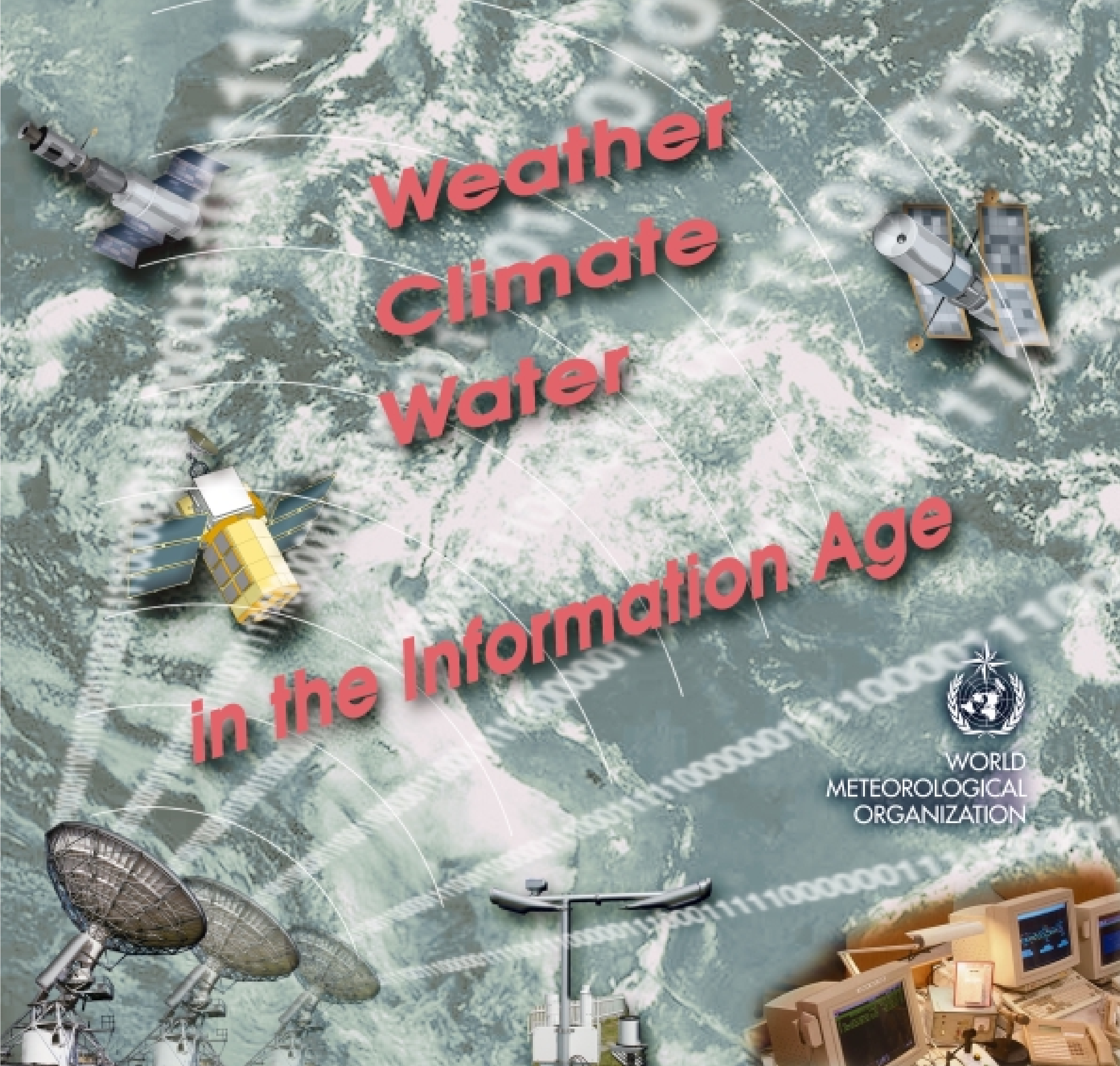

Weather Climate Water in the Information Age

WORLD METEOROLOGICAL ORGANIZATION

Weather
Climate
Water

in the Information Age

WMO-No. 970
Geneva, Switzerland
2004

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METEOROLOGICAL
ORGANIZATION

WMO–No. 970

ISBN 92-63-10970-2

NOTE

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FOREWORD

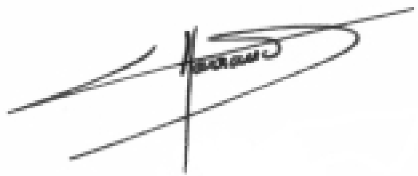
World Meteorological Day 2004 commemorates the coming into force on 23 March 1950 of the Convention that created the World Meteorological Organization (WMO), as the successor to the International Meteorological Organization (IMO), established in 1873. This year therefore marks 131 years of formally organized international cooperation in meteorology, hydrology and related geophysical sciences. It is also the 25th anniversary of the Global Weather Experiment, a model of international scientific cooperation. This unique experiment triggered advances in monitoring and scientific understanding of dynamic and physical processes of the atmosphere and its interaction with other Earth systems.

The year also marks the silver jubilee of the First World Climate Conference that established the World Climate Programme (WCP), the pillar of our knowledge, awareness and initiatives on issues related to climate, climate change and related environmental matters.

These landmark events and the benefits derived from them have been possible due to new and increasingly sophisticated tools that technology has provided for the development of meteorology, hydrology and related geophysical sciences and the dissemination of useful products. These tools include automatic weather stations and Doppler radars, remote-sensing capabilities of operational meteorological and research and development satellites, as well as rapid telecommunication capabilities, supercomputers and easily accessible and powerful personal computers. Major boons for the information age have been the media and the Internet, which have contributed significantly to enhancing accessibility and awareness about the value of weather and climate information. It is in recognition of such contributions to various socio-economic sectors and human well-being that the theme chosen for World Meteorological Day 2004 is “Weather, climate and water in the information age”.

Over the years, WMO and the National Meteorological and Hydrological Services (NMHSs) of its Members have been applying technological developments to meet the growing demands for information and services related to weather, climate and water. These include increasingly accurate weather forecasts and warnings that are essential for the safety of lives and property, as well as data and products that are vital for a wide range of socio-economic activities, including agriculture, forestry, water management, transportation, tourism and the protection of ecosystems and the environment. Such information is also essential for policy formulation in areas such as climate change, desertification, ozone depletion and biodiversity. In view of the concern about the degradation of the environment and the increasing call for sustainable development, the challenge to WMO is to promote research and capacity building, using up-to-date technology so that all nations, especially developing countries, are able to meet their needs related to weather, climate and water.

I wish to thank Mr J. P. Bruce (Canada) for preparing the manuscript of this brochure. It is my hope that the information it contains will assist readers in recognizing the close linkages between air, water—including oceans—the land surface and ecosystems, and the vital role that technology plays in advancing our understanding of these Earth systems and in contributing to the prediction of future developments. The modernization of NMHSs, as coordinated through WMO and its scientific and technical programmes, is essential if humanity is to secure major economic, social and environmental benefits, through the appropriate use of these information products of international cooperation, both now and in the future.



(M. Jarraud)
Secretary-General

INTRODUCTION

Earth is often known as the “water planet”. Of all the forms of life that have inhabited Earth, humans have drawn most heavily on the planet’s natural resources. In so doing they have been highly successful in developing and using new technologies and increasing their numbers, wealth, dominance over other life forms, longevity, and improving their health, although these benefits are far from being evenly distributed.

Sustainable development—a concept introduced by the World Commission on Environment and Development in its study “Our Common Future”—refers to development that meets current needs, while not compromising the needs of future generations. This implies an intimate knowledge of the workings of the major components of Earth’s environment and an understanding of how the main components—atmosphere, water, land and vegetation—interact. Among others, the sciences of meteorology, hydrology and oceanography play critical roles in contributing to sustainable development. In particular they are essential in assessing the sustainability—or lack thereof—of many human activities.

Over the years the monitoring and prediction of the behaviour of the atmosphere and water systems have improved with ever-evolving technology, including:

- New methods of measuring the components of weather, climate and water;
- More rapid and sophisticated facilities and techniques to analyse and use the data; and
- Advanced means of communications within the scientific community and with users.

This brochure describes how the development of meteorology, hydrology and related geophysical sciences has benefited from advances in technology in the areas of monitoring, data processing and exchange, and from wider access to the products and, in turn, how these sciences contribute to achieving sustainable development and the objectives of the United Nations Millennium Development Goals. The sectors highlighted include disaster mitigation, agriculture, water resources, drought, pollution control, health, and energy.

INFORMATION AGE—SOME OF THE TOOLS

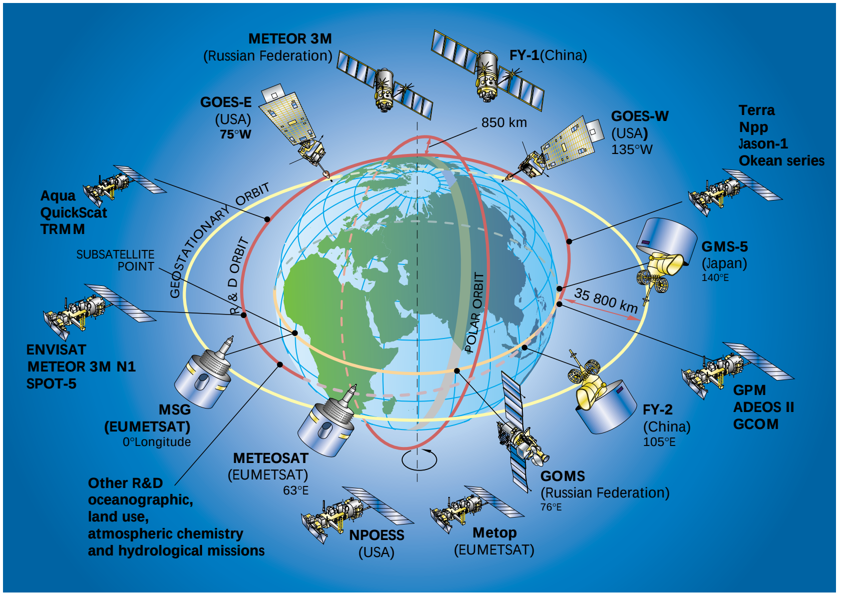
Comprehensive and integrated monitoring

The insights into the processes that cause weather and climate, and the distribution of water and ice, the capability to predict them and assess changes affecting the planet, were made possible by technological developments which have gained considerable momentum in the information age. Earth-orbiting meteorological satellites keep track of weather phenomena, vegetation and the spatial distribution of ice and snow. In recent decades, looking down from satellites and up from ground stations and ships, spectroscopes, radars and lidars and instruments using infra-red and microwave bands, have provided new perspectives on broad geographical scales not only of tropical cyclones, floods and forest cover, but also of water vapour in the atmosphere, clouds, air and sea-surface temperatures. These form part of the Global Observing System of WMO's World Weather Watch (WWW). Several of the instruments also provide information on some of the key chemical contaminants and constituents of the atmosphere. In this case, space-based measurements are combined with atmospheric chemistry monitoring at the surface through WMO's Global Atmosphere Watch (GAW).

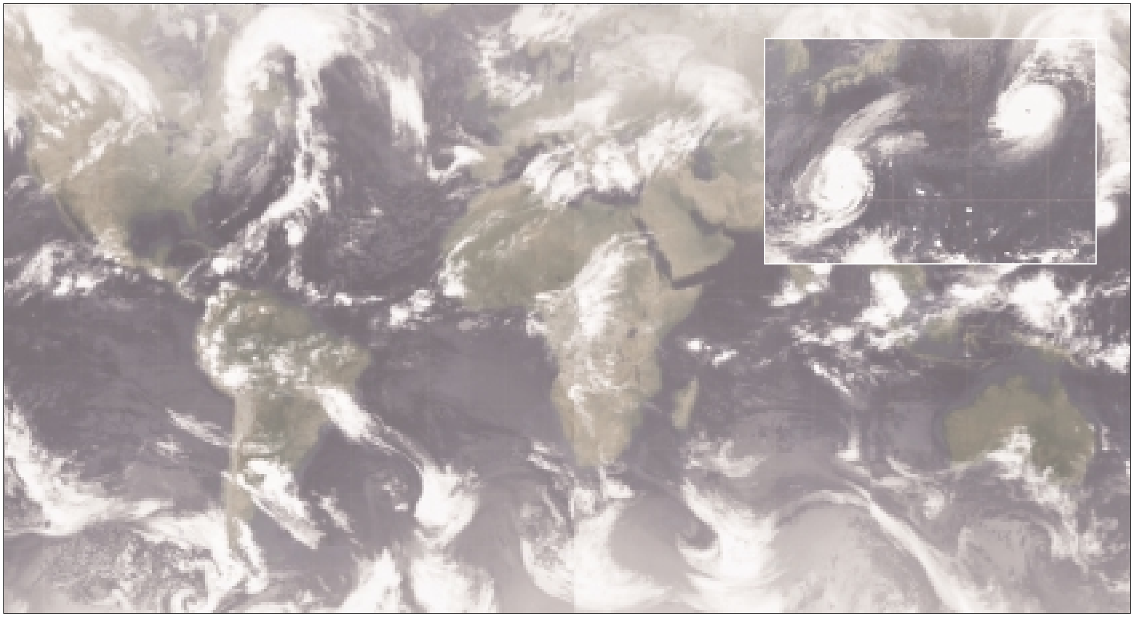
Among other things, the instruments have revealed an increase in greenhouse-gas concentrations in the global atmosphere, depletion of the ozone layer, variations in ocean temperatures, sea-level changes and the long-range transport of many toxic airborne pollutants. Some instruments enable the monitoring of cloud particles and the assessment of precipitation enhancement. Other instruments enable the monitoring of precipitation, river flow and lake levels.

Improved forecasts—more powerful computers

Computer technology has advanced rapidly to permit better assimilation of all these new

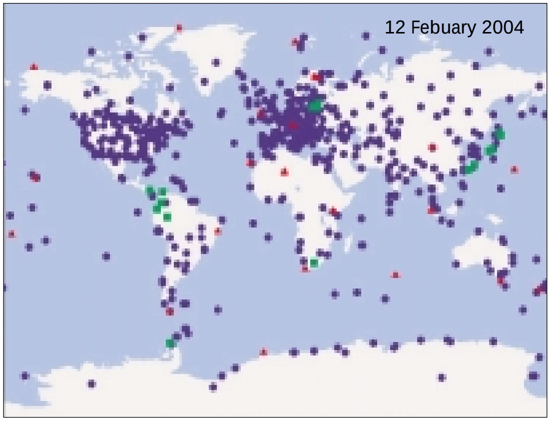


Space-based component of the Global Observing System of the World Weather Watch



Improving the skill of forecasts of high-impact weather events and their associated hazards: global mosaic of cloudiness made from satellite images. (SRC Planeta, ROSHYDROMET)

types of data, as well as the more traditional measurements taken at fixed points and times. This has permitted the initialization and verification of ever more complex mathematical models of the atmosphere-ocean-land system



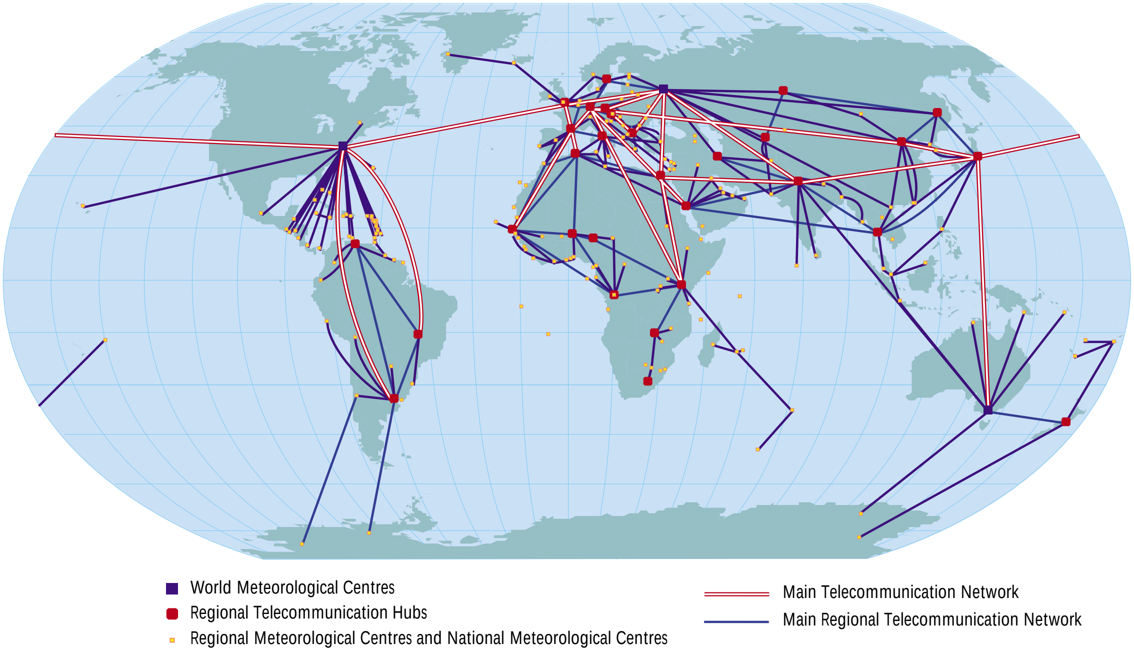
WMO/GAW global atmospheric composition monitoring network of global regional and contributing stations.

● GAW Regional Station
■ Contributing Station
▲ GAW Global Station

for regular operational forecasts and warnings of disastrous weather.

To produce reliable weather and flood forecasts and warnings needed to reduce natural disaster losses, National Meteorological and Hydrological Services (NMHSs) make observations and use and exchange results compiled with modern information systems and technology. Numerical weather prediction now provides the solid foundation to produce forecasts and warnings on a regular basis. Forecasts and warnings use satellite images, for example, to detect and track tropical cyclones, and computer models of the atmosphere-ocean system to predict their intensification and paths.

This modern system of observations, computers and communications serves not only to provide warnings of severe weather



Global Telecommunication System of WMO's World Weather Watch

events, but also forms the foundation of day-to-day weather forecasts in all countries. The development of numerical weather prediction techniques over the past three decades has permitted forecast improvements. As a result, over most regions, seven-day forecasts now have the reliability of three-day predictions 30 years ago. Such forecasts are essential for the safety and efficiency of aviation and shipping, farmers, merchants and energy suppliers, as well as the general public.

More effective communications

Modern communications technology such as that of the WMO-coordinated Global Telecommunication System, as well as the Internet, is now used to exchange information among countries and permits the highly accurate prediction and more rapid dissemination of forecasts and warnings. The longer lead-time has enabled populations to take precautionary measures, resulting in the saving of life and property.

In the case of small-scale severe thunderstorms and tornadoes, specific warnings are possible only a few hours, or even minutes, beforehand. Even for those critical few hours, warnings now rely on the technology of Doppler radars, skilled forecasters, and high-speed telecommunications, radio and television systems.

WMO promotes the free and unrestricted international exchange of data and analyses to ensure the wide availability of reliable weather, climate and water forecasts. It also ensures the exchange of guidelines on how best to tailor the forecasts to meet the special needs of all types of user and the general public.

Projecting our future climate

Moreover, for longer-term planning, better projections of future climate are needed based on complex mathematical models of the Earth system. Coupled atmosphere-ocean general circulation models requiring extremely fast computers and sets of parallel processors to run in a reasonable length of time, can now reproduce past global climates with considerable fidelity and make future climate predictions. These require projections of greenhouse-gas emissions that will be determined by future population and economic growth rates, the energy technology widely adopted, and whether countries move towards the goals of the United Nations Framework Convention on Climate Change. The extent to which countries move towards those goals, however, depends on the availability and accessibility of information technology.

Delivery of weather information to the public

The advent of the information age has not only resulted in the increased sophistication of meteorological information but has also revolutionized accessibility by the wider public. Television channels devoted to weather information and forecasts have been established in many countries. Weather forecasts with the latest images from satellites and radars, weather maps

Warnings of avalanches are of increasing importance given the popularity of winter sports. Many people are killed and more injured in mountain accidents every year.
(David McGuirk)

Many NMHSs now have Websites to communicate up-to-date weather, climate and water information to the media. These NMHHs can be found on the WMO Website (www.wmo.int "Members"). A WMO project to collect global weather information for selected cities at a centralized site culminated in the World Weather Information Service (www.worldweather.org), to which 1 002 cities in 153 WMO Member countries were contributing in January 2004, and the Severe Weather Information Centre (www.severe.worldweather.org). These two Websites are hosted by the Hong Kong Observatory.

Website of the Bolivian NMHS

Website of the WWIS

and attractive and colourful graphics of evolving temperature, precipitation and violent phenomena, are aired on prime time on national and international television. The national and international press is also giving increased importance to weather. In most countries, weather forecasts are counted among the most popular of broadcast programmes. The emergence of the Internet, e-mail, mobile technologies, the short message service (SMS) and technologies such as instant messaging, wireless fidelity (Wi-Fi), and broadband connection at home and in the work place will continue to transform public access to, and understanding of, weather information.

These developments have resulted in a demand for increasingly accurate forecasts with longer lead time. The NMHSs are thus being incited by the public, decision-makers and the private sector not only to enhance the accuracy of the forecasts and warnings but also to improve their presentation and accessibility. The public limelight brings its own challenges and opportunities to the meteorological and hydrological communities.

To respond to some of the challenges, WMO's Public Weather Services Programme assists NMHSs in providing reliable and effective weather and related services in support of safety of life and protection of property, as well as for general welfare and well-being. WMO has also adopted a Global Communication Strategy aimed at bringing to the wider public domain the contributions of meteorology and hydrology to sustainable development.

NATURAL DISASTERS

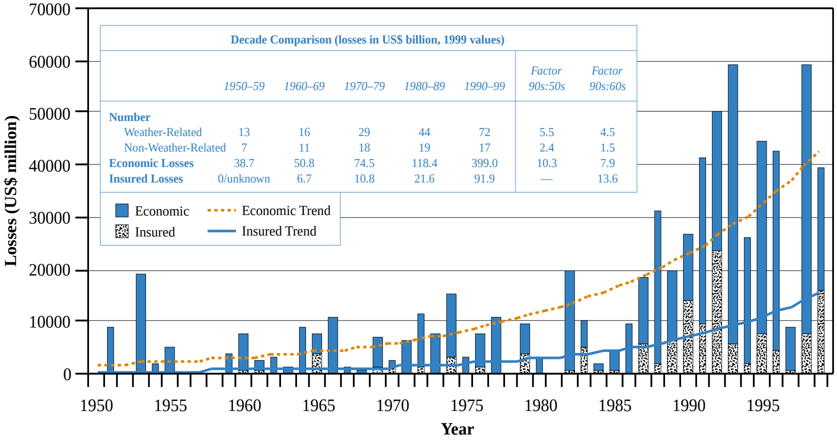
Storms, floods and droughts

The value of predictive science is best illustrated through early warnings that contribute to minimizing loss of human life and damage from natural disasters and so reduce serious threats to sustainable development. Economic losses from all natural disasters, including those of hydrometeorological origin, earthquakes and volcanic eruptions, were estimated at US$ 4 billion and US$ 40 billion per year in the 1950s and 1990s, respectively. More than 80 per cent of these losses were from weather-, climate- and water-related disasters, i.e. storms, floods and droughts. In the 1990s, for example more than 280 000 deaths were attributed to drought. For developing countries, such losses can set back economic gains for as much as a decade. An example was hurricane *Mitch*, which struck Honduras and Nicaragua in 1998, and caused more than 12 000 deaths. A good forecast of an extreme weather event, a flood, or a seasonal drought can be used to save many lives and avoid a substantial portion of economic losses. In Bangladesh, where efforts have been made to improve predictions, as well as the timely dissemination of warnings of tropical cyclones and preparedness measures,

Floods continue to be one of the most damaging of natural disasters. Early warnings disseminated by the media help communities take precautionary measures to save human life, livestock and supplies of food and water. (DMC-Nairobi) the death toll has decreased from an estimated 300 000 in 1971, to 13 000 in 1991 and 200 in 1994.

The World Meteorological Organization and the NMHSs of its 187 Members have established a global system for warnings. This involves observing the atmosphere, water and land surface from the ground and from satellites and the rapid international exchange of data and predictions using telecommunication networks and the capability of data-processing centres. Each country needs to establish and reinforce its preparedness measures to take advantage of these warnings.

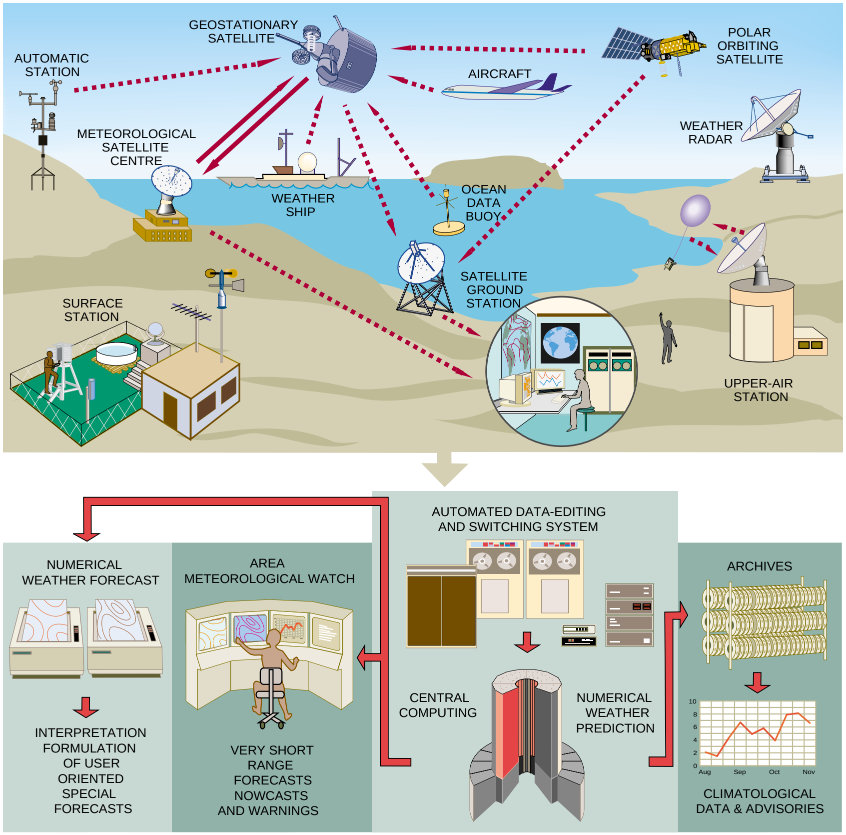
WMO's worldwide prediction, warning and dissemination network depends upon international cooperation to track tropical cyclones, weather systems which cause drought and floods, such as El Niño or La Niña events, and severe extra-tropical storms. For small-scale violent disturbances such as heavy rains, flash floods, thunderstorms, tornadoes and smaller-scale snow- and ice-storms, countries need to develop their capabilities. WMO has initiated research in such phenomena through its World Weather Research Programme. For floods on larger rivers, international collaboration is necessary to provide adequate forecasts and warnings, especially in large river basins shared by two or more countries.



Decade Comparison (losses in US$ billion, 1999 values)							
	1950–59	*1960–69*	*1970–79*	*1980–89*	*1990–99*	*Factor 90s:50s*	*Factor 90s:60s*
Number							
Weather-Related	13	16	29	44	72	5.5	4.5
Non-Weather-Related	7	11	18	19	17	2.4	1.5
Economic Losses	38.7	50.8	74.5	118.4	399.0	10.3	7.9
Insured Losses	0/unknown	6.7	10.8	21.6	91.9	—	13.6

Trends in disaster losses
(IPCC 2001, WG 2 Report)

Storms can devastate entire forests with major environmental and socio-economic impacts. Severe storms are likely to become more frequent with global warming.

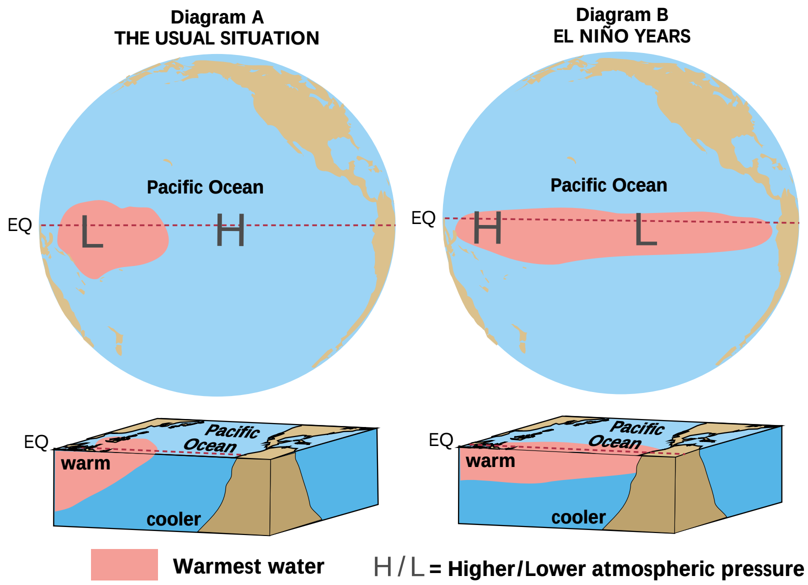


The World Weather Watch and the operations of a National Meteorological Service

Climate variability—seasonal prediction

Natural variations in the climate system have always occurred and will continue to produce high-impact events leading to disasters. Among the most important natural phenomena leading to climate variability are El Niño/ Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the linked North Atlantic (NAO) and Arctic Oscillations (AO). ENSO is most closely linked to disastrous weather, floods and droughts. ENSO is an oscillation of Pacific Ocean waters, linked with the tropical atmospheric circulation, and results in periodic episodes of abnormally warm surface waters off the equatorial west coast of South America (Ecuador and Peru), while surface waters are abnormally cool in the south-west Pacific. This is known as the El Niño phase. The La Niña phase is the opposite, with unusually warm surface waters in the equatorial west Pacific and cool waters off the coast of South America. The severe weather associated with these two phases of ENSO include floods near the warm water areas and droughts in other tropical and subtropical regions. The 1997/1998 El Niño is estimated to have affected 110 million people worldwide and resulted in damages of US$ 96 billion.

An array of observation platforms across the tropical Pacific transmit data by satellite relay which, combined with traditional observation programmes and satellite remote-sensing, permit prediction a season to a year in advance of a strong El Niño or La Niña. This, in turn, allows countries to take steps to minimize the impacts of floods or droughts by issuing forecasts which alert the authorities to take the necessary preventive measures. WMO has assisted in establishing the International Research Centre on El Niño in Guayaquil, Ecuador, to coordinate global predictions of ENSO and its impacts, thus complementing other centres having prediction responsibilities. WMO's Climate Information and Prediction Services (CLIPS) project assists countries to take maximum advantage of climate information and predictions regarding disaster



El Niño and the Southern Oscillation

mitigation, agriculture, fishing, water and energy management, and other sectors of the economy.

Advance prediction of drought conditions enable countries to take mitigation actions, especially in the agriculture and water-resources sectors. For agriculture, if adequate warning is provided, more drought-tolerant crops can be planted, and the timing of planting and harvesting can be adjusted to take maximum advantage of favourable conditions. For example, reservoirs and ponds can be filled in advance and the water conserved for different needs.

Trends in extreme weather, climate and water events

The design of buildings, drainage facilities, bridges, roads, runways, erosion control

More than two-thirds of the water withdrawn from the Earth's rivers, lakes and aquifers is used for irrigation. (M. Marzot/FAO) structures, canals, dams and reservoirs, and vulnerability indices are based upon statistical analyses of records of climate and water flows and the frequency and intensity of extreme events, heavy rains, strong winds and highest and lowest flows. Proxy data and measurements confirm an increase in the concentrations of greenhouse gases in the atmosphere, evidence of higher temperatures, changes in precipitation patterns and rise in sea-level. Rates of warming are greatest in the Arctic, where satellite measurements have shown sea-ice extent decreasing 2.5 per cent per decade since 1973 with summer temperatures increasing 1.2°C per decade. Antarctic ice trends have been more variable, but glaciers worldwide are in retreat with significant impacts on the flow of rivers. With rapid glacier melt, estimated in total at about 100 km^3/year, river flows initially increase. As the areas of the glaciers shrink, runoff from this source declines, as is now evident in most of the rivers rising on the east slopes of the Rocky Mountains in North America.

Hurricane Mitch left many thousands dead and some two million homeless in Central America. Socio-economic development was set back at least 10 years. (Victor R. Caivano/AP)

Evidence is now accumulating of changes in the occurrences of extreme events. In particular, an increase in the number of very hot days can have devastating effects, as shown by the hundreds of heat-related deaths in North America in 1988 and thousands in western Europe in 2003. Subtropical and tropical regions are also being affected by greater temperature extremes, as has been experienced in Agades, Niger, where night-time temperatures have been extremely high since 1950. The same is true of the Caribbean, where data from some 30 observing stations show that this region has experienced an upward trend in extreme maximum temperature. Abnormally high night-time temperatures may have even more severe health impacts than very hot days, and daily minimum temperatures have been rising more rapidly than maximum daytime temperatures in most regions. Heat stress can be a serious outcome of a warmer climate. With minimum and maximum daily temperatures both exhibiting higher extremes, reduced cooling at night provides less relief from the rigours of hot days.

Based on Caribbean data of heavy rain events and storms, intense rainfall events increased from 1955 to 2000. The same is true for Canada, parts of China, Japan, the Russian Federation, and the United States. In

Europe, large changes in precipitation extremes took place from 1946 to 1999.

Weather- and water-related economic losses increased 5.5 times from 1950 to 1990, while geophysical disasters (e.g. earthquakes) increased only 2.4 times. The total comparative number of reported hydrometeorological disasters increased even more rapidly in the 1990s.

Future trends

Having studied the evidence of recent increases in extreme events and the climate model projections of such trends, the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) in 2001 concluded that more intense precipitation events were very likely in the future over many areas and would thus cause increased flash floods, landslides, soil erosion and avalanches. There would continue to be more hot days and nights, but fewer very cold nights. The IPCC also concluded it was likely (66-90 per cent chance) that there would be an increase in summer drying over most mid-latitude continental interiors with an associated risk of drought and an increase in intensity (but not frequency) of the strongest tropical cyclones. However, with sea-level rise observed to date (10–20 cm) and projections to 2100 (another 9–88 cm), coastal inundation by storm surges accompanying tropical cyclones would cause even more devastation.

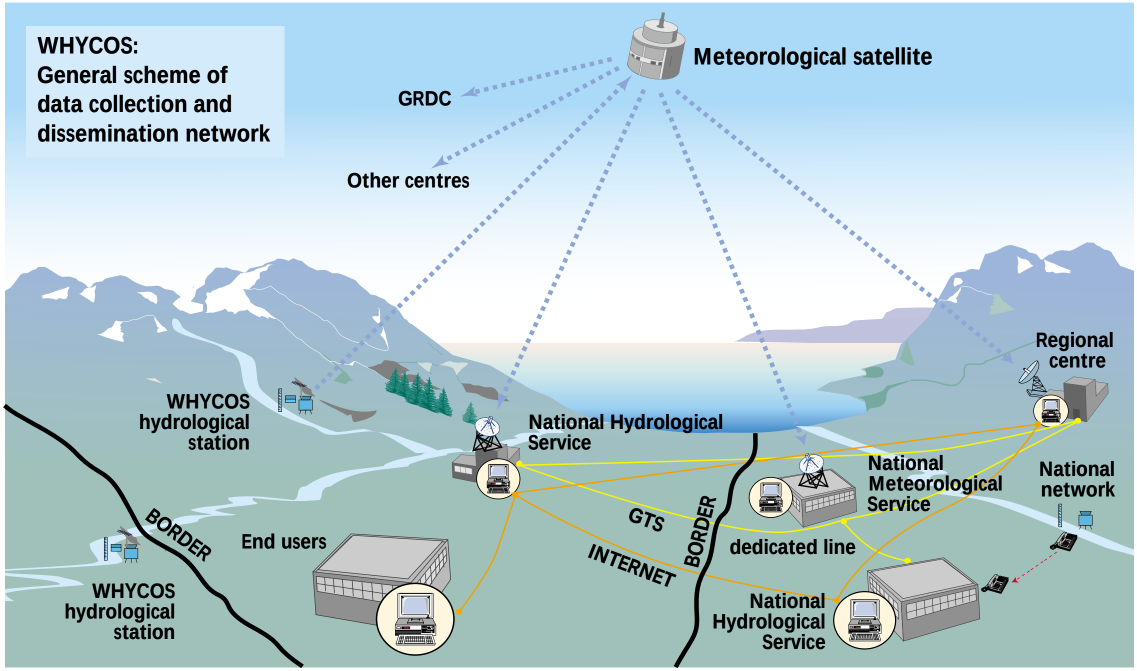
The effects of fires, mainly on forests, appear to be increasing around the world. Drought conditions in western North America in 2003 resulted in widespread fires and destruction of forests. The 1997/1998 El Niño brought drought to South-East Asia and huge forest fires in Indonesia. These resulted in smoke pollution which caused widespread health and air-navigation problems. In dry conditions, forest fires are often caused by human carelessness, but, in more remote areas, more than 50 per cent of fires are ignited by lightning. Climate models project an earlier start of the annual fire season in the boreal forests of Russia and Canada, as well as increases in those areas of the world experiencing high and extreme fire danger.

Smoke produced by forest fires is a hazard for human health and air navigation. National Meteorological Services keep public health and civil aviation authorities, as well as the general public informed about air quality, extent of haze, prevailing winds and visibility.

WATER MANAGEMENT ISSUES

Technology for managing water resources

Technology and scientific developments, as well as political and social commitment, can help solve the problems of freshwater supplies and water management. In an attempt to assess the availability of water, measurements of precipitation, streamflow, groundwater and water levels are made using *in situ* and remote-sensing techniques. The data are then transmitted by various means, including satellite relay, to central offices of National Hydrological Services or Water Agencies. This is being achieved, in part, through WMO's World Hydrological Cycle Observing System (WHYCOS) and its regional components. Water-level measurements by traditional gauges are increasingly being supplemented by laser and infra-red sensors of water-surface elevation, and by acoustic current-profilers, which measure flows directly, making use of the Doppler effect. Sea-level measurements from

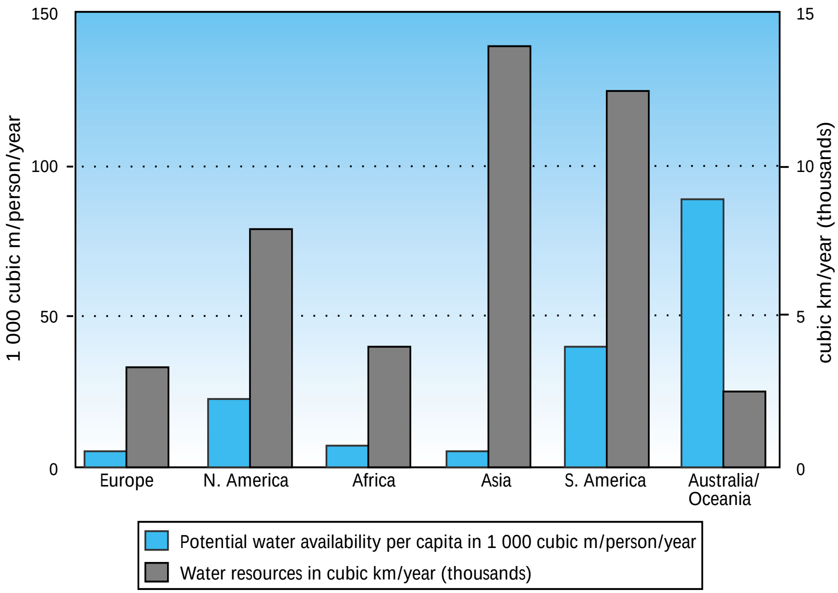


World Hydrological Cycle Observing System (WHYCOS)—Integrated information systems contribute to improved water management.

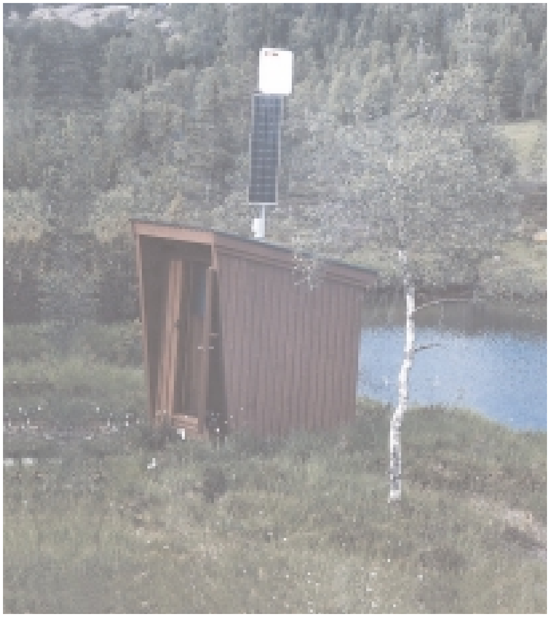
satellites and tidal gauges are useful in monitoring salt intrusion in coastal freshwater.

Some common chemical and biological measurements which indicate the quality of the water, can be used for automatic instruments, or by community groups with only little training. More complex analyses of toxic contaminants, such as persistent organic pollutants, methylated mercury, arsenic and other metals, and of potential endocrine-disrupting drugs in water, fish and other aquatic organisms, require sophisticated and costly laboratory equipment and highly skilled analysts. Remote-sensing from satellites of lakes and reservoirs is being used to assess the amount of chlorophyll in surface layers.

Such measurements are useful in addressing the global problem of dwindling water resources, as well as for hydrological modelling, integrated water-resources management and ensuring clean water supplies. Much of this information which is of interest to users and the public, is made available through the media and the Internet.



Average water withdrawals by continent



Hydrometric stations transmit data via satellite.
(Norwegian Water Resources and Energy Directorate)

Dwindling water resources

Clean water is essential to human survival and well-being. The water available at the Earth’s surface, as opposed to deep groundwater, is determined by climatic conditions of the previous months and years. Driven by energy from the Sun, water evaporates to supply water vapour to the atmosphere, which condenses into clouds when upward vertical motions are induced. The clouds, in turn, can produce rain or snow, thus causing the hydrological cycle to start again.

Although Earth is often referred to as the water planet, the water is not evenly distributed.

Precipitation is unevenly distributed and evaporation from the surface varies according to the climatic conditions. As a result, some areas of the globe face serious water shortages, while others are well watered. Africa and Asia have the least amount of water available per person. Europe also has relatively low water availability per person, but has lower population growth.

Current estimates are that more than one billion people do not have ready access to safe drinking-water. Poverty and lack of adequate water supplies are closely related. Alleviation of the effects of poverty goes hand in hand with the provision of safe water. Present water availability per capita in Africa has dropped by an estimated 75 per cent and in Asia and South America by some 65 per cent since 1950. Using United Nations projections of population growth, the numbers of inhabitants of water-scarce countries would rise to 2.4 billion by 2050. These estimates do not take into account the loss of usable water due to increasing pollution, nor regional changes in water distribution accompanying climate change.

In addition, some 17 per cent more water will be needed by 2025 to grow the crops to feed larger populations. At the same time, it must be recognized that water courses and bodies sustain valuable ecosystems, some of which also serve human needs. These must also be preserved in the face of the growing demand for water withdrawal.

Competition for water may well lead to serious conflicts. International basin organizations have been established to deal with such transboundary issues.

Hydrological modelling

Hydrological cycle models are incorporated in climate-prediction and weather-forecast models, especially those designed for quantitative precipitation forecasting. Such integrated atmospheric-hydrological models are showing promise for warnings of floods, low flows and scheduling of water uses.

Integrated water resources management

Many countries have adopted integrated watershed-management systems. This approach—which relies on hydrological and ecosystem models, as well as on economic data—recognizes that natural occurrences and human activity in the river basin or watershed influence the quantity and quality of water downstream.

In water-scarce regions, conservation and the effective use of water are essential to meet needs. A warming climate can place even more stress on water systems by increasing demand for irrigation and cooling. Indeed, irrigation is by far the greatest consumer of water. When using inefficient techniques, 60–70 per cent of the water is evaporated before it ever reaches the plants. Drip irrigation, for example can reduce these losses greatly.

Clean water supplies

To ensure safe drinking-water, treatment of water from surface and underground sources is increasingly required. In many parts of the world, groundwater can be a source of good-quality drinking-water. In other locations, serious contamination problems exist. For example, in some countries, natural sources of arsenic contaminate much of the groundwater, thus making treatment necessary before safe domestic use. In fertilized farm land, nitrate levels in groundwater are not uncommon, due to overfertilization of fields. In urban settings,

Some 20 per cent of the world's population in 30 countries face water shortages. At any given time, half the people in developing countries are suffering from water-related diseases. (IFAD/Louis Dematteis)

The monitoring of tropical cyclones and the issue of advisories to media and populations are vital for the sustainability of socio-economic development in affected countries. (RSMC Tokyo-Typhoon Center)

leakage from underground storage tanks can pollute groundwater with gasoline, oil and chemicals. In coastal zones, saltwater intrusion, especially with sea-level rise, can contaminate community groundwater supplies and turn freshwater sections of estuaries into saline water. This is a particular problem in small island States which have limited groundwater and long coastlines. In some cases, costly desalination has been required to obtain potable supplies.

Planning for the future

Much research has been done on the effects of projected climate change on water availability in various regions. In northern regions of the northern hemisphere, most river flows are expected to increase. In the Mediterranean basin and the Sahel, drier conditions and low or zero flows are, at times, expected. In already arid and semi-arid regions, a small decrease in rainfall and an increase in evaporation can result in quite significant declines in runoff. On the other hand, in the North American Great Plains, peak discharge in spring floods has tended to be lower in recent decades because greater melting of snow cover in warmer winters has left the snow pack diminished at the time of the spring melt. Peak flood discharges have been increasing, in many cases, as rain intensities increase. This is a particular concern in countries affected by tropical cyclones.

Lakes are particularly vulnerable, with small changes in precipitation and evaporation resulting in relatively large changes in levels and water quality. Climate changes affect lake water in several ways. Greater soil erosion, with nutrients and toxics attached to sediment particles, due to higher intensity rains, is beginning to occur.

Temperate-region lakes can be affected by shorter ice-covered seasons. This can change the microclimate of the near-shore land zones by increasing frost-free periods, and the intensity of lake-effect snow squalls which result from cold air outbreaks over open warmer water.

Water quality, in already somewhat polluted lakes, is also beginning to be affected by warmer surface temperatures. These encourage increased phytoplankton growth near the surface which sinks to the bottom and decays, using up oxygen in the bottom waters and resulting in death and damage to flora and fauna.

Adaptation to changing water conditions

The projected 1.4–5.8°C global warning increase in the present century, as well as changes in precipitation patterns, will undoubtedly require increasing adaptation to changing water conditions. In the 1990s, an estimated 1.5 billion people were affected by floods and, in many cases, economic progress was set back many years. Flood damage-reduction measures are needed in many river and lake systems and improved drought-management techniques are needed in many regions.

This approach includes establishing reliable flood-forecasting and warning systems based on modern technology.

Moreover, increased erosion protection in the face of more intense rains will be required in many countries. Greater attention to reducing pollution will help protect water bodies and their ecosystems. Likewise, reducing unnecessary water losses in irrigation and urban systems can save water for more productive uses. The need for, and costs and benefits of, these and other possible adaptation measures, can be assessed by adopting a risk-management approach.

The quantity and quality of water in lakes are particularly vulnerable to even small changes in precipitation and evaporation.
(B. Pikhanov/WMO)

ENVIRONMENTAL AND HUMAN HEALTH

Long-range transport of pollutants

Data from WMO's Global Atmospheric Watch stations and from wind and atmospheric circulation measurements reveal that some pollutants are transported long distances and across borders. Perhaps the best known aspect of this phenomenon is the so-called "acid rain". Emissions of sulphur dioxide and nitrogen oxide are transported long distances. These chemicals react with water droplets in clouds and result in sulphate and nitrate deposition, thus increasing the acidity of rain and snow at locations far from the origin of the pollutants. This has been seen to cause acidification in lakes and the degradation of soils and forests.

International agreements have resulted in significant reductions in sulphate emissions and deposition, but other emissions continue. Thus, while lake acidification in some affected areas is not worsening, the overall improvements which were hoped for have not generally been achieved.

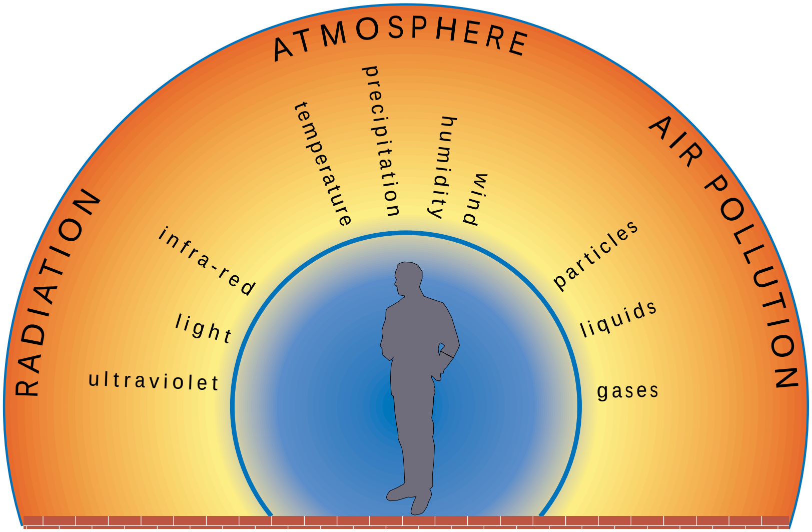
Toxic metals and organic contaminants are a major source of pollution of the Mediterranean—greater than riverine sources for certain pollutants. Mercury emissions to the atmosphere from all continents often end up in the food chain. The Arctic region

Cleaning up after an oil spill. Meteorological information is a valuable aid. (Helge Sunde) receives persistent pollutants through the atmosphere, which tend to concentrate in the cold water, air and ecosystems and, through the biota, in foods. Indigenous people on some Arctic islands and in Greenland have been detected with concentrations of contaminants in their bodies above those considered safe. The persistent toxic substances transmitted by the atmosphere have serious health implications.

Owing to atmospheric transport mechanisms, the emissions of harmful substances can have not only local effects, but can also affect people and ecosystems far away. International cooperation in the monitoring and prediction of the transport of pollutants is essential to address this problem. In the context of WMO's emergency response activities, its Regional Meteorological Specialized Centres monitor and provide information on human-induced and other environmental incidents.

Impacts of natural disasters

While the economic impacts of weather, climate and water events and conditions are significant, their effects on human health are often overlooked. The more obvious are those associated with natural disasters and severe weather events. The numbers of deaths after such events are made known, but not always the numbers of those whose health and well-being are affected. For example, over the last three decades, the number of people killed in disasters of all kinds was 4.7 million, while the number adversely affected was 2.1 billion. After a severe flood or tropical storm, housing and



safe water supplies are at serious risk and major water-borne disease outbreaks can occur. Droughts bring famine and, ultimately, leave millions of children and adults malnourished and starving.

Vector- and water-borne diseases

Water-borne diseases often accompany warm episodes or trends towards higher water temperatures. In the oceans, toxic algae have increased in frequency, range and virulence over the past 15 years. Such algae can pass their toxicity to humans through the consumption of fish and molluscs. High ocean temperature episodes also cause coral bleaching, and death of reefs and of fish and shell-fish. This has a serious impact on those communities for which sea food is the main source of protein.

Changes in climate can induce the spread of many vector-borne diseases, especially

Weather- and climate-monitoring systems incorporating health indicators result in public warnings such as for heatwaves and hazardous air pollution.

those transmitted by mosquitoes, which breed in shallow ponds. It has been noted that the incidence of malaria in Colombia is closely related to ENSO, with high numbers of cases in the warm, wet El Niño periods. The present worldwide toll of malaria is 400–500 million cases and 1 million deaths per year. With a warming climate, the range of malaria-bearing mosquitoes is expected to extend further into subtropical and even temperate climate zones and to move to higher elevations. The latter effect has already been observed in parts of Africa and South America. Dengue fever currently affects tens of millions of people per year and is expected, like malaria, to increase in range altitudinally with warmer temperatures and shift to more temperate climate zones. Many other vector-borne diseases, such as schistosomiasis transmitted by a water snail, are influenced by water and air temperature, as well as by precipitation. Public health organizations should increase their levels of prevention and preparedness, especially in newly affected areas, taking into account meteorological and hydrological parameters.

Ozone

Respiratory problems, especially asthma, are often associated with smog conditions in cities. Among the harmful constituents of smog are small particles from smoke stacks and vehicles which can lodge in human lungs together with their acidic or toxic chemicals. Another important smog component is ozone. The occurrence of smog episodes is controlled by weather conditions

The inhabitants of developing countries are particularly vulnerable to climatic variations and extremes.
(A. Rahim Peu)

as well as by emissions. They require sunshine to cause the chemical transformations involved, stable conditions in the lower atmosphere to limit the upward dispersion of the pollutants, and high temperatures. Climate warming is likely to cause more health problems with increasing smog and ozone episodes.

Ozone is also concentrated in the stratosphere some 15–25 km above the surface of the Earth and in its natural state provides health benefits, rather than health problems which it causes when near the ground. The ozone layer protects humans, plants, aquatic life and animals from the harmful effects of ultraviolet B (UV-B) radiation from the Sun. This form of radiation causes skin cancer, cataracts, and damage to the human immune system. Human actions have again intervened in the natural processes which long maintained stratospheric ozone, by emitting ozone-depleting substances, such as chlorofluorocarbons from industrial and cooling processes. Alarmed by clear evidence of mid-latitude declines in the ozone layer, averaging 5–6 per cent, and by as much as 50 per cent during the Antarctic spring, countries agreed to the Montreal Protocol on Substances that Deplete the Ozone Layer. The assessments of ozone-layer depletion were based on measurements provided by the WMO GAW, British Antarctic expeditions and the US National Aeronautics and Space Administration (NASA). The Protocol has been successful in significantly reducing such emissions, and in halting further decline of the ozone layer. However, since the ozone-formation process is slow, it is expected that the ozone layer will take several decades to heal. Research has also shown that there is a linkage between the climate of the stratosphere, strongly influenced by ozone depletion, and surface climate. This is especially so in the Antarctic.

A depleted ozone layer means increased ultraviolet radiation and a higher risk of diseases such as skin cancer.
(S. Béliveau/WMO)

Adaptation measures

Steps can be taken to reduce adverse health impacts arising from variations in air and water quality. Many of these are public health measures, but others must be taken at the individual level. The results of UV-B radiation monitoring are widely and routinely disseminated to the public today.

For episodes of smog and heat stress, weather forecasts can play important roles. Warnings of high temperatures and smog, based on weather forecasts, are being used in a number of cities to limit emissions and/or to move susceptible citizens and the elderly to air-conditioned facilities. These precautions can reduce respiratory attacks and lower the death toll. Seasonal climate forecasts have also been used to predict the likely future incidence of dengue-bearing mosquitoes.

To address the health implications of the long-range transport of pollutants, increased study is required of atmospheric and ocean transport mechanisms and transformation of contaminants in the atmosphere. Such investigations can reveal the source of contaminants reaching a given location or receptor, be it a lake, a forest or an urban area. The source countries must then take appropriate action within the framework of international agreements to reduce harmful emissions.

In short, there are many adaptation measures that can minimize health impacts. Some of the most useful actions depend directly on weather and hydrological forecasts and their availability through the various channels of public communication. For longer-term adaptation to floods, droughts, increased heat and pollution, reliable projections of future climate changes are needed. Cooperative international studies, under the World Climate Research Programme (WCRP) coordinated by WMO, the Intergovernmental Oceanographic Commission and the International Council for Science, are leading to continued improvements in the reliability of climate change projections.

OCEANS, WEATHER AND CLIMATE

Changes in ocean systems have also been profound. From a biological perspective, more than 50 per cent of coastal mangroves have been removed, productive wetlands along the coasts have shrunk by more than one-third, and over-exploitation of marine fisheries now affects over 50 per cent of the stocks. The oceans exchange heat, water, carbon dioxide and certain chemicals with the atmosphere. Their currents transport a significant amount of heat from the tropics to the poles.

Ocean-climate variability

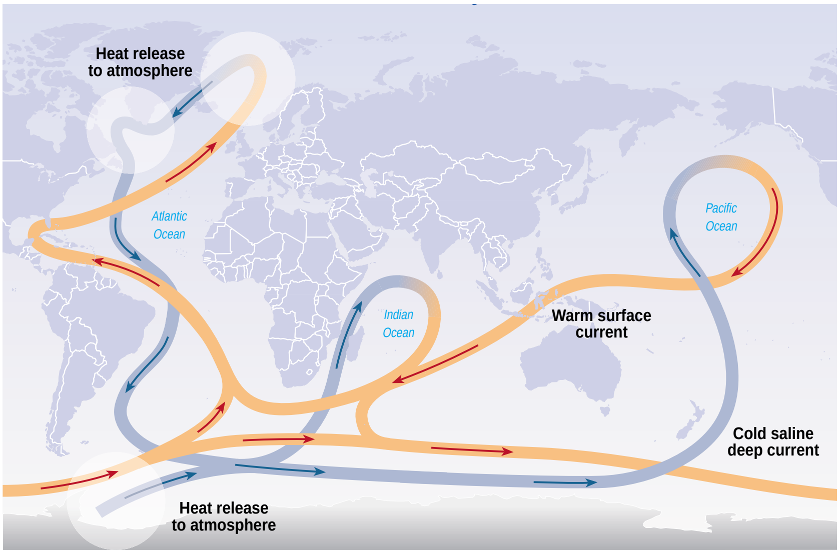
At the same time, oceans play a key role in climate variations, especially on a seasonal and multi-annual basis, through close links between ocean temperatures and currents, and the overlying atmosphere. Of these, the El Niño/Southern Oscillation of the Pacific is well known. Others include the North Atlantic Oscillation and the Pacific Decadal Oscillation (PDO)

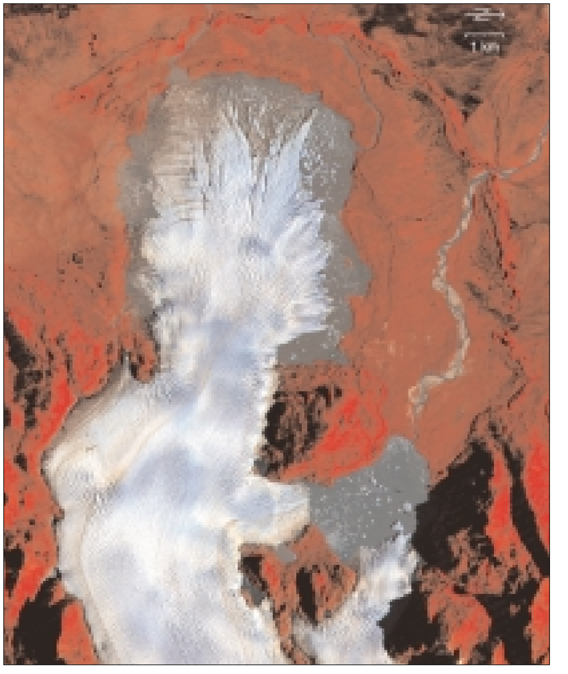
Major shifts in the PDO observed over the past century, most recently in the mid- to late 1970s, have been associated with warmer and drier climate conditions in western North America. They also resulted in a regime shift in ecosystems of the North Pacific affecting zooplankton, shrimp and salmon populations and some 100 other biological and environmental variables.

Oceans and climate change

In addition to short-term seasonal and interannual changes in the ocean, long-term changes also take place, which will affect climate. The upper 300 m of the global oceans have been warming since the mid-1970s. Analysis of heat content in intermediate and deep waters also indicates a warming trend, especially in the Atlantic and South Indian Oceans. This warming of the vast ocean waters will have long-term implications for global climate.

Better understanding of the ocean circulation's role in climate has resulted in improved models for use in weather and ocean forecasting and for climate studies.





Satellite observations of glaciers contribute to understanding of natural hazards, environmental evolution and the water cycle.
(NASA/GSFC/MITI/ERSDAC/JAROS and USA/Japan ASTER Science Team)

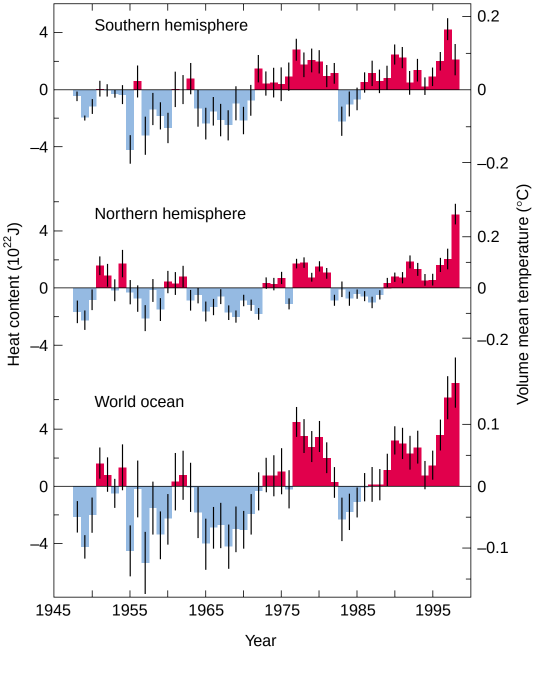
Sea-ice

The melting of sea-ice at high latitudes can greatly alter the planet's energy balance. Ice surfaces reflect most incoming solar energy but open water absorbs almost all, i.e. it has much lower reflectivity. This melting amplifies climate warming at high latitudes. Observed and modelled sea-ice extent from 1900 to 2050 for the northern hemisphere suggests continued loss of Arctic ice and subsequent profound effects on regional and global climate.

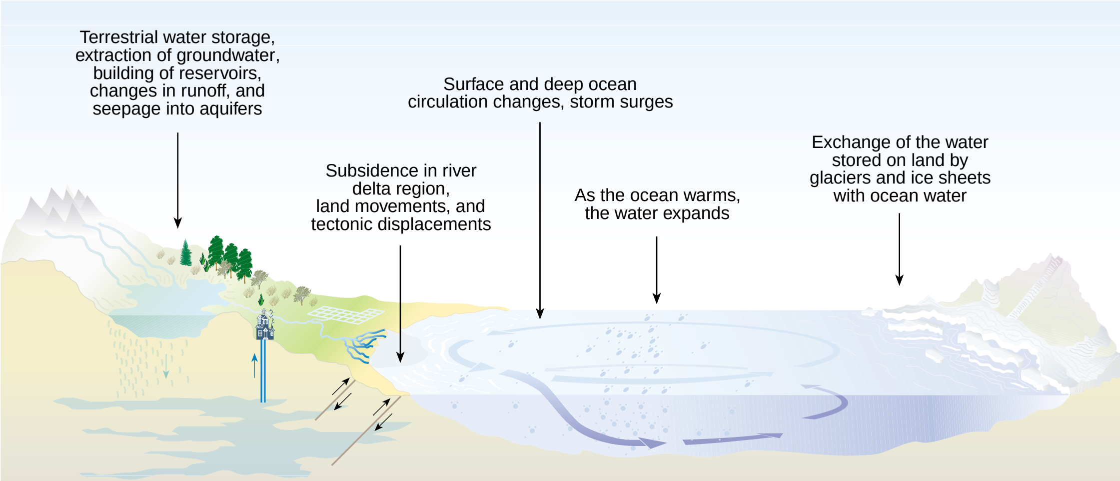
Sea-level rise

A major concern for coastal communities is projected sea-level rise. The expansion of ocean water due to higher water temperatures has been the largest contributor to the rising seas and is expected to continue to be so. The estimated rate of mean sea-level rise from 1910 to 1990 was between 1 and 2 mm/year. Glacier melt is also a significant contributor. One confounding factor, which is difficult to estimate, is the increase in the past century in the amount of water prevented from flowing to the oceans by dams and reservoirs on rivers and other human water withdrawals.

A summary of the projected range of mean sea-level increases by 2050 and 2080 is given in the table overleaf. The range reflects the uncertainties in both the modelling of sea-level rise and future emission scenarios.



Ocean heat content changes 1948-1998
(Climate Change 2001, The Scientific Basis, IPCC, WG I)



What causes sea level to change?
(Climate Change 2001, Synthesis Report)

There is a long lag time from greenhouse-gas emissions to sea-level rise. This means that sea-level would continue to rise for several hundreds of years at the current level of emissions.

Operational issues

To achieve safety at sea requires being prepared for severe storms and high waves. Close cooperation between the meteorological, oceanographic and marine user communities is needed to provide the necessary advisories or warnings. Just as airlines save fuel and time by taking maximum advantage of forecast winds in the upper atmosphere, so ship routeing strategies based on meteorological and oceanographic predictions can save time and money on long voyages.

In order to address these and other ocean-atmosphere issues, WMO maintains close cooperation with the Intergovernmental Oceanographic Commission of UNESCO. These bodies have long been partners and have established the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) to address operational issues, such as coordinating observing systems at sea using various kinds of buoys, ships and satellites. Many recent technological developments for measurements at sea are being deployed to improve understanding of air-sea interactions and provide services for marine users.

Some 3 000 Argo floats gather both temperature profiles down to 2 000 m and

Projected mean sea-level changes

	Scenario 1 (low)	Scenario 2 (high)
2050	0.08 m	0.44 m
2080	0.13 m	0.70 m
Eventual	0.50 m	2.00 m

Mean sea-level rise
(Source: IPCC, 2001)

Meteorologists and oceanographers work together for the protection of life and property at sea and the safeguarding of the oceans.

measurements of subsurface currents, and then rise up to the surface to transmit the collected data by satellite relay. These data complement the weather and water temperature observations collected by more than 6 000 voluntary observing ships, 1 000 drifting buoys, 300 fixed buoys and 600 fixed platforms. The latter three types of systems make both meteorological and oceanographic measurements. These observational systems, along with remote-sensing by satellites, provide full coverage of the oceans for operational forecasts and warnings, and for research as part of the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS).

Among the important frameworks for operational use of better forecasts and warnings over the high seas is the International Convention for the Safety of Life at Sea (SOLAS), which now incorporates the Global Maritime Disaster and Safety System (GMDSS) of the International Maritime Organization.

Many NMHSs are concerned with predictions for coastal zones. These predictions are required on a real-time operational basis for the safety of near-shore fishermen, for harbour operation and maintenance, for recreation and for other uses, including coastal development. The complexity of the interactions of land and sea breezes, ocean currents, waves, tides and surges, and inflow from rivers, makes operational prediction in the coastal zone a special challenge. Determining the impact of storm surges and waves on beaches, shoreline erosion, saltwater intrusion in freshwater aquifers and upstream in estuaries, protection of coral reefs and fisheries, are issues to be addressed, even more so with the threat of higher temperatures and rising sea-level.

Marine pollution incidents also threaten coastlines and near-shore biological resources, algae, shellfish, fish, seabirds and vegetation. Techniques have been evolving for corralling or dispersing oil slicks, as their movements depend on the winds and ocean currents at the time of the incident, as well as immediately after. Meteorologists and oceanographers are therefore key players in the Marine Pollution and Emergency Response Support System (MPERSS) for international waters. These professionals are among the first to be consulted on spills within national coastal waters and inland waterways.

The provision of this wide range of marine services is facilitated by innovative technologies which are constantly adapting to users' requirements.

THE ENERGY CONNECTION

Weather and hydrological forecasts are used both to meet demands and to schedule the production and distribution of electricity and natural gas more efficiently. In temperate zones, the highest energy demands occur on very cold days for heating and very hot days for air conditioning. Similarly, forecasts of inflow to reservoirs allow more efficient use of water for hydropower production. Some utilities employ meteorologists and hydrologists to tailor forecasts from NMHSs to achieve maximum efficiency benefits.

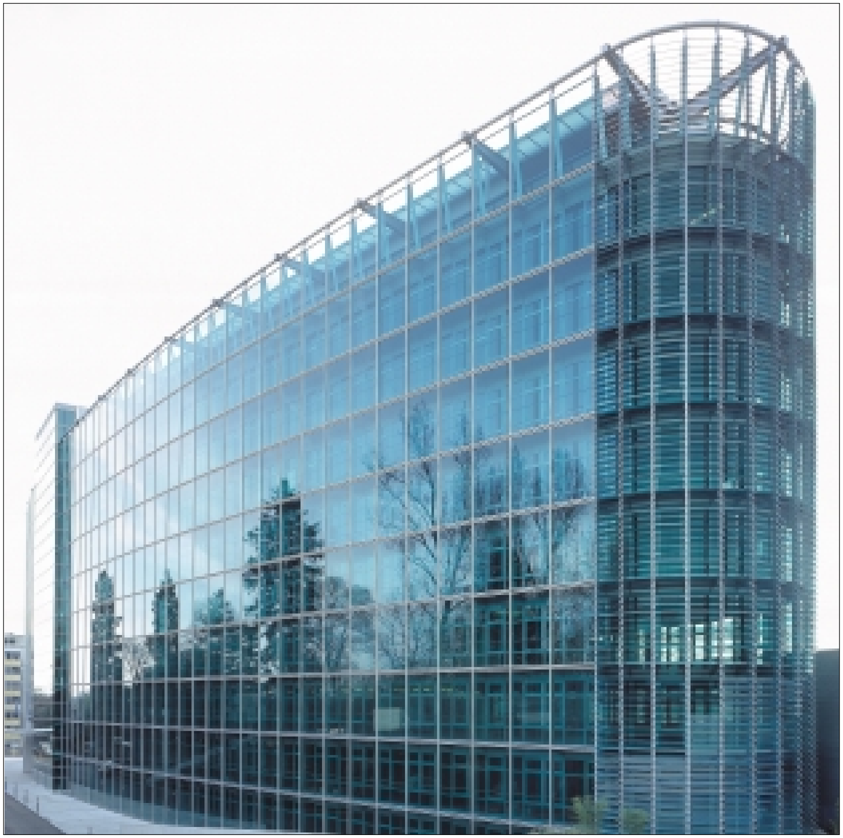
On considering whether less carbon-intensive scenarios continue to serve the growing energy needs of a much larger world population, the following issues must be considered.

Wind energy: selecting optimum sites for wind farms is not a simple matter. Not only does there need to be an assessment of average, lowest and highest general air movement in the area, on a daily, monthly and annual basis, but also the microscale influences, due to small changes in land elevation, vegetation, buildings, etc., can affect both local winds and economic return. Of the renewable sources of electricity, the price of wind power is closest to that of electricity from fossil fuels. The technical potential of wind power is estimated at 1.5 times current world energy use.

Solar energy: this form of energy has costs that continue to decline but, at present, remain generally higher than those of fossil fuels. However, direct water heating by solar energy is generally cheap, and has great potential in tropical and subtropical areas. As one moves away from the tropics or desert areas, a more careful analysis of hours of sunshine and solar intensity can be helpful in determining the economic returns.

Hydropower: this form of energy provides some 20 per cent of global electricity. The additional technically usable potential is estimated to exceed present production, but that which is considered economically viable at

Hydropower has great potential for future electricity production. Hydrometeorological data are required for the design and safety of structures and optimal exploitation.
(William Torres)



The WMO Headquarters building reflects the Organization's concerns for local and global environments. Optimal yet environmentally friendly use is made of heat retention and cooling and the penetration of light.

current electricity prices would yield a 50–80 per cent increase over present production. To design a dam and hydropower project, hydrometeorologists must analyse and extrapolate hydrometric and climatic records to assess the 1 000-year return period flood, for example. For dams upstream of populated areas, hydrometeorologists must use physical means to assess the probable maximum precipitation and flood, in order to ensure safety of the structure itself. Estimates of minimum flows likely to occur and maximum evaporation loss also lead to appraising the long-term economic viability of the project.

Biomass energy: the greater use of biomass-derived products such as biogas and ethanol as vehicle fuel or to co-generate electricity and central heating, can make significant contributions to the energy mix. Wood is already in common use in many countries. If biomass use is followed by replanting farm crops or trees, it can be substituted for fossil fuels, and carbon dioxide emissions can thus be significantly reduced.

CONCLUSIONS

Information age technology offers the most promising prospects for humanity to benefit from the advances in meteorology, hydrology and related geophysical sciences. Computer applications are ubiquitous, space-based technologies are revolutionizing environmental observation systems, and modern communications, including the Internet, are facilitating global and regional cooperation.

Information technology is important for everyone. Radio, television and the Internet enable warnings of storms, floods and droughts to reach populations quickly. At the same time, people are made aware of the devastation caused by these phenomena through daily reports and images. This, in turn, makes preparedness a much more urgent matter in the public eye.

At the same time, public media provide scientific information on weather, climate, water and the environment. The public media are essential partners in transmitting authoritative scientific information on atmospheric, climate and water issues and in helping to disseminate weather information and warnings. It is, therefore, imperative that National Meteorological and Hydrological Services, as well as professionals in the area, work effectively with them.

In protecting the global environment and managing Earth's resources efficiently, we are arriving at several crossroads. Scientific efforts need to be accelerated to be able to predict the effects of human activity with more certainty. Public and political will to act upon what is already known needs to be stimulated and reinforced. Moreover, since many of the issues are transnational, and even global, international cooperation, through United Nations agencies such as WMO, needs vigorous support.

Above all, the developments of new technology must be encouraged and exploited fully in order to reduce adverse impacts of weather, climate and water but also to take full advantage of the positive benefits of these environmental resources. Special attention should be given to the needs of developing countries: support to their National Meteorological and Hydrological Services means benefit to the world as a whole.

The issues and dilemmas facing humankind early in the 21st century require increased emphasis on the meteorological, hydrological and oceanographic sciences, the adoption of advanced environmentally sensitive technology, and the full exploitation of new avenues of scientific and public communication.

Despite all our efforts we were unable to identify the photographer of the photo on page 18. We have included the photo in the belief that the photographer would want to have his/her work included in this booklet

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