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WEATHER, CLIMATE AND WATER

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WORLD METEOROLOGICAL ORGANIZATION

Weather, Climate and Water

This background document is being prepared by the World Meteorological Organization as an evolving document in the process leading to the World Summit on Sustainable Development. Revised versions will be presented at the third and fourth meetings of the Preparatory Committee (New York, March and Jakarta, May 2002) and at the Summit in Johannesburg, South Africa, August - September 2002.

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1. The Context: supporting sustainable development

Weather, climate, water and society

Over the course of the 20th century we became increasingly aware of the fragility of the environment in which we live. We saw the beginnings of human-induced climate change, increasing climate variability, and a host of interconnected issues, such as land and water degradation, loss of biological diversity, stratospheric ozone depletion. All too often, there were many that suffered the impact of a natural disaster.

In the 21st century probably the greatest challenge facing humankind is the need to provide a good standard of living (i.e. sufficient food, water, health care and energy) for the present, and in the future a much larger population. Yet we need also to show greater respect for our environment than we did in the last century. These indeed are the challenges of sustainable development.

National Meteorological and Hydrological Services

Two of the most fundamental obligations accepted by governments through the ages have been the protection of the safety and welfare of their citizens and the collection and safeguarding of important historical records for future generations. For more than a century, virtually all countries of the world have fulfilled their obligations to minimize the adverse effects of weather and climate on community safety and welfare and to provide a comprehensive and reliable national climate record through the operation of a National Meteorological Service (NMS). In most countries the NMS is complemented by a National Hydrological Service (NHS), or in some cases the two are integrated into a single National Hydrometeorological Service.

There is no doubt that the citizens of all nations will expect to contiue to enjoy the range and quality of weather, climate and water-related services that modern science and technology have now made possible. However, science and technology alone would have been quite inadquate were it not for the fundamental basis of international cooperation that underpinned the 1950 intergovernmental convention establishing the World Meteorological Organization (see Section 7). The need to maintain that cooperation in order to provide effective weather, climate and water-related services is as crucial at the beginning of the 21st Century as it was fifty-two years ago, perhaps even more so.

Sustainable development

Agenda 21, one of the main outcomes of the 1992 Earth Summit in Rio de Janeiro, reflects most of the major socio-economic and environmental issues relevant to the achievement of sustainable development. One of the fundamental themes running through Agenda 21 is that:

"Integration of environment and development concerns will lead to the fulfilment of basic needs, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can — in a global partnership for sustainable development" (*Chapter 1, Agenda 2).*

The 1992 Earth Summit in Rio de Janeiro, therefore, was a crucial catalyst. It brought together nations of the world and numerous international organizations and inspired them to modify their programmes by pooling resources and global intellectual capital, in order to provide governments and society with vital information on climate change and ozone levels, and to improve climate forecasts and prediction. Rio also led national institutions such as National Meteorological and Hydrological Services (NMHSs) to put new techniques into action around the world that would help establish a firm base for future efforts at reaching sustainable levels of development. Such techniques relate to the enhancement of early warning systems of severe weather, monitoring of the climate system, improved assessments of freshwater resources, pollution monitoring and control, and climate change detection.

The Atmosphere

Chapter 9 of Agenda 21 dealt with fundamental atmospheric issues, including the gaps in our knowledge of human-induced climate change, stratospheric ozone layer depletion and transboundary atmospheric pollution. WMO has been contributing with several partners in the improvement of the scientific basis for decision-making by promoting:

- Research on the natural processes affecting and affected by the atmosphere, as well as the linkages between sustainable development and atmospheric changes, including effects on ecosystems, human health and economic sectors;
- The collection of data on the atmosphere (often through the training of technicians and experts in developing countries) and the exchange of research findings.

International initiatives on the atmosphere

WMO spearheaded the campaign to alert the world community to the potential effects of global warming, climate change and sea-level rise. Decisive meetings, such as the First and Second World Climate Conferences, raised awareness of these issues among decision-makers and the wider public. This campaign led directly to the adoption of several important regional and global environmental conventions and agreements seeking to curb the effects of increasing pollution on human health and biota. The most significant of these are:

- United Nations Framework Convention on Climate Change and its Kyoto Protocol, which seek to protect the climate system for present and future generations by tackling increasing atmospheric concentrations of greenhouse gases through emission reductions and controls, and as necessary, through the implementation of adaptation strategies;
- The 1985 Vienna Convention for the Protection of the Ozone Layer and its subsequent 1988 Montreal Protocol and Amendments, seeking to phase out the production and consumption of all ozone depleting substances such as halons and CFCs;
- The Convention on Long-Range Transboundary Air Pollution and its Protocols, seeking to assess the efficacy of controls of emissions of harmful gases and pollutants (notably sulphur dioxide) from countries within Europe;
- The Acid Deposition Monitoring Network in East Asia, providing for monitoring of both wet and dry acid deposition onto soils, vegetation, the built environment and water;

- The 1991 Air Quality Agreement between Canada and the United States, seeking to control emissions of pollutants that contribute to acid deposition; and
- ASEAN Transboundary Haze Pollution Agreement, managing the episodic smoke/haze events in the South-East Asian region.

Climate change

Our picture of the climate system has been evolving over the course of the past century, but this was initially a slow learning process with few practical applications until cooperative international programmes of research began to draw together the growing data banks of systematic observations. Today, our vastly improved knowledge of climate derives from global scientific and technical programmes coordinated primarily by WMO, the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources.

It has been recognized for more than a century that sustained human activity could alter the climate system. WMO's predecessor, the International Meteorological Organization (IMO) began constituting a unique database of atmospheric observations soon after it was founded in 1873. In 1929, the IMO had established a Technical Commission for Climatology, which was carried forward under the WMO. Concern about the potential for an alteration in the existing balance between incoming and outgoing radiant heat on the earth's climate system mounted to the point that, in 1979, WMO convened the First World Climate Conference in collaboration with other UN organizations and the International Council for Science (ICSU). From that conference emerged the World Climate Programme, comprising four components dealing respectively with climate data, climate applications, climate research and climate impacts.

In response to growing concerns about human influences on the climate system, the WMO and United Nations Environment Programme (UNEP) established in 1998 the Intergovernmental Panel on Climate Change (IPCC). Its task then was to assess the state of knowledge on several crucial issues, including the role of carbon dioxide and other greenhouse gases in altering the earth's radiant heat balance. IPCC now conducts periodic and special assessments on international research and on the current state of development of climate models able to accommodate the complex interactions of atmospheric, oceanic and land surface processes necessary to for generating possible scenarios of human influence on climate change. The IPCC First and Second Assessment Reports of 1990 and 1995 each involved more than a thousand scientists from around the world. The main conclusions, no less valid in this new century, were that:

- "The balance of evidence suggests a discernible human influence on global climate";
- Carbon dioxide remains the single most important contributor to human-induced climate change; and
- Projections of future temperature and sea-level rises back up the fear that unchecked human activity will change the Earth's climate at a rate unprecedented in human history.

The First Report was endorsed at the WMO-sponsored second World Climate Conference in Geneva in October 1990 and became the primary scientific basis for the United Nations Framework Convention on Climate Change (UNFCCC) signed by 154 countries at Rio in 1992. The Third IPCC

Assessment Report (issued in 2001) confirmed the magnitude of recent climate change and provided further support for projections of global warming stemming from human influences. The report also identified more detailed characteristics of the changing climate, including differences in minimum and maximum temperature trends and regional changes in rainfall distribution and intensities.

The Climate Agenda

Created in 1993, the Climate Agenda, created as an outcome of the ministerial-level Second World Climate Conference, is an inter-agency mechanism to provide overall guidance and coordination for the implementation of the World Climate Programme as a scientific substructure underpinning relevant aspects of sustainable development and Agenda 21. It was designed to support the environmental conventions on climate change, desertification and biodiversity while at the same time serving national and global socio-economic interests in the most cost-effective manner. WMO is one of a number of international organizations that have formally committed to the Climate Agenda.

Enhanced protection and management of water

At Rio it was also acknowledged that without better protection and management of water resources, shortages would soon undercut social and economic progress. The key here would be funding for broader and deeper expert knowledge of the quality, size and likely depletion of water reserves.

Chapter 18 of Agenda 21 addressed the question of how to protect and manage freshwater, i.e. to ensure adequate supplies of good quality water while preserving the hydrological, biological and chemical functions of ecosystems. In the context of its mandate, WMO has contributed to:

- Strengthening the institutional capacity of countries required to assess their water resources;
- Providing accurate and efficient flood and drought forecasting services;
- Reinforcing cooperation between the various agencies responsible for hydrological activities (enhanced data collection and management systems and improved dissemination of information) especially in the management of transboundary rivers.

International initiatives on water

WMO has played a leading role in international initiatives on water issues, and continues to highlight the need for baseline data and knowledge upon which to build sound management of water resources. This requirement was acknowledged in 1977 by the UN Water Conference in Mar del Plata, Argentina, which called for increasing support to water resources assessment activities through strengthened institutional frameworks, for the development of training and research programmes, and for enhanced international cooperation.

The next benchmark event was the International Conference on Water and Development, convened by WMO in Dublin in 1992. In the resulting Dublin statement on water and sustainable development, more than 100 countries recognized water as a finite and vulnerable resource that has to be shared between competing users. The statement called for a participatory approach to its development and management, with special emphasis on the role played by women. To support these basic principles the Conference recommended several steps, including the development of the knowledge base on all the components of the water cycle, and the promotion of capacity building for better assessment and management of water resources. The concerns of the Dublin statement were taken up at Rio and were reflected in Chapter 18 of Agenda 21. The Dublin Statement has also served as a broad basis for subsequent international initiatives directed at sustaining the world's freshwater resources.

2. Observing, predicting and researching the world's weather and climate

WMO's pioneering role in the global coordination of operational and research programmes in meteorology contributed to remarkable advancements in weather forecasting and the geophysical sciences. Landmarks include the International Geophysical Year (1957/1958), establishment of the World Weather Watch (1963), Global Weather Experiment (1978/1979) and the Tropical Ocean and Global Atmosphere (TOGA) programme (1990-1995). Some of these programmes and their related projects benefited from the cooperation of non-governmental international scientific bodies, notably the International Council for Science. This spirit of cooperation is very much alive today and is reflected in WMO's ongoing contribution to global research that has led to our current understanding of weather and climate and in particular, of climate change.

In the past decades, WMO and coordinated international research programmes sponsored by WMO in collaboration with other organizations have brought considerable benefits to the global community. In particular, systematic observations using standardized methods have provided worldwide data for analysis, research and modelling of the atmosphere and its changing patterns of weather systems. Specialized programmes of observation, concentrating on the physical properties and chemical constituents of the atmosphere and of the circulation of the oceans have led to a better understanding of climate variability and change, especially of the interactions between the four domains of the climate system (the land surface, the hydrosphere, the cryosphere and the atmosphere). These efforts have culminated in:

- Improved weather forecasting skills. Early warning of severe weather events is crucial for the mitigation of natural disasters.
- Identifying the causes of seasonal to interannual climate variability. The development of prediction skills on these time scales facilitates more efficient management of land and water resources and the prevention of desertification and degradation.
- Identifying the causes of stratospheric ozone depletion. International agreements now limit the manufacture and use of ozone depleting substances in order to allow the recovery of the ozone layer as a protective barrier against harmful ultraviolet radiation.
- Verifying increasing concentrations of greenhouse gases in the atmosphere. Human activities have been found to be interfering with the climate system to such an extent that there is the likelihood of potentially dangerous climate change.
- Improved observation of the changes in hydrological cycle. The World Hydrological Cycle Observing System (WHYCOS) and Global Terrestrial Network for Hydrology (GTN-H) will contribute to the detection of the effects of climate change on water resources and assessments of the sustainability of water use.

World Weather Watch

Observation of weather and climate on a global scale can be said to have come of age during the latter half of the 20th century, with the use of an array of tools including land networks, ships, aircraft and satellites. The World Weather Watch (WWW) was set up by the WMO in 1963 to focus on a narrow set of observational parameters in support of weather forecasting. Since then it has embraced an enormously expanded range of technology to answer a wider range of needs, including climate prediction and environmental monitoring. WWW is organized and coordinated by WMO to ensure that every country enjoys access to the data and knowledge required to provide weather forecast and warning services on a day-to-day basis, especially when life and property are at risk.

WWW facilitates the development, operation and enhancement of worldwide systems for observing and exchanging meteorological and related observations, and for the generation and dissemination of analyses, forecast products, severe weather advisories, warnings and related operational information. The WWW basic infrastructure comprises thousands of observing stations on land, at sea, in the air, and several environmental geostationary and orbiting satellites; telecommunication networks and facilities for the rapid collection and exchange of observational data and forecast products.

A network of meteorological centres focusing on global and regional scale analysis and prediction provides the backbone for collecting all the observed data and generating advisories, warnings and specialized forecast products required by NMHSs and other agencies. These centres, some of which focus on specialized topics such as tropical cyclone prediction, provide increasingly reliable products spanning forecast ranges from instantaneous to long-term and from local to global scale, improved early warning services for the mitigation of meteorological disasters and effective advice for emergency response to environmental catastrophes.

Surface weather

The core of the atmospheric observing subsystem is a network of 10,000 stations where observations are made at three-hourly intervals at, or near, the Earth's surface. Over recent years, manual observing instruments have been gradually replaced with automated weather stations. This has allowed significant increases in the geographical coverage and frequency of observations. Special care is needed, however, in making these replacements to ensure the continuing integrity of the long-term climate record.

The upper atmosphere

For more than half a century, hydrogen or helium filled balloons have carried radiosondes to heights of between 20 and 40 km (to measure temperature, wind, humidity and pressure and to radio the observations to receiving stations). These radiosondes have routinely provided detailed information on the changing structure and circulation of the atmosphere. There is now a global network of about 1000 radiosonde stations providing soundings of the atmosphere at least once a day.

Observations at sea

Today WMO coordinates a programme of marine meteorological observing systems that includes more than 6,700 Volunteer Observing Ships from among the world's international commercial fleets, and also approximately 1,000 buoys drifting around the world's oceans that regularly provide data from places that are off the main shipping routes.

Satellites

Weather forecasters were among the first to make use of satellites on a systematic and regular basis. The complex array of satellite-borne instruments provides global coverage for a variety of measurements, including temperature and humidity profiles of the atmosphere, the extent of sea ice and snow cover, cloud-drift atmospheric winds, estimated precipitation rates, ocean wave heights (sea-surface topography) and associated ocean surface winds. In the course of the past few decades, satellites enabled the global coverage of distribution and changes of numerous atmosphere properties and constituents.

Weather Radar

Radar is used in the observation of thunderstorms and other severe weather events, including tornadoes and microbursts (especially in the vicinity of airports), and to monitor and provide early warning of the development and movement of severe storms including tropical cyclones.

The Global Climate Observing System

The Global Climate Observing System (GCOS), which was established in 1992, facilitates improvements in an increasing array of observations required for climate-related activities. It is a partnership between the WMO and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, ICSU and UNEP. It can be described as a product of the second World Climate Conference, which had given powerful expression two years earlier to the need for improvements in the geographic coverage, quantity and quality of climate observations. GCOS builds on the WWW observing system for the atmosphere, but has expanded the coverage of observations to include the oceans and the land surface. GCOS was established to develop an operational system capable of providing the comprehensive observations required for:

- Monitoring the climate system (including physical, chemical and biological properties);
- Detecting and assessing the effects of climate change and climate variability;
- Research to improve understanding, modelling and prediction of the climate system.

GCOS does not itself make observations, generate data or generate products. Its role is to stimulate, coordinate and otherwise facilitate this work, which is undertaken by national and international organizations in the pursuit of common goals (as well as to meet their own requirements). The principal global networks for atmospheric observations related to climate are the GCOS Surface Network (GSN), the GCOS Upper Air Network (GUAN), and the Global Atmosphere Watch (GAW). GSN and GUAN are part of WWW and provide data on meteorological parameters, including temperature, pressure, precipitation, wind velocity, and humidity.

WMO collaborates with other agencies in supporting other parts of GCOS in the other observing domains, viz. the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS). For example, a Joint Technical Commission for Oceanography and Marine Meteorology has been recently established by WMO and Intergovernmental Oceanographic Commission of UNESCO to act as a reporting and coordinating mechanism for all operational marine activities of WMO and IOC, in particular for the Global Ocean Observing System.

One of the main tasks is to provide for the future an integrated global observing system that is both interdisciplinary and operational. Such a system would enhance the predictability of climate variability and refine assessments of likely climate change, and hence further improve decision-making for adaptation and mitigation policies. The system must include a combination of sustained satellite missions and broad scale, long duration series of *in situ* observing systems.

Exchanging data

The value of all the data that is collected around the world on weather, climate, water and the environment would be seriously diminished if those data were not available to the global community. The agreement to free and unrestricted exchange of meteorological data on a routine basis was a founding principle of the WMO. Without it, the advances made in weather forecasting would not have been possible. As the need to derive a fuller understanding of all the earth's environmental systems becomes ever more pressing, so does the need to retain this principle and to extend it as necessary to all environmental domains.

In a land-breaking agreement to codify the principle, the WMO in 1995 agreed that all its Member countries shall provide, on a free and unrestricted basis, the essential data and products that are neccessary for the provision of services in support of the protection of life and property and the well-being of all nations.

Atmospheric and environmental research

The main responsibility of the Atmospheric Research and Environment Programme (AREP) is to provide scientific support to a number of international agreements on protecting the atmosphere. These include in particular the Vienna Convention on evolution of stratospheric ozone, the UN Framework Convention on Climate Change concerning the increasing concentrations of greenhouse gases in the atmosphere. AREP also provides valuable atmospheric information for scientists, policy assessors and governments on the changing composition of the atmosphere.

The composition of the atmosphere

Human activities affect climate in many ways but particularly through emission of gaseous pollutants and minute particles called aerosols. Twenty-two global and over 300 regional observatories have been established by NMHSs and research institutions to provide data over time on the chemical composition and physical and chemical characteristics of the atmosphere. The observatories monitor greenhouse gases, ozone concentration, aerosols (particularly those involved in acid deposition) and ultraviolet radiation. This data is taken by a network of ground-based stations operated by national governments and coordinated by AREP within the framework of WMO's Global Atmospheric Watch (GAW) Project. This Project has been one of WMO's most important contributions to the study of environmental issues in the post-UNCED period. Information derived from its network of measuring stations feeds directly into the UNFCCC (through the IPCC assessment process), as well as the Vienna Convention and Montreal Protocol regarding ozone and other regional environmental agreements.

Research on the world's weather

AREP also plays a role in support of the objectives of the International Strategy for Disaster Reduction (ISDR), particularly with respect to improving the scientific knowledge associated with high impact weather events such as flooding, high winds and aircraft icing. The World Weather Research Programme (WWRP) acts as a framework stimulating international research campaigns designed to lead to improved forecasts of weather events with important social and economic consequences. A key feature of the WWRP is its holistic approach, integrating scientific advances in the ability to predict extreme weather events together with efforts to increase the understanding of how the complex effects of these events ripple through societies and their economies. As the WWRP develops further it is expected to benefit many NMHSs through the development and subsequent transfer of forecasting technologies capable of predicting more accurately weather situations that could result in loss of life and property.

Global cooperation on climate

The World Climate Programme was established following the First World Climate Conference in 1979. Its purpose is to provide an authoritative international scientific voice on climate and climate change, and to assist countries in the application of climate information and knowledge to national sustainable development through the implementation of Agenda 21 and associated instruments in order to achieve the maximum possible benefit for national economies and social welfare.

The World Climate Programme is an integrating and catalytic agent for initiating and coordinating activities in the areas of climate data collection, applications, impact studies and research. Within the programme, WMO gives special attention to developing national climate services through regional cooperation. The World Climate Programme supports the provision of authoritative assessments on climate science, social and economic effects, and possible response options to climate change, especially through the work of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC). Such assessments provide the scientific and technical basis for adopting national and international response measures within the United Nations multilateral environmental agreements aimed at the implementation of Agenda 21. The World Climate Programme can provide critical support to enable nations to meet their commitments under these environmental agreements.

The World Climate Programme is implemented in four components under the overall framework of the Climate Agenda[*]:

- World Climate Data and Monitoring Programme
- World Climate Applications and Services Programme
- World Climate Impacts and Response Strategies Programme
- World Climate Research Programme

[*] UNEP is the lead-agency for the World Climate Impact and Response Strategies Programme. WMO is the lead-agency for the other components.

Monitoring and documenting climate

The World Climate Data and Monitoring Programme facilitates the effective collection and management of climate data and the monitoring of the global climate system. These activities include the establishment of the basic statistics of climate, the maintenance of world weather records, the establishment and enhancement of regional and global data archives, and the detection and assessment of climate variability and changes. It also promotes the development of comprehensive climate data management systems, and ensures that high-quality data from global observing systems for climate are readily available for use in:

- modelling climate processes;
- detecting climate change;
- monitoring climate variability;
- developing climate applications and services; and
- assessing the effects of climate

Specific activities carried out and coordinated through the World Climate Data and Monitoring Programme include:

- The provision of climate anomaly warnings and the continual monitoring of the climate system;
- The provision of annual statements on the status of global climate, biennial reviews of climate and other monitoring reports;
- Support for the development of climate databases, enhancement of climate data exchange mechanisms,
- Issuance of guidelines on climate observations and by other climate data management activities;
- The transfer to developing countries of climate database management technology and the facilitation of data exchange and data rescue activities.

Climate Applications and Services

The World Climate Applications and Services Programme assists individual nations and international organizations in furthering the applications to maintain public safety, health and welfare, to alleviate poverty and to promote sustainable development. It also fosters the provision of climate services, including where possible the prediction of significant climate variations on seasonal to inter-annual time scales.

Showcase projects: heat/health warning systems

Poor air quality in many cities is the result of both high gaseous emissions and certain meteorological conditions. Urban environments are man-made and have climates that differ appreciably from the surrounding natural or rural areas. The urban heat island effect causes discomfort to inhabitants through excess heat radiation and consequent temperature stress. This consequence is especially detrimental to the health of elderly people and the very young, and in extreme cases can lead to significant loss of life. WMO is currently involved in the heat/health warning systems project that is developing intervention techniques which use procedures that emphasize climate and health effects, and assist in implementation of warning and response systems that save lives. Showcase projects have been successfully implemented in Rome and Shanghai. These are based on proven climate applications that correlate historical climate and mortality data with dangerously heated air masses. When an extreme and life-threatening heatwave occurs, a heat emergency can be declared and city dwellers at risk helped to cope with it.

Climate Information and Prediction Services

The Climate Information and Prediction Services (CLIPS) project is an initiative to encourage the use of information about current climate conditions and new capabilities for climate prediction that have demonstrated useful skill in some parts of the globe. With improved scientific prediction of EI Niño and La Niña events in the tropical Pacific, seasonal forecasts of climatic conditions with lead times of up to a year are now becoming possible. CLIPS is designed to assist countries in using past climate data in their planning, in sectors such as agriculture, water management, tourism, disaster preparedness and other economic activities. A primary application of climate information and predictions is in management of land and water resources and their effective utilisation in a framework of sustainable development. Developing countries with primarily agricultural economies will be the major beneficiaries of the project.

Responding to the impacts of climate variations and change

The World Climate Impacts and Response Strategies Programme assesses the impacts of climate variability and changes that could markedly affect ecosystems, economic or social activities and provides relevant advice to governments. It also contributes to the development of a range of social and economic response strategies that could be used by governments and the community. In the implementation of the World Climate Impacts and Response Strategies Programme, WMO and UNEP have worked together closely on a number of initiatives over the last twenty years. For example, following the devastating 1997-1998 El Niño event, WMO spearheaded the preparation of a scientific and technical retrospective analysis of the event including documention of the weather, climate and hydrological effects experienced in many parts of the world. To complement this analysis, UNEP arranged sponsorship of a collaborative, multi-agency study on fifteen countries whose social and economic structures were seriously affected by the event. Together, these two studies now provide an unprecedented basis for countries to learn from the lessons of the past and to prepare for the onset of future El Niño events.

Research on the climate system

The World Climate Research Programme (WCRP) aims to increase our understanding of the Earth's climate system, and thereby distinguish more clearly between natural climate variability and human-induced climate change. WCRP studies cover the Earth's entire physical climate system (the land surface, the hydrosphere, the cryosphere and the atmosphere), and also feed directly into the scientific assessments of IPCC.

WCRP achievements result from remarkable worldwide collaboration across many scientific disciplines, and from cooperation between governmental and non-governmental organizations and the academic community, as envisaged by its three co-sponsors — WMO, the International Council for Science, and the Intergovernmental Oceanographic Commission of UNESCO. The widely acknowledged strengths of WCRP are its multidisciplinary approach and its organization around observational and modelling projects, focusing on aspects of climate too large and complex to be addressed by any one nation or individual scientific discipline.

WCRP is currently involved, for example, in projects investigating:

- the global circulation patterns of both the atmosphere and oceans.
- the role of the cryosphere (the world's ice masses) as a whole in global climate;
- the extension of useful predictions of climate variations and refining the estimates of anthropogenic climate change;
- the dynamical and physical processes determining the global water cycle and earth's energy budget; and

Looking to the future

The operational and scientific research programmes of the WMO have been vital in expanding our knowledge of weather, the climate system and the hydrological cycle. Data collected through these programmes is already facilitating decisions that benefit countless communities around the world. The applications are up and running, and being improved all the time: farmers are benefiting from improved agricultural methodologies, precious water resources are being managed more efficiently, and it is now possible through early warnings of impending natural hazards to partially mitigate the devastating effects of natural disasters on vulnerable communities.

WMO is especially concerned with the social and economic effects of climate and climate change. It is conscious of the need for further research on how the atmosphere interacts with ocean and land surfaces to modify local regional and global patterns of weather and climate. If we are to respond comprehensively to large-scale economic and social problems, we must first understand natural climate variability, the susceptibility of climate to human influence, and the predictability of weather and climate for periods ranging from days to decades. On success in these endeavours rests the assurance of sustainable development in the 21st century.

3. Mitigation of Natural Disasters — Early warning of hazardous weather and climate events

Challenges posed by natural disasters

The human and economic losses associated with natural disasters can be devastating. A single disaster can, at a stroke, wipe out a lifetime of work by individuals, families and communities, set back the economic growth of entire regions for years and cause environmental degradation that remains in evidence decades later. Such disasters have become all too common in recent years, and their frequency continues to rise. From 1990 to 1996, the insurance industry paid out US$ 48 billion worldwide for claims from weather-related losses. By way of comparison, claims payments in the 1980s totalled US$ 14 billion for the entire decade.

Mitigation of natural disasters

Extremes of nature are not inherently catastrophic, and with time the natural environment usually shows remarkable powers of adaptation and regeneration. Extreme events typically become disasters when they seriously affect people, their property and the environment. In a few cases, it is possible to avoid natural disasters in certain hazard areas by removing human settlement from a floodplain or river delta. In other cases, it is a matter of restricting new construction, elevating structures to remove the threat of flooding, building to higher specifications in tropical cyclone areas or, in the case of drought, adapting agricultural practices. Long-term preventative measures to mitigate the effects of natural disasters will therefore include wiser land use, especially in marginal areas, coastal zones and flood plains, and the construction of safer buildings. There is also compelling evidence that adequate warning systems and other preparations can reduce loss of life and minimize damage to property.

International Strategy for Disaster Reduction

WMO has worked closely with the International Strategy for Disaster Reduction (ISDR) secretariat and has developed partnership programmes with other UN agencies in several areas including health, agriculture and forestry, water resource management and tourism. The agencies jointly set up multidisciplinary teams to bring together scientific knowledge of the Earth system processes with expertise in social and economic systems. The teams apply their combined knowledge and expertise in the formulation of impact assessments and preparedness strategies covering a range of extreme meteorological and other geophysical events.

National Meteorological and Hydrological Services in disaster mitigation

Among the primary objectives of National Meteorological and Hydrological Services (NMHSs) in providing service to communities are the ensuring of public safety and the protection of property. By identifying incipient meteorological hazards in a given region, NMHSs are often able to soften the impact of potentially damaging phenomena. Climate records collected by NMHSs assist in identifying local meteorological and hydrological hazards. As national repositories of climate data, NMHSs play an essential role in planning and developing model community response plans to mitigate impacts. Planning, involving rigorous design requirements, and the provision of weather and flood warnings, can save lives, and minimize damage. Although these measures cannot avert severe natural phenomena, they have demonstrably shortened the recovery period afterwards. In many regions the mitigation of meteorologically related natural disasters has already been achieved, sometimes repeatedly, through planning centred on robust public infrastructure and arrangements that draw fully upon meteorological, hydrological and related information.

WMO's Public Weather Services Programme helps equip NMHSs to meet community needs, particularly in the area of public safety. The programme ensures that NMHSs benefit from the international exchange of data, techniques and specialist products for the facilitation of forecasts and warnings of extreme weather events. Through its World Weather Watch, WMO provides vital infrastructure for the exchange of the Public Weather Service Programme's important meteorological and hydrological warnings, as well as information in the form of advisories and forecasts covering a range of natural hazards.

Settlement and economic development in flood-prone areas — including informal settlements on the periphery of cities in many developing countries — continue to aggravate problems of flooding, erosion and pollution. WMO's Hydrology and Water Resources Programme (HWRP) promotes the use of forecasting techniques and hydrological modelling in support of disaster mitigation through early warning and through zoning of flood-prone areas.

Tropical cyclones

Tropical cyclones, variously called hurricanes, typhoons, or cyclones, are a manifest danger to low-lying coastal areas and Small Island developing states in the lower latitudes. Their effects are often devastating. Experience has demonstrated that preparedness backed up by efficient warning systems can dramatically reduce loss of life and significantly reduce damage to property. Regional and even global cooperation is required to mount effective prediction and warning services. This is being achieved through five WMO Regional Tropical Cyclone Committees involving the meteorological and disaster preparedness agencies of 72 countries/territories, including 31 Small Islands Developing States (SIDS).

The programme in each region comprises three elements: meteorological, hydrological and disaster prevention/preparedness. The first two are concerned with ensuring that adequate observational networks, communication systems and forecasting techniques are in place to predict the path and intensity of cyclones, and the flooding potential. Meanwhile, the third element consists of specialized regional centres and NMHSs working with disaster preparedness agencies to devise and ensure implementation of appropriate measures to minimize loss of life and damage to property. These preventive measures must be based on comprehensive analysis of the probable frequency, severity and location of strong winds, heavy rains, and flooding.

It is through the WMO that regions and countries at risk obtain reliable and timely information, forecasts and warnings on tropical cyclones and related flood and storm-surges.

Managing safe communities in urban areas

The United Nations has predicted that, by the year 2030, 4.9 billion people will live in cities, out of a world population of 8.1 billion. That compares with 2.9 billion out of 6.1 billion at present. This rapidly expanding urban environment consumes most of the world's energy and potable water, and it is where pollution and natural disasters, including flash floods, cause the most devastation.

The pace of urbanization is putting enormous pressure on water supplies, sewerage, housing, transport and other services. As energy consumption soars, cities represent larger and more pronounced heat islands, leading to increased morbidity (particularly among the elderly population), and lost productivity. In the short-term, urban areas place significant and immediate stresses on natural resources, primarily clean air and freshwater, while over a slightly longer timeframe urban activities are major contributors to the threat of global climate change as a result of their intensive use of energy and associated emissions of greenhouse gases.

Vulnerable and unsustainable locations

Many communities have evolved in geographic locations, such as river flood plains and deltas, which sustain the local economy but remain vulnerable to specific meteorological and hydrological hazards. City dwellers are becoming increasingly vulnerable to extreme meteorological events because of high population densities and settlement in flood-prone marginal lands.

Climate, weather and water all affect cities directly and are at the same time affected by them. Meteorological and hydrological information is vital in planning community housing and public infrastructure able to withstand extreme climate events and seasonal extremes of climate. Local climatological information is also an important element of town planning, as is the availability of fresh drinking water, sanitation and waste disposal, and air pollution management. It is impossible to establish effective building standards for housing, public infrastructure, and all community systems, without reliable baseline data on the local climate and especially on the probable frequency and intensity of extreme weather events.

Urban and transboundary air pollution

With increased urbanization comes increased urban air pollution associated with the transportation, energy and industrial sectors that are major characteristics of large cities. The environment of urban areas or a region can also be adversely affected by emissions of pollutants from other cities or industrial areas many hundreds and even thousands of kilometres away. WMO is working with NMSs to improve urban air pollution forecasting by assisting them in the application of meteorological information and the provision of forecasting and warning services for the improvement of local air quality.

Urban pollution is either generated locally or transported from hundreds and even thousands of miles away, also from large-scale forest fires. WMO has responded by establishing the Urban Research Meteorology and Environment project that recognizes the unique capabilities resident within NMHSs with respect to meteorological measurements and forecasting. Many countries experiencing urban pollution problems are assisted by this project through a programme of capacity building activities (workshops, training courses, etc.) on topics such as elucidating the chemistry of air pollution formation, air quality measurement and forecasting systems and the evaluation of mitigation strategies.

The first in a series of pilot projects to demonstrate how NMSs can successfully undertake or expand their urban environment programmes are being promoted in Beijing and Moscow. WMO will pursue linkages with national, regional and international programmes and agencies in fully developing GURME.

WMO's Emergency Response Activities (ERA) Programme provides training and support for operational arrangements in the event of environmental emergencies. Atmospheric transport models are used to track the movement of pollutants. Such models provide essential scientific support for international agreements to minimize and/or eliminate those hazards, which exert the most deleterious effects on distant environments. Likewise, air circulation studies and local climate data can assist with urban planning and management; airshed circulation studies can, for example, be used to assess the suitability of potential residential sites in the vicinity of industrial zones.

Spotlight on floods

Floods are a natural component of the hydrological regime. It is natural for rivers to overrun their banks with greater or lesser frequency and occupy their flood plains. Many societies have historically lived in harmony with this environment, using the floodwaters to irrigate crops (e.g., the Nile). For others, such natural events have too frequently brought nothing but destruction (e.g., the Yangtze).

Flood forecasting is widely seen as one of the most cost-effective non-structural means of reducing loss of life and property. WMO's programmes on Forecasting and Applications in Hydrology assist National Hydrological Services in applying hydrological modelling and forecasting techniques to the prevention and mitigation of water-related disasters. The programmes also work towards a better understanding of the effects of climate variability and change on water resources.

Several efforts to reduce the effects of flooding on certain communities have been ineffective. By contrast, mitigation has tended to succeed when preparedness has been rigorously planned and implemented, with the involvement and support of the community.

Associated Programme on Flood Management

In order to focus efforts and attention on the growing problem of flooding, WMO launched the Associated Programme on Flood Management (APFM) in August 2001 in collaboration with the Global Water Partnership (GWP). For the APFM, floods are an important element to be considered within overall Integrated Water Resources Management (IWRM). IWRM is built on a holistic view not only of scarcity and ambient quality, but also of an excess of water. The APFM therefore weighs all options, paying due regard to drought and water quality management in its quest for flexible structural and non-structural solutions suited to each flood-prone region.

The APFM will focus on non-structural measures, including: catchment management; re-zoning of flood plains; the development of water legislation in support of flood-plain policies; public awareness and emergency preparedness; and the use of economic tools, such as flood insurance.

4. The challenge of monitoring and managing freshwater resources

A resource under threat

Freshwater makes up a mere 2.5 per cent of the earth's water and most of that is permanently trapped in the ice caps of Antarctica and Greenland, or in deep aquifers. Freshwater in rivers, lakes, wetlands and other easily accessible surface water bodies accounts for just a few 100ths of one per cent of the Earth's water. Yet it is a resource upon which the world's growing population has placed huge demands — domestic consumption, industry, agriculture, energy production — sometimes disregarding the sustainability of aquatic ecosystems and the recharge of aquifers.

The availability and the sound management of freshwater resources are fundamental to sustainable development. Human pressures on this precious resource have reached critical levels in many parts of the world. Solutions are urgently needed if we are to avoid further shortages or pollution of sources and the inevitable consequences for health, society and the environment.

A fresh vision

The Ministerial Declaration of the Hague on Water Security in the 21st Century (March 2000) outlined a new drive to integrate the management of water resources in an approach encompassing both quality and quantity, surface water and groundwater. The Declaration acknowledged that water is used for a wide variety of purposes and drew special attention to: transboundary water resources (river basins and aquifers); international threats, both human and natural, posed by over-use, pollution, major floods and climate change; and conservation or rehabilitation of aquatic ecosystems as a vital component of integrated water management.

Water cannot be wisely managed without an accurate picture of the quantity and quality available, taking into account spatial distribution and fluctuations over time. Accurate and reliable hydrological data (e.g. river flow, water levels, water quality, and sediment transport) have a wide range of applications. These include flood protection and forecasting for the millions living in riparian communities, the construction and operation of hydraulic structures, regional planning, and evaluation of the effects of climate change.

Unfortunately, basic technical and administrative work remains to be done precisely at a time when there is an increasing demand for such information and for regional cooperation in the assessment and management of water resources. Systems for collecting and managing hydrological information are deteriorating or inadequate in much of the world. Among the main difficulties are: a lack of funding to run observing stations, outdated or lack of systems for their subsequent storage and management, varying quality assurance procedures and standards, and unreliable telecommunications systems.

National Hydrological Services and sustainable use of water

It is to National Hydrological Services (NHSs) that the primary responsibility devolves for collecting, interpreting, analysing and disseminating hydrological information required by those who plan and manage the use of water resources. The information they provide is of crucial value in protecting people and property from floods and droughts; assessing the quantity and quality of available water resources; determining the environmental, economic and social effects of management practices and determining the impact of urbanization on water resources.

International hydrological monitoring

WMO's Hydrology and Water Resources Programme (HWRP) has been at the forefront of international efforts to promote, coordinate and set standards for the measurement and assessment of the quantity and quality of water. It has actively supported efforts to strengthen the technical and institutional capacities of NHSs to capture and process hydrological data, and thereby meet end users' requirements (for basic data as well as trends observed and extrapolated).

The World Hydrological Cycle Observing System (WHYCOS)

If successful water resources management begins with an accurate assessment of water resources, then every country must have an up-to-date system for data collection, storage, and management. Unfortunately, many countries are unable either to maintain their systems for acquiring water-related data, or to disseminate the data to decision-makers and the general public. This situation prevails most frequently in developing countries, but it is not uncommon in developed countries. Besides affecting a country's capacity to manage its own water resources, it also constrains that country in its efforts to cooperate with its neighbours in the management of transboundary rivers and other shared water bodies.

WMO's response in 1993 to the challenge of UNCED was to launch WHYCOS: a system designed above all to foster international cooperation in hydrology. Composed of regional components (HYCOSs), it is developed and implemented upon request by interested countries. It focuses on technology transfer and capacity building with the aim of reinforcing the observing network, strengthening data management capacity and developing information products tailored to the needs of end users. WHYCOS is designed to complement — not to replace — national efforts to provide the information required for the effective management of water resources.

5. Support for trade and economic activities, and the alleviation of poverty

There was a phenomenal surge in the numbers of people and the volume of goods transported around the world during the closing decades of the last century. Globalization of the world economy became a reality, easily quantifiable in terms of the figures for transport by land, sea and air. For example, seaborne trade recorded its fourteenth consecutive annual increase in absolute terms in 1999 (5.23 billion tons shipped); meanwhile, 40 per cent of the world's manufactured exports (by value) were exported by air. In 2000, commercial aircraft carried 1.6 billion passengers. Yet, at the same time, poverty remains endemic in many countries of the world.

Trade and commerce are the lifeblood of most societies around the world. To sustain growth, transport infrastructure needs to be robust and reliable. In an increasingly global economy, systems of trade must allow competitive access to suppliers and markets, by means of an uninterrupted flow of goods and services, unimpeded by extreme weather events. Any disruption or delay in the movement of people and goods will carry a heavy price: firstly the cost of repairing or replacing damaged infrastructure, and secondly the cost of rebuilding disrupted trade. Too often, it is a repetitive cycle of damage to infrastructure that inhibits lesser-developed countries from breaking out of the grip of poverty.

Unfortunately, land, sea and air transport continues to be affected by extreme weather events, and weather factors are still major contributors to accidents. However, NMHSs through programmes coordinated internationally by WMO, can provide a broad range of precise and specialized meteorological services, including information and warning services vital for the safe transport of people and goods. NMHSs can also provide data essential for the design of the transport and communications systems upon which trade and commerce depend.

Putting meteorology to work

The WMO Applications of Meteorology Programme supports NMHSs in their provision of services to aviation and marine transport. The programme provides support for the safety and efficiency of all forms of transport. Tailored forecasts are provided by NMSs for safe shipping and air navigation, particularly for the critical periods of exposure during aircraft take-off and landing and ship docking. The programme also provides support to the agricultural community through a wide range of weather and climate services tailored to different cropping and animal husbandry regimes.

Services to aviation

From the earliest days of aviation, meteorological information has been vital in flight planning and for the safe conduct of flights. As 40 per cent of all accidents are caused by the weather, one of the major challenges for the meteorological community has been to provide more timely and accurate forecasts and warnings of hazardous weather to the aviation industry. Meteorological information is vital for safe and efficient aviation services, i.e. increased passenger safety, along with reduced flight delays, flight time, and fuel consumption.

WMO ensures that the aviation industry has access to operational meteorological information required for safe and efficient air navigation. Advances in automated observations, telecommunications, computer technology, and the science of meteorology itself, including improved numerical weather prediction models, now make it possible for the two World Area Forecast Centres (in London and Washington) to supply the aviation industry with high quality, timely and high-resolution en-route meteorological forecasts in standardized formats. The availability of high quality basic meteorological data and satellite imagery from the WWW Global Observing, Telecommunication and Data Processing Systems has helped to improve the accuracy and timeliness of operational aeronautical meteorological information. Moreover, the Aircraft Meteorological Data Relay (AMDAR) programme established in 1998 is now providing more than 100,000 cost-effective observations a day from in-flight aircraft, significantly enhancing the upper-air watch.

The World Area Forecast System (WAFS) for aviation provides global upper atmosphere wind conditions, temperatures and weather forecasts vital for flight planning and documentation. WAFS data is now accessible to 156 countries around the world and has been universally welcomed by the aviation community.

Protecting oceans and coastlines

The protection of marine navigation was among the first applications of the systematic analysis and prediction of weather systems. As early as 1853, leading seafaring nations organized the first formal international meteorological meeting to coordinate voluntary weather observation at sea. By early 2000, there were some 6700 vessels from 52 countries participating in the WMO Voluntary Observing Ships Scheme. Meteorological observations from these ships are essential for the daily weather forecast services crucial to safe sea transport. The data also feeds increasingly into important global climate studies.

The WMO Marine Programme coordinates the provision of data, information and services in support of the safety of life and property at sea, the protection of the marine environment, the monitoring and prediction of global climate trends, and the efficient management of marine resources. These services are based on the global collection and integrated management of a large range of meteorological and oceanographic data.

Integrated coastal area management

Coastal communities are among the most densely populated and fastest growing in the world. Two out of three of the world's cities of over 2.5 million inhabitants are now located in coastal regions and nearly two-thirds of the world's population is on or near the coast. Many coastal communities depend on healthy coastal ecosystems and clean coastal waters for their survival. The world's oceans provide the environment for a substantial proportion of the earth's biodiversity and are a source of both food and mineral resources. However, growing demand for access to the coasts has resulted in urban sprawl and pollution, the price being the loss of habitats, and even entire species. Climate change poses a major threat to many coastal communities, especially from sea level rise and consequent salt-water intrusion into freshwater systems, coastal erosion and increased threats from storm surges.

Coastal area management includes the design of coastal infrastructure and buildings, the management of coastal ecosystems (onshore and offshore resources), and the control of land and sea-based transport. All these aspects require extensive analysis of present and past meteorological and oceanographic conditions, including assessments of the risk of coastal flooding by rivers, storm surges, wind waves, or all three combined. In estuarine areas, river flow data often provides the key to coastal currents and therefore the retention of beaches and ecosystems.

What is required is a comprehensive interdisciplinary understanding of coastal systems. This would lead to the development of a robust classification scheme that would in turn enable more effective detection and prediction of changes in coastal systems on local, regional and global scales. Such a scheme must be based on an understanding of the dynamics of coastal systems and the complex forces impinging on them from the adjacent oceans, from the local coastal drainage basins and from the atmosphere.

Small Island Developing States

In many parts of the world, it is impossible to discuss future of coastal area management without consideration of the issues of climate change and sea-level rise, including the potential for changes in the frequency and intensity of tropical cyclones and related storm surges. In many Small Island Developing States (SIDS), coastal areas are inhabited by hundreds of vulnerable communities. These are frequently indigenous peoples, including traditional fishing communities, but also include others compelled by poverty to occupy areas vulnerable to natural disasters. WMO has been assisting a group of low coral atoll island nations for whom a rise in sea-level could mean serious loss and degradation of precious land or at worst, annihilation.

Coastal tourism

Tourism is the world's largest industry. It generates the lion's share of foreign currency earnings in many countries and is emerging as a key driver of 21st century economic and social development. Coastal tourism and recreation is the largest and fastest-growing sector within the tourism industry. In the USA, for example, it accounts for 85 per cent of all tourism-related revenues.

Tourist bureaux use climatic and hydrological data on temperatures, hours of sunshine and frequency of rain, collected by NMHSs, in promotional activities to attract visitors. The siting of hotels and tourist facilities must take account of the frequency of rain and strong winds, cooling wind regimes, wave climates, the stability of beaches and the availability of freshwater resources. The day-to-day operation of tourist facilities and tourist-related activities also depends directly on meteorological conditions, and thus on directly targeted meteorological services, such as wind, wave, cloud, ultraviolet radiation and rain forecasts.

Tourism is the dominant economic sector in many developing regions with tropical coastlines. This critical source of income will diminish if their coastlines are further degraded. The world's coral reefs are important natural assets that are also threatened by climate change. Rich in aquatic species, living coral reefs support recreation and commercial activities, such as fishing. They also play a critical role in the formation and maintenance of reef islands and serve as a protective barrier for coastlines.

Marine weather services

Countries provide basic marine weather services for the safety and welfare of those engaged in maritime activities such as fisheries (as required of them as signatories to the International Convention for the Safety of Life at Sea). These essentially public services also include warnings of storm surges and coastal flooding, and as such they serve to mitigate natural disasters. Other services are geared towards protection of the marine environment.

There is also an increasing demand from marine users for a range of more specialized meteorological and oceanographic services in support of economic and related interests. Meteorological and oceanographic data, information, products and services are vital for the sustainable exploitation of the global ocean and coastal environment. Marine weather services were very substantially expanded over the past half-century to meet the specific requirements of offshore oil and gas development, coastal engineering and other types of marine industry including weather-sensitive activities at sea such as fisheries and aquaculture.

NMHSs have a clear and increasing role to play, especially in the following areas critical for sustainable development in the marine environment:

- Marine environment protection. The WMO Marine Pollution Emergency Response Support System (MPERSS) provides timely and accurate meteorological and oceanographic data and products required during marine pollution emergencies (e.g., oil spills) be they on the high seas or in coastal waters.
- Sustainable management of the marine environment. This requires the availability and application of meteorological and oceanographic data and products. Effective integrated coastal area management involves both real time and climatological data on the marine atmosphere, coastal land surface and coastal ocean.

WMO provides this fundamental information for improved management of coastal areas and their resources. A number of WMO programmes assist and coordinate work in SIDS on: climate change, including changes in storm frequencies and intensities, sea-level rise, ocean wave characteristics, currents and temperatures; the provision of marine meteorological and oceanographic services; hydrology and water quality assessment; and airborne and seaborne transport of pollutants.

Support for food security

The WMO Agricultural Meteorology Programme is designed to assist nations in the provision of meteorological and related services to the agricultural community in order to help develop sustainable and economically viable agricultural systems, and above all to ensure long-term food security. The main emphases are to:

- improve production and quality;
- reduce losses and risks, and hence decrease costs;
- increase efficiency in the use of water (especially on semiarid and drought-prone lands);
- conserve natural resources;
- combat drought and desertification; and to

- decrease pollution by agricultural chemicals or other agents that contribute to the degradation of the environment.

The programme deals with applications to agriculture of climate information for mainly strategic planning purposes, and recent weather data and forecasts for use in mostly in day-to-day agricultural operations.

Agricultural meteorology and sustainable development

The need to achieve sustainable development points to a new and important role for agricultural meteorology. The broad long-term objective of WMO's Agricultural Meteorology Programme (AgMP) is to enable countries to provide the effective meteorological services needed by agriculture, forestry and related sectors, not only on a day-to-day basis, but also for planning economically viable, high quality production.

AgMP promotes the development and application of basic knowledge of the relationships between meteorological factors and the quality of agricultural output, within the framework of the World Food Summit Plan of Action, which stresses the need for sustainable management of farming systems, forestry and livestock. The programme encourages greater use of seasonal to interannual climate forecasts and current weather advisories. AgMP promotes the development of procedures and techniques for the efficient and well-targeted dissemination of agrometeorological information to farming communities.

Climate variability and sustainable agriculture

The importance of applications of agrometeorology to sustainable agriculture is thrown into sharp relief when considering climate variability. Climate variability, with or without contributions from anthropogenic climate change, has always been the principal source of fluctuations in food production, particularly in the semiarid tropical countries of the developing world. It is often a cause of economic hardship, famine and population displacement. In the developing countries, where improved technologies have been adopted too slowly to counteract the adverse effects of varying environmental conditions, climate fluctuations are indeed the main cause of hunger – often exacerbated further by social and economic disruptions.

To ensure food security, the farming community must be provided with the means to adapt to climate variability. Various agrometeorological adaptation strategies are available, including:

- Regular weather advisories on farming, production and cropping systems. These must be tailored to the needs, and adaptability, of different farming communities;
- Dissemination of information through on-line current advisories, on different time scales and for specific geographical locations as required i.e., weather and climate forecasts in support of proposed dates for sowing, weeding, fertilizer application, spraying, integrated pest management, harvesting and drying;
- Promoting the more active use of current climate information and of seasonal to inter-annual climate forecasts in agricultural planning and operations to decrease vulnerability to climate variability and climate change.

Degradation of the land

Inappropriate land use such as overgrazing, poor tillage and cropping practices, and excessive irrigation on soils with saline water tables, have frequently led to catastrophic degradation of the land in many countries. When these patterns of agricultural activity are coupled to normal patterns of climate variability that will inevitably include periods of drought, the results can be devastating, thus forging another link in the shackles of endemic poverty. This 'desertification' of the land led to another outcome of UNCED, that of the UN Convention to Combat Drought and Desertification. The key to combating desertification lies in a combination of respect for the soil and the application of sound knowledge of the natural forces associated with weather, climate and water that can lead to soil degradation. WMO's advice and action in implementing the Convention is therefore crucial in achieving success in eliminating this all too prevalent scourge from the landscape.

Challenges for agricultural research

Until the 1980s agricultural research was oriented mainly towards the question of how to raise productivity and thereby feed burgeoning populations. The success in several developing countries of the so-called “green revolution” lay in increased use of external inputs: improved seed, fertilizers, pesticides, fungicides and more water. As we move into the 21st century, a more challenging question is being posed: how to balance the continuing need for increased productivity against mounting concern about the sustainability of high-input production systems and environmental degradation. Through support from the WMO Agricultural Meteorology Programme, the agricultural research community will be better equiped to tackle a number of the critical problems on how to secure adequate and reliable food supplies for current and future generations.

6. Building capacity and transferring technology

If global efforts to reduce the impacts of natural disasters and to achieve sustainable development, are to succeed, then all countries must be fully committed to the contribution of basic information to the rest of the world on weather and climate information from within their borders of responsibility. For many developing countries to meet this commitment they will require increased support, including technology transfer from more developed countries, in order that they can build the necessary local scientific, technical and institutional capacity. Unfortunately, a number of NMHSs lack sufficient, trained personnel to organize systematic observations on a national basis. Furthermore, they frequently lack the national meteorological and hydrological infrastructure needed to process and exchange data in a timely manner, and hence to provide adequate weather and climate services.

Technology transfer through voluntary cooperation

WMO strives to enhance and develop the capabilities of NMHSs in need so that they can participate effectively in its operational programmes. A range of WMO capacity building activities provide support to these NMHSs through the transfer from developed countries of the technology and expertise on which modern meteorology and operational hydrology depend.

The WMO Technical Cooperation (TCO) Programme helps NMHSs to provide meteorological and hydrological products and services and to participate fully in international weather and climate activities. The Programme focuses on the development and operation of key WMO programme infrastructure, education and training, and the development of a wide range of early warning services (related to weather prediction, climatology and hydrology).

The WMO Voluntary Cooperation Programme (VCP) is a key financial mechanism. It provides for support to Member countries, at their request, either in the form of equipment and services, or as direct finance (derived in either case from voluntary contributions by Member countries). The VCP framework has supported the implementation of key components of the World Weather Watch and the World Climate Programme, Global Atmosphere Watch (GAW) stations, meteorological activities related to environmental protection, training seminars and the award of fellowships.

Regional cooperative activities

WMO supports several cooperative regional data processing and forecasting centres in different parts of the world. The African Centre for Meteorological Applications and Development (ACMAD) in Niamey, Niger, is a weather and climate watch centre for the continent which provides information and warnings to African governments on drought and other climate phenomena that can have serious socio-economic effects. The ASEAN Specialized Meteorological Centre in Singapore, the National Space Research Institute in Brazil, and the Drought Monitoring Centres in Nairobi and Harare are at various levels of development and, like other Regional Specialized Meteorological Centres, generate regionally focused products.

Education and Training

WMO's Education and Training Programme promotes efforts in Member countries to ensure the availability of sufficient expertise in meteorology, hydrology, and engineering as well as efficient management of infrastructure, and the smooth running of early warning systems. The programme has played a vital role specialized training of personnel, especially in developing countries. The training is generally carried out at the 23 WMO in the development and strengthening of relevant national institutions through formal and Regional Meteorological Training Centres (RMTCs), national training institutions, and research centres.

7. World Meteorological Organization

The World Meteorological Organization (WMO), of which 185 States and Territories are Members, is a specialized agency of the United Nations. The purposes of the Organization are:

(a) To facilitate world-wide cooperation in the establishment of networks of stations for the making of meteorological observations as well as hydrological and other geophysical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;

(b) To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;

(c) To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;

(d) To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;

(e) To promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services; and

(f) To encourage research and training in meteorology and, as appropriate, in related fields and to assist in coordinating the international aspects of such research and training.

(Convention of the World Meteorological Organization, Article 2)

The Organization consists of the following:

- The *World Meteorological Congress*, the supreme body of the Organization, brings together the delegates of Members once every four years to determine general policies for the fulfilment of the purposes of the Organization, to approve long-term plans, to authorize maximum expenditures for the following financial period, to adopt Technical Regulations relating to international meteorological and operational hydrological practice, to elect the President and Vice-Presidents of the Organization and members of the Executive Council and to appoint the Secretary-General;
- An *Executive Council*, composed of 36 directors of National Meteorological or Hydrometeorological Services, meets at least once a year to review the activities of the Organization and to implement the programmes approved by Congress;
- Six *Regional Associations* (Africa, Asia, South America, North and Central America, Southwest Pacific and Europe), composed of Members, coordinate meteorological and related activities within their respective Regions;
- Eight *Technical Commissions*, composed of experts designated by Members, study matters within their specific areas of competence (technical commissions have been established for basic systems, instruments and methods of observation, atmospheric sciences, aeronautical meteorology, agricultural meteorology, oceanography and marine meteorology, hydrology, and climatology);
- A *Secretariat*, comprising around 250 regular staff members headed by the WMO Secretary-General, serves as the administrative, documentation, and information centre of the Organization. It also provides support to the work of the constituent bodies of WMO described above and to the collective effort of the National Meteorological and Hydrological Services of its Members. The WMO headquarters are located at 7 bis, avenue de la Paix, Geneva, Switzerland. Postal address: World Meteorological Organization, P.O. Box 2300, CH-1211 Geneva 2, Switzerland. Homepage: http://www.wmo.ch.