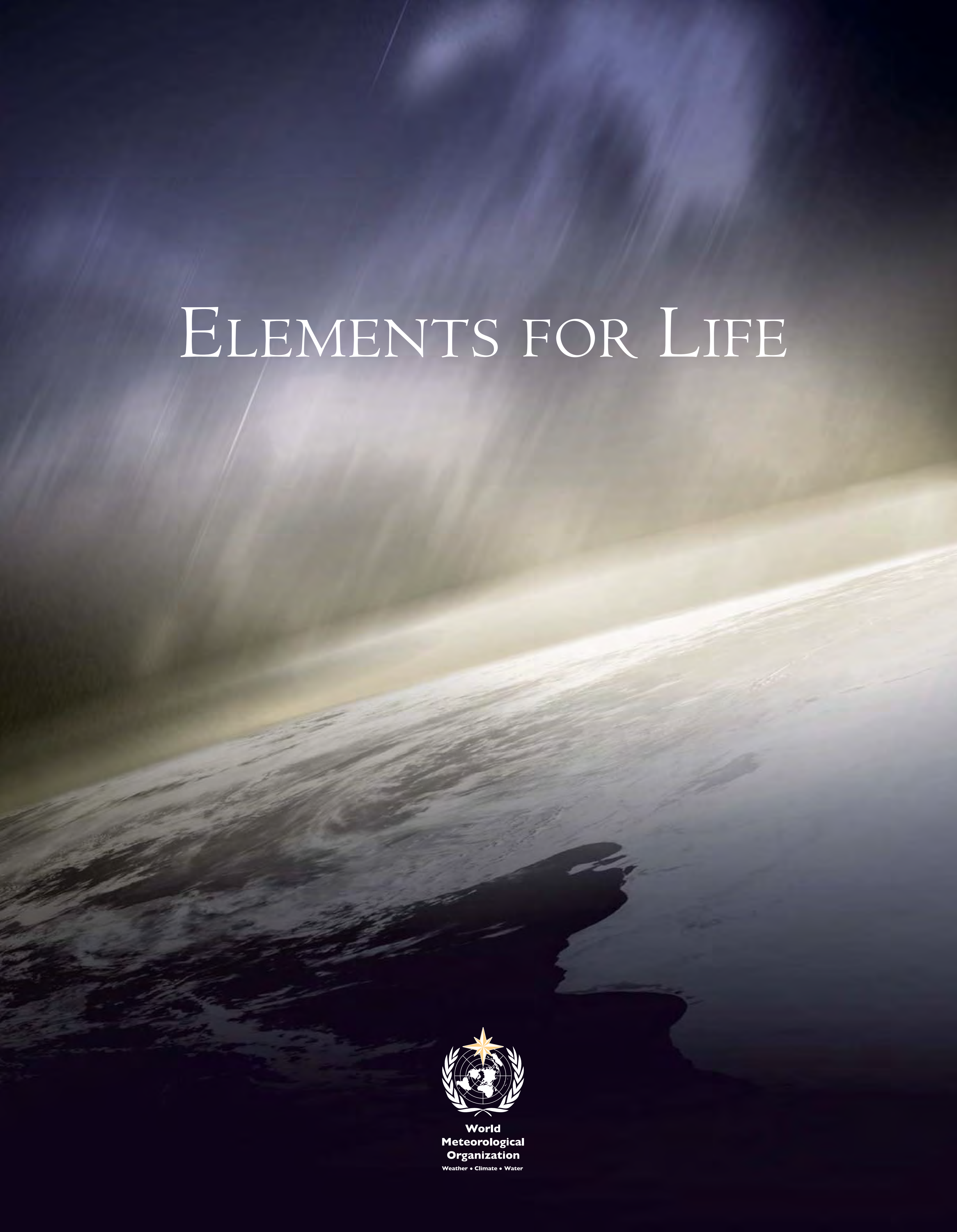
ELEMENTS FOR LIFE



World
Meteorological
Organization
Weather • Climate • Water

Elements for Life

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Organization
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Foreword

Over the last two to three decades, meteorology and hydrology have undergone a major evolution. This has been facilitated by outstanding advances in science and technology, resulting in unprecedented volume, quality, types and coverage of observational data, especially those made by satellites. Such advances have also led to the development of supercomputers and numerical weather prediction systems; expanded capabilities for telecommunications including the Internet, and the sustained coordinating and catalytic role of the World Meteorological Organization (WMO). At the same time, the rising sophistication and strength of the world economy and international trade, the increasing toll of natural disasters and the escalating concern for the environment, have led to an ever-increasing demand for timely and accurate information on the present and future states of weather, climate and water resources.

Indeed, the transformation of this expanded knowledge base into concrete practical applications in the areas of poverty reduction and increased human well-being has made considerable headway. Areas where socio-economic benefits have been assessed include disaster prevention and mitigation, food production, water resource management, climate change science and adaptation, pollution control, energy production, insurance and support to health, among others. However, the exchange of this information and its successful application to sustainable socio-economic development, environmental protection and decision-making must be further intensified if all nations are to benefit equally from this progress. This is where the National Meteorological and Hydrological Services (NMHS), as well as the research and academic communities, have an additional and very crucial role to play.

Elements for Life is being published with the intention to provide a fresh perspective on the subject by a wide range of users of hydrometeorological information. The variety of issues included demonstrates that investments in meteorological and hydrological activities are very cost effective in supporting national and international efforts to enhance human welfare and promote sustainable development.

At the same time, this publication is an expression of the coordinating efforts of the WMO and the crucial role of the NMHS in developing and delivering essential services to the public, decision makers, the private sector and the wider user community. *Elements for Life* documents many of these important services in qualitative and quantitative terms and will no doubt serve as a record of the growing benefits that humanity gains from meteorology and hydrology and the potential that these sciences hold for human welfare in the years to come.

On behalf of the WMO, I would like to express my appreciation to Tudor Rose for the initiative to publish this volume, and for selecting and organizing the relevant articles. I am equally grateful to all the authors and institutions that have amiably contributed to this historic publication.

Michel Jarraud
Secretary-General of the World Meteorological Organization

Preface

Since its establishment, the World Meteorological Organization (WMO) has excelled in monitoring the environment, and in predicting its future state with increasing accuracy on all timescales from nowcasting to climate projections. For this achievement, the organization has coordinated and promoted on a worldwide scale the development of advances in science and technology and their application to meteorology, and fostered an unprecedented level of self-help and international cooperation.

This global capacity has brought to the fore of the world's agenda issues such as increasing greenhouse gases and the resulting global warming; potential climate change and its impact; improved early warning and a multi-hazard system against natural and environmental disasters; dwindling water resources; the depletion of stratospheric ozone and increasing levels of pollution. Such knowledge, provided by WMO's unique system and maintained and operated by its 188 members, has enabled humanity to address these issues with a sense of urgency and concern for future generations.

In addition, there is a considerable number of other areas where hydrometeorological knowledge is being successfully applied to socio-economic development and environmental security. Some of the domains include agriculture, disaster mitigation, human health, water resources management, environment, desertification control, tourism, energy, insurance, trade, transport, construction — indeed, most human activities. The range of services is expanding rapidly.

Each nation invests in hydrometeorological science, but in most cases the advantages derived are limited to a few major areas. In order to benefit from the full potential that hydrometeorological knowledge can bring to human affairs, a multidisciplinary and inter-institutional approach as well as further investment and cooperative arrangements are required. The National Meteorological and Hydrological Services (NMHS) need to work with economists, social scientists, decision makers and other users to broaden the range of services provided and demonstrate the value of hydrometeorological information in the successful implementation of national development plans as well as regional and international strategies.

In this regard, WMO has the crucial responsibility to ensure the exchange of knowledge and experience and to increase the visibility and public awareness of the NMHS both at national and international levels. WMO's Statement on the Role and Operation of NMHS for Decision Makers contributes to this effort especially in the context of changes in the world and in the United Nations system. The NMHS and WMO have unique competence and comparative advantage in contributing to socio-economic development and environmental security as well as towards the attainment of internationally agreed development goals such as poverty alleviation as contained in the Millennium Development Goals and other global and regional strategies. This is the challenge faced by WMO in this early part of the 21st century.

We would therefore like to thank Tudor Rose for providing another opportunity to the meteorological and hydrological communities and various users to show the valuable contributions of WMO and the NMHS to human welfare and environment sustainability, and the further support they require in taking their work ahead for the benefit of this and future generations.

Alexander Bedritsky
President of the World Meteorological Organization

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STATEMENT FROM CRISTINA NARBONA, ENVIRONMENT MINISTER OF SPAIN

Human activities have always been closely linked to the evolution and behaviour of our planet, especially of its atmosphere. From ancient times, man has observed the clouds, winds, or the colour of the sky to try to predict the future so that due preparations can be made. Today, man continues to observe the atmosphere but now is able to consult meteorologists and climatologists who can indicate what to expect over the coming hours, days, weeks or even seasons. Humanity has developed spectacularly, but is still vulnerable. Science, together with a more consolidated, supportive social structure, allows us to mitigate the effects of adverse atmospheric changes, especially in the less developed parts of the planet which are often those that suffer their consequences most. All this is becoming even more important now that climate change and its effects are having a global impact, indicating more clearly than ever how the fate of humanity is tied to the planet on which it lives and that man's relationship with his environment must be nurtured.

Joint efforts are needed to hold back this process or at least mitigate its effects and, in general, to improve the usefulness of environmental information and forecasting so that we can improve people's health and living conditions. But, above all, it is essential that we extend and improve systems to warn populations of possible adverse natural phenomena. To achieve this, a constant dialogue must take place between scientists, politicians and representatives of the sectors and populations that are most at risk.

I would like to express my thanks to all those who participate in these valuable tasks, and I would like to encourage them to persevere. I am sure that their efforts to promote research and dialogue will contribute to better understanding between man and his environment and, therefore, to improved living conditions for humanity as a whole.

Cristina Narbona, Environment Minister of Spain

STATEMENT FROM SÁLVANO BRICEÑO, DIRECTOR
SECRETARIAT OF THE INTERNATIONAL STRATEGY FOR DISASTER REDUCTION

A series of high-profile disasters — the 2004 Indian Ocean tsunami, the Atlantic hurricane season, the South Asian earthquake and East African drought in 2005 — underscored the importance of how better cooperation between government authorities and international and scientific organizations would have played a critical role in helping people make life changing decisions about where and how they live before the disaster strikes, especially in high-risk urban areas. Without taking into consideration the urgent need to reduce risk and vulnerability, the world simply cannot hope to move forward in its quest for reducing poverty and ensuring sustainable development.

The *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters*, adopted at the World Conference on Disaster Reduction (Kobe, Japan, 18-22 January 2005), represents the most comprehensive policy guidance in universal understanding of disasters induced by vulnerability to natural hazards, and reflects a solid commitment to the implementation of an effective disaster reduction agenda. By working together in building a strong ISDR system as envisaged in the Hyogo Framework, we can effectively reduce risk and vulnerabilities, and build our resilience to disasters that affect us all.

The role of National Meteorological and Hydrological Services (NMHS) in national platforms for disasters risk reduction — a main element of the Hyogo Framework — is essential. The ultimate objective of a natural hazard warning is not only to issue it on time, but also to make sure it reaches people, allowing for lives and assets to be saved and for minimal disruption to their livelihoods. In this sense, the contribution of NMHS to the understanding of natural hazards, their impact and human and social vulnerability is a key component of risk management. The study and utilization of the Hyogo Framework must become a basic task for NMHS and the regular dialogue with relevant national and local stakeholders a common practice in carrying out their functions.

I welcome the partnership between WMO and Tudor Rose and the timely initiative in commissioning this publication, *Elements for Life*. The publication can certainly become an important tool to increase understanding and knowledge of individuals and organizations involved in meteorological and hydrological services and disaster risk management to develop team efforts to reduce risk and vulnerability.

Sálvano Briceño
Director, Secretariat of the International
Strategy for Disaster Reduction (UN/ISDR)

STATEMENT FROM MARGARETA WAHLSTROM, OFFICER-IN-CHARGE OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS

I welcome this publication of the World Meteorological Organization, which examines some of the key instruments needed to tackle today's development challenges.

Vulnerability to floods, droughts, wildfires, storms, tsunamis, earthquakes and other natural hazards is affecting more people around the world. In the decade 1976-1985, close to a billion people were affected by disasters. By the recent decade, 1996-2005, the decade total had more than doubled to nearly two-and-a-half billion people.

A series of extremely high-profile disasters — the Indian Ocean tsunami in 2004, Caribbean hurricane season, the Pakistan earthquake and the East African drought in 2005 — all underscored the importance of better cooperation between information service providers, government authorities and the international community for mitigating risks and saving lives.

Overall, disaster deaths have markedly reduced over the past 50 years, despite the rapid growth in global population and significant growth in the number of people affected by disasters. Today, we are better prepared, with meteorological services, early warning and response systems, to prevent massive mortality. The challenge we now face is how to use our formidable knowledge and technology to reduce our vulnerability to natural hazards, beginning with actions taken at the household level and extending up through the highest reaches of government.

In January 2005, a ten-year plan of action, the *Hyogo Framework for Action 2005-2015; Building the Resilience of the Nations and Communities to Disasters*, was adopted by some 160 governments at the World Conference on Disaster Reduction in Kobe, Japan. In tandem with the World Meteorological Organization and our other partners in the International Strategy for Disaster Reduction (ISDR), we are working to support governments in implementing the Hyogo Framework. Together, we can reduce the risks posed by natural hazards, and in so doing, help save countless lives.

Margareta Wahlstrom
Officer-in-Charge
Office for the Coordination of Humanitarian Affairs
and Acting Emergency Relief Coordinator

I

POLICY PLANNING & GOVERNANCE

Development challenges — working with the elements

Michel Jarraud, Secretary-General, World Meteorological Organization

Recent developments including those aimed at the reduction and the mitigation of natural disasters and adaptation to climate change have resulted in growing interest in the cost and benefits of meteorological services. National Meteorological and Hydrological Services (NMHS) are required to reduce costs, improve service levels, contribute towards national priorities, increase accountability and sometimes supplement public funding through cost-recovery and commercial activities.

As a result, economic valuation is becoming an integral part of the management of weather services. The valuation serves to demonstrate, often in monetary terms, the socio-economic value of meteorological information. Also, valuation enables assessment of overall performance of service delivery, changes in decision making and behaviour, client satisfaction, awareness of meteorological issues and of effectiveness in delivery of public good and economic benefits.

Global challenges – poverty eradication and environmental sustainability

The eight Millennium Development Goals (MDGs) are key in determining the cornerstone of international policy, channelling of development funds and prioritization of international agenda up to the year 2015. The cost of implementing these and the associated socio-economic benefits has not been quantified, but is largely perceived as essential for human welfare. Those of most direct relevance to WMO are eradication of extreme poverty and hunger, developing a global partnership for development, combating malaria and other diseases, and ensuring environmental sustainability.

The challenges are interdependent and transnational, and their solution requires interdisciplinary and collaborative action among governments, international organizations, scientists, the media, the private sector, academic institutions and NGOs. The resources required are considerable, and priorities often vary significantly. Nevertheless, the challenges serve as a framework for action and for assessing implementation costs and benefits.

An enviable track record

The socio-economic value of WMO's contributions to humanity has been considerable since its establishment in 1950. The atmosphere is continuously monitored, with data and products exchanged freely and in an unrestricted manner. Improved weather forecasts and early warnings with longer lead time are available to all nations. Today a five-day weather forecast is as reliable as a two-day forecast was 20 years ago. Seasonal forecasts based on El Niño and climate projections are regularly available. The first WMO statements on ozone (1975) and on climate change (1976) led to the formulation of related conventions on these subjects.

Economic benefits

In the USA it is estimated that 15 per cent of gross domestic product (GDP) is affected by weather. Experts' assessments indicate that the average annual value of economic losses from hydrometeorological causes in Russia is 60 billion roubles (approximately USD2.2 billion). In Kenya, up to 60 per cent of all economic activities are weather and climate sensitive and investment in meteorological and hydrological services is known to save lives and yield returns of 7:1. Overall, the benefits to investment ratios in meteorology approximate between 5:1 and 10:1, and can even be much higher.

Agriculture

Specialized agrometeorological services, including seasonal forecasts, contribute to combating droughts and desertification, and ensuring effective irrigation and natural disaster preparedness.

Developing countries, where agriculture accounts for over 50 per cent of GDP, often pool resources to establish regional centres such as the AGRHYMET Centre in the Sahel region of West Africa and drought monitoring centres in Eastern and Southern Africa.

Water resources management

WMO's efforts on water are vital for a wider range of sustainable activities including agriculture, hydropower, health, preventing and mitigating water-related disasters, and ensuring effective environmental management.

For cost-effectiveness, a number of nations collaborate within internationally shared basin organisations. WMO supports these organisations by providing expertise in various areas including hydrological forecasting and integrated flood management.

It is estimated that by 2020, 20 per cent of the world's energy will originate from hydropower. In the USA, hydrological forecasting is estimated to yield benefits to costs of 12:1. Hydrological forecasting results in reduced flood losses of USD240 million and economic benefits of USD525 per annum.

Health

The MDGs call for halting, and beginning to reverse, incidences of major diseases by 2015. Occurrences of malaria, dengue fever, the common cold, respiratory problems from atmospheric pollu-

Benefits to agriculture

- Use of agrometeorological information led to an increase of up to 30 per cent in crop yields in Mali
- Meteorological information is used in forecasting the hatching of locusts and their subsequent movement in Northern Africa
- Benefits of El Niño forecasts (altering variety of crops) amount to USD10 million annually in Mexico
- In Canada, weather forecasts result in benefits of CAD6-36 per acre per year of alfalfa dry hay production.

tants, heat wave and cold spells, and diseases like SARS require increased vigilance on weather conditions.

Energy

Energy sources such as solar, wind and biomass offer a renewable, clean, decentralized and environment-friendly option. These alternative energy systems, however, represent a challenging technological and social process, but socio-economic benefits can be estimated for a wide range of applications.

Climate data are used in mapping the potential for such energies and in computer simulation programmes in the design, operation and distribution of both traditional, and new and renewable energy. This includes the design of biomass energy plants and cooling towers, the operation of landfills and modelling for environmental impact studies.

Weather forecasts are useful in assessing power requirements, especially in times of extreme weather conditions, and in decision-making relating to the daily performance of energy systems.

Transportation, tourism and construction

Air, sea, rail and road transport systems that are essential to trade, leisure, socio-economic well-being and development, require timely and accurate weather information for safety and efficiency.

Marine activities benefit from forecasts of weather, wave and weather-related hazards in areas such as ocean routing, offshore marine resource development, coastal engineering, towing operations and pollution clean-up.

Meteorological support to road transportation extends to providing current and forecast information. For example, the forecast of snowfall enables authorities to plan road clearing and salting with considerable benefits to society.

Tourism is of growing importance for the economy of many countries, especially those of small island states. Climate change and sea-level rise, severe weather, damage to infrastructure and erosion of beaches would make the islands and coastal zones less attractive to tourists.

The construction industry is very sensitive to weather and climate conditions for the design of buildings, their construction and maintenance. In the United Kingdom, the average annual loss associated with weather-related damage is estimated at USD1.6 billion. Damage to residential and commercial structures is usually the largest portion of this figure.

Natural and human-induced disasters

Over the last 25 years, nearly two million people have lost their lives, with economic losses of over USD1 trillion caused by over 7,000 natural disasters related to weather, climate and water. The number of disasters increased fourfold, with economic losses increasing fivefold, but with loss of life decreasing threefold. This achievement is due to several factors, including the implementation of effective end-to-end early warning systems. WMO is involved in all aspects of disaster mitigation from preparedness to relief, and ensures collaboration among nations within cyclone basins, and with relief agencies.

The insurance industry regularly assesses the cost benefit of disaster mitigation. It reckoned that for every dollar spent on prevention and preparedness, approximately USD100-1,000 is needed for an equivalent effort after a disaster has taken place.

Environment

WMO extensively supports environmental activities. It coordinates the measurement of many physical parameters related to the environment. Assessment of socio-economic value of such activities should take into account the short- and long-term benefits that all nations derive from such activities. Climate change and ozone related activities exemplify some of the issues involved.

Climate change

Climate change is a major environmental issue. Facts including the continued increase of greenhouse gases, the rise in global average surface temperature during the last 100 years by 0.74 degrees Celsius, the global average sea-level rise between 0.1 and 0.2 metres, changes observed in weather phenomena and ecosystems, and the melting of glaciers are a source of serious concern.

Based on model projections, the 2007 WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) scientific assessment report states “Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations” For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios. The best estimate for the low scenario is 1.8°C (likely range is 1.1°C to 2.9°C), and the best estimate for the high scenario is 4.0°C (likely range is 2.4°C to 6.4°C). The upper ranges of sea level rise for various scenarios would increase by 0.1 m to 0.2 m.

The associated impacts include increased occurrences of droughts and flood, beach erosion, infrastructure, fresh water salinization, siltation of waterways and reductions in crop yields, decreased water availability, melting glaciers, greater exposure to vector- and water-borne diseases and more intense warm periods and cold spells. The 2007 IPCC report states that the probability of human activities being responsible for global warming is over 90 per cent.

Ozone

The 1985 Vienna Convention and its 1987 Montreal Protocol catalysed global action to reduce the use of chemicals damaging to the ozone layer, which shields the earth from ultraviolet radiation. Since then, developed countries have virtually eliminated ozone-depleting substances, with the developing world not far behind. Without these reductions, ozone depletion would have increased tenfold by 2050 compared to current levels, resulting in millions more cases of melanoma, other cancers and eye cataracts. The benefits to humanity cannot be overestimated.

Evaluating international governance and policy planning

WMO has been exemplary in global efforts to provide data on and assessment of scientific aspects of atmospheric, environment and water issues, culminating in the adoption of conventions of significance to international environmental governance.

Indeed, the various Conventions, namely those on ozone, climate change, biological diversity and desertification are the fruits of meteorological and hydrological sciences. Some other international policies, strategies and plans of action that have benefited from meteorological and hydrological input include food security, water, oceans, natural disasters, habitat and transboundary pollutants.

In conclusion, the requirement to assess the economic benefits of meteorological and hydrological services presents significant challenges to the world community. Social scientists, economists and academia should be involved. In view of the pervasive nature of the sciences and their global reach and relevance, the results of indepth socio-economic studies may serve as a model for other mulitidisciplinary sciences.

From National Meteorological Institute to Spanish Meteorological Agency: towards the future

Francisco Cadarso, Director General, Spanish National Meteorology Institute

Located at a geographical crossroads between the subtropical and medium latitudes, and between the Atlantic and the Mediterranean, Spain has a varied and complex climate. In many ways this is beneficial for the country, but there are also many negative aspects ranging from periodic droughts to other adverse phenomena such as torrential rainfall, heat waves, strong winds, snowfalls or serious storms at sea. Moreover, Spain's location to the south of Europe makes it very vulnerable in the present global scenario of climate change. All of this results in a framework in which meteorological, climatic and hydrological research and forecasting are of great importance.

Spanish meteorologists, through the National Meteorological Institute (INM), the national weather service of Spain, have always aimed to offer Spanish society the best possible information with the resources available. In addition to the traditional tasks of supporting aviation, shipping and farming, they took on hydrological and then industrial activities as well as services for the tourism sector and the mass media. Although warnings of adverse weather conditions have always been a priority, it was only from 1982, as a result of a combination of meteorological events, technological developments and political timing, that scientific, technological and operational capabilities for monitoring and forecasting were really promoted.

The INM has worked together with the Civil Protection authorities on increasingly advanced operational plans, leading up to the current Meteoalerta plan which is based on the new criteria for warnings as laid down by the European Meteorological Services. With its different forecasting products for the very short, short and medium terms, the Institute is able to cover all the geographical scales including more than 8,000 municipal districts in Spain, with increasing quality and accessibility. This is demonstrated by the spectacular increase in visits to its website, which offers thorough and up-to-date information.

As is to be expected, the INM also acts as the 'notary' of the Spanish climate. Its archives, containing data from all the

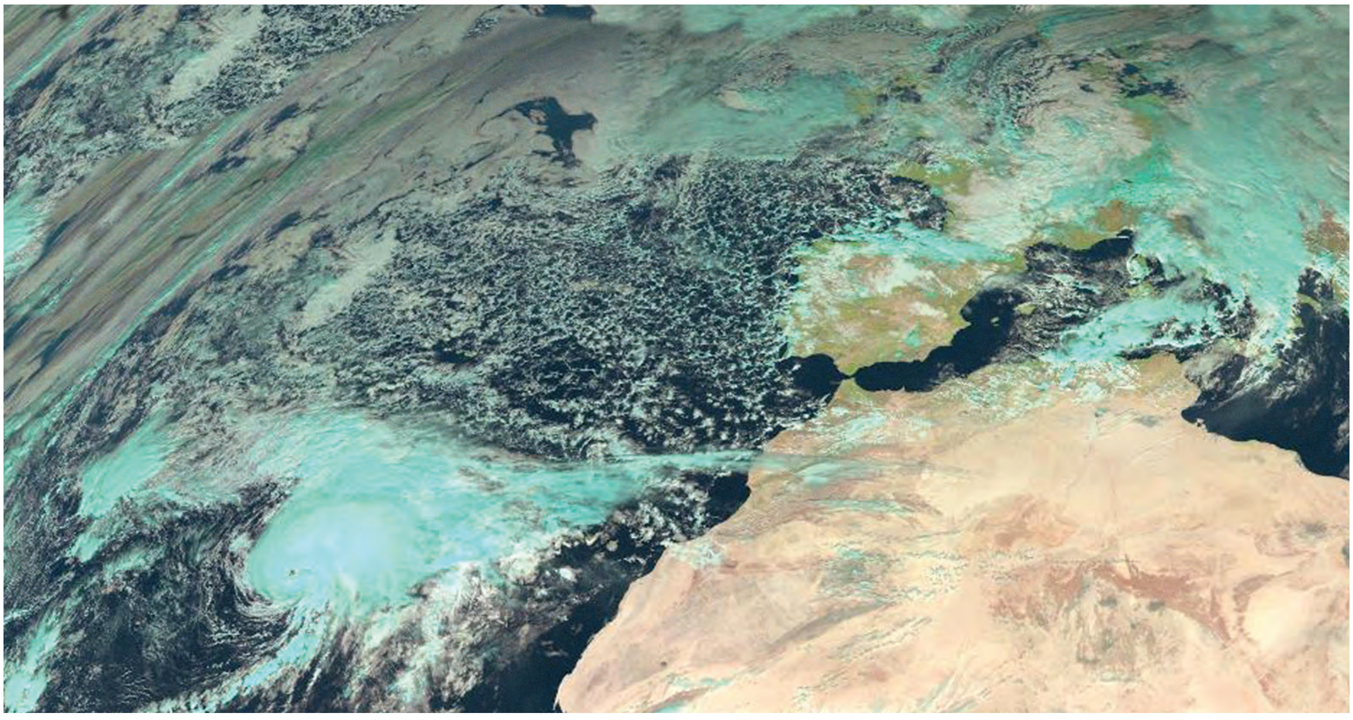


Image: The European Organization of Meteorological Satellites (EUMETSAT)

Tropical storm Delta in the vicinity of the Canary Islands

Spanish meteorological stations, serve a large number of institutions and private users and form the basis of many studies, especially in the context of climate change in which the monitoring of trends is a top priority.

None of these activities would be possible without the necessary infrastructure. The INM has an extensive observation network both in real time and of a climatic nature, with almost 300 automatic stations providing real-time and meteorological information. There is a network with 15 radars and another for lightning detection, as well as several stations for receiving data from various meteorological satellites and a large network for measuring radiation. From the data processing point of view, the institute has Spain's second most powerful computer, enabling it to use the most advanced forecasting and climate trend models.

The INM also has a broad territorial scope, with 15 regional meteorological centres, most of which have regional forecasting and monitoring groups as well as research, application and user service units. All of this enables the specific and increasing needs of users in the various autonomous communities of Spain to be met.

Notwithstanding the above resources, there are few activities in the world requiring such extensive collaboration as meteorology. For this purpose, INM collaborates actively within the World Meteorological Organization (WMO) and with other European meteorological bodies, such as the European Centre for Medium Range Weather Forecasts, the European Meteorological Satellite Agency and The Economic Interest Grouping of the National Meteorological Services of the European Economic Area. In fact, INM's international responsibility goes beyond this by focusing on collaboration with Latin America. This has led to bilateral collaboration with the meteorological services in the different countries and to common programmes drawn up in coordination meetings held among their directors. Moreover, many Latin American meteorologists have received training within the institute, or thanks to grants offered annually in collaboration with WMO. Also, Spanish professionals pay frequent visits to Latin America for seminars, congresses, or for the purpose of offering technical assistance.

Another field of international activity in which the Spanish Institute plays a leading role is in the coordination of research into the upper atmosphere. This is conducted through the Izaña Observatory on the island of Tenerife, a centre of international renown. This observatory carries out measurements and studies on radiation and environmental pollution in the framework of national and international scientific projects.

Within Spain, there is ongoing collaboration with the meteorological services in the autonomous communities and with many public and private organizations. Activities are also carried out with universities in the fields of research and education.

The fact that the institute forms part of the Ministry of the Environment has led to effective synergies in matters relating to climate change and adaptation to it with other units and with the administration in general. This has resulted in a multidisciplinary approach, promoting collaboration not only in Spain but also within the Latin American community among meteorologists, climatologists and those responsible for environmental policies and civil protection.

All these activities have made the INM a paradigm of quality and generated a close relationship with Spanish society, as well as providing important support for global meteorology. The institute is aware, however, that this role must be strengthened and that enhanced services should be offered to its users. It is therefore trying to improve its channels for communication with society and to increase its visibility. This is being achieved through better product adaptation, constant presence in the media, a variety of publications and open days.

Despite its myriad achievements, the INM still faces many challenges. Some result from environmental trends and others from changes in Spanish society. On one hand, the process of climate change and the appearance in recent years of many adverse phenomena relating to temperature, rainfall, wind, etc. require a new strategy for observation and monitoring of variables. There is also a need for new studies to document the occurrence of such changes and help design policies for adaptation to change. In addition, Spain's marked economic growth and fast-changing society is constantly demanding better and more extensive meteorological coverage. This is leading to the development of improved products and forms of communication, and to effective collaboration between the INM and the various Spanish autonomous communities.

In order to meet these challenges, the Institute must adapt and function in a more flexible way to tie in better with the needs of society. Over the next few months, it is to adopt a new organizational and administrative structure as a State Meteorology Agency. It is hoped that, under the new structure, the national weather service will continue to act as a meteorological landmark for all Spanish citizens and will serve as a venue for collaborative international activities in the field of meteorology.

Finally, it is vital that meteorological services are promoted and consolidated as far as possible. This is the only way in which we can effectively guarantee the basic infrastructure and essential meteorological and climatological products that society needs with increasing urgency. We must ensure that society views the meteorological services as accessible, useful and reliable organizations. This will only be possible if we are fully aware of users' specific needs and are able to offer quality, accessibility and reliability.

INM headquarters in Madrid

Weather, climate, water and air quality, and the risk to development

Dr David P. Rogers, Switzerland

The potential for natural environmental hazards to undermine the internationally agreed Millennium Development Goals (MDGs) is significant. This is recognized in Section IV of the Millennium Declaration, which states the objective "to intensify our collective efforts to reduce the number and effects of natural and man-made disasters."[1] Between 1980 and 2000, more than 1.2 million people lost their lives due to floods, droughts and storms[2] with a total financial cost exceeding USD900 billion.[3]

In recent years, thanks largely to advances in forecasting and assessments, people are better prepared and the number of people killed by extreme events is decreasing. However, the disruption to livelihoods and human well-being is increasing because population growth is forcing more and more people to live in coastal zones, flood plains, arid areas and other places which are more vulnerable to natural hazards. In addition, climate-sensitive diseases claim more than one million lives each year, mostly children under five years of age in developing countries and, without properly considering and responding to the impact of climate change on human development, more people will be at risk. Economic losses are also growing, especially in high human development countries. Elsewhere, while the losses may be less in absolute terms, the financial impact on countries with low gross domestic product is sufficient to halt or slow human development.

The financial consequences of natural hazards on human well-being are difficult to estimate from current data; however, it is clear that they are large and, unless we understand and reduce the vulnerability of people to natural hazards, human development itself is at risk. Climate change and weather extremes put at risk investments in infrastructure, agriculture, human health, water resources, disaster management and the environment. For example, the transportation infrastructure in Africa is crucial to bringing the continent out of poverty. However, every year large parts of this network are affected by flooding. The Mozambique floods of 2000 damaged roads and railways with costs exceeding USD32 million and USD7 million respectively.[4]

While these financial losses are undeniably significant, it is important to recognize environmental hazards as complex, multifaceted problems. For example, ecosystem changes, arising from alterations in rainfall patterns and temperature, are changing the behaviour of crop pests and human exposure to climate-sensitive diseases, as well as changing the length of the growing season and irrigation requirements. Meteorological and hydrological hazards clearly influence, and potentially hinder all aspects of human life, and thus the human development process itself. Every problem that results from such hazards has far-reaching and critical effects.

For every person killed in a flood or storm, it is estimated that an additional 3,000 lives and livelihoods are disrupted

For every person killed in a flood or storm, it is estimated that an additional 3,000 lives and livelihoods are disrupted through the death or incapacitation of a primary income earner, the consequences of migration or resettlement, or the number of people experiencing secondary health and educational impacts.[5]

United Nations Development Program (UNDP), International Strategy for Disaster Reduction The World Meteorological Organization, other UN agencies, international organizations,[6] and many national governments have recognized that sustainable development depends on understanding and responding to the issues that can prevent a natural hazard from triggering a human disaster.[7] The goal of the development and environmental communities is to minimize the human risk of natural hazards by reducing the vulnerability of the population in order to protect and sustain social and economic development. In this way natural disaster preparedness and management not only saves lives, but can also promote early and cost-effective adaptation to climate risks. Many studies have estimated that the internal rate of return from disaster reduction initiatives is between 20 per cent and 50 per cent and often provides additional, sometimes unanticipated, social benefits.[8] Flood-alleviation projects, for example, increase the availability of water for irrigation, and can offset the impacts of drought.

Vulnerability is the susceptibility and resilience of society and the environment to natural hazards. Different population segments and sectors can be exposed to greater relative risks because of their socio-economic conditions of vulnerability. The impact of a natural hazard on a population already suffering from extreme poverty, epidemic disease, or armed conflict is likely to be catastrophic since that population will probably lack the organizational capacity to protect itself against that hazard. Reducing disaster vulnerability requires knowledge of the social, cultural, political and economic conditions of the population, and the likelihood, consequences, imminence and presence of natural hazards. Thus risk assessment requires the complementary input of physical and social scientists to determine the vulnerability of the population to natural hazards.

Each of the MDGs must interact with disaster risk. One would expect that the goals would contribute to reducing human vulnerability; however, unless these risks are properly factored into the development process, well-meaning social and economic development efforts may inadvertently increase the vulnerability of a population and slow down or undermine efforts to achieve the MDGs. UNDP has explored the relationship between development and disaster risk in great detail.[9] In its view, achieving more sustainable development that meets the MDGs is not possible unless risk management is included within the programme. The challenge lies in devising tools for policy makers that justify the closer cooperation of disaster and development policy. UNDP defines three steps:

1. The collection of basic data on disaster risk and the development of planning tools to track the changing relationship between development policy and disaster risk levels
2. The collation and dissemination of 'best practice' information on development planning and policy that reduces disaster risk
3. The galvanising of political will to reorient both the development and disaster management sectors.

Step one must engage the meteorological and hydrological community at all levels, from the local to the global, to work within the risk management sector. More effort is needed to create tools that properly assess risk and can take into account its dynamic nature — climate change and variability, urbanization, the spread of disease and economic changes. The present weakness in the availability of relevant climate information in many developing countries must be addressed if climate-change risks are to be factored into risk reduction strategies. Central to climate risk management services is real-time environmental monitoring, without which it is difficult to create meaningful regional and local climate change assessments. Advances have already been made in the development of indicators and indices on disaster risk. In all cases, their value lies in the availability of social, economic and environmental vulnerability data. The goal must be to develop robust national and local risk indicators that will influence national development policy and planning.

At the national level, the meteorological and hydrological community must ensure that they are engaged in the country's development agenda; that relevant data is readily available for the development of risk indicators; and that they support the application of these tools to inform national policy and planning. On the development community's side, there is need for greater openness to the potential contribution of National Meteorological and Hydrological Services and their partners.[10] A good example of this integration of risk management awareness into development policy is presented by the World Bank. It has identified climate change as a risk management issue for development and has begun to factor this risk into its development project cycle with the dual purpose of protecting its investments, and improving the impact of development efforts.[11] A critical step is the mainstreaming of climate risk management into countries' economic planning, and capacity building in ministries of finance and economic planning to use climate information to manage risks to public sector investment.[12] In a long-term programme to help Kiribati adapt to climate change, for example, a Global Environment Facility project was started in the Ministry of Finance and Economic Planning and then moved to the Office of the President as part of a National Strategic Risk Management Unit, highlighting the importance of the effort for Kiribati's development strategy.[13]

At the international level, the meteorological and hydrological community must work to increase the value of long-range predictions so that the impact of climate variability and change can be included in assessments of the likely occurrence of extreme events — floods, droughts, storms — which are critical factors in determining environmental vulnerability.

In conclusion, achieving the MDGs requires a partnership between development planners, policy makers, and the risk management community — a partnership between environmental and social scientists, between understanding natural phenomena and human behaviour. In general, the fragmentation between ministries and agencies in most countries is an impediment to tracking the relationship between disaster risk levels and development planning and policy. The environmental vulnerability component of risk is addressed by understanding hazards of the past, monitoring of the present, and prediction of the future. Combined with social, political and economic factors, risk indices can be built that help the development community make informed decisions that may accelerate human development by ensuring, for example, that schools, water, sanitation, roads, energy, telecommunication, and other infrastructure are built to be disaster resistant.

The consequences of climate change to rail infrastructure

Margrethe Sagevik, International Union of Railways

The transport sector accounts for approximately 25 per cent of global carbon dioxide (CO_2) emissions. It is the sector with the highest growth in emissions, and the second largest contributor overall, after the electricity and heat-supply sector. The additional effects of transport include accidents, noise, congestion, land-use and air pollution; with related damage to health, and to urban and rural environments.

Efforts to mitigate the level of emissions from transport are in evidence. Fuel is cleaner than ever and the manufacture and performance of vehicles is more environmentally friendly and produces fewer, and reduced quantities of pollutants and harmful emissions. However, these efforts are vastly outweighed by the enormous increase in demand for both passenger and freight services, along with the drastic growth in road transport and aviation.

If developing countries adopt western travel patterns, the number of cars and commercial vehicles, currently 800 million, will rise to 1.6 billion by 2030. Based on present population growth estimates, this is approximately one vehicle for every five people on the planet. According to the European Transport Forum 2003, this growth will be predominantly observable in countries such as Brazil, China, India, Korea, Mexico, Russia and Thailand where people are enjoying increased prosperity and seeking greater mobility.

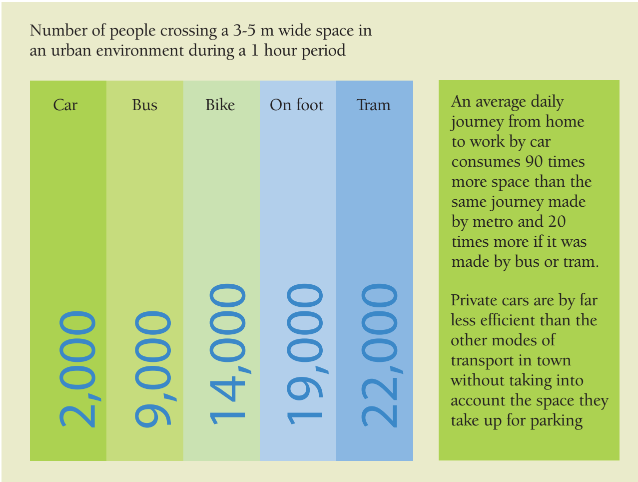
Climate changes have been estimated to represent 30% of the total external costs caused by transport in Europe (IWW/INFRAS 2004). This corresponds to 195 billion Euro of which 57% is generated by road transport, 41% caused by air transport and 1% by railways.

In spring 2006 the European Environment Agency (EEA) launched its 2005 term report, challenging politicians to resolve the conflict between transport and environmental policies. The EEA report identified a gap between the ambitious aim of achieving sustainable development in the European

Photo: Jan Skoglund

Freight train in Swedish landscape

Rail offers the least harmful tranport surface solution in terms of spatial efficiency



Source: Botma & Pependrecht, Traffic operation of bicycle traffic, TU Delft, 1991

transport sector, and what was actually happening. The sector is the fastest growing consumer of energy, and simultaneously the fastest growing producer of greenhouse gases in the European Union. Transport is essential, but also highly environmentally damaging. Thus the aim should be to shed, as far as possible, its terrific costs, whilst retaining viability and sustainability.

Transport policies increasingly recognize the need to restrain the sector's growth, and to improve the market shares of its various transport modes. Fair and efficient pricing, better-targeted investments and spatial planning are some of the policy tools that can help to achieve this.

The environmental advantages and sustainability of railways

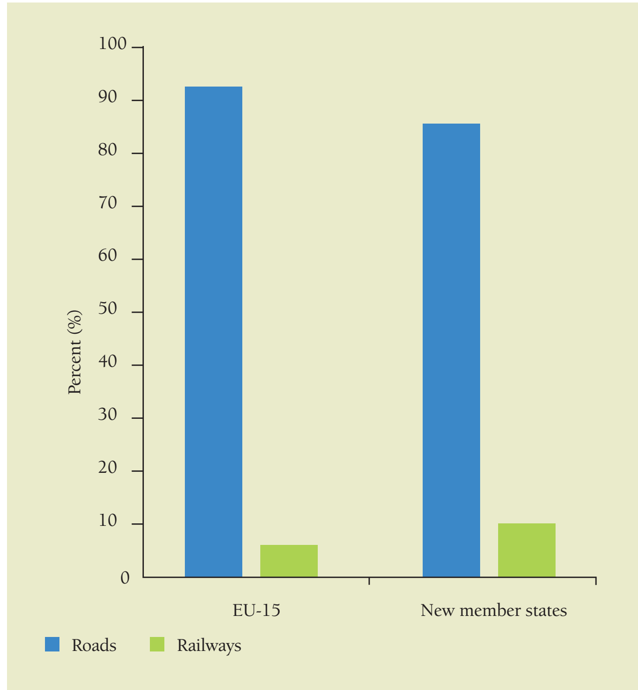
Railways are the potential backbone of smart, sustainable transport systems. They have a low environmental impact, high-energy efficiency, and superb accessibility and safety. Nevertheless, the railway is continuously striving to improve, in order to meet the growing expectations of society and become an ever better, quieter and cleaner service.

All transport surfaces impinge on natural and agricultural areas, and can present a threat to the existence of wild plants and animals. However, in terms of spatial efficiency, rail offers the least harmful of transport surface solutions. This is particularly important in urban and densely populated areas. The transport of 50,000 people per hour along the same routes requires a 175 metre wide road for cars, a 35 metre wide road for coaches, but only a nine-metre wide rail network.

According to the Organisation for Economic Co-operation and Development (OECD), transport infrastructure consumes 25-40 per cent of land in urban areas, and 10 per cent in rural areas. The road network occupies 93 per cent of the total area of land used for transport in the European Union. Rail is responsible for only 4 per cent of this land take.

Railways are crucial in reducing greenhouse gas emissions and creating sustainable transport systems. They offer the most energy efficient performance, both according to passenger/km and tonne/km. A shift of 3 per cent from road to rail transport corresponds to a 10 per cent decrease in greenhouse

Rail uses significantly less land area than roads in the EU



Source: Transport development in EU-15 EC 2003, quoted by VCÖ (www.vcoe.at)

gas emissions. Moving from road to rail is the key to achieving the Kyoto Protocol targets and attaining a sustainable global transport policy for the future. Since 1990, railway is the only transport mode to have decreased its share of CO_2 emissions.

A concrete example of the benefits of rail can be seen in the recent efforts of the German rail system. In 1990 German Railways set themselves the goal of reducing their energy consumption by 25 per cent. By 2002, three years ahead of schedule, they achieved this target. They have already set ambitious targets for reducing energy consumption by a further 15-25 per cent by 2020. These achievements are primarily the result of the network's ongoing EnergieSparen (Save Energy) project. The strategy aims to reduce energy consumption by 10 per cent, through encouraging drivers to act in a more energy-efficient way. Several European railways have adopted similar projects.

A modal shift, from road and air transport to rail, is the key to achieving a sustainable global transport policy for the future. Therefore the mission of the International Union of Railways

Hazards

Hazards are extreme natural events or technological phenomena that can threaten, and potentially damage the population, the environment and material assets. The origin of hazards can be purely natural (e.g. earthquakes) or technological (e.g. accidents in a chemical production plant), as well as a mixture of both (e.g. sinking of an oil tanker in a winter storm and subsequent coastal pollution). These extreme events have closed time spans, after which the initial pre-hazard state is reached again.

Most natural hazards arise from the normal physical processes operating in the Earth's interior, at its surface, or within its enclosing atmosphere.

(Source: on 'Natural hazards' – The ESPON 2006 project)

(UIC) is to 'promote rail transport in order to meet the challenges of mobility and sustainable development.'

Climate change and transport — cause and effect

Global warming is becoming more visibly evident, and with this revelation, climate change is receiving increased global attention. The pressure is on governments and individuals to learn more about the cause and the effects of global warming, and how to deal with it.

However, while we have a decent understanding of the likely causes of climate change, the consequences advance quickly and are hard to predict. Observable effects vary from region to region, and include track buckling, heavy rain, storms, flooding, landslides and avalanches, and catastrophic scenarios such as hurricanes and tsunamis. These threats represent huge potential damage to transport infrastructure, and demand new attitudes toward its planning, construction and maintenance.

It is important to differentiate between natural hazards and the effects of climate change. While the appearance of the two is often similar, the causes and consequences are significantly different.

Traditionally, the threat of natural hazards has been an integrated element in the planning and construction of rail infrastructure. For example, Swedish construction of roads and tracks incorporates specific dimensioning in order to cope with the '50 years deluge'. However, much international rail infrastructure was constructed more than 100 years ago, and in many places rail tracks have suffered from lack of proper maintenance, due primarily to company cutbacks.

The increased occurrence of extreme weather events demands a re-evaluation of how we design and maintain our transport systems. Policymakers, planners and constructors will have to work harder and with greater innovation to ensure transport safety, availability and quality.

Photo: Jan Skoglund

Rail tracks in tough weather

The consequences of extreme weather differ according to factors such as geography, topography, geology and population density. For example, the effects of heavy rain on a landscape will differ depending on the porosity of the soil. Trends in society, such as the urbanization process, are also influential. For example, asphalt and clear-felled areas increase the intensity of flooding.

More specifically for the rail services, extreme weather can lead to actual damage of the tracks, signals, etc. This can cause further damage to trains, staff, passengers and property. In addition, such damage can lead to extended suspension of service. In a vulnerable society where transport and economy are closely linked, this will lead to major costs.

There is also the potential that technical aspects of the train, designed for a certain environment, might not function as expected when the context changes. A rail fleet is normally designed to last 30 years. Thus, changes in the natural environment represent a challenge for the future design of trains. For example, disruptions in UK rail services have been put down to the 'wrong' type of leaves causing wheel slip, or even the 'wrong' type of snow resisting rail clearance procedures. To reduce and avoid such weaknesses in planning and construction, closer cooperation with local climatologists, meteorologists and hydrologists is necessary.

Another practical difficulty resulting from global warming relates to the prediction of soil structure. In particular the impact on mountainous, coastal and riverine regions has been well documented. In Tibet, the enormous railway project to link the area with the rest of China has been dogged by environmental concerns. With the loss of permafrost as a direct consequence of climate change, the long-term sustainability of the project is severely weakened. Similarly, increased rainfall in areas of Asia prone to landslips (Philippines and Indonesia in particular) will prove dangerous to fixed land infrastructure in the future. Early consultation with climatologists can highlight regions of increased disaster probability, and ensure that the tracks are built in more sustainable areas. The study of the consequences of global warming on transport and rail infrastructure is in continuous development; increased observations, studies and data are required to cope with this advancement.

Rail infrastructure: a UIC study

Recently, UIC launched its first study into the effects of climate change on rail infrastructure in Alpine regions, in flat regions near the coast and near rivers in central Europe. The aim of the project is to examine the rise in temperature and its consequences for permafrost areas in the Alpine regions, as well as considering the necessity for early detection of risks, and the securing of tracks. Specific cases for investigation include:

- Hydroelectric power plants as a secure power supply for railways
- Simultaneous melting of snow in the Alps and in the low mountain ranges, and how this will affect seasonal river flow
- Effects of sea-level rise on track safety
- Effects of heavy storms on power supply, tracks (fallen trees) and the driving dynamics related to cross winds and wind shear.

These expected climate change effects, along with the increased demand for rail transport, strongly emphasise the need for environmentally aware rail transport programmes.

Strengthened international and inter-regional cooperation is another evident consequence of global warming. It is essential that this unification be channelled towards the planning and construction of transport infrastructure. Regions that are familiar with extreme climate conditions will have valuable experience to share with less experienced regions. For example, Canadian and Alaskan railway operators are experienced at preparing for, and reducing the effects of landslips on their service. This technology and experience could be transferred to railway infrastructures in less developed economies that are beginning to experience similar problems.

UIC will be at the forefront of international development in the rail sector. For example, the findings and results of the first UIC project regarding climate change effects on rail infrastructure will be transferred to UIC members all over the world.

It is important to bear in mind that in developing countries the consequences of climate change on transport and rail infrastructure have an extra dimension. Transportation represents access to food, medicines, education and employment; everything that represents human well-being and economic growth. More specifically, infrastructure development plays an essential role in the reduction of rural poverty because of its importance to agriculture. Electricity and irrigation are both initially possible only through the advances of transport systems. Furthermore, effective transport is needed to sell agricultural products to the relevant distributors and consumers.

Therefore, new thinking is required when it comes to transport in developed countries and in emerging economies. A smart and sustainable, unified transport system is necessary to reduce human and economic costs. Social and environmental effects of climate change need to be included into cost-benefit analyses and decision-making. Governments must support the development of sustainable mobility by educating the public about the effects of conventional transport on the environment, and by giving the market economic incentives to facilitate the needed modal shift. This should also include incentives for people to make more sustainable transport choices.

What needs to be done

To be prepared for the increasing consequences of global warming to its infrastructure the rail sector is addressing both the causes and the effects of climate change — firstly, by offering a service that causes fewer emissions than its alternatives, and secondly, by expanding its existing expertise to minimise the effects of climate change on rail infrastructure, and thus reducing the damages and costs these effects imply for society.

Such expansion of knowledge and its application will not come easily. New thinking and non-traditional cooperation across sectors and professional areas will be necessary. For example, despite much practical experience, the transport system could benefit from working more closely with meteorologists and climatologists to predict, and mitigate the effects of extreme weather. This technology transfer will lead to new expertise and generate greater 'preparedness'.

Since climate change represents a uniform, international threat, the cooperative process can then be applied to the global stage. This strategy should also include the development of smart, sound and sustainable transport systems in all parts of the world. The advantages of rail recommend it as the ideal backbone for such a system. It promises greater safety, improved access and reduced emissions; in short, a higher quality of mobility, and a higher quality of life.

Photo: UIC

Freight transport offers a more sustainable alternative particularly in terms of safety, landtake and energy efficiency

Monitoring weather, climate and the environment — EUMETSAT's operational satellite service

The European Organisation for the Exploitation of Meteorological Satellites

Mankind cannot control the weather, but with accurate and timely information, the effects of severe weather and natural disasters can be mitigated. Global warming, climate change and increasingly destructive weather events over recent years have alerted governments, scientists and other communities to the importance of finding efficient and cost-effective resources to help prepare for and mitigate the effects of such events on a global scale.

Satellites have been collecting atmospheric observations for decades, and have made a significant contribution to weather forecasting and the long-term monitoring of the planet's well being.

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) works to provide data, products and services to help detect potentially dangerous weather patterns and provide input for computer models to produce forecasts. Even if a disaster has already struck, these information services can support rescue missions as well as planning for the prevention or mitigation of similar events in the future.

Photo: Copyright EUMETSAT

The Metop satellite being encapsulated in the fairing of the launch vehicle before take-off

EUMETSAT is a European organization with a global commitment — it serves 30 states — and its data, services and products can be received in almost every country on Earth — 24 hours a day, every day of the year. The organisation also is a major contributor to global programmes such as the World Meteorological Organization's (WMO) Global Observing System (GOS).

A space-eye view of the Earth

EUMETSAT currently operates six satellites:

- Two second generation Meteosat satellites providing the operational service from geostationary orbit
- Three first-generation geostationary satellites: Meteosat-6 and -7, which provide the Indian Ocean Service, and Meteosat-5 which is due to be de-orbited in spring 2007.
- Metop, launched in October 2006 and soon to provide the operational service from polar orbit.

Technological advances and the increasing sophistication of weather forecasting requirements created a demand for more frequent, more accurate and higher resolution observations from space. To meet this demand, EUMETSAT in 2002 launched the first of a new series of even more advanced weather satellites known as Meteosat Second Generation (MSG), developed in collaboration with the European Space Agency (ESA) and the European space industry. The second satellite in the series was launched in December 2005 and since July 2006 the vital operational service from geostationary orbit is provided by two second generation Meteosats — Meteosat-8 and Meteosat-9. Second Generation Meteosats herald a new era in weather and climate monitoring. With the most advanced imager of all satellites currently in orbit they continuously scan Europe, Africa and parts of the Indian and Atlantic Oceans with visibly improved image quality at 15 minute intervals. The frequent delivery of data is especially important in situations of severe weather. Very short term forecasting, called Nowcasting, makes use of the rapid sequence of high-resolution satellite imagery provided by the new MSG satellites and helps to for example monitor the development of dangerous storms. But even in more 'normal' conditions the information on weather, climate and the environment gathered by the new generation of Meteosat satellites is vital to ensure daily life and business. For scientists, the data gathered by satellites are also invaluable for climate monitoring. However, the geostationary position of the Meteosat satellites implies that in order to deliver the highly detailed observations of atmospheric conditions that meteorologists and climatologists require, a low earth orbit system was needed to complement the geostationary service.

In response to this need, the councils of EUMETSAT and the European Space Agency (ESA) agreed plans to design, develop, launch and operate a polar satellite system for Europe. The EUMETSAT Polar System (EPS) programme was then approved in 1999.

In 1998 EUMETSAT and the National Oceanic and Atmospheric Administration (NOAA) began collaborating on the Initial Joint Polar System (IJPS), comprising two polar-orbiting satellite systems and their respective ground segments. A further agreement in 2003, the Joint Transition Activities agreement, saw the two organizations working to provide an operational polar-orbiting service until at least 2019.

Metop and Numerical Weather Prediction

Numerical Weather Prediction (NWP) is the basis of all modern global and regional weather forecasting, and EUMETSAT's Metop satellites will make a substantial contribution in this area.

Metop serves the operational requirements of the meteorological services and other users around the world, including the WMO and EUMETSAT's Member and Cooperating States. The first satellite of the EPS system was launched in 2006 from Baikonur, Kazakhstan. Its altitude of 837km makes it approximately 42 times closer to the Earth than a geostationary satellite, and it can therefore observe smaller areas in considerably finer detail. Data gathered by Metop will revolutionise the way weather, climate and environment are observed, and will significantly improve operational meteorology.

Data generated by instruments onboard Metop can be assimilated directly into NWP models in order to compute forecasts ranging from a few hours to ten days ahead. Measurements from infrared and microwave radiometers and sounders on board Metop provide NWP models with global information on the temperature and humidity of the atmosphere with a high vertical resolution. The Infrared Atmospheric Sounding Interferometer (IASI), for example, provides important data including highly detailed global measurements of atmospheric temperature and water vapour, making it possible to ascertain temperature and humidity profiles with a vertical resolution of 1km, accurate to 1 degree Celsius and ten per cent respectively, at a horizontal sampling of 20km.

Metop's Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) instrument presents a new method for using satellite observations in NWP models for weather forecasting and climate monitoring. Using radio signals continually broadcast by the GPS satellites of the Global Navigation Satellite System orbiting the Earth, GRAS measures the time delay of the refracted GPS radio signals as the ray signal path skirts the Earth's atmosphere on its way from the transmitting GPS satellite to the GRAS receiver on Metop. This delay is then processed to obtain vertical profiles of atmospheric parameters, such as temperature and water vapour in the stratosphere and troposphere.

The data collected by GRAS will be further processed into sounding products by the GRAS satellite application facility (SAF), which is hosted by the Danish Meteorological Institute. In addition, the NWP SAF hosted by the UK Met Office can exploit Metop's data to generate supporting data, software packages, validation products and other services for use in NWP, climate studies and atmospheric research.

Scatterometer wind measurements are of great importance to weather forecasting and climate monitoring, as demonstrated through various research missions over the past decade. Data from the advanced scatterometer (ASCAT) is further processed by the Ocean and Sea Ice (OSI) SAF, led by Météo-France, to provide global ocean surface wind vectors that are necessary for the definition of atmospheric circulation on small scales and in the tropics. The main application of this is the assimilation of wind measurements into NWP models. Scatterometer measurements can also be used for monitoring sea ice, snow cover or land surface parameters such as soil moisture.

A combination of the advanced TIROS Operational Vertical Sounder (ATOVS) suite and the Advanced Very High-resolution Radiometer (AVHRR), currently flown on NOAA satellites, are also operated on board Metop. ATOVS/AVHRR covers the visible, infrared and microwave spectral regions, making this combination useful for a variety of applications such as cloud and precipitation monitoring, determination of surface properties or humidity profiles, all of which play a key role in NWP.

Monitoring climate and the environment

The likely impact of extreme weather events, climate change and human activities on the environment can be predicted using computer models that use satellite data collected continuously over many decades. These predictions reveal pressing environmental issues and enable them to be addressed more effectively, ensuring that national policies and activities are consistent with the goal of sustainable development.

All the instruments on board Metop contribute to global climate monitoring models and applications, helping scientists to understand the complex interactions between the various factors that influence the Earth's climate system.

In particular, IASI's ability to detect and accurately measure the levels and circulation patterns of gasses known to influence the climate, such as carbon dioxide (CO_2), will herald a breakthrough in the global monitoring of the climate. The data collected by IASI will feed into models to show for the first time the variable global distribution of CO_2 as a function of seasons and circulation anomalies, such as the southern oscillation (also known as El Niño) and the North Atlantic oscillation.

The depletion of the ozone layer is currently of particular environmental concern, and is especially noticeable over the Arctic and Antarctic regions. The resulting increased levels of ultraviolet radiation have harmful effects on agriculture, forests and water ecosystems — and people.

The Global Ozone Monitoring Experiment (GOME-2) will measure ozone profiles, total columns of ozone and other atmospheric constituents like nitrogen dioxide and sulphur dioxide. The trace gases observed are related not only to the depletion of ozone in the stratosphere, but also to sources such as volcanic eruptions and biomass burning. Long-term monitoring of the trace gases will provide more insight into the impact of man-made sources of pollution on the environment (including air quality) and the climate, on both regional and global scales.

GOME-2's capacity to significantly extend the long time series of measurements already gathered by GOME-1 is very important, as this will significantly impact our capability to model the climate system, leading to improved medium to long-term climate forecast capabilities.

Towards operational ocean altimetry — Jason-2

To better understand the forces behind global climate changes and to predict seasonal anomalies in weather patterns, it is vital to understand the physics of the ocean. Satellites offer a real-time global view of the oceans, in addition to sparse in-situ observations. Radar altimetry can measure the height of the sea surface and detect the slightest variation in ocean levels to the nearest centimetre. Using this information to study the growth and evolution of surface waves in response to winds and tidal forcing will enable calculations of dynamic topography to derive the positions and intensities of ocean currents, eddies and thermal fronts.

The Jason mission is built around a series of satellites that will collect global ocean surface data on a continuous basis for several decades. EUMETSAT will soon extend its activities and services into ocean altimetry, with the launch of Jason-2 in 2008. Jointly developed by NASA and the French space agency, Jason-2 will be operated by NOAA and EUMETSAT. The satellite will overlap with the Jason-1 mission to allow more precise cross-calibration between the two systems, to within a few tenths of millimetres.

Jason-2 is a Low Earth Orbit (LEO) satellite, flying at an altitude of around 1300km. The main instruments on board are a radar altimeter, a microwave radiometer, and several precise orbit determination systems. The aim is to measure the global sea surface height to an accuracy of a few centimetres every ten days, in order to determine ocean circulation, climate change and rising sea levels.

These data can be applied in marine meteorology, operational oceanography, seasonal prediction and climate monitoring. The information on sea surface height can be assimilated into numerical ocean circulation and wave models, and in combination with in-situ measurements it will provide vastly improved ocean forecasts, both for shorter and longer timescales.

Jason-2 is expected to provide an important contribution to EUMETSAT's future activities in the field of oceanography, serving the marine core services of the Global Monitoring for Environment and Security initiative (GMES).

Global Monitoring for Environment and Security

EUMETSAT is working to provide a major contribution to the GMES initiative, led by the European Commission and ESA. The initiative is a strategic response to environment and security issues, and contributes to the Global Earth Observation System of Systems.

The goal of GMES is to establish an operational European capacity for the timely provision of quality ground, air and space-based data, information and knowledge in support of a wide range of European policy areas. EUMETSAT's work as a provider of timely, high quality near-real-time satellite data on a continuous basis is crucial to the operational remit of GMES and constitutes a key element of its operational services.

These services are provided through EUMETSAT's operational satellite systems. The latest of these, MSG, will be fully operational until 2015, and planning is already underway for Meteosat Third Generation (MTG) satellites to continue the service beyond this timeframe. EUMETSAT will also be the operator of the ESA GMES satellites (called "Sentinels") for operational oceanography and atmosphere monitoring.

High-capacity data distribution

EUMETSAT's unique high-capacity data distribution system, EUMETCast, has already demonstrated its ability to deliver a wide variety of data gathered by its own and other satellite networks, all of which are potential sources of data for GMES. Any EUMETCast user station can provide end-users with rapid, with rapid, low cost operational access to global data and imagery in near real time, 24 hours a day, every day of the year.

Among its many uses, EUMETCast supplies continuous satellite data and products free of charge for the African Monitoring of the Environment for Sustainable Development Initiative, in which EUMETSAT plays a key role. The service is also set to play a significant role in the future of global climate monitoring.

In the longer term, EUMETSAT has the capability to become the satellite operator for selected future GMES missions. The organization plans to achieve this through the operation and management of satellite and ground systems, as well as onboard instruments on behalf of the EC, and by facilitating opportunities for EC-sponsored instruments to be carried on the satellites of EUMETSAT's international partners.

View of EUMETSAT headquarters at Darmstadt, Germany

Ocean data, information, products and predictions in the service of society

Dr Peter Dexter, Co-president, JCOMM, Melbourne
Johannes Guddal, past Co-President, JCOMM, Bergen
Candyce Clark, Intergovernmental Oceanographic Commission (IOC) Secretariat, Paris

STRICTLY SPEAKING, Planet Earth should more properly be known as Planet Water, or Planet Ocean. Monitoring and forecasting the behaviour of the ocean is a major challenge for the 21st century, as it equates to the sustainable development of economic activities in the open sea and in coastal areas, and to the implementation of global climate monitoring and prediction systems.

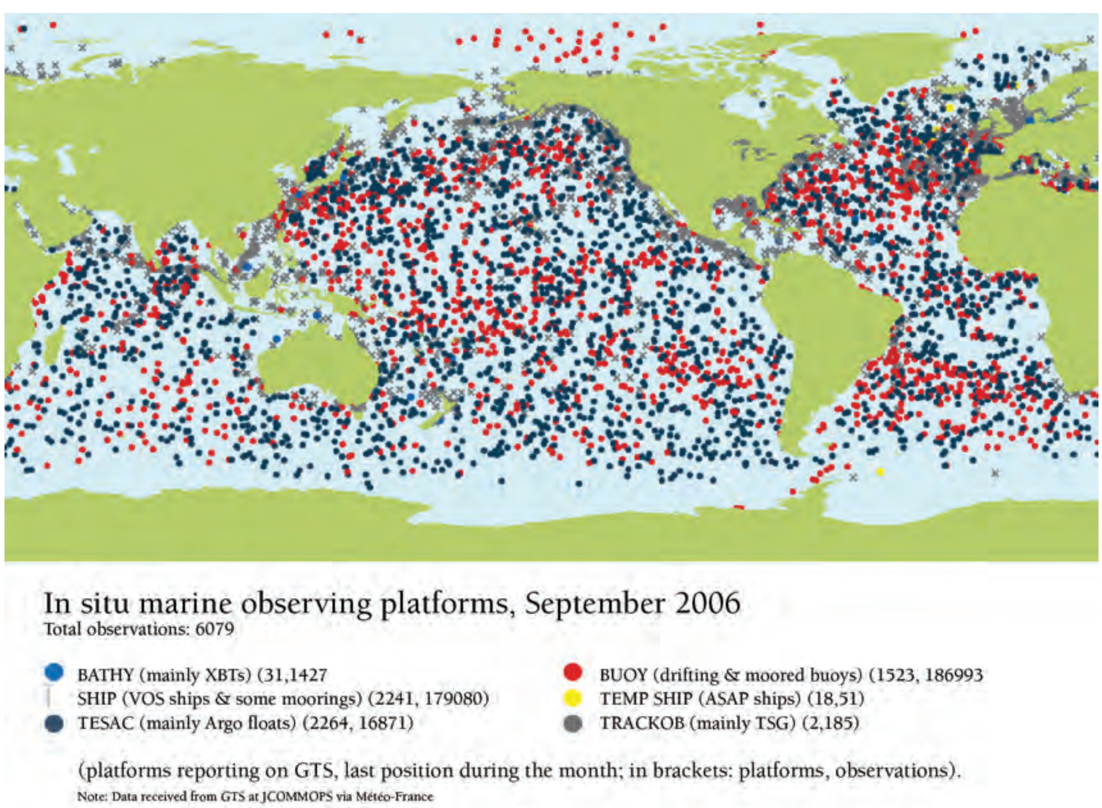
Real-time operational data, information, products and predictions will increasingly be used in support of a large and expanding range of societal applications and benefits. Undeniably then, the oceans constitute a critical component of the lifeblood of our society — thus monitoring, in order to understand and manage them, is vital.

The observing system

Delivery of effective ocean products and services requires long-term and reliable access to global data of guaranteed quality. The Global Climate Observing System's second report gives a summary of the capability of the present observing system to address large-scale climate requirements, and recommends the implementation of the initial global ocean observing system. This strategy will, in practice, support a full range of diverse user requirements, including numerical weather prediction, marine hazard warning and mitigation, and marine environmental monitoring and management.

Ocean observations are currently collected entirely on an independent, national basis. In the interest of greater range, accuracy

In situ ocean observing system status, September 2006 (JCOMMOPS)



Source: JCOMMOPS

The tsunami at Phuket, Thailand, 26 December 2004

Photo: Trevor Gilbert (Australia)

The future of all species depends on an understanding of the oceans

and effectiveness, international coordination and compliance with agreed standards is necessary. Most in situ ocean observation activities are currently coordinated by the Joint IOC/WMO Technical Commission for Oceanography and Marine Meteorology (JCOMM). However, it is clear that there are few national commitments for sustained global ocean observations.

Applications and benefits

Natural hazards and coastal impacts — There is a clear requirement for ocean data, information and products to facilitate the prediction and mitigation of natural hazards, including storms, tropical cyclones, tsunamis, coral bleaching, climate impacts (in coastal regions and island states) and harmful algal blooms HABs).

Integrated coastal management — Integrated coastal management is a prominent theme at regional, national and international levels. The World Summit on Sustainable Development, Johannesburg 2002, and the Commission for Sustainable Development, have both highlighted the importance of effective integrated coastal area management. These policies stress the importance of efficient access to ocean information, to guide the development of management strategies and to contribute to the implementation and sustained operation of management processes. Coastal management issues include human habitations, coastal and shoreline industry and engineering, food production including aquaculture, coastal marine ecosystems and marine protected areas, and the increasingly important marine tourism and recreation industry.

Issues that are of direct and increasing relevance to coastal users and applications include:

- Storm surge and wave prediction models
- Linking estuaries to offshore
- Warnings of harmful algal blooms
- Downscaling of the impacts of climate variability and climate change
- Zooplankton and fish diseases
- High-resolution hydrodynamic models for coastal navigation and hazard reduction
- Sediment transport and turbidity
- Advance warning of environmental impacts/events.

Marine ecosystems management: fisheries and biogeochemistry — Maritime nations share the challenge of managing and sustaining the oceans' living and non-living marine resources for present and future generations. This requires an integrated ecosystems approach. Such strategies are characterized by accurate knowledge of the factors that affect the oceans, and estimates and predictions of circulation and biogeochemical interactions and cycles. These issues are a major focus of Global Ocean Observing System's coastal ocean observing system design and implementation plans.

There is a growing need for oceanographic information of various timescales in order to support the monitoring, and sustainable management of fisheries. The most important information relates to extreme ecosystem events, since these will have the greatest impact on the largest number of people. Extreme weather predictions can be used effectively in predicting, and thus mitigating the effects of global problems such as coral bleaching, HABs, river pollutant pulses and mass extinction due to ecosystem imbalance.

Crisis management: search and rescue, and marine emergency response — In what is generally termed 'public good services', ocean data, products and predictions are made available for a range of activities and operations which take place in the public domain, or for which governments have a direct responsibility.

There are two types of applications:

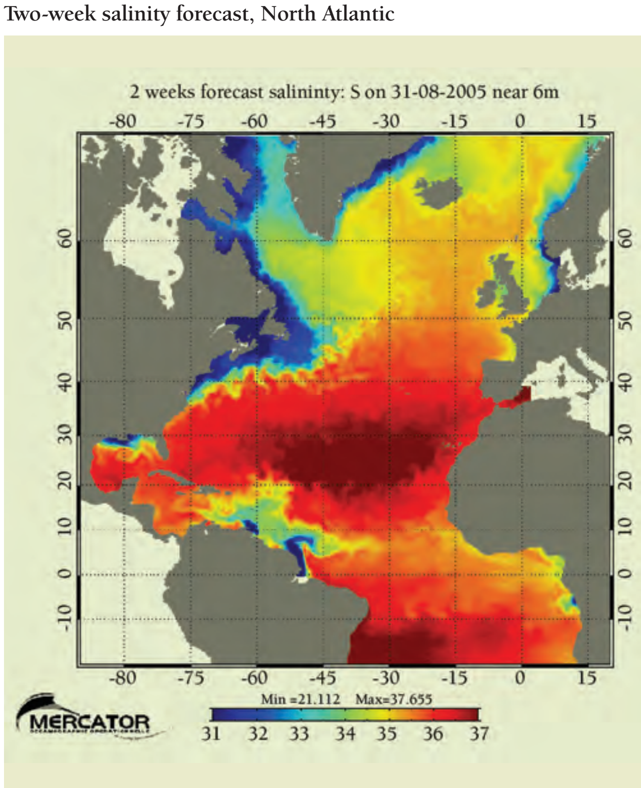
1. Data and products used in an immediate and disposable fashion to mitigate or alleviate the impacts of crises such as oil spills or search and rescue
2. Data and products that are used regularly in the operation of a business or service, to manage risk associated with the marine environment and to enhance efficiency and effectiveness.

Ocean data and products provide substantial improvements to the operational decisions made in crisis management. If such data and products are fully integrated into the existing response tools and procedures, effective reaction time is much improved. Accessibility, reliability and timeliness are vital to the success of such strategies. Crisis management operations require relevant information as soon as possible if they are to implement effective responses to, for example, a search and rescue operation or a major oil spill. In order to improve services and crisis response, operational agencies are working with direct end users and 'middle users' in the private sector, to adapt products and information to meet the specific requirements of different crisis situations.

Risk management — industry, engineering, defence and other at-sea operations — Risk management is a key issue for all industries operating within the marine environment. They require dependable, accurate information to develop appropriate strategies and plans for efficient and effective modes of operation. Such information is often gathered as it is needed by the specific sector or by individual operators. However, this is often not adequate in accuracy or scope. As a result, and due to the recognized importance of risk management data and products to marine industries, such services are frequently provided by private and/or public companies (middle users) that specialize in the provision of such information.

Climate: assessment and prediction of climate variability and change — Climate and climate change are prominent issues for both the developed and developing communities. Knowledge of the ocean is needed for initialisation and verification of predictions, as well as for assessing and understanding climate variations and change. Operational ocean products are most frequently used as the basis for research into understanding the long-term variability of the ocean and for defining the requirements and strategy for an ocean observing system for climate monitoring.

Two-week salinity forecast, North Atlantic



Source: Mercator Project, France

Ocean monitoring and prediction for society

Our ability to measure and monitor the oceans, and our understanding of ocean processes and behaviour, is growing rapidly. The future of human society, and of the very planet and its life forms is, and will increasingly be, dependent on our understanding of the oceans, on predicting their future states, and on applying this knowledge in the service of society and the global environment. This can only be realistically viable through long-term and sustained ocean monitoring — in effect, taking the pulse of the planet's lifeblood.

JCOMM has, as its primary mandates:

- The further development of observing networks in the world's oceans and seas
- The implementation of data management systems to meet the needs of real-time operational services and global observing systems
- The delivery of products and services needed by both operational and scientific user communities.

Thus WMO and IOC, working through JCOMM as a primary coordination mechanism, stand at the forefront of our efforts to understand, harness and responsibly manage the oceans and their resources in the interests of humanity and the future of the earth.[1]

Photo: Australian Maritime Safety Authority

A case for crisis management

The climatic and meteorological vulnerability of the population and economy of Russia as a factor in safe and sustainable development

A.I. Bedritsky, Head of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet); President, WMO

Every day, the life and the economic prosperity of millions of people throughout the world depend on the decisions taken in various countries on the basis of available hydrometeorological information and generalized analysis of the climate. This indisputable fact, which is borne out by a multitude of research, shows the important role of National Hydrometeorological Services (NHMS) in the sustainable development of the economy and of society as a whole.

This is particularly apparent in cases where adverse weather conditions and hazardous hydrometeorological conditions affect the population and economy. As research and experience have shown, this effect is often considerable.

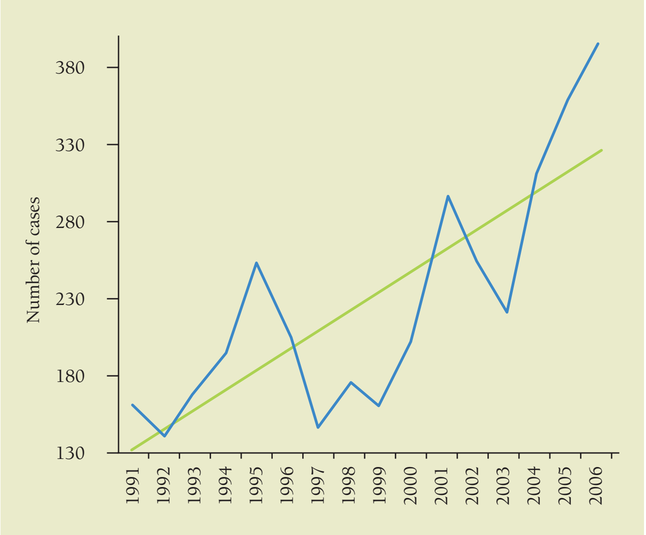
According to data from the World Conference on Natural Disaster Reduction (Yokohama, 1994) the number of disasters that caused a high level of economic damage (on a scale of more than 1 per cent of the annual gross domestic product of the country in which they occurred) rose 4.1 times globally between 1984 and 1994. The number of victims rose 3.5 times, and the number of deaths 2.1 times. Over the past 25 years, natural disasters have claimed more than 3 million lives, 90 per cent of which were in developing countries.

Over the past decade, even more hazardous manifestations of weather and climate change have been noted. Thus, in 2002, the annual report of the Munich Reinsurance Company stated that between 1991 and 2001, the number of significant natural disasters increased 2.6 times in comparison with the 1960s. This led to an increase in economic losses of 7.3 times.

According to the available statistical information, between 1994 and 2004 natural disasters caused more than 730 billion dollars worth of damage and affected 1.1 billion people.

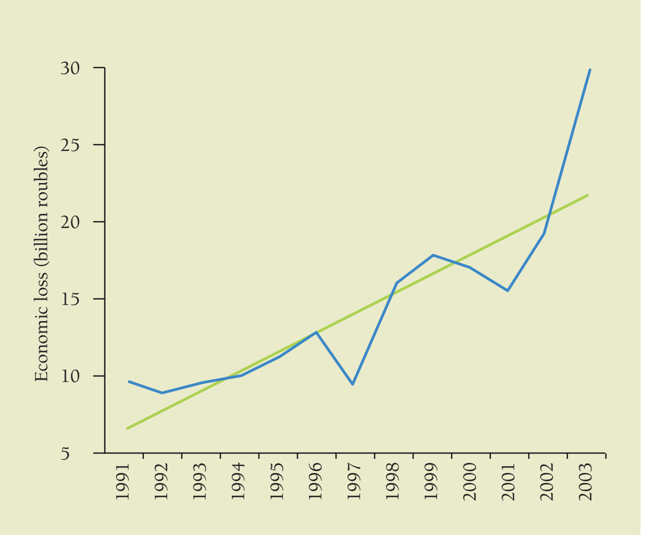
The same trend can be seen in Russia: the graph below shows the distribution of the total cases of adverse weather conditions and hazardous hydrometeorological conditions that caused social and economic damage between 1991 and 2006. Furthermore, the concentration of hazardous weather that grips individual regions of Russia (for example, the North Caucasus region, Chita Oblast, Altai Krai, Kemerovo Oblast) is a cause for particular alarm. Other countries face the same situation.

Distribution of cases of adverse weather conditions and hazardous hydrometeorological conditions that caused social and economic damage in Russia between 1991 and 2006



Source: A. I. Bedritsky

Economic losses (in billion roubles) in the agricultural sector owing to the effect of hazardous hydrometeorological phenomena and adverse weather conditions



Source: A. I. Bedritsky

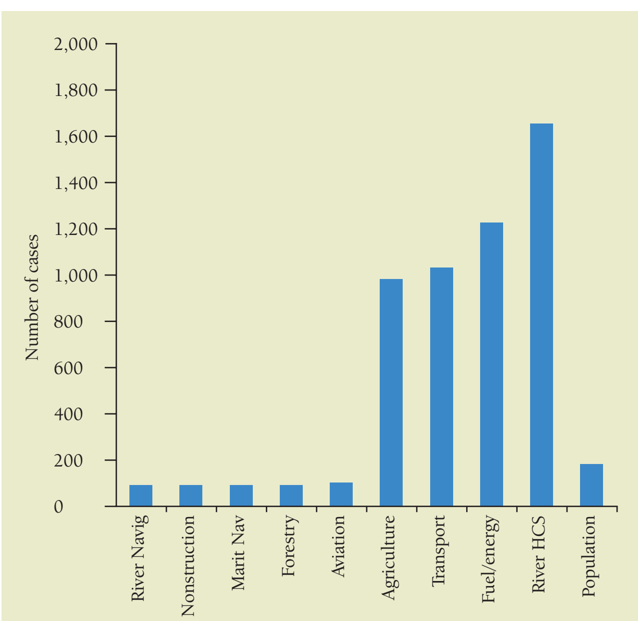
If one takes the world economy as a whole, then the economic losses resulting from the impact of hydrometeorological phenomena at the beginning of the 21st century amount to more than USD100 billion per year. These losses are constantly growing, which shows that the true test of the elements for society is still to come.

The severe economic damage and the large number of human victims resulting from the flooding, series of avalanches and heavy rainfall in the North Caucasus, Siberia and Russian Far East show how vulnerable the Russian Federation is today when it comes to hazardous weather phenomena. Assessing the impact of these phenomena on the economy therefore takes on particular importance for Russia. This is also true given the increase in economic losses. The economic losses resulting from the impact of hazardous hydrometeorological phenomena and adverse weather conditions on agriculture across various years can be seen in the second graph which also shows the growth trend of those losses.

According to expert assessments, between 1995 and 2003, the average annual value of economic losses from hydrometeorological causes in Russia reached 60 billion roubles. The whole social and economic sphere of the country therefore finds itself in a regime of constantly being put to the test by adverse weather conditions and hazardous hydrometeorological phenomena. In 2005, almost every day, some kind of hazardous phenomenon causing economic and social losses was recorded. And, over the past 5 years, the individual regions of Russia (Yakutia, federal subjects of the North Caucasus, etc.) have found themselves on the brink of social and economic disaster.

Much attention has therefore been devoted to the issue of research into the effects of weather — particularly adverse weather conditions and hazardous hydrometeorological conditions — on sustainable economic growth. Many aspects of the information on weather conditions that cause economic and social losses is generalized and systematized with a view to aiding decision-making and implementation of measures aimed

Distribution of cases of adverse weather conditions and hazardous hydrometeorological conditions that caused social and economic damage to the population and various sectors of the economy in Russia between 1991 and 2006



Source: A. I. Bedritsky

at further reducing the consequences. One such aspect is the study and analysis of the meteorological vulnerability of territories and industrial and economic installations.

It should be noted that a variety of concepts are currently used for characterizing the impact of hazardous phenomena. In current work, the notion of the meteorological vulnerability of territories and industrial and economic installations is being used. In the context of the present report, meteorological vulnerability is considered to be the physical manifestation of how liable industrial and economic installations in a given territory are to the effects of the natural environment. There is more to vulnerability than putting protectability to the test, including the natural adaptation of territories and installations to weather and climate conditions. In the long run, hydrometeorological effects manifest themselves in the form of economic and social losses. Thus, hydrometeorological losses, relating first and foremost to hazardous weather conditions against a backdrop of increasing climatic instability, reflect the level of vulnerability of the industrial sphere.

In the end, being vulnerable is an unhealthy position for the Russian economy to be in, with its weak hydrometeorological immunity, the particular physiogeographic characteristics of the country's vast territories and the territorial differentiation of the productive potential of weather-dependent sectors of the economy.

Vulnerability, as a particular meteorological state of the economy, is a composite function, involving: the scale of the industrial installation or process; the specific nature of the industry (weather dependency); the level of protectability; the peculiarities of the regional position that reflect the meteorological risk and a range of other characteristics specific to that branch of industry. This shows that complex concepts are involved, concerning not only meteorological characteristics and indicators but also macroeconomic ones.

In any country, including Russia, the industrial and technogenic sphere is generally shaped by external conditions, determined by nature. However, the natural environment, in the form of weather conditions, is having a more severe impact on society. This manifests itself as an increase in the number and intensity of adverse weather conditions and hazardous weather conditions causing social and economic damage. Thus, this increased severity of the impact of the natural environment on society is spreading to all fields of vital activity (both economic and social).

The level of vulnerability, which is reflected in the scale of the economic losses resulting from the effects of adverse weather conditions and hazardous weather conditions, is first and foremost due to how liable and sensitive industrial and economic installations (territories) are to growing climatic instability and weather-dependence. These indicators of vulnerability (the variability of weather conditions and the risk of impact on the population and economy) are confirmed by thorough scientific and industrial analysis.

Thus, for example, research has shown that the economic sphere and sectors of the economy such as agriculture, transport, energy, housing and communal services (HCS) are particularly vulnerable. These sectors are the most weather-dependent.

Of particular interest is the extent to which the population is liable to the effects of hazardous phenomena. The second graph shows that that the population is most sensitive to the phenomena in groups 1 and 2, which comprise convective phenomena (squalls, heavy showers, etc.), observed in relatively few areas. The majority of the gaps relate to these categories (where 70 per cent and 71 per cent respectively of the cases were predicted). New approaches are therefore needed for forecasting regional synoptic processes, their energy concentration, cyclogenetic activity, and other manifestations of processes on the synoptic scale.

The variability of weather conditions is defined as the climatic characteristic of non-periodic variation in weather conditions in a given territory. The extent to which extreme values vary (deviate) from mean values of the main meteorological variables was selected to depict that characteristic. In order to assess variability, a corpus of daily meteorological data for the period 1991 to 2004 was selected: minimum temperature (Tmin), maximum temperature (Tmax), precipitation (P) and maximum wind speed (Wmax) observed during a 24-hour observation period. Calculations are done according to the formula.

$$Y = \frac{T_{max}}{T_{max}} \bullet F_1 + \frac{T_{min}}{T_{min}} \bullet F_2 + \frac{P_{max}}{P_{max}} \bullet F_3 + \frac{W_{max}}{W_{max}} \bullet F_4$$

Where Y is the dimensionless indicator of the variability of weather conditions;

T_{max}, T_{min}, P_{max} and W_{max} — signifying the absolute extremes of maximum temperature (the highest air temperature observed during the given period), the minimum temperature (the lowest observed during the given period), the maximum daily total of precipitation (the highest quantity of daily precipitation observed during a given period), the maximum wind speed (the highest wind or gust speed observed during a given period) — have been chosen from the statistical distributions of meteorological variables being examined in a selected region;

T_{max}, T_{min}, P_{max} and W_{max} are the average climatic values of meteorological variables being examined — are calculated according to statistical distributions.

Fi is the average annual recurrence (frequency) of extreme values for meteorological variables. The maximum and minimum temperatures and maximum wind speed are calculated as the number of cases, within a 5 per cent range, divided by the number of years in the sample. The maximum daily total of precipitation is the number of cases, within a 10 per cent range, divided by the number of years in the sample. This is done in order to minimize the influence of the span of the sample on the size of the indicator of the variability of the weather conditions in a given territory.

The maps below show an example of the variability of weather conditions in a territory in the central and southern part of European Territory of Russia. It is clear from the integral variability coefficient Y, the 40 federal subjects being studied from the point of view of extreme phenomena possess territorial particularities. In the warm period, a smooth transition from north to the south is observed in the increase in variability of weather conditions. The greatest variability can be seen in the Volgograd and Saratov oblasts. In the cold period, variation is more diverse, but there is still an increase towards the south. This indicates the high level of meteorological vulnerability of federal subjects in the southern part of the European Territory of Russia, from the point of view of the impact of hazardous hydrometeorological conditions and adverse weather conditions on the economy.

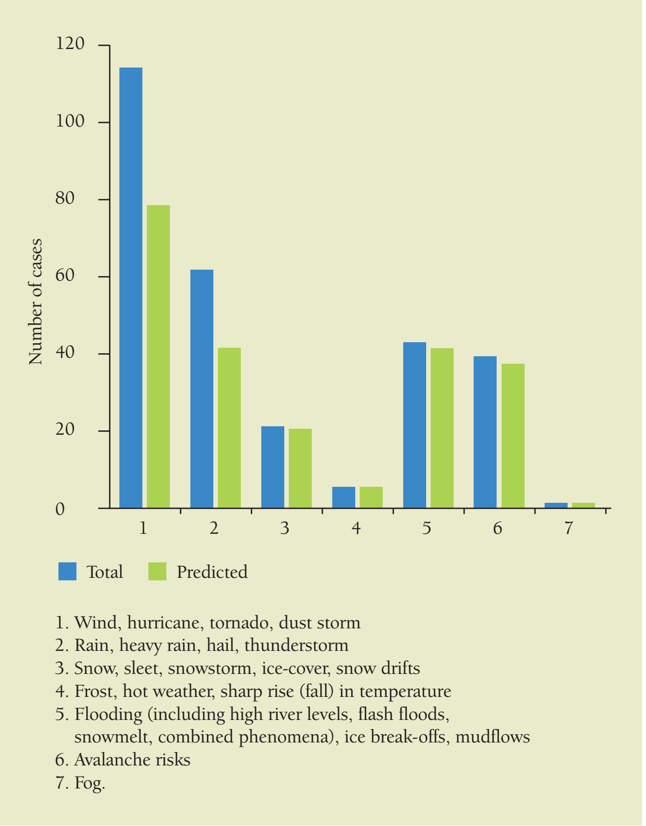
In terms of the increased severity of effects of the natural environment on society and industrial and economic installations users of hydrometeorological information, particularly forecasts have to adopt a policy of optimal adaptation (technical, technological and informational) to current and expected weather conditions. Optimal adaptation — meaning optimal (economically effective) use of hydrometeorological information – allows maximum reduction of vulnerability.

It must be pointed out that the effects of weather conditions may be long-lasting, reflecting the adverse effects of many years of climatic variability. Climate trends of a meteorological dimension that are shaped by this variability give rise to integral climatic costs (economic losses) in sectors of the economy, which can be obtained on the basis of statistical reports at local and federal level. The costs of this kind show the climatic vulnerability of individual types of industrial activity in the economic sphere. Knowledge of climatic vulnerability calls for the amendment of statistical evaluations, prospects, and trends in economic development.

The atmosphere, along with other components of the environment, will also be resource-loaded. As was the case historically, and remains so today, meteorological resources can be used for supporting life. Forecasting and giving warnings of hazardous weather conditions are fundamental meteorological resources.

Various sectors of the economy use daily information about expected weather conditions and timely warnings of hazardous weather conditions provided by the forecasting division of

Distribution of cases of adverse and hazardous weather conditions (by type of phenomenon) that led to loss of human life or social and economic losses for the population between 1991 and 2006



Source: A. I. Bedritsky

Roshydromet. This is an invaluable natural resource for the economy — a social product, whose general and economic significance is universally recognized.

At present, the success of weather forecasting and warnings reaches 85 per cent to 90 per cent. Routine use of Roshydromet's forecast information products by sectors of the economy enables them essentially to avoid weather-related losses. Forecast information allows for timely preparations for the impact of the weather, in order to reduce the vulnerability of the industrial sphere and its infrastructure. Even more pertinent is specialized hydrometeorological information support, which is specific to the individual or address and meets the demands and needs of users in the territories of federal subjects.

According to the assessments of Russian specialists, the reduction of weather-related losses for each sector of the economy ranges from 10 to 85 per cent of the maximum possible losses. On average, the coefficient of prevented losses for the economy as a whole is 40 per cent, and prevented losses total 23 to 24 billion roubles. This solves the issue of the conceptual unity of reducing meteorological vulnerability and the ensuring hydrometeorological safety, which contributes dynamically to the sustainable development of society. It therefore follows that hydrometeorological safety is not only component of Russia's economic security, but also of the country's national security as a whole.

At present, it is generally possible to assess the order of magnitude of use of hydrometeorological resources. This is aided by newly developed joint economic and meteorological models of optimal adaptation, selection of optimal regulations for activities, and assessment of the economic usefulness of hydrometeorological forecasting. These modern mathematical solutions are employed in operational synoptic practice. By way of example, over the past five years, the value of prevented meteorological losses is at least 47 billion roubles. The Russian NHMS has therefore made a substantial contribution to preserving the economic wealth of the country.

Such sectors of the economy as agriculture, fuel and energy, transport and HCS are the most liable to the weather conditions. In each of these sectors, the approach to the use of hydrometeorological information, particularly weather forecasts, is far from rational, economic, or prudent. Often, the decisions and actions taken are far from adequate given the expected weather conditions.

Hydrometeorological information support, directed to the specific nature and needs of each individual sector — in other words, specialized hydrometeorological information support — is regarded as invaluable for saving economy's material resources and ensuring the safety of industrial and other activity. Moreover, the development of specialized hydrometeorological information support enables economic losses to be minimized. The NHMS of Russia therefore meets social and economic needs.

However, in many cases, use of hydrometeorological forecasting is still too basic. The protective measures taken by users of hydrometeorological information are inadequate in relation to the expected effects of the weather and climate. An intuitive approach based on past industrial experience or the current weather patterns is not always effective. At present, scientific findings that guide users to best effect are often ignored.

Roshydromet research establishments have developed methods for optimal adaptation by users to expected weather conditions, selection of a optimal number of solutions (level of protective measures), assessment of the economic effects and the success of using meteorological forecasts. All these modern developments must be employed to their full capacity by the organizations of Roshydromet and by users of hydrometeorological information.

The Roshydromet system has a well-defined assessment system in place throughout the territory of Russia. Thus, the economic impact (approximately — the prevented losses) of the use of hydrometeorological information in 2004 was 11.4 billion roubles (80.6 per cent of the effect occurs in the most weather-dependent sectors — agriculture, transport, energy, HCS), and in 2005 it was 13.9 billion roubles (80.4 per cent respectively). These reductions are confirmed by the specific users of hydrometeorological information. However, it must be noted that the existing method of evaluating the economic impact has not yet taken on a interdepartmental character.

The development of specialized hydrometeorological information support in the current economic circumstances requires a more dynamic approach to taking up market methods for conducting business, ensuring greater guarantees of the quality of hydrometeorological products on the one hand, and on the other, more effective application of these products by its users. This will lead to a maximum reduction of economic losses. Thus, hydrometeorological information support is a reliable State mechanism for reducing meteorological vulnerability and consequently, ensuring social protection and the economic potential of the country.

Roshydromet's programme of technical renovation and research and production development constitutes the basis for a further reduction in hydrometeorological vulnerability and all the negative consequences of adverse weather conditions and hazardous hydrometeorological conditions. However, at the same time, partnerships between State and private entities are not ruled out for investment in regional programmes. Thus, overall, the following is envisaged:

- Assurance of the safety of the population in their living and working environments
- Preservation of the physical state of the technosphere, industry, and infrastructure
- Development of energy and resource reduction
- Efficient functioning of industry.

All this will be possible once the following fundamental issues of meteorology and economic meteorology have been resolved.

First issue — To develop new and perfect existing methods of forecasting meteorological values and weather phenomena on the basis of which, the introduction of highly effective hydrometeorological information products is envisaged.

Second issue — In accordance with the expansion of the procedures for concluding General agreements with ministries and departments, to plan, introduce, and implement in economic practice the aforementioned methods for optimal use of hydrometeorological forecasts. In addition, resolution of this issue also requires the development of an Inventory of sector-specific hydrometeorological losses, and in accordance with the established research methods their formal presentation in matrix form. It will simply not be possible to secure new successes in the use of specialized forecasts without setting up such a mechanism.

Given that hazardous synoptic processes grip an increasing number of countries simultaneously, the development of this kind of inventory may require joint international efforts in the search for the determining factors.

Third issue — Interdepartmental assessment of the reliability and economic usefulness of hydrometeorological forecasts, which requires perfection of the technology for collecting, collating and analysing information, particularly about economic losses.

The issues presented above must be highlighted and their sector-specific solutions given as part of the '*Hydrometeorological passportization*' project developed in conjunction with users. It is a substantial task of federal significance, which must be put into practice in Roshydromet's territorial Administrations on the basis of a conceptual programme. The programme is determined by the fact that alongside the nationwide problems of economic development remains the problem of ensuring the daily hydrometeorological safety of the population and economic practices. The user must learn to understand the economic content of the meteorological environment, its natural indifference, and its dangers, and by means of a mechanism such as the optimal use of forecasts, know how to preserve its beneficial effects, reduce meteorological losses, and develop economic gains.

Thus, it is glaringly obvious that the hydrometeorological vulnerability of the economy and the social and economic sustainability of society share a common cause-and-effect relationship: namely the need to reduce meteorological losses, ensure hydrometeorological safety and therfore contribute to sustainable social and economic development.

At the present time, the country has an industrial infrastructure adapted to previous climatic conditions, although these are now changing. However, climatic changes that are taking place at global and regional level, particularly their extreme manifestation beyond the usual level of intensity, can give rise to catastrophic damage in economic and social spheres. In this connection, the battle to reduce economic and social losses will never be won if they are not taken into account at State level. This is particularly important for minimizing the losses, which leads to a reduction in meteorological vulnerability.

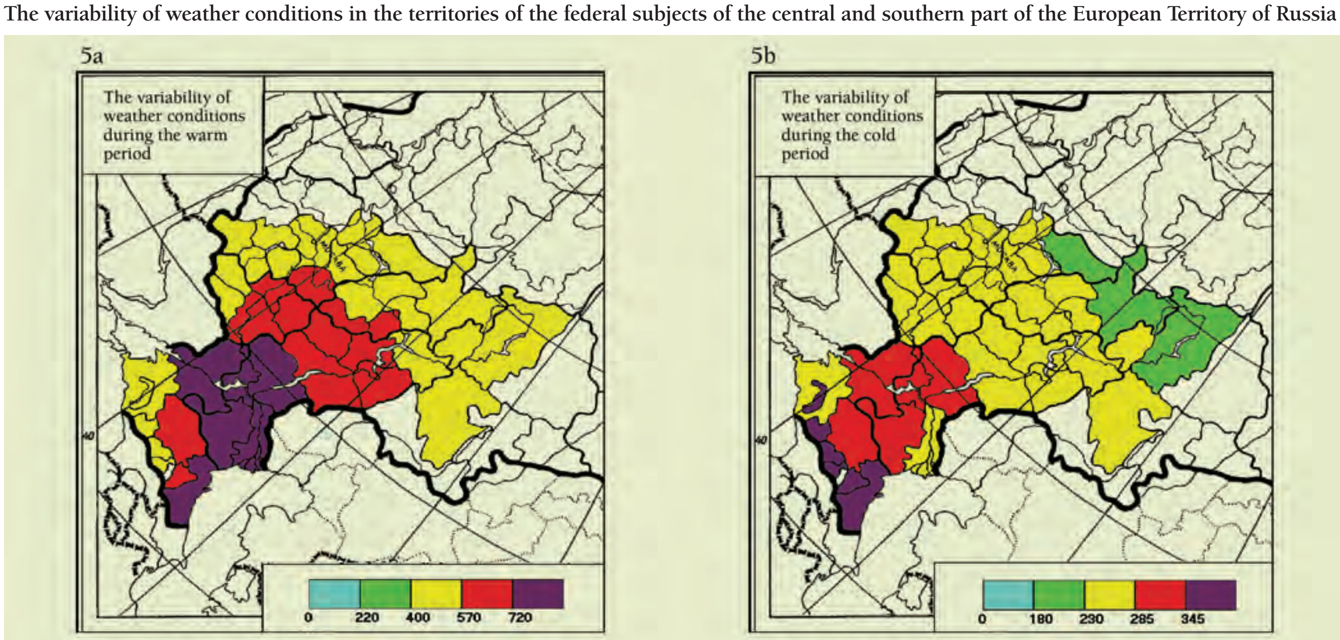
Taking into account these losses at State level and their minimization requires ministries and departments to develop of common interdepartmental procedures for evaluating the damage caused by extreme natural events and for classifying and taking stock of these extreme situations. Interdepartmental procedures are needed for evaluating the losses that were avoided by using of hydrometeorological information and taking protective measures.

The development of interdepartmental procedures for evaluating the prevented losses, taking stock of and analysing these losses enables ministries and departments to develop guidelines for taking the optimal decisions regarding weather and the economy that are required for implementing the essential rational protective measures that lead to a maximum reduction in losses.

In carrying out national and sectoral assessments of the effects of weather conditions and meteorological vulnerability, Roshydromet has had to develop and supplement on a regular basis databases on adverse weather conditions, hazardous hydrometeorological phenomena and extreme manifestations of climate change, which ought to help reduce the losses experienced by the population and economy of federal subjects. These assessments are important for planning current activities and for the development of a State "reaction" strategy, needed for coping with future extreme phenomena.

A permanent archive is required, to be created using the aforementioned databases. This is because comparative analysis of the negative consequences of adverse weather conditions and hazardous hydrometeorological phenomena enables more precise procedures for forecasting the effects on humanity of hazardous phenomena, and weather as a whole, to be developed, and measures for anticipating them to be formulated. It is also required for perfecting standard forecasts and forecasts about hazardous hydrometeorological phenomena, particularly difficult to forecast convective phenomena, and for perfecting systems for effectively conveying those forecasts to the people making decisions about the protective measures to be taken.[1]

The variability of weather conditions in the territories of the federal subjects of the central and southern part of the European Territory of Russia



Warm period: April to October

Cold period: Novemeber to December of the previous year and January to March of the current year

Source: A. I. Bedritsky

Technical cooperation for weather, water and climate services in developing countries

Steve Palmer, UK Met Office[1]

Weather, climate and water cross all national boundaries, and affect every aspect of life. Over the last 150 years, scientists have been sharing their observations and information about weather, climate, water and the environment, and using the best available communication and scientific tools in order to produce useful weather and climate forecasts, and other knowledge-based products and services. Monitoring and predicting our weather and climate and how they affect the Earth's environment and society requires international cooperation. However, in developing countries, limited resources and lack of human capacity prevent them from producing and applying information for the benefit of their own communities, as well inhibiting the dissemination of data to other centres.

The World Meteorological Organization recognized this problem, and set up the Voluntary Cooperation Programme (VCP).[2] The aim is to link the needs of National Meteorological and Hydrological Services (NMHS) of developing countries with the technical ability and funding available in developed countries. The VCP provides a mechanism through which the NMHS of developing countries can request assistance in terms of equipment, expert services, training and education, in order for them to be able to participate in the programmes of WMO. These programmes cover the role of NMHS in taking observations, communicating them to stakeholders, archiving them for climatology studies, and in producing forecasts and warnings for their users. There are various types of end-user services, but first among these is ensuring the safety and well being of their nations' citizens. NMHS are responsible for monitoring weather, climate and the natural environment, and for giving public warnings and information in a timely, reliable and comprehensive manner. Each NMHS has links through its government to national disaster prevention and risk management authorities. They also have knowledge of the local environment in order to assess potential impacts, as well as an awareness of culture and languages, so as to be able to communicate directly to the people, particularly at the local community level. The forecasts and other information on weather- and climate-related events that the NMHS provide are a vital component in the decision making processes for many weather-sensitive sectors.

Developing countries are often the most vulnerable to natural disasters, because they are located in regions prone to

Photo: Met Office, UK

Launching a radio-sonde at Gan, Maldives after the station was re-equipped by USA and UK VCP contributions

Photo: Synergy Media Services

A forecaster in Sri Lanka finishes her weather presentation for broadcast on the national TV company using equipment provided by UK VCP natural hazards, and usually lack the resources to invest in adequate infrastructure. Poverty limits choice, and forces people to take risks, such as living on land vulnerable to flooding or landslip. Many humanitarian and environmental disasters are directly related to weather and water. Some occur on very short timescales, such as hurricanes and flash floods. Others, such as droughts and food shortages, can be stretched over a period of months, or even several years. Even when not directly involved in a hazard, weather often complicates attempted relief and rescue operations. In the short term, disaster warning systems can prevent much loss of life and livelihood by alerting people to particular threats. Climate change will alter the incidence of natural disasters, as well as having impacts on the sustainability of environments and livelihoods over the coming decades. Because of this, quality information is vital to prepare people to adapt their livelihoods.

The primary source of funding for NMHS is for the provision of the public weather service. Thus, validation of this service has become increasingly important in order to justify government funding. In developing countries, as a broad generalization, NMHS get very little funding from private-sector work, even where they are able to exploit commercial opportunities. Commercial aviation weather services, for those NMHS which provide them, are a very important part of the justification argument, since international civil aviation pays the national authorities in hard currency. Unfortunately, in many countries this does not translate directly into funds for the NMHS.

Developing country NMHS have great difficulty with affording the equipment for observing the environment. This is particularly the case with the consumables for upper-air measurement. Each radio-sonde observation costs approximately USD200. With developments in numerical weather prediction and satellite capability, as well as the data gathered by Aircraft Meteorological Data Relay (AMDAR) equipment on civil airline flights, there is no longer scientific justification for upper air observations, as beneficial to local forecasting. The exceptions are for low-level aviation forecasting and applications such as tracing pollutants and disease vectors. Increasingly, the primary requirements for a network of high-quality upper air observations are to provide a long-term record for monitoring global climate, and to provide the baseline calibration for satellite instruments. Surface observations generally have lower costs. Though the capital cost of equipment may be significant, the unit cost for each observation will be made up mainly from staff and communication expenses. There is also a much stronger argument for the utility of surface observations in providing local and national benefit. Surface observations are also communicated and used globally; under international agreements through WMO, observations from the Global Climate Observing System and other networks are freely available through NMHS and global data centres.

It can be seen that environmental observation data and metadata has high costs, but the value of the observation lies in the use made of it, and not in the observation itself. Hence it is unrealistic to argue that any individual user of the observation should pay a particular proportion of the cost. Even if charges are levied on users for the cost of observations, it is very difficult to make these equitable, and the result is likely to be that potential services will be rendered uneconomic. In contrast, it

Photo: Instituto Nacional de Meteorologia, Spain

Commissioning a solar photometer at Tamanrasset in Southern Algeria with support from Spain to monitor aerosols and dust in air masses over the Sahara desert, especially for early warning of dust clouds

is generally in the interest of NMHS to increase the number and range of users of their data in order to strengthen their case for adequate government funding for the public weather service. Therefore charges for the use of data should reflect the value added by the information and services derived from said data.

It is instructive to consider these data using the concept of 'Global Public Good'[3] where 'good' means a thing or condition (in this case data and the metadata needed to interpret it) but makes no assumptions about the costs, benefits or valuation of the good; 'global' means spanning all divides and borders; 'public' refers to the general population, civil society organizations and corporate citizens; the 'global public' includes states and international organizations. These observations therefore meet the economists' definition of 'public good' as having both non-excludable and non-rival benefits, as well as being non-exclusive. It is worth emphasising the huge potential current and future benefits of these observations in providing a climatological record during a period of rapid change, in supporting current forecasting on periods from immediate response to seasons, and in providing the baseline and future verification as the climate changes. However, only some of these benefits will accrue in the countries where the observations are taken, particularly in the developing countries. Remote islands are especially important for global observations, and many of these are in Small Island Developing States. It is likely that the majority of economic benefits of "global public good" observations will accrue in developed countries, despite the developing countries suffering most from the social impacts of extreme events and climate change.

This analysis shows why it is difficult to persuade development aid partners, whose interests are primarily to enhance free trade and economic growth, achieve sustainable development, promote good governance and democracy and increase safety and security, to be interested in funding observations, particularly of the upper air. For funding by NMHS of developed countries, including through the WMO VCP, it is reasonable to argue that such voluntary contributions are not 'aid' but investments in global public good through delivery of the observations which primarily benefit the developed countries. This is an imperfect method of achieving an equitable provision of global public goods, because the voluntary nature does not fit with long-term planning. On the other hand, the 'club' nature of the partners to WMO VCP means that there is a high degree of understanding, and therefore efficiency in the detail. In the future, it may be that a coordinated mechanism will be realized to fund global observations, in much the same way as Europe has developed its own.

The VCP partners are not only concerned with the global supply of meteorological and hydrological observations, but also work with other development agencies, and therefore also consider aims including the Millennium Development Goals and natural disaster mitigation.

Extending this analysis, the NMHS of developing countries need to be sustainable organizations, and therefore they must deliver effective and sustainable services to the public in their countries. These will include services as part of their national disaster plan, and their national development strategy. Such services will include statistical information using current and past data, forecasting on a range from a few hours to seasonal, and the setting of all this into the context of climate change impacts. The VCP donors appreciate the need for the NMHS of developing countries to be effective and sustainable, and therefore support projects across this range of services. Recent VCP projects include the provision of Numerical Weather Prediction products specifically for the developing countries, systems for communication such as satellite and the Internet, workstations for forecasters to visualize the weather and produce forecasts with, systems for climatology databases and assessing regional climate change impacts, and equipment for delivering services to the public. Sustainable organizations need people trained as effective practitioners, and here the VCP donors also help by supporting a range of training and professional development.

Examples of projects supported through WMO VCP

Training and fellowships

Training and fellowships form an important component of the VCP Programme. Whilst almost all VCP Projects have some form of training associated with them, there is a need to develop the basic and specialist skills of personnel within NMHSs. The aim is to build a "critical mass" of people who can manage and nurture the services provided by an NMHS, from observations through to forecasting and understanding the likely impacts of climate change. Traditionally this has been achieved by offering a range of fellowships for short- and long-term courses hosted by other NMHSs, WMO designated Regional Training Centres and universities around the world. Much of this is coordinated by the WMO Education and Training Department.

Recent projects have explored the benefits of using e-learning techniques to improve the efficiency, quality and accessibility of this training. One example is the Statistics in Applied Climatology Programme (SIAC). The "e-SIAC" was developed by a team from Reading University in the UK, with support primarily from UK VCP. The e-SIAC teaches participants how to analyse climatic data and produce simple products that are useful primarily in the agricultural sector, but also to those working in health, food security, construction and tourism. These products are becoming increasingly important as it is widely recognised that knowledge of climate variability is key to understanding the likely impacts of climate change. The e-SIAC has so far successfully engaged over 100-participants from more than 20 Countries in Africa and is also proving popular in other regions. For further details visit: www.met-elearning.org/moodle.

RANET

RANET is an international collaboration to make weather, climate, and related information more accessible to remote and resource poor populations. RANET undertakes this mission in order to aid day-to-day resource decisions and preparedness

Photo: Météo-France

A training workshop for several South Pacific countries held by Météo-France in Noumea on ensemble forecasts and application to monthly and seasonal forecasts

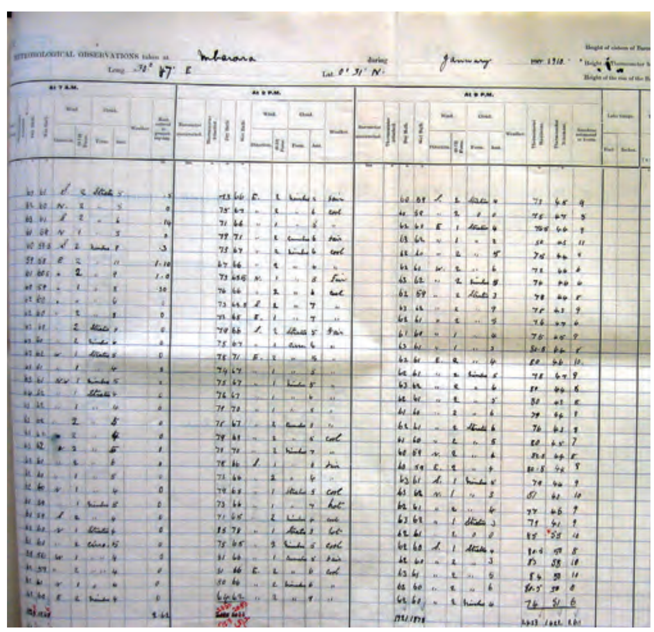


Photo: Met Office, UK

A monthly observations sheet for Mbarara, Uganda in January 1910. Digital photos of paper archives are easy to share and can be digitised to add to climatology databases against natural hazards. The program combines innovative technologies with appropriate applications and partnerships at the community level in order to ensure that the networks it creates serve the all a community's information needs. Community ownership and partnership is the core principle of RANET's sustainability strategy.

RANET uses web content broadcast over satellite radio from global and national information providers. This is then linked to solar-powered community radio stations and community information centres. Other techniques include wind-up radio receivers, email via satellite and HF radio. Community weather stations promote interest and 'ownership' of weather and climate information.

RANET first started in Africa, and has now spread to Asia and the Pacific Islands, where it is a key part of emergency management systems. While none of the technologies is uniquely successful, combined they are highly effective and valued by communities. RANET's strategy is to work with a variety of NGO and government information producers. This is a holistic approach to sustainability and disaster reduction. While weather and climate information is important, RANET recognizes that there are often more immediate needs at the community level.[4]

Media weather presentation

A perfect weather forecast is of little use if it is not communicated to the appropriate people. TV is one of the most effective ways of communicating to a wide variety of people quickly and in a way that is easily understood. Local TV companies operate in almost every country, and as the cost of satellite TV broadcasting has fallen, they can now reach beyond the urban population. Providing information in local languages is important; often, national broadcasters will have schedules for each of the national language groups, and targets for locally-provided content.

TV weather presentation studios have been provided to the NMHS of about 35 developing countries. These use equipment which is carefully selected to give a high quality TV image without the flexibility and expense needed in the usual TV studio. Having the studio in the NMHS, and providing the broadcast to the TV company on tape means that the forecaster has editorial control of the content, thus ensuring that the presentation is clear and correct.

Observations

Support for observations was the starting point for WMO VCP. Many recent projects have focused on the change to digital radio-sondes for upper air soundings, along with replacing or upgrading ground equipment. Each observation uses a radio-sonde and balloon, which cost approximately USD200. A station meeting the full recommendation will launch two per day. Many stations use hydrogen as the lifting gas in balloons, the generators of which are expensive, but do have a long life.

Automatic weather stations, especially those which have manual input of data such as cloud type, are becoming more widely used, giving more surface observations especially at night. Systems for communicating the observations are also supported by VCP, and email and cell phone communications are becoming widely used.

There are a small number of stations with further specialised equipment, such as the solar photometer installed with support from Spain at Tamanrasset, southern Algeria for monitoring desert aerosols and dust.

Over a long period, VCP support for climate database management systems on PC has been very useful. The CLICOM system originally developed with USA support was widely used, and replacement systems are being implemented with support from many VCP partners. In particular, the Climsoft system was developed in the NMHS of Zimbabwe, Kenya and Guinea with support from the UK and Australia.

As awareness of climate change increases, there are projects to digitise old data in paper archives using digital photography, and subsequent conversion to climate databases.

Photo: Care, Zambia

Participants in the e-SIAC training engaging with farmers and agricultural extension workers in Southern Zambia about information products

Photo: Met Office, UK

An observer at the surface station at Narok, Kenya. Kenya Met. Dept. have pioneered a project to distribute information products to communities using their local observers

Planning and governance: Bahrain Meteorological Service

Abdulmajeed Husain Isa, Assistant Undersecretary for Meteorology, President of Regional Association II (Asia)

From its relatively small beginnings as a reporting station in the early part of the last century, the Kingdom of Bahrain has grown, despite its tiny geographical proportions, to become a major force in the world of meteorology in the Middle East, and within the family of nations that is known as the World Meteorological Organization (WMO) Regional Association II (Asia).

Over the past few years, thorough training and planning within the Bahrain Meteorological Service (BMS) has reduced a staff of 90 to a more manageable and economically viable 65, with most of the remaining and newly recruited staff at graduate level or its equivalent. The leadership of the Deputy Prime Minister H.E. Sheikh Ali Bin Khalifa Al Khalifa has been fundamental to this transformation.

Services have been extended to include an automated aviation service for both military and civil aviation, and a marine service that covers the entire Arabian Gulf region including the Gulf of Oman and its approaches.

Tailor-made services are also available for commerce and industry. In addition to these vital services, BMS is the official voice for meteorological warnings and advice for the general populace, as well as for the Government of the Kingdom of Bahrain.

A proportion of the high-level staff training has been due to the help and advice given by the WMO and the United Nations Development Project (UNDP). This support is freely acknowledged and highly appreciated by BMS.

The BMS is now itself a training entity and has provided meteorological training for a number of Gulf States in statistical analysis, general meteorology, and pre-initial forecasting. Its plans are in place to extend this operation in an effort to offset core costs funded by the Government.

Partnership with WMO

A productive and cordial partnership between BMS and WMO goes back many years. The guidance and advice provided by WMO has been invaluable.

Photo: BMS

Bahrain Meteorological Service forecast operation centre

Practical assistance is given in many areas, not only in staff training but also through the provision of equipment under the auspices of the UNDP. The most notable example of this is the UNDP Project (Bahrain) 1998, which provided for short and long-term fellowships for staff, and the supply of vital equipment to extend remote sensing capability through the installation of automatic weather stations in and around the Kingdom of Bahrain.

A number of senior staff were given short-term fellowships. These entailed on-the-job training in many different countries including the People's Republic of China, Poland, South Korea, Hong Kong and Egypt. This comprehensive training included satellite meteorology, agricultural meteorology, marine meteorology, remote sensing, environmental meteorology and radar meteorology.

This type of training for senior and experienced staff proved to be most beneficial. Feedback was very positive, and attendees were subsequently able to train junior staff in their newly acquired expertise.

Long-term fellowships awarded under the UNDP scheme provided graduate courses for 13 members of staff, including both junior and senior members. This part of the UNDP scheme kick-started BMS's long term plans to employ only graduate staff, an initiative that is now close to completion.

After a stringent testing and interviewing process, the staff selected for the programme successfully completed a BSc or MSc degree in business and administration, computer science, applied geography, physics, mathematics or meteorology. Most courses were held at the University of Bahrain, but some staff attended courses in the UK.

Participation in this scheme has raised the academic standards of BMS staff and, perhaps more importantly, has increased enthusiasm among other staff for involvement in educational schemes. Staff-strengthening schemes seem to have a 'ripple effect', and this has certainly been the case for BMS. Junior members of staff now demonstrate a desire to improve their status and to undergo further training.

The effect of the training provided by the UNDP scheme, in addition to the extensive ongoing programme of locally initiated and funded training programmes, has raised the standard of general competence. This is reflected in BMS's services to the military, civil aviation and marine activities (both commercial and leisure), through a tremendous improvement in the accuracy of our forecasts. The five-day forecast is now widely promulgated and is the subject of very positive feedback, not only from commercial users, but also from numerous government departments and royal family members who have come to rely on its content.

Improvements in the aviation sector

Great strides have been made over the past five to seven years in the methods and distribution of aviation sector products.

Initially, all forecast upper wind charts were analysed by hand with streamlines, copied, reduced and distributed by hand to various users. Significant weather charts above FL200 internationally, and above FL100 regionally were also hand-drawn with local modification, before being distributed in a similar manner.

The introduction of the forecaster workstation system dramatically altered methods of production. Charts received through Meteorological Data Distribution (MDD) broadcasts were produced automatically, though still with the facility to be modified locally for both forecast upper winds and forecast significant weather charts. After an initial period when these products were delivered via fax systems, they are now delivered electronically to the airport computer network, from which the briefing officers, aircrew and users can extract them. This has significantly speeded up the process of production and dissemination.

Climate change

As the Kingdom of Bahrain is an archipelago of 33 islands, the effects of climate change will significantly impact the population. Under normal climate conditions Bahrain has to mitigate the natural affects of desertification and the long dry periods experienced throughout the year. However, the extreme effects of climate change need urgent attention if further damaging effects such as a rise in sea level are to be allayed.

Comprehensive information and advice is necessary if changing climatological conditions are to be offset, and BMS has long been aware of the need to provide an infrastructure for this. Its newly extended climate section is conducting ongoing research with highly qualified staff and has a number of programmes in hand to this end.

During the past two years a completely new database management system has been purchased and installed to replace the old Climate Computing Project (CLICOM) system. This new system has greater capabilities for the analysis and presentation of statistical data, and has significantly extended the scope for both research purposes and for commercial exploitation.

Regional Association II (Asia)

The Assistant Under-Secretary for Meteorology, Abdulmajeed Hussain Isa, has been the President of the WMO Regional Association for Asia since 2001. This has been of great benefit

Photo: BMS

BMS Meteorological enclosure

Photo: BMS

School visit to BMS

to the Kingdom of Bahrain and has raised the profile of BMS globally.

The president has worked tirelessly throughout the tenure of his office and has initiated and overseen a number of successful projects. This has been done in addition to his work as head of BMS and with the assistance of a very small but highly qualified staff.

WMO sub-regional office

The sub-regional office is an integral part of the Secretariat of the Organization. It is located in the city of Manama, capital of the Kingdom of Bahrain. Its responsibilities are defined by the organization and its specific activities by the Secretary-General. Its responsibilities include liaising with the Members of Regional Association II (Asia), with the WMO regional office for Asia and the South-West Pacific, with the regional offices of the United Nations, the United Nations Development Programme and of other UN subsidiary bodies, with regional offices of other specialized agencies, and with regional intergovernmental organizations in the fields of meteorology and operational hydrology related disciplines.

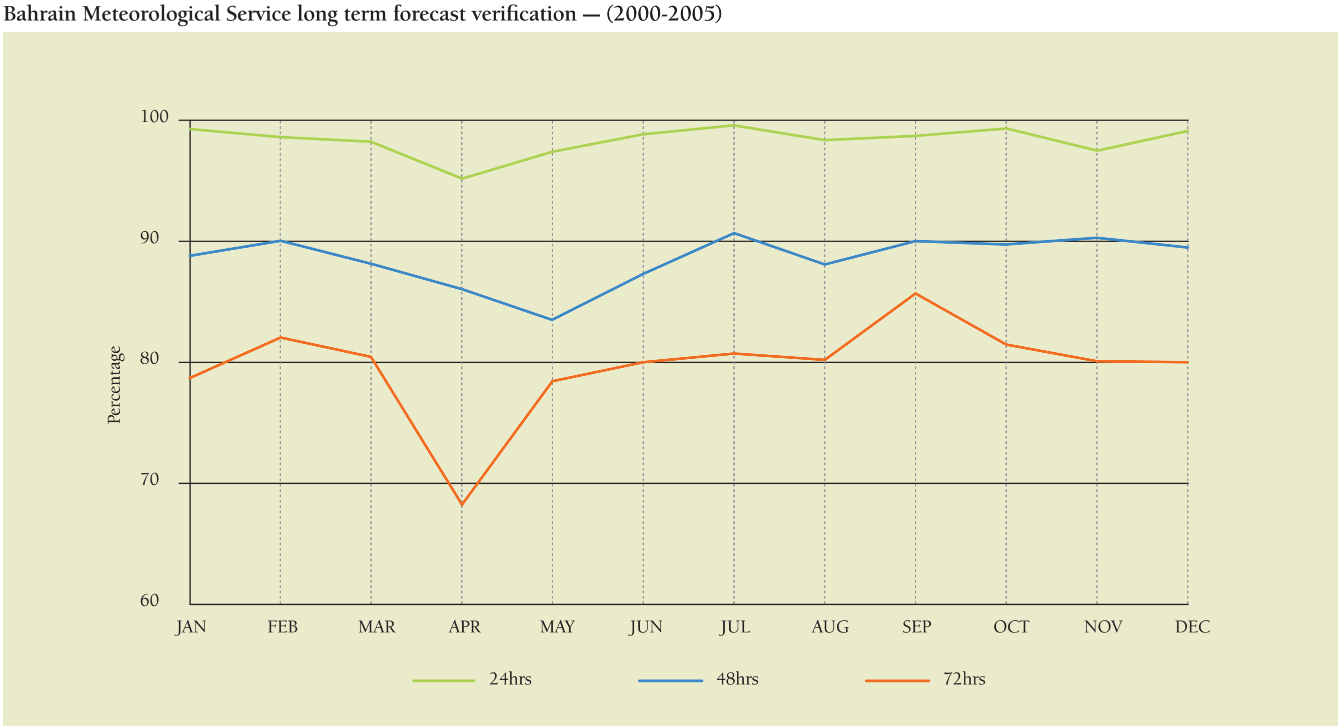
The establishment of a WMO sub-regional office in Bahrain should mitigate this workload.

Aviation services provided by BMS

Pre-flight briefing — This is achieved through the provision of pre-flight briefing documents, including forecast en-route winds, forecast en-route significant weather, and forecast climb and descent winds, issued to all aircraft departing from Bahrain International Airport for international and regional destinations. This service is part of the aeronautical information services provided by the briefing office through the recently established automated system.

In-flight meteorological services — The meteorological operations centre is linked directly to the control tower, approach, and area control centres, where information collected from automatic weather stations and satellite distribution (SADIS) is processed and then displayed at air traffic controllers' work stations for onward transmission to all appropriate users in flight.

Bahrain Meteorological Service long term forecast verification — (2000-2005)



Source: Bahrain Meteorological Service (BMS) — Climatology section — 2001

In addition to these services, all other necessary and appropriate meteorological reports are made available on the broadcast systems and volume meteorological (VOLMET) centres through designated radio frequencies and data links.

Dissemination of routine METARs and TAFs

Bahrain has been designated one of the main collection and distribution centres in the Middle East region within the International Civil Aviation Organization (ICAO) regional Operational Meteorological (OPMET) bulletin exchange scheme. All aviation routine weather report (METAR, from the French) and terminal aerodrome forecast (TAF) issues are sent though a data link to the Bahrain Aeronautical Fixed Telecommunication Network/Common ICAO Data Interchange Network (AFTN/CIDIN) centre for onward transmission in accordance with predefined address lists.

Services to the media

BMS has for many years provided services to the press, radio and television:

Radio — Live radio broadcasts are made to the Bahrain Radio and Television Company several times each day in the Arabic language. These broadcasts are immensely popular with the general public and very often lead to lively discussions regarding the weather. Regular feedback is generally very positive.

Press — Forecasts are made to all published newspapers in the Kingdom of Bahrain, both English and Arabic-speaking. Feedback is positive and any letters to the press regarding weather phenomena are answered fully and promptly.

Television — BMS has for many years provided both the English-speaking station and the Arabic-speaking station with written forecast scripts. In 2002, a TV graphics system was purchased to enable a comprehensive broadcast to Bahrain television. This service appeared to be popular with the viewing public, but unfortunately staffing difficulties necessitated its suspension in 2005. BMS recently upgraded the TV graphics system, and after successful negotiation with Bahrain TV, the service is due to resume in the near future.

All of these media services can be used to issue urgent messages of highly inclement weather that could endanger or inconvenience government services and the general public.

Flight safety

It is clear that weather phenomena have a significant impact on flight safety, even allowing for major improvements in aircraft construction and onboard instrumentation. BMS will continue to provide all the necessary resources within its budget to maintain and improve its contribution to flight safety and convenience of delivery.

To this end, it has recently installed the latest forecaster workstation system incorporating the Meteosat second-generation satellite receiving system. It will continue to review all major developments in equipment and techniques for providing the best and safest possible service.

Forward planning

Planning for the short and long-term future of meteorological services is a vital part of BMS's strategy in conjunction with the Deputy Prime Minister responsible for Meteorology. We are confident that this policy will continue to flourish.

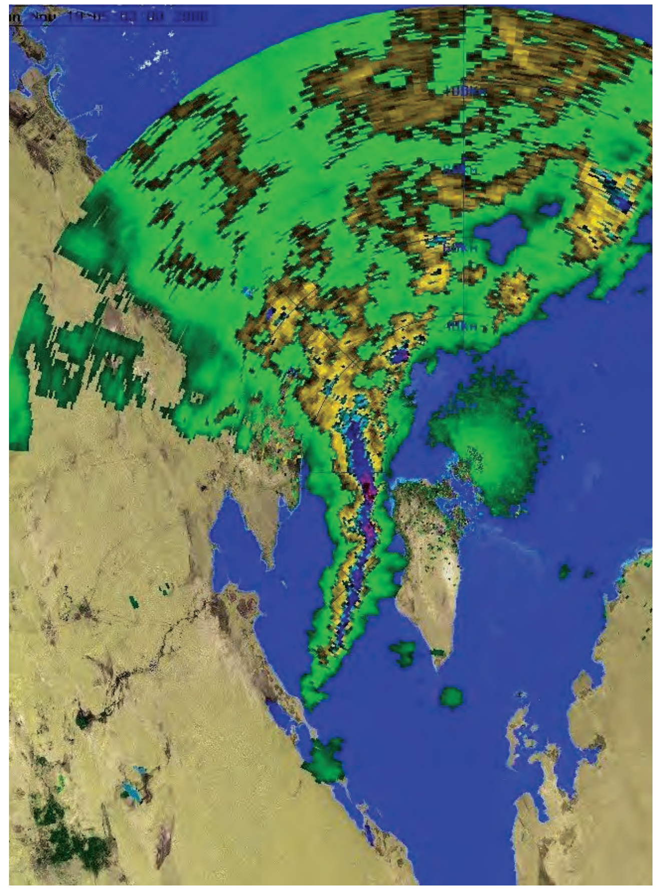


Photo: BMS

BMS weather radar image, 19 Nov 2000

With this in mind we have appointed specialists within BMS to constantly review and inform the Assistant Under-Secretary for Meteorology of all developments and revised techniques in providing the best services possible to the aviation sector.

Our in-house specialists will advise on:

- Developments in computing equipment and services relevant to meteorological services
- Developments in satellite reception and analysis
- Climate change and research
- Developments in communication and dissemination techniques.

Staffing

Many of the current BMS staff members are graduates at BSc or MSc level. Those who are not graduates are at senior staff levels, persons of long experience in operational forecasting. Such staff members have undertaken postgraduate courses relating to meteorology. They have also attended courses in numerous countries on disciplines such as satellite meteorology, agricultural meteorology, remote sensing and marine meteorology.

BMS management intends to replace these experienced members of senior staff, upon their retirement, with graduates. Future recruitment of junior-level operational forecasting, climatology, computing and research staff will be at graduate level. In addition, support staff are being encouraged to undertake graduate training.

BMS wishes to express its gratitude to the individuals and organisations that have contributed to its success and development over recent years.

Reducing disaster risk in Canada: new legislation and policies that enable citizens to adapt to weather and climate extremes

Magda Little, Environment Canada, David Grimes, A/Assistant Deputy Minister, Meteorological Service of Canada, Environment Canada and Alvin Lau A/Coordinator, Business Policy Directorate, Meteorological Service of Canada, Environment Canada

In Canada, weather-related disasters and extreme events continue to place increasing burdens on citizens and the economy. Flooding disasters alone are about four times as frequent today as they were 50 years ago. The ice storm of 1998 was the single most expensive natural disaster in Canadian history, resulting in over 30 deaths and USD5.5 billion in damages. In addition, wildland-urban interface fires have, over the last several summers, presented unique management challenges related both to property loss and the design of evacuation and response plans.

Canada is signatory to the Hyogo Framework for Action, which calls upon all nations to reduce the frequency of disasters within a decade. As over 80 per cent of all Canadian disasters have been weather related in the past, weather and climate adaptation strategies will almost certainly reduce disaster risk in the future. Adaptation strategies can take many forms — the more successful are those that seek a balanced approach emphasizing both long and short-term lines of defence.

As a consequence, within Canadian disaster management circles, it is commonly accepted that the Meteorological Service does, and will continue to play an increasingly important disaster risk reduction role. However, Canada's geographic extent and decentralized approach to emergency management presents a unique challenge. Canadians from coast to coast are regularly exposed to a variety of environmental conditions, making a nationally consistent approach difficult to achieve.

Photo: Corel Corporation 1994

Working with provinces and insurance companies, the Meteorological Service of Canada has developed RWIS to ensure safe driving conditions for Canadian highways

Canada's Meteorological Service is housed within the Department of the Environment and, through the Department of the Environment Act, mandated to provide meteorological information for all civil and military purposes. This is a broad mandate but when combined with other federal legislative tools including the Emergency Preparedness Act, coverage is sufficient.

Emergency management legislation in Canada, as in many nations, has its origins in political conflict. Not until 1988 was the antiquated War Measures Act replaced with the Emergencies Act due to a perceived need for emergency legislation during peacetime. This recognition came about in part as a result of an effort to manage the impacts of natural hazards including floods and earthquakes. The Emergencies Act is rarely invoked and is intended for use only in times of national crisis, or when national resources are overwhelmed.

A second act, the Emergency Preparedness Act which also came into force in 1988, outlines the roles and responsibilities of all the federal departments in relation to preparedness. This includes the development of effective tools, policies, procedures and plans for how to best manage an actual event. The Emergency Preparedness Act designates the Meteorological Service of Canada (as agent of the Minister of the Environment) as responsible for:

- The identification of environmental hazards and their associated risk
- Conducting observations and forecasts, and providing timely warnings to the general public and to emergency responders with respect to weather, ice and sea-state
- Projecting the dispersion of toxic or polluting substances in air and water
- Placing under coordinated federal control, where required, any meteorological, limnological, or hydrological resources, facilities and services in Canada (except those operated by the Canadian Forces)
- Providing increased meteorological, limnological or hydrological support to the Canadian Forces.

These activities, though important within the spectrum of emergency management activity, do not directly address mitigative strategies for disaster risk reduction. However, emergency management legislation in Canada is in a state of transition. A new Emergency Management Act is set to replace the Emergency Preparedness Act. The intent of this new act is to better address all aspects of emergency management including prevention/mitigation, preparedness, response and recovery, as well as the respective and often interlinked roles of federal departments. Proactive measures are emphasized which were not addressed in the Emergency Preparedness Act. The Emergency Management Act has now passed a second reading within parliament, but has not yet been legislated. This act has significant implications for disaster risk reduction programming on a national level within Canada.

Under the current system of government, responsibility for emergencies rests primarily with the individual. Different orders of government intervene only as the individual's ability to manage is compromised. If an individual cannot cope, municipal resources are tapped. Provincial involvement is restricted only to instances where municipal resources are inadequate or intercity/interagency coordination is required. Federal governments are involved only when aid is formally requested by the provinces, or when activity is within the federal purview, as is the case for trans-border and international issues. Through this system of government the provinces are left to develop emergency preparedness and disaster mitigation planning and are responsible for the assessment of potential impacts of natural disasters within their communities. As there are no meteorological services at the provincial level, assessment of natural hazard impact scenarios from both a day-to-day standpoint and a more long-term planning one is difficult. With the exception of a few fledgling programmes, provinces and other stakeholders have been forced to rely on informal consultative networks with the Meteorological Service to develop emergency plans.

As the new Emergency Management Act emphasizes federal involvement in all four pillars of emergency management including prevention/mitigation, preparedness, response and recovery, through this proposed legislation federal departments are tasked with the assessment of risk for hazards within their jurisdiction. For the Department of the Environment and its Meteorological Service, this encompasses risks associated with weather and climate. Assessment of risk has traditionally been within the provincial jurisdiction, while federal involvement has been focused on hazard assessment. Although this new proposed Act does raise some questions related to federal versus provincial purview, it does show great promise as it allows for the development of nationally consistent emergency management policies and programmes including natural hazard risk assessments.

For the Meteorological Service of Canada, this new Act comes at a good time since internationally, as well as nationally there is renewed interest in the services that National Meteorological and Hydrometeorological Services (NMHS) are able to provide with respect to the mitigation of natural hazard impacts. International focus, led by the UN International Strategy for Disaster Reduction (ISDR) and the World Meteorological

Photo: Corel Corporation 1994

The Canadian Ice Service provides a wide range of products and services to the navigation sectors

Organization's disaster mitigation/prevention, has turned to the development of products and services for the early warning of natural high impact events that reduce disaster risk.

Early in January 2007, in the aftermath of the Stanley Park blow-down which destroyed thousands of historic trees in one of Canada's most visited national parks, federal, provincial and territorial ministers responsible for emergency management announced a framework for emergency management emphasizing a federal role in disaster mitigation, early warning and disaster financial assistance arrangements. Although disaster mitigation and hazard assessment services are related, they are not one and the same. Disaster mitigation is readily recognized as focused on the impacts rather than the quantification of the hazard itself. This is what differentiates disaster mitigation from the more traditional meteorological services. In fact, new legislation and the new national emergency management framework for Canada result in a good prognosis for harnessing the capability of the Meteorological Service of Canada in terms of developing weather and climate adaptation measures benefiting all Canadians, their livelihoods and their natural environment. Although there are many other avenues to pursue which are enabled by impending legislation and policies, the Meteorological Service of Canada with its many partners has provided, and continues to provide citizens with some of the tools they require to reduce disaster risk. Some examples of such provisional measures are detailed below.

Air quality — In collaboration with provincial governments and regional authorities, the Meteorological Service of Canada has established a strong air quality forecast system. Air quality in Canada is based on the Air Quality Index and is monitored on a daily basis. Air quality forecasts are issued in partnership with provinces, while air quality advisories are issued once air pollution levels exceed national standards in partnership with provinces and local regional health authorities. Advice is issued in these advisories intended to protect the health of Canadians and the environment.

Northern Rangers — The Meteorological Service of Canada collaborates with the Northern Rangers, a group of 4,000 volunteers and reservists within the Canadian military, primarily consisting of members of the Inuit and Native communities. Their main role is to maintain a Canadian presence in the North while performing other tasks such as training the Canadian military, collecting data and conducting surveillance using traditional geographical, navigational and survival skills. Recent trends such as the melting of sea ice in the Arctic, have amplified the role and importance of Canada's Northern Rangers.

Road Weather Information System — One of the Meteorological Service of Canada's most successful programmes is the Road Weather Information System (RWIS). In partnership with Transport Canada, the provinces and the private sector, the RWIS is a complex road condition monitoring system. Automatic sensors report road forecasts, current conditions and data to decision makers, resulting in safer driving conditions and a reduced usage of unnecessary road treatment chemicals. There have now been negotiations with the United States and Mexico to implement a continental system for the entire road and highway network across North America.

Online information — The Meteorological Service of Canada has developed an online database and Web site detailing background information and maps regarding natural hazards in the province of Ontario. A collection of background information and maps assists local decision makers and individuals in preparation for disasters and the evaluation of associated risks. This Web site has been a useful tool for local municipalities in emergency preparedness planning, as required by provincial law.

Warning preparedness meteorologists — Warning preparedness meteorologists act as a useful resource for the media and emergency management personnel. In the event of a natural disaster or emergency, they act as coordinators and advisors. In numerous events of severe weather hazards, this programme has provided scientific advice for the media. The meteorologists are also responsible for training and educating the Canadian public on severe weather related issues, through a series of workshops and forums with emergency management personnel and decision makers.

Canadian Ice Service — The Canadian Ice Service provides products and services to the offshore gas and oil industry by providing iceberg and sea ice information for exploration and production, both onsite and in transit. This includes the monitoring and tracking of icebergs and the forecasting of marine weather conditions, mostly on the Atlantic Coast.

Hot weather information — The Meteorological Service of Canada is responsible for issuing weather forecasts and related hot weather information. Actual heat warnings and advisories are to be issued at the discretion of local health authorities. At the request of local and provincial authorities, Environment Canada will assist in the event of extreme heat conditions. The Meteorological Service of Canada has developed a national measurement system called the Humidex, based on high temperature and humidity to assist local authorities with heat wave related decision making. The city of Toronto was selected as one of the UN and World Health Organization's trial cities to pilot the heat wave warning system, and plans are underway to explore and develop a national heat wave warning system.

Weatheradio — The Meteorological Service of Canada's Weatheradio network broadcasts from 185 locations across the country, reaching over 92 per cent of Canadians. These are passive systems enabling citizens to be alerted to high impact events even when not actively seeking information. Now, 92 per cent of Canadians can access a Weatheradio signal, and recent technological advances have made it possible for listeners to programme radio receivers to deliver only certain types of warnings for their specific locations. 'Weatheradio is evolving into an "all-hazards" alert system. Warnings for non-weather related natural disasters, technological accidents, AMBER alerts and terrorist attacks will eventually be added to the broadcasts'.

Photo: Sgt Frank Hudec, Department of National Defence Canada, 2004

A member of the Canadian Forces discusses training exercises with two Northern Rangers

Weather and climate information services for socio-economic benefit: challenges in Japan

Koichi Kurihara, Japan Meteorologial Agency

Socio-economic activities in Japan, as well as in other parts of East Asia are increasingly vulnerable to weather and climate variability. Timely and user-oriented weather and climate information is needed in order to prevent and mitigate adverse weather effects, and to produce socio-economic benefits. For this reason, the Japan Meteorological Agency (JMA) has been engaged in operational daily-to-seasonal forecasts disseminated to central and local governments and to the public, while making efforts in collaboration with user communities to facilitate application of weather/climate information.

Pilot project: tailored weather/climate information service

After the cool summer of 2003, which caused extensive damage to socio-economic activities, especially agriculture, JMA initiated collaborative research with eight prefectural governments in Japan. These were intended as model cases to develop tailored weather/climate information for agriculture, based on medium- and extended-range ensemble forecasts.

Tailored forecasts for different types of agricultural damage were identified in cooperation with local governments. Relevance differs from region to region, due to difference in crop natures, weather/climate conditions and other reasons. For example, paddy rice cultivation in northern parts of Japan is vulnerable to cool weather. Deep-water-irrigation management is an effective measure to protect the rice from cool-weather damage, especially in the early stage of the growth period. Thus, in Hokkaido, the prefectural government issues agricultural management advice to farmers, when daily minimum temperatures of 13 degrees Celsius or below are predicted by the weekly weather forecast.

In order to verify tailored forecasts and the timing of issuance of agricultural advice, a simulation study was conducted with the forecast services in Hokkaido for the cool summer of 2003. In this experiment, a meteorological observatory issued a special agro-meteorological report, which consisted of a brief description of the expected weather situation and a probabilistic forecast of temperature below specific thresholds derived from medium/extended-range ensemble forecast. The local government issued an agricultural management report according to the forecasts. The simulation result indicated that the agricultural management advice could have been issued five times, whereas it was actually issued only once. The results also indicated that the ratio of sterile rice could have been reduced by 5 per cent from 14-23 per cent, if early warnings and agricultural management advice had been issued more promptly to guide farmers.

These pilot studies confirmed that it is essential for meteorological and agricultural organizations to form collaborative approaches in developing appropriate and timely weather/climate information, which can be incorporated into users' decision-making processes.

Following this successful investigation, other meteorological observatories, in collaboration with local governments and institutions, started to consider the possibility of issuing tailored probabilistic forecasts and agrometeorological information to mitigate agricultural damage related to weather and climate. Since June 2006, tailored forecasts and information using ensemble forecasts have been operational in 14 prefectures out of 47 in Japan, with a further ten under consideration.

Early warning information on extreme temperature events

In March 2007 JMA initiated the provision of early warning information on extreme temperature events (hereafter, called 'early warning information'). The early warning information forecasts the possible occurrence of significantly high/low temperature events with a one-to-two-week lead time. This information aims to mitigate the impacts of the extremely high/low temperatures on socio-economic activities such as agriculture, electric power industry, and human health.

Through dialogues with user communities, it became evident that the early warning information was expected to be applicable to a variety of sectors.

Agriculture — Deep-water irrigation is one of the most effective management measures to prevent and mitigate cool weather damage to paddy rice. In citrus cultivation, early prediction of low temperatures can prompt early harvesting, thus reducing frost and freeze damage.

Electric power — Scheduled maintenance of power plants is conducted through the year to guarantee stable service. Rescheduling of maintenance is reliant on power supply outlook, which is closely related to temperature variations. Thus early warning information on extreme temperature events will aid the more effective running of power plants.

Health — Early warning information on extreme temperature events can be used for predicting the numbers affected by temperature-sensitive diseases such as flu or heat stroke. This

Selected tailored forecasts for agriculture in Japan

Prefecture	Crop	Targeted damage or operation	Tailored probabilistic forecast			Target period	Damage prevention management
			Target element	Threshold Degrees (°C)	Used forecast		
Hokkaido	paddy rice	cool-weather damage	daily minimum temperature	below 13	weekly weather forecast	July to August	deep-water management
			weekly mean temperature	below 19	weekly mean forecast one-week ahead		
Aomori and Miyagi	paddy rice	timing of harvesting	accumulated daily mean temperature from head spout	960 or above	weekly mean forecast up until one-month ahead	mid August to mid September	
Iwate and Miyagi	paddy rice	cool-weather damage	daily minimum temperature	17 or below	weekly weather forecast	July to early August	deep-water management
Miyagi	paddy rice	warm-weather damage	daily minimum temperature	25 or above	weekly weather forecast	August to mid September	water-flow management
Nagano	apple	frost damage	daily minimum temperature	below -4, -2, 0 or 2	weekly weather forecast	April to May and October to November	fanning and combustion
Hiroshima	citrus	frost damage	daily minimum temperature	below -2 or 0	weekly weather forecast	December to March	early harvesting
			weekly mean temperature	below 4	weekly mean forecast one-week ahead		

Source: Investigation on the improvement of agrometeorological service (in Japanese). JMA, 2005

information helps medical institutions to prepare, and to raise public awareness.

Disaster prevention — Snowfall is one of the major factors which considerably affects socio-economic activities in northern Japan and areas along the Sea of Japan. Early information on snowfall enables local governments to prepare human resources and snow-removal machines for quick response.

Early warning information is issued when an extreme temperature is predicted within two weeks, and with a probability of occurrence at 20 per cent or more. An extreme temperature event is defined as having a climatological occurrence rate of less than 10 per cent. The information consists of a brief description of the expected weather situation and probabilistic forecast information. The probabilistic prediction products derived from the extended-range ensemble forecast for 11 climatological divisions over Japan are produced twice a week, thus allowing regular updates.

The early warning information service is operating on a trial basis until early 2008, with limited provision to specific organizations, each of which is well experienced in utilizing probabilistic forecast information (hereafter, called 'cooperative organizations'). In the trial period, the information will be reviewed and improved according to requirements and suggestions from the cooperative organizations. After the trial, the information will be improved based on feedback from users. There are also plans to develop early warning techniques for other extreme climate events associated with precipitation and sunshine duration in the near future.

International cooperation

Techniques and knowledge accumulated in Japan are expected to be applicable in other parts of the world. JMA has been assisting National Meteorological and Hydrological Services (NMHS) in the Asia-Pacific region with climate services through the Tokyo Climate Center (TCC). TCC provides various kinds of climate monitoring and forecast products via its Web site (http://okdk.kishou.go.jp/) and has organized training courses and workshops.

In order to further assist NMHS in advancing climate information application, JMA has developed statistical techniques downscaling one-month ensemble forecast GPV data to observation stations in East and Southeast Asia. Probabilistic forecasts for the stations will be available through the website.

Towards upgrading climate information services

Fully user-oriented weather and climate information services, where information supports each user to judge and act properly in respective socio-economic activities, is our long term goal. JMA is also planning to expand the contents of early warning information according to emerging needs, and based on an improved understanding of weather and climate predictions.

Efforts in Japan towards providing user-oriented weather/climate information and forecasts unquestionably contribute to socio-economic benefits. However, it is necessary to continue, and extend cooperation with NMHS, sharing expertise and experience, in order to improve international weather and climate service.

New challenges to meteorological services for human settlement and sustainable development in megacities

Xu Tang, PhD, Director-General, Shanghai Regional Meteorological Center, China Meteorological Administration

IN VIEW OF the increasing global urbanization and disaster vulnerability of megacities, Meteorological Services must meet new challenges not only from disaster risk management, but also from human settlement and sustainable development. This includes public security, energy supply, environment protection, and transportation control.

With its rapid urbanization and population growth, Shanghai, a megacity of China, has become more vulnerable to disasters such as typhoons, severe convective weather, thick fog, heat waves and city fires. Sometimes non-severe weather may bring serious problems because an increasing number of activities are more sensitive to weather and climate. For example, a light snowfall of 1.7 millimetres caused a severe traffic jam in Shanghai on 28 February 2005.

The Shanghai Regional Meteorological Center, China Meteorological Administration (SRMC / CMA) recognizes the importance and relevance of Meteorological Services in megacities such as Shanghai, and aims to explore and understand them as far as possible.

Meteorological Services in multi-hazard mitigation

Multi-agency preparedness, multi-hazard integration and multi-phase response are three crucial factors of disaster risk management in megacities. As 89 per cent of disasters involve the weather, water, climate-related hazards and conditions, Meteorological Services should play a basic but very important role in multi-disaster risk management, especially in the establishment of early warning systems.

Multi-agency preparedness — This requires joint efforts from multiple government agencies to support disaster risk management. In Shanghai, the Emergency Response/Mitigation Committee consists of 50 members from government agencies, collectively equipped to deal with matters including flooding, severe weather, earthquakes, fire, traffic accidents, chemical

Seamless dissemination of multi-hazard warning information accidents and public health. Under this committee, the joint Shanghai Emergency Response Center (ERC) responds to emergencies by providing first aid to local residents.

Multi-hazard integration — This involves the integration of multiple hazard information and information platforms. An integrated GIS-based urban information platform in Shanghai provides information on land type, infrastructure systems (street network, drainage system etc.), emergency response facilities and other associated data pertaining to city operations. The SRMC operational information system is a key component of this platform. Weather observations, forecasts, warnings and hazard assessment are disseminated to the policymakers, social and economic users, and the public.

Multi-phase response — This represents the integration of monitoring, prediction and warning, preparedness, mitigation rescue and assistance phases into one chain of disaster prevention and mitigation (DPM). This is an embodiment of the 'End-to-End-to-End' concept. Through the chain, information flows to related government agencies and to the end user — in this case, the public. In the initial period of DPM (monitoring, prediction and warning phases), timely and accurate weather information facilitates the government's quick and efficient response actions. Weather information also supports other phases of the chain (disaster preparedness, mitigation, rescue and assistance).

Grassroot experiences

Because of the highly concentrated population in megacities, it is effective to provide Meteorological Services founded on the basic management unit of the city. It is also very important to build a residential community-centred strategy that endorses public awareness, preparedness and the participation of response to disasters. The government should play an important role in providing support to this strategy.

Basic Grid Unit (BGU) strategy — In Shanghai, a BGU management method is being used for in situ event handling and for management in residential communities. The area of an average BGU is approximately 10,000 square metres. All BGUs are monitored and managed by supervisors, who are responsible for collecting community information and sending it to the city and district operations centre through the BGU network. According to the information, the response centre will send commands to related agencies and departments to deal with events in the BGU. SRMC provides many products based on BGU management, such as a GIS-based dynamic rainfall-runoff simulation system, and a chemical accidents emergency response system.

Residential, community centred strategy — Residents' awareness, preparedness and participation is very important for disaster prevention and mitigation. Part of the community-centred strategy involves Shanghai residents rehearsing annual preparedness and multi-hazard mitigation exercises. For example, on 23 March 2005, a rehearsal was held for a typhoon warning issued by SRMC. In response to the warning level and associated preparedness plans, the residents were able to take relevant and effective action.

Seamless dissemination of information

Seamless dissemination of information is fundamental to the Meteorological Services. For this reason it is vital that these services are integrated within the city's information system. In Shanghai, through the public media and facilities, meteorological information can be dispersed throughout the entire city. Whether on the road, at home or in the office, residents can easily receive meteorological information including observations, forecasts, warnings and advice via the Internet, SMS, digital televisions in large buildings and public transport, and electric street screens.

Mechanisms to establish standard and operational services

Categorized, standard and operational services are required in megacities, along with the implimentations of the following mechanisms into Meteorological Services.

Jointly developed and issued products — To improve the effectiveness of meteorological service information in the social and economic decision-making procedure, SRMC has reached collaboration agreements with the agencies for agriculture, transportation and health, energy and environmental protection. Some decision assistance products have been jointly developed and issued, such as ultraviolet index, pollen index, air pollution index (API), heat wave index (HWI), water and energy control forecasts and the medical weather index. For example, the HWI has helped the Government to manage electric power production and consumption to ensure energy security.

Push and pull mechanism — SRMC sends forecasters to users (e.g. 'meteorological official in harbour') to help them understand and correctly use meteorological information. Alternatively, some special users and some experts are invited to help SRMC develop appropriate products and services (e.g. 'veteran captain in meteorological office'). Volunteers are invited to participate in weather observation, information dissemination and forecast verification processes. SRMC collects users' feedback from symposiums and surveys on Meteorological Services. This interaction presents an effective way to bridge the gap between SRMC and service users.

Categorized service based on the relationship with users — Point-to-point services are driven by users' requirements — the first point is SRMC, while the second point represents key agencies and departments

- Point-to-line services are provided for key social activities, where 'line' means that Meteorological Services should be provided throughout the entire sequence of activities.
- In point-to-area services, 'area' designates the general public. A point-to-area service is one in which public Meteorological Services should cover the whole of society.

Further consideration

Rapid economic development, dense urban population and increasing disaster vulnerability due to climate change has brought new challenges to Meteorological Services in megacities. Meteorological departments need to optimise their systems of organization, their techniques, and their mechanisms in order to meet the needs of human settlements and support sustainable development in megacities. The fulcrum of this responsibility is to fulfil the basic role of providing early warnings in order to facilitate multi-hazard mitigation and emergency response.

Multi-hazard mitigation in megacities requires the central integration of both BGU strategy and residential community-centred strategy. Specialized meteorological service products developed collaboratively present valuable approaches to improve the decision-making process for social and economic activities. The push-and-pull' concept is valuable when considering the vital interaction between providers and users.

A better meteorological service means a better city, and thus a better life for its populace. However, it is clear that much needs to be done to attain such an aim.

NMHS Strategy in south-eastern Europe

Ivan Čačić Meteorological and Hydrological Service (DHMZ), Croatia

South-eastern Europe is surrounded by the Adriatic and Ionian seas to the west, the Black and Marmara seas to the east, and the Mediterranean and Aegean seas to the south. On the northern border it touches the Pannonian lowland. The southern edges of the Alps, the Carpathians and the Dinaric Alps indicate the parameters of the area. According to these various influences, a multitude of climate types prevail, including continental, mountainous and maritime (Mediterranean). This in turn results in a broad range of recorded temperature and precipitation. The annual average precipitation ranges from 500 millimetres in the east lowland up to 5,000 millimetres in the West Mountains. The highest temperature is above 40 degrees Celsius and the lowest below –35 degrees Celsius.

The area is frequently subjected to strong winds — for example, Bora experiences gusts of up to 70 metres per second along the Eastern Adriatic Coast and through Košava in the Danube River valley. It is also common to find deep snow in the mountainous areas during the winter season. Agriculture suffers every year due to spring and autumn frosts. Heat and cold waves, landslides, flash floods and droughts represent a permanent risk to human safety, the environment and the economy. Severe thunderstorms are frequent in the summer period, as well as hail, and water and land spouts. More frequent and severe weather extremes, the visible symptoms of global climate warming, are also evident. Such occurrences indicate the necessity for closer collaboration between NMHSs (National Meteorological and Hydrological Services) in the sub-region.

Photo: Public web

South Eastern Europe

Countries

South-eastern Europe constitutes a small overall area, but embraces a plethora of countries each representing a different culture and a different level of economy. The following are considered to represent south-eastern Europe: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Hungary, Israel, the Former Yugoslav Republic of Macedonia, Republic of Moldova, Montenegro, Romania, Serbia, Slovenia and Turkey.

Recent conflict has detrimentally affected the sustainability of the area, including the attempts at collaboration over meteorological and hydrological policy. This prompted the WMO to bring back the alliance of the countries, by organizing the Informal Conference of South-Eastern Europe (ICEED) with all NMHS Directors invited. The first ICEED meeting held in Sofia, Bulgaria in 2001 resulted in the attending countries signing a Memorandum of Understanding. Each successive ICEED meeting (2002: Geneva, Switzerland; 2003: Athens, Greece; 2004: Bucharest, Romania; 2005: Sarajevo, Bosnia and Herzegovina; 2006: Dubrovnik, Croatia) has produced significant progress in collaboration over ideas and actions. Similar success is expected of the Belgrade, Serbia meeting in 2007.

Constraints and challenges

In general, the gathering and sharing of meteorological and hydrological information in South-Eastern Europe is not at a satisfactory level. Other areas of Europe gather data more thoroughly and more frequently, as well disseminating the results to forecasting centres with speed and reliability.

This important topic was discussed at the Sixth Annual Meeting of the ICEED held in Dubrovnik, Croatia in May 2006. The need for sharing data in order to improve the short, medium and long term accuracy of weather and flood forecasting was officially recognized. This sharing ideology was envisaged on a regional level, along with data-sharing protocols and capacity building for fully operational instrument networks.

The expectation of the ICEED directors is that the feasibility study will enable them to identify the gaps in their capacity as well as to improve coordination among the various countries. Furthermore, the feasibility study could be the basis for a sub-regional programme supported by the WMO, World Bank, Finnish Meteorological Institute, and other potential donors.

There are clear advantages of a regional approach to supporting the NMHS:

- South-eastern Europe includes many small countries that lack independent weather and flood forecasting resources, and thus particularly require the input of other countries
- Implementation of the system will be much cheaper if it is designed regionally; for example, the number of expensive radars for each country will be reduced significantly.

Photo: DHMZ

The morning of the Dubrovnik waterspout, and the evening afterwards

By improving regional coordination, the countries will not only achieve more accurate forecasting, but may also significantly reduce costs.

A root cause of the under-financing of NMHS is that the benefits of accurate weather and flood forecasting are often misunderstood by senior government staff. Good forecasting is important in saving lives as well as in the reduction of the economic impact of natural disasters. Furthermore, good weather and flood forecasting is crucial for many sectors of the economy, including development and implementation of crop, drought and flood insurance, power generations e.g. hydropower and wind power plants; municipal services e.g. snow removal; and preparation and implementation of land-use plans at the local level. With the aim of securing the sustainability of NMHS and improving awareness of their potential value to the national governments — the WMO has organized a regional conference on the social and economic benefits of such services in Zagreb, Croatia in February 2007.

Joint actions

Following the WMO Action Plan for Region VI established in Heidelberg 2005, the ICEED meeting in Dubrovnik agreed on the strategy for the formation of Sub-Regional Centres of Excellence. These include the following:

- Instrument Centre
- Drought Management Centre
- GCOS Training Centre for Usage of Satellite Data in Climate Monitoring
- Marine Meteorological Centres for the Eastern Adriatic and Black Sea
- Climate Centre
- Hydrology Centre
- Education and Training Centre on NWP
- Agro-meteorology Centre.

With the support of the ICEED countries, Croatia has requested support and assistance from WMO in the creation of the Marine Meteorological Centre for Eastern Adriatic, in Split.

ICEED countries are strongly supportive of the cooperative actions in the Sava River Project, including the collaboration between the Sava River Commission and the Danube Commission, as well as projects concerning the exchange of disaster warnings and capacity building through networking. Unified official representation has been recognised as crucial for the visibility and performance of NMHS. Of equal importance is the formation of relationships with other meteorological communities such as GEO, EUMETSAT, ECMWF, EUMETNET, ECOMET and ALADIN/LACE, as well as the promotion of twinning programmes with EU NMHS's.

Photo: DHMZ

AMS Prevlaka

II

ECONOMIC & SOCIAL ISSUES & PERSPECTIVES

Weather, climate, and water information for agricultural applications

Dr Pai-Yei Whung, Agricultural Research Service, US Department of Agriculture
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Weather, climate, and water information is critical for agriculture in two key areas, firstly, with regard to risk assessment. This involves evaluations and predictions concerning such issues as the potential spread of plant and animal diseases, the progression of invasive species and the probability of extreme events. The second application of meteorological data is concerned with agricultural production system management. Examples of this include crop and range planning, and irrigation scheduling. This suite of agricultural services provided by National Meteorological and Hydrological Services (NMHS) has hitherto been primarily concerned with the information needed for agricultural production systems. In the future, it will be imperative for increased attention to be given to risk assessment.

Agricultural risk assessment is important because of the inherent vulnerability of agricultural systems to climate variability, and also because of the direct linkage to plant disease pests. The availability of weather, climate and water data and the informational products derived from this information are also of paramount importance. Its application can help agricultural producers, managers and policy makers better understand the risks at critical points before and during the growing season, in order to minimize production losses.

Citrus canker and wheat stem rust

Various approaches can be applied to the agricultural production system to greatly enhance the efficiency and scope of the management, and risk assessment of a specific area.

Crop planning

Seasonal climate data such as temperature, humidity or soil temperature, can be usefully applied to facilitate crop planning. For example, the US Southeast Climate Consortium used available climate data to provide early spring planting forecasts for peanuts.

Irrigation scheduling for water-use efficiency

The US Department of Agriculture's Agricultural Research Service (ARS) has developed a water-use efficiency system for arid areas such as the southwestern United States, the Middle East and North Africa. The system includes a weather sensor that is capable of measuring and recording wind speed, air temperature, relative humidity and solar radiation.

There follow two specific examples of the practical application of weather, climate and water information to the process of agricultural risk assessment.

Early warning for invasive species

P. truncatus (Giant Grain Borer) — The giant grain borer was introduced to Africa from Mexico late in 1990. Within a short period of time the species became a threat to the entire grain supply of Africa. The International Institute for Tropical Agriculture, in conjunction with the Danish Institute for Agriculture Science, developed a climate simulation model for an early warning system of the potential spread and growth of the giant grain borer. The strategy was designed to manage the threat the pest presented and thus reduce the overall loss of grain. The borer is extremely sensitive to temperature and humidity, and tends to spread south during the warm seasons. Advanced and more precise climate forecasts will result in a more accurate borer risk assessment model. This will improve the effectiveness of pest management in Africa and enhance food supply security.

Spread of plant diseases

Citrus canker and wheat stem rust can cause severe damage to the plants that they affect. Citrus canker was introduced to the

United States during the 2004-2005 hurricane season. Wheat stem rust (Ug99) was identified in 1999 in Uganda. The Consultative Group for International Agricultural Research estimated that the potential spread of wheat stem rust throughout Africa, the Middle East and South Asia would destroy 19 per cent of the total world wheat production. Wind is one of the primary transport mechanisms for this disease. Collaborations between agricultural scientists and meteorologists are expected to result in significant improvements in the wheat stem risk assessment map. This, in turn, would allow the development of a more effective early warning system for the disease.

Drought mitigation through the application of climate-based decision support tools

The National Drought Mitigation Center (NDMC) was founded in 1995 to help people and institutions in the US and throughout the world implement risk management measures to reduce vulnerability to drought. The NDMC is involved in numerous projects with the US Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA) to develop appropriate decision support tools to help agricultural producers, natural resource managers and policy makers. Such decision support tools aim to facilitate more timely and appropriate risk-based management decisions before and during the growing season. This relates especially to minimizing losses associated with severe drought conditions.

The NDMC also focuses on improving monitoring, mitigation and preparedness for drought events. An example of one of the recent tools developed by the NDMC, in collaboration with the US Geological Survey, is the Vegetation Drought Response Index (VegDRI). The VegDRI tool produces a map at a 1-km spatial resolution that categorizes drought-induced vegetation stress. It provides a detailed view of drought stress conditions over large geographic areas, but has adequate spatial detail to characterize localized drought patterns as well. This map is useful in assessing the potential impact of drought conditions on crop and range production.

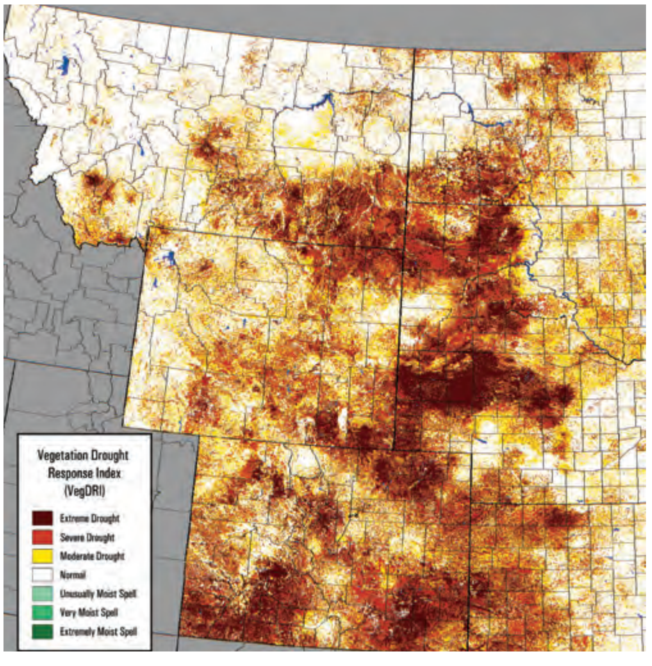
Collaboration between NMHS and other agencies

A memorandum of understanding between the NMHS and the USDA created the Joint Agricultural Weather Facility (JAWF). This serves as an excellent example of a cooperative effort between the NMHS (Climate Prediction Center, NOAA) and another federal agency. JAWF is located within the World Agricultural Outlook Board (WAOB) under the USDA's Chief Meteorologist. WAOB has the operational responsibility for monitoring and analyzing the impact of global weather on agriculture. The current contribution of information from USDA and NOAA to JAWF is approximately two parts to one, respectively.

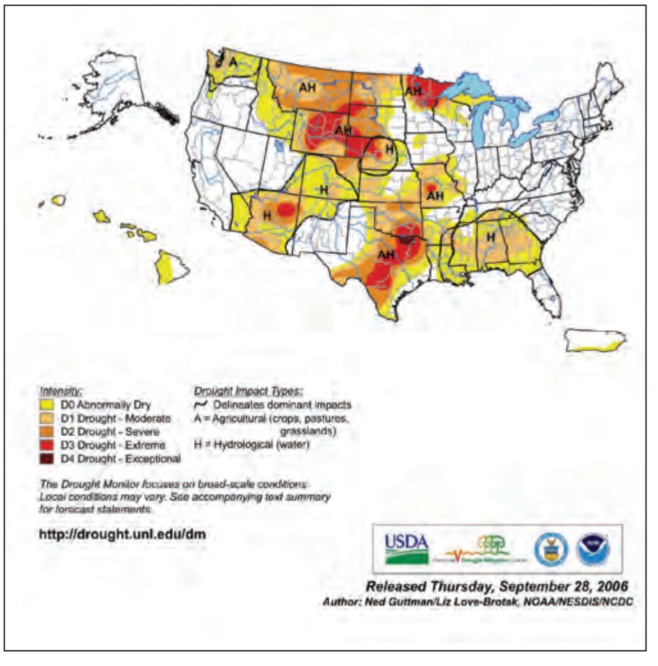
As a result of more than 20 years of collaborative effort, JAWF is providing a suite of short-term tactical agricultural weather products. These include routine and special agricultural assessments, weekly weather and crop bulletins, and enhanced regional weather data. There are also long-term strategic agricultural weather products, including USDA crop and livestock supply and demand estimates, and crop planting recommendations.

An outgrowth of this collaboration is the cooperation between these two federal agencies and the National Drought Mitigation Center. Together, they have developed the US Drought Monitor (USDM). This comprises a weekly Web-based product that depicts the spatial extent and severity of drought across the US. The USDM is based on multiple indices and indicators, and presents a comprehensive snapshot of drought conditions. This product has not only improved awareness of the severity of drought conditions, but is also being used widely for policy decisions by USDA on eligibility for drought-related disaster assistance.

One of the key elements in effectively applying weather, climate, and water information to agriculture is an efficient relationship between users and providers. The USDM actively solicits the input of experts across the country in the preparation of its weekly map. This action helps to 'ground truth' the accuracy of the characterization of drought conditions.



VegDRI map for 25 July 2002



US drought monitor, 26 September 2006

Global warming, climatic trends and climatic threats in Latin America and the Caribbean

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The loss of biodiversity and a significant deterioration of soil productivity have resulted from a number of causes such as agricultural practices, ecosystem fragility, human pressure and climate aggressivity. In tropical areas, sugar cane cultivation during the last three centuries, and especially in the late 18th century, was the primary cause of forest cover removal as unsustainable production systems were installed. Much of this land had only shallow and fragile soils, which were highly prone to erosion due to the steepness of the slopes. Consequently it the loss of significant amounts of topsoil was observed in many areas, especially in the volcanic soils of Meso America. Although the worst affected areas are no longer in cultivation, the natural vegetation that has recolonised these areas is much poorer in species composition and accumulated biomass than the original vegetation

In arid and semiarid parts of the continent, low rainfall and frequent periods of drought stress generally produce poor stands of sparse vegetation, which provide ineffective protection to the soil from the erosive effects of rainfall. The same low rainfall reduces the rates of weathering that lead to soil formation, thus tilting the balance towards a shallower soil.

Argentina has significant soil erosion in La Rioja, San Luis and La Pampa provinces. Overgrazing has been severe, causing erosion and river sedimentation. In the west, salinization due to unsound irrigation practices has become a serious problem.

The semiarid North East of Brazil supported cotton plantations for centuries, moving to sugar cane in the last decades. The small size of exploitations, poverty and high climatic variability make this extensive area highly vulnerable. Periodic droughts and land degradation provoked massive migrations to the south and the Amazonian states.[1]

The Andean region from Venezuela to the Patagonia is very sensitive to climatic extremes due to the presence of populated human settlements in the highlands, and to its complex topography and hydrology. Land slides and avalanches are a permanent threat. In some areas of the Chilean Andes, having a Mediterranean climate with a long dry spring and summer, the first precipitations in winter fall over a dry, bare soil, provoking erosion and massive sedimentation transported by the rivers to the lower land of the Central Valley. This phenomenon was exacerbated in the last century as a consequence of the change of natural shrub cover by degraded annual herbs. In some areas close to the cities, the Andean piedmont has been urbanized, provoking a rapid runoff and flooding during intensive precipitations.

Populated highlands of Bolivia, as high as 3,800 metres at the border of Titicaca Lake, support intensive agriculture (potatoes, quinoa). In addition, these highlands support grazing pressure from Llamas and Alpacas. Soils are moderately to intensely degraded by water and Aeolian erosion. The intensive extraction of water from the small watershed is pushing rich and biodiverse wetlands to desiccation.

The Valdivian Forest in Chile is one of the last two extensive temperate rainforests on Earth. After a century of logging, under 2,600 km^2 of Alerc forest remains (in the rugged, rainy coastal mountains south of Puerto Montt). Today, 18 per cent of the original Alerc forest survives; this is the second oldest forest in the world (trees aged more than 2,500 years).

The tropical rain forest continues to be cleared to open land for pastures. Fire continues to be used for this purpose. In 2000, more than 12,260 km^2 of rainforest were cut down in the Amazon. On the southwestern coast of Brazil, the Mata Atlantica vegetation has been reduced to small patches.

In Central America about 36 per cent of tropical forest losses seem to be attributable to grazing. Tropical South America's share of total tropical deforestation is 610,730 km^2 per decade, while Central America and Mexico's share is 111,200 km^2 per decade. These figures indicate a total rate of tropical deforestation via grazing of 480,000 km^2 per decade plus whatever occurs elsewhere in the world. The original forests of Latin America covered 6.93 million km^2. The estimate for 2000 is 3.66 million km^2.

The human drivers of land degradation interact in this continent with climatic trends everywhere. On the South Pacific coast of Chile, rainfall showed a clear negative trend throughout the 20th century. At the same time this trend was positive in the Atlantic coast of Argentina and southern Brazil, as in many other parts of the world.[2] There is evidence of increased climatic variability in northeastern Brazil and negative trends in water regimes of the Amazonian basin. Mean temperature has increased about 0.6 degrees in the last century, provoking a rapid reduction in the Andean permafrost and glaciers, the lower edges of which have moved up by 300 metres or more in a century. Some glaciers from Southern Argentina and Chile have retreated hundreds of metres and reduced their thickness at a rate of 100 centimetres per year. All these trends are affecting global hydrology and water availability for irrigation.

Main changes forced by global warming in Latin America and the Caribbean

Ice bodies	Elevation of lower border of Andean glaciers, decrease in the Anctartic Ice extent, retreat of the Patagonic glaciers, reduction of permafrost, reduction of solid precipitation and snow reserves in the Andes and high elevations.
Freshwater availability	Increased runoff in winter reducing availability of water in spring and summer. Loss of capacity of hydrological regulation of the main river basins in the Andes Mountain based on snow reserves. Decreasing precipitation is reducing potential for rainfed agriculture in arid environments. As consequence of this, groundwater is being overused, increasing depth of water tables.
Water quality	Intensive storms are more frequent, causing more soil erosion and sediment transportation to rivers. Higher temperatures tend to reduce dissolved oxygen impairing aquatic organisms. Stalinization of river deltas due to the increase in sea level.
Climatic variability	Extreme climatic events are increasing in frequency, making life hazardous. This is affecting wildlife and agriculture. Some ecosystems from the Atacama Desert border are in ecological regression due to the increased climatic variability which magnifies human pressures. Drought, floods and landslides are affecting agriculture and human settlements. In some cases causing loss of human lives.
Rangelands	Important areas of the continent support extensive cattle production, in some cases this activity represents an important export product (Uruguay and Argentina). These agricultural ecosystems are threatened by water and wind erosion due to increased climatic aggresivity.
Forests	The continent holds one of the bigger world forest reserves. Tropical forest is threatened by a combination of human action and climate. Tropical forest soils in the Amazon basin are very sensitive.
Biodiversity	Global warming and changes in water regime are threatening important biodiversity of tropical rain forest (Amazon basin and Central America), Semiarid tropical steppes (Caatinga from the NE Brazil), Cold Steppes of the Andean highlands (mainly Peru, Bolivia, Argentina and Chile), Subdesertic and semiarid temperate Steppes in Mexico, Peru, Chile and Argentina, Humid temperate forest (evergreen and deciduous) in Chile and Argentina and Cold Patagonian Steppes. Primary factors of degradation of these biomes is soil desiccation and droughts, displacement of isotherms faster than species adaptation and frequent intense storms which degrades or saturate soils. Temperature increase also creates favorable conditions for new species of insects or diseases.
Soil carbon and organic mater	Higher temperatures favour organic matter degradation when soils are cultivated. This accelerates the loss of carbon from cultivated soils. This is the normal situation in tropical soils, which is shifting to temperate zones.
Crop seasonality	Higher temperatures will be compensated with changes in crop seasonality. Sowing dates will move towards the coldest season to maintain yields. In Mediterranean climates this could help in a better use of winter rains, reducing water requirements. This paradox has already been seen during simulation models in South America.

Source: modified from Santibañez (1991), IPCC (2001) and van Dam et al. (2002), Campos, 1996

In extensive areas of the continent, the productivity of agricultural lands shows a decreasing trend affecting the livelihood of population, and ecosystems as well as natural plant cover and biodiversity. This is the final result of a number of causes, such as unsound agricultural practices, ecosystem fragility, human pressure and climate change, which is becoming more hazardous. Land degradation is the first phase of a long chain affecting the integrity of the ecosystems, ecosystem services and the capacity of the territory to hold human activities. One example of this is the El Niño-La Niña phenomenon. During the warm period of Pacific waters, intensive precipitations occur in the Southern Cone (Peru, Chile, Argentina, Pacific and Atlantic coasts), while droughts affect Colombia, Venezuela, Mexico, northeastern Brazil and the Amazon basin. During cold spells, antagonic effects tend to occur. This phenomenon, apart from being a threat to human settlements, produces floods and landslides, creating unfavourable conditions for investments in agriculture. Under highly hazardous climatic conditions, farmers prefer to work with low inputs for agriculture, in order to reduce economic risk. This leads to low yields and low income, and consequently, social deterioration. Very often, it is the primary cause of migrations. This phenomenon has been very marked in northeastern Brazil, northern Argentina, Chile and Mexico.[3]

Crop yield decreases, especially in tropical climates, are caused primarily by the increase in temperature, which shortens the duration of crop growth cycle. Biological phenomena occur faster at high temperature, reducing the time of dry matter accumulation and, consequently, the production of fruits, grains and plant aerial organs. In arid climates of the continent (northeastern Brazil, northern Mexico, Peru and Chile, and southern Argentina), this negative impact is reinforced by a decreasing annual rainfall. In humid tropical climates (Amazon basin,

Photo: Professor Raul Aguilera, Space Studies Centre, University of Chile

After decades of intensive cultivation, soil erosion and precipitation decrease from 150 to 100 millimeters per year, lands are abandoned provoking poverty and migrations from the arid Steppes of the Southern border of the Atacama desert in Chile

northern Argentina and Meso America) the higher temperatures have interacted with a more aggressive and unstable precipitation pattern in recent decades. Along the Central American-Caribbean watersheds, coffee and banana crops could be additionally stressed if climate change leads to increasing frequency of storms and heavy precipitation.[4] Ozone depletion[5] also contributes, in the southern part of the continent, to increased UV levels that impair the growth of some crop species.

Higher temperatures and air humidity will affect the geographic distribution of insect populations. Also, climate change is shortening the time to complete life cycle of insects and pathogenic agents causing diseases.[6] Indirectly climate change can increase sensitivity of hosts, reduce predators and competitors. There is some evidence that the risk of crop loss will increase as a result of poleward expansion of insect distribution ranges. Insect species characterized by high reproduction rates are generally favoured.[7]

The activity of plant fungal and bacterial pests depends on temperature, rainfall, humidity, solar radiation and dew. Friederich (1994) summarizes the observed relationship between climatic conditions and important plant diseases.[8] Humid conditions lead to earlier and stronger outbreaks of late potato blight (Phytophthora infestans), as in Chile in the early 1950s.[9] Warmer temperatures would facilitate the shift the of these diseases into presently cooler regions, especially to high mountain and temperate ecosystems.[10]

Farmers with limited financial resources and basic farming systems have little adaptive capacity to mitigate or reverse the impacts of climate change. Mitigation of global warming impacts require efficient irrigation and water management systems, management of pests and diseases, and strict control of climatic risks,[11] adaptation of genetic resources (to change crop seasonality and increase resistance to pests and diseases), technological management of pesticides and fertilizers (to prevent contamination of waters and foods). Some areas will never be able to adapt to these conditions at the required speed. Marginal agricultural populations may suffer significant disruption and financial loss from relatively small changes in crop yield and productivity.[12]

Estimated net economic impacts of climate change on crops are negative for several Latin American countries,[13] even when modest levels of adaptation are considered. Argentina could be an exemption because, as a major exporter of grain, it should benefit from high world prices even if yields fall.

Globally, Latin America and the Caribbean will observe important climatic changes all over the territory. Changes in South America could be moderated by the important extension of Oceans in the southern hemisphere. Despite this, important modification is expected in the behaviour of climatic oscillation such as El Niño-La Niña, which may increase climatic variability in almost all continental extensions. Isotherm displacements are occurring faster than adaptation mechanisms of natural ecosystems; this could become a severe threat for important biomes of this continent, mainly in the Amazon basin and temperate rain forests. The water reserves of this continent are among the most important in the world. Modification of rainfall regimes and the retreat of ice bodies could reduce available water in the coming decades. Global warming will force important adaptation in agricultural systems, including the better use of technology and a shift in crop seasonality.

Weather and climate in Caribbean agriculture

Adrian R. Trotman, Agrometeorologist, Caribbean Institute for Meteorology and Hydrology

THE FIRST OF the Millennium Development Goals (MDG) focuses on eradicating extreme poverty and hunger. In developing countries, growth of the agricultural sector is one of the keys to reaching this MDG. In these countries, where poverty is often associated with rural communities, agricultural growth also goes hand-in-hand with socio-economic development, including livelihood security and food security.

Weather and climate help to determine the agricultural activity and productivity of an area. Weather information can facilitate decision making with regards to the scheduling of activities such as land preparation, sowing, harvesting, irrigation timing and quantities, and timing of chemical spraying. Climate influences longer term planning, such as choice of farming, crop variety, irrigation and pest control systems.[1] One challenge to agricultural sustainability is variability in weather and climate. Climate variability contributes significantly to both transitory and chronic poverty and food insecurity.[2] In the Caribbean, rainfall has for a long time been acknowledged as the most limiting and variable meteorological influence on agriculture. For this reason, the amount of water available for crops has always been given priority. In many cases, deficits in available water are made up by irrigation. On the other hand, flooding is the most common hazard in Caribbean community and common market (CARICOM) states, resulting in major agricultural losses.[3]

Agriculture and food in CARICOM

Traditionally, most of the Caribbean practised estate or plantation monoculture inherited from colonial days. The primary focus of this form of agriculture was export to Europe. These markets were often protected with guaranteed prices for commodities such as sugar and bananas at higher than global market prices through conventions such as Lomé. In the post World Trade Organization (WTO) period, foreign exchange earned from agriculture by CARICOM states decreased due to the loss of preferential markets in Europe. Limited human and capital resources were reallocated away from agriculture. Many farms and estates moved away from agriculture thereby increasing unemployment, poverty and food insecurity. Many migrated to or sought work in urban areas.

As a consequence of this, CARICOM states became net food importers (except for Guyana and Belize). The economic and social fallout from the removal of preferential markets has forced the region to change its approach to the agricultural sector. For example, many states are engaging in discussions and activities that enhance the value of agriculture. In Barbados, for example, the dominance of sugar cane in the agricultural sector has been maintained through the introduction of varieties of sugar cane that are particularly suited to the production of biofuels. In his discussion of the 'new agriculture' for CARICOM, Atkins outlines a paradigm shift which "entails efficiency in resource use and competitiveness in production."[4] It seems widely accepted that use of weather and climate information must play a greater role in Caribbean agriculture if resources are to be used efficiently to make agriculture more competitive.

Weather and climate in CARICOM agriculture

The farming community in the Caribbean has benefited in the past from weather forecasts which they have used, and continue to use, in short term decision making. The Caribbean Institute for Meteorology and Hydrology (CIMH) also produces a seasonal rainfall outlook, which can be used in longer term planning and decision making.[5] These products, however, are not necessarily tailored for the agricultural community and can at times use language difficult for agricultural workers to interpret and use in the management of their activities.

Across the world, hazards and uncertainties associated with climate variability have contributed to poverty and food insecurity. Events such as droughts, floods and tropical cyclones have wrought havoc on agricultural systems worldwide. Poor communities that rely on small scale farming and fishing for food and livelihoods, are impacted most.[6] Rainfall variability poses the major threat to Caribbean agriculture as it is not unusual to have significant dry spells in the wet season, just as there can be significant flood events during the dry season.[7]

In recent times, the agricultural sectors in CARICOM states have been experiencing significant financial losses from extreme weather events. Etched in our memories are the devastation of the spice industry in Grenada by hurricane Ivan in 2004 and the floods in the coastal areas of Guyana in 2005 and 2006. In Grenada, direct and indirect damage to the agricultural sector totalled almost USD40 million and 91 per cent of forest and watersheds were stripped of vegetation. Damage to the nutmeg subsector bore major implications for the approximately 30,720 persons it directly and indirectly employs.[8] The floods in Guyana from January to February 2005 caused approximately USD55 million in damage, directly and indirectly, to the agricultural sector, which in 2004 accounted for 35.4 per cent of Guyana's gross domestic product (GDP).[9] A similar flood event in 2006 caused total losses to the sector of USD22.5 million.

Droughts and dry spells have long been associated with crop failure in Caribbean agriculture. The El Niño/Southern Oscillation (ENSO) is seen as the major cause of drought in the Caribbean.[10] However, dry periods are not always yield reducers for crops such as sugar cane, but in such cases can increase the sucrose yield in the months just before harvesting, whereas when occurring in July to September sugar cane growth is significantly retarded. Unfortunately, agricultural drought monitoring in the Caribbean has been limited to basic rainfall and crop indices.

CIMH has been involved in a number of projects and initiatives to increase agricultural production, enhance food and livelihood security through research, and influence policy and decision making strategies.

Climate change adaptation initiatives in the Caribbean

Climate change is one of the major concerns for Caribbean agriculture. Changes in temperature and other climate parameters, sea level rise and in particular uncertainties in the patterns of future rainfall have serious implications for biodiversity, water and agriculture in the Caribbean.[11] Such implications mean that urgent attention has to be paid to the resilience of Caribbean agriculture and strategies to adapt to future changes in climate.

Mainstreaming Adaptation to Climate Change (MACC)

In 1999, the Caribbean Planning for Adaptation to Global Climate Change (CPACC) project began sensitising the region to the implications of climate change. At that time, the focus was mainly on sea level rise, which has implications for saltwater intrusion and, by extension, water quality and salinization of soils. This is particularly crucial in Guyana where the majority of the population and agricultural activity is located within 10 km of a coastline that is below sea level. Research showed that sea level rise associated with anthropogenic climate change can result in increased salinity of the water supply, in particular the surface water.[12] On the completion of the CPACC project the region recognized the need to mainstream climate change information into the productive (agriculture and tourism) and supportive (water and health) sectors. From this, the MACC project was developed.

The MACC project includes the dynamic downscaling of the global climate models (GCMs). Work has begun in developing a strategy for coupling these GCMs with models in the agricultural and water sectors to support impact and vulnerability studies which will help to guide policy making and planning. CIMH will support these studies by investigating issues such as the potential impacts of climate change on crop yields, growing seasons, crop water use and requirements and agro-ecological zones in Guyana.

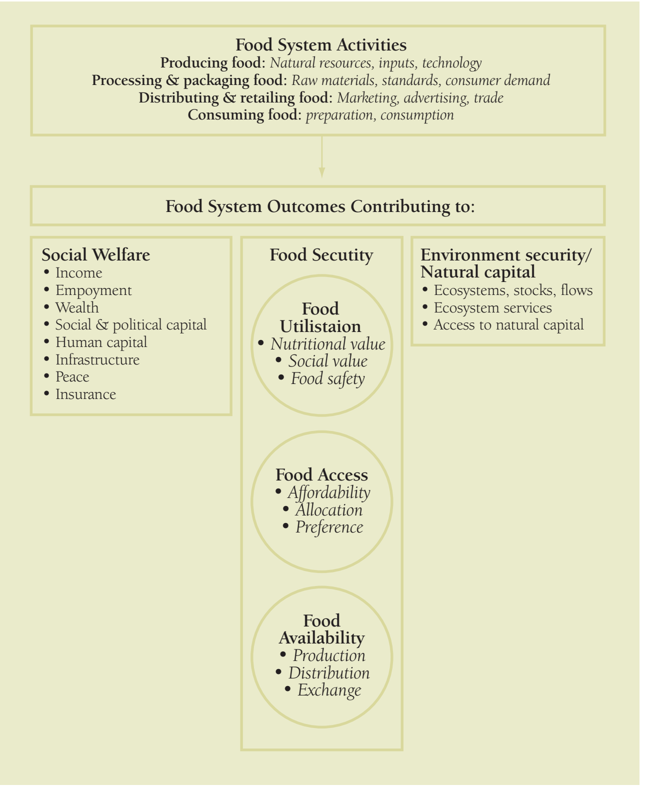
Global environmental change and food systems (GECAFS)

GECAFS is an "international, interdisciplinary research project focused on understanding the links between food security and global environmental change."[13] Its goals are:

- To develop adaptation strategies to cope with the impacts of environmental change on the food system
- To assess the environmental and socio-economic feedback of such adaptation strategies.

Environmental changes addressed in GECAFS include changes in climate, quality and quantity of water, nitrogen cycling, atmospheric composition, sea level and conditions, land cover, soils and biodiversity. Note that a food system encapsulates production, processing, distribution and consumption of food leading to outcomes which have consequences for food and environmental security and the society at large.[14]

Main features of food system



Source: Global Environmental Change and Food Systems (www.gecafs.org)

GECAFS has a regional project in the Caribbean to implement its conceptual framework. CIMH is a key organization involved in the development and implementation of this framework. The overarching questions for GECAFS Caribbean research are:

- How will global environmental change (GEC), especially land degradation, variability in rainfall distribution, sea surface temperature, tropical storms, hurricanes and sea-level rise, affect vulnerability of food systems in the Caribbean?
- What combinations of policy and technical diversification in food harvested and traded for local consumption, in export commodities and in tourism would best provide effective adaptation strategies in light of GEC?
- What would be the consequences of these adaptation strategies for national and regional food security, local livelihoods and the natural resource base?

A suite of scenarios has been developed for food systems in the Caribbean.[15] These scenarios are regionally downscaled versions of the Millennium Ecosystem Assessment (MA) scenarios.[16] A team from the region recently completed a science plan and implementation strategy for GECAFS Caribbean. The plan is being reviewed by key stakeholders in the region.

Disaster risk management

Through the Caribbean Disaster Emergency Response Agency (CDERA) the Caribbean region has been in the process of developing a five year strategic plan for disaster mitigation and management of the agricultural and food sectors as a part of a comprehensive disaster management (CDM) strategy.[17] Food and livelihood security in the face of natural disasters is the key to the CDM strategy.

Other efforts in the mitigation of disaster management include the development of flood plain maps for some Caribbean territories through the Japanese funded Caribbean Disaster Management project.[18] CIMH was one of the key institutions involved in the production of these maps. It is expected that this activity will be expanded to vulnerable areas in all Caribbean countries.

Five year strategic plan for agrometeorology in the Caribbean

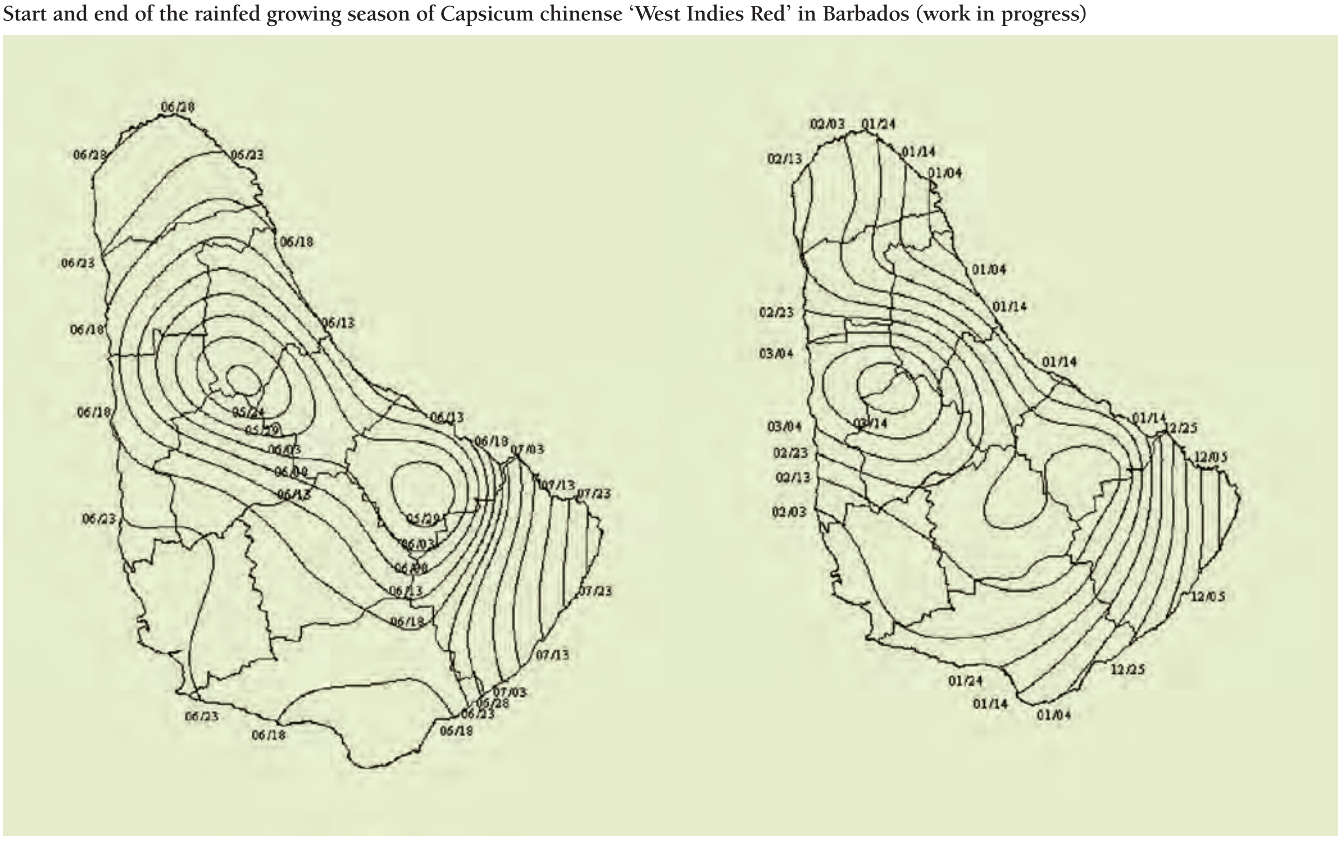
CIMH is developing a strategic plan for agrometeorology in the Caribbean. In the light of the erosion of preferential markets, the need to diversify agriculture in the Caribbean, the greater emphasis being placed on food security, and the changing patterns of the Caribbean climate, it is imperative that meteorology play a greater role in agriculture than it has in the past. The main aim is to provide valuable products and information to the farming, decision-making and policy communities in an effort to develop sustainable forms of agriculture in the region. The figure below, which shows the beginning and end of the rainfed growing season of hot peppers in Barbados, is an example of such products. This illustrates that planting and harvesting of the pepper crop under rainfed conditions would be better at different times according to the location of the farm. Important in the strategy is a proposal to revamp the focus of meteorological services to tailor information and products for the productive and supportive sectors like agriculture and water resources. Capacity building in the meteorological services and agricultural institutions is a key component of the strategy. CIMH has a wealth of experience in the region in capacity building.

The main achievements expected by the end of the five-year period (2007-2012) are:

- Trained personnel in meteorological services and key agricultural institutions in agrometeorology
- Dialogue and collaborative links developed between national and regional institutions
- Links developed with national and regional projects with agrometeorological implications such as MACC and GECAFS.
- Expansion of the network of persons within the collaborative and dialogue forum CarAgMet[19]
- Improved agrometeorological databases and data collection networks
- Pilot study sites using agrometeorological information that can be used as examples of the benefits of such information. Proof of concept will be illustrated mainly through cost-benefit analyses and social improvements.

CIMH will be the regional institution implementing the strategy and will be engaging key regional stakeholders such as the Caribbean Community Climate Change Centre, the Caribbean Agricultural Research and Development Institute and the Inter-American Institute for Cooperation in Agriculture, farmer cooperatives and ministries of agriculture. Through its strategic planning and research and development roles in projects in the region, CIMH is poised to be one of the key regional institutions in the revival and efficient management of the agricultural sector in the Caribbean.

Start and end of the rainfed growing season of Capsicum chinense 'West Indies Red' in Barbados (work in progress)

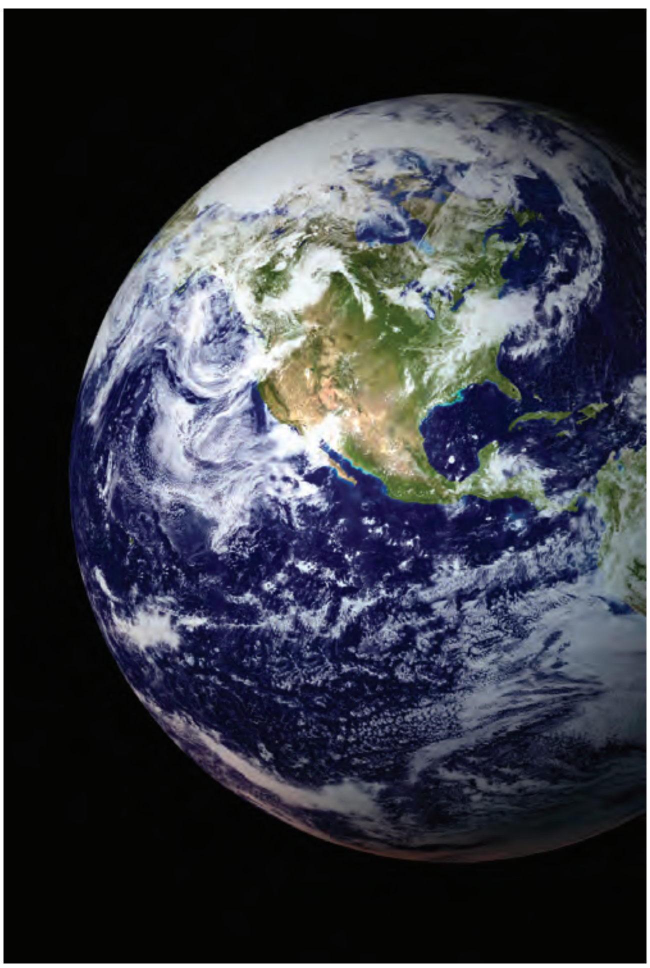


Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

The hydrologic cycle and the sustainability of water resources

Shahid Habib, Chief of the Office of Utilization; Stephen Ambrose, Programme Manager, Disaster Management, Applied Sciences Programme; Fritz Policelli, Technical Manager, Office of Science Utilization; and Ted Engman, Science Applications International, NASA

Recent speculation on the possible past existence of water on Mars reinforces the idea that our home planet, with its abundance of surface water, is unique in our solar system. So much so that Earth is known as the blue planet. Earth as seen from space reminds us of a fact we sometimes take for granted — the Earth is a world of water. These images show that roughly 70 per cent of the globe is covered by water. One only has to look at the land surfaces to understand the regional differences in the distribution of water. Lush green areas reflect regions of adequate water resources and yellow-brown regions are indicative of perpetual water shortages.



The blue planet as seen from space

Life on Earth began in water and, other than oxygen, water is the single compound most necessary for sustaining life. Some simple organisms can exist without air, but none can survive without water. Great civilizations arose around abundant water and subsequently disappeared from the lack of it. Over millions of years water has shaped and reshaped our planet through glaciers, erosion, and sedimentation. In today's society, water, along with other nutrients, is vital to making soil suitable for producing the food we eat; it also powers the machines of modern technology and provides a medium for the transport of people and goods.

What is it about water that makes it uniquely indispensable? Water has a variety of unusual properties that help to set it apart. As a chemical it is odourless, colourless and without flavour, as well as being compound of unusual stability. It can exist simultaneously in three phases, as a gas, a liquid and a solid. When frozen, it expands rather than contracting; contrary to almost all other substances. It can also absorb and release more heat then most other substances. These qualities allow for the establishment of an astonishing mechanism that we call the hydrologic cycle — an endless recycling process of the water in the Earth's system where water is used, disposed of, purified and used again.

The water cycle is tightly linked to a global energy cycle that distributes the sun's radiant energy over the Earth's surface. The energy cycle is responsible for providing the heat necessary to change liquid water into water vapour — evaporation from oceans, lakes and from plants — and this heat is released during a reverse process known as condensation-precipitation. Consequently, weather systems in the atmosphere move enormous quantities of water and energy around the globe. The impact of the water cycle is not limited to weather. Water is a very powerful solvent that is responsible for transporting chemicals over the land and into lakes and oceans. Thus, the water cycle is linked to the other major cycles necessary for life — for example the carbon and nitrogen cycles — and their ecosystem functions.

A global water balance

The total amount of water on Earth has remained unchanged for millions of years. The amount of water in various phases however has changed over the millennia due to glacial formation and melting.

The world's water supply

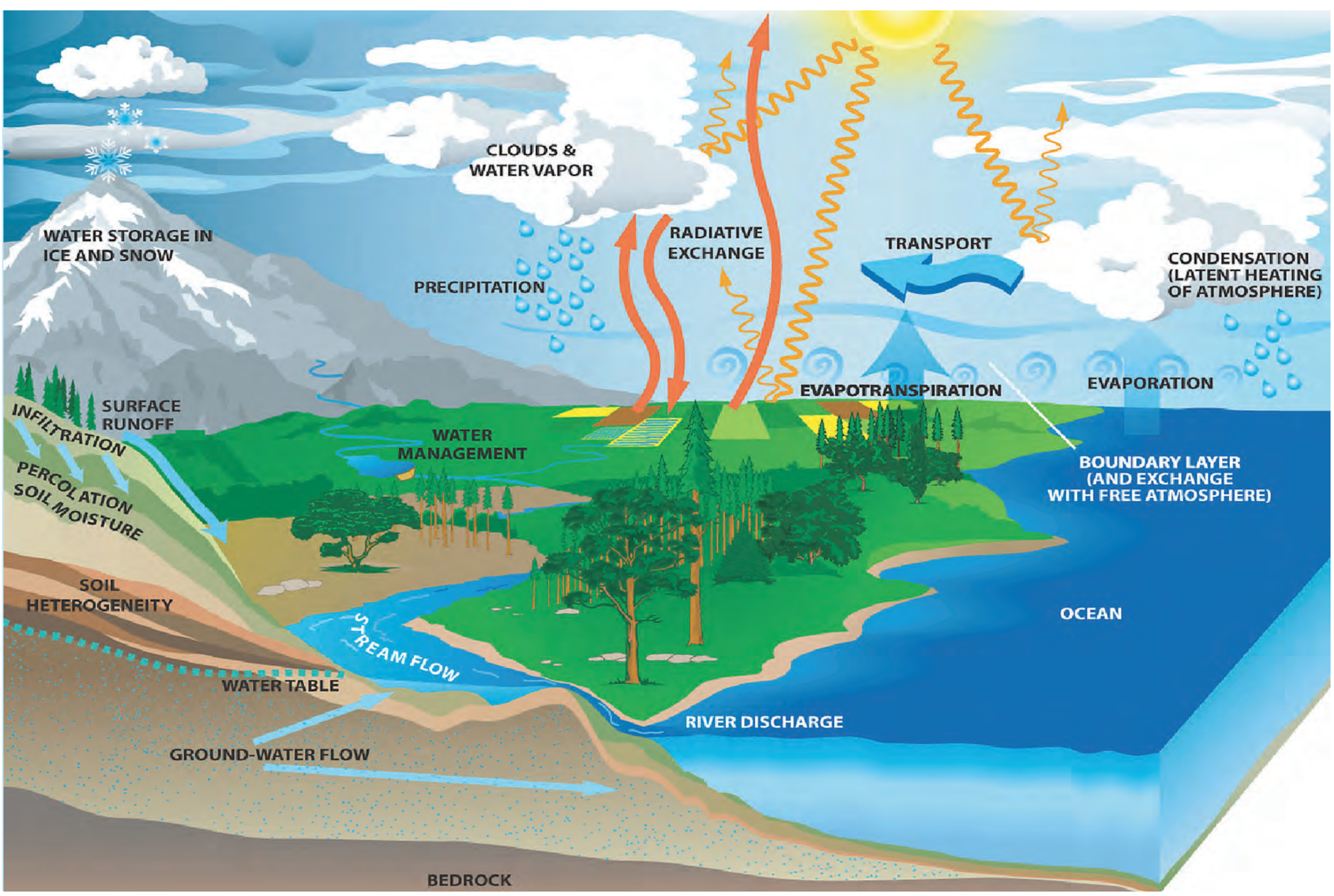
Location	Volume, cubic km	Per cent
Total water	1,358,000,000	100
Oceans	1,321,000,000	97.2
Atmosphere	12900	.001
Icecaps and glaciers	29,100,000	2.15
Subsurface water		
Soil moisture	66,700	.005
Ground water (near surface)	4,168,000	.31
Ground water (deep)	4,168,000	.31
Surface water		
Fresh water lakes	125,000	.009
Saline lakes	104,000	.008
Rivers and streams	1250	.0001

Source: NASA

Most of the world's water — approximately 97.2 per cent — has little potential for human use because it is salt water. This means that just 2.8 per cent of the world's water is potentially useful for humans, and most of this is locked up in ice sheets at the poles or as deep groundwater. The fresh water accessible to humans amounts to a paltry 0.26 per cent of the total available water.

Sustainability of water resources: the issues

Even in an ideal world the natural variations in the hydrologic cycle from day-to-day and place-to-place would result in huge discrepancies in the amount of available water. In addition, human impacts on the hydrologic cycle can be dramatic, and increases in the global population have put major constraints on available fresh water supplies. For example, the global runoff per capita in 1970 was (on average) 12,900 metres^3. By 1995, this had decreased to 7,600 metres^3 due to increases in the global population. This is still a lot of water, but it represents a global average, and not the amount available where the population pressures are the greatest. Human activities can modify the local hydrologic cycle and can seriously pollute the water, rendering scarce water supplies unusable. Changes in



A schematic of the major features of the hydrologic cycle

Image: NASA

land use and land cover, climate change, building dams and channels, inter-basin transfers, irrigation, and drainage can all dramatically change the local hydrological balance.

Sustainability of water resources: assessment

Water resources assessment is necessary to the development of sustainable activities such as domestic and industrial water supplies, maintenance of human health, hydropower, irrigation, flood protection, droughts, navigation, recreation, and preservation of the environment. The first step in developing a water resources sustainability strategy and management plan is to know the quantity and quality of water available. This is not a trivial task even in data-rich regions of the world, but in data-sparse regions it becomes almost impossible. One has to start with adequate reliable hydrologic data on the quantity and the quality of the available water resources. One must then account for modifications in the hydrology brought about by human uses, agriculture, manufacturing, and pollution control. For many regions of the world, and particularly in the developing world, these data do not exist or are unreliable. Embarking on a data collection campaign with traditional methods and instrumentation is extremely expensive and requires a large supporting infrastructure.

A satellite hydrology solution

The major space agencies and their partnering meteorological services maintain a vast array of Earth observing satellites capable of providing basic measurements of hydrological data, weather, climate, land use, water use and diversions, and natural and anthropogenic hazards. Recognizing the potential of Earth observations has lead to the establishment of the Group on Earth Observations (GEO) and the Global Earth Observation System of Systems (GEOSS), an international partnership promoting the free exchange of Earth observational data. The US participates in GEO and GEOSS through the United States Group on Earth Observations (US GEO) — a standing subcommittee that replaced the Interagency Working Group on Earth Observations (IWGEO) — consisting of representatives from a collection of 15 US Federal agencies that either supply or use observational data. Data collected and information created from Earth observations have the potential for providing critical inputs to sustainable water resources development and management. These Earth observations also provide information for informed decision-making and for monitoring conditions and progress at multiple special and temporal scales. NASA's fleet of satellites are able to provide important measurements of the hydrologic cycle that can be used for water resources assessment and management in regions of the world where traditional data are insufficient or nonexistent.

Satellite contributions to sustainability of water resources

There are numerous examples that demonstrate how measurements obtained from Earth observing satellites have been used in data-sparse regions of the Earth. The following are brief examples of some, but not all of the existing satellite data and products that could make significant contributions to water resources assessment for sustainable development.

Snow cover and snow water equivalent — The Aqua and Terra satellites provide daily images of global snow cover via the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. In addition, the Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) passive microwave measurements are being used to augment snow cover products by providing estimates of snow water equivalent for much of the Earth.

Ground water — The Gravity Recovery and Climate Experiment (GRACE) mission, under the joint partnership of NASA and the German Aerospace Agency Deutsches Zentrum für Luft- und Raumfahrt (DLR), was launched in March 2002 with the goal of obtaining accurate global and high-resolution measurements of the static and time-varying components of the Earth's gravity field. Variations in the gravity field can be used to monitor changes in large ground water aquifers, and thus provide measurements of abstractions or recharge.

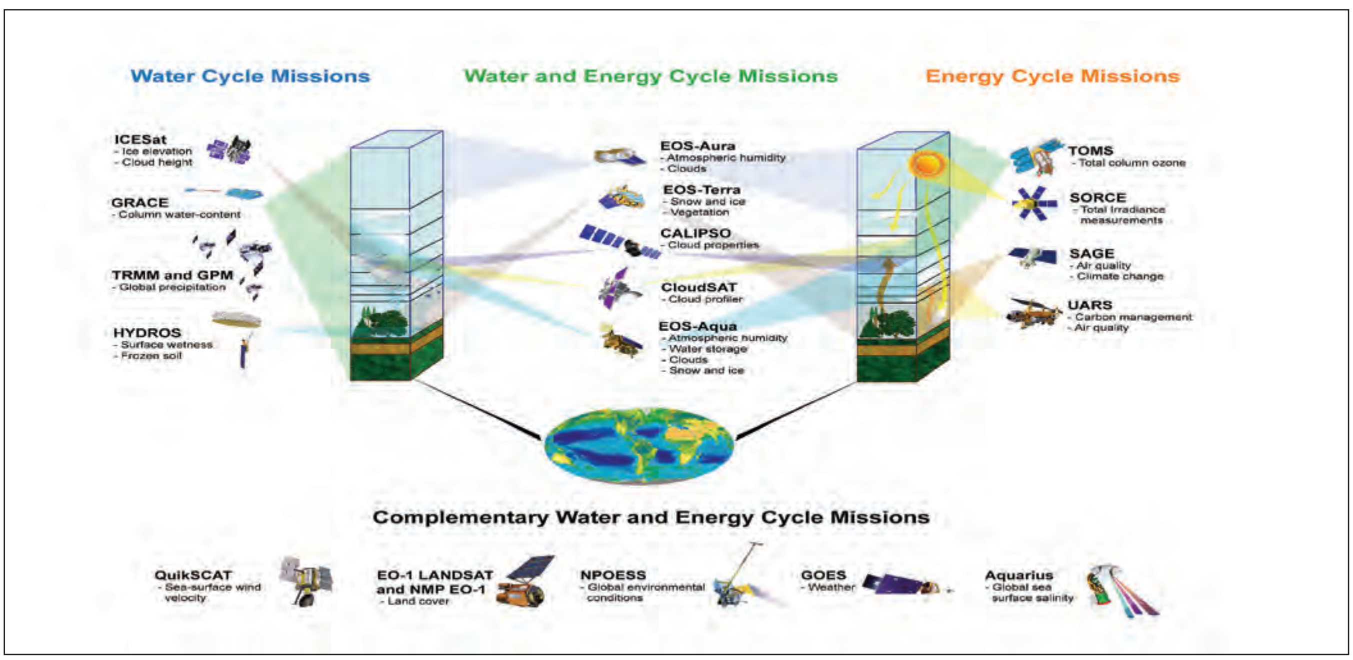


Image: NASA

NASA missions for water resources assessment and management

Water quality — The visible and near infrared regions of the spectrum can be used to empirically detect water quality indicators such as suspended sediments, algae, eutrophication indices, and thermal pollution. In addition, remote sensing products such as Landsat images provide for excellent tracking of these water quality indicators, spatially and temporally, in large lakes, reservoirs and estuaries.

Data assimilation — Data assimilation projects are characterized as real-time, hourly, distributed, uncoupled, land-surface simulation systems that are scaled to different domains and resolutions. Data assimilation merges satellite data, in situ land surface measurements, and model estimates (all at differing time and space scales) into one uniform product. The Global Land Data Assimilation System (GLDAS) project is designed to produce optimal output fields of land surface states and fluxes for water cycle research, initialization of weather and climate models, and water resources applications. To fully address land surface and application research problems, GLDAS has been implemented globally to a high resolution of 1 km with finer Universal Transverse Mercator (UTM) level scales and 1-hour and shorter time scales through the development of a prototype software library called the Land Information System (LIS). The current LIS tools consist of a high performance land surface modelling and data assimilation system to quantify terrestrial water and energy fluxes (precipitation, runoff) and storages (soil moisture, snow), critical for applications in water resources assessment and management. Remotely sensed hydrologic state or storage observations (temperature, snow, and soil moisture) are integrated into the LSMs to improve prediction and produce research-quality datasets.

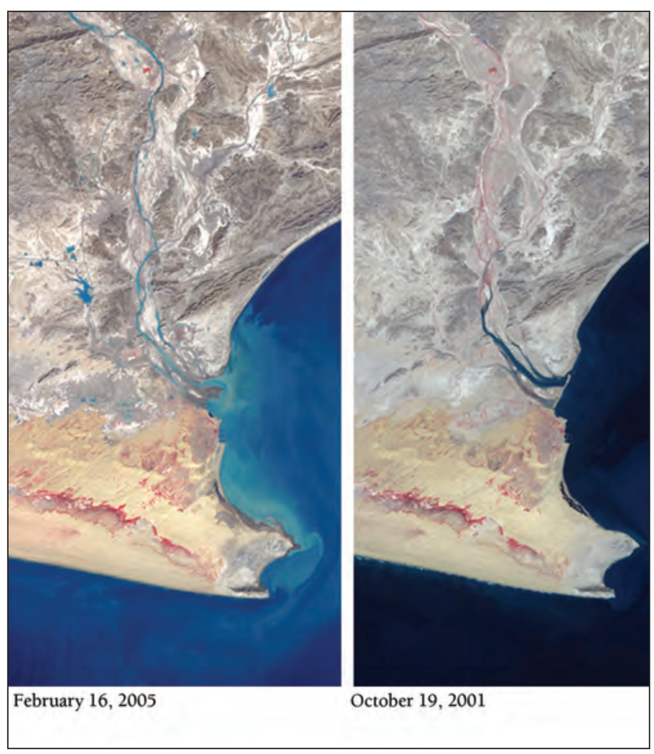
Steps needed to realize the potential of satellite hydrology

Unfortunately, there is a substantial gap between the potential of satellite products and their application to real-world problem solving and the development of water resources sustainability strategies. There is an opportunity for developing countries to 'leap-frog' into the 21st century and adapt these technologies immediately. To do this we suggest the following steps:

1. Select a real water resources sustainability problem. Examples might be:
   - A ground water management problem to prevent over-pumping or salt water intrusion
   - A flood warning and damage mitigation scheme
   - A fresh water supply for human consumption
   - A new town with supporting agriculture, industry and fresh water supply for human use.
2. Identify the decision support tools (DSTs) available to conduct an assessment for the implementation of a sustainable water resources management plan
3. Identify those data required by 2 that may be met with remote sensing data or data products
4. Arrange to obtain these data from the various space agencies
5. Arrange for training and capacity building in the use of the DSTs and interpretation of the data
6. Implement the assessment and the DSTs
7. Define the initial baseline and document the improvements made and the improvements possible with the remote sensing data
8. Set up the infrastructure for implementing the procedures and maintaining the sustainability of the particular water resources issue
9. Integrate the technical DST products within a framework that includes social sciences, legal frameworks, and environmental considerations.

Most of these steps cost little or nothing. Many remote sensing data and DSTs are free, and much of the organizational work could be done through existing governmental ministries with little or no added expense. Training and capacity building may result in the largest expense. Item 9 is an essential step if all stakeholders are going to accept the proposed plans for implementation. This item is also one that is often ignored or not implemented for lack of experience in methods for involving stakeholder participation. Fortunately, there are now organizations and programmes that focus on public participation in decision-making. The United Nations Educational, Scientific and Cultural Organization (UNESCO) crosscutting programme Hydrology for the Environment, Life and Policy (HELP) is an example of this. HELP provides a framework that encourages scientists, stakeholders, managers, and law and policy experts to come together to address locally defined water-related issues. Water communication and public participation are central to creating effective water policy issues. HELP provides a platform for sharing experiences across an international network of catchments.

In summary, sustainability of water resources is essential for almost all aspects of a successful and healthy society. Developing sustainable water resources requires technical knowledge of the type and extent of available water, and the necessary tools to make plans and management decisions for the benefit of society and the economy. Unfortunately, in many parts of the world the basic data for planning and management are sparse or nonexistent, However, recent advances in Earth remote sensing provide an alternative source of data and information for the planning and management of water resources.



Heavy rains flooded the Pasni area of Pakistan in 2005

Operational weather and climate forecasting, and its impact on water management in Australia

Geoff Love, Director of Meteorology, Bureau of Meteorology, Australia

Australia is a large island continent in the southern hemisphere with a diverse range of climate zones. These vary from tropical regions in the north, through the arid expanses of the interior, to temperate regions in the south.

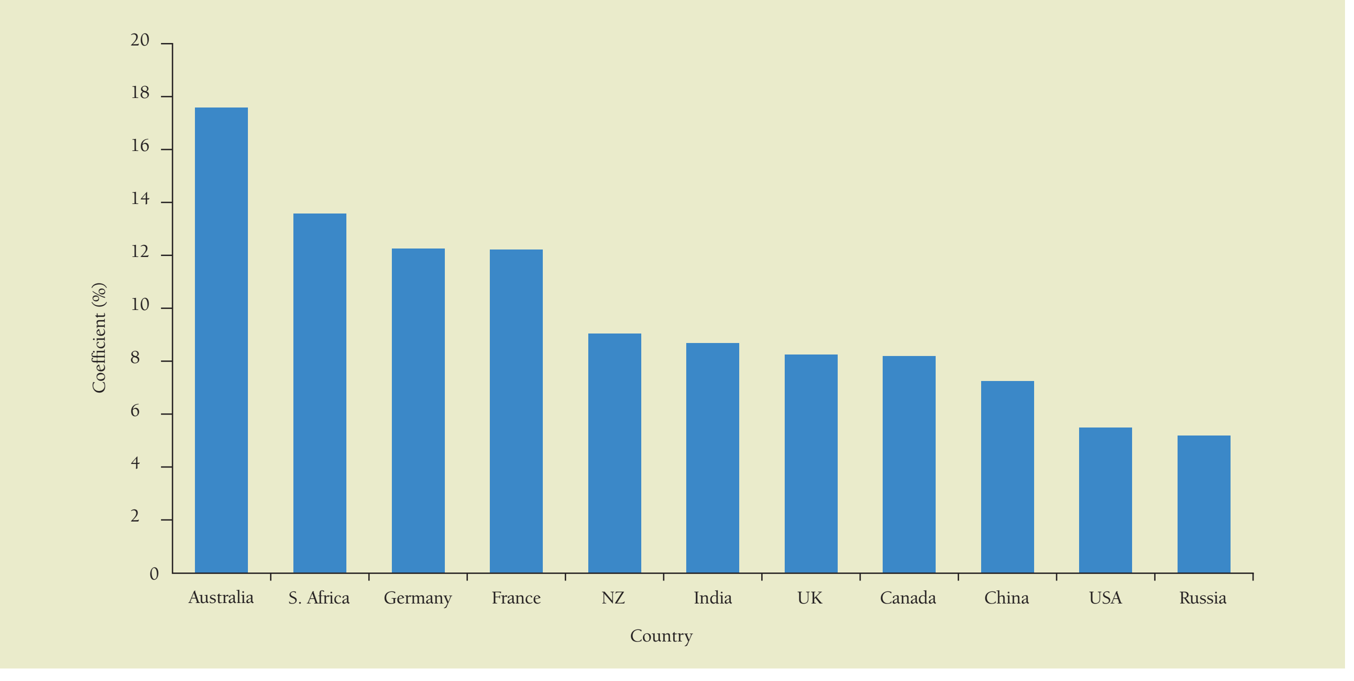
Australia's rainfall is the lowest of the five continents (excluding Antarctica). Around 80 per cent of the land mass receives less than 600 mm of rainfall per year, and 50 per cent receives less than 300 mm. Low rainfall combined with very high evaporation (particularly inland) leads to low surface-water flows and seasonal river systems, contributing to problems of salinity and algal blooms.

The most notable feature of Australia's climate is its high year-to-year rainfall variability. This is influenced by the Southern Oscillation, which is driven largely from the tropical Pacific Ocean and overlying atmosphere. El Niño is part of this system and makes a significant contribution to this variability. The El Niño-Southern Oscillation is linked to persistent seasonal anomalies in many parts of the globe, but Australia is one of the most affected continents, experiencing major droughts interspersed with extensive wet periods.

Federal, state and local governments have various responsibilities for managing these risks, protecting citizens and ensuring the well-being of constituents. Risk management requires an understanding of the risks, and the impacts associated with them.

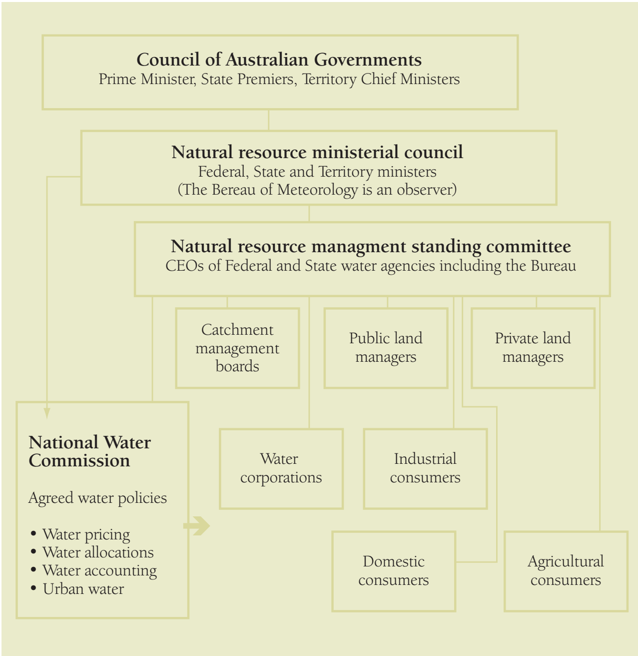
The Bureau of Meteorology (the Bureau) is the national meteorological authority for Australia. Its role is to observe and understand the Australian weather and climate, and provide meteorological, hydrological and oceanographic services both nationally and internationally. A key responsibility is to provide warnings on a range of phenomena that can lead to natural disasters/hazards. The Bureau is also responsible for managing the national climate database, monitoring and predicting the Australian climate, and providing information on the likelihood

Variability of rainfall for major agricultural producers (the ratio, expressed as a percentage, of the standard deviation of the long term national rainfall divided by the mean)



Source: Bureau of Meteorology

The framework for water policy development and implementation in Australia and the contributions made by the Bureau of Meteorology.



Source: Bureau of Meteorology

of rainfall deficiencies. Most of the meteorological services it provides, are government funded.

Water management

Given Australia's low and variable rainfall, there is environmental concern about the sustainable management of surface water, its use, quality and even its existence in some places.

Over the last two decades, water management and the need for water reform have gained the increasing attention of governments and policy makers. The Australian Government has identified water management as "the key national conservation challenge of our age."[1] Water restrictions have become part of the normal way of life in Australian cities, as have droughts in rural areas.

The Bureau of Meteorology is one of many agencies involved in supporting the National Water Initiative but it has an important role beyond this. Policy makers need to understand the actual long-term patterns of rain and water supply and be informed about the potential effects of climate change.

The Bureau is among the scientific agencies and research groups that have formed a coalition in support of advanced water management, with the goal of taking a coordinated whole-of-government approach to the preparation of high quality, targeted and timely water research and advice to meet the needs of government and the National Water Initiative through the National Water Commission.

Bushfire management

Bushfires are a natural and devastating part of the Australian summer landscape, with communities across the country regularly struggling with loss of life, loss of property and the huge financial costs of bushfires, from infrastructure damage, reduced agricultural and forest production, livestock losses, and the direct costs of fire-fighting. Bushfires also impact upon biodiversity, clean air and water, and Australia's cultural heritage.

The value of fire weather services

Fire weather services ranging from warnings to special forecasts for hazard reduction burns are important inputs into the decision making processes of fire-management authorities. They enable effective decision making at various stages of fire management. Two examples illustrate the value of these services:

- Over the Christmas/New Year 2006 period, severe fire weather conditions developed quickly. As a result of early warnings of the impending conditions, the Rural Fire Service issued pre-emptive fire bans across the state. Although there was one major fire on New Year's day, the Fire Service credits the Bureau's early advice for preventing many more catastrophic fires.
- The Rural Fire Service was preparing the costly exercise of mobilising heavy equipment in a high threat area. Despite their natural instincts that conditions would persist, the Bureau provided direct advice to the Fire Service that rain was imminent. The Fire Service acted on this advice and were able to save significant costs by avoiding redeploying equipment.

The south-east region of Australia is particularly vulnerable to bushfires — along with southern California and southern France it is identified as one of the three most fire-prone areas in the world. Over the past three decades, Australia has been affected by between 20 and 25 major bushfires, and every year many small-scale bushfires occur across Australia. The risk to property and human life continues to grow as forest areas on urban fringes become more densely populated.[2]

One of the primary objectives of the Bureau's fire weather service is to provide fire-management authorities, civil defence organizations, police, and other emergency services with:

- Detailed routine forecasts during the fire season
- Special forecasts for hazard reduction burns
- Advice regarding the installation and operation of special meteorological stations operated by fire authorities
- Climatological advice and information to assist with assessment of risk, development of fire prevention strategy, and other aspects of fire management.

The Bureau is also a key player in the Bushfire Cooperative Research Centre (CRC), which is focusing on the provision of research to enhance the management of bushfire risk in an economically and ecologically sustainable way. The Bushfire CRC is a partnership between state fire and land management agencies, eight universities, and federal government agencies, Emergency Management Australia and the Commonwealth Scientific and Industrial Research Organisation.

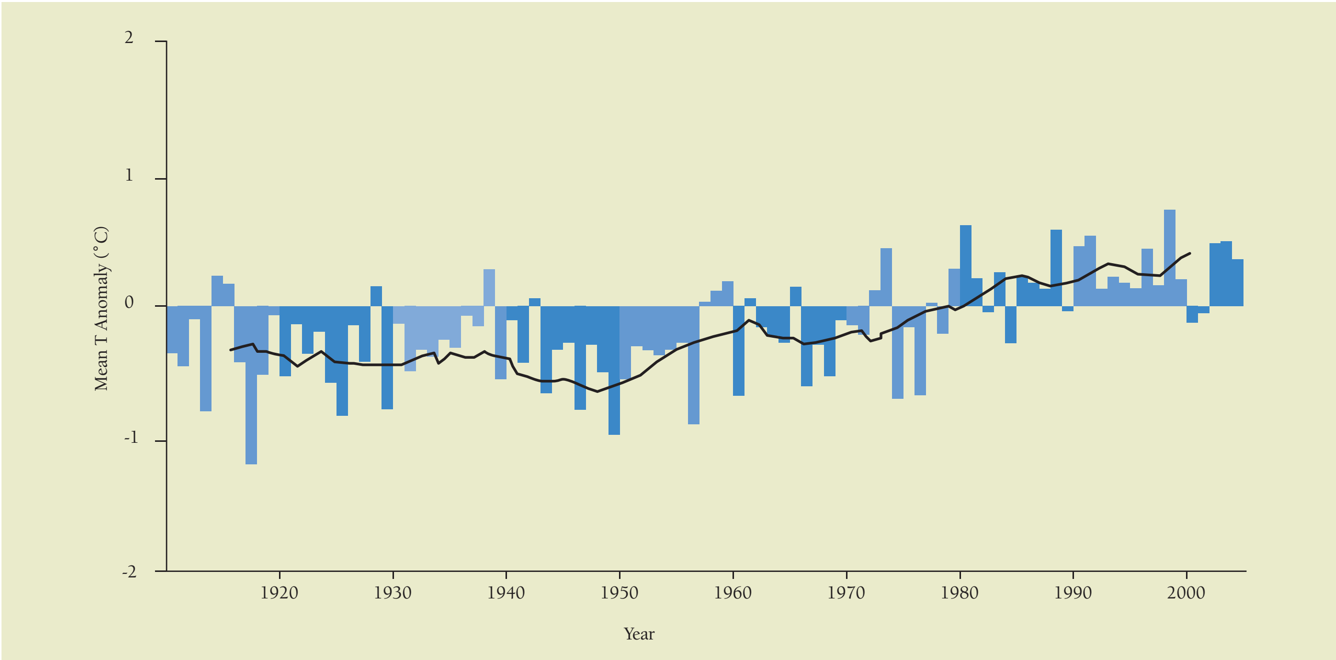
Climate change

Australia is experiencing climate change. Since the mid-twentieth century, temperatures have, on average, risen by around 0.7 degrees Celsius, with increased frequency of heatwaves and a decreasing number of frosts and cold days.

Rainfall patterns have also changed — the north-west region has seen an increase in rainfall over the last 50 years, while much of eastern Australia and the far south-west of the country have experienced a decline.

The significant vulnerability of Australia to the drying trend already observed in the southern and eastern part of the continent since 1950 has adversely affected water resources, agricultural productivity and unique ecosystems across substantial areas. The cause of this climate change is not fully understood, and the likelihood of its continuance yet to be firmly established. Given the

The Australian annual mean temperature (blue bar) and five-year running mean temperature anomaly from the 1961-1990 long term mean



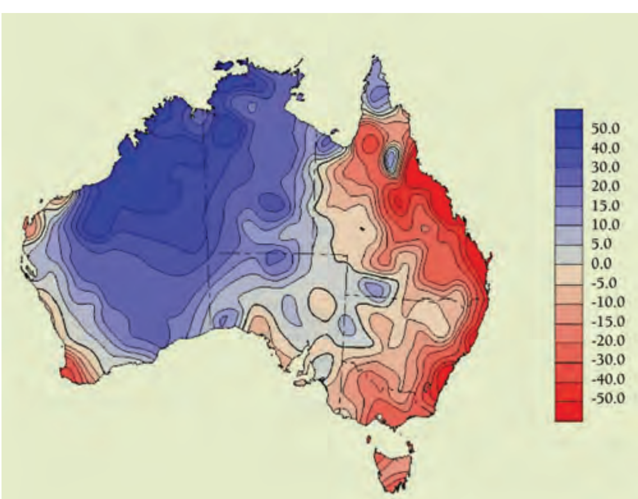
Source: Bureau of Meteorology

national significance of this long-term drying trend, it is important that we move to address these knowledge gaps and to take climate change into account in long-term planning.

When it comes to understanding and mitigating climate change, the Bureau has a number of key roles. In the first instance, the Bureau has a particular role in informing policy makers about the scientific basis for climate change. Secondly, information on historical climate variability and change is available to help government and industry better comprehend how climate variations might affect their interests. Thirdly, the Bureau promotes the formulation of more effective strategies to lessen the adverse impacts and exploit the opportunities.

Regular briefings of government ministers and their advisers on current climatic conditions and outlooks support government planning and the development of policy priorities and responses.

The trend in annual rainfall over the interval 1950 to 2003 (in mm per decade)



Source: Bureau of Meteorology

The production of special statements has continued to evolve to meet the growing demand for concise factual data relating to significant climate anomalies or short-term weather events that break long-standing records. These statements have also formed the basis for press statements and briefings to external agencies.

The Bureau also collaborates with the Australian Greenhouse Office and the Commonwealth Scientific and Industry Research Organization to develop and implement scientific agenda on climate change research and communication strategies for informing governments and industry.

El Niño/Southern Oscillation and its effects

Australia's rainfall climate consists of about three good years and three bad years out of ten. These fluctuations have many causes, but the most significant is the Southern Oscillation. This is a major air pressure shift between the Asian and east Pacific regions — its best-known extreme is El Niño. The opposite extreme is known as La Niña.

The Bureau produces a national Seasonal Climate Outlook every month, which gives the likelihood of warm or cool, and wet or dry conditions occurring in the subsequent three months. The Bureau's coupled climate model, the Predictive Ocean Atmosphere Model for Australia (POAMA), is used to provide eight-month forecasts of the likely evolution of El Niño/La Niña processes in the Pacific Ocean. The value of this modelling system has been demonstrated in recent years, with an excellent long-lead forecast of the decay of the 2002-2003 El Niño event, and a successful long-lead prediction of the persistent above-average sea-surface temperatures that prevailed through the second half of 2004 and early 2005.

One major impact of variable rainfall and El Niño is drought. The Bureau's Drought Watch Service has been a key component of national drought management since 1965. It is based on a nationwide daily rainfall measuring network and established relationships between rainfall deficiency and the severity of recorded drought. This information assists government, business and the rural community. It also helps to assess the current situation, providing early indication of the need for contingency action or drought relief.

Using monthly rainfall analysis, areas suffering from rainfall deficiencies appear in the Drought Statement as well as the *Monthly Drought Review*. If the accumulated rainfall over three successive months (six months for arid regions) was within the lowest 10 per cent on record, a drought watch begins and the region is highlighted. Consideration is also given to whether an area is usually dry at that time of the year. There are two rainfall deficiency categories:

- Severe rainfall deficiency exists where rainfall for three months or more is in the lowest 5 per cent of records
- Serious deficiency lies in the next lowest 5 per cent, ie. the lowest 5-10 per cent of historical records for three months or more.

Allowing for seasonal conditions, the drought watch may continue for many months and only ceases when plentiful rainfall returns. 'Plentiful' is defined as well above average rainfall for one month, or above-average rainfall over a three-month period.

Rural productivity, especially in Queensland and New South Wales, is linked to the behaviour of the Southern Oscillation. An understanding of how the climate affects agriculture, and how agricultural producers can better use climate information, is vital to the sustainability of agricultural enterprises. To assist planning and decision making across the agricultural arena, the Bureau's Silo Web site provides a rich source of meteorological and agricultural data of particular interest to policy makers and farm operators. The Silo Web site is supported by a number of other state and federal agencies with expertise in agriculture and primary production. Its objectives include:

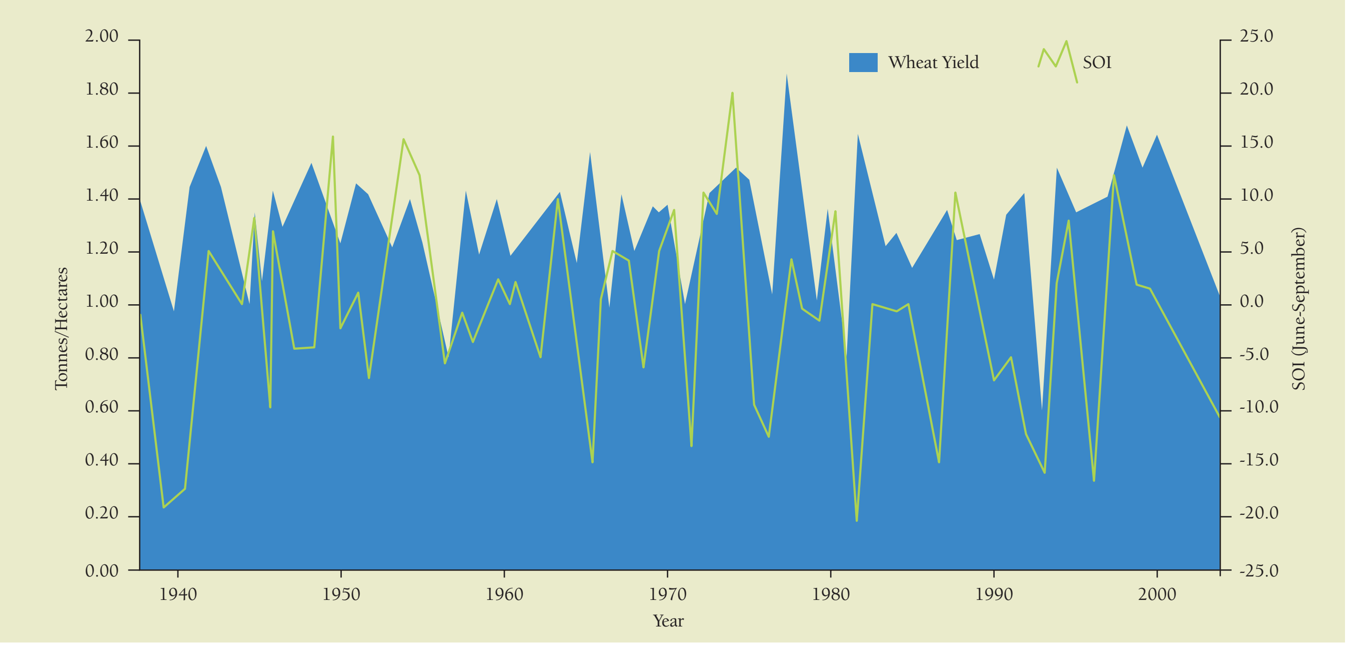
- Providing a rich source of national meteorological and agricultural data that is readily accessible to decision makers, researchers and educationalists, particularly in the agricultural area
- Developing a coordinated information service that will facilitate further adoption of climatic risk management techniques by landholders and agribusiness
- Providing a framework to encourage future additions to the agrometeorological data bank
- Establishing the collaborations required to ensure the system remains operational beyond the term of the research funding.

The Bureau has recently released a 'Water and the Land' Web site which provides an integrated suite of information for people involved in primary production and natural resource management. The site brings together information from different Bureau services and presents links in groups organized by weather elements including rainfall, cloud, temperature, wind, pressure, El Niño and La Niña, humidity, evaporation and sunshine. Depending on the range of products available for the group, long-term outlooks are listed first, followed by shorter-term forecasts, latest weather, recent weather, averages, and long-term trends.

One example of the Bureau's seasonal forecasts being used to fine-tune farming practices is in crop selection.[3] In April and May, when the Southern Oscillation index (SOI) is negative, there is a high chance of poor wheat yields and negative profits. But sorghum in the summer following a negative SOI in April and May often proves profitable. Farmers at Roma in Queensland found sorghum more profitable than wheat during the El Niño years of the 1990s and that a cutback in wheat area in these years was profitable.

Meteorology and related fields such as hydrology and oceanography, have applications at every level of government, in all sectors of the economy and for every citizen. This is no time for complacency. Greater pressure on water resources, increased focus on sustainability and the likely impact of climate change will continue to pose challenges for governments at all levels.

Australia's annual wheat yields and the Southern Oscillation Index (SOI) from 1939 to 2002.
Generally speaking an El Niño is considered to be underway when the SOI remains less than -10 for 5 months or more.



Source: Bureau of Meteorology

Seasonal forecasting in West Africa: a strategic partnership for a the sustainable development of a cross boundary river catchment

Axel Julie, OMVS & JP Céron, Direction of Climatology, Meteo-France

Inaugurated in 1987 on the Bafing River in Mali, the Manantali dam controls approximately half of the river flow downstream in the valley of the Senegal River. Shared property of the member states of the Organisation pour la Mise en Valeur du fleuve Sénégal (OMVS), this structure responds to multiple goals which contribute to the sustainable development of the sub-region.

The first challenge of the water management of the Manantali dam is an economical one, targeting a yearly energy production of 800GWh, guaranteed for nine out of every ten years for three countries of West Africa: Mali, Senegal and Mauritania. But there is also the challenge of dealing with environmental considerations contributing to the maintenance of the ecological equilibrium of the catchments of the Senegal River, or to socio-economic goals such as securing and improving the income of local populations thanks to the traditional agriculture allowed into the valley. The traditional flood recession cultures, which are sown in the ground that was submerged once the waters have receded, will remain vital to the valley's inhabitants for a long time yet. Their yield depends on the extent of the flood. The ecological equilibrium of the Senegal valley, also linked to the annual flood and very important in the arid context of the region, must be preserved.

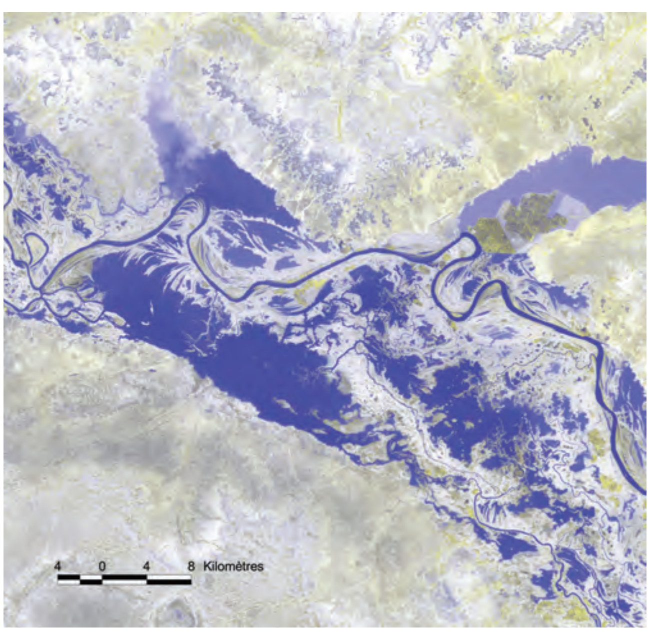


Photo: IRD and OMVS

Artificial flood of the floodplain of the Senegal river in October 1999. Region of Kaédi (Mauritania)

The provision of drinking water for the main towns of the sub-region including the capital cities of riverside countries like Dakar (or neighbouring Nouakchott) is strongly related to the optimization of dam management. Support for the navigability of the river, still in progress, is also a crucial aspect of the life all along the river.

The *Charte des Eaux du fleuve Sénégal* (OMVS- May 2002) defines the clauses used for an interdependent, fair and participating management of water resources. It is essential and the reference for all actors and users of the cross boundary Senegal River's basin.

The water resource management of the Manantali dam is notably based on the scheduling of water releases in order to flood the downstream valley and consequently to allow recession cultures (traditional) which need this resource. Additionally, the maintenance of a stable minimal water level during the December-June period is also considered. The amplitude of the water release which defines the potential cultivable surfaces once the waters have receded is proposed to the Minister Council of OMVS by the Permanent Water Commission which brings together, on 20 of August each year, all the stakeholders and decision makers concerned with the catchment's water resources.

This crucial decision leads to the scheduling of water releases, and to sufficient flooding for permitted recession culture surfaces which totally depend on them. These water releases are mainly issued during September. However, the impact of the flood on the other objectives is mainly related to the remaining water stock at the end of the rainy season, which is highly dependent on the targeted hydrogram during the flooding episode. Obviously, one tries to minimize the impact of this decision on energy production as well as on low water level monitoring. Consequently, the potential amount of rain during the September-October period (which is the end of the rainy season) is a crucial piece of information for the dam manager and the Water Permanent Commission in order to anticipate the partial restoration of water stock into the dam and consequently to issue a better decision for concurrent uses of the water during the dry season (from November to May).

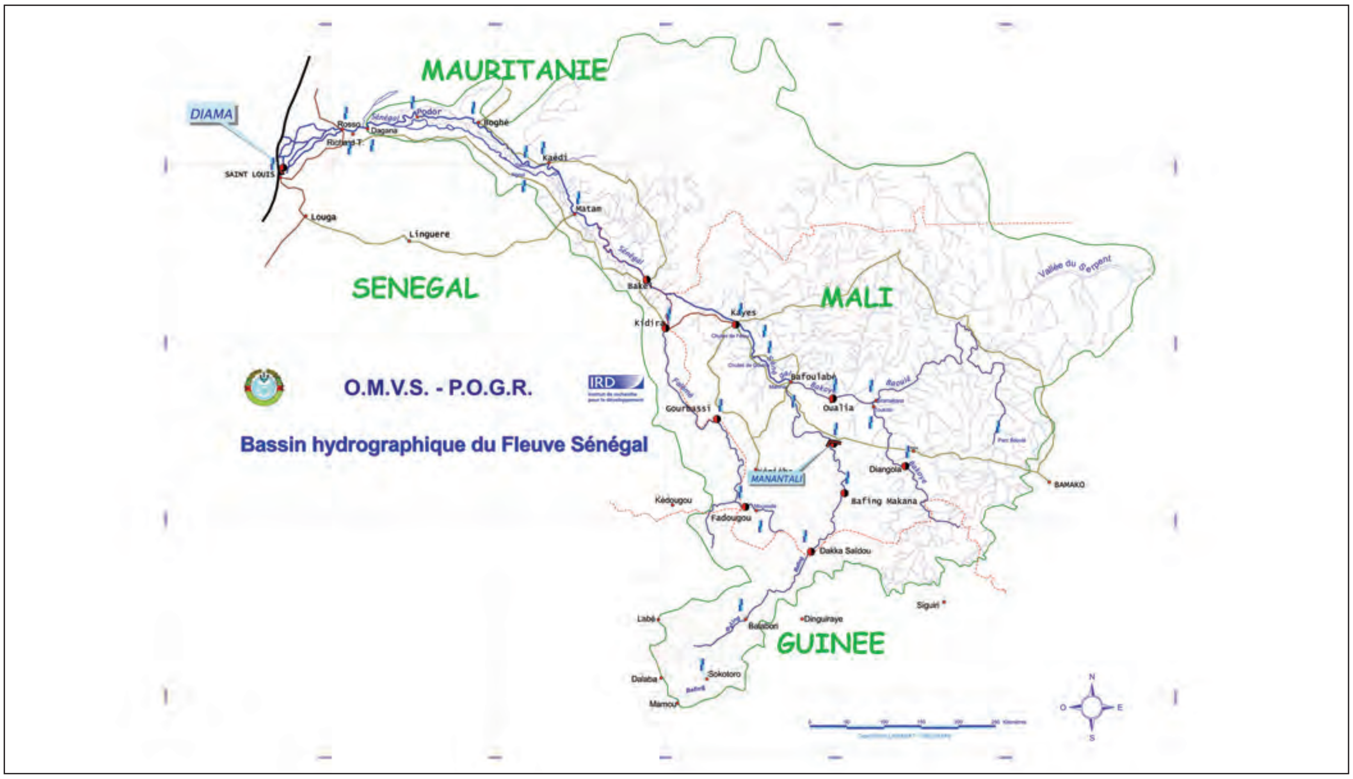


Photo: IRD and OMVS

The catchment of the Senegal River, with blue bars delineating the zone where recession crops are evaluated. Calibrating the forecasting model: using forecast and downscaled rainfall from the Arpège model and adapting them to the specific flow forecast to estimate the 'natural' flow of the Senegal river at Bakel, September-October

By the end of July, the seasonal forecasting model developed by the Institut de Recherche pour le Développement (IRD) and Météo-France allows estimations of the natural flow of the Senegal River at Bakel (at the entrance of the valley, downstream of the dam) over the September-October period. Using downscaled information (both in space and time) derived from the forecast rainfall of the Arpège Climat model, this provides very accurate forecasts of the river flow. Interestingly, critical years, which correspond mainly to dry years, are quite well predicted. Consequently, the information brought by this model limits the risk of taking a bad water resource management decision in such years. A first evaluation using simulations on the hindcast experience, showed that the use of seasonal forecasting information brings around 80 per cent of the maximum possible profits corresponding to a perfect forecast of the flow river. This information coupled with the optimization management software of the Manantali (POGR – a joint effort between OMVS and IRD), brings energy production optimization to near 35-40 per cent, and the artificial flood, allowing a surface of 50,000 hectares for recession culture, is guaranteed for 20 years over 24, compared to only five years in a natural regime (over the 1970-1994 period).

The concrete procedure starts from Toulouse, where rainfall forecasts are issued at the end of July. These forecasts are specifically formatted and sent to Dakar at the beginning of August using mail facilities. The information is then transformed into a flow forecast and introduced into the POGR software in order to issue the relevant information to the Water Permanent Commission. According to the available water stock on 20 August and related to the decision about a minimal surface of recession cultures in the valley, an idealized hydrogram in Bakel is targeted. This hydrogram is then realized until October by releasing a sufficient discharge at Manantali, taking into account of the real-time discharge of Bakoye and Faleme Rivers, which are downstream of the dam. This time, scheduling allows the starting of recession cultures before mid-November, in relation to the properties and needs of the plants.

The now research aims to improve the potential benefits given by the forecasts for Manantali. With this aim, many different rules for use of the forecast in management will be tested leading to an improved set of management rules. Furthermore, similar research will be done for neighbouring catchments of West Africa, aiming to forecast the natural flood discharges of rivers like Niger or Volta with Arpége results. The use of the probabilistic forecast will be also tested in the near future, notably translating it in terms of possible scenarios and actions for the dam manager. Finally recalibration of the whole application will be scheduled by the end of 2007/beginning of 2008, in order to benefit from an improved version of the Arpège model, namely a coupled version using improved parameterisations and improved assimilation for the oceanic state, an increased size for the ensemble (41 members) and for the hindcast experience. These perspectives are clearly supported by the agreement signed in November 2005 between OMVS, Météo-France and IRD (Protocol of Paris) allowing the whole process to be put into a sustainable form, notably with the provision of forecasts free of charge by Météo-France until 2015.

So, the partnership between OMVS, Météo-France and IRD stands, without any doubt, as a prominent international reference in terms of use of seasonal forecasting information to the benefit of a cross boundary African river basin, contributing to an interdependent and sustainable development of this semi arid region.

Weather patterns and water resource management in Taiwan, Province of China

Chung-ho Wang and Bor-ming Jahn, Institute of Earth Sciences, Academia Sinica, and Hen-biau King, Taiwan Forestry Research Institute

THE ISLAND OF Taiwan, Province of China, with its several surrounding islets, is located about 175 km off the eastern coast of southeast China and at the western edge of the Pacific Ocean. It is bisected by the Tropic of Cancer, and so has a subtropical climate in the north and a tropical climate in the south. The climate of Taiwan, Province of China is also strongly influenced by Asian monsoons, with prevailing north-easterly monsoons associated with cool fronts in the winter and prevailing south-westerly monsoons associated with torrential rain and strong winds in the summer.

Globally, there is strong evidence of rising atmospheric Carbon Dioxide (CO_2) levels since the 1960s, and various models suggest this as a cause of global warming.

Recent studies in Taiwan, Province of China have shown drastic changes in weather patterns. Over the last century, the mean annual air temperature has risen by 1.2 degrees Celsius, with an accelerating annual increase of 0.3 degrees Celsius during the past three decades. This increase is significantly higher than the global temperature increase of 0.6 degrees Celsius during the twentieth century. Over the last century, Taiwan, Province of China has seen temperatures increase by 2.7 degrees Celsius in summer and 1.6 degrees Celsius in winter. Daily departures in temperature have greatly decreased, particularly since 1970, while daytime and nighttime maximum temperatures have increased by 1.3 degrees Celsius and 2.3 degrees Celsius, respectively.

In addition, future weather patterns are likely to be more unpredictable, and the frequency of extreme climate events, such as typhoons and droughts, will increase. Disasters like landslides, floods, and wildfire are also likely to increase in frequency and severity.

Water resource management has therefore become critically important, particularly as Taiwan, Province of China is an area with high population density and heavy demand for available water.

Precipitation in Taiwan, Province of China is predominantly influenced by the summer monsoon climate and winter

Photo: courtesy of Po-lin CHI

Groundwater supplies about one third of total use. Over drafting of it for aquaculture farming is causing serious land subsidence up to 3 metres in some coastal areas in Taiwan, Province of China

Mongolian high pressures. Climate patterns are further complicated by Taiwan, Province of China highly varied topography. The island is only 36,000 km² but has more than 200 mountain peaks over 3,000 metres in elevation. The highest peak reaches nearly 4,000 metres above mean sea level.

Rainfall mainly occurs during the typhoon season (from June to September), accounting for about 60 per cent of annual precipitation in the north and 90 per cent in the south of Taiwan, Province of China. This uneven distribution causes water availability problems in some areas, creating a challenge in terms of water resource management.

Annual mean precipitation averages 250 cm and has varied very little since the 1940s, but the amount has increased in northern Taiwan, Province of China and decreased in southern Taiwan, Province of China relative to the long-term average. In the same period, however, the annual number of rainy days has decreased significantly across the island as a whole. The decrease was more pronounced in the southwest region than the northern region, and exacerbated by a high runoff ratio.

The intensity of tropical storms has increased over the last fifty years, posing flooding risk, especially in lowlands that have experienced substantial land subsidence, and accelerating landslides in foothill residential areas.

Typhoon occurrence in Taiwan, Province of China averaged 3.5 events annually over the last 100 years, but the ten most severe typhoons during this period have occurred in the last ten years. Of five droughts occurring during the last 100 years, four were during the last 50 years.

These changes in weather patterns, together with other factors, have had a severe impact on water resource management. Dependence has increasingly shifted from surface water to groundwater over the last 25 years. This change is, in part, due to changes in seasonal distribution patterns of precipitation, surface water pollution, and increased demand in water supply.

Water quality is an equally important issue when considering water availability and strategies of water resource management. River pollution is the top factor in reducing water intake from surface water. Industry, agriculture, and untreated municipal sewage discharge are major sources of river pollution. The proportional length of river considered highly polluted has increased from less than 20 per cent in the early 1980s to about 40 per cent. As of 2002, only one third of river length was classified as clean. Official reports showed that the most seriously polluted rivers were found in the southern region, where dry winters were prevalent and water was required for irrigation and aqua-cultural practices.

Groundwater accounts for nearly one third of total water consumption in Taiwan, Province of China. This annual consumption amounts to 5.7 billion metric tons with annual natural recharging rate of 4.0 billion tons. Over-pumping of groundwater results in many environmental problems.

Twenty per cent of flood plain area, or nearly 2,700 km², has experienced land subsidence to varying degrees. Subsidence averaged 1.9 metres and could have been up to 3.3 metres in some areas in 2004. The groundwater tables of the 171 metre-deep monitoring well in ShiKang have dropped at 1.2 metres per year, totaling over 12 metres between 1994 and 2004. The damage caused by land subsistence is extensive.

Saltwater intrusion into inland areas presents other environmental and socio-economic problems when excessive pumping of freshwater from aquifers is practiced. It is almost impossible to stop subsidence with current technology. In the case of southern Ping-tung Plain, the saltwater intrusion rate averages 300 to 500 metres annually. The affected area of deep aquifer was about 115 km², and 85 km² of it was at shallow free water depth. As a result of this intrusion, 3 billion metric tons of groundwater capacity is regarded as unfit for drinking or irrigation.

These recent changes in temperature, precipitation patterns, rainy days, flood intensity, drought severity and frequency, intensity of storms, extreme weather conditions, and dependence on aquifers for freshwater are all compelling indications of the climate changes occurring in Taiwan, Province of China.

Taiwan, Province of China's precipitation averages 250cm per year, but with varying topography and a monsoon climate, its rainfall is highly variable. These phenomena create great stresses for water resource management. Water bodies are also home to countless fish and plants, and the impact on these ecosystems should not be ignored. Water policy planners should not merely focus on adapting water resource management to climate changes, but also on pervasive pollution, depletion of groundwater supply, falling of groundwater tables and damage to ecosystems.

It is vital that water policy makers implement simultaneous efforts in a number of areas, including:

- Enacting and enforcing laws and regulations regarding the sustainable use of water resources
- Investment in and development of new technologies and processes to enable the more efficient use of existing water resources
- The protection and preservation of ecosystems.

In conclusion, in pursuing a sustainable society, it is inarguably necessary to create a universal environmental ethics guide to manage not only water resources, but the environments and ecosystems dependent upon it.

Photo: courtesy of Dong-kun LIAO

Reservoirs supply slightly less than 30% of total water consumption in Taiwan, Province of China. Te-chi Reservoir, highest in elevation at 1,245 meter a.s.l. and one of the 49 reservoirs, was designed for electricity generation and water supply for central Taiwan, Province of China

Singapore integrated water management

Singapore Public Utilities Board

Singapore is a small island nation located just north of the equator. With a land area of 699 km2 and a population of 4.4 million, Singapore has been ranked by the UN as the 170th among a list of 190 countries in terms of fresh water availability. This is not because of a lack of rainfall (2,400 millimeters per year), but because of limited land to catch the rainfall. As a densely populated city, the pressure of competing land uses such as those for industry, housing, recreation and commerce abound. Water supply is but one facet of society that requires the use of scarce land. Thus, there exists a crucial need for a comprehensive planning strategy to holistically deal with water cycle management as part of overall urban planning and management.

The development of Singapore's local supply sources began in the mid-19th century, with the first reservoir completed in 1867. Then known as the Thomson Reservoir, it was later renamed the MacRitchie Reservoir. In the early years, Singapore's water supply came from water catchments in protected areas, characterized by limited development and pristine water. However, with economic growth and population increase, the lack of land availability meant that the development of water catchments in other non-protected areas had to be looked into.

The Public Utilities Board (PUB) was set-up as a statutory board on 1 May 1963 to take over the responsibility of providing water, electricity and piped gas from the former City Council. PUB embarked on a programme of building estuarine reservoirs in the 1970s, impounding a slew of mangrove swamps and rivers to increase Singapore's water storage capacity. The 1980s saw PUB move into urbanized areas, with the development of reservoirs that utilize storm water runoff. The higher level of impurities in urban storm water runoff meant that urbanized catchments were previously infeasible, but through the advancement of treatment technologies, such water could now be harvested.

PUB was reorganized in 2001 to become Singapore's national water agency, overseeing the management of the entire water loop, from the supply of potable water, to the collection and treatment of used water, and the management of the drainage system.

In addressing the need to manage water resources comprehensively, PUB's water management strategy includes both

Photo: PUB — Singapore's National Water Agency

Marina Barrage: 'the reservoir in the city' supply and demand side management. This is encapsulated in our corporate tagline — 'Water for All: Conserve, Value, Enjoy'. Water for All refers to our supply augmentation strategy to increase the number of sources of water as well as to use existing sources more efficiently. On the demand side, PUB's efforts largely include the engagement of the public in order to educate them about the value of water and encourage conservation.

Supply management

To maximize the collection of rainwater, the existing water catchments already form about half of Singapore's total land area. With the completion of the two new reservoir schemes, including Singapore's 15th reservoir, the Marina Reservoir, the water catchment will grow from the current half to two-thirds of Singapore's land area by 2009.

Many cities around the world are built around reservoirs, but PUB is creating a reservoir right in the middle of the city. Dubbed 'the reservoir in the city', the Marina Reservoir will be formed by building a dam across the mouth of the Marina Channel.

One of the key features of the Marina Reservoir is its multiple functions. Primarily, it provides water storage, but is also a venue for water-based recreation, as well as a means of flood control. The dam, spanning 350m, can be utilised during a heavy storm to pump water out to sea. Thus the Marina Reservoir will serve to maximise water supply capacity during times of low rainfall as well as substantially lower the risk of flooding in the event of a storm.

NEWater is the zenith of Singapore's water supply diversification strategy. Produced from the reclamation of treated used water, it is now a reliable source of water supply for the commercial and industrial sectors, accounting for almost 7 per cent of Singapore's water demand.

The idea of NEWater started way back in the 1970s. However, the high cost of membrane technology then meant that water reuse was not feasible. When membrane technology improved in the 90s, the idea of water reuse was revisited and a full-scale demonstration plant was commissioned in 2000 to undertake extensive studies on the quality of reclaimed water and the reliability of membrane technology.

After an extensive battery of tests and analysis by an international panel of experts comprising renowned local and foreign experts in the fields of engineering, biomedical science, chemistry and water technology, NEWater was certified to be of a consistently high quality, and well within the requirements of the USEPA and WHO standards for drinking water. This lead to the full-scale production of NEWater as an alternative source of water.

Through using each drop of water more than once, NEWater effectively multiplies Singapore's water resources and contributes significantly to its water sustainability. There are currently four NEWater plants in operation, capable of supplying 55 megagallons per day (mgd) of NEWater, with further expansion plans in the pipeline to cater to the anticipate growth in demand. PUB's current target is to meet 15 per cent of the water demand through NEWater by the year 2011.

NEWater is the result of an important shift in paradigm to view wastewater as an important resource, to be recycled and re-used. This is in contrast to the previous mindset which was to simply dispose of wastewater in the sea. To reflect this change, PUB has introduced new vocabulary, replacing the term "sewerage" with the new term "used water". This signals a new approach to water management and communicates to the public the need to view water as a renewable resource.

Besides NEWater, Singapore also opened its first seawater reverse osmosis (RO) desalination plant last year. Built through a Design, Build, Own and Operate (DBOO) partnership with

Photo: PUB — Singapore's National Water Agency

Sports and leisure: dragon boat racing in Singapore River the private sector, the plant is one of the biggest seawater RO plant in the world, and has the capacity to supply 30 mgd of desalinated water.

Although desalination reduces Singapore's reliance on traditional water supply sources, it also makes it more energy-dependant. This, coupled with rising climate stress compounds the need to secure energy sources that do not have such a large impact on the environment. Desalination may also have detrimental impacts on local marine ecology if its seawater intake and discharge is not well monitored. To this end, PUB has commissioned a long-term study of the quality of seawater surrounding Singapore. It is through such measures that PUB aims to mitigate environmental impacts.

Demand management

As well as expanding water supply, PUB also believes that a People-Public-Private approach is essential. This method of demand side management involves the design of programmes that will engage the community, businesses and civic groups. This includes programmes aimed at encouraging water conservation and promoting public ownership of water resources.

In the area of water conservation, PUB adopts a multi-prong approach of appropriate water pricing, mandatory water conservation measures, public education and efficient management of the water distribution system to keep our water consumption levels in check.

On water pricing, PUB's water tariff is set to recover the full cost of production and distribution. In addition, to encourage water conservation, and reflecting the limited supply of water in Singapore and the higher incremental cost of additional supplies, a water conservation tax is also levied. This tax is imposed on the first drop consumed to drive home the message that every drop is precious. The tax is increased for households that consume more than 40 cubic metres per month.

To promote water conservation, PUB also adopts a host of mandatory and voluntary measures. Mandatory measures include the use of low capacity flushing cisterns and constant flow regulators. PUB has also embarked on community-driven public education programmes such as the 'Water Efficient Homes' programme and the 'Water Efficient Buildings' programme to encourage homeowners and building owners to adopt water conservation habits and measures. This has resulted in the reduction of per capita domestic consumption from 165 litres per day in 2003 to 160 litres per day last year.

In order to further lower consumption to 155 litres per day, PUB has embarked on its latest programme — The 10-Litre Challenge. This programme aims to encourage all Singaporeans to reduce their daily water consumption by ten litres through simple but effective water saving tips, such as how to install water bags in cisterns to reduce the amount used for flushing, taking shorter showers and washing full loads of laundry.

In terms of unaccounted-for-water, PUB has made much effort to ensure that leaks in our water pipe network are kept to a minimum, and water sold to customers is accurately metered. This has enabled PUB to lower unaccounted-for-water from 10 per cent in the early 1990s to about 5 per cent today. Hence, by reducing water losses, water demand is kept in check and there is less pressure to expand our water sources.

Beyond water conservation, PUB has launched the "Our Waters" Programme and the Active, Beautiful, Clean (ABC) Waters Programme to get people to value and enjoy our water assets.

Under "Our Waters", organizations and community groups can adopt stretches of water and pledge to take care of the water resources by conducting clean-ups, river patrols and seminars to promote greater awareness of water issues among the community. With ABC Waters, utilitarian drains will be transformed into beautiful and vibrant community spaces for recreational

Photo: PUB — Singapore's National Water Agency

Connecting with the community: kayaking in our reservoirs activities. This will not only enhance the overall quality of life for Singaporeans, but will also help foster a greater sense of environmental ownership, leading to a deeper awareness of the environment and the importance of its precious resources.

Our next step

As a small-island state, Singapore is far from immune to the effects of globalization. In order to keep pace with global technology developments, Singapore needs to continue to invest heavily in research and development to ensure technological relevance in this fast-changing world. As such, the Singapore government has ear-marked USD5 billion to fund R&D projects in three sectors, including the environmental and water technology sector, with an Environment and Water Industry Development Council (EWI) set up to map out strategies and oversee growth in this sector. It is Singapore's goal to be a Global HydroHub, the centre of a vibrant global industry, a place for the generation and exchange of ideas in the field of water.

Running parallel to this strong belief in the merits of idea exchange is PUB's active participation in global water events such as at the 4th World Water Forum in Mexico, the International Desalination Association Forum in Tianjin, China last year and of course, the World Water Week in Stockholm. Singapore will also be playing host to the International Water Association's Leading Edge Technology conference in a few months time. Singapore's HydroHub and the existing opportunities for international partnerships not only complement each other, but are vital if progress in this sector is to be maintained.

Climate change is no longer speculation, it is reality. For PUB, the key areas of concern will be the impact of rising sea levels on flooding and coastal supply infrastructure. As such, PUB is currently monitoring developments in the international arena to facilitate forward planning. Through such measures, PUB hopes to reduce water supply uncertainty as a result of meteorological events.

The road forward

Implementing an integrated water management system requires vision and proper planning. However, these factors alone are not sufficient. The key to the success of a multi-stakeholder, multi-use system is strong political will and good governance. It is only through a cohesive national effort that any large-scale system can attain its goal.

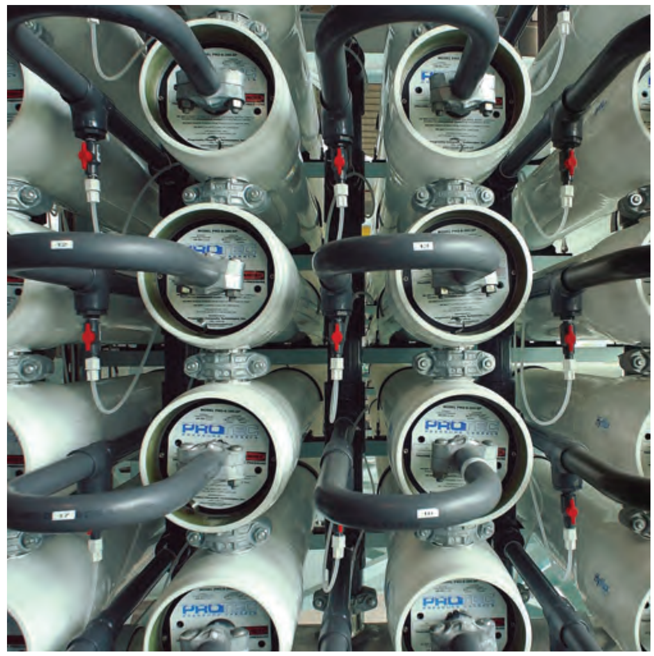


Photo: PUB — Singapore's National Water Agency

Reverse osmosis membranes for NEWater production

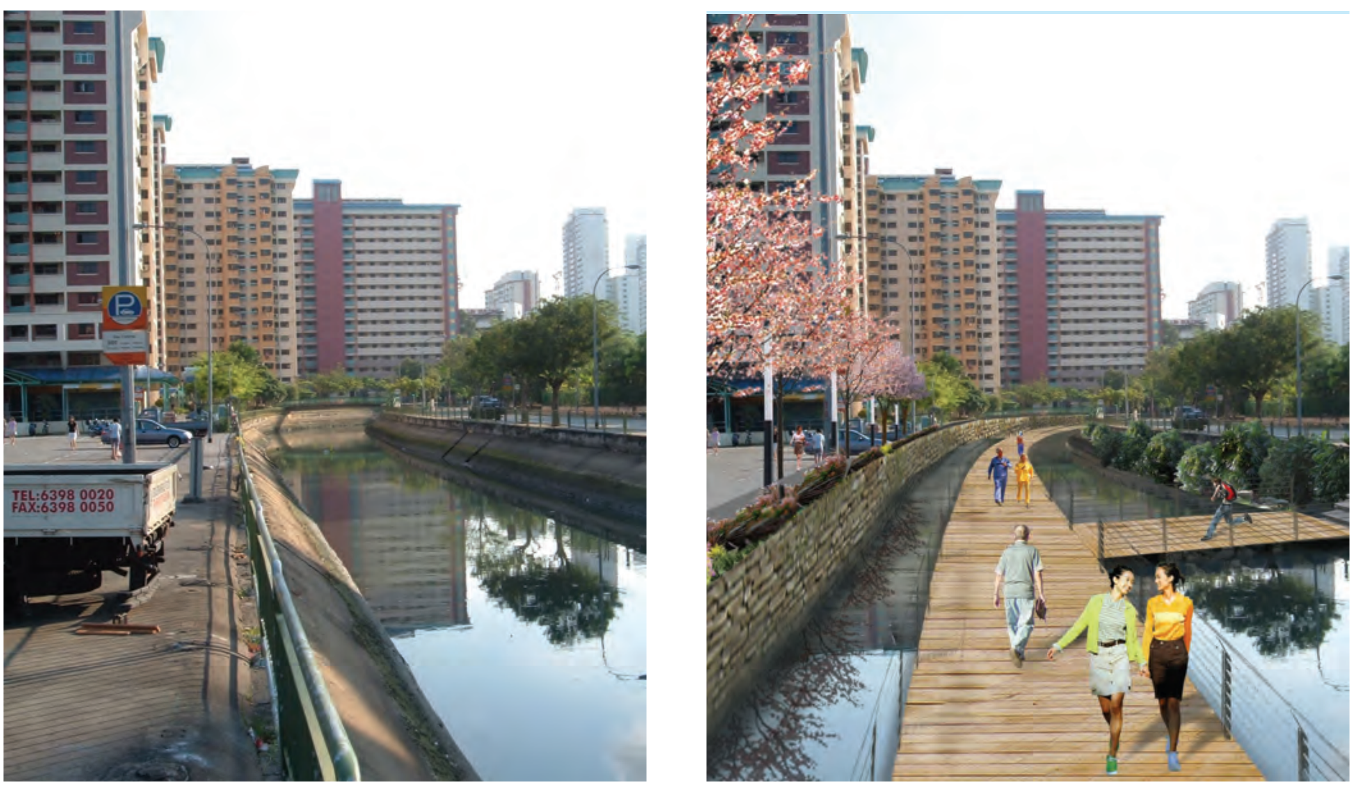


Photo: PUB — Singapore's National Water Agency

Active, beautiful and clean waters: transforming our waterways — Rochor Canal (before and after)

Fostering sustainable water resources: the Prince Sultan Bin Abdulaziz International Prize for Water

Dr. Abdulmalek A. Al Al-Shaikh, General Secretary of the Prince Sultan Bin Abdulaziz International Prize for Water, Riyadh, Saudi Arabia, www.psipw.org

In Riyadh, Saudi Arabia on 21 October 2002, His Royal Highness Prince Sultan Bin Abdulaziz, Crown Prince, Deputy Prime Minister, Minister of Defence and Aviation and Inspector General, announced the commencement of candidates' nominations for the 'Prince Sultan Bin Abdulaziz International Prize for Water'. This international scientific prize represents a significant contribution from the Kingdom of Saudi Arabia to the global water issues that represent one of the most pressing human, economic and political concerns worldwide.

The prize council is headed by His Royal Highness Prince Khalid Bin Sultan Bin Abdulaziz. The General Secretariat of the prize is headquartered in the Prince Sultan Research Centre for Environment, Water and Desert, at King Saud University in Riyadh, Kingdom of Saudi Arabia. There follows an account of the centre and its activities, including a more in-depth look at the reasons and accomplishments of the prize.

The Prince Sultan Research Centre for Environment, Water and Desert (www.psrcewd.edu.sa)

Prince Sultan Research Centre for Environment, Water and Desert (formerly known as the Centre for Desert Studies) was established in 1986 as an independent administration directly linked to the office of the Rector of King Saud University. It was set up as part of a national initiative, under the leadership of the Custodian of the Two Holy Mosques, to create specialized research centres, particularly in important areas concerning the prevailing dry desert climate of the Kingdom. Its purpose is to design and conduct scientific research related to desert development and combating desertification in the Arabian Peninsula in general, and in the Kingdom of Saudi Arabia in particular.

The centre works to fulfil its mission through scientific studies and research, particularly in the realms of combating desertification, preserving natural and environmental resources and organizing their exploitation through afforestation and the expansion of natural vegetation cover, forest and rangeland. It also endeavours perpetually to ameliorate its technical and research capacities in the field of remote sensing and geographical information systems, in order to support its scientific research activities. In addition, it uses these technologies in its work with specialised authorities to implement applied research projects devoted to studying the Kingdom's desert environment.

Among the research products published by the centre are several scientific and advisory publications. It acts as a home

Photo: PSIPW

HRH Crown Prince Sultan bin Abdulaziz (centre) with HRH Prince Khalad bin Sultan bin Abdulaziz and Professor Howard Wheater

Photo: PSIPW

Some winners of the PSIPW 2nd Award 2004-2006 for data documenting and support for desert-related scientific research activities conducted by the specialized divisions of the university. The centre is also continually committed to cooperating and strengthening links with the authorities concerned in drought and desert studies at local, regional and international levels. It has participated in various academic activities, particularly 'University Days' and 'Community Days' and has provided the relevant authorities with seeds and trees.

The centre has also provided students and researchers, from within the university and from outside, with technical counselling. It has organized various scientific conferences and seminars, and has taken an active part in such events in accordance with its focus on cooperation and the exchange of data and knowledge. Its cooperation with governmental authorities and non-governmental bodies at all local, regional and international levels, has led to its participation in a number of research and scientific projects, including agreements of cooperation with some outstanding organizations that share its research activities.

Having laid a firm foundation due to the support and assistance offered by the university administration, the centre started working to improve its goals and extend its activities in tune with more recent developments. Thus, the terms 'environment' and 'water' were added to its name to reflect broader environmental concerns and the need for processes to conserve water and make it more available by developing new, low-cost technical methods. In these areas, several studies and applied projects were implemented, such as 'King Fahad's Project for rainwater harvesting and storage in the Kingdom'. In addition, the centre adopted the Prince Sultan bin Abdulaziz International Prize for Water and became its secretary's headquarters, with the director of the centre as secretary general.

The prize

The Prince Sultan bin Abdulaziz International Prize for Water is intended to reward the efforts undertaken by innovative scholars and scientists as well as applied organizations in the realm of water resources worldwide. It was established to acknowledge the special contributions that have been made to the development of scientific solutions that help solve the problems associated with the provision and preservation of adequate and sustainable water resources, particularly in arid regions.

The prize includes awards according to five categories:

- Creativity prize
- Surface water
- Ground water
- Alternative (non-traditional) water resources
- Water resources management and protection.

The creativity prize is SAR1 million (approximately USD266,000), while each of the other categories carries a prize of SAR500,000 (USD133,000). Prizewinners also receive a gold medallion, a trophy and a certificate.

Prizes are awarded every two years, and nominations must be received by the end of each odd-numbered year — for example, **nominations for the third awards (2006-2008), nominations must be received by 31 December 2007**.

The creativity prize covers several different water-related subjects simultaneously. It is awarded for any original work (research, invention, technique etc.) that is considered as a breakthrough in any water-related field. The work must be practically applicable, economically feasible and environmentally friendly while each of the other four prize categories varies with each award

The second awards (2004-2006)

In the second awards (2004-2006), prizes were awarded as follows:

- The topic for the surface water prize was water harvesting. No prize was awarded due to a lack of nominations that met the required standards and conditions.
- Management of coastal aquifers was the topic for the ground water prize, which was awarded to the water section research institute at the King Fahd University for Petroleum and Minerals, Kingdom of Saudi Arabia and to Professor Abdelkader Larabi of Morocco.
- In the alternative (non-traditional) water resources branch, the prize was based on the treatment and reuse of wastewater, and was awarded to Professor Abdul Latif Ahmad of Malaysia.
- For water resources management, the prize focused on integrated and sustainable water resources management in arid and semi-arid regions, and was awarded to Professor Howard S. Wheater of the United Kingdom.
- The King Abdulaziz City for Science and Technology — The Kingdom of Saudi Arabia won the prize for the protection of water resources for its work concerning ground water pollution by urban activities.

The third awards (2006-2008)

Looking towards the third awards, which will be given in 2008, the topics for specialised branches are as follows:

- Surface water: sedimentation control in surface water systems
- Ground water: exploration and assessment of ground water
- Alternative (non-traditional) water resources: innovative methods and systems in desalination
- Water resources management and protection: water demand management in urban areas.

Any individual or organization that has made a pioneering scientific contribution in one of the branches of the prize will be considered eligible for nomination. The entrant must be nominated by a well known scientific organization.

Academic or scientific organizations can nominate one or more individuals or organizations. A scientific organization can nominate itself, but nominations put forward by individuals, whether on their own behalf or on behalf of others, will not be accepted.

No more than five research or work projects can be submitted for nomination. All of these should be related to the current nominated prize topic, and must not have previously been awarded any international prize, either on its own or jointly with another organization.

Nominated works are sent to specialized referees across the world, and winners are announced in September of the prize year (e.g. 2006; 2008), when the topics for the next prizes are also announced.

By perpetuating this two-year cycle of renewed topics within the prize categories, the Prince Sultan Bin Abdulaziz International Prize for Water can help to ensure continued work and progress towards the provision and preservation of adequate and sustainable water resources across the world, and especially in the arid regions where they are needed the most.

Managing climate-related health risks

Dr Stephen J. Connor, Director, PAHO/WHO Collaborating Centre on Early Warning Systems for Malaria and other Climate Sensitive Diseases; Director, Environmental Monitoring Research International Research Institute for Climate & 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. 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, the community and public services are showing increased awareness of these associations, and climate and health interactions are the focus of considerable research today.

Climate may impact on health through a number of mechanisms. This could be directly, through cold or heat stress, or indirectly through its impact on communicable and non-communicable diseases. The World Health Organization (WHO) recently identified 14 climate sensitive communicable diseases, including malaria, cholera and dengue. WHO describes these diseases as being promising candidates for the development of climate-informed early warning systems.[1] It also acknowledges that some non-communicable coronary and respiratory diseases are climate sensitive.

Evidence-based health policy

The role of evidence in the creation of health policy has been strongly promoted in recent years through, for example, the Cochrane systematic reviews.[2] 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
- Evidence that using climate information is a cost-effective and practical means to improve health outcomes.

Photo: CDC/Dr. Edwin P. Ewing, Jr

Poor air quality due to atmospheric smog over New York

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 three diverse examples illustrate this.

Heat stress in Europe

The European heat wave during the summer of 2003 is associated with an estimated 40,000 excess deaths, with 15,000 of these deaths occurring in France alone. Since then, the European Office of WHO, with funding from the European Union (Euro-Heat), has joined research institutions, healthcare providers and many of the National Meteorological Services in studies to establish the factors and mechanisms responsible for these deaths. This information is then used to set up early warning systems to increase public awareness and to reduce vulnerability and associated risk.[3]

The socio-economic factors implicated with heightened risk and vulnerability are complex but include age, existing medical conditions, poor levels of physical fitness, urban residence 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.

Meteo-France, a Euro-Heat partner, recently declared July 2006 as the warmest on record. Yet preliminary figures suggest that heat-related deaths in France number only a few hundred, and for Europe a few thousand. While this is extremely good news, and suggests that early warning systems are working well, the importance of socio-economic factors vis-à-vis climatic factors is yet to be clearly understood.

Respiratory disease in North America

There are numerous studies linking atmospheric air quality, airborne particulate matter (airborne PM: particulate matter less than 10 micrometres in size), 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.

The Canadian Meteorological Service produces a daily air quality forecast. Air quality is expressed using an Air Quality Index (AQI).[4] 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. Similar activities are taking place across the border in the United States.

Epidemic malaria in Africa

It is now widely recognized that malaria is a major constraint to both socio-economic development[5] and the MDGs[6] in Africa, where there are an estimated 90 per cent of all malaria deaths, and immeasurable sickness occurs.[7] 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.[8]

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,[9] 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[10] and weather scale information[11] received through the National Meteorological Services as part of an effective Malaria Early Warning System. Botswana's example is being promoted by WHO to encourage other African countries to follow suit.[12]

However, if such initiatives are to perform at the scale required, significant interdisciplinary collaboration is essential. Training must be provided, and mechanisms developed across disciplines, to address socio-economic vulnerability to severe disease outcomes.

Photo: Christopher Phelps

Air quality: meteorological services for safeguarding public health

Dr Liisa Jalkanen, WMO Secretariat

Air pollution is the cause of many environmental and public health problems. Exposure to particulate matter and ozone can cause cardiovascular and respiratory systems diseases. While the health risks presented by some air pollutants, such as second-hand tobacco smoke or carbon monoxide, have led to campaigns to raise awareness of the risks, other forms of air pollution are more difficult to avoid: particulate matter can be generated from a variety of sources including vehicle emissions, road dust, power generation, construction and demolition processes, pollens, molds and even sea spray. Many people are unavoidably exposed to these pollutants throughout their lifetime, and need more information about air quality in order to mitigate the risks.[1]

Environmental problems arising from this include regional haze, impairing visibility in national parks and wilderness areas; acidification of lakes, streams and forests; acidic damage and erosion to buildings and other materials; ozone damage to plants, and eutrophication in coastal areas. In addition, the accumulation of toxic compounds in plants and wildlife results in associated effects on the ecosystem and public health.

Awareness of these hazards has grown in recent years, and several measures are now taken to address air quality issues. These include:

- Environmental conventions to establish a broad framework for cooperative action on reducing the impact of air pollution and to set up a process for negotiating concrete measures to control the emission of air pollutants through legally binding protocols
- Development and implementation of air pollution control strategies
- Accounting for emissions
- Developing, achieving and maintaining air pollutant standards
- Taking regular measurements of pollutants, providing air quality modelling and forecasting, and air quality index (AQI).

In particular, developing countries with rapid economic growth have serious problems in balancing the need for economic and social development on one hand, and issues of resource conservation and environmental protection on the other.

The WMO and its Members carry out a combination of measurement and modelling activities to provide air quality information for use by decision makers and the general public. Given the widespread effects of pollution, these services can be applied by communities at all levels to mitigate the environmental and public health risks associated with air quality in a wide range of activities.[2,3]

Emissions

Among the many sources of emissions that cause air pollution, some are particularly problematic:

Power generation — In most countries, power generation is responsible for the major part of the sulphur dioxide (SO_2) and nitrogen oxides (NO_x) released into the environment by human activity.

While measures in many countries have significantly improved air quality, additional reductions are necessary to address persistent public health and environmental problems. Because these pollutants move beyond local and regional boundaries, individual localities experiencing environmental effects cannot always control them. In addition, current laws in many countries tend to address each environmental problem independently, even if one pollutant contributes to several problems.

Transportation — This equates mainly to ozone and particulate pollution. Measures taken to protect public health and the environment include regulating air pollution from motor vehicles, engines, and the fuels used to operate them, and by encouraging travel choices that minimize emissions. As an alternative to using private cars, governments may seek to improve public transport, provide tax incentives for more environmentally friendly cars, and put in place restrictions on fuel and vehicle use. Consumers can help by learning what can be done to reduce air pollution, and how to make decisions that improve air quality.

Effects

Air pollution contributes to respiratory and cardiovascular diseases, cancer, and nervous system and developmental disorders. The link between exposure to air pollution and consequences on health, depends upon the pollutant and the disease, and is also influenced by genetic constitution, age, nutrition, lifestyle, and socioeconomic factors such as poverty and level of education.

As reported by WHO, the environmental factor with the greatest impact on health in Europe is indoor and outdoor air pollution.[4] The European Commission Clean Air for Europe (CAFÉ) programme, found that in the EU about 350,000 people died prematurely in 2005 due to outdoor fine particulate matter pollution. This corresponds to an average loss of life expectancy of 9 months per EU citizen, and is comparable to the life expectancy loss due to road accidents in the EU.[5] There are great differences between East and West Europe, and between industrialized and developing countries. Globally there are about 1.5 million deaths annually from lower respiratory infections, largely caused by indoor and outdoor air pollution.[6] It has also been found that during heat waves, 20-40 per cent of excess deaths are due to air pollution.

Public and preventive health strategies that consider environmental health interventions are often cost-effective and yield benefits that contribute to the overall well-being of communities. Respiratory health improves when air quality improves as has been shown by many intervention studies. Examples include industrial plant shutdowns and lowering of fuel sulphur content. The Olympic games are usually a great incentive for improving air quality. For instance, during the summer 1996 games in Atlanta implementation of an alternative transport strategy resulted in lower traffic emissions. Hospital admissions of children with acute asthmatic symptoms fell by 41.6 per cent during the period of the games.[7] More recently, Beijing has conducted some of China's most ambitious environmental actions, including controls on emissions, adopting alternative fuel use, and relocating heavily polluting plants outside of Beijing. The importance of regional air quality has also been recognized and possible measures are being considered.

Excessive UV radiation is harmful to humans, as well as flora and fauna. Reporting of a UV index, a service that is provided by many National Meteorological and Hydrological Services (NMHS), may initiate preventive measures against conditions that can cause skin cancer, certain types of cataracts and immune system suppression.[8]

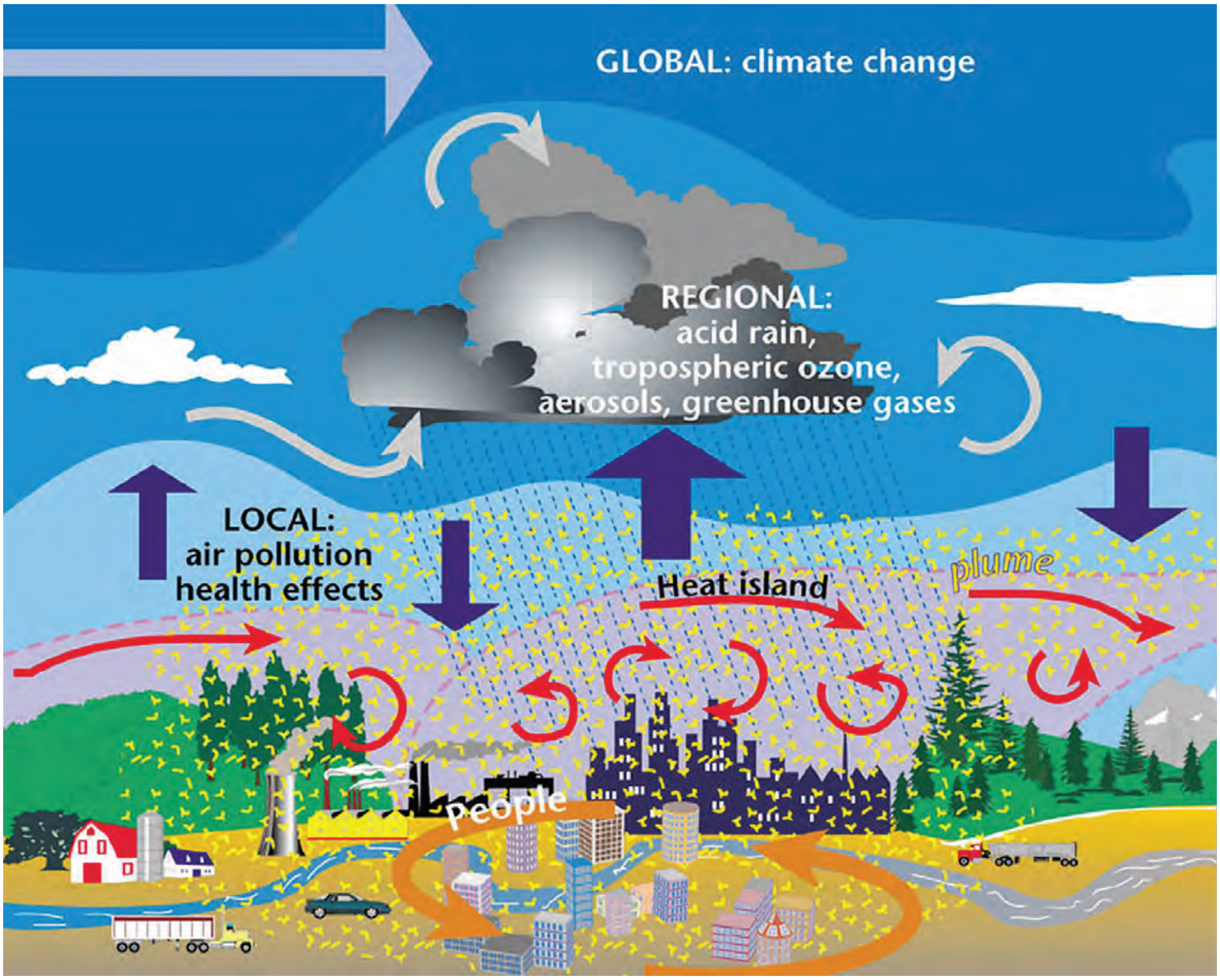
Tourism can suffer significant economic impacts from increased air pollution and reduced visibility. Environment Canada surveyed tourists in the Greater Vancouver area regarding poor visibility and found that for a single extreme visibility event, a loss of USD7.45 million in tourist revenue was predicted.[9] Evidently, these losses can seriously threaten regional economies that rely heavily on tourism.

Biomass burning is a major contributor of gaseous and particulate air pollutants in many parts of the world. As a consequence it has a severe effect on the health of the population, civil aviation operations, maritime shipping, agricultural production, and the tourist industry. Southeast Asia witnessed one of the worst smoke and haze episodes in autumn 1997, with estimated economic losses at USD 9.3 billion.[10]

Air quality services

Amongst other services, NMHSs, working alone or together with environmental agencies, issue AQIs giving details of daily air quality, as well as air quality forecasts (AQF) in a simple and instructive manner. These are designed to enable the general public and authorities to take appropriate measures both in immediate and future actions, thus counter-acting the negative effects as far as possible.

WMO addresses air pollution problems on all scales



Source: GURME (GAW Urban Research Meteorology and Environment project)

Improved air quality in Singapore

Foong Chee Leong, Director-General, Meteorological Services Division,
Joseph Hui, Director-General, Environmental Protection Division,
The National Environment Agency, Singapore

Singapore is a small city state comprising of one main island and a number of islets. Located about 1.5 degrees north of the equator; it has a climate with uniform temperature and pressure, high humidity and heavy rainfall.

With a land area of only 699 km^2, Singapore has a population of more than 4.3 million, has over 750,000 motor vehicles, and handles 423 million tonnes of sea cargo and over 1.8 million tonnes of air cargo each year. Furthermore, Singapore has many large-scale industries such as oil refineries, petrochemical complexes, and pharmaceutical and electronic factories. As a result, the challenges Singapore faces in achieving and sustaining a clean and healthy environment are immense, in particular ensuring good air quality to protect the health and well-being of its inhabitants.

Despite its many challenges and constraints, Singapore has succeeded, over the years, in keeping its air healthy. Singapore continues to enjoy good ambient air quality, assessed as 'good' most days of the year. The average levels of key air pollutants are low and have been stable over the years, except for 1994 and 1997, because of trans-boundary smoke haze from land and forest fires in the region. Singapore has adopted the use of the Pollutant Standards Index (PSI) to measure its air quality. This indicator, which was developed by the United States Environmental Protection Agency (USEPA), shows that in 2005, Singapore enjoyed 88 per cent of days with 'good' air quality, with the remaining 12 per cent in the 'moderate' range.

Environmental management in Singapore

The main cause of air pollution in Singapore is the burning of fossil fuels in industrial processes, electricity generation and transportation. Fuel consumption, with its resulting emissions, inevitably increases with economic and population growth. Although climate and geography do play a role in facilitating the safe dispersion of the air pollutants emitted, there is a limit as to how much emission the environment in Singapore can assimilate without resulting in a deterioration of its air quality. A rigorous environmental management programme, comprising of environmental planning and development controls, regulatory control, ambient air quality monitoring, partnership initiatives and international cooperation, is required to keep emissions

Photo: National Environment Agency and Singapore Environment Council

Singapore continues to enjoy good air quality most days of the year

Photo: National Environment Agency and Singapore Environment Council

Environmental considerations are incorporated in land-use planning, development and building control within this limit and the ambient air quality in the 'good' range. The National Environment Agency (NEA) of Singapore is responsible for environmental management in Singapore.

Environmental planning and development control

Right from the conceptual and planning stages of a development, potential air pollution problems are assessed and minimized or prevented by incorporating a judicious mix of siting, technical design and pollution control measures. This is implemented using an integrated land-use planning and development control approach that encompasses all new developments, whether residential or industrial. This approach enables environmental considerations and factors to be incorporated at the land-use planning, development control and building control stages. Under this integrated approach, NEA works with the various authorities of Singapore, such as the Urban Redevelopment Authority (URA), the Jurong Town Corporation (JTC) and the Housing and Development Board (HDB) as well as private sector industrial developers on all land use and development proposals.

In addition, NEA assesses all industrial proposals to ensure that they meet siting and technical requirements. These siting and technical requirements help ensure that the proposed industries, when in operation, do not pose unmanageable hazards or pollution impacts. Large-scale industrial projects are required to carry out pollution impact studies and quantitative risk assessments with accredited consulting firms to quantify potential pollution risks and hazards. These studies take into account the prevailing climatic conditions and the design of the plants. NEA reviews these studies and imposes technical requirements to minimize the identified pollution impacts and hazards. The technical requirements imposed include:

Fuel quality — The type and quality of fuel used by proposed industries are stipulated. The maximum sulphur content in fuel oil used by power stations is controlled at 2 per cent by weight. Other industrial plants are allowed to use fuel oil with the sulphur content capped at 1 per cent. Fuel-burning equipment such as boilers, in premises which are located near to or in built-up areas, is required to use cleaner fuel, such as diesel with 0.005 per cent sulphur content or gas (liquefied petroleum, compressed natural gas (CNG) or town gas).

Pollution control equipment — Industries are required to prevent emissions as much as possible through design measures and to further mitigate them by installing appropriate pollution control equipment to meet the stringent emission standards stipulated under the environmental legislation in Singapore.

Regular dialogues are held with professional engineers, architects, contractors and developers to disseminate new environmental codes and technical requirements as well as to seek feedback on environmental control requirements. Comprehensive guidelines and codes of practice are available on the NEA Web site (www.nea.gov.sg) to guide these professionals and developers in their work. In addition, NEA provides walk-in consultation sessions for engineers and architects to seek clarification and waivers to facilitate the approval of pollution control equipment.

Regulatory control

Air pollution in Singapore is regulated under the Environmental Pollution Control Act. The latest air emission standards for industry are stipulated in the Environmental Pollution Control (Air Impurities) Regulations 2000.

A source emission testing scheme is set up to ensure operators of major industrial plants monitor their emissions regularly and, if necessary, take corrective measures to comply with the stipulated air emission standards. NEA officers also carry out inspections on industrial and trade premises to ensure compliance with pollution control requirements, as well as conducting fuel analyses and smoke observations.

Air emissions from vehicles are kept in check through the implementation of stringent emission standards for new vehicles, mandatory periodic inspection of vehicles, and enforcement operations. Over the years, NEA has tightened the emission standards in tandem with advances in vehicle technology. In Singapore, diesel vehicles contribute approximately 50 percent of the total particular matter (PM) 2.5 emissions. PM2.5 is very fine particulate matter of 2.5 microns in size and smaller, and high levels of PM2.5 pose health risks such as asthma and other respiratory diseases. NEA implemented the Euro IV emission standards for all new vehicles in October 2006 to help reduce PM2.5 emissions. As part of the efforts to reduce PM2.5 emissions, NEA implemented the Euro IV emission standards for all new vehicles in October 2006. The quality of fuel used by vehicles is also controlled. Unleaded petrol was introduced in January 1991 and leaded petrol was phased out by 1 July 1998. The sulphur content of diesel was reduced to 0.005 per cent by weight in December 2005. Various tax incentives were also introduced to promote the early introduction of Euro IV diesel vehicles, CNG vehicles and green vehicles.

Ambient air quality monitoring

The ambient air quality in Singapore is continuously monitored through the Telemetric Air Quality Monitoring and Management System (TAQMMS). The system, which comprises 13 remote air monitoring stations linked to a central control system, provides an efficient means of obtaining air quality data. Eleven of the stations measure ambient air quality and two stations measure roadside air quality. Automatic analysers and equipment are deployed at the stations to measure the concentrations of major air pollutants such as sulphur dioxide, oxides of nitrogen, carbon monoxide, ozone and respirable suspended particles.

Partnership initiatives

Partnering with other stakeholders in the environment, such as the private and voluntary (people) sectors, is essential for sustaining good air quality. Key partnership initiatives include the following:

Motor Industry Certification Board — To help provide vehicle owners with a better standard of maintenance, NEA initiated the formation of an industry-led Motor Industry Certification Board (MICB) for the administration of the Certification Scheme for Motor Workshop on 1 September 2000. Under this scheme, certificates are awarded to motor workshops with trained mechanics, proper equipment and procedures and quality assurance checks for the maintenance of diesel-driven vehicles to prevent black smoke emissions. Currently, more than 30 workshops are certified under this scheme.

Promoting use of cleaner fuel — Natural gas is a cleaner fuel than either petrol or diesel. The use of natural gas vehicles will reduce the emission of air pollutants and carbon dioxide. In 2002, NEA and its project partners, a gas supply company and a bus company, launched the first CNG refuelling station and a pilot project to introduce CNG buses to the masses. A taxi company has also registered and deployed a fleet of CNG taxis since December 2005. NEA will continue to promote vehicles that use cleaner fuel.

National Climate Change Committee — The National Climate Change Committee (NCCC) is an inter-agency committee with people, private and public sector (3P) representation. It seeks to integrate the promotion of energy efficiency and the use of clean energy sources with the reduction of emissions of air pollutants and greenhouse gases in the power generation, manufacturing, building, transportation and consumer sectors. The key thrusts of the NCCC are promotion of energy efficiency, promotion of the use of cleaner energy sources and test bedding of innovative and alternative energy technologies. A USD6.5 million co-funding scheme for energy studies to improve energy efficiency in the manufacturing and building sectors was launched in April 2005.

Power generation — Power generation is a major source of air pollution. Using clean fuel and adopting efficient generating technologies helps to reduce emissions of air pollution and carbon dioxide. About 80 per cent of electricity in Singapore is generated from natural gas and using combined cycle generation or cogeneration.

Partnerships with NGOs — The Singapore Environment Council (SEC), an environmental non-governmental organization (NGO), introduced the Associate Green Corners Programme in July 2005 to encourage retailers to display air-conditioners and refrigerators labelled under the Energy Labelling Scheme. The SEC also administers the fuel economy labelling scheme for passenger vehicles. The two schemes are voluntary labelling schemes aimed at promoting energy efficient appliances and passenger vehicles. NEA had also developed the Energy Smart Building Scheme jointly with the National University of Singapore to recognise energy efficient buildings. To support this, an accreditation scheme for energy services companies was launched in April 2005.

Singapore Green Plan 2012

In 1992, Singapore unveiled the Singapore Green Plan (SGP), the national environmental master plan that sets out the strategic directions Singapore should take to further improve its living environment and raise public health standards. The SGP also maps out the policies and strategies the government would implement to transform Singapore into a model green city.

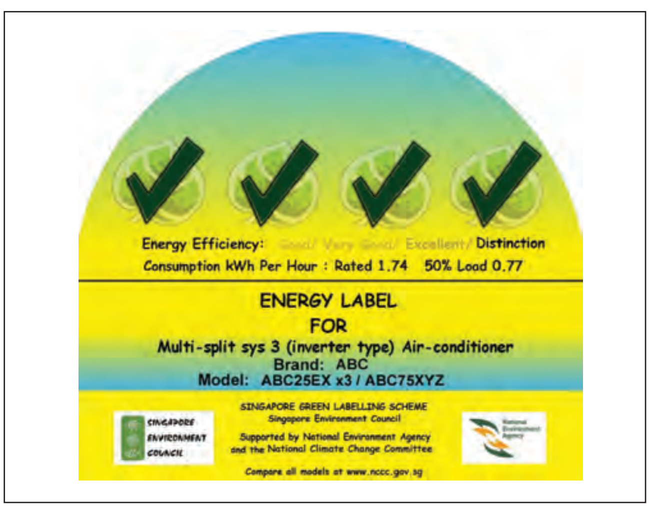


Photo: National Environment Agency and Singapore Environment Council

An energy label for air-conditioner

The successful implementation of action programmes under the SGP has helped to keep Singapore's environment clean and green even as Singapore's economy has continued to grow over the past decade.

With changing economic and environmental landscapes, a review was initiated to keep the SGP relevant. In August 2002, the SGP 2012 was launched in Singapore. The SGP 2012 was circulated at the World Summit on Sustainable Development (WSSD) in Johannesburg in August and September of 2002.

The SGP 2012 relays the message to our nation and the world, that the challenge Singapore now faces is to move beyond environmental performance towards environmental sustainability. This updated master plan charts Singapore's approach to achieving environmental sustainability over the next ten years. It also sets out the broad directions and the strategic thrust that will help ensure Singapore's long-term environmental sustainability.

International cooperation

NEA also works through bilateral, regional and international programmes to strengthen Singapore's environmental cooperation with regional countries and international organizations. At the bilateral level, the Malaysia-Singapore Joint Committee on the Environment (MSJCE) covers environmental issues of mutual concern such as the control of vehicular emissions. Similarly, the Indonesia-Singapore Working Group on the Environment (ISWGE) discusses various areas of collaboration and projects between the two countries, such as the trans-boundary haze pollution problem. In June 2006, the inaugural bilateral meeting of the Brunei-Singapore Working Group on the Environment (BSWGE) was convened in Singapore. This bilateral cooperation provides opportunities for both countries to share their experiences in various environmental challenges, which include air quality management and vehicular emission control.

Since its inception in 2003, Singapore has been chairing the Association of Southeast Asian Nations (ASEAN) Working Group on Environmentally Sustainable Cities (AWGESC). Under AWGESC, an ASEAN Initiative on Environmentally Sustainable Cities (AIESC), which focused initially on key urban environmental issues such as clean air, water and land, was established. A total of 24 cities in ASEAN are currently participating in this Initiative. In 2006, a set of key performance indicators and award criteria to measure the state of environmental sustainability in participating cities was established.

Looking ahead

Despite being highly urbanized and industrialized, Singapore's ambient air pollutant levels have generally been kept within the US Environmental Protection Agency (USEPA) ambient air quality standards through strong planning and regulatory controls. However, as its industrial and transport base expands and energy demand grows, maintaining clean air as a resource will be a key challenge to Singapore.

Singapore will continue to tighten emission controls and to move towards cleaner fuels for both stationary and mobile sources of pollution. The promotion of clean fuel burning equipment in industry will continue to be encouraged, especially with greater availability of natural gas. Singapore is moving towards a sustainable transport system, with a comprehensive and seamless public transport network and greater adoption of green vehicles.

The watch warning system on heat waves with effect on mortality

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It is known that meteorological conditions, and climate in general affect human health. The effects can be direct, such as through increased heat stress and loss of life in floods and storms, or indirect through alterations in the range of diseases as well as food availability and quality.

Thus, it is becoming increasingly important, taking into account global warming, that health and meteorological authorities form a close partnership and cooperate in order to mitigate the impact of meteorological conditions on human health.

Such cooperation began in Portugal in 1999 between the Portuguese Institute of Meteorology and the Portuguese Health Institute, with the aim of creating an operational watch warning system on heat waves with effect on mortality.

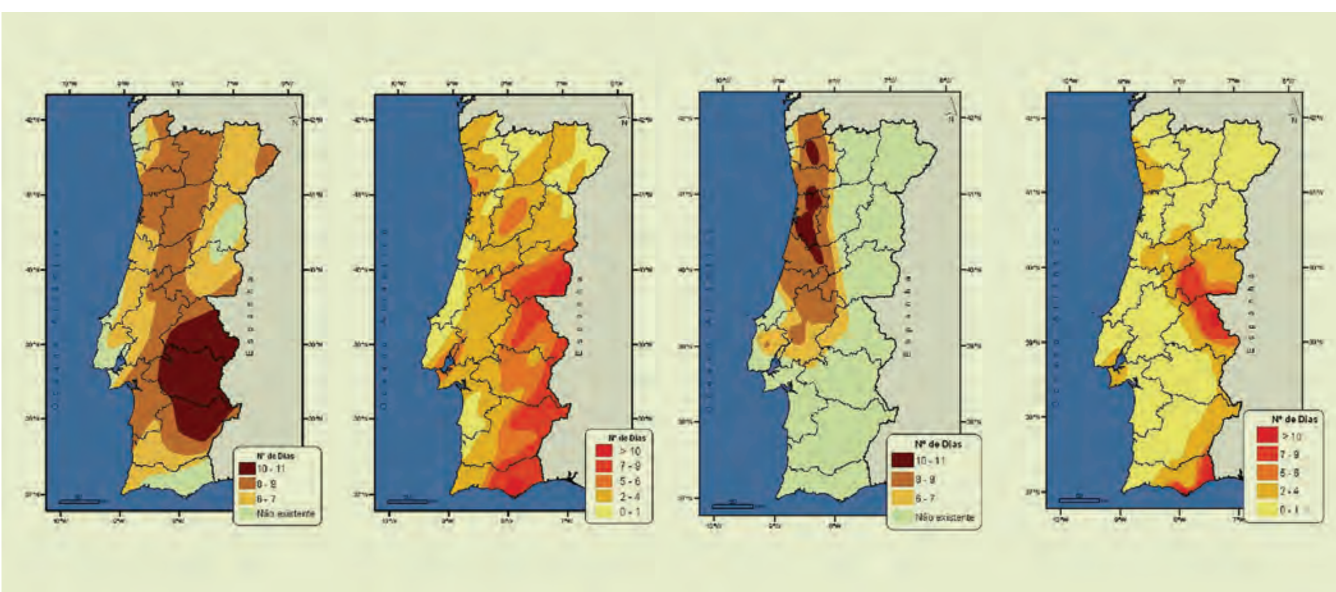
The occurrence of heat waves is recognized as a danger to public health,[1] since it is a phenomenon causally associated with avoidable excess mortality. Still fresh in our minds is the European heat wave of 2003, which is estimated to have caused approximately 50,000 excess deaths.[2] Whilst the impact of heat waves on human mortality rate is widely established, there are also causal links to disease, and excess strain to health care services.[3]

During the heat wave of 1980, average daily temperatures in Memphis, USA, rose above the mean on 25 June and remained elevated for 26 consecutive days. During the July period 83 heat-related deaths were recorded, most of which involved elderly, poor, black inner-city residents.[4]

A heat wave occurred in July 1988 in Allegheny County, USA, with daily maximum temperatures near or above 90 degrees Fahrenheit for 15 consecutive days.[5] During that period there were a total of 694 related deaths in the county, with the most affected being persons over 65 years old.

In July and August of 1995, during a heat wave in England and Wales, 619 extra deaths were estimated relative to the expected number of deaths based on the 31-day moving average for that period. Excess deaths were apparent in all age groups, most noticeably in women and for respiratory and cerebrovascular disease.[6]

Heat Wave Duration Index (left), number of consecutive tropical nights (Tn ≥ 20°C) (second left), 7-18 July 2006 – (third left), and 1-14 August 2006 – (right)



Source: IM Portugal

Expected and excess of deaths (95% confidence intervals) during the heat waves of 2003 and 2006 in the Portugal Mainland

Heat waves	Comparison period	Expected deaths	Excess of deaths	CI 95% for the excess of deaths	Ratio observed/expected
30thJuly to 15th August 2003	2000-2001	4499.3	1952.7	(1866.1 ; 2039.3)	1.43
7th-17thJuly 2006	July 2004	4163.9	1122.5	(876.3; 1381.0)	1.27

Source: Instituto Ricardo Jorge

In Japan, a study made by Nakai, Itoh and Morimoto,[7] which investigated heat-related deaths from 1968 through 1994, concluded that such fatalities were most likely to occur on days with a peak daily temperature above 38 degrees Celsius, and that the incidence of these deaths showed an exponential dependence on the number of hot days. Thus, even a small rise in atmospheric temperature may lead to a considerable increase in heat-related mortality. Furthermore, 50.1 per cent of these deaths occurred in children (four years and under) and the elderly (70 years and over) irrespective of gender. This clearly indicates the importance of combating global warming.

Portugal is no exception to this danger. Episodes of excessive heat have sporadically occurred in Lisbon throughout the 20th century. The impact of the heat wave of June 1981 on the population of the district of Lisbon was first published in 1988.[8] In fact, multiple episodes of heat waves with different durations and health consequences have been identified in Portugal between 1980 and 2006.

In terms of vulnerability, advanced age; cognitive limitations; existing illness; the consumption of certain medication; hydration level; isolation and habitation conditions are all relevant.[9] Case-control studies carried out in France found that loss of autonomy and social isolation played a major role in the risk factors for the elderly, as did living directly below the roof of a building, particularly in cities.[10]

Whilst there is general agreement that the elderly are most vulnerable to severe heat impacts, there are cases in which all age groups have been affected, such as the heat wave of June 1981 in Portugal.[11]

Forecasting the effects on mortality

Most European countries have implemented heat wave surveillance and alert systems.[12] However, time of occurrence and the expected consequences of these heat waves in terms of duration, intensity and populations affected, are difficult to estimate precisely.[13]

With knowledge based mainly on the incidents of 1981 and 1991, a warning system for heat waves and their effects on mortality[14] was developed by the National Observatory of Health of the National Institute of Health, Dr Ricardo Jorge and the Institute of Meteorology, and has been operational since 1999. This warning system, the ÍCARO surveillance system of heat waves, was implemented using a statistical model for the relationship between high temperatures and mortality in Lisbon.[15]

The ÍCARO surveillance system operates yearly from May to September and calculates an index — the ICARUS INDEX — that relates predicted deaths (based on three-day forecasts for air temperature provided by the Institute of Meteorology) due to the occurrence of high temperatures to those expected without such climate effect. Whenever a heat wave is predicted within the next three days, institutions involved in the surveillance system, which includes Direcção Geral de Saúde (National Directorate for Health) and Serviço Nacional de Bombeiros e Protecção Civil (National Service for Civil Protection) receive a warning in order to enable action to mitigate the possible severe consequences of the phenomenon.

Recent heat waves in Portugal

In recent years the population of Portugal's mainland has been exposed to several heat waves associated with large excesses of mortality.

Four heat episodes with a large impact on mortality occurred in June 1981 with estimated excess deaths of approximately 1,900.[16] Also in July 1991, there were estimated excess deaths of approximately 1,000.[17] In July/August 2003 estimated excess deaths were approximately 1,953,[18] and in July 2006 estimated excess deaths were approximately 1,123.[19]

Heat episodes with a lower impact on mortality occurred in Portugal during the following periods: 14-25 July 1990 (estimated excess deaths 690); 19-28 May 1991 (estimated excess deaths 475); 27 May to 2 June 2001 (estimated excess deaths 441)[20]; at regional level, in Algarve 27 July to 4 August 2004 (estimated excess deaths 80)[21], 3-7 and 12-16 August 2005 (estimated excess deaths 462)[22] and 4-8 August 2006 (estimated excess deaths 136).[23]

The table above shows the calculations leading to the estimation of the number of excess deaths for the two most recent, severe heat waves. The observed deaths were estimated through a system that surveys daily mortality. The number of expected deaths was based on figures from an appropriate comparison period.

The number of excess deaths was then calculated by the difference 'observed' minus 'expected' (O-E) and an estimation of the relative excess was obtained by the ratio 'observed' divided by 'expected' (O/E).

The heat wave[24] of 29 July-14 August 2003 was a rare and unprecedented event in terms of both unusually high maximum and minimum temperatures, and accompanying low relative humidity. Occurring in the inland territory with a duration of 17 days, it was the longest recorded heat wave in Portugal since 1941.

The highest values for both maximum and minimum temperatures were exceeded in this period. In Amareleja on 1 August, Portugal's highest ever temperature was measured at 47.3 degrees Celsius. In 97 per cent of meteorological stations, maximum air temperatures above 35 degrees Celsius were recorded between 1 and 14 August; maximum air temperatures above 40 degrees Celsius were recorded in two out of three stations. As to minimum air temperature, 97 per cent of meteorological stations recorded temperatures above 20 degrees Celsius and 40 per cent above 25 degrees Celsius.

Reference should be made to the heat wave that occurred between 7 and 18 July 2006. Occurring in the Alentejo region, this was the longest recorded heat wave in July since 1941. It is noticeable that during this heat wave a large number of warm days and nights occurred, where the values of maximum and minimum air temperature were above values that only occur in 10 per cent of cases. There were also a great number of consecutive days with very high minimum air temperatures. Of particular relevance is the observation that the greatest values of the number of consecutive days with minimum temperature ≥ 20°C (tropical nights) were exceeded in the period 8-18 July.

From 2 to 13 August a heat wave occurred in coastal northern and central regions, with a duration of 8-11 days; however the greatest values of the number of consecutive days with minimum temperature ≥ 20°C occurred in central and southern inner regions.

Weather stress index

The weather stress index (WSI) is related to human physiological discomfort, and is based on the calculation of Net Effective Temperature (NET). The parameters used in the NET computation are temperature, relative humidity and wind, all of which are derived from numerical weather prediction models. The effective temperature (the NET predecessor), initially proposed by Missenard in 1937,[25] included the relative humidity effects, but was limited to hot conditions. Modifications by Gregorczuk[26] incorporated the wind effect and generalized its use to include cold conditions.

The NET is consistent with common human perception:

- In hot weather, the NET increases with increasing temperature and/or relative humidity, and decreases with increasing wind
- In cold weather, the NET decreases with decreasing temperature and with increasing relative humidity and/or wind.

Calculation of NET Effective Temperature (NET)

$$NET = 37 - \frac{37 - T}{0.68 - 0.0014RH + \frac{1}{1.76 + 1.4v^{0.75}}} - 0\text{-}29T\,(1 - 0.01RH)$$

T is the dry thermometer temperature in degrees Celsius.
v is the wind speed in metres per second
RH is the relative humidity in per cent

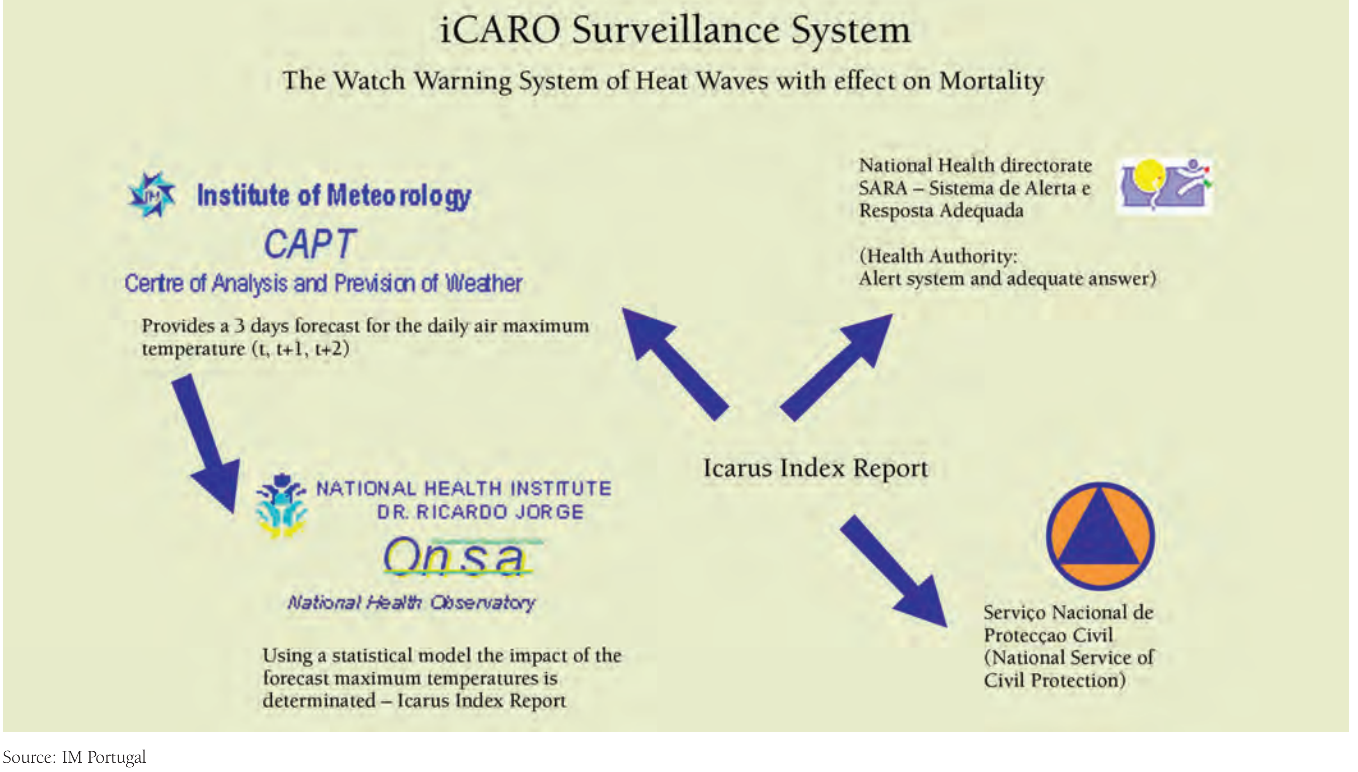
Source: IM Portugal

This is an important advantage over less complex indexes using only the temperature, and over more complex indexes that require parameters, such as radiation, which are difficult to forecast.

The WSI is a percentile derived from the 'NET climatology'. For example, a day with a WSI=99 per cent means that only 1 per cent of the days in the analysed period had a NET greater than the NET calculated for that day. Similarly, a day with a WSI=1 per cent means that only 1 per cent of the days had a smaller NET. Extreme values of WSI are correlated with extreme physiological discomfort, and therefore the WSI can be used as a risk index in bioclimatic studies.

The effect of global climate change, and specifically of global warming on population health is an important issue for all professional groups that work in the field of public health. The task of predicting the consequences and reducing the effects of continuing global warming upon the health of the population must continue. With insight and application, many of the health impacts of extreme weather events can, in fact, be prevented.

iCARO Surveillance System



Source: IM Portugal

Improved weather-related services in cities in the face of climate, weather and population changes

Dr Walter F. Dabberdt, Vaisala, USA

PROJECTIONS FOR GLOBAL population growth indicate that cities will continue to grow rapidly at the expense of rural areas, much as they have since the mid-1980s. Urban growth will continue in both developed and developing regions. At the same time, there is strong empirical evidence that our climate is changing — in large part as a consequence of anthropogenic emissions of radiatively important trace gases (RITG). Computer model projections indicate that these changes are likely to continue for the foreseeable future, pending significant reductions in anthropogenic emissions. Changes in climate will be accompanied by changes in weather, and there are indications that some climate-induced weather changes may already be happening.

In the face of these predicted changes in population, climate and weather, short-range weather forecasts and predictions will be even more important in the future than they are today.

Photo: Vaisala

Flooding in cities like New Orleans (2005) has wreaked havoc, death and destruction. More urban flooding catastrophes can be expected as populations rise and climate warms in the coming years and decades

However, urban forecasts and warnings still depend on observations and data from a synoptic observation system that was designed decades ago, and which cannot provide the precise, high-resolution weather predictions needed in the cities of today and tomorrow. The implications for public safety of this impending 'perfect storm' can be met by the implementation of advanced regional atmospheric observation systems that facilitate markedly improved warnings, forecasts and predictions of hazardous weather. The onus for this rests on National Meteorological Services, non-governmental organizations and private industry.

The population challenge

The United Nations Population Division (UNPD)[1] prepared estimates and projections of urban and rural populations for major areas, regions and countries of the world for the period 1950-2030. By the end of that period, the world's number of urban dwellers is expected to equal the number of rural dwellers in the current year, 2007. In 1950, only 30 per cent of the world's population lived in urban areas, but this had increased to 47 per cent by 2000. According to the UNDP report, the world's urban population reached 2.9 billion in 2000 and is expected to rise to 5 billion by 2030, when the urban proportion will reach 60 per cent. Virtually all the world's population growth between 2000 and 2030 is expected to occur in urban areas, and almost all of this expected urban population increase will occur in less developed regions, whose population is likely to rise from approximately 2 billion in 2000 to just under 4 billion in 2030.

In more developed regions, the urban population is expected to increase slowly, from 0.9 billion in 2000 to 1 billion in 2030. In these regions urbanization is already very advanced — 75 per cent of the population lived in urban areas in 2000. The concentration of population in the cities of the more developed countries is expected to increase further so that 83 per cent of the inhabitants will be urban dwellers by 2030.

By 2030, the urban population percentage in less developed regions is expected to rise substantially to 56 per cent. The less developed regions will reach a level of urbanization in 2030 that is similar to that of the more developed regions in 1950. Table 1 summarizes various indicators of urbanization for the more- and less-developed regions of the world. Compared to 1950, the percentage of the world's total urban population is projected to have doubled by 2030, and it will have more than tripled in the less developed regions.

Table 1: Urban indicators

	Urban Percentage				Urbanization rate (%)		Doubling time (years)	
	1950	1975	2000	2030	1950-2000	2000-2030	1950-2000	2000-2030
World	29.8	37.9	47.2	60.2	0.92	0.81	75	86
MDR*	54.9	70.0	75.4	82.6	0.63	0.31	...	...
LDR*	17.8	26.8	40.4	56.4	1.63	1.11	42	62
* MDR = More developed regions *LDR = Less developed regions								

Source: UNPD, 2001

Earth's changing climate and urban weather

Over the past decade, the climate change debate has shifted dramatically. In the early 1990s, the questions being asked were: "Is the climate really changing?" and "Is there a perceptible contribution from human activities?" Today, the questions are very different: "Will the climate change gradually or abruptly?"; "How can anthropogenic impacts on climate be diminished or reversed?" and "Will the frequency and intensity of severe weather episodes change, and what will be the socio-economic impacts?"

In 1988, the World Meteorological Organization and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess scientific, technical and socio-economic information relevant to the risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The IPCC's assessments are undertaken by hundreds of global experts who base their analyses on peer reviewed, scientific and technical literature. The third and most recent IPCC assessment report was completed in 2001[2] and the fourth assessment is scheduled for completion in 2007. The IPCC's projected changes in climate have been summarized in Table 2.[3] They predict profound socio-economic implications as a consequence of higher temperatures; increased heat indices; more intense precipitation events; increased risk of drought; and increased severity of tropical cyclones.

The urban weather problem is multidimensional. Weather has special and significant impacts on those who live in large urban areas[4]. Conversely, large urban areas can impact the local weather and hydrologic processes in various ways. And urban dwellers have different weather information needs than their rural counterparts, due to the diversity of user groups and population sectors. These include the following:

- the general public
- air quality management agencies
- water supply and sewage providers
- electric power industry
- fuel suppliers — natural gas, fuel oil, coal, gasoline
- transportation sectors — aviation, marine, and surface
- emergency response agencies
- public safety agencies
- insurance companies and underwriters
- health care providers
- recreation facility providers.

Urban heat islands can yield temperatures that are up to 5 degrees Celsius greater than their rural counterparts, but nighttime differences up to 12 degrees Celsius have been observed.[5] These increased temperatures result from the combined effects of the thermal and radiative properties of buildings and road surfaces; anthropogenic emissions of sensible heat; and changes in the air-land exchange of water and the corresponding impact on the radiation budget. Changes in surface roughness in urban areas also affect the exchange of heat, mass, and momentum between the surface and the atmosphere, as well as the depth of the urban mixed layer. Hydrological processes are altered to a significant degree by the effect of buildings and pavements on surface moisture, runoff and streamflow. There are also some indications[6] that large urban areas may influence the genesis, intensity, and movement of convective storms and frontal boundaries.

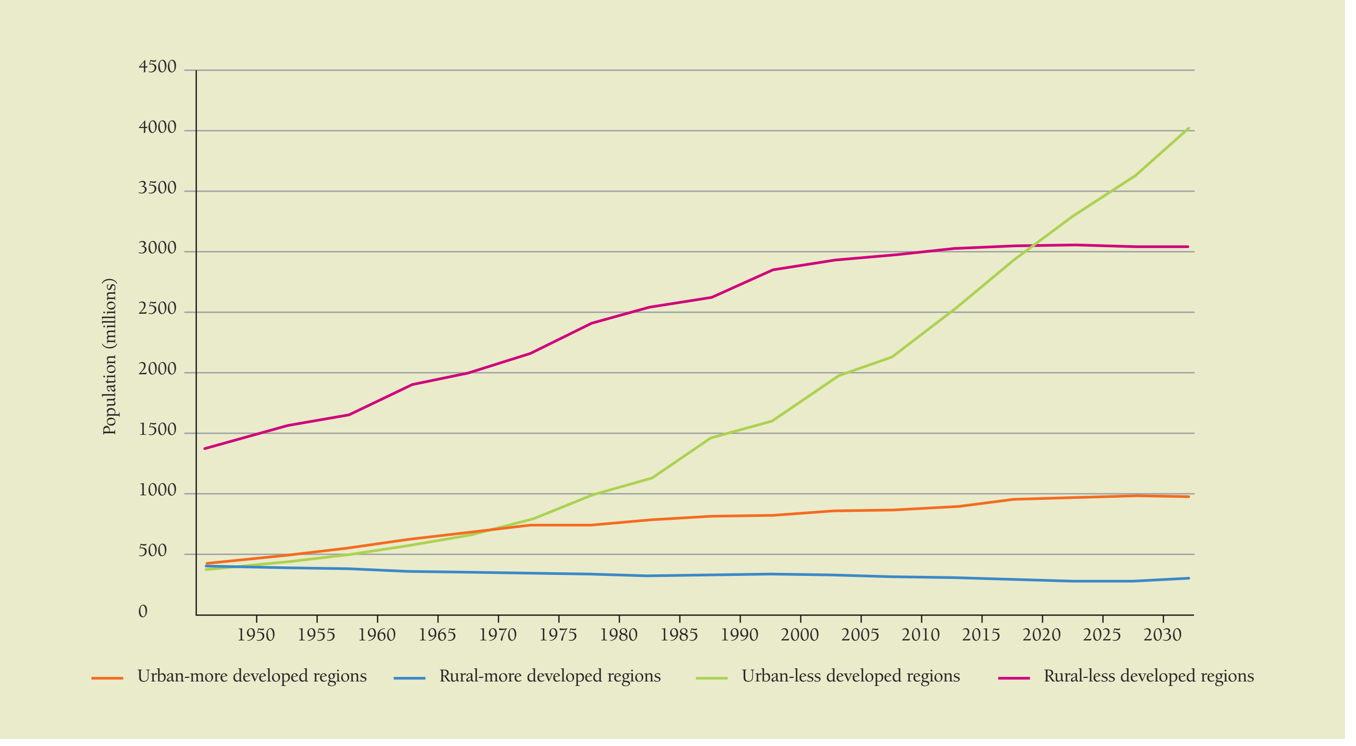
Weather impacts urban areas and urban residents in many ways. Heavy rains can cause severe flooding, snow and freezing rain can disrupt transportation systems, severe storms can cause power failures, and so forth. The major direct impact on human mortality results from heat waves, and urban areas are particularly vulnerable because of their high population densities and because urban areas exacerbate conditions that lead to heat stress. An analysis of deaths from various weather conditions in the United States in the twentieth century clearly showed that heat waves caused more deaths, both on an annual average basis and from single events, than all other weather conditions combined.[7] The temperature-mortality relationship has a strong latitudinal dependence, with mortality rates in northern cities affected more by higher temperatures, and in southern cities by lower temperatures.

As the resolution increases in mesoscale prediction models, it will be ever more important to properly represent urban influences on the radiation budget, surface moisture, sensible heat exchange processes, and anthropogenic heat and moisture fluxes. This also means that weather observation networks will need to be enhanced in order to provide the three-dimensional observations required to properly initialize the models, but also to provide improved information on weather conditions in cities.

Enhanced urban weather observations and forecasts

As important as weather observations and forecasts are today, they will be even more critical in the future, as urban population growth contributes to changes in global and regional climates. The importance of observation systems suitable for tomorrow's cities is receiving international attention. For example, the Global Earth Observation System of Systems (GEOSS) has included a new task in its GEO 2007-2009 work plan.[8] Task US-07-01, Nowcasting and Forecasting User Applications, seeks to "facilitate the transfer of advanced nowcasting and forecasting capabilities from and to major cities in developed and developing countries [by building] upon the Helsinki Testbed experience to develop user applications related to precision weather forecasts, severe weather

Urban and rural population of the more and less developed regions, 1950-2030



Source: UNPD, 2001

warnings, hydrology (including flood control), air-quality forecasting, chemical emergency response, transportation safety, and energy management… The Helsinki Testbed[9] is a Finnish initiative aimed at developing enhanced three-dimensional mesoscale observation networks critical to the advancement of modeling systems and related user applications. It is a public-private-academic partnership. The program is open to all interested parties and the data is freely accessible through the Internet. Related stakeholder groups include homeland security, agriculture, insurance, urban management, coastal zone management, media, and public safety."

A recent community workshop[10] with international participation considered the requirements of effective mesoscale measurement networks, and concluded that: "existing mesoscale measurement networks do not provide observations of the type, frequency, and density that are required to optimize mesoscale predictions and nowcasts. To be viable, three-dimensional mesoscale observation networks must serve multiple applications, and the public, private, and academic sectors must all actively participate in their design and implementation as well as in the creation and delivery of value-added products. The [urban] measurement challenge can best be met by an integrated approach that considers all elements of an end-to-end solution: identifying end users and their needs; designing an optimal mix of observations; defining the balance between static and dynamic (targeted or adaptive) sampling strategies; ensuring data standards and data quality, establishing long-term testbeds (such as evaluation and demonstration programs); and developing effective implementation strategies."

The challenge is to determine the most effective mix of observations, including alternative network configurations and sampling strategies. For example, in improving mesoscale analyses and predictions, it may be more cost effective to sample only the boundary layer, with denser coverage, than to similarly enhance observations in the upper troposphere. It may be more cost effective to deploy intermittent, targeted observations at high resolution than to maintain dense arrays of continuous sensors. Regional testbeds are an intermediate step needed to provide answers to these and other questions. Testbeds must carefully gauge the value of forecast products provided to end users.

Improved mesoscale observations present many challenges. For example, the top observational priority for operational nowcasting is to establish a dense mesoscale network of surface weather stations to measure winds and state variables and provide real-time sub-hourly reports. Minimum station spacing in urban areas should be 10 km or less, and the reporting frequency should be every five minutes or less. Radar is an invaluable tool for nowcasting applications, yet the current operational systems have not kept pace with technological advances. Dual-polarization capability should be implemented on existing radars, and private and academic radars should be integrated into operational networks. Consideration should also be given to deploying X-band polarimetric radars, as well as techniques for improving boundary layer coverage through the use of closely spaced, low power X-band radars. Radar refractivity measurements should be evaluated as a possible tool for improving nowcasting by sensing moisture discontinuities. Products detailing near-surface water vapour fields should be provided in real time to forecasters and assimilated into models to demonstrate their potential to improve nowcasting. There is also a pressing need to provide boundary layer observations using radio frequency (RF) wind profilers. Not only are additional observation systems required — including in situ and remote sensors, both earth- and satellite-based

Table 2: PCC estimates of confidence in observed and projected changes in extreme weather and climate events

Changes in phenomena	**Confidence in observed changes (latter half of the 20th century)**	**Confidence in projected changes (during the 21st century)**
Higher maximum temperatures and more hot days over nearly all land areas	Likely	Very Likely
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very Likely	Very Likely
Reduced diurnal temperature range over most land areas	Very Likely	Very Likely
Increase of heat index (a measure of human discomfort) over land areas	Likely, over many areas	Very Likely, over most areas
More intense precipitation events	Likely, over many Northern Hemisphere mid- to high latitude land areas	Very Likely, over many areas
Increased summer continental drying and associated risk of drought	Likely, in a few areas	Likely, over most midlatitude continental interiors (lack of consistent projections in other areas)
Increase in tropical cyclone peak wind intensities	Not observed in the few analyses available	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Insufficient data for assessment	Likely, over some areas
Virtually certain: greater than 99% chance that a result is true; Very likely: 90–99% chance; Likely: 66–90% chance; Medium likelihood: 33–66% chance Unlikely: 10-33% chance; Very unlikely: 1–10% chance; Exceptionally unlikely: less than 1% chance.		

Source: McBean and Henstra, 2003

— there is also a critical need to seamlessly integrate data from all of the disparate observation systems to extract maximal information.

Projects like the Helsinki Testbed are a valuable intermediate step in designing networks and sampling strategies; evaluating new observation systems; setting data-quality standards; creating products that better meet user needs; and testing the ability of the public, private, and academic sectors to form effective partnerships to enable operational mesoscale networks. Successful testbeds should meet the following criteria:

- Address the detection, monitoring, and prediction of regional phenomena
- Engage experts in the relevant phenomena
- Define expected products and outcomes, and establish criteria for measuring success
- Provide specialised observation networks for pilot studies and research
- Define strategies for achieving the expected outcomes
- Involve stakeholders in planning, operation, and evaluation of the testbeds.

The implementation of advanced 3D mesoscale measurement networks entails many practical issues in addition to the technical and scientific ones. A national collection of regional and urban networks will require a significant commitment and a major infusion of financial resources. In many countries, the most viable model for developing and supporting operational mesoscale networks leans toward a consortium of public, private and academic partners. In the old paradigm of synoptic-scale networks, government took responsibility for all aspects of the observational problem — design, testing, standard-setting, quality assurance, implementation, and operation. But with the reduction in scale size demanding more and improved observations, and improved sampling strategies and modeling systems, a partnership approach may offer the greatest likelihood of successful and timely implementation. Establishing one or more end-to-end mesoscale testbeds is a tangible first step in establishing the urban networks needed by the world's growing cities.

Photo: Vaisala

One example of urban smog – Kuala Lumpur, Malaysia

Weather, climate and water information and the energy sector

Dr Laurent Dubus, EDF R&D

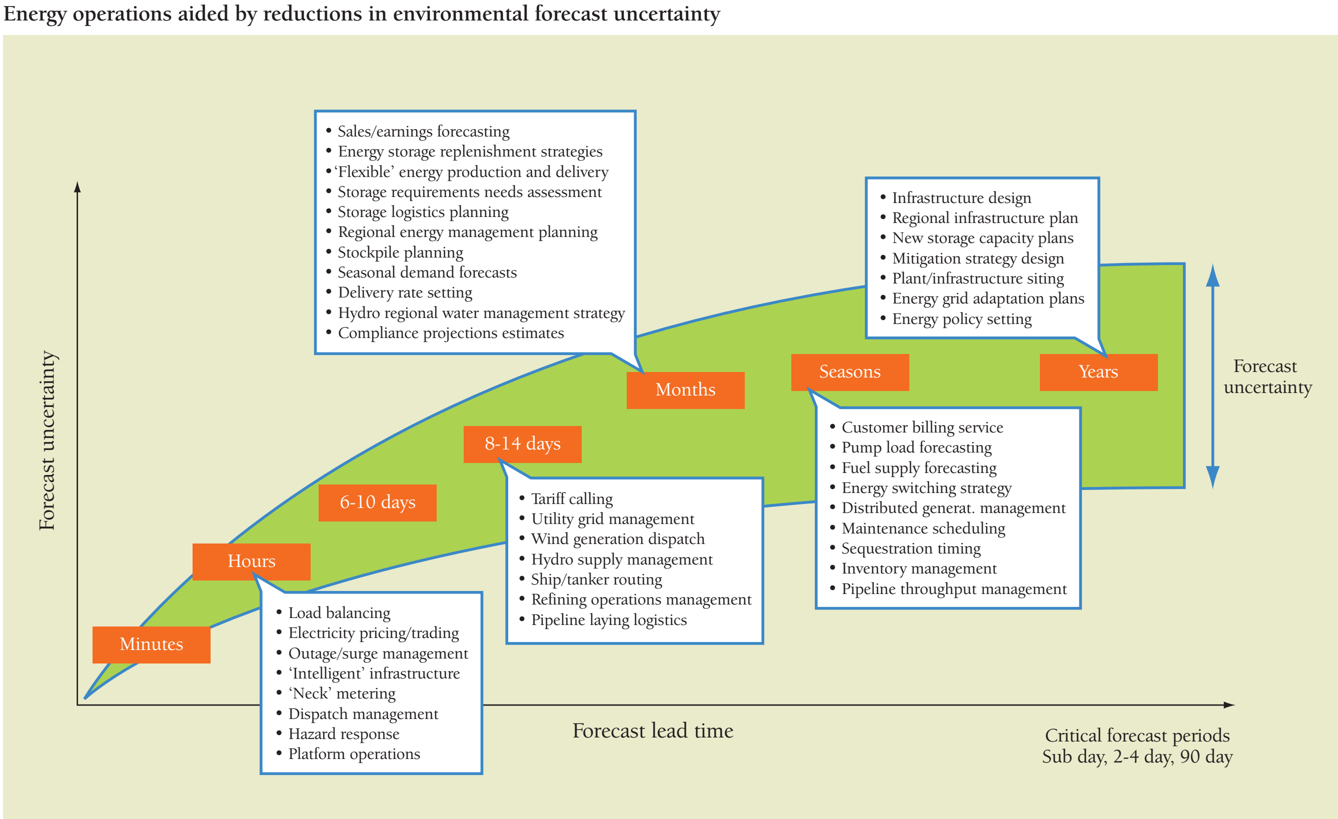
Energy is a global trillion-dollar sector that includes both non-renewable (oil, gas, coal) and renewable (hydropower, solar, wind, geothermal, biomass) resources. It covers a wide range of activities, from energy resources exploration, extraction, storage and transport, to electricity production, transport and distribution.[1] It is also characterized by industrial competitiveness and its influence on political, economic and strategic decisions. An optimal and cost effective management of the energy sector is crucial for national and global economies and development.

Between 1973 and 2004, global energy consumption increased by 66 per cent and there has been a three-fold multiplication of the generation of electricity.[2] Over the next 30 years, global electricity demand is expected to double, and it is anticipated that the global primary demand for energy will expand by about 60 per cent. Two-thirds of this increase will concern the developing world, mostly India and China. Fossil fuels will continue to dominate the global energy mix, raising questions about the sustainability of the current energy system.[3]

The energy sector is highly dependent on climate conditions and water resources, whatever the particular field of activity, means of production or timescale. Moreover, the rising use of renewable energy, while desirable to mitigate the effects of climate change, will make energy production and distribution increasingly dependent on climate conditions.[4]

Weather, climate and water information are very important in short- and medium-term energy management processes. Extreme events such as heat or cold waves, windstorms or floods can have major impacts on production units and electrical grids, but 'normal' weather variations also have an impact on load level, production capacity, transport and distribution. For example, a temperature anomaly of minus one degree Celsius in winter in France corresponds to an increase in production of 1,500 megawatts, equivalent to the capacity of

Energy operations aided by reductions in environmental forecast uncertainty



Source: Courtesy of M.G. Altalo, Science Applications International Corp.

one nuclear reactor or about 500-700 windmills. In the USA, electricity generators save USD166 million annually, using 24-hour temperature forecasts to manage the available mix of generating units.[5] Finally, archive data and future climate scenarios, including both mean trends and extreme values, are essential to long-term supply planning, production unit dimensioning, and therefore to investment decisions.

Issues and concerns for information providers and user expectations

By 2030, the investment needed to meet projected demand is likely to be around USD16 trillion, with half of this amount needed for developing countries.[6] Reducing the risks associated with those investments and with the management of energy systems is crucial. Weather, climate and water information have a major role to play. Vital issues include environmentally responsible and equitable energy management, a better match of energy supply and demand, a reduction of risk to energy infrastructure, more accurate inventory of greenhouse gases and pollutants, and a better understanding of renewable energy potential.

In developing countries, the vital issues are energy access and reliability, with efficient energy management being a secondary issue. For many of these countries climate variability and risks are significant. Weather, climate and water information are therefore crucial for the development and safety of their energy systems. The primary concern for NMHS is to provide databases that help to establish sites and dimension future grids and production units (especially those based on renewable resources). Secondary concerns include providing services in the short- and medium-term management of energy systems, and issuing warnings to minimize the impact of rare meteorological events.

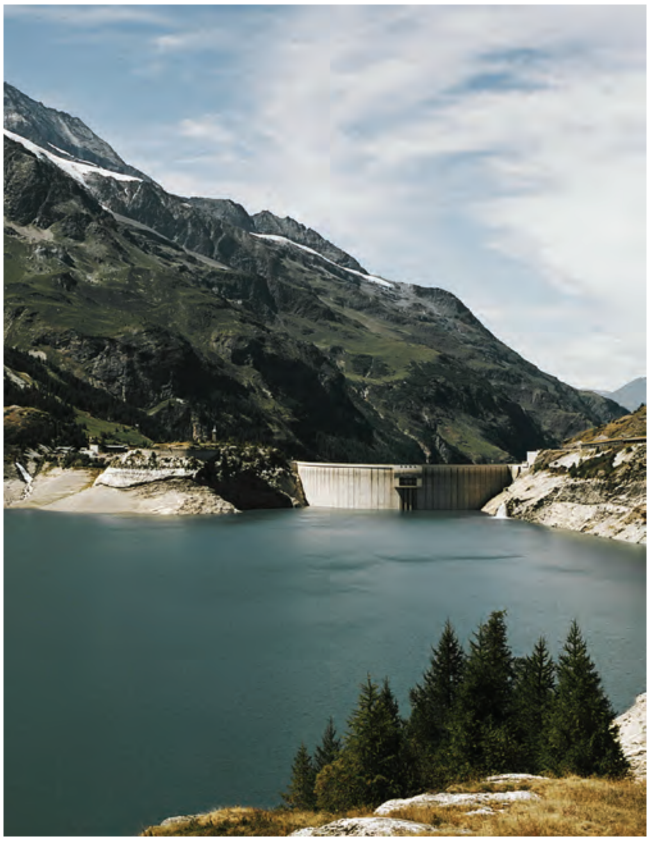


Photo: La mediatheque EDF/Johann Rousselot

Tignes lake and dam (France)

In developed countries, the energy sector is one of the biggest users of earth observation products and weather forecasts. The priority over the next decade is to promote a better and shared use of existing data and forecast information, and to prepare the industry to use new products as they become available. These will include medium-term weather predictions (notably ensemble predictions) and atmospheric environment monitoring products.

Optimizing information delivery

Due to the complexity of energy systems management, it is important for energy companies and NMHS to collaborate. The level of weather, climate and water information needed in the energy sector is high, and it is necessary to master complex information such as ensemble forecasting. Energy sector personnel have to deal with very diverse problems, and do not always have the necessary expertise in earth sciences. It is therefore desirable to establish an intermediary between disciplines.

User training is also important, in order to ensure an up-to-date knowledge of products and services and to identify potential future developments of interest to the sector. A coordination team should be formally set in place, and regular meetings with feedback and event review mechanisms should be planned, in order to maintain good communication.

Bridging gaps between users and providers

There are many challenges ahead in improving and rationalizing the use of weather, climate and water information in the development of environmentally responsible and equitable energy systems. These challenges include:

- Raising awareness among the general public, scientists and decision-makers about the potential impacts of energy consumption on climate and environment
- Ensuring recognition that advances will require an investment in research to improve scientific and technical capabilities
- Ensuring recognition that resources for HMS are investments that are highly beneficial to the energy sector, and to society, rather than needless expenditures
- Maintaining and developing the operational capability of the service providers
- Ensuring that the users are aware of and understand the limitations of data and forecasting and warning systems
- Developing the use of short-, medium- and long-term weather and climate forecasts, with a particular focus on ensemble predictions
- Understanding that failures will occur, but that the application of risk management approaches can minimize the possible impacts, and that doing nothing will always be worse.

In conclusion, energy is a prerequisite for economic and social development. It will therefore be a crucial element in the United Nations Millennium Development Goals.[7] Efforts from NMHS and energy companies and agencies will be necessary at both local and national levels, to meet each country's needs. However, regional and international efforts will also be essential to ensure a global, equitable and sustainable development of energy systems. Here, international organizations like the World Meteorological Organization, The Group on Earth Observation, and the International Energy Agency will have a major role to play.

Meteorological services and the social and economic benefits of energy saving in the Beijing heat supply

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HEAT SUPPLY MANAGERS need sound scientific information on which to base their decisions. In order to achieve this, in 2000 the Beijing Meteorological Bureau has initiated a study of the benefits of meteorological services, focusing on energy saving in the heat supply market, particularly during the winter months. Through preliminary applications in the heat supply market, the findings of this study have been proven to have clear impacts on the heating sector. The meteorological information can be used as a basis for household heating management. Also targets for both energy-saving and pollution reduction are achievable through the provision of dedicated meteorological services. On average, approximately CNY 100 million Yuan (USD12.5 million) can be saved annually in the heating sector alone.

Basic features of the heat supply in Beijing

Normally, the winter heating season begins on 15 November every year, and ends on 15 March the following year. However, according to the climatic situation at the time, these dates can vary. In so-called 'warm winters,' the intensity of heating levels weakens to a larger extent and, in general, it seems that the length of annual heat supply is being shortened.

Although more clean energies (e.g. hydro-power, natural gas, etc.) are being progressively used and overall power or gas consumption is increasing, municipal heating still depends mostly on coal burning, and annual coal consumption is up to eight million tons. Coal burning is a major source of sulphur dioxide and suspended particles, and therefore it is also the main source of air pollution during the winter in Beijing.

Outstanding issues in the application of meteorological information to the heating sector

A number of factors have an impact on the heat supply and energy saving.The heat supply industry has yet to attach enough importance to the potential of meteorological services in this context. At the same time, meteorological information is too generalised to target the sector, and thus gives it an inaccurate description of changing weather. Another main factor is the irrational schedule of heat supplies, which often leads to a waste of energy.

More specifically, a public weather forecast gives the daily maximum and minimum temperatures. The average of these is the mean daily temperature, and its deviation from the situ mean temperature differs by one degree Centigrade, and in some cases even by two or three degrees Centigrade. Obviously, such information leaves too much doubt to be used as a basis for adjusting both inflow and outflow heat temperatures.

The public weather forecast is so inadequately refined that it cannot be downscaled to cover all temperature differences at

A total of 800 tons of coal has to be burned in order to keep households warm enough within the Beijing municipality any specific localities in different periods of a day within the municipality, particularly for a winter morning. For example, in the various segments within Ring Road 4, the maximum air temperature difference may vary from three to four degrees Centigrade in the same day, and this variation is expected to be even larger across the outskirts of Beijing.

The elements in the public weather forecast do not satisfy demand. Apart from air temperatures, solar radiation, wind intensity and other factors are also relevant.

Benefits of a meteorological service dedicated to the heating sector

Taking 1998 for example, the total isolated floorage scattering within the city is up to 121 million metres^2, and the coal consumption is 0.026 ton per square metre, with a cost of about CNY 600 million. On condition that the specialized meteorological information is appropriately used to keep the household indoor temperature no lower than 16 degrees Centigrade, it means that energy can be saved by five per cent, saving at least 156,000 tons of coal or equivalent to 30 million CNY annually. Similarly, it can be estimated that the benefits of energy saving from central heating facilities will also be substantial. Some specific cases are given below to illustrate the practical economic benefits made through energy saving, based on meteorological services by four companies in Beijing:

1. *Beijing Heat Supply Group* — heat supply floorage 9,000 metres^2. It is estimated that the company can save approximately 17 million giga joules per year, which equates to CNY 42.427 — a saving of 5.3 per cent in terms of energy or 89,500 tons of coal, giving a 430-ton reduction in sulphur dioxide emissions and an additional reduction of 4475.4 tons of soot annually.
2. *The Beijing Aircraft Maintenance Engineering Company* — a Sino-German joint venture with heating floorage of 450,000 metres^2. Appropriate application of household heating-oriented weather forecasts for scheduling the company's heat-generation boilers and for controlling the temperature adjustment range of both heat inflow and outflow pipes provided by a local meteorological office, saves about 800 tons of coal compared with normal heating seasons, with an energy saving rate up to 14 per cent.
3. *Beijing Yanqing Heat Supply Company* — the heating floorage is 300,000 metres^2. The enterprise accepted heating-oriented weather information by strictly following the heating index issued by a meteorological office, adjusting the outflow temperature and controlling inflow water temperature. As a result, it saved 0.006 ton per metres^2 in terms of coal consumption while ensuring that all households enjoy a comfortable and warm indoor temperature. This practice saves CNY1.2 per square metre, or around 1,800 tons of coal in one heating season alone.
4. *The Hengyouyuan S/T Development Company* introduced a nationally advanced geothermal heating technology. Its total heated floorage of 2.4 million metres^2 is distributed in different locations surrounding Beijing. By applying dedicated meteorological information, energy consumption (electricity) has been reduced by 5.3 per cent in comparison with the annual average.

According to the national Category 2 Emission Criteria, combustion of one ton of coal releases 11.5 kg of sulphur dioxide, 7.7 kg of nitrogen oxide and 11.4 kg of suspended particles. Again taking 1998 as an example, a total of 800 tons of coal has to be burned in order to keep households warm enough within the Beijing municipality. Supposing five per cent of coal is saved, this means a saving of 400,000 tons of coal — the emissions of sulphur dioxide, nitrogen oxide, NOx and total suspended particles can be reduced by 4,600, 3,080 and 4,560 tons respectively in one season, which will make a significant contribution to the effort to reverse aggravating pollutants over the capital.

Meteorological offices at various levels keep a close watch on the changing weather and climate and provide more specialized, refined and targeted meteorological information, which can be used by heat suppliers and relevant decision makers as a useful scientific reference to control the heating facilities, all aimed at maintaining more comfortable living conditions. This demonstrates the meteorological offices' awareness that the well-being of people is their fundamental interest.

Meteorological products for winter heating

Temperature, total solar radiation, temperature rise and net solar radiation all have negative effects on heat supply capacity forecasts. During daytime, the effect of temperature accounts for 60 per cent while that of solar radiation amounts to 18.8 per cent — hence solar radiation is a factor that must be considered in forecasting daytime heat supply capacity. However, at night the effect of temperature contributes 80 per cent so that the effect of solar radiation is negligible.

Wind speed also has an effect. Temperature drop caused by high winds has a significant impact on a heat supply capacity forecast, and increased wind speed has a positive effect on the forecast. On 4 December 2005, a temperature drop caused by strong winds made natural gas consumption soar from an average of 14 million metres^3 per day to 21.85 million metres^3 per day.

Humidity can affect the speed of heat transfer for outer walls. The effect of humidity on the forecast differs during day and night. In daytime, due to solar radiation, the greater the humidity, the more heat will be absorbed by outer walls. Therefore, heat release from the room would be slowed down and less heat supply capacity is needed. On the contrary, at night the greater the humidity, the easier it is for heat to be released from the inside to the outside of the outer wall.

Temporal and spatial resolutions of weather forecast products

The time validity of forecasts is as follows: forecasts of mean diurnal temperature cover one to three days; weather element forecasts for morning, noon and evening are issued twice a day; three to five-day forecasts are given for the beginning and end of the heating season; and significant weather forecasts are produced on an irregular basis.

There are also localized forecasts — the city is divided into four zones: northeast, northwest, southeast and southwest. Location-specific forecasts on water temperature of inflow and outflow pipes will be updated according to the heat island effect of each zone.

Application of meteorological information to the heat supply

Firstly, a monitoring network needs to be set up for collecting information and data, such as indoor temperature in the neighbourhood, ambient temperature and wind speed, as well as the temperature of inflow water and outflow water to and from boilers.

Secondly, short-term and medium-term forecast numerical models are created for predicting both inflow and outflow water temperature on the basis of the collected information and data analyses.

Thirdly, a one to three-day diurnal temperature forecast model is established considering the local heat island effect.

A model for revealing the relationship of the energy-saving temperature to heat supply in function of weather conditions is then developed, based on thermodynamic and meteorological principles, and the energy-saving indices are established.

Finally, a management system that incorporates heat supply monitoring and weather forecasting is established; respective operational platforms are created at relevant meteorological offices for producing one to three-day weather forecast and energy-saving temperature and heat-supply indices, and weather information application terminals are installed at heat suppliers. This will constitute a complete meteorological forecast system for winter heating sectors in Beijing, which will provide professional services for energy saving from heat supplies.

Applications by heat suppliers

At the application terminals, the forecasts continue to be updated every 12 hours, including diurnal air temperatures (daytime and night time means, maximum, minimum and daily means), heat-supply related weather indices, thermal parameter forecasts, indoor and outdoor temperatures as well as temperatures of both inflow and outflow water for the next one to three days. With this information, in particular the temperature of the water cycle for the next few days, heat supply managers will be in a better position to calculate the total heat supply capacity needed for a specific day, to adjust the temperature of supplied water, and to anticipate the amount of fuel to be used. This will improve heating quality, energy-saving efficiency and pollution reduction.

Medium- and long-range forecasts and three to five-day forecasts for both the beginning and end of a heating season will facilitate proper arrangements of fuel procurement and storage, which helps to maximize capital use.

Assessment of the benefits of meteorological services for heat supply

Assessments and analysis of the benefits of meteorological services from energy saving in various heat suppliers, indicate the following:

Meteorological Services can improve the energy efficiency of the heat supply. Weather monitoring and forecasts provide scientific guidance for the heating industry at both the macro and micro levels. It is helpful to carry out heating operations in a more targeted and timely manner, and to achieve the best heating efficiency in a most cost-effective fashion.

Apart from the temperature, wind speed, humidity, solar radiation, cloud cover and precipitation, other meteorological elements also have an impact on the heat supply. The meteorological offices need to develop forecasts about additional meteorological elements in order to achieve greater benefits for energy-efficient heating.

As heat supply is a weather-sensitive sector, not only are nowcasting and short-term weather forecasts useful for decision-makers in the heating sector, but medium- and long-range forecasts are also playing an increasing role along with the development of forecasting capabilities.

Due to urban heat island effects and the different underlying impacts, the existing forecasts by zone and the 24-hour mean temperature forecast in the forthcoming one to three days does not satisfy the actual demands for different zones during heat supply season. With the rise of living standards and social-economic development, there is an imperative need for more refined and specific meteorological services.

Suggestions for improving meteorological services for energy-saving heat supply

Enhance communication with end users — meteorological information itself does not create values. Only its application by the users can achieve significant socio-economic benefits. Therefore, meteorological offices should proactively communicate with users, investigating their changing needs in order to provide targeted meteorological information that meets their demands.

Providing further guidance to users on the use of meteorological information — meteorological services yield added value when users are fully utilizing them while avoiding their potential risks. It is also vital that users know when such information is disseminated. Therefore, meteorological offices should have a clear understanding as to how users apply meteorological information and provide them with guidance in their practical decision-making process.

Enhance the combination of scientific research with operational applications — including faster transfer of scientific research to operations. Market-oriented demands and service-oriented products imply that meteorological services have tremendous economic potential for the heat supply industry. However, the simplicity of existing meteorological information can no longer meet user needs, and current service products remain inadequate in terms of their depth, comprehensiveness, refinement and flexibility. Personalized weather information can yield benefits only after this information is processed and analysed according to user requirements.

Meteorological Services bring about tremendous benefits for energy saving in the heating sector. Regardless of the fuel used for heating — be it coal, electricity or natural gas — the heating industry consumes energy. According to 2001 statistics, the application of meteorological services to heat supply could save three to five per cent of the energy consumed. Based on an average saving of four per cent, CNY 144 million can be saved in Beijing in terms of expenditure on energy consumption every year, while the ecological and environmental benefits can be significantly increased.

In addition, there is considerable market potential for special meteorological services. Although only a few large heating corporations currently take full advantage of the meteorological forecast, there will be growing demand for meteorological information from various sectors. Meteorological offices will play an increasingly important role in various national economic sectors. In the rapid socio-economic development process, and with improved meteorological offices, the general public has an increasingly greater awareness about risks and they will increasingly depend on meteorological information. In particular, some weather-sensitive companies have realized that if they want to remain well placed in the competitive market, they should attach greater importance to meteorological information.

The effect of climate change on glaciers and hydropower in Iceland

Tómas Jóhannesson, Icelandic Meteorological Office
Árni Snorrason, Hydrological Service Division, National Energy Authority

Energy production in Iceland is primarily from renewable sources. The primary energy supply is made up of 55 per cent geothermal, 16 per cent hydropower and 29 per cent fossil fuels. About 81 per cent of the production of electricity is from hydropower. Hydropower is highly dependent on runoff from ice caps and glaciers, which cover about 11 per cent of Iceland and receive about 20 per cent of the precipitation that falls on the country. They store, in the form of ice, the equivalent of 15–20 years of annual average precipitation over the whole country. Substantial changes in the volume of glacier ice may, therefore, lead to large changes in the hydrology of glacial rivers, with important implications for the hydropower industry and other water users. Glacial runoff is particularly important for the hydropower industry because hydropower plants use runoff from highland areas, where glaciers tend to be located.

The consequences of climate change for the Nordic Energy sector, in particular for the use of renewable energy sources, have been investigated in several collaborative Nordic research projects, the most recent of which is Climate and Energy (CE), which was financed by Nordic Energy Research under the Nordic Council of Ministers. The main national hydrological and meteorological institutes in the Nordic countries have in these projects joined forces with the energy industry to assess the impact of climate change on the energy system and to advise the industry regarding adaptation to long term changes in climate and water resources. This paper describes the main results of glaciological investigations within the CE project with emphasis on implications for the hydropower industry in Iceland.[1]

Role of glaciers

The effect of climate warming on glacial runoff includes an initial increase in total runoff and peak flows, and a considerable amplification in the diurnal runoff oscillation, followed by significantly reduced runoff totals and diurnal amplitudes as the glaciers retreat. In addition to the direct effect on runoff caused by glacier mass balance changes due to variations in climate, feedback effects caused by glacier dynamics may lead to migration of ice divides, sub glacial watersheds and changes in sub glacial water courses. This can in some cases cause very large relative changes in the discharge of rivers that comes from glacier margins, with implications for bridges, roads and other infrastructure.

Photo: Kjøllmoen, 2006

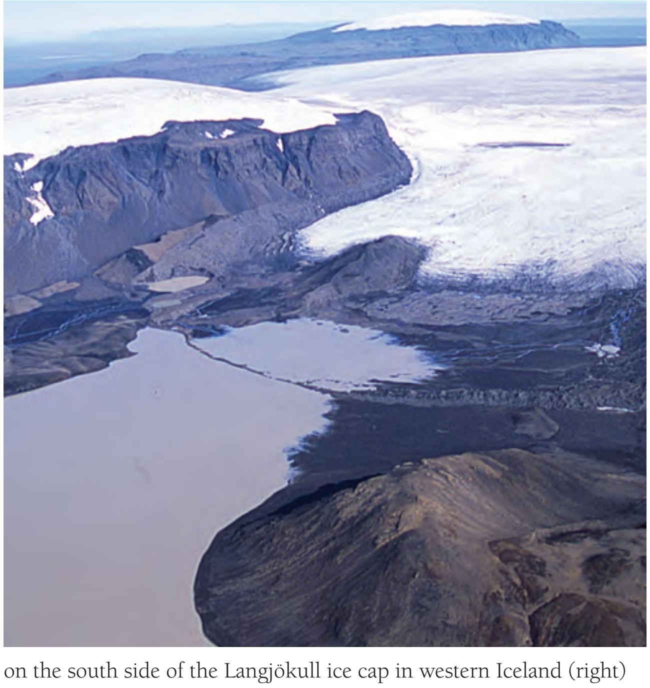


Photo: Oddur Sigurðsson, 2003

The forefields of Brikdalsbreen in western Norway (left) and an outlet glacier on the south side of the Langjökull ice cap in western Iceland (right) show clear signs of past changes in the position of the glacier margin

Glaciers and ice caps in the Nordic countries have retreated and advanced during historical times in response to climate changes, which are believed to have been much smaller than the greenhouse-induced climate changes that are expected during the next 100–200 years. These changes have in many cases left clear marks on the landscape in the neighbourhood of the glaciers.

Simulated changes in ice volume and glacial runoff

Several ice caps and glaciers in the Nordic countries were studied within the CE project using mass balance and dynamic models to project future changes in ice volume and glacial runoff based on scenarios for future climate change.

In simulated ice wastage for the modelled glaciers, simulations with a 2D ice flow model are run to 2200, but the Norwegian and Swedish glaciers are only run to 2100 because of limitations in a simplified dynamic model used for these glaciers. The time evolution of ice volume has a similar character for the modelled glaciers, except for Engabreen in Norway and Mårmaglaciären in Sweden. The modelled ice volume is reduced by more than half within the next 100 years, and the glaciers essentially disappear in 100–200 years after the start of the simulations, given that the rate of warming with time remains the same. One of the Norwegian glaciers retreats more slowly because of a substantial increase in precipitation, which is projected by the CE scenario for the area where this glacier is located.

The projected change in the mass balance of the glaciers leads to a marked increase in runoff from the area covered by ice at the start of the simulations. Due to the large amplitude of the projected changes, the changes with respect to the runoff at the start of the simulations are similar to changes with respect to a 1961–1990 baseline, which was not explicitly modelled for most of the glaciers. By around 2030, annual average runoff is projected to have increased by approximately 0.4–0.7 m$^{w.e.}$.a^{-1} for the Norwegian and Swedish glaciers, and 1.5–2.5 m$^{w.e.}$.a^{-1} for the Icelandic ice caps. The runoff increase reaches a comparatively flat maximum between 2025 and 2075 (except for Engabreen in Norway) when the increasing contribution from the negative mass balance is nearly balanced by the counteracting effect due to the diminishing area of the glacier. For all the glaciers, this maximum in relative runoff increase is over 50 per cent with respect to the current runoff from the area presently covered with ice.

For the Icelandic ice caps, the specification of a comparatively large change in climate during the initial decades of the simulation, based on the observed climate of recent years, and the seasonality of the climate change with the largest warming in spring and fall, leads to a rapid increase in runoff with time. The simulated runoff changes may be compared to average runoff from these ice caps between 1981 and 2000, which is in the range 2.4–4.1 m$^{w.e.}$.a^{-1}. In model results for Engabreen in Norway, although the precipitation increase for the other glaciers is of much smaller importance than the temperature change, the assumed precipitation change can significantly alter the simulation results in cases where substantial precipitation changes take place. The fact that this only happens for one of the glaciers highlights the uncertainty of the climate change scenario.

These results clearly suggest large changes in runoff from glaciated areas, which are projected to have reached quite

Image: Fenger (2007)

Location of the the glaciers and ice caps studied in the CE project

significant levels compared with current runoff, well before 2030. The associated changes that may be expected in diurnal and seasonal characteristics of glacial runoff will come on top of the changes in the annual average.

Hydropower is the most important renewable source of electricity in Iceland and it is the renewable energy source most strongly affected by climate. The results from the CE project and the related national research programmes show that this impact can be quite strong. Global warming will shorten the winter season, make it less stable and lengthen the ablation season on glaciers and ice caps. This leads to a more evenly distributed river flow over the year, which is a profitable situation for the industry.

There is also potential for increased hydropower production as the highest modelled increase in river flow is simulated in highland areas that are most important for hydropower. This implies that the projected hydrological changes may be expected to have practical implications for the design and operation of many hydroelectric power plants, and also for other use of water, especially from glaciated highland areas.

One negative aspect is that the new annual rhythm in runoff indicated in the simulations will put more stress on the spillways. They will probably have to be operated more often in winter, as the unstable winter climate will generate more frequent sudden inflows when reservoirs may be full. This will also have an impact on the infrastructure with more frequent flooding problems downstream at the reservoirs. These areas are normally adapted to the present-day climate with stable winters and without high flows from autumn to spring.

In summary, the power industry needs to develop a new strategy characterized by flexibility because it must be possible to adapt the operation and even the design of power plants as climate change leads to changes in the discharge and seasonality and other hydrological characteristics. Continued research on climate change is essential to address the added uncertainty with which the industry is faced due to this situation and in order to supply the necessary information for proper adaptation to the evolving climate.

Aviation meteorological services: pioneers in supporting decision making for safe, efficient and economic air transport

Dr Herbert Puempel, World Meteorological Organization Secretariat

In 1903 Wilbur and Orville Wright, brothers with a passion for aeronautics, wrote to the weather bureau at Kitty Hawk, North Carolina, to ask for guidance on winds and conditions at the site that they had chosen for the first powered flight. It was the first step in a long-standing relationship between meteorology and aviation.

Aviation was perhaps the first industry with a formal decision-making process based on weather information. The effective decisions of air crews, operations control and dispatch departments of airlines all use current and forecast weather conditions to calculate the required amount of fuel, the necessary safety measures such as ground de-icing, and even the appropriate time to serve meals considering predicted periods of turbulence.

Aviation safety and weather information

Aviation has come a long way since the days of spruce-built single-engine flying machines, but to this day a significant proportion of aircraft accidents, particularly in general aviation, involve weather conditions as a major contributing factor in the causal chain. Even major jet-propelled airliners are still at risk from phenomena such as thunderstorms and hail; wind shear and turbulence, severe in-flight or ground icing (the last crash landing of a jet airliner due to icing happened only two years ago). Even though complete losses of aircraft have become very rare due to weather causes alone, hundreds of passengers suffer injuries during incidents of severe turbulence, particularly if they ignore the recommendation to wear a seatbelt at all times. Also the

The de-icing of an aircraft at Innsbruck Airport, Austria

Photo: Armin Stotter, Head of Passenger Services, Tiroler Flugahfen Ges., Innsbruck, Austria serious stress on pilots in severe weather has contributed to fatal pilot errors.

Advance warnings of serious weather hazards are provided during flight planning, in the form of charts of significant weather, depicting critical areas to warn crews in good time of expected turbulence or convection. Proper estimation of both the required flight time and the conditions expected at the terminal aerodrome are used to enable calculation of the required amount of fuel, including a safety margin in case of unexpected problems.

New challenges to aviation weather provision arise from the non-linear dependence of acceptance rates at major hub airports on extreme forms of weather. Here, passing thresholds that are difficult to define a priori lead to a breakdown of air traffic in areas around the aerodrome affected by severe, widespread convection or massive snowfalls. New products for advanced planning are currently being developed by individual aviation weather service providers, but international coherence and coordination of such procedures will be necessary to avoid economic losses and delays to the travelling public.

Aircrews in flight are alerted by significant meteorological information (SIGMET) and airmen's meteorological information (AIRMET) messages transmitted to the aircraft by uplinking or voice communication. In addition, new forms of digital communication such as automatic dependent surveillance broadcast (ADS-B) permit rapid, unambiguous and targeted information on critical situations. These systems contribute to making airline flights the safest way of travelling in terms of passenger deaths per mile travelled. The procedures to be adhered to by all stakeholders are defined very precisely by the International Civil Aviation Organization (ICAO) in close cooperation with the World Meteorological Organization (WMO), with safety and security taking first priority.

Economy and regularity of aviation operations under ICAO and national aviation authorities

Aviation, in terms of passenger miles flown per year, has shown a robust growth of an average five to seven per cent over the past 30 years. Short downturns following world crises such as oil shortages, terrorist attacks and epidemics such as severe acute respiratory syndrome (SARS) and Avian Influenza have typically been compensated for by increased growth during subsequent years. Growth rates of aviation are typically linked to the speed and strength of economic growth, as can be currently seen in East Asia, where growth rates in double figures are now common, and aircraft are purchased at the rate of around one per day. Despite these healthy growth rates, the economics of scheduled aviation are far from easy, with capacity often running ahead of demand, leading to a serious price war. This fierce competition leads to a very detailed scrutiny of all external costs to the airlines. Service providers, from airports and air navigation services to aeronautical meteorologists, are asked to prove a positive cost-to-benefit ratio.

The growth of aviation in many areas of the world is now limited by the acceptance capacity of airports, which is strongly linked to prevailing weather conditions. These acceptance rates may be reduced to less than half in conditions of low visibility, cloud-ceiling height, thunderstorms, or with snowfall and icing. Several studies undertaken in the US and Europe have shown a direct link between weather and air traffic delays, leading to costs of millions of US dollars or euros for a single large airport on a day affected by severe weather conditions. Although it is difficult to specify exactly what percentage of theses losses could be avoided with the aid of accurate and reliable weather information, it is safe to say that the potential benefits far outweigh the costs for the provision of these services.

All services to the aviation industry have to be provided under the regulations given in the annexes of the ICAO convention, and are subject to approval and directions by the national or, as in the case of the emerging Single European Sky, trans-national aviation authorities. These regulations are beginning to have an impact on the nature of service delivery — enforcing, for example, the implementation of quality management systems, accountability and regional harmonization of procedures. It is expected that these regulations will further contribute to a restructuring of service provisions on the national and international level.

Aviation and the environment

Increasing concern about the effects of aviation on global climate change is becoming apparent from Intergovernmental Panel on Climate Change (IPCC) assessment reports. Concerns regarding local air quality are also beginning to affect planning permission for extensions of existing hub airports in the vicinity of megacities. Not only is the contribution of aviation to levels of carbon dioxide and nitrous oxides considered, but also the radiative forcing from aviation contrails and cirrus clouds, particularly at night, where they have a clear warming impact. It is expected that the inclusion of aviation in national inventories will be debated in future meetings of the United Nations Framework Convention on Climate Change (UNFCCC), Conference of Parties, and other relevant bodies. Aviation meteorology may be able to contribute to mitigating measures, for example by identifying dry layers unlikely to produce contrails and cirrus clouds, and to issues of local air quality by determining and forecasting episodes of high concentrations of pollutants that could be used in advance traffic planning.

User-provider cooperation and information transfer

Though it is clear that the potential savings based on accurate weather information are very large, the devil is, as always, in the detail. Even a perfect weather forecast has no economic value if it is not used properly in the decision-making process. The formal requirements established by regulatory authorities (national and international) were designed with safety as the first priority, and their universal application in all states, independent of technological development, makes them a very slowly reacting tool for economic decisions. The lack of precise statistical data on the reliability of the forecasts, which is in part due to antiquated code forms and product specifications, makes it difficult to use the information in an optimal statistical manner. Decision making in a typical cost-loss situation requires the full spectrum of probabilities for all event categories, and full knowledge of the verification characteristics of all forecast and warning products. In the context of its Aeronautical Meteorology Programme, WMO in close cooperation with ICAO, will address this issue over the coming years as a matter of priority to ensure that services to aviation continue to be a good investment and are viewed by the industry as such.

WMO and ICAO: working together for international air navigation

OM Turpeinen, International Civil Aviation Organization Secretariat[1]

Meteorological information plays an essential role in air navigation and is required to ensure the safety and efficiency of civil aviation operations. Most people working in the aviation industry or meteorology are familiar with the effects of hazardous weather phenomena on flights. Pilots, dispatchers and air traffic controllers need observations, reports and forecasts as well as warnings of such phenomena. What is often less clear is the important effect that seemingly 'innocent' meteorological elements (such as surface and upper winds, visibility and runway visual range, temperatures and surface pressure) can have on the safety and efficiency of flight operations.

Information on wind direction and speed is vital for take-off and landing, and is the basis for the choice of runway. If the head or tailwind component and the crosswind components are made available separately, the length of runway needed can be determined. One can also ascertain whether the crosswind component falls within the design limits of individual aircraft. For the en route phase of flight, information is required on winds along the route at cruising levels. Strong headwinds mean that more fuel must be carried at the expense of passengers or freight.

Pilots need to know what the temperature will be at their flight level because temperature affects jet engine efficiency. The same applies during take-off: a higher temperature results in a longer take-off run because temperature affects air density. Temperature affects the lift at a given speed and hence also the take-off run. Similarly, atmospheric pressure affects the take-off run due to its relationship with air density.

The surface wind, temperature and pressure referred to above have to be accounted for in pre-flight calculations for the take-off run. The provision of accurate and timely information on these meteorological elements helps ensure the safety of flight and also improves the efficiency of airline operations.

Information on visibility and runway visual range is of critical importance as landing and take-off minima are determined on the basis of these elements, and precision approach operations cannot take place without them. Furthermore, the height of the cloud base is highly useful

A higher temperature results in a longer take-off run because temperature affects air density when assessing whether the prevailing conditions are above the landing and take-off minima and whether the pilot is in a position to establish the required visual reference at the decision altitude.

With regard to hazardous weather phenomena for take-off or landing, pilots need to be warned of the existence or forecast of fog, snowstorms, wind shear, tropical cyclones, etc. During the flight, pilots need to know whether they are likely to encounter severe thunderstorms involving hail, severe turbulence, icing or volcanic ash to enable them to avoid these hazardous phenomena. Thunderstorms are notorious for extreme up- and downdraughts, and the associated turbulence can easily exceed the structural limits of the aircraft. Moreover, thunderstorms are particularly dangerous in the vicinity of aerodromes as the associated downdraughts can cause aircraft to sink below the glide path. This may mean that the aircraft could strike an obstacle or the ground before it can regain its flight path.

Explosive volcanic eruptions produce clouds of dense ash that can reach into the stratosphere. When the ash is ingested into aircraft jet engines, these are severely damaged and may flame out completely, as has happened on at least three occasions. This is a serious hazard to aviation and has been addressed over the last few years by the International Civil Aviation Organization (ICAO), in coordination with WMO.

WMO and ICAO working arrangements

In order to meet the needs of international civil aviation in an efficient manner, it is important that ICAO and WMO work closely together and ensure that stated aviation requirements can be met without any unnecessary overlap of activities. This has been recognized from the early days of aviation, and working arrangements between WMO and ICAO were established as early as 1953.[2] These arrangements can be summarized as follows:

- ICAO is responsible for defining aeronautical meteorological requirements
- WMO is responsible for defining the most appropriate methods for fulfilling the requirements, including the training of aeronautical meteorological personnel.

It is important to note that the dissemination of operational meteorological (OPMET) data is the prerogative of ICAO and that the planning for such dissemination is undertaken by it. Furthermore, the provisions in Annex 3/Technical Regulations [C.3.1] stipulate that the ICAO aeronautical fixed service should be used for the dissemination of such information.

One constant challenge is to ensure that the work is carried out in an efficient and cost-effective manner. To this end, proper coordination between the two organizations has to be constantly maintained with full consultation and cooperation at every stage of the process. This coordination is also achieved by the systematic participation of WMO in the work of ICAO operations and study groups, and of ICAO in the work of the relevant WMO technical commissions. This ensures that:

- No aviation requirement is generated that is impossible to fulfil
- No methodology is developed for a requirement that is not foreseen to exist
- Both organizations continue to operate according to the working arrangements, to avoid the duplication of effort and redundancy of services and facilities established for international civil aviation by their respective members.

The meteorological requirements for international air navigation are laid out in Annex 3 – 'Meteorological service for international air navigation to the Convention on International Civil Aviation'.[3]

The various chapters of Annex 3/Technical Regulations [C.3.1] outline the overall responsibilities of the designated meteorological authority for the provision of services and facilities for international air navigation. The associated appendices provide detailed specifications for use by those actually providing these services. The areas covered include aerodrome observations and forecasts; warnings (both in the terminal area and en route); forecasts for en route issued by the World Area Forecast Centres (WAFC) in London and Washington; advisories for volcanic ash and tropical cyclones; air reporting; needs for meteorological information by air traffic service units and communications requirements.

A number of other documents are issued as guidance material by ICAO and WMO in order to provide ICAO Contracting States and WMO members with additional information to assist them in implementing the provisions contained in Annex 3.[4]

In accordance with the working arrangements between the two organizations, major amendments to Annex 3 are developed by conjoint ICAO/WMO meetings. Between meetings, most of the proposed amendments are developed by the ICAO Secretariat with the assistance of ICAO operations and study groups. These are composed of experts nominated by states and international organizations, including WMO. Currently, there are six such groups working on the World Area Forecast System, satellite distribution system for information relating to air navigation (SADIS), international airways volcano watch, wind shear, automatic meteorological observing systems and the use of data link for the uplink and downlink of meteorological information. All draft amendments developed by these groups are sent for consultation to ICAO Contracting States and WMO Members before being submitted for adoption by the ICAO Council and approval by the WMO Executive Council.

In accordance with the working arrangements, through the WMO Commission for Aeronautical Meteorology (CAeM) which is responsible for implementing the WMO Aeronautical Meteorology Programme (AeMP), WMO is responsible for training meteorological personnel and for specifying the technical methods and practices to be used for the provision of meteorological services to international air navigation.

CAeM has established expert teams to deal with training, improvements to forecasts in the terminal area, quality management, customer focus and cost recovery. The Commission is also involved in the Aircraft Meteorological Data Relay (AMDAR) programme and in studies related to the impact of aviation on the global atmospheric environment. In order to ensure that the needs of aviation users are fully addressed, representatives of ICAO, the International Air Transport Association (IATA) and the International Federation of Air Line Pilots Associations are invited to participate in meetings of CAeM. Furthermore, in 2004, WMO and IATA established focal points between the two organizations to facilitate frequent contacts followed by similar arrangements with EUROCONTROL in 2005. This was prompted by the increased involvement of that organization in activities related to the newly established Single European Sky.

In addition, the WMO Commission for Basic Systems (CBS) is actively involved in ensuring the timely availability of basic meteorological data on which aviation weather forecasts are based. In this regard, the contribution of the AMDAR programme to the availability of timely and accurate upper-air observations at various forecasting centres, including the two WAFCs, has resulted in positive impacts on aviation forecast accuracy.

CBS is also responsible for developing and updating the aeronautical meteorological codes used to disseminate meteorological aviation information. In this context, any new or updated aeronautical requirements included in ICAO Annex 3 are subsequently reflected in the WMO Manual on Codes[5] following approval by CBS. ICAO is also interested in the emergency response activities of CBS, in particular the Comprehensive Nuclear Test Ban Treaty Organization/WMO Emergency Response Activities. The potential usefulness of monitoring information for the early detection of explosive volcano eruptions could serve as an early indication of the possible presence of airborne volcanic ash that is a serious threat to flight safety.

The contribution of the WMO Commission for Instruments and Methods of Observations (CIMO) is essential for ensuring that the latest information concerning the capability of automatic meteorological observing systems are forwarded to ICAO for the development of future requirements. The Commission for Atmospheric Sciences (CAS), through its World Weather Research Programme, is accelerating research on the prediction of high-impact weather and encouraging the use of advances in weather prediction systems to the benefit of all WMO programmes including the AeMP.

WMO is responsible for the training and qualification of personnel providing meteorological services for international air navigation. In this regard, guidelines for the education and training of personnel in aeronautical meteorology, as well as relevant training material, are developed by the WMO Education and Training Programme (ETR) in close collaboration with relevant CAeM structures and the active involvement of ICAO. This collaborative effort is expected to be actively pursued in the future.

Key challenges to the meteorological community for ensuring the continued availability of good-quality, timely and cost-effective meteorological service to aviation include the need for ensuring the sustainability of the WMO World Weather Watch programme that provides the basic data, data processing, transmission and forecasting on which meteorological services to aviation are based; increased automation of aerodrome meteorological observing systems; and improved terminal forecasts. Capacity building needs to be enhanced to ensure that aeronautical meteorologists, particularly those in developing countries, are abreast of new technologies and adequately trained.

Other challenges include increased reliance on the recovery of meteorological service costs from the aviation industry to fund aeronautical meteorological activities and meteorological infrastructure, particularly in view of a noted trend toward the disengagement of states from fully funding the traditional providers of service to aviation, namely National Meteorological Services (NMS). This tendency has resulted in the increased use of alternative service delivery for aeronautical meteorological services, including the commercialization of some of these services and, increasingly, the establishment of fully autonomous national meteorological entities.

Continued closer contacts with aviation users and their representative organizations at the global, regional and national levels are particularly important to ensuring that the services provided meet users' needs and that users understand the existing capabilities and limitations of such providers to deliver the required services to the aviation industry. In view of the financial difficulties being experienced by a number of airlines, due in part to increased expenditure on fuel, and other constraints such as more competition among air carriers, the airline industry is more than ever before insisting on the transparency of charges paid to air navigation service providers.

The airlines have developed strict procedures for the use of meteorological information to improve safety and cost effectiveness, based on a thorough evaluation of the value and limitations of meteorological observations and forecasts. With continuing aviation growth and demands for safety, efficiency and capacity, airlines and air-traffic management organizations are more than ever dependent on weather information for planning and safety. Future challenges will be for meteorological service providers to exploit the increasing availability of information and relevant detail in predictions from numerical models to improve the accuracy, content and relevance of the information provided to the aviation industry.

Future perspectives

The future requirements for aeronautical meteorology are expected to reflect technological developments which will allow more efficient methods of production and dissemination of meteorological information. The recent investments in research by the two WAFCs are expected to result in their ability to produce gridded forecasts of turbulence, icing and convective clouds. Conceivably, in the future, these forecasts will replace the current significant weather information. Gridded forecasts will provide aviation users with more accurate information at the pre-flight planning stage and that the production of such forecasts will be more efficient and will, ultimately, be fully automated.

One of the most important anticipated developments over the next few years will be the introduction of table-driven codes (principally BUFR) for METAR/SPECI and TAF. The current communications infrastructure operated by ICAO is not able to cope with such digital codes. A careful planning process for this migration at the global, regional and national levels will therefore be necessary. The intention is that the migration will be completed globally by 2015.

Requirements for meteorological information in support of the ICAO air traffic management (ATM) concept are expected to be developed by a number of ICAO initiatives over the next few years. The purpose of the ATM systems is the optimization of the use of airspace. In this context, it is expected that new requirements will be formulated for meteorological information. Work in this area will involve close coordination with the relevant Air Traffic Services authorities, and it is expected that specific proposals by ATM and meteorological experts will be developed by ICAO in close coordination with WMO.

EUROCONTROL and the Single European Sky

Since 2001, air traffic management in the European Union (EU) has been undertaken by member states cooperating through EUROCONTROL, an intergovernmental organization comprising EU member states and most other European States.

The Single European Sky initiative is intended to organize airspace and air navigation at a European rather than at a local level. It will organize this airspace uniformly, with air traffic control areas based on operational efficiency, not national borders, integrating civil and military air traffic management.

Airlines and weather

Adriaan Meijer, International Air Transport Association

Flying means taking an aeroplane into the air - the air is an environment with very specific characteristics that has to be treated with respect. Many natural disasters are weather related. Be it a thunderstorm, a hurricane, heavy or freezing rain, all these events can have serious consequences if not handled properly.

Aviation and weather are intimately related. In between 15 and 20 per cent of all aviation accidents, weather is a factor. This highlights the importance of correct weather information for a safe flight.

Over the years, weather information has improved dramatically. Accurate weather forecasts are extremely important for a safe and efficient flight. Both National Meteorological Services (NMS) and private weather service providers, whether these are private companies or airline meteorological departments, continue to work towards improving the performance of their prediction models and services. The implications of these improvements are not limited to airlines and air travel — indeed, the aviation industry is itself involved in providing vital meteorological data, and the benefits stretch far and wide.

Airlines as end users

Airlines need accurate weather information and predictions in order to plan flight schedules efficiently and ensure passenger safety. Both the safety and operating efficiency of aircraft are greatly affected by the accuracy of meteorological forecasting. But weather services also have a significant environmental impact — as airlines strive to limit emissions and minimize the environmental effects of air travel, better flight planning can help keep fuel usage, as well as costs, to a minimum.

The World Area Forecast System (WAFS) is responsible for providing basic, essential meteorological products to the aviation community in a cost-effective manner, through a comprehensive, integrated and consistent worldwide system. There are two World Area Forecast Centres (WAFC), one based at the UK Met Office and one at the US National Oceanic and Atmospheric Administration in Washington and Kansas City (the National Weather Service's Aviation Weather Center). The WAFCs provide global significant weather, wind and temperature forecasts, and a suite of OPMET data. Each works to support and back up the other in providing real-time meteorological information broadcasts for aviation purposes. Both the London and Washington WAFCs have studied possible failure scenarios in their WAFS operations, and each centre is able to replace the other in the event of a failure, ensuring that there is no break in the provision of these crucial services.

Each WAFC operates its own satellite-based broadcast system to distribute data to airports across the world for pilot briefings. The UK Met Office's Satellite Distribution System (SADIS) primarily covers Europe, Asia, the Indian Ocean and Africa, while NOAA's International Satellite Communications System (ISCS) mainly covers America, the Atlantic and the Pacific Oceans. WAFC broadcasts are supervised by the International Civil Aviation Organization (ICAO) under the requirements of ICAO Annex 3, which concerns meteorological information for international air navigation.

Both WAFCs continually strive to improve the performance of their numerical prediction models of upper air wind and temperatures. The graph below shows WAFC London forecasts of winds at 250 hectopascals (hPa), flight level (FL) 340. It indicates that forecasts of winds at 250hPa (FL340) have improved in accuracy by around 20 per cent over the northern hemisphere in the past six years.

This can be attributed to higher resolution models (WAFC London's global model now has a horizontal resolution of 40 kilometres); better model physics, and an increased density of observations both from aircraft and satellites.

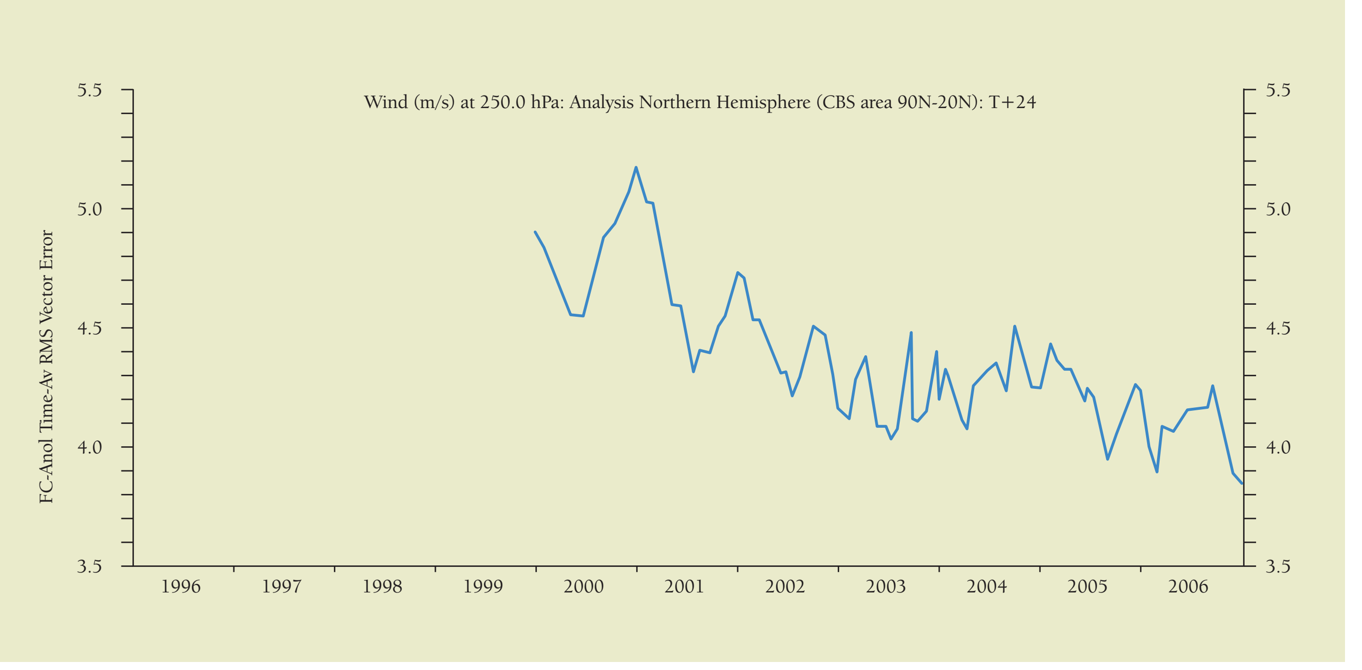
The net result is that forecasts of flight durations for long-haul flights are typically within a few minutes accuracy. Adverse weather can lead to much greater delays en route (for example thunderstorms and turbulence) and within the terminal area. It is the aspects of weather forecasting of the latter where the greatest environmental benefits can be made in the coming years. By working more closely with Air Traffic Management authorities, National Meteorological Services can provide timelier, more accurate and more detailed weather information up to 24 hours in advance, and this will provide the greatest gains in terms of improved capacity and fuel savings in the future.

While aviation meteorology focuses on mitigating the effect of hazardous weather on passengers and operations, the environmental record of the aviation industry is coming under increasing scrutiny. Air transport represents 2 per cent of global carbon emissions, but airlines are working hard to limit this. Airlines are continuously modernizing their fleets, and one of the effects of this is a reduction in fuel burn for the same payload. For example, at one US air carrier, a switch from DC10 to A330 aircraft has reduced fuel burn for the same payload by over 30 per cent — in other words, 30 per cent less carbon dioxide is being left in the atmosphere for the same number of passengers. Overall fuel efficiency has improved 10 per cent over the past five years. The new generation of aircraft such as the Airbus A380 will have a fuel consumption of less than three litres per 100 passenger kilometres, lower even than a hybrid car.

Airlines as information providers

However, limiting emissions is not the only benefit from improvements in aircraft technology. While the role of satellite technology in weather monitoring is fairly well-known (satel-

WAFC London wind forecasts



Source: http://www.metoffice.gov.uk/icao/wind/nhemi.html

lite pictures have been featured in television weather reports for some years now) the role of aircraft in providing weather information is perhaps less familiar.

For an accurate weather forecast, no matter what its purpose, information about the air movement and temperature, and increasingly humidity, at various altitudes is critical. Without such information, no accurate weather forecast can be provided. The only reliable information about these events is collected and transmitted by aircraft crossing vertically and horizontally through these layers of air. In this way, more accurate information is delivered enabling forecasters to more precisely do their work.

The aviation industry funds and provides a significant amount of crucial meteorological data. Two programmes in particular provide millions of observations for use in the global model, which is used not only for near-time forecasting but also to help establish a baseline for climate models, due to its understanding of how the atmosphere works. In addition, the climate community uses surface observations from the aviation community to establish a baseline.

MDCRS and AMDAR

Over recent years it has become evident that significant valuable meteorological data can be obtained from large areas of the world by collecting data from aircraft. The Meteorological Data Collection and Reporting System (MDCRS) and the Aircraft Meteorological Data Reporting (AMDAR) system are designed to support improved weather forecasting, particularly for upper-air wind and severe weather. Both systems work to feed information to their respective homeland WAFC, in the US for MDCRS and Europe for AMDAR.

The systems collect and organize up to 28,000 real-time, automated position and weather reports per day from the aircraft of participating airlines. The data are then forwarded to the relevant WAFC where it is used as input for the global forecast model.

By helping forecasters to more accurately predict winds aloft and areas of severe weather, the system contributes to better flight planning, greater safety for aircraft, passengers and crew, and industry cost savings.

Funded by the aviation industry, the benefits of these systems stretch far beyond this in terms of meteorological forecasting and the climate. It is making an increasingly important contribution to the observational database of the WMO's World Weather Watch (WWW), and the data they supply is expected to supersede manual air reporting.

In recent years the numerical weather prediction community's requirement for capturing substantial amounts of automatic meteorological data from aircraft has continued to grow, necessitating further investigation into ways of capturing this data. As a result, several national AMDAR programmes have been set up, some of which are operational and some still in the planning stage.

Far-reaching benefits

While airlines clearly stand to benefit economically from increasingly accurate weather forecasts, they also make a significant contribution to them. In addition, the benefits stretch far beyond the world of commerce and air travel. Better, more accurate meteorological information can enable more accurate predictions of weather phenomena, such as the course and intensity of hurricanes, the type of winter precipitation expected and the severity of thunderstorms. Thus, it enables better, more timely and accurate warnings of dangerous weather events, and helps to save lives. In the event of a disaster, the same services contribute vital information for the planning and execution of rescue and aid operations.

The relations between aircraft and their natural environment, the air, will remain challenging. Aircraft will continue to fly through the air. They will increasingly provide real-time feedback to the ground about the quality of the layers of air they are crossing. Doing so provides increasingly more accurate weather prediction possibilities. This enables more safe and more efficient flights and provides the world with a better weather predicting capability in general.

Applications of weather and climate information in road transportation: examples from Canada

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Jean Andrey, Department of Geography, University of Waterloo

As is the case with many nations, Canadian economic and social activities are highly dependent on road surface transportation. In 2002, trucks carried 63 per cent of the CAD531 billion worth of goods traded with the United States.[1] According to the Canadian Vehicle Survey, Canada's 17.3 million light vehicles generated over 500 billion passenger-kilometres worth of travel in 2000.[2] The mobility and wealth derived from road transportation is possible through large investments by local, provincial/territorial and federal government agencies — over CAD14 billion was spent in 2002-2003 on road infrastructure alone.[3] Protecting and maintaining this asset to ensure the safe and efficient movement of people, goods and services is a primary objective of public road authorities. Significantly, this asset is one that is sensitive to weather and climate variability.[4]

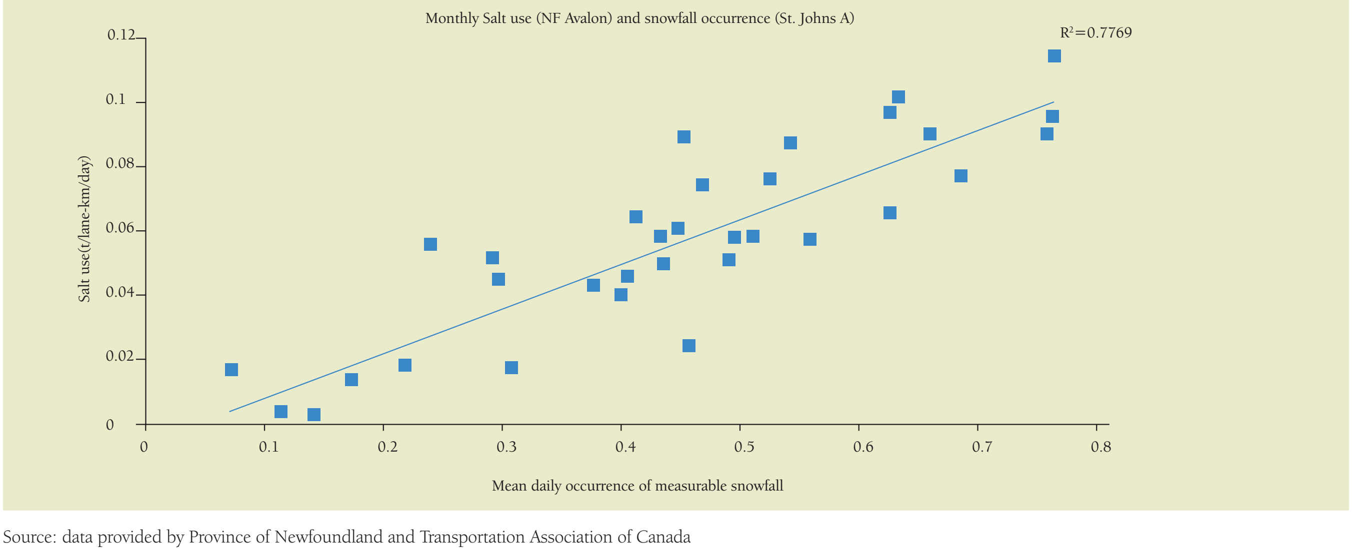
Many of the weather and climate information products and services provided by Environment Canada are oriented towards users in the road transportation sector. This includes the driving public, trucking industry and authorities responsible for designing, constructing, operating and maintaining highway infrastructure. The services encapsulate routine public weather forecasts; severe weather watches, advisories and warnings, along with a variety of climatological products. There follows a description of some of the weather service needs pertaining to winter maintenance operations, infrastructure design and maintenance, and road safety.

Winter road maintenance

The most significant application is the provision of road weather modelling and forecast services in support of winter maintenance operations conducted or funded by provincial and municipal government agencies.[5] These agencies must balance the need to maintain safe road conditions without excessive costs or use of road salts, which have been shown to damage surrounding environments[6] — provincial and municipal agencies spent and estimated CAD1.3 billion in 2003 on winter maintenance activities,[7] and an estimated 4.5 million tonnes of road salt are applied to Canadian roads each year.[8]

In 2005, after several years of road weather model development and application, these technologies and services were made available to the private sector meteorological community. While Environment Canada no longer conducts operational road weather forecasting, it has developed a Road Weather

Standardized road salt use and mean daily occurrence of measurable snowfall for the Avalon region of Newfoundland, 1998-2005



Source: data provided by Province of Newfoundland and Transportation Association of Canada

Information Network (RWIN). RWIN supports private sector providers and road transportation users by managing, archiving and quality controlling data from the national system of road weather observing stations, as well as facilitating access to core meteorological datasets. At longer timescales, winter severity indices constructed using climatological data and related to indicators of winter maintenance, can be used by road authorities to evaluate monthly or annual operations.[9] Road salt application is strongly correlated to weather variables such as the mean daily occurrence of snowfall.

Infrastructure design and maintenance

Road infrastructure is in perpetual need of maintenance and reconstruction, as weather and climatic factors interact with traffic, construction, structural and maintenance characteristics to influence pavement deterioration and performance.10 Seasonal thaw weakening processes are a major factor in the premature deterioration of secondary roads in Canada. Once sufficiently frozen, a pavement structure can carry extra weight relative to the preceding unfrozen period. However, during the spring thaw the load-bearing capacity of roads rapidly weakens and the structure becomes vulnerable to permanent deformation even from average loads. Road authorities apply seasonal weight restrictions (SWRs) to reduce premature deterioration, allowing extra loads once structures are frozen, and limiting weights once the thaw commences.[11] Inappropriate decisions to implement restrictions can lead to extensive damage and repair expenditures.

In terms of weather information needs, one-day to 14-day forecasts of temperature are a primary consideration for determining when to activate and remove seasonal load restrictions. Historical climate observations are also consulted to establish basic relationships between pavement strength, frost penetration and air temperature. Climate change may also have important implications for the timing of the spring thaw, and render dependence on historical data or fixed SWR dates much less reliable in the future.[12]

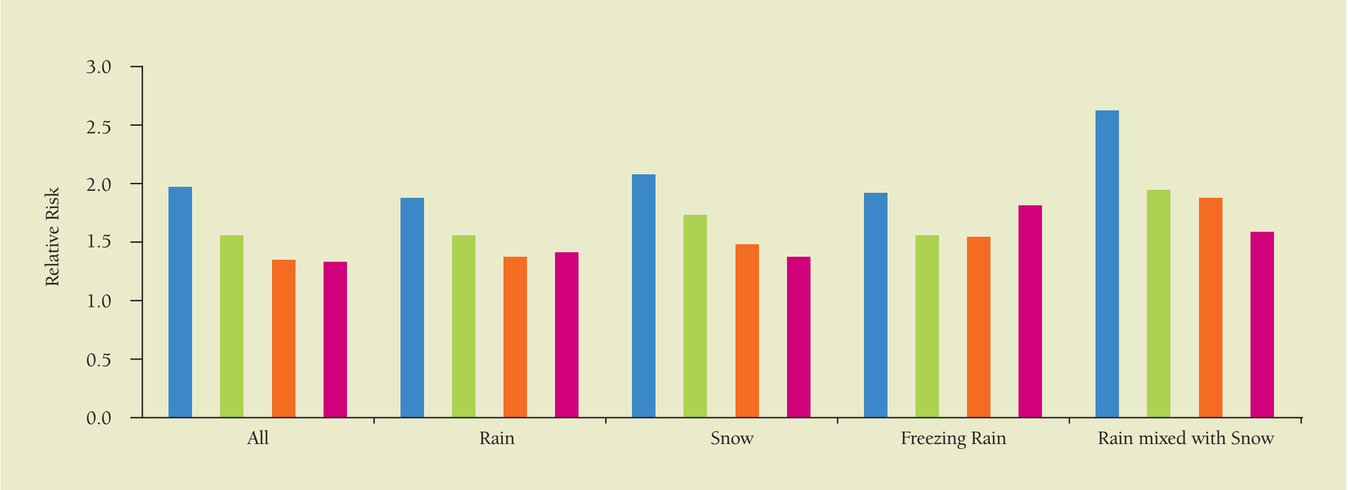
Road safety

The final example relates to road safety, specifically the routine forecasts, watches, advisory and warning products and services that Environment Canada provides to the driving public. Surveys conducted by Ipsos-Reid suggest that transportation concerns are the most important weather-related risks facing Canadians, particularly during the winter season.[13] Motor vehicle collisions exact a significant toll on Canadians each year — 2,917 deaths and 227,500 injuries in 2000 alone.[14] This translates into approximately one injury for every 140 citizens per year. Research has been completed in Canada to estimate the relative risk of motor vehicle collision injuries during precipitation, as compared with dry, seasonal conditions.[15] Results aggregated over 28 Canadian cities during the period 1984-2000 are presented in diagram below. Relative risks greater than 1.0 indicate that weather, in this case different forms of precipitation, is consistently associated with higher numbers of injuries than would be expected under dry, seasonal conditions. A relationship between injury severity and relative risk is also apparent, with minimal and minor injuries showing a greater increase during precipitation as compared with major and fatal injuries.[16]

This work provides substantive empirical support of the Ipsos-Reid survey results, and suggests a promising continued role for weather information applications. However, the actual influence of weather watches, advisories, and warnings on road safety — or the effectiveness of the previous applications in terms of user-relevant outcomes — remains unclear and is the focus of continued research. Initial investigations by Andrey and Mills suggest that current watch, warning and advisory thresholds for heavy rainfall, snowfall and winter storms are much higher than thresholds where weather-related collision risks begin to increase. However, in the cases examined, reductions in relative risk coincident with the timely (i.e., within 24 hours) issuance of weather watches, advisories and warnings are also apparent.[17]

In summary, many aspects of the road transportation sector in Canada are sensitive to weather and climate. Information and services provided by Environment Canada at a variety of scales (e.g. short-term forecasts through to climate change predictions) can help users to manage risks and take advantage of opportunities. The effectiveness or value of this information is only beginning to be determined, but is rooted in changes to user-relevant outcomes such as safety, and will vary according to the characteristics of the user, nature of the weather-related sensitivity, and decisions taken.

Aggregate risk of motor vehicle collision injury in 28 Canadian cities during various types of precipitation relative to comparable periods without precipitation (1984-2000).



Source: Audrey et al., 2005

The economic value of snowstorm forecasts in winter road-maintenance decisions

Erik Liljas, Swedish Meteorological and Hydrological Institute

There follows a summary of results from a study of the economic value of short-range forecasts of snowstorms in winter road-maintenance decisions in Sweden.[1] The study had two objectives — to assess the value of these forecasts in economic terms, and to assess ways of improving decision-making and all aspects of the service quality. Thus, when quality is mentioned it should be understood to be technical quality (TQ).

When viewed as weather-related decision-making problems (DMPs), three types of Swedish road-maintenance DMPs can be identified:

- Snowstorms
- Black-ice
- Frost problems.

Each type of problem arises under distinct meteorological conditions and involves different road-maintenance strategies. The case study described here is concerned exclusively with snowstorm problems.

This decision-analytic approach involves several steps, including the structuring of the DMP, the quantification of the relevant costs and losses, and the specification of probabilities of the relevant weather events given the forecast information in question. Optimal strategies and forecast-value estimates are determined here under the assumption that the overall goal of Swedish road authorities is to minimize total expenditure where these expenses consist of both road-maintenance costs and snowstorm losses.

The case study reported here focuses on snowstorm-related winter road-maintenance activities on major highways in a district in south-central Sweden. The relationship between forecast quality and forecast value in the context of this snowstorm/road-maintenance DMP is briefly examined.

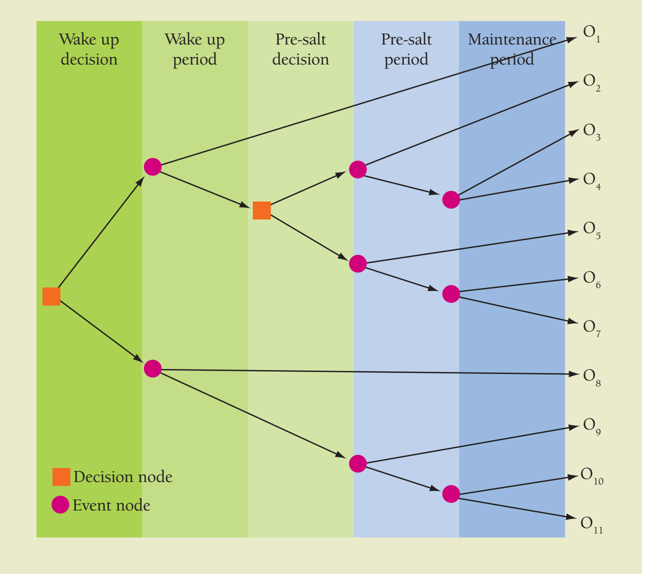
Basic structure

A decision tree depicting the basic structure of the snowstorm/road-maintenance DMP is presented in the diagram below. The tree identifies the actions and events included in the model, as well as the outcomes associated with the various sequences of actions and events. Two sequential decisions are considered:

- The wake-up decision made by central road-maintenance authorities
- The pre-salt decision made by local road-maintenance authorities.

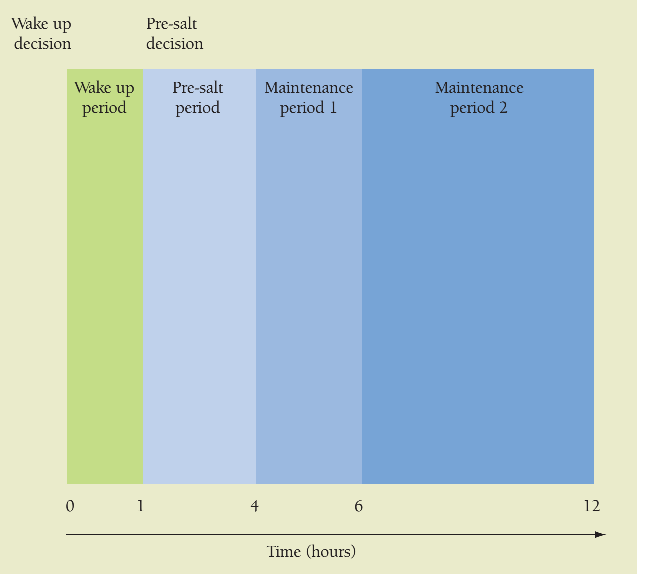
Both decisions are assumed to involve a choice between binary actions: namely, wake-up (W)/don't wake-up (W') in the case

Basic decision tree for snowstorm/road-maintenance DMP



Source: Liljas, E., and Murphy, A.H.

Timeline for decision-making



Source: Liljas, E., and Murphy, A.H.

Table 1: Types, categories, and dimensions of expenses associated with terminal outcomes

Type	Category	Dimension
Snowstorm losses	Accident losses (L_a)	Injuries Deaths Vehicle damage Roadway damages
	Delay Losses (L_d)	Loss of work time Loss of leisure time Inconvenience
Maintenance costs	Maintenance costs(C_m)	Personnel costs Equipment costs Material costs
	Environmental costs (Ce)	Salt damage to environment Salt damage to vehicles Salt damage to roadway

Source: Liljas, E., and Murphy, A.H.

Table 2: Expenses associated with terminal outcomes in the case of state-of-the-art snowstorm forecasts

Terminal outcome	Expense (1,000 SEK)	Terminal outcome	Expense (1,000 SEK)
0_1	11,200	0_7	11,206
0_2	9,300	0_8	11,400
0_3	8,500	0_9	1 1,400
0_4	1 1,453	0_{10}	11,400
0_5	11,100	0_{11}	11,006
0_6	11,000		

Source: Liljas, E., and Murphy, A.H.

of the wake-up decision and pre-salt (S)/don't pre-salt (S') in the case of the pre-salt decision. The weather events are also assumed to be binary in nature: namely, the occurrence (x = 1) or non-occurrence (x = 0) of a snowstorm in a particular period.

The timeline identifies the time (in hours) at which the decisions are made. The wake-up decision is taken as the arbitrary point in time at which this DMP initially arises (t = 0), and the pre-salt decision is made one hour later (t = 1). This diagram also defines the time intervals associated with the four periods of interest; namely, the wake-up period (x1 : $0 \le t \le 1$), the pre-salt period (x2: $1 \le t \le 4$), maintenance period 1 (x3: $4 \le t \le 6$), and maintenance period 2 (x4: $6 \le t \le 12$).

Each branch of the decision tree terminates in a node that represents the outcome of the corresponding sequence of actions and events. Eleven distinct outcomes (or branches) are identified, denoted here by 01, 02, …, 011. Outcomes 04, 07, and 011 are associated with sequences of actions/events in which the snowstorm does not occur during any of the four basic periods. In these cases it is assumed that road-maintenance authorities face this same decision-making problem again at a later time. This assumption leads to an extended version of the basic DMP. In effect, the basic wakeup/pre-salt decision-making process is reiterated on these three branches of the decision tree until the snowstorm occurs, or until the incremental change in the associated terminal expense becomes insignificant.

Outcome expenses

The expenses associated with the outcomes are assumed to be of two basic types:

- Losses due to the snowstorms themselves
- Costs due to maintenance activities.

Each type of expense (the generic term for costs or losses) contains two categories of loss or cost. In the case of snowstorms, the expenses are losses due to traffic accidents (La) and losses due to traffic delays (Ld). In the case of maintenance activities, the expenses are costs due to maintenance activities (Cm) and costs due to environmental impacts of maintenance activities (Ce). In addition, each category of cost or loss possesses two or more dimensions. The types, categories, and dimensions of the expenses considered in this snowstorm/road-maintenance DMP can be seen in the table.

Road and traffic statistics, as well as basic data related to losses due to accidents/delays and costs due to maintenance activities/environmental impacts, were obtained from publications prepared by road/traffic organizations in Sweden and from discussions with Swedish road authorities. On the basis of these data it was possible to estimate most of the dimensions of the costs and losses identified here. However, the data available were inadequate to derive reliable estimates of the losses associated with both accident-related roadway damages and inconveniences caused by traffic delays, as well as the costs due to salt damage to roadways, and these three dimensions of the expenses have been ignored in this study.

In estimating the total expenses associated with the various action-event sequences (or branches of the tree), an additive model of losses and costs has been assumed. That is, the terminal expense assigned to a particular branch of the tree is the sum of the costs and/or losses associated with the particular combination of actions and events that define this branch. The total expenses calculated for the eleven basic terminal outcomes are listed in the second table.

Outcomes 04, 07, and 011 are associated with action/event sequences in which the snowstorm event has not yet occurred. In these cases, expected expenses associated with subsequent iterations of the snowstorm/road-maintenance DMP have been added to the basic terminal expense. These expected expenses vary depending upon the type of snowstorm information used as a basis for decision making in these iterations. The terminal expenses given in the table relate to the situation in which these decisions are based on forecast information.

Snowstorm events and snowstorm forecasts

A typical snowstorm event in this district in south-central Sweden has a duration of six hours, with snow falling at a rate of approximately 1cm per hour. In this study, it is assumed that snowfall is continuous; specifically, a snowstorm event consists of uninterrupted snowfall for a six-hour period, with a total accumulation of 6cm. The unknown characteristic of snowstorms of interest here is their time of initiation. Thus, the short-range snowstorm forecasts evaluated in this case study are forecasts of the initiation time of snowfall events.

Three types of snowstorm information are considered in this study:

- Climatological information based on current weather data from automatic stations along highways and roads and weather radar information
- Forecast information
- Perfect information.

Table 3: Marginal probabilities of snowstorm-event occurrence in four basic periods for three types of information

Period (Event: hours)	Climatological information	Forecast information	Perfect information
Wake-up (x1: 0-1)	0.060	0.025	0.000
Pre-salt (x2: 1-4)	0.399	0.150	0.000
Maintenance-1 (x3: 4-6)	0.266	0.550	0.720
Maintenance-2 (x4: 6-12)	0.275	0.275	0.280

Source: Liljas, E., and Murphy, A.H.

Table 4: Expected expense and expected value associated with optimal strategies for different types of meteorological information for Jönköping district in south-central Sweden

Type of Information	Expected expense (1,000 SEK)		Expected value (1,000 SEK)	
	Per snowstorm	Per year	Per snowstorm	Per year
Climatological	10,285	205,700	0	0
Forecast	9,806	196,120	479	9,580
Perfect	8,955	179,100	1,330	26,600

Source: Liljas, E., and Murphy, A.H.

Each type of information is assumed to specify the probability of occurrence of a snowstorm event in the four basic periods. Further, it is assumed here that in the absence of forecast information, road-maintenance personnel base their decisions on (tailored) climatological information. In effect, climatological information defines the zero points (or baseline values) on the scales on which forecast quality and forecast values are measured. Perfect information, although obviously not available in the real world, provides a useful upper boundary for the quality and value of imperfect forecasts.

Conditional and marginal distributions characterizing forecast quality for the wake-up, pre-salt, and maintenance-2 periods are related to this maintenance-1 period forecast information.[2] To facilitate the comparison of snowstorm event probabilities for the three types of information, the marginal probabilities of snowstorm events initiating in the four basic periods are required.

Results

As previously noted, it is assumed that the goal of Swedish road-maintenance authorities is to minimize total expected expenses on each occasion on which a snowstorm constitutes a threat to traffic safety and highway maintenance in the Jönköping district. The value of snowstorm forecasts of a specified level of quality is determined as the difference in total expected expense between the situation in which the wakeup/pre-salt decisions are based on climatological information, and the situation in which these decisions are based on forecast information.

Optimal strategies

When the wakeup and pre-salt decisions are based on climatological information, it is always optimal for central authorities to

Photo: Kerstin Ericsson

A snowplough (Swedish: plogbil) during a snowstorm in Sweden

Quality/value relationship for snowstorm/road-maintenance DMP. Q* and V* are rescaled measures of quality and value, respectively, where Q* = 0 and V* = 0 for climatological information and Q* = 1 and V*=1 for perfect information. Q* 0.725 and V* = 0.360 for state-of-the-art snowstorm forecasts

Source: Liljas, E., and Murphy, A.H.

wake up district personnel and for these road-maintenance personnel to initiate pre-salting activities. On the other hand, the optimal strategy given forecast information is to wake-up and pre-salt given the forecast f=1 and to not wake-up or pre-salt given the forecast f=0. It is through the difference in optimal strategies between climatological information and forecast information that the latter acquires its positive economic value. Perfect information leads to the same optimal strategy as forecast information.

Forecast-value estimates

The expected expenses associated with optimal strategies based on climatological, forecast, and perfect information are indicated — on a per-snowstorm basis and on an annual basis (assuming 20 snowstorms on average per year) — in Table 4. Expected forecast value is also listed in this table, under the assumption that climatological information defines the zero point on the value scale. The economic value of snowstorm forecasts (of current quality) is 0.48 million SEK per snowstorm or 9.60 million SEK for a typical year. Corresponding estimates for perfect information are 1.33 million SEK and 26.60 million SEK, respectively. Thus, current forecast information realizes approximately 36 per cent of the value of perfect information in the context of this DMP.

Quality/value Relationship

In addition to estimates of the value of forecasts of current quality, the relationship between forecast quality and forecast value is also of interest.[3] The basic quality/value question can be posed as follows: Given a specific change in the level of forecast quality, what change can be expected in the level of forecast value?

The availability of a model of the snowstorm/road-maintenance DMP including a submodel that characterizes forecast quality — makes it relatively easy to evaluate the quality/value relationship in this context. To simplify this analysis, a scalar quadratic error measure of forecast quality was introduced.[4]

Various incremental changes (improvements and deteriorations) in forecast quality were postulated, and the snowstorm/road-maintenance model was used to determine the optimal strategies and forecast-value estimates corresponding to each level of quality. Relative forecast value V* is plotted against relative forecast quality Q* in the graph here (these rescaled quantities are defined in the figure legend). This diagram reveals that the quality/value relationship is approximately linear for relatively modest levels of quality but is highly nonlinear over higher levels of quality. In this regard, the Q* value for forecasts of current quality is 0.725.[5]

Short discussion of the winter road maintenance problem

This paper has summarized some results of a decision-analytic study of the value of short-range snowstorm forecasts in road-maintenance decisions in the Jönköping district in south-central Sweden. The study focused on the wake-up/pre-salt decisions made by central/local road-maintenance authorities, evaluated a relatively broad range of expenses associated with maintenance activities and snowstorm events, and estimated the economic benefits — in the context of this DMP — of state-of-the-art forecasts from the time of initiation of a typical snowstorm. Specifically, the incremental benefits of basing these road-maintenance decisions on forecast information — instead of on climatological information — is approximately 0.5 million SEK per snowstorm or about 10 million SEK per winter season. It should be kept in mind that these estimates refer only to the economic benefits of snowstorm forecasts in decisions involving main roads in the Jönköping district. The overall annual economic benefits of forecast information in road-maintenance decisions relating to both snowstorm and black-ice events for all major roads in Sweden are estimated — by a rough scaling-up process — to exceed 300 million SEK.[6]

In evaluating these estimates of benefits, it is also important to recognize that a relatively sophisticated form of climatological information has been used as a standard of reference in this study. If road-maintenance authorities only had access to a relatively rudimentary form of climatological information in the absence of snowstorm forecasts, then the value of the forecast information of interest here would increase (because the economic value of the zero point had decreased). Alternatively, this relatively sophisticated climatology could be viewed as an intermediate form of information (between the rudimentary form of climatology and state-of-the-art forecasts) with considerable economic value in its own right.

When looking at the combined result of nowcasting as the result of mapping of current weather by radar, satellite and automatic stations (~700) +, forecast information, and the assumption that the user optimised the economic outcome with efficient decision-making, a figure on the order of 100 million euros was saved in Sweden each winter. Of this, 60 per cent came from improved decisions due to better mapping by weather radar, satellite images and automated weather stations (AWS); 40 per cent came from the forecasts for the next 12 hours. Potential to improve the outcome by increasing forecast quality was postulated. A clear conclusion was that an effective decision-making process is important in order to improve the outcomes of weather services to save lives, health, the environment and money.

Sustainable, energy-efficient building: the BCIL approach

By Chandrashekar Hariharan, Biodiversity Conservation (India) Ltd

Humans are just one of the many species affected by climate change — the number could be anywhere from four million to 8.5 million, according to various scientific and historical sources. But there is clear evidence that human excesses have caused significant environmental damage over the past 100 years, and that we now need to find ways to reverse this trend or to use natural-resource management that enable efficiency while continuing conventional development objectives.

One hugely significant element of this problem is that nearly 50 per cent of all fossil energy consumed in the world goes to just one industry: building. This understanding is essential if humans are to find effective ways of reducing the consumption of fossil fuel and the damage it does to the environment.

For 50 years, many in the environment sector have focused on how to get governments to enact policies that will make businesses behave more 'responsibly' in their use of natural resources. Embedded in this logic is a notion that there is a conflict between markets and the environment.

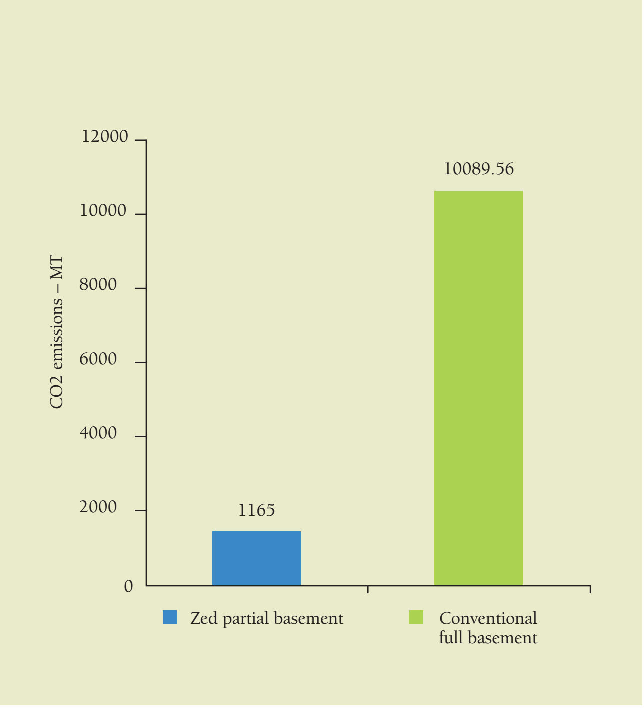
Beyond the Green Brigade

Over the past decade there has been significant growth in India, with a compounded annual average growth of eight per cent on gross domestic product. New avenues have opened out, enabling some 'renegade' institutions in the development sector to move away from 'activism', beyond the current crop of the 'Green Brigade.' Instead, they are looking for solutions using technology, both ancient and modern, which can continue to serve the conventional objectives of economic development while being sensitive over the use of natural resources.

Sangharsh (in Hindi, meaning struggle or political activism) and nirmaan (development that brings social and economic value) represent polar opposites that have been seen by environmentalists and governments in India — and throughout the world — as mutually exclusive, conflicting objectives.

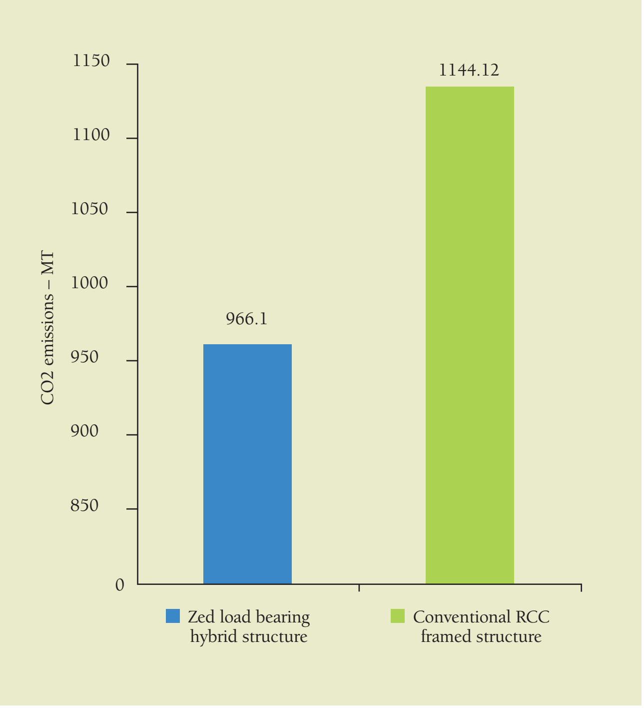
Management gurus today are beginning to see that the world's business sector and governments have to take a different view. C. K. Prahalad, hailed recently by BusinessWeek as a business prophet, says: "Increased efficiency through innovation is the key to sustainable development." Arthur D. Little talks of how

Basement structure



Source: BCIL

Independent home super structure



Source: BCIL

"sustainability is the key to winning tomorrow's markets." And Kofi Annan said recently: "I hope corporations understand that the world is not asking them to do something from their normal business; rather it is asking them to do business differently."

BCIL's raison d'etre

In 1994, a fledgling group of development workers in the sub-Himalayan districts of India chose to move away from 'social models' of development with grants and subsidies. The group established an enterprise that sought to identify an array of technologies in building, water and energy management that could demonstrate resource-sensitivity while also being financially viable. Eleven years down the road, Biodiversity Conservation (India) Ltd. (BCIL) has shown that sustainability can be a central platform for business growth.

In 1995, its first year of operations, BCIL had a business value of USD 500,000. From this modest beginning, it has grown to become a USD 25 million enterprise. This clearly suggests that markets are both willing and in need of processes and technologies that make no compromise on the defined urban frameworks of development, comfort and convenience, while delivering efficiency in natural resources.

This philosophy lies at the core of BCIL, which is India's largest Sustainable Built Environment (SBE) enterprise today. BCIL has made a case in every business and development forum for ending the present perverse system of offering subsidies and incentives in the form of artificially lower prices for 'green' technologies. BCIL sees a highly productive marriage between the two forces of growth and environmental responsibility, which need to be made compatible.

With 330 per cent annual growth registered in just the past year of performance, BCIL is a standing testimony for moving away from such regressive thinking on 'nurturing' green development. Since its inception, BCIL has promoted successful business models that have mainstreamed the 'alternative'. In doing so, it has shown that governments must first dispel the notion that there is a trade-off between growth and being environmentally friendly. As a developing country that imports 70 per cent of its energy, India cannot ignore the need for strategies in the building industry that will reduce consumption by enhancing the country's energy security.

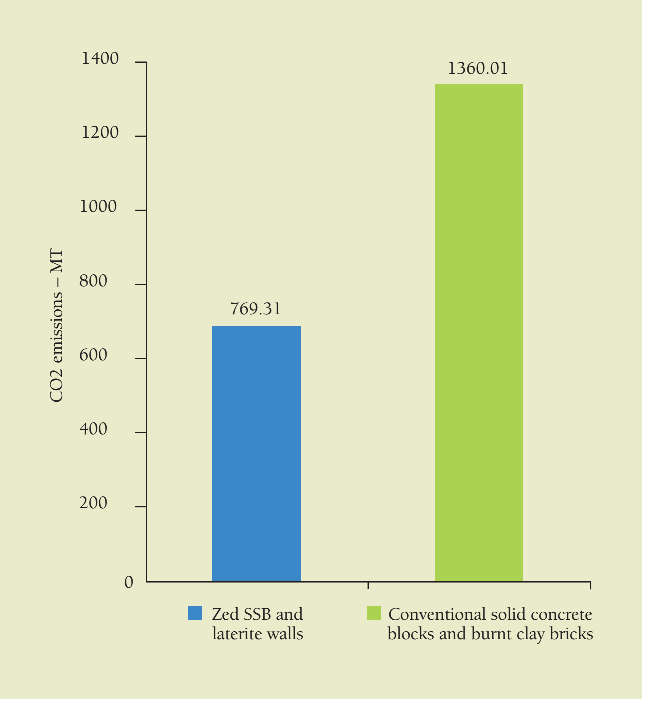
Energy security is not primarily about generation so much as it is about achieving energy efficiency. The question that BCIL has often asked is: if economic agents reduce their energy use, and therefore their costs, how can this be bad for the growth and productivity of a company or government?

If you observe the quality of a product and service, or customization in the marketplace, you will see that until very recently, these goals were considered costly to achieve. What BCIL has effectively done over the past decade, with every evolving project, is to break free from this dominant logic and use quality and customization as means to both acquire customers and reduce costs. This is both applicable at the capital stage of construction, and at the post-project stage when reduced energy and water use brings financial savings to customers. The graphs accompanying this article illustrate the approach, the strategy and the process management methods that are employed to achieve such goals at the brick-and-mortar level.

Incentives and subsidies only encourage excess use, and waste precious resources. Energy efficiency does not need any incentive, for it always shows a positive impact on corporate bottom lines across the board. That is adequate motivation for companies like BCIL, and should be so for all corporations. Subsidizing energy or water costs, instead of focusing on their efficiency, is against growth, as indeed it is against sustainability.

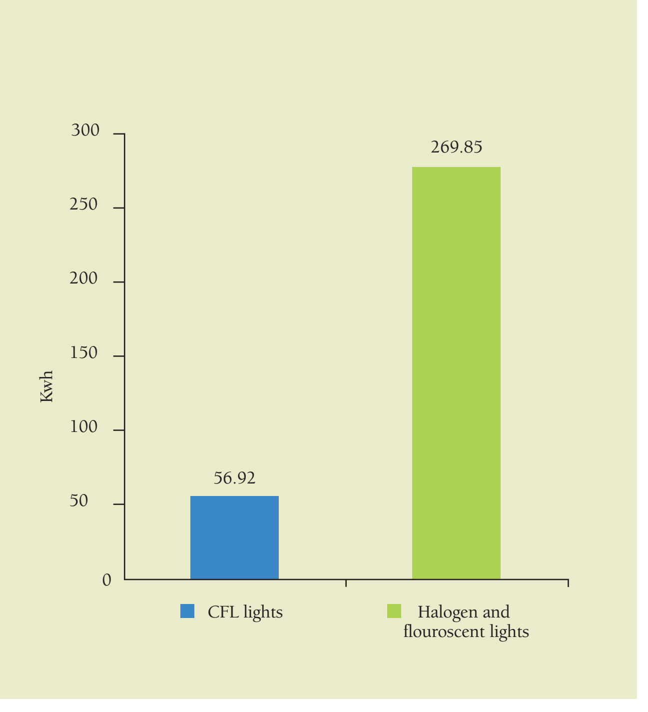
As a corporate enterprise, BCIL has been mindful of the comfort and convenience that our products offer to our customers, be it in the segment of the urban rich or the rural poor. Normal market behaviour suggests that higher comfort means higher use of resources.

External walls



Source: BCIL

Home lighting



Source: BCIL

In every one of the 1.4 million square feet [or 150,000 square metres] of building projects that the enterprise is executing today, BCIL has looked at implementation that pursues a four-pronged strategy for bringing natural resource efficiency:

- Environmental compatibility
- Economic efficiency
- Endogeneity
- Equity.

These are addressed while focusing on two primary ideas:
1. How to improve transport energy within our campus areas
2. Building efficiencies in home energy use — this covers better washing machines, refrigerators, air-conditioners and water coolers; smarter lighting systems; efficient cooking systems and water heating systems.

BCIL's adherence to these values, as a profit-making company, is non negotiable. BCIL is about the human spirit; our mission statement is merely a hollow catchphrase. As an organization, we have pushed the boundaries of economic possibility, always knowing that we will not bend to curtail that spirit or the soul of our company.

With this bedrock foundation, we have created an entirely new business model in India, which offers us the opportunity to grow exponentially as an organization. If the past five years has shown a cumulative growth rate of a staggering 5,000 per cent — from USD500,000 to USD25 million — the next three years (financial years 2007-2010) will take us to a top line revenue, on projects that are already committed to being executed, to the region of USD150 million. The bulk of the revenues today arise out of sustainable buildings, while our businesses in areas of sustainable built environment — water supply to the urban and rural poor; organic farm products that enhance growth potential and improve soils; and afforestation with corporate partnerships — are all well on the way to becoming robust revenue models over the coming years.

While many analysts have successfully outlined contours of such strategies for the building industry as a view from the sky, little is available in the world from companies that have successfully created projects and management systems that recognize these imperatives at the stages of design, architecture, and further down into the various components of execution.

There is either a fixed mindset that refuses to comprehend the compatibilities that lie between successful business models and ecological compatibility, or there is an unwillingness to invest in innovation and incubation that can show the way for the future. The idea in itself is not new, of course. Inventors like Thomas Alva Edison in the late nineteenth century regretted their inability, or lack of time to work on technological directions for such a future: "We're like tenant farmers," said Edison, "chopping down the fence around our house for fuel when we should be using nature's inexhaustible sources of energy — the sun, wind and tide." With breathtaking foresight, Edison added, "I'd put my money on solar energy. What a source of power! I hope we don't have to wait until coal and oil run out before we tackle that. I wish I had more years left."

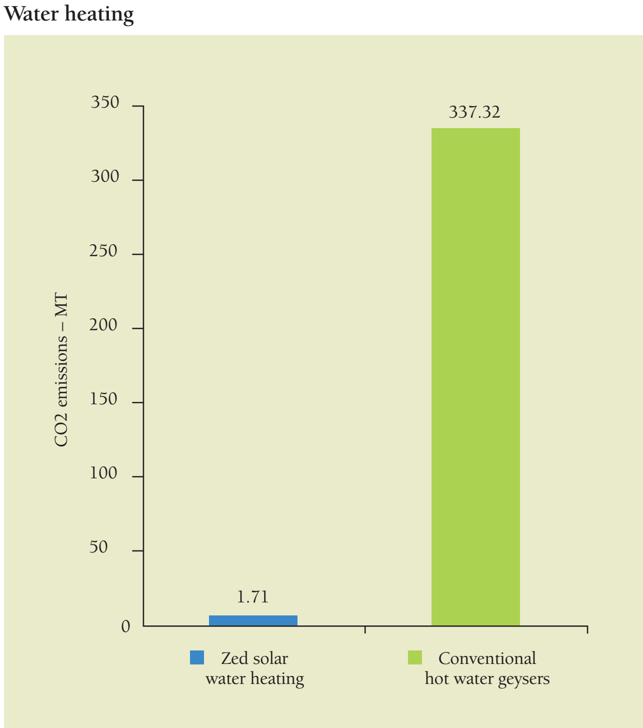
Case study: T-Zed

The T-Zed campus is the first of its kind. Located at Airport Whitefield Road, Bangalore, this five-acre site comprises 95 homes built on the principles of sustainable resources.

Every aspect of T-Zed has been designed to conserve natural resources and to have minimal impact on the environment. In these homes, built-in, customized environment-friendly (brine-based), zero electricity fridge-freezers, fully controlled air-conditioning based 100 per cent on fresh air, and built-in energy-efficient lights are among the features that help to bring down energy consumption in the home while preserving comfort levels and ensuring market value.

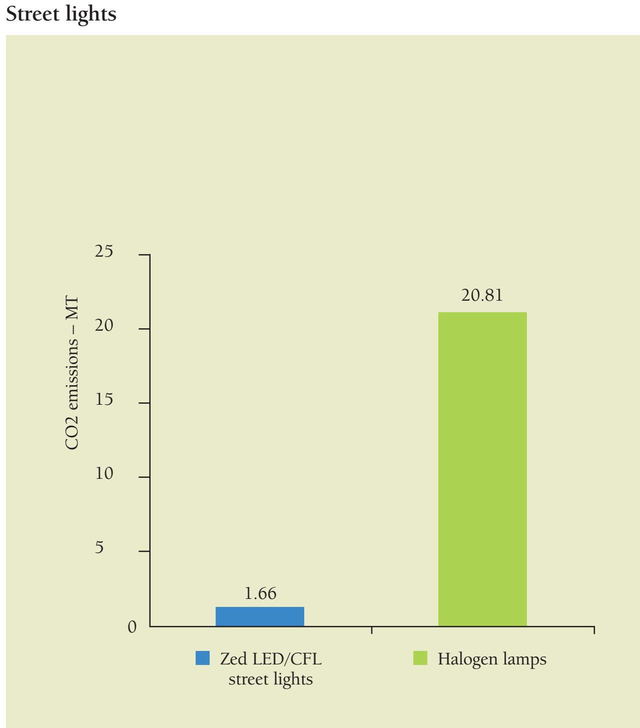
At another project of ours, BCIL Collective, we have devised air conditioning systems that keep homes dust-free and cool

Water heating



Source: BCIL

Street lights



Source: BCIL

Photo: Harris Backer

Blending aesthetics and sustainability: Club Zed, India's first carbon-neutral residential campus that hosts 95 homes in the Silicon City of Bangalore

using energy-efficient appliances such as earth tunnel venting systems, nocturnal cooling systems, or the stack effect, which draws ambient air and cools it by convection

Intelligent lighting systems blend motion sensors, ambient light sensors and timers to ensure that lights are switched off when not needed. Compact fluorescent lamps and light emitting diodes are used, cutting power consumption by up to 80 per cent while protecting lighting efficiency.

Washrooms are ventilated using noiseless, energy-efficient DC and AC fans. DC fans are powered by photovoltaic panels and run from dawn to dusk, while AC fans can be switched on and off as needed.

External walls are built using soil-stabilised blocks, laterite blocks and surface engineering with stone chip plastered surfaces. This ensures that surfaces are non-erodable, need no external paint applications, and are thermally efficient.

Green roofs or 'sky gardens' also contribute to the thermal comfort of the dwellings. These provide a planting space for every home while serving as thermal insulation for adjoining and lower-built spaces. Each sky garden uses lightweight mulch and coir pith instead of heavier soil, and is irrigated via a drip method. The degree of self-sufficiency enabled by this promotion of urban agriculture also helps to decrease the 'food miles' and encourage more organic urban agriculture.

Rubberwood which is a non-forest timber is used for door shutters, and as flooring. Palm wood has been for external walkway decking. We have also used compressed coir door panels for door shutters, while bamboo composites provide roofing for parts of the club and interior woodwork in places. These are local resources which cost less than imported timber and use less energy to produce, thus reducing carbon emissions.

A centralised, district refrigeration system using an ammonia-based chilling unit means that there are no compressors in the individual refrigeration units installed in each home. This in turn enables better management of cooling needs and more space for storage within each fridge.

A self-sufficient and secure water supply system is also provided, using rainwater collected from the roof and stored in a shallow aquifier, through a system of drains, percolation pits, trenches and wells. Trenches are shallow at ten metres, so ground water is not depleted. Water treatment costs are reduced via direct tapping of rooftop rainwater.

Each home also has 'conscience meters', monitoring electric watts and water consumption. As the number of electrical devices increases, so does power consumption. An electric watt meter fitted in each home indicates the wattage used at a particular time and thus allows users to monitor their power consumption and introduce efficiencies. Meters on the kitchen and bathroom taps help to monitor the volume of water used in litres.

How BCIL goes about its business

'Technology' at BCIL is not some new-fangled, modern-day electronic wizardry. A 200-year-old traditional system of lift irrigation is as much 'technology' as is a microchip-based motion or temperature sensor that brings lighting efficiency.

The key to decision-making in the organization has been a combination of six factors:
- Cost (always relative to what you are 'buying')
- Aesthetics (should gain acceptance among customers)
- Function (must serve the basic purpose and not be there for its own sake)
- Ease of execution (skills and material resources must be available within a reasonable distance and time),
- Time (else, the organization fails as a delivery company)
- Environment (has to be resource-sensitive and/or bring social value, or must bring domino impact of replicability and scale).

Design must recognize the 'Four E's' of Ecological compatibility; Economic efficiency; Endogeneity and Equity.

Architecture must adhere to a six-strand approach entailing integrated management of all aspects that relate to:
- Earth (avoid bricks that employ precious topsoil and use 400 deg C energy; use soil stabilized blocks)
- Energy (both embodied energy and active energy use on consumption, while engineering active and passive elements on energy saving)
- Water (infrastructure approaches and plans that help communities grow their own water; waste water management that reduces fresh water use)
- Waste (to ensure that communities of companies in an office block or of homes in a residential enclave assume responsibility for managing the spectrum from degradable to toxic wastes)
- Air (with passive cooling and active cooling systems that are energy-efficient and ozone non-depleting)
- Biomass (to improve the microclimate of a land zone in a way that reduces demands on cooling).

activities. This will not only enhance the overall quality of life for Singaporeans, but will also help foster a greater sense of environmental ownership, leading to a deeper awareness of the environment and the importance of its precious resources.

Our next step

As a small-island state, Singapore is far from immune to the effects of globalization. In order to keep pace with global technology developments, Singapore needs to continue to invest heavily in research and development to ensure technological relevance in this fast-changing world. As such, the Singapore government has ear-marked USD5 billion to fund R&D projects in three sectors, including the environmental and water technology sector, with an Environment and Water Industry Development Council (EWI) set up to map out strategies and oversee growth in this sector. It is Singapore's goal to be a Global HydroHub, the centre of a vibrant global industry, a place for the generation and exchange of ideas in the field of water.

Running parallel to this strong belief in the merits of idea exchange is PUB's active participation in global water events such as at the 4th World Water Forum in Mexico, the International Desalination Association Forum in Tianjin, China last year and of course, the World Water Week in Stockholm. Singapore will also be playing host to the International Water Association's Leading Edge Technology conference in a few months time. Singapore's HydroHub and the existing opportunities for international partnerships not only complement each other, but are vital if progress in this sector is to be maintained.

Climate change is no longer speculation, it is reality. For PUB, the key areas of concern will be the impact of rising sea levels on flooding and coastal supply infrastructure. As such, PUB is currently monitoring developments in the international arena to facilitate forward planning. Through such measures, PUB hopes to reduce water supply uncertainty as a result of meteorological events.

The road forward

Implementing an integrated water management system requires vision and proper planning. However, these factors alone are not sufficient. The key to the success of a multi-stakeholder, multi-use system is strong political will and good governance. It is only through a cohesive national effort that any large-scale system can attain its goal.

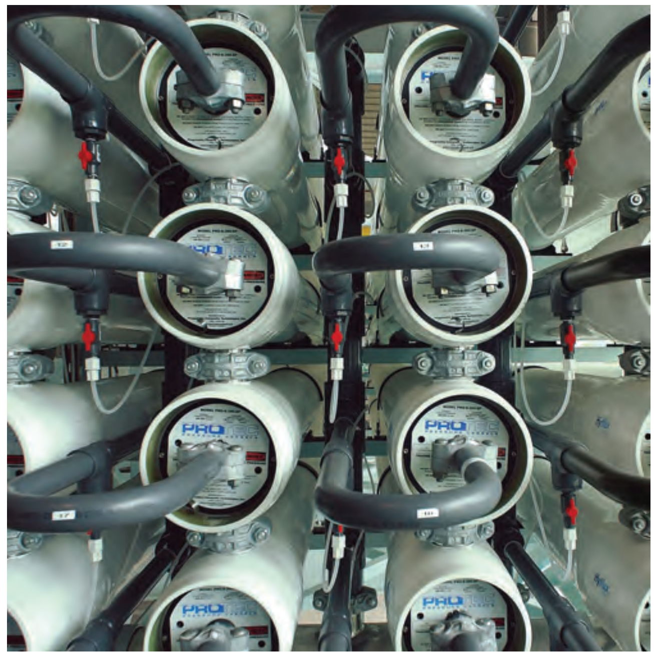


Photo: PUB — Singapore's National Water Agency

Reverse osmosis membranes for NEWater production

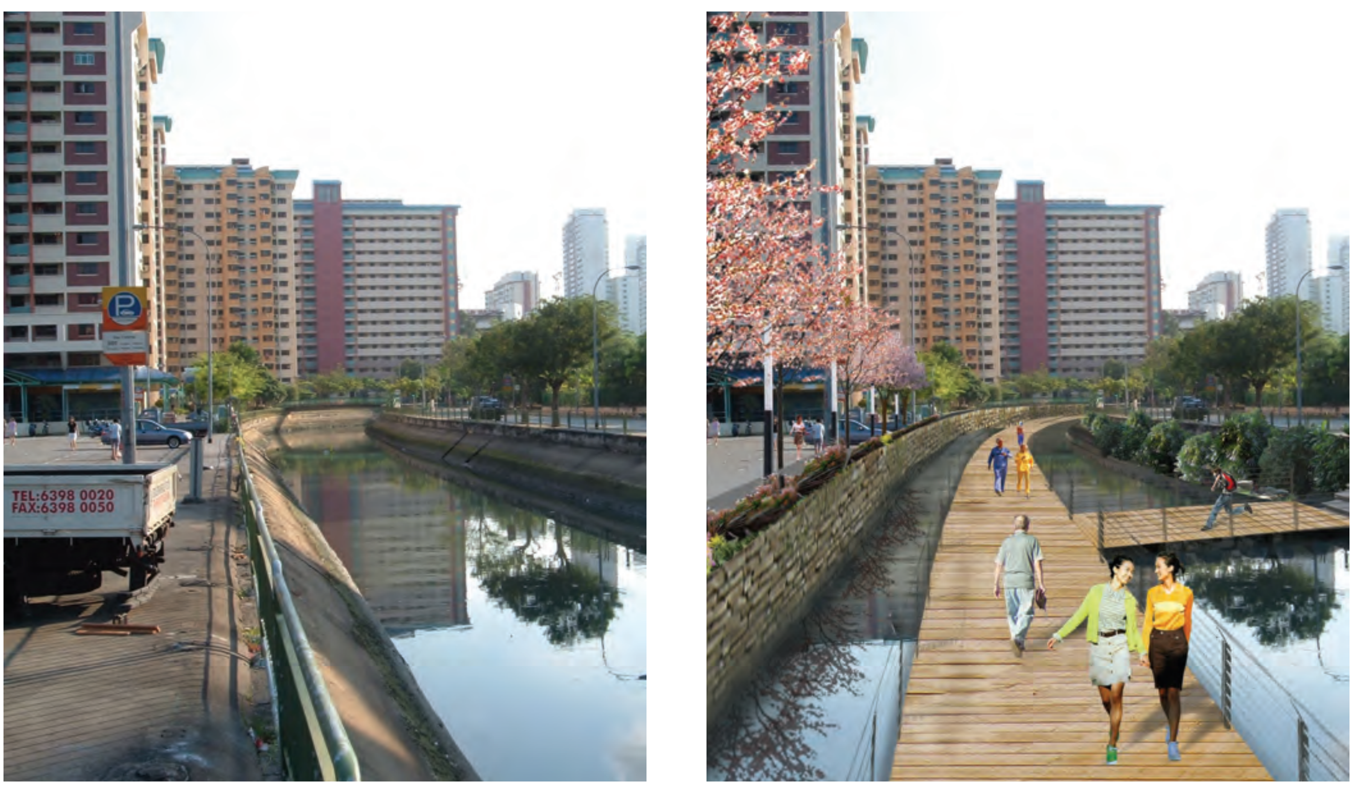


Photo: PUB — Singapore's National Water Agency

Active, beautiful and clean waters: transforming our waterways — Rochor Canal (before and after)

Location of the glaciers and ice caps studied in the CE project

Image: Fenger (2007)

Glaciers and ice caps in the Nordic countries have retreated and advanced during historical times in response to climate changes, which are believed to have been much smaller than the greenhouse-induced climate changes that are expected during the next 100–200 years. These changes have in many cases left clear marks on the landscape in the neighbourhood of the glaciers.

Simulated changes in ice volume and glacial runoff

Several ice caps and glaciers in the Nordic countries were studied within the CE project using mass balance and dynamic models to project future changes in ice volume and glacial runoff based on scenarios for future climate change.

In simulated ice wastage for the modelled glaciers, simulations with a 2D ice flow model are run to 2200, but the Norwegian and Swedish glaciers are only run to 2100 because of limitations in a simplified dynamic model used for these glaciers. The time evolution of ice volume has a similar character for the modelled glaciers, except for Engabreen in Norway and Mårmaglaciären in Sweden. The modelled ice volume is reduced by more than half within the next 100 years, and the glaciers essentially disappear in 100–200 years after the start of the simulations, given that the rate of warming with time remains the same. One of the Norwegian glaciers retreats more slowly because of a substantial increase in precipitation, which is projected by the CE scenario for the area where this glacier is located.

The projected change in the mass balance of the glaciers leads to a marked increase in runoff from the area covered by ice at the start of the simulations. Due to the large amplitude of the projected changes, the changes with respect to the runoff at the start of the simulations are similar to changes with respect to a 1961–1990 baseline, which was not explicitly modelled for most of the glaciers. By around 2030, annual average runoff is projected to have increased by approximately 0.4–0.7 $m^{w.e.}.a^{-1}$ for the Norwegian and Swedish glaciers, and 1.5–2.5 $m^{w.e.}.a^{-1}$ for the Icelandic ice caps. The runoff increase reaches a comparatively flat maximum between 2025 and 2075 (except for Engabreen in Norway) when the increasing contribution from the negative mass balance is nearly balanced by the counteracting effect due to the diminishing area of the glacier. For all the glaciers, this maximum in relative runoff increase is over 50 per cent with respect to the current runoff from the area presently covered with ice.

For the Icelandic ice caps, the specification of a comparatively large change in climate during the initial decades of the simulation, based on the observed climate of recent years, and the seasonality of the climate change with the largest warming in spring and fall, leads to a rapid increase in runoff with time. The simulated runoff changes may be compared to average runoff from these ice caps between 1981 and 2000, which is in the range 2.4–4.1 $m^{w.e.}.a^{-1}$. In model results for Engabreen in Norway, although the precipitation increase for the other glaciers is of much smaller importance than the temperature change, the assumed precipitation change can significantly alter the simulation results in cases where substantial precipitation changes take place. The fact that this only happens for one of the glaciers highlights the uncertainty of the climate change scenario.

These results clearly suggest large changes in runoff from glaciated areas, which are projected to have reached quite significant levels compared with current runoff, well before 2030. The associated changes that may be expected in diurnal and seasonal characteristics of glacial runoff will come on top of the changes in the annual average.

Hydropower is the most important renewable source of electricity in Iceland and it is the renewable energy source most strongly affected by climate. The results from the CE project and the related national research programmes show that this impact can be quite strong. Global warming will shorten the winter season, make it less stable and lengthen the ablation season on glaciers and ice caps. This leads to a more evenly distributed river flow over the year, which is a profitable situation for the industry.

There is also potential for increased hydropower production as the highest modelled increase in river flow is simulated in highland areas that are most important for hydropower. This implies that the projected hydrological changes may be expected to have practical implications for the design and operation of many hydroelectric power plants, and also for other use of water, especially from glaciated highland areas.

One negative aspect is that the new annual rhythm in runoff indicated in the simulations will put more stress on the spillways. They will probably have to be operated more often in winter, as the unstable winter climate will generate more frequent sudden inflows when reservoirs may be full. This will also have an impact on the infrastructure with more frequent flooding problems downstream at the reservoirs. These areas are normally adapted to the present-day climate with stable winters and without high flows from autumn to spring.

In summary, the power industry needs to develop a new strategy characterized by flexibility because it must be possible to adapt the operation and even the design of power plants as climate change leads to changes in the discharge and seasonality and other hydrological characteristics. Continued research on climate change is essential to address the added uncertainty with which the industry is faced due to this situation and in order to supply the necessary information for proper adaptation to the evolving climate.

III

NATURAL & HUMAN-INDUCED DISASTERS

Using what we know about disasters for safer lives and livelihoods

Sálvano Briceño, Director, International Strategy for Disaster Reduction (UN/ISDR)

The elements of weather and, water in its different forms and their interaction in climatic processes, make up the basis for sustaining various life forms in nature. These natural forces, acting together with the soils and land of Earth are responsible for the life and well being of people and their communities. Together with humankind's collective knowledge and experience, these natural resources also provide all the other forms of sustenance that people need to prosper and for communities and nations to develop.

Elements of life — as well as risk

Since the beginning of recorded history people have gathered, lived, and created assets of social and economic value in locations where they could take advantage of rich, watered floodplains, abundant grasslands and forests, bountiful coastal shores, and other areas nurtured by conducive weather and productive climatic conditions. However, as the global population increases, and more people choose to live in productive or otherwise desirable locations of opportunity, they continue to court disaster at least in part because they have often failed to identify vulnerability and risk, and thus failed to protect themselves and their livelihoods sufficiently from harm and loss.

Forces of weather encroach on societies with the ever-present risk of disruption, destruction and loss that people associate with the occurrence of extreme events. Every year, extreme weather, water and climate conditions intrude on the lives and critical functioning of millions of people living together in societies. They disrupt food production, access to water, public health, assured shelter, functioning institutional infrastructure, transportation, provision of essential supplies, individual personal livelihoods and the benefits of combined economic endeavour.

Natural hazards, such as wildfires, which occur and are fanned by specific climatic conditions; or avalanches, land-, mud- and debris slides which are generated or augmented by hydrometeorological conditions; or the complex association of hazards identified with climatic variation attributed to El Niño conditions or other seasonal anomalies and global warming, all display the powerful forces that can and do destroy the lives, livelihoods and physical infrastructure which humankind has otherwise created.

During 2006 there were 375 disasters with nationwide consequences. These disasters killed more than 20,000 people and caused USD18.3 billion worth of damage in 106 countries.[1]

In 2005, there were 650 major natural hazard events around the world, amounting to a record USD219 billion in losses. Although about 90 per cent of the 100,000 fatalities during the year were attributable to the Himalayan earthquake that struck Pakistan and India in October 2005, typically about 85 per cent of the disasters and more than 95 per cent of the losses were based on weather, water or climate-related hazards.

For Munich Re, the annual losses for 2006 alone totalled USD45 billion, around one-fifth of the previous year's figure. Dr Torsten Jeworrek, a member of Munich Re's Board of Management commented: "The fact nevertheless remains that, in the longer term, the number of severe weather-related natural catastrophes is set to increase due, among other things, to global warming. Combined with further increasing concentrations of values in exposed areas, this means continually rising loss potentials."[2]

During its 61st session, The UN Secretary General reported similar concerns to the UN General Assembly, highlighting that between June 2005 and May 2006 there were 404 disasters with nationwide consequences. That was 25 per cent higher than the average for the preceding 10-year period. Altogether, 115 countries were affected and the economic costs were 2.6 times the 10-year average, reaching USD173 billion. The number of floods was nearly 50 per cent higher and accounted for 97 per cent of these economic damages.[3]

These dynamic conditions call for expanded political leadership and enhanced technical capacity of practitioners from many professional disciplines. They also require information dissemination, awareness-raising campaigns and greater community involvement to motivate individual and collective behaviour to protect life-sustaining conditions from unnecessary loss. Educational opportunities, access to information and means of communications must reach, in their languages, communities in disaster-risk areas and become more instrumental in developing a 'culture of disaster resilience'.

How 'natural' are disasters?

Disaster reduction begins with the identification of natural hazards, recognizing the risks they pose to people, livelihoods and human settlements before they become a disaster. While these adverse circumstances are routinely referred to in a general sense as 'catastrophes' or 'disasters', it is useful to understand that a disaster can be elaborated further as 'a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.' This demonstrates that much can be done to minimize people's exposure to unnecessary harm and loss by enhancing their resources and capabilities. Despite the fact that the hazards or physical forces that generate these disasters may be natural in origin as cited above, resulting in the commonly used phrase of 'natural disasters',[4] a much wider importance needs to be given to minimizing the conditions that contribute to their most severe effects.

Any potential disaster is a function of the risk process, occurring from the combination of a physical hazard and the conditions of vulnerability or physical, social and economic exposure in which people live. The extent of public understanding about the natural hazards to which people are exposed to in a specific location, and the existing institutional capacities or operational abilities local communities possess, equally can reduce their exposure to threatening hazards. Technical knowledge and a variety of communications services are essential for maintaining such states of disaster preparedness and risk management.

While natural hazards are part of nature and cannot be avoided, there is much existing knowledge, technical, and professional experience already existing within societies that can be employed to minimize people's exposure to the threats posed by weather, water and climatic conditions and thus reduce disaster risk. Many of these abilities exist within the National Meteorological Services of all countries.

Given the nature of global weather and climate, as well as disaster risks which know or respect no political boundaries, it is essential that multi-disciplinary relationships dedicated to greater disaster awareness and risk management be created within and between countries through organized international structures like the United Nations International Strategy for Disaster Reduction (UN/ISDR).

Learning from disasters

Recent disaster events can illustrate some of the challenges as well as the opportunities for galvanizing a wider public recognition and motivating professional responsibilities and policy commitments in order to reduce future disasters. The tragic Indian Ocean tsunami of 26 December 2004, in which more than 230,000 people died and which devastated the livelihoods and property of millions more in the 12 countries directly affected, was a dramatic example of the rationale for education and effective early warning systems. Work has proceeded rapidly over the past two years to recover, with shared resources committed through the participation of many governments, international and local organizations, commercial businesses, NGOs, media and communications providers.

The global recognition of the practical value of early warning, and its feasibility to save people's lives at the time of a disaster was another direct benefit of the tsunami disaster. The international ISDR Platform for Promotion of Early Warning (PPEW) located in Bonn, Germany is dedicated to advancing the systematic development of 'people-centered' early warning systems. Through greater awareness and practical projects such as those showcased at the Third International Conference on Early Warning, held in Bonn in March 2006, these expanding institutional commitments bring together the linked responsibilities of risk assessments, hazard monitoring and warning services, means of communications and better-prepared communities.

Global early warning received a further boost by the request of UN Secretary General Kofi Annan to conduct a global survey of early warning systems to assess capacities, gaps and opportunities for building a comprehensive global early warning system for all natural hazards. Undertaken by a working group of the Inter-Agency Task Force of ISDR co-chaired by the World Meteorological Organization and the UN Office for the Coordination of Humanitarian Affairs, the resulting report was presented to the 61st session of the UN General Assembly in October 2006.[5] The report concludes that while some warning systems are well advanced, there are numerous gaps and shortcomings, especially in developing countries and in terms of effectively reaching and serving the needs of those at risk. It then recommends the development of a globally comprehensive system in support of existing early warning systems for various hazards. It also suggests a set of specific actions towards building national and local people-centred early warning systems, filling in the main gaps in global early warning capacities, strengthening the scientific and data foundations for early warning, and developing the institutional foundations for a global early warning system.

Only months after the Indian Ocean tsunami, the period of particularly numerous and intense hurricanes along the Atlantic and Caribbean coastal regions provided the unforgettable images of Hurricane Katrina's impact on New Orleans and nearby areas of the United States of America. Despite advanced technical capabilities and adequate advance warning of the various meteorological, hydrological, and even environmental and infrastructure threats involved, the severe policy, organizational and operational failures demonstrated the crucial importance of shared knowledge associated with the need for prior investment in risk management.

There extensive losses must lead to more mutually aware and effective actions between the public, technical practitioners and political leaders at multiple levels of responsibility. None of these professional disciplines, nor the various responsible sectors of society, can any longer remain secure in only relating to their own immediate, isolated, subject areas. Modern disaster risks demand much greater outreach and wider ranging relationships among technical professionals if their work is to have wide public merit.

The Himalayan earthquake spanning Pakistan and India in October 2005 demonstrated the severe consequences of weather and climatic conditions for relief and recovery activities as more than three million people lost their houses just as harsh winter conditions rapidly approached. Without minimizing the needs for effective and timely relief services, the long-felt implications of this Himalayan earthquake have demonstrated the limitations of relying only on emergency relief capabilities, as Pakistan now seeks to establish a comprehensive national approach to disaster risk awareness and management.

Other seasonal considerations and the need for wide ranging global communication capabilities were also apparent during the northern hemisphere's winter of 2005-06. The threat of a widespread global pandemic such as avian influenza, spread by such uncontrollable factors as wildfowl migration, is causing much political anxiety and frantic contingency planning. In more localized environments, such as in tropical Africa, the need for local communications between government authorities, health professionals, meteorologists and local community leaders has been recognized as crucial to capitalize on the well-known temporal relationship between weather conditions and the outbreak of serious malaria incidents.

Throughout this period, the growing concern about the effects of global warming, climate variation and change continued. The ten warmest years on record occurred during the period 1995-2006. In the words of Professor Peter Höppe, Head of Munich Re's Geo Risks Research, "No one seriously disputes climate change any more. In the long term, it will be a factor which increases the number of severe natural catastrophes."[6]

A UK Government report highlighted several possible consequences of climate change related to future disasters:[7]

- There will be more examples of extreme weather patterns
- Extreme weather could reduce global gross domestic product (GDP) by up to 1 per cent
- Floods from rising sea levels could displace up to 100 million people
- Rising sea levels could leave 200 million people permanently displaced
- Melting glaciers will increase flood risks
- Melting glaciers could cause water shortages for 1 in 6 of the world's population
- Wildlife will be harmed; at worst up to 40 per cent of species could become extinct
- Droughts may create tens or even hundreds of millions of 'climate refugees'
- Crop yields will decline, particularly in Africa.

These examples provide indications that both the nature and the potential magnitude of disaster impacts are changing, with far-reaching implications in global terms. These implications must drive together the interests of policy makers, national and local government authorities, business leaders, and professionals or practitioners engaged with disaster risks, climate, food production, or other natural resource use or stewardship. There needs to be a thorough reconsideration of how people in positions of responsibility understand the disaster risks that they are likely to be exposed to, and a much greater need to reach out and relate to other associated professional interests.

It becomes increasingly important too, to identify and relate to 'wider area networks' in spatial, professional and communications terms. In the inter-connected, globalized world of the modern era it is not even necessary for a crisis to occur in people's immediate environment for them still to be affected. This recognition needs to become the basis for wider public awareness, further education and systematic global arrangements in order to link future disaster reduction with the ideal of more secure and safer societies and to protect the development accomplishments and ensure sustainability.

Opportunities for action through the ISDR system

A key development in shifting global awareness towards a more active engagement in disaster risk reduction was the United Nations World Conference on Disaster Risk Reduction (WCDR) held in Kobe, Japan in January 2005, a few weeks after the Indian Ocean Tsunami tragedy. There, representatives of 168 countries adopted the *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters*.[8] This framework lays out a detailed ten-year plan to make disaster risk reduction an essential component of development policies, plans and programmes. The many subjects related to disaster risk reduction span abilities and concerns routinely identified within professional disciplines engaged with various development sectors, environment, hazard studies and risk management practices, as well as those of disaster or emergency management, response and recovery programmes.

As the basis for future accomplishment and an expression of the key elements of effective disaster risk reduction in practice, the Hyogo Framework puts forward three strategic goals which may serve as guiding principles in any efforts to advance future education for disaster reduction. It calls for the integration of disaster risk reduction into sustainable development policies and planning; the need to develop and strengthen institutions and capacities to build resilience to hazards; and the systematic incorporation of risk reduction practices into emergency preparedness, response and recovery programmes.

Most importantly, it provides a basis that commits governments as well as regional, international, and non-governmental organizations to reduce disaster risks through a range of possible approaches and activities presented in five priority areas for action. This framework provides an outline and elaborates many possible activities to be pursued by various actors that will necessarily be involved, practitioners of different professional disciplines in commercial, educational, public or private entities.

The five priority areas of action of the Hyogo Framework are cited below, with some suggestions whereby technical practitioners and professionals engaged in weather, water and climate practice can apply their knowledge and experience in the realm of disaster risk reduction.

1. *Governance* — to ensure that disaster risk reduction is a national and local priority with strong institutional basis for implementation:

- National Meteorological and Hydrological Services (NMHSs) can provide important leadership and support to participation in national disaster reduction platforms, given their long-standing institutional viability, public visibility and relationship with many social, economic and technical activities
- National climate change planning processes should become crucial instruments for wider disaster risk reduction commitments
- The trans-national aspects of weather, water and climate combined with extensive established and continuous international communications provides an existing network for disaster risk communications, and as may be required, mobilization related to disaster risks with neighbouring countries
- NMHSs should develop closer and interactive relationships with various other sectors involved in DRR for continuous exchange of information and development at local and national levels.

2. *Risk identification* — to identify, assess and monitor disaster risks and enhance early warning:

- The wealth of accumulated national historical data and analytical abilities existing within NMHSs provides a firm foundation to develop national or local hazard and disaster databases, essential for disaster risk assessments
- Specialized technical centres can provide institutional focus for disaster risk monitoring, analysis and communications for routine economic and commercial endeavours as well as early warning activities at time of specific threat
- Hazard identification, technical analysis and monitoring are inherent to effective early warning of potential disaster circumstances

- Existing NMHSs communications for technical data, sector-relevant information, and public information are critical elements for all aspects of disaster risk assessment processes and early warning practices. When associated with accumulated data and information resources, such communications facilities provide a basis for wider professional synergy and commercial engagement in managing disaster risks.

3. *Knowledge* — use knowledge, innovation and education to build a culture of safety and resilience at all levels:
- The extensive influence of weather, water and climate throughout societies provide considerable opportunities for the development and delivery of educational materials — for policy relevance, professional training, private and public educational curricula, and public information and awareness
- Opportunities abound to link weather, water and climate information and knowledge with wider societal awareness and policy commitments to disaster risk management opportunities — prior to the onset of (as well as following) emergency or crisis conditions
- Multi-disciplinary and wide-spread, policy relevant research agendas that relate to weather, water, climate, and disaster risks can be spearheaded by NMHSs, with particular relevance given to their shared economic, commercial or social implications
- Develop joint NMHS — educational institution programmes with research, learning, or professional training opportunities that marry weather, water, climate and disaster risk interests and insights.

4. *Reduce underlying risk factors* that increase the likelihood of disasters by involving ('mainstreaming') disaster risk awareness and management with other professional or sectoral subject areas:
- Associate climate and disaster risk interests, data and communications abilities within NMHSs explicitly with the roles and interests of other professional, commercial and policy requirements of related sectors, including those of:
  - Agriculture, animal husbandry, fisheries
  - Food processing and distribution
  - Water resource use and management
  - Environment, natural resource management
  - Health
  - Energy generation, distribution, and use
  - Transportation
  - Tourism, recreation and sports
  - Construction, engineering, critical public infrastructure
  - Information and communications technology
  - Space technology, remote sensing, planning and land-use analysis
  - Economics, financial investment, risk transfer, insurance
  - Social benefits, public information and engagement, community participation.

5. *Strengthen disaster preparedness* for effective response:
- Provide data and historical knowledge as contribution to the creation, review or revision of national disaster and risk management legislation, land-use regulations, zoning practices, etc
- Prior establishment of data and information requirements of governing authorities, emergency services and/or commercial interests related to disaster requirements in air, on land or water at the time of crisis or as may be appropriate for longer-termed climatic threats such as social and economic implications of El Niño, global warming, etc
- Prior established roles and capabilities related to data, information, analysis or research related to weather, water or climate and disaster risk implications following crisis management / emergency response event; post facto lessons learned and communicated to wider community of interests, within an immediate affected community, regional, national, provincial officials or metropolitan local authorities and/or specific business interests affected by the crisis.

The challenge now is to turn these many possibilities and opportunities into practical measures and activities at all levels, and within means by which progress in disaster reduction can be measured. Contrary to conventional public views, there is an abundance of technical knowledge, professional experience and even specific examples especially within the professional communities associated with weather, water and climate, that can guide and inform efforts to lessen disaster risks much more widely and with considerable effectiveness.[9]

A great need remains, however, to sustain the allocation of resources and to realize institutional capabilities to use, and to share more widely, what is already known, so that more people may be safe from disasters by reducing their vulnerability to natural hazards.

Photo: Mr. Jorge Jenkins, PAHO

El Salvador Earthquake, 2001

Learning new methodologies to deal with large disasters: near space monitoring of thermal signals associated with large earthquakes

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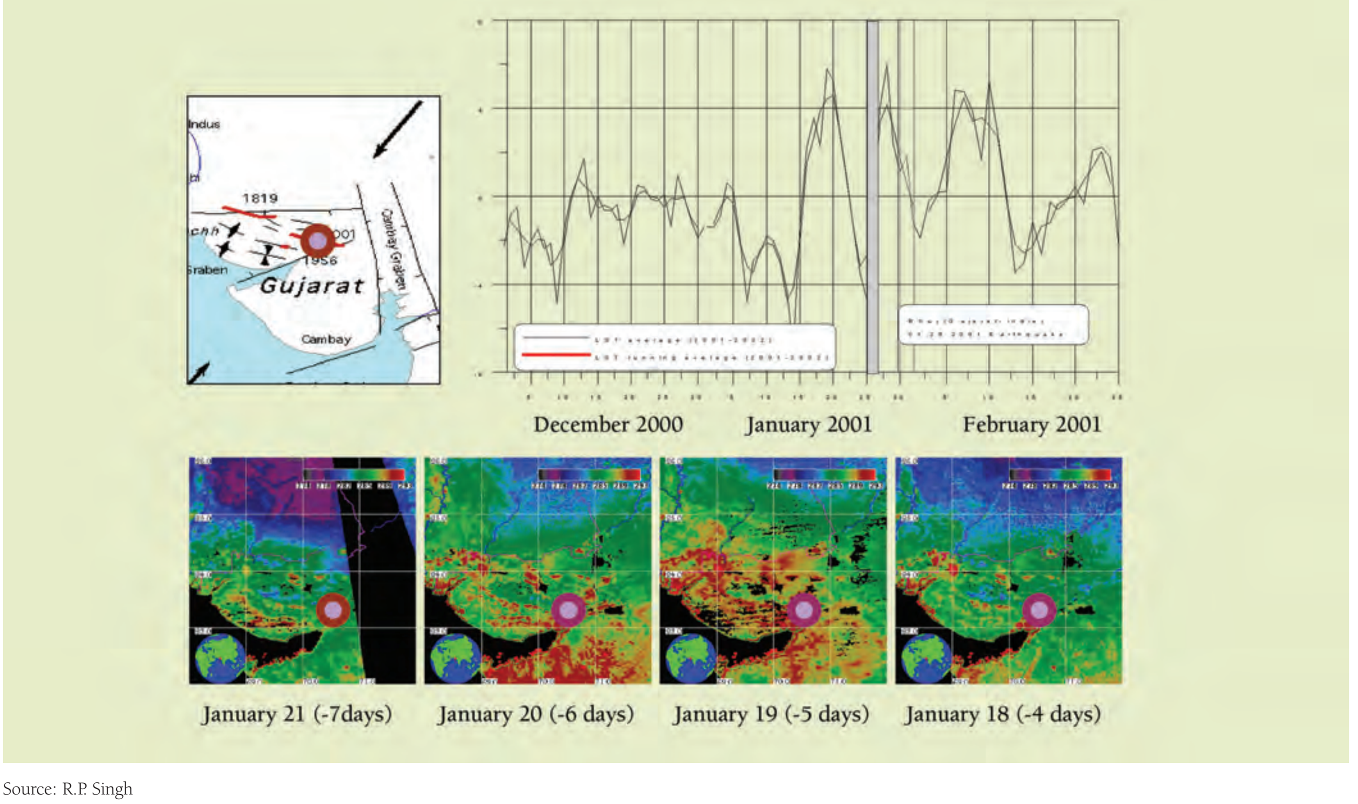
Approximately once a year, a catastrophic earthquake — measuring magnitude 7.0 or greater on the Richter scale — strikes somewhere on Earth. These quakes can claim thousands of lives, cause billions of dollars of damage and trigger tsunamis, floods, and landslides in their wake. The destructive potential of these catastrophic earthquakes has increased in recent years with the emergence of large cities, high dams and other facilities whose destruction would pose an unacceptable risk to society. It is generally accepted that a successful effort to reduce the risk associated with earthquakes and other natural disasters will require the convergence of a wide variety of knowledge and observations, including the latest in space technology and remote sensing. The growth in global earth observations and the maturation of the Global Earth Observation System of Systems (GEOSS) may make such a convergence possible in the near future, and allow the benefits of an integrated earthquake monitoring system to become a reality.

There have been numerous studies and publications identifying electromagnetic (EM) anomalies associated with pre-seismic activity, and several theories have been formulated to explain their causes. There is a strong indication that development of an earthquake hazard prediction scheme requires diverse interdisciplinary and integrated efforts. Such an inte-

Time series mean nighttime MODIS/Terra LST, 100x100 km anomaly, comparing 2001 vs 2002 over the Bhuj, Gujarat region, M7.6 Jan 26, 2001



Source: R.P. Singh

grated, interdisciplinary approach is advocated by US seismologist Ari Ben-Menahem, who said: "Unless we launch a concentrated interdisciplinary effort, we will always be surprised by the next major earthquake."

Current scientific research indicates that satellite thermal imaging data has not only revealed stationary (long-lived) thermal anomalies associated with large linear structures and fault systems in the Earth's crust[1] but also transient (short-lived) features prior to major earthquakes.[2] These short-lived anomalies:

- Typically appear between four and fourteen days before an earthquake
- Affect regions of several to tens of thousands of square kilometres
- Display a positive deviation of 2-4 degrees Celsius or more
- Die out a few days after the event.

These anomalies are not simply the result of thermal variations caused by a heat pulse rising from below the Earth's crust, as the speed at which the anomalies appear and disappear is much more rapid than what is seen with a heat pulse.

Feasibility of space observations for earthquake studies

Observational and scientific evidence collected over the last 20 years confirms that EM phenomena often accompany or precede earthquake events. Recent studies also confirm that there is strong coupling between EM activity in the atmospheric boundary layer and the ionosphere — both direct coupling through EM phenomena and indirect coupling through tectonically forced vertically propagating gravity waves that are strongly related to enhanced tectonic activity. The concept of lithosperic-atmospheric-ionospheric coupling (LAIC)[3] links increased gas emanations in advance of seismic activity to a chain of physical processes involving ionisation of air molecules and plasma chemical reactions in the ionosphere. LAIC views the ionosphere as part of the global electric circuit, and suggests that the ionosphere immediately reacts to changes in electric properties near the ground. A number of different spacecraft have detected these kinds of phenomena from space over the past few decades.

It is unlikely that any single existing method for advance earthquake detection — for example magnetic field, electric field, thermal infrared, surface latent heat flux (SLHF), and global positioning system (GPS)/total electron count (TEC) – can provide sufficient information to detect potential earthquake phenomena from space on a global scale. Rather, the envisioned solution would bring together a number of different satellite Earth observations and ground measurements in an integrated 'sensor web' to provide the information necessary for advance warning of tectonic events.

Using TIR measurements to detect earthquakes

Thermal infrared (TIR) measurements are a possible method of detecting earthquakes in advance from space. The increased number of satellite measurements (including a number of National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) satellites) of surface temperature at different infrared wavelengths in recent years has opened up this 'thermal brand' of detection techniques. TIR surveys gave an indication of the appearance — from days to weeks before the event — of anomalous space-time TIR transients that have been associated with the location (epicentre and local tectonic structures) and time of a number of major earthquakes with a magnitude greater than 5.0 and a focal depth of less than 50 km.

NASA analysed data from a number of satellites including: NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua; NASA's Atmospheric Infrared Sounder (AIRS) on Aqua; NOAA's Geostationary Operational Environmental Satellite (GOES) and Polar Orbiting Environmental Satellites (POES); the French Centre National d'Etudes Spatiale's Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions (DEMETER); and ground observations The rationale for using this ensemble of observations was sufficient spatial and temporal coverage of precursor signals to enable correlations to past earthquake events.

Bhuj, India

On 26 January 2001, a magnitude 7.7 earthquake struck Bhuj (Gujarat), India. The quake occurred during a period of clear weather, which is ideal for TIR observations. NASA analysed data fromTerra/MODIS, which observes the Gujarat region twice a day. As shown in the image above, the main stress was released along the Katrol Hill and Mainland faults.[4] The time series in the upper right shows the average land surface temperature (LST) anomaly (departure from average) as measured by the nighttime overpass of Terra/MODIS from December 2000 to February 2001 as well as a running average that smoothes out some of the more extreme values — the day of the quake is shaded in grey. The time series shows that there is a pronounced and statistically significant positive LST anomaly, with temperatures running up to 4 degrees Celsius above the average background values. This anomaly starts five to six days prior to the quake in the area within 200 km of the epicentre.[5] Shown in the bottom portion of the illustration are a series of images from Terra/MODIS taken between 18 January and 21 January that show the evolution of the LST anomaly over a 100 km^2 region a few days prior to the quake. The anomalously high temperature values are observed over this period, and values return to near normal on 22 January. This kind of anomaly could be associated with stress-related changes of air near the ground in response to the release of radon gas and changing humidity levels. (Water vapour and radon would be highly absorbed in the 10-11 µm range).[6]

Colima, Mexico

On 21 January 2003, a magnitude 7.8 earthquake struck Colima, Mexico. NASA used a variety of independent data sources to analyse the atmospheric variations caused by the quake. For this analysis, we had access to data from MODIS on both Terra and Aqua — Aqua had not yet launched at the time of the Gujarat eruption — and we also analysed ground-based temperature data. The appearance and temporal evolution of the atmospheric variations are synchronised in time and demonstrate a similar spatial distribution in all of the datasets used. Using nighttime emissions from polar orbiting satellite data, we have analyzed the LST data over 90 days by means of the 11-12 metre emissivity ratio covering an area of 100 km^2 around the epicentre.[7]

The graph illustrates the variations of the nighttime LST for Terra (curve A) and daytime LST for Aqua (curve B) for the period from 1 December 2002 up to 1 March 2003 for the square 100km^2 around the Colima epicentre. Between 15 and 17 January, a pronounced LST increase can be observed for the area close to the epicentre of the event. To verify the significance of this enhancement we built the yearly LST anomaly between 2002 and 2003.

LAIC concept can explain the existence of the TIR anomalies prior to major earthquakes. Using the collected experimental data, we can reconstruct the possible evolution of the atmosphere-ionosphere anomalies preceding the Colima earthquake. From the end of December 2003 we observe nighttime surface temperature increases in the area of the earthquake preparation (Curve A). One can associate this anomaly with the start of the possible radon gas anomaly — the heating starts in the surface ground layer. Then the gases appear in the near surface layer of the atmosphere and heating becomes noticeable on the daytime records of MODIS and on the records of the local meteorological observatories (Curve D). The thermal air anomaly reaches its maximum in the middle of January and is accompanied by the absolute monthly minimum of the relative air humidity.[8]

In summary, the complex analysis of TIR satellite data retrieved by polar orbiting satellite measurements around the time of selected earthquakes reveals that transient TIR anomalies occurred prior to these earthquakes and confirmed the earlier findings. The process starts along the main tectonic fault zone and variations could be seen in a radius of approximately 100km around the epicentre over the land and sea. The optimal conditions for detecting similar anomalies are dry, cloud-free, low-vegetation scenes with a long observation baseline. Independent techniques based on different Earth observation satellite sources confirms the existence of positive TIR anomalies prior to strong earthquakes, characterised by different seismo-tectonic settings. This outcome could be used as basis for theoretical studies refining the mechanism of these phenomena and for creating a new layer of a global earthquake monitoring system which could benefit the current seismic regional network and have huge economic and societal effects on the building of early warning systems over the major hazardous regions.

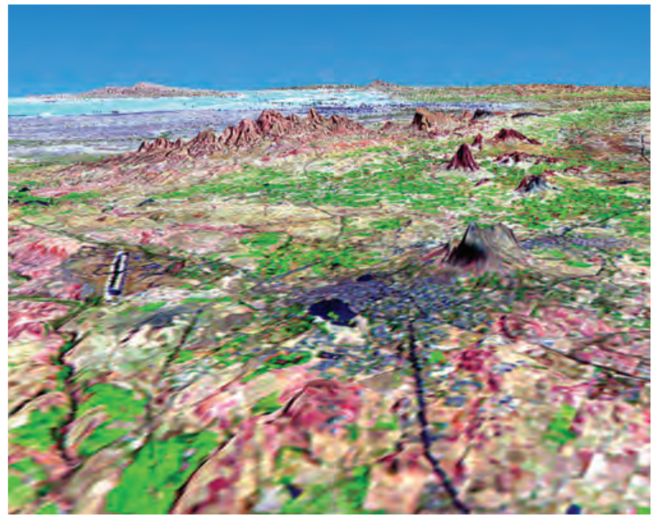
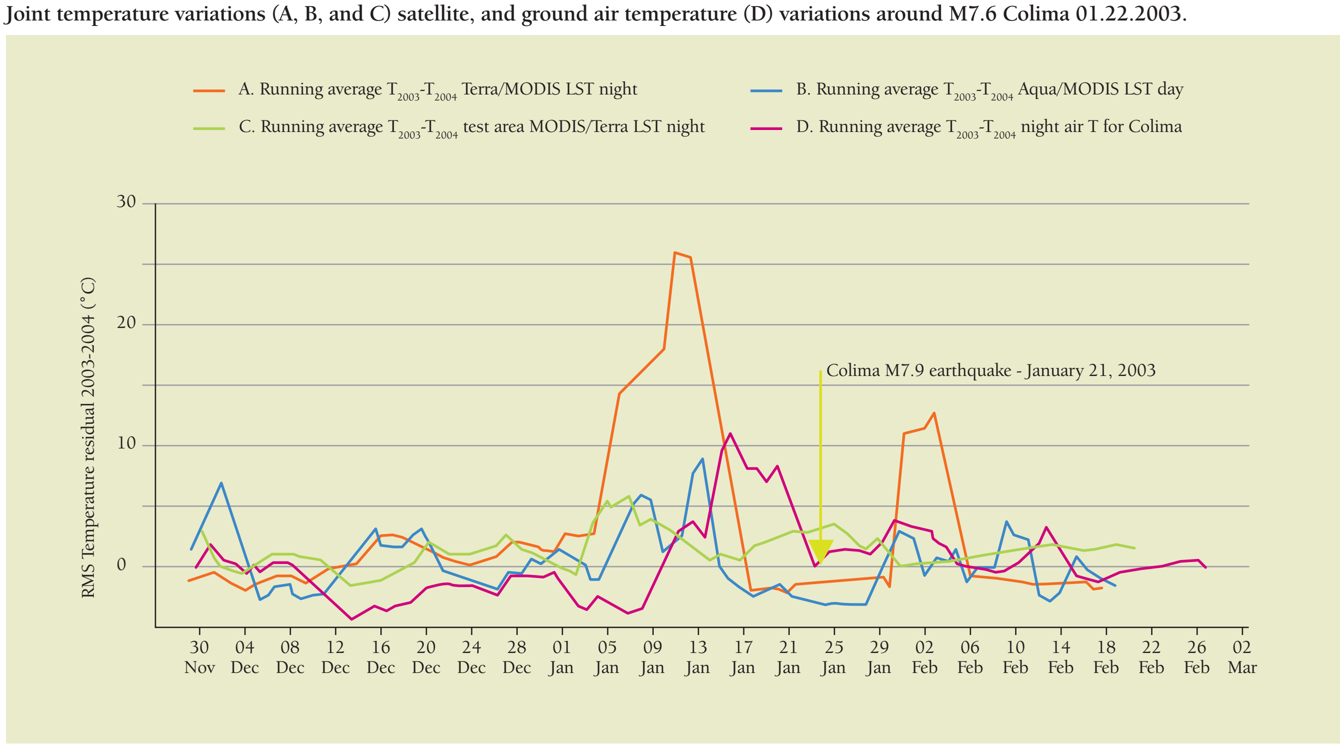


Photo: NASA/JPL/NGA

Bhuj earthquake 2001: Image created by combining Landsat 7 and SRTM data. The gray area in the middle of the picture shows the city of Bhuj, which was almost completely destroyed

Earthquakes have significant impacts on society through the destruction they bring. A local earthquake has the potential for global impact when one includes societal loss in production, energy, health, food and water resources. The ability to sense earthquake potential could have enormous benefits for society if the information is used intelligently to relay risk potential. Much more research is needed in this area, but it certainly offers a great deal of potential and should be an area fully supported by the science community. We advocate a sizeable increase in the Earth observations used for land remote sensing. This will allow us to understand the uncertainty in such predictions, and realise the social science impacts of earthquake prediction.

Joint temperature variations (A, B, and C) satellite, and ground air temperature (D) variations around M7.6 Colima 01.22.2003.



Source: NASA

Disaster mitigation and preparedness: flood forecasting and warning

Mr Bruce Stewart, President, WMO Technical Commission for Hydrology

There have been many recent studies suggesting that losses due to flooding have increased over the past twenty years. Some studies claim that these losses have been increasing at a faster rate than growth in population and economic development. This in turn suggests that the number of people in danger, the amount of property at risk and the frequency of severe events may also be growing.

Flood forecasting and warning systems are an integral part of emergency and floodplain management. Effective flood warning systems maximize the opportunity for the implementation of response strategies aimed at securing the safety of people and property, and reducing avoidable flood damage. The total flood warning system concept has been promoted to represent all of the elements of a system that need to work together to provide effective forecasts and warnings. The total system includes elements of monitoring, prediction, interpretation, message construction, communication and protective behaviour. For flood warning systems to be effective, they must provide information for emergency service groups and the public, that is timely, accurate, easy to understand and clear in its practical application.

Specific requirements will depend on local conditions, including the scale of the problem and the level of access to information. However, as a general principle, initial requirements are:

- Advance warning of when a river will reach a specified height that will cause flooding
- Sufficient warning lead-time for appropriate protective action to be taken
- Awareness of the potential future level of flooding
- Assure awareness of the flood risk in the threatened community.

Basic hydrological information, river height and flow, catchment modelling capabilities and any additional weather information that will contribute to the warning lead-time are essential factors to the forecast and warning agency.

Concerns of information providers and user expectations

The primary issues and concerns for information providers include the operation and maintenance of monitoring systems, the quality of modelling capabilities, the accuracy (measure of uncertainty) of the forecast and the amount of warning lead-time that can be provided. In particular, key steps undertaken by information providers include the operation of in-situ monitoring and measuring devices (both rainfall and river level) and the

Flood impact is usually widespread

development of hydrological models that can use current and forecast information to provide estimates of future flood levels.

Information users including the emergency services, industry, the community at risk and the media, are primarily concerned with access to the information, its accuracy, and understanding the actions they need to take. Users expect to receive accurate and timely information on which they can make specific decisions and undertake prescribed actions, such as providing supplies and equipment, prompting evacuations or building sandbag levees. Users also need information on the expected period of inundation, the possibility of follow-up events and the status of key services such as power, water supply and sewerage.

A further issue is that providers need to be prepared to 'persuade' users. Users must be sensitized to the information that will be provided, so that they are ready to take the right action. Public education also plays a role here, but it is not the whole story.

In the case of floodplain management, users require advance information on areas and services at risk of flooding. This allows them to undertake appropriate and effective land-use planning, thus mitigating the impacts of future flooding. Such information is also valuable in the development and construction of physical flood control works. However, a balance between structural and non-structural measures aimed at 'living with floods' is promoted.

How to optimize information delivery

Delivery processes usually fall into 'push' or 'pull' mechanisms. Because of the need to deliver information promptly and efficiently to all of the required recipients, most information is provided using push techniques. These will vary from situation to situation, but include facsimiles, phone calls, SMS messages, e-mails, sirens, loud speakers, radio, television and word of mouth. The delivery mechanism will depend on the characteristics and location of the community at risk, the amount of lead warning time required and the capabilities and limitations of the early warning system in place.

Consultation and communication are therefore the key elements in determining the optimum delivery mechanism in each case. This must involve discussions and input from all of the responsible authorities and stakeholders, and in particular the community at risk. National Meteorological and Hydrological Services, water authorities, emergency service agencies and local government groups must work together to develop and implement sound and sustainable systems. The community at risk must understand when it is best to implement prescribed actions, and the possible consequences of such actions. The media can therefore play a significant role by warning of danger, but also by contributing to community education and preparedness.

The importance of community awareness should not be overlooked. The use of pamphlets, fridge magnets, newspaper articles, school education programmes, television shows and community groups should be strongly considered. In particular the Internet is invaluable as both an information source and a service delivery mechanism.

Bridging the gap between users and providers

A healthy relationship between users and providers is essential, but presents numerous challenges. A fundamental, shared understanding of the risk that floods represent is needed. This includes the recognition that floods are event-based and can occur at any time, but also that there can be long periods between events, during which awareness can decline.

In a more practical sense, it is imperative that the maintenance and operational capability of service providers is ensured, and that users understand the importance of the sustainability of these systems. Furthermore, users must be aware of, and grasp the implications of the capabilities and limitations of the warning systems. This includes the vital understanding that the total system will only be as strong as its weakest link, and therefore all components must be regularly reviewed and examined. Lastly, both parties must appreciate that advances will require an investment in research to improve the scientific and technical facets of the service.

Service providers, of course, have an equal responsibility to maintain the relationship. They must understand the specific requirements of the users in each situation, determine the key trigger points as well as when and what type of action should be taken. However, it is also necessary to consider social and cultural issues. There is no one specific solution for all situations, and even within a community, vulnerabilities differ and thus require different approaches for the effective warning of each group. There should also be common recognition that with growing populations and economies, and also the possible implications of climate change, the community at risk may be increasing and therefore that problems can arise in previously unaffected areas.

Ultimately, success relies on a balance in the relationship between the users and providers. Vitally, contact must be maintained between the two. Most users and providers have other roles and responsibilities, and therefore interaction and coordination must be formally set in place and regularly reviewed. It is also vital to recognize the important role of the media in the provision of services, and to consider how to optimise this under current arrangements. Finally, adequate feedback and event review mechanisms must be implemented, with the conditional understanding that mistakes will occur and that while negative consequences can be minimized through the application of risk management approaches, having resilient community structures in place to learn from such failures is also essential.

Floods affect significant sections of the community

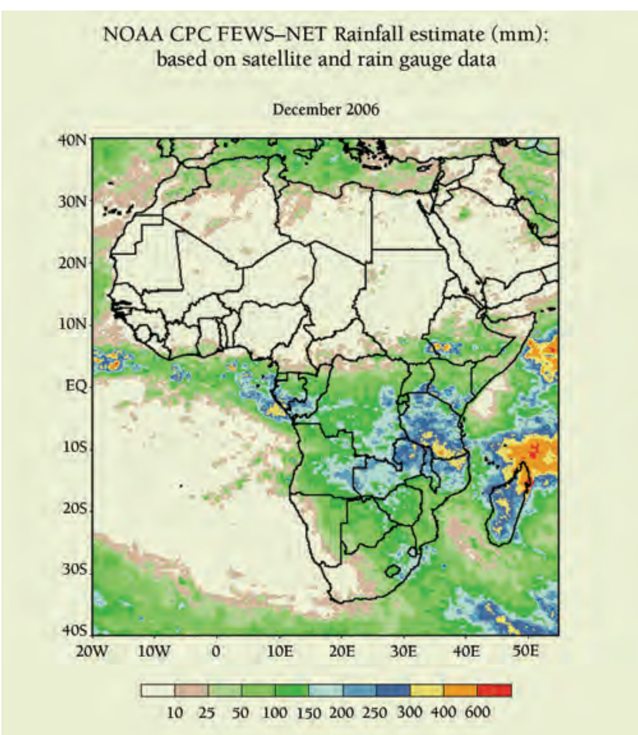
Satellite remote sensing for early warning of food security crises

Molly E. Brown, NASA Goddard Space Flight Center

Solving complex human environment problems has increasingly required that organizations employ interdisciplinary strategies.[1] Organizations that have been able to successfully integrate data and ideas from both the social sciences and the physical sciences are of particular interest to remote sensing data producers seeking to demonstrate the societal benefit of their work. The US Agency for International Development's (USAID) Famine Early Warning System Network (FEWS NET) uses biophysical datasets to inform the political process of humanitarian aid and response to food security crises in the developing world.

Interdisciplinary organizations such as FEWS NET face many challenges, among them a large and continually changing body of stakeholders; working with and understanding diverse concepts; finding a common language to communicate ideas and strategies; trusting research that many team members haven't the skills to assess, and having strong leadership to ensure mission success and ultimately continued funding. How these challenges are met will have a significant impact on the organization's ability to continue to secure funding and to be successful in achieving its mission.

Rainfall data from the National Oceanic and Atmospheric Administration's Climate Prediction Center's rainfall estimate in mm during the month of December, 2006



Source: NASA

As a long-standing USAID-funded project, FEWS NET provides an example of the processes and methodologies required for a large interdisciplinary decision support system. FEWS NET has recently been reauthorized until 2009, and since its inception in the mid-1980s, has used state-of-the-art social science methodologies for food security monitoring, coupled with advanced models, satellite measurements and geographic information system (GIS) technology for monitoring threats to food production and biophysical hazards. FEWS NET provides decision support to a wide range of decision makers, from heads of international organizations to local and national decision makers who require specific, integrative analysis for small geographical areas. By focusing on the food security impact of biophysical variations, FEWS NET is able to connect images of remote sensing to their impact on the lives and livelihoods of local residents.

Satellite remote sensing data from NASA are used in many aspects of FEWS NET's work. By providing spatially complete, accurate, and timely data, NASA contributes significantly to the ability of the humanitarian field to provide appropriate decision support to a wide variety of decision makers. In a complex decision-making environment, remote sensing information provides a robust foundation upon which consensus regarding the needs and hazards facing a particular community can be built. Although FEWS NET has a broad range of other information sources, remote sensing information remains a critical input to their analysis.

USAID's Famine Early Warning System Network

The goal of FEWS NET is "to provide decision makers with accurate, timely and actionable information to prevent hunger-related deaths, mitigate food insecurity, and strengthen livelihoods in Africa, Central America and the Caribbean, and Afghanistan through providing early warning information related to food security threats, developing information networks, and building capacity for information generation and dissemination".[2] FEWS NET involves an intergovernmental agreement between USAID, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the US Department of Agriculture (USDA) and the US Geological Survey (USGS).

Although FEWS NET activities conducted in the participating organizations are important to its ability to provide data and analysis, FEWS NET decision support and reporting are carried out primarily by a USAID contractor which employs most of the social scientists involved in the project, as well as the FEWS NET local representatives in the field. Data products and dissemination mechanisms are focused on ensuring that effective products are developed and the right people see them promptly. By defining FEWS NET's primary audience as local decision makers, locally relevant, actionable policy information is generated which can then be disseminated to audiences at a variety of decision-making levels — local, regional, and international.

Linking early warning activities to effective intervention requires both short- and long-term actions.[3] Short-term response to an identified hazard involves preparedness and contingency planning that allow immediate response to the situation. FEWS NET has become increasingly involved in contingency planning as a method of generating relationships with local government actors and decision makers who are the audience for its products and therefore must be involved in any determination of and response to crisis conditions.[4] Participation of local decision makers, national government agencies, and non-governmental personnel is critical to achieving FEWS NET's goal of reducing the loss of lives and livelihoods during food crises. Contingency planning and the strengthening of networks of decision makers will ultimately reduce overall vulnerability to these climatic hazards.[5]

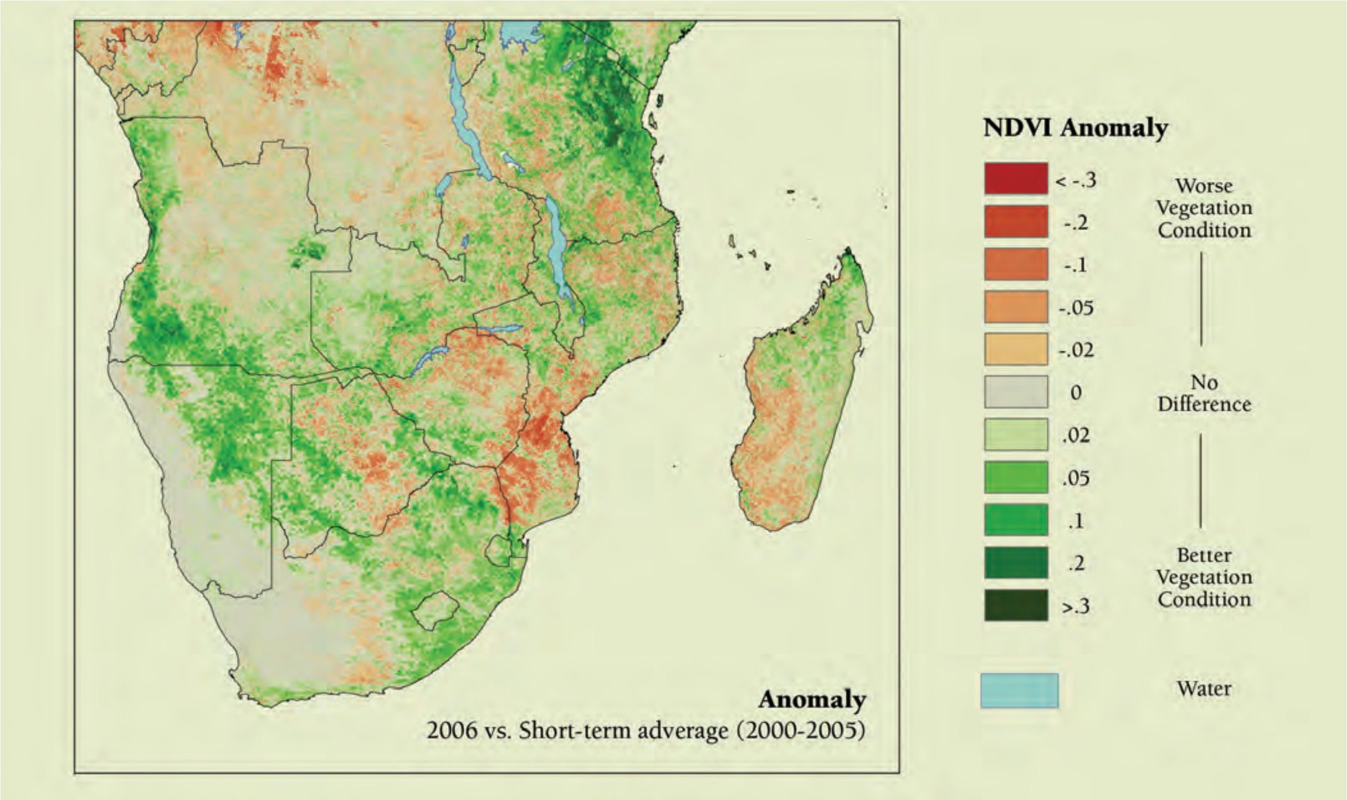
Food security has three main components: food availability, food access, and food utilization. FEWS NET focuses on collecting data on food availability from biophysical parameters and food access through socio-economic datasets. Other organizations investigate food utilization, for example the individual's ability to use the food they eat effectively. The next two sections describe the data and processes that FEWS NET uses to provide decision support.

Remote sensing in FEWS NET analytical processes

Biophysical data provides information on the yields of the food production equation, and threats to pastoral resources and ultimately to the agricultural economy as a whole. To identify abnormally wet or dry periods, FEWS NET relies on data on vegetation, temperature, and rainfall derived from remote sensing and local measurements when they are available. Currently, the FEWS NET early warning function begins with a weekly assessment process that includes members of NASA, NOAA, USGS, USDA, USAID, the University of California at Santa Barbara (UCSB), and a variety of technical specialists in Africa, Central America, and Afghanistan. The data includes precipitation gauges and gridded data from merged satellite models; vegetation data from the Advanced Very Hight Resolution Radiometer (AVHRR), Système Pour l'Observation de la Terre (SPOT), MODIS and Landsat; gridded cloudiness products; global climate indicators; precipitation forecasts (24-72 hours); modelled soil moisture; gridded fire products; snow extent products; hydrological models for flood forecasting; and seasonal forecasts.

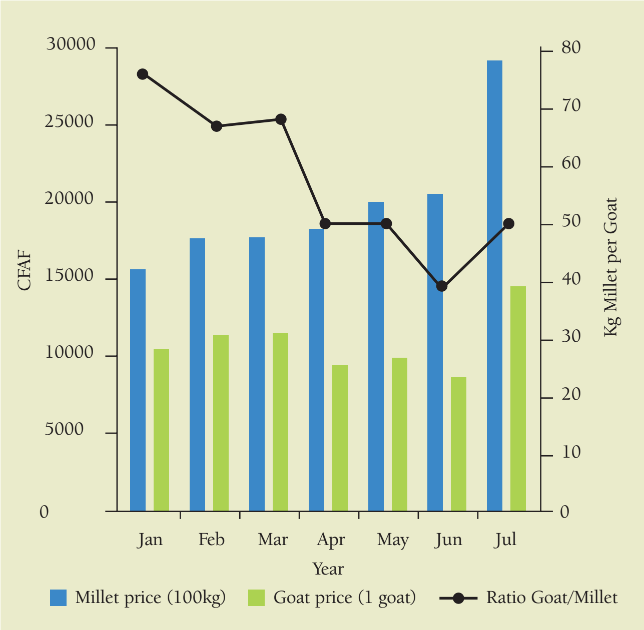
Rainfall has been used extensively to drive many models, but rainfall measurements are notoriously prone to errors. Errors can occur in approximating the degree of cloudiness, the amount of rain that has fallen from these clouds, the intensity of the rainfall, the impact of topography on rainfall, the sensitivity to the density of the rainfall measurements and accuracy of local rainfall gauge measurements, and other effects which result in significant random error and non-negligible bias.[6] Fortunately, scientists have found a much more stable proxy for rainfall measurement. In addition to making rainfall

Vegetation data anomaly from MODIS for southern Africa, from 19 Dec 2006 – 03 Jan 2007



Source: NASA

Analysis of the terms of trade for pastoralists and farmers in Niger seeking to sell livestock to augment food supplies



Source: NASA

measurements, they also use normalized difference vegetation index (NDVI) measurements to assess the impact of rain on local vegetation. NDVI data derived from satellites measure the photosynthetic activity resulting from vegetation growth that occurs as a result of rainfall, and are an important source of information for FEWS NET.[7] Because they measure very different things, both variables continue to be of value to hazard identification.

Members of the many FEWS NET organizations teleconference weekly to discuss and identify potential flood and drought hazards, and then prepare and issue weekly weather hazard reports, which are posted on the FEWS NET site.[8] These reports are delivered to a large local, regional, and international audience in Africa, Latin America, Asia, and in the United States. They provide information that indicates where more intense, on-the-ground monitoring should occur. The weekly weather hazard discussions are led by the meteorologists at NOAA's Climate Prediction Center, and guided by FEWS NET food security experts who orient hazard discussion towards identifying its affect on local livelihoods.

By collaborating with scientists from NOAA, NASA and USGS, as well as with FEWS regional and country representatives and the USGS FEWS NET regional representatives, expert FEWS personnel work together to determine the impact of these weather hazards on local communities. This is done using a livelihoods-based analysis system that provides the framework for interpretation of routine monitoring data, for example rainfall, vegetation, crop production, and market prices. These monitoring data are valuable indicators of food security, but it is difficult to link changes in these indicators to changes in the food security status of affected households.[9]

Using remote sensing data constructively in a complex environment

The FEWS NET activity is on its fifth reauthorisation at USAID, and in the next phase FEWS NET will be charged with continuing its current activities, expanding its geographic scope, and increasing the types of issues it reports on. This extraordinary length of experience coupled with the diversity of its interagency and international partners make the FEWS NET project worthy of study. Although FEWS NET is unable to solve the underlying structural and fundamental problems of the humanitarian and development sector, it plays a key role in helping to prevent people from perishing in crises, and ensuring that these crises are not ignored by the wider world.

The need for FEWS NET reporting is projected to continue to increase, and as it does it is crucial that the information and presentation of its decision support analysis be as audience-focused as possible. In many regions, FEWS NET is operating in a continually worsening environment, where environmental hazards, increasing populations, and declining investment in local data and information gathering, holding and reporting activities result in increased reliance on outside sources of information. Working in concert with multiple governmental and non-governmental development agencies, FEWS NET continues to play a key role in information gathering and distribution for early warning of food insecurity in the regions in which it works. The credibility of the information it produces is one of FEWS NET's primary assets in its role of consensus building. Remote sensing information and analysis remains at the centre of these efforts, as it is the foundation upon which FEWS NET's hazard identification and food production analysis rests.

Examples of satellite contributions to humanitarian action

There are numerous examples that demonstrate how data from Earth-observing satellites have been used in data-sparse regions of the Earth, improving estimates of food aid needs in vulnerable areas. The following are some brief examples of the existing products that have contributed to decision support.

Snow depth for water available for irrigation — The product is used in estimating irrigated water supply and ultimately food security for the northern regions of Afghanistan. Due to an early melt of the snow pack in the spring of 2006, food prices increased significantly in northern Afghanistan following the harvest. Coupled with a shortage of animal food, livestock prices have decreased by 30-40 per cent in the northwestern provinces. These factors together have increased food insecurity, and the remote sensing data has provided a good understanding of what was happening in an otherwise inaccessible region.

Extreme rainfall impacts on crop production in Honduras — NASA data informs hazard analysis in Honduras, a country that is very vulnerable to severe tropical weather. Basic grains, African palm, banana trees, and sugar cane are particularly at risk from damage caused by heavy rainfall throughout the country. Immediate hazards to citizens from floods and landslides are also monitored. Heavy rains increase the risk of crop plagues and disease (such as oidium) which can result in crop losses between 25 and 30 per cent.

Crop production monitoring using MODIS data — MODIS anomalies from a five-year mean are used to estimate crop production anomalies and pasture deficits in semi-arid regions of West Africa. The five-year mean from 16-31 October 2006 in West Africa indicated strongly positive conditions enabling a recovery of food insecure regions of Niger.

Climate change, flooding and the protection of poor urban communities in Africa

Ian Douglas, Emeritus Professor, School of Environment and Development, University of Manchester, Jack Campbell and Yasmin McDonnell, Emergencies and Conflict Team, ActionAid International

In new research with slum dwellers in six African cities, ActionAid has uncovered that there are few, if any, collective mechanisms for reducing flood risks or for managing floods once they do happen. Instead, poor people are left to fend for themselves however they are able.[1]

Urbanization and climate change in Africa

Environmental refugees are already swelling the tide of rural-to-urban migration across Africa. The trend is expected to increase as climate-related drought and floods intensify and grow more frequent, and rural Africans seek a more secure life in the city. By 2030, the majority of Africa's population will live in urban areas. However, global warming is also bringing increased chronic flooding to the cities, increasing the vulnerability of the urban poor throughout Africa.

Already the urban poor have no choice but to build their homes and grow their food in hazardous places such as river flood plains. Others construct their shelters on steep, unstable hillsides, or along the foreshore on former mangrove swamps or tidal flats. Whether already vulnerable to destructive floods, damaging landslides or storm surges, climate change is making the situation of the urban poor worse.

The right to adequate housing and 'continuous improvement of living conditions' was recognized more than three decades ago by the governments that ratified the International Covenant on Economic, Social and Cultural Rights. Six years ago, at the UN Millennium Summit, world leaders set a specific target for realizing that right by pledging to achieve 'a significant improvement in the lives of at least 100 million slum dwellers' by 2020. However, in Africa — the world's fastest

Photo: Gideon Mendel/Corbis/ActionAid

Flooding in Lagos, Nigeria

urbanizing region — climate change is already threatening that goal, putting the continent's already strained urban cities under additional stress.

Flooding in urban areas is not just related to heavy rainfall and extreme climatic events, but also to changes in the built-up areas themselves. Urbanization aggravates flooding by restricting where floods waters can go, covering large areas of ground with roofs, roads and pavements, obstructing sections of natural channels, and building drains that ensure that water moves to rivers more rapidly than it did under natural conditions. As people crowd into African cities, these human impacts on urban land surfaces and drainage intensify. Even quite moderate storms now produce high flows in rivers because more of the catchment area supplies direct surface runoff from its hard surfaces and drains.

Flooding from rising sea levels as a result of climate change is a potential hazard for the quarter of Africa's population living in coastal zones.[2] It is estimated that the average annual number of people in Africa impacted by flooding could increase from one million in 1990 to 70 million in 2080.[3] The capital of The Gambia, Banjul, could disappear in 50-60 years through coastal erosion and sea-level rise, putting more than 42,000 people at risk.[4]

Trends in urban flooding in Africa

Many African cities have experienced extreme flooding since 1995. Heavy rains and cyclones in February and March 2000 in Mozambique led to the worst flooding in 50 years and brought widespread devastation to the capital city, Maputo. Upwards of one million people were directly affected. Water and sanitation services were disrupted, causing outbreaks of dysentery and cholera.

In Ethiopia in August 2006, floods killed more than 100 people in the capitalAddis Ababa, and destroyed homes in the east of the country after heavy rains caused a river to overflow. The overflowing Dechatu river hit Dire Dawa town at night drowning 129 people and wiping out 220 homes.

The clear messages emerging are that:

- Urban flooding is becoming an increasingly frequent and severe problem for the urban poor
- Climate change is altering rainfall patterns and increasing storm frequency and intensity, thus increasing the potential for floods
- Local human factors, especially urban growth, occupation of flood plains and lack of attention to waste management and maintenance of drainage channels, are also aggravating the flood problem.

Case study: Kampala, Uganda

In Kampala, Uganda, construction of unregulated shelters by poor inhabitants has reduced infiltration of rainfall, increasing runoff to six times that which would occur in natural terrain. Some of the increase is probably due to climate change, but some is the direct result of land cover change.

Fifty-nine-year-old Masitula Nabunya, of Bwaise III Parish in Kampala said that after the 1960 floods a channel from Nsooba to Lubigi was dug and workers were employed to clean it regularly. There were no further flood problems until the 1980s, but since then she has had to rebuild her house after flooding six times. Flooding in these places is now much more frequent, every small downpour appearing to produce intense flooding. Some of this is because the main drainage channel, originally two metres deep, is now only 30 cm deep due to an accumulation of sediment and rubbish. It is also linked to the increased number of houses which yield much more runoff from a given quantity of rain.

Local Kampala people claim that floods are now more frequent and more severe. The flooding used to occur in predictable cycles in the two main rain seasons of April-May and October-November, but now occurrences have become erratic and unpredictable

The response to floods in July 2006 was characterized by ad hoc individual short-term efforts to survive and protect property. In addition, some residents undertook collective work to open up drainage channels, some temporarily moved to lodges and public places like mosques and churches until the water level receded and others constructed barriers to water entry at the doorsteps. Some made outlets at the rear of their houses so any water entering their homes flowed out quickly. There were limited collective efforts at the community level, and virtually no significant intervention by the relevant local government at the division level.

What helped the residents most was the fact that the rains that caused the flooding were not the continuous peak rains that last several days, such as those experienced in April and November. What limited the response of the residents was the fact that almost all activities were uncoordinated, and were at the individual level.

Case study: Maputo, Mozambique

In Block 40B of the Luis Cabral slum neighbourhood of Maputo, Mozambique, residents argue that flooding has worsened since 1980, pointing out that the 2000 floods completely destroyed the area. A single one-day rain event can cause floods that persist for three days. If the rains persist from three days to one week, the water depth rises to one metre and it may take a month to disappear.

Girl affected by flood

Photo: ActionAid Sierra Leone. Freetown, Sierra Leone

Case study: Accra, Ghana

Women in Alajo, Accra, observed that patterns of rain and flooding have become unpredictable since the 1980s: "In some years the rain will fall greatly and destroy everything and other times nothing will happen." They noted that it used to rain heavily in June and July but since 2000, the heavy rains sometimes start earlier than June and in other years after July. Consequently, it is difficult to prepare for flooding in Alajo.

Men in Alajo described the impact of the flooding on their lives: "Flooding makes people go hungry for days." Slum dwellers' livelihoods depend on such activities as small-scale commerce, petty trading and artisanal trades, which are disrupted by floods: "Flooding makes the inhabitants of Alajo unable to do anything." People lose working time, economic opportunities and income during floods. Several Alajo residents engage in petty trading and petty merchandising in wooden kiosks which do not withstand the force of the floods. The immediate impact is the loss of livelihood support for food and bills, including children's education and health bills.

In the Alajo community people dealt with the June and July 2006 floods in a variety of ways. Some used blocks, stones and furniture to create high places on which to put their most valuable possessions during floods. Some placed their items on top of wardrobes and in the small spaces between ceilings and roofs, sharing such high places with others who have no similar 'safe' sites. Others temporarily moved away from the area to stay with friends and family during the flood.

One woman in Alajo described her experience: "As soon as the clouds gather I move with my family to Nima to spend the night there. When the rain starts falling abruptly we turn off the electricity meter in the house. We climb on top of our wardrobes and stay awake till morning. Our house was built in such a way that ordinarily water should not flood our rooms, but this is not so. Our furniture has been custom made to help keep our things dry from the water. For instance, our tables are very high and so also are our wardrobes, they are made in such a way that we can climb and sit on top of them. These measures are adaptive strategies as old as I can recollect. I have two children but because of the flood my first child has been taken to Kumasi to live with my sister in-law."

When residents of Alajo were in danger, they resorted to self-help or were rescued by other members of the community using locally manufactured boats, for example, not by any government disaster agency: "When the rain and the floods come, women and children suffer. You can be locked up for up to two days with the flood. Sometimes we take our children out from the room to the rooftop. Then people bring boats to evacuate people."

The research found more evidence of individual, rather than collective coping strategies. Sometimes people share protective storage or accommodation on higher ground. Spontaneous community action to unblock drainage channels is relatively rare. However, no coordinated action for emergency shelter or rapid response to flooding appears to exist in the studied cities. That said, local people in poor communities have an acute awareness of the solutions that are required and possible, and have strong views on who is responsible for taking action. However, there are different levels at which the various stakeholders in flood mitigation can operate to contribute to creating solutions.

Responsibilities and actions

The management of localized flooding, resulting from inadequate drainage, should be undertaken by the affected communities themselves. This is where local voluntary groups, with assistance where necessary, could be highly effective. Local communities are stakeholders in the good drainage and

Photo: Gideon Mendel/Corbis/ActionAid

Urban flooding in Lagos, Nigeria

rapid water removal from their own areas. They benefit from their own actions in improving and maintaining drainage channels.

Local authorities are best placed to cope with flooding from small streams whose catchment areas lie almost entirely within the built-up area. They administer the regulations and bylaws concerned with land use planning and should be involved in local disaster management. However, most African local authorities lack the human resources and financial power to carry out such responsibilities effectively.

Where major rivers flood towns and cities, urban flood protection must be seen in the context of the entire river basin, which may cross political boundaries. Where a river basin lies within a single nation state, integrated river basin management principles should be applied by an agency cutting across ministries concerned with both rural and urban interests to ensure that activities in upstream areas do not worsen the flood situation for towns and cities downstream.

In the Mozambique floods of 1996-1997, the trigger was heavy rains in the Shire river basin. If the Shire and Zambezi rivers were managed as one basin system, it would have been possible to alleviate flooding in the Zambezi delta by manipulating Zambezi river flow, using the flood control capacity of Lakes Kariba and Kabora Bassa.[5]

Cities faced with coastal flooding from the sea, or by a combination of high tides and high river flows from inland, have to integrate both river basin and coastal zone management, ensuring that the natural wetlands can continue to function as flood storage areas as far as possible.

The reality: Kampala, Maputo and Accra

In Ghana, relatively little has been undertaken by local government to combat urban flooding. Local authorities had not done any work on the drains and were not doing any cleaning and maintenance. The city's big drains were "choked with weeds and filth, while developers, possibly factory owners, have built structures and walls over some of the drains," the Ghana News Agency reported.

In Uganda, despite noble ideals in the national disaster management strategy, the ActionAid research team found that the translation of the disaster management policy into practice is far from being realised. Local council leaders are failing to enforce regulations that govern building houses and sanitation. No district disaster management committee exists in Kampala district, and floods are not seen as a key issue afflicting slum dwellers.

Following the war and severe flooding in Mozambique, the Government established a new organization, the National Institute of Disaster Management, with the aim of ensuring effective emergency coordination and establishing a new perspective, based on prevention. With this new organisation the annual contingency plans were institutionalized and are now part of the state general budget.

A policy of disaster management was also approved by the Mozambique Government in 1999 and, with the consolidation of the second national poverty reduction strategy, a new master plan for prevention and mitigation of natural disasters was approved in March 2006, with a focus on reducing the vulnerability of those communities most exposed to natural disasters. The master plan is part of the strategy for poverty reduction for the period 2005-2009, and also addresses the issues at a national level, but does not give special attention to urban areas.

The National Adaptation Programme of Action (NAPA) for the least developed countries aims to prepare urgent projects on adaptation by the sectors of society considered most vulnerable to the effects of climate change. The process of developing the NAPA for Senegal, Kenya and Mozambique involved a cross-section of consultations with many stakeholders in the public and private sectors. This included non-governmental organisations and vulnerable communities. While the preparation of these plans showed that the respective governments recognised the losses caused by climate change, especially drought, floods and landslides, the NAPAs do not emphasise, or focus on the way flooding affects the urban poor.

International action

The Hyogo Framework for Action promotes disaster risk reduction strategies that are integrated with climate change adaptation.[6] The framework foresees dialogue, coordination and information exchange between disaster managers and development sectors. But this will be slow in reaching the local governments and communities that need to work on alleviating urban flooding affecting poor communities. ActionAid's surveys found that, at present, local governments know little about the framework. Many however would be happy to cooperate in the types of partnership the framework envisages in order to improve service delivery.

Local initiatives to reduce vulnerability and increase community participation may be facilitated by training, capacity building and resource transfers. This is where international action of the type suggested in the Kyoto protocol is appropriate.

There are serious limits as to what international actions regarding adaptation can achieve. Such actions need to be developed in ways that support the adaptive capacity and resilience of vulnerable communities. There is a clear challenge to international organizations to get their assistance operating effectively at the appropriate level.

Urgent tasks

The solutions to the severe flooding of poor urban communities in Africa are relatively simple. Many people understand what needs to be done. Communities can do much for themselves, however, the tasks are best tackled through partnerships with national and international support. All parties concerned need to collaborate in:

- Making sure the growing human challenge of urban flooding is addressed in all national and international development policies, planning and actions by governments, UN systems, IFIs and NGOs
- Investing in proper and safe infrastructure, such as drainage, as locally appropriate
- Ensuring that poor people participate in all decision-making processes equally with experts in flood reduction policies
- Taking all possible measures to ensure that poor people's rights to adequate and disaster-safe housing are realized and their tenure is secured
- Making sure that critical services such as health, water and sanitation are disaster prepared, which means they are able to provide adequate services during floods
- Holistic thinking in aid programmes to incorporate the effects of flooding
- Implementing the Hyogo Framework for Action at all levels of urban planning and service delivery.

Climate change and its impact on natural risk reduction practices, preparedness and mitigation programmes in the Caribbean

David A. Farrell, Kathy-Ann Caesar, and Kim Whitehall,
Caribbean Institute for Meteorology and Hydrology, Barbados

The Caribbean is often described as one of the two most natural-disaster prone regions in the world by virtue of its geographic location and geological setting. The geographic location of the islands of the Caribbean coincides with a zone of severe tropical storm activity and converging unstable air masses that traverse the region annually between June and November. Many of the islands of the Caribbean owe their origin to the volcanic activity present at the zone of subduction where the Caribbean plate overrides the Atlantic plate. Because of their genesis and location, many of the islands are subject to volcanic eruptions, earthquakes, and other associated phenomena including tsunamis. In an effort to reduce the potential impacts of natural disasters in the region, an extensive range of disaster mitigation, preparedness and reduction strategies have been developed and implemented at national and regional levels.

Programmes related to weather phenomena in the Caribbean

Weather-related phenomena significantly affect the socio-economic development of Caribbean countries through impacts on public health, agriculture, and tourism. The most recent example demonstrating the intricate relationship between weather-related phenomena and national development within the Caribbean is the impact on Grenada following the passage of Hurricane Ivan in 2004. In addition to a significant death toll, 90 per cent of structures were either damaged or destroyed in the wake of Ivan. The nutmeg industry, which accounts for a significant amount of the island's foreign exchange earnings, suffered a tremendous setback that will take decades to mitigate.

The Caribbean Disaster Emergency Response Agency (CDERA) is a Caribbean community and common market (CARICOM) organization responsible for coordinating disaster management including risk reduction, preparedness and mitigation across member states in the Caribbean region. However, each member state generally has at least one agency that is responsible for national disaster management and which coordinates its activities with CDERA. Given the annual passage of hurricanes through the Caribbean region, most of these national agencies have a strong focus on


Photo: Esther Jones

Property damage on Grenada caused by Hurricane Ivan. Damage to the official Governor General's residence is shown in the top portion of the image impacts caused by weather phenomena. To effectively perform their functions, organizations responsible for disaster management rely on an integrated structure that couples several other specialized organizations into a comprehensive decision-making framework.

In Barbados, the Central Emergency Relief Organization (CERO) is one of the agencies responsible for natural disaster risk reduction, preparedness and mitigation. When severe weather threatens Barbados, CERO's decision-making framework includes inputs from, and coordination with, organizations such as the Barbados Meteorological Services, the Barbados Fire Service, the Royal Barbados Police Force, the Barbados Defense Force and the Barbados medical fraternity, among others.

National Meteorological Services in the Caribbean provide vital information that support decision-making associated with potential weather-related disasters and disasters that may be exacerbated by meteorological processes. As a matter of national policy, these services are responsible for issuing warnings and advisories during periods of severe weather. These activities and responsibilities require staff within these Services to interact with individuals from a range of disciplines and to provide information that is easy to understand and easily integrated in a multidisciplinary natural disaster management framework. With the growing complexity of natural disaster management in the Caribbean, disaster management interactions within multidisciplinary teams can no longer be limited to on-the-job training, but must be an integral part of academic and professional training programmes.

The Caribbean Institute for Meteorology and Hydrology (CIMH) is a World Meteorological Organization (WMO) recognized Regional Meteorological Training Centre (RMTC), responsible primarily for training staff to serve in national meteorological services. Training is performed in-house at diploma level and in collaboration with the University of the West Indies (UWI), Cave Hill Campus, at degree level. Staff at CIMH are also key participants in graduate research programmes in pure and applied meteorology at UWI.

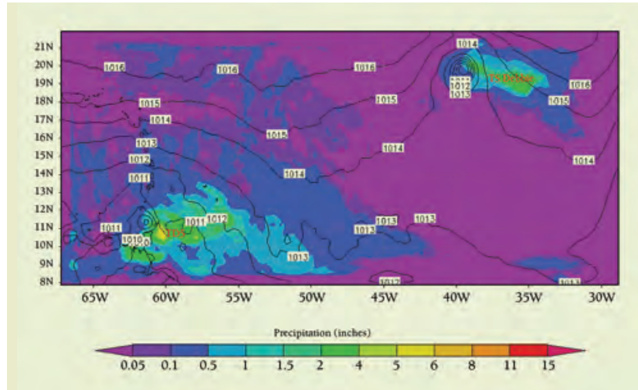
CIMH has not traditionally included natural disaster management in its training programmes. However, given the changing demands on National Meteorological Services in the Caribbean, CIMH is in the process of formally integrating natural disaster management into its training programmes to prepare students for integration into natural disaster management teams.

CIMH is involved in a number of collaborative efforts that support natural disaster management through the identification of vulnerabilities and the formulation of mitigation strategies. For example, the organization has been involved in:

- Flood plain mapping projects that provide information to guide land-use and flood mitigation policies at the national level
- Storm surge mapping to support the identification of vulnerable coastal communities
- Research programmes using numerical simulators to better forecast regional and local weather systems that may have an adverse effect on public health and safety
- Agrometeorological programmes that address the vulnerability of food systems in the Caribbean to natural disasters.

Information from these activities, as well as input from relevant stakeholders such as regional and national disaster management agencies, is being used to develop a weather-related disaster management component to CIMH's programmes.

Example of numerical weather prediction produced by CIMH staff using the MM5V3 model in operational mode during the 2006 Atlantic hurricane season



Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

Programmes related to future climate change in the Caribbean

Natural disaster risk management, reduction and mitigation programmes in the Caribbean are primarily focused on the immediate threats posed by annual regional weather phenomena. However, within the last decade there has been increasing activity focused on preparedness for the distant future. These activities centre on:

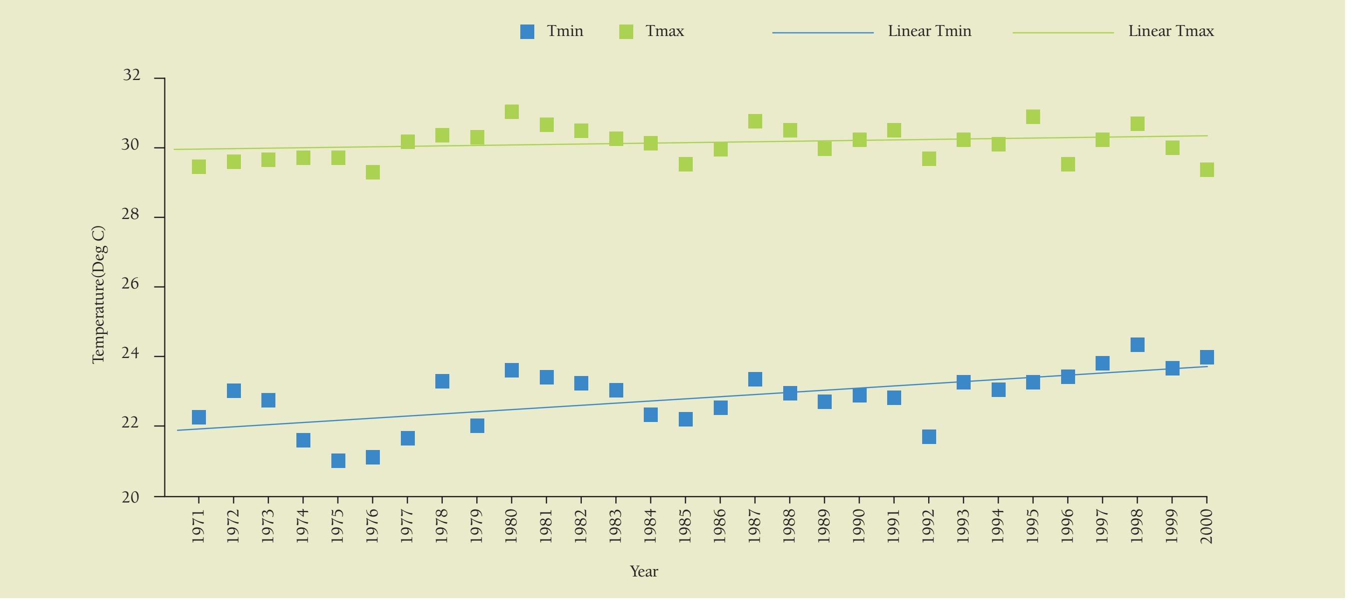
- Identifying the vulnerability of Caribbean societies to global climate change and climate variability
- Developing mitigation and adaptation strategies to minimize the risks posed to Caribbean societies by these phenomena.

Significant efforts at national and regional levels have been expended to quantify the impacts of global climate change on the Caribbean region. These have put particular focus on regional initiatives, especially their effectiveness in identifying regional vulnerabilities to climate change and in developing and implementing strategies for their mitigation.

Global climate change is expected to result in increasing temperatures in both the Earth's atmosphere and oceans. Increasing atmospheric temperatures are accelerating the melting of the Earth's polar ice caps, thereby increasing the volume of water present in the oceans. Thermal expansion of the water is causing sea levels to rise globally. Within the Caribbean region, the affects of global climate change are anticipated to be sea level rises, increasing mean annual temperatures, increasing rainfall variability, and increasing tropical storm activity and intensity.

The most significant impacts of sea level rise in the Caribbean and coastal regions of South and Central America will be inundation of low-lying coastal zones. For example, in Guyana sea level rise is expected to result in the permanent inundation of thousands of square miles of the coastal region and the significant inland migration of seawater up river channels. The combination of these processes is expected to lead to the displacement of significant numbers of coastal residents, salinization of aquifers and soils, and the destruction of traditional farming areas. Increases in sea levels, coupled with storm surges, may further exacerbate flooding in low-lying coastal communities. The combined effects of these outcomes are expected to result in considerable economic losses at the local and national levels if significant mitigation and adaptation measures are not put in place.

Temperature trends on Barbados during the period 1971-2000: Trends in the maximum and minimum temperatures recorded (squares represent the measured data; solid line represents the inferred linear trend)



Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

Higher temperatures coupled with increased rainfall variability are expected to impact the type of agriculture currently practiced in the region. For example, variability in rainfall and increased temperatures are expected to reduce soil moisture and increase heat stress to animals and plants, thereby reducing agricultural productivity and increasing economic losses. Rainfall variability is expected to lead to increased surface water runoff and reduced infiltration and recharge of aquifers. These processes are expected to increase the risk of severe flooding and aquifer depletion.

Several regional initiatives geared to addressing the impact of climate change and variability on Caribbean societies have been funded by regional and international agencies including the World Bank, the Global Environmental Fund (GEF) and the Canadian International Development Agency. These are managed by regional institutions including the CARICOM Secretariat and the Caribbean Community Climate Change Centre (CCCCC). Regional institutions involved in climate change activities include the University of the West Indies, the University of Guyana, the University of Belize, and CIMH among others. National agencies are generally integrated into regional activities through the provision of data, expertise, and services to support sectoral analyses at local pilot sites. Outcomes from these studies not only benefit local agencies but also provide a basis for further development and implementation regionally.

The first major regional initiative related to climate change in the Caribbean was the Caribbean Planning for Adaptation to Climate Change (CPACC) initiative, which received USD 6.5 million from GEF and operated from 1997 to 2001. The CPACC initiative was implemented by the World Bank, executed by the Organization of American States, and overseen by a Project Advisory Committee chaired by the CARICOM Secretariat. The objectives of the CPACC initiative were to build capacity in the Caribbean region for adaptation to the impacts of climate change, particularly sea level rises. These objectives were achieved through a series of vulnerability assessments, adaptation planning exercises, and capacity building initiatives. The CPACC initiative included:

- Design and implementation of a sea level/climate monitoring network
- Establishment of databases and information systems
- Inventory of coastal resources
- Formulation and application of initial adaptation policies.

Key achievements of the CPACC project were:

- Establishment of 18 sea level monitoring stations in 12 countries in the region
- An increased appreciation of climate change issues by regional policy makers and planners, and the articulation of regional positions on the issue
- Establishment of coral reef monitoring protocols
- Improved access to and availability of regional data on climate change
- The articulation of climate change adaption policies and implementation plans in eleven of the twelve participating countries.

The CIMH was a beneficiary of the CPACC initiative as it provided CIMH with an opportunity to enter into regional climate change research through the provision of climatic data for the region that extended in some cases over 100 years, and through the sea level monitoring programme, in which CIMH was heavily involved.

The Adaptation to Climate Change in the Caribbean (ACCC) initiative extended the climate change activities started under the CPACC initiative. The ACCC initiative lasted from 2001 to 2004 and received CAD3.5 million in funding from the Canadian International Development Agency (CIDA). Important achievements of the ACCC initiative were:

- Political endorsement and the establishment of the basis for financial self-sustainability for the CCCCC
- Development of a set of guidelines to facilitate incorporation of climate change effects into the Environmental Impact Assessment process
- Development of capacity building programmes

Temperature trends on Barbados during the period 1971-2000: Decreasing diurnal temperature range (squares represent the measured data; solid line represents the inferred linear trend)

Source: Caribbean Institute for Meteorology and Hydrology (CIMH)

- Implementation of pilot projects on climate change impacts in the water, health and agricultural sectors
- Generation of statistically downscaled climate scenarios for Jamaica, Trinidad & Tobago, and Barbados
- Development of a regional public education and outreach strategy on climate change.

Within the context of the capacity building programmes, CIMH staff benefited from training related to detection and analysis of trends in climate data. This training supports CIMH's ongoing development of climate change products using its extensive climate databases. The climatic databases currently being stored at CIMH are being used by individuals participating in climate change research.

The Mainstreaming Adaptation to Climate Change (MACC) initiative builds on the achievements of CPACC and ACCC. This initiative, which runs from 2004 to 2007, received USD 5 million of funding from GEF and is being implemented by the World Bank and executed by the regional Caribbean Community Climate Change Centre. The MACC initiative seeks to:

- Further build capacity in the region to address climate change issues including the mitigation of vulnerabilities identified under the CPACC initiative
- Rehabilitate and strengthen climate change data collection and monitoring networks
- Extend the analysis of the impacts of climate change on critical sectors (including water resources, tourism and agriculture) within the Caribbean region
- Expand public education and outreach programmes.

The CIMH's role within the MACC initiative is considerably greater than in previous initiatives. In particular, CIMH will be a key participant in the reestablishment and maintenance of sea level monitoring stations, installed under the CPACC initiative and currently inoperable. This inoperability reflects to some degree the low priority that some national government agencies have assigned to global climate change monitoring during CPACC. It is hoped that by placing the responsibility for maintaining these stations within a regional organization, the performance and sustainability of the sea level monitoring network will be significantly improved.

The CIMH is also taking a leading role in sectoral analyses that examine the impacts of climate change on agriculture and water resources in the region. The CIMH will be a key regional institution involved in the design and simulation of the climate change scenarios used to support sectoral analyses.

Future directions

Reduction of the risks posed to life and to the economy is bringing climate change preparedness to the forefront in the Caribbean. As a result, regional institutions are expected to provide leadership in these areas. The CIMH, through its mandate and training programmes, is integral to weather- and climate-related risk reduction, preparedness and mitigation programmes in the area. As such, CIMH plays an important role in the mainstreaming of adaptation and mitigation strategies related to climate change and other weather phenomena.

With this in mind, CIMH is expanding its role in these areas beyond the provision of support for regional programmes. In particular, the organization intends to include aspects of natural disaster risk reduction, preparedness, and mitigation in its training programmes. This integration will encompass both weather- and climate-induced events, and will build on relationships that CIMH has developed with regional organizations.

More specifically, CIMH intends to include aspects of weather and climate modelling in its training programmes, along with projects emphasizing multidisciplinary data analysis and decision-making to sensitise students to integrated disaster management environments. CIMH staff will continue to build on completed and ongoing work on natural risk reduction to assess the impacts of climate change and climate variability on food security and water resources.

A virtual centre for disaster reduction in South America: monitoring, prediction and early warning of severe weather events

Antonio Divino Moura, Instituto Nacional de Meteorologia, Brazil

Extreme weather events exert tremendous stress on societies and economies worldwide. Civilizations have learnt throughout the years how best to cope with their specific, average climate. Deviations from climatic means or average weather conditions can bring loss of life and destruction of property, in proportion to the severe or extreme meteorological phenomena that occur. For example, extreme rainfall (high or low) values can cause flooding or drought, causing tremendous losses to society, agriculture and energy production. However, it is also possible that 'good' weather and climate will bring beneficial rainfall, favourable to the sustenance of water supplies, hydroelectricity or irrigation.

A recent example is the massive impact of hurricane Katrina on the New Orleans population. There were immense losses to local and national economies, as well as significant social and political ramifications. Another example is the sudden and swift polar air movements over California and San Antonio, Texas, in mid January 2007. These caused large losses to citrus fruit production in California, interruption to power lines in several areas and the closure of airports due to freezing rain.

In South America, 'hurricane' Catarina (so called because it landed over the State of Santa Catarina, Brazil) brought tremendous loss of life and significant material and architectural damage. It also raised the concern that Catarina might indicate the first regional impacts of global warming as a result of forest burning, as well as increased fossil fuel usage in industrial activity and transportation. In addition, areas of southern Brazil vital to grain production (soybean, wheat, corn, rice) for export and for internal consumption suffered recurrent droughts, which brought huge losses to the local and national economy as well as to the insurance companies.

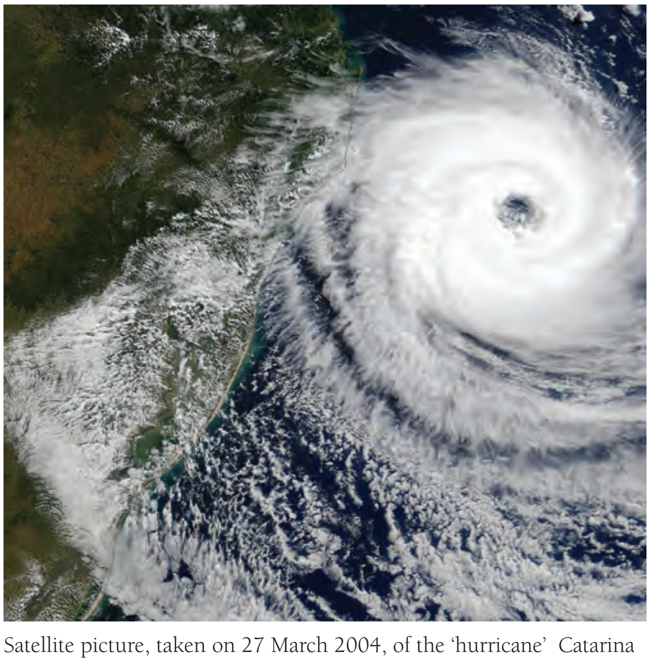


Photo: Jacques Descloitres – NASA/GSFC – MODIS satellite

Satellite picture, taken on 27 March 2004, of the 'hurricane' Catarina

'Hurricane' Catarina on the Brazilian coast

Between 27 and 28 March, 2004 a hurricane-like phenomenon developed in the South Atlantic. This was the first 'hurricane' recorded over the South Atlantic basin since the initiation of geostationary satellite imagery during the mid 1960s. The storm hit the coast of southern Brazil at Santa Catarina on 28 March. Even though no direct measurement was made (the nearby radar was non-operational at the time) the intensity of the winds was estimated by models and satellite imagery to the order of 90 kilometres per hour, with winds of up to 150 kilometres per hour.

Usually, hurricanes do not form in the southern Atlantic due to greater wind speeds at high altitude, which prevent storms from gaining height and strength. Catarina started from a cut-off low in the mid South Atlantic. In almost all observed cases, these lows move towards the south-eastern Atlantic and dissipate. Catarina however, moved towards the coast of Brazil and changed structure and dynamics in a very unusual manner, building up strength and forming a hurricane-like phenomenon that became known as 'hurricane Catarina'. The inaccurate prediction of Catarina's intensity, development and impact generated a high level of media and public criticism of the meteorological institutions involved.

The need for an integrated regional operational project

In the wake of Catarina, the National Meteorological Services (NMS) of several countries in southern South America began discussions and activities aimed at the mitigation of such disasters. Since severe weather phenomena over the region usually have their genesis in higher latitudes in the south, intensifying as they move from Argentina to Uruguay to Paraguay and Brazil, it is obvious that a joint effort is needed for maximum effectiveness.

The region is large and requires improved data (in-situ, satellite and radar derived) on land, and on the south-western South

Atlantic, where almost no direct oceanic measurements are currently made. Better understanding of phenomena that bring severe or extreme weather, and improved methods to predict them are also required.

Fundamental to the success of this endeavour is institutional capacity building, as well as the training of specialized personnel for the Meteorological Services of each region. This would provide the fundamental basis for a high quality virtual centre for the reduction of disaster impacts. Such a centre would provide precise and timely information that could be immediately released to the relevant decision makers (civil defence services, authorities etc.) in each country.

Project concept and components

The envisaged southern South American regional virtual centres for monitoring, prediction and early warning will be built on the strength of each country's capability in terms of operational services, as well as existing research and training facilities. The virtual centre is in fact a network of national institutions, closely coordinated by a national node that connects all of the countries. It will deal with all aspects of data collection, dissemination and the exchange of forecasts and conferencing between service providers. When a product is finalized, its dissemination and the issuance of warnings, in close coordination with Civil Defence, will be the purview of each country. The meteorological aspects (data, forecast) of the joint venture are common to all participants, but the final dissemination is exacted by each individual NMSs of Argentina, Brazil, Paraguay, and Uruguay in view of the differing national implications and institutional frameworks for decision making.

Data gathering — There is a need to further enhance the network of automatic weather stations in each country of the region. Also, better use of the satellite and radar information currently available is a must. Since many of the phenomena that bring severe weather events have their genesis and/or amplification in oceanic areas, the implementation and maintenance of oceanic buoys and meteo-oceanographic stations in costal areas deserves special attention.

Understanding the genesis and evolution of extreme weather events — There is a need for more research into understanding both synoptic scale and mesoscale weather systems that are prone to severe conditions. Fortunately, there are excellent research and university groups capable of producing information on the events that potentially bring flooding, as well as extreme conditions related to frost, wind storms, and so on.

Forecasting — The virtual centre forecasters will be trained in Madrid, thanks to cooperation with the Instituto Nacional de Meteorologia (INM) of Spain. This indicates the beginnings of a live network of the people and institutions involved on a national basis. The training will bring the team up to date on current forecast methodology as well as modern ways to release products to the civil defence services, media and public authorities of each country.

Routine exchange of data, products and information — The NMS around the world regularly exchange geophysical data and products using the Global Telecommunications System of the World Meteorological Organization. In addition, a special intranet connection will be established for all participating agencies and forecasters involved with the operation of the virtual centre. This closed link is necessary due to the nature of the data and products exchanged, and the particularities of each partner institution within a country.

Product dissemination to national Civil Defence services — The dissemination of forecasts and products is the foundation of each country's NMS. Such distribution ensures the optimal use of information and will prevent any national service releasing information in an inappropriate format or language, or at an unsuitable time, due to its lack of awareness of the possible regulations, restrictions or implications entailed.

Coordination — The regional virtual centre will have its work coordinated by each node of the participating network of institutions, and the NMS will also be connected among themselves. This will constitute the regional network. Within each country, according to internal arrangements, national operational and research institutions may also form a network coordinated by the NMS for that individual country.

Participating countries and institutions

The regional network is comprised of the Servicio Meteorologico Nacional of Argentina, the Instituto Nacional de Meteorologia of Brazil, the Dirección de Meteorologia e Hidrologia of Paraguay and Dirección Nacional de Meteorologia of Uruguay. These regional nodes will constitute the focal points for the network of participating countries.

In the case of Brazil, an internal, national network is being formed by INMET, with the National Meteorological Institute as the focal point. This development is possible through close coordination with INPE/CPTEC (Center for Weather Prediction and Climate Studies), the Center for Hydrography of the Brazilian Navy, the Meteorological System of Paraná State (SIMEPAR), and the Center for Integrated Environmental Resources of Santa Catarina (CIRAM).

Expected benefits

Improved monitoring, prediction and coordination, as well as enhanced expertise in severe weather phenomena will provide a basis for the provision of timely and comprehensive information. Such information will be released to decision makers within Argentina, Brazil, Paraguay and Uruguay. Technical benefits will include the ability to:

- Test the capacity of Meteorological Services to use a variety of numerical products, including multi-model ensemble forecasts, in the dissemination of results to existing institutions, in order to minimize risks under severe weather conditions
- Control and decrease the time needed for emission alerts
- Improve the interaction between meteorological services and Civil Defence bodies in each country
- Augment the accuracy of products offered by global models and global centres when adapted to local usage
- To use a hierarchical (cascading) process for disseminating information.

The major, tangible benefit will be a decrease in disaster impacts on the population. This will be realized through a reduction in loss of life and damage to property caused by dangerous synoptic and mesoscale meteorological phenomena such as flooding, windstorms, freezing rain and frosts.

The regional cooperation of meteorological institutions will allow the effective application of knowledge in order to deal with common regional phenomena. This example may trigger other regional collaborations in the field of geophysical sciences connected to biological issues (e.g. malaria and dengue epidemics) and social sciences applications.

The rising incidence of natural disaster events on the Korean Peninsula due to climate change

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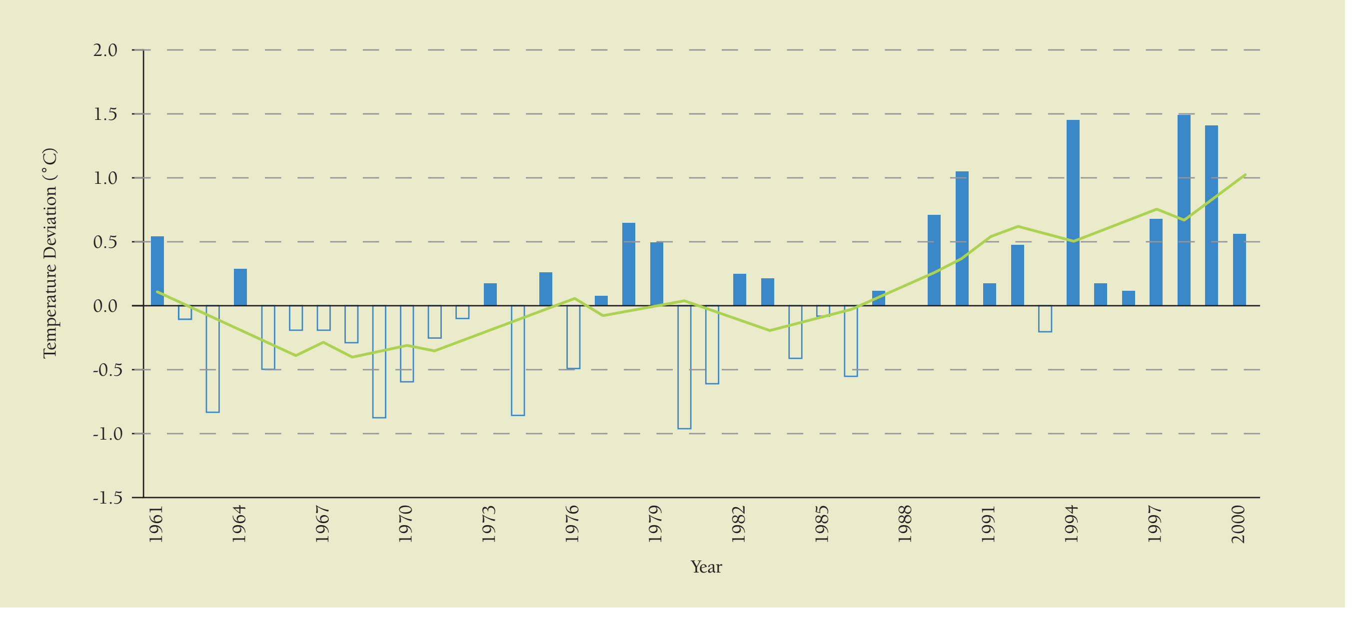
According to the Korea Meteorological Administration (KMA), the average temperature in Korea is increasing. The annual average temperature from 1908 to 1940 was recorded between 10 and 11 degrees Celsius, whereas it was recorded between 12 and 13 degrees Celsius from 1970 to recent years. This trend can be seen clearly when comparing monthly average temperatures. In April, from 1960 to 1965 the average temperature was 11.5 degrees Celsius, and from 1995 to 2000 it was 12.9 degrees Celsius in the same month. Temperature demonstrates a dramatic increase after 1987. It was also found that the temperature in the eastern coastal area of the Korean peninsula has increased by 1.8 to 2.0 degrees Celsius during the last century, which exceeds the global average.

Because of climate change in the Korean peninsula, new threats from natural disasters such as floods, droughts, wild fires, and blizzards are emerging and the ecosystem is changing, including the spatial and seasonal coverage of cultivating plants. In the last three decades the temperature in Korea increased by 1.2 degrees Celsius, which again exceeds the global average 0.8 degrees Celsius. The impact of temperature increase is more severe in urban areas during the winter. Korea has had almost continuous, abnormally warm winters since 1986.

In the 1960s and the 1990s the average temperature in January, and monthly minimum temperature in metropolitan areas such as Seoul and Daegu increased by 2.7 degrees Celsius and 3.0 degrees Celsius, respectively. This increase is believed to be related to human-induced environmental factors such as increased consumption of fuel, population, emission, buildings, traffic, urbanization and deforestation. Conversely, in preserved rural areas like Chupungryeong, temperature increase was found to be as low as 0.4 degrees Celsius.

The pattern of precipitation is also changing. In Korea 40 to 60 per cent of annual precipitation is concentrated during the summer, i.e. from June to August, and is affected by typhoons and monsoons. Recently, the activity of the seasonal rain front has become irregular and the overall precipitation is decreasing during the wet season. However, the precipitation by typhoons and concentrated rains after the regular wet season is increasing.

Changes in annual average temperature in the Korean Peninsula from 1961 to 2000



Source: KMA

Before the 1970s the Seoul metropolitan area precipitation was concentrated in prolonged wet seasons from the end of June to the end of July. However, recent statistics show that most precipitation now occurs from the end of July and August through localized torrential rains, after the regular wet season.

Whilst there is no explicit change in the total precipitation levels, the total days of precipitation is steadily decreasing, whilst the precipitation intensity, which has direct correlations with water-related disasters, is increasing dramatically. As shown in statistics since the 1920s, the annual precipitation in the last two decades has increased only 7 per cent compared to the 1920s. However, the days of precipitation decreased by 14 per cent and, thus, the intensity is estimated to increase by 18 per cent.

From 1992 to 2001 the frequency of concentrated rains which exceeded 100 millimetres per day was 325, which is 1.5 times more than the number measured in the 1970s. Of particular note was 31 August 2002, when a record-breaking 870.5 millimetres precipitation was measured in Gangneung City.

The change in summer precipitation patterns is not the only problem in Korea. Droughts in the Spring is an increasing worry. The Korean peninsula, which is located between the Eurasian continent and the Pacific, is affected by continental high pressure developed in China during the autumn. This continental air mass is replaced by oceanic air mass in May and when strength of the continental air mass is not weakening, Korea experiences the spring drought. 2001 was the worst year of drought since the beginning of Korean modern climate observation in 1911.

Compared to normal precipitation levels, the amount in the spring of 2001 was only 12 per cent in the middle of the Korean peninsula, whilst the maximum was 74 per cent on Jeju Island, which is located in the most southern part of Korea. Precipitation in most areas was recorded as less than 50 per cent and the Seoul metropolitan area recorded only 10 to 30 per cent. In June the total water volume in reservoirs was less than 39 per cent of the normal volume, which presented a serious threat to the whole country.

Most of the natural disaster damages in Korea are due to water and wind-related events. From 1997 to 2006, an annual average of 117 people lost their lives, mostly from floods and landslides caused by typhoons and torrential rains in the summer. Typhoons caused 58 per cent of the property damages, while torrential rains were responsible for 23 per cent.

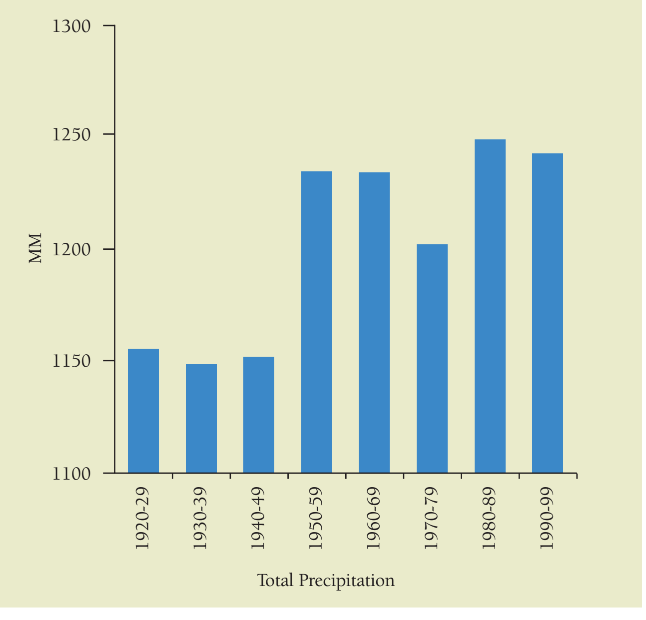
Property damages from natural disasters during the last 10 years amounts to USD2.1 billion per year, as well as USD3.7 billion spent each year on recovery costs. Although general human loss has decreased, property damage, which is converted and normalized by current values, is increasing due to the affect of climate change on vulnerability. Eight out of ten of the most severe natural disasters occurring between 1958 and 2006 took place in the last ten years.

According to KMA the temperature and precipitation intensity in the Korean peninsula has undeniably increased since the 1980s. The most severe drought in 90 years occurred in 2001, and in August 2002 sunshine hours were 50 per cent less than normal. In 2002 and 2003, property damages by typhoon Rusa and Maemi were USD6.6 billion and USD4.7 billion, respectively. In March 2004 a sudden blizzard caused mass societal panic because nobody was prepared for such a natural hazard in the spring.

Water and wind-related disasters are anticipated to increase in the Korean peninsula. Normally, typhoons develop in the South Pacific where they downgrade to extra tropical depressions due to the low sea surface temperature as they approach the Korean peninsula. However, when the sea surface temperature in the typhoon's path is not low enough, they carry on to the Korean peninsula at full strength and cause severe damage.

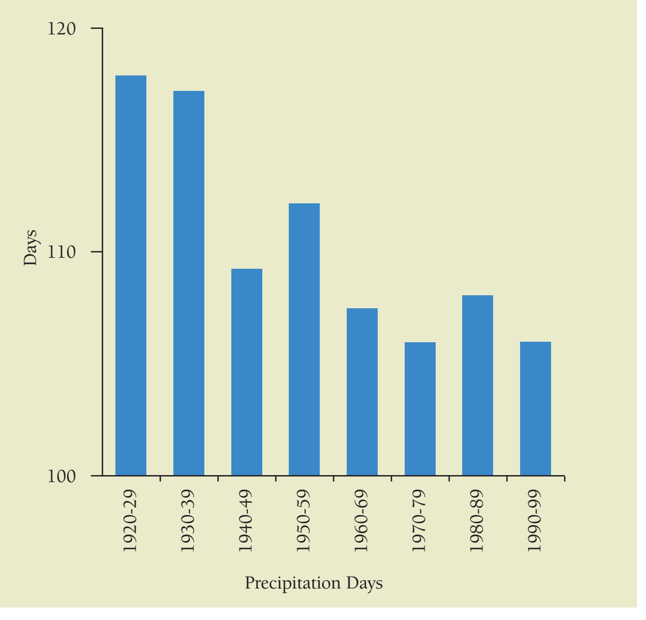
The Korean government is setting up systematic countermeasures such as multi-hazard warning systems, to cope with the emerging risks, and to minimize the damage on critical infrastructure. One of the most effective preventive measures in Korea is the implementation of the Disaster Impact Assessment (DIA) system. DIA aims to eliminate the potential causes of disasters inherent in various development

Total precipitation in the Korean Peninsula



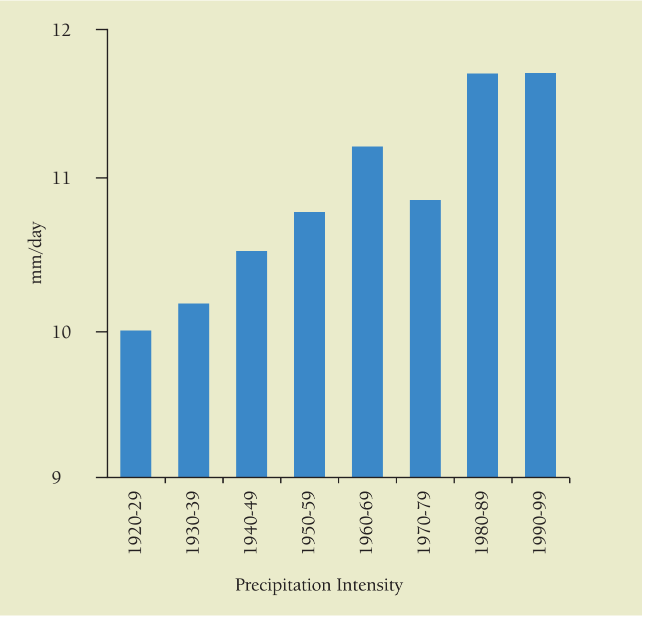
Source: KMA

Precipitation days in the Korean Peninsula



Source: KMA

Precipitation intensity in the Korean Peninsula



Source: KMA

projects, in advance. This system is a good example of supporting sustainable development. The DIA system is implemented centrally when the area of targeted development is at least 300,000 square meters. For smaller development projects, each city and province has introduced a local disaster impact assessment system. DIA was introduced in 1996 and by 2001 the coverage had expanded to cover 48 administration plans and 47 development areas.

The Korean government is also focusing on disaster preparedness during the summer season. To reduce the loss of life, property damage, and economic hardship caused by natural disasters, the "Disaster Preparedness Period" is designated from February to May. The E-30 emergency evacuation system has also been implemented. This involves the complete evacuation of a disaster-prone area when a warning alarm is triggered, and is designed to improve the safety of citizens.

Korea identified 787 sites susceptible to inundation, collapse, and isolation by typhoons, floods, and landslides, and labelled them as Disaster Prone Areas. A total of USD3.3 billion will be invested for numerous improvements between 1998 and 2007. In 2004 and 2005 USD822 million and USD169 million was invested in 326 and 107 sites, respectively.

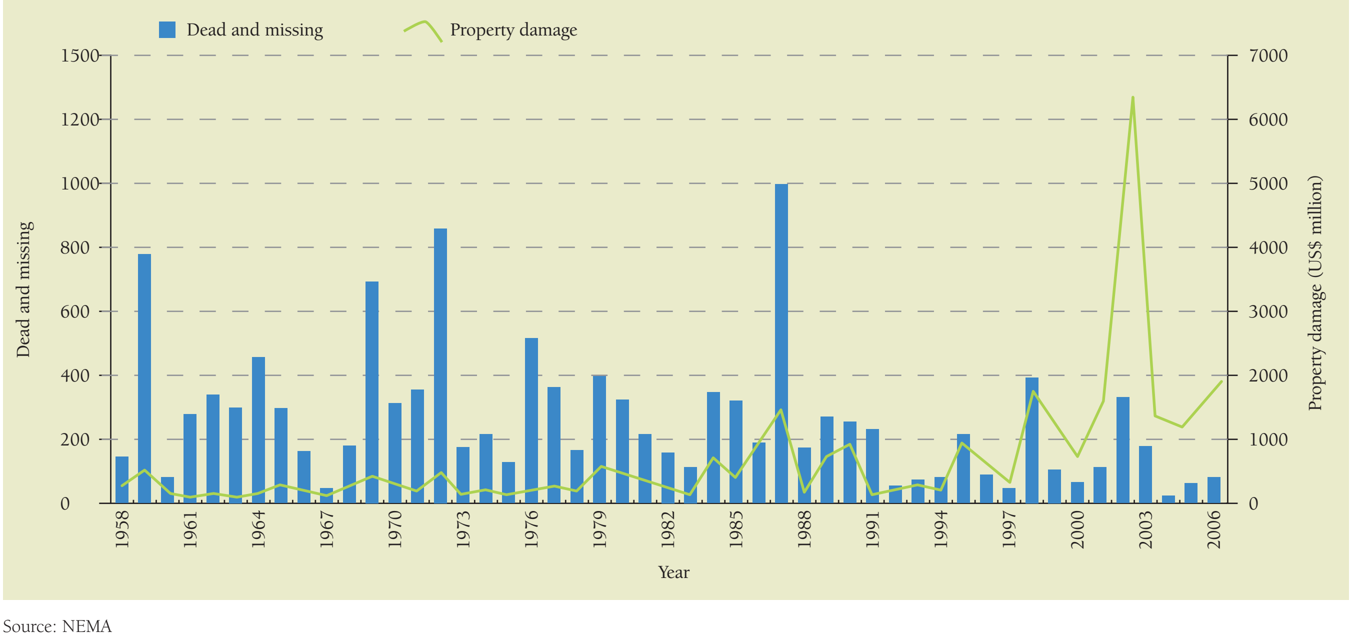
Since prompt and accurate information is so important for protecting people's lives and national infrastructures, a comprehensive network has been established connecting disaster management agencies and disaster prevention facilities. Equipment and various resources for rescue activities have been secured, and emergency countermeasures against transportation cut-off and isolation situations are in place.

From the use of conventional, commercial electronic display boards to cutting-edge information technologies; six different early warning systems are in place for natural disasters in Korea. These include: CBS mobile phone message system, automatic verbal notification system, automatic rainfall warning system, disaster notification board system, TV disaster warning broadcasting systems, and radio disaster warning broadcasting system using radio data system (RDS).

Rehabilitation plans have been developed, and vulnerable sites and structures have been strengthened in response to the potential affects of climate change. This practice is important because previous recovery plans simply restored the damaged sites and facilities to their original status, thus leaving them vulnerable to relapse.

Despite the various measures and systems developed to counteract the emerging risks posed by climate change, the recent disaster figures suggest that Korea will continue to pay an increasing price. It is difficult to estimate the overall cost to society, but it is clear that the negative effects of climate change need to be studied and quantified as far as possible. Such knowledge and understanding can then be applied in disaster management systems that will mitigate the price of climate change as far as possible.

Human loss and property damage by natural disasters in Korea from 1958 to 2006



Source: NEMA

Adapting to climate change through resilience to natural disasters

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INDIA, DUE TO its unique geography and climatology, is prone to a large spectrum of natural disasters ranging from avalanches in the snow-clad Himalayan slopes, to tsunamis and tropical cyclones along the coasts in the southern peninsula. Floods, droughts, cyclones, earthquakes and landslides have been recurrent phenomena. About 60 per cent of the landmass is prone to earthquakes of various intensities; over 40 million hectares is prone to floods; about eight per cent of the total area is prone to cyclones and 68 per cent of the area is susceptible to drought.

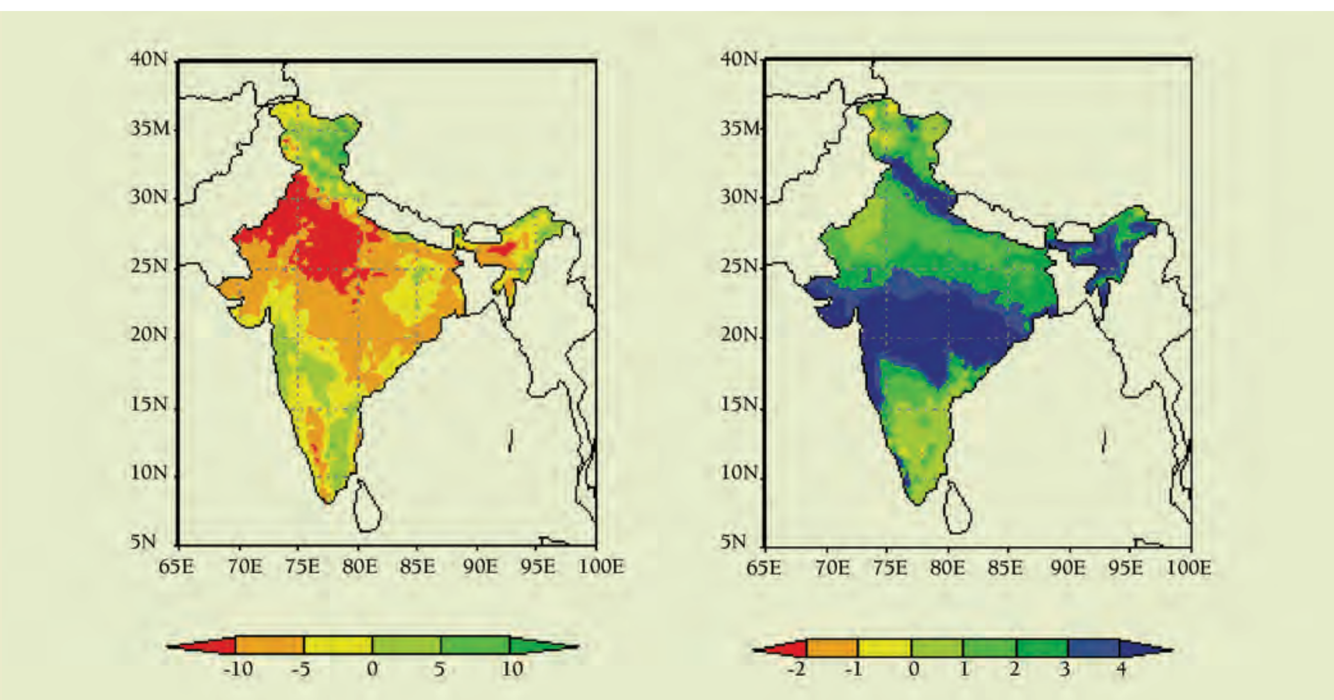
Between 1990 and 2000, an average of 4,344 people lost their lives and about 30 million people were affected by disasters every year. Increasing population densities, changing land-use patterns and climate have contributed to the vulnerability, particularly to that of the poverty-ridden communities in the region. These factors are set to exacerbate as time goes on, leading to irreparable damages affecting sustained development. The major positive aspect is that due to the intricate linkages among these issues, actions initiated to mitigate the effects of any one will have collateral benefits.

The climate change context

Climate change is not only a major global environmental problem, but is also an issue of great concern to a developing country like India. The changes observed in the regional climate have already affected many of the physical and biological systems and there are indications that social and economic systems have also been affected. Climate change is likely to threaten food production, increase water stress and decrease its availability, resulting in a rise in sea level that could flood crop fields and coastal settlements, and increase the occurrence of diseases such as malaria.

India is a large developing country with a population of over one billion, whose growth is projected to continue in the coming decades. Its rural populations depend largely on the agriculture sector, followed by forests and fisheries for their

Climate change scenarios over India produced by Hadley Center PRECIS Regional Climate Model showing expected changes in number of rainy days (left panel) and rainfall intensity (mmday-1) of rainy days



Source: : Krishna Kumar, Indian Institute of Tropical Meteorology, Pune, India livelihood. Indian agriculture is monsoon dependent, with over 60 per cent of the crop area under rain-fed agriculture that is highly vulnerable to climate variability and change. Given the lack of resources, and access to technology and finances, many countries in the Asia region presently have limited capacity to develop and adopt strategies to reduce their vulnerability to changes in climate.

In India, apart from the strong seasonality of rainfall (with most of the rainfall occurring during a span of three months during mid-June to mid-September), there are remarkable variations within the season from one year to another. Such variations produce extremes in seasonal anomalies resulting in large-scale droughts and floods, and also short-period precipitation extremes in the form of heavy rainstorms or prolonged breaks. The Indian climate is also marked by cold waves during winter in the north, and heat waves during the pre-monsoon season over most parts of the country. Tropical cyclones, affecting the coastal regions through heavy rainfall, high wind speeds and storm surges, often leave behind widespread destruction and loss of life, and constitute a major natural disaster associated with climatic extremes. Indeed, it is these extremes that have the most visible impact on human activities and therefore, receive greater attention by all sections of the society.

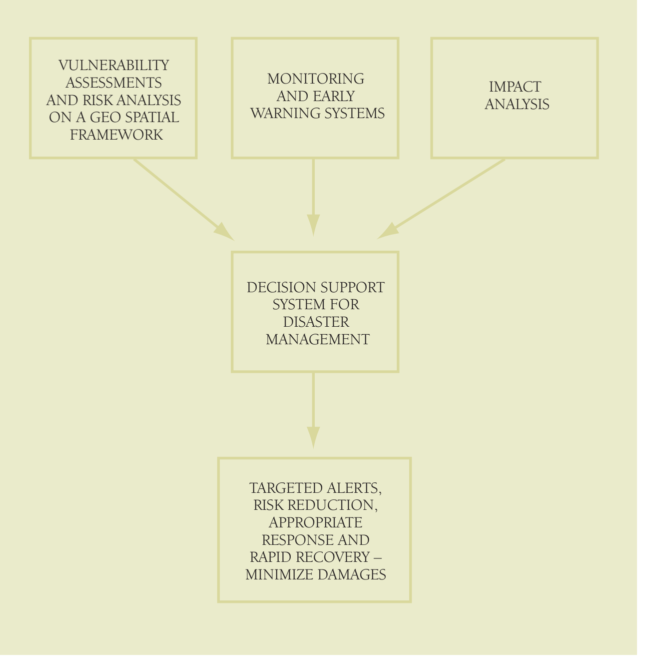
Future projections with high-resolution regional climate models indicate an all-round increase in temperatures, and a general increase in rainfall during the monsoon season qualified with large spatial variations. An overall decrease in the number of rainy days over a major part of the country coupled with an increase in the rainy day intensity can be seen. The temperature projections indicate an increase (maximum and minimum) of the order of 2-4 degrees Centigrade over the southern region, which may exceed 4 degrees Centigrade over the northern region. Although this summary of projected changes compiled in India's National Communication[1] come with caveats of large model uncertainties, they do point to a future possibility of enhanced extreme weather events.

Linkages between climate change and natural disasters

Adaptation refers to actions to help communities and ecosystems cope with changing climatic conditions. The international community has given a high priority to these measures, of which disaster reduction is a crucial part. Reducing vulnerability to climatic hazards today is essential to building future resilience. We need to significantly strengthen our ability to withstand the adverse effects of current and future natural disasters, which are likely to be even more severe.

Although adaptation to climate change is a global issue, it is particularly relevant to developing countries, as they are likely to be the hardest hit by the effects of climate change. We must evolve systems that raise the adaptive capacity of the most vulnerable groups, through strategies for risk reduction and effective response. As a large proportion of natural disasters have meteorological causes, the national meteorological services have a key role to play in building adaptive capacities of nations. This significant and urgent role can however be played by the meteorological services only if they get connected to the users in a very intricate and sensitive manner — with the clear recognition that 'adaptation' has to happen in these communities. This means that the forecasts have to translate into useful information that can be directly used in decision-making.

R&D components that need to be integrated for an effective Disaster Management System



There are several cases of extreme rainfall events in the recent years that have lead to loss of lives and property in India. The most significant of these was the Mumbai heavy rainfall event of 26 July 2005, followed by similar incidents in Bangalore 24 October 2005 and Chennai and surroundings during 2-4 December 2005. All these cases occurred in densely populated urban areas. Many more such examples can be quoted from all over the globe — and perhaps are glimpses of the most plausible scenarios under the influence of climate change that we may witness frequently in future.[2] These cases have brought to our attention the need to look at heavy rainfall spells in combination with the prevailing conditions under which they occur.

In his observations on the Mumbai heavy rainfall event, R. R. Kelkar highlighted: "Had Mumbai received the rainfall of 94.4 mm in a day a century ago, the severity of problems would surely have been much less. The population of Greater Bombay, now called Brihan Mumbai, was less than a million at the beginning of the last century. The mid-century figure was around three million. By 2001, the population had grown to almost 12 million. The city has risen vertically, open spaces have dwindled, the arterial roads cannot be widened any further, smaller roads have become car parks, and the drainage systems cannot keep pace with the ever-increasing needs of the metropolis. Many people are literally living on the edge, in areas that are known to be prone to landslides."[3]

The key message for the national weather services here is that weather forecasts of the future cannot be stand-alone, but must be presented with a context that makes them socially relevant, and aids decision making. For this to happen, we need to take an integrated approach that includes vulnerability analysis and impact assessments.

Recent efforts in disaster management

Recognizing the importance and need for an effective disaster preparedness framework, the Government of India has set up

Photo: Sushma Nair

Mumbai, India after the heavy rains on 26 July 2005

a National Disaster Management Authority (NDMA) in the year 2006, as an apex body at the highest level under the Chairmanship of the Prime Minister. All activities related to disasters are being brought into this framework to make well-orchestrated efforts across the concerned departments of the Central government and the various state governments that would be the actual responders. A dedicated institution called the National Institute for Disaster Management has been established for training and improving awareness at all levels.

One of the significant priorities of the NDMA, has been to bring together the existing scientific capacities in research institutes to address disaster management issues. This effort is being supported by the Department of Science & Technology, with an ultimate aim to create systems for enhancing the relevance of early warnings through customized decision support and rapid information/alert delivery through novel communication protocols. Once created, these integrated frameworks should also have capabilities to dynamically upgrade themselves by assimilating state-of-the-art technologies. Creating systemic linkages among research institutions specializing in the various components of the integrated system will ensure sustained capacities.

The following enhancements are planned:

- *Observational aspects* — Improved observational systems over the land and oceans, enhanced use of satellite data and improved weather radar networks
- *Forecasting and warning* — Improved processing of observational data, multi-model ensemble forecast systems that can give probabilistic tropical cyclone landfall scenario generation at finer scales and warnings of extreme weather
- *Impact assessment* — Development of appropriate regional scale models for storm surge inundation, Wind Damage Assessment and catchments-scale coastal river hydrological models for heavy rainfall induced inundation combined with GIS capabilities to identify regions of maximum risk
- *Vulnerability (Physical, Economic and Social)* — enhancement and integration of topographic and thematic layers under the National Database for Emergency Management (NDEM) Project for multi-hazard vulnerability assessment
- *Communication and Dissemination* — Integration of multi-departmental communication infrastructure and institutionalization of 24-7 operations of hazard mitigation information and dissemination infrastructure at national and state levels, and development of multiple communication options for alerts and in post disaster situations.

Integrating technologies and capacities for disaster management

Effective disaster management strategies must be able to bring together a variety of expertise that may be available with a diverse set of research groups. For example, information about the impending risks from a severe cyclonic storm must incorporate information about the area that will experience maximum winds/rains, magnitude of surge near the coast and likely regions of damage by high winds and heavy rains. This information should be available to decision makers in a user-friendly graphical interface on a geo-referenced platform. In a post disaster situation we must be able to restore communications within the shortest possible time to facilitate aid and medical redress. Building robust disaster management systems will enable us to adapt to the threats of severe weather induced by climate change.

Regional assessments, especially in developing and under developed countries, have shown that many systems and policies are not well adjusted even to today's climate and climate variability. Increasing losses both in terms of human lives and capital costs, from drought, storms and floods demonstrate the current vulnerability. Integrating technologies and research, leading up to better decision-making and evolution of strategies for disaster management would not only contribute towards adaptation to future climate change, but also improve the existing systems. Appropriate research and policies that are consistent with broader societal objectives will promote sustainable development in communities.

Climate, man and forest fires

Domingos Xavier Viegas, Department of Mechanical Engineering,
University of Coimbra, Portugal

Some natural disasters are strongly linked to meteorological conditions, and among these forest fires play a very important role as a major threat to vegetation-covered areas in many parts of the world.

The impact of fires in a given region is usually evaluated by the number of fires and the size of the burned area. Unfortunately, there is no uniformity in these data throughout the world to render the statistics relevant for comparison.[1] The relative importance of the problem in a given area depends both on its dimension and frequency, and on the perceptions of local people.

Forest fires are a complex mixture of human and natural factors. Man is quite often the originator of such fires, intervenes during their development, and is also impacted by them. Overall, it is very difficult to assess precisely the relative roles of man and nature in forest fires. We can only say that there are aspects of forest fire in which human and social activity are the most relevant; but there are also aspects in which nature plays the dominant role.

Fire is part of nature and has shaped vegetation cover and life throughout millennia. It cannot be eliminated from the landscape without damage to biodiversity. Conversely, man has used and continues to use fire for the management of rural and wild spaces. Therefore it is necessary to distinguish between controlled fires and wild fires. The latter include those events, either natural or anthropogenic, in which fire cannot be controlled before causing undesired damage.

The advent of technology has created the illusion that man can dominate natural forces and overcome the laws of nature. One of the consequences of this attitude is the illusory ideal of excluding fires from the forest altogether. We have to recognize that even if all anthropogenic fires could be avoided, natural events such as lightning strikes might originate fires in conditions that are beyond the control of even the most advanced technologies.

The role of climate and meteorology

It is commonly accepted that physical factors such as topography, vegetation cover, climate and meteorology contribute greatly to the conditions needed for a fire to start and to spread. Climate and topography determine to a great extent the type of vegetation cover, its quantity and distribution.[2] Meteorological factors such as precipitation, air temperature and humidity affect the growth of fine vegetation and determine its proliferation and dryness. The moisture content of fine vegetation, particularly in dead plants, is strongly related to the risk of ignition — above a certain moisture threshold it is very difficult to ignite or maintain. Conversely, very dry fuels provide an ideal environment for fires to start and spread. The presence of slopes or wind can also contribute to an increase in the rate of spread of a fire, to a point that may make its control virtually impossible. In certain conditions including steep slopes and canyons, the convection induced by the fire modifies the burning conditions and thus increases its rate of spread.[3]

Photo: Pedro Palheiro/ADAI

Forest fire at the borders of River Zezere in Pampilhosa da Serra, Central Portugal, 1 August 2003

Even in areas of the world where fires are mainly caused by human actions, there is a strong correlation between good burning conditions and fire incidence. It is therefore convenient to express these burning conditions in the form of a fire danger index. This index is based on meteorological parameters and takes into consideration the fire history of the region. Its establishment is a very basic step towards the management of forest fires. The Canadian Fire Weather Index is rapidly becoming a common standard for the assessment of fire danger worldwide.

Natural fires caused by lightning have, over millennia, modified natural vegetation to balance and contain biomass growth. In some regions this fire cycle has a period of tens of years, while in other regions it can take several centuries before a given area is burned again. In some areas of the world, where intensive forest exploitation is not possible, this natural cycle still occurs. However, human intervention has changed this pattern, sometimes introducing new species and controlling fuel accumulation cycles through harvesting. The result is that it is increasingly difficult to protect both native and introduced species from fire.[4]

Climate change, with its likelihood of a rise in temperature and a decrease in relative humidity, is likely to exacerbate fire risks, and even to promote fire risk in currently less fire-prone areas. Increased temperature and reduced precipitation in the long term will modify vegetation cover, promoting fire-prone species. Global warming, with the increase of energy in the atmosphere, will produce greater variability in meteorological conditions. As a consequence, fire seasons will be extended, and the number of very high-risk days will tend to increase. As a result of these changes, many countries have already experienced increased fire incidence over the last decade.

Forests act as a sink for carbon monoxide and contribute to settle the overall balance of carbon in the atmosphere. But when they burn, not only is this sink effect lost, but very large quantities of carbon monoxide, carbon dioxide and other noxious products are also emitted, compounding the problem.

The role of man

From initially passively observing fire working in nature, man began to use it to clear vegetation for habitation, crops and grazing. In modern times the destruction of natural habitats has been restricted, and some areas have been legally protected. Prior to this there had been a kind of equilibrium, due to an extensive consumption of biomass by fire. The exclusion of fire in this context, in combination with other social and natural factors, brought about an accumulation of vegetation. Episodic fires that threatened human life and property created the need to suppress them in an organized way. In response to this some countries reintroduced fire in controlled conditions in a tentative effort to re-establish the natural balance. In spite of this effort, fire remains a threat not only to natural and cultivated areas, but also to urban areas.

Forest fires are unique among natural disasters in that human intervention can be effective at all stages of their development: before, during and after. In non-natural landscapes such as rural areas and forest plantations, the organization of the area and the way the plantations are planned and managed can modify the conditions that facilitate fire ignition and spread. The choice of species and reduction of fuel loads can contribute to reducing fire impact in most high-risk conditions, with the exception of the very extreme. The existence of fire-breaks and a distributed network of fire detection and fire-fighting systems will help to suppress fires while they are small, under normal conditions. Repeated, frequent incidence of fire disrupts the economy of a region, and in the long term may challenge the sustainability of biodiversity and of forest activities. Recovery actions after a fire can minimize the loss of biodiversity, loss of soil, and other irreversible effects in burned areas.

An ever-increasing problem is that of the urban/wild land interface, in which wildfires reach populated areas, from isolated houses to the suburbs of large cities. This problem is associated with many factors, including the desirability of living 'closer to nature', the lack of planning and management in some areas, as well as changes in the climate.

Smoke produced by fires can be as much a problem as the fire itself. Smoke can travel a long way from the site of the fire and persist for long periods of time, limiting visibility and creating a health hazard in populated areas.

It is imperative to change attitudes to forest fires around the world, particularly in those regions where fires are mainly caused by human actions. We know that it is not possible or even desirable to exclude fire entirely from nature, but incidences of anthropogenic forest fires should clearly be eliminated.

An increase in fire prevention activities is needed everywhere, ranging from the planning and management of forested and rural areas to the creation of well-organized fire detection and initial attack services to stop fires while they are still small. Investment in expensive fire-fighting equipment — although necessary up to a point — is not the solution to the problem. It never will be if other activities are not carried out, including the fundamental involvement of the entire population in this common effort.

Forest fire incidence is not uniform throughout the world, but everywhere it is the result of both natural and anthropogenic factors. Climate change is already bringing an increased risk of forest fires, and this tendency is likely to lead to even larger and more widespread problems in the future.

Science and technology can support man in managing and controlling fire in rural areas, but not in mastering it and even less in eliminating it from nature. A common effort by all institutions and citizens is required to minimize the incidence of fires, especially in these days of high risk. Man is part of this problem and must be part of its solution.

Photo: Luis Pita/ADAI

Fire spreading in a valley near Maxial-Sertã, Portugal, 6 August 2003

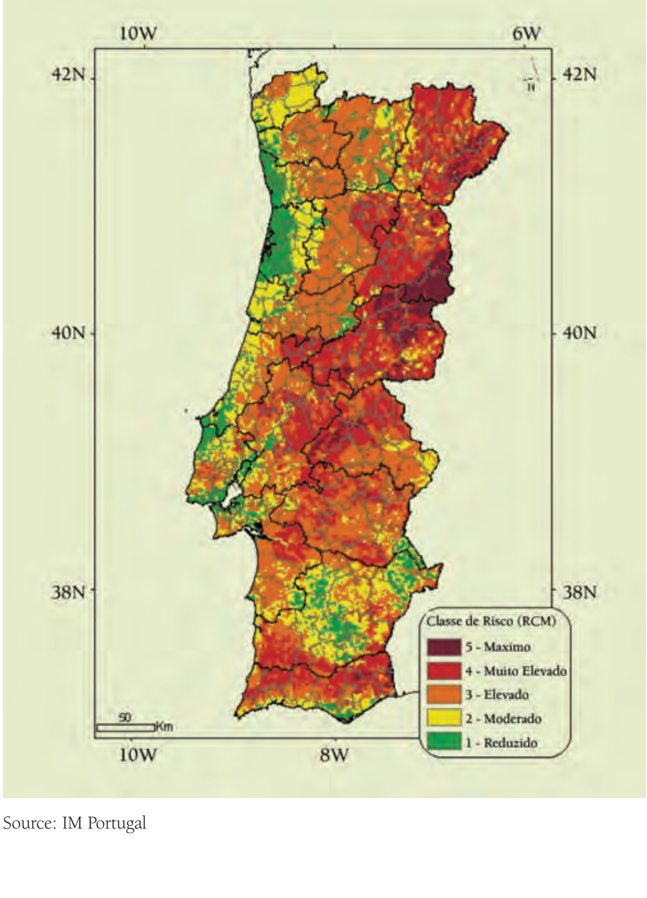
The Portuguese Institute of Meteorology and forest fires

Luis Pessanha, Julia Silva and Teresa Abrantes, Instituto de Meteorologia, Portugal

FOREST FIRES ARE one of the most serious natural risks affecting Portugal, especially during the summer time. They are dependent on many factors and produce various effects, making them a very complex and challenging problem. For the deflagration of a forest fire it is necessary to have combustible substance and a source of heat. Its evolution depends on atmospheric conditions and the state of the vegetation.

In countries with a Mediterranean climate, the predominant meteorological conditions over the summer months such as heat and dehydration of vegetation encourage the occurrence of forest fires. Portugal has a relatively long warm and dry season, during which wild fires can occur. In the period of the fire season, considered to be between May and October, Portugal suffers a large number of forest fires and burnt area. Forest fire spread is related to social factors, often consuming a vast forested area.

Forest fire risk classes by regions



Source: IM Portugal

In Portugal, different institutions are directly involved in the prevention and combat of forest fires. These include the Portuguese Civil Protection and Fireman Service, the Forestry Service and the Portuguese Institute of Meteorology. In recent years, research and a successful collaboration between these institutions has led to a better understanding of the deflagration and propagation of the forest fires and the investment of time and resources to provide guidelines and possible solutions.

When evaluating the global risk of forest fires, it is absolutely essential to take into consideration the impact of meteorological conditions. The fire risk brings together detailed information from meteorological net stations all over the world, aiming to provide a very precise analysis of meteorological conditions, weather forecasts and climate conditions affecting all domestic territories.

The research from the Portuguese Institute of Meteorology includes, beyond all the general meteorological information, specific products, such as the Fire Weather Index (FWI) of the Canadian System and the Combined Risk Index of Forest Fire (ICRIF), which are all directly used to support the prevention of forest fires. This information is made available to all national entities that have responsibilities in the prevention and combat of forest fires. A daily brief is established between the Weather Forecasting Centre and the National Civil Protection and Fireman Centre. The information is made available to the public during the most critical parts of the year.

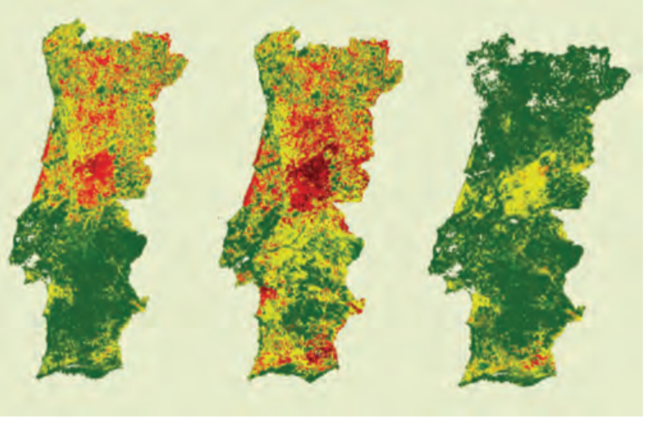
Fire Weather Index

The information distributed by the Portuguese Institute of Meteorology is based on the Fire Weather Index (FWI). The calculation of the FWI includes several meteorological variables; the temperature, the relative humidity of air, the wind speed at surface and the amount of precipitation observed in all the meteorological stations, taking into account the forecast for the next two days.

The information also contains charts with different classes of fire risk defined by regions. The predicted fire risk classes are based on the FWI integrated with the country vegetation type map from the Portuguese Forestry Service. The different classes of Fire Risk are shown in different colours, relative to the intensity of risk from yellow to red.

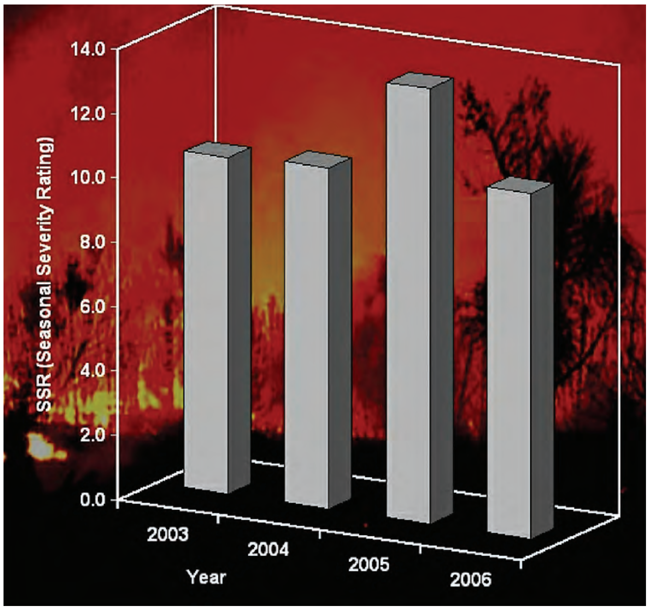
The Portuguese Institute of Meteorology also computes a daily combined Forest Fire Risk Index, the ICRIF (Índice Combinado de Risco de Incêndio Florestal). It is a dynamic index, combining meteorological, vegetation status and structural information and computing, not just the probability of forest fire ignition, but also the capability of fire spread.

ICRIF values showing the evolution of the fire risk



Source: IM Portugal

The evaluation of seasonal severity of fire risk in Portugal



Source: IM Portugal

The ICRIF agglomerates several factors, taking into account both structural and meteorological indices, combining the FWI with a fuel map and a vegetation parameter. It is calculated by weighting the FWI value with a factor connected with a fuel burn index, obtained from the CORINE 2000 (Coordination of Information on the Environment), and a vegetation index, the NDVI. The weights are values scaled from 0 to 100 and the final value of ICRIF can range from 0 to about 100.

The CORINE 2000 database is an update of the old CORINE 1990, a programme introduced by the European Commission in 1985, in order to gather information relating to the environment for the European countries. CORINE land cover is a European wide land cover and land use classification, produced using satellite images. The mapping accuracy is at least 100metres.

Forests are periodically burned, resulting in an immediate change of the land cover in the burned surface. This can result in the recovery of natural vegetation or forest species that were present before the fire affecting the structural fire risk map. The new characterization of the land cover is completed, updating the value of the fuel risk pixel. This update is done at least once a year at the beginning of the fire season (April) and can be done using imagery and observing changes in the NDVI index.

The Normalized Difference Vegetation Index (NDVI) is one of the most used vegetation indexes and is a measure of the amount and vigour of vegetation at the surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. NDVI is calculated using measurements from the Advanced Very High Resolution Radiometer (AVHRR) on board the USA's NOAA polar orbiting meteorological satellites. The reflectance measured from Channel 1 (visible: 0.58 - 0.68 microns) and Channel 2 (near infrared: 0.725 - 1.0 microns) is used to calculate this index. The differential reflectance in these bands provides a means of monitoring density and vigour of green vegetation growth using the spectral reflectivity of solar radiation. Green leaves commonly have larger reflectance in the near infrared than in the visible range. As the leaves come under water stress, become diseased or die back, they become more yellow and reflect significantly less in the near infrared range.

Clouds, water and snow have larger reflectance in the visible than in the near infrared, leading to a negative value of NDVI, while the difference is almost zero for rock and bare soil. The NDVI is affected by a number of different phenomena, including cloud contamination, atmospheric perturbations, variable illumination and viewing geometry, all with an impact of reducing the NDVI value. To address these effects, NDVI data is often used as a composite, taking the maximum value over a specified time period, usually a week or ten days. To minimize the error due to illumination and viewing geometry, every day a program chooses the image NOAA with the best observational zenith angle below 45 degrees and the best solar zenith angle below 35 degrees of the solar elevation angle. With this image a geometric correction is automatically made by the receiving station with several reference ground control points. The final error is estimated on a one-pixel basis.

An example of the ICRIF is shown here, which illustrates that by the end of May and beginning of June there were very good synoptic conditions for forest fires in the northern part of Portugal. On the contrary, in the southern part of Portugal, the lower temperature and cloudy conditions were observed with precipitation in some of the regions.

The third image illustrates the severity of the fire risk registered in Portugal during the fire season over the past years. You can see that the severity rating has been generally very high, but in the year 2005 it reaches an exceptional value. Although in 2006 the fire risk was also very high on some days, they were interspersed with periods of precipitation, impacting the overall risk assessment for the year.

Both FWI and ICRIF are used by the civil protection agency to prevent and combat forest fires. From this information several measures can be taken to protect the areas where the risk is higher.

During the summer of 2006, the value of the fire risk was recognised as very useful information, reducing the impact of forest fires, and therefore reducing the number of occurrences and burn area. This daily contribution to support forest fire prevention and combat is an example of successful cooperation between decision makers, in this case the Portuguese Civil Protection Service and the Portuguese Institute of Meteorology.

Battling extreme weather under a temperate climate — Hungary

Gyuró, Gy., Á. Horváth, M. Lakatos, S. Szalai and J. Mika, Hungarian Meteorological Service

Surrounded by the Alpine mountains to the west, and the Carpathian mountains to the north and east Hungary's basin situation is accompanied by several long and short-term weather extremities despite its temperate climate, which is accredited to its 46-48 N geographical latitude. Four such extreme events are droughts, heat waves, vast local precipitation (flash-floods) and convective windstorms. By looking at the phenomenology and regional characteristics of these events, it will be possible to point to the relevant services provided in each case by the National Meteorological Service (NMS), including forecasts and warnings of the event.

The phenomena are listed in decreasing order of their time scales. Hence, the possibility and importance of forecasting (i.e. the factor of timely warning) rapidly increases, whereas our ability to judge more recent and future trends, diminishes.

Drought

Hungary is situated in the Carpathian basin, surrounded by mountains but open to the south. This geographical position can also contribute to the fact that precipitation tendencies in Hungary are similar to those in the Mediterranean region. In addition, the largest decrease of precipitation can be found in the more humid areas. Therefore, almost the whole territory of the country suffers from water scarcity, mostly through frequent drought events.

Monthly precipitation can reach 200 millimetres in almost any month and region, but months without a drop of precipitation may also occur in any season. Sometimes both flood and drought are experienced in the same region during the same year. Annual and seasonal precipitation amounts are decreasing, with one exception. The summer precipitation totals have no definite trend themselves, but the water management situation is still worsening, as precipitation occurs in fewer cases and with higher intensity. Besides this inconvenient dosage of precipitation, positive temperature trends also intensify the problem.

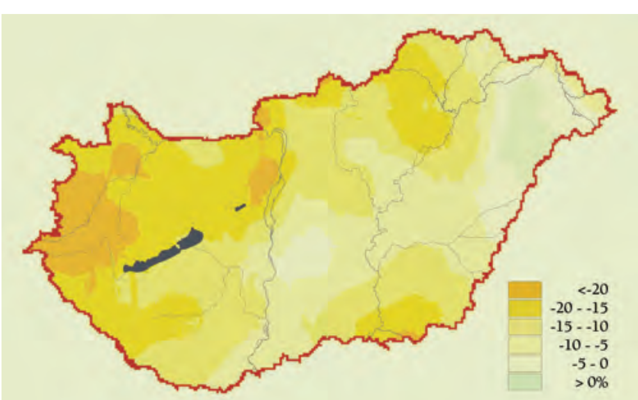
The average situation is well characterized by the temporal evolution of annual minima and maxima of the Palmer Drought Severity Indices (PDSI) in Debrecen. Both the annual maxima and minima have a decreasing tendency, indicating an increasingly large chance of droughts. Debrecen is situated in the north-east region of Hungary. From among the three typical climats that influence Hungary (oceanic, Mediterranean and continental), the climate of Debrecen is mainly governed by the latter.

The Hungarian Meteorological Service (HMS) operates an interactive irrigation advisory system through its homepage, free of charge (www.met.hu). The irrigation model uses the observed data of precipitation and plant-specific, estimated evapotranspiration, all obtained from automatic weather stations to describe the actual plant water demand.

Heat waves

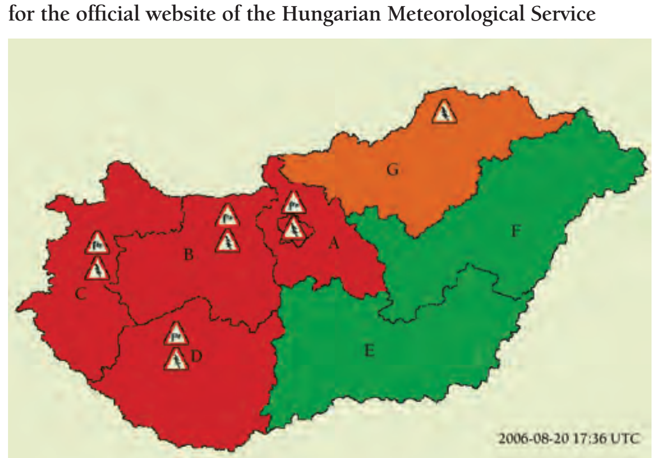
The mean summer temperature was 19.6 degrees Celsius in the 1961-1990 normal period. Since its end, however, both the average and the deviations from it seem to have changed significantly. Parallel to global warming, the simple linear trend of the summer

Change in annual precipitation (%) in Hungary for the period 1951-2004. Exponential trend estimation is applied, and the results relate to the 54-year long interval



Source: OMSZ

Severe weather warning for 20 August 2007, issued at 17:38 UTC for the official website of the Hungarian Meteorological Service



Source: OMSZ

temperature (the steeper and the most significant one among the seasons) in Hungary is ca. 1.0 degrees Celsius for 1901-2006.

Under the climate of Hungary, summer heat waves occur rather frequently, hence an operative heat alarm system has been in use since 2004. According to the Hungarian heat alarm experience, if the daily mean exceeds 25 degrees Celsius on at least three consecutive days, the medical risk rises by 15 per cent. If the daily mean is above 27 degrees Celsius for at least three consecutive days, the increase in risk is 30 per cent.

According to the definition of heat alarm levels, the HMS issues a warning signal for the National Ambulance Service and the National Public Health Service. The warning signal is also appears on the Web site of the HMS according to the regions of the country. The actual extreme weather conditions are analysed on the Web site of the HMS to inform the public.

According to climate statistics, the occurrence of hot periods with 25 degrees Celsius average temperature grew by around six days, trend estimation suggests. Heat waves with over 27 degrees Celsius temperature exhibited a three-day increase during the 1901-2006 period.

Flash floods

Monitoring of flash floods depends on population density, due to the small coverage of such phenomena. Chronicles usually mention them in connection with large damages. Therefore, we know about many flash flood events in Hungary from the Middle Ages.

Preliminary studies concerning regional climate changes indicate that, besides the more frequent drought events in Hungary, short-term precipitation intensity is also increasingly likely, according to the finer resolution models and empirical analyses.

Several flash floods have occurred in Hungary in the recent years. For example, experts from the Disaster Management Directorate of Nograd County (northern Hungary), one of the 19 counties of Hungary with an area of 2,540 square kilometres, noted five flash floods in 2004, seven in 2005, and six in 2006. Altogether, more than 400 houses were damaged in the small villages among the hills and around 600 people became temporarily homeless. The total damage of these events was in the region of EUR2 million.

HMS experts in radar meteorology have a calibrated precipitation archive extending more than ten years, where 15 minute area means are prepared in 2x2 km resolution. These maps are used in two ways. In the given case they contribute to documentation and re-compensation of damages. More generally, they provide good guidance for local governments to elaborate flexible warning systems in anticipation of further events, including proactive measures to mitigate damages.

A large flash flood devastated Mátrakeresztes on 18 April 2005. The nearby precipitation gauge (Mátraszentlászló) measured 111 millimetres in two hours. Simultaneously, hail rained down for about 40-50 minutes. Precipitation during these two hours was higher than the monthly averages even during the wet months, before 2005.

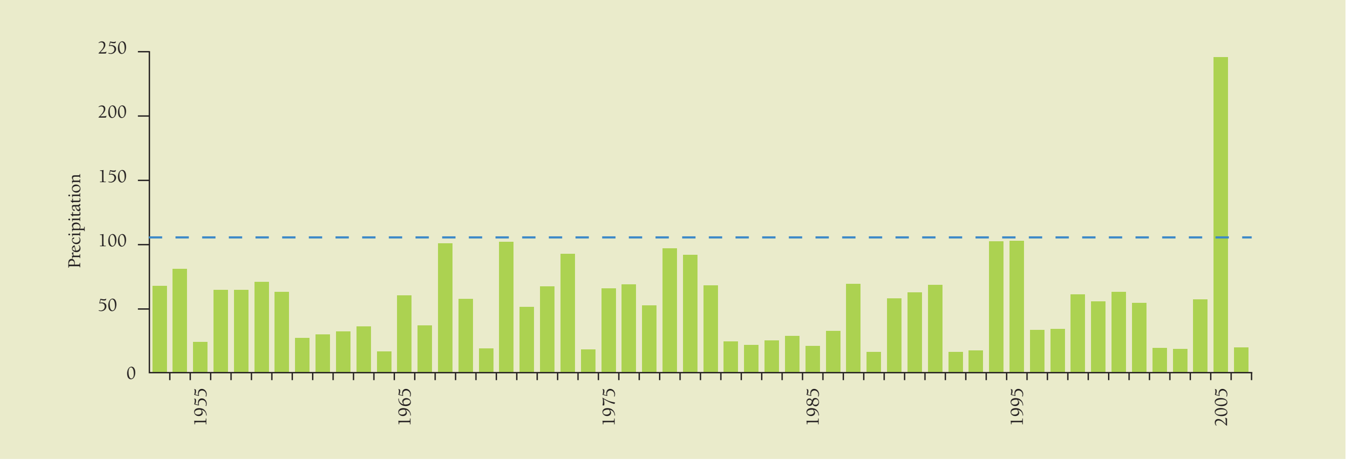
Windstorms

Severe storms are not unusual in the Carpathian basin. They are mostly connected with intense extratropical cyclone activity. Windstorms in Hungary partly occur in winter and are recorded in a very severe cyclone, a so-called cyclonic bomb. Summer storms are consequences of intense convection in the atmosphere. Fast running cold fronts, squall lines and thunderstorm supercells can generate heavy storms with gusts stronger than 30 m/s (108 km/h). The highest wind gusts in Hungary are ranked as follows: Szarvas (southeast Hungary), 3 August 1988: 44.5 m/s (160.2 km/h); Szeged (south Hungary), 12 July 1993: 44.3 m/s (159.5 km/h) and Sopron (west Hungary), 15 February 1990: 41.9 m/s (150.1 km/h).

Since early 2006 the HMS has been providing official weather warnings for the public. Warnings for windstorms, heavy precipitation, heavy snowfall, fog, icing, thunderstorms, heat waves and very low temperatures are published on the HMS Web site and transmitted to the Hungarian Disaster Recovery Authority.

On 20 August 2006, a very severe cold front reached the capital of Hungary at 9:00 pm, whilst simultaneously the traditional King St. Steven's Day fireworks started. The front with a thunderstorm supercell generated heavy precipitation and wind gusts with a peak of 34.1 m/s (132.1 km/h). More than one million people gathered on the Danube bank and, despite correct forecasts, there were four fatalities and dozens of injuries. This incident pointed out the urgent need for the refinement of collaboration between state authorities and meteorologists and the need for information packages for the public.

April precipitation sums since 1953 at Mátraszentlászló, Hungary. The dashed line shows the precipitation sum that occurred in two hours on 18 April 2005



Source: OMSZ

IV

ENVIRONMENT

Knowledge for sustainable development: assessing a decade of African climate forecasting

Jordan R. Winkler, Boston University
Anthony Patt, International Institute for Applied Systems Analysis
Kabineh Konneh, NOAA Climate Programs Office

The African droughts of the 1990s brought worldwide attention to the devastating effects of severe weather events. The dependence of African economies on rain-fed agriculture, combined with weak institutional and physical infrastructure, social conflict, and an inconsistent political environment, puts African livelihoods at high risk to climatic fluctuations. Over the past 20 years scientists have improved their understanding of the role played by El Niño-Southern Oscillation (ENSO) — the coupled ocean-atmosphere interactions in the equatorial Pacific Ocean — in African climate variability. Recent improvements in sea surface temperature models enable scientists to predict the onset of ENSO events, and also their effect on global climate. To explore how climate prediction could be used as a social benefit the United States National Oceanic and Atmospheric Administration (NOAA) has launched a number of programmes aimed at studying policy processes under climate variability and the utility of seasonal climate predictions. The results have brought to light the intricate relationship between climate and society, and point to the opportunity for climate science to become a critical component of African development policy.

Since 1995 NOAA, along with key partners such as the United States Agency for International Development Office for Foreign Disaster Assistance (USAID-OFDA), has funded over 100 workshops and research projects across Africa. The work provides support for local organizations to create and disseminate seasonal climate forecasts, and identifies areas where forecasting can be used to promote socio-economic stability. Through these projects NOAA recognized that accurate information on seasonal precipitation has the potential to benefit decision-making in multiple sectors. Within the agricultural sector the most important decisions are when and where to plant. Accurate forecasts allow farmers to know when to plant drought resistant seeds, or capitalize on good rain years by supplementing with cash crops. At the government level this information helps determine the amount of food to import and distribute to maintain national food security. Many vector and water borne diseases are dependant on swings in temperature and precipitation. The ability to forecast these variations has the potential to warn health ministries of an impending outbreak. Given this information, officials within the health sector can stockpile medication and fresh water, perform indoor residual spraying, and distribute insecticide treated nets where needed. Within the water management sector information on cumulative rainfall can be used to manage dam levels. In particular, information on a dry year can give hydroelectric officials time to seek out alternative power supplies.

NOAA has used a wide range of approaches to address the diversity of institutions that stand to benefit from accurate forecasting. The first priority has been creating integrated programmes that bridge scientific research with decision-making at the local level. Currently, NOAA supports three main regional climate centres through direct funding and research support: the African Centre of Meteorological Applications for Development (ACMAD) in Niger, the Southern African Development Community Drought Monitoring Centre (SDMC) in Zimbabwe, and the Intergovernmental Authority on Development Climate Prediction and Application Center (ICPAC) in Kenya. All provide the opportunity for members of the National Meteorological and Hydrological Services (NMHS) from various countries to work together on regional forecasting projects.

Each centre creates a seasonal climate forecast for its region prior to the start of the rainy season. The forecast indicates the likelihood that a given area's rainfall will be close to, above or below a thirty year average. To ensure visibility of the forecast and encourage its timely distribution, each centre organizes a Climate Outlook Forum (COF). The COFs provide an opportunity for scientists to present findings to stakeholders from all sectors. In turn, the stakeholders gain a platform for sharing their needs. The result is an enhanced understanding of the complexity surrounding how society responds to climate information.

While the COFs represent the most visible efforts, they are only one of the many research activities NOAA and USAID-OFDA support. By holding workshops with small communities of subsistence and commercial farmers, NOAA has gained insight on the needs of the end users. Workshops can be broken down into two main categories: exploratory and educational. The exploratory workshops aim to determine if the forecasts are being used. Most have indicated that while many farmers are aware of the existence of an official seasonal forecast, few use it in their planning. Interviews have shown that farmers are eager to use the forecasts; however, they do not receive information in time to adjust their behaviour accordingly. The education and outreach workshops give participants the ability to ask questions regarding the forecast process, and gain a better understanding of the terminology of the forecasts.

Other research efforts have focused on improving the process of creating and adjusting forecasts for specific applications. Within the health sector, new understanding of the link between malaria and temperature and precipitation, has led to the development of malaria forecast models. These models combine the seasonal forecast with daily ground monitoring and allow officials to predict malaria outbreaks months in advance. In Kenya, daily monitoring is being utilized for hydroelectric management on the Tana River and is combined with information on sea surface temperatures to create river flow models.

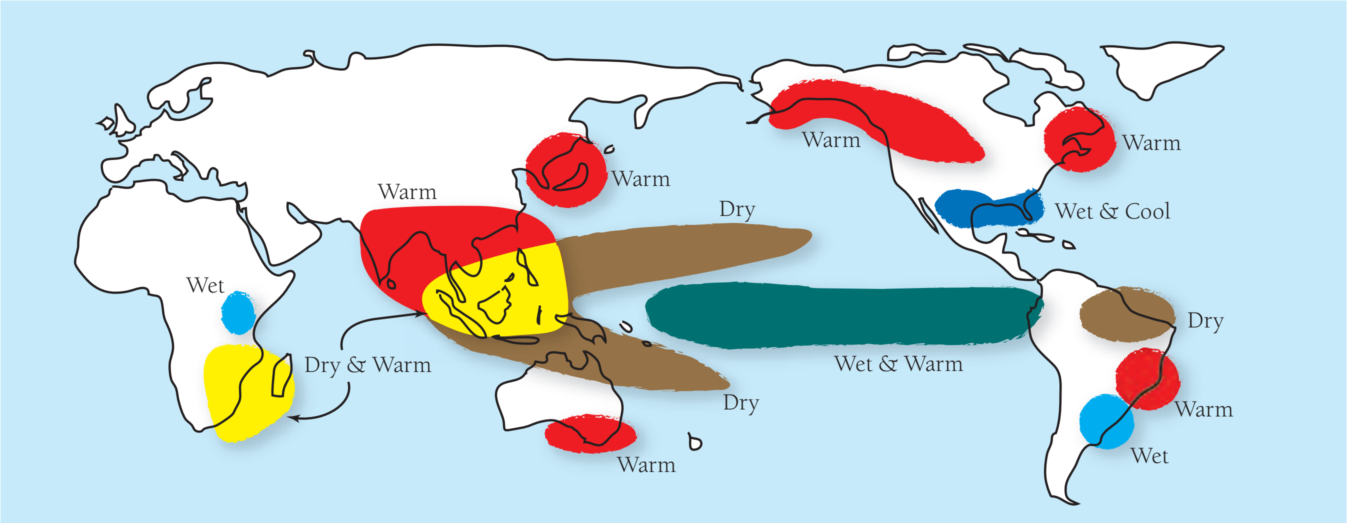
In hopes of evaluating the effectiveness of these efforts, NOAA has engaged a team from Boston University and the International Institute for Applied System Analysis to conduct two research tasks. First, the team is conducting a meta-analysis of the published and unpublished empirical findings from the past decade. Second, the team is gathering feedback from governmental and non-governmental agencies within the region. The primary goal of the work is to organize and evaluate the results around a set of thematic issues present at both the top and bottom of the process. Within each issue they will describe the state of knowledge that existed prior to the start of the NOAA programmes. Next, the methodologies of the research are examined and presented alongside the results, allowing the reader to assess the reliability of the work. Most importantly they are attempting to identify gaps in the current state of knowledge, which will provide a stimulus for future research. The purpose is not to answer definitively the questions associated with these issues, or promote application in any particular sector, but to offer a neutral assessment for policy-makers.

The preliminary findings have shown common achievements and setbacks through nearly every sector. The majority of successful applications occur where end users have a high level of education, regular exposure to the forecasts, or work in a sector with well-established links to climate scientists. But it is clear that knowledge of the forecasts is not limited to the educated. Media coverage of the 1997-1998 ENSO events drew widespread attention to the existence of the forecasts; however, the amount of use among less educated groups is limited due to issues with communication and dissemination.

Once the forecast is given at the COFs the responsibility for dissemination is left to the national, provincial and local governments. Often training is minimal, funding is low, and forecasts get caught up in the bureaucratic process. By the time they have reached the end user they are incomplete or too late. Radio has been identified in many studies as a primary source of forecast delivery; however, workshop participants pointed out an inability for listeners to ask questions or receive clarification. The most effective communication method will constitute a two-way process with active participation from the end user.

Often, the form of the forecast offers little help to the recipient. In some cases, the information may conflict with indigenous methods and can be met with distrust. The probabilistic forecasts offer no information on temporal distribution of precipitation. Many farmers are accustomed to the accuracy and detail of the ten-day updates they regularly receive from NMHS, and expect similar detail for the seasonal forecasts. Other times the spatial scale may be inappropriate and require adjustment. There have been cases where NMHS have waited until the season started to scale down the forecast for fear of being incorrect. Training must be available at all levels of the dissemination process.

These results, though preliminary, offer insight for future research. The main objectives of future studies should be to support and enhance existing successes while improving forecast design, communication, and training for both users and producers. A need exists to tailor forecasts based on the specific requirements of national agencies and smaller user groups. More effective means of mass communication need to be developed, including sensitising the media to act as a responsible partner in the dissemination process. Lastly, every project should work towards enhancing regional ownership of the processes that are now internationally sponsored. This can be achieved by developing frameworks for regional and national funding and identifying sustainable sources for COFs and other outreach. The responsibility of scientists and policy makers remains to provide the information and education necessary for the end users to gain the most benefit from utilizing the forecasts. The end users' opinions, their ability to use the forecasts, and the benefits they ultimately derive from them, should be the most important measure of success.



Source: IRI

Global effects of El Niño, showing conditions over Africa

Environment, efficiency and solidarity: a challenge

Cristina Narbona, Environment Minister of Spain

At a time when concern about climate change and its effects is growing to the extent that it is taking root in global economic and social awareness, the challenge of appropriate and effective environmental management in a framework of sustainable development and adaptation to change has become a top priority.

Spain has always had to deal with climate variability. This has led, together with the country's economic and social development, to a range of complex scenarios requiring specific solutions based on the principles of efficiency and solidarity. The search for, and adoption of such solutions is the responsibility of the Ministry of the Environment. The Spanish Government's aim is to ensure that economic and technological innovation combines with a sense of social cohesion, sensible use of natural resources and reduction of pollution, in order to develop in a fair, healthy and sustainable manner.

Undoubtedly, the main environmental challenge for Spain and for the Ministry of the Environment is climate change. In addition to significant efforts to create awareness at all levels of society, a National Plan for Adaptation to Climate Change has been drawn up, a Commission for Coordinating Climate Change Policies has been created and contributions have been made to various planned strategies for renewable energy and energy efficiency. There is also a new assignment plan, and constant monitoring is carried out to ensure that Spain does everything possible to meet its international commitments. Moreover, in view of the importance of international collaboration in this area, we have set up the Ibero-American Network of Climate Change Offices, and have signed several memorandums agreeing coordination with other countries.

Water management is another significant challenge for Spanish environmental policy. The uneven natural distribution of water amongst the different regions of Spain, and the cyclical drought patterns create a scenario in which the criteria of rationalisation and efficiency, and the use of new methods for obtaining drinking water are of growing importance. This is especially pertinent when we consider the fact that new climate scenarios for our geographical area show an increase in the variability and intensity of rainfall. Our government is drawing up legislation to fight speculation, wastage and pollution of water, and to promote the sharing of water rights amongst the different river basins. At the same time, it is building new infrastructure, especially desalination plants, for irrigation and for supplying water to coastal cities. Finally, on an international

Photo: Environment Ministry of Spain

The appropriate management and use of water resources is a fundamental issue in Spain, where precipitation presents a variability, both in timeframe and in spatial distribution level, it has helped establish cooperation with Latin America in the fields of water availability and management.

Forest fires are another serious challenge. The long periods of drought, high temperatures and a growing number of open air activities are giving rise to a large number of fires. A proper forestry policy, with legislation that takes into account the current situation and promotes public awareness, would present a simple but effective line of defence against this threat.

The preservation and improvement of biodiversity in natural areas of Spain is also of special importance to the Ministry. Conservation strategies are in place, the creation of new national parks is planned, and a thorough review of the policy for coastal area management is being implemented.

Another problem is the social, economic and environmental effects of adverse atmospheric phenomena in Spain. Heavy rainfall in the Mediterranean areas, heat waves, strong winds and snowfalls often have direct consequences for our society. Preparedness along with a fast and effective response are essential. Our Ministry makes a substantial contribution to attaining this through the National Meteorology Institute. The institute operates and maintains a modern warning and forecasting system, which benefits from active coordination with other European meteorological institutions.

When drawing up long-term policies and strategies, or adopting urgent measures, one of the key requirements for the planning and management of weather services is the availability of high-quality climatic, meteorological and hydrological forecasts. The development of regionalized climatic scenarios is essential for the adaptation and development of weather services in the long term. Also, precise meteorological and, where appropriate, hydrological forecasts are a basic requirement for activities in the short and medium term, and for facilitating fast reactions to adverse weather events. The Spanish National Meteorology Institute has extended its traditional tasks in order to meet these challenges and to provide more substantial support to environmental planning and management in general. It is essential to maintain well-equipped, effective state meteorological services — services that can provide reliable observations and basic climatological, forecasting and surveillance products, in order to meet the needs of users in general, and of an increasing number of economic and social activities.

Although great improvements have been made in the quality and availability of such environmental information, further progress is still necessary, along with a fresh multidisciplinary approach. Through international collaboration, experts across the world have been able to compile, share and refine their data and research so that accurate, effective application is possible. We have invested large amounts in international development, notably through the Araucaria XXI programme and an agreement with the Spanish Agency for International Cooperation regarding the Azahar programme. We have also significantly increased our contribution to United Nations Environment Programme, for the purpose of fighting desertification in Africa, improving access to drinking water in Latin America and training personnel in environmental tasks. Also, by bringing together experts from different areas on a national level, we are able to offer a greater quantity of information and produce more valuable conclusions. This enables swift, accurate short and medium term responses. We have fostered the Sectoral Conference on the Environment, and the Advisory Council on the Environment, while intensifying media campaigns for environmental awareness amongst both the general public and professionals in all sectors of economic and social activity.

However, we need to continue working towards solving global environmental problems. Useful solutions require better knowledge of the atmospheric environment and its trends. Scientists must develop a clearer understanding of the needs of users, and an awareness of those who will be most affected by meteorological and climatic events. Conferences such as Secure and Sustainable Living: Social and Economical Benefits of Weather, climate and Water Services 2007 are of fundamental importance. The guaranteed availability of accurate forecasting would enable effective environmental management. Such an improvement would enhance the living conditions for all humanity.

Photo: Environment Ministry of Spain

Spain is one of the leading countries in the exploitation of renewable energies, particularly wind energy

Photo: Environment Ministry of Spain

Preserving biodiversity is a high priority in environmental protection activities in Spain. This is implemented through a wide network of natural parks and protected spaces

The African Monitoring of the Environment for Sustainable Development Initiative: a timely initiative to save an endangered continent

Paul Counet, the European Organisation for the Exploitation of Meteorological Satellites

Sub-Saharan Africa is home to many of the world's developing nations — and to some of its poorest, for whom life is precarious. Crop failure, environmental degradation and increasing competition for scarce natural resources caused by extreme weather events and climate changes are posing unprecedented threats to economies, livelihoods and traditional ways of life.

Weather forecasting capabilities across the continent have been greatly enhanced in recent years by initiatives such as Preparation for the Use of MSG in Africa (PUMA), the first pan-African technology project focusing on Earth observation funded by the European Union. PUMA has made available data and products from the latest satellites of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), enabling African National Meteorological and Hydrological Services (NMHS) to provide accurate weather forecasts, monitor extreme weather events, improve disaster management and forestall drought and starvation.


Photo: Copyright EUMETSAT

Signing of the Dakar Declaration, 29 September 2002

The African Monitoring of the Environment for Sustainable Development (AMESD) initiative takes PUMA a stage further by significantly extending the use of remote sensing data to environmental and climate monitoring applications. AMESD, in which EUMETSAT also plays a key role, is financed out of the European Union's European Development Fund. Like PUMA, AMESD is an international cooperation project with the objective of providing all African nations with the resources they need to manage their environment more effectively and ensure long-term sustainable development in the region.

The European Union's strategy for Africa

Peace, security and good governance are prerequisites for sustainable development in Africa. Accordingly, the European Union's strategy for Africa addresses actions in areas that are critical to creating the necessary environment for economic growth, stability, trade and infrastructure. In particular, the strategy promotes investment in sectors which impact directly on the United Nations Millennium Development Goals (MDGs). These goals aim to eliminate poverty, promote sustainable development and improve the health, education and well being of the world's developing and impoverished nations.

Earth observation technologies have been identified as vital tools in the MDGs' pursuit of sustainable development, especially with regard to the environment. AMESD is, therefore, expected to play an essential role in the implementation of the European Union's strategy for Africa.

AMESD would also be the precursor of the extension of Europe's Global Monitoring of the Environment and Security (GMES) initiative to Africa, as requested by key African decision-makers in the Maputo Declaration signed on 15 October 2006 at the seventh EUMETSAT African User Forum in Mozambique.

AMESD builds on PUMA's success

PUMA laid the groundwork for AMESD by providing the NMHS of all African countries with the equipment, training and support required for receiving the latest space-based images and products from EUMETSAT via the EUMETCast distribution system.

In creating a successful pan-African network with operational access to state-of-the-art satellite technology, PUMA provided each country with the means to develop their own applications with the potential to enhance quality of life

Photo: Copyright EUMETSAT

Like PUMA, AMESD is an international cooperation project with the objective of providing all African nations with the resources they need to manage their environment more effectively and ensure long-term sustainable development

through, for example, better water and agricultural management. It also equipped them with effective tools to monitor and mitigate extreme weather events and improve disaster management strategies, thus saving lives and property.

PUMA also established six successful pilot projects to foster the use of Earth observation data for non-meteorological purposes for example, monitoring coastal fish stocks off Kenya and Senegal, as well as providing South Africa's power grid industry with an early warning system for land fires (a major cause of power outages and service disruptions).

In August 2002, the World Summit on Sustainable Development, held in Johannesburg, South Africa, published an implementation plan prioritising the need for timely access to accurate and reliable satellite information. It was acknowledged that meeting the plan's objectives required developing countries to build and strengthen their capacity to assimilate and generate knowledge about their environments and support sustainable development through the use of modern satellite imaging technologies.

As a direct consequence of PUMA, the five participating African Regional Economic Communities were able to respond almost immediately. In September 2002 they signed the Dakar Declaration, requesting the European Union to commission and fund a feasibility study of AMESD as a natural progression of PUMA.

Safeguarding Africa's people and natural resources

AMESD extends the operational use of Earth observation technologies and data from merely meteorological, to environment and climate monitoring applications. The initiative will enable all African national and regional institutions focusing on environment and natural resources, as well as the continent's NMHS, to catch up technologically with their counterparts in Europe, America and Asia, all of whom have benefited from the use of operational space technologies in environmental monitoring for some time.

The programme aims to provide decision-makers in the Regional Economic Communities, the Commission of the African Union and at national level with full access to the environmental data and products they need to improve national and regional policy and decision-making processes. It is hoped that this will enable better management of natural resources and confidence to successfully face the challenges of sustainable development.

AMESD will provide continuity to PUMA by ensuring that the equipment deployed during the latter project is maintained and upgraded. Additionally, AMESD will greatly expand the resources and capabilities of the national and regional institutions involved in the daily management and monitoring of environmental resources such as water, croplands, rangelands, natural habitats and coastal and marine resources. The initiative will also benefit institutions in environment-related sectors such as disaster management, including hydrometeorological, agricultural, livestock, forestry, wildlife and sea safety services.

Most importantly, however, AMESD aims to improve the lives and prospects of the 350 million disadvantaged people in Africa currently enduring poverty and hardship, whose livelihoods depend heavily on their environment.

EUMETSAT: making AMESD a reality

EUMETSAT's participation in AMESD — and in PUMA before it — reflects its commitment to supporting, through its satellite data, products and services, sustainable development in Africa. EUMETSAT's role, as the organisation responsible for Europe's operational meteorological satellites, is fundamental to the successful implementation of AMESD. It encompasses:

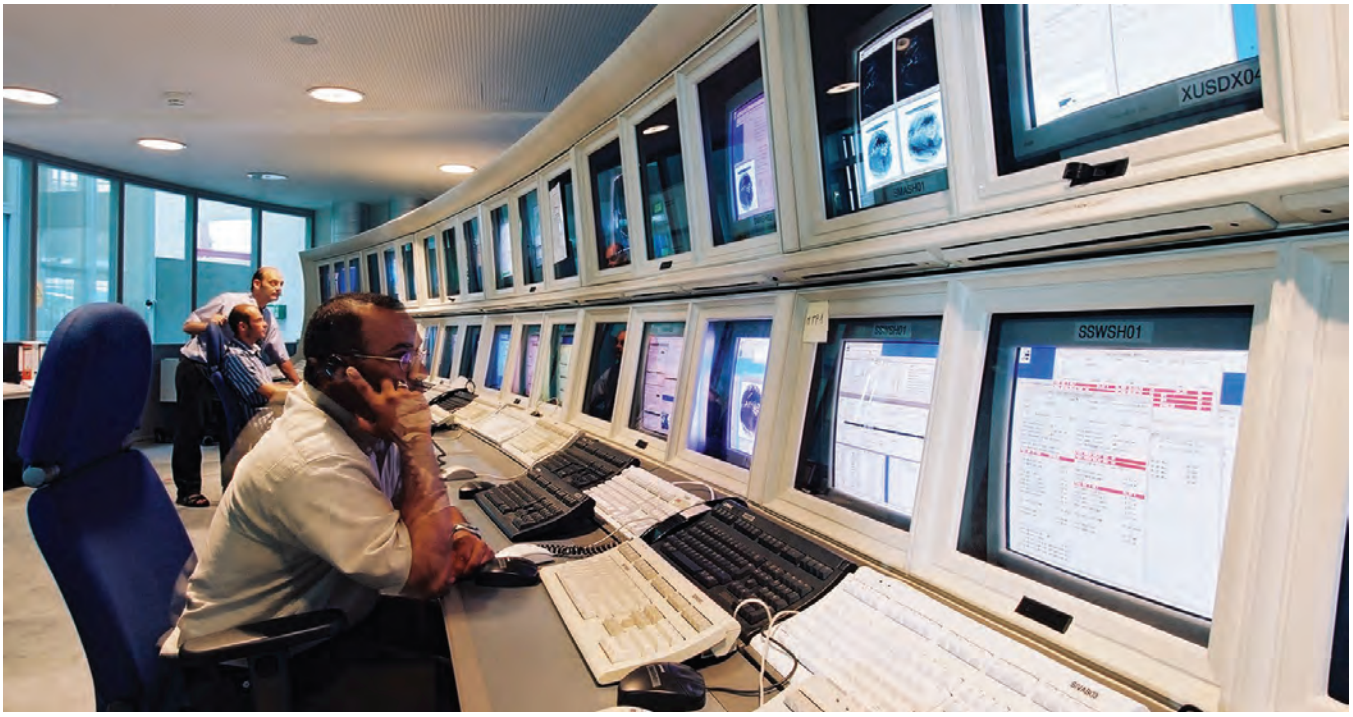


Photo: Copyright EUMETSAT

The Meteosat Transition Programme (MTP) control centre in EUMETSAT headquarters, Darmstadt, Germany

- Continuous supply of its satellite data and products free of charge via the EUMETCast dissemination service
- Providing AMESD with support in the maintenance and upgrading of receiving stations and equipment
- Continuing its training programmes for African National Meteorological and Hydrological Services personnel
- Providing managerial support to the committee in charge of supervising the project
- Offering, through its biennial African User Forum, an opportunity for the African user community to meet, discuss and exchange information and ideas about AMESD and EUMETSAT data and products.

AMESD's plan for securing sustainable development

The AMESD programme has four main areas of focus:

- Providing the African user community with better access to Earth observation, field and ancillary data, as well as the infrastructure, local capacity and services necessary to sustain long-term environmental monitoring
- Setting up operational regional information services to support and improve decision-making in environmental management. AMESD will focus on five themes as requested by the Regional Economic Communities:
  - Water resources management in the region of the Communauté Economique et Monétaire de l'Afrique Centrale (CEMAC)
  - Crop and rangeland management in the region of the Southern African Development Community (SADC)
  - Land degradation and desertification mitigation, and natural habitat conservation, in the region of the Intergovernmental Authority on Development (IGAD)
  - Marine and coastal management in the region of the Indian Ocean Commission (IOC)
  - Agricultural and environmental resource management in the region of the Economic Community of West African States (ECOWAS).
- Establishing national, regional and continental environmental information processes, frameworks and activities enabling African governments to meet their obligations regarding international environmental treaties more effectively and participate in strategic global environment surveillance programmes such as Europe's Global Monitoring of the Environment and Security (GMES) initiative and the Global Earth Observation System of Systems (GEOSS)
- Organising specialised training and staff exchange programmes to maintain the technical capability of African AMESD stakeholders in the long-term, with the aim of ensuring self-sufficiency.

AMESD: a continued support from the European Commission

The European Commission is supporting the use of Earth Observations technologies for the operational monitoring of the Environment in Africa since many years. Following the funding of the PUMA project in 2001, the European Commission will finance AMESD at a level of 21 Millions of Euro from the European Union's European Development Fund (EDF).

AMESD's key players

The programme's principal partners include the European Commission, EUMETSAT, the Commission of the African Union, the five participating African Regional Economic Communities (CEMAC, SADC, IGAD, ECOWAS and IOC) and the Secretariat of the African, Caribbean and Pacific Group of States (ACP).

AMESD will be presided over by a programme steering committee, which will supervise the initiative's implementation. This will be comprised of representatives of the regional economic communities, the ACP Secretariat, the delegated regional authorising officer nominated by the Commission of the African Union and his/her deputy, as well as representatives of the European Commission, the World Meteorological Organization and EUMETSAT.

Climate information applications for sustainable development in Africa

Dr Leonard N. Njau, Mohamed Kadi, Marie Christine Dufresne, Jocelyn Perrin, Dr Anthony Patt, and Dr Andre Kamga

Natural variations in climate can be seen on all timescales, whether days, months or years. They may occur due to external influences such as changes in the sun's energy output, or they may be generated by interactions among the different components of the global climate systems: the atmosphere, oceans, biosphere, ice cover, and land surface. Natural variability of weather and climate can produce extreme events such as droughts, floods, severe storms, heat waves and frosts, among others. Accurate prediction and early warning of such changes depends on the availability of accurate diagnostic tools.

Africa is one of the most vulnerable regions to the impact of weather and climate on national economies and community livelihoods, with such phenomena often associated with food shortages, severe famine, lack of water, energy, diseases, loss of life and property and many other socio-economic disruptions. The demographic pressure and the vulnerability of rainfall-dependent agricultural systems make Africa one of the most food-insecure and drought-prone regions in the world. The low level of preparedness as well as inadequate capacity for rapid and effective response to disasters poses a serious threat to the continent's achievement of the UN Millennium Development Goals (MDGs). Climate-related disasters are threatening development and limited gains in many countries in Africa. Extreme climate events such as droughts and floods have in recent years had devastating socio-economic impacts in various parts of the continent. Still fresh in our memories are the October-November 2006 floods across the Greater Horn of Africa (GHA) countries, the Sudan, Ethiopia, Somalia and Kenya, which affected an estimated 1.8 million people.

Recent progress in climate research and forecasting has resulted in further development of methods for predicting short-term variations in climate and their socio-economic impacts. These advances have provided enormous economic benefits in coping with extreme weather and climate events. In Africa, seasonal rainfall variability is one of the major threats to sustainable socio-economic development. The heavy rains and floods that occasionally affect the continent are as equally devastating as the severe, protracted droughts. The greatest threat to food security posed by excess rainfall is not related to production or marketing, but to the inability of farmers to dry their harvested crops.[1] The application of climate information could significantly improve planning and management of climate sensitive activities and reduce the associated socio-economic catastrophes prevalent in many parts of the continent.

Climate products and services

The African Centre of Meteorological Applications for Development (ACMAD) participates in supporting African initiatives in climate impact studies and multidisciplinary activities related to climate variability. Using specialized international products and observed meteorological data, the centre has developed methods and techniques to monitor and predict extreme climate events. ACMAD is responsible for the preparation and dissemination of climate information and products for early warnings on agriculture and food security, water resources, energy, health and climate disaster risk reduction in Africa.

To improve weather and climate monitoring, prediction and early warning systems continent-wide, ACMAD uses Meteosat Second Generation (MSG) data with the support of partners in the Satellite Application Facility (SAF) consortium, with particular emphasis on severe weather and extreme climate events, as well as product development. Such products include seasonal forecasts for West Africa rainfall and Climate Watch Africa monthly and dekadal bulletins. In order to enhance and improve the quality of weather and climate products and services, ACMAD is involved in the development and application of improved models to provide skilled predictions. It has made great advances in the ongoing development of new techniques for applying numerical weather prediction model outputs to the production of synthetic weather analyses and forecasts. Some of these activities have been realized within the framework of the ongoing African Monsoon Multidisciplinary Analysis (AMMA) project for West Africa, which is now being extended to the rest of Africa.

In collaboration with partners, ACMAD has maintained the provision of products and services to assist users and stakeholders in deciding on response strategies and adaptation measures to mitigate the impacts of weather and climate-related disasters. This partnership has continued to strengthen national capacities to cope with effects of climate variability and change, thereby enabling countries to develop national, social and economic policy, as well as programmes to ensure the sustainable development and achievement of MDGs.

Sector-specific application of climate information

The emerging demonstration of good practices in the application of early warning systems and the integration of seasonal forecasts in poverty reduction, food security, health, water resources and energy resource management should be encouraged. It is imperative, therefore, that appropriate mechanisms be established to raise awareness and promote better understanding through the provision of climate information and user demand-driven products as management tools.

ACMAD's Seasonal Rainfall Forecast Forums have been held for nearly ten years. At the ninth session, held in west Africa, participants made strong recommendations for continuing the work undertaken at the preceding forum. The objectives were to better respond to the needs of users and their use of seasonal forecast products, in the process of ensuring improved food security and the prevention and management of natural hazards. This initiative requires greater synergy between the producers of climate and environmental information, public and private users and the media, at the national and regional levels. In particular, the first meeting of these groups allowed the development of several recommendations and a plan of action for ACMAD and its partners including:

- Supervising a survey of users to identify the existing uses of climate forecasts, new potential uses, and areas where users need additional assistance in understanding forecasts
- Collaborating with ongoing efforts sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the World Meteorological Organization (WMO) to assess forecast use in relation to the survey.

To this end, ACMAD circulated a questionnaire to identify focal points in the countries, after which responses were posted to both ACMAD and Boston University's Web sites. A total of 48 responses from climate-dependent sectors (agriculture, water resources and health, among others) in 14 countries were analysed.

Agriculture and food security

Agriculture is the economic mainstay and major employment sector of several countries in Africa. Extreme climate events such as floods and droughts have had severe impacts on agricultural yield, survival of livestock and marine ecosystems. This in turn heavily impacts food security, often resulting in hunger, malnutrition, diseases and loss of life. Studies have shown that heat stress and drought are likely to have a negative impact on animal health, production of dairy products, meat and reproduction. Climate information can be used to develop strategies and programmes for sustainable agricultural development. In 1999 ACMAD launched a pilot demonstration project using radio and Internet (RANET) technology as a tool to disseminate climate information to rural communities and stakeholders. Economy-wide modelling in Mozambique suggests considerable potential aggregate benefits from market applications of climate forecasts in staple grain markets. Farm system models that incorporate details of soils, crops and management options have been developed for application.[2] Integrating seasonal forecasts into food security assessment has been explored at sub-regional levels.

The economies of many African countries are driven by rain-fed agriculture. Studies have shown that gross domestic product (GDP) is strongly correlated with rainfall in these countries. The occurrence of poor rainfall or drought will adversely affect agriculture and food security with serious implications for economic growth in Africa.

Water

Africa's water resources are not evenly distributed, and are often not located in areas with the greatest demand. Africa has 17 major river basins with catchment areas of above 100,000 km². However, rainfall is the major source of water, be it surface water or groundwater. The construction of dams in rivers is mainly to generate hydropower for both manufacturing industries and domestic use. Geothermal power generation also depends on groundwater, which is recharged by rainfall. The application of climate information has played a significant role in integrated water resources management (IWRM) and in the development of long-term implementation strategies under conditions of water scarcity. The management of several dams in major rivers in Africa is highly dependent on seasonal rainfall forecasts. Several authorities in charge of water resource management have not only integrated climate products into the management of water resources, but also formed partnerships with climate product providers in developing models as water resource management tools. For example, ICPAC has developed a regional capacity in streamflow forecasting and the regional/national Food Risk Information and Early Warning System (FRIEWS). Several countries in Africa rely on hydroelectricity, which is controlled by rivers' streamflow into hydropower generating dams. ICPAC has developed simple models relating the sea surface temperature and rainfall variability to hydro-energy production.[3]

Energy

The energy sector is very important for the socio-economic development of countries in Africa. Electricity is vital for both industrial manufacturing and domestic use. Hydropower production is significantly affected by extreme climate events such as droughts and floods. Too much rainfall causes silting that could damage turbines as well as posing a threat to dam structures, as witnessed in the November 2006 floods in Kenya. Severe droughts have led to power rationing, disrupting various socio-economic activities in many countries in Africa. The provision of climate information and products that are sector-specific for integrated hydropower resources management has contributed greatly to sustainable power generation.

Health

Temperatures in most African countries fall within a range of 15-25 degrees Celsius. Information on temperature is important in the control of malaria and other vector-borne disease outbreaks. Incidences of cholera are higher in areas with high temperatures and during periods of heavy rain accompanied by floods. Temperatures between 20 and 28 degrees Celsius with high rainfall (high relative humidity) favour the survival of the vector and the development of the parasite, resulting in very high incidences of malaria even in low prevalence areas. High temperatures (above 30 degrees Celsius) and low humidity would greatly reduce the lifespan of the anopheline mosquito, resulting in a lower incidence of malaria. Low temperatures (below 18 degrees Celsius) would reduce the development of the protozoan parasite in the mosquito, resulting in low transmission of malaria and low incidence of the disease.

Studies and experiences in eastern Africa have shown that heavy rains are strongly linked to epidemics of vector-borne diseases such as Rift Valley Fever, malaria, yellow fever and dengue fever.[4] The heavy rains of 1997 and 1998 in Kenya and southern Somalia were associated with an outbreak of Rift Valley Fever that caused 46 human deaths. The health ministries in Uganda, Rwanda and Burundi used the ICPAC climate outlook in its decision to order more drugs and mosquito nets to curb malaria outbreaks. Further, Kenya, Uganda, Sudan, Tanzania, Rwanda and Burundi governments used the same consensus climate outlook to initiate some vector-borne disease management practices that also involved clearing of drainage systems.[5]

The perceived benefit of climate information to health services is demonstrated by donor support for meteorological stations and early warning activities at health facilities in Eritrea and Niger. This is a clear demonstration of good practice in the use and application of climate information to mitigate catastrophic impacts of extreme climate events. An integrated warning system approach, combining seasonal climate forecasts with vulnerability assessment within a national malaria control programme, has been demonstrated in Botswana over the past few years and is seen as an example of best practice in the region. The African Development Bank is currently planning to invest substantially in epidemic malaria control in East and West Africa, where implementing organizations are keen to learn from the Southern African experience.

Disaster management

The climate information and support services are used by decision makers in governments, the private sector and civil society to meet priority needs in operational climate risk management and overall social and economic development. The climate outlook forums and users capacity-building workshops have prompted a number of stakeholders to initiate efforts towards the development of integrated regional/national management policies.

The global centres' products and data banks have been used to improve climate model and prediction methods. National atlases for sectoral risk zoning on climate stress have been developed. Climate stress information has been used by UN systems and donors to estimate levels of donor assistance and operations. National platforms on disaster risk reduction (DRR) advocating enactment of the Disaster Management Bill 2005 are already available in most African countries, and such initiatives will help to harmonize further intervention strategies. Climate Watch Africa, an early warning system of ACMAD, is an effective tool for disaster risk reduction management. These initiatives will lead to integrated capacity and policy implementation in climate DRR management for improved community livelihoods and economies in Africa.

Women and youth

The provision and application of climate early warning information for rural women and youths is becoming increasingly crucial for poverty reduction, disaster risk management and sustainable development in many countries in Africa. This awareness has been created through capacity building, education and access to information for enhanced effectiveness in the use of climate information. Climate information providers are working with WMO and other partners to address climate challenges and variability and the role of women and youths in several countries.

Wildlife and tourism

Wildlife management and tourism are dependent on climate. Growth in the tourism industry contributes to development through the generation of foreign exchange, the creation of income-earning opportunities, agricultural market expansion and the development of local entrepreneurship. Extreme climate events pose a substantial threat to the survival of wildlife and the tourism industry.

Trade and industry

Several trade and industry activities depend on natural resources and prevailing climate conditions. Trade in the majority of African countries relies on agricultural goods. Extreme climate events have often disrupted agricultural production and activities, affecting markets, transport systems, infrastructure and industry systems, resulting in heavy losses. The integration of climate information into trade development planning and industry policies would enhance Africa's future competitive power. For example, a weather index insurance based on a trigger point related to rainfall accumulation is being piloted in Ethiopia and Malawi. Such insurance schemes can be used to overcome delays in early responses to climate-related crises. In Malawi, index-based insurance, designed around good rainfall records, has enabled the private sector to lend funds to farmers for improved seed varieties. The Ethiopian pilot project compared climatologies from 30 weather stations to enable the private industry to design an appropriate insurance product.

Infrastructure

In Africa, extreme weather and climate events destroy buildings, railways, roads and dams, impacting heavily on the economy. It is necessary to integrate climate information into development policy and planning for the management of climate-related disasters to reduce this vulnerability.

Looking forward

There are potential socio-economic benefits to be derived from recently developed climate prediction tools that are capable of forecasting extreme climate events. These tools have sufficient lead time to allow early warning of impending catastrophic climate events. However, decision makers in African countries face many challenges in understanding how to integrate climate information into development policy and planning in the management of limited natural resources. There is a need to enhance national as well as local community-driven integrated programmes for addressing climate variability with a view to improving applications of seasonal forecasts. Education and awareness through community participation on issues that could affect their livelihoods is of crucial importance.

Satellite observations of the increasing nitrogen dioxide emissions in China

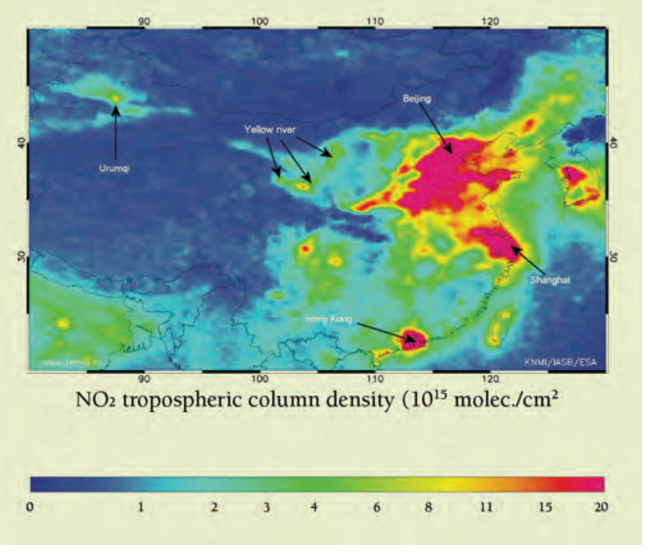
Ronald van der A, Bas Mijling, Jeroen Kuenen, Ernst Meijer, Hennie Kelder, KNMI

China has one of the fastest growing economies in the world. Between 1990 and 2004 its gross national product has increased by a factor of seven. This growth in economic activity is accompanied by a strong increase of emissions from tropospheric pollutants, leading to extra pressure on the environment.

The European Space Agency (ESA) and the National Remote Sensing Centre of China (NRSCC — an entity under the Ministry of Science and Technology of the People's Republic of China) have cooperated in the field of Earth observation application development for the last ten years. The cooperation has now taken on a new momentum with the creation of a dedicated three-year Earth observation exploitation programme called Dragon. Within Dragon, the Royal Netherlands Meteorological Institute (KNMI) has been working on the Air quality Monitoring and Forecasting In China (AMFIC) project to analyse the air quality in China using a ten-year data set of satellite observations of nitrogen dioxide (NO_2).

NO_2 is an important precursor of smog and is formed mainly by combustion of fossil fuels. Using a chemical transport model, concentrations measured by satellites can be connected to nitrogen dioxide emissions. Model calculations show a trend in increasing NO_2 emissions over China, which is proportional to the country's economic growth. The calculations also show that the consequences are not limited to China but affect the entire global environment.

The yearly average tropospheric NO_2 density measured by SCIAMACHY for 2004. High values are measured above the major cities. The industrial area around the yellow river (Huang He) is also noticeable and highlights the river stream



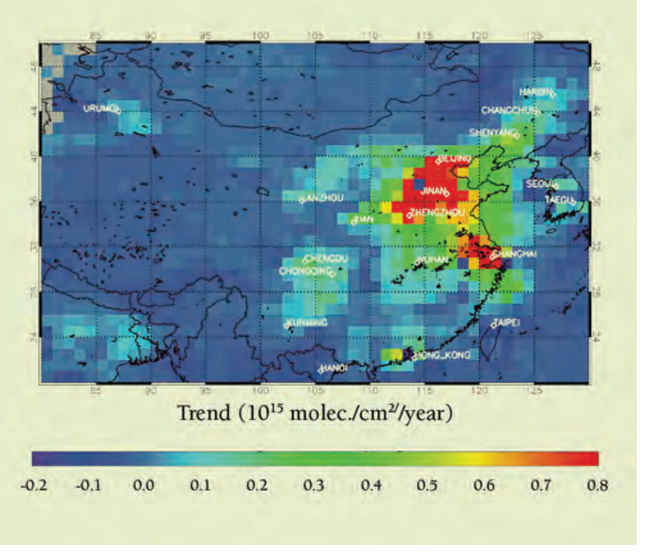
Source: KNMI

Atmospheric nitrogen oxides

Nitrogen oxides (NO_x, the collective name for NO and NO_2) play an important role in atmospheric chemistry. They have both natural sources (lighting and soil emissions) and anthropogenic sources (biomass burning, fossil fuel combustion). Nitrogen oxides are bad for the health of both humans and animals. They irritate the lungs and lead to lower resistance to respiratory infections such as influenza. Frequent exposure to high concentrations may cause acute respiratory illness. Another serious problem caused by NO_x is the formation of aerosols and tropospheric ozone (i.e. smog), which also has harmful health effects.

The most significant source of nitrogen oxides is the combustion of fossil fuels, mainly by traffic and large power plants, but the burning of biomass and lightning are also important contributors. Close to the ground surface, the lifetime of NO_x is just a few hours, which is why NO_2 concentrations will be highest close to the source.

Trend of the NO_x concentration over China for the period March 1996 – November 2005



Source: KNMI

Satellite observations of tropospheric nitrogen dioxide

Satellite instruments use spectroscopy to retrieve atmospheric trace gas concentrations in the atmosphere. By comparing the measured spectrum of the backscattered light from the Earth's atmosphere with a reference spectrum, the column density of nitrogen dioxide along the light path can be determined. The NO_2 stratospheric column is deduced from a chemistry-transport model assimilation run of the NO_2 column data. Subsequently, the assimilated stratospheric column is subtracted from the retrieved total column, resulting in a tropospheric column.[1]

NO_2 has been monitored by satellite since 1995 with the Global Ozone Monitoring Experiment (GOME), since 2002 with the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), and since 2004 with the Ozone Monitoring Instrument (OMI), the latter two instruments having the advantage of a high spatial resolution.

The yearly averaged NO_2 column for 2005 as measured with SCIAMACHY can be seen in the first image. It shows high concentrations of NO_2 above highly populated regions like Beijing, Shanghai, Hong Kong and South Korea. It can also be seen that the satellite detects the emissions around the Yellow River (Huang He). Over the sparsely populated western part of China, low NO_2 concentrations are observed, except over the large city Urumqi in the northwest.

Growth of NO_2 concentrations over China

The combined measurement series of both GOME and SCIAMACHY span almost a decade, which favours a trend analysis of Chinese emissions. To do this, the averaged monthly tropospheric NO_2 columns are fitted with a linear model that also includes a sinus to represent the seasonal variation of NO_2.

Seasonal variation is mainly determined by the changing day length over the year. In the absence of sunlight NO_2 has a longer lifetime in the atmosphere, which explains why the NO_2 columns are higher on average during wintertime. The second image shows the derived annual growth in the tropospheric NO_2 columns from this analysis. The highest trend is found in east China, where economic growth is faster. The fastest growing city with respect to both economy and tropospheric NO_2 is Shanghai.[2]

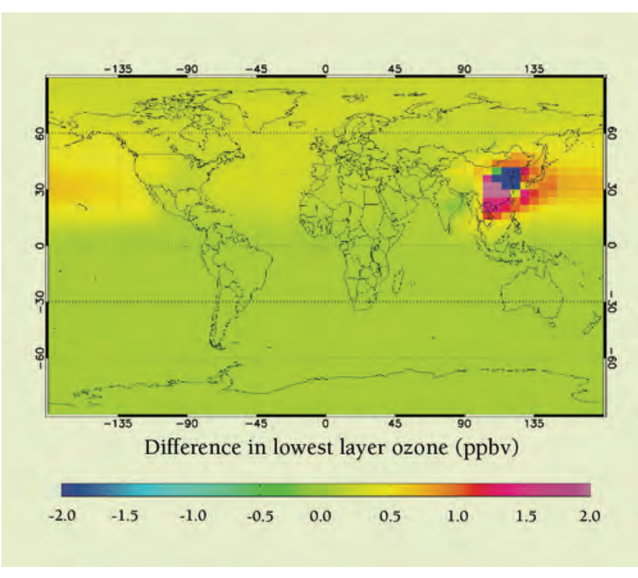
Global implications

The fast growing emissions in China lead locally to rapidly increasing NO_2 concentrations, which affect local ozone concentrations. Clearly these large increases will have severe consequences for local air quality, but effects on a global scale can be expected, because the lifetime of tropospheric ozone is much longer than the lifetime of NO_2.

Therefore, ozone can be transported over large distances by the wind. Using a chemical transport model the change in ozone due to increasing emissions in China can be calculated. The image below shows increasing ozone concentrations in the northern hemisphere caused by growing Chinese emissions in the period 1997-2005. In this period of eight years the global averaged tropospheric ozone column has increased by 0.54 per cent. The largest growth in tropospheric ozone is found in a plume reaching from China to the east along the direction of the prevailing winds. From this image, we conclude that the tropospheric ozone concentrations in the entire northern hemisphere are increased due to the growing emissions in China. These increases seem small, but are still important. In Europe, air pollution has been increased as a result of intercontinental transport. In addition, since ozone is a strong greenhouse gas, the effects on climate change cannot be neglected.

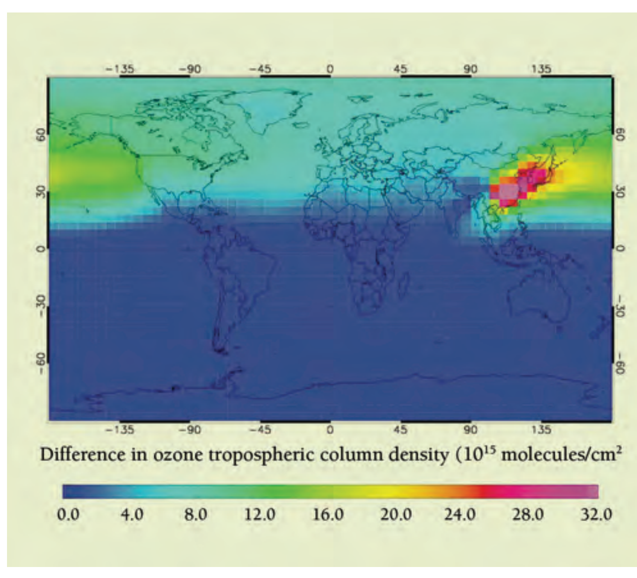
A decade of satellite observations of nitrogen dioxide in the atmosphere has been used to find trends in emissions in China. As expected, the nitrogen dioxide concentration is growing most rapidly in east China, where there is the most economic growth. By feeding the derived trends to a global chemical transport model of the atmosphere, the effects on the concentrations of the worldwide tropospheric ozone can be determined. According to the model, the background concentration of ozone has been increased in the entire northern hemisphere as a result of the growing emissions in China.

The difference in ground-level ozone caused by the increase of Chinese NOx emissions between 1997 and 2005



Source: KNMI

The increase in tropospheric ozone columns caused by rising Chinese NOx emissions between 1997 and 2005



Source: KNMI

The Kingdom of Saudi Arabia: weather, climate and environment in a precarious balance

David G. Aubrey, PhD, Woods Hole Group Middle East, representing the Presidency of Meteorology and Environment, Kingdom of Saudi Arabia
Dr. Sameer A. Bukhari, Presidency of Meteorology and Environment, Kingdom of Saudi Arabia

The need for acquisition, analysis, data banking, and dissemination of meteorological and hydrological data and information to the stakeholders in the Kingdom of Saudi Arabia, particularly the agricultural and pastoral communities, is critical in order for its citizens to continue to live within traditional cultural activities in the marginal arid environment of the region. The Kingdom's efforts to provide this type of data has displayed significant improvements in the delivery of data and information. However, more local, regional, and international cooperation in this arena would enhance the delivery of these critical information requirements.

The importance of climate to the traditional cultures of the Kingdom should be looked at from geological and historical perspectives. In discussing the relevant meteorological agency in the Kingdom, we will explore some past efforts in these arenas, and illustrate some relevant ongoing projects that will address the need for timely and urgent meteorological and hydrological data requirements.

Geological view

The geological and climatological histories of Saudi Arabia reflect global influences in these processes. The geological history is linked to global tectonic frameworks including the rift processes in the Red Sea, whereas the climatic history reflects external and internal climatic processes over the entire globe. Located along the Tropic of Cancer, a key climatic gradient, the Arabian peninsula is sensitive to changes in climate the world over (and even to external influences such as solar insolation variability).

Bordering the zone of influence of the Arabian Sea/Indian Ocean Monsoon, the Arabian peninsula is particularly susceptible in climate to the vagaries of that global climatic feature. At present, the Arabian Sea Monsoon has direct influence only on the southern areas of the Arabian peninsula, notably the small area surrounding Dhufar in southwest Oman, and along western Yemen and into southwest Saudi Arabia. At various times in the past (80,000 years before present (YBP), 30,000-35,000 YBP, and 8,000-5,000 YBP), the monsoon influence extended well into Arabia, to the extent that the present arid areas (precipitation of some 50-100mm per year) experienced three to five times that rainfall, transforming much of the desert into a savannah-type grassland area, still hot, but less dry. Vast lake areas dominated what is now the 700,000 square kilometres of desert, including the Ar Rub Al Khali to the south of Saudi Arabia. This standing water gave rise to extensive human habitation as well as a hippopotamus and other savannah-type mammals.

Studies of sediment cores taken off the south Yemeni coast have shown that the monsoonal shifts have occurred through much of the past 100,000 years over the Arabian peninsula, with their occurrence related to such items as variation in solar radiation, snow-pack over northern Europe, the El Niño-Southern Oscillation (ENSO) system, and so on. These external and internal (to the Earth's climate) factors have caused a waxing and waning of the monsoon's extension over the peninsula, and hence to precipitation and habitability within the peninsula. In addition to the monsoons, other factors also contribute to local climate, including the semi-permanent pressure systems, winter-time migratory weather systems, and topography. The past 5,000 years have in general been quite dry compared to the geological past, with only small variations compared to these larger ones of the previous millennia.

Historical view

Human habitation has reflected this climatological variation, with periods of more abundance reflecting the availability of more food and drinking resources in the area. Following the return of rains to the Arabian peninsula in about 9000 YBP, thick permanent grassland was established and standing water was available. These conditions attracted an increasing number of humans to the area. This new chapter in human habitation brought a Neolithic Stone Age culture to the region, previously unknown here. Domestication of the camel and donkey some millennia later permitted greater wandering, and hence better adaptation of the peoples to the warmer climate of the past 5,000 years.

At present, the deserts are home to millions of Bedouins and their means of livelihood, including camels and sheep. Their nomadic lifestyle has been guided by their historical patterns. Each tribe has a *dirah* or central part of its range of movement during the year, and this area includes wells where the tribe settles for the dry summer months. Each year, based on celestial signs, the Bedouins will depart their summer *dirah* for winter foraging, and perform the reverse trek. These celestial timings are based on centuries of observation of climatic conditions in the region.

Optimization of seasonal migrations is now possible using more solid short-term climatic and weather data, such as are commonly available through the local meteorological agency (Presidency of Meteorology and Environment) and international agencies, such as World Meteorological Organization (WMO) and adjuncts. Such information, if disseminated properly, would assist the cultural usages of the desert which still remain key activities for the Saudi population in general.

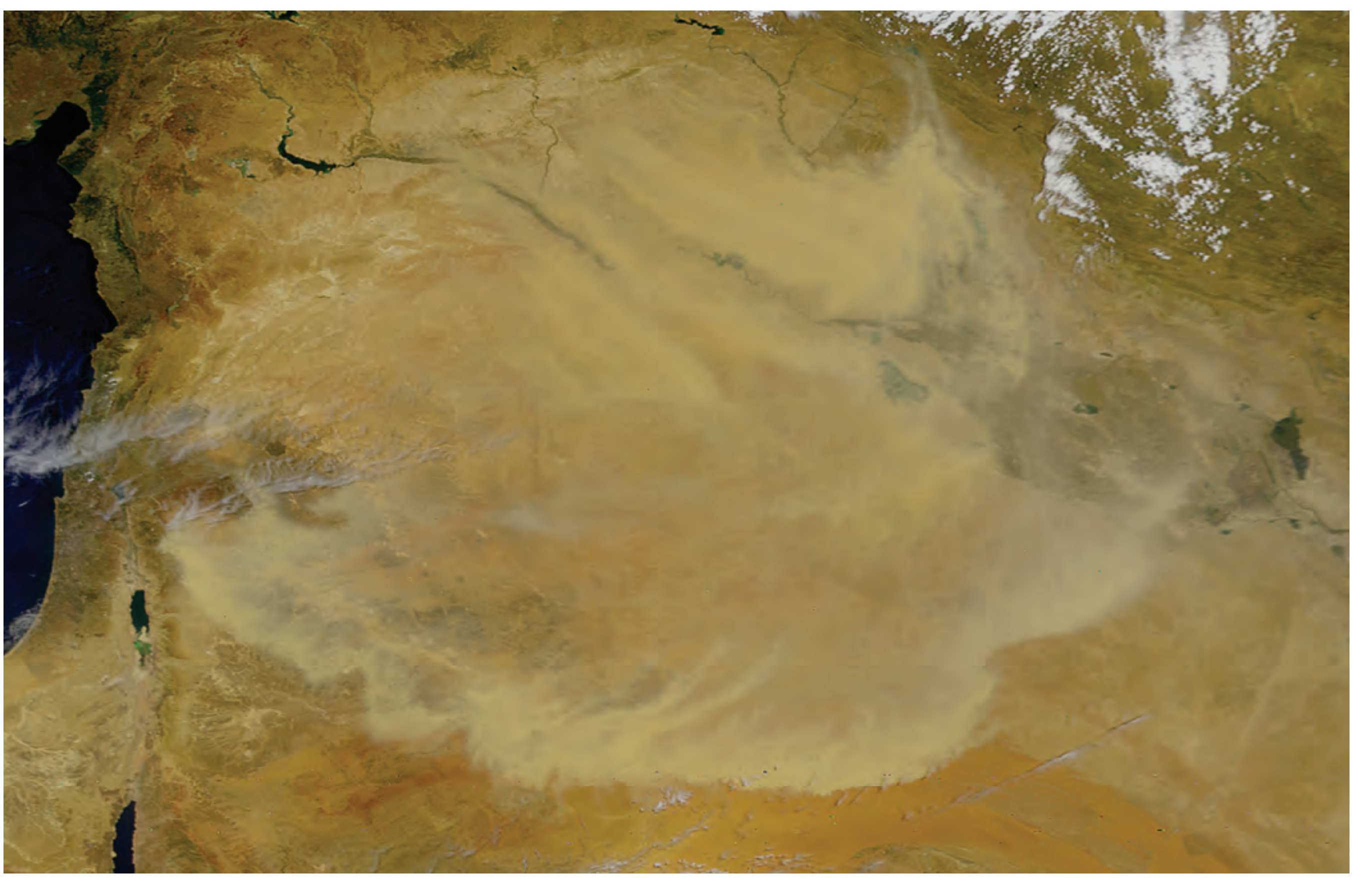
The Presidency of Meteorology and Environment

As Saudi Arabia developed from a nomadic culture to a more modern urban culture, and especially with the introduction of air transport, the need arose for a local meteorological service. Accordingly, in the year 1370 Hijrah (H) or 1951 Gregorian (G), the Department of Meteorology was established within the Civil Aviation Directorate.

Further growth in demand for meteorological services from a diversity of users increased requirements for climatological and operational information in the fields of planning, industry, agriculture, transport and various other activities. A separate directorate with its own technical and administrative staff was established based on a Royal Decree establishing a General Directorate of Meteorology issued on 1.7.1386 H (15.10.1966 G). The directorate was directly related to the Ministry of Defence and Civil Aviation, but with its own budget.

During the following two decades, as the Kingdom of Saudi Arabia witnessed rapid development in economic and industrials sectors, the General Directorate of Meteorology was designated as the central agency responsible for environmental protection, including the response to pollution of all kinds and the establishment of the different environmental standards with this remit. This mandate was established by Royal Decree on 24.4.1401 H, (28.2.1981 G), in accordance with the recommendations of the High Committee tasked with a national administrative review. The title of the organization was changed to Meteorology and Environmental Protection Administration (MEPA). In 2002 G, the status of MEPA was raised again, this time to the Presidency of Meteorology and Environment (PME) led by HRH Prince Turki bin Nassir bin Abdulaziz. PME operates a network of meteorological stations throughout the Kingdom, from which climatic data are extracted.

Meteorological stations for the Kingdom of Saudi Arabia



NASA Goddard satellite image from May 2001 of a large-scale sand storm (natural disaster) over the Arabian Peninsula

Prior human ecology/climate studies — MEPA conducted several studies on the conditions of the nomads over the last two decades of the twentieth century. One of these was *Environmental Support of Nomads* (ESON), a pilot study conducted from 1994 through 1997 in close collaboration with the Office of Arid Lands Studies of the University of Arizona. The objective of the study was to provide information to Nomads and other pastoralists that would assist them to use the marginal range resource in a sustainable and economically viable manner. These studies were conducted to investigate the situation of the Bedouin nomads in the Kingdom, including their socio-economic, cultural, and geographical aspects. The ESON study culminated in the publication of a major work clarifying the condition of the nomadic population in the pilot study area, and suggested areas where MEPA might concentrate further efforts to improve the sustainability of the Bedouin culture.

Ongoing PME activities

Having conducted studies on Nomads in the past (as MEPA), and with an improved understanding of the needs of the nomads, the PME is undertaking a number of major initiatives intended, to assist the condition of the nomads. Some of these activities are listed below.

Human ecology — Starting in 2007, the PME will be undertaking a national programme of human ecology and urban development in the Kingdom of Saudi Arabia. Based on the second article of the Saudi Environmental Law, PME has been given responsibility for environmental planning related to industry, agriculture, urban development and other matters. According to article ten of the Saudi Environmental Law, the national programme of ecology and urban development will be responsible for the environmental planning, management, and conservation of rural and urban areas in the Kingdom.

Public awareness — The Kingdom of Saudi Arabia recently announced the opening of a first ever environmental television channel. A public-private partnership, this channel will be broadcasting general items of concern about the environment, including meteorology and climatology. This soon-to-be pan-Arabian channel is now broadcasting throughout the Kingdom, and demonstrates a commitment to get information from the PME to users throughout the Kingdom.

Cloud seeding — Understanding the paucity of water in the peninsula, the Kingdom continues to undertake experiments in cloud seeding to optimize the geography and timing of delivery of precipitation to rural areas. Previous experiments on cloud seeding were in the Abha area in 1989 and 2004. This year, experiments are being conducted in the central region of Saudi Arabia.

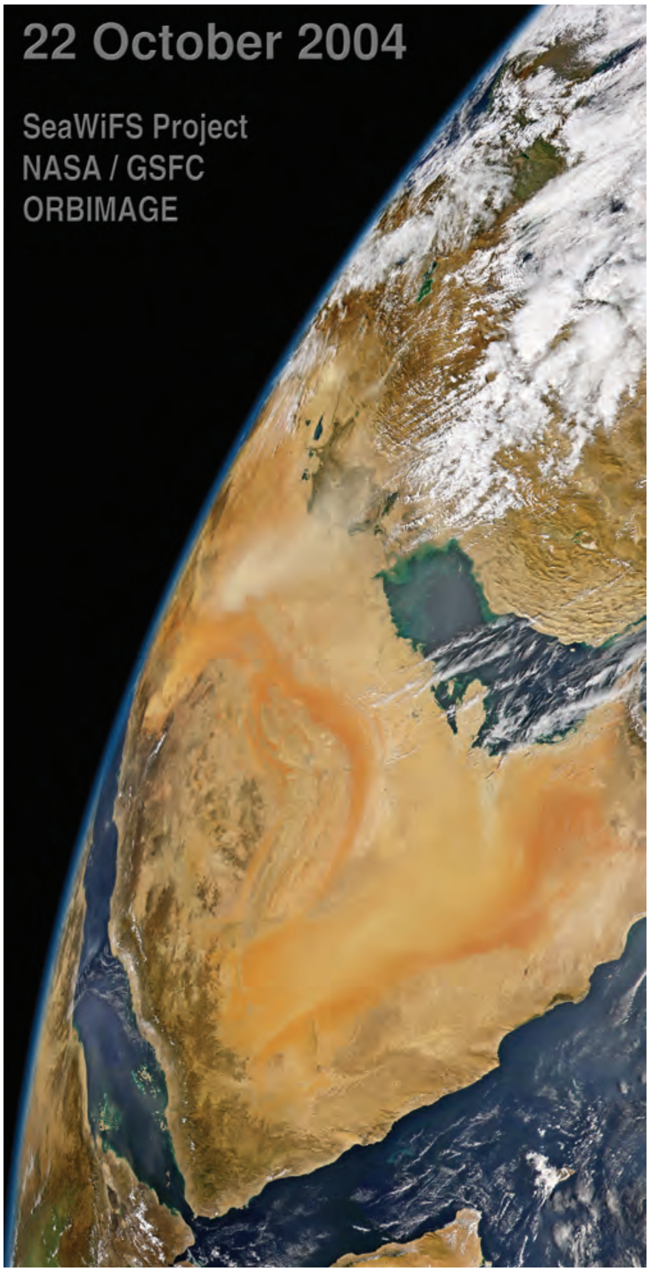
Critical issues

The geographical-geological-climatological context of Saudi Arabia includes a marginally usable resource for agriculture and pastoralism, due to the lack of water, extreme heat, and strong seasonal climatic variability. The socio-economic context of Saudi Arabia includes rapid change from rural to urban habitation, relative impoverishment of the rural population, and a switch from domestic pastoral use of rangelands to more market-oriented herding with subsequent destruction of the environment. In order to maximize the use of the desert rangeland resources, optimization is required. This must include aspects of rangeland management, information transmission and sharing, and perhaps economic incentives to modify pastoral behaviours. Since desert life is essential to the culture of the Arabian peninsula, there is great public demand for its preservation and extension.

Critical issues include the need to acquire, process, analyse and disseminate climatic information, including those in the following areas;

- Global and regional climate change
- Natural disasters: dust storms associated with “Shamal” or northern and “Aziab” or southern winds and droughts
- Rainfall: patterns and intensities
- Agriculture and pastoralism
- Nomadic status: socio-economic, geographical, and cultural aspects.

As indicated in the discussion above, PME has initiated projects to facilitate acquisition, analysis, availability, dissemination, and use of data by appropriate stakeholders at all socio-economic levels within the Kingdom.



The SeaWiFS Project is among the initiatives supported by PME

Saving the public from the Asian Dust Storm

Nam Jae-Cheol, Korean Meteorological Administration

The first record of dust phenomenon in Korea was found during the reign of the Silla Dynasty's King Ahdalla (174 A.D.) and was called 'Woo-To'. At that time, people believed that the god became so angry he lashed down dirt instead of rain or snow. Since then, the Asian Dust has been considered an unavoidable natural phenomenon in Korea, which comes uninvited every year.

However, unprecedented severe Asian Dust, about forty times more severe than usual, attacked Korea in March 2002 and caused the temporary closure of 4,373 primary schools, 164 flight cancellations and the reduction of working hours in factories for semi conductors and other precision products. Following this, both the media and the general public demanded that the government should take all possible measures to reduce the impact of the Asian Dust Storm.

The most fundamental measure to protect Korea from the Asian Dust was to forest the desert areas in China and Mongolia, which are deemed to be the source of the Asian Dust. However, as desertification progresses faster than forestation, the best way for the Korea Meteorological Administration (KMA) to protect the people from the Asian Dust was to more accurately predict the density of the Asian Dust which comes from China, and provide quantified information on it. For this, the establishment of an observation network for the Asian Dust in China is needed.

(a) 10:00 LST 21 March 2002

(b) 10:00 LST 23 March 2002

Photos: KMA

During and after the dust in Korea

In cooperation with the Korea International Cooperation Agency (KOICA) and the Korea Ministry of Foreign Affairs and Trade (MOFAT), KMA negotiated with and persuaded the China Meteorological Administration (CMA) to establish the joint monitoring network of the Asian Dust. About three years later KMA and CMA accomplished this and have shared the Asian Dust data observed at the five joint monitoring stations in real time since March 2005. The observed data from the KMA-CMA joint monitoring stations is used as input data for the numerical prediction model for the Asian Dust. Since then, it has been possible to produce more accurate and quantitative forecasts.

The Meteorological Research Institute (METRI) of KMA developed the trajectory model that has been used routinely to forecast the air stream movement including dust since 2000. The trajectories are initiated in the source region on the isentropic surface of 295K, 300K, and 305K.

Recently, KMA raised the forecast accuracy of the Asian Dust, named the Asian Dust Aerosol Model (ADAM), which was jointly developed by METRI and Seoul National University.

After the installation and optimization of ADAM on the KMA supercomputer, KMA has made great strides in producing more rapid Asian Dust forecasts. ADAM is operating routinely to forecast the dust concentration after 48 hours at intervals of three hours.

The KMA-CMA joint network proved its real capability in April 2005. The extremely severe Asian Dust affected the Korean peninsula again on 20 April 2005. But the situation was quite different from that in 2002. It was possible for KMA to issue and deliver the pre-warning report of the Asian Dust to the media and related agencies on 19 April, giving them time to take measures and prepare for the events of the next day.

Even though the thick dust covered the sky over the Korean peninsula on 20 April, following the countermeasures made on the previous day, industries had already changed filters of the air cleaners before the dust attacked Korea, and primary schools allowed the students to return home after morning classes on 20 April. This clearly illustrates that the people coped with the event calmly and systematically. It was a striking contrast to the case of 2002.

KMA is processing the project in cooperation with CMA to extend the joint monitoring network in the northeast area of China for better monitoring and forecasting of the Asian Dust which moves from the Inner Mongolia to the north area of the Korean peninsula. CMA agreed with KMA on the extension of

Photo: KMA

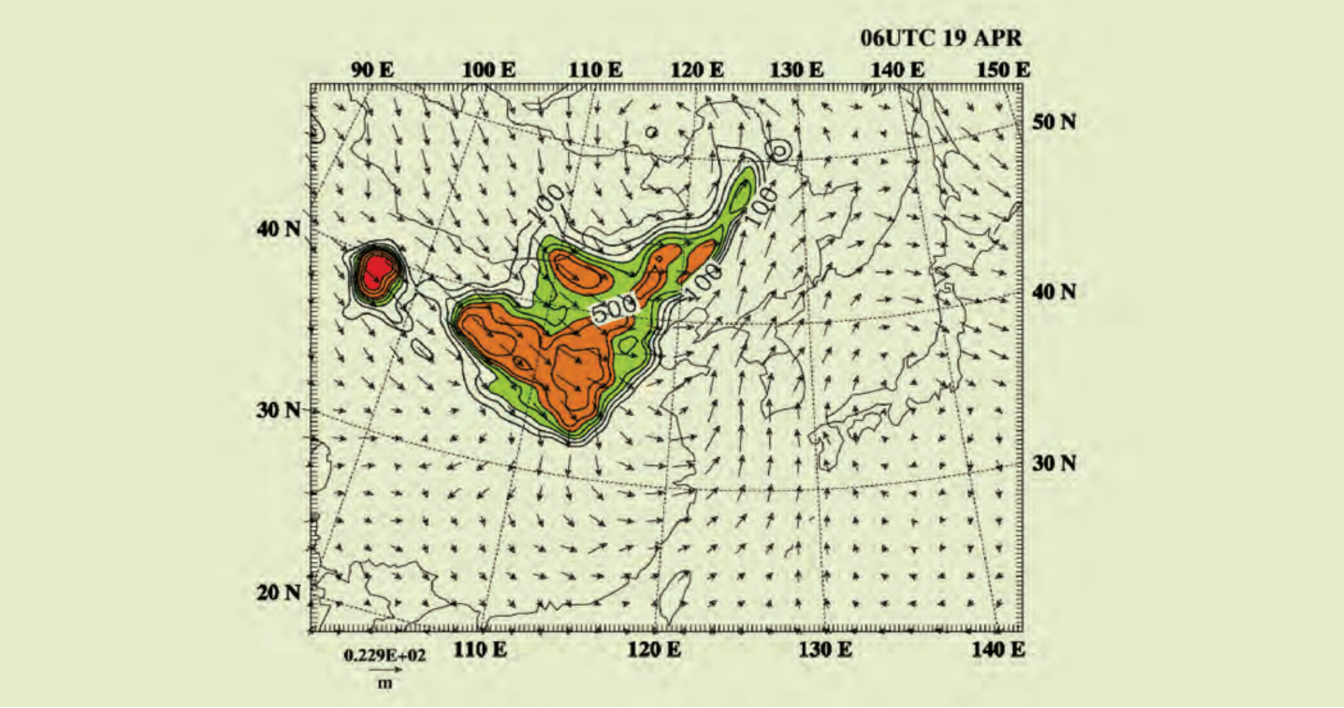
Red circles indicate the joint monitoring stations

the joint monitoring network with five more observation stations in 2006 with financial support by KOICA.

KMA and CMA are executing the project, aiming to finish it in March 2007. KMA also has a plan to establish a joint observation tower for the Asian Dust in the Gobi desert to monitor the meteorological condition of the Asian Dust at the source area, in cooperation with the National Agency for Meteorology, Hydrology and Environmental Monitoring (NAMHEM).

Minimization of economic and public losses in Korea can be expected following completion of the project, with the establishment of radical measures against the Asian Dust by providing more accurate and rapid predictions.

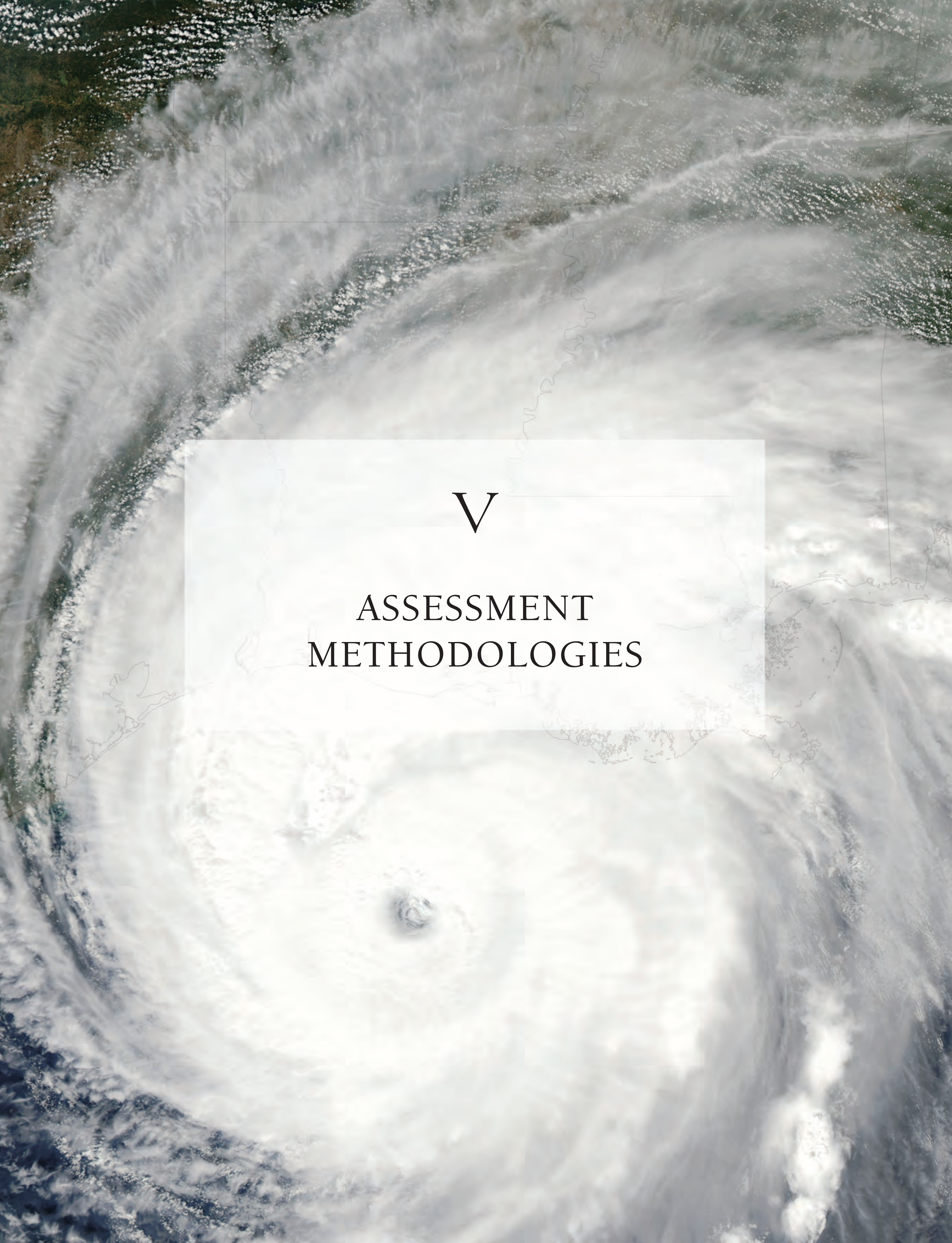
Forecast chart of dust concentration from ADAM on 19 April 2005



Source: KMA

V

ASSESSMENT METHODOLOGIES



Methodologies for assessing the economic benefits of National Meteorological and Hydrological Services

Jeffrey K. Lazo, National Center for Atmospheric Research
Thomas J. Teisberg, Teisberg Associates
Rodney F. Weiher, Chief Economist, National Oceanic and Atmospheric Administration

This article briefly introduces methods for assessing the economic value of hydrometeorological information provided by National Meteorological and Hydrological Services (NMHS).

Weather, water, and climate information and forecasts (hydrometeorological information) help people avoid the danger of hazardous weather conditions and reduce the costs associated with unfavourable weather or climate conditions. It also allows individuals to take increased advantage of favourable conditions. In most cases, any number of people can use this information without diminishing its value to other users, meaning that the information is 'nonrival'. In addition, it is inherently difficult to prevent people who have not paid for the information from using it, meaning that the information is 'nonexclusive'. For these reasons, hydrometeorological information and improvements to it are appropriately treated as 'public goods'.

Photo: NASA

Hurricane Katrina from space

Because hydrometeorological information is a public good, economists would generally agree that competitive markets would not provide it at socially optimal levels. Consequently, there is justification for paying for its provision from public revenues and distributing it to anyone who wants it, charging only the marginal costs of its distribution. We note that in the United States, a limited number of private companies have successfully found a role in distributing weather information by tailoring its presentation to appeal to wide audiences, or by meeting the specialized needs of particular users.

However, the public good status of hydrometeorological information alone does not justify making it widely available. Instead, if we are to determine the right kind and amount of information to produce and disseminate, we must understand the costs and the benefits of the information. If the total benefit accruing to users exceeds the total cost of producing the information, then the service is justified.

Although the cost of producing hydrometeorological information is usually straightforward to estimate, the benefits typically are not.

Steps in benefit estimation

To quantify the benefits of hydrometeorological information, we need to consider how humans and hydrometeorological systems interact, how access to hydrometeorological information improves these interactions, and how we measure improvements in the interactions.

If information is to change the interactions between hydrometeorological systems and humans, that information must make it possible for people to change their behaviour in ways that produce better results, on average, over time. When accessing the benefits of such information it is helpful to apply a six-step process:

1. Identify the hydrometeorological system/human interaction affected
2. Identify the changes in human behaviour that may result because information is available or improved
3. Choose one or more measures that will be used to quantify the benefits of changes in behaviour
4. For the measure(s) chosen, estimate the change (or expected change) in the benefits, in each instance where behaviour is changed because of the information content

Photo: NOAA

Transport and agriculture are among the sectors that benefit most from accurate snow warnings

Forecasting of snow and snow events

Potential benefits from better forecasting of snow and snow events include:

- Improvements in frost forecasts (up to USD6,000 per hectare per year for fruit orchards)
- Long-range stream flow forecasts (over USD170 million per year in hydropower benefits for three river systems)
- Temperature predictions (over USD500 million per year from natural gas and electric utility providers)
- Icing diagnostics at airports (exceeds USD600 million per year at US airports)
- Predictions of road ice formation and fog (exceeds USD29 million per year from rerouting trucks in the US)
- Marine forecasts of winds and waves (exceeds USD95 million per year from transit time savings and cargo loss reductions in US coastal waters).

Source: Adams, R, Houston, L and Weiher, R. *The value of snow and snow information services*. Report prepared for NOAA's National Operational Hydrological Remote Sensing Center, August 2004.

5. Estimate the number of instances (e.g. people, transactions) where behaviour is changed
6. Combine the results of steps 4 and 5 to estimate a total benefit of information.

Benefit measures

Many metrics can be used to measure interactions between hydrometeorological systems and humans. Although it is possible to measure the effect of people on hydrometeorological systems, the focus here is on measuring the effect of those systems on people. These effects include the number of lives lost to natural disasters, along with measures of economic activity (e.g. output, employment) or economic welfare (e.g. willingness to pay), in weather-sensitive industries or activities.

The distinction between measures of economic activity and measures of economic welfare is important. Measures of activity, even if expressed in monetary units, do not tell us the value of the activity. These measures do not tell us what people would be willing to pay for that activity. Welfare measures, on the other hand, are specifically designed to quantify what people are willing to pay for something. As a result, welfare measures of benefits are appropriately compared to the costs that people pay for those benefits.

Programmes that save lives pose a special and important problem in benefits estimation. Saving lives may be seen as desirable regardless of costs. Public and private decisions, however, routinely make implicit trade-offs between costs and risks to human life. In policy analysis, economists do not put a value on any specific individual's life — instead they look at how much people are willing to pay to reduce the risk of people dying in future events. For instance, suppose a study determines that one million people in a city are each willing to pay USD50 per year on average for a programme to reduce the chance of death by 1 in 100,000 per year — say from 20 in 100,000 to 19 in 100,000 each year. Total willingness to pay is thus USD50 million (USD50 × 1,000,000) and the programme would save ten lives per year on average; thus, the people of the city are willing to pay USD50 million to prevent ten deaths. So the value per statistical life (VSL) is USD5 million. The US Environmental Protection Agency, for example, uses a similar VSL in cost-to-benefit analyses of programmes that reduce mortality risk, such as reducing air pollution.

There are three general approaches to estimate the benefits of hydrometeorological information using welfare measures:

- Stated preference
- Economic modelling
- Data analysis.

The value of weather forecasts to US households

Because weather forecasts have the properties of public goods, little market data exist on the value that households place on hydrometeorological information. Economists can use two basic approaches to estimate the economic value of 'nonmarket goods': revealed preference methods and stated preference methods. Revealed preference methods are applied to actual behaviour and market transactions. Such information may reveal the values implicitly placed on a nonmarket good in the context of the choices people make about market goods. In stated preference

Tornado warnings

Between 1992 and 2004, the National Weather Service's (NWS) NEXRAD radar system prevented over 330 fatalities and 7,800 injuries from tornadoes, at a monetized benefit of over USD3 billion, compared with a total capital and site acquisition and preparation cost of less than USD1.7 billion (in 2004).

Tornadoes during the day are much less dangerous than at night, with fatalities 64 per cent lower and injuries 43 per cent lower for daytime tornadoes. This provides indirect evidence that tornado warnings are saving lives, but suggests that improvements in the dissemination of warnings at night could save more lives.

Residents of mobile homes remain at risk from tornadoes: over 40 per cent of fatalities occur in mobile homes, and the fatality rate is more than ten times greater than that for residents of permanent homes.

In 2002, 186 million person hours were spent under tornado warnings in the US, and the value of this time was about USD3 billion. The NWS is experimenting with refining its tornado warnings from the current county basis. This could reduce the person hours under tornado warnings by half, or more.

Source: Sutter, D and Simmons, K. *The value of tornado warnings and improvements in warnings*. Presentations at the American Economics Association annual meeting (Boston, January 2006) and the American Meteorological Society annual meeting (February 2006).

Photo: NOAA

The economic benefit of tornado warnings is huge

studies, we estimate value using surveys in which a representative sample of the relevant population expresses a stated preference. This preference can then be directly or indirectly used to determine willingness to pay for a good or service. The value obtained for the good or service is contingent on the nature of the constructed market described in the survey scenario.

A recent study used the stated preference approach to estimate US households' values for potential improvements in day-to-day weather forecasts.[1] In this study, the researchers developed a survey instrument to elicit the value placed by households on improved weather forecasting services. The investigators took great care in developing the survey to ensure that respondents would understand the commodity being valued (weather forecasts) and to make sure that the survey's results would be valid and reliable. In addition to valuation information, the survey elicited information on households' sources, uses, and perceptions of weather information.

Four attributes of weather forecasts were considered in the survey: the frequency of forecast updates, the accuracy of one-day forecasts, the accuracy of multiday forecasts, and the geographic detail of forecasts. Different combinations of improvements in forecast quality were offered to individuals who were asked to choose between forecast 'packages' and a proposed cost for the forecast improvement. This means that the study used a 'stated choice' approach to stated preference valuation. The researchers then used statistical analysis to determine individuals' marginal values for changes in the different forecast attributes.

Using the values estimated for changes in the attribute levels, the study calculated individuals' value for a programme that would increase all attributes to their maximum level as USD17.88 per year per household. As expected, values for improving weather forecasts were found to be related to sociodemographic characteristics such as income and education, the amount of time an individual spends working outdoors, and how individuals use weather information in making behavioural decisions.

Using a different valuation question, the study also elicited individuals' value for weather forecasts as currently provided through both public and private distribution channels. This value was USD109 per year per household.

Based on 2000 census estimates of approximately 105 million US households, the investigators estimated the total value for improving weather forecasts to the maximum levels proposed in the survey to be USD1.87 billion per year. Similarly, the total value to US households for weather forecasts as currently provided was estimated to be USD11.4 billion per year.

The benefits of improved weather forecast quality, as estimated in the US households study, could be used to evaluate a programme to improve forecasting capabilities, if an estimate of the cost of improvement is available. Consider the following hypothetical illustration: in the 1980s, the National Weather Service undertook the Modernization and Associated

Agriculture

A recent study of the potential benefits of improved NOAA hydrological information by the Office of the NOAA Chief Economist examined the potential economic value of soil moisture information for private irrigation management in the semi-arid Great Plains.

The study estimated significant benefits to farmers which, if aggregated for the states of Nebraska and Kansas, are worth USD55 million per year and potentially over USD200 million per year.

About 45 per cent of these benefits result from more profitable irrigation and 55 per cent from the opportunity value of conserved groundwater. Other private or public benefits of soil moisture data would add to these advantages.

Source: Supalla, R, Martin, D, Adams, R and Weiher, R. *Potential economic value of soil moisture data for irrigation management in the central Great Plains*, October 2005: www.economics.noaa

Restructuring (MAR) Programme to significantly upgrade observing and forecasting systems at a cost of approximately USD4.5 billion over 20 years. Suppose, that the improvements specified in the US households study would cost twice as much and would also take 20 years to complete. Further, assume that maintenance and operation costs would begin in the tenth year at a rate of USD60 million per year. Finally, assume that one tenth of the benefits (USD0.187 billion) begin in the tenth year and increase linearly over ten years to the full level estimated in the study, USD1.87 billion a year. Using a 5 per cent rate of discount, the net present value of such a program (over a 100-year time horizon) is USD13.5 billion. This means that the present value of the benefits of this programme is about 3.02 times as much as the present value of the capital, maintenance, and operation costs over the time period. This illustration demonstrates how the values estimated from research such as the US household study could be used in policy decision-making to evaluate weather forecast improvement programs.

The value of temperature forecasts in electricity generation

In some situations, we can use a model to directly represent economic activities. By a model, economists indicate a set of equations or relationships that is used to describe behaviour,

Photo: NOAA

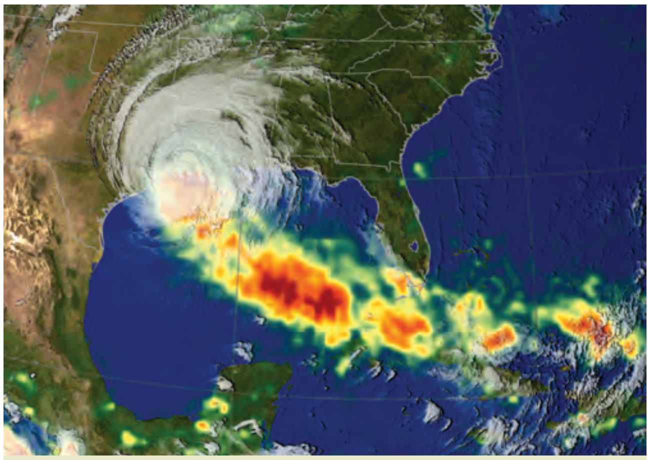
The agricultural industry saves money if given accurate predictions of wind and rain

production costs, decision making, or similar economic processes. For such a model to be useful for estimating the value of information, information itself has to play a role in the model's operation. Then we can use the model, with different kinds or amounts of information available within it, and observe how the different information available changes the model results. From this, we can infer the economic benefits of different kinds, amounts, or quality of information.

An example of the economic modelling approach is presented in a recent estimate of the cost savings in US electricity generation from using 24-hour temperature forecasts to plan production operations.[2] Particularly in the southern United States during the summer air-conditioning season, next-day temperature has an important influence on next-day electricity demand.

An electricity generator typically has many alternative generating units, and any combination of these units could be used to serve the next day's demand for electricity. Among the various units, lead times and cost characteristics differ. For example, preparing different units for service may require different lead times (with varying costs), and operational costs may differ as well once a unit is operational. As a result, the costs of generation to meet a given demand for electricity can be reduced if a good next-day forecast is available.

In the example study, the investigators used three levels of modelling to produce an estimate of cost savings from temperature forecasts in electricity generation. First was a model that chose, in advance, the best set of generating units to prepare for next-day use, given a forecast of next-day electricity demand. Second was a model that made appropriate 'real-time' adjustments on the next day to compensate for error in the previous day's forecast. This modelling step produced a relationship between the degree of accuracy in the electricity demand forecast and the ultimate cost of meeting the next-day electricity demand. The third step in the modelling procedure involved



Coastal ocean observing systems

Preliminary estimates of the potential economic benefits from new investments in regional coastal ocean observing systems in US waters range from USD500 million to USD1 billion per year, estimated largely in terms of increased economic activity and social surplus realized as a result of improved information about coastal marine conditions.

The estimates are constructed for ten geographic regions encompassing all coastal waters of the US, and cover a wide range of industrial and recreational activities, including recreational fishing and boating, beach recreation, maritime transportation, search and rescue operations, spill response, marine hazards prediction, offshore energy, power generation and commercial fishing.

Source: Kite-Powell, HL, Colgan, CS, Kaiser, M et al. *Estimating the economic benefits of regional ocean observing systems*. A report prepared for the National Oceanographic Partnership Program, Marine Policy Center, Woods Hole Oceanographic Institution, 2004.

representing the connection between the accuracy of the 24-hour temperature forecast and the electricity demand forecast. From this third step, the researchers could infer the extent of electricity production cost savings that result from having temperature forecasts (versus no forecasts), or from having improved temperature forecasts (relative to the current forecast quality). The study concluded, that the availability of 24-hour temperature forecasts of the current quality produces annual cost savings in the US of USD166 million relative to having no forecasts available.

Data analysis: the value of a heat wave warning system in Philadelphia

In some cases, data can be generated by experiment, in which information availability is dependent on time and place. In these situations, we can analyse the data to determine whether the existence, or use of the information, created benefits.

A study of a heat wave warning system implemented in Philadelphia in 1995 provides an example of this kind of approach.[3] Largely because of split responsibilities for devising and implementing the warning system, warnings were declared during some, but not all, of the periods of time when heat was potentially a health risk. The investigators in this study analysed mortality data for Philadelphia during this time period to determine whether heat wave warnings reduced mortality.

Photo: NOAA

The aftermath of Katrina

When a warning was issued, a number of steps were taken to ameliorate the effects of heat, particularly for those most susceptible to it. These steps included publicizing the impending heat event through mass media, publicizing and staffing a 'Heatline' made available to answer questions from the public, directly contacting nursing homes to alert them to the situation, encouraging formation of "buddy systems" to look in on vulnerable neighbours, increasing staffing for emergency medical teams, and extending hours of operation for air-conditioned senior centres.

To measure the benefits of warnings, the researchers collected data on mortality for people aged 65 and older and expressed these data as excess mortality relative to an underlying trend estimated from historical data. Next, they used statistical analysis to relate this excess mortality to possible causal factors, including whether or not a heat wave warning was in effect. Overall, this study concluded that the heat warnings that were issued during this three-year period saved 117 lives. Based on several relevant VSL studies, investigators concluded that the amount people would be willing to pay to save this many lives was on the order of USD500 million.

National Meteorological and Hydrological Services produce hydrometeorological information that delivers benefits to a wide spectrum of people and activities that are affected by weather, water, and climate. Most of this information is appropriately thought of as a public good, legitimately funded from public sources. Because there are always competing uses for public funding, however, we must be able to compare the benefits and costs of hydrometeorological information when deciding how much and what kind of information to produce.

We believe that estimating benefits of hydrometeorological information using economic welfare or willingness to pay measures is key to this endeavour. These benefit measures can be appropriately compared to the monetary costs of producing the information, allowing us to determine if benefits of the information exceed its costs.[4]

Evaluating the value of seasonal climate forecasts for subsistence farmers: lessons from NOAA applications research in Zimbabwe

Anthony Patt, International Institute for Applied Systems Analysis, Austria

Events of 1997-1998 marked an important turning point in the application of climate forecasts in southern Africa. It had been known for several years that it was possible to issue a rainfall forecast for the summer growing season up to six months in advance, based on the developing understanding of the statistical relationship between the El Niño-Southern Oscillation (ENSO) and rainfall patterns over the region. But making these forecasts is an imprecise art, and the development of several competing forecasts had led to confusion among decision makers over which forecast to trust, and what actions to take in response. In 1996, key players in the early warning community for the region began to plan for a single regional consensus forecast. This was to be followed by the National Meteorological and Hydrological Services (NMHS) issuing national forecasts consistent with the regional forecast, with the forecasting community taking a proactive role in communicating these predictions to users. With support from several international donors, including the United States National Oceanic and Atmospheric Administration (NOAA), the Southern Africa Drought Monitoring Centre hosted the first Southern African Regional Climate Outlook Forum (SARCOF) in Kadoma, Zimbabwe, in September 1997.

Photo: Anthony Patt

Seasonal climate forecasts can help subsistence farmers plant appropriate crops, such as short-season maize and groundnuts

The participants at the 1997 SARCOF had something important to say. In the first half of 1997, it had become clear that an intense El Niño was developing, suggesting the high likelihood of drought over much of the region. By June, alarms bells were ringing, and organizations such as the Famine Early Warning System (FEWS) began to track the development of sea surface temperatures. Participants at SARCOF issued a forecast of a high probability of drought for much of the region. Over Zimbabwe, for example, the prediction for the important January-February-March rains was of a 50 per cent chance of below normal rains, a 35 per cent chance of near normal rains, and a 15 per cent chance of above normal rains. The media reported that the 'mother of all El Niños' was developing, and warned of catastrophic crop failures to come. Many subsistence farmers then restricted their planting to a small area of their fields, either by choice or because they were unable to obtain credit. When summer rains fell that were in the near normal range, there was widespread criticism of the NMHS, namely that they had misled people into taking inappropriate actions, leading to a lower harvest than would otherwise have occurred.

Potential value of forecasts to farmers, and barriers to adoption

In the months and years following these events, a number of studies suggested that forecasts could be of use to farmers if used correctly. Farmers could optimize across the range of seed varieties — trading off potential yield for water requirements and growing season length — and by changing the crop density, the time of planting, and the application of fertilizer. At the same time, however, these studies suggested that a number of factors prevented farmers from making these optimal choices. First, farmers may not trust the forecasts, based on their experiences in past years. Events in Zimbabwe following the 1997-1998 season, and in Brazil following a similar experience in the early 1990s, suggested that a perceived error of one forecast could lead to lower trust for years to come, and an unwillingness to use the information at all. Second, farmers may not see the forecast as a legitimate basis for action, both because it could be seen as supplanting established forecasting methods within the community, and because it could be seen to be benefiting the political and financial elite, such as bankers who restricted credit, rather than the individual farmers themselves. As with a lack of credibility, a lack of legitimacy may lead farmers to reject the information.

Third, the forecast may be at too coarse a scale to benefit farmers. In a geographically heterogeneous country such as Zimbabwe, it was not obvious to farmers how to apply a national-level forecast to their own particular village. Fourth, farmers may not understand the forecast. Many had interpreted the 1997 forecast in Zimbabwe to mean that there would be no rains, and acted accordingly rather than taking its suggestion of probability into account. Fifth, established procedures may stand in the way of using the forecast. If the forecast is communicated to farmers via the local agricultural extension service offices, and if this requires a series of meetings at the national, provincial, and then local level, it can take weeks, meaning that the forecast reaches farmers after they have had to purchase their seeds and begin planting. Finally, particular choices may simply be unavailable to particular farmers: the local store may have decided not to stock the seed variety that the forecast suggests is appropriate, or families may not have access to draft power to plant at an appropriate time.

In theory, better communication practices by the NMHS and the agricultural extension services could overcome at least four of these constraints. First, the services could alter their standard procedures for information flow in order to reach farmers within days of the SARCOF meeting, giving them the opportunity to use the forecasts in their seed purchasing decisions. Second, they could better explain the forecasts' probabilistic character. This would address the constraint of understanding the forecast, and may also increase the credibility of forecasts following years in which something other than the most likely events occurred. Third, they could work with farmers to develop response strategies at the village level, incorporating both local geographical factors and the traditional indicators. This would address the legitimacy and scale constraints. NOAA funded a pilot project in Zimbabwe led by Anthony Patt and Pablo Suarez of Boston University, and Chiedza Gwata of the University of Zimbabwe, to test whether these theoretical solutions would work in practice, and whether actual benefits to farmers could be demonstrated once these constraints had been addressed.

Photo: Anthony Patt

An agricultural extension officer discusses local soils and precipitation at a forecast workshop

Using probabilistic information

The first issue explored in the project was whether farmers could actually understand a probabilistic forecast. The researchers used experimental techniques from psychology and behavioural economics to examine the responses to probabilistic information among a sample of almost 100 subsistence farmers from seven different farming communities.

The participants played a series of gambling games with a modified roulette wheel, choosing which colour to place their bets on. In one game, for example, the roulette wheel was exactly half red and half green, and the rules of the game were that a successful bet on red would win a prize of ZWD2 (Zimbabwe dollars), while a successful bet on green would win a prize of ZWD3. Participants who were able to optimise would place all of their bets on green, while those with a poorer understanding of probability and uncertainty would be tempted to bet on red at least some of the time. In another game, the regions of the roulette wheel were marked to represent 'good rains' and 'drought'. The bets consisted of planting maize, which paid ZWD5 if the wheel landed on good rains and nothing for drought; and planting millet, which paid ZWD3 for good rains and ZWD2 for drought. Over a series of plays, the researchers changed the relative sizes of good rains and drought on the wheel, and observed the effect that this had on the bets farmers placed.

The results of the experiment showed that farmers clearly could work with probabilistic information, if given the opportunity to familiarize themselves with it. When participants played five rounds of the red/green betting game at the beginning of the session, almost all of them placed some of their bets on red, even though it had a lower expected payoff. Over ten rounds of the maize/millet game, farmers changed their bets in response to different probabilities of good rains and drought. In another five rounds of the red/green game, coming at the end of the experimental session, almost half of the participants placed all bets on green — the correct strategy. Women outperformed men: close to 60 per cent of the women had adopted the optimal strategy, compared to slightly more than 30 per cent of the men.

A methodology to identify forecast value

The next stage of research was to explore whether subsistence farmers, having access to a timely probabilistic forecast that they could discuss with agricultural advisors and compare with their traditional indicators, would use the forecast to make different decisions and derive added value as a consequence. Zimbabwe was an ideal country to conduct this research, since the NMHS was already active in broadcasting the forecast via radio, making it possible to test the added value of a participatory approach.

Beginning in 2000 and continuing through 2004, the researchers organized and facilitated annual forecast workshops in four representative farming communities. Working with the local agricultural extension service and other community leaders, they invited a representative sample of roughly 50 farmers to each workshop. Farmers presented their interpretation of the previous season's events: what had been forecast; how the rains had actually fallen; and which crop varieties had produced the best results. They then presented their own local indicators for the coming growing season. Next, the researchers presented the probabilistic forecast, which had been issued only days before at the SARCOF and downscaled by the Zimbabwe NMHS. They answered farmers' questions about the forecast, including the role of ENSO and other global drivers, and a comparison of the forecast with the local indicators. With consideration of local historical rainfall records, they discussed what the probabilistic forecast implied in terms of actual rainfall quantities. Representatives from the agricultural extension service then discussed with farmers specific actions — the selection of crop varieties and planting dates — that could be taken in response to the forecast and other economic considerations. The workshops ended with a meal, where other community issues were discussed.

To reach robust conclusions about the value of the forecast, the researchers administered a household survey at the conclusion of the growing season, asking farmers about the planting decisions they had made, and their estimated yields for each crop variety from that season and prior seasons. Over two years of the survey (2003 and 2004) enumerators obtained valid data for 495 households, a random sample within each community including both those who had and had not participated in the pre-season workshop.

Results of the study

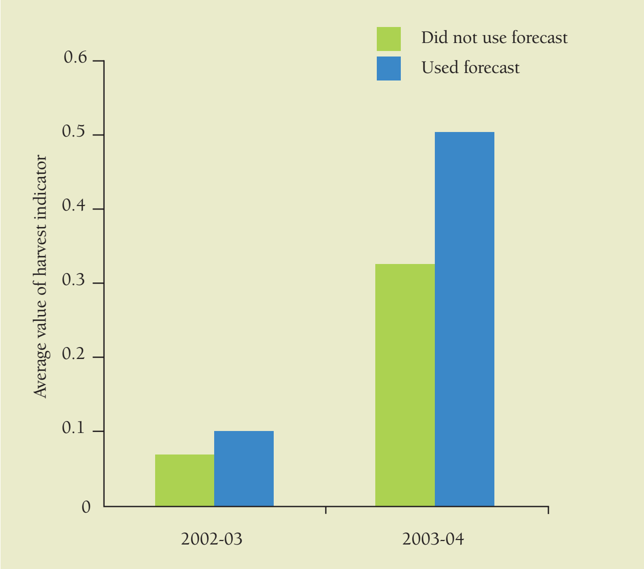
The study generated both qualitative and quantitative results, which were published in the 30 August 2005 issue of *Proceedings of the National Academy of Sciences*. At the workshops, farmers expressed enthusiasm for receiving the forecast, and participated actively in discussion of ENSO and other rainfall determinants. They expressed greater confidence in the forecast after they had been able to ask questions about it, and said that this opportunity also increased their appreciation of the forecast they heard over the radio, realizing that it was fundamentally the same forecast. Data from the survey was used to provide one of the first robust estimates of the forecasts' added value, and the added value of a participatory communication approach.

To examine forecast value, the researchers compared farmers' yield estimates with their estimated historical yields to generate a relative harvest indicator. The indicator corrected for individual farmers' estimation error and took into account diverse growing conditions. The first year of the survey, 2003, had been an El Niño year with normal, to below normal forecasted rains. The actual rains had been below normal. The relative harvest indicator showed that most farmers had received close to their lowest historical yields. In this year, farmers who reported using the forecast to make different decisions outperformed those who did not use the forecast by an average of 3.6 per cent, although the difference between the two groups was not statistically significant. The second year, 2004, had neutral ENSO conditions, and actual rains that were in the near-normal range. The yield indicator showed that most farmers had obtained yields that were close to their historical average. In this year, farmers who reported using the forecast to make different decisions outperformed those who had not by an average of 18.7 per cent. The difference was significant at a 90 per cent confidence level, using both parametric and non-parametric statistical tests. Averaged over the two years, farmers who reported using the forecast outperformed those who had not by an average of 9.4 per cent, a difference significant at a 95 per cent confidence level. These data provided the most convincing evidence to-date that forecasts could benefit individual subsistence farmers.

The second quantitative finding was that workshop attendance made a large difference in farmers' use of the forecast. In two of the communities, the data indicated that the farmers who had attended the workshops represented a biased sample of very good farmers, making it impossible to compare them with those who had not attended the workshops. In the other two communities, however, there did not appear to be a difference between the two groups, making a comparison possible. The majority of farmers who had attended a workshop reported using the forecast to make different decisions, whereas roughly 10 per cent of those who had not attended a workshop but had heard the forecast through another channel reported using it to make different decisions. Thus, workshop attendance boosted forecast-use by a factor of five.

These results were the first of their kind, in that they showed benefits from forecasts using a participatory dissemination strategy, with a research methodology that allowed for robust statistical tests. In these communities, which faced growing conditions similar to those across much of the region, seasonal climate forecasts made a profound difference to those farmers who chose to use the information. Using the information, however, is not easy, and a participatory communication strategy was the major determinant of farmers' using the information. Timely and accurate seasonal climate forecasts can help subsistence farmers — among the poorest of the poor — but NMHS need to continue to work with other stakeholders to communicate the information in ways that increase farmers' understanding of, and trust in, the information.

Harvest indicator showing how farmers performed relative to their own historical yields



Source: Patt, Suarez and Gwata, Proceedings of the National Academy of Sciences, 30 August 2005

Economics of weather impacts and weather forecasts

Jeffrey K. Lazo, National Center for Atmospheric Research, US

WEATHER HAS SIGNIFICANT and increasing societal and economic impacts in every country and in almost every human activity. Weather forecasts allow decision makers to mitigate some of the impacts of weather and thus create significant economic value. Understanding the economic impacts of weather and weather forecasts is critical to National Meteorological and Hydrological Services (NMHS) efforts to serve society. It is important therefore to understand the economic aspects of weather impacts and weather forecasts, in order to gain a better understanding of several key perspectives:

- The distinction between weather impacts and weather forecasts
- How to value weather impacts and weather forecasts
- How economic information is important in the decision making that supports NMHS.

Weather impacts and forecasts

The term, 'economics of weather *impacts*' relates to the way in which different weather conditions change or affect economic activity and decision making. Weather impacts include the loss of crops to freezing temperatures, or energy demands that increase with higher temperatures. The economics of weather *forecasts* relates to how decision makers respond to weather predictions — for example, protective action in response to freeze warnings to reduce crop losses, or an investigation into the extent of energy-cost savings that can be realized with better one-day temperature forecasts.

The relationship between the economic impact of weather and the economic value of weather forecasts is neither direct nor clear. In general though, if weather forecasts are to have value, decision makers must be able to change their behaviour in response to weather information. If they cannot make changes, the forecasts can have no direct value.

Valuing impacts and forecasts

To assess the value of forecasts then, it is necessary to understand the relationships between the impacts of weather, and the information given in weather forecasts. In addition, it is important to be aware of how decision makers use that information, how decisions change with different forecast information, and how economic impacts alter with changes in decision making and behaviour. This leads to the question: what exactly should be taken into account when we talk about the value of weather forecasts?

The process of valuation always entails the comparison of the value in one situation to that in another situation. The valuation of weather forecasts involves comparing two different levels, qualities or types of weather information, based on the assumption that all other factors are equal. The diagram below shows a continuum of weather-information value, beginning with 'no information' and ending with 'perfect information'. When speaking of the value of weather information, it is necessary to specify which components of the continuum are being compared.

Other aspects of the valuation problem include:

- Who is receiving the value (e.g. the users of the information)
- The temporal and spatial scales of the valuation study
- The type of information being valued (e.g. all weather information or just temperature information).

In order to make it possible to estimate economic value, it is also important to understand the weather forecast and impact 'value chain', (represented in the second diagram below). Although NMHS focus mainly on activities in the 'weather forecast enterprise' box, much of the value added or lost occurs in the 'communication' and 'users and decision making' boxes.

Continuum of weather-information value

[1] The value of climatology may be higher or lower than persistence but is shown as lower for the current purposes

Source: Jeffrey K. Lazo

Ultimately, value accrues from the behaviour of users and the impacts of their decisions.

It is clear that there is no simple answer to the question: 'what is the value of a forecast?' Equally complex is the question of where resources would be best allocated to improve the societal benefits of NMHS. If current levels of forecast information are underused, for example, it may be best to invest more in communication and decision making.

Because economists have a wide range of tools and approaches for valuing the benefits and costs of goods and services, including those provided by NMHS, there is no need to invent new methods for valuing weather forecasts. The basic approaches for valuing weather forecasts are discussed in Lazo, Teisburg, and Weiher in this volume. Accepted theories and methods pertinent to issues in valuing weather information services include:

- Estimating benefits of services that are not actually bought and sold in competitive economic markets (this includes most weather forecasts)
- Valuing benefits and costs that occur over a range of time periods
- Valuing the impacts of weather and forecasts on lives saved or lost
- Valuing information about uncertain future events (which is the fundamental value of weather forecasts).

It is important to note that, just as economists should not be forecasting the weather, the meteorological community would do well to work with economists to bring the appropriate theories, methods and tools to the economic analysis of weather impacts and forecasts.

Assessing the economic benefits of NMHS and their services

There is a variety of reasons for assessing the economic value of NMHS products and services. It is important to understand why economic valuation is of interest as this effects the type of values assessed, the accuracy needed in assessing these values, and how information about these values is communicated.

Justify programmes — Showing the net positive economic benefits of NMHS is becoming more critical as these services do battle to justify their budgets. Data on the economic value of such services can carry significant weight for policy decision making and budget setting — even recognizing that many political decisions are made irrespective of economic trade-offs.

Evaluate programmes — When determining whether to invest in a specific program, many local, national, and international funding agencies require an economic assessment of the net benefit of such a programme, often in the form of a benefit-cost analysis. Although quantifying costs can be relatively straightforward, estimating benefits from NMHS can be more difficult because those receiving the benefits are usually not the NMHS but rather a wide variety of economic and societal sectors.

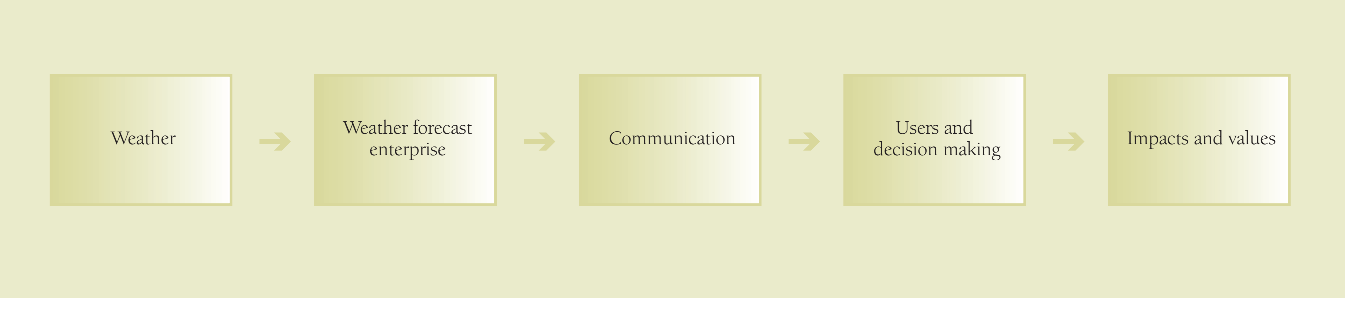
Guide research investment — Similar to benefit-cost analysis, assessments should be made when agencies decide what research to undertake in order to improve or maintain weather services. Identifying likely outcomes of alternative investments and quantifying benefits and costs helps to guide choices between research investments. Even if rigorous analysis is not possible because of uncertainties or lack of economic information, framing the problem in terms of benefits and costs can help decision makers identify which projects to undertake and which ones to put aside.

Inform users about benefits — Understanding the use and benefits of forecasts is also important for informing potential users about how and why they could use weather information. Demonstrating value to the users goes a long way towards gaining their involvement and support.

Develop end-to-end-to-end systems — Ultimately, the best use of economic information will combine all these approaches into integrated end-to-end-to-end forecast and warning systems. In such systems the preferences, needs and values of users will guide decision making throughout the system in terms of what types of information to provide and how to disseminate it, along with what research to undertake and what programmes to support.

Weather impacts such as the loss of crops can be mitigated through protective action in response to weather forecasts

Weather forecast and impact value chain



Source: Jeffrey K. Lazo

Moving from hindsight to foresight: a challenge in the application of valuation research

Brian Mills, Adaptation and Impacts Research Division,
Atmospheric Science and Technology Directorate, Environment Canada

NATIONAL METEOROLOGICAL AND Hydrometeorological Organizations (NMHOs) aim to provide their respective citizens with world class meteorological and environmental information, predictions and services to ensure the safety of the population, support economic activity and facilitate improved environmental decision-making. This information includes millions of weather forecasts and thousands of severe weather warnings that are issued each year, along with billions of archived environmental observations and associated applications for decision-makers in health, agriculture, energy, forestry, transportation, construction, insurance and many other sectors. The production of this information in Canada is dependent on a public monitoring, computer, telecommunication and research laboratory infrastructure valued at over CAD330 million, and on the contributions of about 2,000 meteorologists, scientists, technicians and support staff. A significant effort is also provided through the academic community, private meteorological service providers, media and experts employed directly by large user businesses, institutions and organizations.

In light of such investments, public meteorological agencies the world over have become increasingly interested in identifying, tracking and evaluating the costs and benefits of providing timely, precise and accurate information about the past, current and future states of the atmosphere. This desire is also driven by broader globalisation pressures that have encouraged the proliferation of international quality control, quality assurance and other standard-setting and performance-measuring practices. Clearly there is a need to justify the cost of current operations and this objective has underpinned public agency support to date for societal and economic valuation research.

Photo: J. Suggett

Understanding the decision-making behaviour of users — in this case drivers — is critical to developing improved weather services

For all of the past improvements in weather forecasting, achieved through the development of numerical modelling and investments in global observations, telecommunications, science, and forecaster training,[1] one is left wondering whether a concomitant degree of value has been imprinted on society. This may be because, until recently, the societal and economic value and use of weather information has been under-studied, rarely measured, and often assumed to exist by those purportedly funding or conducting societal problem-oriented atmospheric research.[2] A small but growing body of literature has emerged over the past 40 years to address this significant need by documenting and estimating the use and value of weather information.

In *Economic Value of Weather and Climate Forecasts*, Katz and Murphy provide one of the most critical and comprehensive collections of referenced work and critique a wide spectrum of methods available to determine economic value (e.g. contingent valuation, market-based cost-loss functions, cost-benefit analysis, etc.).[3] Elsewhere, recent examples of sector-specific studies on aspects of agriculture,[4] energy,[5] health,[6] forestry/fire management,[7] transportation,[8] and water resources management[9] are complemented with broader evaluations of multiple sectors and public or households' willingness to pay for weather services.[10] Such studies most often examine the value of information that is currently received or that could be obtained with some specified level of improvement in quality (i.e. precision, accuracy, delivery frequency or medium). Other researchers have examined a particular component of the monitoring and forecast system, such as the impact of an expanded network of Doppler radar infrastructure in Canada,[11] or Weatheradio.[12]

The future of weather-related economic valuation research will no doubt continue to be influenced by advances in general economic theory and applications by academics and professionals. The most critical necessity is an improved treatment of assumptions concerning the decisions and behaviour of potential users of weather information. In order to move beyond the flawed static linear model of decision-making which assumes that more information with greater precision and accuracy automatically leads to better decisions and desired outcomes (reduced risk or enhanced benefits), greater consideration of the user's problem and decision-making context will be required, including:

- Outcomes or consequences of concern to the user (e.g. safety of citizens, units of production, profitability) and associated measures (e.g. casualty rates, crop yields, etc.)
- Important relationships between weather, climate and outcomes (i.e. source of key variables, transfer functions or 'events')
- Responses or alternatives available for the user to manage risks or take advantage of opportunities (including characteristics of those responses such as tactical/operational or strategic; frequency, duration, flexibility)
- Role of weather or climate information in current or potential responses (i.e. how is it used; required levels of precision, accuracy, frequency, etc.)
- User values, beliefs, and worldviews
- Organizational, socio-cultural, financial, technical, legal, and political factors in user environment that may constrain or facilitate adoption of response options.

This type of understanding is not neatly contained within one academic silo[13] — a key challenge is to foster an environment conducive to transdisciplinary research that includes experts from meteorology, hydrology, statistics, decision science, economics, psychology, sociology, anthropology, geography and other communities. Such research would benefit from the greater engagement of users. Participatory research methods have received considerable attention in the climate change adaptation community[14] and are no less relevant for weather information over shorter timescales.

Relative to the academic and professional communities, NMHOs will have an equal if not greater role to play in guiding the next generation of studies — one that goes beyond the provision of financial support necessary to advance theory, methods and techniques. A significant but latent potential of this research lies in its ability to shape the future and planning context of NMHOs. Understanding the value of providing hydrometeorological and climatological information could be a fundamental input to measuring and improving services or making critical decisions with respect to the application of new technologies and changes to existing monitoring networks, observation strategies, communications, computer infrastructure, human resource management and priorities for research and development.

Instead of only using ad hoc valuation studies to justify past investments, NMHOs could incorporate a more systematic, strategic and long-term approach to designing, conducting and applying societal and economic valuation research. This is a substantive shift that will involve developing an internal capacity that is closely integrated with the academic and professional research communities. Advances being made in Canada,[15] the United States, and elsewhere through WMO programmes such as THORPEX,[16] are encouraging. Hopefully, in hindsight ten years from now, we will be able to admire and measure our tremendous foresight in terms of saved lives and user benefits — however, much remains to be done.

Photo: S. Tighe

A Falling Weight Deflectometer is used to assess the strength of a road. Weather information is important for calibrating such instruments and in predicting seasonal weaknesses in pavements

Customizing methods for assessing economic benefits of hydrometeorological services and modernization programmes: benchmarking and sector-specific assessment

V. Tsirkunov, S. Ulatov, M. Smetanina, A. Korshunov

There is a growing understanding that hydrometeorological data, and weather forecasts in particular, bring economic and social benefits to any country. The use of hydrometeorological information in decision-making makes it possible to minimize economic damages and loss of human lives, as well as to gain additional economic benefits from the forecasts of favourable weather conditions. However, existing methods for assessing the economic benefits of hydrometeorological information and services require reliable econometric and specialized data, considerable resources and expertise. All or many of these ingredients are missing in the developing countries, making it difficult for national hydrometeorological services (NMHS) to demonstrate the economic efficiency of their services and justify the need for adequate public support.

The World Bank was first faced with the need to develop a method for an express assessment of the economic efficiency of NMHS in 2003 while preparing the National Hydrometeorological Modernization Project in Russia. The results of the study, carried out jointly with Roshydromet, were well received by the Russian Government and World Meteorological Organization (WMO). This positive experience has encouraged the bank to launch further studies in cooperation with NMHS.

Over the past 15 years, the NMHS of the transition economies in the Europe and Central Asia (ECA) region suffered greatly from the massive underfunding. This resulted in increased economic losses from hydrometeorological hazards and unfavourable weather conditions, the frequency and scale of which increased in most ECA countries. Modernization of NMHS and improvement of hydrometeorological service (HMS) delivery is one of the key factors in minimizing economic losses from these events and increasing pubic safety. Before allocating resources for such modernizations, the national governments demand that NMHS prove the economic benefits of such a decision.

For most NMHS, this poses a great challenge due to the absence of a generally accepted methodology for assessing the effectiveness of HMS delivery or modernization programmes; lack of basic econometric information needed to assess losses and benefits, and the shortage of expertise in NMHS and weather dependent sectors capable of making this assessment. The process of collection and evaluation of the information is time-consuming and requires substantial funding which is often unavailable.

The World Bank, jointly with a number of NMHS in Europe and Asia (among them Albania, Armenia, Azerbaijan, Belarus,

Photo: Mr P Lurie

In the last five years, 15 cases of waterspouts have occurred 3-5 km from the coast, on two occasions causing the loss of human lives

Main parameters and results of economic efficiency of HMS delivery and proposed modernization programmes (economic parameters are in USD of 2000 constant prices)

	Albania	Azerbaijan	Armenia	Belarus	Georgia	Kazakhsatan	Serbia
Average Annual GDP, $ million	4,229	7,061	2,579	15, 011	3,620	23,991	9,763
Territory, thousand km²	28.8	86.6	29.8	207.6	69.7	2,720	89.0
Population, million.	3.1	7.8	3.0	10.3	4.9	15.1	8.1
NMHS funding, $ million	0.44	1.7	0.47	2.96	0.47	4.21	5.15
Share of agriculture in GDP, %	24	12	30	10	25	7.0	17
Weather dependent sectors in GDP, %	65	51	69	43	62	45	44
Meteorological vulnerability	«relatively high»	«relatively high»	«relatively high»	«relatively high»	«relatively high»	«relatively high»	«average»
State of NHMS and HMS delivery	«poor»	«poor»	«poor»	«poor»	«poor»	«poor»	«satisfactory»
Adjusted share of losses incurred, benchmarking (% of GDP)	1.00	0.5	1.25	0.38	0.99	0.32	0.44
Assessment of economic losses,$ million benchmarking	37.9	35.5	32.2	57.5	35.8	77.9	42.
Assessment of economic losses (direct and indirect), $ million sectoral assessments	32.1	54.5	50.1	72.3-83.1	53.6	-	95
Assessment of preventable losses, $ million, benchmarking	10.5	13.9	7.0	28.8	9.3	39.0	33.5
Assessment of efficiency of the existing HMS delivery (%), benchmarking	432	165	277	206	362	198	219
Annual incremental effect of improvement the status of NHMS and HMS delivery to "adequate" – benchmarking assesment, $ million	2.5	3.8	1.6	8.6	2.2	11.5	5.5
Annual incremental effect of improvement the status of NHMS and HMS delivery to "adequate" – sector-specific assesment, $ million	1.8-3.9	12.3	9.2	7.9-9.1	8.0	-	4.34
Estimated cost of modernization program, $ million	4.0	6.0	5.3	11.5	6.0	14.9	4.4
Investment efficiency, % (across 7 years), benchmarking	630	430	210	530	260	540	880
Investment efficiency, % (across 7 years), sector-specific assessment	320-680	1440	1070	480 –550	1,050	-*	690

Source: Authors' estimates based on official statistics and national hydrometeorological and sectoral experts' assessment

Georgia, Kazakhstan, Russia and Serbia), has been engaged in developing and piloting new approaches for estimating additional economic benefits from the modernization and development of HMS, as well as for assessing the current economic benefits from existing HMS. These efforts were driven primarily by practical considerations in the process of development modernization initiatives and fostering a better dialogue between HMS and national economic and fiscal authorities. As a result of this cooperation, two simplified methods — benchmarking and sector-specific assessment — have been developed. These two approaches are independent and yet complementary.

Why benchmarking?

Benchmarking offers an express method of obtaining results about damages caused by weather impacts in the absence of essential information, and with financial and time constraints for more detailed studies. The method employs the available official statistics and expert assessment of the weather-dependence of a country's economy, meteorological vulnerability of its territory, and existing NMHS provision.

The benchmarking method has two stages: determining the benchmarks; and correcting them according to country-specific characteristics.

Determining benchmarks

In order to estimate benchmarks, we have used various data and estimates obtained from studies conducted in other countries alongside estimates from experts working for NMHS. For the purposes of this study, the following values for principal benchmarks have been assumed:

1. Average annual level of losses from adverse and dangerous weather conditions as a percentage of GDP — 0.45 per cent. The range of annual losses is assumed to be 0.1-1.0 per cent of GDP. There is no comprehensive database on this important parameter, the estimates available in the literature vary from about 0.1 per cent to over 5 per cent of GDP
2. Average annual level of prevented losses as a percentage of total losses — 40 per cent (range — 20-60 per cent).

It is also assumed that the country corresponding to these benchmarks would have the following characteristics:

- Weather dependence (aggregate share of weather-dependent sectors in GDP) — 50 per cent
- Share of agriculture in GDP — 15 per cent
- Meteorological vulnerability — 'average'
- Status of HMS provision — 'satisfactory'.

The meteorological vulnerability of the territory was assessed according to specially designed methodology that took account of the observed extreme values of major meteorological components, among them temperatures (minimum and maximum), precipitation and wind, along with characteristics of their statistical distributions.

Correcting benchmarks

At the second stage, the benchmarks are corrected according to country-specific characteristics. The intervals for possible distribution of country-specific estimates and the methods for adjusting benchmarks were devised on the basis of expert assessment and the results of studies conducted in other countries. Finally, the estimates obtained for a specific country are used for calculating the marginal efficiency of the existing HMS and its potential improvement in case of proposed modernization.

One of the constraints of this method is that it allows for assessing the efficiency of HMS only in relation to prevention of direct losses, while indirect losses (including the loss of human lives, profits etc.) are not factored in. As a result, the obtained estimates of economic benefits from NMHS substantially understate their real economic value. Another important constraint comes from the assumption on homogeneity ofa country's territory with regards to its meteorological vulnerability and weather-dependence, which imposes constraints on its use in large and diverse countries. However, the benchmarking method is appropriate for large countries if their territories are broken down into more homogeneous zones.

Methodology on sector-specific assessment

The *methodology on sector-specific assessment* is based on the specially-designed surveys of experts from weather-dependent sectors and aims at obtaining:

1. Information on the level of direct and indirect losses from hazardous weather events and adverse weather conditions in a specific sector
2. Estimates of possible variations in the share of preventable losses and costs of protective measures due to more accurate and timely hydrometeorological information and forecasts as a result of modernization programmes. The data received through these surveys are then used to evaluate the marginal effects from modernization for each weather-dependent sector and the integral effect for the economy as a whole.

One of the advantages of sector-specific assessment is the possibilty of factoring into efficiency estimates some indirect losses from hazardous weather events and adverse weather conditions, in particular those related to lost profits. This method could be particularly useful for the evaluation of NMHS modernization projects, as it allows for estimation of the potential benefits related to improvements in the provision of general and specialized HMS, and takes into account the present and future needs of specific users.

In spite of significant constraints, both methods — the benchmarking and sector-specific assessment — help to generate useful indicative economic estimates of NMHS performance in the surveyed countries. The table presents the baseline parameters for the benchmarking method, the main results of evaluation of economic efficiency of the existing NMHS and efficiency of proposed modernization programmes by both methods — benchmarking and sector-specific assessments — applied in studies carried out in Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Russia, and Serbia.

The state of national NMHS and HMS delivery was rated by national experts of all the countries (except for Serbia) as 'poor'. Meteorological vulnerability for all the countries (except for Serbia) was calculated as 'relatively high'. The estimates of economic losses from hazardous weather events varies between 0.32 per cent of GDP for Kazakhstan and 1.25 per cent of GDP for Armenia.

For the target countries the assessment of the prevented losses was undertaken for the first time and the results should be viewed as tentative. Nonetheless, we believe they indicate a high economic value of the hydrometeorological services and information. The benchmarking estimates of losses were usually lower than the ones evaluated based on sectoral assessments, as the latter attempt to evaluate both direct and indirect losses.

Estimates of relative economic efficiency of the existing NMHS, calculated by comparing the estimates of prevented losses and the cost of NMHS funding, show that the efficiency (or benefit-cost ratio) is rather high, ranging from 165 per cent for Azerbaijan to 568 per cent for Albania. Overall, for each dollar spent for supporting the existing NMHS, the countries usually gain two or more dollars through the avoided economic losses.

Both methods show that an annual incremental benefits of the proposed modernization (improving the status of NMHS and HMS delivery from 'poor' to an 'adequate') will be quite substantial for all the countries concerned. The repayment period of investments in NMHS modernization will be within two to three years. The economic efficiency of the proposed modernization (assumed to be accrued evenly over the seven-year period) ranges from 210 per cent for Armenia to 880 per cent for Serbia assessed by the benchmarking method. Estimates based on sector-specific assessment show even more favourable efficiency ranging from 500 per cent for Belarus and Albania to 1,440 per cent for Azerbaijan. The variability of the results between the two methods is smaller for the countries with better quality of data (Serbia, Belarus). Data in Kazakhstan has proved insufficient to undertake a sectoral assessment.

The results of this study have been discussed at the national workshops in the surveyed countries. The importance of proposed approaches and preliminary results were confirmed by the HMS specialists, sectoral experts and governmental officials. The participants expressed the opinion that the results of economic assessment could be used for justifying adequate financial support of existing NMHS activities as well as for potential NMHS modernization. Some participant countries have already embarked on preparation of large-scale NMHS modernization programmes.

Being fully aware of the deficiencies of the proposed approaches, we believe, nevertheless, that the proposed express method of economic assessment and its preliminary findings can be a useful tool both for the hydrometeorological services in positioning themselves as important public sector, and for the national fiscal/economic authorities seeking rational justification for better targeting its scarce resources.

The value of weather forecasts: quality, decision-making and outcome

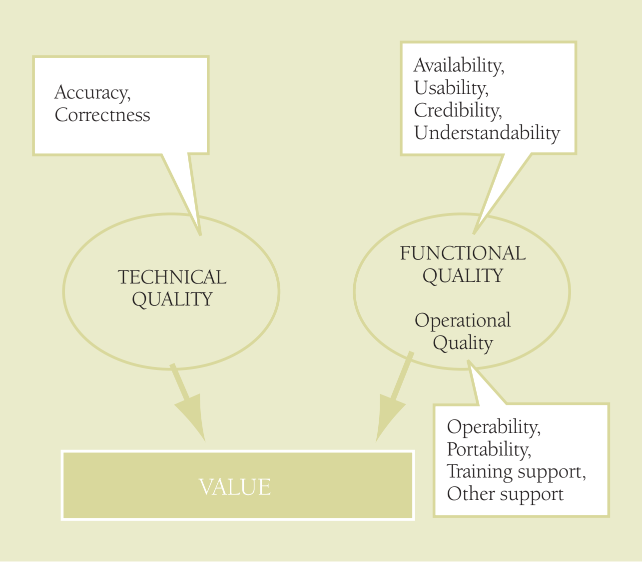
Erik Liljas, Swedish Meteorological and Hydrological Institute

Forecasting and other weather-related information provision has improved immensely during recent decades. The improvement in forecasting means that it is possible to describe coming weather events in terms of attributes such as intensity, location and duration. Due to this more complete set of variables and probabilities, not only weather variables but also other related variables are identifiable. New means of communication and visualization are contributing to improved possibilities for forecasting services, and other important decision-making materials can be more easily integrated.

A prerequisite for positive forecasting outcomes is that decisions are made over and over again based on the content of good forecasts. The predictability of weather is such that, while the outcome of individual forecasts might be inaccurate, the integrated value over time should be accurate.

Quality is not only an academic issue; it has to embrace several dimensions in order to develop an optimised decision-making process. It is important to take into account continuously developing technologies and techniques to enhance the value of forecasting, both in economic terms and in terms of mitigating damage from predicted strong weather events. This view of forecasting will hopefully provide some new thinking on how to optimise service quality and how to improve it in an adequate parallel to the developing sophistication of meteorology as a science, where the state-of-the-art is now based on supercomputer and space techniques.

Quality components of a successful service



Source: From the validation concept of PREVIEW — a project within the 6th Framework Programme of the European Union.

On quality

Verification measures are expected to reveal the quality of forecasts. However due to the breadth and varied skill levels of its audience, an accurate forecast may still be confusing for one end user while providing a lot of useful information to another. A forecast can be considered to exhibit value if it helps the end user to make decisions on the basis of that particular forecast, regardless of skill.

A service meeting its users' expectations is not necessarily 100 per cent accurate. If it provides an acceptable mean to facilitate decision making, it may still be a satisfactory service. The main goal of validation is to authenticate and quantify the delivered products, so that users can be informed on the quality and limitations (and therefore the applicability) of the information that they are receiving.

Quality definitions

The outcomes of validation processes will be a measure of the quality of the service/products, in its broadest sense. The concept of quality should be clearly broken down, since all these quality components are identified as part of a successful service.

The product value should depend on technical quality (TQ) and functional quality (FQ). Operational quality (OQ) can be seen as apart of the FQ, but also as a separate part of the full quality concept.

Technical quality — TQ is directly related to the service's technical specifications. It gives information on the accuracy and scientific maturity of the products. The TQ of a categorical or probabilistic forecast is a measure of the accuracy of the forecast statement, with accuracy measured using the relevant range of metrics that quantify how close the forecast was to the observed value or the analysed value it was intended to predict. TQ might describe how well the predicted precipitation, temperature, water level etc. corresponded to the actual measurements. It might also be described as the skill involved in the forecast. However, TQ is understood in quite different ways by different users. The requirements associated with it could differ between those of a user wishing to overview a year and one looking at a specific hazardous event. The quantification of TQ must be performed by taking into account the nature of the service and the type of information relevant to each thematic domain.

Photo: SMHI image archive

Shipping has to a great extent a well developed weather-information-sensitivity

Functional quality — TQ is not a guarantee of FQ. For example, a perfect forecast that is communicated to the user too late has zero functional quality although it is technically correct. A less accurate forecast that is communicated to the user early enough to allow protective action to reduce potential losses, is technically less correct but functionally more valuable. This example illustrates the fact that the distinction between technical and functional quality is not academic, but reflects the real-time use of the forecasts.

FQ is mainly related to the 'quality in use' of the products: it includes both subjective judgment and understanding by the user, and technical capabilities regarding service provision.

The former is mostly user-centred, and can be defined as the usability of the service/product — that is, the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a context of use. The latter globally identifies the context of use for the service, encompassing the following parameters: availability of the service, frequency of delivery, means of delivery, performance, timeliness, understandability and learnability.

To sum up, FQ measures the efficiency of the service to meet the users' needs, resulting in user satisfaction and productivity. It is directly related to the capability of the service to be understood, delivered and used in accordance with users' expectations.

Operational quality — Even if a service meets users' expectations (FQ) and the delivered products are technically/scientifically correct (TQ), it does not necessarily mean that its operational deployment satisfies the user. For example, if the service is not accessible at the right time, if it is too often unavailable because of insufficient reliability, or if the user encounters too many problems regarding training or user support for the service, then it will not be useful in an operational sense.

OQ measures the capabilities required for a successful operational deployment, such as reliability, operability, efficient support, maintenance, training, interoperability, security and portability. OQ also depends on TQ and FQ values, in the sense that a zero TQ or a bad FQ would mean a poor OQ.

These technical-functional-operational dimensions are complementary and partially interwoven, and all have to be continuously validated. Correctness, accuracy, functionality, reliability, efficiency and usability determine the total quality for an end user in an operational context.

Only when weather dependence is fully understood and the relevant FQ is fully deployed will there be a direct correlation between TQ and outcome. We can then say that weather-dependence has been transformed into weather-information-dependence.

Forecasting and other varieties of weather information have improved immensely during the last decades, even if traditional verification shows only moderate improvements. But have the benefits followed the same trend? Yes, in some branches where the weather-information-sensitivity is so high that all quality aspects are immediately updated to maximize the outcome. In other cases, the availability and immediacy of information online has had the impact of prioritising simplistic data at the expense of more complex insights.

Too much high value information remains in temporary databases at meteorological institutes. Many institutes are certified according to the ISO 9001 manual and procedures. However, this is no guarantee that weather information is converted to savings in terms of safety, economy or disaster mitigation. The chain of processes has to be thoroughly investigated. Quality aspects should improve in such a way that a direct link between technical quality and outcome is possible. In parallel, the decision-making process should focus on recognizing what auxiliary information is needed to make optimal decisions.

The ideas presented here are mainly relevant for sophisticated users of weather information, but not only commercial customers. Civil protection authorities, local and central, are perhaps the most important targets for this enhanced quality and decision making. The developing sophistication of meteorological science, where the state-of-the-art has supercomputers and space techniques as integral factors, also requires a more thorough look into the world of the users of our service. This is central for further stimulation, feedback, justification and funds.

Annexes

Resolution 40 (Cg-XII, 1995)

WMO policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities

The Congress,

Noting:

1. Resolution 23 (EC-XLII) — Guidelines on international aspects of provision of basic and special meteorological services
2. Resolution 20 (EC-XLVI) — WMO policy on the exchange of meteorological and related data and products
3. Resolution 21 (EC-XLVI) — Proposed new practice for the exchange of meteorological and related data and products
4. Resolution 22 (EC-XLVI) — WMO guidelines on commercial activities
5. The report to Twelfth Congress of the chairman of the Executive Council Working Group on the Commercialization of Meteorological and Hydrological Services, established at the request of Eleventh Congress by the Executive Council in Resolution 2 (EC-XLIII) — Working Group on the Commercialization of Meteorological and Hydrological Services.

Recalling:

1. The general policies of the Organization, as set down in the Third WMO Long-term Plan (1992–2001) adopted by Eleventh Congress, which include, inter alia, that Members should reaffirm their commitment to the free and unrestricted international exchange of basic meteorological data and products, as defined in WMO Programmes (Third WMO Long-term Plan, Part I, Chapter 4, paragraph 127)
2. The concern expressed by Eleventh Congress that commercial meteorological activities had the potential to undermine the free exchange of meteorological data and products between national Meteorological Services.

Considering:

1. The continuing fundamental importance, for the provision of meteorological services in all countries, of the exchange of meteorological data and products between WMO Members' national Meteorological or Hydrometeorological Services (NMSs), WMCs, and RSMCs of the WWW Programme
2. Other programmes of world importance such as GCOS, GOOS, WCRP, and IGOSS, which are sponsored and implemented in cooperation with other international organizations
3. The basic role of WMO Members' NMSs in furthering applications of meteorology to all human activities,
4. The call by the world leaders at UNCED (Brazil, 1992) for increasing global commitment to exchange scientific data and analysis and for promoting access to strengthened systematic observations
5. The provision in the UN/FCCC committing all Parties to the Convention to promote and cooperate in the full, open, and prompt exchange of information related to the climate system and climate change.

Recognizing:

1. The increasing requirement for the global exchange of all types of environmental data in addition to the established ongoing exchange of meteorological data and products under the auspices of the WWW

2. The basic responsibility of Members and their NMSs to provide universal services in support of safety, security and economic benefits for the peoples of their countries
3. The dependence of Members and their NMSs on the stable, cooperative international exchange of meteorological and related data and products for discharging their responsibilities
4. The continuing requirement for Governments to provide for the meteorological infrastructure of their countries,
5. The continuing need for, and benefits from, strengthening the capabilities of NMSs, in particular in developing countries, to improve the provision of services
6. The dependence of the research and education communities on access to meteorological and related data and products
7. The right of Governments to choose the manner by, and the extent to, which they make data and products available domestically or for international exchange.

Recognizing further:

1. The existence of a trend towards the commercialization of many meteorological and hydrological activities,
2. The requirement by some Members that their NMSs initiate or increase their commercial activities
3. The risk arising from commercialization to the established system of free and unrestricted exchange of data and products, which forms the basis for the WWW, and to global cooperation in meteorology
4. Both positive and negative impacts on the capacities, expertise and development of NMSs, and particularly those of developing countries, from commercial operations within their territories by the commercial sector including the commercial activities of other NMSs.

Reminds Members of their obligations under Article 2 of the WMO Convention to facilitate worldwide cooperation in the establishment of observing networks and to promote the exchange of meteorological and related information; and of the need to ensure stable ongoing commitment of resources to meet this obligation in the common interest of all nations;

Adopts the following policy on the international exchange of meteorological and related data and products:

As a fundamental principle of the World Meteorological Organization (WMO), and in consonance with the expanding requirements for its scientific and technical expertise, WMO commits itself to broadening and enhancing the free and unrestricted[1] international exchange of meteorological and related data and products;

Adopts the following practice on the international exchange of meteorological and related data and products:

1. Members shall provide on a free and unrestricted basis essential data and products which are necessary for the provision of services in support of the protection of life and property and the well-being of all nations, particularly those basic data and products, as, at a minimum, described in Annex 1 to this resolution, required to describe and forecast accurately weather and climate, and support WMO Programmes
2. Members should also provide the additional data and products which are required to sustain WMO Programmes at the global, regional, and national levels and, further, as agreed, to assist other Members in the provision of meteorological services in their countries. While increasing the volume of data and products available to all Members by providing these additional data and products, it is understood that WMO Members may be justified in placing conditions on their re-export for commercial purposes outside of the receiving country or group of countries forming a single economic group, for reasons such as national laws or costs of production
3. Members should provide to the research and education communities, for their non-commercial activities, free and unrestricted access to all data and products exchanged under the auspices of WMO with the understanding that their commercial activities are subject to the same conditions identified in Adopts (2) above.

Stresses that all meteorological and related data and products required to fulfil Members' obligations under WMO programmes will be encompassed by the combination of essential and additional data and products exchanged by Members;

Urges Members to:

1. Strengthen their commitment to the free and unrestricted exchange of meteorological and related data and products
2. Increase the volume of data and products exchanged to meet the needs of WMO Programmes;
3. Assist other Members, to the extent possible, and as agreed, by providing additional data and products in support of time-sensitive operations regarding severe weather warnings
4. Strengthen their commitments to the WMO and ICSU WDCs in their collection and supply of meteorological and related data and products on a free and unrestricted basis
5. Implement the practice on the international exchange of meteorological and related data and products, as described in Adopts (1) to (3) above
6. Make known to all Members, through the WMO Secretariat, those meteorological and related data and products which have conditions related to their re-export for commercial purposes outside of the receiving country or group of countries forming a single economic group;
7. Make their best efforts to ensure that the conditions which have been applied by the originator of additional data and products are made known to initial and subsequent recipients.

Further urges Members to comply with:

1. The Guidelines for Relations among National Meteorological or Hydrometeorological Services Regarding Commercial Activities as given in Annex 2 to this resolution
2. The Guidelines for Relations between National Meteorological or Hydrometeorological Services and the Commercial Sector as given in Annex 3 to this resolution.

Invites Members to provide explanation of the WMO policy, practice, and guidelines to the commercial sector and other appropriate agencies and organizations;

Requests the Executive Council to:

1. Invite the president of CBS, in collaboration with the other technical commissions as appropriate, to provide advice and assistance on the technical aspects of implementation of the practice
2. Invite the president of CHy to continue his work on the issue of commercialization and the international exchange of hydrological data and products
3. Keep the implementation of this resolution under review and report to Thirteenth Congress.

Requests the Secretary-General to:

1. Keep Members informed on the impacts of commercialization on WMO Programmes and to facilitate the exchange of relevant information on commercialization among NMSs
2. Report on a timely basis to all Members on those meteorological and related data and products on which Members have placed conditions related to their re-export for commercial purposes
3. Maintain effective coordination with IOC and other involved international organizations in respect of joint programmes during WMO's implementation of the practice.

Decides to review the implementation of this resolution at Thirteenth Congress.

Annex 1 to Resolution 40 (Cg-XII)
Data and products to be exchanged without charge and with no conditions on use

Purpose

The purpose of this listing of meteorological and related data and products is to identify a minimum set of data and products which are essential to support WMO Programmes and which Members shall exchange without charge and with no conditions on use. The meteorological and related data and products which are essential to support WMO Programmes include, in general, the data from the RBSNs and as many data as possible that will assist in defining the state of the atmosphere at least on a scale of the order of 200 km in the horizontal and six to 12 hours in time.

Contents

1. Six-hourly surface synoptic data from RBSNs, e.g. data in SYNOP, BUFR or other general purpose WMO Code;
2. All available in situ observations from the marine environment, e.g. data in SHIP, BUOY, BATHY, TESAC codes, etc.
3. All available aircraft reports, e.g. data in AMDAR, AIREP codes, etc.
4. All available data from upper air sounding networks, e.g. data in TEMP, PILOT, TEMP SHIP, PILOT SHIP codes etc.
5. All reports from the network of stations recommended by the regional associations as necessary to provide a good representation of climate, e.g. data in CLIMAT/CLIMAT TEMP and CLIMAT SHIP/CLIMAT TEMP SHIP codes, etc.
6. Products distributed by WMCs and RSMCs to meet their WMO obligations
7. Severe weather warnings and advisories for the protection of life and property targeted upon end-users;
8. Those data and products from operational meteorological satellites that are agreed between WMO and satellite operators. (These should include data and products necessary for operations regarding severe weather warnings and tropical cyclone warnings).

Annex 2 to Resolution 40 (Cg-xii)
Guidelines for relations among national meteorological or hydrometeorological services (NMHS) regarding commercial activities

Purpose

The purpose of these guidelines is to maintain and strengthen in the public interest the cooperative and supportive relations among NMSs in the face of differing national approaches to the growth of commercial meteorological activities.

Guidelines

In order to ensure the maintenance of the international exchange of data and products among WMO Members, and to develop the applications of meteorology, while adapting to the new challenge from the growth of commercial meteorological activities:

1. NMSs should provide the first point of receipt within a country for WWW data and products, in order to

have complete and timely access to all the information necessary for the production of weather forecasts and warnings and other meteorological/climatological services necessary for the protection of life and property and other public interest responsibilities entrusted to the NMSs and without prejudice to the national laws of their territory of location

2. NMSs should make their best efforts to ensure that the conditions which have been applied by the originator of additional data and products[3] are made known to initial and subsequent recipients
3. In the case where conditions accompanying the exchange of additional data and products are not honoured, the originating NMS may take appropriate actions including denial of access of these additional data and products to the receiving Member
4. NMSs may export NWP regional model products employing additional data and products for commercial purposes outside the country of the Member running the model, unless objected to by an affected Member. Every effort should be made to coordinate the provision of such services prior to implementation to avoid possible harm to other Members
5. NMSs may distribute and export products from global NWP models without regard to conditions which were attached to the original data used in the models
6. Services or products whose construction would suffer significant degradation by removal of the additional data or products and from which the additional data and/or products can be retrieved easily, or their use can be identified unambiguously, should carry the same conditions on their re-export for commercial purposes as those additional data or products
7. An NMS receiving a request from a local client for service that it cannot fulfil may seek assistance from another NMS with the capacity to provide it. Where appropriate to enhance the free and unrestricted exchange of data and products among WMO Members, the service should as far as possible be made available through the offices of the NMS of the country within which the client is located
8. Similarly, unless other arrangements have been agreed to, an NMS receiving a request to provide service in another country should refer the request back to the NMS in that country, i.e. to the local NMS. In the event that the local NMS is unable to provide the service for lack of facilities or other legitimate reasons, the external NMS may seek to establish a collaborative arrangement with the local NMS to provide the service
9. Where the service originated by one NMS is likely to affect other Members (e.g. in the provision of regional broadcasts of meteorological information or the wide distribution of seasonal or climate forecasts), the NMS originating the service should seek, well in advance, and take into account the response of the NMSs of the affected Members, to the extent possible
10. NMSs should, to the extent possible, refrain from using basic WWW data and products received from other countries in ways which jeopardize the performance of the public interest responsibilities of the originating NMSs within their own countries. If an NMS finds that, in the undertaking of its public interest responsibilities it is affected adversely by a public or private organization in another country, it may warn the NMS in the country from which the organization is deriving the data and products. The latter NMS should consider measures to mitigate these adverse effects and take those actions appropriate under its national laws
11. NMSs with experience in commercial activities should make their expertise available, on request, to other NMSs, especially NMSs of developing countries, through the WMO Secretariat and bilaterally, and provide relevant documentation, seminars and training programmes to developing countries, on request, on the same financial basis as other WMO education and training courses are provided.

In implementing these guidelines, NMSs should take into account and, as far as possible, respect the different legal, administrative, and funding frameworks which govern the practices of NMSs in other countries or group of countries forming a single economic group. NMSs should, in particular, note that other NMSs will be bound by their own national laws and regulations regarding any trade restrictive practices. Furthermore, where a group of countries form a single economic group, the internal laws and regulations appropriate to that group shall, for all internal group activities, take precedence over any conflicting guidelines.

Annex 3 to Resolution 40 (Cg-XII)
Guidelines for relations between national meteorological or hydrometeorological services (NMHS) and the commercial sector

Purpose

The purpose of these guidelines is to further improve the relationship between NMSs and the commercial sector. The development of the exchange of meteorological and related information depends greatly upon sound, fair, transparent, and stable relations between these two sectors.

Guidelines

These guidelines apply to the commercial sector engaged in meteorological activities, which includes government organizations engaged in commercial meteorological activities.

In order to enhance the relationship between the two sectors:

1. In the common interest, the commercial sector is urged to respect the international data exchange principles of the WWW and other WMO Programmes
2. The commercial sector is urged to recognize and acknowledge the essential contribution of NMSs and of WMO to the activities of the commercial sector. NMSs and the commercial sector are urged to recognize the interdependence and mutual benefit possible from cooperative interaction
3. In the case where the NMS of a country, particularly of a developing country, were to consider itself affected by the commercial sector's commercial use of data originated in its own country, all parties involved shall undertake negotiations to achieve appropriate and satisfactory agreements
4. Unless authorized to do so by the relevant Member, commercial sector providers of meteorological services should not publicly issue warnings and forecasts relevant to the safety of life and property in the country or maritime area where they operate. Warnings and forecasts relevant to the safety of life and property publicly issued by the commercial sector should be consistent with those originated by NMSs or by other official originators in the course of the performance of their public service responsibilities
5. In providing services, the commercial sector should be encouraged to employ meteorological terminology consistent with established national and international practice
6. Commercial sector providers of meteorological services should respect the sovereignty and rules and regulations of the countries in which they deliver services;
7. NMSs are encouraged to discuss with their countries' meteorological community and professional societies the issues associated with the international activities of the commercial sector
8. NMSs are encouraged to collaborate with their countries' commercial sector and their professional societies to maximize the use of meteorological information within their country.

Annex 4 to Resolution 40 (Cg-xii) Definitions of terms in the practice and guidelines

Practice

Specifications for the classification of, and the conditions attached to, the use of data and products exchanged among WMO Members.

Re-export

Redistribute, physically or electronically, outside the receiving country or group of countries forming a single economic group, directly or through a third party.

For commercial purposes

For recompense beyond the incremental cost of reproduction and delivery.

Commercial sector

Governmental or non-governmental organizations or individuals operating for commercial purposes.

Meteorological and related data and products

Geophysical (meteorological, oceanographic, etc.) observational data and products developed from these data acquired and/or produced by Members to support WMO Programme requirements.

Notes:

1. Meteorological and related data and products are considered to include climatological data and products
2. Hydrological data and products, at this stage, are not included in the application of the practice
3. Aeronautical information generated specifically to serve the needs of aviation and controlled under the Convention on International Civil Aviation (Chicago, 1944) is not included in the application of the practice.

Free and unrestricted

Non-discriminatory and without charge (Resolution 23 (EC-XLII) — Guidelines on international aspects of provision of basic and special meteorological services. "Without charge", in the context of this resolution means at no more than the cost of reproduction and delivery, without charge for the data and products themselves.

Research and education communities

Researchers, teachers and students in academic and research institutions, in other research institutions within governmental and non-governmental organizations, and these institutions themselves, as provided for in national laws and regulations.

RESOLUTION 25 (CG-XIII, 1999)

Exchange of hydrological data and products

The Congress,

Noting:

1. Resolution 40 (Cg-XII) — WMO policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities
2. The inclusion of dedicated observations of the climate system, including hydrological phenomena, as one of the four main thrusts of The Climate Agenda, which was endorsed by Twelfth Congress
3. That Technical Regulation [D.1.1] 8.3.1(k), states that, in general, the routine functions of national Hydrological Services (NHSs) should include, inter alia, "making the data accessible to users, when, where and in the form they require" and that the Technical Regulations also contain a consolidated list of data and product requirements to support all WMO Programmes
4. That the nineteenth Special Session of the United Nations General Assembly agreed, in its overall review and appraisal of the implementation of Agenda 21, that there is an urgent need to "... foster regional and international cooperation for information dissemination and exchange through cooperative approaches among United Nations institutions, …" (A/RES/S-19/2, paragraph 34(f))
5. That the fifty-first session of the United Nations General Assembly adopted, by resolution 51/229, the Convention on the Law of the Non-navigational Uses of International Watercourses, Article 9 of which provides for "regular exchange of data and information"
6. That the Intergovernmental Council of the International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization (UNESCO) adopted at its twelfth session Resolution XII-4 which dealt with the exchange of hydrological data and information needed for research at the regional and international levels.

Considering:

1. The significance attached by the International Conference on Water and the Environment (ICWE) (Dublin, 1992) to extending the knowledge base on water and enhancing the capacity of water sector specialists to implement all aspects of integrated water resources management
2. The call of world leaders at the United Nations Conference on Environment and Development (UNCED) (Rio de Janeiro, 1992) for a significant strengthening of, and capacity building in, water resources assessment, for increasing global commitment to exchange scientific data and analyses and for promoting access to strengthened systematic observations
3. That the United Nations Commission on Sustainable Development (CSD) in its Decision 6/1 "Strategic Approaches to Freshwater Management" has strongly encouraged States to promote the exchange and dissemination of water-related data and information, and has recognized "the need for periodic assessments … for a global picture of the state of freshwater resources and potential problems"
4. The call by the nineteenth Special Session of the United Nations General Assembly "for the highest priority to be given to the serious freshwater problems facing many regions, especially in the developing world" and the "urgent need … to strengthen the capability of Governments and international institutions to collect and manage information … and environmental data, in order to facilitate the integrated assessment and management of water resources"
5. The requirements for full, open and prompt exchange of hydrological data and products in support of various international conventions, such as the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the Convention to Combat Desertification
6. The requirement for the global exchange of hydrological information in support of scientific investigations of world importance such as those on global change and the global hydrological cycle, and as a contribution to relevant programmes and projects of WMO, other United Nations agencies, the International Council for Science (ICSU) and other organizations of equivalent status
7. The opportunities for more efficient management of water resources and the need for cooperation in mitigating water-related hazards in transboundary river basins and their water bodies which depend on the international exchange of hydrological data and information

8. The increasing recognition through scientific and technical endeavours, such as the Global Energy and Water Cycle Experiment (GEWEX), of the importance of hydrological data and products in improving the understanding of meteorological processes and subsequently the accuracy of meteorological products.

Recognizing:

1. The responsibility of Members and their NHSs to provide for the security and well-being of the people of their countries, through mitigation of water-related hazards and sustainable management of water resources
2. The potential benefits of enhanced exchange of hydrological data and information within shared river basins and aquifers, based on agreements between the Members concerned
3. The continuing need for strengthening the capabilities of NHSs, particularly in developing countries,
4. The right of Governments to choose the manner by which, and the extent to which, they make hydrological data and products available domestically and internationally
5. The right of Governments also to choose the extent to which they make available internationally data which are vital to national defense and security. Nevertheless, Members shall cooperate in good faith with other Members with a view to providing as much data as possible under the circumstances
6. The requirement by some Members that their NHSs earn revenue from users, and/or adopt commercial practices in managing their businesses
7. The long-established provision of some hydrological products and services on a commercial basis and in a competitive environment, and the impacts, both positive and negative, associated with such arrangements.

Adopts a stand of committing to broadening and enhancing, whenever possible, the free and unrestricted[1] international exchange[2] of hydrological data and products, in consonance with the requirements for WMO's scientific and technical programmes;

Further adopts the following practice on the international exchange of hydrological information:

1. Members shall provide on a free and unrestricted basis those hydrological data and products which are necessary for the provision of services in support of the protection of life and property and for the well-being of all peoples
2. Members should also provide additional hydrological data and products, where available, which are required to sustain programmes and projects of WMO, other United Nations agencies, ICSU and other organizations of equivalent status, related to operational hydrology and water resources research at the global, regional and national levels and, furthermore, to assist other Members in the provision of hydrological services in their countries
3. Members should provide to the research and education communities, for their non-commercial activities, free and unrestricted access to all hydrological data and products exchanged under the auspices of WMO
4. Respecting (2) and (3) above, Members may place conditions on the re-export3, for commercial purposes, of these hydrological data and products, outside the receiving country or group of countries forming a single economic group
5. Members should make known to all Members, through the WMO Secretariat, those hydrological data and products which have such conditions as in (4) above;
6. Members should make their best efforts to ensure that the conditions placed by the originator on the additional hydrological data and products are made known to initial and subsequent recipients
7. Members shall ensure that the exchange of hydrological data and products under this resolution is consistent with the application of Resolution 40 (Cg-XII) — WMO policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities.

Urges Members, in respect of the operational and scientific use of hydrological data and products, to:

1. Make their best efforts to implement the practice on the international exchange of hydrological data and products, as described in Further adopts (1) to (7)
2. Assist other Members, to the extent possible, and as agreed upon, in developing their capacity to implement the practice described in Further adopts (1) to (7).

Requests the Executive Council to:

1. Invite the Commission for Hydrology to provide advice and assistance on technical aspects of the implementation of the practice on the international exchange of hydrological data and products
2. Keep the implementation of this resolution under review and report to Fourteenth Congress.

Decides to review the implementation of this resolution at Fourteenth Congress.

EC STATEMENT ON THE ROLE AND OPERATION OF NMHS FOR DECISION MAKERS (EC-LVII, 2005)

Executive council statement on the role and operation of national meteorological and hydrolological services for decision-makers

Key social and economic drivers

1. Governments are striving to improve the well-being of their citizens. Population growth, reducing poverty, water security, food security, increasing prosperity, and improving public health, safety and security are key drivers. To deal with these issues, governments have to develop and implement effective policy, and promote fundamental tenets of societal and environmental governance. However, as regards the environment, it is common knowledge that we are challenged by our natural environment, made worse by changes in the climate, which threatens the sustainable development of human societies through extreme weather events causing disasters, reduced food security, reduced availability of uncontaminated freshwater, and the rise and spread of diseases. This is further compounded by growing urbanization and the expansion of human habitation into previously unoccupied places, such as arid zones, mountain slopes, flood plains and the sea's edge. These are exposing populations to air and waterborne diseases, heat stress, drought, landslides, floods, storm surges and tsunamis
2. The safety of life and protection of property is important for all countries but especially for the sustainability of emerging economies. These countries are highly vulnerable to natural disasters, which can wipe out 10 to 15 per cent of a developing nation's gross domestic product. Only with a clear understanding of the potential threats, advanced warning, and adequate disaster reduction and mitigation efforts can we properly protect our societies
3. These are issues that must be dealt with if the global community is to attain the targets set through the 2000 Millennium Declaration, which are also highlighted by the 2002 Johannesburg Plan of Implementation of the World Summit on Sustainable Development.

The role of National Meteorological and Hydrological Services

4. As has been the case since the beginning of the modern era of societal and environmental management, knowl edge of weather and climate is key to all aspects of human endeavours. It is within this framework that National Meteorological and Hydrological Services (NMHSs) in various countries have been well positioned to identify and deal with a wide range of weather-, climate- and water-related issues that affect human life and socio-economic development. For example, with regard to natural hazards, NMHSs have been tasked to sensitize the population to their impacts, and to provide warnings of individual events, to save lives, to sustain productivity, and to reduce damage to property
5. NMHSs constitute the single authoritative voice on weather warnings in their respective countries, and in many they are also responsible for climate, air quality, seismic and tsunami warnings. To reduce and mitigate disasters requires well prepared NMHSs as well as governments and populations to take appropriate action in response to warnings. NMHSs, within the framework of the World Meteorological Organization (WMO), are working to help governments improve decision-making to enable populations to adapt to climate change, mitigate natural hazards and sustain development. By helping governments and the people to avert potential disasters, NMHSs are a fundamental component of the risk management infrastructure of countries in their nation-building endeavours and, indeed, a contributor to sustainable development, particularly the poverty alleviation effort. NMHSs are working together to implement the WMO Multi-hazard Prevention Strategy, which aims to reduce by 50 per cent over the decade 2010-2019 the number of fatalities caused by meteorological-, hydrological- and

climate-related natural disasters compared with the 10-year average fatalities of 1995-2004

6. NMHSs are continuously monitoring the environment through observations of the Earth system and predicting changes in this system. They provide governments with timely and precise warnings of most potential natural hazards and contribute essential environmental information and services for urban planning, sustainable energy development, access to freshwater, and food production
7. Cooperation between various organizations is essential to provide governments with these services. Partnerships between NMHSs and academia, government departments, international and non-governmental organizations, and where appropriate and possible, the private sector, help society make better decisions based on more complete and accurate weather, water and climate information. These partnerships provide better data coverage and information processing, higher resolution models, and more precise and useful specialized products for societal benefits, including opportunities to provide better support to governments and other decision makers regarding safety, economy and security. NMHSs are encouraging these partnerships by adopting open and unrestricted data policies which make their information easy to access in real time, in useful forms, and at low cost.

Future requirements

8. In the year 2000, through the internationally-agreed development goals, including those contained within the Millennium Declaration, the international community set forth specific targets to be reached by 2015. To ensure that these goals are met, it is essential that governments take advantage of the myriad advances in science and technology provided by NMHSs and their partners, that include the provision of multi-hazard warnings and related services, 24 hours a day, seven days a week for 365 days a year, which when properly applied can provide societies with the underpinning information to reduce and mitigate natural disasters. International cooperation is essential, both between countries and within the larger United Nations framework
9. Access to good communication ensures that information is available wherever it is needed. Governments must recognize the importance of continuous monitoring of the environment and the ability of their NMHSs to provide timely and accurate information to support critical decisions. Governments should sustain the NMHSs and their modernization and development
10. It is essential that societies be prepared to act appropriately in response to warnings. Education and training is paramount for improvement of preparedness. Early warning systems for natural hazards work only if governments and their public know how to respond. Information must be easy to understand and use
11. Climate change requires societies to understand and assess impacts and to develop the necessary adaptation strategies. By providing fundamental knowledge of the climate system and predictions based on climate models, NMHSs can help societies transform
12. To be completely effective, NMHSs and their international network, coordinated through the WMO, must be recognized as critical partners in societies' goal to reduce poverty and increase the prosperity of the world's citizens.

Geneva declaration of the Thirteenth World Meteorological Congress

WE, THE DELEGATES from 170 Member States and Territories of the World Meteorological Organization (WMO), meeting in Geneva from 4 to 26 May 1999 at the Thirteenth World Meteorological Congress, declare as follows:

We *note* that the United Nations General Assembly, the Economic and Social Council and the regional economic and social commissions have appealed to WMO to contribute, within its field of competence, to the action taken at the international, regional and national levels to promote and support sustainable development, especially activities pertinent to weather- and climate-related natural disasters, climate change and the protection of the environment.

We *further note* the contributions already made by, and through, WMO in response to the above appeal, particularly through the global ensemble of national Meteorological and Hydrometeorological Services which is crucial to international strategies for the protection of the global environment such as in addressing climate change and stratospheric ozone depletion issues, among others.

We *recognize* the importance of a unique and integrated international system for the observation, collection, processing and dissemination of meteorological and related data and products, implemented within the framework of WMO's World Weather Watch.

We are *aware* of the need to ensure the appropriate implementation of the letter and spirit of Resolution 40 adopted by the Twelfth World Meteorological Congress on the "WMO policy and practice for the international exchange of meteorological and related data and products, including guidelines on relationships in commercial meteorological activities".

We *appeal* to all Governments to ensure that the national practices in force in their countries, especially through their national Meteorological and Hydrometeorological Services, conform with the above referred policy, practice and guidelines for the international exchange of meteorological and related data and products.

We *reaffirm* the vital importance of the mission of the national Meteorological and Hydrometeorological Services in observing and understanding weather and climate and in providing meteorological and related services in support of national needs. This mission may be expressed as a contribution to national needs in the following areas:

(a) Protection of life and property
(b) Safeguarding the environment
(c) Contributing to sustainable development
(d) Ensuring continuity of the observations of meteorological and related data including climatological data
(e) Promotion of endogenous capacity building
(f) Meeting international commitments
(g) Contributing to international cooperation.

We *are cognizant* that, weather and climate systems do not recognize political borders and are continuously interacting. Hence, no one country can be fully self-reliant in meeting all of its requirements for meteorological services and countries need to work together in a spirit of mutual assistance and cooperation.

We *express* deep concern about the potential impacts on the provision of meteorological services worldwide of any development which endangers the unique and integrated international system for obtaining and exchanging meteorological and related data and products; a system which has benefited the global community for over 100 years. These developments can adversely affect the effective and efficient provision of appropriate meteorological data, information, products and services as well as the role and operation of national Meteorological and Hydrometeorological Services, resulting in unfavourable impacts on national economies, the environment, the well being of peoples and the whole world community.

We *recognize* that it is for the various stakeholders in each country, in full awareness of their country's national goals, requirements, resources and aspirations to evaluate and decide on a country-specific strategy for future provision of meteorological and related services and to find the greatest possible harmony between the principle of their national sovereignty and their international obligations under the WMO Convention and other related environmental treaties and agreements.

We *urge* that whatever form or model the national Meteorological and Hydrometeorological Services take, government financial support be provided to operate and maintain the required relevant basic infrastructure, monitoring and services in the national and global public interest, and that such support be strengthened where needed.

We *call* on all Governments to give due consideration to the statements expressed in this Declaration. We believe that this will be in the interest of sustainable development, in support of national economies and social progress; and that this contributes significantly to the reduction of loss of life and property caused by natural disasters and other catastrophic events, as well as to safeguard the environment and the global climate for present and future generations of humankind.

WMO statement on the status of weather modification

Introduction

For thousands of years people have sought to modify weather and climate so as to augment water resources and mitigate severe weather. The modern technology of weather modification was launched by the discovery in the late 1940s that supercooled cloud droplets could be converted to ice crystals by insertion of a cooling agent such as dry ice or an artificial ice nucleus such as silver iodide. Over 50 years of subsequent research have greatly enhanced our knowledge about the microphysics, dynamics and precipitation processes of natural clouds (rain, hail, snow) and the impacts of human interventions on those processes.

Currently, there are dozens of nations operating more than 100 weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. The purpose of this document is to present a review of the status of weather modification.

The energy involved in weather systems is so large that it is impossible to create artificially rainstorms or to alter wind patterns to bring water vapour into a region. The most realistic approach to modifying weather is to take advantage of microphysical sensitivities wherein a relatively small human-induced disturbance in the system can substantially alter the natural evolution of atmospheric processes.

The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited.

The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially. As knowledge of cloud physics and statistics and their application to weather modification has increased, new assessment criteria have evolved for evaluating cloud-seeding experiments. The development of new equipment — such as aircraft platforms with microphysical and air-motion measuring systems, radar (including Doppler and polarization capability), satellites, microwave radiometers, wind profilers, automated raingauge networks, mesoscale network stations — has introduced a new dimension. Equally important are the advances in computer systems that permit large quantities of data to be processed. New datasets, used in conjunction with increasingly sophisticated numerical cloud models, help in testing various weather modification hypotheses.

Chemical and chaff tracer studies help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent. With some of these new facilities, a better climatology of clouds and precipitation can be prepared to test seeding hypotheses prior to the commencement of weather modification projects.

If one were able to predict precisely the precipitation from a cloud system, it would be a simple matter to detect the effect of artificial cloud seeding on that system.

The expected effects of seeding, however, are almost always within the range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.

Comparison of precipitation observed during seeded periods with that during historical periods presents problems because of climatic and other changes from one period to another, and therefore is not a reliable technique. This situation has been made even more difficult with the mounting evidence that climate change may lead to changes in global precipitation amounts as well as to spatial redistribution of precipitation.

In currently accepted evaluation practice, randomisation methods (target/control, crossover or single area) are considered most reliable for detecting cloud-seeding effects. Such randomized tests require a number of cases readily calculated on the basis of the natural variability of the precipitation and the magnitude of the expected effect. In the case of very low signal-to-noise ratios, experiment durations in the range of five to over 10 years may be required. Whenever a statistical evaluation is required to establish that a significant change resulted from a given seeding activity, it must be accompanied by a physical evaluation to:

(a) Confirm that the statistically-observed change is likely due to the seeding

(b) Determine the capabilities of the seeding method to produce the desired effects under various conditions.

The effect of natural precipitation variability on the required length of an experiment can be reduced through the employment of physical predictors, which are effective in direct proportion to our understanding of the phenomenon. The search for physical predictors, therefore, holds a high priority in weather modification research. Physical predictors may consist of meteorological parameters (such as stability, wind directions, pressure gradients) or cloud quantities (such as liquid water content, updraught speeds, concentrations of large drops, ice-crystal concentration or radar reflectivity).

Objective measurement techniques of precipitation quantities are to be preferred for testing weather modification methods. These include both direct ground measurements (e.g. raingauges and hail pads) and remote sensing techniques (e.g. radar, satellite). Secondary sources, such as insurance data (as have in the past been employed to show changes in hail intensity) are, at least by themselves, not held to be satisfactory in most situations.

Operational programmes should be conducted with recognition of the risks inherent in a technology which is not totally developed. For example, it should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. However, properly designed and conducted operational projects seek to detect and minimize such adverse effects. Therefore, weather modification managers are encouraged to add scientifically-accepted evaluation methodologies to be undertaken by experts independent of the operators.

Brief summaries of the current status of weather modification are given in the following sections. These summaries were restricted to weather modification activities that appear to be based on acceptable physical principles and which have been tested in the field.

Fog dispersal

Different techniques are being used to disperse warm (i.e. at temperatures greater than 0°C) and cold fogs. The relative occurrence of warm and cold fogs is geographically and seasonally dependent.

The thermal technique, which employs intense heat sources (such as jet engines) to warm the air directly and evaporate the fog, has been shown to be effective for short periods for dispersal of some types of warm fogs. These systems are expensive to install and to use.

Another technique that has been used is to promote entrainment of dry air into the fog by the use of hovering helicopters or ground-based engines. These techniques are also expensive for routine use.

To clear warm fogs, seeding with hygroscopic materials has also been attempted. An increase in visibility is sometimes observed in such experiments, but the manner and location of the seeding and the size distribution of seeding material are critical and difficult to specify. In practice, the technique is seldom as effective as models suggest. Only hygroscopic agents should be used that pose no environmental and health problems.

Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. Because the effects of this type of seeding are easily measured and the results are highly predictable, randomized statistical verification generally has been considered unnecessary.

Precipitation (rain and snow) enhancement

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subject of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically-viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e. the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that, under certain conditions, precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of surface precipitation records from some long-term projects indicate that seasonal increases have been realized.

Physical studies using new observational tools and supported by numerical modelling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have, to date, been of limited scope. The cause and effect relationships have not been fully documented, and thus the economic impact of the increases cannot be assessed.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities and the times and situations in which it is not advisable to seed, thus optimizing the technique and quantifying the result.

Also, it should be recognized that the successful conduct of an experiment or operation is a difficult task that requires qualified scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system.

Stratiform clouds

The seeding of cold stratiform clouds began the modern era of weather modification. Shallow stratiform clouds can be under certain conditions made to precipitate, often resulting in clearing skies in the region of seeding. Deep stratiform cloud systems (but still with cloud tops warmer than –20°C) associated with cyclones and fronts produce significant amounts of precipitation. A number of field experiments and numerical simulations have shown the presence of supercooled water in some regions of these clouds and there is some evidence that precipitation can be increased.

Cumuliform clouds

In many regions of the world, cumuliform clouds are the main precipitation producers. These clouds (from small fair weather cumulus to giant thunderclouds) are characterized by strong vertical velocities with high condensation rates. They can hold the largest condensed water contents of all cloud types and can yield the highest precipitation rates. Seeding experiments continue to suggest that precipitation from single cell and multicell convective clouds have produced variable results. The response variability is not fully understood.

Precipitation enhancement techniques by glaciogenic seeding are utilized to affect ice phase processes while hygroscopic seeding techniques are used to affect warm rain processes. Methods to assess these techniques vary from direct measurements with surface precipitation gauges to indirect radar-derived precipitation estimates. Both methods have inherent advantages and disadvantages.

During the last 10 years there has been a thorough scrutiny of past experiments using glaciogenic seeding. The responses to seeding seem to vary depending on changes in natural cloud characteristics and in some experiments they appear to be inconsistent with the original seeding hypothesis.

Experiments involving heavy glaciogenic seeding of warm-based convective clouds (bases about +10°C or warmer) have produced mixed results. They were intended to stimulate updraughts through added latent heat release which, in turn, was postulated to lead to an increase in precipitation. Some experiments have suggested a positive effect on individual convective cells but conclusive evidence that such seeding can increase rainfall from multicell convective storms has yet to be established. Many steps in the postulated physical chain of events have not been sufficiently documented with observations or simulated in numerical modelling experiments.

In recent years, the seeding of warm and cold convective clouds with hygroscopic chemicals to augment rainfall by enhancing warm rain processes (condensation/collision-coalescence/break-up mechanisms) has received renewed attention through model simulations and field experiments. Two methods of enhancing the warm rain process have been investigated: first, seeding with small particles (artificial CCN with mean sizes about 0.5 to 1.0 micrometres in diameter) is used to accelerate precipitation initiation by stimulating the condensation-coalescence process by favourably modifying the initial droplet spectrum at cloud base; and second, seeding with larger hygroscopic particles (artificial precipitation embryos about 30 micrometres in diameter) to accelerate precipitation development by stimulating the collision-coalescence processes. A recent experiment utilizing the latter technique indicated statistical evidence of radar estimated precipitation increases. However, the increases were not as contemplated in the conceptual model but seem to occur at later times (one to four hours after seeding), the cause of this effect is not known.

Recent randomized seeding experiments with flares that produce small hygroscopic particles in the updraught regions of continental, mixed-phase convective clouds have provided statistical evidence of increases in radar-estimated rainfall. The experiments were conducted in different parts of the world and the important aspect of the results was the replication of the statistical results in a different geographical region. In addition, physical measurements were obtained suggesting that the seeding produced a broader droplet spectrum near cloud base that enhances the formation of large drops early in the lifetime of the cloud. These measurements were supported by numerical modelling studies.

Although the results are encouraging and intriguing, the reasons for the duration of the observed effects obtained with the hygroscopic particle seeding are not understood and some fundamental questions remain. Measurements of the key steps in the chain of physical events associated with hygroscopic particle seeding are needed to confirm the seeding conceptual models and the range of effectiveness of these techniques in increasing precipitation from warm and mixed-phase convective clouds.

Despite the statistical evidence of radar estimated precipitation changes in individual cloud systems in both glaciogenic and hygroscopic techniques, there is no evidence that such seeding can increase rainfall over significant areas economically. There is no evidence of any extra-area effects.

Hail suppression

Hail causes substantial economic loss to crops and property. Many hypotheses have been proposed to suppress hail and operational seeding activities have been undertaken in many countries. Physical hypotheses include the concepts of beneficial competition (creating many additional hail embryos that effectively compete for the supercooled water), trajectory lowering (intended to reduce the size of hailstones) and premature rainout. Following these concepts, seeding methods concentrate on the peripheral regions of large storm systems, rather than on the main updraught.

Our understanding of storms is not yet sufficient to allow confident prediction of the effects of seeding on hail. The possibilities of increasing or decreasing hail and rain in some circumstances have been discussed in the scientific literature. Supercell storms have been recognized as a particular problem. Numerical cloud model simulations have provided insights into the complexity of the hail process, but the simulations are not yet accurate enough to provide final answers. Scientists in operational and research programmes are working to delineate favourable times, locations and seeding amounts for effective modification treatments.

A few randomized trials have been conducted for hail suppression using such measures as hail mass, kinetic energy, hailstone number and area of hailfall. However, most attempts at evaluation have involved non-randomized operational programmes. In the latter, historical trends in crop hail damage have often been used, sometimes with target and upwind control areas, but such methods can be unreliable. Large reductions have been claimed by many groups. The weight of scientific evidence to date is inconclusive, neither affirming nor denying the efficacy of hail suppression activities. This situation is motivation for operational programmes to strengthen the physical and evaluation components of their efforts.

In recent years, anti-hail activities using cannons to produce loud noises have re-emerged. There is neither a scientific basis nor a credible hypothesis to support such activities. Significant advances in technology during the last decade have opened new avenues to document and better understand the evolution of severe thunderstorms and hail. New experiments on storm organization and the evolution of precipitation including hail are needed.

Other severe weather moderation

Tropical cyclones contribute significantly to the annual rainfall of many areas, but they are also responsible for considerable damage to property and for a large loss of life. Therefore, the aims of any modification procedure should be to reduce the wind, storm surge and rain damage, but not necessarily the total rainfall. Hurricane modification experiments were conducted in the 1960s and early 1970s. However, there is no generally accepted conceptual model suggesting that hurricanes can be modified.

While modification of tornadoes or of damaging winds is desirable for safety and economical reasons, there is presently no accepted physical hypothesis to accomplish such a goal.

There has been some interest in the suppression of lightning. Motivation includes reducing occurrences of forest fires ignited by lightning and diminishing this hazard during the launching of space vehicles. The concept usually proposed involves reducing the electric fields within thunderstorms so that they do not become strong enough for lightning discharges to occur. To do this, chaff (metallized plastic fibres) or silver iodide have been introduced into thunderstorms. The chaff is postulated to provide points for corona discharge which reduces the electric field to values below those required for lightning, whereas augmenting the ice-crystal concentration is postulated to change the rate of charge build up and the charge distribution within the clouds. Field experiments have used these concepts and limited numerical modelling results have supported them. The results have no statistical significance.

Inadvertent weather modification

There is ample evidence that biomass burning, and agricultural and industrial activities modify local and sometimes regional weather conditions. Land-use changes (e.g. urbanization and deforestation) also modify local and regional weather. Air quality, visibility, surface and low-level wind, humidity and temperature, and cloud and precipitation processes are all affected by large urban areas. As environmental monitoring and atmospheric modelling capabilities are improved, it is increasingly evident that human activities have significant impacts on meteorological parameters and climatological mechanisms that influence our health, productivity and societal infrastructure. Inadvertent effects need to be considered in the design and analyses of weather modification experiments and operations (e.g. changes in background aerosol distributions affect the cloud structure and may affect precipitation processes).

Economic, social and environmental aspects of weather modification

Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example, increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, hail, lightning, thunderstorms, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups. Economic, social, ecological and legal aspects should be taken into account. Thus, it is important to consider all the important complexity and recognize the variety of possible impacts, during the design stage of an operation.

Legal aspects may be particularly important when weather modification activities are performed in the proximity of borders between different countries. However, any legal system aimed at promoting or regulating weather modification must recognize that scientific knowledge is still incomplete.

The implications of any projected long-term weather modification operation on ecosystems need to be assessed. Such studies could reveal changes that need to be taken into account. During the operational period, monitoring of possible environmental effects should be undertaken as a check against anticipated impacts.

Summary statement and recommendations

To answer the need for more water and less hail in many regions of the world, some progress has been made during the past 10 years in the science and technology of weather modification. Large numbers of programmes in fog dispersion, rain, snow enhancement and hail suppression are in operation. Several research experimental programmes are supported in some countries and include randomized statistical evaluations. Improved observational facilities, computer capabilities, numerical models and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible. New technologies and methods are starting to be applied and will help to lead to further understanding and development in this field.

In the light of this review of the status of weather modification, the following recommendations are made to interested Members of WMO:

(a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations

(b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component

(c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist, advantage should be taken of facilities of other Members

(d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project

(e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects.

While some Members may not have access or resources to implement these technologies, collaboration between Member States (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

Guidelines for advice and assistance related to the planning of weather modification activities

1. These guidelines are addressed to Members requesting advice or assistance on weather modification activities. They include recommendations that are based on present knowledge gained through the results of worldwide theoretical studies as well as laboratory and field experiments. A synthesis of the main basic concepts and main results obtained in the weather modification programmes is given in the WMO Statement on the Status of Weather Modification. This Statement was revised during the twentieth session of the Executive Council Panel of Experts/CAS Working Group on Physics and Chemistry of Clouds and Weather Modification Research and was approved by the fifty-third session of the Executive Council in June 2001

2. Members wishing to develop activities in the field of weather modification should be aware that research and operational applications are still under development

   It should not be ignored that under certain conditions, seeding may be ineffective or may even enhance an undesirable effect (increase of hail, reduction in rain). However, properly designed and conducted projects seek to detect and minimize such adverse effects. It is recognized that scientific evaluation may be a difficult task, but this is the only way presently known to avoid negative results, quantify positive economic effects and allow improvements in the understanding and methodology that is used. The revised WMO Statement on the Status of Weather Modification referred to in paragraph 1 distinguishes the various types of weather modification and the degree of confidence necessary to obtain the desired effect from cloud seeding. The confidence level is very high for operational dissipation of supercooled fog and moderate for increasing snowfall from orographic clouds. The confidence level is not high for suppressing hail.

3. WMO recommends that operational cloud seeding projects for precipitation modification be designed to allow evaluation of the results of seeding through physical measurements and statistical controls associated with some randomization of the seeding events. The physical measurements should include characterization of the seeding material. Care should be taken to engage qualified operators. The objective evaluation should be performed by a group independent of the operational one. Such programmes should be planned on a longduration basis because precipitation variability is generally much greater than the increases or decreases claimed for artificial weather modification. The use of

appropriate numerical models may help in reducing the time required to evaluate the project

4. WMO recommends that a detailed examination of the suitability of the site for cloud seeding should be conducted similar to that done in the Precipitation Enhancement Project, for which WMO reports are available. To increase the chances of success in a specific situation, it should be verified through preliminary studies that:

(a) The climatology of clouds and precipitation at the site indicates the possibility of favourable conditions for weather modification
(b) Conditions are suitable for the available modification techniques
(c) Modelling studies support the proposed weather modification hypothesis
(d) For the frequency with which suitable conditions occur, the changes resulting from the modification technique can be detected at an acceptable level of statistical significance
(e) An operational activity can be carried out at a cost acceptably lower than the socio-economic benefit that is likely to result.

All prospective studies require expert judgement and the results are expected to depend on the site chosen and on the season.

5. There are no quantitative criteria for the acceptance of the results of a weather modification experiment.
   Acceptance will depend on the degree of the scientific objectivity and the consistency with which the experiment was carried out and the degree to which this is demonstrated. Also important are the physical plausibility of the experiment, the degree to which bias is excluded from the conduct and analysis of the experiment, and the degree of statistical significance achieved. There have been few weather modification experiments that have met the requirements of the scientific community with respect to these general criteria. However, there are exciting possibilities now for making progress in our understanding of weather modification issues using modern research tools, including advanced radar, new aircraft instruments and powerful numerical models
6. Weather modification should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult to achieve. In particular, if there are no clouds, precipitation cannot be artificially stimulated. It is likely that the opportunities for precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry periods
7. The Members should be aware that the scope of efforts involved in the design, conduct or evaluation of a weather modification programme precludes the WMO Secretariat from giving detailed advice. However, if requested, the Secretary-General may assist (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

(a) Costs will be met by the requesting country
(b) The Organization can take no responsibility for the consequences of the advice given by any invited scientist or expert
(c) The Organization accepts no legal responsibility in any dispute that may arise.

WMO Recommendations related to Drought and Desertification

Noting:

1. The UN Conference on Environment and Development; (UNCED), 1992, Rio Declaration and relevant parts of Agenda 21
2. UN General Assembly Resolution 49/234, 1994, on the elaboration of an International Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa
3. Ratification of the United Nations Convention to Combat Desertification in December 1996
4. The Abridged Final Report with Resolutions of the Fourteenth World Meteorological Congress (WMO-No. 960) general summary, paragraph 3.2.2.15
5. UN General Assembly Resolution 54/223, 2000, on the implementation of the United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa
6. UN General Assembly Resolution 58/211, 9 February 2004, on the declaration of 2006 as the International Year of Deserts and Desertification (IYDD)
7. UNCCD Decision 20 from COP-7, October 2005, on the Programme of work of the Committee on Science and Technology.

Considering:

1. The role played by climate and climatic factors in desertification processes and the importance of meteorology and hydrology in many aspects of the combat against desertification
2. That drought and desertification have continued to affect many countries
3. That drought and desertification have serious implications for socio-economic development and the environment in many countries, especially in arid, semi-arid and dry sub-humid areas
4. That WMO has for many years contributed to the combat against the adverse effects of drought and desertification at national, regional and international levels,
5. Articles 10, 16 and 19 of the UNCCD
6. That WMO has participated effectively in the sessions 1 to 7 of the Conference of Parties (COP) of the UNCCD, and will continue to do so in future sessions of COP,
7. That WMO has produced a brochure entitled "Climate and Land Degradation" in support of IYDD
8. That WMO and UNCCD are working together to organize a workshop entitled "Climate and Land Degradation", from 11 to15 December 2006 in Arusha, Tanzania also in support of IYDD.

Recognizing that the subject of drought and desertification has been considered in detail by UNCED,

Urges Members of WMO:

1. To continue to strengthen national and regional meteorological and hydrological networks and monitoring systems to ensure adequate gathering and dissemination of basic data and information nationally, regionally and internationally
2. To support as appropriate national, regional and global programmes for integrated data collection and to carry out assessment and research related to land degradation and desertification and mitigation of drought problems
3. To continue to review, study and undertake research on the interactions between climate, drought and desertification, and their socio-economic impacts
4. To draw the attention of appropriate authorities and experts to the use and applications of meteorological and hydrological information in National Action Programmes for the implementation of UNCCD
5. To stimulate education and training on the meteorological and hydrological aspects of the multi-disciplinary fields in the combat against desertification
6. To support the Secretary-General in the further implementation of the recommendations of UNCED.

Requests the Secretary-General:

1. To bring the relevant recommendations on the follow-up to UNCED to the attention of all Members
2. To continue to circulate to Members for information and appropriate action any relevant decisions of COPs of UNCCD which may have implications for Member countries of WMO
3. To continue to take steps towards the implementation of actions recommended by UNCED, which are of direct relevance to WMO
4. To cooperate, as appropriate, within the budgetary resources, with other relevant international and regional organizations in the implementation of the UNCCD
5. To ensure that WMO continues to participate effectively, as appropriate, in the implementation activities in support of the UNCCD.

WMO statement on the scientific basis for, and limitations of weather and climate forecasting

1. Introduction

1.1 Every day around the world, the NMSs and the private sector meteorological service providers of the Member States and Territories of WMO provide hundreds of thousands of forecasts and warnings of weather and climate conditions and events. These forecasts and warnings provide information for the benefit of the community at large and for a wide range of specialized user sectors, on a broad spectrum of atmospheric phenomena ranging from those with timescales of seconds to minutes and space scales of metres to kilometres, such as severe storms, through to those, such as El Niño-related drought, with multi-year and global impact. The forecast information provided is used to inform and improve decision making in virtually every social and economic sector and the globally aggregated economic benefits of meteorological services are reckoned to be of the order of hundreds of billions of United States dollars

1.2 The capacity to provide these socially- and economically-beneficial services to the citizens of the 185 Members of WMO results from the operation of the unique international system of cooperation of the WMO World Weather Watch Programme which is based on:

(a) The collection and international exchange of the global observational data that are essential to describe the current (initial) state of the atmosphere (and the underlying land and ocean) at any point in time

(b) The fact that the physical and dynamical processes governing the behaviour of the atmosphere and ocean can be represented in numerical models which are capable of providing forecasts of daily weather conditions with significant skill out to several days from the 'initial' state as well as useful indications, in certain circumstances, of general trends of climate for months and seasons ahead

(c) The existence of a coordinated international meteorological system of global, regional and national data-processing and modelling centres producing real-time products from which skilled professional forecasters are able to prepare forecasts and warnings in forms that are relevant and useful to the user community;

(d) The ability to monitor extreme events in real-time and to issue warnings by combining classical meteorological observations, model output and information from remote-sensing systems such as satellites and radar.

1.3 The scientific understanding and technological capabilities underlying this globally cooperative system of weather and climate forecasting have made enormous progress over the past 25 years as a result, in particular, of such cooperative international research programmes as the WMO/ICSU Global Atmospheric Research Programme, the WMO World Weather Research Programme and the WMO/ICSU/IOC World Climate Research Programme. The skill levels and utility of the resulting forecasts and warnings have steadily increased. Indeed three-day forecasts of surface atmospheric pressure are now as accurate as one-day forecasts 20 years ago. But the observational database necessary to describe the 'initial' state of the atmosphere will always be limited by considerations of scale and measurement accuracy, the processes governing the behaviour of the atmosphere are non-linear and the phenomenon known as chaos imposes fundamental limits on predictability. While new techniques are emerging which help potential users of weather and climate forecasts to understand better, and make allowance for, the inherent uncertainties in the forecasts, the WMO Executive Council believes it is important that all those who make use of such forecasts in decision making should be made better aware of both their scientific foundation and their scientific and practical limitations. It therefore requested that CAS prepare a statement on the current status of weather and climate forecasting.

1.4 This statement has been prepared by CAS with input from other WMO and external scientific organizations and programmes including the World Climate Research Programme. It was approved by the thirteenth session of CAS in Oslo in February 2002 and endorsed by the Executive Council at its fifty-fourth session in June 2002. It is provided for the information of all those with an interest in the scientific foundations and limitations of weather and climate forecasting on timescales from minutes and hours through to decades and centuries.

2. The science of weather forecasting

Dynamical and physical processes within the atmosphere, and interactions with the surroundings (e.g. land, ocean, and ice surfaces), determine the evolution of the atmosphere and, hence, the weather. Scientifically-based weather forecasts are possible if the processes are well enough understood and if the current state of the atmosphere is well known enough, for predictions to be made of future states. Weather forecasts are prepared using a largely systematic approach, involving observation and data assimilation, process understanding, prediction and dissemination. Each of these components has, and will continue, to benefit from advances in science and technology.

2.1 Observations and data assimilation

2.1.1 Over the past few decades, substantial advances in science have resulted in improved and more efficient methods for making and collecting timely observations, from a wide variety of sources including radar and satellites. Using these observations in scientifically-based methods has caused the quality of weather forecasts to increase dramatically, so that people around the world have come to rely on weather forecasts as a valued input to many decision-making processes

2.1.2 Computer-generated predictions are initialised from a description of the atmospheric state built from past and current observations in a process called data assimilation, which uses the NWP model (see paragraph 2.3.2) to summarize and carry forward in time information from past observations. Data assimilation is very effective at using the incomplete coverage of observations from various sources to build a coherent estimate of the atmospheric state. But, like the forecast, it relies on the NWP model and cannot easily use observations of scales and processes not represented by the model

2.1.3 The international scientific community is emphasizing the still very poorly observed areas as being a limiting factor in the quality of some forecasts. As a consequence, there is a continued need for improved observation systems and methods to assimilate these into NWP models.

2.2 Understanding of the atmosphere: inherent limitations to predictability

2.2.1 The scientific understanding of physical processes has made considerable progress through a variety of research activities, including field experiments, theoretical work and numerical simulation. However, atmospheric processes are inherently non-linear and not all physical processes can be understood or represented in NWP models. For instance, the wide variety of possible cloud water and ice particles must be highly simplified, as are small cumulus clouds that can lead to rain showers. Continued research effort using expected improvements in computer technology and physical measurements will enable these approximations to be improved. Even then, it will still not be possible to represent all atmospheric motions and processes

2.2.2 There is a wide spectrum of patterns of atmospheric motion, from the planetary scale down to local turbulence. Some are unstable and are arranged so that flow is amplified using, for example, energy from heating and condensation of moisture. This property of the atmosphere means that small uncertainties about the state of the atmosphere will also grow, so that eventually the unstable patterns cannot be precisely forecast. How quickly this happens depends on the type and size of the motion. For convective motions such as thunderstorms, the limit is of the order of hours, while for large scales of motion it is of the order of two weeks.

2.3 Weather prediction

2.3.1 *Nowcasting:* Forecasts extending from 0 out to 6 to 12 hours are based upon a more observations-intensive approach and are referred to as nowcasts. Traditionally, nowcasting has focused on the analysis and extrapolation of observed meteorological fields, with a special emphasis on mesoscale fields of clouds and precipitation derived from satellite and radar. Nowcast products are especially valuable in the case of small-scale hazardous weather phenomena associated with severe convection and intense cyclones. In the case of tropical cyclones, nowcasting is an important detection and subsequent short-term prediction approach that provides forecast value beyond 24 hours in some cases. However, the time rate of change of phenomena such as severe convection is such that the simple extrapolation of significant features leads to a product that deteriorates rapidly with time — even on timescales of the order of one hour. Thus, methods are being developed that combine extrapolation techniques with NWP, both through a blending of the two products and through the improved assimilation of detailed mesoscale observations. These are inherently difficult tasks and, although accuracy and specificity will improve over coming years, these products will always involve uncertainty regarding the specific location, timing and severity of weather events such as thunder and hail storms, tornadoes and downbursts

2.3.2 *Numerical weather prediction*: Forecasts for lead times in excess of several hours are essentially based almost entirely on NWP. In fact, much of the improvement in the skill of weather forecasts over the past 20 years can be attributed to NWP computer models, which are constructed using the equations governing the dynamical and physical evolution of the atmosphere. NWP models represent the atmosphere on a three-dimensional grid, while typical operational systems in 2001 use a horizontal spacing of 50–100 km for large-scale forecasting and five to 40 km for limited area forecasting at the mesoscale. This will improve as more powerful computers become available.

Only weather systems with a size several times the grid spacing can be accurately predicted, so phenomena on smaller scales must be represented in an approximate way using statistical and other techniques. These limitations in NWP models particularly affect detailed forecasts of local weather elements, such as cloud and fog and extremes such as intense precipitation and peak gusts. They also contribute to the uncertainties that can grow chaotically, ultimately limiting predictability

2.3.3 *Ensemble prediction*: Uncertainty always exists — even in our knowledge of the current state of the atmosphere. It grows chaotically in time, with much of the new information introduced at the beginning no longer adding value, until only climatological information remains. The rate of growth of this uncertainty is difficult to estimate since it depends upon the three-dimensional structure of the atmospheric flow. The solution is to execute a group of forecasts — an ensemble — from a range of modestly different initial conditions and/or a collection of NWP models with different, but equally plausible, approximations. If the ensemble is well designed, its forecasts will span the range of likely outcomes, providing a range of patterns where uncertainties may grow. From this set of forecasts, information on probabilities can be derived automatically, tailored to users' needs

Forecast ensembles are subject to the limitations of NWP discussed earlier. Additionally, since the group of forecasts are being computed simultaneously, less computer power is available for each forecast. This requires grid spacings to be increased, making it more difficult to represent some severe weather events of smaller horizontal scale. Together with the limited number of forecasts in an ensemble, this makes it harder to estimate probabilities of very extreme and rare events directly from the ensemble. Moreover it is not possible to modify the NWP models used to sample properly modelling errors, so sometimes all models will make similar errors

2.3.4 *Operational meteorologist:* There remains a critical role for the human forecaster in interpreting the output and in reconciling sometimes seemingly conflicting information from different sources. This role is especially important in situations of locally severe weather. Although vigorous efforts are being made to provide forecasters with good quality systems such as interactive workstations for displaying and manipulating the basic information, they still have to cope with vast amounts of information and make judgements within severe time constraints. Furthermore, forecasters are challenged to keep up to date with the latest scientific advances.

3. Prediction at seasonal to interannual timescales

3.1 Beyond two weeks, weekly average predictions of detailed weather have very low skill, but forecasts of one-month averages, using NWP with predicted seasurface temperature anomalies, still have significant skill for some regions and seasons to a range of a few months

3.2 At the seasonal timescale, detailed forecasts of weather events or sequences of weather patterns are not possible. As mentioned above, the chaotic nature of the atmosphere sets a fundamental limit of the order of two weeks for such deterministic predictions, associated with the rapid growth of initial condition errors arising from imperfect and incomplete observations. None the less, in a limited sense, some predictability of temperature and precipitation anomalies has been shown to exist at longer lead times out to a few seasons. This comes about because of interactions between the atmosphere, the oceans, and the land surface, which become important at seasonal timescales

3.3 The intrinsic timescales of variability for both the land surface and the oceans are long compared to that of the atmosphere, due in part to relatively large thermal inertia. Ocean waves and currents are slow in comparison to their atmospheric counterparts, due to the large differences in density structure. To the extent that the atmosphere is connected to the ocean and land surface conditions, then, a degree of predictability may be imparted to the atmosphere at seasonal timescales. Such coupling is known to exist particularly in the tropics, where patterns of atmospheric convection ultimately important to global scale weather patterns are quite closely tied to variations in ocean surface temperature. The most important example of this coupling is found in the ENSO phenomenon, which produces large swings in global climate at intervals ranging from two to seven years

3.4 The nature of the predictability at seasonal timescales must be understood in probabilistic terms. It is not the exact sequence of weather that has predictability at long lead times (a season or more), but rather some aspects of the statistics of the weather — for example, the mean or variance of temperature/precipitation over a season — that has potential predictability. Though the weather on any given day is entirely uncertain at long lead times, the persistent influence of the slowly evolving surface conditions may change the odds for a particular type of weather occurring on that day. In rough analogy to the process of throwing dice, the subtle but systematic influence of the boundary forcing can be likened to throwing dice that are "loaded". On any given throw, we cannot foretell the outcome, yet after many throws the biased dice will favour a particular outcome over others. This is the sort of limited predictability that characterizes seasonal prediction

3.5 Currently, seasonal predictions are made using both statistical schemes and dynamical models. The statistical approach seeks to find recurring patterns in climate associated with a predictor field such as sea-surface temperature. Such models have demonstrated skill in forecasting El Niño and some of its global climate impacts. The basic tools for dynamical prediction are coupled models — models that include both the atmosphere and the other media of importance, particularly the oceans. Such models are initialized using available observations and integrated forward in time to produce a seasonal prediction. The issue of uncertainty is handled using an ensemble approach, where the climate model is run many times with slightly different initial conditions (within the range of observation errors or sampling errors). From this, a distribution of results is obtained, whereupon statistics of the climate can be estimated. Recently, encouraging results have been obtained from ensemble outputs of more than one model being combined

3.6 There are several limitations attending current predictions. Most coupled models (and to a lesser extent uncoupled models) exhibit some serious systematic errors that inevitably reduce forecast skill. Data availability is a limitation for both statistical models and for dynamical models. In the latter case, very limited information is available for much of the global oceans and for the land surface conditions. Also, current initialisation methods do not account properly for systematic model errors, further limiting forecast performance. A final set of limitations arises for practical reasons. Due to resource requirements, most seasonal predictions cannot be done at resolutions comparable to weather prediction

Furthermore, rather small ensemble sizes (of the order of 10) are used for some models, certainly less than is optimal for generating robust probabilistic forecasts. Current research is addressing the poten tial for regional "downscaling" of climate forecasts by various means and the possibilities for more detailed probabilistic climate information from expanded ensembles of one or more models

3.7 Possible use of seasonal forecasts is currently being explored in various contexts. In each case, effective use will require careful attention to the issue of uncertainty inherent in seasonal forecasts. Future advancements can be expected to improve the estimates of uncertainty associated with forecasts, thus allowing better use of forecast products.

4. Projection of future climate

4.1 As explained above, based on the current observed state of the atmosphere, weather prediction can provide detailed location and time-specific weather information on timescales of the order of two weeks. Some predictability of temperature and precipitation anomalies has been shown to exist at longer lead times out to a few seasons. This comes about because of interactions between the atmosphere, the oceans, and the land surface, which become important at seasonal timescales. At longer timescales, the current observed state of the atmosphere and even those large-scale anomalies which provide predictive skill at seasonal to interannual timescales are no longer able to do so due to the fundamental chaotic nature of the Earth-atmosphere system. However, long-term changes in the Earthatmosphere system at climate timescales (decades to centuries) are dependent on factors which change the balance of incoming and outgoing energy in the Earth atmosphere system. These factors can be natural (e.g. changes in solar output or volcanoes) or human induced (e.g. increased greenhouse gases). Because simulations of possible future climate states are dependent on prescribed scenarios of these factors they are more accurately referred to as "projections" not "predictions" or "forecasts"

4.2 In order to perform climate projections, physically-based climate models are required in order to represent the delicate feedbacks which are crucial on climate timescales. Physical processes and feedbacks that are not important at NWP or even at the timescales of seasonal prediction become crucial when attempting to simulate climate over long periods, e.g. cloud-radiation interaction and feedback, water vapour feedback (and correctly modelling long-term trends in water vapour), ocean dynamics and processes (in particular an accurate representation of the thermohaline circulation). The treatments of these key features are adequate to reproduce many aspects of climate realistically though there remain many uncertainties associated with clouds and aerosols and their radiative effects, and many ocean processes. Nevertheless, there is reasonable confidence that state-of-the-art climate models do provide useful projections of future climate change. This confidence is based on the demonstrated performance of models on a range of space timescales

4.3 Notably, the understanding of key climate processes and their representation in models (such as the inclusion of sea-ice dynamics and more realistic ocean heat transport) has improved in the past few years. Many models now give satisfactory simulations of climate without the need for non-physical adjustments of heat and water fluxes at the ocean-atmosphere interface used in earlier models. Moreover, simulations that include estimates of natural and anthropogenic forcing are well able to reproduce observed large-scale changes in surface temperature over the twentieth century. This large-scale consistency between models and observations lends confidence in the estimates of warming rates projected over the next century. The simulations of observed natural variability (e.g. ENSO, monsoon circulations, the North Atlantic Oscillation) have also improved

4.4 On the other hand, systematic errors are still all too apparent, e.g. in simulated temperature distributions in different regions of the world or in different parts of the atmosphere, in precipitation fields, clouds (in particular marine stratus). One of the factors that limits confidence in climate projections is the uncertainties in external forcing (e.g. in predicting future atmospheric concentrations of carbon dioxide and other greenhouse gases, and aerosol loadings)

4.5 As with NWP and seasonal forecasts, ensembles of climate projections are also extremely important. Ensembles enable the magnitude and effects of natural climate variability to be gauged and affect its impact on future projections, and thereby permit any significant climate change signal to be picked out more clearly statistically (the magnitude of natural climate variability will be comparable with that of climate change for the next few decades).

5. Dissemination to end-users

5.1 The weather forecasts have to be communicated to a vast array of users such as emergency managers, air traffic controllers, flood forecasters, public event managers, etc. in a timely and user-applicable form. This in itself poses another major challenge that is increasingly benefiting from advances in information technology. Predictions at seasonal to interannual timescales and climate projections are also being used by an increasingly wide range of users

5.2 The value of forecasts to decision makers is greatly enhanced if the inherent uncertainty can be quantified. This is particularly true of severe weather, which can cause such damage to property and loss of life that precautions may be well advised even if the event is unlikely, but possible. Probabilities are a natural way of expressing uncertainty. A range of possible outcomes can be described with associated probabilities and users can then make informed decisions allowing for their particular costs and risks

5.3 Forecasts expressed as probabilities, or ensembles, contain much more information than deterministic forecasts, and it is difficult to convey it all to users. Broadcast forecasts can only give a broad picture of the most likely outcome, with perhaps some idea of important risks. Each user's decision may be based on the probabilities of a few specific occurrences. What these are, and the probability thresholds for acting on the forecasts, will differ. So for important user decisions it is necessary to apply their particular criteria to the detailed forecast information.

6. Conclusions

6.1 The skill in weather forecasting has advanced substantially since the middle of the twentieth century, largely supported by the advancement of computing, observation and telecommunications systems, along with the development of NWP models and the associated data-assimilation techniques. This has been greatly facilitated because of the vast experience of both forecasters and decision makers in producing and in using forecast products. Nevertheless, each component within the science and technology of weather forecasting and climate projection has its own uncertainties. Some of these are associated with a lack of a complete understanding of, or an inherent limitation of, the predictability of highly complex processes. Others are linked still to the need for further advances in observing or computing technology, or to an inadequate transfer between research and operations. Finally, one cannot underestimate the importance of properly communicated weather forecasts to well educated users

6.2 Without a doubt, significant benefits will result from continued attention to scientific research and the transfer of knowledge gained from this work into the practice of forecasting. Furthermore, a recognition of the limitations of weather forecasts and climate projections, and when possible, an estimate of the degree of uncertainty, will result in the improved use of forecasts and other weather information by decision makers. Ultimately the objective is for the scientific and user communities to work better together, realizing even greater benefits.

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Transportation

WMO and ICAO: working together for international air navigation

1. The author gratefully acknowledges the contribution of the WMO Secretariat in producing this article, which is based on a previously published piece: 'WMO and ICAO work together for international air navigation', *WMO Bulletin* 55:2, April 2006.
2. See 'Working arrangements between the WMO and ICAO', (ICAO Doc 7475 and WMO-No. 60).
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4. A complete list of ICAO and WMO manuals and guides is available from the ICAO and WMO Web sites at www.icao.int and www.wmo.int, respectively.
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Construction

Sustainable, energy-efficient building: the BCIL approach

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III
Natural & Human-induced Disasters

Using what we know about disasters — for safer lives and livelihoods

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Unjust waters: climate change, flooding and the protection of poor urban communities in Africa

1. This article is an edited version of the research report 'Unjust Waters' (ActionAid, 2006. Download at *www.actionaid.org)*, and highlights findings from three cities from the study, Accra in Ghana, Maputo in Mozambique and Kampala in Uganda. The other cities in the study are Freetown (Sierra Leone), Maputo (Mozambique) and Nairobi (Kenya). Policy analysis was also carried out to understand whether there is a gap between poor urban people's experiences of climate change impacts and current disaster management policies. ActionAid International works with more than 13 million individuals across Africa, Asia, Latin America and the Caribbean through some 2,000 civil society partners. For more information, visit www.actionaid.org or contact jack.campbell@actionaid.org
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IV
Environment

The African Monitoring of the Environment for Sustainable Development Initiative: a timely initiative to save an endangered continent

1. About EUMETSAT: EUMETSAT is responsible for operating Europe's weather satellites in geostationary and polar orbits, and for delivering satellite data, services and products to the European National Meteorological Services, research and training institutions and other end users. EUMETSAT currently has 20 Member States and 10 Cooperating States and works in close collaboration with the World Meteorological Organization (WMO), the European Union, the European Space Agency and other European and international partners, industrial companies and space agencies. In addition to AMESD and PUMA, EUMETSAT contributes to other strategically important projects such as the European Global Monitoring for Environment and Security (GMES) initiative, the Global Earth Observation System of Systems (GEOSS) and the WMO's World Weather Watch and Global Observing System.

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V
Assessment Methodologies

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4. The authors thank Charles S. Colgan for helpful discussions.
All economic sectors, regions, and individuals on Earth are affected by weather.
In any application areas, a better understanding of these interactions could enhance personal safety, reduce property damage, and increase economic efficiency, saving multiple lives and millions of dollars each year. If we are to realize these potential benefits, we need to thoroughly understand how individuals and socioeconomic sectors do and could use different types of weather information.
To learn more about work toward this goal, visit NOAA's Economics & Social Science (NESS) Web site at www.economics.noaa.gov. As an agency, NOAA is focused on the earth's physical sciences, but recognizes that interactions between earth science and social science are vital to its ultimate goal – giving users what they need. The NESS programme and Web site is part of NOAA's Office of Program Planning and Integration (PPI). Another valuable resource can be found at www.sip.ucar.edu. NCAR, with funding from the US Weather Research Program, established the Collaborative Program on the Societal Impacts and Economic Benefits of Weather Information (SIP) to create a dedicated focal point for assembling, coordinating, developing, and synthesizing research and information on the societal impacts and economic benefits of weather information.

Moving from hindsight to foresight: a challenge in the application of valuation research

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