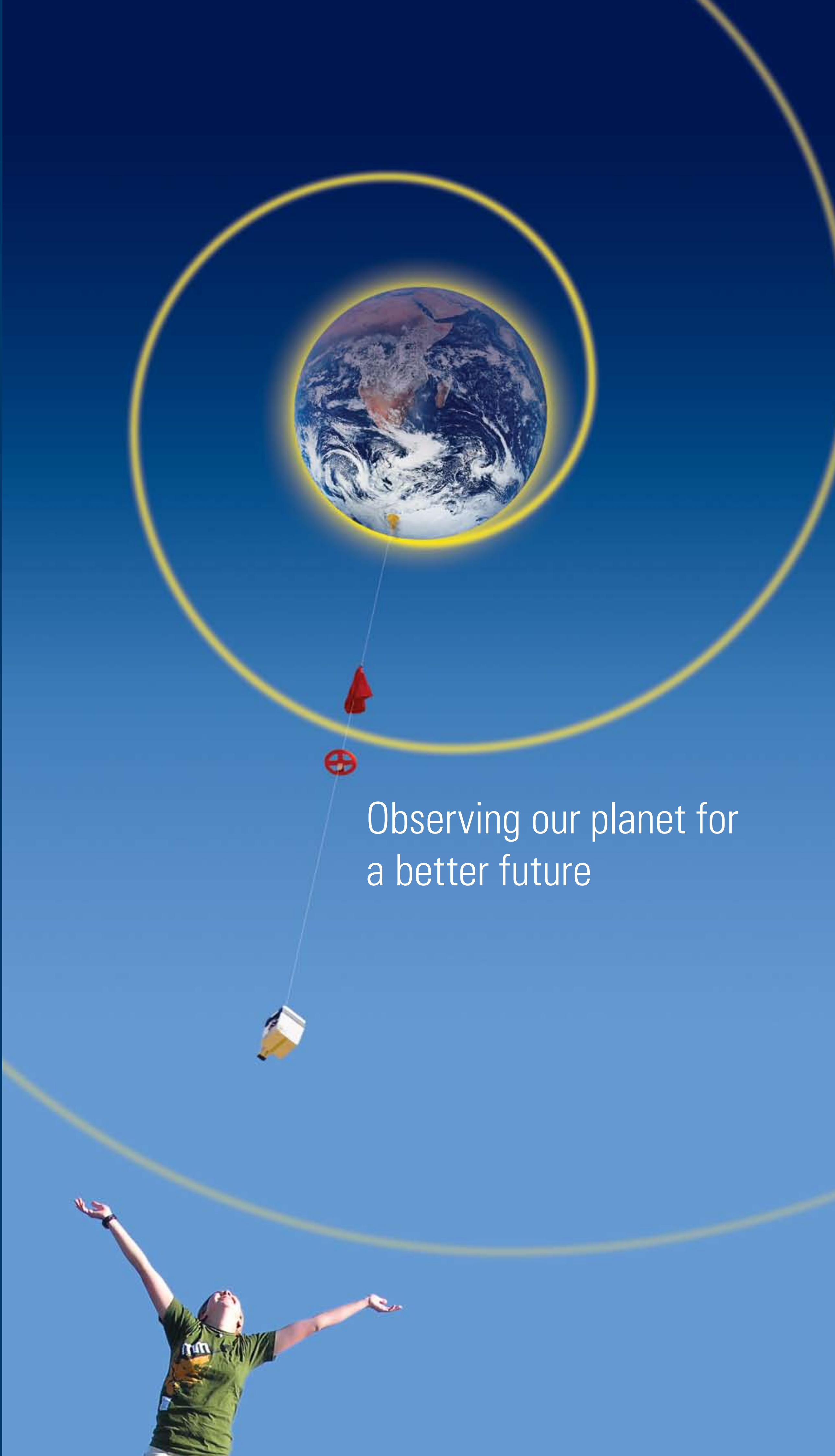

Observing our planet for a better future

World Meteorological Organization
Weather • Climate • Water

WMO - No. 1030

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ISBN 92-63-11030-1

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FOREWORD

Michel Jarraud, Secretary-General

Every year on 23 March, the World Meteorological Organization, its 188 Members and the international meteorological community celebrate World Meteorological Day, commemorating the entry-into-force on that day in 1950 of the WMO Convention creating the Organization. I wish to recall that WMO thereby assumed the responsibilities of its predecessor, the International Meteorological Organization, which had coordinated international cooperation in meteorology since 1873. In 1951, WMO was designated a specialized agency of the United Nations system.

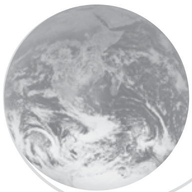
On the occasion of its 58th session (Geneva, 20-30 June 2006), the WMO Executive Council decided that the theme for the World Meteorological Day 2008 would be "Observing our planet for a better future", in recognition of the scientific and socio-economic benefits derived by WMO Members and their National Meteorological and Hydrological Services (NMHSs) from the expanded, wide-ranging and authoritative observations made in the context of WMO's mandated activities in weather, climate and water.

Fifteenth World Meteorological Congress (Geneva, 7-25 May 2007) supported this key concept and approved the enhanced integration of all WMO observing systems through the establishment of a comprehensive, coordinated and sustainable structure ensuring interoperability between its component observing systems. Congress decided to refer to this initiative as the WMO Integrated Global Observing System (WIGOS), which should proceed in parallel with the planning and implementation of the new WMO Information System (WIS). This would allow for an integrated WMO system of systems designed to improve the capability of Members to effectively provide a widening range of services and to better serve WMO research programme requirements.

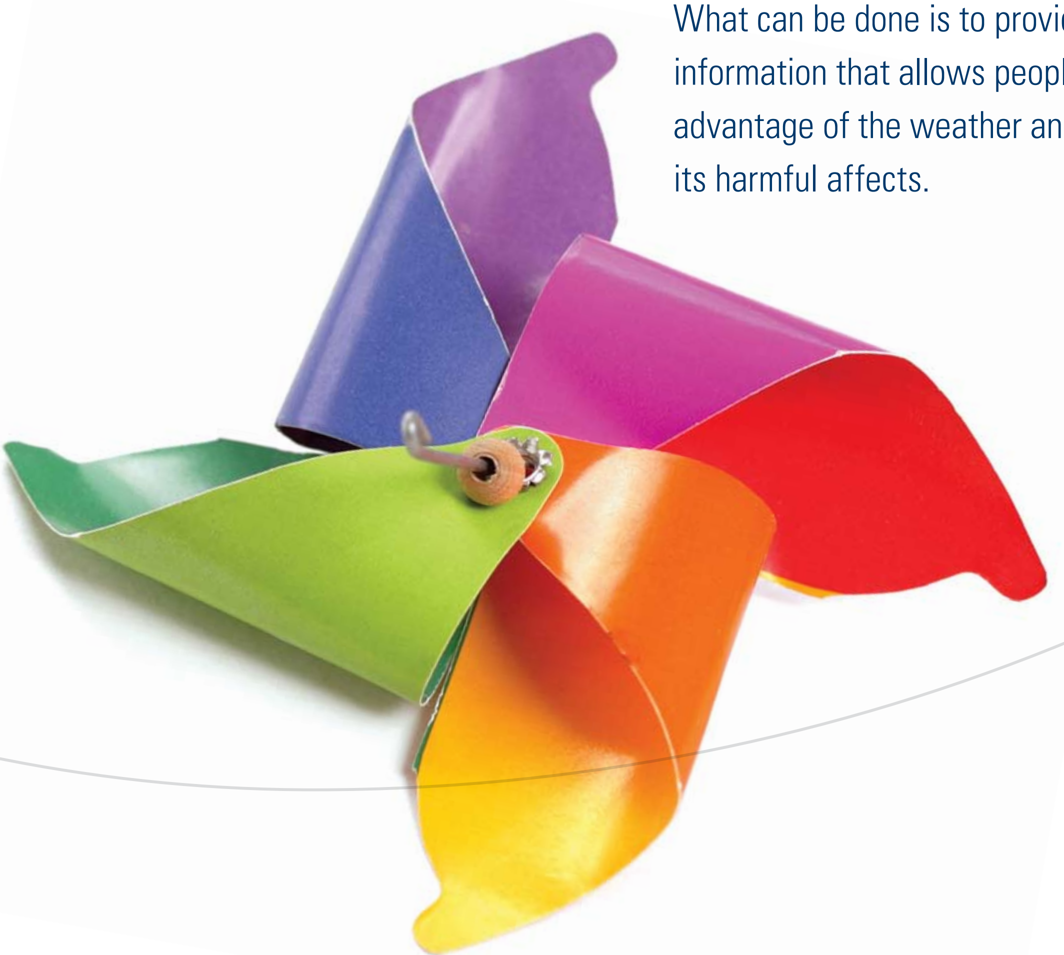
I am confident that this publication will be useful to WMO Members, in particular to their decision-makers, financial experts and emergency response managers, currently in the process of implementing and upgrading their respective observing systems, especially their end-to-end multi-hazard early warning systems and environmental data-acquisition capabilities. These systems and capabilities will become ever more vital to them in the context of a changing climate and an economy increasingly sensitive to hydro-meteorological impacts.

I wish to congratulate all WMO Members on the occasion of the World Meteorological Day 2008.

(M. Jarraud)
Secretary-General



"Everybody talks about the weather, but nobody does anything about it." (popularly attributed to Mark Twain, 1835-1910)
What can be done is to provide information that allows people to take advantage of the weather and minimize its harmful affects.



DORA MITSONIA

OBSERVATION—A BASIC BUILDING BLOCK

Weather, climate and water have an impact on almost every facet of life. The public and decision-makers are therefore increasingly concerned about the degradation of the environment, more frequent occurrences of natural disasters with projected climate change and the impacts on human survival and well-being.

Awareness of Earth's dwindling resources and the adverse impact of human activities on the environment and the climate are largely the result over the last 150 years of systematic monitoring, sharing and application of authoritative, quality-controlled and timely information about weather, climate, freshwater and the oceans. Such information is available freely and readily to all nations.

In this historic task, the National Meteorological and Hydrological Services (NMHSs) of Members of the World Meteorological Organization (WMO) have played a pioneering role in developing and maintaining an operational observational system. Other monitoring systems such as those of ecosystems have evolved as complementary components. Today, all these observations form the foundation for the provision of reliable and steady services and products required in short-term or long-term decision-making for a sustainable future.

USES OF OBSERVATIONS

Advances in science and technology in observing the atmosphere, water and oceans and in predicting their future states have been harnessed with considerable success for the benefit of humanity.

Almost every aspect of human endeavour requires information about weather, climate and water. Observations or the information derived from them are used in countless ways in decision-making. The corresponding uses can be grouped broadly as follows:

- Reducing human suffering and enhancing the safety of life, property and well-being by mitigating the impact of natural disasters and improving and sustaining health;
- Improving the efficiency and effectiveness of a wide range of weather-sensitive activities such as agriculture, water-resources management, energy, transportation, leisure and tourism, as well as ecosystem and land-resources management;
- Providing the necessary tools to decision-makers for addressing current issues and policy-making in long-term concerns such as climate change and its impacts;
- Contributing to the protection of the environment and supporting sustainable development.

Access to such services requires the availability of adequate facilities and human resources to transform the basic meteorological, climatological and hydrological observations into useful products. It is particularly crucial for developing countries not only to make and access observations but also to have the capability to apply them to meet their present and future needs.

DATA ANALYSIS AND ASSIMILATION

To predict the weather even a short time ahead, it is essential to know the current state of the atmosphere—this provides the starting conditions for numerical weather prediction (NWP) models. Regular observations on land, at sea (ships and buoys), in the air (radiosondes and aircraft) and in space from satellites provide us with information about pressure, temperature, wind speed and direction and humidity.

In practice, however, this is not sufficient for an unambiguous representation of the atmosphere. In addition to the errors we would expect from any set of measurements, the geographic and temporal distribution of observations is rather uneven with some areas and levels in the atmosphere covered poorly or not at all. Earlier forecasts are available, however, which provide full geographic coverage and we know that the atmosphere evolves according to well-known physical principles.

Bringing the observational and forecast data together in a mathematically rigorous fashion and ensuring the component fields are in physical balance is a process known as data assimilation: the estimate of the state of the atmosphere obtained is called the analysis.

TURNING OBSERVATIONS INTO SERVICES

Every day, hundreds of thousands of observations are made by all countries. Although most of them are used nationally, many are exchanged regionally or globally through an agreement concluded by WMO. Observations from ground-based stations, satellites, ocean buoys, ships, aircraft and weather radars are used in analysing the extent, intensity, structure and other features of weather patterns. They are also used in understanding past weather and climate conditions. Observations are the starting point for forecasts and predictions on time-scales ranging from tens of minutes for a

WORLD BANK

More and increasingly accurate observations yield more and increasingly useful and targeted products and services for socio-economic benefit, sustainable development and human well-being on a daily basis.

International cooperation for comprehensive monitoring

As weather, climate and the water cycle know no national boundaries, international cooperation in observing these fields is vital. WMO provides the framework for such international cooperation.

WMO promotes cooperation in the establishment of networks for making meteorological, climatological, hydrological and other geophysical observations, as well as for facilitating the free and unrestricted exchange of data and information, products and services, processing and standardization of related data. It assists in technology transfer and in training and research. It also fosters interdisciplinary and multidisciplinary collaboration, as well as cooperation with other relevant organizations, the academic community, the media and the private sector.

The National Meteorological and Hydrological Services of WMO Members use the platforms and the opportunities provided by WMO to enhance their capacity and contribute substantially to the protection of life and property against natural hazards, to enhancing the economic and social well-being of all sectors of society and to safeguarding the natural environment for the future.

tornado to several days for a tropical cyclone, a week or more for a heat wave and beyond to seasonal and climate projections over decades or a century or more.

In view of the large volume of information available, powerful supercomputers are used to model the weather systems and predict their evolution using numerical weather prediction techniques. A five-day forecast today is as reliable as a two-day forecast 20 years ago. All countries are able to access such information on the global or regional scale and use it, together with their own observations, to develop products that meet their domestic requirements. This is facilitated by the availability of computers that are readily accessible and affordable. The products are aimed at local, national and regional decision-makers, business, industry and service sectors and the general public.

There is also a growing demand for specialized services. These include detailed and accurate short-term localized forecasts for sporting events and monitoring wind-shear conditions for take-off and landing at airports.

Numerical prediction systems are also being used effectively to make forecasts on time-scales of a month, a season or a year ahead of slow evolving phenomena such as El Niño and La Niña and their impacts on the regional or global scale. For such predictions, interaction with ocean parameters such as sea-surface temperature is critical.

In a modified form, taking into account the atmosphere, ocean and a growing range of other parameters, the models are being used to project climate decades to a century or more ahead. The projections of climate change and its potential impacts have become more reliable and are

NOAA

Voluntary observing ships and moored and drifting buoys are vital components of WMO's observing systems. These systems flourish thanks to the steadfast cooperation of WMO Members in recognition of the fact that weather and climate know no boundaries.

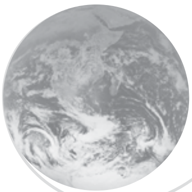
being increasingly used for policy-making on long-term issues such as the mitigation of climate change and sustainable development for future generations.

COOPERATING TO OBSERVE OUR PLANET

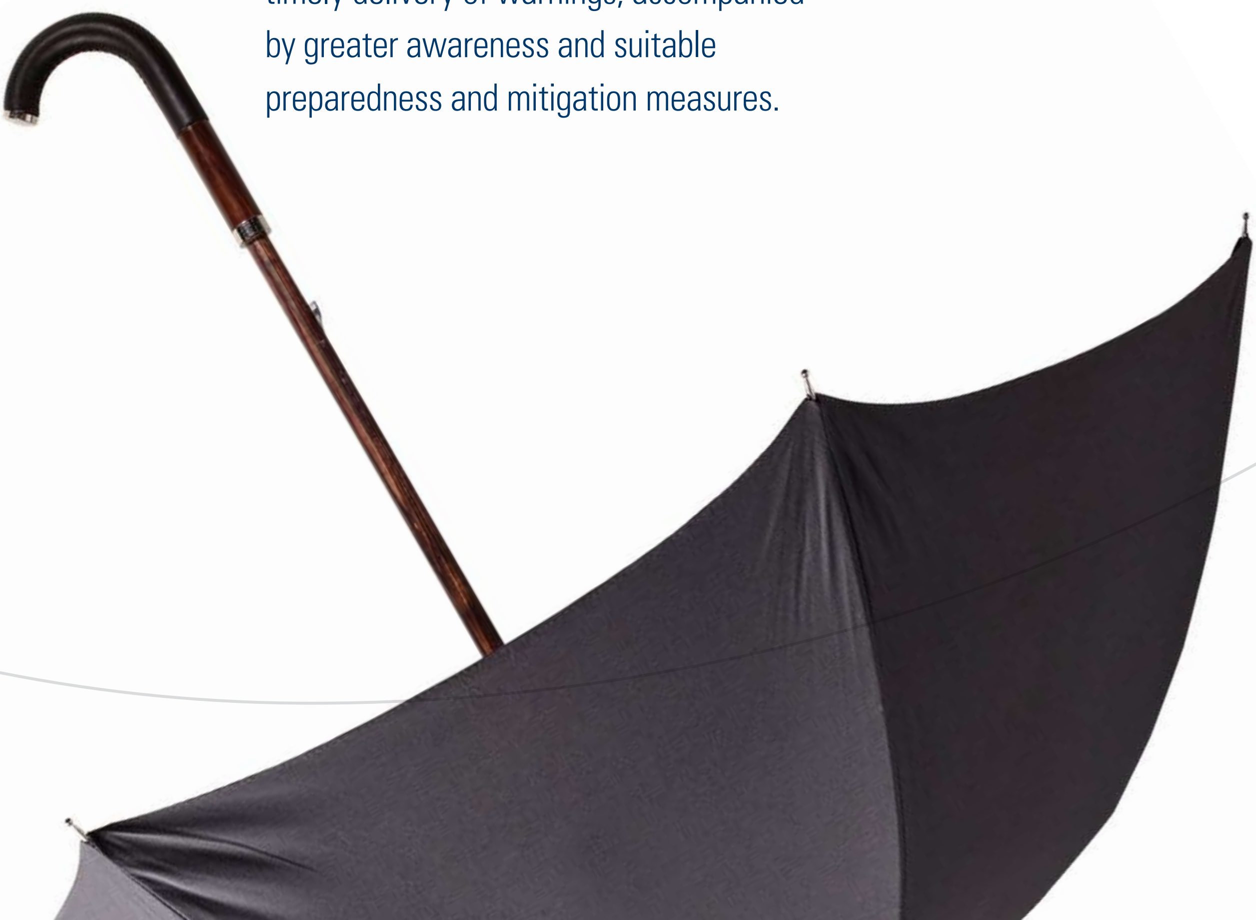
The development and availability of innumerable products in response to new requirements have been possible, thanks to a corresponding development in technologies for the monitoring of the atmosphere, freshwater bodies, the oceans, the land surface and the ecosystem in general. For example, new instruments on board satellites provide a continuous and an ever-wider range of environmental information.

The required frequency and density of observations at the surface and at various levels in the atmosphere depend on the scale of the meteorological phenomena being analysed and forecast. Short-term forecasts require frequent observations from a dense surface network for a limited area to detect small-scale phenomena and their development (particularly important for severe weather events such as tornadoes). As the length of the forecast period increases, so does the area from which observations are required. This means that forecasts for three to five days ahead require global observations.

Each country makes the observations it needs for its national purposes, at its own expense. In accordance with an international agreement adopted under the auspices of WMO, however, each country shares some of the observations and receives freely and in an unrestricted manner observations made by other nations, as well as products from global and regional centres. Some of these centres provide advisories on tropical cyclones, regional and global weather forecasts or specialized products, such as those on the transport of pollutants across national boundaries. The maintenance of a global observing system and a global telecommunication system for the exchange of observations, as well as the development and sharing of forecast products at major centres, is a unique feature of international cooperation in meteorology.



Natural hazards represent a growing threat to the safety of life and property. The best safeguard involves improved monitoring, more accurate prediction and timely delivery of warnings, accompanied by greater awareness and suitable preparedness and mitigation measures.



ISTOCKPHOTO.COM

ENHANCING SAFETY, CONTRIBUTING TO WELFARE AND PROSPERITY

Between 1980 and 2007, disasters related to weather, climate and water caused the deaths of 1.3 million people. The corresponding cost to the economy is estimated to have been more than US$ 1.2 trillion.

Experience in many parts of the world has shown that the provision of early warnings of the occurrence of floods and severe weather, such as violent storms, tornadoes and tropical cyclones, and of services, such as risk and vulnerability assessments for policy-makers and those involved in disaster mitigation and rehabilitation, can significantly reduce the harmful effects of natural hazards.

As the observed recent increase in the number of natural disasters and their adverse consequences are expected to continue, early warnings based on more refined observations and accurate forecasts are vital for enhancing safety.

MAKING THE WORLD A SAFER PLACE

Climate variability and extreme events associated with weather, climate and water can dramatically affect lives and livelihoods: they threaten food security, reduce the availability of freshwater, increase the spread of disease and undermine development. The number of vulnerable communities has grown as a result of increased urbanization, population growth in fragile areas such as coasts, lowlands and floodplains, and the expansion of communities into arid zones. Any increase in the intensity and frequency of extreme events would exacerbate their vulnerability.

Generally speaking, a natural hazard becomes a natural disaster when there is destruction of life and property. Nine out of 10 natural disasters globally are related to weather, climate or water and evidence points to an increase in associated social, economic and environmental costs. Developing countries experience the worst impacts of natural disasters, as well as the greatest difficulty in recovering from them. Socio-economic development can be set back by several decades.

Some natural hazards affect large areas and are long-lasting (e.g. drought), whereas others are local and short-lived (e.g. tornadoes and violent thunderstorms). Droughts develop slowly and can affect most of a continent and huge populations for months or even years, with water supplies drying up, damage to health, crop failure, forest fires and death of livestock.

The more short-lived violent events are mostly associated with high winds and heavy rainfall or other forms of precipitation. Rainfall can lead to flash floods and mudslides. Floods threaten human life and property worldwide. Some 1.5 billion people were affected by floods in the last decade of the 20th century. Winter storms can bring high winds and heavy snow or freezing rain. Mountain areas are prone to avalanches. Accurate observations are essential for warnings of these severe weather events.

Observations of the atmosphere are used in computer models to provide an indication of the areas where tornadoes are likely to form. More detailed warnings about where the tornadoes will hit the ground are based on radar data that can detect their formation. The same kinds of techniques are used to forecast severe thunderstorms.

Observations from land, ships, other ocean platforms and satellites contribute to identifying the formation of a tropical cyclone, its intensity, extent and track. Doppler radars provide more detailed information as do reconnaissance flights, when possible. Reliable warnings can thus be given well in advance to those places which are likely to suffer from extreme weather engendered by a cyclone.

Decision-makers, both within governments and the private sector, and emergency response managers require information to formulate

NASA

In October 2007, powerful winds fuelled large wildfires in California, USA. Dense plumes of smoke stretched across hundreds of kilometres from Los Angeles to the Mexican border. The fires destroyed more than 1 300 homes, commercial buildings and forced more than 500 00 people from their homes. Satellite imagery facilitates the tracking of wildfires and smoke plumes and contributes to ensuring the safety and health of people and optimal functioning of socio-economic activities.

contingency plans in the event of severe weather occurring. This information is usually based on an analysis of the frequency, nature and intensity of past events and an assessment of vulnerability of local populations. In addition, there is a need for detailed forecasts of location and severity: this is only possible if adequate observations are available to ensure that the forecasts are accurate.

Some National Meteorological and Hydrological Services and specialized centres have responsibility for monitoring geophysical hazards, including volcanic explosions (airborne ash) and tsunamis, airborne matter (radionuclides, biological and chemical substances) and urban pollution.

Detailed satellite imagery allows for monitoring the extent and advance of wildfires and movement of the resulting smoke plumes. Firefighters use the information in their attempts to contain the flames, while residents may be warned to evacuate or take measures to protect themselves from the fumes, such as by staying indoors and wearing masks. Air and road transport agencies also benefit from warnings of fire and smoke which disrupt their operations and can cause chaos at airports and on roads.

Increasing emphasis is being placed on ensuring that everyone is fully prepared when the warnings are issued and be aware of the measures to be taken ahead and in the aftermath of the event. This involves equipping National Meteorological and

Information about severe weather

Severe weather can cause tremendous destruction and loss of life. It is important, therefore, that information about severe weather is made available effectively. National Meteorological and Hydrological Services (NMHSs) have responsibility for issuing warnings for their territory. WMO's Regional Specialized Meteorological Centres provide advisories on tropical cyclones occurring in all cyclone basins. A variety of mechanisms exists for disseminating them, in most of which the media play a key role.

The Severe Weather Information Centre (severe.worldweather.wmo.int) provides access to official warnings and information issued by Regional Specialized Meteorological Centres and NMHSs. They deal with tropical cyclones, heavy rain and snow and thunderstorms. In addition, official weather observations and forecasts and climatological information for selected cities supplied by NMHSs can be found at the World Weather Information Centre (worldweather.wmo.int). Both these Websites are developed and maintained by the Hong Kong (China) Observatory on behalf of WMO.

Information about extreme weather expected to occur in Europe can be found through meteoalarm (www.meteoalarm.eu), developed by EUMETNET, the Network of European Meteorological Services. This facility warns of the possible occurrence of heavy rain with risk of flooding, severe thunderstorms, gale-force winds, heat waves, forest fires, fog, snow or extreme cold with blizzards, avalanches or severe coastal tides. It also gives an indication of the severity of the danger and possible impacts.

Hydrological Services with sufficient infrastructure and skills and ensuring they have access to the widest range and types of observations and up-to-date forecasts to warn the public in a timely and effective manner. Collaboration with the media and educating the public on weather hazards and warnings are vital for making the world a safer place.

HUMAN-INDUCED DISASTERS

In the event of environmental emergencies with large-scale transboundary air pollution, caused in particular by major nuclear accidents, volcanic eruptions, chemical accidents, oil spills and land fires, WMO assists the National Meteorological and Hydrological Services, as well as other agencies and international organizations to respond effectively. This is done by designated regional centres through the provision of specialized products such as information about the intensity of the pollutants and the direction of their movement. Other services include the development and implementation of procedures for the provision and exchange of specific observational data and training for users.

SUPPORTING SOCIO-ECONOMIC ACTIVITY

Weather, climate and water information support specific socio-economic activities, such as agriculture, transport, energy production,

Monitoring and early warning of locust swarms

Desert locusts can inflict immense damage in Africa, Asia and the Middle East. A very small part of an average swarm (about one tonne of locusts) eats the same amount of food in one day as about 10 elephants or 2 500 people!

Locust populations are sensitive to environmental conditions. The development of eggs depends upon soil temperature and moisture. They can dry up if exposed to wind and be destroyed by flooding or high soil temperatures. Within a few months of breeding, huge swarms can form and fly downwind in search of food.

In favourable wind conditions, they can travel thousands of kilometres and threaten the food security and livelihoods of up to one-fifth of the world's population. Locust plagues between 2003 and 2005 cost an estimated US$ 400 million and affected 8.4 million people (source: Food and Agriculture Organization of the United Nations).

National Meteorological and Hydrological Services in affected countries support the monitoring and control of locusts by providing observations and forecasts of weather elements such as precipitation, temperature, humidity and wind. More generally, the World AgroMeteorological Information Service (www.wamis.org) affords access to a wide variety of near-real-time agrometeorological products.

leisure, health, water-resource management, and environment protection brings enormous benefits and contributes to the efficient use of the Earth's resources. Our ability to adapt to the weather and climate depends on having access to reliable meteorological and hydrological services.

Weather forecasts and derived products and services require an efficient global observing system. An integral part of that system is the timely exchange of accurate observations and the ability to process the data into useful products and services and make them available to users.

Weather, climate and water services support a wide range of socio-economic activities and environmental concerns. They fall into three broad categories: those based mainly on past data that support strategic decisions; current data used in the assessment of present conditions; and forecasts that are used for operational decisions for minutes to hours or days, a season or longer ahead. Projections of climate change and its potential impacts are vital to making decisions and adopting policy options for the future at national, regional and international levels.

Agriculture is one of the most weather-sensitive activities. Food security can be significantly enhanced by making observations of relevant meteorological and hydrological parameters. These are used to make both short-term and seasonal forecasts to increase the efficiency of agricultural production. As well as providing information on the likely weather, these services can also give early warnings of outbreaks of pests and diseases and the potential impacts of winds, drought and floods.

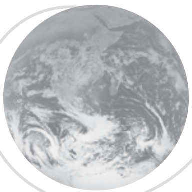
Transport and communications benefit from observations in support of operational and planning decisions. Forecasts are vital to minimize the impact of weather on day-to-day operations of aviation and marine and offshore activities, as well as road and rail transport. The services improve the efficiency of the various activities and help ensure they are safe, timely and efficient. Specialized services provided to the construction sector fulfil a similar role.

Energy production and use and water management are highly sensitive to local weather and climate conditions. Observations form the basis for forecasts for making strategic decisions. The day-to-day operation of these utilities is subject to customer demand, which, in turn, is often dependent on the weather. Services based on forecasts help ensure that demand can be met in a cost-effective way.

Renewable energy is an environmentally friendly and cost-effective option for all nations. The optimal siting and operation of such facilities are highly dependent on prevailing weather and climate conditions.

Seasonal forecasts are used in long-term planning, while projections of the potential impact of climate change are essential in planning for decades ahead. Risk assessment in the insurance industry can be complex; it needs to encompass climate-change scenarios, as many risk calculations based uniquely on historical data might not be representative of future conditions.

Public weather reports provided by radio, television and the Internet form an essential part of services provided today. They allow people to make decisions about activities associated with work, recreation and leisure, while warnings of severe weather events can help them take informed decisions affecting their safety and enjoyment.



Systematic observations of the Earth, that were initiated more than 150 years ago, are being pursued using increasingly sophisticated ground-based instruments, such as automatic weather stations and Doppler radars, or carried in balloons or dropsondes, or on board satellites. These observations form the basis of information for ensuring safety, efficient socio-economic activities and decision-making related to the climate.

OBSERVING OUR RESTLESS ATMOSPHERE

MAINTAINING A GLOBAL OBSERVING SYSTEM

The Global Observing System, a component of WMO's World Weather Watch, was developed in the 1960s. It consolidated and reorganized measurements made for over 150 years at the Earth's surface and the atmosphere. Subsequent technological developments have allowed the provision of timely and quality-controlled observations worldwide and for a growing number of elements to respond to evolving requirements.

The WMO Global Observing System comprises two major components. The *in situ* component provides observations from land and sea stations, aircraft and other platforms. Surface-based measurements can seldom be performed with the required density and geographical spread, so space-based observations are used to complement them and determine conditions over large areas, especially over the oceans. However, observations from space require ground truth to ensure reliability.

MAKING SURFACE OBSERVATIONS

More than 10 000 approved sites make land-based observations at least every three hours; some every hour. About 4 000 of these sites provide data that are exchanged globally in real-time.

The instruments at these sites provide quantitative information, including atmospheric pressure, wind speed and direction, air temperature, precipitation and humidity. To ensure consistency, international standards are set for the location of these instruments and observing procedures. The observers read the instruments and make visual observations of cloud amount, cloud type, visibility and type of weather. Some sites have additional instruments for making observations for specific use such as in agriculture, water-resources management and air-quality control.

Automatic weather stations have sophisticated sensors and processing algorithms. As they can be used without human intervention for long periods, they are being implemented more and more and are of particular value in remote or hostile environments.

Recruited under the WMO Voluntary Observing Ship Programme, some 7 000 ships make observations of the atmosphere and provide important information about sea temperature, wave height and wave period. Stationary platforms, such as oil rigs, provide similar observations. In data-sparse oceans, ship observations are complemented by those from moored and drifting buoys.

Observations taken at a particular location can be supplemented by detailed information from weather radars on the intensity and distribution of precipitation. A sequence of radar images provides information on the movement and development of rainfall systems, including those found during extreme events such as storms, tropical cyclones and tornadoes. Such information forms the basis for understanding the structure of the system and for producing warnings of heavy rainfall, potential flooding and landslides.

MONITORING THE ATMOSPHERE ALOFT

To understand the behaviour of the atmosphere and make forecasts of its future state, it is necessary to have information about the vertical structure of the atmosphere. Radiosondes are instruments that are carried up through the atmosphere by free-rising balloons filled with hydrogen or helium. They provide observations of pressure, temperature and humidity, which are sent back to ground stations by radio for processing. Wind profiles are derived from measuring the changes in the positions of a balloon with respect to its launch site.

There are about 900 upper-air stations worldwide, of which more than two-thirds make concurrent observations around the globe twice a day. Other stations make observations once a day.

So-called pilot balloons without any instruments are launched from some sites to provide wind measurements.

Instruments attached to a parachute and dropped from an aircraft are called "dropsondes". They provide the same information as radiosondes and are used mainly for research purposes or to gather information about the structure of a hurricane.

Traditional radiosondes are now being complemented in several locations by observations from wind profilers. A wind profiler in conjunction with a radio acoustic sounding system provides an almost continuous profile of wind and temperature near the ground.

Aircraft observations are another valuable source of information on conditions in the upper atmosphere. More than 3 000 aircraft provide more than 150 000 daily reports of pressure, temperature and wind during ascent and descent, as well as at cruising level. This information, provided from an automated aircraft meteorological data relay system, is especially useful over the oceans, from where there are little or no radiosonde data.

Small, robust, robotic aircraft called unmanned aerial vehicles (UAVs) can fly safely into severe storms and provide detailed observations. They are fitted with observing instruments and sensors and a satellite communications system to relay the information on temperature, pressure, humidity, wind and sea-surface temperature in real-time. Comparisons between *in situ* and satellite-derived observations help initialize and verify operational and research-oriented numerical simulations. UAVs therefore hold enormous potential for weather prediction and disaster prevention and mitigation.

PROBING THE ATMOSPHERE FROM SPACE

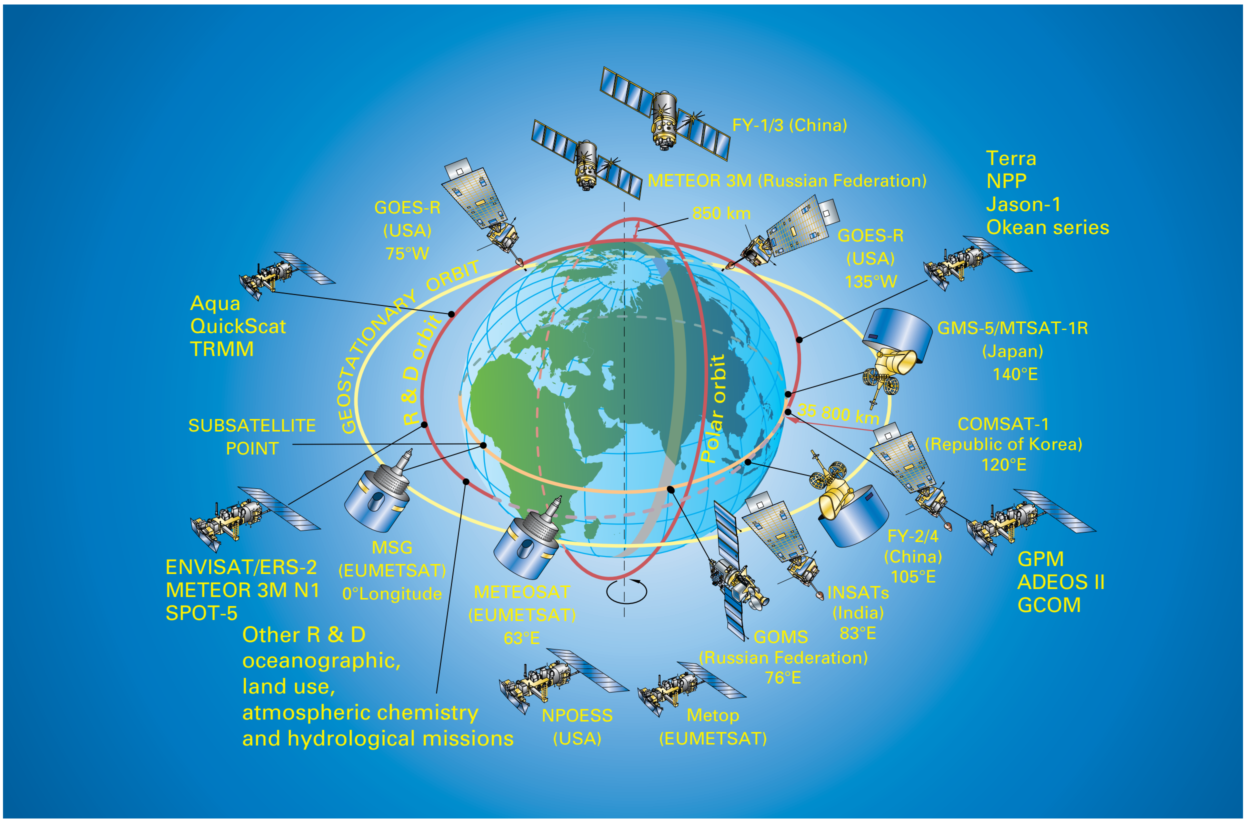
The space-based component of the Global Observing System consists of at least 16 operational and environmental research and development satellites. WMO assists in the coordination of the system to ensure continued global coverage. Satellites provide an ever-increasing range of hydrometeorological information to complement the surface-based and other *in situ* observing systems. This is particularly useful over the world's oceans, deserts, forests, polar regions and other uninhabited or sparsely inhabited areas. Space-based observing systems play a fast-growing and critical role in providing data, products and services. They afford exciting prospects of an even broader range of significant environmental information.

Satellites provide useful primary data for use in numerical modelling of the atmosphere and climate system. The processed information, often presented in the form of images, is widely distributed and used in weather forecasts and severe weather warnings. Derived products are also used in a wide range of other applications, including agriculture, forestry and fisheries and the monitoring of forest fires, sea-ice extent and state, sea-level and sea-surface temperature, ozone and other climate and environmental variables.

New research satellites show that increasingly sophisticated information concerning the state of the environment, such as the carbon cycle, the cryosphere, vegetation cover and aerosols, could be available operationally in the future to enable nations to better monitor climate change and protect the atmosphere.

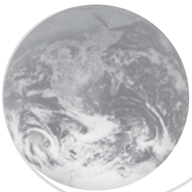
COMPLEMENTARY OBSERVING SYSTEMS

The WMO Global Observing System is complemented by, and contributes to, other systems for observing parameters related to weather, climate and water. The Global Ocean Observing System and the Global Climate Observing System are described in the sections "Protecting the oceans" and "Monitoring and Protecting Climate", below, respectively. The Global Terrestrial Observing System is



The space-based component of the WMO Global Observing System

a programme for observing, modelling and analysing terrestrial ecosystems so that scientists and policy-makers can detect and manage global and regional environmental change and thus contribute to sustainable development. WMO participates in the Global Terrestrial Observing System, together with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme, the International Council for Science and the Food and Agriculture Organization of the United Nations.



Accurate and timely observations of maritime weather and ocean conditions are essential for food security, coastal zone management, economic prosperity and mitigating the adverse impacts of maritime hazards.

HOKUSAI: THE GREAT WAVE OFF KANAGAWA

PROTECTING THE OCEANS

The oceans cover some 70 per cent of the Earth's surface and play a fundamental role in influencing our weather and regulating our climate. They are also a vital source of food, energy, water and hydrocarbon and mineral resources; shipping is a crucial global economic activity.

More than half of the world's population lives near the coast in some of the largest cities. Tourism is a main source of income for many island States and coastal communities. Coastal populations are growing in size and also in vulnerability, owing to direct and indirect impacts associated with the oceans, such as storm surge, high waves, tsunamis and the potential rise in sea-level under projected climate change.

Moreover, the oceans are under the threat of pollution from ships, intensified coastal activities and from pollutants transported from land and the atmosphere. We therefore need to monitor the oceans in order to use their resources judiciously and protect them for the future.

KEEPING COASTAL COMMUNITIES SAFE

Rough seas, freak waves, storm surge and strong currents make many coastal and marine activities difficult, even hazardous. Tropical cyclones and associated phenomena produce some of the most dangerous conditions faced by mariners and coastal populations. Forecasts of these events help to reduce the risks. Such forecasts are based on models requiring input on atmospheric and oceanic surface conditions. More numerous and accurate ocean observations will improve weather forecasts and warnings with consequent widespread benefits.

High waves and storm surge can lead to coastal flooding, which can be particularly severe when combined with heavy rainfall and high tide. Sea-level rise associated with climate change would increase the vulnerability of coastal areas and islands to flooding, salinization of freshwater, beach erosion and damage to infrastructure. The provision of flood warnings requires an extensive network of observations coupled with accurate forecast models and good communication systems.

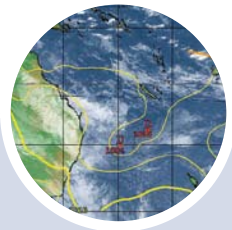
SUPPORTING ECONOMIC ACTIVITY

Marine transport plays a vital role in the global economy, being responsible for 95 per cent of world trade by tonnage. It is affected by ocean and weather conditions. In stormy conditions, good forecasts will allow vessels to set a course that will optimize their route and minimize the risks. In fair weather, the location and speed of ocean currents can be taken into account to reduce sailing time and plan for docking. Close to port, information about visibility and water level is important for docking safely.

Some one billion people depend on fish and seafood as their primary source of animal protein. Commercial fishing also benefits from information on winds, waves and currents, while that on sea temperature helps locate stocks: understanding ocean conditions in which fish reproduce and thrive ensures the sustainability of fisheries and the livelihood of fishermen.

Offshore oil and gas production plays a key role in the world economy. Operations such as oil drilling and pipeline laying are highly sensitive to weather and ocean conditions. Offshore operations are moving increasingly into deeper water. They are carefully planned to avoid damage to equipment and interruption of production. Good-quality marine forecasts of winds, waves and surface temperatures are therefore required, as are warnings of extreme events, such as severe storms and tropical cyclones.

Sound information about currents, sea conditions and weather is essential for leisure activities on the coasts and at sea, pollution clean-ups and search-and-rescue operations.



El Niño-Southern Oscillation (ENSO)

Probably the best known occurrence of climate variability is the El Niño-Southern Oscillation (ENSO) phenomenon. El Niño occurs every three to eight years, when above-average temperatures develop in the tropical Pacific Ocean off the coast of Peru. The corresponding period of cold temperatures is referred to as La Niña. The atmospheric component is called the Southern Oscillation, referring to an oscillation in the surface pressure between the south-eastern tropical Pacific Ocean and the Australian-Indonesian regions. When an El Niño event occurs, there is a drop in surface pressure in the eastern Pacific and a rise in the west. The reduction in the pressure gradient is accompanied by a weakening of low-latitude easterly trade winds.

The sea-surface temperature variations associated with ENSO have a profound influence on the weather across the equatorial Pacific—but also in other parts of the world.

The monitoring and prediction of El Niño events up to a year ahead are important in view of their far-reaching social and economic consequences. A network of buoys measures temperature, currents and winds in the eastern Pacific.

The ability to predict the onset of El Niño and how the climate will change from one year to the next leads to better management of agriculture, water supplies, fish stocks and other resources in many parts of the world.

CLIMATE VARIABILITY AND CHANGE—THE OCEAN LINK

The oceans contribute significantly to climate variability. Observations of the surface and upper layer of the oceans are essential for monitoring such variability. A better understanding of the interaction of the oceans and the atmosphere leads to improved climate models, which, in turn, provide better climate predictions, especially on the seasonal scale, upon which far-reaching decisions can be made. Today, for example, it is possible to forecast critical phenomena such as severe drought or heavy rain in many parts of the tropical belt, several months in advance. The seasonal forecasts are prepared using a combination of observations, statistical techniques and model forecasts.

In addition to the ENSO phenomenon observed in the tropics, there is growing evidence over several other parts of the world of strong interaction between the ocean and weather conditions.

This reinforces the need for enhanced observations and a truly inter-disciplinary scientific approach for the sustainable development and management of the marine environment.

MAINTAINING AN OPERATIONAL OCEAN OBSERVING SYSTEM

About 4 000 active Voluntary Observing Ships (VOS) form part of WMO's Global Observing System; of these, 800 make daily surface meteorological measurements. The VOS Climate Project (VOSClim) fleet currently comprises 220 ships. The Ship of Opportunity Programme makes subsurface temperature profiles using 51 frequently repeated and high-density expendable bathythermographs. In addition, some 1 250 drifting buoys provide observations of sea-surface pressure and air pressure, together with more than 200 moored buoys (including 120 tropical moored buoys) and 60 ocean reference stations. Tide gauges also provide useful sea-level information.

The temperature and salinity of the upper layers of the ocean have an important role in controlling the deep ocean circulation and long-term climate. Until recently, all such information came from measurements made by research vessels and merchant ships. Today, the Argo global array comprises some 3 000 robotic floats which sink and drift with ocean currents to provide temperature and salinity profiles to a depth of about 2 000 metres and sub-surface velocity of ocean currents at 1 000 metres. Together with satellites, the Argo array forms the oceanic equivalent of the present operational observing system for the global atmosphere.

Satellites play a key role in observing the oceans. They provide information on conditions such as sea-surface temperature, winds, ocean colour, salinity, sea state and level and ice cover. The satellite observations are complemented by measurements from ships, floats and fixed moorings.

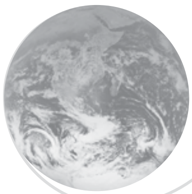
Global Ocean Observing System (GOOS)

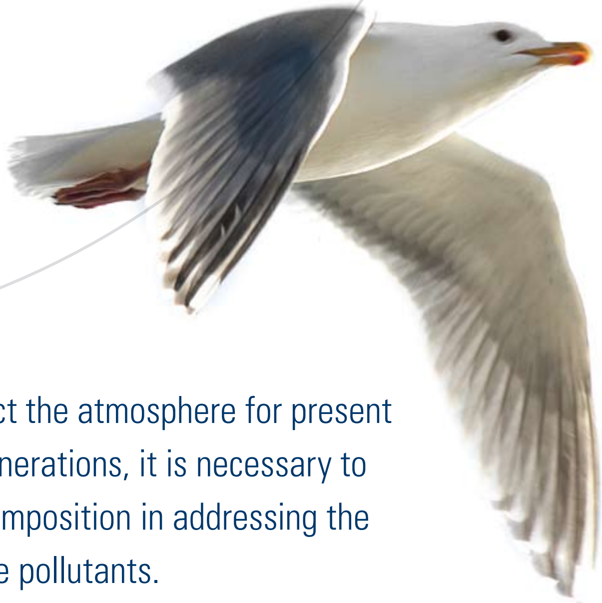
The Global Ocean Observing System (GOOS) is a global system for observing, modelling and analysing marine and ocean variables to support operational ocean services worldwide. It provides a comprehensive description of the present state of the oceans, including living resources, and forms the basis for forecasts of future sea conditions and climate change. It benefits from existing observing systems, especially those operated by WMO. GOOS is sponsored by the Intergovernmental Oceanographic Commission of UNESCO, WMO, the United Nations Environment Programme and the International Council for Science.

Satellites also provide information on ocean circulations and are essential elements for producing seasonal forecasts. Infrared radiometers and microwave sensors on board satellites provide sea-surface temperature information which is merged with observations from ships of opportunity, buoys and other platforms to provide global fields of sea-surface temperatures.

Sea ice covers about 7 per cent of the Earth's surface. It is sensitive to climatic conditions and has a large impact on the energy exchange between the atmosphere and underlying surface and, therefore, on regional weather. Long-term sea-ice measurements are important for understanding sea-ice processes and climatic fluctuations, especially in high latitudes.

Information on surface winds is also used by numerical systems that forecast atmospheric conditions and ocean waves. Measurements from which wind speed and direction at the ocean surface and wave height can be estimated are provided by ships, buoys and satellites.





To help protect the atmosphere for present and future generations, it is necessary to monitor its composition in addressing the impacts of the pollutants.

BRIAN HILL

KEEPING A HEALTHY ATMOSPHERE

The composition of the atmosphere has undergone significant changes since the start of the Industrial Revolution in the 19th century. Some are due to natural causes but most are human-induced. Those caused by human (anthropogenic) activities include the increase in greenhouse gases, such as carbon dioxide, methane and nitrogen oxide, and may adversely affect the well-being and livelihoods of people, as well as wildlife and habitats. These changes, as well as those affecting aerosols, air quality, ozone depletion and acid rain, are major environmental issues.

MONITORING GREENHOUSE GASES AND AEROSOLS

The natural greenhouse effect is responsible for keeping the Earth suitable to sustain life, i.e. about 33°C warmer than it would otherwise be. Changes in concentrations of carbon dioxide, methane and nitrous oxide, in addition to changes in the water content of the atmosphere, however, modify this greenhouse effect and greatly impact climate conditions. Projected global warming and the associated changes in precipitation patterns, sea-level and the frequency and intensity of extreme weather events can have far-reaching affects on all aspects of life. Biodiversity, agriculture, forestry, water resources and health could all be affected.

Continued monitoring of the concentrations and movement of halocarbons, containing bromine and chlorine, as well as reactive gases, such as carbon monoxide, sulphur dioxide and oxides of nitrogen, is required in order to protect human health. These gases also have an impact on ozone concentration and the climate.

Aerosols are solid and liquid particles suspended in the air. They come from the Earth's surface or are created by chemical reactions in the atmosphere. Many aerosols occur naturally as volcanic ash, dust, sand and sea spray, but others result from human activity. Changes in the concentration of aerosols can affect the climate directly by absorbing and reflecting radiation and indirectly by altering the optical properties of clouds. Overall, aerosols have a cooling effect that partly offsets the warming associated with greenhouse gases. Monitoring of the types and density of aerosols is essential for ensuring good air quality and making climate projections.

IMPROVING AIR QUALITY

The impact of pollutants on human health depends on their concentration and on individual human sensitivities, especially those with asthma, heart conditions or lung diseases. Children and the elderly are the most vulnerable.

There are many natural sources of pollution: volcanoes, oceans, biological decay, lightning strikes and forest fires can produce oxides of sulphur and nitrogen. In addition, plants and trees can produce pollen, while dust- and sandstorms lift particles into the air. Of course, natural pollution occurs all the time, but certain events produce concentrations which may cause distress.

The most common sources of pollution caused by human activity are associated with high levels of smoke and sulphur dioxide arising from the combustion of fossil fuels such as coal, oil and gas. Other sources of these pollutants include forest burning, waste incineration and chemical, fertilizer and paper manufacture.

Motor vehicles, especially in highly populated areas, pose a major threat to clean air by emitting a wide variety of pollutants, principally carbon monoxide, oxides of nitrogen, volatile organic compounds and particulates. Ships and aircraft generate similar pollutants.

The most severe air pollution problems occur in cities with a high population density. Pollution associated with particulate matter is of special concern as it is known to increase mortality rates. The monitoring of pollution

The Global Atmosphere Watch (GAW)

The Global Atmosphere Watch (GAW) is one of WMO's contributions to addressing environmental issues.

It was established in response to the need to understand the complex mechanisms with respect to natural and anthropogenic atmospheric change; to improve the understanding of the interactions of the atmosphere, ocean and biosphere; and to provide reliable scientific data and information for national and international policy-makers. Several operational products have originated from GAW, including ultraviolet advisories and pollution levels in urban areas.

GAW's aims are to:

- Make reliable and comprehensive observations of the chemical composition and selected physical characteristics of the atmosphere on global and regional scales;
- Provide the scientific community with the means to predict future atmospheric states;
- Organize assessments in support of formulating environmental policy.

is essential for issuing timely advisories and early warnings and for the establishment of control measures to improve air quality and hence protect health.

Biomass burning and industrial pollution are also sources of aerosols and various gases (including ozone, carbon monoxide and nitrogen dioxide) that affect air quality away from cities. Ground-based and satellite observations have revealed regional and intercontinental transport of pollutants. This has led to the establishment of various international conventions and protocols to address the problem.

To manage and improve abatement strategies, information is needed about the distribution of surface ozone, aerosols and various gases affecting air quality. The same information is used in models to predict air quality. Sophisticated models take account of the emission, development and transport of pollutants. In many countries, information about current and predicted air quality now forms part of regular weather reports for the public.

PROTECTING THE OZONE LAYER

Ozone has both beneficial and harmful affects. Occurring naturally in the stratosphere between 20 and 30 km above the Earth's surface—the ozone layer—it shields the Earth from solar radiation that is harmful to human, plant and aquatic life and causes the degradation of certain materials such as some kinds of plastics. Produced near the ground as a result of chemical reactions involving traffic fumes and sunlight, however, it can cause respiratory problems.

Ozone concentrations in the stratosphere fluctuate naturally. Weather conditions, the intensity of solar radiation and volcanic eruptions all play a role in determining ozone amount. In unpolluted air, there is a balance between the production and destruction of ozone so that the concentration of ozone remains relatively constant.

Observations made over the Antarctic in 1985 showed that man-made substances (chlorofluorocarbons (CFCs)) used in refrigeration,

Sand- and duststorm warnings

Sand- and duststorms have a significant impact on air quality and can affect life, well-being and property.

The Sahara and Gobi/Taklimakan Deserts are the world's most important sources of airborne sand and dust. Sand and dust not only affect these regions but are also carried long distances by the wind into Europe and across the tropical Atlantic and North Pacific. As well as having an impact on weather, climate and ecosystems, sand and dust can adversely affect air quality, health, transport and agriculture. Warnings of storms and the transport of sand and dust help people take precautions to reduce damage to property and other harmful effects.

In 2006, WMO established the Sand and Dust Storm Warning System to coordinate the activities of a global network of regional centres that monitor and forecast sand- and duststorms. The aim is to provide products and services to a wide range of users that allow them to reduce the impact of these storms.

At present, 11 institutions provide sand- and duststorm forecasts over the Internet. Two major nodes of the system are in Beijing and Barcelona and a third is being considered in the Americas. These institutions make use of information provided by satellites, aircraft and surface-based networks.

aerosols and cleansing agents had harmed the ozone layer. An "ozone hole" was letting more ultraviolet radiation through than in the past. The hole was subsequently seen to grow larger and deeper each year. More recently, observations have revealed extensive ozone loss also over the Arctic that could put people living there at risk. Smaller but still significant reductions in the ozone layer have been found elsewhere.

Concerns about the reduction in ozone and the possible consequences to human health and food production, first voiced by WMO, led to the Vienna Convention on the Protection of the Ozone Layer and its Montreal Protocol on Substances that Deplete the Ozone Layer, which were implemented in 1987. The Protocol and the subsequent amendments thereto have resulted in a reduction in the emission of substances containing chlorine and bromine, which are particularly effective at destroying ozone. These measures have prevented the situation from becoming worse and have laid the foundation for a durable recovery. The success serves as a tribute to the monitoring efforts achieved through international cooperation. Continued monitoring of stratospheric ozone, chlorine and bromine is essential to assessing the ozone layer's recovery to natural levels.

Models which incorporate atmospheric constituents, especially stratospheric ozone, can be used to make ultraviolet exposure forecasts based on ozone concentration predictions. Many Meteorological Services already use such forecasts in weather presentations as a way of advising the public to take precautions.

DEALING WITH ACID RAIN

Many pollutants that affect air quality are also involved in the formation of acid rain. In the 1970s and 1980s, there was concern about the effects in higher latitudes of acid deposition on trees and freshwater arising in large part from the transport of pollutants from others regions. At the same time, depletions and disease of fish populations in lakes, and damage to trees were recorded.

Rain is naturally acidic because of the carbon dioxide in the atmosphere. Naturally occurring oxides of sulphur and hydrogen can add to the acidity. Human activities, such as the burning of fossil fuels and motor transport, can make the rain even more acid through a series of chemical reactions. The problem of acid rain in Europe and North America has been compounded by increased emissions there of these pollutants.

Pollution can be transported long distances from its source so that acid rain falls far away. To address this problem, the Convention on Long-Range Transboundary Pollution was established in 1979. It led to a significant decrease in the emissions of sulphur dioxide. Nitrogen oxide emissions have not fallen so quickly because of increases in motorized traffic. Acid rain remains an environmental problem: monitoring pollutants to support control measures and assessing the acidity of rain are still essential.

OPERATIONAL WATCH ON ATMOSPHERIC CONSTITUENTS

During the last 50 years, there has been a revolution in the techniques used for ground-based measurement of atmospheric constituents. Instruments now make local measurements based on an analysis of the composition of air samples. Other instruments, called spectrometers, use radiation measurements to provide information on gas and aerosol concentrations in the vertical.

For more detailed information about the profiles of ozone and water vapour, instrument-carrying

PAUL BIRNSTIHL

The most common sources of pollution caused by human activity are associated with high levels of smoke and sulphur dioxide arising from the combustion of fossil fuels.

Solar radiation warnings

People benefit from small amounts of ultraviolet radiation from the Sun for the production of vitamin D. Prolonged exposure, however, can cause major health problems in terms of skin cancer and cataracts and adversely affects the immune system. It is estimated that between two and three million people suffer from skin cancer each year. Over 100 000 of these have malignant cancers, which, in some cases, can lead to terminal illnesses. Cataracts cause blindness in between 12 and 15 million people—up to 20 per cent of which may be a result of enhanced exposure to sunlight. This is a particular problem in the Indian sub-continent and the "cataract belt" close to the Equator. The result is a debilitating health hazard to individuals and a financial burden to health care systems.

It is important to raise awareness of the health hazards from ultraviolet radiation through education campaigns. At the same time, it is beneficial to provide information about the likely exposure to damaging radiation so that people can take protective measures. This has led to the development of the solar UV index as a way of warning the public about the risk of exposure to ultraviolet radiation. In many countries, this index is published with the weather forecasts in the newspapers or given as part of weather presentations on radio and television.

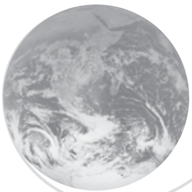
balloons are released that automatically measure the concentration of these gases and send the information back to a ground station. Another technique is based on lidar, which is similar to radar but uses light instead of radio waves. It can provide high-resolution profiles of the concentration of various atmospheric components.

Ground-based instruments can be used to detect long-term trends in atmospheric concentrations, monitor air quality and understand the long-range transport of pollutants. They are also vital for developing and evaluating models that include atmospheric chemistry input and for calibrating and validating satellite observations.

Compared to point measurements made by ground-based sensors and route measurements from aircraft, space-based sensors provide continuous three-dimensional coverage. This is particularly valuable for making observations over oceans and parts of Africa, Asia and South America where there are few ground-based observations. The new generation of satellites provides information about atmospheric constituents such as carbon dioxide, carbon monoxide, methane and aerosols, as well as ozone and nitrogen dioxide.

Data-assimilation techniques amalgamate the information derived from observations of atmospheric constituents to provide a more complete picture of their distribution. Such a synthesis yields valuable information on the quality of measurements so that trends and variability and sources and sinks of constituents can be quantified.

With increasing concern about the environment, there will be a need for more information about the composition of the atmosphere, which will be provided by new instruments and techniques.



Minimizing "surprises" by providing accurate and timely climate projections supports socio-economic development and assists in planning and policy decisions relating to the mitigation of, and adaptation to, climate change.

FEDERICO BELLOLI

MONITORING AND PROTECTING CLIMATE

Climate is a vital factor for the availability of food, water and shelter and in ensuring security. Indeed, climate affects most human activities. Dealing with the consequences of extreme aspects of climate such as drought is a major challenge in many parts of the world—a challenge that is expected to be even more daunting with climate change.

Comprehensive oceanic, atmospheric and terrestrial observations of physical, chemical and biological properties acquired over a long period are needed to monitor and understand the climate system. These observations are supplemented by palaeo-climatic records that set the context for the interpretation of current trends and variability. This information can be used to detect climate variability and change, identify the causes and assess the impacts. Monitoring can also support decision-making on how to adapt to climate change. New tools, combined with international collaboration and information sharing, help in this process.

Enhanced understanding of the climate system leads to improved models used for predicting the climate and its impacts. To make seasonal predictions of climate, it is necessary to make observations of land-surface conditions, including soil moisture, snow and ice cover and vegetation and the upper levels of the oceans.

Models are used to study climate change. Included in the model simulations are assumed changes in the concentration of greenhouse gases and aerosols, solar radiation amounts and land-surface properties. Knowledge of past and current conditions are used in climate modelling. Projections about climate change can then be used by policy-makers to make decisions about mitigating, and adapting to, the impacts of climate change.

Reliable observations need reliable instruments: through rigorous instrument intercomparisons, WMO ensures continuous and homogenous measurements on the global scale.

BENEFITS OF CLIMATE DATA

Climate data and seasonal predictions assist in the planning and management of socio-economic activities and allow informed decision-making about preparing for extreme climate events.

- Health: floods, storms and heat affect health directly; climate affects health indirectly through its influence on air pollution, on the ecosystems that provide food and water and on vectors and pathogens that cause infectious diseases;
- Energy: climate information supports optimal planning, development and use of renewable energy resources, such as hydropower and wind, solar and biological energies;
- Tourism: the tourism industry, particularly in coastal zones and mountain areas, is highly vulnerable to weather hazards and climate change. Climate information helps to better understand the risks and supports effective planning for adaptation and mitigation;
- Urban and building climatology: climate information about heat or cool islands, winds and air quality, as well as storms, floods and

droughts, is vital for urban design, well-being and management;

- Water: effective integration of climate and hydrological information in decision-making for water-resource management reduces risk from climate variability and change;

- Agriculture: the use of seasonal predictions and climate-change scenarios is important for managing agricultural production and ensuring long-term food security.

MONITORING CLIMATE VARIABILITY AND CHANGE

The Earth's climate varies naturally on a range of time- and space-scales. Observations have produced evidence of climate change in terms of increases in global air and ocean temperatures, widespread melting of snow and ice and rising average global sea-level. Based on data provided by National Meteorological and Hydrological Services and other institutions, it is noted that:

- The global surface temperature in 12 of the last 13 years (1995–2007) ranks amongst the 13 warmest since instrumental records began in the 1850s;

- The global average temperature has risen by 0.74°C since the start of the 20th century;

- Mountain glaciers and snow cover have decreased in both the northern and southern hemispheres;

- Global average sea-level rose at an average of 1.8 mm/year during the period 1961-2003 and 3.1 mm/year since 1993;

- Over the last 25 years, the Arctic Ocean has lost 17 per cent of its sea ice. Arctic sea ice will have disappeared in the summer in the next 30-40 years;

Climate monitoring in the polar regions: although remote from major populated areas, the polar regions are of great significance in the global climate system. Changes at high latitudes can have an impact on human society and ecosystems through factors such as sea-level rise and variations in atmospheric and oceanic circulations.

- Carbon dioxide has increased by 36 per cent since the Industrial Revolution. Other greenhouse gases, such as methane, have also increased considerably.

The WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (2007) concluded that the warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea-level. Most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in greenhouse-gas concentrations resulting from human activities. These results show the importance of making reliable observations over long periods of time.

Drought monitoring and early warning

It is estimated that over 250 million people are directly affected by drought, land degradation and desertification and that about one billion people in more than 100 countries are at risk. Improved monitoring and early warning systems can contribute to the effective management of droughts. A long-lasting drought can lead to land degradation and, eventually, to desertification.

Drought occurs when precipitation over a season or longer is insufficient to meet the demands of human activities and the environment. The results are crop damage and water shortage. It is a creeping phenomenon which builds up over many weeks or months and can happen in virtually all climate regimes. The severity of the drought depends upon the degree of moisture deficiency, its duration and the size of the region affected. Once a drought is established, it can persist for months or years.

A variety of indicators can be used for monitoring drought and providing early warnings. Most are based on meteorological observations from which the departure from normal of a climatic parameter can be determined (e.g. rainfall in six months being less than 75 per cent of normal). To be fully effective, a warning system needs to integrate these climate observations with hydrological information such as soil moisture, streamflow and groundwater, reservoir and lake levels. Use can also be made of satellite observations of vegetation, soil surface temperature and soil moisture.

Drought monitoring centres based in Nairobi (Kenya) and Gaborone (Botswana), together with the Regional Centre for Agricultural Meteorology and Hydrology in Niamey (Niger), advise national authorities on the occurrence of drought. The National Meteorological and Hydrological Services of the region, as well as national institutions and development partners, participate in the undertaking.

WMO, together with the Secretariat of the United Nations Convention to Combat Desertification, is working towards the establishment of a Drought Management Centre for South-Eastern Europe. Hosted by Slovenia, it will serve 10 other countries in the region.

Based on climate models, which have been largely successful in reproducing past climate and, in particular, the increase in greenhouse gases, the IPCC projects a rise in global average temperature of 1.1-6.4°C and an average sea-level rise of 0.18-0.59 m by the end of the 21st century. In addition, anthropogenic warming and sea-level rise are expected to continue for centuries, owing to the time-scales involved with climate processes and feedbacks, even if greenhouse-gas concentrations are stabilized. Again, observations play a key role in making these assessments.

There is increased emphasis on using regional climate models. Assessments of the impact of global climate change at local or regional level will support decision-making about strategies for mitigation and adaptation.

It is likely that many people in the developing world would be most affected, whilst being least able to

Automatic weather stations are being used more and more for weather and climate observations, as they can be used without human intervention for long periods. They have sophisticated sensors and processing algorithms and are of particular value in remote or hostile environments, such as deserts and mountainous regions.

adapt. Populations already under stress would be particularly vulnerable, as would communities in coastal regions, low-lying islands and semi-arid regions. Increased exposure to natural hazards and extreme weather are likely to have most impact on people already at risk.

It is essential to have observing systems that provide long-term high-quality data to support predictions of global climate change and the development of complementary mitigation and adaptation strategies.

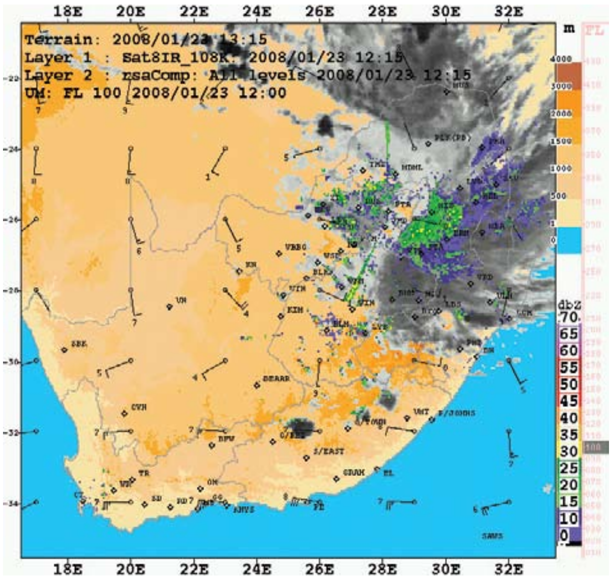
MAKING OBSERVATIONS TO MONITOR THE CLIMATE

No single technology can provide all the essential climate variables. It is necessary, therefore, to use a composite system of surface-based instruments and radiosondes, as well as satellites carrying a variety of instrumentation for remote-sensing of the Earth's surface and atmosphere.

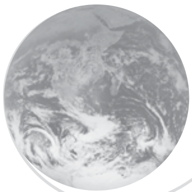
A subset of about 1 000 stations making surface observations of a variety of atmospheric variables are designated as climate stations. They have been selected according to agreed criteria, including their representativeness of the area where they are located and have an extended record of high-quality observations.

It is also necessary to know about the climate at upper levels of the atmosphere. Consequently, 150 stations of those making regular upper-air observations have been selected to provide a climate network. These stations have a good spatial distribution and provide information about temperature, moisture and wind throughout the atmosphere. The observations are used to monitor trends and variability in the troposphere and stratosphere. This provides for a better understanding and evaluation of climate variability and leads to improved understanding of large-scale climatic phenomena and their prediction.

Climate observations must be accompanied by appropriate metadata, such as information on how and where the observations are taken. Arrangements are needed for the collection and retention of observations and efficient mechanisms for scientists and decision-makers to access the data.



Weather radars are used in analysing the extent, intensity, structure and other features of weather parameters and patterns. They are also used in understanding past weather and climate conditions.



Floods, droughts and desertification result in loss of life and property, poor health and crop failure. They all put pressure on freshwater resources and adversely affect economic development.

LEVI SZEKERES

MANAGING WATER RESOURCES SUSTAINABLY

The Earth's ecosystems and human life depend on water in its three forms—vapour, liquid and ice. Even though only a small amount of the water is in the atmosphere, it plays a key role in driving atmospheric motions. Knowledge of the complex processes involving water and its distribution are essential for predicting weather and climate.

Understanding the continuous cycling of water between the oceans, atmosphere and land is vital for ensuring that water supplies are maintained. This is not easy, owing to the complexity of the interactions and impact of water management and other human activities on the water cycle. Also, there is much variability in the components of the water cycle in time and space. A wide range of observations is required to monitor the water cycle and its variations, assess the impact of human activity and understand the causes of its variability.

Maintaining adequate supplies of freshwater to human society is a key priority: the demands on water resources have increased considerably, while there has been a reduction in the quantities available.

The problems of water scarcity are most acute in arid and semi-arid regions affected by drought and climate variability, especially if combined with high population growth and economic development. Urbanization and deforestation also affect water availability. In some places, water is extracted from groundwater reserves faster than it is being replenished. In addition, pollution from human activity has an adverse effect on freshwater availability. Maintaining water supplies requires detailed knowledge of the stores of water and the amount falling to the ground as rain and snow, as well as information about other processes involved in the water cycle.

Water resources cannot be managed effectively unless there is information available about the quality and quantity of water and how these are likely to change in the foreseeable future. There is a need to promote international cooperation in the collection, transmission and archiving of hydrological data and in helping countries develop expertise to assess and manage their water resources.

MONITORING AND PLANNING WATER RESOURCES

Climate change can impact the availability of water resources and the frequency of extremes in the water cycle, such as droughts and flooding. Monitoring the water cycle and identifying long-term change requires long-standing records from meteorological and hydrological stations. Such records must be reliable, with a consistent approach to taking measurements.

Atmospheric measurements are in a fairly adequate state for monitoring the water cycle but better precipitation data are needed. In the last 25 years, significant advances have been made in the instruments available for hydrographic measurements and associated procedures. In many countries, however, fewer measurements are being made and, even when standards have been set, measurement practices are likely to be inconsistent. The problem is sometimes compounded by a variety of institutions being involved in making the measurements.

Planning water resources and land use is becoming increasingly important, especially in many parts of the developing world. Planning activities tend to be built on ground-based meteorological and hydrological data coupled with information about social and economic factors. Remote-sensing from satellites provides a greater range of information that can be combined with surface observations to support water-resource and land-use planning.

Water-quality monitoring in many other parts of the world is inadequate and even in decline. When available, observations come mainly from river and lake sampling. Having better information about water-quality variables from satellites, used in combination with data from ground stations would help ensure that water quality is adequate.

AGRICULTURE AND HEALTH

Agricultural planning and production depend on both weather and climate, with the amount and timing of precipitation being particularly important. The availability of water for irrigation is a key issue, particularly in arid and semi-arid regions.

Much of the information on rainfall comes from raingauges, supplemented by rainfall deduced from radar and satellite measurements. These observations can be used to monitor environmental conditions and provide input into models for forecasting up to a season ahead. Monitoring and forecasting aid decision-making and, when used effectively, maximize crop production.

Shortages of water and inadequate sanitation limit the ability of people to cope with a wide variety of diseases. This situation is exacerbated if only poor-quality drinking water is available. The scale of the problems caused by inadequate access to safe water is immense:

- 1.1 billion people lack access to an adequate supply of water and 2.6 billion people have inadequate sanitation;
- There are four billion cases of diarrhoea each year with 2.2 million deaths, mostly of children under five;
- One million people per year die from malaria and many millions are affected by water-related diseases.

Some infectious diseases are influenced by environmental factors, such as precipitation and humidity. Standing water and floods can cause health problems. Additional studies of the links between environmental factors and human health and better environmental measurements will lead to improved knowledge and warnings of outbreaks of some diseases.

USING WEATHER AND CLIMATE PREDICTIONS

Accurate and timely flood forecasts and warnings allow communities to prepare themselves and reduce their vulnerability. Flood forecasting is usually based on a combination of satellite information and ground-based hydrological measurements.

Satellite and ground station observations can be used to monitor droughts and models can be used to forecast the likelihood of a drought occurring. It is likely that a wider range of measurements from satellites will improve drought monitoring and forecasting.

Global climate change can impact water resources and the frequency of extremes events such as droughts and floods. This means that timely, accurate, reliable and comprehensive information is required on the status of water resources. Water cycle observations can also help address important scientific questions about the role of water in maintaining Earth's climatic stability and feedback processes involving clouds and land surfaces that influence climate change.

MEASURING PRECIPITATION, CLOUD AND WATER VAPOUR

Measuring precipitation and predicting its occurrence are crucial aspects of weather forecasting. Precipitation measurements are also important for understanding the processes affecting the water cycle and predicting the climate. Currently, the best results in terms of accuracy and coverage are obtained by combining measurements from satellites, radars and gauges.

An integrated approach to flood management

Floods can disrupt life and economic activity, in some cases with devastating effects. In recent years, economic losses from flooding have increased. Yet, floods can also be beneficial, as they replenish freshwater resources, recharge groundwater and support agriculture. Settlements in floodplains often depend upon regular flooding to ensure the continued fertility of agricultural land.

Population growth and increased economic activity in floodplains and changes in land use have all contributed to increasing the vulnerability of communities to flooding. Changes in the intensity and duration of precipitation patterns as a result of climate change could increase the frequency of flash floods and seasonal floods.

An integrated flood management approach is needed to maximize the benefits from floodplains, whilst reducing the negative impacts of floods. This requires emphasis on flood management rather than on flood control. Attempts to control floods in the past have often resulted in the economic benefits of the floodplains not being fully realized and the shifting of floods to other places. The new approach includes:

- Managing the water cycle as a whole, while considering all floods;
- Integrating land and water management, as both have impacts on flood magnitudes and risks;
- Adopting integrated hazard management approaches, taking into account the risks from all related hazards.

Raingauges provide the most accurate measurements of rainfall but few are located in mountainous areas or over water.

Ground-based radar can estimate rainfall rates and provide a much better spatial coverage than gauges. Measurements from a network of radars are increasingly being combined to provide composite maps covering large areas.

Satellite measurements of visible and infrared radiation from clouds are used for many years to estimate precipitation rates. The temperature of cloud tops, as revealed by infrared images, give an indication of the likely presence of precipitation but do not provide quantitative information about its intensity. Radiation detected by microwave imagers is strongly related to the presence and intensity of precipitation but is less effective over certain types of surface, such as snow and ice.

A new, dedicated, precipitation-measuring mission is planned in the next five years. It will involve a constellation of several satellites and a variety of measuring instruments.

Cloud and water vapour (another greenhouse gas) also play a key role in the Earth's energy balance. To make accurate predictions of the climate, full understanding of how radiation interacts with water vapour and clouds is required.

World Hydrological Cycle Observing System (WHYCOS)

WHYCOS has been developed in response to the scarcity or absence of accurate data and information accessible in real- or near-real-time on freshwater resources.

WHYCOS aims to:

- Promote regional and international cooperation in the collection, analysis, exchange, dissemination and use of water-related information, using modern information technologies;
- Build the capacity for water-resource assessment at the national, river basin, regional and global levels;
- Be a vehicle for technology transfer, training and capacity building.

The outcome is a better supply of reliable water-related data and information to planners, decision-makers, scientists and the general public. The data will support international scientific programmes which require water-related information.

WHYCOS consists of regional components, referred to as Hydrological Cycle Observing Systems (HYCOSs).

Each HYCOS brings together several National Hydrological Services which have common interests: they share a common drainage basin or are in a well-defined geographical and hydrological region.

A HYCOS is launched when the countries concerned have expressed their collective desire for such a development and their commitment to making it a success.

So far, three HYCOS are being implemented and several more are being developed.

Cloud observations are made all over the world in traditional ways by an observer who records the height, amount and type of cloud. As with nearly all other ground-based observations, there are areas where few observations are made, notably over oceans. Satellites provide visible and infrared images showing the horizontal distribution of cloud.

The conventional way of measuring water-vapour profiles is by radiosondes, but there are other ways of obtaining this information. Microwave radiometers borne by satellites can estimate the total amount of water, water vapour and ice in a vertical column of the atmosphere. Information can also be derived from the influence of water vapour on Global Positioning System signals.

MEASURING OTHER VARIABLES

Soil moisture plays a critical role in agriculture: shortages reduce yield, while excess damages plants. Soil moisture also influences the climate significantly. Its observed distribution and that of sea-surface temperatures are essential inputs to models used for climate predictions. As yet, there is no coordinated network of soil-moisture measurements but it is expected that satellites will eventually provide this valuable information.

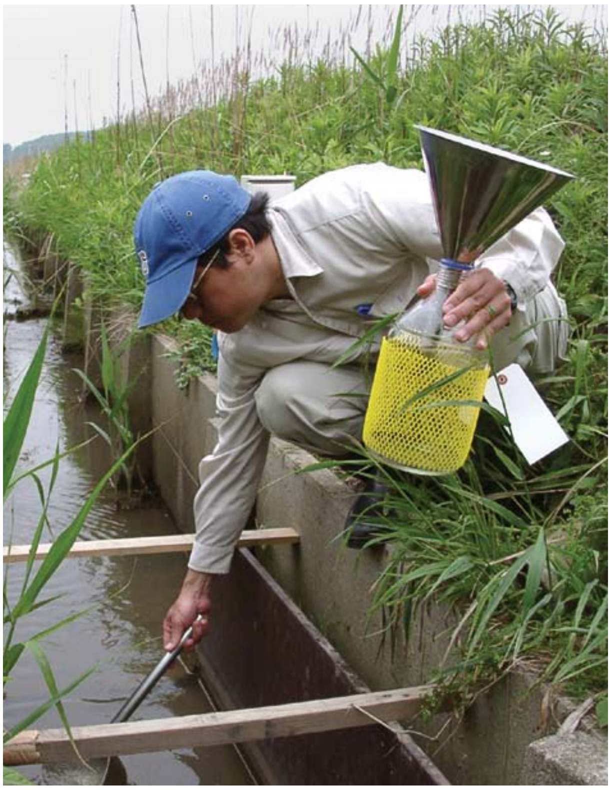
Information about streamflow, water storage and groundwater is required for water management. Ways are being sought for satellite instruments to supplement existing ground-based measurements of these components of the water cycle.

Seasonal snow cover and glaciers store large amounts of freshwater, making them critical components of the water cycle, especially as they have seasonal variations. Snow reflects a great deal of solar radiation—in other words, it has a high albedo. While there are local measurements of snow depth, snow-cover extent estimates from satellites are the only source of data for many regions.

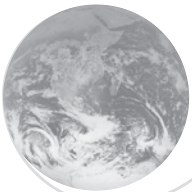
Monitoring freshwater quality is a key water-management issue. Carried out for many years by analysing samples, satellites now have the capability to collect the necessary information.

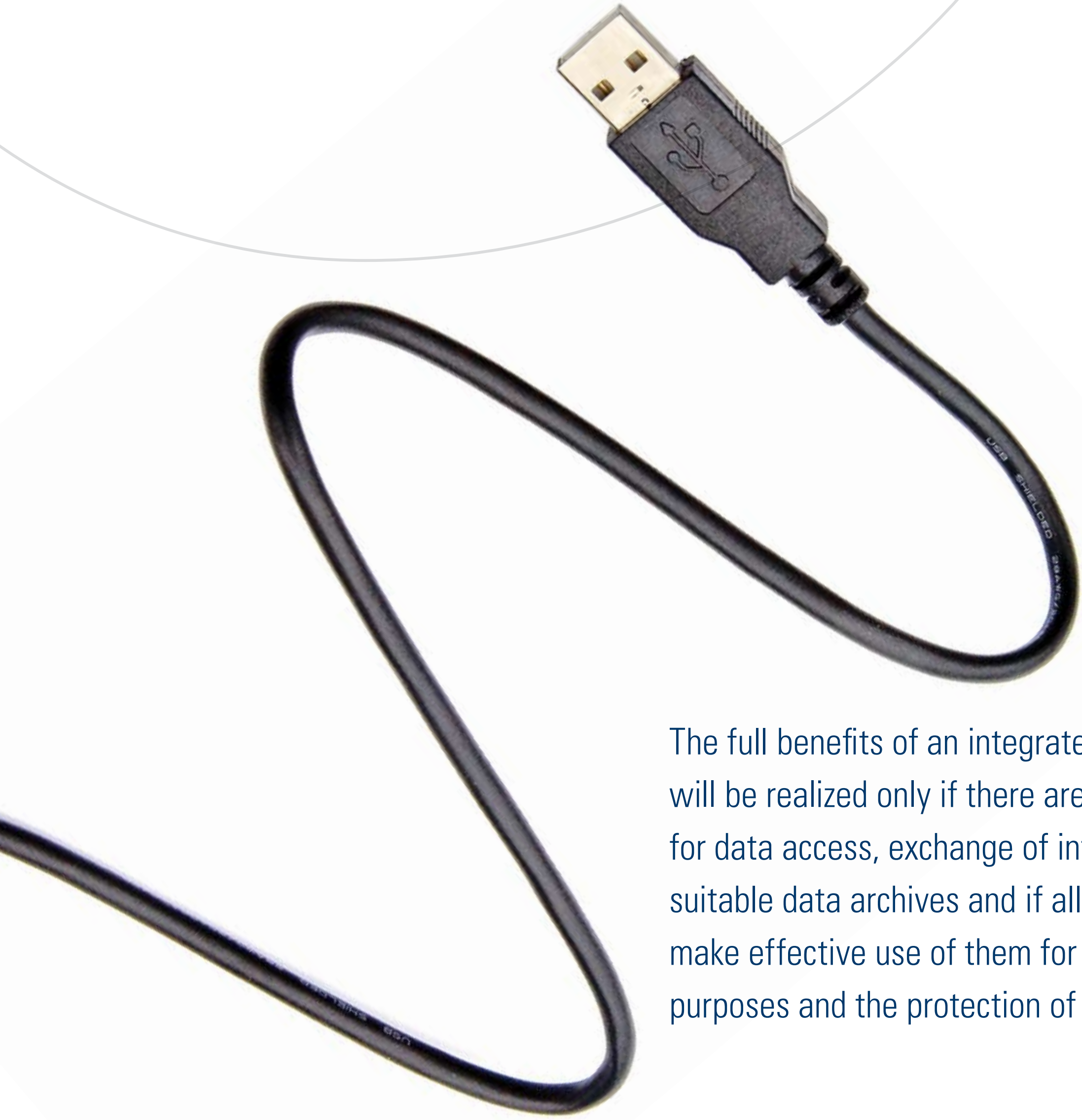
Assessing the quality of ocean water is based on sea-surface colour, measured by optical instruments on board satellites, providing information about the presence and concentration of phytoplankton, sediments and dissolved organic chemicals. These remote measurements are validated and supplemented by observations from ships and moored and drifting buoys. An integrated programme of water-quality measurements would provide immense benefits.

Many observations are made that help understand and monitor the water cycle. However, progress is still needed towards an integrated water-cycle observing system, based on data from existing systems and new platforms, together with emerging data-assimilation and modelling capabilities. Such an integrated system would provide the information required for the effective management of the world's water resources and a full understanding of the water cycle. Enhanced ability to assess trends in variables associated with the water cycle will help address key scientific issues concerning climate change.



Water quality sampling: safe drinking water is taken for granted in the developed world but for millions of people in developing countries, it is an unheard-of luxury.





The full benefits of an integrated observing system will be realized only if there are effective mechanisms for data access, exchange of information and suitable data archives and if all nations are able to make effective use of them for their socio-economic purposes and the protection of their environment.

SPARKY

INTEGRATING THE OBSERVING SYSTEMS

Significant advances in monitoring and predicting weather, climate and water have been made, thanks to a synergetic combination of international cooperation across disciplines and developments in science and technology. The resulting improved predictions and warnings and new products and services have been underpinned by investment in global observing systems that have provided an increasing variety and density of observations.

A number of areas, such as finance, insurance and legal issues, also require observations and specialized services. The challenge is to further the progress realized in the past decades so that environmental remote-sensing of the oceans, atmosphere and land increases our understanding of the processes affecting our lives today and those of future generations.

General awareness of the benefits of Earth observations can be achieved by having outreach programmes in partnership with various institutions. The fact that World Meteorological Day in 2008 is devoted to "Observing our planet for a better future" is part of the process of engaging with users of Earth observations and those that are beneficiaries of the products and services based upon those observations.

The complementary observing systems in place provide a vast array of measurements. Data exploitation and development of forecast and prediction models have brought immense benefits in terms of reducing human suffering and supporting economic activities. Improved accuracy and wider coverage of observations will bring further benefits.

Some shortcomings in current observing systems are a lack of access to data, erosion of technical infrastructure, large temporal and spatial gaps in various types of observations, inadequate data integration and interoperability, uncertain continuity of observations and insufficient long-term data archival. Operating and maintenance costs are also a problem for many countries in sustaining their observing networks.

GEOSS—INTEGRATING COMPLEMENTARY INFORMATION

In addition to WMO's efforts to develop an integrated observing system, the inter-governmental Group on Earth Observations (GEO) has been established to lead a worldwide effort to build a Global Earth Observation System of Systems (GEOSS).

GEOSS is designed to integrate environmental information in a comprehensive. coordinated and sustainable fashion and extend its utility to a number of additional socio-economic applications. The vulnerability of modern humanity, economies and the environment to high-impact weather, climate and water events has been amply demonstrated by the Indian Ocean tsunami in 2004, droughts and disastrous flooding on every continent and widely occurring severe weather, including extreme heat and cold.

Effective mitigation of the impacts of, and adaptation to, such events requires accurate observation and prediction at global, regional and local scales, combined with enhanced capacity of disaster-risk reduction managers and policy-makers to exploit this information. GEOSS provides a framework essential to support such action—and WMO's World Weather Watch of the 21st century is a key contributor to this new framework.

WMO INTEGRATED GLOBAL OBSERVING SYSTEM

Observing systems must be integrated to improve coordination and synergies. The WMO Integrated Observing System (WIGOS) is therefore being developed to enhance such coordination among the various systems that have evolved independently. The aim is to have information with the resolution, accuracy, reliability and timeliness that will meet the needs of users. This will require

WMO Integrated Global Observing System (WIGOS)

SPACE

Operational and research and development satellites provide visible and infrared cloud images, water-vapour images, wind-structure indicators and temperature and humidity soundings, atmospheric chemistry profiles and many other geophysical parameters. Geostationary satellites simultaneously gather a wide variety of land-surface changes, atmospheric aerosol, global cloud cover, ocean temperature, stratospheric temperature and Earth thermal radiation budget data.

LAND

Manned weather stations provide important information about weather conditions near the ground. Automatic weather stations are increasingly important with the development of sophisticated sensors and processing algorithms. Land stations such as these measure temperature, wind, rain and humidity. Other instruments on land observe parameters that are important for agriculture, water resources and air quality.

ATMOSPHERE

Weather balloons, ozonesondes and aircraft observations help define the three-dimensional structure of the atmosphere and its composition. Temperature, wind and moisture measurements from aircraft provide the only information available in some areas of the world on the detailed vertical structure of the atmosphere. More instrumentation on balloons and aircraft will measure turbulence, icing and atmospheric chemistry. These complement satellite measurements.

OCEAN

Ships are recruited for taking and transmitting surface and upper-air observations and surface oceanographic observations. Moored and drifting buoys and platforms provide observations from large data-sparse areas. A global array of robotic floats sink and drift with ocean currents, collecting temperature and salinity profiles. Other systems measure conductivity, sea-surface velocity, current profiles and phytoplankton concentration.

research and development of improved and new instrumentation to supplement existing observing systems. Scientific effort will also be required to improve data-assimilation techniques and the associated models so that the observations render the maximum amount of useful information.

It is expected that, having an effective integrated observing system, coupled with other scientific and technological developments, will lead to the improvement of:

- Weather forecasts and warnings;
- Climate predictions and assessments;

WMO Information System (WIS)

A key part of the World Weather Watch (WWW) is a telecommunication system that provides for the efficient, rapid and reliable collection and distribution of observations and related data, forecasts and alerts.

The WMO Information System (WIS) is the pillar of the WMO strategy for managing and transmitting weather, climate and water information in the 21st century. WIS provides an integrated approach to meet the requirements for:

- The routine collection and automated dissemination of observed data and products;
- Timely delivery of data and products;
- Ad hoc requests for data and products;

WIS is designed to extend significantly the ability to collect and disseminate data and products. It will be the core information system utilized by WMO Members, providing linkages to all WMO and supported programmes associated with weather, climate, water and related natural disasters.

WIS encompasses three types of centres:

- Global Information System Centres will collect and distribute the information meant for routine global dissemination, while serving as collection and distribution centres in their areas of responsibility;
- Data Collection or Production Centres will be responsible for the collection or generation of sets of data, forecast products, processed or value-added information and/or for providing archiving services;
- National Centres will collect and distribute data on a national basis and will coordinate or authorize the use of the WIS by national users.

A major benefit will be that WIS will provide a single entry point for all data requests. The use of off-the-shelf technologies should allow more countries to participate in WMO programmes, especially the World Weather Watch.

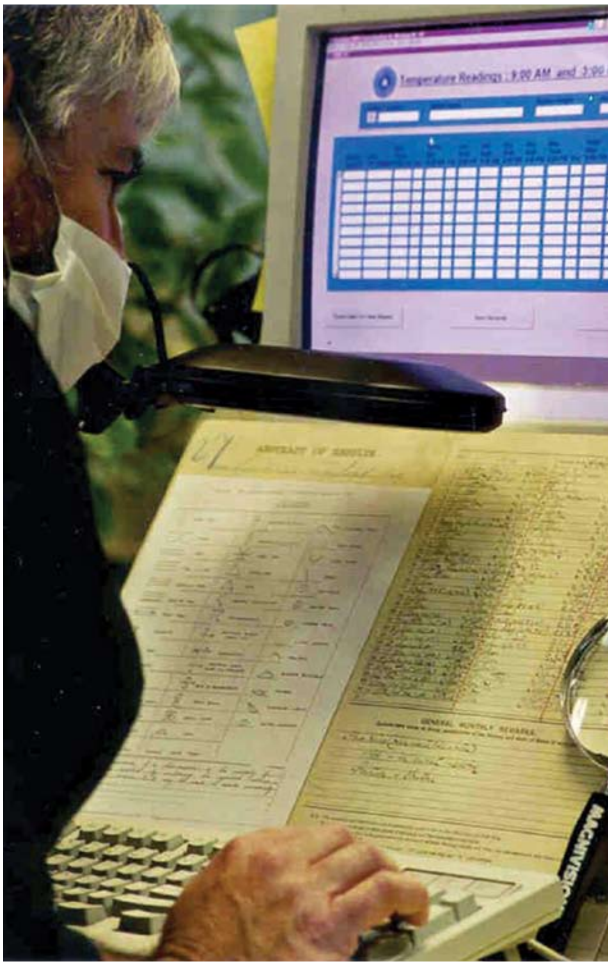
- Hydrological forecasts and water-resource assessments.

In addition, an integrated observing system should provide measurements to support new products and services, such as air-quality alerts, seasonal climate outlooks and other environmental products.

DATA AND INFORMATION—FREE ACCESS AND UNRESTRICTED EXCHANGE

The full benefits of an integrated set of observing systems will be realized only if there are effective mechanisms for data access and the exchange of information. The WMO Global

Telecommunication System (GTS) has been used to support the free and unrestricted exchange of observations and other meteorological and related data. In view of the rapid increases in data volume and the development of new data-exchange and management technologies, the GTS will be replaced by the new WMO Information System (WIS). WIS is the pillar of WMO's strategy for managing and moving weather, climate and water information in the 21st century. It provides an integrated approach to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centres and Member countries.



AUSTRALIAN BUREAU OF METEOROLOGY

Converting data from historical records into digital format yields an invaluable resource for the country concerned and the entire world.

An integrated global observing system supported by an integrated information system will make a major contribution to realizing socio-economic benefits from a wide range of products and services concerning weather, climate and water. The range of global observations needed to understand and monitor the Earth's processes and assess human impacts exceeds the capability of any one country. WMO therefore takes a cooperative and integrated approach based on strong partnerships.

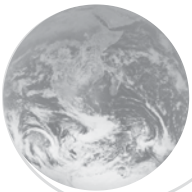
DATA ARCHIVES—A COMMON HERITAGE

Weather, climate and water data compiled from a number of sources over more than 150 years comprise a unique dataset of past climate. As such, they constitute a unique common heritage for humanity.

Each country archives and manages its data. In addition, in agreement with the country concerned, some of the data collected nationally are archived at World Data Centres and some regional centres, such as the African Centre of Meteorological Applications for Development. In all cases, an acknowledgement must be made to the data providers or owners and the data centre when these data are used in a publication. The US National Climatic Data Center archives weather and climate data, including monthly mean values of pressure, temperature and precipitation, as well as station metadata. It has published the World Weather Records since 1927.

Other World Data Centres are responsible for the archiving of one or more measurements of atmospheric constituents including stratospheric ozone and ultraviolet radiation (Canada); solar radiation (Russian Federation); greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons) (Japan); reactive gases (surface ozone, carbon monoxide, nitrogen oxides, sulphur dioxide, volatile organic compounds) (Japan); aerosols (European Commission); precipitation chemistry (USA); and aerosols and ozone from satellites (Germany).

It is estimated that the National Hydrological Services operate more than 475 000 hydrological stations worldwide. In addition to archiving these and other hydrological data nationally, some of the data are archived at global centres: runoff and precipitation data (Germany) and groundwater data (Netherlands).



Investing resources in strengthening weather, climate and water observing systems is, beyond any possible doubt, an excellent investment.

STEFANIE L.

LOOKING TO THE FUTURE

Human experience in making, sharing and applying weather, climate and water information under the aegis of WMO and its predecessor, the International Meteorological Organization, has been positive and is historically unique. Such cooperation has contributed to the establishment of technical and scientific institutions and the formulation of conventions such as those related to climate change, natural disasters and transboundary pollutants. It now shows the way to further improvements in making observations, facilitating wider access to data and building capacity to apply the data effectively in a broader range of human endeavour.

Collaboration among institutions at national and international levels and across disciplines, including scientific and social communities, has proved most productive in addressing some of the major challenges facing humanity—safety from natural hazards, degradation of the environment, dwindling water resources, degradation of biodiversity and climate change. Advances in science and technology will continue to provide new and increasingly powerful tools for monitoring processes and for the processing and exchange of data.

Investing resources in strengthening weather, climate and water observing systems is, beyond any possible doubt, an excellent investment. We may rest assured that the international community will continue to cooperate for the benefit of all, with the unstinting and steadfast contribution of WMO to this global effort.

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