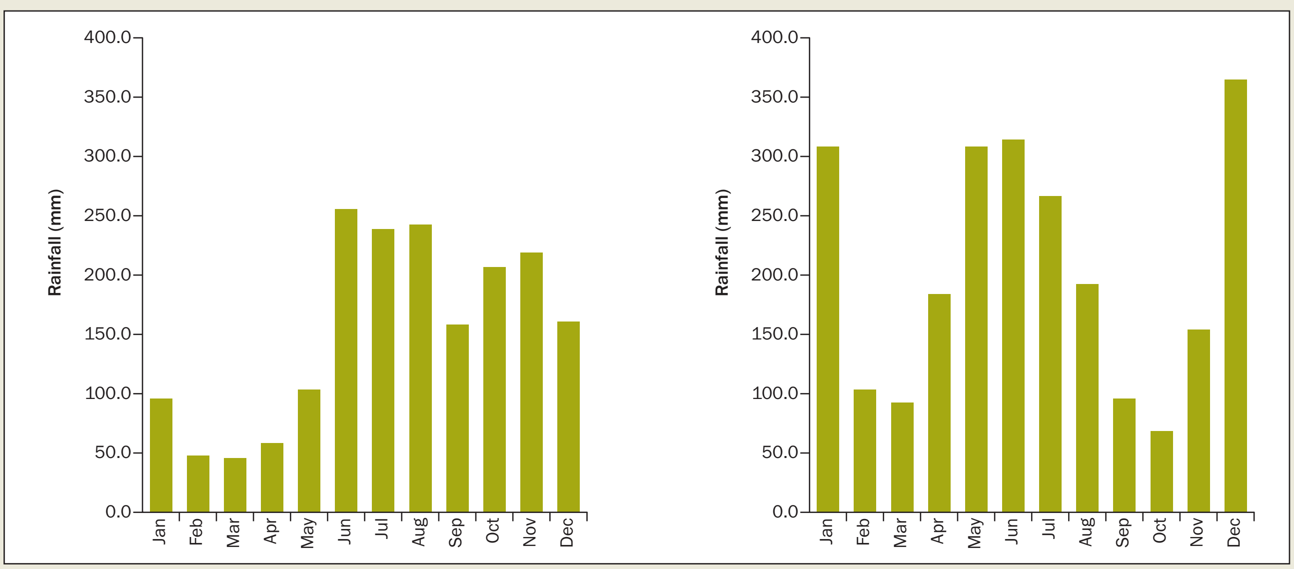
The socioeconomic development of the Caribbean region is strongly dependent on how its citizenry adapts to local climate changes in both the short- and the long-term. As a result, considerations of climatic factors are a critical component in the region's planning process. Depending on the sector and the activity, the inclusion of climate into planning processes may be based on climate forecasting approaches that have been developed from traditional knowledge to those steeped in modern science. Regardless of the approach taken, the goal is essentially the same: maximizing productivity to ensure the survival of the community and the region.

The Caribbean consists of countries and states that are relatively small in size — generally less than 500 square miles. Exceptions include Jamaica, Trinidad and Tobago, Haiti, the Dominican Republic and Cuba. Although Guyana and Belize are located in South and Central America respectively, from a regional perspective they are considered part of the Caribbean. Apart from being generally small, common features of many Caribbean islands and states include: small economies, lack of economic diversity and high risk exposure to climate hazards. In fact, the performance of many local economies is strongly dependent on climate. Hence adapting to climate is critical to the socioeconomic development of the Caribbean region.

Climatic regions in the Caribbean include both semi-arid areas and tropical rainforests. In addition, the region experiences tropical cyclones annually. Caribbean climates are complex and are regulated by weather systems that originate off the west coast of Africa before migrating westward into the Caribbean. Systems moving northwest from the South American continent and southeast from the North American continent also influence the region's weather and climate. In addition to transporting moist or dry air into the Caribbean region, weather systems entering the Caribbean may also transport aerosols such as Sahara Dust and particulate matter from biomass burning.

Annual rainfall totals in the Caribbean region range from less than 750 millimetres to greater than 2,500 millimetres in some localities. Northern sectors of the Caribbean exhibit a bimodal rainfall pattern with the primary rain season coinciding with the North Atlantic hurricane season (from June to November) and the less prominent rain season occurring

Mean monthly precipitation for the period 1998 to 2008



Mean monthly precipitation for the period 1998 to 2008, Piarco Airport, Trinidad (left); Georgetown, Guyana (right)

Source: Caribbean Institute for Meteorology & Hydrology, St. James, Barbados between March and May. The eastern Caribbean exhibits a unimodal rainfall regime with the majority of rainfall occurring during the North Atlantic hurricane season, which is associated with unstable air masses producing significant precipitation.

Guyana exhibits a bimodal rainfall pattern with the primary rain season occurring from December through to February. It is during this season that extensive flooding was observed in Guyana in the latter part of December 2004 to February 2005. The secondary rainy season in Guyana extends from May to August.

Existing climate patterns in the Caribbean may be modified as a result of global climate change, changing land use and increasing industrialization. Current observations and outputs from global and regional climate models indicate that future climate changes could include: increasing temperatures with the difference between average day and night time temperatures decreasing; changes in rainfall patterns, reduction in total annual rainfall, more intense rainfall events and on average longer dry periods; and an increase in the average intensity of tropical cyclones.

Broad ranges in parameter values can be used to define current and future climates across the Caribbean. Yet within this scope significant uncertainty, exacerbated by phenomena such as El Niño Southern Oscillation (ENSO), exists. These uncertainties in climate parameter values from year to year and from season to season can, and often do, have significant impacts on climate sensitive sectors in the Caribbean.

Climate sensitive sectors

The performance of such sectors as tourism, agriculture, energy, water, health, insurance and financial services, recreation, and sport is critical to the socioeconomic development of the Caribbean, but these sectors also happen to be particularly sensitive to climate. Their ability to generate profits and provide services in an efficient and effective manner relies in part on timely and accurate climatic forecasts that allow them to adapt their operations over short and long timescales.

Although agricultural productivity is decreasing across many Caribbean states, agriculture still represents a significant foreign exchange earner and in many rural communities it is still the primary source of employment and income. Climate dictates the type of agriculture practiced as it influences such factors as water availability (for both rain and irrigation-based agriculture), soil moisture conditions, and rain-fed growing seasons. Because of this, not only is a historical understanding of climate important for agriculture, but so too are climate forecasts which can be used to support on-farm decision making (such as type of crop to be sown, irrigation scheduling and harvest times) to maximize productivity and revenue. Climatic information, for example, is particularly important for determining the timing of interventions such as the application of pesticides and fertilizers where significant expenditure and environmental degradation may occur from poorly planned applications. However, the application of climate products to inform farming activities is not as widespread as it should be in the Caribbean, instead climate indicators based on traditional knowledge are still commonly used to inform farming in rural communities. Although the use of traditional knowledge is acceptable under some circumstances, the rapid changes in climate currently observed and predicted may marginalize the use of such traditional knowledge which is based on a long history of observations. The susceptibility of Caribbean agriculture-based economies to extreme weather and climatic events was demonstrated during the floods in Guyana from December 2004 to February 2005, which accounted for USD55 million in agricultural losses and in Grenada, which lost the majority of its nutmeg industry following the passage of Hurricane Ivan in 2004.

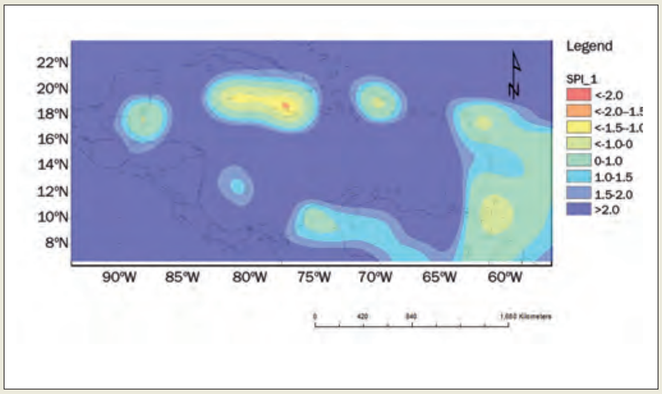
The Caribbean climate is valued by people from around the world because of its positive health benefits, but said climate is also responsible for potential negative health effects. Vector-borne diseases represent one climate related health concern for which a body of literature on the subject exists. Joint research by the University of the West Indies (UWI) Climate Studies Group Mona and the Caribbean Epidemiology Centre on the epidemiology patterns of dengue fever in the Caribbean concluded that in the region the illness has a well-defined climate seasonality. In particular, it was observed that warm and dry conditions followed by rainfall appear to enhance the probability of the epidemic occurring. The research also showed a strong correlation between fever outbreaks and the occurrence of ENSO events. Based on these findings, the research teams proposed a moving average temperature index to identify periods where the potential for dengue fever outbreaks may be high.

Other health concerns that may be attributable to seasonal climate tendencies include asthma, bronchitis, respiratory track infections and diarrhoeal illness. Personal injury rates on average across the Caribbean also tend to be higher during the North Atlantic hurricane season. Of the ailments listed, however, asthma has received particular attention.[1] Depradine and Lovell's paper demonstrated that in Barbados, incidences of asthma were greatest along the eastern portion of the island and that in general asthma cases peaked during the rainy season when there is an increase in moulds, spores, pollen and other chemical aeroallergens in the atmosphere. The study further showed that peak incidences of asthma occurred approximately three to four weeks after a peak in atmospheric moisture.[2] Increases in the number of cases and severity of occurrences of asthma have been linked to occurrences of Saha Dust over the region. However, there is a growing body of literature that is challenging the assertion.[3]

Existing seasonal forecasts for the Caribbean region

As already discussed, there is a distinct correlation between seasonal characteristics in the Caribbean and socioeconomic development and productivity. Given this, and the region's vulnerability to climate related hazards, improved efficiency and resilience in socioeconomic sectors must be achieved through the use of seasonal climate forecasts, which may cover periods ranging from two weeks to several months. Critical atmospheric variables considered in such forecasts include surface temperatures, precipitation, and speed and direction of wind. Several seasonal climate forecasts are issued for the Caribbean region annually. The annual 'North Atlantic Seasonal Hurricane Forecast' offered by Professor William Gray of Colorado State University is perhaps the most well known and anticipated climatic forecast due to its perceived socioeconomic implications for the Caribbean region. These annual predictions have a significant impact on the financial positions and risk that insurance companies assume for any given year.

SPI for April 2009



CDPMN generated standard precipitation index (SPI) for the Caribbean region for April 2009

Source: www.cimh.edu.bb/precipindex.html

Less well known, but another economically important seasonal forecast for the Caribbean region is the Precipitation Outlook (www.cimh.edu.bb/curprecip.htm), which is produced by the Caribbean Institute for Meteorology and Hydrology (CIMH) and covers six consecutive three-month periods during the year. Forecasts presented in the Precipitation Outlook are based on both subjective considerations (the professional judgment of the forecaster) and objective considerations that include outputs from statistical and dynamic models. The dynamical models used include global models and, where applicable, regional models. The overall strategy used to create the Precipitation Outlook therefore includes model outputs; monitored and forecast climatic indices known to exhibit correlations with Caribbean precipitation and temperatures; and knowledge of regional climatic conditions and global relationships. Unfortunately, few model outputs that are regularly updated (for example, that from the European Centre for Medium-Range Weather Forecasts) cover the Caribbean region at a high enough resolution to be extremely informative to the small states of the region. To develop such information, global climate models must be downscaled using statistical methods. Unfortunately, these methods introduce some level of subjectivity into the modelling process. To address this matter, the CIMH is currently expanding its computational facilities to assist the regular running of dynamic models on a regional scale.

A recently implemented forecast product in the region is the Caribbean Drought and Precipitation Monitoring Network (CDPMN), which forecasts the precipitation status across the Caribbean over one, three, six, and twelve month intervals (www.cimh.edu.bb/precipindex.html). The CDPMN is a CIMH product funded in part by the Caribbean Water Initiative, which is a joint programme between the Brace Centre at McGill University, Canada and CIMH. The Canadian International Development Agency funds the overall initiative.

Other countries within the Americas are also leading the way in producing seasonal forecasts. The Cuban meteorological service Instìtuto de Meteorologìa de la República de Cuba, for example, produces one and six month outlooks of precipitation and temperature across the various zones in Cuba.[4] Other regions within the Americas such as Central America and South America are also participating in similar activities in an effort to support social and economic activities.

Support for strategic planning

Strategic planning takes into account the respective activities of the various stakeholders, the objectives of the organization, and known constraints (available or potential resources, organizational capacity and existing regulations) to ensure achievement of objectives, the sustainability of the organization and maximization of the return on investment. The Precipitation Outlook and CDPMN are two CIMH climate products that are integral to forming strategic plans for climate sensitive industries in the Caribbean. These two products form part of CIMH's ongoing strategic thrust into the provision of climate services, a provision that is an important component of the World Meteorological Organization's (WMO) new strategic direction. Both the Precipitation Outlook and CDPMN are gaining in popularity, with the former, which has a longer and more established history, being used routinely by several agricultural planners and water resources managers. Two limitations of the existing Precipitation Outlook are that it provides only a three-month forecast and that its output requires a certain level of sophistication to interpret. The latter limitation, which is a significant concern, is being addressed by staff at CIMH. Other areas where the Precipitation Outlook and CDPMN can be applied include: forecasting seasonal flood risk, which represents an area of considerable interest to the insurance and disaster management communities; and seasonal forest fire risk, which is important for forest-based industries and services (for example, the Iwokrama International Centre for Rainforest Conservation and Development in Guyana).

The insufficiency of climate data for the Caribbean presents a significant challenge to the development and validation of climate services and products. Although considerable data may has been collected in the region over the last 50 to 100 years, much of this data remains on paper thereby making it unusable for analysis and interpretation. Efforts are underway to encourage donor and grant funding institutions to support conversion of this data into electronic databases. In addition several projects including: Carib-HYCOS, which is funded by the French government and represents a component of the WMO World Hydrological Cycle Observing System initiative; Caribbean Disaster Management Project Phase II, funded by the Japan International Cooperation Agency and implemented by the Caribbean Disaster Emergency Response Agency; and Enhancing Resilience to Reduce Vulnerability in the Caribbean funded by the Italian government and implemented by the United Nations Development Programme, will establish new hydro-meteorology networks and associated databases in the Caribbean region. Information provided for these new networks will support numerous climate change and seasonal climate forecasting, as well as validation initiatives.

It is the goal of CIMH and other Caribbean institutions to increase the number of seasonal forecasts they provide in order to support strategic planning and to ensure there are no unexpected climate-related events or effects that may adversely impact the region's socioeconomic development or result in significant loss of life.

Seasonal climate outlooks for assistance in water management

Charles Pearson, National Institute of Water and Atmospheric Research, New Zealand

Water managers and engineers make use of climate information and predictions at a range of temporal and spatial scales, and also use their own techniques to account for climate variability. In the longer term, the impacts of global warming will be of significant interest to water managers, as will improved short- and medium-term climate and hydrological predictions. For the short (seasonal) to medium (interannual) term, some knowledge of climatology and climate variability is useful for water managers, engineers and decision makers.

Some national hydrological services are now taking advantage of regular climate outlook information to produce regular seasonal hydrological predictions. The predictions can be particularly useful for the freshwater sector, for such uses as irrigation scheduling, water resources management, water supply, hydropower operations and hazard mitigation (floods and droughts). Typical water variables predicted, based on good climate data and predictions (air temperature and rainfall) and good hydrological data, include soil moisture, likely mean river flows and groundwater and lake levels for the season ahead.

These predictions rely upon good communications and data transfer between national hydrological and climate services. Typically the predictions are made by consensus among experienced hydrologists. As with climate predictions, hydrological predictions rely upon international collaboration to extend predictions to regional bases. The advent of increased monitoring during the International Hydrological Decade (1965-74) and a number of regional Hydrological Cycle Observation Systems projects, led by the World Meteorological Organization (WMO), are enabling regions and countries to validate hydrological predictions with reliable data.

Many water resource managers use their own techniques to account for climate variability, on seasonal and longer timescales. For example, in designing a flood protection scheme, a water engineer will estimate the flood frequency for a river location, estimating the flood peak flow magnitude of a given risk of occurrence. If the protection scheme has a design life of 50 years ahead, then engineers are aware that climate change, variability and upstream land use change all have potential to impact upon the occurrence of flood peaks.

Some national and international meteorological and climatological services produce climate information and predictions ahead for one to three months and beyond for their country and surrounding region. Information produced includes status of rainfall and air and sea temperatures for the immediate past period, and predictions of rainfall and air temperatures for a season ahead. In some cases, hydrological agencies engage with climatological counterparts to produce corresponding downstream predictions of terrestrial hydrological variables such as soil moisture, river flow, lake and groundwater storages.

Climate information is produced from good quality climate data records, and timely extraction of the data into information on the status of current conditions. Tabular and mapped information can be produced on air temperatures, rainfall and precipitation, sunshine, solar radiation, barometric pressure and sea surface temperatures.

Climate prediction relies upon global signals such as the status of the El Niño Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation, and their implications (from previous records and science) at regional and country scales. Local scientific knowledge on circulation and seasons, and developed statistical prediction tools such as similar past analogous situations and regression schemes, are used to predict climate variables one to three months in advance. Over ten global climate models provide predictions on the state of Pacific sea surface temperatures and ENSO up to nine months ahead.

Typically, climatologists take into account all available information to form a consensus view to predict seasonal outlooks of variables such as air temperatures and rainfall.

Hydrological information can be generated from hydrological monitoring networks. It is necessary to know the initial status of water fluxes and storages before making predictions.

New Zealand's National Climate Centre has predicted ahead three monthly rainfall, air temperatures, soil moisture levels and streamflows for six defined regions of the country since 1999. The predictions are published in a monthly newsletter *The Climate Update* (now Web-based), and disseminated through media releases. Users of the predictions include the agricultural and horticultural sectors, hydropower and irrigation companies, and local government bodies responsible for water resource and hazard management.

The method used to translate these predictions into on the ground soil moisture and river flow predictions

Lake Pukaki, South Island – New Zealand's largest hydropower generation source

relies upon routine communication between the Centre's climatologists and oceanographers (based at offices in Wellington and Auckland) and hydrologists (Christchurch). Over ten years of monthly operations, greater understanding has developed between the two science areas, and an increased awareness of each discipline's terminology. At the same time an operational environmental forecasting (up to six days ahead) capability is being developed among the weather scientists, oceanographers and hydrologists.

In 2001, the Centre's soil moisture and streamflow predictions changed from simply above normal, normal or below normal predictions for the time of year, to quantitative probabilistic predictions — predicting probabilities of three-month soil moisture levels and mean river flows being in the top, middle or bottom third of their distributions.[1]

The accuracy of streamflow predictions has been assessed. The skill level is better than 'climatology' (the null prediction of apportioning 33 per cent probabilities to each third). Biases in flow predictions have been examined. Predictions of normal or below normal flows predominated over above normal predictions. The biases were associated with the difficulty of predicting the climate for extreme weather events a season ahead. Reliable records of river flows can be presented in near real-time. Knowledge of the status of river flows now is useful as initial conditions for making seasonal predictions ahead, and shorter term flow forecasting (up to four days ahead).

A meeting on the climate information needs of the water planning and management community was held at WMO in 2006. The objective was to provide a platform for dialogue between water managers and climatologists and consider a project concept to facilitate and expand the use of climate information in water resources management. The meeting developed a set of conclusions to guide interactions between water management and climate information, including:

- Recognition that both water managers and climate information providers benefit from addressing common issues
- General consensus that climate information has high potential value, but that there are still large uncertainties with regard to the kinds of quantitative information water managers traditionally use
- Most immediate opportunities exist at the scale of seasonal climate outlooks, as this type of information is easier for water managers to assimilate
- Opportunities should be based on temporal synergies, that is, using climate information on different

Image: Alan Porteous, NIWA

Irrigation systems on the Canterbury Plains, New Zealand

timescales in conjunction with corresponding operational, tactical, and strategic management functions
- Questions remain on the scientific basis for validating predictive skills of climate models and their utility for water management
- Water managers do not make routine use of climate predictions
- There is a need for the climate community to quantify uncertainties in climate predictions and for water managers to explore how probabilistic climate products can be used more routinely
- A project concept and plan for facilitating the use of appropriate climate information by water managers was developed.

The meeting also provided inputs to the concept of pilot projects to facilitate national hydrological services in meeting the new expectations that have emerged due to climate change awareness. Two pilot projects were initiated in Mexico and Egypt. Based on the experience gained thus far, it is clear WMO, working as it does with both the climate scientific and hydrological communities, is in a unique position to provide support to facilitate this multi-stakeholder activity.

Water engineers, and most of the agencies in charge of water management do not yet rely on forecasts that extend normal weather models by using ENSO and other type indicators, because of the large uncertainties. It is the engineers that are responsible for the planning and design water projects, rather than the hydrologists, climate forecasters or meteorologists. Recent articles testing the predictive skill of hydrological forecasts at short timescales demonstrate large uncertainties.[2] This is one principal reason why water managers and engineers, who make project decisions, and are accountable for the consequences, do not have full confidence in the predictions and forecasts over a range of timescales derived from climate and hydrological models.

Many hydrological modelling tools are being developed to model hydrological processes at an appropriate range of temporal and spatial scales,[3] in parallel to the development of global/regional/mesoscale climate models. Links between the climate and hydrological models may facilitate physically-based and scientific short-to-medium-term climate and hydrological information and predictions, of more practical use to water managers. Identical physically-based climate models are now used at temporal scales from short-term weather forecasting to century scale climate change modelling. Likewise physically-based hydrological models, linked with climate models, are being tested for forecasting and prediction at a range of time spans.[4] Such multi-model ensembles and downscaling techniques might improve prediction skills and reduce the current large uncertainties within the next 25 years.

To validate climate and hydrological models, ongoing monitoring and data storage, quality assurance and analysis needs to be maintained to at least their current levels.

Changes in the climate of East Asia tropical cyclones

Johnny C. L. Chan, Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong

Tropical cyclones (TCs) are one of the most devastating weather phenomena. Over the ocean, they pose extreme hazards to all vessels, from small fishing boats to large container ships and oil tankers. As they make landfall, they can bring about heavy rain and severe winds, causing significant damage or even fatalities in the coastal regions. A better understanding of the climate variability of TC activity in a region can help produce good seasonal predictions of TC activity, which will enable relevant authorities to be better prepared for potential disasters. Such an understanding will also help project changes in TC activity under global warming.

Some recent results in understanding the changes in the climate of East Asia TCs based on the analyses of various datasets are presented here. All these results show that the frequency of TC landfall in various parts of East Asia and that of TC occurrence in the entire western North Pacific Ocean have large variations on timescales, ranging from annual to decadal. Because of these large variations, it is difficult to detect any long-term trend that may exist in such occurrences. However, this does not necessarily mean that global warming will not cause a trend in the future. How such changes may be projected for the future under global warming scenarios is also discussed.

Landfall in the Philippines during the last 100 years

The Philippines is frequently hit by TCs every year. It is therefore of great importance to understand whether the frequency of landfall has any detectable trend. Recently, Kubota and Chan[1] created a dataset of the annual number of TCs making landfall in the Philippines by combining the historical observation records of the Monthly Bulletins of Philippine Weather Bureau and the US Joint Warning Typhoon Center best-track data for the period 1902 to 2005. During these 104 years (except for the Second World War period), the annual number of landfall TCs does not show any long-term trend. Rather, the annual landfall number has an apparent oscillation of up to 32 years before 1939 and between 10 and 22 years after 1945. Such variations are found to be related to different phases of the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). During the low PDO phase, the annual number significantly decreases in El Niño but increases during La Niña years. During the high PDO phase, however, the difference between ENSO phases becomes unclear. These results suggest that natural variability related to ENSO and PDO phases appears to prevail in the interdecadal variability of the annual number of TCs making landfall in the Philippines.

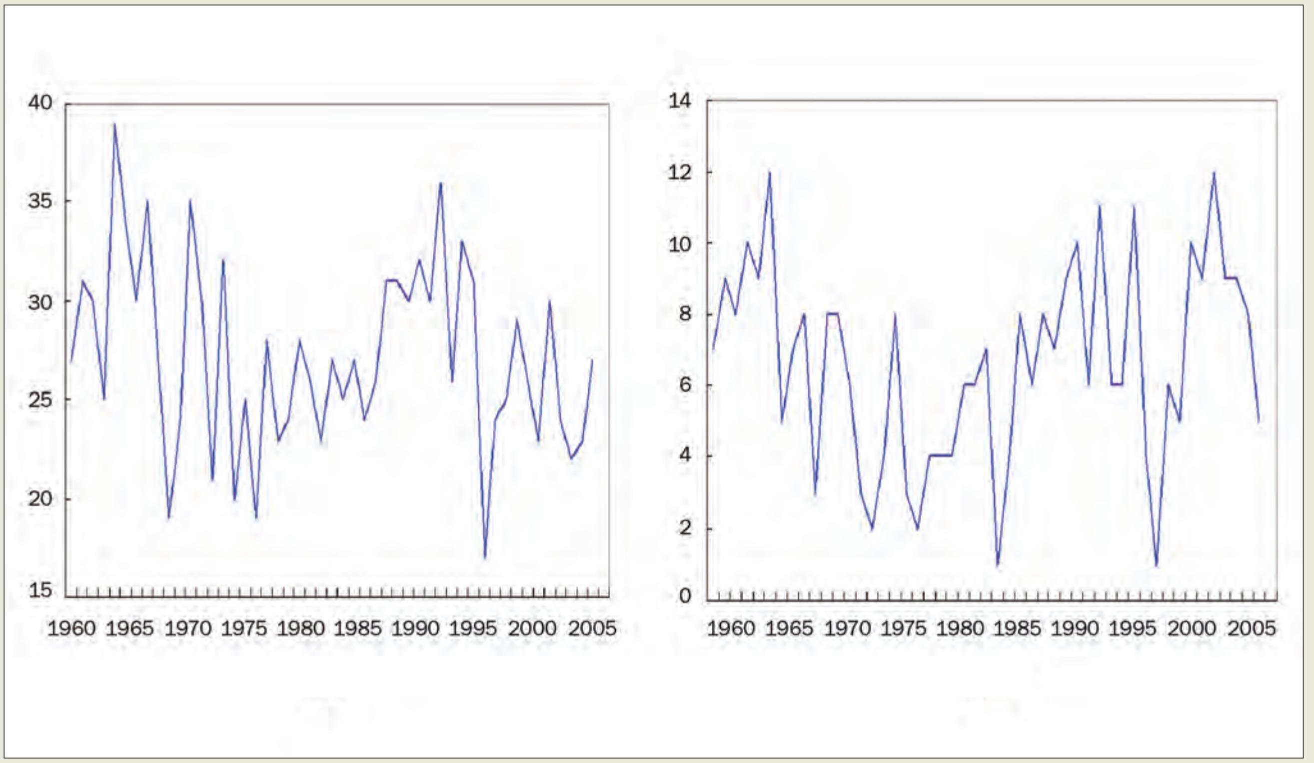
Landfall in East Asia during the last 60 years

On average, about 12-15 TCs every year make landfall in various countries in East Asia, which can produce significant casualties and substantial property loss. Understanding the variability in the annual number of landfalling TCs in various parts of East Asia is therefore crucial in disaster preparedness and mitigation. Chan and Xu[2] recently made a detailed study of such variability during the period 1945–2004 by dividing the coastal areas into three regions: South (Philippines, Vietnam and south China), Middle (east China, including the island of Taiwan) and North (Korean Peninsula and Japan). Consistent with the findings already described, none of the time series of the annual number of landfalling TCs for each of these three regions shows a significant linear trend. Instead, each time series shows large interannual (2–8 years) and multi-decadal (16–32 years) variations. In some periods, the annual number of landfalling TCs varies in unison among all regions of Asia. In others, one region would have an above normal number of landfalling events, while the other regions have below normal numbers. Changes in the frequency of landfall in various regions on multi-decadal timescales have been found to be related to variations in the atmospheric flow patterns on similar timescales, which led to changes in the steering flow and hence the TCs made landfall in different locations.[3]

Tropical cyclone activity in the western North Pacific Ocean during the last 50 years

Among all ocean basins, the western North Pacific has the largest share of TCs,[4] with an average of up to 27 tropical storms and typhoons per year. However, this number varies quite significantly from year to year, ranging from a low of 17 in 1998 to 39 in 1964. It is also obvious from the graphed data that this number does not have any rising or decreasing trend during the last 50 years. Similarly, no trend can be detected in the annual number of the strongest of these TCs, those with intensities in the Category 4 or 5 in the Saffir-Simpson scale.[5] It must be pointed out that before 1965, no meteorological satellite was available and therefore some TCs might have been missed. Furthermore, in the early days of meteorological satellite coverage, the

Annual number of tropical storms and typhoons in the western North Pacific Ocean



Annual number of tropical storms and typhoons (left), and Category 4 and 5 typhoons (right) in the western North Pacific Ocean during the period 1960-2008

Source: US Joint Typhoon Warning Center dataset

quality of the satellite pictures was quite poor so that it could be difficult at times to estimate the actual intensity of the TC when no aircraft reconnaissance was available. The numbers prior to the mid 1970s are therefore likely to be underestimates of the actual values.

Nevertheless, even given these limitations, it is clear from the graphed time series that the number of TCs goes through large variations on both interannual and inter-to multi-decadal timescales, with maxima in the 1960s and 1990s and minima in the mid 1970s and late 1990s. The variation in the number of intense typhoons goes through similar cycles, which are found to be related to variations in the atmospheric and oceanographic conditions with similar periods.[6] It is also important to note from the graphed data that since the mid 1990s, the number of TCs and of intense typhoons has generally been on a decrease, which is in contrast to a continued increase in air and ocean temperatures. A reconstruction of the intense typhoon time series based purely on satellite re-estimates gives very similar results.[7]

Intuitively, an increase in ocean temperature as a result of global warming should lead to more energy available for convection in the atmosphere, which should therefore provide more fuel for a TC to develop. However, TC formation and intensification do not depend on thermodynamic conditions such as ocean temperature or moisture availability alone. Rather, dynamic conditions such as horizontal and variation of winds are also important. In fact, as demonstrated by Chan and Liu[8] and Chan[9], the thermodynamic conditions for TC formation and intensification in the western North Pacific are generally sufficient throughout the year so that any increase in thermodynamic energy due to global warming will have a minimal or undetectable effect. On the other hand, changes in the dynamic conditions are crucial in determining whether a TC can continue intensifying, and variations of such dynamic conditions have not been found to have a similar trend as that of air or ocean temperature. For this reason, no detectable trend in TC activity in the western North Pacific can be identified.

Projections for the future

Many climate models have been run to project what might happen to TC activity in various ocean basins under different global warming scenarios but the results are far from consistent. In the western North Pacific, some have projected a decrease in frequency[10] while others suggest an increase.[11] For intense typhoons, a similar diversity in results is also found.

One major problem with many of these models is the relatively coarse resolution. This means that the vortices simulated in the models are not quite the same as those in the real atmosphere. To obtain more realistic simulations requires a higher resolution, which can either be accomplished using a variable resolution model[12] or downscaling studies.[13] Through these various methods, better projections of TC activity should be possible.

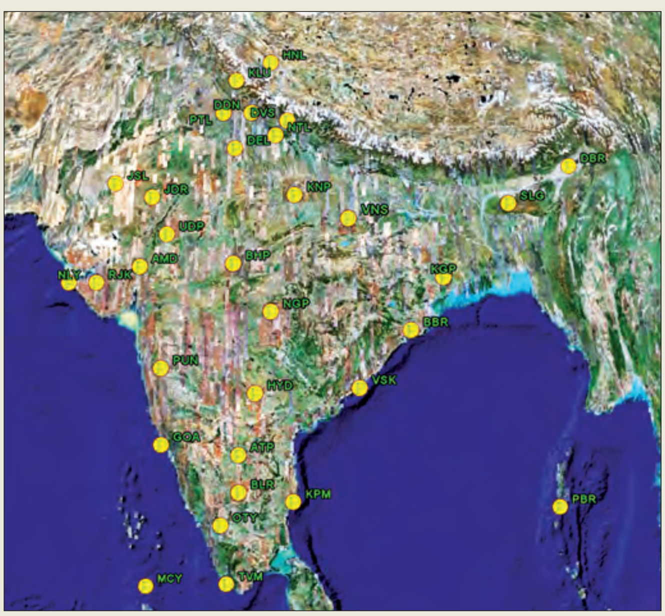
Climate implications of atmospheric aerosols and trace gases: Indian scenario

K. Krishna Moorthy, S. Suresh Babu, Space Physics Laboratory, Vikram Sarabahi Space Centre;
S. K. Satheesh, Centre for Atmospheric and Oceanic Sciences, Indian Institute of Sciences;
Shyam Lal, M M Sarin, S. Ramachandran, Physical Research Laboratory; C.B.S. Dutt, ISRO HQ

Having identified the climate implications of atmospheric aerosols and trace gases over the complex, heterogeneous and densely populated south Asian region, the Indian Space Research Organization (ISRO) has been pursuing focused and thematic research to quantify the regional climate implications through a series of projects.

Atmospheric aerosols are a suspension of tiny solid particles or liquid droplets in the air, of a natural or anthropogenic origin. Though the global aerosol abundance is dominantly natural (sea salt, dust), regionally the anthropogenic species (sulphates, nitrates, soot, organics) dominate in areas of high population density, industrialization and urbanization, or regions of extensive biomass burning. The most important parameter to represent the impact of aerosols is aerosol optical depth (AOD). This is the vertical integral through the entire height of the atmosphere of the fraction of incident light at any wavelength, scattered and/or absorbed by aerosols. Aerosols affect the energy budget of the Earth-atmosphere system by scattering and absorbing radiation (direct effect) and by modifying the amounts, and microphysical and radiative properties of clouds (indirect effects). The resulting change in the energy budget is termed aerosol radiative forcing (ARF).

The ARFI network of aerosol observatories



Source: ARFI, I-GBP

ARF of the atmosphere refers to the energy absorbed by aerosols and dispensed in heating the atmosphere. Such heating, combined with surface cooling caused by the reduction in solar energy reaching the surface, is shown to increase atmospheric stability and adversely affect the hydrological cycle, rainfall and crop yield.[1] Though ARF due to anthropogenic species attracts wide research interest, forcing due to natural aerosols is equally significant for climate change.[2] Moreover, no proven methods exist for quantitatively measuring the regional anthropogenic aerosol component; satellite retrievals are only qualitative and the best estimates attribute ~20 per cent of AOD over the oceans to human activities.[3]

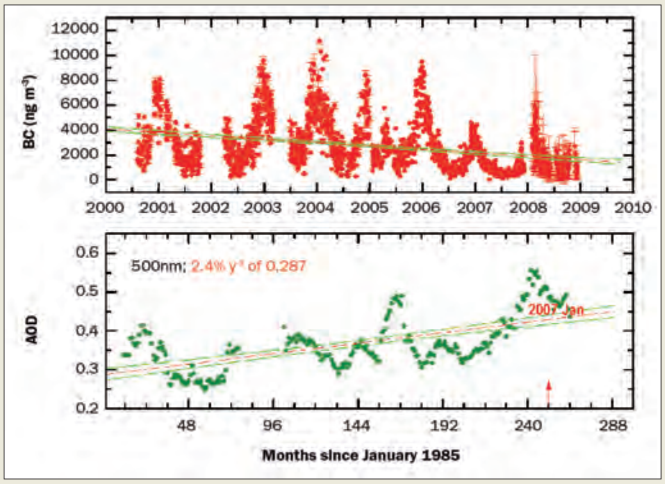
ARF exhibits large heterogeneity in spatial, temporal and spectral domains, primarily due to the spatio-temporal heterogeneity of aerosols (diverse sources and sinks and their heterogeneous distribution), the short and varying atmospheric lifetime, as well as chemical and microphysical properties. This heterogeneity makes the climate-impact assessment of aerosols a challenging task, despite the concerted efforts of the global scientific community over the past decade or more.[4] The key to reducing this lies in accurate characterization of aerosol properties from space, integrated field campaigns, establishing ground-based networks, determining size dependent chemistry on short timescales, accurately determining aerosol single scattering albedo, the vertical distribution of all these properties and incorporation in models.

The Indian scenario

Climate change has great significance in South Asia in general, and India in particular. It has diverse and contrasting geographical features, high population density, rapid urbanization and industrialization, and above all the synoptic meteorological conditions that produce the Asian monsoon.

Though Indian research to characterize regional aerosol properties began in the forties,[5] systematic spectrally and spatially resolved measurements began during the Indian Middle Atmosphere Programme. ISRO took up the development of suitable ground-based instruments, formed a mini-network for measurements of spectral AOD on a long-term basis,[6] and carried out rocket and

Trends in aerosol optical depth and black carbon mass



Trends of AOD at 500nm (bottom) and black carbon mass concentration (top) over Trivandrum. The points are monthly means for AOD and daily means for black carbon. Mean trend lines and 95 per cent confidence bands are also shown

Source: ARFI, I-GBP

balloon borne measurements of the altitude distribution of aerosols and trace gases.[7] As a result, ISRO, while formulating its Geosphere Biosphere Programme (I_GBP), identified Aerosol Climatology and Effects (ACE) and characterization of trace gases as central activities.

ACE activity proliferated under I_GBP to become a national effort. A network of ground-based observatories were established for regional aerosol characterization. As the programme matured, it became the Aerosol Radiative Forcing over India project (ARFI), which is now a network spanning the entire country and surrounding oceans. Some of its stations have databases of more than two decades for AOD and several years for black carbon (BC), enabling quantifying of long-term trends.

Data from Trivandrum, a remote coastal location in the southern peninsula, shows the monthly AOD at 500nm. While the increase in AOD of ~2.4 per cent per year from its base value in 1985 is of concern, it is equally interesting that the concentration of BC, normally considered as a tracer for human impact, shows a decreasing trend of ~250 ng m-3 y-1. This has several implications. The reduction of surface BC could be considered an indicator of emission control strategies, while the increase in AOD indicates an overall increase in columnar abundance. It remains to be seen whether this increase is occurring at higher levels, above the atmospheric boundary layer.

Natural and anthropogenic

Despite the need to focus on anthropogenic aerosols from the climate change mitigation perspective, the role of natural aerosols in ARF should not be underestimated over the Indian region. Campaign mode observations over the oceans[8] and long-term measurements from islands and the mainland have shown dramatic change in aerosol characteristics (abundance, vertical distribution, composition, and size distribution) due to large influx of marine aerosols, leading to large reduction in AOD, and flattening of its spectral response. This caused a significant reduction (by more than a factor of >2) in the 'top of the atmosphere' and atmospheric ARF.[9] Chemical speciation analysis shows an increase in the concentration of water-soluble salts from 29 per cent in winter to 44 per cent in summer.[10]

Strong signatures of marine aerosols are even reported in the interiors during summer.[11] Over central and northern India, dust, produced locally or transported from the arid regions of Africa, Arabia and Asia, contributes significantly to aerosol abundance and AOD throughout the spring and summer. A synergy of ground-based and satellite infrared measurements shows that the absorption efficiency of dust is higher over Asia than Africa[12] during winter — when the dust is aged and mixed with soot — while the more nascent summer dust has lower absorption efficiency. Chemical reactions involving this dust result in neutralization of acidic and maintain alkaline rainwater.[13]

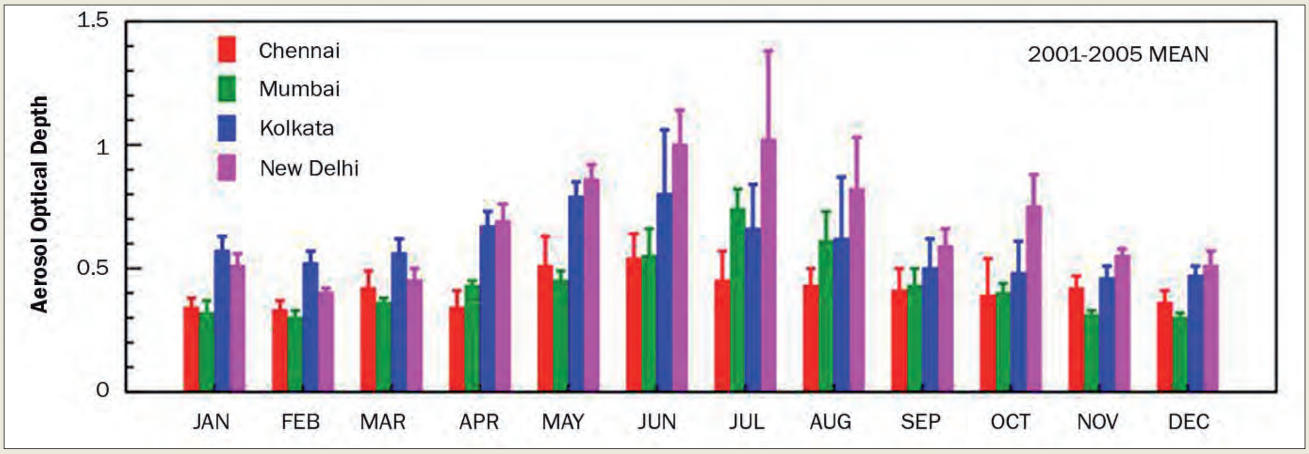
Urbanization has resulted in the evolution of urban conglomerations in India. An analysis over four regional mega cities — Chennai, Mumbai, Kolkata and New Delhi — showed high AOD with strong seasonal variations. Of these, Chennai had the least AOD, while Kolkatta (eastern coast) had the most fine mode aerosols throughout the year. In the other two cities, the fine mode contribution varied as a function of season; being very high in winter. During pre-monsoon and summer, coarse mode aerosols associated with dust and sea salt dominated the distribution.[14] Thus, even the mega cities show temporal heterogeneity, making it difficult to model for regional ARF estimation.

Modulation by atmospheric dynamics

Aerosol abundance, composition and vertical distribution over India is strongly modulated by the natural dynamical features of the atmosphere. Based on multi-year, multi-station data on AOD, it has been shown[15] that AOD over the peninsula tends to be higher in the years when the southward excursion of the intertropical convergence zone is smaller. Long-range transport of aerosols leads to significant modulations in aerosol properties, and corresponding changes in ARF and in forcing efficiency, which implies changes in the aerosol types and impacts. While the advection of mineral dust-rich West Asian and Arabian desert aerosols are important over the Arabian Sea and western parts of the peninsula during March to May,[16] advection of fine and accumulation mode aerosols from the East Asian regions cause large perturbations in spectral AOD and BC concentrations over the Bay of Bengal during January to April.[17] Over the Ganga basin, the dynamics of the shallow atmospheric boundary layer (ABL) strongly influences the build-up and spatial confinement of aerosols and trace gases from local emissions.[18] While the deepening ABL in spring and summer flushes the pollutants further aloft resulting in a dilution in their surface concentration,[19] stronger long-range transport leads to increase in AOD and ARF over the entire north-Indian Plains.[20] This leads to large space-time heterogeneity in AOD and its spectral variation over India.[21]

The tropical atmosphere supports a variety of planetary scale wave motions, the propagation of which causes significant modulations to the abundance and type of aerosols resulting in corresponding modulations in ARF. The eastward propagating Madden Julian

AOD measurements in mega cities



Monthly mean 550nm aerosol optical depths obtained by averaging the data from 2001 to 2005 over Chennai, Mumbai, Kolkata and New Delhi. Vertical bars indicate ±1α from the mean

Source: PRL, (DOS)

Oscillations and westward propagating Rossby waves in the lower atmosphere significantly modulate AOD and its spectral dependence over the tropics. These intra-seasonal oscillations contribute as much as 45 per cent to long-term seasonal mean AOD.[22] Changes in circulation parameters (wind convergence and vorticity) also produce strong perturbations in the spatial distribution of AOD, on timescales of 7-10 days over a fairly large area.[23]

Field campaigns

Field campaigns address region-specific problems, through intense multi-instrumented and multi-platform observations, but over a limited spatial and/or temporal scale. In this context several field experiments were applied over India during the last decade. The Indoex – (India) programme, satellite validation cruises and Arabian Sea Monsoon Experiment[24] — focused on oceanic regions around India under varying continental impacts. In addition, two land campaigns (LC-1, LC-2) organized by I_GBP examined the mainland features.

While LC-1 was a mobile campaign focusing on the spatial variation of aerosol parameters over peninsular India, LC-2 examined the spatio-temporal variations over the Indo-Gangetic Plain using a chain of observatories. A synthesis of LC-1 data revealed potential hotspots of enhanced aerosol concentration (near surface) and AOD difference over the peninsula implying a heterogeneous vertical distribution.[25] This was confirmed from airborne measurements of concentration and extinction.[26]

ICARB

The pilot field campaigns eventually developed into fully integrated campaigns. These involved concurrent measurements over the entire domain for long periods, employing multiple instruments for accurate and independent measurements of several aerosol properties over the land, ocean and atmosphere. The first of the Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB) series, executed in March-May 2006, was the biggest and most exhaustive field experiment ever conducted over this region,[27] and made considerable inroads into regional characterization of aerosols and trace gases. ICARB brought out new observations, raising several serious issues relating to the regional climate implications of aerosols, including possible modifications to the Indian monsoons. Surprisingly, low single scattering albedo — implying high aerosol absorption — were observed in the central oceanic regions, far from the coastal regions that are believed to be strong sources of anthropogenic aerosols.[29]

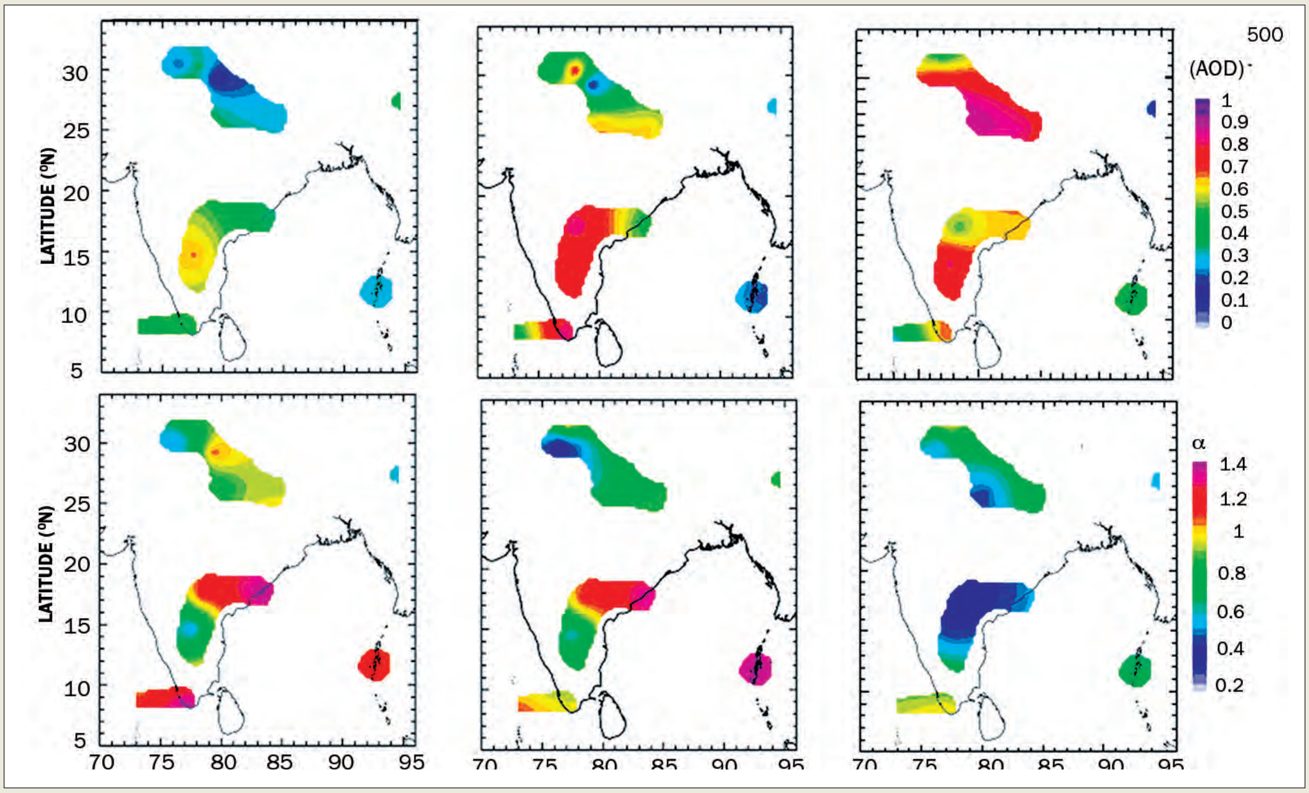
For the first time in India ICARB brought in a synergy of multi-platform measurements, satellite data, and multi-layer radiative transfer models. This synthesis led to the discovery of the prevalence of extensive elevated layers of aerosol extinction over India between one and five kilometres above the surface – within which aerosol extinction was several times higher than that at the surface.[30] The consequent absorption resulted in strong warming at higher levels of the atmosphere. It also provided the first observational evidence of a meridional gradient in this warming, which increased from ~0.4 K day-1, at ~2 kilometres over the northern Indian Ocean, strengthening gradually to reach more than 1.5 K day-1 at ~3.5 kilometres over Central India. Viewed in the light of recent simulations suggesting that aerosol warming over the Tibetan Plateau acts like an elevated heat pump drawing in warm and moist air over the Indian sub-continent leading to advancement of the Asian monsoon, the Icarb findings of the meridional gradients assume regional importance.[31]

Anthropogenic trace gases

Anthropogenic trace gases (such as CO, NO_x, SO_2 and hydrocarbons) have significant climate forcing, so there has been focused study on these under I_GBP. Establishing 'environmental laboratories' to quantify the regional distribution of these species has now become a national concern. Rising levels of these gases are of major concern for global warming and climate change. Moreover, increased levels of these gases alter the chemistry of the atmosphere, affecting the biosphere and human health as well as crop yields. Ozone in the troposphere is photochemically produced from these trace gases.

Extensive investigations of ozone and its precursors have been made using network observatories, rockets and

Space-time synthesis of AOD



Space-time synthesis of the AOD showing the large heterogeneity in AOD (top row) and its wavelength dependency expressed through the Angstrom exponent (bottom row). The panels in each row correspond to months of March, April and May, from left to right

Source: ICARB, I_GBP

balloon payloads. To understand the distribution of chlorofluorocarbons (CFCs) measurements of vertical distributions were made using high altitude balloons and cryogenic air samplers. A comparison of surface ozone levels at Ahmedabad shows an average linear rate of 0.5 per cent y-1 during the period 1954/55 to the mid 1990s.[32] In addition, ozone production per molecule of NO_x is lower in India than in the USA or Europe.[33] Simultaneous measurements of surface level CO, NO_x and non-methane hydrocarbons, as well as OC to BC ratio have indicated dominance of biomass burning over fossil fuel, especially in north India.[34] These factors lead to the observed higher ΔCO/ΔNOx. Satellite data show increasing levels of columnar NO_2 at many Indian sites. These gases, having long residence time in the free troposphere, are transported long distances. Vertical distributions of ozone and surface level measurements of various trace gases over India and the surrounding oceans clearly show the influence of long-range transport of these pollutants from North Africa and southern Europe, especially during the winter.[35]

Future directions

Reducing uncertainties in current understanding of the climate implications of aerosols and trace gases requires progress in all aspects of aerosol-climate science. New observational systems, field experiments, assimilation methods and regional and global scale synthesis are essential. The large difference between observed and modelled aerosol radiative impacts is due to inadequate modelling. This calls for more realistic simulations of aerosol, clouds, and atmospheric processes to be incorporated into models, and greater synergy among different types of measurements, models, as well as between measurements and models. Incorporation of the mixing state of aerosols in models is still something of an enigma.[36] When smaller aerosols accumulate over larger ones the radiative impact is significantly different compared to that of an external mixture.[37] This is particularly important over the Asian region, where natural and anthropogenic aerosols coexist.

The vertical distribution of aerosols with respect to clouds is important, particularly over the tropics, to further our understanding of aerosol-cloud interaction and the consequent impacts on ARF. The surprising observation of elevated aerosol warming and its northward gradient over India — as well as possible implications for regional weather and climate — will be the immediate focus. To quantify this an ARFI field Regional Aerosol Warming Experiment (RAWEX) is planned, which will carry out intense observations over the Himalayas and its foothills. In the longer-term, future ISRO programmes on aerosol and radiation will be built on the synergy of ground-based observational networks (eventually leading to regional mapping of aerosol radiative forcing), three-dimensional mapping of physical and chemical composition using integrated campaigns, satellite missions focusing on space-time synthesis of aerosols, and accurate assimilation of all these studies into regional and global models.

Projecting globally, planning locally: a progress report from four cities in developing countries

Robert Kehew, Human Settlements Advisor, UN-HABITAT

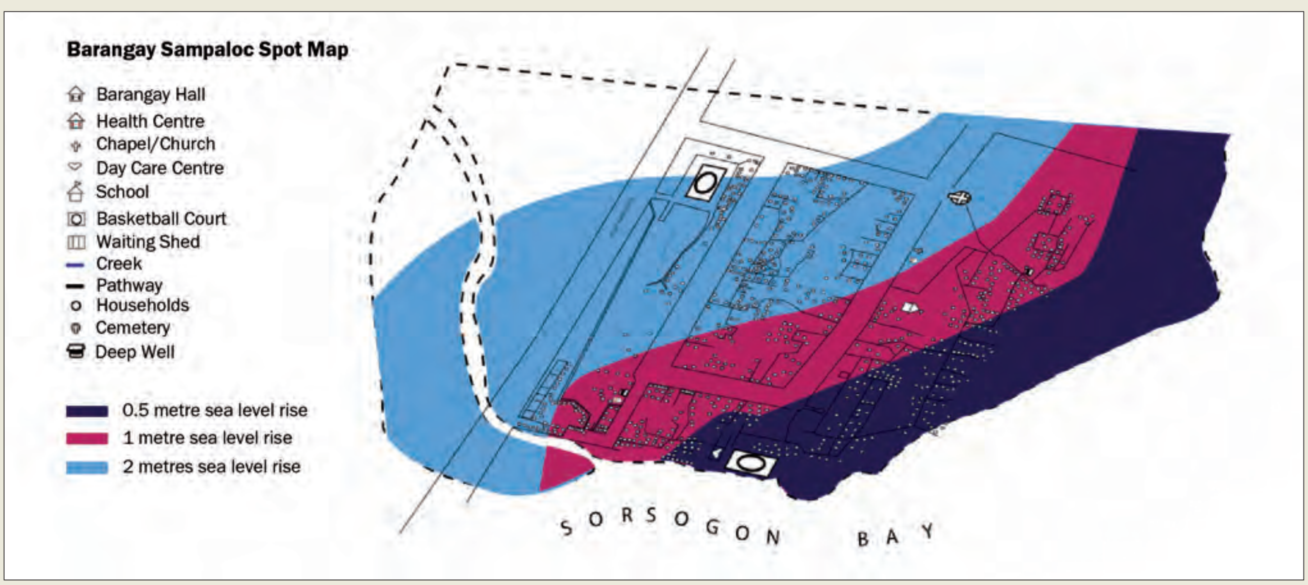
Obtaining climate change projections and trying to apply them at the local level is a challenge that urban planners and local officials must increasingly confront. Planners disagree about whether current projections are adequate. Among the more sanguine are the authors of the World Bank's Framework for Urban Climate Risk Assessment, who conclude that: "relatively straightforward downscaling of global climate model simulations provides ample information for assessing urban-scale vulnerability and risks, at least in initial stages".[1] Of the contrary opinion are urbanists such as David Dowall of the University of California, Berkeley, who states flatly that the 'biggest problem' with current climate projections is that they: "are too gross-grained for planning purposes".[2] Still others have been frustrated not so much with the scale of projections but that some models disagree as to the basic direction of climate change impacts for a given locale.

Research is presented here from the practical field perspective of urban management practitioners who are users or consumers of climatological information at the local level, rather than climatologists. It is based on the initial efforts of the Cities and Climate Change Initiative (CCCI) of the United Nations Human Settlements Programme (UN-HABITAT), to assist four pilot cities to help vulnerable populations adapt to the impacts of climate change and/or reduce greenhouse gas (GHG) emissions.[3] Information needs and available planning tools vary, depending on the type of climate change phenomenon under discussion. This report is intended to afford scientists insight into priorities for refining relevant projections and their application by urban users.

Cities and Climate Change Initiative pilot cities

Currently the CCCI is working in four cities in different regions of the developing world. Two of these are intermediate in size (one to five million inhabitants), while the other two are small (100 to 500 thousand inhabitants). In devising approaches to address climate change, these cities represent an important target population: the world is mostly urban, and more than 75 per cent of the urban population lives in cities in those size

Sorsogon City: SLR simulation relative to area elevation projected against Barangay Sampaloc base map

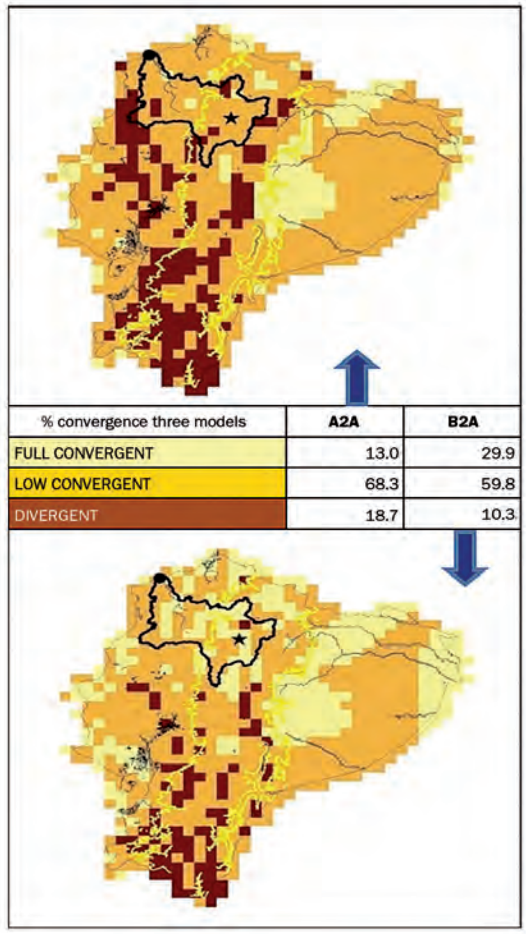


Source: UN-HABITAT, Climate change assessment for Sorsogon City, the Philippines, 2009 ranges.[4] Residents of CCCI cities face a gamut of climate-related stresses and risks:

- Kampala (population 1,654,000) — an inland city, is the capital of Uganda. An estimated 45 per cent of residents live in low-lying areas at risk of flooding
- Maputo (population 1,094,000) — is the capital of Mozambique. In 2000, cyclones and torrential rains inundated this coastal city, killing 700 people and wreaking USD600 million in property damage. In recent years the region has also suffered from drought
- Esmeraldas (population 195,000) — is a coastal city in Ecuador. Planners estimate that almost 60 per cent of the population lives at medium-to-high risk of flooding or landslides
- Sorsogon City (population 151,000) — lies at the southern tip of Luzon, the largest island in the Philippine archipelago. Cyclones have buffeted this coastal city in recent years. In 2006 Typhoon Milenyo affected around 27,000 families and severely damaged 10,000 houses.

Climate change is likely to further impact these cities in the coming decades. CCCI teams are helping local stakeholders to assess impacts and vulnerabilities, and devise adaptation and mitigation strategies and demonstration projects. As of July 2009, all four are still in an early stage of assessment. The teams begin by assembling historical data regarding flooding and landslides, then review available projections, including those found in the Contribution of Working Group II to the Fourth Assessment Report (AR4) prepared by the Intergovernmental Panel on Climate Change (IPCC). Teams additionally gather available regional or national projections. CCCI teams are in the process of overlaying that data upon local-level geographically-referenced information regarding land use, populations and infrastructure, to preliminarily gauge vulnerabilities. This technical analysis occurs alongside, and informs, consultations with stakeholders — this process will lead to strategic plans for priority actions.

Comparison of three climate models under two emissions scenarios in Ecuador



% convergence three models	A2A	B2A
FULL CONVERGENT	13.0	29.9
LOW CONVERGENT	68.3	59.8
DIVERGENT	18.7	10.3

Source: UN-HABITAT, Climate change assessment for Esmeraldas, Ecuador, 2009

Applicability of urban management tools to climate change phenomena

Officials can use different types of urban management tools to address various climatological phenomena. Broad types of tools and specific examples include:

- Planning — a general plan that guides a city's long-term growth
- More specific development regulations — a zoning ordinance that defines what types of land use can occur
- Property acquisition — a decision to purchase undeveloped lands due to a public interest
- Public infrastructure and facilities — a resolution regarding the siting of a water treatment plant
- Building standards — a code that promotes energy efficiency.[5]

These tools have different applications in relation to impacts. Building codes can address increases in mean temperature, zoning regulations can respond to sea-level rise (SLR), and so on. A much more robust suite of tools exists for addressing certain types of phenomena (such as storm surge) than others (such as heat waves).[6]

Findings regarding the use of climate change projections for urban management

Climate change projections must be sufficiently precise, and of a sufficient level of confidence, that officials can apply an appropriate urban management tool to effectively address the impact in question. Meeting this threshold of adequacy means that officials will be able to explain risks to constituents, build political support for appropriate measures, and defend approved legislation against legal challenge.

Rather than pointing towards sweeping conclusions as to whether projections are adequate, the CCCI's initial experience in pilot cities is yielding a more nuanced answer. First, projections regarding GHG emissions are adequate for planning mitigation measures. Projections have been of a sufficient degree of confidence to jolt the international community into setting up carbon finance mechanisms — these can finance projects that will contribute to net reductions. The desire to implement such projects is likely to be the immediate driver for cash-strapped cities with regards to mitigation, and current climate projections are adequate for that purpose.[7] A number of cities have calculated baseline GHG emissions and committed themselves to reductions at the city, project or building level.[8] No further refinements of global or regional models are required to take such actions. Unfortunately, however, it is adaptation and not mitigation that is the pressing concern, and here the record is more uneven.

Housing at risk of flooding in Kampala, Uganda

In devising urban adaptation responses, it is helpful first of all if projections agree on the direction of future change and with local historical trends. Such a consensus provides the basis for at least initial planning activities. This is generally the case with SLR. In Sorsogon City the team found that observations taken since the 1970s at a nearby tidal gauge station revealed a gradual increase in mean sea level. IPCC AR4, of course, shows this trend as continuing. Based on such inputs the CCCI team was able to preliminarily map the vulnerability of barangays (villages) and public facilities to different levels of sea-level rise. These simple vulnerability maps for 'hotspot' barangays have proven sufficiently detailed to open discussions with stakeholders — many of whom could pinpoint their houses on such maps — regarding options for adaptation measures. Action should be possible even though projections do not fully agree as to the likely rate or extent of sea-level rise in the future.[9]

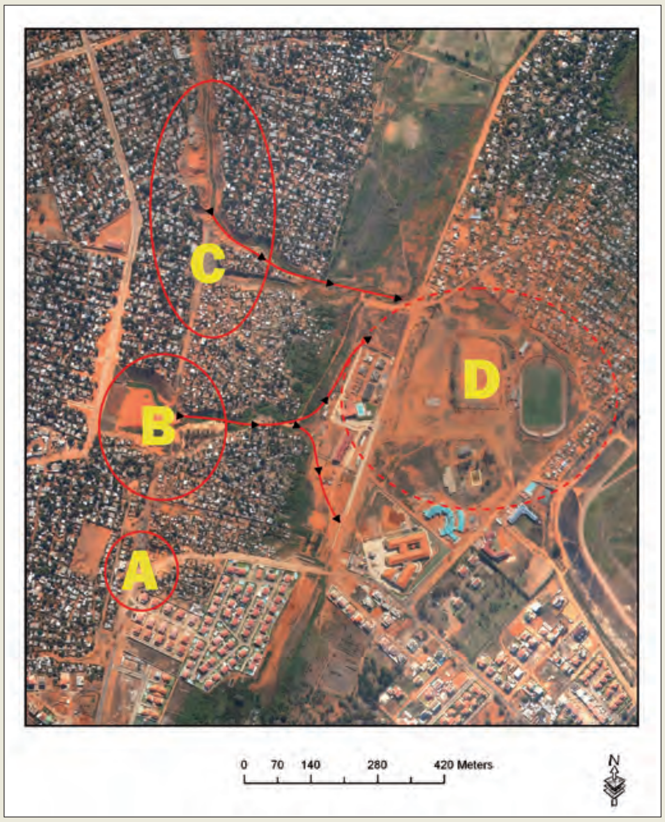
Even when projections diverge as to the extent or even the direction of a climate change impact, city officials may still be able to take action if a national government publishes a reasonable official or quasi-official projection. When downscaled to the local level, an officially endorsed scenario may give local decision-makers sufficient backing to act. On the other hand, if ministry representatives announce that such projections are forthcoming, local planners may prefer to wait rather than implement a legal measure whose technical basis might be undercut later. Such concerns account for a current delay in Sorsogon City, where the CCCI team and local planners are standing by for updated national-level projections of natural hazards that are reportedly immanent.[10]

Effective city-level action is most difficult where projections of impacts do not agree on direction, and there is no logical official position. This has been the experience in Ecuador. Five relevant climate simulation models were identified and compared. While these models agreed on some projections, for example a general increase in temperatures, they were divided on others. Two project that Ecuador will become drier in the future, while three project a wetter climate.[11] Such divergences occur regardless of the fact that the models in question were relatively fine-grained, with resolutions of 10-40 kilometres.

This sort of contradictory projections place local-level planners in an awkward position.[12] The only tenable urban management solutions involve focusing either on current priorities regardless of the future, and/or on those phenomena where greater consensus exists as to future conditions. In general, however, there is no dearth of opportunities for action in cities in the developing world — for example Kampala, where nearly half of homes currently lie in flood-prone areas.

For certain types of planning decisions, even though current projections may converge at a relatively fine scale, additional localized hydrological modelling is recommended. This is the case for the siting and design of certain critical infrastructure improvements such as: port facilities, sea walls as bulwarks against increased storm surge and roads and bridges to accommodate riverine flooding. In Maputo, heavy rains in 2000 led to the flooding of important low-lying areas of the city. Officials put the damage at USD12.8 million — reconstruction under future climate scenarios could drive costs even higher. Where relatively expensive infrastructure investments are involved, and facility design will not permit incremental engineering improvements, localized hydrological modelling becomes crucial for finalizing

Detailed mapping of road interruptions and damages along Avenue Julius Nyerere, Maputo



A: New trajectory of Avenue Julius Nyerere and alternative way to Avenue Marginal Maputo. B: The point where the bridge fell down and evident source of soil erosion during the rainy season. C: Second point of the avenue interrupted. Pavement damaged and source of soil erosion during the rainy season. D: Confluence zone of material, soil erosion and water during the rainy season and infrastructures of Costa do Sol Stadium use to be affected

Source: UN-HABITAT, Climate change assessment for Maputo, Mozambique, 2009

specifications. Such modelling should inform more long-range urban management applications, such as definition of lands that will be at risk of flooding and are to be covered by a hazard setback ordinance.

For other sorts of climatological phenomena, while climate change projections generally agree, taking action seems to be a low priority for local decision-makers. This is the case with addressing projected heat or cold waves, as well as mean temperature rise. While responses such as modernized building codes are possible, to date such measures have not attracted priority attention in the CCCI countries. This is because other issues such as flooding are seen as more urgent – despite the real havoc that heat or cold waves can cause (the heat wave that struck western Europe was blamed for killing more than 35,000 people). At present none of the pilot cities are planning to undertake more sophisticated localized modelling of temperature change, such as taking into account radiation from asphalt and paved surfaces.

Implications for the World Meteorological Organization and partners

Research leading to a higher level of convergence among projections is a priority. This is particularly the case where localized projections disagree as to the direction of change, as the CCCI team in Esmeraldas found with projections for mean precipitation. However, different models will always yield somewhat different results, so increased capacity-building for officials and urban managers as to how best to pick and choose between conflicting projections when this issue materializes would be of great assistance.

Establishing and operating meteorological stations that collect data of adequate quality and quantity is important. Several decades of trends of changes in temperature, rainfall, mean sea level and similar phenomena help local decision-makers to convince a sceptical public about the risks. They also serve as an important reference point when taking up regional climate projections. Furthermore, local weather stations need to be able to support urban or river basin-level hydrological modelling with adequate data. Efforts at local modelling and subsequent risk and vulnerability mapping run into difficulties if only one local station is actively collecting data, and where daily but not hourly rainfall data are available.[13]

Some actions, from the perspective of mid-sized cities in the developing world, appear to be of lower priority. Researchers suggest that much work remains to be done to generate site-specific urbanized data, by developing advanced models based on computational fluid dynamics.[14] However, to the CCCI cities such sophisticated modelling (particularly where the outputs would focus primarily on improved projections of mean temperature and heat waves) would be a lower priority than an improved hydrological model of the city. This is because a family will be more concerned as to whether their house will be swept away due to flooding than about a more precise projection of future temperature rise.

Future scenarios

In an uncertain world, local officials and planners crave certainty upon which to base decisions. Where such certainty is not possible — as it rarely if ever is — officials at least desire clear future scenarios that they can understand and explain to constituents. When making decisions planners have often sought out vulnerability assessments based on a clear future scenario (a 100 year flood event), rather than full-blown probabilistic analyses of various risks. Full-scale risk analyses have not been used extensively for planning purposes, possibly because planners and local officials are less familiar with these concepts and methods, and because of the relative paucity of land use management tools based on risk rather than vulnerability.[15]

This preference for certainty is as deeply, if not more profoundly, felt in the new and relatively unfamiliar terrain of climate change. UN-HABITAT welcomes the recent surge of interest in the urban dimension of change, for example the upcoming IPCC Expert Group Meeting that will take up the topic, and a special report on human settlements being prepared for the IPCC's fifth annual meeting. UN-HABITAT's hope is that such research will lead to projections that are more useful to practitioners at the city level, and that will allow planners to embrace a fuller range of tools to address climate change in all of its various manifestations.[16]

AsiaFlux — sustaining ecosystems and people through resilience thinking

Joon Kim, AsiaFlux Main Office, Global Environment Laboratory, Yonsei University, Korea;
Yu Guirui, AsiaFlux Beijing Office, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science; Akira Miyata, AsiaFlux Tsukuba Office, National Institute for Agro-Environmental Sciences, Japan

There are very few people in this world who ever ask the right questions of science, but they are the ones who affect its future most profoundly. Great thinking precedes great achievement and the right question gives birth to a vision that is greater than the visionary. Vision is the key to unity, the magnet for commitment, and the determinant of our destiny.

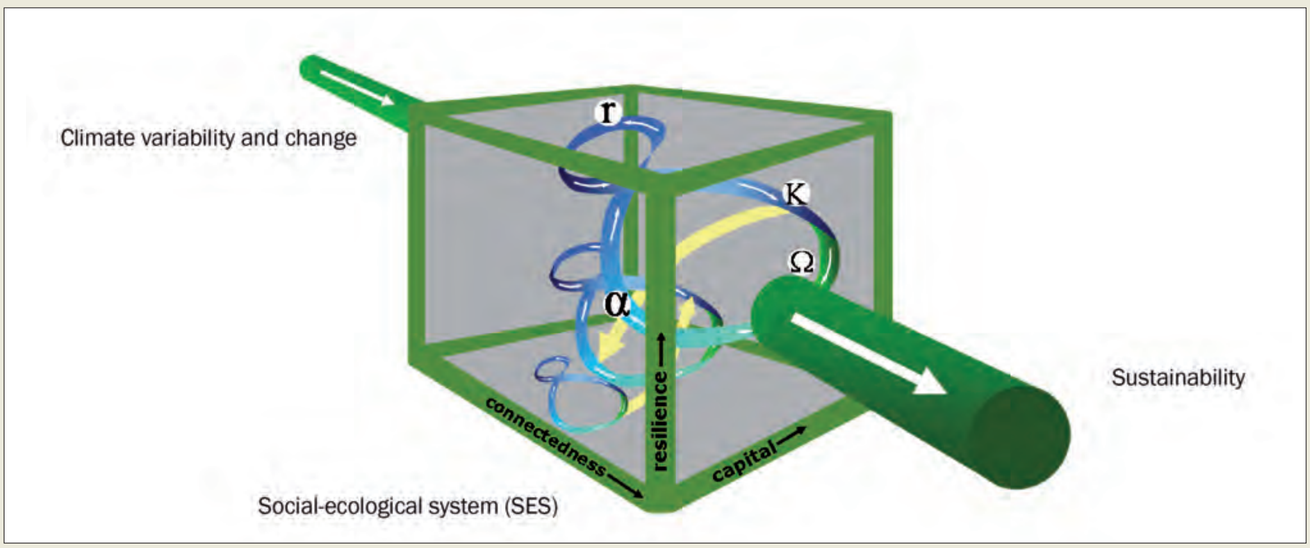
The vision of World Climate Conference-3 is a global framework for climate services that link climate predictions and information with risk management and adaptation, towards sustainability. What does it mean to be sustainable? What kind of management and adaptation do we need towards sustainability? Even more important questions would be sustainability of what and to what? Why are current approaches to sustainable natural resource management failing us despite a plethora of information? Are we properly acknowledging how the world actually works?

Defining and understanding the system

Some available definitions of sustainability are:

- The use of environment and resources to meet the needs of the present without compromising the ability of future generations to meet their own needs
- The likelihood an existing system of resource-use will persist indefinitely without a decline in the social welfare it delivers
- A cultural adaptation made by society as it becomes aware of the emerging necessity of non-growth.

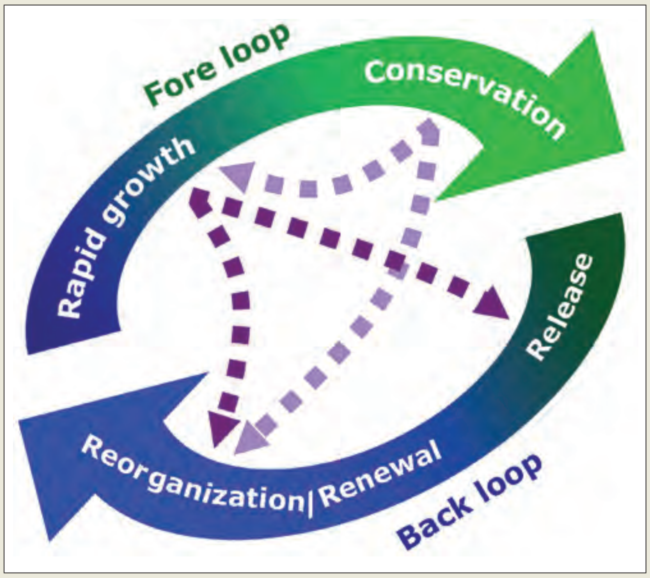
Social-ecological system with the focus on adaptive capacity for sustainability



At each scale, the social-ecological system moves through its own adaptive cycles. These recurring cycles consist of four phases: rapid growth (r), conservation (K), release (Ω), and reorganization/renewal (α). The adaptive cycles are pictured in three dimensions: (1) X axis — the degree of connectedness among controlling variables; (2) Y axis — the capital (or potential) that is inherent in the accumulated resources; and (3) Z axis — resilience, the capacity of a system to absorb disturbance and remain within the same regime, retaining the same function, structure, and feedbacks. The structure and dynamics of the system at each scale is driven by a small set of key processes and, in turn, these linked set of hierarchies govern the behaviour of the whole system

Source: Gunderson and Holling (2002) and Berkes et al. (2003)

A simple representation and variants of the adaptive cycle



Source: Adapted from Walker and Salt (2006)

These definitions make clear that sustainability is not an end product but a dynamic process that requires adaptive capacity for social and ecological systems to deal with change. Here, a dynamic process features the relationships between the motion (towards sustainability) and properties of a complex system, (social and ecological systems) and the forces (climate variability and change) acting on it. When considering the earth climate system, a complex social-ecological system, it is important to consider it as a whole. This 'human-in-ecosystems' (not human-and-ecosystems) perspective is a way to think about the relationship between nature and society and all the interfaces between the two.[1]

Worldview and global trajectory

Worldview is a term taken from the German weltanschauung, meaning 'look onto the world'. It refers to the framework through which an individual interprets the world and interacts in it. It is communal in scope and structure, and provides a view by which the world can be ordered and illumined. A diversity of worldviews linked to cultural diversity and evolution provides social-ecological systems with the ability to persist in the face of change. Such social and ecological memory bridges the values and truths of a society and the social-ecological environment. In opposition, modern belief systems and institutional frameworks seem to create homogenized and optimized social-ecological systems. Such systems lack diversity and the capacity to adapt to change and crisis, thereby creating their own vulnerability.

The consideration of worldviews naturally leads us to another important question of global trajectory, namely, whether humanity at the global scale is currently on a sustainable or unsustainable path. As was pointed out by the global think tank 'the Club of Rome' almost four decades ago, the current global trajectory is unsustainable for both ecological and social systems.[2] More recently, the Stern Review of the Economics of Climate Change provided rigorous analysis of the costs and risks of climate change, and of reducing greenhouse gas emissions.[3] While the details are still debatable, the main thrust of the report is clear and compelling — the expected benefits of tackling climate change surpass the expected costs. The question is no longer whether we can afford to act, but whether we can afford not to. And yet, with less than six months to go to Copenhagen and little communal action, most countries are hesitant to move forward.

Lance Gunderson and C.S. Holling condensed the major obstacles to sustainability into the lack of three basic categories: understanding of the dynamics of complex systems; willingness to implement; and capacity to perform the actions and changes needed.[4] The pursuit of services linking climate information with management and adaptation towards sustainability pose new challenges to the ways we define problems, identify solutions and implement actions.

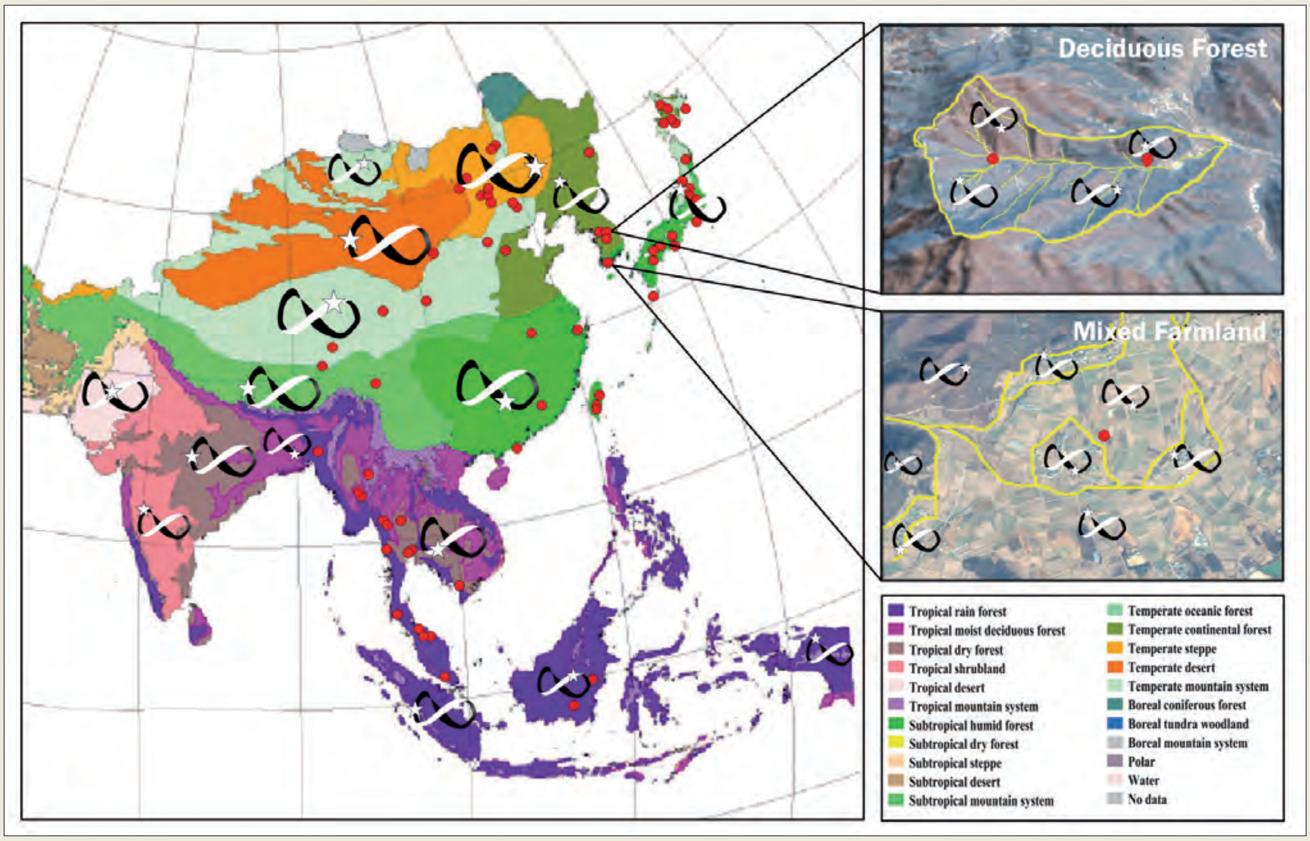
Resilience thinking

C. S. Holling and his colleagues offer a new paradigm, the idea of resilience as a potential organizing concept and scoping device for understanding and managing our social-ecological systems.[5] They define resilience as the amount of change a system can undergo before it crosses a threshold and flips to an alternate stability regime of that system. In resilience thinking, three main concepts need to be recognized. Firstly, complex adaptive systems are self-organizing. Secondly, these systems are non-linear in their trajectories of change, which leads to their potential for alternative stability regimes. Third, and finally, such systems go through adaptive cycles that describe a repeated process of four phases: rapid growth (r), conservation (K), release (Ω), and reorganization and renewal (α).[6]

During the r phase resources are readily available and species or actors exploit niches and opportunities. During the K phase, resources become increasingly locked up and the system becomes less flexible and responsive to disturbance. When the Ω phase is reached disturbance causes a chaotic unravelling and release of resources. In α phase, system boundaries become tenuous. New species, actors, and ideas can take hold, and generally lead into another r phase. Taken as a whole, the r to K transition is referred to as a fore (or development) loop, whereas the Ω to α transition is referred to as a back loop. Most systems move through this sequence of phases, but other transitions are possible. The back loop, characterized by uncertainty, novelty, and experimentation, is the transition time of greatest potential for the initiation of either creative or destructive change in the system.

Resilience thinking captures the dynamic nature of the world. It recognizes the dangers of optimizing for particular states or products of a system, and explains why current approaches to managing resources are failing. It focuses on how the system changes and copes with disturbances, not only anticipating and responding but also creating and shaping them. Successful management and adaptation for social-ecological

Tower flux observation sites in AsiaFlux in different plant functional types in different phases



The various adaptive cycles illustrate that ecological and social memory is maintained in the system through the presence of different functional groups in different phases. Two local sites, a deciduous forest (right top) and a mixed farmland (right middle), are shown to highlight the importance of integrating cross-scale ecosystem knowledge with social practices and the historical profile of disturbances (e.g., drought, fire, typhoon, and land use change)

Source: AsiaFlux (www.asiaflux.org) and Mizoguchi et al. (2009)[12]

sustainability requires resilience thinking — institutional capacity to respond to environmental feedback, to learn and store understanding, and be prepared and adaptive to allow for change. In a nutshell, resilience is the key property of sustainability and the measure of vulnerability and adaptability.[7]

AsiaFlux — science frontier

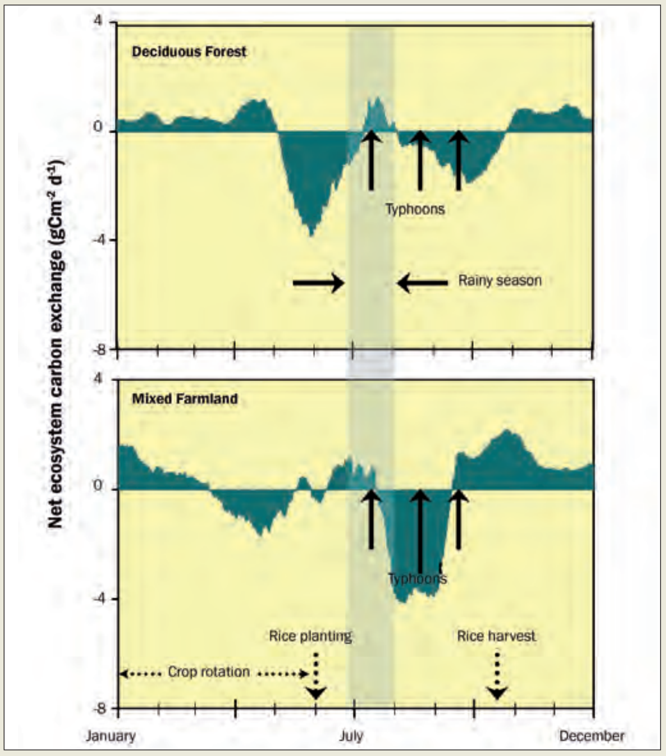
AsiaFlux is a science community with a mission to 'bring Asia's key ecosystems under observation to develop and transfer scientific knowledge to ensure sustainability of life on earth'. It is the Asian arm of Fluxnet, the worldwide flux research network, and one of the key components of the Global Earth Observation System of Systems (GEOSS). The GEOSS vision is to provide the right information to the right people at the right time to make the right decisions. The purpose of AsiaFlux is to develop collaborative research and data sets on the cycles of carbon, water, and energy in key Asian ecosystems. It also aims to provide workshops and training on current and related global climate change science and technology. Finally, AsiaFlux seeks to cultivate the next generation of scientists with skills and perspectives to address global climate change as informed leaders and stewards.

AsiaFlux has grown from a small network of independent flux monitoring groups in 1999 to a multi-national science community with 449 members from 28 countries. Currently, there are 109 tower flux observation sites in Asia and more sites are on the way. The biomes covered in AsiaFlux range from rainforest near the equator to tundra in the Arctic and Antarctic, and from wetland near sea level to grassland in high altitudes such as the Tibetan Plateau.

AsiaFlux celebrated its ten-year science, service, and stewardship in November 2008 by hosting the 7th International AsiaFlux Workshop in Seoul, Korea. During this workshop, 'Re-thinking global change science: from knowledge to policy', the refined vision of AsiaFlux was launched to serve as 'science frontier' in carbon, water and energy cycles. It aims to develop and transfer scientific knowledge characterized by:

- Consilience — the synthesis of knowledge in holistic, exploratory, pluralistic and perspectival ways
- Contextualization — the reformulation of scientific knowledge in social and pedagogical context by embracing its implications as well as the applications
- Cultural diversity — building resilience by welcoming diversity and conflict, tolerating ambiguity, and embracing paradox through teaching and learning.

Net ecosystem carbon exchange (NEE) in a deciduous forest and a mixed farmland in Korea



Positive NEE indicates carbon release and negative NEE indicates carbon uptake. Terrestrial ecosystems are strong sinks of atmospheric CO_2. Climatic disturbances such as monsoon, typhoons and management practices can, however, dramatically change the ecosystem processes and feedbacks

Source: KoFlux (www.koflux.org)

Embracing resilience thinking

The idea of resilience thinking is deceptively simple, but its application has proven profound and there is much to learn. Walker and Salt[9] suggest a resilient world would be characterized by:

- Diversity — promoting and sustaining all forms of diversity (biological, landscape, social and economic)
- Ecological variability — embracing and working with ecological variability rather than attempting to control and reduce it
- Modularity — consisting of modular components
- Acknowledging slow variables — having a policy focus on slow controlling variables associated with thresholds
- Tight feedbacks — possessing tight feedbacks, but not too tight
- Social capital — promoting trust, well developed social networks and leadership
- Innovation — emphasizing learning, experimentation, locally developed rules and embracing change
- Overlap in governance — having institutions that include redundancy
- Ecosystem services — including all the unpriced ecosystem services in development proposals and assessments.

Folke et al. proposed four principles for building resilience: learning to live with change and uncertainty; nurturing diversity for reorganization and renewal; combining different types of knowledge for learning; and creating opportunity for self-organization.[9]

Overall, building resilience will require dynamic interplay between diversity and disturbance, along with recognition of cross-scale dependencies. Resilience thinking encourages scientists and practitioners to work together with the public to produce trustworthy knowledge and judgment that is scientifically sound and socially robust. The science, service, and stewardship of AsiaFlux are complementary with resilience thinking. It provides qualitative monitoring, management, and long time series of local observation and ecological and social memory for understanding ecosystem change throughout the adaptive cycle.

AsiaFlux entering the agora

By 2011 AsiaFlux hopes to provide a report on the Asian carbon and water budget and develop infrastructure for an Asian carbon and water tracking system. Furthermore, it aims to develop a synthesized measurement and modelling system that keeps track of emissions and removal of CO_2 and H_2O in Asia. Reliable knowledge can become socially robust only if society perceives the production process to be transparent, open and participative. This, in turn, depends on reciprocity in which the public understands how climate change science works but, equally, climate change science understands how the public works. The AsiaFlux vision will guide such enhanced mutual understanding and communicate and demonstrate it by embracing resilience thinking.

AsiaFlux will continue to create space to deal with emerging paradigms for re-thinking science processes such as cultural boundaries and authority of climate change science, its co-evolution with risk society, context-sensitive science, and the challenge of nurturing diverse functional groups.[10] The latter may include: knowledge carriers and retainers; interpreters and sense makers; networkers and facilitators; stewards and leaders; visionaries and inspirers; innovators and experimenters; entrepreneurs and implementers; and followers and reinforcers.[11] Such efforts guide AsiaFlux to enter a new community space, the agora. The agora was an open place of assembly in ancient Greek city states, where citizens would gather for military duty, to hold markets or to hear statements of the ruling king or council.

This October in the beautiful city of Hokkaido in northern Japan, AsiaFlux will host the 8th AsiaFlux Workshop on 'Integrating cross-scale ecosystem knowledge: bridges and barriers'. The workshop consists of a regular science session and many special sessions such as 'CarboEastAsia', 'Global biogeochemical cycles', 'Bridges between ecosystem observation and remote sensing', 'Barriers in flux measurements', and 'Interfaces between carbon science and society'. These sessions consist of a diversity of individuals, workgroups, institutions, and organizations with different but overlapping roles within and between critical functional groups, thereby building resilience. The workshop will not only bring students, scientists, technologists, capitalists, entrepreneurs, diplomats, and policy-makers together, but also help us cross cultural, disciplinary, geographic, and hierarchical boundaries. Thus, we invite all to our new community space in which science meets and interacts with others and where interests, values, and decisions are discussed, fought over, and perhaps settled. Welcome to the AsiaFlux agora.

Research, implementation and use of climate information in mountainous regions: a collaboration between Switzerland and Peru

C. Huggel, N. Salzmann, L. Angulo, P. Calanca, A. Díaz, H. Juárez, C. Jurt, T. Konzelmann, P. Lagos, A. Martínez, C. Robledo, M. Rohrer, W. Silverio, M. Zappa[1]

Fragile ecosystems, rapidly retreating glaciers, threatened water resources, extreme events and disasters in harsh environments, as well as demanding livelihood conditions make mountain regions particularly vulnerable to ongoing climate change. For many developing countries adequate response and short- to long-term adaptation strategies to climate change will be the big challenges over the coming decades. However, overcoming these challenges will also be fundamental to the future existence of many societies in mountain regions. The Andes in Peru is expected to be seriously affected by climate change.[2] The Swiss and Peruvian governments have therefore joined forces — through the Swiss Agency for Development and Cooperation and the Ministry of Environment, respectively — to improve the scientific baseline for climate change adaptation, and to implement an adaptation programme in the Cusco and Apurímac regions of the Peruvian Andes. The Programa de Adaptación al Cambio Climático (PACC) was initiated in 2008 and is implemented by a non-governmental organization consortium including Intercooperation, Predes and Libélula. The programme is also supported by Peruvian and Swiss scientific institutions. The Swiss consortium is led by the University of Zurich and includes: Meteoswiss; Meteodat; Agroscope Reckenholz-Tänikon ART; the Swiss Federal Institute for Forest, Snow and Landscape Research WSL-SLF; and the University of Geneva.

The PACC focuses on three major thematic lines: disaster risk reduction; water resource management; and food security. This allows for an important integrative research approach across several sectors. Climate change impacts and adaptation is highly complex, both on a scientific and implementation level. The main reason for this is that impacts affect different ecological services and socioeconomic systems, vary in related feedback effects, and occur in a multi-actor environment through different levels of social and political systems. International collaboration is needed to address these key problems. The Peruvian-Swiss collaboration aims to improve the baselines of expected climate change impacts on the regional and local level, in order to enable better planning and implementation of effective and socially consistent adaptation measures.


Image: M. Rohrer

Ground stations in the Andes are often maintained by local people

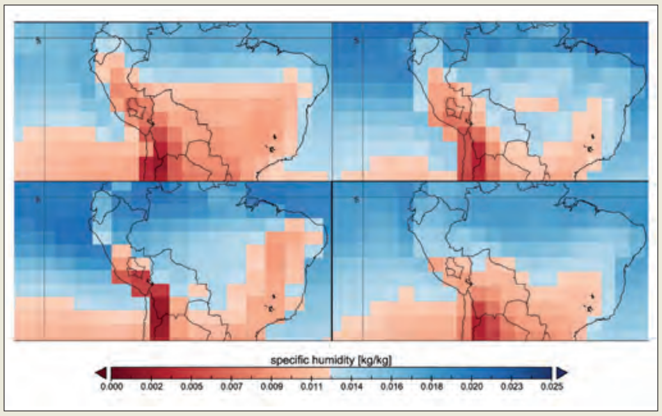
Observed and projected climate impacts in the Andes

Cusco and Apurímac are Andean regions in the south of Peru between approximately 3,000 and more than 4,000 metres above sea level, with mountain peaks rising over 6,000 metres above sea level. The combined population of both regions is around 1.5 million, with about 40 per cent suffering from malnutrition and over 75 per cent are without basic needs. Poverty-related problems are particularly pronounced in rural areas. As a consequence, there is limited adaptive capacity to the adverse effects of climate change.[3] The Andean regions of Peru have two distinct seasons, a rainy period in austral summer and a dry period in austral winter. During the dry season, many of these regions rely on glaciers as a primary water resource. As such, indigenous rural people are observing the glacier retreat of the past decades with increasing concern.[4]

However, glacier retreat and changing water resources is not the only evidence of climate change impacts in the region. The picture is far more complex. Extreme climatic events such as cold waves have been observed to strike more severely in recent years. The rural population, in particular, is badly affected by loss of crops and cattle caused by cold waves and droughts. Drought intensities range from moderate to severe for time periods of 1, 3 and 12 months, especially in the south Andean regions of Peru.[5] In addition to slow-onset climatic disasters, the magnitude and recurrence of rapid geomorphic hazards, such as landslides, may be altered due to climate change.

Past and present climate trends, as well as future projections, are not understood in sufficient detail for

An example of climate projections. Mean specific humidities are shown for June 2046-2065 for South America



IPCC-AR4 based results from four Global Circulation Models lack detail as to whether the dry austral winters in Cusco and Apurímac will be even drier in future

Source: IPCC

the Peruvian Andes. This due mainly to the region's strong incidence of natural climate variability. In general, a temperature increase of up to 0.3°C a decade has been observed, but this pattern is not homogeneous.[6] For the Urubamba catchment in Cusco the temperature has increased by about 0.4°C a decade.[7] Furthermore, annual precipitation shows a decreasing trend for the southern Peruvian Andes over the last five decades, but the trend is less clear on a monthly or seasonal basis.[8] Trends for extreme precipitation events have not yet been sufficiently analysed, while climate projections for the region still bear considerable uncertainties as well.[9] Hence, there is a strong need to improve the scientific baseline concerning the type and magnitude of climate change impacts on the local and regional level using appropriate downscaling methods. Thorough analysis of existing long-term climate series should be a fundamental part of any impact assessments. Because of this, the typically poor data availability for the Andean regions proves an especial problem — emphasizing the importance of improving current monitoring networks and integrating additional data sources — such as satellite data.

Climate information for improved adaptation

The PACC takes an interdisciplinary and interinstitutional approach. The analysis of cross-sector effects through the thematic lines of water resources, food security and natural disasters is thereby important. The human dimension is integrated in this concept to allow for a more complete view on vulnerabilities to climate change. A better understanding of people's perception of climate change — its risks and potential adaptation strategies — as well as their perception of different local, regional and national actors will enable improved design of adaptation mechanisms. It is particularly important to maintain an integrative perspective in this context, because the impacts of climate change are multiple and their severity, potential damage and cost need to be analysed in an integrated framework. Corresponding methodologies, however, are poorly developed on the local level and therefore need to be advanced. The interdisciplinary approach and multi-actor environment encompassed by the PACC represents both its strength and complexity. The PACC represents a major opportunity to improve the dialogue between the scientific community, implementing agencies and practitioners, and the political and community levels to find more sustainable mechanisms of climate change adaptation.

In this context, climate information and related dissemination plays an essential role in the PACC. On the level of the regional governments — and especially on the level of local governments — important gaps have been identified with respect to information on climate, climate change and related impacts. Access to, and adequately prepared analysis of, climate information is key for short-term response as well as in the longer-term sustainable design and implementation of adaptation measures. New and improved early warning systems, for instance, may help farmers take early measures against upcoming droughts, or prepare themselves before immediate hail events. One of the challenges in this context is a smooth line of information and communication from the relevant national institutions to the regional agencies, and eventually to the local level. The PACC is thereby in a particularly promising position since it involves all these levels.

However, preparation and communication of relevant and useful climate information by scientists for end-users is complex and spans several levels. This can be illustrated by the contrast between a scientific climate modeler producing scenario runs, and an indigenous herdsman in the Andes who may need climate information tailored to his needs, and possibly even more importantly, to his cultural and social context. Without a deeper knowledge of the local cultural context it is nearly impossible for the climate modeler to produce the right kind of information. It is vital to include the human dimension in the process of climate information and communication. While climate projections, such as the example above, may be important for a climate scientist, for a local farmer in the Andes they are not. The spatial resolution is much too coarse and the time horizon of several decades too far ahead, and essentially, he is not able to interpret such a graphic. The inability to interpret this kind of graphic may also apply for authorities in local or regional governments. In fact, recent studies in Peru have shown, that on the level of regional governments there may exist a gap in understanding climate change information, such as future climate projections.[10] The traditional knowledge of local communities on past climate change, as well as related adaptation experiences, can be important to consider for current and future adaptation. However, climate is increasingly changing beyond the historical experience of local people and it therefore needs to be investigated carefully how best to use traditional adaptation strategies in the face of new challenges.

A further difficulty is the communication of uncertainties that are inherent to climate times series, climate projections and climate change impacts. The difficulty pervades communication at several levels, from science to international and national policy levels, to the public and the local level. In climate science uncertainties have been an important issue for quite a while, but they have only recently been systematically approached in the field of climate change adaptation.[11] The key for adaptation projects such as the PACC is to find adaptation measures that are robust against uncertainties but feasible to implement.

An overview of the European Community climate research programme

José Manuel Silva Rodríguez, Director General, DG Research, European Commission

Climate change is happening and represents one of the greatest environmental, social and economic threats the planet is facing. The overwhelming scientific evidence gathered on the causes of climate change and possible response measures urges us to act. The European Union (EU) is leading the way by both taking ambitious action on its own and through its commitment to working constructively for a global agreement aimed at controlling climate change.

The EU's objective is to ensure that global average temperature does not increase above 2°C over pre-industrial levels. To achieve this goal, global emissions of greenhouse gases must peak before 2020 and then decrease below 50 per cent of 1990 levels by 2050. The necessary cuts in global emissions can be achieved only if all countries contribute their fair share, according to their respective responsibilities and capacities. However, reducing greenhouse gas emissions worldwide will not be sufficient. Even if the global average temperature increase stays below 2°C, significant adaptation efforts will be required in many, if not all regions of the world.

The key priority for the EU is to achieve a successful conclusion to the international negotiations on a global agreement for the period after 2012 at the UN climate change conference in Copenhagen.[1] Reducing global emissions of greenhouse gases will require action by both developed and developing countries. Developed countries must take the lead and cut their collective emissions to a level 30 per cent lower than 1990 by 2020. The EU has set an example by committing to this reduction target, if other developed countries agree to comparable cuts. The EU has already adopted policy measures to reduce its own emissions by 20 per cent from 1990 levels.[2] The European Commission also published a strategy paper to foster policy action on adaptation to climate change.[3]

Such policy actions are only possible because they are built on solid climate science. Serious climate change impacts and risks have been identified, analysed and assessed, most notably in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). However, to ensure efficient and effective action, knowledge needs to progress further: in the understanding of the climate system; on the evaluation of the impacts of climate change; and on the identification and assessment of options for mitigation and adaptation. This endeavour requires and will continue to necessitate significant sustained support to research activities on climate change.

Climate research and observations activities at the EU level are undertaken within the Framework Programme of the European Community for research, technological development and demonstration activities.[4] European Community (EC) research funding complements research activities supported by the 27 Member States of the European Union and Associated Countries. EC-Framework Programme projects are characterized by: the involvement of a diversified set of research institutions based in the EC; their strong international dimension structuring the European Research Area; and by going well beyond European borders in terms of participation. The 7th Framework Programme (FP7), covering the period 2007-2013, is the world's most open research programme to international cooperation.

Climate relevant collaborative research under FP7 is mostly undertaken in four thematic areas. These are environment, energy, transport and global monitoring.

Environment

The objective of relevant activities under the environment theme is to improve our knowledge of the Earth system. This involves the enhancement of our capacity in observing and predicting the evolution of the climate system, improving the accuracy of climate information at regional and local levels as well as developing our knowledge on adaptation. This can be achieved through the 'downscaling' of modelling techniques and their application to smaller areas. Additional research focuses on integrating the physical and socioeconomic aspects of climate change in order to quantify its impacts and costs, and thus design more effective technologies and sustainable development strategies for mitigation and adaptation in Europe and beyond. This will help to further develop knowledge of vulnerability assessments and responses to natural climate-related disasters, as well as in the assessment of climate-induced changes on natural resources and impacts on human health.

Energy

Energy research activities support the development of a less resource intensive and carbon-emitting energy system to address the pressing challenges of energy supply and climate change. This involves improving energy efficiency throughout the energy system, accelerating the increase in renewable energy sources' share of the energy mix, reducing greenhouse gas emissions, decarbonising power generation and the transport sector.

Transport

The main objective is to promote the development of integrated, 'greener' and 'smarter' European transport systems

Environment research strengthens understanding and prediction of climate change, as well as our capacity to manage and adapt to it

in order to reduce greenhouse gas emissions and congestion. This involves 'greening' air transport by developing technologies to reduce the environmental impact of aviation, with the aim of halving carbon dioxide emissions from their current level. Surface transport can also be greener by developing technologies and knowledge to reduce air pollution (including emissions of greenhouse gases). Finally, research on the use of alternative fuels for transport, particularly hydrogen, is financially supported.

Space and global monitoring

Climate change can be monitored through Earth observation including from satellite systems. This involves developing appropriate satellite-based monitoring and early warning systems, for environment assessments and protection issues.

The European Commission has prepared an overview of completed and ongoing climate research projects funded since 2003 for World Climate Conference-3 (WCC-3).[5] The 134 EC-funded research projects included in this overview involve an overall budget of EUR543 million of EC funding. These projects contribute significantly to knowledge on climate change and its impacts through modelling and observations activities — including evaluation of the costs of response strategies (mitigation and adaptation). This research offers key contributions to the efforts launched by WCC-3 in moving towards science-based climate services and operational climate prediction.

Meeting the objectives proposed for the provision of climate services by WCC-3 will require significant further progress in knowledge on modelling, observations, impact and vulnerability assessments, research on adaptation, and also on the transition of research into the operational domain.

With regard to modelling activities, some remarkable projects funded by the EC such as DYNAMITE,[6] ENSEMBLES[7] and AMMA[8] have been instrumental in developing climate modelling capacities, improving climate forecasts, measuring their accuracy and addressing the regional aspects of climate projections. Results from these projects have played an important part in the preparation of the IPCC 4th Assessment Report. Further model developments are expected from a project recently started, COMBINE.[9] New projects with relevance to IPCC assessments take into consideration needs for the preparation of the IPCC 5th Assessment Report.

Regarding observations, the EC is a key supporter of major international initiatives such as the Group on Earth Observations,[10] and implements additional programmes

Precise and detailed forecasts of climate change consequences will require a further leap forward in understanding

such as Global Monitoring for the Environment and Security, which pioneers EU activities towards operational environmental services.[11] The Joint Research Centre of the European Commission also participates in important initiatives regarding capacity for monitoring and assimilating space-based climate change observations.

On adaptation to climate change the projects ADAM,[12] ClimateCost[13] and CCTAME[14] are providing innovative results and policy relevant outputs. The focus on research for adaptation has been strengthened in most calls for proposals in the activity 'Environment (including climate change).'

Currently, the progress in observation, climate modelling, impacts and vulnerability studies is not sufficient to meet the needs of operational climate services. The establishment of means for the provision of climate services as proposed by WCC-3 will need to set new foundations for the provision and use of science-based climate information and prediction. Precise and detailed forecasts of the consequences of climate change at temporal and spatial scales corresponding to the needs of society will require a further leap forward in understanding, as well as sustained efforts in climate research and observation.

One of the scientific challenges to be met is to develop the capacity for providing a seamless climate prediction system that can provide forecasts at all relevant timescales (seasonal, multi-annual, decadal and multi-decadal). The framework to be established aims to make such forecasts available on the geographical scale relevant to regional projections, vulnerability assessment and for the design of adaptation measures. Bridging the gap in the timescales covered by the model forecasts will require both extending medium-range weather forecast tools (mostly used for meteorological purposes) to longer timescales and increasing the accuracy of climate forecasts (from multi-decadal to decadal) over shorter forecasting periods. Such convergence would represent a big leap forward. It will require continued support to model development and the extensive use of models . It will also necessitate close collaboration between modellers and observation experts to ensure that simulations integrate the most recent and up-to-date data sets with the most relevant data assimilation techniques. From a user perspective, climate predictions need to be reliable in order to be useful. Therefore the measurement of model predicting skills is part of the overall challenge of the provision of climate services.

There is no silver bullet, no single mega-model that will bring all the responses needed. Progress will come from sustained collaboration between meteorologists, climatologists, impacts and vulnerability assessment scientists, and experts from other disciplines, including social sciences and the user community. From an institutional perspective, such endeavours can best be achieved through close collaboration between the EU and its Member States, and the relevant UN agencies, as well as by the structuring of various major initiatives through international research programmes. The European Commission has addressed, and will continue to address, the research needs posed by the provision of climate services. It will sustain its funding efforts and ensure that the research priorities identified by the high level taskforce of independent advisers established by the conclusions of WCC-3 are given due consideration.

World Climate Research Programme: the scientific foundation for climate information in the 21st century

Ghassem R. Asrar and Antonio J. Busalacchi, World Climate Research Programme

The World Climate Research Programme (WCRP) was established in 1980 under the joint sponsorship of the World Meteorological Organization (WMO) and the International Council for Science (ICSU). Since 1993 the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization has also sponsored the programme. The main objectives of the WCRP are to determine the predictability of climate and the effect of human activities on it. These objectives went on to serve as the foundation of today's adaptation and mitigation response strategies to changes in climate. Due to the WCRP, it is now possible for climate scientists to monitor, simulate and project global climate — in turn this information can be used for governance, in decision making and in support of a wide range of practical applications.

During the past 30 years, new disciplines of climate science have emerged that transcend the traditional fields of atmosphere, oceans and land sciences. Many of these new disciplines have led to routine seasonal to interannual climate predictions, as well as longer-term climate projections. In parallel with such studies of the natural fluctuations of the coupled climate system, coupled climate models driven by changes in the radiative forcing of greenhouse-gas emissions have also been developed. Such models provided the climate change projections that underpinned the assessments of the Intergovernmental Panel on Climate Change (IPCC) and the United Nations programme on atmospheric ozone depletion/recovery.

While climate is a global phenomenon, the effects of its variability are felt at lower levels, including region, city and community. Furthermore, climate change affects different sectors of the global economy — such as agriculture and food production, water resources and fresh water distribution, energy and transportation, leisure and tourism, and environment and health — in different ways.

The need for climate information by different regions and sectors must be taken into account when organizing a network of experts to carry out required research and assessments in the future. The international scientific community is adjusting its research, modelling and observational priorities to respond to this need as rapidly as possible. This change is also reflected in scientific coordination programmes such as the WCRP and the International Geosphere-Biosphere Programme. The goal is to have in place, by the middle of the next decade, regional assessments that are well organized and based on the best scientific understanding and knowledge available at the time. Further developing and sustaining this network of regional and local experts constitutes a major challenge, especially for less developed and developing regions of the world.

Managing the risks and benefits associated with climate will involve managing the entire continuum of activities relating to it. This process includes: observing and understanding the Earth's climate system; projecting and assessing climate variability and change for different regions and economic sectors; and ultimately delivering this knowledge to decision makers. Transferring knowledge gained from research to decision and policy makers stands a far greater chance of success if the scientific community coordinates its research with the development of alternative solutions for mitigating the adverse impacts (and realizing the full benefits of) climate change for different regions and economic sectors. Such a 'solution-based' approach requires greater coordination and integration by the WCRP and its sibling international research programmes. For example, tackling the anticipated changes in regional temperature and precipitation may require a different set of agricultural and food production practices to those used today. As such, climate expertise must be supplemented with agronomic expertise to assess which crops are most suitable for the emerging climate conditions, as well as to develop best practices for optimum production under such conditions.

The scientific foundation for climate prediction

The scientific foundation for today's climate prediction and projection techniques can be traced back to the physically-based numerical models of atmospheric and oceanic circulations created in the 1950s and 1960s. Over the subsequent few decades a major limiting factor was the lack of high quality, long-range climate observations. The advent of remote sensing and space-based Earth observations helped significantly to address this limitation. These observations provided the first global perspective of the Earth's atmospheric circulation and climate system. This, in turn, enabled global climate studies and the identification of the key physical climate system processes.

The idea of an international research programme on climate change came into being at the Eighth World

Meteorological Congress in May 1979 and lead to the formation of the WCRP. The major foci of the WCRP are understanding and predicting the climate system, and assessing the influence of human activities on it. In its 1984 Scientific Plan the WCRP identified the complexity and breadth of the scientific challenge at hand — recognizing clearly the role of radiation, clouds, the oceans, the hydrological cycle and the biosphere in the formation and variability of the Earth's climate. Oceans, land surfaces, the cryosphere and the biosphere all need to be represented realistically in global climate models for future projections to be realistic. Today's four core WCRP projects — Global Water-Energy Experiment (GEWEX), Climate and Cryosphere, Climate Variability and Predictability (CLIVAR), and Stratospheric Processes and their Role in Climate (SPARC) — were established to achieve this task.

Extensive model development and numerical experimentation required exploration of climate sensitivity to changes in atmospheric carbon dioxide concentration (as well as other gases and aerosols). Early studies on the assessment of the effects of carbon dioxide on climate accommodated IPCC needs. In view of the critical role of oceans in the climate system, close cooperation was established with the oceanographic community — IOC joined as co-sponsor of the WCRP in 1993. The first WCRP coupled atmosphere-ocean initiative, the Tropical Ocean and Global Atmosphere (TOGA) project, studied the influence of the slowly varying thermal inertia of tropical oceans on large-scale atmospheric circulation. Recognition of the longer timescale or memory inherent to the oceans enabled short-term climate forecasts to extend beyond days to weeks. The requirement for ocean observations to initialize coupled forecasts established the prototype of the ocean observing system now in place. During the previous decades, routine observations of the air-sea interface and upper ocean thermal structure in the tropical Pacific Ocean were provided in real time by the Tropical Atmosphere Ocean array. These observations have since been sustained in the Pacific and extended to the Atlantic and Indian Oceans, thus building a solid foundation for today's ocean observing system.

Ocean data assimilation proved to be a key element of the initialization of seasonal-to-interannual climate forecasts. Coupled ocean atmosphere prediction models were implemented at many of the world's major weather prediction centres. This led to key breakthroughs in seasonal climate forecasts based on observations, understanding and modelling of worldwide anomalies in the global atmospheric circulation, temperature and precipitation patterns linked via teleconnections to El Niño. The WCRP-sponsored CLIVAR, TOGA and WOCE projects have established a solid foundation to study the ocean's role in climate. The ocean observations collected and disseminated by these projects — supported by more than 30 nations — were fundamental in the development of basin-scale ocean models and have shaped the current understanding of mixing processes for energy and nutrients in the oceans. These efforts have had a positive impact on: knowledge of the global oceans; adoption of new technology used by oceanographers; and overall changes to the scientific methods for ocean research.

Advances in ocean technology played a major role in permitting a global ocean perspective. Continuous observations of global sea surface height were provided by the TOPEX/Poseidon satellite, the Jason satellites and the European Remote Sensing satellite radar altimeters. Active and passive microwave satellite sensors provided all-weather measurements of the ocean surface wind velocity, temperature and biological activities. Improved instrumentation and calibration led to refinements in air-sea flux measurement from both ship- and mooring-based platforms. Experimental devices such as gliders demonstrated the potential for performing repeated measurements in regions of the ocean historically difficult to observe.

Ocean modelling efforts — enabled significantly by advances in computer and information technologies — have resulted in global ocean models that represent the energetic nature of boundary currents and associated processes. They are also capable of providing a dynamically consistent description of many observed aspects of the ocean circulation that contribute to the formation and variation of the Earth's climate system. A combination of real-time ocean observations and ocean models offers the possibility of operational oceanography on a global scale — an important theme of the upcoming Ocean Observations '09 Conference, which is to be held in Venice, Italy. As such, the scientific community is now on the verge of realizing the oceanographic equivalent of a World Weather Watch — the system responsible for modern weather forecasts.

Challenges and opportunities in providing climate information

Looking to the future, the WCRP Strategic Framework for the 2005-2015 period aims to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. A key focus of the Strategic Framework is the seamless prediction of weather, climate and, ultimately, the whole Earth system. There are many theoretical and practical reasons for adopting this approach. The extension of 'climate prediction' to the more encompassing 'environmental prediction' requires recognition that the climate system is inextricably linked to the Earth's biogeochemistry and to human activities. For the WCRP to achieve its goals of understanding and predicting climate variability and its effect on society at large, it must, and will, contribute to studies of the fully integrated Earth system.

Developing a unified approach to weather, climate, water and environmental prediction requires a broadened Earth system perspective beyond the traditional atmospheric science disciplines. The development of climate prediction, and ultimately environmental prediction, is not a simple extension of numerical weather prediction. For example, the scientific disciplines required to support weather, climate and environmental prediction span meteorology, atmospheric chemistry, hydrology, oceanography and marine and terrestrial ecosystems.

While atmospheric nowcasting and short-range weather forecasting are primarily initial value problems, extension to, medium- and extended-range weather forecasting brings in the coupling of land surface processes, as well as the role of soil moisture feedback and other surface-atmosphere coupled processes. Long-range forecasting from weeks, to months, to a season involves atmosphere-ocean coupling, with the initial conditions of the memory inherent in the upper ocean leading to longer lead-time predictive skill. Decadal climate prediction is determined by both initial and boundary conditions. On these timescales, deeper oceanic information and changes to radiative forcing from greenhouse gases and aerosols play determinant roles. When considering interdecadal to centennial climate projections, not only do future concentrations of greenhouse gases need to be taken into account, but also changes in land cover/dynamic vegetation and carbon sequestration governed by both marine and terrestrial ecosystems.

One of the WCRP's major challenges is to determine the limits to predictability on the decadal timescale. Within the concept of a unified suite of forecasts, decadal prediction bridges the gap between predicting seasonal-to-interannual climate variability and change, and the externally forced climate change projections over very long periods. A focus on decadal prediction may help expedite the development of data-assimilation schemes in Earth system models and the use of Earth system models for shorter-range prediction. For example, seasonal predictions can be used to calibrate probabilistic climate change projections in a seamless prediction system. Hence, there is common ground on which to base a convergence between weather forecast and seasonal to interannual climate prediction.

Over the past 20 years, the link between WCRP observational and modelling efforts has been atmospheric re-analyses — these have greatly improved the ability to analyse past climate variability. The current climate records are usually made up of analyses of observations taken for many other purposes such as weather forecasting in the atmosphere, or core oceanographic research. There is now recognition that global climate can be understood primarily by ensuring the collection and maintenance of quality observations of the atmosphere, ocean and land surface (including the cryosphere). Many climate datasets are inhomogeneous: the record length is either too short to provide decadal scale information, or the record is inconsistent owing to changes in sensors or operation, and absence of adequate attention to archive and preservation of such records. As such, major efforts were required to homogenize the observed data and make it useful for climate purposes.

Reanalysis of atmospheric observations using a constant state-of-the-art assimilation model has helped enormously in making the historical record more homogeneous and useful. Indeed, in the 20 years since reanalysis was first proposed, there have been great advances in the ability to generate high quality, temporally homogeneous estimates of past climate. With the ongoing development of analysis and reanalysis in the ocean, land and sea ice domains, there is great potential for further progress and improved knowledge of the past climate record. There has also been some development of coupled atmosphere-ocean data assimilation, which lays the foundation for future coupled reanalysis studies, and may lead to more consistent representations of the energy and water cycles. This latter area is a major focus for the GEWEX project.

Another challenge confronting climate researchers is the provision of regional-level climate information that investors, business leaders, natural resources managers and policy makers need to help prepare for the adverse impacts of potential climate change on industries, communities, ecosystems and entire nations. While global mean measurements of temperature, precipitation and sea-level rise are convenient for tracking global climate change, many sectors of society require actionable information on considerably finer spatial scales. The increased confidence in attribution of global-scale climate change to human-induced greenhouse gas emissions, and the expectation that such changes will increase in the future, has led to an increased demand in predictions of regional climate change to guide adaptation.

Although there is some confidence in the large-scale change patterns of certain predicted parameters, the skill in regional prediction is much more limited and difficult to assess. This is because the WCRP does not have data for a selection of different climates against which to test models. Much research is being done to improve model predictions, but progress is likely to be slow. In the meantime, the WCRP recognizes that governments and businesses are faced with making decisions now and, as such, require the best available climate advice today.

Despite their limitations, climate models are the most promising means of providing information on climate change. As such, the WCRP encourages unrestricted access to climate predictions to help in decision making — provided the limitations of such predictions are made clear. The WCRP has begun to develop a framework to evaluate regional climate downscaling (RCD) techniques — enabling global climate projections to be used for regional applications.[1] Such a framework would be conceptually similar to the successful coupled model comparisons undertaken by the Working Group on Coupled Modelling (WGCM) and would have the goal of quantifying the performance of regional climate modelling techniques, as well as assessing their relative merits.

An international coordinated effort is envisioned to develop improved downscaling techniques and to provide feedback to the global climate modelling community. A specific objective will be to produce improved multi-model RCD-based high-resolution climate information over regions worldwide for input to impact/adaptation work and to the IPCC Fifth Assessment Report (AR5). This would promote greater interactions between climate modellers, those producing downscaled information and end-users to better support impact/adaptation activities, as well as to better communicate the scientific uncertainty inherent in climate projections and information. An important theme in this activity will be to promote the greater involvement of scientists from developing countries.

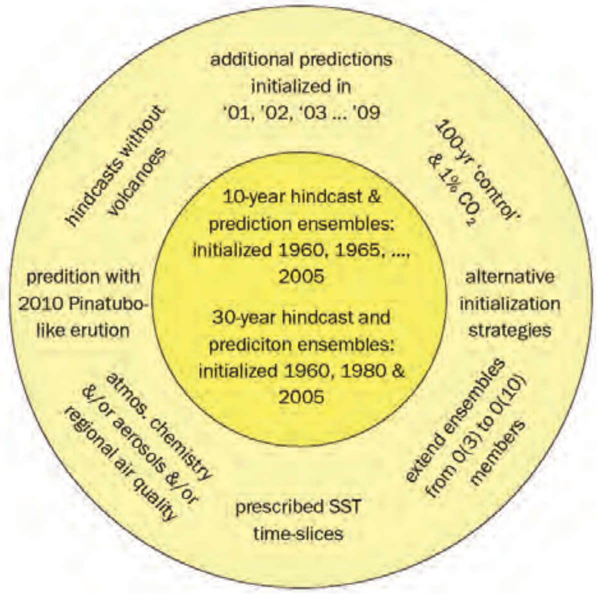
The WCRP will continue to provide scientific leadership for major international climate assessment activities. Currently, under the leadership of the WCRP's WGCM, the fifth phase of the Coupled Model Intercomparison Project (CIMP5) is under development in support of IPCC AR5. The grand challenge for climate models participating in this activity is to resolve regional climate changes to which human societies will be forced to adapt, as well as to quantify the magnitude of the feedbacks in the climate system. The scientific community has formulated such coordinated experiments to address key science questions in support of decision makers. Since these experiments will constitute the major activity of the international climate change modelling community over the next few years, the results will be eligible for assessment by AR5.

For longer timescale projections (to 2100 and beyond), intermediate resolution (~200 kilometres) coupled climate models will incorporate the carbon cycle, specified/simple chemistry and aerosols. These models will be forced by new mitigation scenarios referred to as 'representative concentration pathways'. Mitigation and adaptation scenarios with permissible emission levels that allow the system to reach gradually targeted concentration are to be used (in place of the previous IPCC Special Report on Emissions Scenarios). The new scenarios will have implicit policy actions to target future levels of climate change.

Since we can only mitigate part of the problem, the challenge is to use climate models to quantify time-evolving regional climate changes to which human societies will have to adapt. A new focus area for CMIP5 is a set of near-term projections that encompass 10- and 30-year prediction studies and high-resolution time slice experiments.[2] WCRP researchers believe there are reasonable prospects for producing decadal forecasts of sufficient skill to be used by planners and decision makers. There are two aspects to the decadal problem, the externally forced signal, and the predictable part of the internally generated signal. The latter signal comes from intrinsic oceanic mechanisms, coupled ocean atmosphere processes, modulation of climate modes of variability (for example, the El Niño/Southern Oscillation) and — potentially — land and cryospheric processes.

The WCRP will continue to support the quadrennial WMO/United Nations Environment Programme Ozone Assessment. The SPARC Chemistry Climate Model Validation Activity (CCMVal) is the main model-based analysis for the connection between atmospheric chemistry and climate. CCMVal provides strategic modelling support to the ozone assessment process, which is mandated by the Montreal Protocol. Ozone is a major constituent in radiative processes and is also affected by dynamics and transport. Only CCMs can simulate the feedback of chemical processes on the dynamics and transport of trace gases. The CCM simulations are designed to support the WMO/UNEP Scientific Assessment of Ozone Depletion/Recovery: 2010. The main focus will lie on model validation against observations, as well as on assessments of the future development of stratospheric ozone.

CMIP5 Decadal Predictability/Prediction Experiments. Draft from WGCM meeting, September 2008



WCRP and the International Geosphere-Biosphere Programme combined their expertise to advance climate model development and, hence, prediction capabilities. By incorporating the more complex Earth system processes, models are also being tested for their response to different forcings. Within the WCRP, the Working Group on Coupled Modeling leads the development of coupled ocean-atmosphere-land models used for climate studies on decadal and longer timescales

Source: Taylor et al. (2008)

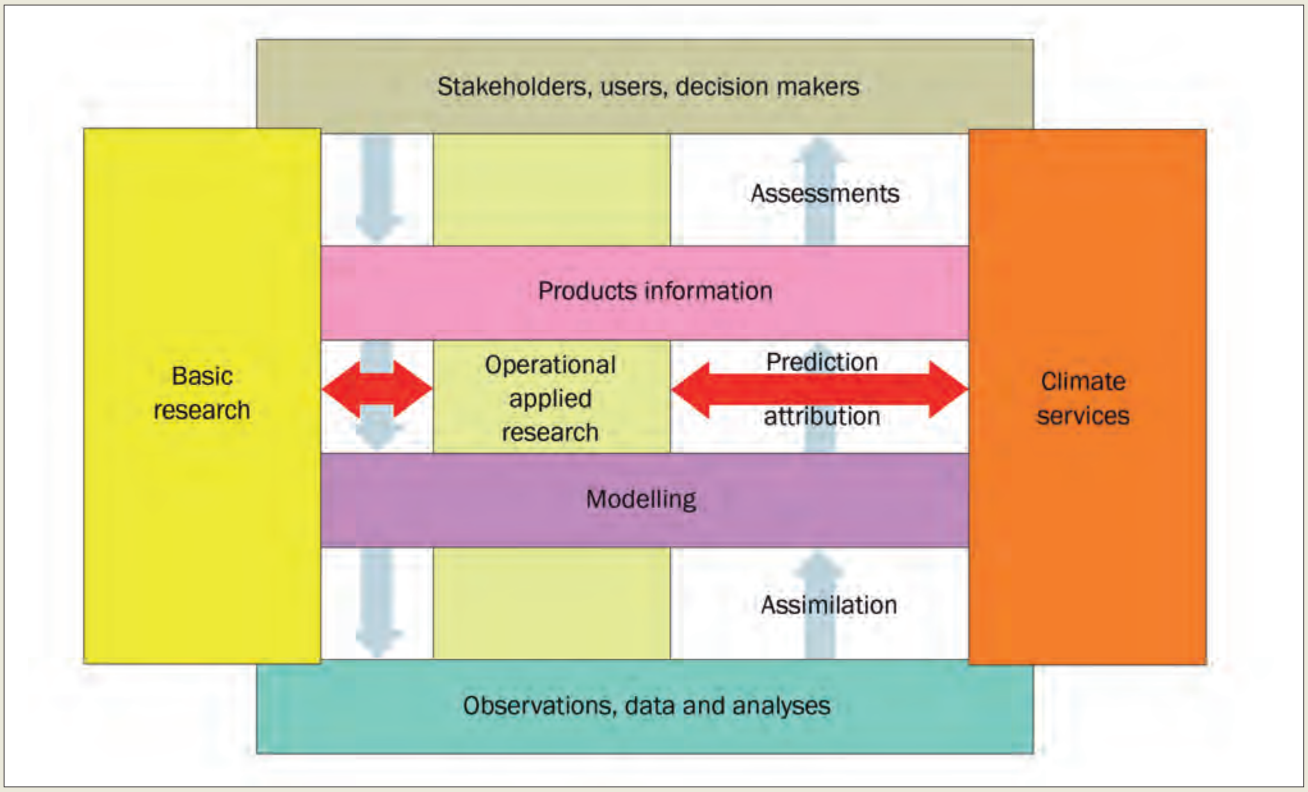
At present, ozone recovery is expected to take place until the middle of the century,[3] when column ozone is expected to reach 1980 values in southern polar latitudes. This development is determined, on the one hand, by a decrease in ozone depleting substances (ODSs) and on the other by a decrease in stratospheric temperatures — due to enhanced greenhouse gas concentrations in the atmosphere, which affects polar stratospheric cloud formation and heterogeneous ozone destruction. An important issue is how changes in the tropospheric abundances of ODSs translate to changes in the ozone-depleting active chemicals in the stratosphere. For studies of the future development of stratospheric ozone it is of great importance to take into account interactions between radiation, dynamics and the chemical composition of the entire atmosphere.

To date, climate projections have generally treated internal variability as a statistical component of uncertainty. Though there is no marked decadal peak in the spectrum of the climate system, long timescales exist and are potentially predictable. The challenge of prediction/predictability studies is to identify the mechanisms associated with regions/modes of predictability, to better understand the connection between oceanic modes and terrestrial climate variability, and to investigate predictive skill by means of prognostic (including multi-model) decadal predictions. The results of predictability studies and demonstrations of forecast skill provide the foundations for initiating a coordinated WCRP study of decadal climate variability, predictability and prediction.

In summary, the WCRP has made great strides in advancing understanding of the coupled climate system from seasonal to centennial timescales. WCRP research efforts formed the foundation of today's seasonal climate forecasting products and services. The WCRP has played a major role in converting the resultant scientific information and knowledge about the Earth's climate system for use in policy decisions. This has been achieved via the IPCC, the UNFCCC Conference of Parties and its Subsidiary Body on Scientific and Technological Advice. More than half of the scientific and technical contributions used in the IPCC assessments were provided by WCRP-affiliated scientists.

The WCRP has made a concerted effort to provide worldwide access to its model predictions/projections and research results. With such access scientists from developing and least developed countries are able to assess

The Climate Information System



The vertical flows depict the basic activities starting from: the observations and their use and development into products; attribution and prediction; assessments; and interactions with stakeholders and users to accommodate their needs as best possible. The WCRP is engaged in all but the delivery of climate services

Source: Keven Trenberth, modified by Ghassem Asrar

the consequences of potential climate variability and change on major economic sectors — such as food, water, energy and health — for their country or geographic region. The WCRP's accomplishments and progress were all made possible by the generous and sustained contributions of its sponsors: WMO, ICSU and IOC, and their network of more than 190 Member countries.

The research coordinated by the WCRP has established unequivocally that the Earth System will experience real climate change over the next 50 years, exceeding the scope of natural climate variability. A question of paramount importance confronting nations is how to adapt to this certainty of climate variability and change in the next half century. In response, the upcoming World Climate Conference-3 will consider how comprehensive climate services can best inform decisions on adaptation.

The delivery of climate observations, information and services involves the transition across basic research, applied research, operations, applications and engagement with the user community. Yet most of the effort to date has been focused on observing and understanding the climate system and not products and services. Furthermore, climate impacts assessment and provision of services involve sectors such as business, finance, agriculture, engineering, public health, public policy and national security.

In order to satisfy the needs of society for climate services, a climate information system is required to aid decision makers in policy, infrastructure development and investment decisions. Such a system would be based on: reliable climate predictions over timescales of seasons to decades; tailored forecasts for regions and localities; integration of atmospheric, oceanic, terrestrial and social data into a comprehensive Earth System prediction model; and decision-support interfaces that can be adjusted to provide user-specified 'if-then' scenarios. The realization of a climate information system will require the coupling of models across the physical climate system, biogeochemical cycles and socioeconomic systems. Furthermore, it will require the synthesis of disparate datasets from in situ and space-based observations, new terrestrial and orbital sensor systems, dedicated high performance computer infrastructure and software. Ultimately such a system requires an unprecedented synergy between the climate research community, the operational delivery arm of climate services and the end users.

Much akin to the situation 60 years ago with the advent of numerical weather prediction, we now find ourselves in a new era of climate information and services. This era is underpinned by climate research aimed at improving, expanding, and refining our understanding and ability to predict the climate system on seasonal, decadal and longer timescales. Investing in such a system is the best way to insure that our generation, our children and those who follow them have the ability to manage the risks and realize the opportunities associated with climate variability and change.

The importance of high quality regional scientific information in coping with global climate change

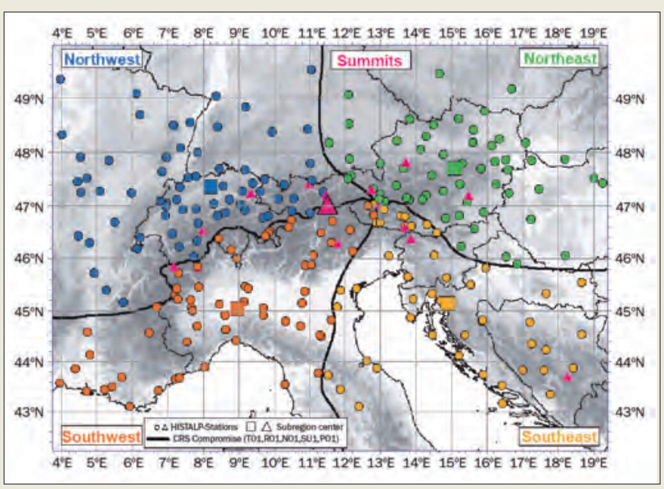
Ingeborg Auer, Reinhard Böhm and Wolfgang Schöner, Central Institute for Meteorology and Geodynamics, Austria

ZAMG, the Austrian weather service, regards the production, the quality control and the analysis of high-quality climate data as one of its core duties. This includes the maintenance of a meteorological network adequately vast to cover the complex terrain of the country. However, national borders do not usually correspond precisely with climate domains. In the late 1990s ZAMG began formal and informal cooperation with the national met-services and other data providers of the greater alpine region (GAR) to create and maintain the common climate database HISTALP.[1]

The intention was to aim for the following principles:

- Long-term — fully exploiting the potential of systematically measured data
- Dense — network density adequate with respect to the spatial coherence of the given climate element
- Quality improved — outliers removed, gaps filled
- Homogenized — earlier sections adjusted to the recent state of the measuring site
- Multiple — covering more than one climate element

The greater alpine region in south-central Europe



Showing its five principal horizontal and vertical coarse resolution sub-regions and the network of HISTALP stations for long climate time series

Source: www.zamg.ac.at/histalp

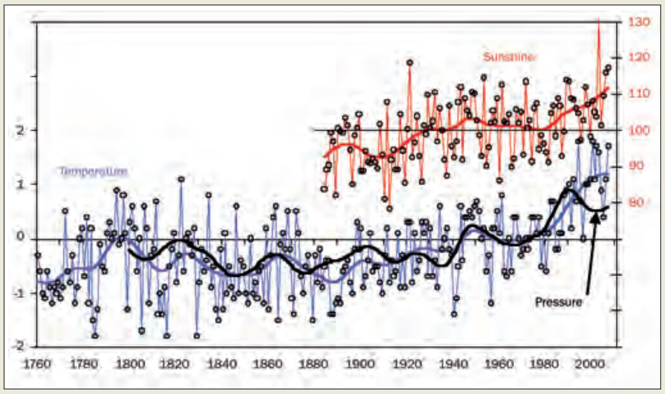
- User friendly — well described and kept in different modes for different applications, in scientific research as well as for technical, educational applications and for providing quality information about climate variability and change for the general public.

So far HISTALP has concentrated on longer monthly series (some 30 of them starting in 1800 and earlier) allowing us to better solve the homogeneity problem — for which severe problems still exist with respect to daily or sub-daily series. However, the first steps towards the inclusion of daily series are underway. HISTALP data are kept in three modes: station-mode (original and homogenized for all seven climate elements); grid-mode-1 (anomaly series of temperature, precipitation and air pressure at a grid size of 1 degree latitude-longitude, respectively); and CRSM-mode (coarse resolution sub-regional means — anomaly series of all seven climate elements as spatial means of five principal sub-regions of the GAR, objectively detected via PCA).

The GAR is climatologically characterized by a complex terrain of three different large scale climate regimes: Atlantic-maritime influences from the west versus continental climate from the east, as well as the Mediterranean climate with its annual cycle of subtropical highs further north in the summer and further south in the winter. These three horizontal regimes are overlain by the vertical gradients of all climate parameters. This makes the region interesting for scientific study; specifically the study of a situation where nature and human societies exist in a sensitive mountain region. The area serves as a great example of the potential practical applications that can be derived from regional climate change research.

A few examples serve to illustrate some of the leading climate change and variability patterns, as well as demonstrate their scientific and applicative relevance. Firstly, the GAR has warmed twice as much as the northern hemisphere land surface since the late 19th century.[2] The main driving force behind this additional 1°C warming above the global background is a northward shift of the subtropical high pressure system. Put simply, this has produced more incoming radiation. This synoptic feature

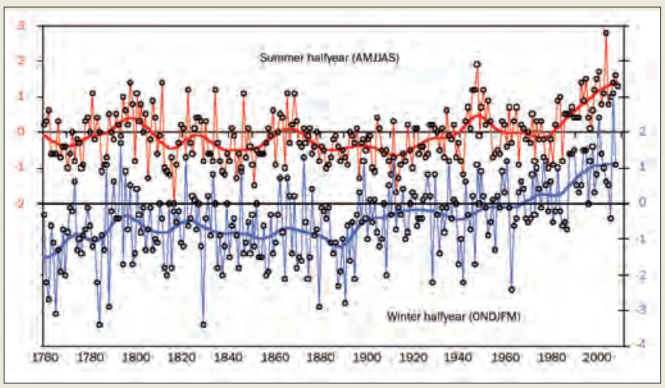
Regional annual mean time series of three closely linked climate elements in the GAR



Blue shows a low elevation mean temperature, while red indicates high elevation mean sunshine. Black shows low elevation mean air pressure and is the only smoothed curve

Source: www.zamg.ac.at/histalp

GAR mean temperature between 1760 and 2007



Low elevation mean temperature series for the summer- and winter-half years between 1760 and 2007

Source: www.zamg.ac.at/histalp

is clear because of the high elevation sunshine, which is neither influenced by low stratiform clouds nor by anthropogenic changes of atmospheric turbidity (global dimming versus global brightening). As a rule of thumb, we can state that the region has warmed by another 1°C beyond the given 1°C stemming from the global background.

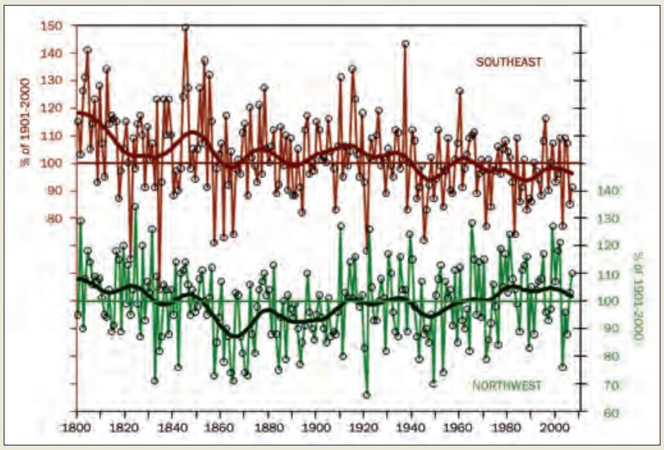
Of course this covers only annual series averaged over the entire GAR. For temperature this makes sense, as the average overall single HISTALP series is highly representative for each of the sub-regions concerning the decadal to centennial evolutions: they have warmed at the same rate in Marseille, Karlsruhe, Budapest and Perugia, as well as for the mountain observatories at altitudes between 2,500 (Säntis) and 3,500 metres above sea level (Jungfraujoch). So the mountains of the Alps may be more sensitive in respect to some climate impacts, but they are not in terms of their reaction to climate forcing.

This similarity of temperature trends with respect to different subregions is not applicable with regards to different seasons. In general, 19th century winters were colder in comparison to summers of the early instrumental period. This results in a general decrease of the annual amplitude during the past two and a half centuries. As the majority of natural proxies used for the estimation of indirect climate reconstruction provide more summer than winter information, such proxies tend to have a summer bias and should not be regarded as being representative for annual trends — at least in the Alps. A good example is the coincidence of mild winters and cool summers in the 1910s that produced remarkable glacier advances — advances that cannot be explained through the annual temperature means.

The high spatial homogeneity of temperature trends does not exist for precipitation. For the two principal sub-regions — northwest at the windward side of the Alps towards the prevailing western winds and southeast at the leeward side — we have observed opposite centennial trends. The northwest has seen a long-term increase of approximately 10 per cent in the last 150 years, while the southeast has seen a 10 per cent decrease in the same period. Only the first part of the 19th century saw a parallel decreasing trend in both sub-regions. This dipole-like structure corresponds to the same pattern expected for the 21st century by most of the regional European climate model experiments. What we can learn from the past is that the gap between wetting and drying is most likely to sharply following the main crest of the Alps — with a smooth transition over hundreds of kilometres less likely.

The last example concerns different long-term trends in the third dimension, for which only a region like the Alps can provide the necessary information. Namely, a comparison of the annual mean air pressure evolution at both low elevation stations and high elevation observatories. In the Alps a number of summit observatories have produced 100 to 150 years of air pressure series, opening up the unique possibility of applying the principle of 'relative topographies' (calculating the virtual temperature of an air column from the ratio of the air pressure at its upper and lower boundaries). The high elevation air pressure curve has increased to a much greater degree than the low elevation sites' equivalent (which has also increased). So, the principle mechanism is most accurately explained by the measured air pressure series: the air columns between low- and high-elevation measuring sites have warmed, expanded and thus transported more mass above the summit observatories, while the total mass above the low elevation sites has only changed due to large scale synoptic rearrangements. The practical importance of such independently measured 'non thermometric temperature series' is high. If they show the same warming as those measured directly using thermometers, then this overrules once and for all the argument that global warming is merely the product of increasing heat islands in developing cities. This idea has been described already in Auer et al.[3] and we are currently working on an in-depth analysis of the concept. Initial internal results show the feasibility of such an analysis, but only under the condition of a carefully homogenized series that allows the isolation of a climatic signal of approximately 1 hectopascal/century from the non-climatic noise of the original series.

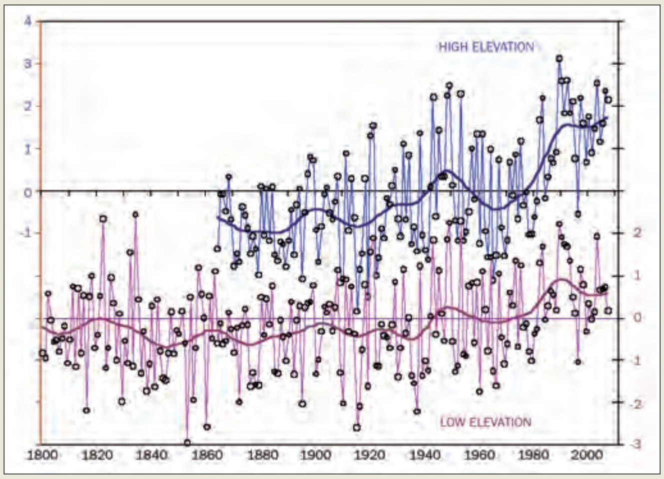
Sub-regional annual precipitation



Two sub-regional annual precipitation series for the northwestern and southeastern CRSs of the GAR

Source: www.zamg.ac.at/histalp

Sub-regional annual air pressure



Two sub-regional annual air pressure series for the mean low elevation series below 600 metres at sea level and for the high elevation summit sites above 2,000 metres at sea level

Source: www.zamg.ac.at/histalp

This last example in particular is intended to illustrate that high quality climate data is an indispensable precondition not only for sophisticated scientific research, but also for practical interdisciplinary application, as well as for political discussion in the general public.

Reaction of glaciers to climate change in the Austrian Alps

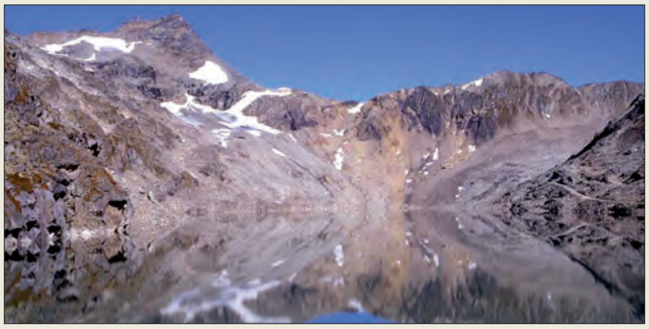
Glaciers are among the natural phenomena on Earth with the highest sensitivity to the climate. Thus a small change signal in the climate — especially in global radiation, air temperature or precipitation — can result in a distinct change of glacier mass and even, after a time delay, an advance or retreat of the glacier front. This high sensitivity makes glaciers especially valuable when:

- Documenting climate impact and climate change
- Deriving climate proxy information from observations of glacier changes.

Additionally, ice cores from glaciers and ice sheets are among the most important climate proxy sources.

Beside Scandinavia the European Alps are among those regions worldwide with the longest series of documented glacier changes. In particular, documents of glacier changes include paintings and photographs, front position measurements, volume changes (from interpretation of maps, aerial photographs and satellite data) and measurements of mass balance and glacier surface flow. Outside of these observations the mass balance of a glacier is the key measure, as it constitutes a direct and timely signal of climate perturbation. Observations of mass balance date back only to about the 1950s in the Alps and about the 1940s in Scandinavia. Contrary to mass balance observations, systematic front position measurements of Alpine glaciers go back as far as the late 19th century, but are limited by aggregated information including both climate and glacier dynamics. The advent of regular front position observation prompted an international glacier monitoring effort, which is today coordinated by the World Glacier Monitoring Service.[4]

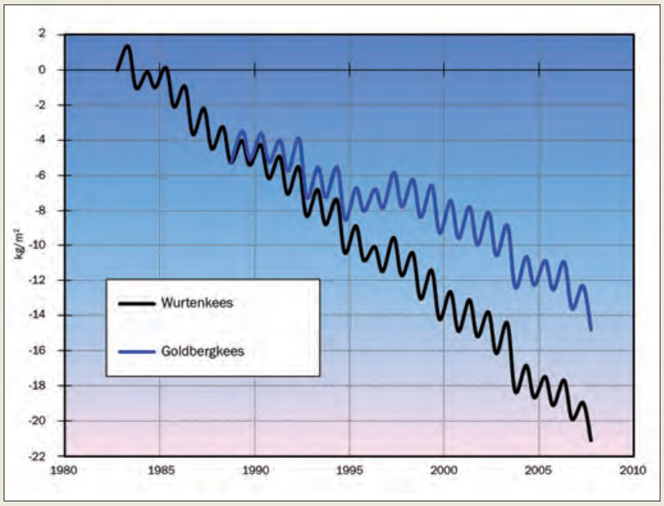
The retreat of the Wurtenkees glacier

The retreat of the Wurtenkees glacier (eastern Austrian Alps) evident in photographs taken in 1896 and 1999

Image: A.E. Forster (left); R. Böhm (right)

Accumulated specific mass balances for the Wurtenkees and Goldbergkees glaciers



Observations since 1983 show that, on average, Wurtenkees loses one metre per year

Source: www.zamg.ac.at/forschung/klimatologie/glaziologie

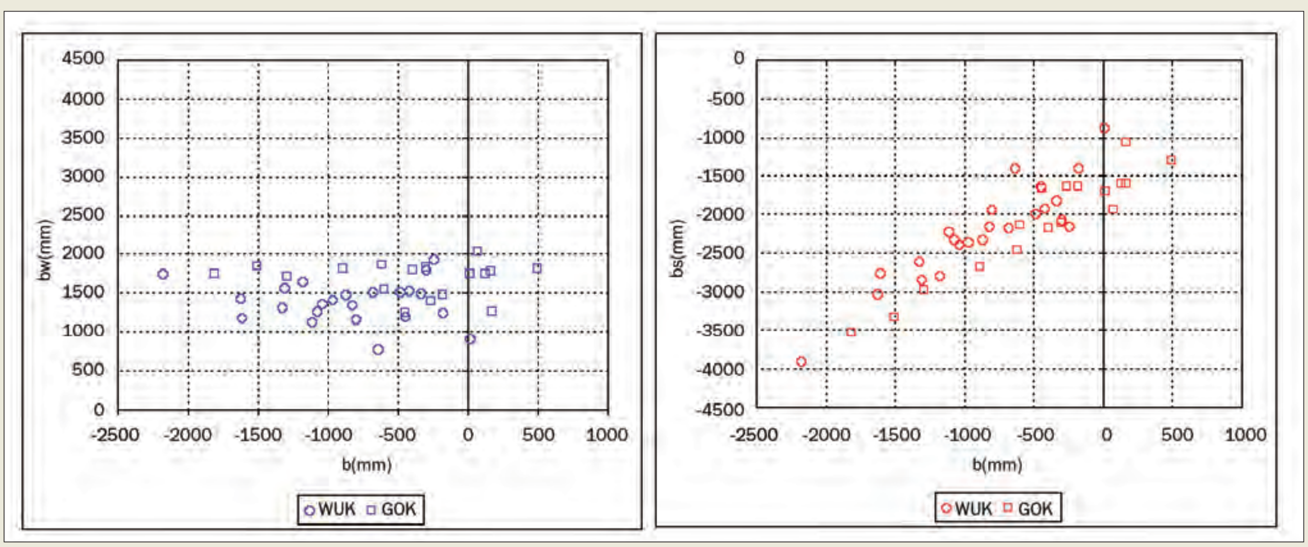
Image: Gernot Weyss

Science walk to Sonnblick Observatory in July 2006. A national park ranger explains the first information board of the glacier trail

ZAMG runs a detailed glacio-hydrological monitoring programme in the Sonnblick region of the eastern Austrian Alps covering three smaller glaciers (about 1 square kilometre) and the largest glacier in Austria; Pasterze. Since the end of the 19th century all the glaciers investigated have shown a general retreating trend, and in particular a clear retreat since the beginning of the 1980s, which is a common signal of Alpine glaciers. The retreating trend observable since the end of the 19th century is clearly visible in photographs of glacier Wurtenkees taken in 1896 and 1999. The Sonnblick region is characterized by strong climate gradients; from a high precipitation region north of the Alpine main divide to an inner-alpine dry valley south of it. The monitoring in this area includes measurements of glacier mass balance (for both winter and annual net balance), surface flow, glacial discharge and ionic composition of snow cover. The monitoring is part of a research programme by the nearby Sonnblick Observatory, which covers a wide range of atmospheric chemistry as well as physics, mountain meteorology and permafrost research.

The spatial patterns of climate are well reflected in the mass balance of the glaciers, with much higher winter accumulation at the glacier north of the Alpine main divide compared to the glaciers south of it. The north-south pattern is also visible in the annual net balance of glaciers Wurtenkees and Goldbergkees with more negative

Net balance relationships



Relationship between annual net balance (b) and winter net balance (bw, left) and summer net balance (bs, right) for Wurtenkees (WUK) and Goldbergkees (GOK) from observations since 1983

Source: www.zamg.ac.at/forschung/klimatologie/glaziologie mass loss for Wurtenkees. On average Wurtenkees loses about 1 metre (mean over total glacier size) of ice per year under the present climate. As maximum ice thickness for this glacier is less than 80 metres, the vanishing of most of the glacier area is to be expected within a few decades.

Several studies[5] were carried out to understand the climate-glacier mass balance relationship for the glaciers of the Alps and the Sonnblick region in particular. It was shown that only the summer season (melting of snow and ice) and not the winter season (accumulation of snow) estimates affects annual net balance. Such studies have shown that only summer balance is highly correlated to annual net balance and that variability of summer balance is much higher compared to winter balance. However, it has to be taken into account that this result is derived from observations going back only as far as 1983 (a period with strong glacier retreat) and that in earlier periods this relationship may well have been different.

An important discussion in Alpine glaciology refers to the question of the contribution of such glaciers to river flow. This was studied in the small catchment area of Goldbergkees (close to Sonnblick),[6] as well as in the much larger catchment area of Upper Pinzgau (river Salzach). Upper Pinzgau covers about 600 square kilometres, of which 5 per cent is glacierized. Detailed modelling approaches[7] show that for a year with average climate conditions the contribution of glaciers to the river flow of the main rivers of the Alps is negligible. However, under climate conditions measured in 2003 the contribution of glaciers to the river flow of larger rivers was significant and ranged up to 70 per cent in August 2003 for the Salzach in Upper Pinzgau. Because 2003 can be used as a realistic scenario for future climate states (up to around 2100) the importance of the glaciers to river flow can be easily estimated. If glaciers vanish in the future we can expect a significant deficit for the large rivers of the Alps, as well as a net loss of discharge for smaller rivers.

Local climate information for two central Alpine valleys in an inter- and trans-disciplinary dialogue

Events such as the latest International Scientific Congress on Climate Change in Copenhagen have roused public knowledge of climate change to some extent. However, do people really feel sufficiently informed and what are their opinions and attitudes on climate change? *A Tale of two Valleys — the contrary strategies in two neighboring Alpine valleys to deal with climate variability and climate change*, an Austrian interdisciplinary research project on regional climate change (www.zamg.ac.at/a-tale-of-two-valleys) combined the local knowledge of people in region and scientists to create an overall picture of the perception of climate change. Schools and selected stakeholders have also formed part of the project team to cover the aspects of long-term climate variability, natural dangers and risks, landscape and land-use, tourism, employment and income, demography, mobility, education and gender.

Two small municipalities confronted with regional climate change impacts decided to develop local scenarios in response. Income for both municipalities is largely dependent on winter tourism. However, the dominant touristic concepts are somewhat contradictory. The first concept is a glacier ski resort called Mölltaler Gletscher in Flattach (1,373 inhabitants and an employment rate of 47 per cent). This clashes with the other idea of a national park concept and a fairly small 'family and 50+ skiing region' in Rauris (3,107 inhabitants and an employment rate of 45 per cent). Touristic income and employment bears a close relation to snow availability, although artificial snow can compensate somewhat during warm and snowless winters.

An opinion poll carried out in these two villages showed that about 70 per cent of adult inhabitants feel well informed about climate change. However, special questionnaires distributed in regional schools indicated that the sample of 14 to 15 years old adolescents were unsatisfied with their information level on climate change.

Simplified but nevertheless correct information and cooperation was at the centre of the concept from the start. Start-up meetings were held in each of the municipalities and partner schools. Those meetings, held in January 2006, offered lectures presented in an understandable scientific language, keeping in mind scientific correctness and sufficient time for personal thoughts, discussions and questions. In July 2006 three science days were organized in the project region. Public scientific lectures and informative posters were combined with talks from local authorities and supplemented by a 'scientific walk' to the high mountain Sonnblick Observatory (3106 metres). This involves a walk through climate sensitive vegetation zones near the glacier region up to the high alpine area. Scientific knowledge of climatology, glaciology, tree-ring research, biology, history and sociology were merged with local expertise to produce the experience.

Since glaciers constitute highly visible evidence of climate warming a glacier trail has been constructed in cooperation with the alpine club Naturfreunde. This *Gletscherlehrpfad Goldbergkees* guides participants through the history of climate and glaciers. Thirteen information boards have been installed to form a trail, which runs between 2,190 and 2,395 metres above sea level, to document long-term glacier retreat and its relationship to climate.

Special partnerships have been established between the project team and schools to promote the idea of 'cognition = research + education'.[8] Climate change topics have been integrated with the curriculums of more than one field of study including: physics and chemistry, geography and economy, history, biology, language courses and even music. Besides dealing with ecological and economical questions students gained insight into the work and methods of scientists. A follow-up effect is also expected with the transfer of this newly acquired climate change awareness from the school children to their families.

Another good example how to raise awareness on climate change in school pupils is demonstrated by the efforts of the children of Hauptschule Rauris. On the occasion of the annual *Rauriser Literaturtage* they presented their thoughts and attitudes on climate change in the form of songs, stories and poems.

During the running time of the *A Tale of Two Valleys* study local scenarios were developed and presented to the citizens of Rauris and Flattach. The majority of residents favoured a scenario based on sustainability. However, on the other hand, the majority of residents did not believe that the sustainability scenario was the one likely to be selected.

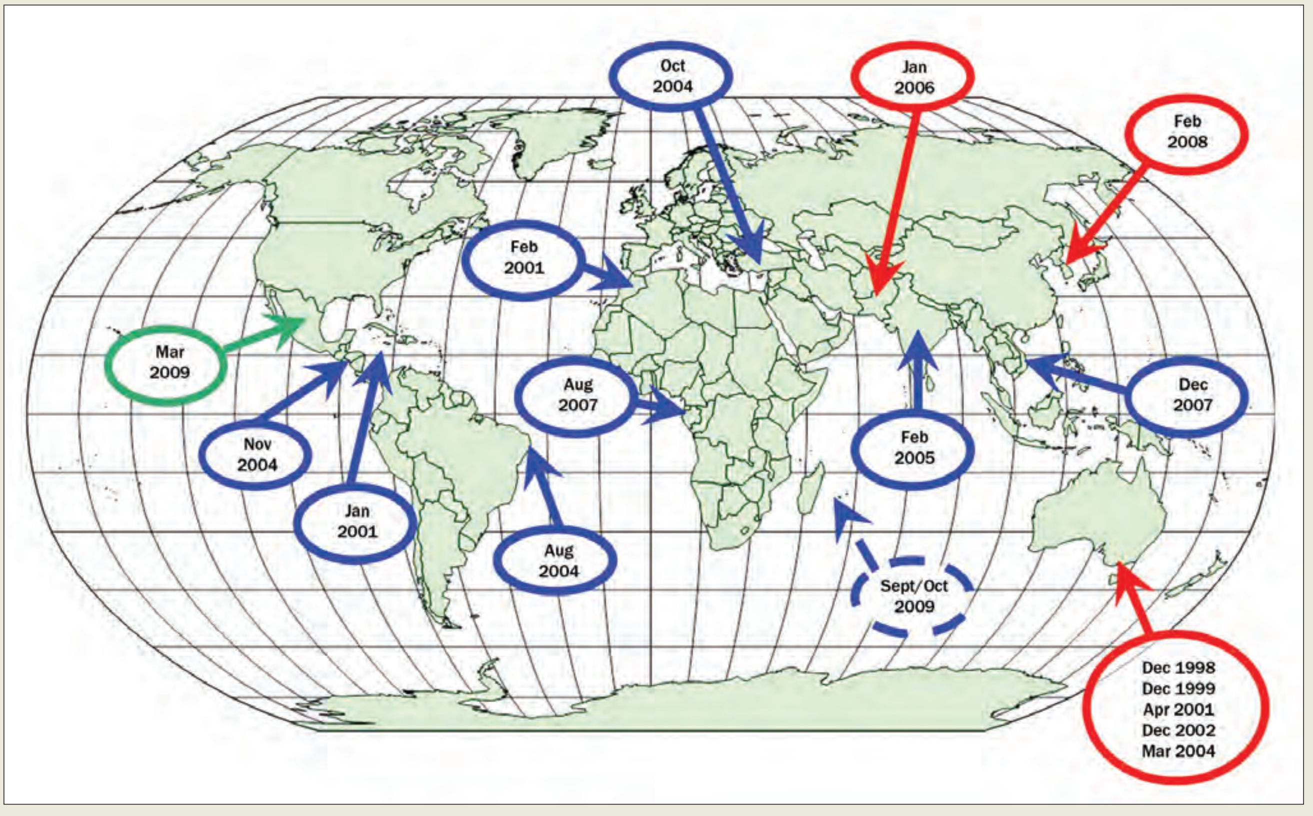
Simple indices for the monitoring of weather and climate extremes

Xuebin Zhang, Research Scientist and Francis W. Zwiers, Director, Climate Research Division, Environment Canada

In its fourth assessment the Intergovernmental Panel on Climate Change concluded that: "warming of the climate system is unequivocal" and that: "most of the observed increase in global average temperature since the mid-20th century is very likely human-induced." Evidence also suggests that widespread changes in the temperature and other aspects of the climate system are now affecting many physical and biological systems on all continents. It is thus increasingly evident that action is required to limit the extent and impacts of human-induced climate change by reducing greenhouse gas emissions. However, even very aggressive mitigation actions will not entirely stop climate change in the coming decades, thus adaptation to a changing climate will be necessary.[1]

Informed decisions for adaptation require reliable information and knowledge about both past and future climate conditions. Unfortunately, climate science is not yet able to provide all of the information needed for adaptation.[2] There is, however, considerable certainty that human activities have changed the global climate, and that climate change will continue. On the other hand, impacts resulting from climate typically occur on regional or local scales and very often result from extremes in weather and climate. It remains necessary to quantify the role of human influence on the climate system on smaller regional and local scales and on aspects of the climate system not directly related to warming.

Climate workshops



The locations and dates of Asia-Pacific Network for Global Change Research (red), ETCCDI (blue), and ETCCDI assisted (green) workshops between 1998 and 2009

Source: Based on Table 1 of Peterson and Manton (2008; updated)

This has proven to be a difficult task. Detection becomes increasingly difficult at smaller regional and local spatial scales and for extreme events, because the signal to noise ratio is reduced in both of these circumstances.[3] This feature is not attributed to a weaker signal at the local scale compared to the global scale, rather it is due to the fact that influences of natural variability on all aspects of the climate are larger on local scales. In addition, it remains a challenge to document past climate change for some places of the world due to the limited availability of assessable data or resources. Understanding the past and current climate at small spatial scales will not only provide a baseline for the future, but also a means to validate and constrain future projections. It is, therefore, a necessity for the development of sound adaptation strategies.

The ETCCDI indices

Long-term, high quality and reliable climate records with a daily (or higher) time resolution are required for assessing changes in extremes. However, the compilation, provision, and update of a globally complete and readily available full resolution daily dataset are very difficult tasks. This comes about, in part, because of the traditional focus of climatologists on monthly data and the inability of some countries to exchange long-term daily climate records. Nevertheless, adequate adaptation requires the development of quality, daily climate records and the ability to use those records to track changes in the climate and its extremes. The joint Expert Team on Climate Change Detection and Indices (ETCCDI) and its predecessors have coordinated the development and application of a suite of indices for monitoring climate change from daily data.[4] The use of agreed indices allows comparison of analyses conducted in any part of the world.[5]

The indices focus primarily, but not solely, on extremes. The extreme indices describe different aspects of temperature and precipitation including frequency, intensity and duration. There are three different types of indices. One type involves counting the number of days in a season or a year that exceed specific thresholds at which impacts of weather may occur — such as daily temperature below 0°C or daily precipitation amounting to greater than 20 millimetres. The number of such events may not be evenly distributed across a large region. The specific thresholds may, or may not, represent extreme events in a given region under current climate conditions, and it is possible such events may not occur at all in some regions. Impacts also vary across regions. To overcome such shortcomings, a second type of ETCCDI index uses thresholds based on percentiles to assess moderate extremes that typically occur a few times every year – such as daily temperature greater than its 90th percentile. The third type of index is of more relevance to the derivation of design values in applications that involve values of absolute extremes. These indices include, as examples, the annual maximum daily temperature and highest five day precipitation amount in a year. The indices are widely used for monitoring changes in extremes,[6] climate model evaluation[7] and the assessment of future climate.

The software

To facilitate the calculation of the indices, Environment Canada, under the auspices of WMO and ETCCDI in particular, has developed a standard software package RClimDex. This software uses the open source statistical programming language R (www.r-project.org), which runs on a variety of computer platforms. It is freely available from http://cccma.seos.uvic.ca/etccdi and comes with a tutorial (in both English and Spanish). A graphical user interface is provided, so knowledge of R is not necessarily required. A basic data quality control procedure that checks for outliers (unusual values that might be the result of, for example, a data transcription error) and does a basic homogeneity assessment is also built into the software. Though the indices have simple definitions, their calculation is not necessarily simple, particularly if one wants to avoid inducing artificial inhomogeneities (jumps) in the index time series[8] or bias in percentile-based indices due to a lack of precision in observational data.[9] Innovative approaches have been implemented in RClimDex to ensure the indices it calculates are homogeneous.

Furthermore, to ensure that the index time series are homogeneous, the climatic time series from which they are calculated should also be homogeneous. However, climatic time series may contain spurious (nonclimatic) jumps and/or gradual shifts due to changes in station location, environment exposure, or instrumentation and observing practices.[10] Such inhomogeneities would hinder the identification and assessment of change in climate, and thus Environment Canada has also developed and made available a free R-based data homogenization package called RHtest.[11] A detailed user manual for RHtest is provided in both the English and French languages and is continually updated to reflect results from new research. For example, the most recent version of RHtest is able to automatically detect single or multiple change-points in climate time series consistently throughout the length of the series. Both software tools will allow all interested parties to benefit from improved monitoring of climate change with broader spatial coverage than was previously available, thus directly contributing to the goals of the Nairobi Work Programme.[12]

The ETCCDI workshops

To promote the analysis of extreme events around the world and help build capacity in the less developed world, ETCCDI has also organized several regional workshops. These workshops, which followed the model pioneered in December 1998 at an Asia-Pacific Network for Global Change Research (APN) meeting in Melbourne, have proven to be very successful. The core component of each workshop is the hands-on analysis of national observational data with daily resolution, which have often never been analysed prior to the workshop. RClimDex and RHtest are used to perform the analysis. An ETCCDI workshop usually involves participants from neighbouring countries and several well-qualified experts from around the world to provide guidance on the analysis of climate data. In some cases, computers for the participants have been provided by sponsoring agencies for the workshops.

A workshop typically starts with each participant presenting information on the climate of their country, as well as their daily precipitation and temperature data. The participants then learn data quality control and homogenization procedures, and conduct the computation and trend analysis of climate indices. At

Participants from nine countries improving their capacity to process climate change data and interpret the results at the ETCCDI workshop for Central Africa, which was held from 23-27 April 2007, in Brazzaville, Congo

the end, the participants give a brief presentation on their national results, and an expert collates the results and gives an overview of the trends and variability in extremes across the whole region. The benefits of working across national borders are numerous: confidence in local analyses is increased by placing them in a larger, regional context that includes results from neighbouring stations and countries; regional research synergies are also enhanced by sharing insights and improve analyses between neighbouring countries. A post-workshop follow-up process produces a peer-reviewed journal article on analysis of climate change for the given region, and makes available the indices data in the analysis. The workshops therefore enhance the capacity of countries to extract important climate change information from their long-term daily data, and foster regional collaboration in climate analyses.

Between 1998 and 2004, APN sponsored a total of five workshops in Melbourne to promote this activity in Southeast Asia and the South Pacific. At the same time, ETCCDI coordinated workshops in the Caribbean and Africa. Owing to a number of difficulties, only parts of the results were available in time to contribute to the global extreme analysis prepared for the IPCC Third Assessment Report. A second series of ETCCDI workshops provided much improved input to the IPCC Fourth Assessment Report (AR4). Since the release of AR4, new workshops have also been conduced and planned.[13] ETCCDI indices have been released and are available at http://cccma.seos.uvic.ca/etccdi; they have already been of great use to scientists working on adaptation and climate model validation. The National Oceanic and Atmospheric Administration's National Climate Data Center and the Climate Research Division of Environment Canada are jointly developing a variant of the ETCCDI index set as a basis for the North American Climate Extreme Monitor.

Effective adaptation to the changing climate requires not only more and better information about future changes in climate from improved climate models, but also better information about past climate change and current climate. To address this need, ETCCDI has coordinated the formulation of a suite of climate indices that describe different aspects of moderate temperature and precipitation extremes including frequency, intensity and duration. Environment Canada has also developed open source software for the calculation indices and for climate data homogenization, and has made this software freely available. These tools — together with a series of ETCCDI coordinated regional capacity building workshops[14] — have played and will continue to play an important role in monitoring changes in extremes, climate model evaluation and assessment of future climate. These processes, in turn, provide the vital climate information that is required for climate change adaptation.

Better climate information for a better future — climate research

Won-Tae Kwon, National Institute of Meteorological Research, Korea Meteorological Administration

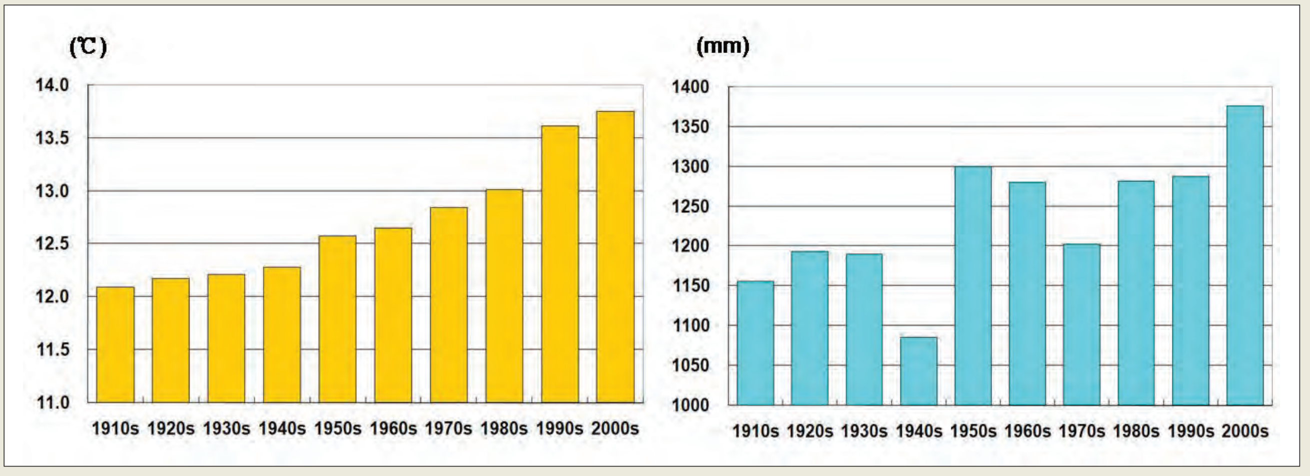
The climate is closely linked to everyday life, with its impact felt in all pockets of society. However, in the past, due to the uncertainties of climate science information and its lack of user-friendliness, it was rarely utilized by the general public and decision makers despite its importance. To improve the application of climate information and the satisfaction of end-users, it is necessary to reduce uncertainties and to tailor information to users.

Since its establishment in 2000 as part of the National Institute of Meteorological Research and the Korea Meteorological Administration (KMA), the Climate Research Laboratory (CRL) has been contributing to the scientific understanding of climate variability and climate change information. The main interests of the CRL lie in global and regional climate change, climate model development, seasonal-to-interannual prediction, understanding the physical and internal processes of the climate system, tailoring climate information to a variety of end-users, and promoting interdisciplinary climate change science networks at national and international levels. Climate change research includes analysis of the observed data, detection of climate change signals, development of models, and generation of global and regional climate change scenarios.

Analysing the observed climate data is essential for better understanding trends in unfolding climate change. The CRL has been analysing climate change trends in Korea using meteorological observation data going back to 1904 — all compiled in digital format by the KMA. An analysis of data observed for the Korean peninsula 1912-2008 shows an annual mean temperature increase of 1.7°C and annual mean precipitation increase of 19 per cent. Compared with climate in the earlier half of the 20th century, the latter half exhibits warmer and wetter characteristics, an increased frequency of extreme rainfall, a higher hot climate index and a lower cold climate index. Observed trends show the duration of summer lengthened and the duration of winter shortened, with an earlier spring flowering date. Habitat shift of plants and animals to higher elevations and latitudes is also observed. These changes suggest characteristics of a warmer climate in Korea.

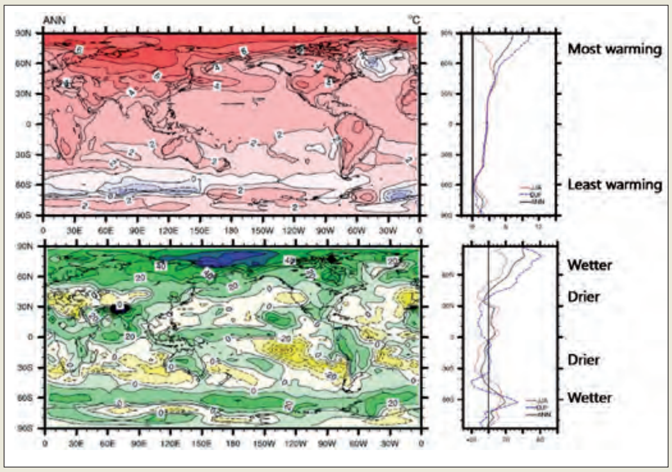
Generating climate change forecast scenarios is crucial in projecting the earth's future climate. The CRL, in collaboration with Germany's Max Planck Institute for Meteorology (MPIM), contributed to Climate Change 2007 — the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) — by generating scenarios using the ECHO-G climate

Decadal mean trends in temperature and precipitation over the Korean Peninsula based on six sets of long-term observation data



Source: National Institute of Meteorological Research (NIMR) in KMA

Climate projection using the ECHO-G model based on the IPCC SRES A1B Scenario



Source: National Institute of Meteorological Research (NIMR) in KMA

model developed by MPIM. Time-slice experiments using a high-resolution Atmospheric Global Climate Model (AGCM) suggest that weakening of the North Pacific jet stream will occur by the late 21st century due to global warming. The change in the jet stream appears to be due to the decrease in latitude temperature over the Asian continent, as well as eddy activity. The same experiment found that while the frequency of tropical cyclones over the northwest Pacific Ocean decreases, the intensity of tropical cyclones is likely to increase.

To project regional climate change over Korea, scenarios were generated by the CRL through dynamic downscaling using SRES A1B and the MM5 regional models. Downscaled data was obtained by simulating years 1971-2100 with a spatial resolution of 27 kilometres. The findings show that by the end of the 21st century, the mean surface temperature over Korea is projected to increase by 3.8ºC, and as much as 4.5ºC at 400hPa. Hot days and cold days exceeding the 95th percentile of climatic average will increase fivefold and decrease 99 per cent respectively. Precipitation is projected to increase 17 per cent, with an increased risk of extreme rainfall events in the summer. The daily maximum temperature in the summer and daily minimum temperature in the winter is projected to increase by 3.8ºC and 5.3ºC respectively. While results from dynamic downscaling are more skillful and sophisticated than ever before, a key caveat is that there exists significant uncertainty for regional climate scenarios. To reduce the uncertainty, further research is needed.

Image: NIMR

International Conference on Climate Change Science and Impacts
19-22 November 2008, International Convention Center, Jeju, Korea

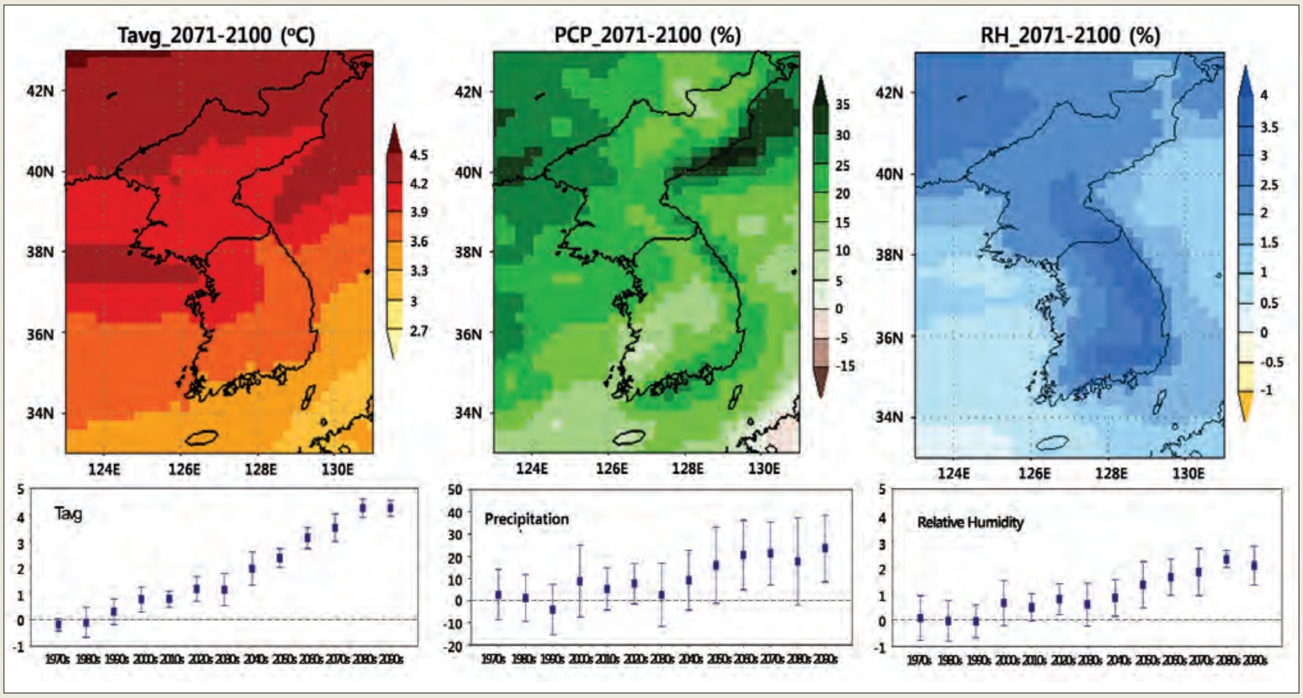
The CRL provides regular 3-month forecast data to KMA and the APEC Climate Center using the Global Data Assimilation and Prediction System — an AGCM developed by KMA. Recently, through the Joint Program for Unified Model Collaboration with the UK Hadley Centre, the CRL is planning to provide 3-month ensemble forecast with the UK Met Office. As a result of the collaboration, development and production of 12-month forecast data by 2012 is also in the works.

The CRL earth system model project was launched in 2008 in order to better understand and predict climate change and variability by improving the current global model. The project, in its initial stage, has completed construction of a coupled atmosphere-ocean-sea ice model, using the OASIS coupler, UM, and MOM4. Future plans include the development of an integrated earth system framework — combining a terrestrial module, an aerosol module, and a carbon cycle and sulfate module — by 2012.

The understanding of climate science and the quality of climate information has seen dramatic progress of late. With information on climate change gaining more exposure, society has come to realize its potential importance. By tailoring available climate information to the general public, end-users with specific needs, and various sectors of society, the CRL is improving the societal usefulness of climate information. The CRL provides a wide range of climate change and forecast information, as well as information about climate science, to the Korean public through the Korean Climate Change Information Center.[1] The CRL has also provided climate change scenarios and information to Korean government organizations for their assessment reports, including the Mitigation and Adaptation Plan from the Ministry of Environment and Impact Assessment of the Impact of Climate Change on the Agricultural Sector, by the Korea Rural Economic Institute.

The CRL has been active in outreach programmes to raise the awareness of the Korean public. Although the mission of the CRL is to further the scientific understanding of the climate system, it also understands the social responsibilities and roles of scientists in informing the public and decision makers about climate change. In addition to publishing articles in peer-reviewed academic journals, the CRL also works with various media outlets including magazines, newspapers, television and radio, providing climate change science and information. The CRL also offers presentations

Differences in temperature, precipitation, and relative humidity between 1971-2000 and 2071-2100 based on the IPCC SRES A1B scenario



Source: National Institute of Meteorological Research (NIMR) in KMA

and seminars for professionals, students and the general public in order to disseminate information. Recently, the CRL published and distributed a three-volume series entitled Understanding Climate Change, which includes the main findings from the IPCC AR4 as well as climate change in Korea, making information easily accessible to the general public and decision makers.[2]

Cooperation and collaboration is crucial for progress in climate science research. As such, the CRL has been collaborating with the UK Hadley Centre, the Japan Meteorological Research Institute, the Canadian Climate Research Division, MPIM and the Voeikov Main Geophysical Observatory on climate prediction and climate change research. At the 6th Asia-Pacific Network for Global Change Research Workshop, the CRL and scientists from the Asia-Pacific region collaborated to investigate extreme climate events in the Asia-Pacific region. The CRL also hosted the International Conference on Climate Change and Impacts inviting climate science experts in the Asia-Pacific region to share research information.

In Korea, the CRL has been hosting an annual climate change conference since 2003, helping both climate change scientists and mitigation and adaptation experts to network and share information. As a result of the effort, the Korean Society for Climate Change Research, an academic society consisting of members from various higher education institutions, was launched in February 2009.

Improving climate information is critical to better understand climate variability and change, improve existing climate models, and reduce the uncertainty of climate prediction. However, no information is useful if it fails to consider the needs of the end-user and tailor results accordingly. The importance of this information can no longer be ignored, as climate has shaped the evolution of the world and human society since the dawn of time. Human history faces a climate change that can potentially threaten the survival of the species. While we cannot predict the future in its entirety, better climate information will enable us to more accurately anticipate the future, reduce damage and casualties from future disasters, and enable sustainable development in a changing world — providing us all with a better future.

Understanding Climate Change I, II, and III

CRL published and distributed a three-volume series Understanding Climate Change, making information easily accessible to the general public and decision makers

Source: National Institute of Meteorological Research (NIMR) in KMA

Climate watch — purpose and requirements

Omar Baddour, World Meteorological Organization, Chief Data Management Applications Division;
and Pierre Bessemoulin, Météo France, President, World Meteorological Organization Commission for Climatology

Natural climate variability operates on multiple scales at all times and can affect global and regional atmospheric and oceanic circulations. Many of these variations are recurrent and are usually recognized as well known climatic patterns — warming/cooling of Sea Surface Temperatures in the tropical oceans such as the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Madden-Julian oscillation and the strengthening/weakening of the upper level jets — and are often characterized in terms of climate indices (for example, ENSO or NAO index). They correlate significantly with departures from the mean state of climate parameters at monthly, seasonal and interannual timescales, as well as with the possible onset at some regional levels of extreme climate and weather events leading to direct and indirect impacts on lives, goods, properties and the well-being of societies. Droughts, heat waves, cold waves, flooding, extreme wind storms, landslides, bush and forest fires, and coastal erosions are just a few of the impacts that can be triggered by one or several of such anomalies. In the context of global warming these extremes are expected to become more frequent, more severe and of a greater geographical extent than previously recorded.[1] Some of the observed increases in climate extremes already fit in with such projections.

Image: NOAA

Climate watches help people and the authorities to prepare for extreme weather conditions and mitigate the damage caused

Example of sector applications

Sector	Climate extremes	Impacts
Health	Heat/cold wave	Cardiovascular, respiratory and heat stroke mortality
	Flood, landslide, windstorm	Deaths and injuries, infectious diseases and mental disorders
	Drought	Starvation, malnutrition and diarrhoea and respiratory diseases; strain on health due to poorer drinking water quality and availability
	Temperature and excess of rainfall	Mosquito, tick-borne diseases; rodent-borne, water-borne and food-borne diseases
Agriculture	Flood, heavy rainfall, hailstorm	Effects on early seeding, damage to crops and submergence, inefficiency of applied fertilizers; food and shelter for livestock; diseases such as cholera, worm infestation
	Drought	Early establishment in high lands, low plant stand, damage to crops; outbreak of diseases such as black quarter, anthrax in cattle
Transport	Flood, heavy precipitation	Flooding of roadways, rail lines, subterranean tunnels and runways, road washout, damage to rail-bed support structures, damage to pipelines
	Heat wave	Compromised pavement integrity, deformation of rail lines, thermal expansion of bridge joints, heat buckling of runways
	Drought	Increased susceptibility to wildfires Decreased visibility at airports located in drought-prone areas
Water resources	Heavy rainfall	Increased river discharge, inundation, dam management
	Dry spell	Lower water quality, reduction of water resources, effect on reservoir management and fresh water distribution in urban areas
Energy	Heat/cold wave	Increase of energy heating or cooling demand, reduced energy supply, affects gas and fuel pipelines
	Precipitation deficiency	Reduction of hydropower energy production

For more than a decade setting up an efficient early warning system for climate anomalies and related extremes has been a major focus of the World Meteorological Organization (WMO) and the National Meteorological and Hydrological Services (NMHSs), with the aim of improving climate risk management capabilities among nations. Such climate warning systems — for example, climate watch systems — are designed to provide advisories (climate watches) to inform the users, particularly those involved in natural hazard preparedness, mitigation and response on ongoing, pending and/or expected climate anomalies and their negative impacts. As such, NMHSs should be adequately equipped and prepared to continuously monitor and assess the state of the climate, evaluate available long range forecasts, and when possible, provide users with concise and understandable early warning climate information on a weekly, ten-day, monthly and seasonal timescale.

System components and requirements

The availability of quasi-real-time and historical climate observations is necessary for the efficient monitoring and forecasting of extreme climate events. Monitoring climate extremes usually requires high-quality and high-resolution data. Therefore a good quality observation network able to capture the space and time features of climate events is necessary. At national level such networks should be manageable in an integrated way, incorporating a central, real time data collection system and robust climate data management facilities. This infrastructure should enable the quick access and retrieval of current and historical data along with adequate applications to perform climate analysis to the required accuracy. Climate databases and users databases need to be set up together to analyse climate hazards and related impacts. The use of a geographic information system helps to integrate both databases in an efficient manner, as well as allowing customized criteria for climate watches. Climate monitoring has been strengthened by using space-based observations, which provide useful environmental information needed to assess the intensity, evolution and extent of climate related hazards.

Most NMHSs currently issue warnings (typically for two days in advance) based on weather predictions of the occurrence of severe weather conditions including: tropical cyclones; heavy rain with risk of flooding; severe thunderstorms with risk of tornadoes or hail; gale-force winds; heat waves and cold spells; snow; ice; severe coastal tides; storm surges; landslides; avalanches; forest fires; fog and sandstorms. A good example of this type of set-up is the European Meteo Alarm system (www.meteoalarm.eu). Additional information on the severity/intensity of the risk, its expected time period and possible impact, as well as some advice on how best to behave under the circumstances are usually also provided. The use of longer lead-time forecasts (seven to ten days) issued from medium-range forecast centres is also extremely useful for issuing pre-warnings.

Such systems also use long-range forecasting products (from one month to two years) that are provided by Global Producing Centres and Regional Climate

The monthly Climate Watch Africa bulletin provides analysis on important climatic factors including monsoon winds, rainfall and temperature

Example of a climate watch

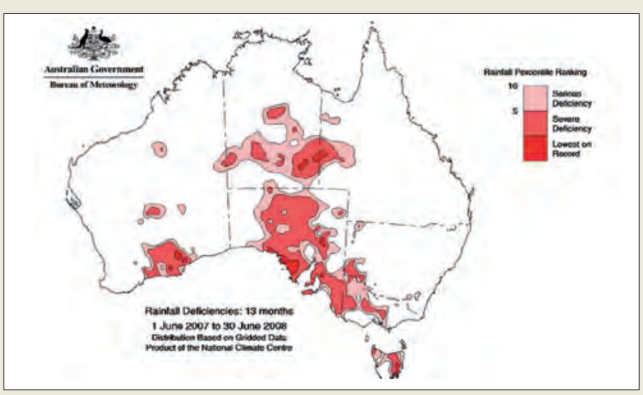
Initial climate watch
Bureau of Meteorology National Climate Centre

CLIMATE WATCH FOR RAINFALL DEFICIENCY
Climate Watch valid for South Australia and western Victoria.
Issued on 3rd July 2008 — Valid until 4th August 2008

Areas of serious to severe rainfall deficiencies across South Australia and western Victoria are likely to persist during the coming season. Most of SA and western Victoria have recorded rainfall totals in the lowest decile range for the thirteen-month period from 1st June 2007 to 30th June 2008. The outlook for the next three months, July to September, derived from the Bureau of Meteorology's statistical forecast model, shows that the chance of exceeding the median rainfall is only between 30 and 40% for these areas affected by rainfall deficits. Outlook confidence for this forecast is moderate over northern and central SA, with a skill level of around 60%. The confidence level for western Victoria low, although in several areas the July to September rainfall total would need to be decile 8 or higher for the deficits to be removed.

These figures meet or exceed the criteria for a rainfall deficit Climate Watch for this region, being:
— Rainfall for the past three or more months: decile one or lower.
— Chance of rainfall being greater than the median: 40% or lower.
— Forecast skill score: 55% or greater.

Climate situation: Sea surface temperatures in the central equatorial Pacific have gradually increased over the previous two months and are now generally close to average. The final remnants of the 2007/08 La Niña event continue to linger in the western Pacific, although the overall ENSO state is rated as neutral. A majority of computer models in a recent survey indicated that neutral conditions are likely to persist for the next three to six months. However, these same models show that a positive dipole of Indian Ocean temperatures (IOD) may persist for a few more months. This phase of the IOD has been linked with reduced rainfall over central and southeastern Australia.



Source: Australian Bureau of Meteorology (BoM)

Centres. In addition, consensus forecasts provided by Regional Climate Outlook Forums (RCOFs) should be considered whenever they are available.[2] Adaptation and downscaling of these products to a scale pertinent to the geographical scope covered by climate watches is also required and should be based on scientifically sound techniques and methods. These products are generally based on the probability of averages of selected parameters (from weekly for monthly forecasts to thrice-monthly for seasonal forecasts) and whether these averages are below, close to, or above the local climatological references (normals).

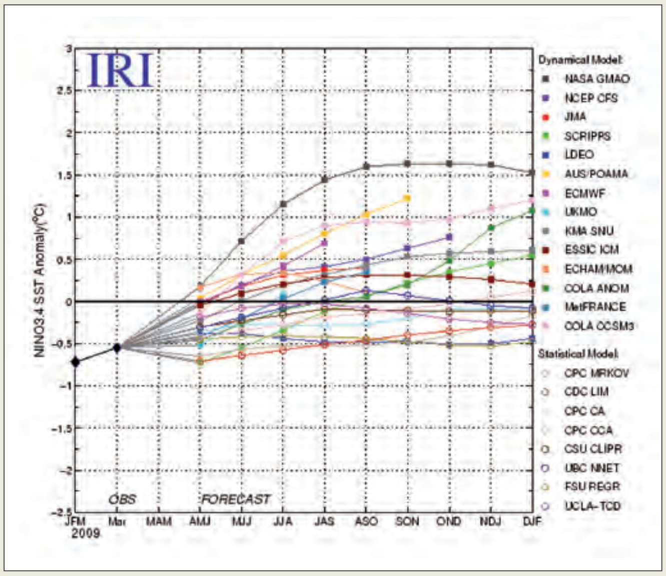
The output of a climate watch system[3] includes: initial reports outlining the ongoing and/or expected climate anomaly; updated statements at user-agreed time intervals informing on the progress of the anomaly; and final statements stating the expiration of the warning. The content, format and dissemination plan of climate watches should consider specific purposes and geographical scope, as required by the target users. It is also important that the system includes a performance verification procedure, which should be carried out systematically as an integral part of the system operation. Users should be informed of verification results on a regular basis. This builds trust between the issuing organization and the users, as well as constituting an assessment of the effectiveness of the user-agreed criteria. Long-term, the verification system provides a knowledge asset that can be used for performance improvement.

System requirements

The issuing organizations (NMHSs) need to meet a minimum set of requirements for operating a climate watch. They should be able to provide the following climate functions on an operational basis:

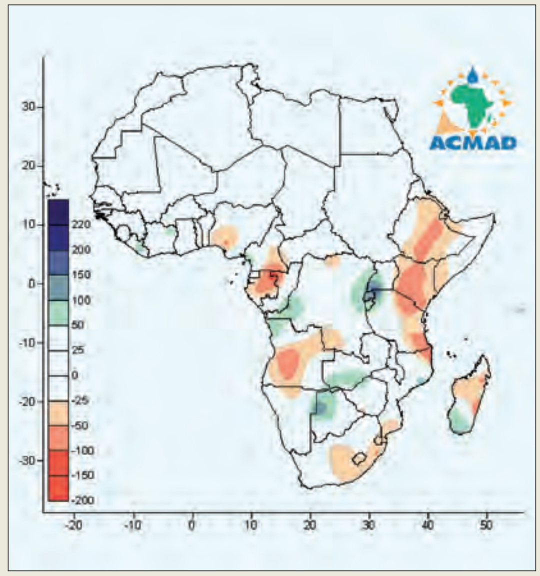
- Timely observations of current climate conditions for their area of responsibility, as well as adequate historical climate data
- Timely monitoring and analyses of current climate anomalies
- Access to current global climate forecasts and the technical capabilities to interpret and downscale them to their region

Model forecasts for ENSO from April 2009



Source: International Research Institute for Climate and Society (IRI)

Rainfall anomalies in Africa for March 2009



Source: African Centre of Meteorological Applications for Development (ACMAD)

- Probabilistic climate forecast products that are understandable to the user community
- Continuously updated records of past forecasts and analyses of past forecast performance
- Effective methods for the routine dissemination of climate information to user groups and sectors
- An active collaboration and feedback mechanism developed with the user community to provide guidance for the design of climate watches, as well as to evaluate their effectiveness.

If any of these aspects are lacking they must be developed. There are two aspects to consider simultaneously when planning for building capacity in climate watch systems. The first includes those activities required to ensure that NMHS personnel have the capabilities to operate a climate watch system. The second involves building capability amongst users, which requires dedicated and sustained efforts and is best achieved by regular interaction and partnership. This aspect requires a parallel outreach programme to ensure an adequate use of the system outputs, as well as understanding the system's limitations and where improvements can be made.

Supporting programmes and activities

At a global level the WMO World Climate Data and Monitoring Program facilitates international efforts in climate data and climate monitoring. It produces the WMO annual statements on the status of the global climate,[4] which highlight major global and regional climate anomalies occurring during the year. This publication, along with others of its kind, provide users operating at global, regional and national levels with useful information relating to the geographical extent and time frame of various climate extremes including: droughts; heat waves; flooding; heavy precipitations; and tropical cyclones. At the same time efforts are underway to build the capacity of NMHSs in climate data management and data rescue, as well as in implementing climate watches in developing and the least developed countries.

Since 1997 the WMO has been issuing the 'El Niño Update'. The report results from cooperation between the WMO and the International Research Institute for Climate and Society, along with contributions from many meteorological services and regional centres and organizations. The El Niño updates[5] are coordinated by the WMO World Climate Applications and Services Program. In 2004, Kousky and Higgins[6] developed an alert classification system for monitoring and assessing the ENSO Cycle.

In addition, the WMO has procedures and guidelines for the designation and establishment of WMO Regional Climate Centres (RCCs).[7] These centres constitute the main regional WMO operational climate institutions and provide regional products including climate analysis and long-range forecasts, as well as regional data sets and maps. These products serve as input for NMHSs operating climate watch systems at national levels. The RCC designation process has already started in WMO regions II and VI.

In Africa, the monthly Climate Watch Africa bulletin is developed by the African Centre of Meteorological Applications for Development . The bulletin provides comprehensive analysis of the current state of the African climate, including, monitoring the Inter-Tropical Convergence Zone, monsoon winds, rainfall, and temperature and soil moisture. It also includes seasonal climate outlooks and possible related impacts at continental and sub-regional scales (www.acmad.ne/en/climat).

The International Center for El Niño Research (CIIFEN) in Guayaquil, Ecuador, uses climate information from the Global Producing Centres as the basis for El Niño outlooks in South America (www.ciifen-int.org). CIIFEN also contributes to the RCOFs in the area.

IV

RISK GOVERNANCE AND MANAGEMENT

Early warning, early action

Maarten van Aalst, Associate Director and Lead Climate Specialist, Red Cross/Red Crescent Climate Centre, International Federation of Red Cross and Red Crescent Societies

When disasters strike, Red Cross or Red Crescent volunteers are often among the first to provide relief to the victims. But in most cases, we can save more lives and reduce more suffering if we can act before a disaster. We have known for decades that it is much more effective to evacuate people before a flood than to rescue them after the event. It is more effective to support farmers in finding alternative livelihoods than to provide food aid when the harvest has failed. The Red Coss and Red Crescent is investing more into people-centred early warning systems, using information at all timescales to address the rising risks of extreme weather events in a changing climate.

Early warnings abound

Fortunately, thanks to remarkable advances in science and technology, we have access to a wide range of early warnings. Global computer models and satellite images, regional centres of expertise, national meteorological offices and other government agencies, local field reports and community observations all allow us to better understand the present, and to anticipate the likely future. At the shortest timescales, a warning of an impending storm can help communities prepare and take immediate action — such as evacuation to reduce the loss of life. At intermediate timescales, a seasonal forecast may give warnings that an upcoming storm season could be particularly severe, a rainy season could bring unusual floods, or that a continuing drought could result in food scarcity. At even longer timescales, climate change projections and trends such as urbanization and population growth present early warnings of increasing risks.

Early action

An early warning has no effect without early action. Numerous examples illustrate how reliable information about expected threats was insufficient to avert a disaster, including Cyclone Nargis, Hurricane Katrina, and the food crisis in Niger. At the shortest timescales, such action could simply be evacuation. On the longest timescales, it means working closely with local communities to assess and address the root causes of the changing risks they face. Houses on stilts, planting trees against landslides, dengue awareness and prevention campaigns, water catchment systems and many other risk reduction measures can be taken. Early action also includes updated contingency planning and volunteer mobilization. The more we act upon the warnings on the longest timescales — by identifying communities at risk, investing in disaster risk reduction and enhancing preparedness — the more lives and livelihoods can be salvaged at the shortest timeframes when a flood does arrive.

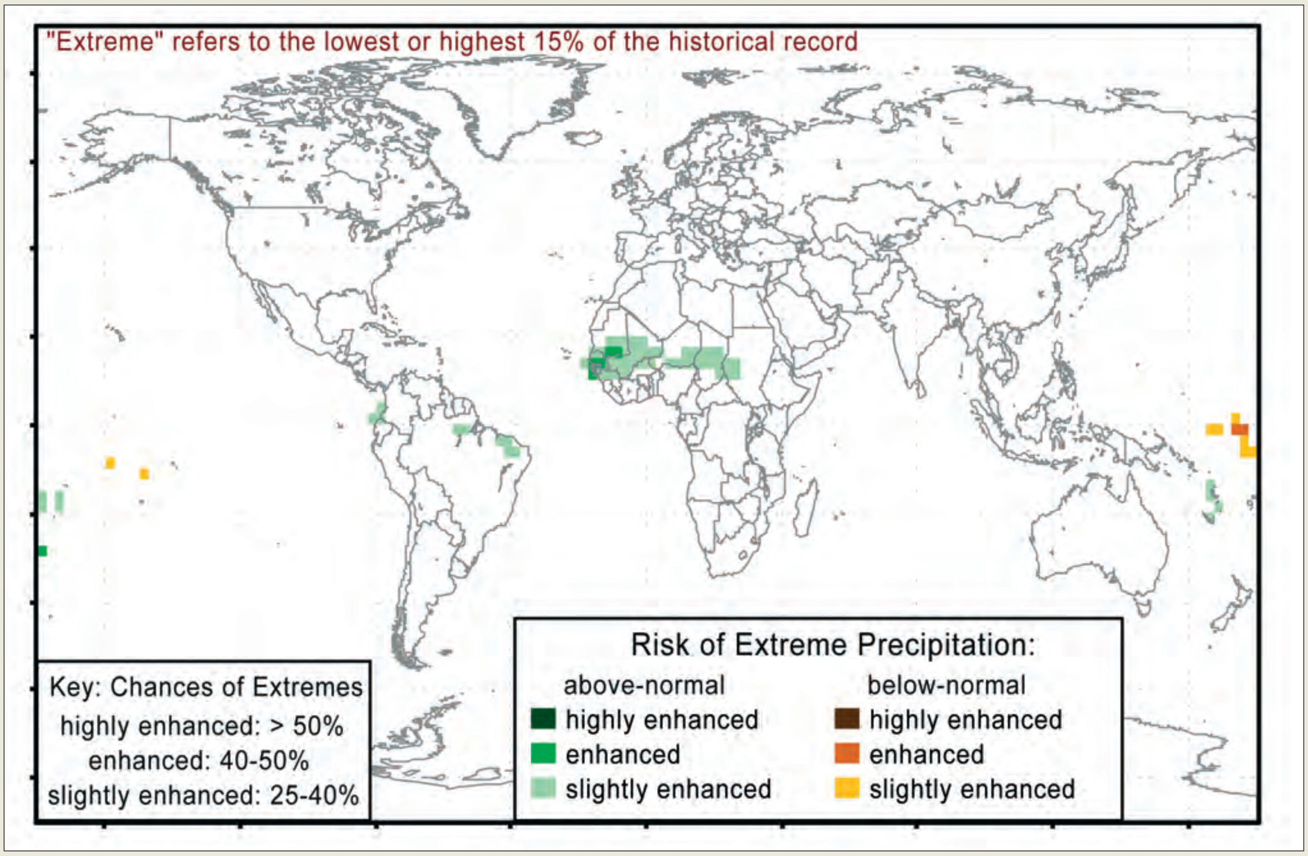
Early action also spans a range of geographical scales. While effective international humanitarian preparedness and response is essential, especially for major disasters, many activities to prepare for disasters, and particularly to reduce risk, need to be implemented at the most local level — often by local communities themselves. Better links to global, regional and national knowledge centres can only facilitate more effective action at local level if we ensure the information is received in time, understood and trusted by those at risk, and interpreted to inform local action.

Early action in the 2008 West Africa flood season

In May 2008, the West and Central Africa zone office of the International Federation of Red Cross and Red Crescent Societies (International Federation) in Dakar, Senegal, took advantage of new partnerships with climate professionals on both sides of the Atlantic — including the African Centre of Meteorological Applications for Development and the International Research Institute for Climate and Society (IRI) — to try to prevent history repeating itself in West and Central Africa. Floods across Africa in 2007 were the worst in several decades. Hundreds of thousands of people were displaced in nearly 20 countries. Nearly 300 died as a direct consequence of the flooding, which came in the wake of several relatively heavy flood seasons since 2000. This appeared to fit a pattern of increasing rainfall variability, possibly related to global warming, and clearly a concern for the Red Cross in the region. However, long-term model projections provide little guidance in this region - even annual average rainfall may go up or down. All we could do is be better prepared for a wider range of risks, and in particular making use of information at shorter timescales — not merely waiting for more disasters to unfold.

By 2008, the zone office was regularly monitoring seasonal climate forecasts. In late May 2008 forecasts received from two trusted sources raised an alarm. One was by the IRI, from a dedicated climate risk maproom, part of the International Federation's Disaster Management Information System. The other was presented at PRESAO, the regional climate outlook forum, attended for the first time by the International Federation's disaster management coordinator in Dakar, Youcef Ait-Chellouche. Both showed a high probability of 'wet' and 'very wet' conditions in the same countries that were flooded in 2007. The International Federation released initial funding from its Disaster Response Emergency Fund, which can finance early action based on evidence of a probable imminent disaster. Given the potential scale of the flooding, the International Federation also launched, for the first time ever, a wholly pre-emptive appeal for flood preparedness assistance based on seasonal forecasts, worth nearly USD750,000 and covering the entire at-risk region. This

Multi-model probability forecast of extreme precipitation for June-August 2008, issued May 2008



Source: IRI

enabled the zone office to provide support to National Societies for action before and during the floods, which indeed arrived as projected. The International Federation positioned relief stocks in Dakar, Accra and Yaoundé, ensuring supplies did not have to be flown in from Dubai but were already in the region, allowing faster and cheaper distribution. Regional disaster response teams were trained for flood response, and National Society disaster managers learned to interpret six-day rainfall forecasts to monitor upcoming risks. Visas were requested and medical insurance acquired in advance, so that teams could be mobilized within 24 hours of an emergency.

In Togo, an especially vulnerable West African country, more people were affected by the 2008 floods in more densely populated areas than in 2007. Yet data tracked by the International Federation suggests only 16 deaths occurred in 2008 compared to 25 previously. This reduction may not be directly attributable to Red Cross action, but Togo Red Cross staff believe their 2008 response was faster and better because they received early seasonal forecasts, and had learned lessons from the previous year. They now had contingency plans, a larger number of volunteers on call, and an effective communications system allowing information to pass between national headquarters, focal points in the regions and local communities.

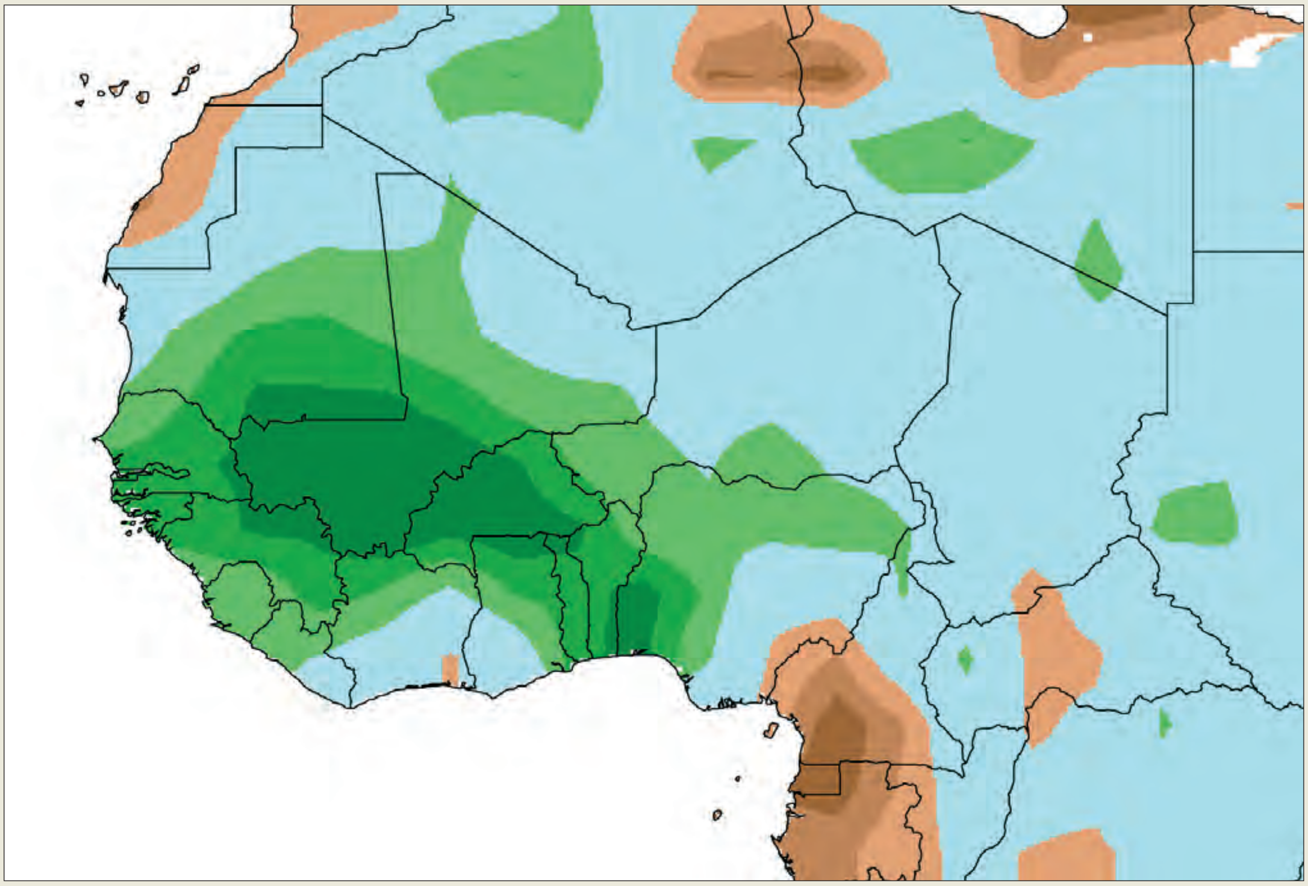
In Ghana, Red Cross volunteers helped to prevent a disaster when they learned that water from the Bagre Dam in the Volta River would be spilled, warning fishermen not to go out on the river on the days of the excess spillage — something they had been monitoring based on the warning from the seasonal forecast and the disastrous consequences of a similar discharge in 2007, they advised fishermen not to go out on the river. Across the region, the Red Cross was able to respond better and faster. In 2007, it took over a month to get supplies to where they were needed. In 2008, most countries received supplies within days.

At the end of the flood season in September 2008, the IRI issued its seasonal precipitation forecast for October, November and December, predicting above-average rainfall for the dry season. The zone office held a community meeting to consider the risks if the dry season was wetter than usual. Farmers quickly raised concerns about crops, mostly nuts and cereals that are typically dried outdoors in these months. If there was rain during this period they could easily rot, putting food security and livelihoods at risk. In partnership with the World Food Programme and the Food and Agriculture Organization, the zone office identified the exact drying period. Staff then contacted regional National Societies, asking them to inform farming communities that rain was possible and they should be prepared to cover or shelter their crops, keeping an eye on short-term rainfall forecasts. This simple information enabled many farmers to preserve their harvest.

Preparing for the certain and the uncertain

The West Africa example, along with several others, show that combining information on various timescales pays

Observed rainfall for July-August 2008, West Africa



Brown shading indicates the drier than average areas; green shading, the wetter areas

Source: Simon Mason, IRI

off. But using climate information on longer timescales is not a trivial undertaking for humanitarian organizations.

One challenge is uncertainty. It is clear that climate change exists and will lead to gradual changes such as melting glaciers and rising sea levels, as well as more weather extremes. However, specific consequences in individual places are often vague and probabilistic, and may seem irrelevant in the face of pressing day-to-day concerns. But, rather than confusing us by their lack of clarity, these long-term warnings of rising risks and uncertainties should be a strong incentive for increased early action through disaster preparedness and risk reduction. We have long assisted communities to prepare for the threats they know. Climate change now requires us to help prepare them for threats that are unpredictable in both severity and nature.

Similarly, probabilistic seasonal forecasts, while less precise than a warning of a storm about to hit a particular city, give us a valuable heads-up to prepare for higher levels of risk and be ready to act upon more specific warnings at shorter timescales.

Communication and capacity for action

A second challenge is communication. Early warnings are irrelevant if they are not received, understood and trusted by those who need to act. New sources of scientific information provide us with new opportunities, but also continuously raise questions. What does it mean to have a higher level of risk, sometimes including a higher level of uncertainty? Should the national Red Cross or Red Crescent society act, or wait? When does the risk get so significant that we when does the risk become so significant that we mobilize resources and volunteers? And how do we present that knowledge to those at risk in vulnerable communities? There is a need to transform scientific information, which is often complex and in the form of maps or percentages, into simple and accessible messages that allow local people to make sensible decisions on how to respond to an impending threat.

This requires firstly a continuous dialogue between humanitarian professionals and volunteers and knowledge centres at national, regional and global levels. A good example of this is the 'partnership to save lives' between the International Federation and the IRI, which stood at the basis of the successful preparedness appeal in the 2007 West Africa flood season. It also requires expanded investment in disaster risk reduction and preparedness at all levels — community, local, national and international.

Only by combining scientific advances with the resources and capacities to respond to warnings — at all timescales and all geographical scales — will we be able to counter the rising risks in a changing climate.

Managing risk in a changing climate

Stephen E. Zebiak, International Research Institute for Climate and Society

We live in a time of rapidly escalating concern about climate change. Although scientific evidence has been steadily building over many years, only recently has the consensus concerning observed impacts and future scenarios reached a level to capture the world's attention. Increasingly, the question of the reality of climate change is being replaced with the question of what to do about the problem. It is also increasingly appreciated that the response will require concerted efforts not only to control atmospheric greenhouse gas emissions, but to adapt to and manage the effects of climate change as well.

Climate shocks in the form of droughts, floods, cyclones, and related problems such as epidemics, food insecurity, infrastructure loss and the like have been playing out year by year, throughout recorded history, but with increasing severity as populations are becoming increasingly vulnerable. A growing body of evidence points to the direct effects of climate on economic and human development, particularly in low-income countries. The ability to cope better with the climate is thus a paramount issue of the present, and a potentially even greater issue in the foreseeable future. 'Win-win' approaches to better manage current climate risks, and to build capability to cope with the climate of the future, are especially needed.

Image: Curt Carnemark/World Bank

Farmers in Chile, part of South America's Southern Cone region

Many of the world's leading development institutions — including the United Nations Development Programme, the World Bank, regional development banks, foundations, bilaterals and non-governmental organizations — recognize that efforts to meet development goals, in particular the Millennium Development Goals, are threatened by climate risk. As a result, they have begun reviewing their programmes from the perspective of climate-related risk assessment and risk management. Similarly, national governments and decision makers at the local and regional levels are now asking how they can better manage climate-related risk.

A great deal of relevant information is now available to assist these efforts. Under the United Nations Framework Convention on Climate Change, and particularly through the work on the Intergovernmental Panel on Climate Change (IPCC), authoritative assessments of the current climate and possible future climate scenarios are readily available. In addition, routine monitoring information and seasonal-to-interannual climate forecasts are available in several centres. In practice, however, it has proven difficult to cast this information in terms that can inform decisions and policies in key socio-economic sectors. As a result, little uptake has been achieved and livelihoods and economies remain vulnerable to climate risk.

The work needed to provide problem-specific information and to advance innovations in the use of such information is the science of climate risk management practice. This work is especially challenging because it involves a complex interplay between physical, natural, and social systems and requires that practitioners engage with good science, good policy, and good practice. At present there are some organizations working to connect these disparate disciplines — but while their work has provided examples of practical ways to manage climate risk, the demand for useable knowledge and information far outstrips what can be provided.

If the global community is to become serious about managing climate risks, it must close the gap between knowledge and practice. In addition to major programmes in climate assessment, international policy, and development assistance, the global community must also provide a mechanism to advance climate risk management practice.

Climate risk management

Put simply, climate risk management is the process of climate-informed decision making. It involves the use of strategies that reduce uncertainty through the systematic use of climate information. Certain strategies may involve the deployment of climate-informed technologies and the implementation of climate-informed policy interventions that transfer some, or part of, the risk away from vulnerable populations. Climate risk management addresses the full range of variability, balancing protection against climate-related hazards with effort to capitalize on opportunity. In this way, climate risk management is an effective way to protect and improve international development.

The fact that climate risk management is effective, however, doesn't make it easy. Indeed, because the process is inherently interdisciplinary, it requires a detailed understanding of complex context-specific interactions between physical, natural and social systems. It also involves collaboration among experts who must work together on cross-disciplinary problems. Though developing the proper strategies is a complicated task, climate risk management can be applied to any sector and on scales that range from local to global, and from near- to long-term.

While the science of climate risk management is still in its infancy, strategies exist in every sector. For instance, an effort to address deepening drought in Western Australia created a constructive engagement between water managers and climate scientists that improved practice in both fields and contributed to better policy.[1] In the realm of public health, a group of partners developed an integrated malaria epidemic early warning and response system that is being implemented in conjunction with the Roll Back Malaria Campaign. The system includes seasonal forecasts, climate monitoring, vulnerability assessments, case surveillance, and response planning.[2]

Similarly, a project in the Southern Cone of South America manages agriculture related climate risk through a series of technological and policy interventions. It also works to reduce the uncertainty associated with the impacts of climate variability on agriculture. Project partners are currently developing information and decision support systems that include long-term climate and agricultural impact information, continuous monitoring of climate and vegetation, and seasonal climate forecasts.[3]

Innovative weather risk transfer solutions have also been developed. This includes index insurance, which provides a way to minimize the livelihood impacts of 'bad years' associated with extreme events. In the future, it may also be possible to combine index insurance with climate forecast information, providing insurance against the uncertainty of the forecast. At the same time, drought index insurance allows relief agencies to respond quickly as droughts unfold, thus avoiding catastrophes that may otherwise destroy livelihoods and force farmers into poverty traps.[4]

Obstacles to effective climate risk management

Unfortunately, while there are examples of successful climate risk management in different sectors, a number of obstacles still stand in the way of widespread implementation. Indeed, despite increased interest in climate evidenced by: the significant resources invested in climate-related research, forecasting, and assessment; rapid developments in climate policy; and increasing support for disaster risk reduction and climate-smart development, the practice of climate risk management as described above is rare throughout the world today. This leaves communities exposed to a great deal of climate-related risk.

This void is evidenced by the very few development organizations that employ climate knowledge, infor-

Image: Dan Osgood/IRI

Discussing index insurance with farmers in Adi Ha, Ethiopia

Image: Anthony Mwangi/Kenya Red Cross

Floods in 2007 caused a number of Kenya's key bridges and roads to wash away, making transportation a nightmare for commuters, students and humanitarian agencies attempting to deliver relief supplies

Image: Shehab Uddin/Drik/British Red Cross

Bangladeshi villagers watch a disaster awareness and preparedness programme

mation products, or related management strategies as part of their overall development toolkit. It is also clear that mainstream practitioner communities in health, water, agriculture, finance, and other key sectors have not yet begun to incorporate climate risk management into their day-to-day programmes. In addition, many climate service providers do not provide information on scales that are relevant to policy and management decisions.

A recent study by the International Research Institute for Climate and Society has characterized the current situation as one of market atrophy — negligible demand coupled with inadequate supply of climate services for development decisions.[5] In this system, the climate information production community is neither invested in, nor informed about, its client community. Meanwhile, user communities are poorly informed about climate, confused by the abundance of disparate information available, and generally mistrustful of the reliability and usefulness of existing information.

In this sense, the main obstacle to the widespread implementation of climate risk management is the lack of engagement and communication between user communities. Climate researchers and service communities develop knowledge and related information products from a disciplinary research perspective — largely uninformed about stakeholder needs. Meanwhile stakeholders in development, policy and planning are not capable of assimilating relevant climate information that is available. As a result, research is not being taken up. Stakeholders increasingly worry about climate but remain largely at a loss about what to do in practice.

The solution to this dilemma requires a focus at the nexus of these communities. It also requires the cooperation of relevant communities on scales from global to local. The extent to which we can meet this challenge will, in large measure, determine the benefit that can be realized from major ongoing investments in research, observations, assessments, international policy and climate-sensitive development programmes in years to come.

Pathways forward in climate risk management and adaptation

Despite challenges, the current state of affairs offers unprecedented potential to advance our capacity to manage climate risks and opportunities. The global dialogue has proceeded from a debate about the reality of climate change to a call for action in both mitigation and adaptation, and the world is now preparing for negotiations on future national and international commitments and action. The linkages between climate risk management, adaptation, disaster risk management, and sustainable development have been identified and are increasingly being recognized and embraced. The desire for significant action seems overwhelming.

Undoubtedly, a key aspect of action addressing 'common but differentiated responsibilities' — but also an opportunity for leadership for developed countries — is to offer substantial commitments in the area of knowledge, information and technology transfer to assist developing countries to more effectively manage climate risks — from the next season up to a couple of decades ahead.

While many new initiatives are likely to be pursued along these lines, the greatest opportunity lies in the creation of a framework that allows global scale coordination and sharing of resources toward improved climate risk management practice. This is because the scope of the challenge is so enormous that no entity, and indeed no country, can best address its own challenges in isolation. All countries, particularly developing countries, can best meet their challenges by having a means to access relevant global scale observations, state-of-the-art global climate prediction (and assessment) products, climate and environmental monitoring information, as well as accumulated knowledge of effective climate risk management practices, tools, and methodologies.

All of this could be provided through a suitably organized global infrastructure. One such option is being proposed as an outcome of the upcoming World Climate Conference-3. Whether implemented through this process or not, such a global framework is needed to seriously address the current climate challenge.

A great deal of attention is given, appropriately, to averting disasters and coping with the potentially disastrous consequences of climate extremes in developing countries. It is important to recognize that the establishment of effective climate risk management practices in developing countries offers not only improved ability to cope with extreme events, but also the opportunity to take advantage of favourable climate conditions. Strategies that allow increased investment in agricultural inputs, or increased water allocations during years with enhanced likelihood of plentiful rainfall, for example, can readily translate into positive social and economic outcomes. Thus there is much to be gained from establishing integrated approaches to climate risk management that address the full spectrum of risks and opportunities.

Experience to-date has led to the realization that to make a difference in operational decision and policy making, attention and effort needs to be devoted to the interface of climate knowledge/information and decision/policy making in key sectors. This work requires significant and sustained engagement between scientific and technical experts, practitioners and policy makers; it is most effective when undertaken in actual problem settings. Such work has been effectively undertaken through boundary organizations, either independently or as units embedded within sector-based organizations. Regardless of the constructs chosen, a great deal more effort needs to be invested at this interface to advance climate risk management practice at the scale needed. To be effective, these efforts need to be strongly science based, and must enable continuing climate risk management research and innovation, demonstration, evaluation, and knowledge sharing. Without this effort, the extensive ongoing investments, and needed improvements, in climate observing systems, monitoring, modelling, prediction, and assessment will not translate into the improved practices that are desired and urgently needed.

To address the scale of the challenge, there is a need to capture, distil, and disseminate the accumulating knowledge of effective climate risk management practices, together with the products that derive from such knowledge. Each local, regional, or national effort to advance climate risk management should benefit from the experience of all other relevant efforts including case studies, publications, data streams and training resources, as well as specialized information (including prediction) products and decision support tools. Only through such a knowledge management effort can collective global investments be tapped in servicing the needs of countless communities that must act to better manage climate risk.

Another opportunity lies in developing the means to coordinate efforts in evaluating the effectiveness of information products and strategies — a process for establishing, reviewing and updating good practices both in technical as well as implementation aspects of climate risk management practices. This would naturally evolve as an element of a coordinated global framework, but at any scale the importance of credible, widely available information on good practices cannot be overestimated.

Throughout the world, but particularly in developing countries, the successful implementation of (sustainable) improved climate risk management practices depends heavily on establishing awareness, and the technical and institutional capacity to take up information and employ it effectively. Addressing this will require substantial support from capable institutions committed to and resourced for capacity building and training, ideally organized at some level as part of a larger framework. In addition, looking toward the future, the greatest opportunities for significant progress in climate risk management rest with a community of professionals throughout all relevant sectors of society who are educated to be able to interpret climate information and to apply it in their fields of practice. There is an important role here for academic institutions in developing the necessary educational curricula and programmes.

One of the important lessons learned from work to-date is that from the decision-making perspective, managing climate is rarely just an issue of the present season, and equally rarely just an issue of the longer-term future. Rather, in most climate-sensitive policy, planning and operational settings, particularly in developing countries, there are significant concerns with managing climate risks and opportunities across a spectrum of timescales ranging from the present to 20-30 years ahead. The information available to support risk management at the subseasonal, seasonal-to-interannual, and decadal timescales differs substantially. Nonetheless, efforts need to be made to address risk assessments and management strategies in an integrated manner, drawing on all available information, tailored to the problem at hand.

Presently, IPCC projections cannot capture any predictability associated with decadal climate variability, and at this stage are not expected to represent the uncertainties associated with this variability correctly. Although research is being devoted to this, and needs to be accelerated, in the meantime the best practices in longer-term risk assessment will need to add information from analysis of historical climate records to make the best possible risk assessments. A time frame integrated strategy that addresses current risks, assesses robustness with respect to best estimates of longer-term risks, and adopts relevant contingency planning — in effect, adaptable adaptation — is the approach that holds the greatest promise and utility in practice.[6]

Innovative risk transfer options as adaptation strategies to growing hydro-meteorological risks in the Caribbean Basin

Simon Young and Ekhosuehi Iyahen, Caribbean Risk Managers Limited, Facility Supervisors, Caribbean Catastrophe Risk Insurance Facility

Climate change is adding to the already severe and steadily worsening risk exposure of the Small Island Developing States (SIDS) of the Caribbean Basin. Exposed to severe hurricane hazards as well as extreme rainfall and related flood and landslide hazards, small islands have a relatively high length of coastline and a huge concentration of economic activity in coastal zones and/or the lower reaches of river valleys. This is due to the high and growing economic importance of tourism (dominantly coastal-based) and the great concentration of the population on coastal flats. The other main economic engine of the region, agriculture, is also highly exposed to hydro-meteorological hazards.

An added problem for small countries with small economies is the devastating effect that single-event catastrophes can have both on physical infrastructure and the socioeconomic fabric of the country. A small regional economy combined with existing physical vulnerabilities often results in an amplified effect from natural hazards on these countries. For example, in 2004 Hurricane Ivan impacted almost 200 per cent of the annual gross domestic product (GDP) in each of two Caribbean islands, Grenada and the Cayman Islands, as well resulting in significant damage in Jamaica. By contrast, Hurricane Katrina's impact in the US was less than one per cent of annual US GDP and only about 30 per cent of Louisiana's annual GDP — assuming half of the total economic impact was in Louisiana.

Although much work remains to be done to fully understand the impacts of climate change on the Caribbean, a consensus is emerging that extreme events are likely to increase in both frequency and severity. This may hold for hurricanes as well as non-cyclonic rainfall events. Evidence provided by the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change provides overwhelming support of the probability of these changes

Image: Mike Whiteman

Damage resulting from Hurricane Ivan's impact on Cayman in September 2004 occurring within the Caribbean. Similarly, predictions summarized in a position paper by the Caribbean Development Bank released in 2008 indicate that by the end of the century temperatures within the region will have risen between +1.4°C to +3.2°C with a greater than 66 per cent probability of an increase in hurricane intensity.

While these forecasts and predictions are useful, it is also important to recognize that the impact of climate change cannot be simply conceptualized or limited to a future possibility. Its effects are already being directly felt within the Caribbean region. The rise in sea level and the increase in sea surface temperature already provide evidence of the increasing dangers being inflicted on these fragile environments and their economic and social landscape. The occurrence of sea-level rise and the warming of oceans has a direct effect on wave and storm surge hazards independent of event frequency/severity changes. These are especially pronounced in the Caribbean where most of the population reside in close proximity to the coast.

Additionally, degradation of coral reefs as a result of coral bleaching due to higher sea temperatures has led to a reduction in the natural mitigation provided by reefs to coastal environments, and in turn the surrounding coastal communities. The destructive impact of climate change on the coral reefs across the region has also resulted in irrevocable damage to the economic base of communities who rely heavily on the marine environment. The challenges created by climate change are therefore much more complex than just alterations to the physical environment within these islands. The challenges are intrinsically tied to physical, social and economic vulnerabilities — placing a disproportionate burden on small island developing states.

There can be no dispute that the challenges created by climate change through its present manifestation and potential future impacts are daunting. However, the Caribbean is leading the world in the development of innovative risk transfer solutions for catastrophe exposure, as part of an integrated risk management and climate change adaptation strategy. The development of the Caribbean Catastrophe Risk Insurance Facility (CCRIF) is an example of a macro scale initiative that can be regarded as a proactive and collective approach by regional governments to adapt to and mitigate the risks associated with their exposure to catastrophe hazards.

The CCRIF is the first risk insurance pool involving multiple countries. It is an example of an innovative risk transfer option in which a risk financing vehicle has been specifically designed to provide Caribbean governments with an efficient and cost effective method of pooling natural hazard risk exposures into a single and better-diversified portfolio. The pooling of these risks facilitates effective access to the global reinsurance and capital markets. The CCRIF currently issues parametric insurance policies, which use modelled hazard parameters as a basis for loss estimation and payment. Current hurricane policies are based on modelled wind speed at representative 'measuring points', the results of which are then used as a proxy for government losses via an index developed by modelling company EQECAT. Parametric policies enable very rapid payouts, providing governments with liquidity to help with immediate post-disaster recovery as well as medium-term rebuilding efforts.

The progress achieved in understanding the science behind meteorological events, coupled with technological advances within the risk management and financial sector has facilitated the emergence of tools and mechanisms such as the CCRIF, as well as the development of supporting informational databases which allow Caribbean governments to better manage their climate related risks. CCRIF's recent development of its own catastrophe modelling platform — with the help of Kinetic Analysis Corporation (KAC) — is a further refinement of the capacity of the facility, and broadens the scope of potential financial instruments which could be made available for risk management and mitigation in both the public and private sectors. This new platform enables the use of either a hazard index or modelled-loss as the basis for parametric contracts. Its modular and highly scalable architecture enables new hazard modules and a variety of exposure database formats (including gridded and point-data exposure) to be simply added.

In addition to the multi-hazard hurricane model (which includes surge and wave action loss generators), CCRIF and KAC, in partnership with the Caribbean Institute for Meteorology and Hydrology (CIMH), are developing a rainfall index aimed at representing flood impacts. The model will produce six-hourly rainfall estimates for the Caribbean Basin based on the Global Forecast System initialization data, run with topographic enhancement. This base rainfall accumulation will be aggregated at the basin level and weighted according to relative exposure within a basin to produce an extreme rainfall impact index.

The rainfall product is of particular interest in the agriculture sector, where index insurance is seen as a potential solution to achieving cost-effective insurance programmes for the region's agricultural industry. The

Image: Simon Young ©GeoSY Ltd

The aftermath of a localised rainfall event which triggered multiple landslides in Dominica in November 2004

Damage on Grand Turk, in the Turks & Caicos Islands, after the passing of Hurricane Ike in 2008

effects of climate change on agricultural production will have greatest impact on those least able to cope. Furthermore, traditional insurance products are either too expensive for most farmers or require unsustainable government subsidies. At the local scale, such index insurance solutions will, however, require significant enhancement of the hydro-meteorological measuring network. Although the lack of extreme event data constitutes a significant hurdle to developing and verifying index insurance products, this is not a problem faced by Caribbean countries alone. Instead it is a part of a wider global problem in which there has been a significant under-investment in technical and institutional infrastructure related to climate monitoring networks, which are necessary to inform effective climate change adaptation initiatives. This problem is particularly acute for extreme event monitoring.

Within the Caribbean the role of collective regional action in addressing these institutional deficiencies — while also developing and implementing national and regional climate change adaptation strategies — is critical. CCRIF's collaborative relationships with institutions such as CIMH, the Caribbean Disaster Emergency Response Agency (CDERA) and the University of the West Indies (UWI) are part of the collective approach required to assist the region as a whole, as well as the individual nations within it. The initiative to develop a Caribbean Risk Atlas — led by UWI's Disaster Risk Reduction Centre in collaboration with national governments, CDERA, CCRIF and the World Bank and funded by the Global Facility for Disaster Reduction and Recovery – reinforces the role of close partnerships and alliances in effectively adapting to the complex impacts of climate change. The creation of a regional risk atlas will permit greater comparison and exchange of information between countries. This in turn can be used to better guide risk mitigation and risk financing strategies on a collective scale, thus providing maximum benefit to the individual countries.

CCRIF's modelling platform — which is designed to enable testing of various future climate input datasets — along with the substantial research already undertaken by KAC in this field could find potential applications within the risk atlas project. They would be especially relevant in informing the planning, policy formulation and decision-making process within national and regional institutions and governments. As climate model outputs increase in resolution, CCRIF hopes to utilize its in-house loss modelling capabilities to provide significant quantitative information to enhance discussions on economic loss aspects of the climate change debate. This will, in turn, inform discussions on adaptation strategies and the role of insurance mechanisms in mitigating future impacts — particularly on small vulnerable states such as those in the Caribbean.

The scope for innovative risk transfer options as part of adaptation strategies to growing hydro-meteorological risks in the Caribbean Basin is therefore promising on a number of levels. It offers some measure of security for Caribbean countries through the provision of mechanisms and tools that can be harnessed to mitigate and adapt to the ever changing risks of climate variability and extremes associated with climate change. The potential of these mechanisms is especially relevant for developing countries, as they provide a means through which they can raise a reliable source of post-disaster recovery funding in the occurrence of a catastrophe event. This reduces, to some extent, the disproportionally large economic and human burdens created by climate change.

But the role and utility of these instruments cannot be limited to the tangible benefits that they can provide in the immediate aftermath of a catastrophe event. Their benefits can be expanded to include the investments that they facilitate in preventative initiatives and the adoption of holistic risk management programmes based on assessments of the vulnerability of these states. CCRIF intends to leverage its cross-departmental role to promote development of an explicit, high level 'Country Risk Officer' position. The role would involve the coordination of the holistic risk management strategy required both by individual countries and across regions in the face of growing hydro-meteorological, financial, health and social risks — many linked to climate change. Investments in the development of supporting technological and infrastructural capacities that build critical information databases that might not have previously existed, can also be powerful tools to inform wider policy and decision-making processes. These supporting investments can have benefits that go far beyond present day relief; indeed they are investments for the future security of the region.

Risk transfer instruments are evidently an integral part of a comprehensive disaster risk management process — but they by no means constitute a complete solution to the current and anticipated risks posed by climate change. Adaptation to and mitigation of the risks associated with growing hydro-meteorological hazards and vulnerabilities within the Caribbean Basin requires a multi-dimensional, collective regional and domestic response. Risk transfer instruments can play a crucial role within such a wide and comprehensive process.

A Nordic perspective on climate change and dam safety

Sten Bergström and Johan Andréasson, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

One fundamental issue in dam safety work is proper assessment of the design flood. If this flood is underestimated, there is a risk of failure of the dam, often with disastrous consequences. There are also environmental concerns related to dam safety. A major dam failure will, of course, have huge environmental consequences when industrialized areas are flooded. But smaller mine tailing dams can also be hazardous. They are also likely to have a longer exposure period, as they are often designed to remain as a deposit of waste after the mining activities are finished. In Sweden alone, there are as many as 10,000 dams for various purposes. The most important ones are components of the hydropower production system.

Design flood determination is one of the most important questions in scientific hydrology. Traditionally, the concepts Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) have been used by many countries. PMF is a very extreme flood that cannot, in principle, be exceeded. Unfortunately, the scientific foundations for the concepts of PMP and PMF are somewhat shaky, with the prospect of global warming further complicating the situation.

For the hydroelectric power industry, a new situation has arisen. Large investments have been made to upgrade dams to comply with the latest safety requirements. At the same time, the mining industry has realised that the hazards of global warming cannot be ignored, and has joined the hydropower industry in studies on climate and dam safety. However, existing regional climate scenarios continue to vary greatly,

Image: Sten Bergström, SMHI

Proper design of the capacity of the spillway is crucial for the safety of a dam. The spillway is activated at the Porjus dam in the River Luleälven in September 2007, after a safety upgrade according to the new Swedish guidelines for design flood determinations especially with regards to extreme precipitation within relatively small catchment areas — in other words, precisely that which is of greatest interest from a dam safety point of view. It is also recognized that new climate calculations are likely to be developed as science itself advances. A new attitude must be developed by dam owners to deal with this moving target. Truly — a new dimension in the philosophy of dam safety has arrived.

Fundamental questions

The question of climate impact on dam safety is one of the subjects addressed within the Nordic Climate and Energy Project — a collaborative effort involving the Nordic and the Baltic countries. It is also a matter addressed in several national research projects in the different Nordic countries. The fundamental questions asked in these studies are:

- What will be the combined effects on dam safety of more irregular winters including altered snow conditions, altered precipitation and altered evaporation?
- How is the best use to be made of scenarios from meteorological climate models in order to calculate the effects on design floods?
- What is the extent of uncertainty in the matter?

Methods

It is not easy to predict how global warming will affect flood risks in the Nordic climate, where the most extreme floods are generated by a combination of snowmelt and rainfall. What is most evident is that a warmer climate will result in shorter and less stable winters, with smaller spring floods and more frequent and less predictable floods in winter. At the same time, climate scenarios indicate that there is a risk of an increase in the most extreme rainfalls. But a higher temperature is also expected to cause increased evaporation. The total picture is therefore a complex one. In regions in the north, with long winters and a lot of snow, a decrease in the problems in conjunction with spring floods may be expected unless there is an appreciable rise in winter precipitation. In the south, where rain floods dominate, flooding problems may increase unless the increase in evaporation is sufficient to counterbalance the rise in precipitation.

Studies of the impact of climate change on water resources in the Nordic area have to be based on a model strategy that properly accounts for the hydrological complexity in the area. This strategy is normally based on the combined use of different greenhouse gases emission scenarios, output from global and regional climate models and a hydrological runoff model. Usually several combinations of modelling components are used, in order to explore uncertainties in the estimates. In our earlier studies the number of combinations used was normally only four: two emission scenarios combined with two climate models. Our recent studies are based on an ensemble of some 15 regional climate scenarios. It is a complex process to go from a climate model to an off-line hydrological simulation without losing statistical information about how temperatures, precipitation and evapotranspiration are changing in the new climate.

Most often the work relies upon regional climate scenarios from national research centres like the Rossby Centre regional climate modelling team in Sweden. These will soon be complemented with results from the European ENSEMBLES project, leading to a rather large internationally co-ordinated ensemble of regional climate scenarios (about 22 in total), which will facilitate uncertainty analyses and other statistical processing.

The hydrological model used in the Nordic countries is usually the HBV hydrological model, which has been widely used for forecasting and design studies for several decades. It has the necessary components to account for snow accumulation and melt, evapotranspiration, soil moisture and runoff generation.

Swedish design guidelines in a changing climate

The simulation scheme for design flood determinations in Sweden is rather unique. It was developed in the 1980s when it became obvious that current criteria were obsolete and could lead to dangerous consequences. The new guidelines were adopted in 1990, and a nationwide re-evaluation programme of all major dams in the country started and is still ongoing. Recently the mining industry has joined the hydropower industry in these efforts.

The Swedish design flood calculation guidelines are based on a classification of the dams into two main categories, depending on the potential consequences of a failure during flood conditions. Flood Design Category I should be applied to dams for which a failure could cause loss of life or personal injury, considerable damage to infrastructure, property or to the environment, or other large economic damage. Flood Design Category II should be applied to dams for which failure could only cause damage to infrastructure, property or the environment.

The PMF/PMP concept was found inadequate when developing the Swedish guidelines because the river systems are very complex, with many reservoirs and floods, which are generated by an interaction between snowmelt and heavy rainfall. Design flood determination in Flood Design Category I is therefore based on a hydrological simulation technique that describes the effects of extreme precipitation under particularly unfavourable hydrological conditions. Reservoir operation is also considered. Dams in Flood Design Category II should be able to pass a flood with a return period of at minimum 100 years at full supply level.

Of particular interest is that in the new edition of the Swedish guidelines for the determination of design floods for dams, it is prescribed that climate change shall be considered in all design studies. This has initiated a research project with the aim of analysing possible impacts of climate change on the design floods, and to find means to account for climate change in future design studies.

A number of drainage basins and dams, relevant for the power industry and the mining industry, have been selected for the studies of climate change impacts on dams according to both Design Flood Category I and Category II. In these basins design floods are calculated to allow for present day climate conditions and with available regional climate scenarios for the future. Focus for the design studies in a changing climate is on the first half of the 21st century, but simulations will also be made up to the year 2100. Results so far show that global warming may have great significance for dam safety, flood risks and the production of hydroelectric power in Sweden. The milder and more unstable winters expected in the future also mean that water will be released more often

A special committee comprising the dam safety authority, the power industry, the mining industry and the SMHI, monitors the impact of climate change on design floods. This will have a strong impact on the future design of dams in Sweden

into rivers where we are used to long calm periods during the extensive cold winters. This affects both dam safety and the lives of those who live along the rivers. Higher winter flows are at the same time beneficial to the production of hydroelectric power.

The results so far also show that there is considerable uncertainty. The difference between distinctive climate scenarios is large when it comes to impacts on design floods. The floods can either increase or decrease depending on how changing precipitation patterns interact with new snowmelt conditions. It is therefore crucial to use more than one climate scenario in this type of study and to take uncertainty head-on, rather than shying away from it. Undoubtedly, there is more than one answer to the question of how global warming will affect the most extreme floods in a river system.

Climate uncertainty from a dam owner's perspective

Understanding climate change and its impact is a challenge for the dam owners. It requires a new way of thinking, where we can no longer rely fully on past observations. It is also a challenge for the scientists to explain why and how the target is moving and why the user cannot expect to obtain one single and lasting answer. Communication between the user and the scientist has thus become crucial. Swedish research on the impact of climate change on design floods for dams is therefore carefully monitored by a special committee with representatives from the dam safety authority, the power industry, the mining industry and the Swedish Meteorological and Hydrological Institute. The task of the committee is to analyse and discuss new results and to recommend how climate change should be accounted for in future design studies. This will have a strong impact on the future design of dams and also on physical planning along the shorelines in Sweden, as the same flood criteria are used for flood risk mapping.

The prospect of a changing climate and the ensuing uncertainty related to the validity of dam safety criteria necessitates a new strategy in dam safety assessments. It is more than ever before important to be cautious and to add extra margins in the design. This may not be so expensive compared to the costs of doing this afterwards, when a project is completed. Another key concept is flexibility. It is very likely that future findings on climate change will force us to reconsider some of our basis for design at a specific site. Flexibility means that a project is designed so that it can be modified technically in the future if this is found necessary.

Decision under uncertainty is not a new problem for the power industry. About 100 years ago the large scale Swedish development of hydropower was started by the decision to build the Porjus hydropower plant in the roadless wilderness of the far north. Little was known about river flow and even the mapping of the water divides was incomplete. Nevertheless the engineers of those days managed to develop hydropower resources to the point where today they cover almost half of the nation's consumption of electricity. This has, of course, required a strategy of successive adoption to new conditions and data. Today the power industry has to face another source of uncertainty; that of climate change. This new situation is difficult in many respects, but considering the challenges faced by the engineers of the early 1900s, it has to be regarded as manageable.[1]

Climate network for disaster mitigation: lessons learned and future directions

Dr N. H. Saji and Dr W. J. Lee, APEC Climate Center, Korea

Hydrometeorological disasters account for the majority of the world's natural disasters, and continue to inflict human suffering and economic loss around the globe. Underdeveloped or developing countries are especially vulnerable to climate disasters, as exemplified by the case of Cyclone Nargis, which caused landfall in Myanmar in May 2008. With 140,000 estimated casualties, Nargis ranks as the deadliest natural disaster on record in Myanmar. However, even the most advanced countries may suffer setbacks from climate disasters, as clearly demonstrated by Hurricane Katrina, which hit Louisiana and Mississippi at the end of August 2005, killing 1,300 people and forcing 1.5 million out of the affected areas.[1]

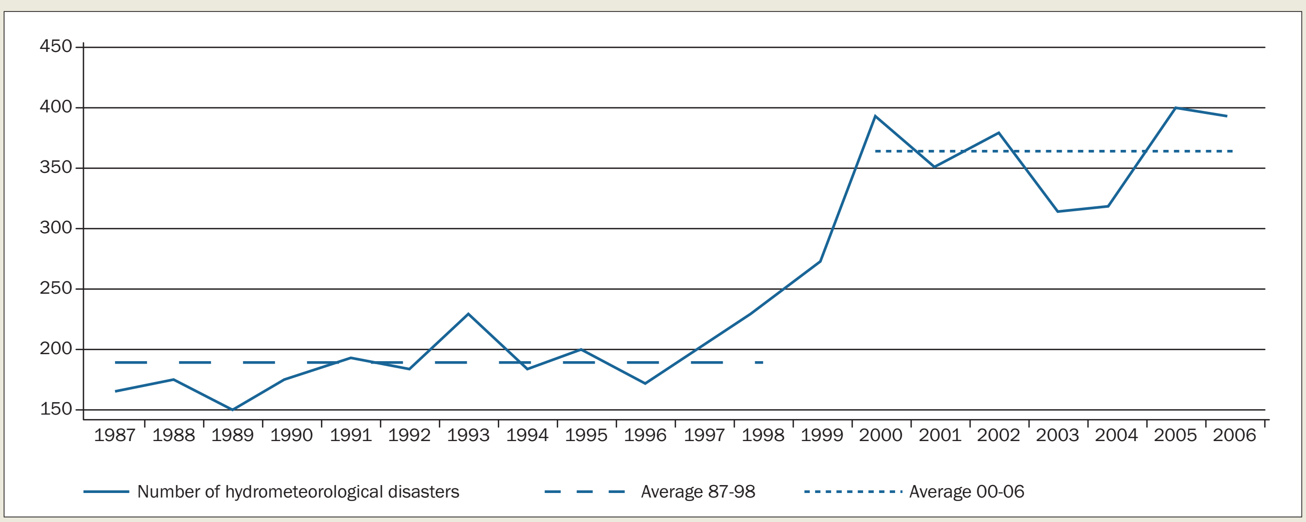
It is a matter of great concern that global economic losses associated with extreme weather and climate events are on the rise. Even more alarming is the significant increase in the average number of hydrometeorological disasters in recent decades. For example, the average hydrometeorological disasters reported for 1987-1998 amounted to 195. For the years 2000-2006, this average increased by 187 per cent to 365.[2] Such climatic catastrophes impact developed nations as well as developing ones, albeit in different ways. It is true that the number of fatalities in the developed world, where warning systems are more sophisticated and effective, is disproportionately smaller than that in developing countries. On the other hand, the absolute magnitude of economic loss is greatest in the developed countries, while its impact is more devastating and enduring in emerging countries [3]

The worldwide increase of climate-related disasters in recent years may herald the dawning of a new era of catastrophes. The multiplying population and greater concentration of assets in high-risk areas, coupled with the potential for even more frequent weather extremes due to climate change, portend even more devastating events in the coming years. One of the expected effects of global warming is higher storm, hurricane and typhoon intensity. This has been predicted by theory and modelling, and supported by empirical data on climate change.[4] With the ubiquitous trend towards globalization, the impacts of these disasters are likely to be felt far beyond where they initially hit in an increasingly interdependent world.

Development of a multi-economy network for disaster mitigation

There is clearly an urgent need for developing and implementing coherent risk reduction and adaptation strategies to reduce catastrophic human and economic loss in the future. Given that climate knows

Occurrence of hydrometeorological disasters: 1987-2006 with averages for the periods 1987-1998 and 2000-2006



Source: P. Hoyois, R. Below, J-M. Scheuren, D. Guha-Sapir, 2007: Annual Disaster Statistical Review — Numbers and Trends, 2006, Catholic University of Louvain, Brussels

Organizations and institutes participating in the joint real-time operational MME forecasts

Source: APCC

no political or geographical boundaries, and that in a globalized economy even local climate disasters have a global impact, it is even more imperative to secure close cooperation between nations for exchanging information and expertise with the common goal of reducing economic loss and human suffering related to extreme weather and climate. In recognition of this urgent need, in 1999 the Asia-Pacific Economic Cooperation (APEC) initiated the development of a regional climate network for the Asia-Pacific region, the APEC Climate Network (APCN), with the participation of all APEC member economies. APCN is intended as a communication channel for the exchange of climate information and technology, with a stated mission to reduce adverse impacts of hydrometeorological disasters and to utilize advanced climate information for social and economic well-being.[5] The APCN consists of 21 national hydrometeorological centres in the APEC region and leading climate research and prediction centres from around the world.

The APEC Climate Center (APCC), located in Busan, Korea, supports APCN in its mission to enhance the socioeconomic well-being of APEC member economies. To this end, it utilizes the latest science and applies innovative climate prediction technologies by:

- Developing a value added reliable real-time climate prediction system, using a state of the art multi-model climate forecast system with model predictions from member economies
- Acting as a centre for climate information with open access for member economies
- Helping to build capacity in member economies for producing and using reliable climate products
- Refining methods of utilizing socioeconomic innovation to mitigate and adapt to climate variations
- Coordinating research toward the development of an APCC integrated climate-environment socioeconomic system model.

Climate prediction through the multi-model ensemble

APCC aims to produce reliable seasonal predictions for user communities, based on a well validated multi-model ensemble system (MME). Currently, APCC-MME uses outputs from operational-mode global climate models of institutes from eight APEC member economies. Organizations and institutes participating in the joint real-time operational MME forecasts are the US National Aeronautics and Space Administration, National Centers for Environmental Prediction, International Research Institute for Climate and Society and Center for Ocean-Land-Atmosphere Studies, Russia's Hydrometeorological Service and Main Geophysical Observatory, Korea's National Institute of Meteorological Research, Korea Meteorological Administration and Seoul National University, the Japan Meteorological Agency, Taiwan's Central Weather Bureau, China's Institute for Atmospheric Physics and Beijing Climate Center, the Canadian Meteorological Center and the Australian Bureau of Meteorology. At present APCC operates the world's largest and most extensive operational MME dynamical seasonal prediction system. The individual model forecasts are statistically post-processed to adjust systematic biases before being combined into an optimized multi-model ensemble forecast. The resultant 3-month rolling monthly MME predictions are distributed through the APCC website 12 times a year in both deterministic and probabilistic formats.

Capacity building and technology transfer

One of the important missions of APCC is to enhance the capability of member economies to adapt to climate extremes in the present and future. To this end, APCC organizes training workshops for climate prediction and adaptation techniques, as well as climate applications. So far, APCC has conducted six training sessions with more than 30 participants from approximately 15 countries on topics related to global and regional climate prediction and adaptation. It also has an active visiting scientist programme and has hosted 11 scientists from 7 countries. To facilitate information and technology exchange in the APEC region and regional cooperation toward the development of effective early warning systems of high impact climate events, APCC and its predecessor APCN have been organizing annual APEC Climate Symposium (APCS) meetings since 2001. The APCS provides a venue for all APCN members to exchange information on and assess the current status of climate prediction science, in addition to discussing ideas on improving climate information services through collaboration in the APEC region. The symposia are attended by NHMS and major climate prediction and research centres in the APEC region. Major achievements of the annual symposia include the development of an operational MME system for the APEC region and the sharing of digital climate prediction information with climate prediction and research communities worldwide.

Besides these activities, APCC has also actively promoted better use of climate information in affected sectors throughout the world by facilitating technology transfer and implementing an open data and information policy. The APEC Data Service,[6] established in 2008, allows registered users to download real-time climate prediction and monitoring data for theoretical

Participants at the 2008 APCC workshop on 'Regional climate predictions using statistical downscaling'

research and operational climate forecasting. A year later, in 2009, APCC launched the Climate Information ToolKit (CLIK),[7] a web-based solution that provides a user-friendly interface for climate prediction computations. CLIK is designed to aid users in easily retrieving and using climate prediction data and information available from APCC data servers. Climate forecasters, disaster managers and researchers anywhere in the world can log on to this service to generate customized climate predictions on seasonal to interannual timescales for their regions of interest. The software is expected to make a considerable contribution to the early warning and management of climate-related disasters, particularly in developing countries around the world.

Lessons learned and future directions

The practical importance of climate forecasts for the protection of life and property, together with concerns over future environmental degradation, has led to the creation of APCC. The most important challenge facing APCC is to provide accurate and reliable climate information for member economies in the Asia-Pacific region, and ultimately to help build capacity in the member economies for generating timely and accurate climate predictions. The first vision can be achieved by coordinated activities, but the ultimate goal calls for a formal and systematic institutional basis.

To address this challenge, APCC is exploring avenues to extend forecast limits to beyond a season, and initiated experimental 6-month climate predictions. These products, if found to yield reliable forecasts, will pave the way for enhanced disaster preparation. Another experimental product currently on trial is for global prediction of extreme hydrological drought and flood.

Even though APCC has taken great strides in improving the quality of global seasonal forecasts, challenges persist. For instance, it is immediately evident once we consider the needs of regional applications that the current forecast products from global models are often inadequate, as their spatial and temporal resolutions are too coarse. To bridge this gap between model outputs and end user requirements, APCC has developed statistical downscaling expertise; in the near future, the Center will develop and implement a suite of user-friendly online interactive statistical downscaling tools which will leverage the end values of MME outputs.

Another challenge is related to the utility of current technology in forecasting high impact extreme meteorological events that occur beyond the weather timescale, but within the seasonal timescale. Examples of these include the prediction of well known intraseasonal variations or that of unusually active tropical storm, hurricane or typhoon seasons in certain years or decades. The potential of using high resolution dynamical models and empirical techniques to predict extreme climate events from the intraseasonal to interannual timescales, such as the Madden-Julian Oscillation and its associated clusters of high impact weather, will also be a key focus for APCC in the years to come.

The years of collective experience within the APCC network expose nontrivial gaps in the translation of climate information into products that benefit society. Much of this is related to the lack of interdisciplinary studies that link, for example, how climate information can benefit activities planning in important sectors such as agriculture, energy, water management and health. APCC will expand its products by venturing into various industrial sectors including agricultural and water management.

The spectre of a changeable and changing climate leading to more intense storms, hurricanes and typhoons, increased flooding, droughts, heat waves and other extreme climate and weather events raises concerns about the vulnerability of present and future societies to climate-related catastrophes. It is not only the poorer countries that are likely to suffer the most. In an increasingly interconnected world, the most developed are equally vulnerable. The climate network fuelling APCC is a positive and fruitful example of cooperative initiatives that both developed and developing economies can undertake in implementing effective adaptation strategies against climate-associated risks.

Preparing for climate change by reducing disaster risks

Reid Basher, Special Advisor to UN Assistant Secretary-General for Disaster Risk Reduction, International Strategy for Disaster Reduction Secretariat

It is now well accepted that climate change will lead to greater extremes in weather conditions such as heat waves, intense rainfalls and severe droughts, and that — all other things being equal — disaster occurrence will increase as a result. Indeed, there are growing signs from disaster databases, as well as from field reports of development and humanitarian organizations, that this trend is already underway.

However, 'all other things' are not in fact equal. Firstly, disasters owe as much, if not more, to the socioeconomic factors that expose us and make us vulnerable to the weather and other natural hazards. Denuded hillsides, settlements on flood plains, poor housing, inadequate preparedness and early warning — factors such as these are what exacerbate the risks we face and lead to more disasters each year. Secondly, and conversely, there is currently an upsurge in awareness of, and commitment to, reducing disaster risks and preparing for climate change, which if successful will reduce countries' exposure and vulnerabilities, as well as lower the impacts of more extreme weather in the future.

We should not, therefore, focus exclusively on the hazard component of the problem and on the extremes. Instead, we should use the opportunity to grapple seriously with the interconnected issues involved, and to achieve a triple win, as advocated by UN Secretary-General Ban Ki-moon, of adapting to climate change, reducing disaster risks and losses, and strengthening development outcomes and poverty reduction.[1]

Image: Reid Basher

Research and monitoring has shown major shrinkages of glaciers and resulting changes in the seasonal river flows, a new challenge for downstream communities

Characteristics of disaster risk

Disasters span a wide range of phenomena, from short-term events such as tornados, earthquakes, tsunami, heat waves, tropical storms and floods, to longer-term and episodic conditions of drought and wild land fire. From 1991 to 2005, 3,470 million people were affected by disasters, 960,000 people died, and economic losses stood at USD1,193 billion.[2] Averaged over the last two decades (1988 to 2007), 76 per cent of all disaster events were hydrological, meteorological or climatological in nature; these accounted for 45 per cent of deaths and 79 per cent of economic losses caused by natural hazards.

Levels of disaster risk vary widely around the world and across different communities. Poor countries and communities are most affected, owing to intrinsic vulnerabilities to hazards and comparatively low capacities for risk reduction measures. For example, while Japan and the Philippines have roughly equivalent population exposure to tropical cyclones, death rates in the Philippines are 17 times greater than in Japan. Bangladesh, China and India, each heavily populated, account for 75 per cent of the global mortality risk from floods. Small countries are also particularly vulnerable — Grenada's losses of USD919 million as a result of Hurricane Ivan in 2004 were equal to 2.5 times its gross domestic product.

In launching the Global Assessment Report on Disaster Risk Reduction,[3] UN Secretary-General Ban Ki-moon said that disaster risk is rising in an alarming way, threatening development gains, economic stability and global security while creating disproportionate impacts on developing countries and poor rural and urban areas. The report draws attention to the growth of repeated disasters for some communities — especially across low- and middle-income countries — which is having a debilitating cumulative effect on livelihoods and assets. In one multi-country study, the damage to housing from persistent, low intensity events has quintupled since 1980.

Action to reduce disaster risks

As a result of growing concern about disaster risks, 168 governments met in Kobe in January 2005 and adopted the 'Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters', as a roadmap for achieving a substantial reduction of disaster losses by 2015.[4]

The framework sets out five priorities for action:

- Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation
- Identify, assess and monitor disaster risks and enhance early warning
- Use knowledge, innovation and education to build a culture of safety and resilience at all levels
- Reduce the underlying risk factors (this covers the many environmental and societal factors that create or exacerbate the risks from natural hazards)
- Strengthen disaster preparedness for effective response at all levels.

The expression 'disaster risk reduction', like that of 'adaptation', represents an abstract strategic and policy goal but tells little of what needs to be done in practical terms to address these priorities.[5] Fortunately, there is vast knowledge on what to do and many solutions and examples of good practice are available.

In developed countries particularly, there are well-established sectoral risk reduction and risk management efforts, the success of which is reflected in much lower death rates and lower relative economic losses. A number of developing countries have also made excellent progress in implementing policies that have cut loss of life especially.

Globally, the issue of disaster risk reduction is coordinated through the United Nations International Strategy for Disaster Reduction (UNISDR) and the biennial sessions of the Global Platform for Disaster Risk Reduction. This platform comprises a broad selection of stakeholders in a forum, which provides a strong mechanism for guiding worldwide action to reduce disaster risks and to reverse the growing losses from disasters.

At the second session in June 2009, political leaders highlighted that reducing disaster risk is critical to managing the impacts of climate change and to avoiding an erosion of social and economic welfare.[6] While there has been a dramatic increase in political will in all regions to address disaster risk, and significant progress has been achieved since the Hyogo Framework for Action was launched in 2005, it was agreed that greater urgency and a major upscaling of effort is required to address the factors that are driving the current increases in disaster risk.

Climate change and disaster risk

Climate change will affect disaster risks in two ways: firstly through the increase in weather and climate extremes, and secondly through the increases in vulnerability of communities to natural hazards. Climate change will add yet another stress to those of environmental degradation and rapid unplanned urban growth, further reducing communities' abilities to cope with even the existing levels of weather hazards.

The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2100 the global average surface air temperature will increase by 1.1 to 6.4ºC and the global average sea level will rise between 18 and 59 centimetres.[7] It is very likely that heat waves and heavy precipitation events will continue to become more frequent, and there will be more precipitation at higher latitudes. It is likely that tropical cyclones (typhoons and hurricanes) will become more intense, and that precipitation will decrease in most subtropical land areas.

It is impossible to be completely certain about the disaster-related implications of these physical changes, for several reasons. Firstly, there is considerable intrinsic uncertainty in climate projections, especially for local scales of interest. Secondly the occurrence of individual extreme events is very random in character. Thirdly, the nature of societal exposure and vulnerability to particular extreme conditions is both diverse and rapidly changing. Nevertheless, decisions and planning must go ahead, irrespective of these uncertainties.

IPCC provides extensive information on the impacts of climate change and there is plenty of information on the processes of historical disasters.[8] By extrapolating past experience to the conditions projected by IPCC — and in the absence of measures to reduce disaster risks — the likely consequences can be estimated in general terms as follows:

More heat waves — will increase the number of deaths, particularly among the elderly, the very young, or among people who are chronically ill, socially isolated or otherwise especially vulnerable.

Increased drought in some regions — will likely lead to land degradation, damage to crops or reduced yields, more livestock deaths, and an increased risk of wildfire. Such conditions will increase the risks for populations dependent on subsistence agriculture, through food and water shortage and higher incidence of malnutrition, water-borne and food-borne diseases, and may lead to displacements of populations.

Increased frequency of high precipitation in some regions — will trigger floods and landslides, with potentially large losses of life and assets. These events will disrupt agriculture, settlements, commerce and transport and may further increase pressures on urban and rural infrastructure.

Increases in the number and intensity of very strong cyclones — will affect coastal regions, with potentially large additional losses of lives and assets.

Sea-level rise, coupled with coastal storms — will increase the impacts of storm surge and river flooding and damage livelihood systems and protective ecosystems. Low-lying settlements may become unviable, which may result in increased potential for movement of population and loss of infrastructure.

Higher temperatures and melting glaciers — may cause glacial lake outbursts that could flood downstream settlements.

Image: Asian Disaster Reduction Center

Education is critical to providing the knowledge and tools that communities need to manage their risks from weather events, climate change and other hazards

The populated deltas, small island states, Africa generally, and the Arctic region have been identified as the most vulnerable regions.

New insights into climate change impacts and their management are expected from the planned IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.[9] Proposed by UNISDR and the Norwegian government in 2008, the report will provide an authoritative assessment of disaster risk reduction and management policies and practices, including their effectiveness and costs, and thereby a sounder basis for action on adaptation and disaster risk reduction. Its preparation by the IPCC will involve hundreds of experts worldwide and will be completed by mid-2011.

Disaster risk and the UNFCCC process

The Parties to the United Nations Framework Convention on Climate Change (UNFCCC) now recognize that existing knowledge and capacities for coping with extreme weather events must be harnessed to adapt to climate change. The Bali Action Plan's directions for adaptation call for the consideration of:

- Risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance
- Disaster reduction strategies and means to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change.[10]

Image: Reid Basher

The monitoring networks and analysis centres of the Japan Meteorological Agency keep track of multiple hazards and provide timely warnings to those at risk

Image: Reid Basher

Political commitment to cutting disaster risks is growing — the 2009 Global Platform for Disaster Risk Reduction attracted heads of state and governments to tackle the problem

The Bali Action Plan also calls for vulnerability assessments, capacity building and response strategies, as well as integration of actions into sectoral and national planning. These points, together with specific reference to the Hyogo Framework, are now part of the draft text that negotiators are considering in preparation of a new international agreement, to be settled in Copenhagen in December 2009.

For its part, the UNISDR secretariat supports the UNFCCC processes by convening processes to provide ISDR-wide coordinated submissions to UNFCCC Parties on disaster risk issues and practical adaptation methods and by assisting disaster risk reduction experts to accompany their national delegations to UNFCCC meetings. It also organizes partner side events at these sessions and encourages links between adaptation and disaster risk reduction groups in countries.

Building data foundations for adaptation and disaster risk reduction

At the local scales where local governments, enterprises and communities mostly operate, climate projections are very uncertain. Effective adaptive action therefore remains highly dependent on the available foundations of historical climate data and analysis. Risk assessments, early warning systems, sector risk management, insurance tools, and public education, for example, all rely on such factual information. The patterns of past climatic variability, over time and across local geographical features, are essential to interpret the global model projections and to generate future climate scenarios for testing different decision options.

Most developed countries are well equipped for the task: having national monitoring networks, databases of historical data and good analysis capabilities. In some cases, however, the effective use of these national resources is unduly restricted by shortsighted user-pays policies.

The situation for developing countries is generally much less satisfactory. Many have inadequate networks, fragmented historical data resources, and minimal capacities to maintain networks and databases or to carry out analysis and advisory services. Given that developing countries are predominantly those most affected by disasters and will be most affected by climate change, it is imperative that substantial new resources are put in place to aid the development of their climate information capacities.

The issue of vulnerability to natural hazards and disaster risks will remain central to the discussions leading to the UNFCCC Conference of Parties in Copenhagen in December 2009. While climate change undoubtedly will increase the hazard threat, it will also raise awareness of disasters and galvanize commitment to action against their root causes. Immediate action conducted under the guidance of the Hyogo Framework will make societies safer. With the support of science, it is possible to simultaneously provide adaptive capacity, increase resilience to future threats, and reduce the current unacceptable and growing levels of disaster risk.

Coping with drought in Slovenia

Drought Management Centre for Southeastern Europe

Drought is a normal, recurrent feature of climate. It occurs in virtually all climatic zones, although its characteristics vary from region to region. One way in which drought differs from other natural disasters is that it is difficult to ascertain onset and duration because consequences accumulate slowly and over a long period of time. However, drought phenomenon receives close attention due to its impact on both economy and society.

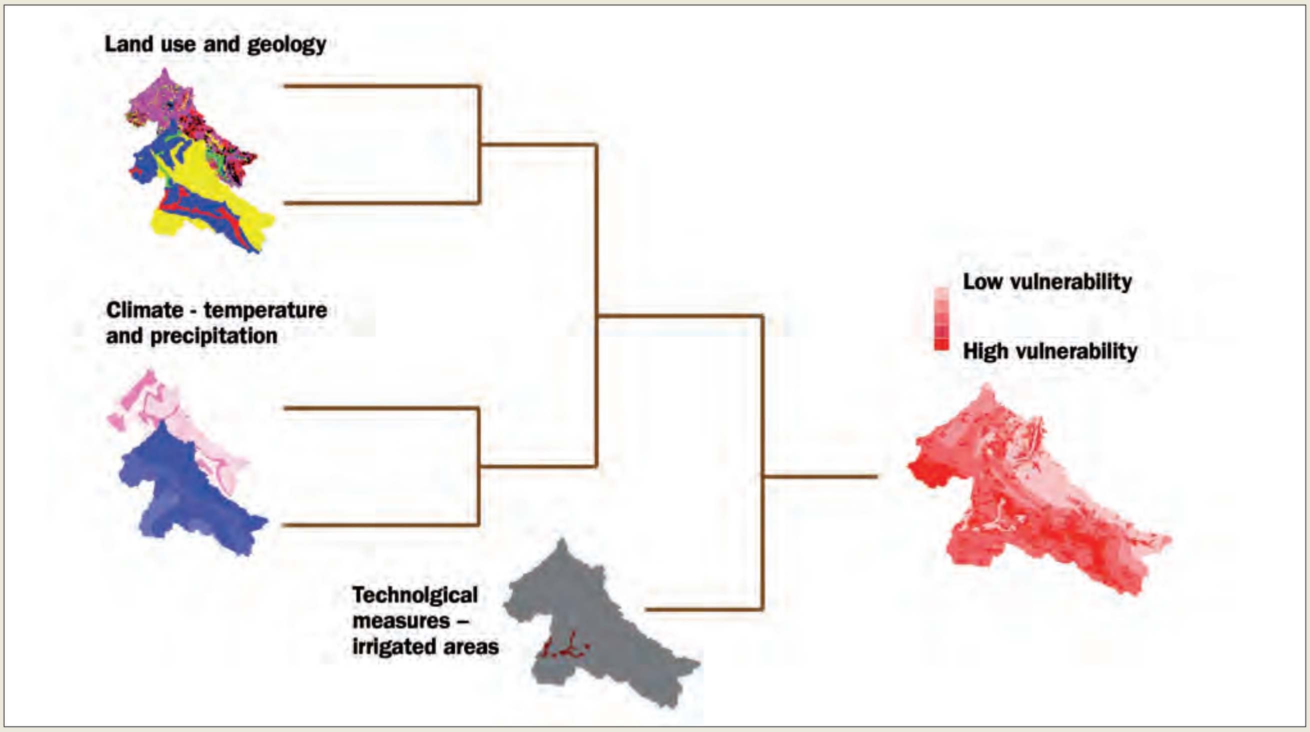
Slovenia is situated in a region with favourable climate and rich water resources. Agriculture, which is the sector most vulnerable to the impact of drought, contributes only a few per cent of gross domestic product. This is the 'big picture', but problems appear when one looks at the details. Agriculture does not contribute a lot to the economy from a financial perspective, but it keeps the countryside populated and prevents migration to the cities. It supplies a basic income to many socially underprivileged people, whilst also providing business and job opportunities to more inventive farmers. Regardless of their background, farmers are among those that are most exposed to unfavourable weather, including drought.

Many characteristics of drought occurrence in Slovenia are shared with neighbouring countries in the region. Southeastern Europe comprises Albania, Bosnia and Herzegovina, Bulgaria, Croatia, the Former Yugoslav Republic of Macedonia, Greece, Hungary, Montenegro, Moldova, Romania, Serbia, Slovenia and Turkey. Frequent occurrences of drought impacts reveal areas where natural resources are probably not managed in a sustainable manner — at least not in the warm season. Southeastern Europe is not affected as severely as some parts of the world, but there is a long history of drought in the region, and these events will continue to occur in the future, possibly with increasing impact, because of predicted climate change and increasing climate variability.

Image: EARS

Drought is among the most harmful natural disasters. Parts of Europe are exposed to the risk, although it is not as severe as in regions with semi-arid climate. Irrigation is among possible mitigation measures

Estimation of drought impact of a small region in western Slovenia



An attempt to assess the categorical vulnerability to drought impact of a small region in western Slovenia. Estimation of vulnerability and risk is not a well defined, straight-forward process. One possible approach is to combine various factors that influence risk

Source: University of Nova Gorica

So how do we cope with drought? By the improvement of existing early drought-detection monitoring systems and the establishment of new ones, as well as the application of an approach to deploy sustainable agricultural practices, achieve sustainable forest management and stop biodiversity loss. To achieve this goal awareness and preparedness must be strengthened by training and technology transfer, in order to increase the knowledge base. Since drought is a regional phenomenon with diverse and complex impacts at the local level, appropriate mitigation and responses must also be locally based. However, the development of appropriate action and policies can be facilitated through the collaboration of countries in the region that share similar problems. This idea led to the establishment of the Drought Management Centre for Southeastern Europe (DMCSEE).[1] Slovenia was entrusted with the organization of the centre. Its mission is to coordinate and facilitate the development, assessment and application of drought risk management tools and policies in Southeastern Europe, with the goal of improving drought preparedness and reducing impact.

Monitoring drought

Drought is usually defined as a naturally occurring phenomenon resulting from precipitation being significantly below normal recorded values, causing serious hydrological and agrological imbalances that adversely affect land resource production systems. Drought is a temporary aberration — unlike aridity, for example, which is a permanent feature of the climate. Seasonal aridity, which is to say a well-defined dry season, also needs to be distinguished from drought. Often long-lasting drought causes deterioration of the land's natural potential in regions that are not adjusted to water scarcity. Drought's consequences accumulate slowly and over long periods of time.

In general there are four different types of drought: meteorological, agricultural, hydrological and socioeconomic. Each type requires an adjusted approach to monitoring. Meteorological drought is defined by the level and duration of precipitation deficit. Agricultural drought refers to situations with insufficient soil moisture levels to adequately nourish crops during the vegetation period. Soil moisture levels and consequent severity of agricultural drought are related not only to precipitation deficit but also to the difference between actual and potential evapotranspiration. The actual water requirement depends on the weather situation (temperature, relative humidity, wind, global radiation), the biological structure of the plant and soil type. Hydrological drought occurs after a longer period of precipitation deficit, usually after meteorological and agricultural drought. Socioeconomic drought occurs when water deficiency starts to affect human life. It connects economic standards with elements of meteorological, agricultural and hydrological drought.

Defining drought is a complex task due to the variety of influencing factors. The process should allow for differences in regions, needs and disciplinary perspectives. The absence of a single and universal definition of drought makes it difficult to determine onset and duration. It is

Image: EARS

Severe drought impacts, which have occurred frequently in Slovenia in recent decades, are raising concerns

not possible to monitor the development of drought using a single meteorological parameter. The most frequently adopted solution to this problem is to combine various parameters into drought indicators, which at least enable us to follow its developing characteristics.

The World Meteorological Organization defines a drought index as: 'an index which is related to some of the cumulative effects of a prolonged and abnormal moisture deficiency'. A drought index should meet several basic criteria:

- The timescale should be appropriate to the problem at hand
- The index should be a quantitative measure of large scale, long-continuing drought conditions
- The index should be applicable to the problem being studied
- An accurate long-term past record of the index should be available or computable
- The index should be computable on a near real-time basis.

A fundamental mission of the DMCSEE is to integrate these criteria through an effective drought monitoring system, which will be able to show regions experiencing drought conditions. In order to achieve this goal, DMCSEE is developing a monitoring system that is based on a synthesis of multiple drought indices.

International cross-border cooperation is of great importance, as demonstrated by past examples, such as the establishment of an international operational weather analysis system. Measurements were standardized and a global telecommunications system was established. Regional drought monitoring is now facing a similar but, due to the complex nature of the problem, even more challenging task. Standardization of drought index calculations and the establishment of exchange procedures are the first logical steps for regional networks such as DMCSEE.

Vulnerability and risk assessment

One of the main aspects of drought mitigation and planning is the assessment of vulnerability, which is the essential ingredient of valid risk assessment. Understanding of the hazard and the factors that influence vulnerability must be improved in order to increase our ability to reduce drought impact. Estimation of vulnerability to the impact of drought lacks standardization, but fortunately several tools and methodologies are available to counter this. The US National Drought Mitigation Centre's *How to Reduce Drought Risk*[2] document guides the reader through step-by-step procedures that result in identification of drought impacts, vulnerabilities and their underlying causes. Additional information can be obtained from the results of the MEDROPLAN project.[3] The project resulted in the publication of drought management guidelines, which define a methodology for risk assessment in order to improve water management and introduce proactive planning. A similar approach is followed in further attempts at risk assessment in Italy[4] and Hungary.[5]

The intention is to develop a methodology for regional drought risk assessment for Southeastern Europe together with our partner institutions based on the above mentioned examples. However, Slovenia, in common with many countries and institutions in the region, has taken initiatives to prepare a draft risk assessment of drought impact. Agriculture is the logical choice to start with due to its high exposure to water shortages. A combination of different approaches to risk estimation has more potential than the application of a single method. Analysis of drought literature and data availability led us to the assumption that a first approximation should be made on the basis of two biophysical factors: climate and soil type, and two social factors: land use and available irrigation infrastructure.

Implementation of these four factors enabled us to produce a draft vulnerability map for a small agricultural region in western Slovenia. Negative impacts were assessed with the help of interaction matrices – a tool which is frequently implemented for examining environmental vulnerability. Interaction matrix methods allow more control and tuning of combinations of impact factors than traditional approaches, such as weighted linear combination. This feature is important for areas where many unfavourable factors interact and cause increased risk of drought impact. It is important that final analysis delineates such areas and informs users of increased risk.

Site and country-specific studies are useful and necessary for understanding the potential impact of drought, to assess vulnerability, and to develop useful drought vulnerability mitigation and adaptation strategies.

Heat health warning systems — an important tool for adaptation to climate change

Paul Becker, Christina Koppe, Deutscher Wetterdienst

Heat waves are an emerging public health problem in many parts of the world. As an example, the 2003 heat wave in Western Europe — which caused over 35,000 fatalities — clearly showed the danger that can arise from a long lasting heat load. France suffered 16,000 of these deaths, with Germany also affected. There are no mortality data for the whole country, but in South West Germany (Baden-Württemberg) alone it was estimated that the summer of 2003 caused between 1,200 and 1,400 heat-related deaths.

In its Fourth Assessment Report the Intergovernmental Panel on Climate Change has stated that it is very likely that the frequency of heat waves will increase over most land areas and that this will lead to an increased risk of heat-related mortality — especially for elderly, chronically sick, very young and socially isolated people.[1]

As a consequence some countries have implemented a heat health warning system (HHWS). Such systems use weather forecasts to predict heat episodes that are (or have been during the calibration period) associated with an increase in morbidity and/or mortality in the target population. The essential roles of HHWSs are: identifying weather situations that adversely affect human health; monitoring weather forecasts (meteorological component); implementing mechanisms for issuing warnings in case such a weather situation is forecast (communication); and promoting public health activities to prevent heat-related morbidity and mortality (public health component).[2] The development of HHWS requires several decisions to be taken and is also based on restrictions concerning the available data, the required accuracy and lead time of the meteorological forecasts and the organizational structure in which the HHWS has to be embedded.

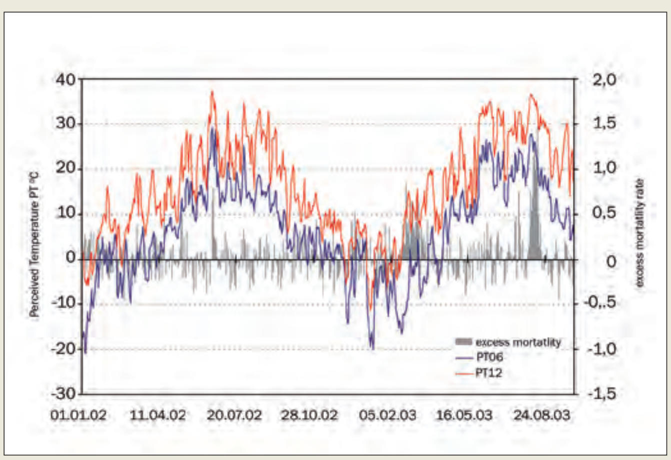
The core piece of the meteorological component of an HHWS is the heat indicator, which aims at identifying heat episodes with adverse effects on human health. The heat indicator can either be a single meteorological parameter (with one or a few parameter indicators) such as daily maximum air temperature, or can consist of several meteorological parameters that are combined into a thermal index (with multiple parameter indicators) or used to identify air masses. The indicator or air mass has to be related to human health impacts. One possibility is to establish a relationship between historical morbidity and/or mortality data and the warning indicator. In order to be able to determine this relationship several years of daily morbidity or mortality data are necessary. This can be a problem in many countries. In addition, a relationship that has been established based on historical health and meteorological data may not be valid in the future.

Another way is to use a heat indicator based on a thermophysiological model of the human body. Such indicators have a physiological meaning and are able to assess the level of thermal stress to which a human body is exposed. They are therefore also suited for regions where no health data is available to establish the heat health relationship.

Once it is decided which kind of heat indicator to use for an HHWS the threshold on which a warning or alert is issued has to be defined. The aim is to determine at which point heat stress conditions become 'sufficiently hazardous' to human health in a given population to warrant a warning.[3] The definition of sufficiently hazardous depends strongly on the target population of an HHWS and the way the warning is communicated. Therefore, the meteorological component of an HHWS cannot be fixed without defining the communication and public health component. A system that is targeted at the general public needs to meet other requirements than a system that directs the warning only to elderly persons living in nursing homes.

Germany's HHWS is based on the DWD (national meteorological service in Germany) weather forecast in combination with an approach which combines a complete heat budget model with short-term adaptation to the thermal envi-

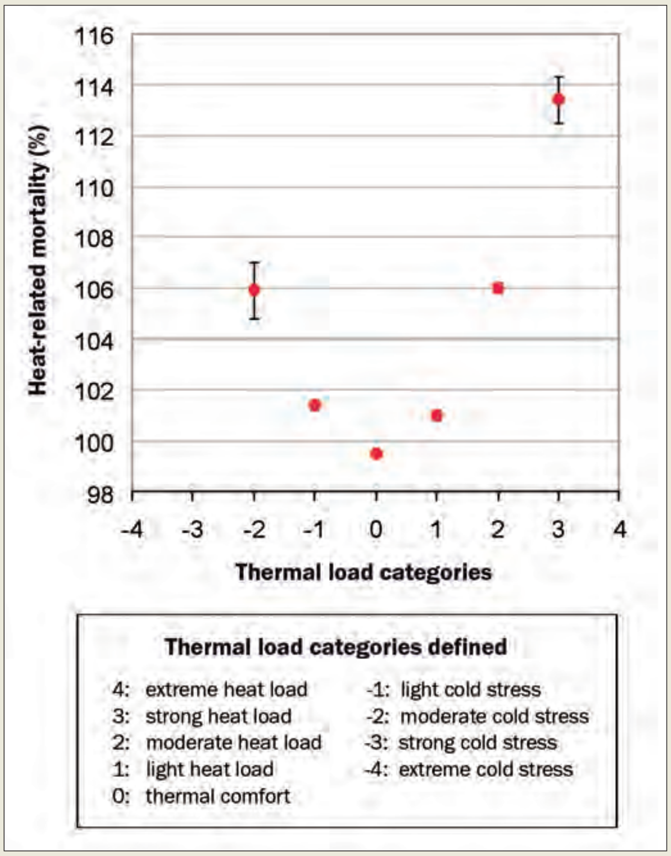
Excess mortality and thermal stress



Total mortality rate per 100,000 inhabitants in Baden-Württemberg and Perceived Temperature values at 06 UTC (PT06) and 12 UTC (PT12). The mortality increase in March 2003 was probably due to an influenza epidemic

Source: DWD

Heat-related mortality comparisons



Heat-related mortality in comparison to the expected total mortality rate (all age groups) for different thermal load categories in Baden-Württemberg (1968 – 2003)

Source: C. Koppe, 2005

Heat advice for the general public and for nursing home staff

Advice to general public:

- Wear light, loose-fitting clothes
- Drink at least 2-3 litres of water a day
- Avoid alcohol and drinks with caffeine
- Eat only light meals
- Avoid strenuous physical activity
- Stay in the shade
- Wear a hat
- Restrict physical outdoor activities to early morning or evening
- Do not waste water.

Advice for nursing home staff:

- Check room temperatures and if necessary try to cool the room
- Take care that patients drink sufficient water or other liquids that contain sufficient minerals in order to avoid dehydration. Be aware that some patients need to be helped to drink
- Check clothes and blankets
- Look for signs of dehydration or other illnesses
- Reguarly check those who can't care for themselves. Make a drinking plan and measure body temperature if necessary
- Call the GP immediately if health status deteriorates.

ronment of the last few weeks. This means that human adaptability to continuously changing weather conditions, and thus the variability of the regional climate, is taken into account. It is important to consider short-term adaptation because the human body reacts differently to its thermal environment due to physiological adaptation (short-term acclimatization), which augments the efficiency of the thermal regulatory system and thus reduces the thermal load effectively acting on an individual. In addition to this, short-term behaviour-based adaptation — such as changing clothes — can reduce the thermal stress acting on the individual. Therefore, epidemiological studies find lower thresholds for which heat affects human health in colder climates than in warmer climates, as well as for the beginning of the summer season compared with the end.

DWD calculates the 'perceived temperature' in order to assess the thermal environment of the human being. The perceived temperature is determined through a simple heat budget model of the human organism, which includes the main thermophysiologically relevant mechanisms of heat exchange with the atmosphere. The most important meteorological parameters included in the model are: air temperature, humidity, wind speed and radiation fluxes in the short-wave and long-wave ranges. The short-term adaptation approach is then used to adjust the threshold upon which a warning is issued. This depends on the meteorological situation of the past few weeks within a certain range. The thermal load category is then determined with the perceived temperature forecast for 12 UTC used for the evaluation of heat and the perceived temperature forecast for 06 UTC used to determine cold. During situations with at least a moderate heat load (cold stress) total mortality is significantly increased.[4] In order to avoid too many warning situations per year in Germany, a heat warning is issued if a strong or extreme heat load is forecasted — where a mortality increase of more than 10 per cent is expected.

As well as the daytime heat, the HHWS in Germany also takes night-time air temperature into account. A warning will only be issued if the night-time temperature does not fall below the 95th percentile. This additional criterion was included because the main target of the German HHWS is the elderly living in nursing homes. Therefore, it is important to include an indicator for the nocturnal cooling potential of indoor conditions. To get a better indication of the indoor environment a thermal simulation model for buildings was also added. This information is considered before the biometeorologist decides whether or not to issue the heat warning suggested by the model. The warning is then disseminated via the internet to the general public and by email and fax directly to care homes — as well as to the health authorities of the Bundesländer, who may decide to place it on the radio and TV programmes of the public channels. The advice given during a warning depends on the local health authorities, but targeted advice is usually given to the general public and to institutions that take care of the elderly or disabled, such as nursing homes. An evaluation of the HHWS in the State of Hessen has shown that hospital admissions due to heat related disorders from nursing home inhabitants have decreased significantly since the introduction of the HHWS.[5]

A precondition for the optimization of a HHWS is that the system is adapted to national, regional and local requirements. These can differ in space and time, even when only considering the meteorological component. Therefore, it would be wrong to conclude that one system is superior to another. Countries that plan to implement or revise a HHWS have to follow local needs.

Climate data and information for a multi-sectorial vulnerability analysis

Markku Rummukainen and Lars Bärring, Swedish Meteorological and Hydrological Institute

Modern society is sensitive to weather and climate events. This is very much evident in the developing regions of the world, but is equally the case in industrialized countries as well.

Society should be familiar with handling climate variability, but this does not always appear to be the case — as is evident in the aftermath of an extreme event such as a strong storm, hurricane or typhoon, or a major heat wave, flooding or drought episode. When assessing the damage, questions on what could have been done to prevent or mitigate the impact are inevitably raised. Often, the answers reveal that a number of measures could have been taken to decrease vulnerability to and, by extension, the impacts of such extreme events.

One reason for such 'forgetfulness' is the intermittent character of extreme events. A long time might elapse from one extreme event to the next, during which time society changes, our perceptions evolve and the collective memory of an extreme event fades away. However, there are ways of systematically factoring in the risk of extreme events to decision processes, whether we have a fresh experience reminding us, or not.

Image: Sten Bergström, SMHI

The Slussen region in central Stockholm. Water channels are a crucial element of Stockholm's infrastructure. They channel water out to sea, preventing flooding, and stop saltwater from intruding the freshwater systems upstream

Today, the prospect of growing climate change adds to the need of addressing vulnerability, not least in order to guide decisions aimed at reducing exposure to climate variability and at enabling informed climate adaptation.

This article describes recent activities in Sweden involving climate data support for multi-sectorial societal vulnerability analyses, designed to improve knowledge on climate adaptation needs, as well as provide recommendations for policy and practical measures. In particular, this article explores the scientific basis of the activities of the Swedish Commission of Climate and Vulnerability between 2005 and 2007.

The Swedish Commission of Climate and Vulnerability

The Commission of Climate and Vulnerability was established by the Swedish Government in 2005. It was tasked to provide a broad assessment of the vulnerability of Swedish society to extreme weather and water events, and climate change. In addition to studying hydrometeorological conditions, the commission maps possible regional and local impacts, calculates related costs and benefits, and proposes measures to deal with such events. The measures proposed include: technical solutions, legislation changes, insurance frameworks, research needs and adapted organizational arrangements at national, regional and local levels. The Commission reported in two stages, the first analysis focussed specifically on conditions around two of the large lakes of Sweden — Vänern in the west and the Hjälmaren-Mälaren system in the east. The final analysis covered a multitude of sectors: communications, technical support systems, developments and buildings, rural businesses and tourism, the natural environment and environment goals and human health. Furthermore, some socioeconomic analyses and considerations of global influences were made.

As a basis for the Commission's analyses, scientific input in the form of a collection of regional climate scenarios, supported by tailored analyses, was solicited and subsequently provided. Importantly, these provisions were made during an extensive researcher/stakeholder dialogue. The latter came from authorities, county and municipal administrations, trade and industry, as well as researcher communities and organizations. This interaction led to a more efficient and informative efforts, as well as nurturing a mutual learning experience.

Climate data as decision support

Typically, the basis for decisions involving weather, water and climate sensitive scenarios has been data or experience derived from past events. However, proper statistical analysis can further extend available data into a more complete picture of the probable occurrence of various conditions such as: return periods (for example, extreme flooding or heavy precipitation); or the magnitude of a 100-year event. Complementary information can be gained from reanalyses, where the data is restricted to short periods. In order to probe possible future conditions, climate change projections and scenarios calculated with global climate models must be used. Unfortunately, in general the resolution of such models is still insufficient, with much of the regional and more or less all local detail being lost. This calls for regionalization by means of statistical (use of empirical relationships between large scale and regional/local conditions) or dynamical downscaling (regional climate modelling).

For use in the Commission's work, the Swedish Meteorological and Hydrological Institute provided a number of regional climate projections. Such information typically consists of basic climate data such as temperature, precipitation, cloudiness and so forth, summarised into annual, seasonal or monthly means. While such averages provide useful, general climate information, as well as indications of possible change in the future, they are often not specific enough for many applications. Instead, what is needed is the translation of climate information into forms that more directly relate to specific impacts. It was this idea that inspired the construction of the 'climate indices'.

Climate indices are tailored communications of often complex climate-climate impact relationships. As a simple example, while mean temperature can provide information on heat waves, a more useful measure is a statistic on the number of days during which a threshold heat wave temperature is exceeded. The possibilities of enhanced climate information provision are almost endless, as the sensitivity of a specific system can focus on factors including exposure time, threshold levels of event intensities and episode frequency. In some cases, the relevant phenomena also relates to other climate aspects. For example, the coldness of a winter could have a direct relation to the risk of insect damage to forestry during the next summer.

Knowledge dialogue

The Commission's main efforts were divided across four working groups, each with representatives from different sectors:

- Agriculture, forestry and natural environment
- Health, water resources and water quality
- Technical infrastructure and physical planning
- Flooding and issues related to the large lakes.

General research information was provided through workshops on: the physical basis of climate change; climate modelling as a research method; and general global and regional climate change scenario results. After this, meetings were organised within each working group to elaborate on more specific information needs and possibilities of provision. The idea behind this approach

Image: Sten Bergström, SMHI

Stockholm is situated where the inland lake system Hjälmaren/Mälaren and the Baltic Sea meet and is thus vulnerable to impacts from changes in hydrology

Image: Ingrid Gudmundsson, SMHI

Climate event in Sweden. The researcher-stakeholder dialogue is a crucial element of climate events, ensuring that information is put to the best use in society

was to refine basic climate data into indices under the sector categories already described. In some cases, sectorial stakeholders did not possess knowledge of crucial phenomena, while in other instances the information needs exceeded the availability, or reliability, of climate modelling results. However, these problems were successively overcome, with the groups eventually defining 51 different indices. Some were relatively simple, such as an index for 'Frost Days' (number of days with a subzero temperature), while some were quite complex, such as 'Zero-Crossings' (number of days when the temperature has been both above and below zero degrees Centigrade).

Provision of climate index information

After defining the desired climate indices and deciding whether these could be meaningfully produced, the data was prepared. The resulting amount of information was vast and represented up to six regional climate model scenarios for many periods. More than one scenario was used to counter, as far as possible, the inherent uncertainty in climate scenarios, which is due to future emission scenarios and climate sensitivity to such forcing. The need to look at different periods arises from the different relevant timescales, depending on the sector and stakeholder. Possible timescales included the last so-called 'climate normal period' (1961-90), the ongoing period (taken as 1991-2005) and successive 30-year periods over the 21st Century (2011-2040, 2041-2070, 2071-2100).

Basic data was provided in the form of prepared maps, available both online via a web-interface and on DVD. All in all, the total number of maps made was well over 10,000, though a somewhat smaller set was eventually used. However, for users wishing to access more detailed information, additional provisions were made, with extended results available via the Swedish Meteorological and Hydrological Institute (SMHI) external website.

Outcome and outlook

The broader picture painted by the scenario analyses was one of slowly changing conditions, towards a warmer and wetter regional climate. This was identified by increases in 'warm' and/or 'wet' indices and decreases in 'cold' and/or 'dry' indices. Crucially, indices on extreme conditions — such as intensity of heavy precipitation, gust winds and dry spell length — were also included.

It was important to provide transparent information on the underlying climate model capacities. For example, even though the simulation of mean temperature is relatively insensitive to temperature biases in modelled results, the same does not apply to measures that reflect specific thresholds — such as the already mentioned 'Zero-Crossings'. In addition the climate index concept is yet to be evaluated scientifically. Nevertheless, it was found that performed analyses did add significantly to the climate information required for vulnerability analyses. Perhaps most importantly, the indices served as a starting point for stakeholders in thinking about vulnerability to both present day climate variability and possible future climate change, in terms that relate practically to their sectorial responsibilities and activities.

The researcher and stakeholder dialogue was a vital part of this achievement. In addition to leading to refinements of the information, it produced insights for both science providers on societal needs and stakeholders on climate impacts, vulnerability and adaptation.

Climate indices are a useful means of providing advanced climate data in an enhanced format. This is true for scenario information, as well as for observed data, where results can be organized into indicators, to monitor impact-related conditions.

The main lessons learnt from the multi-sectorial societal vulnerability analysis process were:

- The usefulness of the climate index concept with regards to climate impact, vulnerability and, by extension, adaptation
- The importance of involving stakeholders in the process of specifying the indices
- The importance of managing the underlying and refined data efficiently, as well as thoroughly planning the ultimate provision of information
- The importance of creating new ways of using climate data in society, especially in the face of a changing climate, calling for conclusions and decisions to be revisited in the face of fresh data
- The importance of being clear about the different roles of: the scientist as provider of climate information and expert advice on how to interpret the information; and the stakeholder as a sectorial expert and decision-maker.

Despite the evident benefits of the climate index concept, it cannot address all the stakeholder questions and needs. Continued development of the concept seems worthwhile. Also, climate indices do not replace the need for impact research and applications in many of the sectors, to provide even deeper knowledge support for decisions. Typically, climate indices are a first step for assessing a specific climatic vulnerability, which may be followed by more sophisticated impact models. Nevertheless, there needs to be a scientific and knowledge-based preparedness of compiling additional tailored climate data. For the society, parallel investments on training and raising awareness would seem sensible activities.

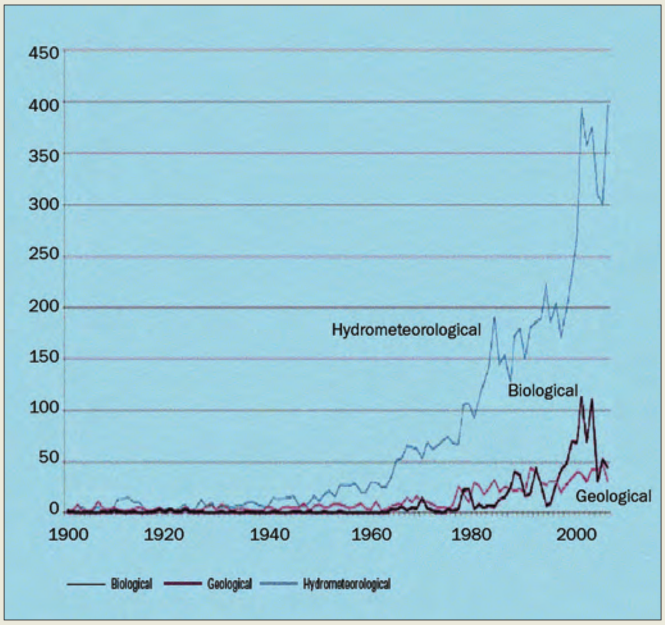
Infrastructure and disaster risk management under changing climate conditions

Heather Auld and Don MacIver, Adaptation and Impacts Research Division, Environment Canada

Evidence from around the world indicates that the cost of weather-related disasters is continuing to increase. While the number of lives lost declined over the last 30 years, thanks to better disaster preparedness and prevention programmes, the number of affected people has increased. Over the last decade, those affected by natural disasters through injury, homelessness or hunger increased significantly, to average over 200 million people annually.[1] The largest rises occurred in developing countries. The rising losses from hydrometeorological disasters highlight the need for meteorological and hydrological services to play an even greater role in disaster management.

While large year-to-year variations in the number and intensity of weather and hydrological hazards are expected, it is not normal for the resulting costs to continue rising significantly. When a natural hazard becomes a disaster, this is as much a result of the way that the community does business or adapts as it is of the hazard itself. The fact that both insured and uninsured losses from weather and water-related disasters have been rising rapidly reflects a failure of communities and society to adequately adapt to current climate variability and extremes.

Global trends in frequency of major natural disasters



Number of great weather and hydrological disasters for each year in the EM-DAT database for the period 1900-2005

Source: EM-DAT, 2006[18]

Varied roles for meteorological and climate services in disaster management

National Meteorological and Hydrological Services (NMHS) and other climate agencies have many roles in disaster risk management. There are two windows for action:

Pre-disaster or risk management planning and prevention through:

- Pillar 1 – disaster risk mitigation/prevention
- Pillar 2 – emergency preparedness

Actions imminently before, during and after disasters (crisis management) through:

- Pillar 3 – emergency response and relief
- Pillar 4 – disaster recovery and rebuilding

Effective overall disaster management requires coordinated and comprehensive integration over all four pillars. In most countries, natural hazard policies traditionally focus on crisis management that minimizes the impacts during a disaster and provides immediate relief and support to victims. Although disaster response is important, it can fail to address the causes of disaster losses. The World Bank has estimated that every dollar spent in preparing through pre-disaster or risk management actions saves seven in response.[2]

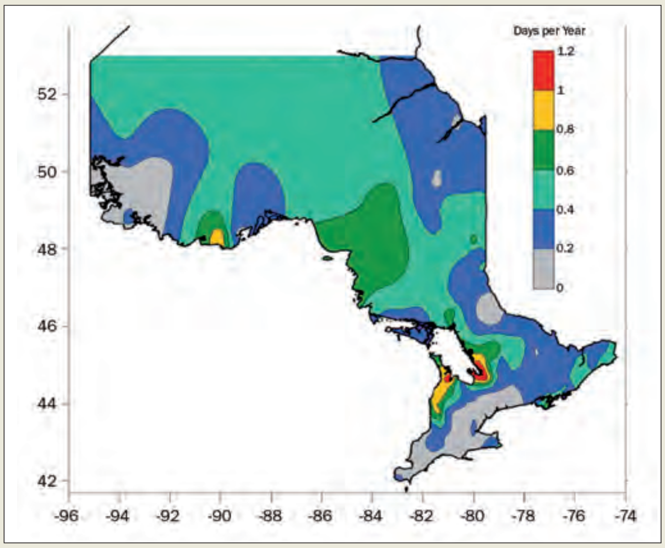
NMHS are well placed to help reduce weather and water-related disasters by:

- Provision of hazard information for community risk assessments and land-use planning
- Improvements to climatic and hydrological design information for safer infrastructure and communities
- Developing environmental prediction and risk interpretation products
- Monitoring to detect hazards and emerging threats
- Forecasting and timely early warnings for emergency response and recovery and rebuilding operations
- Assistance with risk management education and capacity building.

Risk management measures: targeting risks

There is a saying that 'forewarned is forearmed'. Klaus Töpfer, Executive Director of the United Nations Environment Programme (UNEP) said: "When we know

Average number of days per year with daily snowfall >= 25 centimetres, based on data 1971-2000



Numbers on the left side of image are degrees latitude North (42 to 52), and numbers on bottom of image are degrees longititude West (-74 to -96)

Source: Auld, 2008(a)

the threats we face, we are better able to prepare for them". Although natural disasters are not always predictable, they are usually foreseeable, meaning that they can be risk managed beforehand. Many natural hazards can be anticipated using past experience, climatological analyses of atmospheric hazards, analysis of vulnerabilities, forensic analyses and guidance on future climates.

A significant part of risk management planning involves a vulnerability or hazard identification and risk assessment (HIRA) process that integrates the probability of hazards with community critical infrastructure vulnerabilities and risk assessments. For example, the province of Ontario in Canada passed legislation in 2003 requiring that all of its municipal and regional governments identify and prioritize their top ten hazards and risks to public safety.[3] Because capacity varied greatly among municipalities, the process used a simplified system to evaluate hazards, as well as the municipality's response capability. The Ontario HIRA system[4] ranked hazards and risks as follows:

- Frequency or probability, ranked from one to four, where one reflects a low occurrence and four a high occurrence (within the past 15 years)
- Impacts or consequences, ranked from one, negligible, to four, high. Degree of impact can be determined through consultation with experts. A high score reflects a likelihood of severe consequences, including fatalities and the loss of essential infrastructure and services
- Community response capability or adaptive capacity (optional). These are ranked from one, excellent, to four, poor, and can modify the assessment of impacts for low probability but high-impact events, where response experience and capacity may be limited.

In support of this system, Environment Canada developed an Atmospheric Hazards website[5] for regional emergency managers.[6] The website and publications included peer-reviewed or 'authoritative' information on hazard probability and provided tools for spatial and temporal comparison across regions. Information consisted of 'defensible' maps and databases of various hydrometeorological hazards along with trends and documentation on historical high impact events. Events included extreme heat and cold, drought, extreme rainfall, blizzards, hurricanes, ice storms, tornadoes, wind storms, smog, and ultraviolet radiation. Hazards information included analyses on frequencies for selected periods of record, average days per year with conditions exceeding thresholds, extreme precipitation and temperature records, probabilities of an event at a location, most recent occurrences of extremes, return period estimates and climatic design values for engineering, as well as weather warning criteria and potential impacts of specific hazards.[7]

A challenge in designing hazards information is the need to satisfy a wide variety of users ranging from the well trained planner to the less experienced user, while balancing requirements for accuracy and comprehensiveness. Precise information is of little value if it cannot be understood in a rural municipality by the clerk with responsibilities for disaster management planning. Likewise, information that is so highly simplified that it does not accurately convey the actual threat is inadequate for the professional consulting firm hired to advise another municipality of risks and priorities. The challenge is to communicate complex scientific information simply to all users and to ensure that information is scientifically defensible.

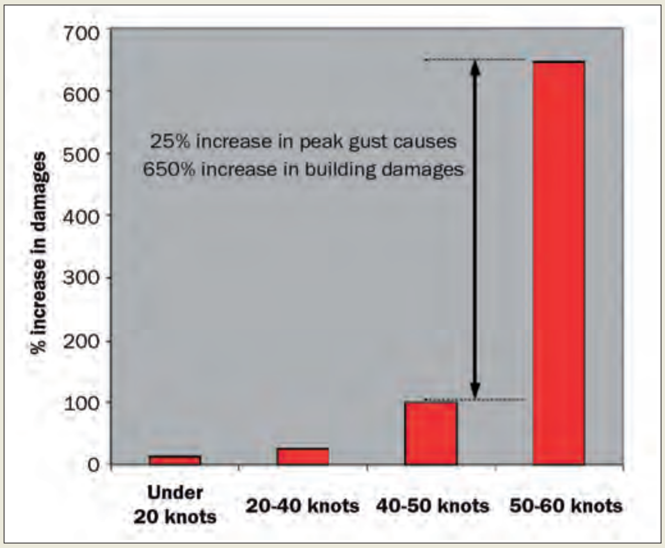
Infrastructure protection and disaster risk reduction

Experience has shown that the house can be the first line of defence against hazards. Forensic analyses often reveal that structural failures of infrastructure (houses, electrical distribution lines, communications structures, dams) result when climate extremes approach the structure's critical design values and safety limits.[8] Above critical thresholds, small increases in weather and climate extremes have the potential to bring large increases in damage, even though the high-impact storms associated with this damage may not be much more severe than those which occur regularly.[9] In many cases, it is likely that the critical thresholds reflect storm intensities that exceed average design conditions for a variety of structures of varying ages and conditions.

An investigation of claims by the Insurance Australia Group indicated that a 25 per cent increase in peak wind gust strength above a critical threshold can generate a 650 per cent increase in building claims.[10] Similar studies indicate that, once gusts reach or exceed a certain level, entire roof sections of buildings are often blown off or additional damage is caused by falling trees. Typically, minimal damage occurs below this threshold.[11] Similar results have been obtained for flood and hailstone damage.[12] Not surprisingly, the quality of construction strongly influences the extent of damage.

Climatic design values used in building codes and standards for the design of reliable and economical infrastructure include quantities such as the 10, 50 or 100-year return period 'worst storm' wind speed, rainfall or snow conditions and are typically derived from historical climate data. Almost all existing infrastructure has been designed based on the assumption that the past will represent conditions over the future lifespan of the structure. This will hold less

Building claims as a function of peak gust speed (Australia)



Source: Coleman, 2002

as the climate changes. Regions where climate trends are encroaching on design limits will require increases in climatic design values for new structures and reinforcements to existing structures identified as at risk.[13]

Crisis management: moving from weather prediction to risk prediction

One of the most effective measures for disaster readiness and emergency response is an early warning system that delivers accurate information dependably and on time. Warnings buy the time needed to evacuate populations, reinforce infrastructure, reduce potential damage or prepare for emergency response. But warning systems are only as good as their weakest link and must be accompanied by effective hazard response policies and actions.

Forensic analysis of disasters often reveals that communication with the public was not effective enough, and scientific and technical information (for example, wind gusts greater than140 kilometres/hour) was not properly interpreted by authorities and the public in terms of risk. Warning messages must be received and understood by a complex target audience, and establish a shared meaning between the issuers and the decision makers they intend to inform. Because emergency responders and the public are often unable to translate scientific information into risk levels, future work is needed to identify general impacts, prioritize the most dangerous hazards, assess potential contributions from cumulative and sequential events and identify thresholds linked to escalating risks for infrastructure, communities and disaster response.

Recognizing that individual and combined hazards (for example, excessive heat and poor air quality) can result in complex emergency response situations, the World Meteorological Organization (WMO), along with its NMHS and UN partners, is working to establish multi-hazard early warning systems. Collaboration is underway with WHO to develop heat health warning systems that enhance adaptation to deadly heat waves and malaria. Other collaborative work with the Food and Agriculture Organization of the United Nations focuses on the monitoring and development needed for early warnings of locust swarms.[14]

Creeping disasters

Some emerging disasters first appear as 'creeping' hazards, evolving over a period of days to months. This timing presents different opportunities for disaster management. Floods and droughts often result from cumulative or sequential multi-hazard events accompanied by an inherent vulnerability. For example, flooding can result from unexceptional rainfall when preceded by several days of rain and saturated ground conditions. Specific criteria for warnings may need to consider antecedent rainfall as well as saturated or frozen ground conditions before entering into a rainfall event. The challenge for forecasting flooding risks under antecedent precipitation is the uncertainty in modelling and predicting preceding soil moisture conditions.

Droughts represent a powerful creeping hazard capable of bringing great losses to very large regions. Monitoring measures need to be region, user and impact specific. Water managers, agricultural producers, hydro-electric power plant operators and ecosystem managers can all require different monitoring indices to characterize the severity of conditions and necessary responses. Consequently, drought early warning systems work best when designed to detect cumulative precipitation deficits using regionally critical thresholds of water supply conditions.[15]

Whether dealing with fast or creeping hazards, early warning systems are most effective when they provide adequate lead times for the activation of emergency response plans and target the people and regions mainly at risk. In many regions, this includes an appreciation of local and indigenous knowledge.

Recovery and rebuilding

The disaster recovery and rebuilding phase requires careful integration of services from all of the other pillars.[16] These include tailored weather warning services to protect affected populations rendered even more vulnerable by the disaster, and updated atmospheric hazards and climatic design information to rebuild more disaster-resilient communities. Critical to recovery operations is the restoration of vital infrastructure. It becomes difficult, if not impossible, to coordinate emergency operations without the benefit of some functioning communications and transportation infrastructure.

Preparing for climate change: 'no regrets'

One of the most threatening aspects of global climate change, given even the most optimistic greenhouse gas mitigation successes, is the likelihood that extreme weather events will become more variable, intense and frequent as storm tracks shift. UNEP financial services initiative anticipates that the global cost of natural disasters will top USD300 billion by the year 2050[17] if the likely impacts of changing climate are not countered with aggressive disaster reduction measures. 'No regrets' adaptation actions taken today provide opportunities for regions to reduce current vulnerabilities and become better prepared for future challenges. Barriers to managing the risks associated with current climate variability are the same barriers that will inhibit regions and nations from addressing future increases in risk due to climate change.

Disaster reduction in Morocco

Dr Abdullah Mokssit, National Centre for Climate and Meteorological Research, Morocco

The role of meteorology in social and economic development is recognized and appreciated more and more in today's world. Over the last twenty years the Direction de la Météorologie Nationale (DMN) — the Meteorolgical Office of Morocco — has made important progress at all levels of application including: model development, data assimilation, model evaluation, weather forecasting, climate forecasting, and ocean and marine forecasting. However, most recently its efforts have been focused on two axes: weather risk management and end-user products.

Weather risk management

Disaster reduction activities are at the core of a number of DMN scientific and technical programmes. These programmes contribute to global capabilities in the detection, forecasting and early warning of hazards, as well as by providing effective means and procedures to minimize the adverse consequences of such hazards through the application of science and technology.

In coordination with the relevant authorities, DMN has developed and implemented a weather risk strategy involving two stages: pre-warning and warning. Whenever there is a chance that the weather could affect one or multiple locations, a meteorologist personally assesses the situation using pre-defined criteria to determine the likelihood of a weather impact. Under these circumstances a pre-warning is disseminated to the relevant authorities. When the forecast team confirms the weather risk, dissemination of warnings to the relevant authorities as well as to the public is enacted.

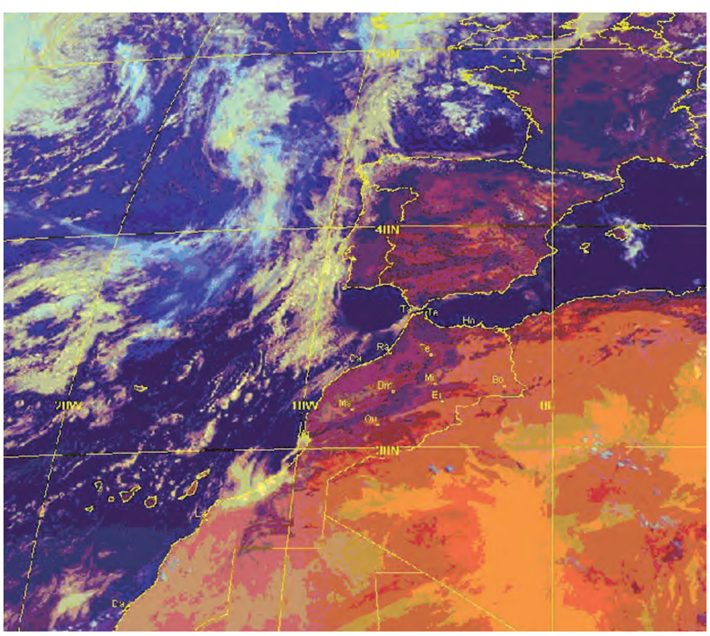


Image: DMN

Increasing global temperatures will have profound impact on North African societies

The procedure of risk management is based on:
- Use of radar, satellite and lightning data for the monitoring of severe weather events over the area
- Operational use of high resolution modelling for the provision of weather forecasts and for all major meteorological parameters including wind, rain, snow and temperature
- Use of wave models to assess strong winds and adverse marine conditions affecting coastal areas
- Presentation of the results and/or warnings in a user-friendly way. This can be via fax, a dedicated web page, e-mails, as well as through short message service and multimedia messaging service to mobile phones.

End-user products

DMN has established a periodic evaluation and guidance council in order to validate and listen to end-users. This event helps DMN to understand the needs of the end-users and provides a platform for the users to learn how to use the information DMN provides. The council is attended by users from all sectors including agriculture, water, energy, air and marine navigation, and scientific research.

In addition to this, as recommended by the council, an annual sector council is organized. The main objective of this council is to stimulate the use of sector-specific information in an ongoing, iterative process of dialogue between the producers of climatic information and the multitude of users in Morocco.

Collaboration with end-users focuses on the following objectives:
- Evaluate user needs
- Develop and demonstrate applications which address practical user needs
- Establish interactive dialogue with primary users
- Develop data/information delivery systems.

The recommendations that result from the council are translated to budgetary actions for developing application tools based on monthly and seasonal products, as well as hydrological and environment tools for delivering useful products and services.

Air quality

Human activities, rising industrial and energy production, the burning of fossil fuels and the dramatic rise in traffic on our roads all contribute to air pollution in towns and cities which, in turn, can lead to serious health problems. For example, air pollution is increasingly cited as the main cause of lung conditions such as asthma — compared with 20 years ago, twice as many people suffer from asthma today.

To help control the evolution of the air quality in Morocco, DMN has installed 21 stations for measuring air quality, a mobile laboratory and three pollen grains sensors. Furthermore, in Casablanca, Fes and Marrakech it has installed two stratospheric ozone sensors and two stations for measuring atmospheric pollution.

Agriculture

As a direct result of establishing a dialogue with users, DMN has created two agro-meteorological centres in Beni Mellal and Taroudant, and developed a tool to aid decision making in the agriculture domain. The purpose of this application is to make users aware of the potential benefits that farmers can gain from improving efficiency and ensuring the sustainability of farm management. Farmers should aim to protect and ensure the continuing health of crops, livestock, and the environment to increase their yield and the market value of their crops, as well as to solve operational problems.

A communication mechanism has been established to explain the purpose of the agro-meteorological centres. Flyers were produced in Arabic (the most widely understood language in Morocco) detailing basic information about the centres — covering their objectives, tools (computing facilities, information systems, observation instruments), products, dissemination techniques and policies on user interaction.

The primary objective of the centres is to provide farmers with information (observations, model outputs) that enables them to improve the efficiency of various agricultural practices.

The information should also enable farmers to limit and reduce the adverse impacts of extreme climate events on agricultural production.

Input requirements

Input requirements refer to the quantity, quality and timeliness of data that are available for the preparation of observational products. The number of reporting stations in key agricultural areas, instrumentation standards and maintenance, data collection and processing methods, data standards and quality control procedures, and human resources are all factors relating to input requirements. Thus, the creation of the two centres was supplemented by the installation of a number of automatic weather stations providing real-time data. Also an expert team has been trained for the development of agro-meteorological models, tools and products.

The service involves converting input data into information that can be packaged for delivery in a form that adds value to an existing knowledge base. Additional tools — such as geographic information systems technology, mathematical models, and remotely-sensed observations — provide resource enhancements that can convey value-added information for the decision-making process.

The agro-meteorological information produced includes:

- Observation data
- General forecast bulletins
- Daily bulletins on the impact of extreme events on agricultural production
- Daily responses to farmer requests
- Warning bulletin.

Seasonal forecasting system

DMN has explored both statistical and dynamical approaches to making seasonal predictions of precipitation in Morocco. This has been enacted through two major projects — Al Moubarak (based on statistical models) and El Masifa (based on both dynamical and statistical models).

The main objective of such long-range prediction is to implement a procedure that generates information that end-users consider helpful in decision-making.

Image: DMN

Timely collection of climate data today is vital for accurate seasonal forecasts tomorrow

Image: DMN

Climate forecasters must engage openly with all sectors of society to increase the effective use of seasonal forecasts

V

ADAPTATION AND MITIGATION STRATEGIES

Adaptation to climate change in Switzerland

Roland Hohmann, Swiss Federal Office for the Environment (Climate Unit)

The fourth assessment report of the Intergovernmental Panel on Climate Change established that despite all efforts to reduce global greenhouse gas emissions, climate change is affecting the development and welfare of human society all over the world.[1] Vulnerability to climate change is particularly high in developing countries situated in the southern hemisphere, but countries in the northern hemisphere are also likely to be affected eventually. In Europe, the Alpine region is considered one of the most vulnerable to climate change, and thus efforts to adapt to changing conditions in this area must be intensified.

The expected impacts of climate change in Switzerland up to the year 2050 were discussed in a comprehensive analysis published in 2007, which in turn was based on a regional climate scenario.[2] The report predicts a warming of approximately 2°C (with a range of uncertainty between 0.9 and 3.4°C) for autumn, winter and spring, as well as a rise of just under 3.0°C for the summer period (range of uncertainty: 1.4 to 4.9°C). Assuming this level of warming, the 0°C-isotherm will rise during winter by about 360 metres (range of uncertainty: 180 metres to 680 metres). Precipitation will increase by about 10 per cent (range of uncertainty: -1 per cent to +26 per cent) in winter and decrease by about 20 per cent (range of uncertainty: -36 per cent to -6 per cent) in summer. Heavy precipitation events are expected to increase in all seasons. In summer, heat waves will become more frequent and severe. In contrast, cold spells will decrease during winter.

In 2006 a rockfall occurred below the fast retreating *Unterer Grindelwaldgletscher* in the Bernese Alps due to decreased slope stability. The debris blocked the meltwater runoff and a lake started to form. By summer 2009 the lake volume surpassed the critical level above which the moraine threatens to break. As an adaptive measure, a subsurface outflow is being constructed to drain the lake and to protect the underlying villages from flooding

Changes in extreme events, as well as gradual changes of mean temperature and precipitation, will affect natural and anthropogenic systems. Probably the most obvious climate impact in Switzerland is the retreat of alpine glaciers. In the European Alps the average loss in overall glacier volume between the end of the 'Little Ice Age' of 1850 and 1975 was about 0.5 per cent per year.[3] This increased to about 1 per cent per year for the remaining volume between 1975 and 2000, and has accelerated to about 2-3 per cent per year since the turn of the millennium. According to model calculations, an additional 75 per cent of the glacier surface area in Switzerland will be lost by 2050 — in contrast with 1971-90 — implying that smaller glaciers at lower altitudes are likely to disappear.

Impacts on the hydrological cycle and natural hazards

Switzerland's hydrological cycle will also be affected by changing temperatures and precipitation. In particular, the maximum river discharge will occur earlier in the year and will be less pronounced. The combined effects of increased precipitation and the 0°C-isotherm being located at higher elevations will cause more rainfall to run off instantaneously, instead of being temporarily stored as snow. As a consequence, the risk of winter flooding is likely to increase, particularly in large catchment areas in the lowlands surrounding the Alps. On the other hand, drier summers will lead to more frequent and severe droughts. With hot and dry summers becoming more common by mid-century, the combination of reduced precipitation, earlier snowmelt and strongly reduced meltwater from vanishing glaciers could lower runoff to critical levels, even in large Alpine rivers. Thus, despite the large water resources in the Alpine region, water stress could become a problem in some parts of Switzerland during hot and dry summers, because of the decreasing availability of river water and the increasing demand for irrigation and freshwater supplies.

One of the biggest concerns in Switzerland with respect to climate change is the evolution of natural hazards. The retreat of Alpine glaciers will result in a decrease in slope stability and an increase in mudslides and rockfalls — as experienced in the resort town of Grindelwald in 2006. In addition, the thawing of permafrost represents a costly risk for a vast array of transport infrastructures in the mountains — including railways, chairlifts and cable cars — as at higher elevations the foundations of pylons and stations are often anchored in the frozen ground. Higher temperatures could loosen such foundations and destabilize entire installations. Possible adaptive measures include detailed monitoring of critical regions and erecting protective structures to shelter residential areas as well as infrastructures. Furthermore, the damage potential in critical areas could be reduced by changing structural planning in rural areas.

The risk of floods is expected to increase as a result of the growing frequency and intensity of heavy precipitation events. This risk is further aggravated by the fact that precipitation increasingly falls as rain instead of snow, due to higher average temperatures. Potential measures to tackle this problem include improving flood prediction, improving flood protection by renaturation, broadening rivers, building dams and altering development plans to reduce potential damage.

In the coming decades, Switzerland will have to make additional investments in order to maintain today's levels of resistance to the threat of natural hazards. Estimates by the Swiss Federal Office for the Environment indicate that by 2020 an additional 200 million CHF per year will be necessary for protective measures against mudslides, rockfalls and flooding.

Impacts on natural systems

Climate change is also expected to have various affects on Switzerland's biodiversity. The species composition of the country's ecosystems will change in the long run because different species react differently to climate change. Flora and fauna will continue to approximate those at lower elevations and in more southern areas. Heat-sensitive species will move to cooler areas at higher elevations. Less mobile species will be radically reduced in their numbers, or disappear altogether. The productivity of forests and agriculture, as well as the availability of clean water, may be affected by the combination of high temperatures and low precipitation. At higher elevations, the productivity of forests and permanent grassland will be somewhat enhanced by warming, while at lower elevations it will be constrained by summer drought. In the future, water resources will also be of increasing importance to ecosystems — in particular to those situated in valleys or hilly country.

To help species adapt to the changing climate, it will be necessary to provide corridors between habitats and nature reserves. This will enable migration as well as reduce the effects of anthropogenic stresses — such as pollution — on both species and ecosystems.

The biggest health impacts of global warming in Switzerland will be due to the expected increase in heat waves, in combination with elevated tropospheric ozone concentrations. However, it is entirely possible to avoid increased, heat-related mortality provided adequate measures are taken. In addition, heat waves can impair the efficiency of the national workforce, with resulting effects on the economy. With higher temperatures, the danger of food poisoning due to spoilt food and water will also increase.

A higher frequency of natural disasters — including floods, mudslides and storms — will lead to more casualties and resulting psychological stress.

The potential effects of climate change on the development of vector-borne illnesses is uncertain. Higher temperatures could generate new vectors or cause a vector to change its host. With illnesses transmitted by ticks, there may be changes in the range of vectors, infection rates and period of activity. The setup of a monitoring system for the various vector-borne diseases is an essential part of developing timely, adequate measures and action plans for the protection of human and animal health.

Impacts on the economic sector

Within the Swiss economic sector, the impacts on tourism will be the costliest. The rising winter snow line means that ski resorts in the foothills of the Alps are likely to struggle increasingly to operate profitably. Furthermore, the expected higher number of tourists in summer will not compensate for the loss of income mountain railways and the hotel sector experience in winter. Ski resorts located at high elevations may possibly benefit. However, the increasing threat of extreme events such as mudslides and flooding, is likely to impinge on traffic routes and thus the accessibility of tourist resorts in the Alps. The attractiveness of alpine tourist areas is also likely to suffer as a result of decreasing or highly variable snow cover, as well as from expected changes in the natural scenery. For tourist destinations to remain competitive, leisure activities must adapt to new conditions, while destination offerings will have to be broadened so that they are less dependent on annual snowfall. It is essential to take possible climatic changes, and changes in landscape, into consideration when planning for new tourism infrastructures.

In the energy sector, the diminishing runoff and decreasing cooling effect of rivers — especially in summer — will have an adverse effect on hydropower and nuclear energy production. Annual power production is expected to decline a few per cent by 2050. On the other hand, less heating energy will be required in winter and more cooling energy in summer. This will mean a shift in the energy demand from fuel to electricity. It is essential to fill this gap between decreasing power production and increasing electricity demand by improving energy efficiency, as well as by establishing new renewable power sources. Renewable energy is expected to become more competitive due to increasing energy prices. The current focus is primarily on energy gained from solar radiation, wind and wood. If long-term trends and the development of the forestry and timber industries are considered, the potential of wood as an energy source may triple.

Swiss agriculture is expected to profit from a moderate warming of temperature if it is less than 2 to 3°C — assuming that the supply of water and nutrients is sufficient and that suitable crops, as well as suitable cultivation and management methods, are chosen. The productivity of meadows and the potential crop yield of many plants will increase as a result of the longer

Image: H. Müller, Forschungsinstitut Freizeit und Tourismus, Universität Bern

As a result of climate change, the snow line in winter is expected to rise and ski resorts in the foothills of the Alps will struggle increasingly to operate profitably. The need for adaptive measures will increase as climate change continues. However, some measures require vast investment, while others will become less effective — such as artificial snow production at low altitudes

vegetation period. Livestock farming will profit from this as well. On the other hand, water supply will decrease in summer, weeds and insects will become more of a problem and damage caused by extreme events will increase. In particular, the increase in heat waves and drought periods represents a major threat. As a consequence, the demand for irrigation will increase in many regions. These risks could be reduced by the diversification of farms and more extensive insurance coverage.

If the average warming exceeds 2 to 3°C by 2050, the disadvantages will outweigh the advantages. Water scarcity will increase during the vegetation period, and faster plant development will result in reduced crop quality.

Adaptation

The above examples illustrate the broad variety of natural and anthropogenic systems likely to be affected by climate change in Switzerland. In order to prevent or diminish adverse effects and to take advantage of positive effects, it is necessary to develop an adequate adaptation strategy and implement appropriate measures.

In its climate legislation, Switzerland plans to include adaptation as a complementary second pillar to mitigation. While adaptation measures will effectively be implemented on a local to regional level, it will be the task of the federal government to provide guidance and to take the strategic lead. The latter will include:

- The provision of sound scientific knowledge regarding the future development of the regional climate
- The identification of risks and opportunities brought about by climate change
- The definition of adaptation goals
- The coordination of the various fields of action
- The development of different possible adaptive measures for the various fields of action
- The evaluation of these measures in terms of effectiveness and cost efficiency
- The prioritization among the different fields of action and among the different possible measures
- The support of their implementation
- The evaluation of these measures after their implementation.

The overall goal will be to achieve the best possible adaptation with the limited resources available.

Switzerland has begun this process with the development of a national adaptation strategy. Scientific information on climate change will form the backbone of this strategy. A survey conducted by the Federal Office of the Environment among its offices showed that high resolution climate scenarios and reliable scenarios of future developments of extreme events, are essential for detailed impact analyses and planning of adaptation in all fields of action. For instance: reliable scenarios of extreme precipitation events and river runoff are needed to optimize flood protection; reliable scenarios of water availability and droughts are needed to guide the adaptation of protection forests to a drier climate; reliable temperature and precipitation scenarios are needed in agriculture to decide which crops should be cultivated; and reliable scenarios of future river discharge are needed to assess the coming availability of hydropower.

Until now, national climate data has been provided by the Federal Office of Meteorology and Climatology (MeteoSwiss), and research has been mainly conducted by research programmes such as the National Centre of Competence in Research Climate.[4] However, since climate information will be required more frequently in the future, it will be essential to update such information on a regular basis. For this reason, MeteoSwiss and the Center for Climate Systems Modeling at the Swiss Federal Institute of Technology will jointly calculate periodical climate change scenarios at the regional level. Furthermore, climate observation and the statistical analysis of observational data will be intensified in order to improve scenarios of future climatic extremes (see also *Challenges for the Climate Services in Switzerland* within this publication).

The survey among the federal offices also showed a substantial need for adaptive measures to be implemented within the next few years. For instance, climate observation needs to be optimized, monitoring systems for vector-borne diseases need to be set up, and more structural measures for protection against thawing permafrost need to be built. These additional measures require significant financial resources. However, compared to the cost of inaction — estimated in a previous study to amount for 0.2 per cent of GDP in 2050, and predicted to increase to about 0.5 per cent of GDP by the year 2100[5] — this cost is very modest.

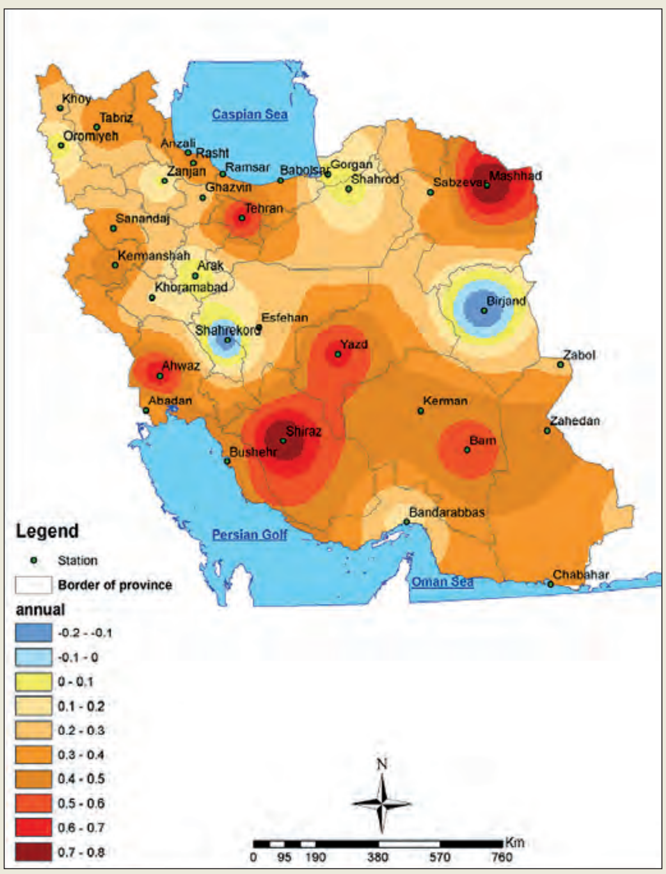
Enhancing adaptation to climate change and variability in Iran

Dr A.M. Noorian, PR of Iran with WMO and First Vice President of WMO

Over the past few decades, Asia, the largest and most populous continent of the world, has witnessed increases in surface temperature and rainfall variability, as well as more frequent and intense extreme weather events.[1] Situated in the southwest of Asia, Iran has been very much affected by these trends.

Recent studies in Iran show that annual mean temperature anomalies for the country have increased since records began in the 1950s. In particular, results suggest a relatively rapid and steady warming through the early 1990s. Seasonal series for Iran show a pronounced warming from 1950 — especially for autumns and summers. The trends for minimum temperature in Shiraz and Mashhad have been 0.7 to 0.8ºC per decade. Surprisingly some of the observed climate trends in Iran are inconsistent with the global picture.

Decadel trend of minimum temperature 1960-2005



Source: Dr A.M. Noorian and F. Rahimzadeh: I. R. of Iran Meteorological Organization (IRIMO) and Atmospheric Science and Meteorological Research Center (ASMERC)

Negative trends for indices representing cold maximum and minimum temperature extremes — such as number of icing days, frost days, cold nights and cold days — have been observed. Conversely, positive trends for indices representing warm maximum and minimum temperature extremes — such as summer days, tropical nights, warm nights and warm days — were also observed in the region. The negative trends — obtained with the Diurnal Temperature Range index — were found to be greater than the positive trends. Indeed, post-1990 many observational stations in Iran have found no use for the Cold Spell Duration Index.[2]

During the period 1950-2007, Iran experienced decreasing trends in annual precipitation, with the most affected area being the northwest of the country — which saw a decline of 150 to 175 millimetres over 60 years. Two-thirds of the country recorded a negative trend for the number of days with precipitation greater than 20 millimetres. Although such results are mostly consistent with IPCC findings, as well as the findings of a Middle East regional study,[3] there are nevertheless local inconsistencies for areas such as the Zagros Mountains.[4]

Besides warmer temperatures, Iran has also seen alterations in other climatic parameters, with temporal and spatial temperature patterns changing over recent decades. Anomalies have also been observed, with Iran experiencing a year of below normal temperatures in 2006.

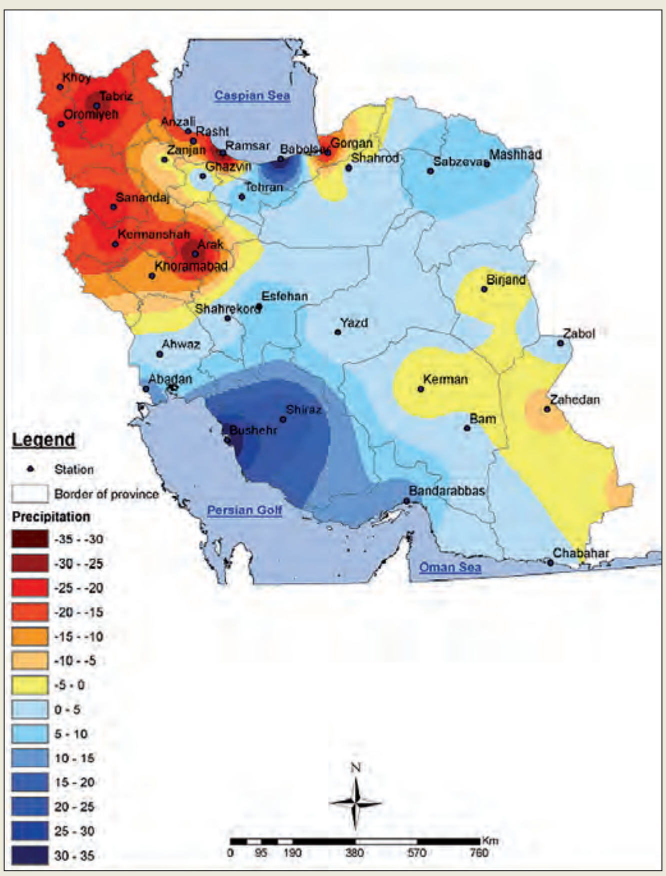
The increasing frequency of extreme weather events — such as heat waves and heavy rain precipitation — has had adverse effects across Iran and the whole of Asia. Heat waves in July 2003 and 2005 and cold waves in early 2007 and 2008 had effects on both daily and horal scale in Iran. Intensive heat and cold stress interrupts various physiological processes in agricultural, damaging crop and affecting cattle. The heat wave that affected many parts of Iran during summer 2005 produced positive anomaly readings of more than 4°C in July.

In southwest Asia, severe cold in December 2007 produced some of the lowest temperatures the region had experienced in decades. Most parts of Iran registered 2 to 4°C and in some stations/parts even 4 to 8°C cooler than long-term recorded temperatures in December. Snow and cold weather affected the north of the country, while heavy rainfall flooded some areas in the south and east of Iran.

Cyclone Gonu caused heavy rainfall on the southeastern coastline of Iran, resulting in flooding and heavy damage. Local observation stations in the Sisitan-Balochistan and Hormozgan provinces — where the annual mean precipitation is less than 200 millimetres — experienced 62 to 111 millimetres of rainfall on 6 June 2007.[5] Waves in Oman and the Persian Gulf reached heights of 6 to 10 metres as a result of storm surge.[6] Intensive rain and floods damaged road and telecommunication links, and disrupted drinking water supplies to villages in the southeast of the Sistan-Baluchestan province. During the summer of 2007, despite most parts of Iran receiving no considerable rainfall, the Sistan-Balochestan province, as well as western Afghanistan and Pakistan, experienced precipitation 200 to 300 per cent above their long-term recorded averages.

The frequency of drought has also increased in Iran over recent decades. The region experienced severe drought during the prolonged 1998–2002 cold phase La Niña event, as well as unusually warm water temperatures in the western Pacific and eastern Indian Oceans.[7] The severe drought affecting the southeast of Iran continued for seven years causing crop failure, livestock loss and mass migration — which in turn resulted in serious problems for the local economy, as well as people's livelihood.

Decadal trend of precipitation during the period 1960-2005



Source: Dr A.M. Noorian and F. Rahimzadeh: I. R. of Iran Meteorological Organization (IRIMO) and Atmospheric Science and Meteorological Research Center (ASMERC)

In 2003 and 2004 relatively wet conditions across southwest Asia helped to ease the effects of the drought somewhat. However, these beneficial conditions did not continue and drought came back to the region in 2005. Despite the drought, Iran also experienced heavy snow in early 2005 combined with a warm boreal spring. These conditions generated widespread flooding in the local basins.

Dust storms are seasonal phenomena in the east of Iran, occurring when a particular synoptic condition is dominant in the region. However, the intensity of said phenomena has increased gradually and spread out over a wider area, so that it now affects parts of Afghanistan, southeastern Iran and western Pakistan during summer and autumn. Due to these increases in severity and scope the dust storms constitute a greater and more hazardous health risk to human beings. Furthermore, during the past few years these conditions have spread into the southwest of the country — though it is worth noting that the regional source of the dust differs for the different areas affected.[8]

Climate change and variability has affected the crop season in Iran, shortening the growing period and thus resulting in crop yield decline. Acute water shortage combined with thermal stress has affected wheat and rice productivity, with many species in Iran becoming extinct as a result of the synergistic effects of climate change. Furthermore, warmer surface temperatures have created favourable conditions for forest fires.

Increased intensity and spread of forest fires in Asia has been observed in recent decades, with climate change — in combination with intense land use — the likely cause. Biodiversity in Asia is also being lost as a result of development activities and continuous land degradation.

In order to enhance adaptation efforts Iran must monitor climate extremes closely, as well as variability and the rate of change. It must also assess the potential impacts of climate change, as well identify people or areas that are most vulnerable. Based on these actions we can implement sound adaptation measures. Iran's key aims relating to climate change adaptation are to:

- Increase awareness among people and policy makers
- Establish adequate observing systems
- Make full use of software and hardware facilities
- Establish an appropriate climate database
- Create better links with users
- Build capacity in human resources and infrastructure
- Increase use of advanced methodologies and new technologies
- Harmonize adaptation programmes regionally
- Use financial resources efficiently.

The Islamic Republic of Iran Meteorological Organization — along with other governmental organizations and non-governmental organizations — aims to enable the country to achieve these objectives, especially in the areas of capacity building and adaptation measures. Asian countries, including Iran, which are vulnerable to climate change and have limited potential to enhance adaptive capabilities should expand their activities.

Coping with climate variability and change in Kenya

Kenya Meteorological Department

Climate change can be described as a permanent shift in the normal patterns of climate. Such a shift could spread over a period of decades, or even longer. There is discernible evidence — derived from numerous climate detection processes —that climate is changing across the entire globe.[1] For a local farmer or herdsman, however, abstract scientific notions of climate change make little sense. A definition relating to livelihood — detailing associated impacts that people can relate to — is essential if we are ever to deal with the problems climate change brings.

As such, climate change can be defined as lack of rain or changes to rainfall patterns. Practical conclusions can be drawn from such a description since it will affect agricultural factors such as: planting times; withering of crops; drying of streams and rivers; dying of livestock; and hotter nights. The significance of climate should not be underestimated. It provides for all the basic needs of living organisms including food, water and air. Furthermore, it renders the earth beautiful by providing flowers, plants, deserts, oceans, rivers and animals. Over many millennia, human beings and the earth's ecosystems have adapted to climate conditions. As such, climate change will necessitate alterations in ecosystems, as well as in human lifestyles through appropriate adaptation strategies.

Image: Daily Nation Newspaper, 2000

Dead livestock due to scarcity of pasture and water following prolonged drought, Masailand

Image: Daily Nation Newspaper, 1999

Wilted maize crop during a drought

Observed climate change signals and impacts in Kenya

Temperature has generally risen all over Kenya. Analysis of trends in temperature indicates that both minimum and maximum temperatures have increased across the country. In the inland areas the minimum temperatures show a steeper increase than maximum temperatures. These trend patterns reverse for stations near large water bodies, such as the Indian Ocean and Lake Victoria. In both cases, the general observation is a decrease in the temperature range.

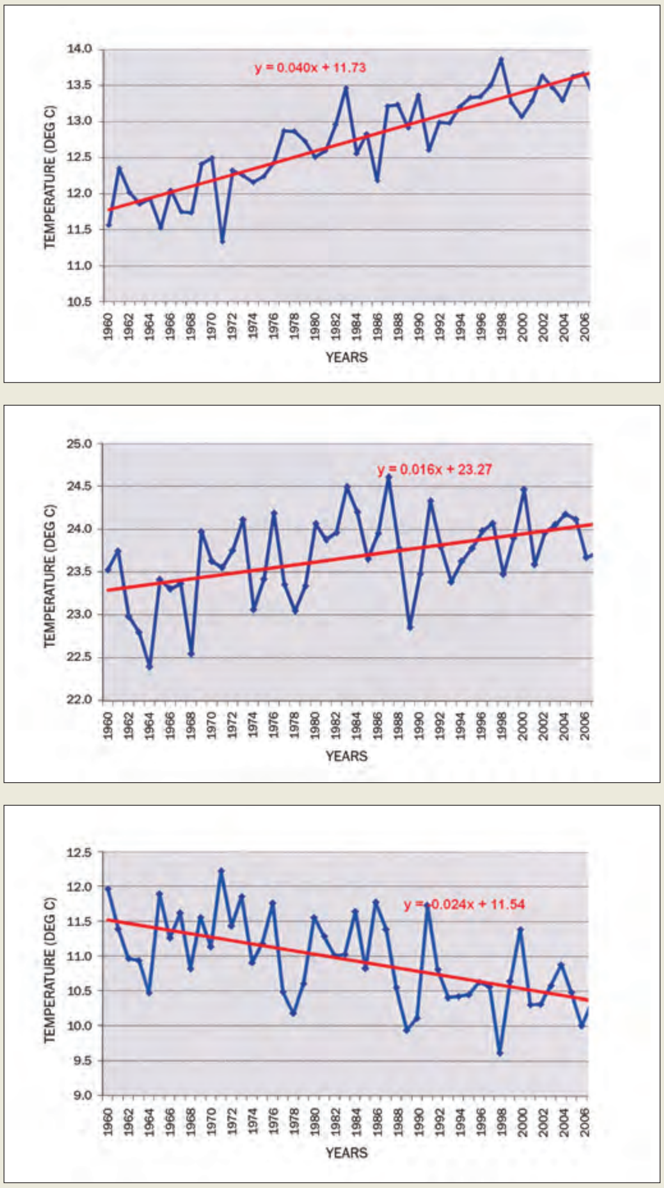
The observed rise in temperature has provided favourable conditions for mosquitoes, enabling them to survive in environments where they could not before. This has resulted in the spread of malaria to initially malaria-free zones, such as the highlands.[2]

Rainfall has also been affected by climate change. Large variations in rainfall are characteristic of Kenya and relate to the variation in topography. Even so, the rainfall patterns over the country have shown distinct changes in the recent past. The changes have been depicted in patterns of onset, distribution and amounts of rainfall received in a season. Observations are also made for more frequent and intense extreme rainfall events such as floods and droughts. Recent extreme events include the El Niño-related floods of 1997/98, as well as floods in 2003 and 2006. Meanwhile, droughts were observed in 1999-2001, 2005 and 2008/09.

Erratic rainfall has had impacts on many socioeconomic sectors such as health, agriculture, energy, water resources and disaster management. Some of the impacts include:

- Food insecurity due to poor harvests and death of livestock
- Resurgence of diseases such as Rift Valley Fever due to heavy rainfall in the semi-arid parts of the country (as witnessed in 1997/98 and 2006)
- Rivers drying up or becoming seasonal
- Displacement of communities
- Enhanced conflicts over limited resources such as pasture and water.

Temperature trends for Dagoretti, Nairobi, Kenya



Trend in annual minimum temperature (top); annual maximum temperature (middle); temperature range (bottom)

Source: Kenya Meteorological Department

The glaciers on Mount Kenya have shown a drastic decline in the face of climate change. This is a very worrying trend, as the highlands act as the source for many of the major rivers in the country. In turn, these rivers are involved in significant activities such as hydroelectric power generation. Reduction of water levels in the dams on these rivers has seen regular rationing of power for both domestic and industrial use.

Climate change also manifests itself through sea-level rise, which has already led to the destruction of infrastructure along the coastal parts of Kenya. This has occurred in various ways, including:

- Rise in saline groundwater levels, causing flooding of shallow wells and boreholes, and contaminating them
- Inundation of coastal wetlands and lowlands has led to disruption of coastal freshwater distribution systems. This has resulted in water shortages and the loss of recreational areas such as beaches through siltation, erosion or submergence
- Reduction of the buffer effect provided by coral reefs and mangrove systems, which has increased the potential for erosion.

Adaptation strategies in Kenya

In Kenya, a number of adaptation measures relating to climate information services are currently in place or planned. Some of the planned activities are designated 'flagship projects' in the First Medium-term Plan, which covers the period 2008 to 2012 under the Kenya Vision 2030 programme.[3]

Kenya Vision 2030 has identified three pillars crucial to transforming the country into a modern, globally competitive, middle income nation by the year 2030. The pillars are: economic, social and political. Six sectors — including agriculture and livestock — have been targeted under the economic pillar to raise the national gross domestic product growth rate to 10 per cent by the year 2012. Sectors such as environment, water and sanitation have been identified to drive the social pillar. Priority programmes and projects have been identified to drive the whole process — some have already been initiated, while others are in the pipeline.

An example of a current project is the government's efforts in the area of livestock farming. This type of farming is mainly carried out in the semi-arid lands of Kenya where climate variability is high and climate extremes are quite prevalent. The government has recently invested resources to rehabilitate the Kenya Meat Commission and procure livestock from farmers in cases of prolonged drought. This is a strategy designed to minimize the economic losses that farmers experience when livestock die due to lack of water and pasture — a situation becoming increasing common in the country.

Another example involves the Arid and Semi-Arid Lands (ASALs) of the country, which are currently underutilized for agricultural purposes. In order to utilize these areas and enhance food productivity, the government has allocated resources to irrigate 600,000 to 1,000,000 hectares in the ASALs. This is based on estimates that intensified irrigation can increase agricultural productivity fourfold and thus resulting income.

The quality of land in the country is suffering a general decline due to, among other factors, unsustainable farming practices and human induced climate change. Forests play a crucial role in protecting water catchment areas, conservation of biodiversity and provision of forest products in the country. One current flagship project envisages full rehabilitation of the five water towers in Kenya. The forest policy is designed to promote sustainable management of the forests to serve as water catchments, biodiversity conservation reservoirs, wildlife habitats and carbon sinks to reduce carbon dioxide concentrations in the atmosphere.

Collaborative adaptation projects

The Western Kenya Community-Driven Development and Flood Mitigation (WKCDD/FM) project is being implemented through the Office of the President with funds from the International Development Association of the World Bank, the Government of Kenya and community contributions. The project is designed to empower local communities to reduce the vulnerability of the poor to adverse outcomes associated with recurrent flooding.

Floodwaters have wreaked immense havoc among the communities situated on the Kenyan flood plains. WKCDD/FM aims to provide these communities with flood forecasting early warning information, as well as guidance on the proper management of floodwaters. This will involve the construction of protection structures such as dykes, as well as the rehabilitation and management of catchment areas.

The WKCDD/FM project follows methodology that has proven successful in other contexts. One such example is the project's use of the Participatory Integrated Community Development approach. Flood risk modelling is conducted daily with input including rainfall measured within the basin and a short-range prediction. Flood risk indicators and forecasts of water levels for the Nzoia River Basin are generated and disseminated to aid in decision-making processes. Success stories — such as the evacuation of vulnerable communities prior to a flood — are already emerging. Using the reliable information provided from the model outputs, the provincial administration is now able to evacuate people living on flood plains far more quickly than before the project.

Another example of a collaborative adaptation efforts is the community drought resilience project that was initiated in 2006 in Sakai, Kisau Division, in the Makueni District. It is one of the three pilot projects being implemented as part of the regional project 'Integrating Vulnerability and Adaptation of Climate Change into Sustainable Development Policy Planning and Implementation in Eastern and Southern Africa'. The project is funded by the Global Environment Facility and the governments of the Netherlands and Norway, and is supported by kind contributions from the governments of Germany, Kenya and Rwanda. It is being implemented by the Centre for Science and Technology Innovations in partnership with the Government of Kenya Arid Lands Resource Management Project.

Aims of the project include:

- Downscaling climate forecasts to guide the choice of crops planted and the timing of agriculture activities
- Improving agronomic practices by providing access to fast maturing and drought resistant crop varieties
- Building sand dams, shallow boreholes and drip irrigation systems to improve access to water for use in crop production.

A number of success stories have been recorded since the inception of the project. It has been established that farmers using the downscaled seasonal weather forecasts and undertaking early land preparation and dry planting are getting better harvests than those who have sustained the 'business as usual' approach. In addition, early maturing varieties of maize and pigeon peas selected on the basis of the forecasts are performing better that the varieties usually used by the farmers.

A final example of a collaborative project is The Kenya Wetland Forum. The forum is a multi-stakeholder institution concerned with the conservation and management of wetlands within the 'wise use principles' of the Ramsar Convention.[4] The programme adopts a holistic approach to address the impacts of climate change on the coastal and marine resources of Kenya. The main goal of the programme is to increase understanding of climate change issues, as well as to prompt the development of adaptation and mitigation strategies.

The objectives of the programme are to:

- Promote an ecosystem-based approach for the conservation and management of critical coastal and marine ecosystems
- Build and strengthen the capacity of local communities and relevant stakeholders to manage local coastal and marine resources
- Promote sustainable livelihood options for vulnerable coastal communities.

There are five main local-level projects:

- Kuruwitu community marine conservation project
- Wasini Island mangrove forest conservation, clean and safe water initiative
- Conservation and sustainable management of coastal and marine resources on the south coast
- Coastal wetlands management and conservation in Jimbo village, Vanga
- Building capacity to adapt to climate change impacts on conservation in East Africa.

Image: Kenya Wetlands Forum

Limited watering points during a dry season can result in conflicts

Image: Wandiga, 2008

A farmers' field day

Icelandic perspectives on adaptation to climate change and variability

Halldór Björnsson and Árni Snorrason, Icelandic Meteorological Office

In good weather, the picturesque Snæfellsjökull ice cap can be seen across the bay from Reykjavík. In the 1864 novel *Journey to the Centre of the Earth*, by Jules Verne, the ice cap serves as the entrance to a passage that led to the middle of our planet. It is the only ice cap that can be seen from Reykjavík, and has existed for many centuries, at least since Iceland was settled in the ninth century. Recent measurements show that this ice cap is shrinking rapidly in size.

The climate of Iceland exhibits considerable variability on annual and decadal timescales. However, long-term temperature records from the weather station at Stykkishólmur, about 60 kilometres from the Snæfellsjökull ice cap, show that during the last two centuries the climate of Iceland has warmed by about 0.7°C per century. In recent decades the warming has been very rapid with significant impacts on many natural systems in Iceland.

Recent measurements show that the Snæfellsjökull ice cap, which has an average thickness of less than 50 metres, thinned by approximately 13 metres in the last decade. At the current rate of thinning it will disappear within the century.

Snæfellsjökull ice cap is not an isolated case in this regard, most monitored glaciers are retreating. The thinning of large glaciers, such as the Vatnajökull ice cap, one of Europe's largest ice masses, reduces the load on the Earth's crust, and the crust rebounds. Consequently large parts of Iceland are now experiencing uplift. However, the uplift does not reach to the urban south west part of Iceland, where subsidence is occurring.

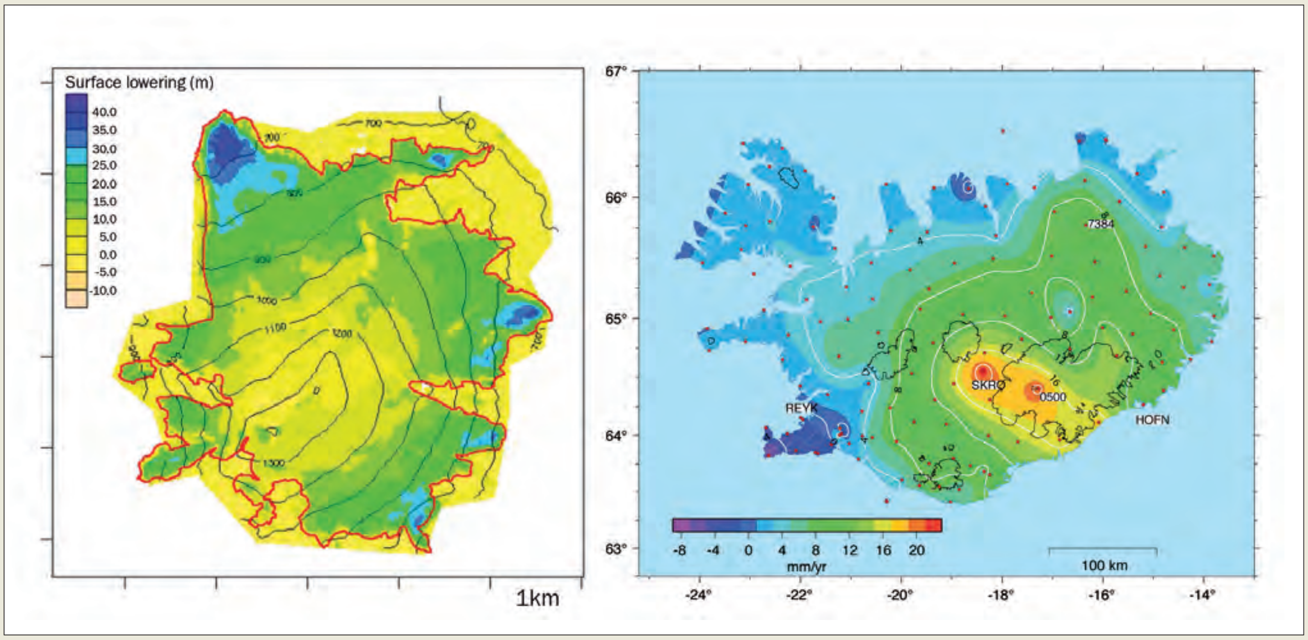
Changes are also evident in glacial river runoff, with earlier onset of the melting season and enhanced late summer melting. Recent warming has also impacted the fauna and flora of Iceland. Tree limits are now found at higher altitudes than before and the productivity of many plants has increased. In the ocean, there have been significant changes associated with warmer sea surface temperatures. Several new species of fish have expanded their range into Icelandic waters, and Icelandic stocks that traditionally were mostly found along the south coast have expanded their range to the north coast.

During the 21st century the climate of Iceland is likely to warm even further. Natural variability, while considerable, will not overwhelm the projected long-term warming of more than 2°C during the century. Because of natural variability the warming is, however, likely to be uneven with the climate exhibiting rapid warming during some decades, but little or none in others.

The projected warming is likely to cause a pronounced retreat of glaciers in Iceland. By the end of the century Langjökull, the second largest ice cap in Iceland is projected to have shrunk to 15 per cent of the size it was in 1990. The projected retreat is not as large for glaciers that are at a higher altitude, but by the end of the century they are still likely to lose at least half the volume they had in 1990.

The Snæfellsjökull ice cap

Thinning of Snæfellsjökull and glacial rebound in Iceland



Left: the changes in surface topography of the Snæfellsjökull glacier 1999-2008. The figure shows a widespread loss of ice, on average about 1.5 metres per year. The red line indicates the outline of the glacier in 2000[1] Right: vertical motion of the land surface in Iceland based on measurements 1993-2004. Positive numbers (green to red colours) indicate uplift, negative numbers (blue to violet colours) indicate subsidence[2]. Dots show the station network

As a consequence, glacial river runoff will increase during the first half of the 21st century and peak before its end. Hydropower potential can therefore be expected to increase in the first half of the century. Based on past experience, changes in glacial riverbeds are likely, which can impact both energy production and road services. Furthermore, it is likely that production of magma will increase under the thinning Vatnajökull ice cap, which may result in more frequent or larger volcanic eruptions in the area.

Concomitant with the projected warming, further changes in biota are likely. The enhancement of plant productivity and upward displacement of tree limits is likely to continue. The impact on marine life is more uncertain, not the least due to insufficient knowledge of the long-term consequences of recently discovered acidification of the oceans.

Impacts of projected climate change are likely to touch all sectors of Icelandic society. Projected increases in hydropower potential, along with enhanced plant productivity will affect the resource base of the country, while increased risk of flooding both from rivers and rising sea levels will influence planning and civil response. Because it is likely that there will also be impacts that are not presently anticipated, decision makers must be equipped to deal with uncertainties in impact projections.

The Fourth Assessment of the Intergovernmental Panel on Climate Change discusses the need for adopting risk management practices in dealing with projected impacts. In Iceland, there is a need to better quantify the magnitude of impacts and assess the probability of significantly adverse outcomes. To this end, further monitoring, systematic attribution and enhanced modelling, both of regional climate change and also of likely impacts, will be required.

Iceland already has substantial experience in dealing with risk management of natural hazards, and existing frameworks can be adopted to deal with some climate risks, such as possible increases in extreme weather, flooding and volcanic eruptions. To deal with impacts that are not related to singular events but rather affect the background conditions of natural and societal systems, policy makers will need different methodologies and frameworks. Examples of these kinds of impact include changes in river runoff that may necessitate changes in the management of energy and water resources.

Capacity building to meet these challenges is ongoing. Institutional realignment, starting with the merger of the Icelandic Meteorological Office (IMO) and the Hydrological Service will enable better support for policy makers. Climate information services must be strengthened to ensure that stakeholders have access to relevant information in a timely manner. It is also important to participate at the regional and international level. IMO has been active in several International Polar Year projects, leading one on hydrology, called Arctic-Hydra. Furthermore, IMO has headed a series of Nordic-Baltic climate impact projects focusing on three main renewable energy resources; hydropower, biofuels and wind power, and how future climate change within the next 20–30 years can impact these resources. All the National Hydro-Meteorological Services in the region are partners in this cooperation, which in many respects constitutes a regional Climate Services Application Program for the Nordic-Baltic region, including Greenland. A future ambition is to develop the network into a formal Regional Climate Service Application Program.

The project also intends to contribute to the Nordic Council of Ministers Top-level Research Initiative Programmes 2009–2013, which will focus on impact studies, adaptation to climate change and the interaction of climate change with the cryosphere, among other themes. Recognizing and responding to the risks and opportunities posed by climate change is a challenging task for both scientist and policy makers alike.

Feasibility issues: mitigation and adaptation to climate change in the Caribbean

Andrea M. Sealy, Caribbean Institute for Meteorology and Hydrology

In recent years, there has been increased awareness of the vulnerability of the Caribbean to climate change and its impacts. One such organization that has been working to enhance the region's ability to mitigate and adapt to climate change is the Caribbean Institute for Meteorology and Hydrology (CIMH).

As a World Meteorological Organization (WMO) designated Regional Training Centre, CIMH has been involved in initiatives such as the Small Island Developing States Caribbean project, Caribbean Planning for Adaptation to Climate Change, Adaptation to Climate Change in the Caribbean and Mainstreaming Adaptation to Climate Change. It also participates in the Global Environmental Change and Food Systems initiative, which is an international, interdisciplinary research project focused on understanding the links between food security and global environmental change. In addition, CIMH has designed the Caribbean Water Initiative with McGill University's Brace Center for Water Resources Management and Caribbean partner governments to address the complex challenges of water management in the region.

Comprising of mostly small islands bounded by the northern, eastern and south-eastern coasts of South, Central and North America respectively, the Caribbean region is particularly susceptible to environmental changes and impacts because of its geographic location and make-up. Islands have a unique vulnerability to climate change because of their relatively small size, limited natural resources and land use, remoteness, high external transport costs, time delays in accessing external goods and reduced quality in information flow. Other factors that exacerbate this region's vulnerability include large coastal zones and limited hazard forecasting capabilities, coupled with public complacency. There are also economic and demographic factors such as limited human resources, densely populated coastal, urban and low-lying areas and small limited economies, which are dependent on high-risk industries such as tourism and offshore banking.

Long-term predictions for small islands

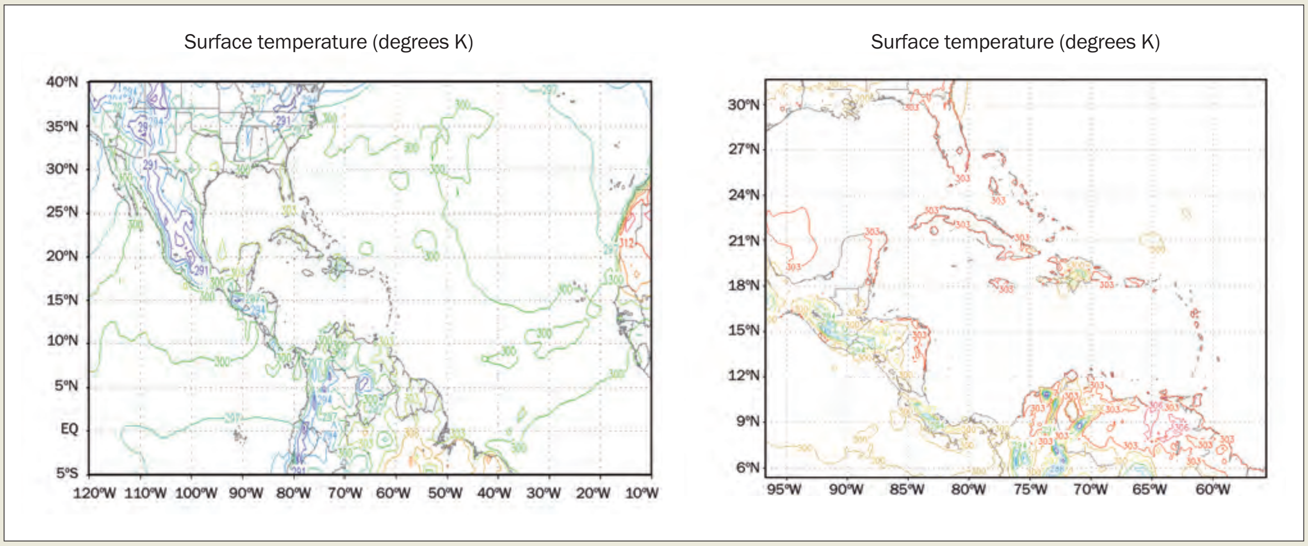
According to the Intergovernmental Panel on Climate Change's Fourth Assessment Report (AR4), rising sea levels are likely to exacerbate flooding, storm surges, erosion and coastal hazards, thus posing a serious threat to the socioeconomic well-being of island communities. This will certainly affect the Caribbean islands where over half of the population lives within 1.5 kilometres of the shoreline. AR4 also predicts that in most climate change scenarios, small islands' water resources are likely

Coral bleaching off the Florida coast

Bleached coral observed at Buck Island, St. Croix, US Virgin Islands, October 2005 (left) and map of preliminary bleaching reports with qualitative severity as reported by field observers from September to November, 2005 (right)

Source: NASA/Ames Research Center and National Oceanographic and Atmospheric Administration

Example of temperature output from GFS (left) and WRF (right) at 100 km and 18 km resolution respectively



Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

to be seriously compromised, especially if water supplies are limited in the first place. Add to this predictions from the Special Report on Emissions Scenarios (SRES), which show reduced summer rainfall for this region, and the likelihood of meeting water demand during low rainfall periods is slim.

The outlook for fisheries, which make an important contribution to the gross domestic product (GDP) of many island states, is also foreboding. AR4 confidently claims that climate change, particularly changes in the occurrence and intensity of El Niño-Southern Oscillation (ENSO) events, is likely to severely impact coral reefs, fisheries and other marine-based resources. In addition to this, an increase in sea surface temperatures, sea levels, turbidity, nutrient loading and chemical pollution, damage from tropical cyclones, as well as a decrease in growth rates due to the effects of higher carbon dioxide concentrations in ocean chemistry, is very likely to lead to coral bleaching and mortality.

It is very likely that subsistence and commercial agriculture, and tourism — which is a significant contributor to GDP and employment on many small islands — will be adversely affected by climate change both directly and indirectly. There is also a growing concern that global climate change is likely to have a negative impact on human health. Many small islands lie in tropical or sub-tropical zones with weather that is favourable to the transmission of diseases such as malaria, dengue, and food and waterborne diseases. If climate change causes an increase in temperatures alongside a decrease in water availability, the burden of infectious diseases in some small island states is likely to increase. A study of the relationships between dengue fever, temperature, and the projected effect of climate change on the transmission of dengue fever was undertaken in the English speaking areas of the Caribbean.[1] Carried out because of the recent increases in dengue fever outbreaks and predicted temperature increases, the study revealed that occurrences of dengue fever are sensitive to factors such as temperature and rainfall. This, and IPCC's projected long-term changes in climate, should be a source of concern for public health officials in the Caribbean.

Given these predictions it is clear that focused region-specific climate model parameterizations need to be developed and assessments need to be conducted, particularly as the models used in AR4 weren't precise enough to calculate climate change in smaller islands, and as the parameters weren't necessarily adjusted for tropical climates.

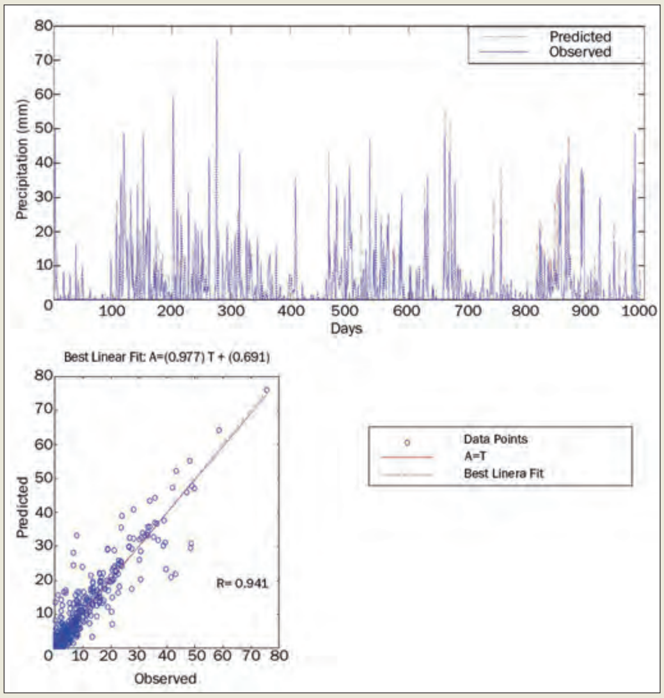
Downscaling to improve climate predictions

According to IPCC's AR4, there have been improvements in the simulation of regional climates. This has resulted in improvements in established regional climate models (RCMs) and in empirical downscaling techniques. The report also states that both dynamic and empirical downscaling methodologies are improving to the point where they can simulate local features in present-day climates using observations provided by current global climate models (GCMs).

In some cases, such as when sub-grid scale variations are minimal or when assessments are global in scale, regional information provided by GCMs may be sufficient. Theoretically, the main advantage of obtaining regional climate information directly from GCMs is the knowledge that the internal physics are consistent from one scale to the next. GCMs cannot, however, provide accurate climate information at scales smaller than their resolution, neither can they capture the detailed effects of sub-grid scale forcings unless they are parameterized. The benefits of downscaling, therefore, depend on the spatial and temporal scales of interest, as well as the variables of interest and the climate information required.

The scale of a study relates to whether or not high resolution information is needed. At a regional/small nation level, for example, there would be a need for high-resolution information given that some nations are not even represented in GCMs or they only occupy a few GCM grid boxes. The Caribbean islands are a prime example of a region that requires high resolution information. Here, statistical downscaling would

Comparison between observed and predicted precipitation



Time series of observed and artificial neural network reconstructed precipitation for 30 per cent of data randomly degraded (top) and scatter plot of reconstructed against observed precipitation for 30 per cent degraded data (bottom)

Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

be appropriate to predict climate change, but a combined approach where regional models are also statistically downscaled would be valuable. Additionally, islands that are small, irregular land masses would benefit greatly from high resolution modelling, as processes such as land/sea breezes, which are a result of the different thermal characteristics of land and ocean, cannot be captured by a GCM.

The type of climate information required may also influence whether or not high resolution modelling is desirable. Certain surface variables, such as surface temperature or precipitation, are more likely to be significantly improved by using high-resolution data as opposed to atmosphere variables such as 500 hectopascal heights. One may have a case where a low resolution model gives fairly accurate mean rainfall, however capturing extreme precipitation events usually requires high resolution models.

In recent years, there has been an increase in use of RCMs throughout the Caribbean. These models use dynamical downscaling and provide more accurate representations of physical processes. There are a number of Caribbean institutions — Climate Studies Group Mona (CSGM), University of the West Indies, Instituto de Meteorologia de la Republic de Cuba and the Caribbean Community Climate Change Centre —that, through their collaborative efforts, have produced regional climate change projections that can be used by researchers and policy makers to assess potential impacts and develop adaptation plans. Extensive work is being done to ensure these products will be readily accessible and available to the wider community in addition to universities and research centres. CSGM also uses statistical downscaling to downscale global projections to specific observational stations. Statistical downscaling of temperature and precipitation from global models to station sites in Barbados, Jamaica and Trinidad was undertaken in an Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sector Small Island States SIS06 project. Information from these climate scenarios would be useful to policy makers for charting adaptation and mitigation strategies for the region.

CIMH has investigated the plausibility of using an artificial neural network (ANN) to reconstruct missing daily precipitation data for a rainfall station in Guyana. This functionality was tested by asking ANN to predict data at a station using incomplete data as well as data from nearby stations. Comparisons of the predicted data to actual measured data at the site showed good correlation, even though the data given to ANN had 30 per cent of its values randomly removed. Further ongoing studies are being conducted to assess the effectiveness of the ANN technique for longer time series. If successful, this would support statistical downscaling of climate models and climate change impact studies in the Caribbean region.

Future work at CIMH

Future climate-oriented work at CIMH will focus on investigating long-term climate variability with the intention of improving predictions and enhancing understanding of climate change in the region. Research will be conducted using mesoscale climate models such as the weather research and forecasting model to obtain information about the variability of climate in the region and to determine the medium- to long-term variability of weather systems affecting Caribbean climate.

Additional research will use mesoscale climate models to examine the effects of Saharan dust on Caribbean climate. Long-term monitoring studies in the Caribbean region have shown large interannual increases in atmospheric dust concentrations. Atmospheric dust can influence the Earth's radiative budget directly, by scattering solar radiation in the atmosphere, and indirectly, by changing cloud condensation nuclei concentrations. Dust has also been linked to reduced precipitation in the Caribbean and to changes in seasonal rainfall patterns.[2] It may also be a major source of tropical hurricane suppression in the Northern Tropical Atlantic due to factors such as cooling of sea surface temperatures in the main hurricane development region[3] and the Saharan Air Layer.[4]

A key regional initiative that would be of great benefit to any mitigation and adaptation strategy would be an objective intercomparability and assessment study, which would enhance understanding of the range and causes of uncertainties in climate model outputs and the model biases for the Caribbean region. It would also be useful in showing how model predictions may change according to different scenarios. Information from all these model simulations and intercomparisons would be useful for adaptation and mitigation initiatives.

Water resource management and adaptation initiatives to the challenges of climate variability and change in Singapore

Chang Chian Wui, Deputy Director Policy and Planning, Public Utilities Board, Singapore

Singapore is blessed with some 2,400 millimetres of rainfall each year. Unfortunately, it is a small island with only 700 square kilometres of land. The growing population and economy exert pressure on land use, with land for water catchments competing with industry and housing. The lack of land to collect and store rainwater, high evaporative losses and lack of natural aquifers has led Singapore to be considered water scarce by the United Nations, ranked 170th of 190 countries in terms of freshwater availability.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) estimates that temperature rise in Southeast Asia over the next century will be similar to the global mean temperature rise of 2.8°C. It also suggests that sea level will rise close to a global mean of 21-48 centimetres and changes in annual precipitation will range from –2 per cent to +15 per cent with a medium of +7 per cent. The projection is broadly for wet season rainfall increase and dry season rainfall decrease. Extreme events are likely to become more intense in the region.

Image: PUB

The Marina Barrage creates a reservoir in the city, alleviates floods and offers an attractive recreation area

The potential impacts are water scarcity, increased flooding and rising sea level. To better understand these impacts, the Singapore Government has commissioned a vulnerability assessment, to be completed in 2009. The study is conducted by the local university, together with a team of foreign experts, and is based on IPCC emission scenarios and global circulation models. It projects the effects of climate change in the next century — changes in ambient temperature, sea levels and currents, storm surges, rainfall intensity and duration, wind patterns and intensity and resulting impacts on water availability, flooding, coastal erosion, land loss and slope stability. The results will facilitate the identification of new adaptation measures and a review of existing ones.

Integrated water resources management

As Singapore's integrated water agency, the Public Utilities Board (PUB) is responsible for the management of the entire water loop — from storm water collection to potable water supply, used water collection and treatment, water reclamation and seawater desalination. Singapore's water strategy can be summarized by PUB's corporate tagline: 'Water for All: Conserve, Value, Enjoy'. 'Water for All' refers to the supply strategy of a diversified and sustainable supply of water. 'Conserve, Value, Enjoy' emphasizes water conservation and PUB's approach to involving stakeholders and the community in its work.

Water for All

A diversified supply system with four different sources is in place — local catchments, imported water, 'NEWater' and desalinated water. 'The Four National Taps' not only meet long-term needs, they also increase resilience against climate uncertainties. Three are primary sources. They are, in effect, the 'first drops' of water obtained from the water catchments or the sea. NEWater is a secondary source created by recycling.

Regarding local catchments — although Singapore has very limited land, segregation of storm runoffs from used water, judicious land use, vigilant surveillance and strict enforcement have enabled half of the area, including housing estates and urban zones, to be tapped for water catchment. The new Marina Reservoir, completed in 2008, is located right in the heart of the central business district. It collects runoffs from the largest, most urbanized catchment (10,000 hectares), and increases water catchments to two-thirds of land area.

Singapore imports water from Malaysia through the 1961 and 1962 Water Agreements, until 2011 and 2061 respectively. Water from local catchments and that imported under these agreements is sufficient to meet Singapore's needs. It has, nevertheless, supplemented them with NEWater and desalination, ensuring there will be no need to renew the 1961 Water Agreement by 2011. This ensures long-term self-sufficiency if necessary. Singapore's first desalination plant was commissioned in 2005 to supply 136,000 cubic metres per day of desalinated water for 20 years.

NEWater is the jewel of Singapore's diversification strategy. It is produced through a multi-barrier treatment process that comprises conventional used water treatment, microfiltration, reverse osmosis (RO) and finally, ultraviolet disinfection.

To ensure safety, a demonstration plant was opened in 1998 and operated over two years to test for robustness and reliability, with more than 20,000 tests carried out for 190 water quality parameters. Results showed that quality was well within USEPA and WHO standards and guidelines. It was also independently verified by an international and local expert panel. NEWater is now supplied for non-potable use on a largescale to major industrial complexes, including wafer fabrication plants, petrochemical complexes, refineries and power stations. A small percentage is introduced into reservoirs for indirect potable use. There are now four plants supplying 15 per cent of demand. When the fifth, and largest plant is completed in 2010, this will increase to 30 per cent.

Apart from freeing up a large amount of potable water for other purposes, NEWater has a strategic role in 'multiplying' the supply achieved through recycling. If 50 per cent is recycled supply could theoretically be doubled. From recycling one drop of water, 0.5 drops could be obtained. This 0.5 can in turn be recycled to get 0.25 and then 0.125 drops, and so on. Theoretically, recycling one drop results in another drop at a multiplier of two. At higher recycling rates, a higher multiplier effect could be achieved. Instead of building all new capacity through catchment expansion or costly desalination, 50 per cent of it can be made up through recycling.

Both desalination and NEWater have important roles to play to mitigate climate change. Both also have the advantage of being independent of rainfall fluctuations, thus increasing resilience against variation. Together, they have put Singapore in a strong position to meet long-term sustainability and the uncertainties of climate change.

Conserve, Value, Enjoy

Reducing demand is another key strategy. PUB recognizes that simply encouraging the public to conserve water is not enough — a holistic approach is required.

PUB has a network management plan to ensure that leaks are minimized, thus reducing unaccounted for water. The use of good quality pipes and fittings, efficient management, active leakage controls, mandatory and accurate metering and strict legislation on illegal draw-offs has reduced losses from 10 per cent in the early 1990s to less than 5 per cent today. The network has less than seven leaks per 100 kilometres annually, a vast improvement from the 1980s, when there were more than 100 per 100 kilometres. This has been achieved by using good pipe materials, systematically replacing old pipelines and the active detection of underground leaks. By reducing losses and keeping them in check, there is less pressure to expand sources.

PUB has also addressed the issue of water pricing. A Water Conservation Tax (WCT) is imposed on every drop of potable water supplied. This is applicable to all users, both domestic and non-domestic. The WCT

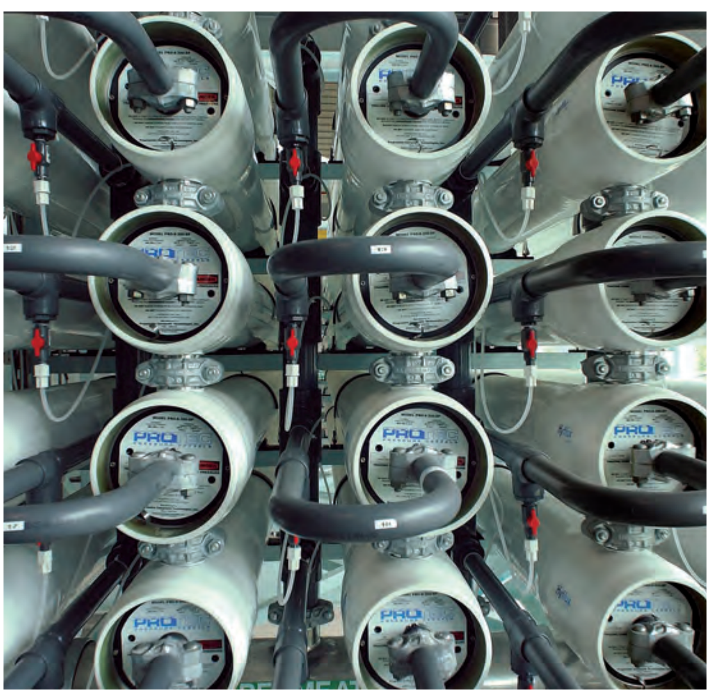


Image: PUB

Reverse osmosis treatment for NEWater

Image: PUB

Bottled NEWater for public education and publicity programmes


Image: PUB

Transformation of waterways

emphasizes that water is a scarce and precious resource from the very first drop. The tariff and WCT are increased for households that consume more than 40 cubic metres per month to encourage conservation.

Mandatory conservation measures include low capacity flushing cisterns, constant flow regulators, self-closing delayed action taps and maximum allowable flow rates. Voluntary measures include community-driven public education programmes such as 'Water Efficient Homes' and the '10 Litre Challenge'. Under the programme, DIY water saving kits consisting of flow resistors, cistern bags and leaflets were supplied to residents free of charge.

Domestic water consumption reduced from a peak of 176 litres per person per day in 1994 to 157 litres in 2007. PUB expects to lower this to 155 by 2012. Annual water demand growth rate since 1995 has been kept low at about 1.1 per cent, despite GDP and population growth of 5.1 per cent and 2.2 per cent per annum respectively.

Active, Beautiful, Clean Waters

Beyond conservation, PUB has embarked on efforts to get people to value and enjoy its 'blue assets' through the Active, Beautiful, Clean Waters programme. Singapore has 32 rivers and will eventually have 17 reservoirs. In addition to source control and mitigation measures to ensure good water quality, PUB also takes a community approach by transforming concrete canals into beautiful and vibrant spaces for recreational activities.

To gain building industry support, PUB developed a set of design guidelines providing instructions on the design of water sensitive landscaping features such as bio-swales and rainwater gardens. Such features soften harsh concrete canal edges while removing nutrients in the storm water. Peak flows in the drains and waterways are also reduced as water is retained for a longer time before reaching the waterways.

Leveraging on innovation and technology

A small country with no natural resources, Singapore has always used technology as part of its nation-building efforts. As such, there have been heavy investments in technology to seek solutions for its water needs.

Seawater desalination is still costly, being over three times more energy intensive per cubic metre than NEWater or conventional treatment. With rising oil prices, this will be accentuated. Future development in desalination lies in reducing energy consumption. PUB is exploring various alternatives such as membrane distillation and variable salinity plants, which treat both freshwater and seawater. The Singapore Government has challenged the research community to produce viable alternatives that desalinate seawater at 50 per cent more energy efficiency than current technologies. It attracted local and overseas research companies, and Siemens Water Technologies clinched the deal with a novel electrically driven desalination process. Siemens received SGD4 million (USD2.7 million) worth of funds to investigate the concept. If successful, it would benefit other countries as well as Singapore.

Flooding and sea-level rise

In the 1960s and 1970s, floods were common and widespread, especially in the city area. In 1978, Singapore experienced its most severe flood when 512 millimetres of rain was recorded over 24 hours, coinciding with a high spring tide. Roads were submerged under a metre of water. Seven people died and more than 1,000 were evacuated from their homes. Since 1973, over USD1.3 billion has been spent to construct new drains and canals. Flood-prone areas have been reduced from 3,200 hectares in the 1970s to 124 hectares today, even as urbanized areas have increased.

Higher sea levels due to climate change will pose a challenge for drainage. As much of Singapore's coast is reclaimed land, in 1991 PUB insisted that reclaimed land is constructed at least 125 centimetres above the highest recorded tide level. This has put Singapore in a stronger position, as IPCC AR4 projects a maximum sea-level rise of 59 centimetres. Plans are in place to ensure that drainage infrastructure can meet the effects of climate change. The Vulnerability Study will review drainage design, produce new flood maps and facilitate adaptation measures; such as the setting of new minimum platform levels for developments and land reclamation, increasing tidal gate height at estuarine reservoirs, and protection of foreshore and coastal areas including beaches and mangrove habitats.

Singapore has taken steps to prepare for climate change. The Four National Taps not only meet long-term needs, they also mitigate future uncertainties, as NEWater and desalination are not affected by the vagaries of weather. The development of NEWater is even more strategic as it effectively doubles Singapore's resources. Conservation and efficient management of the network will continue to be given high priority to keep demand growth low. Innovation has played a key role in developing sustainability and Singapore will continue to invest heavily in research and new water technologies.

Danish perspectives on climate change and adaptation strategies

Connie Hedegaard, Minister for Climate and Energy, Denmark

Throughout history mankind has had to adapt to the prevailing conditions of planet Earth — adjusting his whole way of life according to local climate variability and other related events. But never before has mankind faced such extenuating pressures and threats to its very existence. The increasing concentration of greenhouse gases in the atmosphere is causing unprecedented changes to the balance of our climate system and forcing us to adapt to conditions of which we have no previous experience. Furthermore, the global population continues to rise and is expected to reach 9 billion by 2050. This generates an increasing need for fresh and adequate food and water, new infrastructure and sustainable development — all while addressing climate change. This challenge is nothing short of what Al Gore has repeatedly referred to as: 'a planetary emergency'.

Changes in temperature, precipitation patterns, sea ice extent, sea-level rise and the frequency of extreme weather events have already been observed, with more expected to come. It is predicted that in the coming decades billions of people will experience water shortages, decreases in crop yield and food supply, increased drought and flooding, inundation of coastal areas and health risks to which they are not accustomed. All these things combine to threaten the very lives and livelihoods of the world's people. This is particularly true for those in developing countries, especially least developed countries and small island developing states (SIDS), which are extremely vulnerable and less able to adapt to climate change. The effects of climate change facing the world's poor people and vulnerable groups will worsen their already precarious living conditions and potentially reverse the progress of sustainable development. The lack of financial, social and technological resources available to the world's most vulnerable makes them less resilient. As such, we have a moral imperative and the opportunity — in connection with the 15th United Nations Conference of the Parties (COP15) — to improve this situation.

Image: Henning Thing

The Arctic sea ice extent in 2007 was 38% below average, resulting in an ice-free opening through the Northwest Passage that lasted several weeks. This anomaly caught the attention of the world, including the scientific community

Few other places on earth are as telling of climate change impacts as the Arctic. The region is experiencing an increase in temperature twice that of the global warming average. Although the Arctic has historically been both vulnerable and resilient, the current extent and speed of human-induced climate change is terrifying. The melting, and subsequent retreat, of sea ice and glaciers is occurring at a far greater rate than climate models and scientists perceived possible just a few years ago. Changes in the Arctic will reverberate globally, directly impacting the planet as a whole through rising sea level, and indirectly through impacts on global weather conditions such as feed backs, changes in global albedo, content of atmospheric greenhouse gases and ocean currents. Furthermore, ecosystems and species that thrive in this fragile environment — which often constitute the livelihood of indigenous peoples — are speeding toward an ill fate. This poses new challenges to the resilience of Arctic life and to the adaptive capacity of indigenous peoples in the north. Many such populations depend on hunting, fishing and gathering — not only for food and to support the local economy, but also as a basis for social and cultural identity. Indigenous knowledge and observations have provided an important foundation for survival, but as the pace of climate change accelerates these traditional skills need to be complemented by scientific research. This will strengthen their adaptive capacity to deal with climate variability, climate change and its impacts.

Since the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), it has been clear that the global ecosystem will change and that our societies and ecosystems will need to adapt to climate change and extreme events — even with ambitious greenhouse gas emission reduction targets and rigorous mitigation actions. This has been reinforced in the Fourth Assessment Report from the IPCC. A great deal of work has been undertaken both within and outside the United Nations Framework Convention on Climate Change (UNFCCC) process. However, to assess the impacts of and vulnerabilities to climate change, and determine options and ways to adapt to these impacts, concerted and coordinated efforts at a much greater scale are needed. But where should we begin?

The Fourth Assessment Report of the IPCC offers some guidance on this. Maps identifying future changes, as well as key climate indicators, may help guide initial adaptation efforts around the world. There is no doubt that we need more research — particularly on a regional scale — but we do know enough to act.

Science and information are at the heart of addressing the challenge of adaptation. Although climate change is a global phenomenon, the impacts are experienced at the local level. The degree of vulnerability to these impacts depends on many factors and varies from one place to another. Without timely and spatially relevant climate information, national governments and communities are ill-equipped to plan for and manage emerging climate risks. Denmark has taken the first steps, but many developing countries require strengthened climate research and observation infrastructures in order to obtain locally relevant information.

Having the appropriate information, however, is only the first step of many towards developing a national strategy for adaptation to climate change and building resilience. Given the diversity of circumstances and different priorities of each nation, there is no specific recipe for how to plan for anticipated climate impacts. However, based on its experience, Denmark has found some ingredients to be essential.

Prior to the adoption of its national adaptation strategy in early 2008, Denmark underwent a long intra-

Image: Henning Thing

The IPCC predicts that if global mean temperatures exceed a warming of 2 to 3°C above preindustrial levels, approximately 20 to 30% of plant and animal species are likely to be at increasingly high risk of extinction. This will have enormous implications for ecosystem services on which our global ecosystem depends governmental process to come to terms with the need to adapt to, and best manage, climatic change. Existing climate information and extensive modelling capacities enabled Denmark to predict future climatic changes, which include increased precipitation (particularly during winter), milder winters, warmer summers, sea-level rise, stronger winds and an increasing occurrence of extreme weather events. Thereafter, an inter-ministerial working group was set up to draft a science-based government strategy and conduct public consultations with all relevant stakeholders. After careful deliberation involving all sectors of society, and finally a public hearing, the strategy was adopted by the Danish Parliament. The importance of close partnerships, alliances and participation by many stakeholders in achieving the overall goal cannot be understated.

The Danish strategy encompasses all vulnerable sectors and stresses the importance of early action — both autonomous and at the national level — to implement adaptation measures to climate change. But any national strategy can only be as good as the information upon which it is based. Timely and relevant information at the appropriate scale is crucial. As such, the Danish strategy is flexible enough to incorporate new knowledge and information on future climate change into each stage of planning and development. Flexibility is important so that all stakeholders have the best possible foundation for considering their adaptation options and to learn from lessons and experience gained.

To raise awareness and support action at the national and local level, Denmark has undertaken several initiatives. A cross-ministerial Coordination Forum on Adaptation has been established to evaluate progress in implementing the strategy, as well as to monitor and share knowledge and experience about climate adaptation between sectors and authorities at all levels. An Information Centre on Adaptation was created to communicate the strategy, current knowledge and data relevant to adaptation — including a climate adaptation web portal (www.klimatilpasning.dk). In order to ensure that the strategy is based on the best available science and will sufficiently address anticipated climatic changes, Denmark has also established a Coordination unit for Research on Climate Change Adaptation. This coordination unit will promote cooperation and knowledge sharing among national and international research centres and provide climate data and state-of-the-art climate research results to the Information Centre in order to keep the climate adaptation web portal users up to date. This will include research related to the atmosphere, hydrosphere, biosphere, cryosphere and technosphere.

Although planning for anticipated adverse effects of climate change is invaluable, socioeconomic structures and ecosystems require time to adapt to new conditions. However, there is hope in the fact that 192 very diverse countries agree that humanity is facing a serious problem and are willing to collectively confront the challenge and find solutions. Since its inception in 1992, UNFCCC has been the cornerstone for international action on this topic. For nearly 20 years, these countries have set goals and taken steps to avoid and to adapt to dangerous climate change. However, as science continues to advance and our understanding improves, it has become clear that our goals need to be farther-reaching to address the challenge we face today. In 2007 in Bali, Indonesia, all 192 Parties to the Convention collectively agreed to start a process to determine what is necessary to mitigate climate change, how to enhance action on adaptation, and determine what financial and technological means are necessary to fulfil these common goals. Since that time, Parties have worked diligently with the aim of agreeing the essential elements by December 2009, when they will meet for the 15th time, in Copenhagen. This meeting will provide the tools necessary to make the world a less hazardous place to live in the future.

Climate change knows no borders, nor does it discriminate, but the impacts carry a social imbalance. Weak and poor people are harder hit by extremes compared to more affluent groups of society. And like the butterfly effect, in our global civilisation where our livelihoods and economies are interwoven, climate impacts that affect human beings in one place, have an impact and effect on those in another. Courage and truly global concerted action is needed to address climate change and to build adaptive capacity in developing countries so that we can all cope with the adverse climatic impacts now and in the future. We must uniformly recognize the sense of urgency for adaptation that has been highlighted by the IPCC, by SIDS, and by the many voices in developing and least developed countries, and we must respond accordingly. Leading up to and beyond COP 15, we must all move forward together and create a world that is truly sustainable for our own generation and all those to come. To do anything less, we would be burning the bridge between our rise and fall.

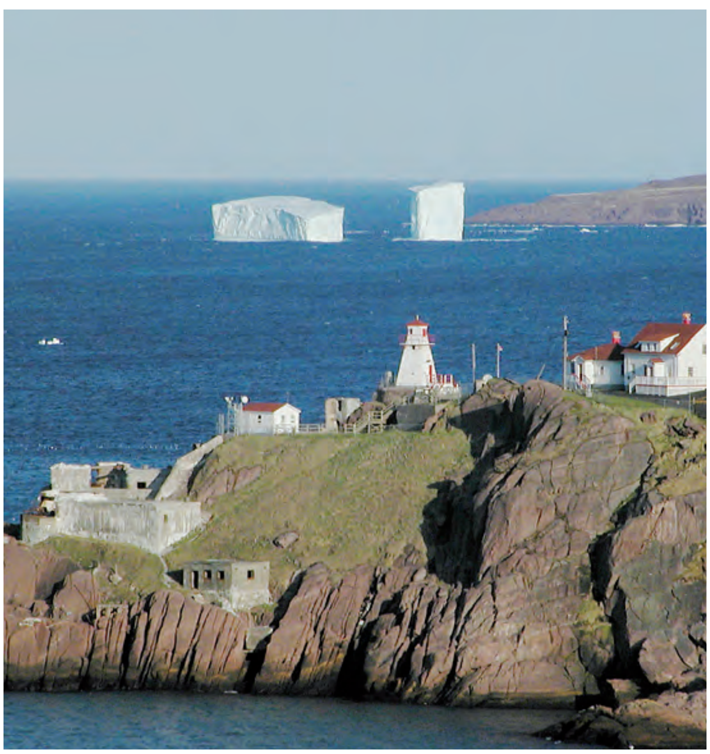


Image: Karen Chappell

Approximately 40,000 medium to large sized icebergs calve annually in Greenland, many of which travel as far south as 47° north latitude. These icebergs have travelled for up to two years, finding their way to the coast of Newfoundland, Canada

Coastal erosion and the Adaptation to Climate Change in Coastal zones of West Africa project

Dr Isabelle Niang, Regional Coordinator of the Adaptation to Climate Change in Coastal zones of West Africa project, United Nations Educational, Scientific and Cultural Organization/BREDA, Dakar

Coastal erosion is a major problem for Africa and was recently the subject of a continental conference initiated by the President of Senegal, His Excellency Abdoulaye Wade. In northwest Africa, the coasts are economically important since a large part of the gross domestic product (GDP) is derived from coastal activities such as fishing, tourism and commerce. This is one reason why populations are concentrated along the coastline, with a rate of urbanization slightly higher than the interiors. As a result, many capitals and major towns are coastal.

Along the northwest coast of Africa average rates of coastal retreat are between one and two metres per year. However, more serious rates of up to hundreds of metres per year have been observed locally, especially when the process has been created by human activities. Coastal erosion has devastating effects, inducing the loss of infrastructure such as roads. It also threatens populations, who can no longer live close to the coastline.

Coastal erosion is expected to increase due to climate change and sea-level rise. This will bring other problems such as salinization of water and soils, degradation of ecosystems and flooding. Such predictions were reiterated in the fourth Intergovernmental Panel on Climate Change (IPCC) report. Moreover, recent studies indicate that sea level observations are already higher than the maximum limit of IPCC projections. This means that we can expect more than the one-metre sea-level rise projected for 2100, a fact that the rapid melting of the Greenland ice sheet, as well as strong indications that the western part of the Antarctic ice sheet is also melting, strongly support.

Image: Fernando Jorge Frederico

Sensitization for scholars in Maio island (Cape Verde)

Whatever the dispute about the rates and amounts of sea-level rise, it is evident that coastal populations and ecosystems will need to adapt to these changes. For human beings only three options are available to combat coastal erosion: retreat, accommodate or protect. A very limited number of studies — conducted mainly during preparation of the Initial National Communications from Parties not included in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) — indicate that the costs of adaptation are likely to be lower than the impacts costs of doing nothing. However, the cost of adaptation is already considered to represent between 5 and 10 per cent of the GDP of affected countries, which is a significant sum, especially for the economies of the least developed countries. This debate is by no means over, since all the elements that could allow a significant cost-benefit analysis are not yet available. A limited number of adaptation options (mainly sea walls) were evaluated but indirect costs (expertise, manpower, technical help) have not been considered. Even the retreat option would have a cost — both economically and socially.

As was stated at the last African Ministerial Conference on the Environment in Nairobi, adaptation is a high priority for Africa. Indeed any post-2012 agreement at the UNFCCC 15th Conference of Parties (to be held in Copenhagen in December 2009) should include a discussion of adaptation, along with concrete actions to support any resolutions made.

The Adaptation to Climate Change in Coastal zones of West Africa (ACCC) project is a tentative response to the problem of coastal erosion. The Global Environment Facility project focuses on three main areas of concern: coastal erosion, biodiversity and climate change. It operates on a sub-regional level and involves five countries: Mauritania, Senegal, Gambia, Guinea Bissau and Cape Verde. National components will develop pilot activities in selected sites — one per country — with the aim of reducing the threat of coastal erosion, while increas-

Image: Joao Raimundo Lopes

Coastal erosion along the beach of Varela (Guinea Bissau)

ing biodiversity and strengthening the adaptive capacities of local communities and ecosystems. The project will also try to include climate change considerations in different development plans — for example, tourism strategy and master plans for coastal towns.

One of these pilot projects will take place in Varela, Guinea Bissau, where extremely rapid coastal erosion is occurring. Activities on the site include cleaning the beach (mostly material left by a former tourist industry infrastructure), mangrove restoration and afforestation. These activities will be conducted with local non-governmental organizations (NGOs) and represent an opportunity to conduct awareness training with different levels of society, including women and the young. At a national level, agreements have been made with the Ministry of Tourism to include climate change aspects, as well as integrated coastal management, in its strategy development.

Regional components will aim to develop training on a variety of related matters. Three regional training workshops have already been organized on climate change and coastal zones, techniques for mangrove restoration and littoral dune afforestation. A shared environment consisting of a website, network and database is being created. This will enable exchange of experiences, support sub-regional activities to increase the opportunities for decision makers to act, and increase the design and implementation of integrated coastal zone management policies.

In the coming months there will be a forum of sub-regional parliamentarians to discuss how they can contribute to better management of the coastal zones in a context of climate change. A ‘training of trainers’ will be organized to launch the Sandwatch programme, which is supported by UNESCO in the Caribbean and Pacific islands regions, and seeks to teach scholars how to monitor beaches effectively. Appropriate communication tools will be developed to enhance the visibility of the project and find co-funding. A monitoring and evaluation framework was defined during the regional inception meeting, which took place in November 2008.

The ACCC project is one of the various sub-regional efforts to adapt to climate change in costal zones, including: the West African Economic and Monetary Union, with its project on coastal erosion; the International Development Research Centre, with its programme on Adaptation to Climate Change in Africa; and Le Programme régional de Conservation de la zone Côtière et Marine en Afrique de l’Ouest, which is a consortium of NGOs focused on protecting the marine and coastal areas of West Africa. The point of this ACCC project is to promote multiple adaptation responses to combat coastal erosion, since no single option can fit all circumstances. The inclusion of stakeholders through sensitization campaigns and activity-integration is an important aspect of this project. By involving stakeholders the project benefits from a wide variety of experiences, as well as becoming a larger network.

The actions taken during this project are also expected to promote the development of biodiversity, since improving the marine environment improves the well-being of the wildlife that depends on it — including turtles and marine birds. Combating coastal erosion by developing adaptation systems clearly works, while preserving biodiversity and involving all stakeholders are efficient ways to prepare communities and ecosystems for better adaptation to climate change and its consequences along West Africa’s coastal zones. Integrated coastal management will also contribute to the resilience of coastal ecosystems and populations to a future environment affected by climate change.

Adaptation as development: an inconvenient truth?

Lloyd Timberlake, Commission on Climate Change and Development, Ministry of Foreign Affairs, Sweden

The international Commission on Climate Change and Development, which published its report in May 2009, assumed that it would be able to narrowly and precisely define adaptation — in terms of adaptation to climate change — and having done so clearly describe how to manage and finance it.[1]

Given that the Commission was chaired by the Swedish Minister for International Development Cooperation, Gunilla Carlsson, there was also a large emphasis on figuring out how much adaptation would add to the basic costs of development.

It is a common assumption, even by the experts, that such reckoning is possible. In a 2008 technical paper on funding adaptation and mitigation, the UN Framework Convention on Climate Change secretariat wrote: "An increased effort to calculate adaptation needs through regional or national bottom-up assessments, as opposed to global top-down estimates, is evident. But regardless of the number of financial assessments, their precision can be improved only through a better understanding of adaptation and how it is additional to a development baseline."[2]

No simple equation

However, after much deliberation and study the Commission concluded that, while such efforts to calculate adaptation needs are helpful, especially by bottom-up assessments, they are unlikely to ever arrive at a precise answer to 'development costs plus adaptation costs'.

True, much 'extra' infrastructure will need to be built in developing countries to manage sea-level rise, changing freshwater availability and the like. All this can be costed. But much of the response to climate change must come in the form of 'software' rather than the hardware of infrastructure, and the costs of this software are much harder to estimate.

Climate change is usually discussed either in terms of a gradual rise in average global temperature or as an increase in major disasters such as hurricanes, floods and droughts. But for most people in the developing world it is experienced as neither, but instead as increased uncertainty. The Malian farmer faces weather

Image: CCCD secretariat

Climate change means countries such as Bolivia face increased uncertainty patterns never seen before: too little rain one year, too much the next. The Samoan fisherman sails on less predictable seas. The highland Bolivian farmer is threatened by malaria for the first time in recorded human history.

Uncertainty increases vulnerability, especially for those whose lives depend directly on natural systems. They need new software in the forms of education, data and knowledge. They need democratic governance and political voices to articulate views and concerns. They need effective local governments connected to national governments. They need markets that work for them so that they can trade and build their assets to tide them through illness, bad harvests and the smaller, local disasters that they are experiencing more of.

In short, they need development, but of a new kind that manages risks. For it is development that decreases vulnerability, and decreasing vulnerability to climate change decreases vulnerability to other threats such as high prices for food and energy.

The adaptation development overlap

The conclusion that adaptation equals development, but a more complicated kind of development, is messy for many reasons.

Firstly, it suggests that 'development plus adaptation' calculations will never give precise answers. Secondly, the development process is challenged by multiple crises and is having trouble reaching the poor, the food-insecure and those without access to modern forms of energy; so making it more complex does not inspire confidence. Thirdly, the development community and the disaster risk reduction community operate in separate silos. That separation is becoming rapidly more damaging. Fourthly, the conclusion is almost 'politically incorrect' in that developing countries want the wealthier countries to honour the UNFCCC and help them with adaptation costs; they see this not as charity but as a debt, a reparation, owed to them by the nations that developed on the basis of carbon emissions. They do not want this debt to become entangled with the broken promises and the charitable nature of official development assistance.

Image: Vassil Anastasov

The highland Bolivian farmer is threatened by malaria for the first time in recorded human history

Yet, perhaps the idea that adaptation and development all but overlap will help governments keep in mind the truth of Lord Nicholas Stern's statement that: "Development and climate change are the central problems of the 21st century. If the world fails on either, it will fail on both. Climate change undermines development. No deal on climate change that stalls development will succeed."[3]

After visiting developing countries in Asia, Africa, and Latin America — and in each case visiting villages and rural areas — the Commission concluded that while climate impacts may be huge, they will be experienced locally, by individuals, families and villages. It is at this level that adaptive capacities and resilience must be increased.

This does not in any way decrease the role of the national government; in fact it suggests that national governments must be much better at connecting with remote areas and peoples. Examples of how this is being done are apparent in the partnerships with non-governmental organizations (NGOs) and UN organizations.

There is also an alarming tendency in some countries for national governments to decentralize responsibilities to local communities — for running things like the schools and health clinics — without decentralizing the funds to do so, or seeing to it that local leaders were trained for the tasks. This tendency increases, rather than decreases, vulnerability.

Yet the instinct to rely on local people is correct, for they have been managing climate variability for centuries and have much pertinent knowledge and many necessary skills. The Commission found that part of the Bolivian government's integrated response to climate change involves systematically gathering material on the traditional strategies the country's various different cultural groups have used in coping with climate variability.

Development with risk management

Once one begins to see adaptation as development with risk management, and view the development process from a local angle, one can see how the various sectors of the development process will need to be managed differently.

Take energy. No nation has developed economically without increasing access to modern energy services. Yet, energy access issues tend to be separated from climate mitigation and adaptation issues.

Recent research has shown that the burning of biofuels such as firewood, crop residues and dung may be more damaging to the climate than using a 'modern' carbon-based fuel like liquefied petroleum gas (LPG). LPG is also healthier in that it causes less indoor air pollution, its use does not tax forests or other ecosystems and it does not have to be laboriously gathered and hauled. Some governments have successfully encouraged shifts from firewood to LPG.

In terms of water management, systems need to be improved at all administration levels. At the regional level the focus should be on defining transboundary

Image: CCCD secretariat

The Malian farmer faces weather patterns never seen before: too little rain one year, too much the next

water management arrangements. Water is best managed in terms of its basin or catchment area, and these rarely correspond with political or administrative boundaries. About 40 per cent of people live within the basins of international rivers, and about 90 per cent of people live in countries that share these basins. Transboundary water management is costly and resource-intensive but can yield tremendous benefits, not only in terms of decreasing risks of floods and shortages, but also in terms of decreasing risks of regional conflicts.

At the international level, the donor community needs to reorient its financial assistance toward supporting countries in water management actions — to increase water's contribution to development in the context of risk and change. Key areas include support for the development of hydrological monitoring systems and public goods that are unlikely to appeal to commercial investors, such as infrastructure for flood control.

In the area of health, development with risk management often means spreading current best practices. Early warning systems for heat waves are in operation in many countries, including some in Asia, and these should be replicated elsewhere and coupled to concrete action plans with activities throughout many different sectors within a society.

Improving water and sanitation infrastructure and increasing awareness of the importance of hygiene is key to reducing a community's vulnerability to extreme weather events and more long-term changes in average water availability or average temperatures. The Millennium Development Goals include the need to improve sanitation and access to safe water — efforts to achieve this must take place at local, national, and international levels. These are clearly positive and crucial measures.

Other such health measures involve getting better at vector control, detection, treatment of vector-borne diseases, and paying attention to the most vulnerable populations. One of the few early warning systems for vector-borne diseases is in southern Africa, where malaria is sensitive to rainfall. The system puts together seasonal rainfall forecasts with data on population vulnerability and coverage of prevention activities. More such systems are needed.

In the forest sector, the new paradigm might be to manage forests as if both people and carbon emissions mattered. The proposal in the climate negotiations known as Reducing Emissions from Deforestation and Forest Degradation (REDD), would encourage emissions reductions in tropical forest nations, while helping to manage the costs of compliance in countries that take on economy-wide caps.

However, there is a danger that if forests are planted and managed only to sequester carbon, they will cease to offer to the poor — and the rest of the planet — the variety of ecosystem services they now provide, many of which are crucial in providing food and shelter.

The Forest Dialogue, a multi-stakeholder initiative including 250 representatives from businesses, trade unions, forestry companies, governments, and local and indigenous peoples, argues that treating forests only as 'sticks of carbon' will fail, as such treatment does not take into account the human dimensions of forest services. However, if based on sustainable forest management principles, a REDD mechanism could lead to mitigation, adaptation and development benefits.

The whole concept of insurance is being reinvented under the pressure of climate variability and climate change. In the public sector the World Bank Group is developing a global facility for hedging development country risk. In


Image: CCCD secretariat

Commissioners and secretariat staff visit Mali to find out how climate change is affecting local people

the private sector the reinsurance company Swiss Re has established a Climate Adaptation Development Programme to build a market for innovative financial risk transfer instruments in low-income areas.

Munich Re initiated the Munich Climate Insurance Initiative in April 2005 to provide a forum and gathering place for insurance-related expertise applied to climate issues. It includes insurers, climate change and adaptation experts, NGOs, and policy researchers intent on finding solutions to the risks posed by climate change.

Most of the novel risk transfer schemes being experimented with are based on indexes that automatically trigger payouts. These indexes can cover things such as rainfall (too much, too little), soil moisture, hail, wind and temperature. Such an approach eliminates the old-fashioned need for expensive damage and loss assessments. It also decreases moral hazards, in that farmers who manage reasonable harvests are still paid. Paying based on an index can also mean very speedy payouts.

These schemes can work at several levels: the macro (in which a national government and perhaps large NGOs are the main players), the meso (involving corporations and small to medium enterprises) and micro (involving farmers associations, banks and insurers).

Sustainable development

The new form of development required is, essentially, sustainable development; meeting the needs of the present in ways that do not increase the vulnerability of future generations.

Development that can be sustained in a world changed by climate must be enabled by building the adaptive capacity of people and defining appropriate technical adaptive measures. Adaptive capacity results from reduced poverty and human development. Adaptive measures require the institutional infrastructure that development brings. Action must be fast, scaled, focused and integrated across sectoral divides:

- Speed — wasting no time; climate change is happening faster than science predicted
- Scale — growing numbers of people are in danger; responses must match the scale of this change
- Focus — managing risks, building the resilience of the poorest and enhancing the ecosystem functions upon which they depend
- Integration — uniting environment, development and climate change, managing synergies between mitigation and adaptation.

One critical input to this new development process will be the production and dissemination of appropriate climate information, tailored to end-user needs and delivered in a timely manner — particularly in developing countries. Institutions at all levels have important responsibilities tied up in this process. Local institutions should ensure that dissemination of climate information reaches the poorest and most vulnerable through appropriate extension services. National governments need to invest more in climate and meteorological information, biophysical monitoring and early warning — integrating such data in their planning. Regional organizations need to become more innovative in helping developing countries produce regional climate information and knowledge.

At the international level, an improved knowledge network is required where the Intergovernmental Panel on Climate Change, together with other institutions including the World Meteorological Organization, disseminate climate knowledge in a rapid and regular manner to developing countries. And all of this is needed immediately.

Ecosystem-based adaptation: managing ecosystems to help people adapt to climate change

Julia Marton-Lefèvre, Director General, International Union for Conservation of Nature

Ecosystem-based adaptation identifies and implements a range of strategies for the management, conservation and restoration of ecosystems to ensure that they continue to provide the services[1] that enable people to adapt to the impacts of climate change.[2] There is growing recognition of the role that well-managed ecosystems can play in supporting adaptation, especially regarding increasing the resilience and decreasing the vulnerability of people and their livelihoods to the impacts of climate change. Well-managed ecosystems have a greater potential to adapt to climate change, resist and recover more easily from extreme weather events, and therefore continue to provide a wide range of benefits on which people depend in the face of climate change. In contrast, poorly managed, fragmented and degraded ecosystems can increase the vulnerability of people to the impacts of climate change. Reducing the buffering that ecosystems can provide may lead to harsher effects from extreme climate-related events.

Ecosystem-based adaptation is appropriately implemented as part of a suite of adaptation responses including early warning, education, training, raising awareness, and structural and engineering measures (where appropriate). Ecosystem-based adaptation shares many of the broader attributes associated with good practice adaptation, such as providing a balanced approach to climate and non-climate risks, helping avoid maladaptation, and supporting short- and longer-term needs. As with other adaptation options, it is also important to monitor and review ecosystem-based measures, and implement adaptive management approaches.

Effective implementation of ecosystem-based adaptation requires the availability and use of climate data, information and predictions at an appropriate scale to the ecosystem being managed — for example at the scale of the watershed for improved water and river basin management. It also requires that such climate data be accessible for use by ecosystem managers and planners, including those with limited understanding of climate systems and processes.

Experiences on the ground

The following provides some examples of how ecosystem-based adaptation can be applied in practice:

Sustainable water management

Many climate change impacts will be felt through water, which is to say, through occurrences such as drought, floods, storms, ice melting and sea-level rise. Water management is therefore a central issue in effective adaptation policies, planning and action. River basins, aquifers, coasts and their associated ecosystems are natural infrastructure for coping with climate change. They provide water storage, flood regulation and coastal defences vital for reducing the vulnerabilities of communities and economies to climate change. Ecosystem-based adaptation that builds and maintains natural infrastructure and other ecosystem services in river basins strengthens water, food and energy security in the face of climate change.

Disaster risk reduction

Well-managed ecosystems act as natural barriers and can reduce the occurrence and impact of, as well as aid recovery from, extreme weather-related events such as flooding, drought, extreme temperatures, fires, landslides, hurricanes and cyclones. Restoration of coastal habitats — such as mangroves and watershed vegetation — to provide natural infrastructure can be a particularly cost-effective measure against storm surges when compared with alternative coastal flood defence options.

Sustainable agricultural production

Ecosystem-based adaptation has many synergies with sustainable approaches to agriculture, including supporting agricultural resilience, landscape-scale management, protection of water resources and the incorporation of local knowledge into agroecological production systems. Many indigenous farming practices are already based on in-depth knowledge of adaptive techniques, using specific crop and livestock varieties to suit changing local ecosystem conditions. This will help them adapt to the impacts of climate change and climate variability.

Conservation and sustainable use of biodiversity

Ecosystem-based adaptation includes practices, such as ensuring ecosystems remain intact and interconnected, to allow for adjustment to changing environmental conditions. These practices can include approaches to maintain and restore fragmented or degraded ecosystems, or direct support for processes such as pollination and nutrient cycling. This yields sustainable benefits for the conservation of biodiversity.

Case study: Pangani river basin, Tanzania

In the Pangani river basin (Tanzania), over-allocation is making water scarcity worse. The 3.4 million people of the basin are further particularly vulnerable to projected drying of the climate. With identification of

In Tanzania, better water governance and practices makes communities less vulnerable to climate change

this vulnerability, and backed by a national water policy based on the principles of Integrated Water Resource Management, efforts are underway to implement 'environmental flows'. This is an ecosystem-based method for allocating water within the limits of availability, based on negotiation among stakeholders of allocations to different uses of water and to sustaining ecosystem services.[3]

Implementation entails developing and coordinating decision-making over water allocation at local to basin scales. Institutional strengthening is thus key, as a means of enabling diverse stakeholders to participate in the discovery of options, in learning and in joint action. Ideally, authorities enlist representatives of competing water users — farmers, hydropower, fishers, residents and ecosystems alike — to help decide how to allocate water. Combining a local sense of who needs what, when and where with scientific data on how much water is available now and might be available under climate change scenarios, the collaborators are piloting a new, and flexible, approach to informed decision-making. They are learning to allocate water within the limits of the river's flow, including to ecosystems in the basin that store water, regulate flows and support livelihoods.

Allocation of water to sustain natural infrastructure, such as wetlands and estuary habitats, and adaptive governance provide capacity to deal with uncertain future events. Better water governance and best practices will reduce pressure on ecosystems and start to make communities and the economy in the Pangani river basin less vulnerable to the impacts of climate change.

The benefits of ecosystem-based adaptation

Ecosystem-based adaptation can provide a cost-effective means to build adaptive capacity. For example, ecosystems can be cost-effective natural buffers to coastal areas. In Indonesia, the coastal protection functions of coral reefs have been estimated at: USD829/km in areas of agricultural production; USD50,000 in areas of high population density (based on cost of replacing housing and roads) and USD1 million in areas of tourism (cost of maintaining sandy beaches).

In addition to the direct benefits for adaptation, ecosystem management also provides significant social, economic and environmental co-benefits. For example, the restoration of mangrove systems provides shoreline protection from storm surges, but also supports fisheries-based livelihoods through increased productivity due to the provision of habitat for fish, and provides mitigation benefits through carbon sequestration.

Ecosystem-based adaptation is the strategy already adopted by many local communities to adapt to the impacts of climate change — often because there are no other options than ecosystem management for natural resource dependent communities. Due to its availability, local practice and cost-effectiveness, this approach to adaptation is often more accessible to the rural poor than actions based on infrastructure and engineering. Ecosystem-based adaptation can also support indigenous peoples by harnessing traditional knowledge on natural resource management as well as incorporating gender-specific needs in relation to natural resources.

Ecosystem-based adaptation builds on existing lessons learned from natural resource management and is delivered through adaptive management, supporting adaptive management options by facilitating and accelerating learning, increasing social and economic resilience to climate change. The approach is consistent with the precautionary approach and can often contribute to climate change mitigation, lowering the risk of 'mal-adaptation'.

An improvement of data and information availability on the impacts of climate change at the appropriate scale, and through appropriate means will help to realize the considerable potential to improve the management of ecosystems to support the most vulnerable communities to better adapt to the impacts of climate change now and in the future.

EDF's perspectives on adaptation to climate change and variability

Laurent Dubus and Sylvie Parey, EDF/R&D

In its last assessment report published in 2007, Intergovernmental Panel on Climate Change (IPCC)[1] confirms the observed evolution of climate since the beginning of the last century. It is attested not only through the temperature increase, but also through the evolution of other linked parameters, such as the melting of ice and snow cover or the elevation of sea level. The significant influence of anthropogenic activities on these evolutions is now also recognised as 'very likely' and will probably continue in the future. Furthermore, changes and impacts at the regional level have been expected since the last 2001 report — with Europe, for example, anticipating an increase in the frequency and intensity of heat waves, combined with an increased drought risk during the summer in south and central Europe, whereas, winter precipitations could increase in northern Europe. EDF will then have to deal with the effect of these modified conditions on electricity production and distribution, together with changes in energy consumption linked to both climatic evolutions and climate change mitigation measures. The consumer behaviour may then evolve in response to the shift in climate conditions, for instance with less heating needs in winter, but potentially more cooling needs in summer. Furthermore, they could be incited to convert thermal heating installations, such as fuel or gas, to electricity, which for EDF could mean higher demand in winter despite the temperature increase.

For these reasons, important research projects are running at EDF/R&D in order to better estimate the climate change impacts on EDF activities, as well as make better use of weather forecasts at different time-scales. However, EDF's needs outstrip the capabilities of current climate models, especially concerning the spatial and temporal scales of the impacts. The adaptation of power plants or networks to new climatic conditions necessitates a precise as possible knowledge of said conditions on the local scale of the facilities. Furthermore, protection of installations or adaptation of crisis plans requires information on the possible evolutions of meteorological extremes, which current climate models still fail to correctly reproduce, especially at the local scale. For this reason studies are being conducted to carefully analyse the evolutions in mean, as well as in variance and extremes of the climate variables, and their possible links, beginning with hot and cold temperatures.[2] For the operation of the system on time-scales from one day to one year, several weather parameters are needed to forecast demand, hydropower and production of other renewable energies, as well as electricity prices. Short to medium-term numerical weather predictions already provide useful information, but improvements are needed to increase quality on the providers' side, as well as to make better use of such forecasts – especially in probabilistic approaches on the users' side. A major need is to develop and improve forecasts from two weeks to one or more years and to replace the current practices based on the use of historical data. This is a big technical challenge, but also very significant in a financial sense.[3]

Means of action in adaptation

EDF envisages climate change adaptation in different ways. Recent meteorological events like the 2003 heat wave or the 1999 wind storms lead to the adoption or revision of respective crisis management plans. These plans are a first step in the adaptation to climate events, which, at least for the heat waves, could be more frequent in the future. The so-called plan aléas climatiques (climatic risks plan) foresees a list of actions to be taken in order to manage and to anticipate future extremes in the best possible conditions. For example, a large number of seaside power plants are now planned to run during the summer, as they are less sensitive to heat wave conditions. Furthermore, river temperature forecasts are currently conducted in the summer in order to anticipate potential cooling problems and then adapt the production plan consequently, or activate any other possibility to balance the supply and demand.

On the other hand, EDF uses the most robust results of international research projects in order to begin the adaptation of the currently running production facilities — especially nuclear power plants. As the most likely climate change impact concerns increase in temperature and heat wave frequency, EDF has started a broad re-evaluation of its running nuclear facilities into how they might be affected by high temperature conditions in the summer. These new evaluations are based on a proposed evolution of the statistical extreme value theory, which allows the identification and extrapolation of recent trends in high temperature extremes in order to derive future very rare high temperature levels.[4] From such an exercise, conducted at EDF/R&D for both air and water temperature, it is possible to verify if safe production would still be possible under these potential, very high temperature levels. If a facility falls short in this area the necessary modifications are made. Concerning the planning of new facilities; their initial proportions now incorporate climate change considerations. Here again, methodologies are worked out and proposed to derive rare levels of high temperatures possible at the

Villagers and solar panels in Towé & Houéddo badgi (Benin)

end of the century, towards which the cooling systems are to be dimensioned. Where the climate change impacts on a given parameter are not yet reliably known, a minimal value — taking present climate change impact knowledge into account — is assumed, and actions are planned correspondingly in order to allow future adaptation measures during the running life of the installation.

Temperature increase is now included in the long-term electricity consumption forecasts. Moreover, research is conducted in order to evaluate and maximize the use of medium to long-term forecasts.

Real and future energy needs using climate information services

The energy sector is probably one of the most important users of weather, water and climate data and forecasts. However, there are still many gaps to fill in order to better manage energy production and distribution systems in developed countries, and to build efficient and sustainable systems in developing countries.[5] One major issue is the development and improvement of forecasting systems at lead times from two weeks to one or several years — the so-called 'seamless prediction systems'.[6] Monthly, seasonal and decadal climate predictions go a good way to answer some of the needs, but there are still many challenges to face. These forecasting systems need to be notably improved in order to be able to deliver reliable information to the users. Even if climate predictability is low over mid-latitudes, current prediction systems show positive scores for some variables, seasons and types of events. These performances may be superior to the current energy sector's practices and closer collaborations between users and providers are the only way to identify possible improvements in the electricity sector applications and decision tools. They may also guide model development in a positive way. In particular, special attention should be paid to both the adaptation of such forecasts to the users' needs — for example using downscaling methods which allow the transformation of large scale models outputs to local users' needs for application models — and on the consistency of the information delivered at different time-scales. The problem here is getting the suitable information adapted to the decision processes, which differ according to the time horizon, rather than to get the best possible information from the climatic point of view. Hydropower production forecasting on an annual time-scale is, for example, a key element of the French electricity management system. Current practices, based on the use of historical data, could be easily improved using climate forecasts and downscaling methods, by simply discriminating between dry/normal/wet periods a few weeks or months in advance. Moreover, long range forecasts are often more accurate in tropical areas, and could therefore be profitably used in developing countries to forecast water resource, in particular, as is already the case in western Africa[7] and South America.[8] This could help such countries to better manage their water resources and their electricity production.

A second major issue is the use of probabilistic information, and its communication to end users. Ensemble (probabilistic) forecasts are particularly well suited to answer risk management needs. But end users do not generally feel comfortable using probabilistic weather and climate forecasts, whereas products and services already exist that may answer current identified needs with little adaptation. With this in mind, National Meteorological and Hydrological Services (NMHSs) have, over the last few years, developed alert systems (for example, in Europe, Meteoalarm and Carte de Vigilance from Météo-France). According to the prevention principle these services generally issue more false alarms than was previously the case, which could be seen as a drawback. But early warnings of severe weather risks allow a quicker reaction and more efficient organization of emergency units, for example. They also enable better communication with national or local authorities, reducing the exposure of people and goods to hazards, and hence the consequences of the event, as taking preventive measures is generally cheaper than treating problems, even if events finally do not occur. Over the next few years special emphasis should therefore be placed on the importance of communication. In particular, emphasis should be placed on fostering communication of uncertainties and discussions between NMHSs and end users. Different kinds of decision can be taken and different levels of reaction can be activated, depending on the forecasted event itself, but also on the uncertainty associated with the forecast. This could notably drive adaptations in the decision processes schemes for different sectors, cross-sectors and authorities.

Adaptation to climate change and mitigation strategies is likely to prompt the development of renewable energy sources, such as electricity production, over the coming decades. This reveals two additional and important needs: the first one concerns the availability of weather and climate data and forecasts that are not currently produced and proposed routinely by NMHSs (for example, wind speed at wind turbines' hub height — around 100 metres). This problem could be easily overcome with an increased dialogue between providers and users. The second need concerns climate projections for the next 30 years, which corresponds to the lifetime of renewable production means, in order to build the best business plans and guide the best investment decisions. Current projects on decadal predic-

Image: EDF Mediatheque/Dhumes Patrice

Water release during the flood of La Loire at the Grangent Dam in November 2008

tions and the next IPCC assessment report are already in progress, showing that the dialogue of previous years between the scientific climate community and the end users has been fruitful. Careful attention should however be put into the dialogue between scientists and users, to ensure that these projects are useful to applications sectors.

The importance of collaboration between users from the energy sector and providers of weather and climate data and forecasts

To match the global projected demand for electricity by 2030, the International Energy Agency estimates that around USD14 trillion in investments will be necessary.[9] Reducing the risk associated with these investments necessitates three actions: improving weather and climate data and forecasts; improving the communication between providers and users; and improving the users' decision making processes.[10] All three fields are of equal importance and any deficit in one is likely to seriously affect the whole chain. If the first and the third points are to be treated mainly by providers and users respectively, the problem of communication has to be addressed in close cooperation between the two groups. Communication is the essential link between the communities, and will condition the development of useful products and services that will be used to improve efficiency, for the benefit of the electricity sector and the whole society. At regional and international levels the World Meteorological Organization, the World Energy Council and other international institutions must play a major role as facilitator, most notably by providing recommendations and guidance. A crucial element is close collaboration at national level between NMHSs and users.

In the last 30 years, EDF has developed national and international collaborations with both scientific institutes and operational centres, among which Météo-France has a central role. This partnership is based both on common research projects with the Centre National de Recherche Météorologique, Météo-France's research centre, and on commercial contracts for the provision of data and forecasts. In addition to existing catalogue products, specific needs are generally addressed in partnership — from the description phase to the final product delivery. The common process is to develop ideas based on operational needs in the frame of research projects, which, if they are successful, are then tested in near-operational conditions. This phase of evaluation is then transformed into a commercial contract when the usefulness of the new product or service has been determined. Of course, new products can then benefit other users and sectors without impinging on confidentiality concerns.

Coordination teams have been formally set in place, and formal meetings with feedback and event review mechanisms take place at least twice a year. Of course, complementary technical meetings are held on demand. This type of organization has proven very efficient both in increasing the quality of communication and mutual understanding.This example could be followed by other companies, as well as in other sectors. In developing countries in particular, upstream communication between providers and users of weather, water and climate information should be emphasized, in order to rationalize the investments in observing and forecasting services — as energy and electricity will be a major component in their development.

Adaptation to climate change: the role of organizations with atmospheric expertise

Professor Petteri Taalas, Director-General, Finnish Meteorological Institute

The potential impact of human emissions on climate, especially the impact of carbon dioxide, has been known for more than a century. Indeed, the Swedish physicist Arrhenius first published his concerns on the subject in 1896.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007 concluded that human induced climate warming is already taking place and it has recorded that over the past century the global average surface temperature has risen by 0.74ºC. This warming is expected to increase until 2060, with development thereafter highly dependent on success in the reduction of the greenhouse gas emissions. According to the International Energy Agency, the growth of greenhouse gas emissions from 2000 to 2007 has exceeded IPCC's maximum estimates by about 20 per cent. If this excessive growth continues, the 2007 IPCC climate change scenarios will be significantly off-target. Because of this, IPCC is now working to establish a new basis for its Fifth Assessment Report on emission and climate scenarios.

Climate change is expected to have severe impacts on the well-being of humans and the world economy. This was demonstrated in the 2006 Stern report, which was carried out by the UK government. Increases in the frequency and extent of drought, flooding, poor air quality episodes, tropical storms, forest fires and heat waves will all effect human lives. Other meteorological changes that will adversely affect human beings include: increased sea-level rise; melting of glaciers and related problems in water discharge; and melting of permafrost and collapse of Arctic infrastructures.

Climate change will lead to negative economic impacts in many parts of the world. It could also create some local positive effects too, but due to the global nature of the economy, no areas will remain unaffected in the long-term.

Proper preparatory planning may soften the negative impacts caused by climate change. For this to happen, national and regional level adaptation reviews need to be carried out. In response to this, IPCC has already gone to the effort of producing global circulation-based models (GCMs) based on emission data. These may be used for understanding and projecting climate change in the coming decades and centuries. Using lower and middle atmospheric physics and chemistry, oceans, cycles of carbon and nitrate compounds, aerosols and other biosphere-atmosphere interaction metrics, the GCMs can calculate climate parameter probabilities. Limitations in computer power, however, have meant that the resolution of these projections is coarse — calculations cannot be made accurately at resolutions greater than 100 kilometres. Unfortunately, this is unsatisfactory for national or regional adaptation studies. Hydrological and coastal changes or changes in mountainous areas, for example, cannot be calculated accurately based simply on GCM outputs.

There is a need, therefore, to be able to run fine scale (5-20 kilometre resolution) regional models using GCM calculations. This process is called downscaling. Regional models are typically based on weather forecasting model physics, but in this instance they may also be used for calculating fine mesh climate parameters such as temperature, precipitation, humidity, wind, radiation, waves, snow/ice cover, frost, evaporation and forest fire risk. Using these models, countries can define what parameters they want to measure to get information that is relevant to them. The result is a 10- to 100-year forecast, which then forms the basis for estimating the impacts of climate change on various sectors in an individual country.

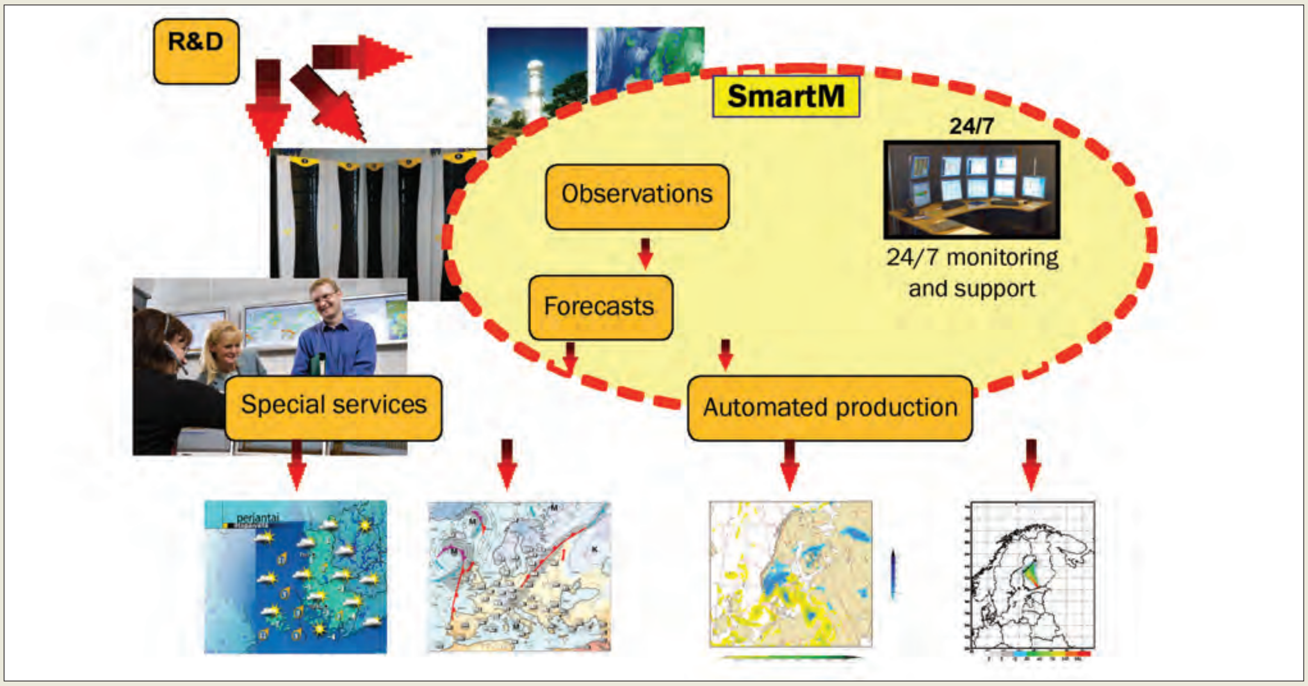
Sectors affected by climate change vary from country to country, although the following are the most common:

- Agriculture
- Forestry
- Infrastructures
- Transport
- Energy
- Nature
- Tourism
- Health and human well-being
- Water resources.

Depending on the country, the importance of weather on the economy varies by up to 50 per cent. Once socio-economic studies are conducted across all sectors, we can estimate the full impact of climate change; not just negative, but positive — in some cases climate change may offer new opportunities such as the opening up of Arctic shipping or easier access to natural resources. It is essential these studies be carried out so that national adaptation strategies can be formed.

There is a particular need for the preparation of national adaptation strategies in developing countries and countries in economic transition. This will require a degree of collaboration between developed and developing country specialists. This kind of collaboration could be funded through national and international development programmes with such organizations as the World Bank, regional development banks and the European Commission. We could also look to private sector and specific foundation funding to provide opportunities in realising climate change adaptation studies. In addition, there is the Climate Adaptation Fund, which is being prepared as a part of the COP15 meeting in Copenhagen, scheduled to take place in

FMI production system/value chain



An example of an operational meteorological service flow chart

Source: FMI presentation material, 2009

December 2009. Financing adaptation to climate change is crucial to minimizing costs in the long-term.

Natural disaster early warning systems

The sensitivity of human and economic activities to weather phenomena has increased considerably in the past few decades. This is due to the growth of the world population, human migration, the expansion of economic activities into more weather sensitive areas (especially coastal zones), the more technical nature of economic activities and, in some instances, climate change.

The vast majority of the disasters are caused, or closely related to, weather phenomena such as: storms; drought; flooding; heat waves; cold spells; ice and snow storms; land slides.

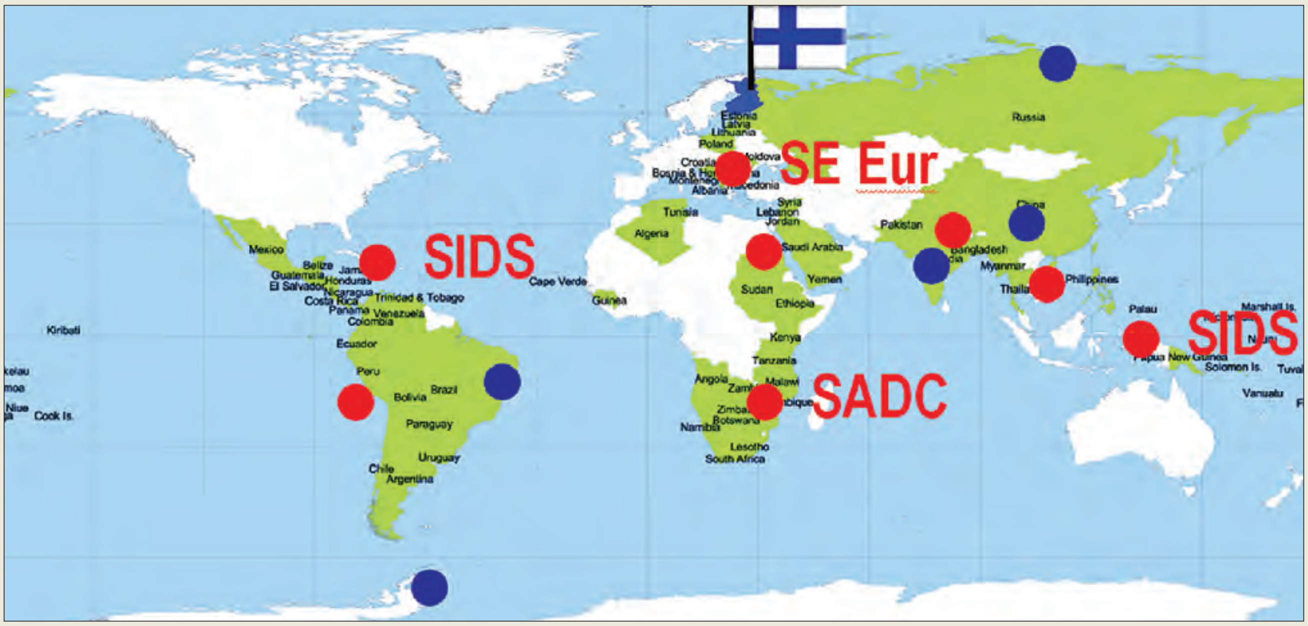
The World Bank and the World Meteorological Organization (WMO) have estimated that modern and well functioning weather services may lead to considerable savings. Typically, the funding allocated to weather services should lead to savings where the return on investment is manifold. In Finland, for example, the annual budget of the Finnish Meteorological Institute in 2007 was about EUR50 million, of which about EUR30 million was related to weather services. The Technical Research Centre of Finland conducted a survey that year to estimate the economic benefit of the FMI weather services on various sectors. According to this study, an economic benefit of at least EUR239-300 million annually may be gained in various sectors. These figures do not include the benefits of radiation safety services, climate services or air quality services.

A well functioning weather service needs relevant research and development investment and usually consists of weather observation networks (ground-based in situ and remote sensing, soundings, radars, aircraft and ship observations, and satellites), adequate telecommunication systems, databases for observation and product storage, computer resources, numerical weather prediction models and their runs, other operational models (sea, hydrology, air quality, dispersion of hazardous materials, drifting models), manual to semi-automatic analysis of the observations and model output, final production of the tailor-made products to various customer groups and finally distribution of the products. Distribution of weather service products to the customer may take place via the Internet, extranets, mobile telecommunications, media, phone, fax or satellites.

It is a fair estimate that the full economic benefit of a hydro-meteorological service organization increases with the growing number of customer sectors and needs served through the products. Typically, the spectrum of available products is greater in developed countries than in those that are less developed. Also, the fewer products a national hydro-meteorological service (NHMS) is able to produce, the less interest there is in allocating financial resources to the NHMS in a country. Because of this, many developing countries are facing problems. Due to lack of adequate financial resources the observing and telecommunication systems, service capabilities, quality and quantity of operational staff, and general operational ability of an NHMS may be considerably restricted. Proper financial resources are essential to a NHMS's ability to serve all sectors where weather has a substantial impact. This has also a major impact on the quality of the services provided.

In some countries, NHMSs are properly resourced and are able to satisfy the needs of a wide range of service sectors. Because of these high levels of satisfac-

Consultancy and development cooperation projects since the 1980s



Scientific collaboration (blue); consultancy/development cooperation (red)

Source: FMI presentation material, 2009

tion, governments and various customers are convinced of their value. This is only helping to ensure adequate financial resources are allocated to NHMSs in the future. The situation in many WMO member countries, on the other hand, is quite the opposite. With NHMSs and weather products in such countries being of a generally low quality and quantity, governments are not seeing the value of allocating additional resources to them. This is having a negative impact on the economy and human safety in affected countries and serves as an obstacle for development, contradicting many initiatives that have been set up to reverse this. The functions of NHMSs, for example, are closely related to five out of eight Millennium Development Goals (MDGs). These goals tackle poverty and hunger, health, education, environment and development partnerships.

A summary of the socioeconomic value of the FMI for different user segments. In 2007 the FMI budget was about EUR50 million

Road transport	13–18
Pedestrians	80–100
Railway transport	0.4
Maritime	32–50
Aviation	54–55
Logistics	Tens of millions
Building construction and facilities management	15–30
Agriculture	34
Expected total benefit with current services	> 239–303

Source: VTT Technical Research Centre Publications 665, 2007

International collaboration and development projects in essential role in strengthening the national capabilities

Both natural disaster early warning systems and climate change adaptation plans offer good perspectives for development cooperation. The expertise of developed country NHMSs and atmospheric research organizations may be used in assisting developing countries and those in economic transition. According to WMO, several countries – including Japan, Korea, China, Australia, Finland, the UK, Spain, France, Germany and the US — are actively assisting developing countries.

Finland and the Finnish Meteorological Institute (FMI), for example, have supported more than 80 countries since the 1980s. At the moment, projects related to adaptation to climate change and natural disaster early warning systems are being run in small island developing states, both in the Caribbean and in the Pacific, the Southern African Development Community countries, Peru, Nepal and Vietnam. The core of current programmes involve institutional cooperation between both FMI and NHMSs in other countries. FMI is also working alongside China, India, Russia, Argentina and Brazil besides several European and North American countries in scientific projects.

Investments in natural disaster early warning systems and preparation of climate change adaptation strategies are good investments. Besides bi-lateral activities these fields offer good opportunities for new programmes, especially under major development donor organization frameworks such as those of the World Bank, regional development banks or the European Commission.

Humanity needs climate sense to survive

Ray Shirkhodai, Dr Heather Bell, and Joseph Bean, Pacific Disaster Center, USA

Climate change and variability is anticipated to have enormous impacts on disaster risks and sustainable development within a generation or two. Luckily though, lessons of the past regarding disaster risk reduction practices are all still relevant in making us better equipped facing the unprecedented challenges of climate that lie before us.

Human beings have always relied on their common sense to survive and thrive. This common sense stems from constant curiosity about the forces of nature, and the consequent development of mental skills sufficient to understand those forces and to devise creative solutions that minimize risks and reduce dangers. Over eons, the practical use of risk and safety information has been streamlined and handed down through generations, leading to coping strategies and some adaptive capacities. But now, humankind may need to develop another new sense to survive the challenges of the new climate into the next millennium.

Everyone is familiar with seasonal variations in temperature and precipitation. People have learned to take advantage of these changes for agriculture, food production and other purposes. Now though, what has become common sense regarding climate variability is no longer adequate.

Recent predictions about climate change and variability anticipate enormous impacts on Earth's atmosphere and oceans. As a result, tremendous shocks and shifts are foreseen in fresh water resources, wildlife, food security, agriculture, health and energy. Among the expected effects is mass migration.

Image: Pacific Disaster Center

PDC Executive Director Ray Shirkhodai greets Dr Nguyen Huu Ninh

These unprecedented impacts on the basic elements of human security and sustainability will gravely endanger the quality of life and even human survival — within the century, by most scientific estimates. While the timing and nature of the shifting risks brought about by the changing climate are open to scientific debate, it is widely agreed that the magnitude of the shocks will be beyond the adaptive capacities of existing human systems. That is, we will be unable to address future risks and ensuing disasters unless attention is given to policy implications and disaster risk reduction efforts, right away.

Short-term tactical solutions and long-term strategies need to be developed, practiced, and streamlined into a mainstream 'climate sense', if we hope to reduce immediate risks, avert long-term consequences, and develop adaptive capacities to help our kind survive. Fortunately, we don't have to start from zero, because what we have learned in the area of disaster risk reduction can help us develop climate sense.

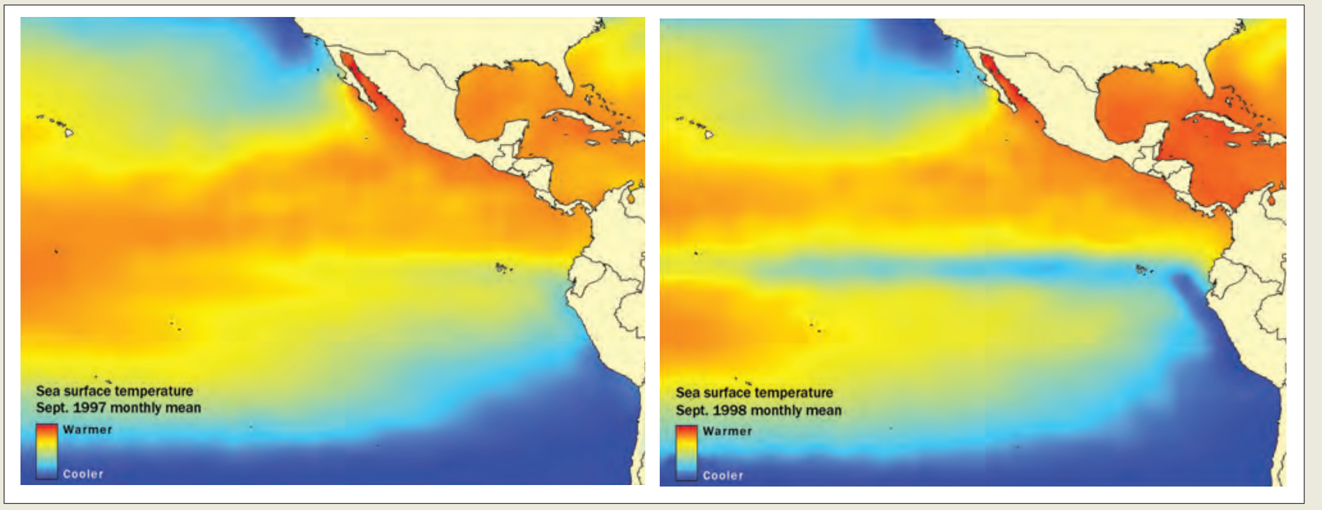
El Niño as a model for shifts in risk

Disaster risk is a function of the physical characteristics of hazards, the susceptibility of exposed elements and systems to negative impacts from hazard events, and the ability of communities and surrounding systems to handle impacts. Disasters happen when human-environment systems are overwhelmed by events, whether chronic, slow-onset, or quick-onset. However, risk is dynamic, changing through time and space. Future risk depends on the relationship between hazard, vulnerability and capacity, but it also reflects any changes in these components.

Climate change and variability alters the hazard-vulnerability-capacity relationship by shifting patterns of both climatological hazards and the conditions in which human-environment systems operate and events occur.

The El Niño Southern Oscillation (ENSO) is a familiar example of climate variability shifting short-term risk. In 1997, the world experienced a particularly strong ENSO that sent sunfish and tuna up to the US Pacific Northwest coast and Alaska, and caused many stocks of fish normally caught in those waters to disappear. Hazard characteristics and environmental conditions were changed substantially. Consequently, those who

Sea surface temperature comparisons 1997/98



Sea surface temperatures during the 1997 El Niño (left) contrast with those recorded during the La Niña cycle that began in 1998 (right)

Source: PDC using NOAA Climate Diagnostics Center data

did not have existing strategies to deal with the changed conditions or who were unable to adapt to them suffered significantly more from losses and disruption — including, for example, Northwest Pacific fishermen.

Others with an understanding of relevant climate information were able to act on it in ways that reduced susceptibility to impact or facilitated effective coping. For instance, according to an article written by Curt Suplee for National Geographic, Peruvian villagers were not surprised by the tremendously increased rainfall. Fairly regularly, he wrote: "the same rainfall had arrived after a pool of hot seawater the size of Canada appeared off the west coast of the Americas." Although 1997 was overwhelming even for the experienced villagers in Chato Chico, forcing evacuations, they were still among the lucky ones compared to other newer villages that were devastated by floods and malaria-carrying mosquitoes, eventually resulting in: "some 30,000 cases in the Piura region alone, three times the average for its 1.5 million residents."

Image: Pacific Disaster Center

East West Center Senior Fellow Allen Clark addresses participants in the Expert Working Group Meeting on Climate Change and Variability

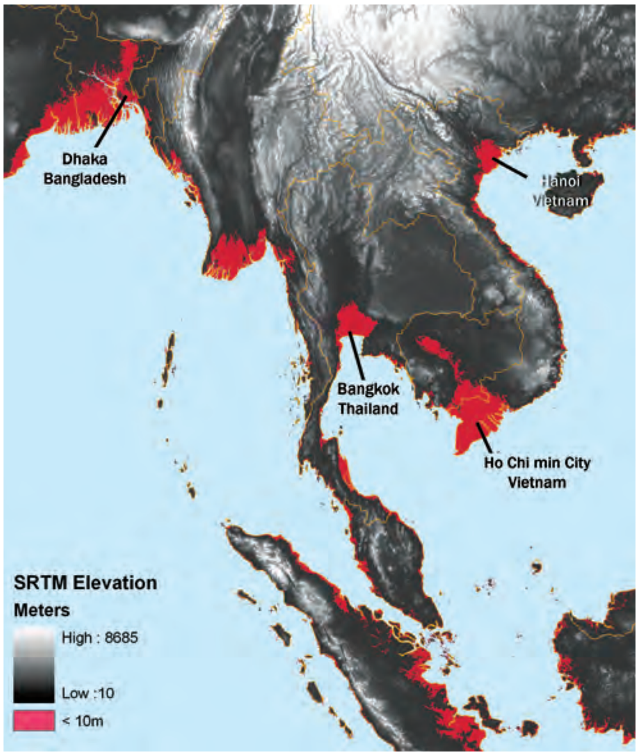
Climate variability expectations

Longer-term climatological changes are expected to contribute to major shifts in environmental conditions and hazard patterns, affecting all components of risk. The UN Intergovernmental Panel on Climate Change (IPCC), which was awarded a 2007 Nobel Prize, predicted in its Fourth Assessment Report that world temperatures could rise as much as 6.4°C (11.5°F) during the 21st century, and that sea levels might rise 18-59 centimetres (7.08-23.22 inches). IPCC also reported a 90 per cent or greater likelihood that heat waves and heavy rainfall will increase, and a slightly lower confidence level associated with increases in drought, extreme high tides and tropical cyclones.

Many of the places expected to experience the greatest increases in hazards and the most significant changes in environmental conditions have low or medium human development, have growing populations, and are experiencing rapid urbanization in highly exposed areas. In addition to affecting hazard patterns, changing temperatures and hydrological conditions will likely impact patterns of water availability and food production. As such shifts take place, they will contribute to mass migration, and to health and security issues.

Globalization (negatively contrasted with regionalization by IPCC), along with its associated technologies, tends to shift the impacts of disaster to widely dispersed people, changing susceptibility. The same processes, however, can facilitate effective response and adaptation, and increase capacity.

Rising sea levels in East Asia



Much of Bangladesh, as well as Hanoi and Ho Chi Minh City in Vietnam, and Bangkok, Thailand, are at risk as sea levels rise

Source: PDC using data from 2007 LandScan and NASA SRTM

As timeframes become longer, there is increased uncertainty about how human and environmental systems will interact and change, and how the relationships between various components of risk will shift. Nonetheless, as we improve our understanding of these relationships and the physical and social sciences of climate change and variability, we can act to build flexibility and strength. We can also familiarize people with the sources and uses of climate data, and we can mainstream disaster risk reduction — climate-related and otherwise — into policy and everyday practice. We can build on existing initiatives and strengths to integrate near-term and long-term approaches into a single framework.

A new risk reduction approach

Traditional disaster risk reduction (DRR) efforts are intended to modify near-term risk in one of three ways: altering the environmental and social conditions in which hazard events occur, altering event properties in a particular place (thereby, often shifting risk elsewhere), and/or building the capacity to respond to and recover from impacts. Efforts related to climate change mitigation and adaptation do the same. The aim is to change social and environmental conditions in such a way that future hazard events do not overwhelm human systems.

Since hazard characteristics and conditions are more uncertain, we must encourage flexibility by maximizing our ability to access, synthesize, and enact creative solutions. We must do what we can to minimize potential exposure, as well.

Approaches focused on building long-term adaptive capacity will contribute to near-term reductions in vulnerability and increases in coping capacity; while near-term actions will set the stage for longer-term conditions and options. Both timescales need to be considered when integrating DRR activities with policy and planning.

Both traditional near-term DRR activities and efforts focused on adaptation to climate change and variability encounter impediments to implementation. The challenges fall into three major categories: technical data issues of resolution, collection, management, and sharing; issues of collaboration and coordination; and difficulties in meaningfully integrating science and practice.

Needed spatial data can be difficult to obtain, and its analysis and use may require specialized resources. In fact, specific skills and technologies are required even for sharing many data types.

Disaster and risk are multi-faceted, multi-sectoral, and multi-disciplinary, however, the emergent nature of disasters, competing resources and goals, historical mistrust, and institutional practices can discourage collaboration and coordination. Finally, scientists, practitioners and the public often operate in different worlds, and speak different languages. So, creating bridges and operationally meaningful ways of framing, analysing, and communicating hazard and risk information is critical to effective decision making, and to facilitating DRR activities and DRR 'mainstreaming.'

Addressing these challenges in the more common context of DRR and near-term risk builds and exercises some of the basic structures necessary to address them within the context of climate change and variability and longer-term risk, fostering resilience in individuals, institutions and communities.

Meeting DRR challenges

Within the context of building resilience and facilitating DRR, the Pacific Disaster Center (PDC) has helped address these challenges by: assisting communities of interest and fostering collaboration among stakeholders; by building relationships with local authorities, national governments, regional organizations, international organizations, military groups, and academia; and by participating in data collection activities directly related to local emergency management. PDC develops and implements decision support systems for emergency management and DRR activities that integrate dynamic and static data and do not require users to have sophisticated technology. While facilitating early warning for sudden hazards, PDC products and services also reduce the difficulties of data collection, management, and sharing, thus supporting long-term security. PDC capabilities and experience include performing risk and vulnerability assessments at multiple scales using numerical modelling, loss estimation, and complex indicator approaches; and performing technical assessments to assist in developing effective data and information management, analysis, and sharing.

Meeting climate variability challenges

The challenges to integrating DRR, especially longer-term DRR, with public policy and planning are immense. In the near-term, interannual fluctuations (like ENSO) complicate matters. In the longer-term, uncertainties compound, making characterization of intertwined multi-sectoral human-environment systems more difficult. Consequently, the assessment and communication of risk are more difficult, too. However, we can and must draw on the results of work done in the context of DRR to integrate climate and weather information into decision making, to build human relationships and strengthen information networks, to conceptualize risk holistically and contextually, and to link research, technology and practice in service of human sustainability. Taking these steps helps decision makers, communities, and individuals produce and access relevant data and analyses, and will help them see hazards, weather and climate as part of the everyday context rather than the extraordinary. The same steps will help increase available options and choices for mitigation and adaptation at multiple scales.

The DRR challenges presented by climate change and variability cannot be met by individuals or even organizations working alone. Understanding this, PDC has taken action to find ways to facilitate teamwork at the highest level.

In 2008, PDC organized an Expert Working Group Meeting on Climate Change and Variability: Shifting Risks, hosted by the East-West Center. Three Nobel laureates and many highly respected urban planners, disaster managers and researchers from various disciplines convened to discuss gaps in knowledge and practice, and identify areas of potential progress and partnership. A year later, PDC is collaborating with Nobel Laureate Dr Nguyen Huu Ninh to establish an International Program on Climate Change and Variability Risk Reduction (IP-CVR).

The IP-CVR includes an international advisory panel to guide its direction and establish a framework of activities; an expert network representing private and public organizations that will exchange information, develop networks, and engage in cooperative projects and applied research; and a 'Collaboratorium' — a forum and knowledge base on climate variability. The Collaboratorium, which has already been prototyped, provides a web-enabled space for sharing data and information sources, research, project and programme ideas, and practical applications. The goal is to synchronize efforts and create synergies between widely different approaches to the applied science of climate variability and DRR – resulting in more effective practices and policies.

One IP-CVR pilot project is a risk and vulnerability assessment of Ho Chi Minh City, in which PDC and Dr Nguyen Huu Ninh will engage programme partners. It will integrate analyses of sea-level rise and coastal flooding, ENSO-related variability in precipitation and riverine flooding, as well as the area's vulnerability and capacity, including social, economic, and environmental measures. The project results will provide vital information for urban planning and development processes.

Other current and near-future PDC projects will also increase both IP-CVR engagement and the programme's knowledge-based strength.

Making connections

Climate change and variability cannot reasonably be ignored in any discussion of how individuals, communities or organizations can reduce future losses. However, that does not mean it is necessary to completely reconfigure established thinking or abandon familiar activities. We can build on structures and activities developed under existing DRR initiatives.

Risk reduction and research activities associated with climate change and variability should not be considered as somehow separate from DRR, but as a key component of both near-term and longer-term approaches to disaster risk reduction and human security. Near-term activities affect longer-term options.

Increased connectivity — through globalization and the communication technologies that underpin it — works to shift and magnify the risks and impacts of hazards. However, those underlying connections present opportunities as well. The central operational mechanism of the IP-CVR is connectivity. It builds on PDC's experience in developing relationships and technology to facilitate access to hazard and risk related information. The Collaboratorium raises connectivity to a new level by taking advantage of social networking technology to facilitate both relationship building and information sharing.

By building open human networks, focused on the applied science of climate change and variability, the IP-CVR:

- Encourages a comprehensive conceptualization of risk
- Advances applied science and practice in climate and risk reduction
- Eases mutual access among people working on any given issue from multiple disciplines
- Facilitates thinking and acting outside the box
- Helps identify common goals
- Streamlines activities, and reduces duplication and funding competition
- Enables access to local knowledge and observations
- Has potential to improve data collection
- Increases the reach of individuals and organizations and the distribution of information
- Builds human and technology networks that can be activated during an extreme event.

The IP-CVR components all aim to facilitate network building and information sharing as ways to foster adaptation, increasing flexibility and responsiveness while developing a common knowledgebase. IP-CVR will support development, for all its participants and constituents, of the capacity to deal with change, improve the range of options to leverage and promote actions to influence policy. In the context of trusted experience and in conjunction with the entire International Program on Climate Change and Variability Risk Reduction, the common knowledge base is central to the development of a new kind of common sense: real climate sense.

Railway infrastructure and adaptation to climate change

Margrethe Sagevik, International Union of Railways

In recent years, climate change has received increasing attention, appearing on both national and global political agendas. There is a growing pressure on society as a whole, and especially on governments and companies, to learn more about the causes and the effects of global warming — as well as how to cope with such impacts.

Railways have always been subject to the effects of the weather, and as such are constructed to 'survive' infrequent natural hazards. However, today's extreme weather will be tomorrow's normal weather, and because the consequences of climate change are advancing rapidly, there is an urgent need to develop and implement appropriate adaptation strategies for transport systems, including rail. The challenge for railways is not only to survive extreme weather conditions, but also to recover quickly from them and to be able to run under circumstances we currently deem abnormal.

The factors predicted to have a significant impact on railways, according to parameters costs and probability, are:

- Flooding
- Storms/gales (inland)
- Intense short time period rainfall
- Extended rain periods (widespread)
- High maximum temperatures
- Lightning strikes and thunderstorms
- Changing vegetation.

Image: Network Rail

Increasing summer temperatures take their toll on existing rail infrastructure

Climate change adaptation strategies — feasibility study

The feasibility study, Impact of Climate Change on Railway Infrastructure and Adaptation Strategies and Measures, was commissioned by the International Union of Railways (UIC) and carried out in 2008 by the Institute of Futures Studies and Technology, in Berlin.

The main objective of this study was to identify if the consequences of climate changes are likely to become an issue for railways, and if so, explore how to deal with them. Following this the study was to identify a structure for how to approach the challenge of adaptation, as well as to define the first steps in that process.

The findings of the study proved that impacts caused by global warming are an increasingly important issue for UIC members. Some members have been more exposed to these impacts than others. The feasibility study provided an overview of the ongoing and planned activities railways are adopting to help them adapt to extreme weather situations and climate change. It classified the main effects of climate change on railway infrastructure — identifying and ranking the main impacts according to their damage potential. The study also provides an overview of the areas of highest priority within this field, as well as a systematic inventory of adaptation measures, strategies and policies in each of the high priority areas.

Ultimately, the feasibility study provided the basis for the UIC research and development project Adaptation of Railway Infrastructure to Climate Change (ARISCC). The project addresses the consequences of climate change on railway infrastructure, as well as adaptation strategies, in detail.

Activities of European railways

The feasibility study indicated that among European railways there is a wide range of ongoing and planned activities concerning adaptation to extreme weather situations and climate change, ranging from monitoring and mapping efforts to impact assessments. The activities can be divided into six priority areas:

- Monitoring weather and infrastructure conditions
- Hazard and vulnerability mapping (locations and assets)
- Improved standards for new and existing infrastructure

Unprecedented summer rainfall in 2007 caused havoc with British railways

- Engineering (maintenance, upgrading and new infrastructure)
- Company adaptation strategies and action programmes
- Networking and knowledge exchange.

Monitoring weather and infrastructure conditions

Monitoring weather and infrastructure conditions can be done using a wide range of approaches from manual on-site monitoring and forecasting approaches to highly sophisticated real-time measurements utilising remote sensors and complex data processing. It is important to consider what processes need to be followed to make the products of such analysis genuinely useful to people. It is also worth evaluating how the new equipment can be integrated with any existing system.

Hazard and vulnerability mapping (locations and assets)

The objective of mapping is to identify the areas, locations and infrastructure with the highest levels of vulnerability. This is usually done by combining weather and climate data and scenarios with the relevant infrastructure data. More advanced approaches tend to be based on geographical information systems.

Vulnerability assessment should always include a careful and detailed location check. When analysing, for example, impacts of the UK summer floods it becomes obvious that 350 hospitals are located on flood plains. Above a certain flood level rivers will always flow into the floodplain, therefore, the vulnerability of these assets can be considered as exceptionally high. Relocation of critical assets like hospitals is, of course, not always feasible or cost efficient, but in some very critical cases it can be the best way to avoid frequent and large-scale damage. As such, it should be systematically checked as a possible option.

Improved standards for new and existing infrastructure

Engineering standards govern all building and maintenance activity and, as such, define the weather and climate load resistance of new and upgraded infrastructure. New standards for new infrastructure are needed, but this will evolve naturally since climate change aspects will be taken more and more into account in new engineering projects. The greater challenge is how to improve/adapt standards for existing infrastructure. Old infrastructure assets were often constructed without any kind of explicit standards. In addition, information about standards and performance levels was often patchy, or even totally absent. Affordability is the main challenge when trying to improve standards for existing infrastructure.

In most countries, modifying standards (whether or not in response to climate change impacts) requires a lengthy consensus-oriented consultation process and the involvement of many stakeholders. Sweden follows a pragmatic approach based on the European Committee for Standardisation's Eurocodes — where standards evolve in close correlation with expected future weather loads, provided by Sweden's Meteorological and Hydrological Institute. The transferability of this approach to other countries should be investigated with high priority.

It is not always necessary to change standards before taking action. Sometimes it makes sense to set policy targets first. For example, in Great Britain a targeted increase in drainage capacity of 20 per cent was set due to predictions of more intense rainfall. Following this action, targeted communication to policy- and decision-makers can then catalyse a change in standards. Thus, urgent engineering work can be started with the modification and adaptation of standards to follow.

Engineering (maintenance, upgrading and new infrastructure)

Planned engineering work will improve the robustness of railway infrastructure against climate change. Work will focus mainly on: new and upgraded drainage systems; stabilization and protection of tracks and substructure; upgrading and protection of catenary and signaling systems; and enhancement of special structures such as tunnels, bridges and dykes. Although most upgrade activities focus on improving factors such as line capacity and speed level, it should be possible to improve resistance against climate loads simultaneously — as long as the time to implementation is a long one and the climate aspects are integrated at an early stage of the planning process.

The greatest challenge — and at the same time the greatest opportunity — of adapting railway infrastructures to climate change in the short and mid-term, is in the area of maintenance activities. The most urgent action to be taken is the general improvement and reinforcement of existing maintenance standards. The corresponding engineering standards do not require adaptation at this time, as this would require a lengthy and complicated process. Over the last three decades the maintenance level in many companies, especially in the areas of vegetation and water management, has dropped significantly due to altered economic priorities. This has led to a higher vulnerability with respect to extreme weather events. The re-establishment of

Image: Network Rail

Rising sea levels increase the threat of flooding to coastal railway lines

former high maintenance levels would enhance the climate performance of today's infrastructures considerably.

Company adaptation strategies and action programmes

The railway sector has taken its first steps towards developing company strategies for adaptation to the consequences of climate change, as well as corresponding action programmes. In general, the awareness of climate change issues is rising in railway companies — often the result of one or more recent extreme weather events causing great damage to the railway infrastructure.

Transport companies such as BV, DB, NR, ÖBB, SBB — which have experience in specialized areas including water management, flood control and weather monitoring — are starting to broaden their perspectives and cover a wider spectrum of adaptation strategy areas. Furthermore, in some cases companies are developing integrated adaptation strategies with explicit links to national and international adaptation strategies and programmes.

Networking and knowledge exchange

The UIC feasibility study clearly shows that there is a great and urgent need for networking and knowledge exchange on different levels to improve the adaptation of railway infrastructures to climate change.

Knowledge exchange between different railway infrastructure managers is the most obvious level. This will enable the sharing of a great spectrum of practical knowledge and experience in areas such as monitoring, vulnerability mapping, vegetation, water management, and the protection of catenary and signalling systems. Communication between railway infrastructure managers and national meteorological offices and research institutions is also important. This would improve the basis for weather monitoring and warning activities and provide access to regional climate modelling initiatives.

Improved networking between railway infrastructure managers and managers of other basic infrastructures such as road, electricity supply, water and waste water also requires increased investment. This would help to develop an integrated approach for critical infrastructures — especially consistent contingency strategies. Better links must also be formed with other stakeholders — such as national and regional governments, and EC policy makers — to broaden the perspective and reach a common understanding of adaptation strategies, measures and priorities.

General findings

The results of the UIC survey underline the need for intensive cooperation. All infrastructure managers regard the establishment of a web-based platform with information and data about the impact of climate change on railway infrastructure as either very useful (6 out of 14 companies) or useful (8 companies). The vast majority said that they would contribute to such a knowledge base with experiences and projects of their own.

Since railways still have a strong national perspective, there is an urgent need for cooperation and new alliances between the European and international railway sectors. Such cooperation should also transcend sector boundaries to include other modes of transport and critical infrastructures, as well as meteorological institutions, academia and policy-makers.

Case studies are planned for two areas that have already experienced impacts of extreme weather events, namely, the Rhine Valley and the UK's west coast. This will include monitoring activities connected to: sudden temperature changes; slippery tracks; lightning strikes; risk management processes for floods; development of modified design criteria for new structures; and reinstatement and renewal of defunct drainage systems.

Results obtained from the case studies should have a high level of transferability to other European regions and transport sectors. The case studies cover a broad range of different geographic and geomorphologic regions, from coastal to mountainous areas.

Next steps

ARISCC primarily addresses European railways, with an especial focus on Eastern and Central Europe, but the intention is to expand it to an international perspective. The working structure for ARISCC comprises the following phases:

- General agreement of railways on very general adaptation strategies and action programmes
- Vulnerability mapping — identify the most endangered assets and locations
- Standards (new and existing infrastructure) — how to adapt these in a way that integrates climate change factors
- Learn from each other — exchange good practices
- Establishing a catalogue of adaptation measures
- Formalize and fine-tune the adaptation strategy and action programme.

This work will be conducted in 2009-2010 as a joint cooperation between the UIC Environment, Energy and Sustainability Platform and the UIC Infrastructure Department.

Notes & References

I
The Impacts and Implications of Climate Change and Variability

Economic and social implications of climate change and variability: new challenges for climate services

1. Karl, T.R., J. M. Melillo, and T. C. Peterson (Eds.), (2009), Global Climate Change Impacts in the United States, Cambridge University Press, also available at www.globalchange.gov/usimpacts

Climate impacts on the society and economy of Croatia

- UNDP, 2008: Climate for change — Climate change and its impacts on society and economy in Croatia. National Human Development Report, Zagreb. 282 pp.

Climate change and food security

1. FAO, (2002), 'The State of Food Insecurity in the World 2001', Rome.
2. Gregory et al., (2005).
3. Wheeler T.R., Ellis R.H., Hadley P., Morison J.I.L., Batts G.R. and Daymond A.J. (1996), 'Assessing the effects of climate change on field crop production', Aspects of Applied Biology 45, 49-54.
4. Intergovernmental Panel on Climate Change. 'Climate Change 2007: Mitigation'. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, (2007c), 862 pp.
5. Wheeler T.R., Craufurd P.Q., Ellis R.H., Porter J. R. and Vara Prasad P.V. (2000), 'Temperature variability and the yield of annual crops', Agriculture, Ecosystems and Environment, 82, p159-167.
6. Meehl GA, Tebaldi C., 'More intense, more frequent, and longer lasting heat waves in the 21st century', Science (2004); 305: p994–997. Schar C, Vidale PL, Lathi D, Frei C, Haberli C, Liniger MA, Appenzeller C, 'The role of increasing temperature variability in European summer heat waves', Nature (2004); 427: p332-336. Beniston M, Stephenson DB, Christensen OB, Ferro CAT, Frei C, Goyette S, Halsnaes K, Holt T, Jylha K, Koffi B, Palutikof J, Scholl R, Semmler T, Woth K, 'Future extreme events in European climate: an exploration of regional climate model projections', Climatic Change (2007); 81: p71-95.
7. Jones PD, Lister DH, Jaggard KW, Pidgeon JD, 'Future climate impact on the productivity of sugar beet (Beta vulgaris L.) in Europe'. Climatic Change (2003); 58: p93-108.
8. Trnka M, Dubrovski M, Zalud Z., 'Climate change impacts and adaptation strategies in spring barley production in the Czech Republic', Clim Change (2004); 64: p227-255.
9. Gomez, (2005).
10. IPCC WG1, (2007), op. cit..
11. Falloon P.D., Betts R.A.., (2009), 'Climate impacts on European agriculture and water management in the context of adaptation and mitigation — the importance of an integrated approach'. Science of the Total Environment (accepted).
12. Bradley et al., (2005).
13. Earl 1997; Cooper et al. 1997; Finlayson et al. 2002; Webb et al. 2005; Montanarella, 2007.
14. Eitzinger et al., (2007).
15. Döll and Siebert (2002), 'Global modelling of irrigation water requirements'. Water Resources Res 38: 1037.
16. IPCC, (2007), op. cit..
17. Oerke E-C (2006), 'Centenary review: Crop losses to pests', Journal of Agricultural Science 144, p31-43.
18. Boxall ABA, Hardy A, Beulke S, Boucard T, Burgin L, Falloon PD, Haygarth PM, Hutchinson T, Kovats RS, Leonardi G, Levy LS, Nichols G, Parsons SA, Potts L, Stone D, Topp E, Turley DB, Walsh K, Wellington EMH, Williams RJ., 'Impacts of Climate Change on the Health Risks of Pathogens and Chemicals from Agriculture'. Environmental Health Perspectives (2009); doi:10.1289/ehp.0800084.
19. Long et al., (2006).
    Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort Dr, 'Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations', Science, 312, p1918-1921.
20. IPCC SRES.
21. Morgan PB, Bernacchi CJ, Ort DR, Long SP, (2004), 'An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean', Plant physiologist 135 (4): p2348-2357
22. Mercado et al., (2009).
23. Easterling WE et al., (2007), Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.
24. Smith et al,. (2007).
25. Graham et al.
26. Gregory et al., (2005).
27. Porter & Semenov, (2005).
28. Brondizio et al., (2007).

Further references

FAO (2003) Trade reforms and food security: conceptualizing the Linkages. Food and agriculture organization of the United Nations, Rome.

Contact details:

richard.betts@metoffice.gov.uk

Corals and climate change

1. Hubbard, D. 1997. Reefs as dynamic systems. In: Birkeland, C (Ed), Life and Death of Coral Reefs. Chapman and Hall, London, pp 43-57.
2. Nurse, L, and Moore, R. 2005, 'Adaptation to Global Climate Change: an Urgent Requirement for Small Island Developing States', RECIEL 14 (2), pp. 100-107.
3. Wilkinson, C, Souter, D. 2008. 'Status of Caribbean coral reefs after

bleaching and hurricanes in 2005'. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville, 152p.

4. Lal, M, Harasawa, H, and Takahashi, K. 2002, 'Future Climate Change and its Impacts over Small Island States', Climate Research 19, pp. 179-192.
5. Intergovernmental Panel on Climate Change. 1996, Climate Change 1995 — Impacts, Adaptation and Mitigation of Climate Change: Scientific-technical Analyses- Contribution of Working Group II to the Second Assessment Report, Cambridge University Press Cambridge University Press, Chapter 9, pp. 289-324.
6. Oxenford, HA, Roach, R, Brathwaite, A, Nurse, L, Goodridge, R, Hinds, F, Baldwin, K, and Finney, C. 2008. 'Quantitative observations of a major coral bleaching event in Barbados, Southeastern Caribbean'. Climate Change 87: 435-449.
7. Intergovernmental Panel on Climate Change. 2001, Climate Change 2001, Impacts, Adaptation and Vulnerability — Contribution of Working Group II to the Third Assessment Report, Cambridge University Press, Chapter 16, pp. 843-875.
8. Intergovernmental Panel on Climate Change. 1998, The Regional Impacts of Climate Change — an Assessment of Vulnerability, Cambridge University Press, Chapter 9, pp. 331-354.
9. Wilkinson and Souter. 2008. Op. cit.
10. Brown, BE. 1997. Disturbances to reefs in recent times. In: Birkeland, C (Ed), Life and Death of Coral Reefs. Chapman and Hall, London, pp 354-379.
11. Hubbard. 1997. Op. cit.
12. Wilkinson and Souter. 2008. Op. cit.

Climate change and tourism: facing the challenges

Alejandro Calvente, Department of Sustainable Development of Tourism, collaborated in the preparation of this article

1. This article is based on research carried out by UNWTO and especially on the publication: UNWTO, UNEP and WMO (2008), Climate Change and Tourism Responding to Global Challenges, UNWTO, Madrid. The authors of this technical study are: Dr Daniel Scott; Dr Bas Amelung; Dr Susanne Becken; Dr Jean-Paul Ceron; Ghislain Dubois; Dr Stefan Gössling; Paul Peeters; Dr Murray C. Simpson.
2. IPCC (2007a), 'Summary for Policymakers', in S. Solomon et al. (eds.), Climate Change 2007: The Physical Science Basis — Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press Cambridge, Cambridge and New York.
3. Ibid.
   IPCC (2007b), 'Summary for Policymakers', in M.L. Parry et al. (eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability — Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press Cambridge, Cambridge and New York.
4. Ibid.
   UNWTO (2003), Climate Change and Tourism: Proceedings of the First International Conference on Climate Change and Tourism, Djerba, Tunisia, 9-11 April 2003, UNWTO, Madrid, (Online), available: http://www.unwto.org/sustainable/climate/brochure.htm (17-12-2007).
   Gössling, S. and Hall, C. M. (2006a), 'An Introduction to Tourism and Global Environmental Change', in S. Gössling and C.M. Hall (eds.), Tourism and Global Environmental Change, Routledge, London, pp.1-34.
   Scott, D. (2006a), 'Climate Change and Sustainable Tourism in the 21st Century', in J. Cukier (ed.), Tourism Research: Policy, Planning, and Prospects, Department of Geography Publications Series, University of Waterloo, Waterloo, Ontario, pp. 175-248.
   Becken, S. and Hay, J. (2007), Tourism and Climate Change — Risks and Opportunities, Channel View Publications, Cleveland.
5. UNWTO, UNEP and WMO (2008), Climate Change and Tourism: Responding to Global Challenges, UNWTO, Madrid.
6. Bartlett, L. (2007), 'Australia Fears Jet Flight Guilt Could Hit Tourism', Agence France-Presse, 18 April 2007, (Online), available: www.spacemart.com/reports/Australia_Fears_Jet_Flight_Guilt_Could_Hit_Tourism_999.html (17-12-2007).
   Boyd, A. (2007), 'Carbon Tax Threatens to Ground Asia Tourism', Asian Times Online, (Online), available: www.atimes.com/atimes/Asian_Economy/ID19Dk01.html (17-12-2007).
   Caribbean Hotel Association and Caribbean Tourism Organization (2007), CHA-CTO Position Paper of Global Climate Change and the Caribbean Tourism Industry, (Online), available: www.caribbeanhotels.org/ClimateChangePosition0307.pdf (17-12-2007).
7. IPCC (2007b), 'Summary for Policymakers', in M.L. Parry et al. (eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability — Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press Cambridge, Cambridge and New York.
   Stern, N. (2006), The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge.
   Barnett, J. (2001), Security and Climate Change, Tyndall Centre Working Paper No. 7, (Online), available: www.tyndall.ac.uk/publications/working_papers/wp7.pdf (17-12-2007).
   German Advisory Council on Global Change (2007), World in Transition: Climate Change as a Security Risk, German Advisory Council on Global Change, Berlin, (Online), available: www.wbgu.de/wbgu_jg2007_engl.pdf (17-12-2007).
8. German Advisory Council on Global Change (2007), World in Transition: Climate Change as a Security Risk, German Advisory Council on Global Change, Berlin, (Online), available: www.wbgu.de/wbgu_jg2007_engl.pdf (17-12-2007).
9. Simpson, M.C., Gössling, S., Scott, D., Hall, C.M. and Gladin, E. (2008). Climate Change Adaptation and Mitigation in the Tourism Sector: Frameworks, tools and practices. UNEP, University of Oxford, UNWTO, WMO: París, France.
10. UNWTO, UNEP and WMO (2008), Climate Change and Tourism: Responding to Global Challenges, UNWTO, Madrid.
11. Becken, S. and Hay, J. (2007), Tourism and Climate Change — Risks and Opportunities, Channel View Publications, Cleveland.
12. UNWTO, UNEP and WMO (2008), Climate Change and Tourism: Responding to Global Challenges, UNWTO, Madrid.
13. UNWTO (2008), From Davos to Bali: A Tourism Contribution to the Challenge of Climate Change, UNWTO, Madrid.

Managing climate related health risks

1. UN (2001). 'Road map towards the implementation of the United Nations Millennium Declaration: Report of the Secretary-General'. New York, United Nations: 58.
2. WHA (2008). 'Climate Change and Health'. Resolution WHA61.19 — Sixty-first World Health Assembly. Geneva, World Health Organization.

3. WHO (2005). 'Using Climate to Predict Infectious Disease Outbreaks: A Review'. Geneva, Communicable Diseases Surveillance and Response Protection of the Human Environment, Roll Back Malaria WHO.
4. Chalmers, I. (1993). 'The Cochrane Collaboration: preparing, maintaining, and disseminating systematic reviews of the effects of health care', Annals of the New York Academy of Sciences, 703: p156-165.
5. WHO-EURO (2009). 'Improving public health responses to extreme weather/heat-waves' — EuroHEAT Technical Summary, Rome, World Health Organization: 60.
6. Thomson, M. C., F. J. Doblas-Reyes, et al. (2006). 'Malaria early warnings based on seasonal climate forecasts from multi-model ensembles', Nature 439: p576-579.
7. Thomson, M. C., S. J. Connor, et al. (2005). 'Rainfall and Sea-Surface temperature monitoring for malaria early warning in Botswana', American Journal of Tropical Medicine and Hygiene 73 (1): p214-221.
8. Connor, S. J., J. DaSilva, et al. (2007). 'Malaria control in Southern Africa', Climate Risk Management in Africa: Learning from Practice. M. E. Hellmuth, A. Moorhead, M. C. Thomson and J. Williams. New York, International Research Institute for Climate and Society (IRI), Columbia University: p45-57.
9. DaSilva, J., B. Garanganga, et al. (2004). 'Improving Epidemic Malaria Planning, Preparedness and Response in Southern Africa', Malaria Journal 3(1): 37.
10. Worrall, E., S. Connor, et al. (2007). 'A model to simulate the impact of timing, coverage and transmission intensity on effectiveness of indoor residual spraying (IRS)', Tropical Medicine and International Health 12 (2): p1-14.
    Worrall, E., S. J. Connor, et al. (2008). 'Improving the cost-effectiveness of IRS with climate informed health surveillance systems', Malaria Journal 7.
11. Ghebreyesus, T. A., Z. Tadesse, et al. (2008). 'Public Health Services and Public Weather Services: Increasing the Usefulness of Climate Information in the Health Sector', Bulletin of the World Meteorological Organization 57 (4): p256-261.
12. Campbell-Lendrum, D.,R. Bertollini, et al. (2009). 'Health and climate change: a roadmap for applied research', The Lancet 373: p1664-1665.

Further references

- Costello, A. and a. others (2009). 'Managing the health effects of climate change', The Lancet 373: p1693-1732.

Climate change migration from low-lying small island communities

1. ISDR (2008), 'Climate Change and Disaster Risk Reduction: weather, climate and climate change', Briefing Note 01, Geneva.
2. Duerden, F. (2004), 'Translating Climate Change Impacts at the Community Level', Arctic Vol. 57, No. 2, p.209.
3. Handmer, J., Dovers, S. and Downing T. (1999). Societal Vulnerability to Climate Change and Variability. Mitigation and Adaptation Strategies for Global Change 4: 267-281. Kluwer.
4. Church J.A., White N.J., Hunter J.R. (2006) Sea-level rise at tropical Pacific and Indian Ocean islands. Global And Planetary Change Volume: 53 Issue:3 Pages: 155-168.
   Woodroffe, C.D. (2008), 'Reef-island topography and the vulnerability of atolls to sea-level rise', Global And Planetary Change, Volume 62, Issue 1-2, pages 77-96.
5. Yamano H., Kayanne H., Yamaguchi T., et al (2007) 'Atoll island vulnerability to flooding and inundation revealed by historical reconstruction: Fongafale Islet, Funafuti Atoll, Tuvalu', Global And Planetary Change, Volume. 57, Issue. 3-4, Pages: 407-416.
6. Connell, J., Roy, P. (1990), 'The Greenhouse Effect: the impact of sea-level rise on low coral islands in the South Pacific' in J. C. Pernetta and P. J. Hughes (Eds.), 'Implications of expected climate changes in the South Pacific region: an overview', UNEP Regional Seas Reports and Studies No. 128.
7. Lang, O. (2009), 'Heightened fears for lowering lands', BBC, http://news.bbc.co.uk/2/hi/south_asia/7814446.stm
   Rakova, U. (2009), Tulele Peisa, www.tulelepeisa.org
8. Shaig, A. (2009), 'Settlement planning for natural hazard resilience in small island states: the population and development consolidation approach', unpublished PhD, James Cook University, Townsville, Australia.
9. O'Collins, Maev. (1990), 'Carteret islanders at the Atolls Resettlement Scheme: a response to land loss and population growth', in J. C. Pernetta and P. J. Hughes (Eds.), 'Implications of expected climate changes in the South Pacific region: an overview', UNEP Regional Seas Reports and Studies No. 128.
10. Ibid.
11. Bayliss-Smith, T. (1974). Constraints on Population Growth: The Case of the Polynesian Outlier Atolls in the Precontact Period. Human Ecology Vol 2, No 4, p259-295.

Climate in the Pacific: building capacity for climate services

1. Seasonal Climate Prediction in Pacific Island Countries is a statistical based model.
2. Cook Islands, Fiji, Kiribati, Niue, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.
3. ClimSoft was developed by Zimbabwe Meteorological Service Inc. ClimSoft has the important advantage of being built around an open source database (which means that countries deploying it are not saddled with ongoing license fees, as is the case with proprietary systems such as Oracle).

Further references

- Droughts in Small Coral Islands: Case Study, South Tarawa, Report under International Hydrological Programme, Kiribati, Ian White, Tony Falkland and David Scott, UNESCO, Paris 1999
- Pacific Islands Climate Prediction Project – Phase 2, Project Design Document, Final version, November 2006
- Pacific Islands Climate Prediction Project website: www.bom.gov.au/climate/pi-cpp
- (Draft) Position Paper on Users Liaison in RCOF, Rodney Martínez Güingla, WMO RCOF Review 2008

Combating climate change: how prepared are poor fishing communities in South Asia?

1. IPCC, 2007. Climate Change 2007: The Physical Science Basis. Summary for Policy Makers. Intergovernmental Panel on Climate Change, Geneva 18pp.
2. Emery and Aubrey, 1989; Das and Radhakrishna, 1993
3. International Comprehensive Ocean — Atmosphere Data Set (ICOADS) (ESRL PSD www.cdc.noaa.gov).
   Nine-kilometre resolution monthly SST obtained from AVHRR satellite data (provided by the NOAA/NASA at http://podaac.jpl.nasa.gov/

Vivekanandan, E., Rajagopalan, M., Pillai, N.G.K., 2009a. Recent trends in sea surface temperature and its impact on oil sardine. In: Aggarwal PK (ed.) Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change, Indian Council of Agricultural Research, New Delhi (in press).
4. Jones, P. D., T. J. Osborn, and Briffa, K. R., 1997. Estimating sampling errors in large-scale temperature averages. Journal of Climate. 10:2548-2568.
5. Vivekanandan, E., Hussain Ali, M., Rajagopalan, M., 2009b. Vulnerability of corals to seawater warming. . In: Aggarwal, P.K. (ed.) Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change, Indian Council of Agricultural Research, New Delhi (in press).
6. Vivekanandan, E., 2009. Impact of climate change on Indian marine fisheries and potential adaptation options. Lecture delivered in the BOBP-IGO Training Programme on 'Adapting to Climate Change: Field-level Capacity Enhancement Programme in Fisheries Sector'. 12-18 July, 2009, Chennai, India.
7. Vivekanandan, E, and Rajagopalan, M.,2009. Impact of rise in seawater temperature on the spawning of threadfin breams. In: Aggarwal PK (ed.) Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change, Indian Council of Agricultural Research, New Delhi (in press).
8. Ministry of Environment, Energy and Water, 2007. National Adaptation Programme of Action, Republic of Maldives, Malé. 114 pp.

Further references

- MoEF, 2008. Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. xvi + 68 pp.

Sustaining fish supplies for food security in a changing climate

1. Kris-Etherton, P.M., Harris, W.S. Appel, L.J. for the Nutrition Committee (2003) Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Arteriosclerosis, Thrombosis, and Vascular Biology 23:20-30
2. FAO (2009) The State of World Fisheries and Aquaculture 2008, Food and Agriculture Organisation of the United Nations, Rome, 2009); http://tiny.cc/fisheries1
3. FAO, (2009) ibid.
4. Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R. & Pauly, D (2009). Projecting global marine biodiversity impacts under climate change scenarios. Fish & Fisheries.
5. Hoegh-Guldberg et al. (2007) Coral reefs under rapid climate change and ocean acidification. Science 318: 177-1742
6. Allison, E. H. et al. (2009) Vulnerability of national economies to potential impacts of climate change on fisheries. Fish & Fisheries 10, 173-196.
7. Ehrhart, C., Thow, A., de Blois, M., and A. Warhurst (2008) Humanitarian impacts of climate change — mapping emerging trends and risk hotspots. CARE International www.careclimatechange.org;8. Allison, E. H. et al. (2009) ibid.
9. von Grebmer, K. Fritschel, H., Nestorova, B., Olofinbiyi, T., Pandya-Lorch, R. & Yohannes, Y. Global Hunger Index: The Challenge of Hunger 2008 (International Food Policy Research Institute, 2008); http://tiny.cc/fisheries4
10. Dulvy, N.K, and E.H. Allison (2009) A place at the table? Nature Reports Climate Change www.nature.com/climate/2009/0906/full/climate.2009.52.html
11. Barange M, et al (2009) Predicting the impacts and socioeconomic consequences of climate change on global marine ecosystems and fisheries: the QUEST_Fish framework. In: Ommer R, Perry I, Cury P & Cochrane K (Eds.) World Fisheries: a Social-Ecological Analysis, Blackwell, Oxford, See also http://web.pml.ac.uk/quest-fish/
12. Dulvy and Allison, ibid.; also FAO (2007) Building Adaptive Capacity to Climate Change . Food and Agriculture Organisation of the United Nations http://tiny.cc/fisheries8; and FAO (2008) Report of the FAO Expert Workshop on Climate Change Implications for Fisheries and Aquaculture: Rome, Italy, 7–9 April 2008. FAO Fisheries Report no. 870 http://tiny.cc/fisheries7
13. Hutchings, J. A. 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. Canadian Journal of Fisheries and Aquatic Sciences, 53:943-962.
14. FAO and UNEP (2009) Fisheries and Aquaculture in a Changing Climate ftp://ftp.fao.org/FI/brochure/climate_change/policy_brief.pdf
15. The Manado Ocean Declaration www.globaloceans.org/planning/pdf/MOD_ADOPTED_ON_14MAY09_Final.pdf

Climate change, land degradation, and forced migration

1. (Art. 1) See: 'Convention Relating to the Status of Refugees, 28 July 1951', in: 189 U.N.T.S.150, entered into force April 22, 1954.
2. El-Hinnawi, Essam, (1985), Environmental Refugees (Nairobi: United Nations Environment Programme).
3. Myers, Norman, (1993), 'Environmental Refugees in a Globally Warmed World', in: BioScience, 43,11: 752-61.
Myers, Norman, (1995), Environmental Exodus. An Emergent Crisis in the Global Arena (Washington, DC: Climate Institute).
Myers, Norman, (2002), 'Environmental Refugees: A growing Phenomenon of the 21st Century', in: The Philosophical Transactions of the Royal Society (Biological Sciences), April 2002.
Brauch, Hans Günter, (1997), 'La emigración como desafio para las relaciones internacionales y como área de cooperación Norte-Sur en el proceso de Barcelona', in: Marquina, Antonio (Ed.): Flujos Migratorios Norteafricanos Hacia La Union Europea. Asociacion y Diplomacia Preventiva (Madrid: Agencia Española de Cooperación Internacional): 17-90.
Brauch, Hans Günter, (1997a), 'Causas a largo plazo de las migraciones desde el Norte de Africa a los países de la Unión Europea. El Factor Demográfico', in: Marquina, Antonio (Ed.): Flujos Migratorios Norteafricanos Hacia La Union Europea. Asociacion y Diplomacia Preventiva (Madrid: Agencia Española de Cooperación Internacional): 241-333.
Brauch, Hans Günter, (1997b), Migration von Nordafrika nach Europa, in: Spektrum der Wissenschaft (August): 56-61.
Brauch, Hans Günter, (2000-2001) 'Environmental Degradation as Root Causes of Migration: Desertification and Climate Change. Long-Term Causes of Migration from North Africa to Europe', in: Friedrich, Peter; Jutila, Sakari (Eds.): Policies of Regional Competition. Schriften zur öffentlichen Verwaltung und öffentlichen Wirtschaft, Vol. 161 (Baden-Baden: Nomos): 102-138.
4. United Nations Population Division, (2001a), World Population Prospects: The 2000 Revision (New York: United Nations).
United Nations Population Division, (2001b), World Urbanization Prospects: The 1999 Revision (New York: United Nations).
UN, (2001), World Population Monitoring 2000. Population, environment and development. ESA/P/WP. 164 (New York: UN Secretariat, Department of Economic and Social Affairs, Populations

Division, 10 January).
5. USCR [U.S. Committee for Refugees], (2001), World Refugee Survey 2001 (Washington, D.C.:U.S. Committee for Refugees).
USCR, (2003), World Refugee Survey, (Washington, DC:)
USCR, (2004), World Refugee Survey, (Washington, DC:)
USCR, (2005), World Refugee Survey, (Washington, DC:)
6. WWF, (2004), Living Planet Report 2004 Gland, Switzerland: WWF.
7. Myers, Norman, (2005), Environmental Refugees: An Emergent Security Issue. Paper EF.NGO/4/05 from 22 May, presented at the 13th Economic Forum, Prague, 23-27 May.
8. Brown, Oli, (2008) 'The numbers game', in: Forced Migration Review 31 (October): 8-9.
9. Prokosch, Peter; Heinrich, Christoph, (2006), 'Der Living Planet Report — die biologische Vielfalt der Erde schwindet', in: Altner, Günter; Leitschuh-Fecht, Heike; Michelsen, Gerd; Simonis, Udo E. (Eds.), 2005: Jahrbuch Ökologie 2006 (Beck: Munich).
10. MA [Millennium Ecosystem Assessment], (2005a), Ecosystems and Human Well-being: Desertification Synthesis (Washington DC: Island Press).
11. UNEP, (2006), Global Deserts Outlook (Nairobi: Earthprint).
12. Reynolds, James F.; Stafford Smith, D. Mark (Ed.), (2002), Global Desertification — Do Humans Cause Deserts? Dahlem Workshop Report 88 (Berlin: Dahlem University Press).
13. Geist, Helmut, (2005), The Causes and Progression of Desertification (Abingdon; Ashgate).
Geist, Helmut (Ed.), (2006), Our Earth's Changing Land, Vol. I. (London: Greenwood Press).
14. Ramankutty, Navin; Achard, Fréderic; Alves, Diogenes; Turner Il, B L.; DeFries, Ruth; Klein Goldewijk, Kees; Graumlich, Lisa; Reid, Robin S., (2005), 'Global Changes in Land Cover', in: IHDP Update 03/2005 (Bonn: IHDP): 4-5.
15. MA (2005a): 2, op. cit..
16. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fibre; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services.
- MA (2005): V, op. cit..
17. MA, (2005b), Ecosystems and Human Well-being: Volume 1 — Current State and Trends (Washington DC: Island Press), 625.
18. Reuveny, Rafael, (2005), 'Environmental Change, Migration and Conflict: Theoretical Analysis and Empirical Explorations', Paper presented at the International Workshop "Human Security and Climate Change" in Asker, Norway, 21-23 June.
19. Myers, Norman, (2005), op. cit..
20. MA (2005a): 8, op. cit..
21. Adepoju, Aderanti, (2005), Creating a Borderless West Africa: Constraints and Prospects for Intra-Regional Migration. Draft Article of the Migration Without Borders Series, (Paris: UNESCO, 1 January), 3.
22. NEF; IIED, (2005), Africa — Up in Smoke? The Second Report From the Working Group on Climate Change and Development (London: IIED).
IPCC, (2001), Climate Change 2001 — IPCC Third Assessment Report (Geneva: WMO).
23. UNU-EHS, (2005), 'As Ranks of 'Environmental Refugees' Swell Worldwide, Calls Grow for Better Definition, Recognition', Support. Press release, 12 October; at: <http:// www.ehs.unu.edu/index.php?cat=23&menu=44&page=12_October_-_UN_Disaster _Day >
24. WBGU [Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen], (2007), Welt im Wandel — Sicherheitsrisiko Klimawandel (Berlin — Heidelberg Springer-Verlag).
WBGU [German Advisory Council on Global Change German Advisory Council on Global Change], (2008), World in Transition — Climate Change as a Security Risk (London: Earthscan).
[Also see source for boxed out text removed for reasons of space, below.]
25. MA, (2005b): 645, op. cit..
26. UNESCO, (2003), Combating Desertification — Rehabilitation of Degraded Drylands and Biosphere Reserves. UNESCO-MAB Dryland Series No. 2 (Paris: UNESCO).
UNESCO, (2004), Combating Desertification — Traditional Knowledge and Modern Technology for the Sustainable Management of Dryland Ecosystems. UNESCO-MAB Dryland Series No. 4 (Paris: UNESCO).
27. Sachs, Jeffrey, (2005), The End of Poverty (London: Penguin Books).
28. A more comprehensive academic version of this article has been published as: Rechkemmer, Andreas (2009), "Societal Impacts of Desertification: Migration and Environmental Refugees?", in: Hans Günter Brauch, Úrsula Oswald Spring, John Grin, Czeslaw Mesjasz, Patricia Kameri-Mbote, Navnita Chadha Behera, Béchir Chourou, Heinz Krummenacher (Eds.): Facing Global Environmental Change: Environmental, Human, Energy, Food, Health and Water Security Concepts. Hexagon Series on Human and Environmental Security and Peace, vol. 4 (Berlin — Heidelberg — New York: Springer).

II
Governance and Policy

Assessment of climate change and adaptation in India

1. IMD, 2008, "Annual Climate Summary", National Climate Centre, IMD Pune.
2. Kothawale, D.R. and K. Rupa Kumar, 2002, "Tropospheric temperature variation over India and links with the Indian Summer Monsoon", Mausam, 2002, 53, 3, 289-308.
3. Guhathakurta, P. and M. Rajeevan, 2008; "Trends in the rainfall pattern over India", Int. J. Clamoto. 28:1453-1469
4. Sinha Ray, K.C. and A.K. Srivastava, 2000; "Is there any change in extreme events like drought and heavy rainfall?", Current Science, 79, 2, 155-158.
5. Joshi, U.R. and M. Rajeevan, Oct. 2006; "Trends in precipitation extremes over India" published by National Climate Centre, Pune, NCC Research Report No, 3/2006.
6. Srivastava, A.K., K.C. Sinha Ray and U.S. De, 2000; "Trends in the frequency of cyclonic disturbances and their intensification over Indian Seas", Mausam, 51, 2, 113-118.
Singh, O.P., T.M. Ali Khan and Md. S. Rahman, 2000; "Changes in the frequency of tropical cyclones over the north Indian Ocean", Meteorology and Atmospheric Physics, 75, 11-20.
7. Singh, O.P., 2001; "Long-term trends in the frequency of monsoonal cyclonic disturbances over the north Indian Ocean", Mausam, 52, 4, 655-658
8. Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R.Laprise, V. MagaÃ±a Rueda, L.Mearns, C.G. MenÃ©ndez, J. RÃ¤isÃ¤nen, A. Rinke, A. Sarr and

P. Whetton, 2007: Regional Climate Projections. In: Climate Change 2007:The Physical Science Basis. Contribution of Working Group I to the Fourth cAssessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)], Cambridge UniversityPress, Cambridge, United Kingdom and New York, NY, USA. Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper,I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007 : Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S.,D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

9. Sabade SS, Kulakrni A, Kripalani RH (2009). Projected Changes in South Asian Summer Monsoon by Multi-model Global Warming Experiments. J Climate (Submitted)
10. Rupa Kumar K., Sahai A.K., Krishna Kumar K., Patwardhan S.K., Mishra P.K., Revadekar J.V., Kamala K., Pant G.B (2006).High-resolution climate changes scenarios for India for the 21st century Current Science, 90, 2006, 334-345
11. Acknowledgements

- The authors are thankful to Dr S. D. Attri, Dr L. S. Rathore, Dr T. A. Khan, Dr A. K. Srivastav and Dr H. R. Hatwar of IMD; and Dr K. Krishna Kumar, Dr A. Kulkarni and Dr Savita Patwardhan of IITM, Pune for the contribution.

Climate change: challenges and opportunities for development in Kuwait

1. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
2. Karl, T.R.,G. Kukla, V.N. Razuvayev, M.J. Changery, R.G. Quayle, R.R. Heim Jr., D.R. Easterling and C. Bin Fu. 1991. Global warming: evidence for asymmetric diurnal temperature change. Geophysical Research Letters 18 (12): 2253–2256.
3. Karl, T.R., P.D. Jones, R.W. Knight, G. Kukla, N. Plummer, V. Razuvayev, K.P. Gallo, J. Lindseay, R.J. Charlson and T.C. Peterson. 1993. A new perspective on recent global warming. Bull. Amer. Meteorol. Soc., 74: 1007-1023.
4. Stone, D. A. and A. J. Weaver, 2003. Factors contributing to diurnal temperature range trends in twentieth and twenty-first century simulations of the CCCma coupled model, Climate Dynamics, 20, 435-445.
5. Sun, D., M. Kafatos, R.T. Pinker, D.R. Easterling. 2006. Seasonal variations in diurnal temperature range from satellites and surface observations. Geoscience and Remote Sensing, IEEE Transactions 44 (10): 2779-2785.
6. Watterton, I. G., 1997. The diurnal cycle of surface air temperature in simulated present and doubled CO_2 climates. Climate Dynamics, 13, 533-545.
7. Ramadan, A. 2008. Rising Temperature in Kuwait; a Clear Evidence of Climate Change. World Renewable Energy Congress X and Exhibition 2008. Glasgow, UK. 19-25 July 2008. PP 2681-2685.
8. Regional Office for West Asia (ROWA). 2007. United Nations Environment Programme, Environmental Impacts of The Arab Oil and Gas Sector:
9. Energy Information Administration (EIA) 2008. International Total Primary Energy Consumption and Energy Intensity. (http://www.eia.doe.gov/emeu/international/energyconsumption.html) - Accessed May 2008.
10. Ramadan, A.A.; S. Alhajraf; and A.R. Khan. 2005. Technical assessment of the air quality impact of SO_2 emission from the power plants in Kuwait until 2030. Kuwait Institute for Scientific Research, Final Report No. KISR 7825.
11. World Bank (WB). 2009: Kuwait Data Profile. [http://ddp-ext.worldbank.org/ext/ddpreports/ViewSharedReport?&CF=&REPORT_ID=9147&REQUEST_TYPE=VIEWADVANCED], accessed July 2009.
12. Global Gas Flaring Reduction (GGFR). 2009. Estimated Flared Volumes from Satellite Data, 2005-2007. (http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTOGMC/EXTGGFR/0,,contentMDK:22137498~menuPK:3077311~pagePK:64168445~piPK:64168309~theSitePK:578069,00.html), accessed July 2009.
13. World Bank (WB) 2005. Middle East and North Africa Economic Developments and Prospects 2005, Oil Booms and Revenue Management. The World Bank, Washington, DC. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/MENAEXT/0,,contentMDK:20449345~pagePK:146736~piPK:226340~theSitePK:256299,00.html [Accessed May 2008].
14. Intergovernmental Panel on Climate Change (IPPC) 2001. Summary For Policymakers, Climate Change 2001: Mitigation. A Report of Working Group III of the Intergovernmental Panel on Climate Change. Sixth Session of IPCC Working Group III (Accra, Ghana, 28 Feb. — 3 March 2001).
15. Ramadan, A and S. Al-Nafisi. 2008. Sabiya and Shuaiba North environmental impact assessment: air pollution. Kuwait Institute for Scientific Research, Final Report-KISR9504.
16. Ramadan, A., M Al-Sudairawi, S. Alhajraf and A.R. Khan. 2008a. Total SO2 Emissions from Power Stations and Evaluation of Their Impact in Kuwait Using a Gaussian Plume Dispersion Model. American Journal of Environmental Sciences. 4 (1) PP1-12.
17. Alhajraf, S. 2006. Fuel consumption optimization study for Az-Zour thermal power plant to maintain air quality standards. Kuwait Institute for Scientific Research, Report No. KISR 8090.
18. Ramadan, A. A.; A.R. Khan; H.S. Al-Menaie; A.A. Al-Shatti; and N.R. Bhat. 2008b. Environmental baseline survey for the clean fuel project at Mina Abdullah, Mina Al-Ahmadi And Shuaiba Refineries. Kuwait Institute for Scientific Research, Report No. KISR 9234.
19. Al-Nassar, W., S. Alhajraf, A. Al-Enizi. 2007. Potential wind power generation in the state of Kuwait. Kuwait Institute for Scientific Research, Report No. KISR 8624.

Challenges for the climate services in Switzerland

1. Seiz, G., Foppa, N., (2007). National Climate Observing System (GCOS Switzerland). Publication of MeteoSwiss and ProClim, 92p.
2. OcCC, (2007): 'Climate Change and Switzerland in 2050: Expected Impacts on Environment, Society and Economy'. www.proclim.ch/products/ch2050/CH2050-report.html

Increasing preparedness for climate change in Hungary

1. Gyuró, Gy., Á. Horváth, M. Lakatos, S. Szalai and J. Mika, (2007), 'Battling extreme weather under a temperate climate — Hungary', Elements for Life, World Meteorological Organization, p152-153
2. Harnos Zs., (2008), 'Climate change and impact on the environment and agriculture modelling case study', AGRO-21 Füzetek No. 55, 5-22

Further references

- Christensen, J.H., Carter T.R., Rummukainen, M. and Amanatidis,

G., (2007). 'Predicting of regional scenarios and uncertainties for defining European climate change risks and effects: The PRUDENCE Project', Climatic Change 81: Supplement 1, May 2007, p1-371.
- Horvath, L., (2008), 'Use of the spatial analogy method to analyse possible land use change in Hungary', AGRO-21 Füzetek No. 55, p5-27

Earth observation and global environmental research for adaptation to climate change – a Japanese perspective

1. 'IBUKI' means breath in Japanese. This nickname was given to GOSAT because it observes the breath of the earth — GHGs.
2. See www.gosat.nies.go.jp/index_e.html
3. See www.apn.gr.jp/en/indexe.html
4. www.env.go.jp/en/earth/cc/wacc_080618.pdf

Seasonal climate forecasts and satellite information: improving decisions in the Uruguayan agricultural sector

1. Ropelewski, C.F. and M.S. Halpert. 1987. Global and regional scale precipitation patterns associated with El Niño/Southern Oscillation. Mon. Wea. Rev. 115:1606-1626.
Ropelewski, C.F. and M.S. Halpert. 1989. Precipitation patterns associated with high index phase of Southern Oscillation. J. Climate, 2:268-284.
Bidegain, M. and P. Krecl. 1998. Comportamiento de la temperatura en el sudeste de Sudamerica (Uruguay) asociado al fenómeno ENSO. Congreso Iberico — Latinoamericano de Meteorologia. Brasilia, Brazil. September 1998.
Pisciottano, G.J; A.F. Díaz and C.R. Mechoso. 1994. El Niño-Southern Oscillation impact on rainfall in Uruguay. J. Climate, 7:1286-1302.
Grimm, A.M.; S.E.T. Ferraz and J. Gomes. 1998. Precipitation anomalies in southern Brazil associated with El Niño and La Niña events. J. Climate:11:2863–2880.
Grondona, M.O.; G.O. Magrin; M.I. Travasso; R.C. Moschini; G.R. Rodriguez; C. Messina; D.R. Boullon; G. Podesta and J.Jones. Impacto del fenomeno "El Nino" sobre la produccion de trigo y maiz en la region Pampeana Argentina. Workshop and Conference on the 1997-98 El Niño: Impacts and Potential Applications of Climate Prediction in Southeast South America. December 1997. Montevideo, Uruguay.
Díaz, A.; C.D. Studzinski and C.R. Mechoso. 1998. Relationships between precipitation anomalies in Uruguay and southern Brazil and sea surface temperature in the Pacific and Atlantic oceans. J. Climate, 11:251-271.
Baethgen, W.E. 1997. Relaciones entre la temperatura superficial del Pacífico tropical y los rendimientos de cultivos en Uruguay. Workshop and Conference on the 1997-98 El Niño: Impacts and Potential Applications of Climate Prediction in Southeast South America. December 1997. Montevideo, Uruguay.
Podestá, G.P., C. D. Messina, M.O. Grondona and G.O. Magrin. 1998. Associations between grain crop yields in central-eastern Argentina and El Niño-Southern Oscillation. Journal of Applied Meteorology 38: 1488-1498.
Myneni, R.B.; S.O. Los and C.J. Tucker. 1996. Satellite-based identification of linked vegetation index and sea surface temperature anomaly areas from 1982-1990 for Africa, Australia and South America. Geophys. Res. Letters. 23:729-732.
2. Baethgen, W.E. 1998. El Niño and La Niña Impacts in Southeastern South America. Review on the causes and consequences of cold events: A la Niña Summit. Proceedings. M. Glantz (ed.) NCAR, Boulder, CO (http://www.dir.ucar.edu/esig/lanina/).
3. Bidegain and Krecl, 1998, op. cit..
Pisciottano et al., 1994, op. cit..
Grimm et al., 1998, op. cit..
Grondona et al., 1998, op. cit..
Díaz et al., 1998, op. cit..
Baethgen, 1997, op. cit..
Podestá et al., 1998, op. cit..
Myneni et al,. 1996, op. cit..
4. Baethgen, W. E., C. Ropelewski and M. A. Carriquiry. 2009. Tilting the odds in maize yields: How climate information can help manage risks. Bulletin of the American Meteorological Society (BAMS) vol. 90 (2)179-184.
5. Ropelewski, C.F. and M.S. Halpert. 1989, op. cit..

Making stream flow monitoring work for biodiversity and social justice

1. Van Wilgen, B.W., Richardson, D.M., Le Maitre, D.C., Marais, C. and Magadlela, D. 2001. The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. Environment, Development and Sustainability 3: 145–168, 2001.
2. Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A. 2000. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. Water SA 26: 397-408.
3. www.dwaf.gov.za/wfw
4. de Satgé, R., Urquhart, P., Manaka, B. and Moahloli, C. 2003. Assessing the social development aspects of the Working for Water programme. Social Team Final Evaluation Report. Working for Water unpublished report.
5. Giraud C., Laurent C., Ricroch A., Allsopp N., Carneiro M.-J., Matose F., Trouvé A., Bonnafous P., Baudry J., Perraud D., Boiron A., CorroyerP.,
LecoeurC., Thurneyssen A. 2008. Difficultés d'accès aux connaissances scientifiques pour les décideurs publics chargés de concevoir les contenus techniques de mesures réglementaires mettant en jeu agriculture et préservation de la biodiversité. Résultats des enquêtes réalisées en
France, au Brésil et en Afrique du Sud. Rapport Ebp-Biosoc, Ensemble de travaux n°1 (ET1). INRA/ANR, 81 p. + annexes. http://www.inra.fr/biosoc_sciences

Adapting to climate change and variability

1. CONAMA, realizado por el Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, 2006, 'Estudio de la variabilidad climática en Chile para el siglo XXI'.
2. Centro de Agricultura y Medio Ambiente, Universidad de Chile, 2008, 'Capítulo 1: Impactos producidos en el sector silvoagropecuario de Chile frente a escenarios de Cambio Climático', 180 pp. Informe Final.
3. Comisión Nacional de Energía, 2008, Política Estratégica: Nuevos Lineamientos, 176 pp.
4. Ibid.
5. RIDES, 2007, 'Integrando la adaptación al cambio climático en las políticas de desarrollo: ¿cómo estamos en Chile?', www.rides.cl.

Information and communication technologies and climate change

1. This number does not include emissions from radiocommunication systems/equipment.

2. www.itu.int/themes/climate/
3. www.itu.int/publications/publications.aspx?lang=en&media=electronic&parent=R-HDB-45-2008
4. www.itu.int/ITU-T/ngn/index.html

III
Observing, Predicting and Projecting Climate Conditions

The Caribbean Drought and Precipitation Monitoring Network: the concept and its progress

1. Enfield, D. B., Alfaro, E. J., (1999), 'The dependence of Caribbean Rainfall on the Interaction of the Tropical Atlantic and Pacific Oceans', Journal of Climate (12), 2093-2103.
2. Trotman A., (1994), 'Agroclimatic study of Barbados, 1970 to 1990: Rainfall'. Technical Note No. 28. Caribbean Meteorological Institute.
3. Burton S., (1995), 'Long-term fluctuations in rainfall over Barbados'. Technical Note No. 30. Caribbean Meteorological Institute.
4. 'Drought, living with risk: An integrated approach to reducing societal vulnerability to drought'. ISDR Ad Hoc Discussion Group on Drought. www.unisDrorg/eng/task%20force/tf-adhoc/droughts/WGD-doc1.pdf
5. 'Reported Drought-Related Effects of El Niño for March 1998'. National Drought Mitigation Center, (1998). Retrieved May 1, 2008 from http://www.drought.unl.edu/risk/world/nino398.pdf
6. USAID, (1998). United States Agency for International Development; Office of U.S. Foreign Disaster Assistance. 'El Niño southern oscillation — ENSO 1997/98 and risk management in the Latin American and Caribbean region'.
7. www.nationsencyclopedia.com/economies/Americas/Jamaica-AGRICULTURE.html
8. Jamaican Information Service, Ministry of Finance and Planning, (2007).
9. UNFCCC, (2000). 'Grenada's Initial Communication to the UNFCCC, October 2000', pp.100. Accessed on: http://unfccc.int/resource/docs/natc/grnnc1.pdf
10. ECLAC, (2005). 'Guyana Socioeconomic Assessment of the Damages and Losses Caused by the January-February 2005 Flooding'. Economic Commission for Latin America and Caribbean.
11. ECLAC, (2006). 'Guyana: The impact on Sustainable Livelihoods Caused By the December 2005 — February 2006 Flooding'. Economic Commission for Latin America and Caribbean.
12. 'Damage Assessment Report from 29th December 2000 - 4th January 2001 heavy rains'. www.odpem.org.jm/Portals/0/Mitigation_Preparedness/Damage%20Assessment/Damage%20Assessment%20Report_Heavy%20Rains_December%202000-Jan%202001%20.pdf
13. Canisius F. and Nancy C., 'GeoFIS: Flood Insurance System for Trinidad - A Case Study for San Juan Downstream'. Accessed 18-05-2009, http://www.urisa.org/files/Canisius.doc
14. Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet and G. Sem, (2007): Small islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 687-716.
15. Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, (2007): Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
16. Ibid.
17. Peterson, T. C., Taylor, M. A. and Demeritte, R., (2002). 'Recent changes in climate extremes in the Caribbean region'. Journal of Geophysical Research, 107, 4601.
18. www.mcgill.ca/cariwin
19. McKee, T.B.; N.J. Doesken; and J. Kleist, (1993). 'The relationship of drought frequency and duration to timescales'. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.
20. Gibbs, W.J.; and J.V. Maher, (1967). 'Rainfall deciles as drought indicators'. Bureau of Meteorology Bulletin No. 48, Commonwealth of Australia, Melbourne.
21. Palmer, W.C., (1965). 'Meteorological drought'. Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington, D.C.
22. Palmer, W.C., (1968). 'Keeping track of crop moisture conditions, nationwide: The new Crop Moisture Index'. Weatherwise 21:156–161.
23. The NCEP/NCAR Reanalysis Project is a joint project between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR).

The Global Climate Observing System as the observational foundation for climate services

1. Mason, BJ, 'The role of meteorology in the national economy', Weather, (Nov. 1966) p382-393
Zillman, JW, 199, 'The National Meteorological Service', WMO Bulletin 48, 2, p129-159
WMO 2009, 'Secure and Sustainable Living; The Findings of the International Conference on Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services'. WMO No. 1034, World Meteorological Organization, Geneva, p101.
2. Davies, DA, 'Forty Years of Progress and Achievement: A Historical Review of WMO', WMO. No. 721. Secretariat of the World Meteorological Organization, Geneva, 1990, 205 pp.
3. Zillman JW, 'The World Climate Programme'. Search 11 4, April 1980, p108-111.
4. GCOS Secretariat 2009, 'Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC'. Report to SBSTA, April 2009.
5. Zillman, JW, GEOSS — 'A new framework for international cooperation in earth observation'. ATSE Focus, 136, 2005pp. 8-12

The UK Climate Projections — Met Office science and headline results

1. This work was supported by the Joint DECC, Defra and MoD Integrated Climate Programme - DECC/Defra (GA01101), MoD (CBC/2B/0417_Annex C5).

Further references

- http://ukcp09.defra.gov.uk/
- www.metoffice.gov.uk/climatechange/guide/ukcp/index.html
- www.ukcip.org.uk/

Bioclimatic modelling: linking biodiversity and climate science

1. Millennium Ecosystem Assessment, (2005). 'Ecosystems and Human Well-being: Biodiversity Synthesis'. World Resources Institute, Washington, DC.
2. IPCC, (2007): Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.
3. Ibid.
4. Midgley, G.F., Hannah L., Millar D., Rutherford M.C., and L.W. Powrie, (2002). 'Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot'. Global Ecology & Biogeography. Volume 11, Issue 6, p445-451
5. Parmesan, C. and G. Yohe. (2003). 'A globally coherent fingerprint of climate change impacts across natural systems'. Nature. Vol 421. p37-42.
6. Pearson, R.G. and T.P. Dawson. (2003). 'Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful?' Global Ecology & Biogeography. Vol 12. p361-371
7. Araújo, M.B., Whittaker, R.J., Ladle, R.J., and Erhard M. (2005). 'Reducing uncertainty in projections of extinction risk from climate change'. Glob Ecol Biogeogr. Vol. 14. p529-538
8. The collection of ecosystems within a particular climatic zone with similar structure but differing species:
   Gitay H., Suarez A., Dokken D. J., and R. T. Watson. (2002). 'Climate Change and Biodiversity': IPCC Technical Paper V. p12. Accessed at: http://www.ipcc.ch/pdf/technical-papers/climate-changes-biodiversity-en.pdf
9. Global Climate Change and Biodiversity. (2003). Summary of papers and discussion. Edited by R. E. Green, M. Harley, L. Miles, J. Scharlemann, A. Watkinson and O. Watts University of East Anglia, Norwich, UK, accessed at: http://www.jncc.gov.uk/pdf/MJHGlobalclimatechange_14.08.03.pdf
10. Gitay, H., et al,. (2002), op. cit..
11. Parmesan and Yohe, (2003), op. cit..
12. As laid down by the IPCC, very high confidence means that more than 95 percent of observed changes are principally caused by climate change.
13. Secretariat of the Convention on Biological Diversity. (2003). 'Interlinkages between biological diversity and climate change. Advice on the integration of biodiversity considerations into the implementation of the United Nations Framework Convention on Climate Change and its Kyoto protocol'. Montreal, SCBD, 154p. (CBD Technical Series no. 10).
14. Parmesan, C. (2006). 'Ecological and Evolutionary Responses to Recent Climate Change'. Annual Review of Ecology, Evolution and Systematics 37: p637–69
15. Secretariat of the Convention on Biological Diversity. (2008). Draft Findings of the First Meeting of the Ad hoc Technical Expert Group on Biodiversity and Climate Change. London, 17–21 November 2008. Accessed at: https://www.cbd.int/doc/meetings/cc/ahteg-bdcc-01/other/ahteg-bdcc-01-findings-en.pdf
16. Ibid.
17. Ibid.
18. Group on Earth Observations. (2008). The Global Earth Observation System of Systems (GEOSS). Accessed at: www.earthobservations.org/

Modelling in earth system science

- NASA Advisory Council, (1988): 'Earth System Science: A Closer View', Report of the Earth System Sciences Committee, National Aeronautics and Space Administration, Washington, D.C., 208pp.
- Budyko, M. I., (1969): 'The effect of solar radiation variations on the climate of the earth', Tellus, 21: p611-619.
- Sellers, W. D., (1969): 'A global climatic model based on the energy balance of the Earth-atmosphere system', J. Appl. Meteor., 8: p392-400.
- Claussen M., et al., (2002): 'A global climatic model based on the energy balance of the Earth-atmosphere system', Clim. Dyn., 18: p579-586.
- Friedlingstein, P., et al., (2006): 'Climate — carbon cycle feedback analysis, results from the C4MIP model intercomparison', J. Climate, 19: p3337-3353.
- Yoshikawa, C., M. Kawamiya, T. Kato, Y. Yamanaka, and T. Matsuno, (2008): 'Geographical distribution of the feedback between future climate change and the carbon cycle', J. Geophys. Res., G03002, DOI:10.1029/2007JG000570.

Acknowledgments

- This article is supported by Innovative Program of Climate Change Projection for the 21st Century of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The Earth Simulator was used for outputs introduced in the article.

Seasonal to decadal prediction: improving accessibility and widening applications

1. Ogallo, L., Bessemoulin, P., Ceron, J-P., Mason, S., Connor, S.J. 2008: Adapting to climate variability and change: the Climate Outlook Forum process. WMO Bulletin, Vol. 57, No.2, 93-102.
   Goddard, L. and Dilley, M. 2005. El Nino: Catastrophe or opportunity. J. Climate, 18: 651-665.
   Glantz, M.H. 2000: Currents of change: El Niño and La Niña impacts on climate and society. Cambridge University Press.
2. Kirtman, B. and Pirani, A. 2009: The state of the art of seasonal prediction. BAMS, 90, 455-458.
3. Ogallo et al,. op. cit.
   IRI publication IRI-CW/01/2, 2000: Coping with the Climate: a way forward.
   A multi-stakeholder review of Regional Climate Outlook Forums concluded at an international workshop October 16-20, 2000, Pretoria, South Africa.
4. Graham, R., Gordon, M., McLean, P.J., Ineson, S., Huddleston, M.R., Davey, M.K., Brookshaw, A., Barnes, R.T.H. 2005: A performance comparison of coupled and uncoupled versions of the Met Office seasonal prediction General Circulation Model. Tellus, 57A, 320-339.
5. ibid.
6. Graham, R., Gordon, C., Huddleston, M., Davey, M., Norton, W., Colman, A., Scaife, A., Brookshaw, A and others 2006: The 2005/6 winter in Europe and the United Kingdom: Part 1 – how the Met Office forecast was produced and communicated. Weather, 61, 327-336.
7. Julie, A. and Céron, J.P. 2007: Seasonal forecasting in West Africa: a strategic partnership for a sustainable development of a cross boundary river catchment. Elements for Life, Tudor Rose and WMO, 70-71.
8. Vitart, F., M. R. Huddleston, M. Déqué, D. Peake, T. N. Palmer, T. N. Stockdale, M. K. Davey, S. Ineson, A. Weisheimer. 2007:

Dynamically-Based Seasonal forecasts of Atlantic Tropical-Storm Activity issued in June by EUROSIP. Geophys. Res. Lett., 34, L16815.

9. Gray, W.M. 1984: Atlantic seasonal hurricane frequency. Part II: Forecasting its variability. Mon. Wea. Rev. 112, 1669-1683. Saunders, M.A. and Lea, A.S. 2005: Seasonal prediction of hurricane activity reaching the coast of the United States. Nature, 434, 1005-1008.
10. Bell, G. D., Halpert, M. S., Schnell, R.C., Higgins, R.W., Lawrimore, J., Kousky, V.E., Tinker, R., Thiaw, W., Chelliah, M., Artusa, A., 2000: Climate assessment for 1999. Bull. Amer. Meteor. Soc., 81 (June), S1–S50.
11. Thomson, M.C. Doblas-Reyes, F.J., Mason, S.J. and others. 2006: Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. Nature, Vol. 439, No. 7076, 575-579.
12. Smith, D.M., Cusack, S., Colman, A.W., Folland, C.K., Harris, G. R., Murphy, J.M. 2007: Improved surface temperature prediction for the coming decade from a global climate model. Science 317, 796-799.
13. Met Office authors were supported by the Joint DECC, Defra, MoD Integrated Climate Programme — DECC/Defra (GA01101), MoD (CBC/2B/0417_Annex C5). Rowan Sutton acknowledges support from the UK National Environment Research Council.

Strategic planning in the Caribbean: the role of seasonal forecasts

1. Amarakoon AMD, Chen AA, Rawlins SC, Taylor MA, 'Dengue Epidemics — its association with precipitation and temperature, and its seasonality in some Caribbean countries', CHRC 49th annual conference, Grenada, April 2004.
2. Depradine C, Lovell E, 'The incidence of asthmatic attacks in Barbados', West Indian Medical Journal, Vol 56, No 5, October 2008.
3. Prospero JM, Blades E, Naidu R, Mathison G, Thani H, Lavoie MC, 'Relationship between African dust carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean', International Journal of Biometeorology, 52:8, 823-832.
4. www.met.inf.cu/asp/genesis.asp?TB0=PLANTILLAS&TB1=PCLIMA &TB2=/clima/pronosticoclimatico.htm.

Seasonal climate outlooks for assistance in water management

1. Pearson CP (2008). Short and medium-term climate information for water management. World Meteorological Organisation Bulletin 57 (3), 173-177.
2. Welles E, Sorooshian S, Carter G, Olsen B (2007). Hydrologic verification: A call for action and collaboration. Bulletin of the American Meteorological Society 88(4), 503-511.
3. Sorooshian S, Lawford R, Try P, Rossow W, Roads J, Polcher J, Sommeria G, Schiffer R (2005). Water and energy cycles: Investigating the links. World Meteorological Organisation Bulletin 54 (2), 58-64.
4. Bandaragoda C, Tarboton DG, Woods RA (2004). Application of TOPNET in the Distributed Model Intercomparison Project. Journal of Hydrology 298(1-4): 178–201.

Changes in the climate of East Asia tropical cyclones

1. Kubota, H. and J. C. L. Chan, (2009): 'Interdecadal variability of tropical cyclone landfall in the Philippines from 1902 to 2005', Geophysical Research Letters, 36, L12802, doi:10.1029/2009GL038108.
2. Chan, J. C. L. and M. Xu, (2009): 'Interannual and interdecadal variations of landfalling tropical cyclones in East Asia. Part I: Time series analysis', International Journal of Climatology, DOI: 10.1002/joc.1782.
3. Liu, K. S. and J. C. L. Chan, (2008): 'Interdecadal variability of western North Pacific tropical cyclone tracks', Journal of Climate, 21, 4464-4476.
4. Frank, W. M. and G. S. Young, (2007): 'The interannual variability of tropical cyclones', Monthly Weather Review, 135, 3587-3598.
5. Saffir, H. S., (2003): 'Communicating damage potentials and minimizing hurricane damage', Hurricanes, R. Simpson, Ed., American Geophysical Union, 155-164.
6. Chan, J. C. L., (2006): Comments on 'Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment', Science, 311, 1713b. Chan, J. C. L., (2007): 'Interannual variations of intense typhoon activity', Tellus, 59A, 455-460. Chan, J. C. L., (2008): 'Decadal variations of intense typhoon occurrence in the western North Pacific', Proceedings of the Royal Society A, 464, 249–272.
7. Kossin, J. P., K. R. Knapp, D. J. Vimont, R. J. Murnane, and B. A. Harper, (2007): 'A globally consistent reanalysis of hurricane variability and trends', Geophysical Research Letters, 34, L04815, doi:10.1029/2006GL028836.
8. Chan and Liu (2004)
9. Chan, J. C. L., (2009): 'Thermodynamic control on the climate of intense tropical cyclones: Atlantic vs. others', Proceedings of the Royal Society A, 465 (in press)
10. Sugi, M., A. Noda, and N. Sato, (2002): 'Influence of global warming on tropical cyclone climatology: an experiment with the JMA global model', Journal of Meteorological Society of Japan, 80: 249-272, DOI:10.2151/jmsj.80.249.
11. Stowasser, M., Y. Wang, and K. Hamilton, (2007): 'Tropical cyclone changes in the western North Pacific in a global warming scenario', Journal of Climate, 20, 2378-2396. Yoshimura, J., M. Sugi and A. Noda, (2006): 'Influence of greenhouse warming on tropical cyclone frequency', Journal of Meteorological Society of Japan, 84, 405-428.
12. Leslie, L. M., D. J. Karoly, M. Leplastrier, and B. W. Buckley, (2007): 'Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model', Meteorology and Atmospheric Physics, 97, 171-180.
13. Knutson, T. R., J. J. Sirutis, S. T. Garner, I. M. Held, and R. E. Tuleya, (2007): 'Simulation of the recent Multi-decadal increase of Atlantic Hurricane activity using an 18-km-Grid regional model', Bulletin of the American Meteorological Society, 88(10), 1549-1565. Emanuel, K., R. Sundararajan, and J. Williams, (2008): 'Hurricanes and global warming: results from downscaling IPCC AR4 simulations', Bulletin of the American Meteorological Society, 89 (3), 347-367.

Further references

- McDonald, R. E., D. G. Bleaken, D. R. Cresswell, V. D. Pope, and C. A. Senior, (2005): 'Tropical storms: representation and diagnosis in climate models and the impacts of climate change', Climate Dynamics, 25: 19-36, DOI: 10.1007/s00382-004-0491-0.
- Hasegawa, A. and S. Emori, (2005): 'Tropical cyclones and associated precipitation over the Western North Pacific: T106 atmospheric GCM simulation for present-day and doubled CO_2 climates', SOLA, 1, 145-148, SOI:10.2151/sola.2005-038.

- Oouchi, K., J.Yoshimura, H. Yoshimura, R. Mizuta, S. Kusunoki, and A. Noda, (2006): 'Tropical cyclone climatology in a global-warming climate as simulated in a 20km-mesh global atmospheric model: frequency and wind intensity analysis', Journal of Meteorological Society of Japan, 84, 259-276.
- Bengtsson, L., K. I. Hodges, M. Esch, N. Keenlyside, L. Kornblueh, J.-J. Luo and T. Yamatata, (2007): 'How may tropical cyclones change in a warmer climate?', Tellus A, 59, 539-561, doi: 10.1111/j.1600-0870.2007.00251.x.

Author contact details:
johnny.chan@cityu.edu.hk

Climate implications of atmospheric aerosols and trace gases: Indian scenario

1. Ramanathan, V., P.J. Crutzen, J.T. Kiehl, and D. Rosenfeld, 'Aerosols, climate, and the hydrological cycle', Science, 294, 2119-2124, (2001).
2. Satheesh, S.K., and K.K.Moorthy, 'Radiative effects of natural aerosols: A review', Atmospheric Environment, 39, 2089–2110, (2005).
3. Remer, L. A., M. Chin, P. DeCola, et al., Executive Summary, in Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA (2009).
4. Intergovernmental Panel on Climate Change (IPCC), Summary for Policymakers. In: Climate Change 2007: Solomon. S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA., (2007).
   Moorthy, K.K., S. K. Satheesh, S. S. Babu and C. B. S. Dutt, 'Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB): An Overview', Journal of Earth System Science, Vol.117,S1,243-262, July (2008).
   Remer et al,. (2009), op. cit..
5. Junge. C.E., Air chemistry and Radioactivity, Academic press Inc., New York, USA, 111-208, (1963).
6. Moorthy, K.K., P. R. Nair, B.S.N. Prasad, et al., 'Results from the MWR network of IMAP', Indian J. Radio & Space Phys., 22, 243-258, (1993).
7. Jayaraman A and B.H. Subbaraya, 'In situ measurements of aerosol extinction profiles and their spectral dependencies at tropospheric level', Tellus (B), 45, 473-478, (1993).
   Patra, P.K., Lal, S., Subbaraya, B.H., et al., 'Observed vertical profile of sulphur hexafluoride (SF6) and its atmospheric applications'. J. Geophys. Res. 102, 8855-8859, (1997).
8. Babu, S.S., K. K. Moorthy, and S.K. Satheesh, 'Aerosol black carbon over Arabian Sea during inter monsoon and summer monsoon seasons', Geophys. Res. Lett., 31(6), L06104, 10.1029/2003GL018716, (2004).
   V. Vinoj, S. S. Babu, S. K. Satheesh, K. K. Moorthy, and Y. J. Kaufman, 'Radiative forcing by aerosols over the Bay of Bengal region derived from shipborne, island-based, and satellite (Moderate-Resolution Imaging Spectroradiometer) observations', J. Geophys. Res., 109, D5, D05203, 10.1029/2003JD004329, 2004Moorthy et al,. (2005).
   Moorthy, K.K., S.S. Babu and S.K. Satheesh, 'Aerosol characteristics and radiative impacts over the Arabian Sea during inter-monsoon season: Results from ARMEX field campaign', Journal of the Atmospheric Sciences, 62, 192-206, (2005).
9. Moorthy, K.K., P.R. Nair and B. V. K. Murthy, 'Size distribution of coastal aerosols: Effects of local sources and sinks', J. Appl. Meteorol., 30,844-852,(1991).
   Moorthy, K. K. and S.K. Satheesh, 'Characteristics of aerosols over a remote island, Minicoy in the Arabian Sea: Optical properties and retrieved size characteristics', Quart. J. Roy. Meteorol. Soc., Part A, 126 (562), 81-109, (2000).
   Moorthy, K. K., S.S. Babu and S.K. Satheesh, 'Temporal heterogeneity in aerosol characteristics and the resulting radiative impact at a tropical coastal station- I: Microphysical and Optical properties', Annales Geophysicae, 25, 2293- 2308, (2007).
   Babu, S.S., K. K. Moorthy and S.K. Satheesh, 'Temporal heterogeneity in aerosol characteristics and the resulting radiative impact at a tropical coastal station- II: Direct short wave radiative forcing', Annales Geophysicae, 25, 2309-2320, (2007).
10. George S. K., P. R. Nair, K. Parameswaran, S. Jacob, A. Abraham, 'Seasonal trends in chemical composition of aerosols at a tropical coastal site of India', J. Geophys. Res., 113, D16209, doi:10.1029/2007JD009507, (2008).
11. Rastogi N and M M Sarin, 'Quantitative chemical composition and characteristics of aerosols over western India: one year record of temporal variability', Atmos. Env., 43, 3481-3488, (2009).
12. Moorthy et al (2007), op. cit..
13. Rastogi and Sarin, (2009), op. cit..
14. Ramachandran, S. (2007), 'Aerosol optical depth and fine mode fraction variations deduced from Moderate Resolution Imaging Spectroradiometer (MODIS) over four urban areas in India', J. Geophys. Res., 112, D12607, doi:10.1029/2007JD008500.
    Ramachandran, S., and R. Cherian (2008), 'Regional and seasonal variations in aerosol optical characteristics and their frequency distributions over India during 2001-2005', J. Geophys. Res., 113, D11201, doi:10.1029/2007JD009070.
15. Saha, A., K.K. Moorthy, and K. Niranjan, 'Interannual Variations of Aerosol Optical Depth over Coastal India: Relation to Synoptic Meteorology', J. Appl. Meterol. 44, (7), 1066–1077, (2005).
16. Moorthy, K.K., S.S.Babu and S.K. Satheesh, 'Aerosol characteristics and radiative impacts over the Arabian Sea during inter-monsoon season: Results from ARMEX field campaign', Journal of the Atmospheric Sciences, 62, 192-206, (2005).
    Beegum, S.N., K.K. Moorthy, V.S.Nair, S. S. Babu, et al., 'Characteristics of spectral aerosol optical depths over India during ICARB', Journal of Earth System Science Vol.117, S1, 303-313, (2008).
17. Moorthy, K. K., S. S. Babu and S.K. Satheesh, 'Aerosol spectral optical depths over the Bay of Bengal: Role of transport', Geophysical Research Letters, 30 (5), 1249, 53-1 to 53-4, doi: 10.1029/2002GL016520, (2003).
    Moorthy, K.K., and S.S.Babu, 'Aerosol black carbon over Bay of Bengal, Observed from an island location, Port Blair: Temporal features and long-range transport', Journal of Geophysical Research, 111, D17205,doi: 10.1029/2005JD006855. (2006).
    Nair, V. S., S.S.Babu and K. K. Moorthy, 'Aerosol characteristics in the marine atmospheric boundary layer over the Bay of Bengal and Arabian Sea during ICARB: Spatial distribution, latitudinal and longitudinal gradients', Journal of Geophysical Research, 113, D15208, doi:10.1029/2008JD009823, (2008).
18. Nair et al., (2008), op. cit..

19. Ibid.
20. K. Niranjan, B. M. Rao, P.S. Brahmanandam, B.L. Madhavan, V. Sreekanth and K. Krishna Moorthy, 'Spatial characteristics of aerosol physical properties over the northeastern parts of peninsular India', Ann. Geophys., 23, 3219-3227, (2005).
Dey S., S. N. Tripathi, R. P. Singh, B. N. Holben, 'Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin', J. Geophys. Res., 109, D20211, doi:10.1029/2004JD004924, (2004).
Beegum et al., (2008), op. cit..
21. Beegum, S. N., K. K. Moorthy, S. S. Babu, R. R. Reddy, and K. R. Gopal, 'Large scale modulations of spectral aerosol optical depths by atmospheric planetary waves', Geophysical Research Letters, 36, L03810, doi:10.1029/2008GL036509, (2009).
22. Ibid.
23. Aloysius, M., M. Mohan, S.S. Babu, et al., "Influence of circulation parameters on AOD variations over Bay of Bengal during ICARB", J. Earth System Sci, 117, S1, 353 — 360, (2008).
24. Moorthy et al., (2001), op. cit.
Vinoj et al., (2004), op. cit..
Moorthy et al., (2005a), op. cit..
25. Moorthy et al., (2005b), op. cit..
26. Moorthy et al., (2004), op. cit..
Gadhavi H and A Jayaraman, 'Airborne lidar studies of vertical distribution of aerosols over Hyderabad, an urban cite in central India and its implication for radiative forcing calculations', Ann. Geophys. 24, 1-10, (2006).
Babu et al., (2008), op. cit..
27. Moorthy et al., (2008), op. cit..
28. A compendium of the preliminary findings is available in the July issue of the Journal of Earth System Sciences, (2008).
29. Nair, V.S, K.K.Moorthy, D. P. Alappattu, et al., 'Wintertime aerosol characteristics over the Indo Gangetic Plain (IGP): Impacts of local boundary layer processes and long-range transport', Journal of Geophysical Research, 112, D13205, doi: 10.1029/2006JD008099, (2007).
30. Satheesh,S.K., K. K. Moorthy, S.S.Babu, V. Vinoj and C.B.S.Dutt, 'Climate implications of large warming by elevated aerosol over India', Geophysical Research Letters, 35, L19809, doi: 10.1029/2008GL034944, (2008).
Babu et al., (2008), op. cit..
31. Lau, K. M., Kim, M. K. and Kim, K. M., 'Aerosol induced anomalies in the Asian summer monsoon- the role of the Tibetan Plateau', Climate Dynamics 26, 855–864, DOI 10.1007/s00382-006-0114-z (2006).
32. Naja, M. and S. Lal, (1996), 'Changes in surface ozone amount and its diurnal and seasonal patterns from 1954-55 to 1991–93 measured at Ahmedabad (23N), India', Geophys. Res. Letters, Vol. 23, p.81.
33. Naja, M. and S. Lal, (2002), 'Surface ozone and precursor gases at Gadanki (13.5N, 79.2E), a tropical rural site in India'. J. Geophys. Res. Vol. 107, p. 8-1 to 8-13.
34. Sahu, L. K., and S. Lal (2006), 'Distributions of C2-C5 NMHCs and related trace gases at a tropical urban site in India'. Atmos. Env., Vol. 40, p.880-891.
R. Rengarajan, R, M.M. Sarin and A K Sudheer, 'Carbonaceous and inorganic species in atmospheric aerosols during wintertime over urban and high-altitude sites in North India', J. Geophys. Res, 112,D21307,doi:10.1029/2006JD008150, (2007).
35. Chand D., Lal S., Naja M., 'Variations of ozone in the marine boundary layer over the Arabian Sea and the Indian Ocean during the 1998 and 1999 INDOEX campaigns'. J. Geophys. Res., Vol. 108, p.doi:10.1029/2001JD001589, (2003).
Lal S., L. K. Sahu and S. Venkataramani (2007), 'Impact of transport from the surrounding continental regions on the distributions of ozone and related trace gases over the Bay of Bengal during February 2003', J. Geophys. Res., Vol. 112, D14302, doi:10.1029/2006JD008023.
Lal, S., Chand D., Sahu, L. K., et al., 'High levels of ozone and related gases over the Bay of Bengal during winter and early spring of 2001', Atmos. Env., Vol. 40, p.1633-1644, (2006).
Gupta S., S. Lal, S. Venkataramani, T.A. Rajesh and Y.B. Acharya, 'Variability in the vertical distribution of ozone over a subtropical site in India during a winter month',
Journal of Atmospheric and Solar-Terrestrial Physics, 69, 1502-1512, (2007).
36. Chandra S, Satheesh SK, Srinivasan, J, 'Can the state of mixing of black carbon aerosols explain the mystery of 'excess' atmospheric absorption?', Geophys. Res. Lett., 31 (19): Art. No. L19109, doi:10.1029/2004GL020662, (2004).
37. Jacobson, M Z, 'Strong radiative heating due to mixing state of black carbon in the atmospheric aerosols', Nature 409, 695–697, (2001).

Further references

- Arking, A. (1996), 'Absorption of solar energy in the atmosphere: Discrepancy between model and observations', Science, 273, 779–782, (1996).
- Rajesh et al.(2009), 'Variations in surface ozone at a high altitude site (Nainital, 29.4 N, 79.5 E, 1958 m amsl) in the Central Himalayas', submitted to J. Geophys. Res.
- Satheesh, S.K., S. Deepshikha, J. Srinivasan and Y.J. Kaufman (2006b), 'Large Dust Absorption of Infrared Radiation over Afro-Asian Regions: Evidence for Anthropogenic Impact', IEEE Geosci. Rem. Sens. Lett., 111, D08202, doi:10.1029/2005JD006374.
- Sheel V., S. Lal, A. Richter and J. P. Burrows (2009), 'Comparison of satellite observed tropospheric NO2 over India with model simulations', submitted to Atmos. Env.

Acknowledgements

We wish to thank ISRO for its extensive support, encouragement and guidance, particularly from its Chairman G. Madhavan Nair. We acknowledge programmatic support from R. Sridharan, and V. Jayaraman. This programme is pursued with the untiring and sustained enthusiasm and cooperation of a large number of colleagues and collaborators from several laboratories and institutions spread across the country. The authors thank all of them and acknowledge their valuable inputs in finalizing this article.

Projecting globally, planning locally: a progress report from four cities in developing countries

1. Mehrotra, Shagun, Claudia Natenzon, Ademola Omojola, Regina Folorunsho, Joseph Gilbridge, and Cynthia Rosenzweig, Framework for Urban Climate Risk Assessment. p3-4.
2. David Dowall, personal communication, 23 June 2009.
3. These local-level experiences help UN-HABITAT's CCCI to develop capacity-building tools, and inform national and international-level activities. For more information on the CCCI, see www.unhabitat.org, and click on 'Programmes', then 'Sustainable Urban Development Network'.
4. Definitions of city size are per UN-HABITAT. Around 2007, for the

first time the world's urban population surpassed the rural. More than 53 per cent of the world's urban population now lives in small cities, while another 22 per cent live in intermediate-sized cities. Between 2000-2015, intermediate cities are projected to grow at a faster rate than other sizes. See UN-HABITAT, State of the World's Cities 2006/7, p4-6.

5. Additional classes of urban management tools include market-based instruments such as tax and insurance-based incentives, and information dissemination. In addition to urban management tools per se, officials also use climate projections for disaster risk management purposes (to develop a hurricane early warning system); such applications lie outside the scope of the present paper.
6. Depending on the country, planners enjoy access to only a portion of the full range of urban management tools that are theoretically possible. In many countries such responsibilities are divided up between different levels of government; the resulting need to coordinate efforts complicates the urban management challenge.
7. In defence of this position, representatives of those cities can rightly point out that it is the developed and not the developing world that accounts for the great majority of GHG emissions.
8. For more on city-level baseline studies and commitments, see Catalogue of City Commitments to Combat Climate Change at www.iclei.org. For an example of project and building-level emissions analyses, see Debra Roberts, 'Thinking Globally, Acting Locally: Institutionalizing Climate Change at the Local Government Level in Durban, South Africa', Environment and Urbanization, (2008), 20: 521-37.
9. Some current research implies ongoing uncertainty as to the extent of SLR that is likely to occur in the 21st century. For the 'large uncertainty' in estimates of the contribution of melting glaciers and ice caps to SLR 1993-2003, see Nicholas Barrand et al,. 'Instruments and Methods: Optimizing photogrammetric DEMs for glacier volume change assessment using laser-scanning derived ground-control points', Journal of Glaciology, (2009), 55: 106-16.
10. In the Philippines the Department of Environment and Natural Resources, along with the university-based Manila Observatory, has already published a country-level map of 'Combined Risk to Climate Disasters'. Updated climate change projections are expected. Such national level modelling may be particularly important in a country like the Philippines, where projected SLR may vary considerably in different parts of the archipelago, than in countries with less extensive coastlines. See Parry et al (eds.), Contribution of Working Group II to the Fourth Assessment Report of the IPCC, p484.
11. The two models that projected drier conditions in Ecuador were a model developed by the Canadian Centre for Climate Modelling and Analysis (CCCMA), and U.S. National Oceanic Atmospheric Administration's TL959 model. The three models projecting wetter conditions were from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Hadley Centre Coupled Model, Version 3 (HADCM3), and the ECHAM model from the Max Planck Institute for Meteorology. Note that HADCM3 and ECHAM were based on regional platforms – the PRECIS regional climate modelling system from the Hadley Centre, and the Eta atmospheric model as used by the Brazilian Center for Weather Forecast and Climate Studies (CPTEC).
12. This Ecuador-level circumstance of disagreement between localized precipitation projections generally mirrors two findings in the Contribution of Working Group II to the Fourth Assessment Report of the IPCC (p. 149). First, that, whereas model simulations showed increases in all regions and seasons in temperatures, models indicated both positive and negative changes in precipitation. And second, that 'almost all model-simulated temperature changes, but fewer precipitation changes, were statistically significant….'
13. A team of consultants upon which the author served experienced this difficulty recently in Sana'a, Yemen, while trying to carry out a probabilistic hazard analysis with flood modelling. This capital city suffers from flash floods and landslides. Obviously it is challenging to model flash floods that result from short cloudbursts, with daily but not hourly rainfall data.
14. See H. Cleugh et al,. 'Climate Information for Improved Planning and Management of Mega Cities'. Unpublished draft.
15. See Raymond Burby, ed., Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities, p123.
16. UN-HABITAT's conclusions echo two of the calls for action that appear in the Contribution of Working Group II to the Fourth Assessment Report of the IPCC (p162): 'new methods and tools appropriate for regional and local application', and 'provision of improved climate predictions for near-term planning horizons… at the scales of river catchments and communities'.

Further references

- The Cities in Climate Change Initiative is funded by the Government of Norway; UN-HABITAT is the executing agency. The Urban Environmental Planning Branch of UN-HABITAT thanks Rodrigo Sierra, Silva Magaia, Paulo Junior, and Shuaib Lwasa for comments that improved the manuscript.
- In addition to draft assessments of cities and climate change, prepared by the CCCI team for Kampala (Uganda), Maputo (Mozambique), Sorsogon City (the Philippines) and Esmeraldas (Ecuador; publication forthcoming), the present paper references the following documents:

Barrand, Nicholas, Tavi Murray, Timothy James, Stuart Barr, and Jon Mills, (2009), 'Instruments and Methods: Optimizing photogrammetric DEMs for glacier volume change assessment using laser-screening derived ground-control points', Journal of Glaciology 55 (2009), 106-16.

Burby, Raymond J. (ed.), (1998), Cooperating with Nature: Confronting Natural Hazards with Land-Use Planning for Sustainable Communities. Washington, D.C.: Joseph Henry Press.

Cleugh, H., R. Emmanuel, W. Endlicher, E. Erell, G. McGranahan, G. Mills, E. Ng, A. Nickson, J. Rosenthal, and K. Steemer. 'Climate Information for Improved Planning and Management of Mega Cities'. Unpublished draft.

Parry, M.L., et al (eds.), (2007), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Roberts, Debra. (2008), 'Thinking Globally, Acting Locally: Institutionalizing Climate Change at the Local Government Level in Durban, South Africa'. Environment and Urbanization 20 (2008), 521-37.

UN-HABITAT, (2006), State of the World's Cities 2006/7. London: Earthscan.

- For more information contact Robert.kehew@unhabitat.org, Human Settlements Advisor, UN-HABITAT, Nairobi, Kenya.

AsiaFlux – sustaining ecosystems and people through resilience thinking

1. www.asiaflux.org
2. www.resalliance.org

Research, implementation and use of climate information in mountainous regions: a collaboration between Switzerland and Peru

1. The full authors list is as follows:
C. Huggel and N. Salzmann, C. Jurt, Department of Geography, University of Zurich, Switzerland
L. Angulo and C. Robledo, Intercooperation Cusco, Lima, Peru, and Berne, Switzerland
P. Calanca, Agroscope Reckenholz-Tänikon, Research Station ART, Zurich, Switzerland
A. Díaz, Servicio Nacional de Meteorología e Hidrología, Senamhi, Lima, Peru
H. Juárez, Centro Internacional de la Papa, Lima, Peru
T. Konzelmann, Federal Office of Meteorology and Climatology, MeteoSwiss, Zurich, Switzerland
P. Lagos, A. Martínez, Instituto de Geofísico, Lima, Peru
M. Rohrer, Meteodat GmbH, Zurich, Switzerland
W. Silverio, University of Geneva, Switerland
M. Zappa, Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf and Davos, Switzerland
2. Bradley, R.S., Vuille, M., Diaz, H.F. Vergara, W. 2006 Threats to water supply in the tropical Andes. Science, 312, 5781, 1755-1756. Magrin, G., C. Gay García, D. Cruz Choque, J.C. Giménez, A.R. Moreno, G.J. Nagy, C. Nobre, A. Villamizar, 2007. Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds.,Cambridge University Press, Cambridge, UK, 581-615.
3. Lagos, P. 2007. Peru's approach to climate change in the Anden mountain region. Mountain Research and Development, 27, 28-31.
4. Orlove, B. 2008. Abandoned villages: The herdsman in the Peruvian Andes know that they cannot adapt to climate change (in German). Kulturaustausch, II, 30-31.
5. Diaz A., Rosas G., Avalos G., Oria C., Acuña D., Llacza, A., and Miguel R. 2009. Escenarios climáticos en el Peru para el año 2030. Proyecto SCNCC, Segunda Comunicación Nacional del Cambio Climático. Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), and Ministerio del Ambiente, Lima Peru.
6. Vuille, M., Bradley, R.S., Werner, M., Keimig, F. 2003. 20th century climate change in the tropical Andes: observations and model results. Climatic Change, 59, 75-99.
7. Rosas, G., Avalos, G., Díaz, A., Oria, C., Acuña, D., Metzger, L. and Miguel, R. 2007. Escenarios de cambio climático en la cuenca de los ríos Mantaro y Urubamba para el año 2100. Proyecto Regional Andino de Adaptación — PRAA, Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), Lima Peru, pp. 124.
8. Vuille et al., 2003 Op. cit..
9. Urrutia, R., Vuille, M. 2009. Climate change projections for the tropical Andes using regional climate model: temperature and precipitation simulations fo the end of the 21st century. Journal of Geophysical Research. 114, D02108, doi:10.1029/2008JD011021.
10. Martínez, A.G., Takahashi, K., Núñez, E., Silva, Y., Trasmonte, G., Mosquera, K., and Lagos, P. 2008 A multi-institutional and interdisciplinary approach to the assessment of vulnerability and adaptation to climate change in the Peruvian Central Andes: problems and prospects. Advances in Geosciences, 14, 257-260.
11. Dessai, S., Hulme, M. 2007. Assessing the robustness of adaptation decisions to climate change uncertainties: a case study on water resources management in the East of England. Global Environmental Change, 17, 59-72.

An overview of the European Community climate research programme

1. The Communication from the European Commission 'Towards a comprehensive climate change agreement in Copenhagen' is available in all EU languages via http://eur-lex.europa.eu/LexUriServ/LexUriServ. do?uri=CELEX:52009DC0039:EN:NOT
2. Information on the 'EU Climate-Energy package' is available via http://ec.europa.eu/environment/climat/climate_action.htm
3. The white paper 'Adapting to climate change: towards a European framework for action' is available in all EU languages via http://eur-lex.europa.eu/LexUriServ/LexUriServ. do?uri=CELEX:52009DC0147:EN:NOT
4. Including the activities of the European Commission Joint Research Centre.
5. See 'European Research Framework Programme: Research on climate change, 2009', European Commission, EUR 23609
6. 'Understanding the Dynamics of the Coupled Climate System': http://dynamite.nersc.no/
7. 'ENSEMBLES' project: http://www.ensembles-eu.org/
8. 'African Monsoon Multidisciplinary Analyses' project: https://www.amma-eu.org/
9. 'Comprehensive Modelling of the Earth system for better climate prediction and projection' project. Contact details: http://cordis.europa.eu/fp7/projects_en.html
10. http://www.earthobservations.org/ag_members.shtml
11. http://www.gmes.info/
12. 'Adaptation and Mitigation Strategies' project: http://www.adamproject.eu/
13. 'Full Costs of Climate Change- ClimateCost' project. Contact details: http://cordis.europa.eu/fp7/projects_en.html
14. 'Climate Change — Terrestrial Adaption and Mitigation in Europe (CCTAME)' project: http://www.cctame.eu

The World Climate Research Programme: the scientific foundation for climate information in the 21st century

1. Giorgi et al., 2009.
2. As summarized in Taylor et al., 2008.
3. WMO, 2007; Eyring et al., 2007.

The importance of high quality regional scientific information in coping with global climate change

1. Auer I, Böhm R, Jurkovic A, Lipa W, Orlik A, Potzmann R, Schöner W, Ungersböck M, Matulla C, Briffa K, Jones PD, Efthymiadis D, Brunetti M, Nanni T, Maugeri M, Mercalli L, Mestre O, Moisselin J-M, Begert M, Müller-Westermeier G, Kveton V, Bochnicek O, Stastny P, Lapin M, Szalai S, Szentimrey T, Cegnar T, Dolinar M, Gajic-Capka M, Zaninovic K, Majstorovic Z, Nieplova E, 2007. HISTALP – Historical instrumental climatological surface time series of the greater Alpine region 1760-2003. International Journal of Climatology 27: 17-46
2. Ibid.
3. Ibid.
4. World Glacier Monitoring Service WGMS (2008): Global Glacier Changes: facts and figures. UNEP
5. Schöner W., Auer I. and Böhm R. 2000. 'Climate variability and

glacier reaction in the Austrian eastern Alps'. Annals of Glaciology, Vol. 31, 31-38.
Schöner W., Böhm R. 2007. 'A statistical mass-balance model for reconstruction of LIA ice mass for glaciers in the European Alps'. Annals of Glaciology, Vol. 46, 161-169.
6. Koboltschnig GR, Schoener W, Zappa M, Kroisleitner C, Holzmann H. 2008. Runoff modelling of the glacierized alpine Upper Salzach basin (Austria): Multi-criteria result validation. Hydrological Processes 22: 3950–3964. DOI: 10.1002/hyp.7112
7. Ibid.
Koboltschnig GR, Schöner W, Zappa M, Holzmann H. 2007. 'Contribution of glacier melt to stream runoff: if the climatically extreme summer of 2003 had happened in 1979...'. Annals of Glaciology 46: 303-308
8. Darnhofer I, Auer I, Gaube V, Kirchengast A, Prutsch A, Seebacher U, Vospernik S, Weigelhofer G. 2007. ForschungsBildungsKooperationen: vom Konzept zur Umsetzung — Transdisziplinäre Forschung mit Kindern und Jugendlichen. www.ccp-online.org/en/aim.php

Simple indices for the monitoring of weather and climate extremes

1. Solomon S., G.-K. Plattner, R. Knutti, and P. Friedlingstein, 2009: Irreversible climate change due to carbon dioxide emissions, PNAS, doi: 10.1073/pnas.0812721106.
IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 996 pp.
2. Zhang, X. F. W. Zwiers, and T. C. Peterson, 2008: The adaptation imperative: is climate science read? WMO Bulletin 57(2), 103-108.
3. Klein Tank, A. M.G., F.W. Zwiers, and X. Zhang, 2009: Guidelines on "Analysis of extremes in a changing climate in support of informed decisions for adaptation", WMO.
4. The CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI, see www.clivar.org/organization/etccdi/etccdi.php) is jointly sponsored by the World Meteorological Organization (WMO) Commission for Climatology (CCl), the World Climate Research Programme (WCRP) project on Climate Variability and Predictability (CLIVAR) and, since 2006, the Joint WMO-Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Culture Organization (UNESCO) Technical Commission for Oceangraphy and Marie Meteorology (JCOMM). The expert team has mandates to:
Provide international coordination and help organize collaboration on climate change detection and indices relevant to climate change detection
Further develop and publicize indices and indicators of climate variability and change from the surface and sub-surface ocean to the stratosphere
Encourage the comparison of modelled data and observations.
5. Peterson, T.C., and M. J. Manton, 2008: Monitoring changes in climate extremes: a tale of international collaboration, BAMS, doi: 10.1175/2008BAMS2501.1
6. Allexander, L., and coauthors, 2006: Global observed changes in daily climate extremes of temperature and precipitation. J. Geophysics. Res., 111, doi: 10.1029/2005JD006290.
7. Christidis, N., et al., 2005: Detection of changes in temperature extremes during the second half of the 20th century. Geophys. Res. Lett., 32, L20716, doi: 10.1029/2005GL023885.
8. Zhang, X, G. C. Hegerl, F.W. Zwiers, 2005: Avoiding inhomogeneity in percentile-based indices of temperature extremes. J. Climate, 18, 1641-1651.
9. Zhang, X., F.W. Zwiers, G. Hegerl, 2008: The influence of data precision on the calculation of temperature percentile indices. International Journal of Climatology, doi: 10.1002/joc.1738.
10. A list of classical examples of inhomogeneities in observational series can be found at http://cccma.seos.uvic.ca/ETCCDI/example.shtml
11. Wang, X.L., 2008: Accounting for autocorrelation in detecting mean-shifts in climate data series using the penalized maximal t or F test. J. App. Meteor. Climatol., 47, 2423-2444. doi: 10.1175/2008JAMC1741.1
12. WMO Statement to the plenary of SBSTA-27 at COP-13, Bail, Indonesia, 03-14 December 2007.
13. See Table 1 of Peterson and Manton, 2008, op. cit., for a list of regional workshops.
14. Peterson and Manton, 2008, op. cit..

Further references

- Aguilar E. and Co-authors, 2009: Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955-2006, Journal of Geophysical Research, doi: 10.1029/2008JD011010.

Better climate information for a better future – climate research

1. www.climate.go.kr
2. Available free of charge at: www.climate.go.kr

Climate watch – purpose and requirements

1. IPCC, 2007: Climate Change 2007. Synthesis report. Contributions of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland (www.ipcc.ch/ipccreports/assessments-reports.htm)
2. Ogallo, L.A. , P. Bessemoulin, J.P. Céron, S. Mason, S.J. Connor, 2008: Adapting to Climate Variability and Change: the Climate Outlook Forum process. WMO Bulletin, Vol 57(2), 93-102
3. Zhai, P. et al., 2005 : Guidelines on climate watches. WCDMP No. 62 , WMO-TD No. 1378 (www.wmo.int/pages/prog/wcp/wcdmp/wcdmp_series/index_en.html)
4. WMO (a): Annual Statements on the Status of Global Climate (www.wmo.int/pages/prog/wcp/wcdmp/statement/wmostatement_en.html)
5. WMO (b): El Niño update (www.wmo.int/pages/prog/wcp/wcasp/enso_updates.html)
6. Kousky, V. E. and R. W. Higgins, 2004: An Alert Classification System for Monitoring and Assessment of the ENSO Cycle. Weather and Forecasting, 22, 353–371
7. WMO (c), 2008: Guidelines for the Designation and Establishment of Regional Climate Centres (www.wmo.int/pages/prog/www/DPFS/Meetings/ICT-DPFS_Montreal2008/documents/GuidanceEstablishmentDesignationWMORCCs.pdf)

IV
RISK GOVERNANCE AND MANAGEMENT

Managing risk in a changing climate

1. Power, S., B. Sadler and N. Nicholls, 'The influence of climate science on water management in Western Australia', Bulletin of the American Meteorological Society, (2005) p834-844.
2. Connor, S.J. and M. Thomson. 'A Framework for Field Research in Africa: Malaria Early Warning Systems'. Roll Back Malaria Campaign, World Health Organization. Rome, (2001).
3. 'Climate Change and Variability in the Expansion of the Agricultural Frontier in the Southern Cone'. A project funded by the Sustainable Energy and Climate Change Initiative of the Inter-American Development Bank. PIs from: IRI, INIA-Chile, INIA-Uruguay, INTA-Argentina, MAGA-Paraguay.
4. IRI. 'Index Insurance for Climate Risk Management and Poverty Reduction'. Climate and Society Publication No. 2. (Palisades, NY: International Research Institute for Climate and Society, 2009).
5. IRI. 'A Gap Analysis for the Implementation of the Global Climate Observing System Programme in Africa'. International Research Institute for Climate and Society. (Palisades, NY: 2006).

6. Acknowledgements

- The perspectives offered in this article derive from the collective experience of the staff of the International Research Institute for Climate and Society, which for the past 13 years has been working to develop the capability to better manage climate related risks and opportunities toward sustainable development goals, with emphasis on developing countries. We represent and advocate a strongly science-based multidisciplinary approach to climate risk management that provides innovation in climate information and risk management strategies, engages in demonstration, outreach, capacity building, and education relating to climate risk management/adaptation. A crucial part of IRI's work consists of direct engagement with partners in specific decision and policy settings (mostly in developing countries), where innovations are developed and demonstrated. Much of our current perspective has been shaped by the interactions with stakeholders and partners 'on the ground', spanning many countries, sectors, and disciplines.
- Special thanks to Cathy Vaughan in the preparation of this paper.

A Nordic perspective on climate change and dam safety

1. The national Swedish research on climate change and design floods is financed by the Swedish dam safety authority (Svenska Kraftnät) and the power industry via Elforsk. The Nordic co-operation, within the CES-project, is financed by Nordic Energy Research.

Further references

- A summary of the Nordic co-operation on Climate change and renewable energy resources, of which design flood is a part, can be found in Fenger (ed. 2007) Impacts of Climate Change on Renewable Energy Sources — their Role in the Nordic Energy System. Nord 2007:003. Nordic Council of Ministers, Copenhagen.
- The new edition of the Swedish guidelines for design flood determination can be found in Swedenergy, Svenska Kraftnät and SveMin (2007). Swedish guidelines for design flood determination for dams — New edition 2007. Available from the Swedish dam safety authority (Svenska Kraftnät) at www.svk.se

Climate network for disaster mitigation: lessons learned and future directions

1. Howard Kunreuther and Erwann Michel-Kerjan, (2008), 'A Framework for Reducing Vulnerability to Natural Disasters: Ex Ante and Ex Post Considerations', Risk Management and Decision Processes Center, The Wharton School of the University of Pennsylvania.
2. Hoyois, P., R. Below, J-M. Scheuren, D. Guha-Sapir, (2007), Annual Disaster Statistical Review — Numbers and Trends, 2006, Catholic University of Louvain, Brussels.
3. Kunruether and Michel-Kerjan, op. cit..
4. Emanuel, K., (2005), 'Increasing destructiveness of tropical cyclones over the past 30 years', Nature 436(4): p686-688
   Webster, P., G.J. Holland, J. Curry and H.R. Chang, (2005), 'Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment', Science, 309: p1844-1846, September 16, 2005.
5. Park, C.-K, (2004), Current status of APEC Climate Network, APEC Climate Network Meeting, Busan, Korea, 9-12 November 2004.
6. http://cis.apcc21.net
7. http://clik.apcc21.net

Preparing for climate change by reducing disaster risks

1. Opening video address to the Second Session of the Global Platform for Disaster Risk Reduction, Geneva, 16-19 June 2009.
2. Disaster statistics and summaries are available from: (i) Centre for Research on the Epidemiology of Disasters (CRED), at website http://www.cred.be; (ii) Munich Reinsurance, at website http://www.munichre.com/en/ts/geo_risks/natcatservice/default.aspx; and (iii) UNISDR, at website http://www.unisDrorg/disaster-statistics/introduction.htm.
3. Global Assessment Report on Disaster Risk Reduction; Risk and poverty in a changing climate. United Nations, (2009). 208pp. See www.preventionweb.net/gar09.
4. Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters (HFA). See website http://www.unisDrorg/eng/hfa/hfa.htm.
5. UNISDR Terminology on Disaster Risk Reduction (2009). UN International Strategy for Disaster Reduction, 2009. Available in the five UN languages at website www.unisDrorg/eng/terminology/terminology-2009-eng.html.
6. Global Platform for Disaster Risk Reduction, second session. UN International Strategy for Disaster Reduction, 2009. See Chair's Summary at http://www.preventionweb.net/globalplatform/2009/
7. IPCC Fourth Assessment Report, Working Group I Report "The Physical Science Basis", Intergovernmental Panel on Climate Change, 2007. See website http://www.ipcc.ch/ipccreports/ar4-wg1.htm
8. IPCC Fourth Assessment Report, Working Group II Report "Impacts, Adaptation and Vulnerability". Intergovernmental Panel on Climate Change, 2007. See website http://195.70.10.65/ipccreports/ar4-wg2.htm.
9. Scoping Paper — IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. IPCC-XXX/Doc.14, Intergovernmental Panel on Climate Change. See website http://195.70.10.65/meetings/session30/doc14.pdf. See also Proposal for an IPCC special report on managing the risk of extreme events to advance climate change adaptation, Government of Norway and UNISDr 2008. IPCC-29, Document 6. See website http://www.ipcc.ch/meetings/session29/doc6.pdf, and http://www.preventionweb.net/english/professional/publications/v.php?id=8150.

10. Bali Action Plan. Agreed at the 13th Conference of the Parties (COP), Bali, December 2007. FCCC/CP/2007/6/Add.1*, Page 3, Decision 1/CP.13. See website http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=3.

Coping with drought in Slovenia

1. www.dmcsee.org
2. http://drought.unl.edu/plan/handbook/risk.pdf
3. www.iamz.ciheam.org/medroplan/
4. www.cnlsd.it/documenti/143948_manuale_2006_42.pdf
5. www.cosis.net/abstracts/EGU05/02530/EGU05-J-02530.pdf

Heat health warning systems — an important tool for adaptation to climate change

1. IPCC, 2007.
   IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.
2. Koppe et al., 2004.
   Koppe, C; Kovats, RS; Jendritzky, G; Menne, B (2004): Heat-waves: Risks and Responses. World Health Organization. Regional Office for Europe. Health and Global Environmental Change, Series No. 2. Kopenhagen, Denmark.
3. Kovats & Koppe, 2005.
   Kovats, RS; Koppe, C (2005): Heat waves: past and future impacts on health. In: Ebi, KL; Smith, JB; Burton, I: Integration of Public Health with Adaptation to Climate Change. S. 136-160.
4. Koppe, C; Jendritzky, G (2005): Inclusion of short-term adaptation to thermal stresses in a heat load warning procedure. Meteorologische Zeitschrift, Vol.14, No. 2, 271-278.
5. Gussmann, V (2009): Survey of the Regierungspraesidium Giessen — personal communication.

Climate data and information for a multi-sectorial vulnerability analysis

- SMHI 2007, Climate indices for vulnerability assessments, Reports Meteorology and Climatology No 111, SMHI SE-601 76 Norrköping, Sweden. (Also available at www.smhi.se/content/1/c6/03/08/47/attatchments/RMK111.pdf , last read on 15 June 2009)
- SOU 2007:60, Sweden facing climate change - threats and opportunities, Swedish Government Official Report, Ministry of the Environment, The Commission on Climate and Vulnerability (also available at www.sweden.gov.se/sb/d/574/a/96002 , last read on 15 June 2009).

Infrastructure and disaster risk management under changing climate conditions

1. Red Cross, (2008), ICRC Annual Report 2008, International Committee of the Red Cross, Geneva.
2. World Bank, (2004), 'Natural Disasters: Counting the Cost', World Bank, Washington, DC, USA.
3. Emergency Management Ontario, (2004), 'Guidelines for Provincial Emergency Management Programs in Ontario', Government of Ontario, Queens Park, Toronto, Ontario.
   Auld, H., D. MacIver, J. Klaassen, N. Comer and B. Tugwood, (2006), 'Planning for Atmospheric Hazards and Disaster Management under Changing Climate Conditions', Occasional Paper 12, Adaptation and Impacts Research Division, Environment Canada, Toronto, Canada.
4. Emergency Management Ontario, op. cit..
5. www.hazards.ca
6. Auld et al., (2006), op. cit..
   Auld, H, (2008)(a), 'Disaster Risk Reduction under current and changing climate conditions', WMO Bulletin 57 (2), Geneva.
7. Auld et al., (2006), op. cit..
8. Auld, H, 2008(b), 'Adaptation by Design: The impact of changing climate on infrastructure', Public Works and Infrastructure, Vol 1: No. 3, Henry Stewart Publications, London, UK, p276-288.
9. Coleman, T., (2002), 'The Impact of Climate Change on Insurance against Catastrophes', Insurance Australia Group, Melbourne, Australia.
10. Ibid.
11. Freeman, P. and K. Warner, (2001), 'Vulnerability of Infrastructure to Climate Variability: How Does This Affect Infrastructure Lending Policies?' Disaster Management Facility of The World Bank and the ProVention Consortium, Washington DC, USA.
    Coleman, T., (2002), op. cit..
12. Freeman and Warner, (2001) op. cit..
    Munich Re, (2005), 'Flooding and Insurance (1997)'. Munich Reinsurance Group, Munich, Germany, Updated by Munich Re for UNFCCC COP events, Montreal, December 2005.
13. Auld, 2008(b), op. cit..
14. WMO, (2006), 'Drought Monitoring and Early Warning: Concepts, Progress and Future Challenges', WMO No. 1006, Geneva, Switzerland.
15. Ibid.
16. Auld, 2008(a), op. cit..
17. ISDR, (2004), 'Progress report on the review of implementation of the Yokohama Strategy and Plan of Action for a Safer World of 1994', Inter-Agency Task Force on Disaster Reduction, United Nations Publications Centre, Geneva, Switzerland.
18. EM-DAT (2006), The OFDA/CRED International Disaster Database (www.em-dat.net), Université Catholique de Louvain, Brussels, Belgium.

V
Mitigation and Adaptation Strategies

Adaptation to climate change in Switzerland

1. IPCC (2007): Climate Change 2007. Fourth Assessment Report of the IPCC.
2. OcCC (2007): Climate Change and Switzerland in 2050.
3. W. Haeberli and R. Hohmann (2008): Climate, Glaciers, and Permafrost in the Swiss Alps 2050: Scenarios, Consequences, and Recommendations. Ninth International Conference on Permafrost. Fairbanks (USA).
4. www.nccr-climate.unibe.ch
5. BAFU (2007): Auswirkungen der Klimaänderung auf die Schweizer Volkswirtschaft (nationale Einflüsse).

Enhancing adaptation to climate change and variability in Iran

1. IPCC Fourth Assessment Report, 2007, IPCC, 2007. Climate Change (2007), "The Physical Science Basis, A Contribution of Working Groups. I, to the Forth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon and the Core Writing Team (eds) ". Cambridge University press. Cambridge United Kingdom , and

New York, USA.
2. Zhang, et al., 2005, Zhang, X., E. Aguilar, S. Sensoy, H. Melkonyan, U. Tagiyeva, N. Ahmed, N. Kutaladze, F. Rahimzadeh, A. Taghipour, T.H. Hantosh, P. Albert, M. Semawi, M. Karam Ali, M. Halal Said Al-Shabibi, Z. Al-Oulan,Taha Zatari, I. Al Dean Khelet, S. Hammoud, M. Demircan, M. Eken, M. Adiguzel, L. Alexander, T. Peterson and Trevor Wallis, 2006: Trends in Middle East Climate Extremes Indices during 1930-2003. J. Geophys. Res., 110, D22104, doi:10.1029/2005JD006181.
3. Noorian, A.M . and F. Rahimzadeh, 2009, Warming in the country and it's impat on the other climatic parameters during 1951-2005. The third Iran water resource management conference, university of Tabriz, Faculty of Civil Engineering, 14-16 october 2008, Tabriz, Iran.
4. Torbali, A., A. Mirzaei, M. Hamzenejad, M. Sisipor, S. Malawi, and A. Pour Asgharian , 2007: Reporto on impacts of Gonu 2007, I. R. of Iranian Meteorological Organization , Hormozgan office , Iran.(In farsi)
5. Salari Fonodi, M.R. and CH. Khajeh Amiri, 2007 : Report on Super Cyclone Goun:2007, I. R. of Iranian Meteorological Organization , Sistan and Balochistan office , Iran .(In farsi)
6. Nazemosadat M. J. and A. R. Ghasemi(2004) Quantifying the ENSO-Related Shifts in the Intensity and Probability of Drought and Wet Periods in Iran Journal of Climate: Vol. 17, No. 20, pp. 4005–4018.
7. WMO-No.984, 2005, The Global Climate System Review 2003, World Meteorological Organization.
8. Rahimzadeh, et.al (2008), Variability of extreme temperature and precipitation in Iran during recent decades, Int. Journal of Climatology, doi:10.1002/joc.1739.

Further references

- Levinson, D. H., State of the climate in 2004, Bulletin of American Meteorological Society, June 2005 .
- Shein K. A., State of the climate in 2005, Bulletin of American Meteorological Society, June 2006 .
- Arcuez, A., State of the climate in 2006, Bulletin of American Meteorological society, June 2007.
- Initial National Communication to UNFCCC, 2003, Prepared by Depatrment of Enviromet, National Climate Change Oddice with cooperation of the United Nations Develpmet Programme (UNDP).

Coping with climate variability and change in Kenya

1. IPCC 2007: Fourth Assessment Report (AR4).
2. Koenraadt, C.J.M. and A.K. Githeko, 2002: Malaria risk in the highlands of western Kenya: an entomological perspective.
   Githeko, A.K., Lindsay, S.W., Confalonieri, U.E., et al., 2000: Climate change and vector-borne diseases: a regional analysis. Bulletin of the World Health Organization, 78 (9), 1136-1147.
   Shanks, G.D., Biomndo, K., Hay, S.I., et al., 2000. Changing patterns of clinical malaria since 1965 among a tea estate population located in the Kenyan highlands. Transactions of the Royal Society of Tropical Medicine and Hygiene, 94 (3), 253-255.
   Shanks, G.D., Hay, S.I., Stern, D.I., et al., 2002. Meteorologic influences on Plasmodium falciparum malaria in the Highland Tea Estates of Kericho, Western Kenya. Emerging Infectious Diseases, 8 (12), 1404-1408.
3. Government of Kenya; 2007: Kenya Vision 2030. Policy document published by Government printers, Nairobi.
4. Muragoli, P.G, 2009: Threats and impacts to our wetlands. Paper presented at the Global Water Partnership workshop on Climate change Resilience, April 2009, Mombasa Kenya.

Further references

- Wandiga, S. 2008: Increasing Community Resilience to Drought in Makueni District. Paper presented at farmers' workshop on the evaluation of socioeconomic benefits of meteorological information and services in the agricultural sector, September 2008, Nairobi, Kenya.
- WWF, 2008: Witness climate change stories published by the Worldwide Fund for Nature.

Icelandic perspectives on adaptation to climate change and variability

1. ©Tómas Jóhannesson, Icelandic Meteorological Office, reproduced with permission.
2. Árnadóttir, Th., B. Lund, W. Jiang, and H. Geirsson, H. Björnsson, P. Einarsson and T. Sigurdsson, 'Glacial rebound and plate spreading: Results from the first countrywide GPS observations in Iceland', Geophys. J. Int.,Volume 177 (2), p691-716,doi: 10.1111/j.1365-246X.2008.04059.x, (2009).

Feasibility issues: mitigation and adaptation to climate change in the Caribbean

1. Chen A. A., D.D. Chadee, S.C. Rawlins, 2006, Climate Change Impact on Dengue: The Caribbean Experience, (ISBN 976-41-0210-7).
2. Prospero, J.M. and J.P. Lamb, 2003, 'African droughts and dust transport to the Caribbean: Climate change and implications', Science, 302: 1024-1027.
3. Lau, K.-M., and K-M Kim, 2007, 'How Nature Foiled the 2006 Hurricane Forecasts', EOS, Vol. 88, No. 9.
4. Dunion, J.P. and C.S. Velden, 2004. 'The impact of the Saharan air layer on Atlantic tropical cyclone activity', Bull. Of Amer. Meteor. Soc., March 2004, Vol. 85, 353-365.

Further references

- Chen, A.A., M. Taylor, A. Centella, D. Farrell, 2008, 'Climate Trends and Scenarios Report of Working Group I, Climate Change and Biodiversity in Caribbean Island', www.canari.org/CCBIC%20WG%20I%20final%2003%2003%2009.pdf
- Mearns, L.O., F. Giorgi, P. Whetton, D. Pabon, M. Hulme, M. Lal, 2003, 'Guidelines for Use of Climate Scenarios Developed from Regional Climate Model Experiments', www.ipcc-data.org/guidelines/dgm_no1_v1_10-2003.pdf
- Parry, M.L., O.F. Canziani, J.P. Palutikof and co-authors, 2007, Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78.
- Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood and D. Wratt, 2007: Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D.

Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Water resource management and adaptation initiatives to the challenges of climate variability and change in Singapore

- UNESCO, Second United Nations World Water Development Report (2006).
- UNESCO, First United Nations World Water Development Report (2002).
- Singapore's National Climate Change Strategy (Mar 2008) (www.mewr.gov.sg).
- Tortajada, C, (2006), Case Study for the 2006 HDR- 'Singapore: An Exemplary Case for Urban Water Management', Human Development Report, (2006).
- K.H. Ng, C.S. Foo and Y.K Chan, (1997), 'Unaccounted-for Water — Singapore's experience', Journal of Water Supply Resources and Technology — Aqua. Vol. 46, No. 5, p242-251.

Adaptation as development: an inconvenient truth?

1. Commission on Climate Change and Development, Closing the Gap, Stockholm, 2009 (www.ccdcommission.org)
2. UNFCCC, Investment and financial flows to address climate change: an update, FCCC/TP/2008/7 26 November 2008
3. Nicholas Stern, Climate Change and Development, 5 November, 2008, www.ipea.gov.br/sites/000/2/forum_mudanca_climatica/pdf/Apresentacao_do_Nicholas_Stern.pdf

Ecosystem-based adaptation: managing ecosystems to help people adapt to climate change

1. Ecosystem services are the benefits people obtain from nature, such as food regulation, storm protection, food, clean water, fuel and shelter.
2. This text draws from, and is usually fully consistent with, the draft report of the Convention on Biological Diversity's Ad-Hoc Technical Expert Group on climate change and biodiversity.

3. Dyson, M., Bergkamp, G. and Scanlon, J. (eds) (2003), Flow. The Essentials of Environmental Flows, IUCN, Gland, Switzerland.
4. Sudmeier-Rieux, K. and Ash, N. (2009), Environmental Guidance Nature for Disaster Risk Reduction, IUCN, Gland, Switzerland.

EDF's perspectives on adaptation to climate change and variability

1. IPCC, 2007, Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.). IPCC, Geneva, Switzerland. pp 104.
2. Parey, S., Dacunha-Castelle, D., Hoang, T.T.H.: mean and variance evolutions of the hot and cold temperatures in Europe, Climate Dynamics, 2009, DOI 10.1007/s00382-009-0557-0
3. Dubus, L., 2009: Practises, needs and impediments in the use of weather/climate information in the electricity sector. In Management of Weather and Climate Risk in the Energy Industry, NATO Science Series, Springer Academic Publisher, to appear. A. Troccoli (Ed).
4. Parey, S., Malek, F., Laurent, C. and Dacunha-Castelle, D., 2007, Trends and climate evolution: Statistical approach for very high temperatures in France, Climatic Change, 81(3-4): 331-352.
5. Dubus, L., 2009, op.cit.
   Dubus, L., 2007, Weather, water and climate information and the energy sector, in: Elements for Life, a WMO publication for the Madrid Conference, Tudor Rose Ed., WMO, Geneva, Switzerland.
   Rogers, D., Clark, S., Connor, S.J., Dexter, P., Dubus, L., Guddal, J., Korshunov, A.I., Lazo, J.K., Smetanina, M.I., Stewart, B., Tang Xu, Tsirkunov, V.V. Ulatov, S.I., Pai-Yei Whung and Wilhite, D.A., 2007, Deriving societal and economic benefits from meteorological and hydrological services, WMO Bulletin 56(1): 15-22.
6. Vitart, F., Bonet, A., Balmaseda, M., Balsamo, G., Biblot, J.R., Buizza, R., Fuentes, M., Hofstadler, A., Molteni, F. and Palmer, T., 2008, Merging VarEPS with the monthly forecasting system: a first step towards seamless prediction, ECMWF Newsletter, 115:35-44.
7. Bader, J.C., J.P. Piedelièvre & J.P. Lamagat, 2006: Seasonal forecasting of the flood volume of the Senegal river, based on results of the ARPEGE climate model. Hydrological Sciences–Journal–des Sciences Hydrologiques, 51(3) june 2006.
8. Coelho, C.,A.S., D. B. Stephenson, F. J. Doblas-Reyes, M. Balmaseda and R. Graham, 2007: Integrated seasonal climate forecasts for South America. CLIVAR Exchanges, Volume 12 (4), October 2007. http://eurobrisa.cptec.inpe.br/
9. IEA (International Energy Agency), 2008, World Energy Outlook 2008, IEA, Paris France, 578 pp.
10. Rogers, D., op.cit: 15-22.
    Lazo, J.K., 2007: Economics of weather impacts and weather forecasts. In: Elements for Life, a WMO publication for the Madrid Conference, Tudor Rose Ed. ISBN: 92-63-11021-2.