Weather, Climate and Food Security

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Cover: *The Valley of Garm in the Alay mountain range in Tajikistan illustrates the range of climates over a short distance and the implications for food production in the valley.* (Photo: FAO/A. Proto)

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NOTE

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FOREWORD

It is estimated that by 2020, the world's population will reach 7.5 billion and that much of this growth will occur in the developing world. To meet the increasing global demand for cereals, for example, the world's farmers will have to produce 40 per cent more grain in 2020. Although the global production of cereals and global cereal yields rose over the 1986–1998 period, the average per capita cereal production for the world remained stagnant over the period and actually fell in Africa and the Middle East. These disturbing trends in some parts of the world have many negative implications for food security and poverty alleviation, especially when viewed in conjunction with the increasing frequency of extreme weather events.

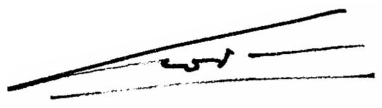
Over the 1996–2000 period, there was an alarming increase in the number of countries affected by natural disasters, which rose from 28 to 46, mostly in the developing world, where disasters have exacerbated the problems of food security, poverty and land degradation. For example, in recent years major storms and floods have struck Bangladesh, Cambodia, the Caribbean, Central America, China, India, Southern Africa, Venezuela and Viet Nam. The direct and indirect costs of the floods in Mozambique caused by tropical storms *Elyne* and *Gloria* in February and March 2000 are estimated at US$ 1 billion, as compared with the country's export earnings of US$ 300 million in 1999. Severe droughts during 1999–2001 affected much of Western Asia, Central Asia and the Middle East, which resulted in large crop losses.

It has been demonstrated that judicious application of meteorological — including climatological and hydrological — knowledge and information, and seasonal and long-range forecasts, can considerably assist the agricultural community in developing and operating sustainable agricultural systems and increasing production in an environmentally sustainable manner. However, the developing countries are most vulnerable and least able to adopt improved techniques and technologies to counteract the adverse effects of varying environmental conditions and climate fluctuations that are among the main factors that prevent the regular supply and availability of food.

For these reasons, the World Meteorological Organization (WMO) coordinates and provides support to the National Meteorological and Hydrological Services (NMHSs) of its Member countries in their respective missions of observing and understanding weather and climate, and providing meteorological and related services in support of their national socio-economic development plans. The NMHSs, as part of the global network under the aegis of WMO, provide scientifically-based forecasting and warning services that enable all nations to forewarn and protect their national communities from the threat of tropical cyclones, severe storms, floods, droughts, forest fires, and other weather-induced natural disasters, and that enhance the efficiency and productivity of the agriculture and forestry sectors.

In the area of food security, the scientific programmes and activities of WMO, including its Agricultural Meteorology Programme, Climate Information and Prediction Services (CLIPS) project and Hydrology and Water Resources Programme, are addressing a number of important issues related to weather, climate and water in collaboration with other

United Nations organizations, such as the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), and other relevant regional and international organizations. This booklet, which is dedicated to the “World Food Summit — 5 years later”, illustrates WMO’s role in contributing to the achievement of food security for all nations. We hope that it will also help to provide a better understanding of the activities and commitment of the meteorological and hydrological communities to support the implementation of the World Food Summit Plan of Action.



(G.O.P. Obasi)
Secretary-General

CLIMATE ISSUES IN THE WORLD FOOD SUMMIT PLAN OF ACTION

The World Food Summit elaborated seven Commitments, of which Commitment 3 — sustainable policies and practices essential to adequate and reliable food supplies and to combat pests, drought and desertification — and Commitment 5 — prevent and prepare for natural disasters and man-made emergencies and to meet transitory and emergency food requirements — are very relevant for the climate community from a sustainable development perspective.

Commitment 3 makes repeated reference to climate and climate change (including the United Nations Framework Convention on Climate Change (UNFCCC)) and the related problems of desertification, the loss of biodiversity, the depletion of the ozone layer, which are all related, at least indirectly, to the unsustainable use of climate resources. This Commitment stresses the need to promote the research needed to continue international efforts to develop, disseminate and apply climate forecast information that will increase sustainable agricultural, fisheries and forestry productivity and be of particular benefit to developing countries.

Commitment 5 emphasizes the need to maintain, promote and establish the preparedness strategies and mechanisms, including development and application of climate forecast information for surveillance and early warning, drought, flood, other natural disasters, pest and disease alertness. It also underlines the need to support international efforts to develop and apply climate-forecast information to improve the effectiveness and efficiency of emergency preparedness and response activities, with special efforts to create synergy and avoid duplication.

INTRODUCTION

Food production in the developing world declined from an average annual growth of 4.2 per cent during the period 1991–1995 to 3.5 per cent during the period 1996–2000. One of the reasons for this decrease was the alarming increase in the number of countries affected by natural disasters, which rose from 28 in 1996 to 46 in 2000. In recent years, major storms and floods have struck Bangladesh, Cambodia, the Caribbean, Central America, China, India, Southern Africa, Venezuela and Viet Nam. As of April 2001, some 60 million people in 36 countries were confronting food shortages of varying degrees.

Efficient use of natural resources is crucial for the success of rainfed cropping systems such as pearl millet/cowpea intercropping systems in West Africa
(WMO/M.V.K. Sivakumar)

Climate variability witnessed in recent years is not new. It has been, and continues to be, the principal source of fluctuation in global food production, particularly in the semi-arid tropical countries of the developing world. In conjunction with other physical, social and political-economic factors, climate variability contributes to vulnerability to economic loss, hunger, famine and dislocation. In the developing countries, where adoption of improved technologies is too slow to counteract the adverse effects of varying environmental conditions, climate fluctuations are the main factors that prevent the regular supply and availability of food, the key to food security. Hence it is imperative that weather and climate variability aspects are well understood so as to formulate more sustainable policies and strategies to promote food production and food security.

From the perspective of world food security, discussions on climate mostly refer to climatic hazards and their impacts on world food production. However, it is important to recognize that food security involves climate, not only as a natural hazard but also as a natural resource. Climate is a renewable resource, but is variable in time and space. For proper and efficient use of the other two natural resources (soil and plant/animal genetic material) for sustainable agriculture, knowledge of the role of climate is an essential precondition. In fact, climate should be regarded as the driving variable for exploitation of plant, animal and soil resources. Many of the ecological implications of agricultural development require an improved understanding of the interactions between the physical, biological and climatic components.

EXTREME METEOROLOGICAL AND HYDROLOGICAL EVENTS

Globally, over 70 per cent of natural disasters are related to weather and climate, but in some countries or regions, these account for the totality of such disasters. The major natural disasters include hurricanes/tropical cyclones/ typhoons, floods, droughts, extratropical storms, tsunamis and storm surges, tornadoes, sand and dust storms, extreme temperatures, weather-related fires, and pests and diseases of crops and livestock. The disasters cause many deaths and economic losses amounting to billions of dollars each year. In the past 20 years, natural disasters have killed over three million people, inflicted injuries, devastated arable lands, facilitated the spread of diseases and displaced over one billion people. Annual economic costs related to natural disasters have been estimated at about US$ 50–100 billion. Indeed, in some years, the global economic losses are much higher, sometimes reaching US$ 440 billion. Furthermore, it is estimated that about 250 000 lives are lost worldwide every year directly or indirectly as a result of natural disasters.

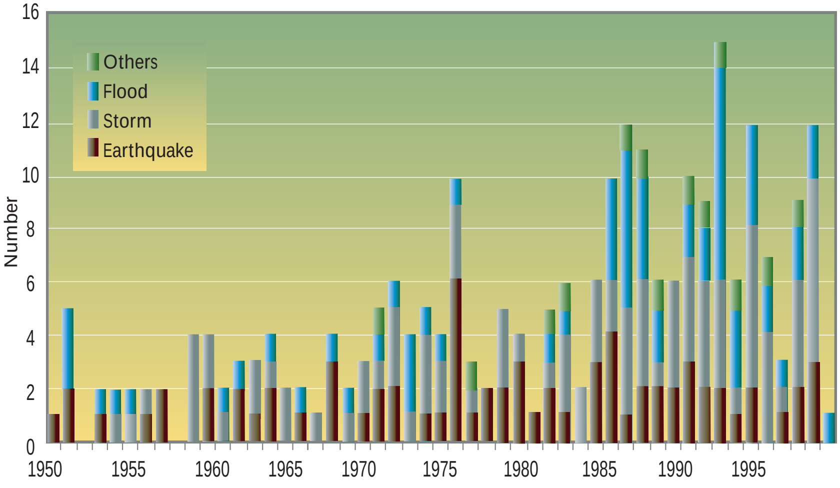
Climate factors are inexorably linked to basics of life, including availability of food, safe drinking water and good health. Destruction of food reserves, damage to or loss of water supplies through drought, or through pollution of traditional water sources during floods, and increased incidence of viral and other infectious diseases, are some of the impacts that can accompany extreme meteorological and hydrological events.

In recent decades, people throughout the world have become increasingly alarmed by natural disasters, which are becoming more frequent and more destructive. Human beings have not so far been able to control the forces of nature. They cannot prevent the formation of a tropical cyclone, nor can they prevent droughts, floods, earthquakes or the eruption of volcanoes. However, they are able to contain rivers, to stem tides and to build structures that will give considerable, if not total, resistance to the forces of nature. Since natural phenomena will continue to occur, the problems these present must be faced, giving due priority to policies for disaster planning, preparedness and prevention.

Tropical cyclones

Tropical cyclones, also known as hurricanes, typhoons or cyclones, afflict most countries in the tropical and subtropical zones, often with devastating effect. Indeed, they are among the most devastating of all natural hazards. Their

Great natural disasters far exceeding 100 deaths and/or US$ 100 million in claims, 1950–2000 (Münchener Rück/ Munich Re)



Far right: Hurricane Mitch *caused severe crop lodging at Choluteca, Honduras* (Paul Jeffrey/CCD)

potential for wrecking havoc caused by their violent winds, torrential rainfalls and associated storm surges, high seas in coastal areas, floods, tornadoes and mud slides is aggravated by their severity, size, frequency of occurrence and the vulnerability of the extensive areas they affect.

Tropical cyclones have severe negative impacts on agriculture and food security, water resources, and on other key social and economic sectors. For example, it has been estimated that, globally, tropical cyclones alone account for an annual average of about 20 000 deaths and about US$ 6 million in damages. In 1992, hurricane *Andrew*, the most destructive tropical cyclone, caused losses in the United States of America estimated at some US$ 16 billion. Other tropical cyclones, which were very intense or which caused or contributed to major disasters, included the 1997 typhoon *Winnie* in China that affected over 400 000 hectares (ha) of crop lands, amongst other things, and hurricane *Mitch* in 1998 that devastated Nicaragua, Honduras and Guatemala and displaced about two million people.

Flooding and soil erosion caused by El Niño affect sustainable agriculture and food security in some developing countries (ISDR)

El Niño and La Niña

El Niño and La Niña are the most significant examples of climate variations that have global economic and social implications. El Niño is a naturally occurring climate phenomenon, observed every two to seven years and lasting from between three and six seasons, marked by extensive warming of the surface waters in the central and eastern tropical Pacific Ocean. The negative or cooling phase of El Niño that makes the eastern pacific waters cooler than normal is called La Niña.

El Niño is generally associated with worldwide anomalies in the patterns of precipitation and temperature, as well as with patterns of tropical storms and hurricane activity, the behaviour of the subtropical jet streams, and many other general circulation features over various parts of the world. It has been found that the El Niño events produce consistent climate patterns. A strong El Niño event is linked to droughts in southeastern Africa, northern Australia, northern Brazil, Indonesia and the Philippines. Wetter than normal conditions tend to occur in tropical east Africa, along the coast of tropical South America and the subtropical parts of North America (Gulf

Coast) and South America (southern Brazil and central Argentina).

The 1997/98 El Niño event has been considered as perhaps the strongest of the twentieth century. This El Niño and the 1998/99 La Niña events imposed considerable socio-economic stress and set back development in many parts of the globe. The notable global impacts included the severe droughts and forest fires in Indonesia and northeast Brazil, and catastrophic floods in tropical east Africa. In Latin America and the Caribbean, to various extents, loss of life, destruction of property, damage to food production, food reserves and transport systems, as well as increased health risk, were among the many socio-economic consequences as a result of Hurricane *Mitch* during the La Niña event. The major burden of the natural disasters was in the developing world. Estimates of global damage from the 1997/98 El Niño range from about US$ 14 billion from mainly property damage to more than US$ 33 billion when other socio-economic losses are assessed.

Droughts

Drought is a natural hazard originating from a deficiency of precipitation that results in a water shortage for some activities or some groups. It is the consequence of a reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors — such as high temperatures, high winds and low relative humidity — that can aggravate the severity of the event. Because drought affects so many economic and social sectors, scores of definitions have been developed by a variety of disciplines; these can be grouped mainly as meteorological, hydrological, agricultural and socio-economic droughts.

Severe droughts in the fragile ecosystems of the arid and semi-arid regions pose problems for vegetation and livestock management (FAO/R. Faidutti)

The widespread misery caused by the recurrent droughts in the 1970s and 1980s in the Sahel and in eastern and southern parts of Africa are well known. In 2001, much of Western Asia, Central Asia and the Middle East suffered the third year of a continuing drought that severely reduced crop yields in many countries. It was estimated that between June 2000 and June 2001, half of Afghanistan's population of about 12 million was affected by drought, three to four million people severely. The extremely low level of precipitation destroyed almost all the rain-fed crops and decimated the livestock. The cereal deficit exceeded 2.3 million tons, more than double that of the previous year. In the Islamic Republic of Iran, a severe drought in 1999 was followed by an extreme drought in 2000 and yet another in 2001. These droughts threatened more than 6.4 million acres of irrigated farms, 9.88 million acres of rain-fed fields and 2.7 million acres of orchards. Agricultural damage across the country is estimated at more than US$ 2.6 billion.

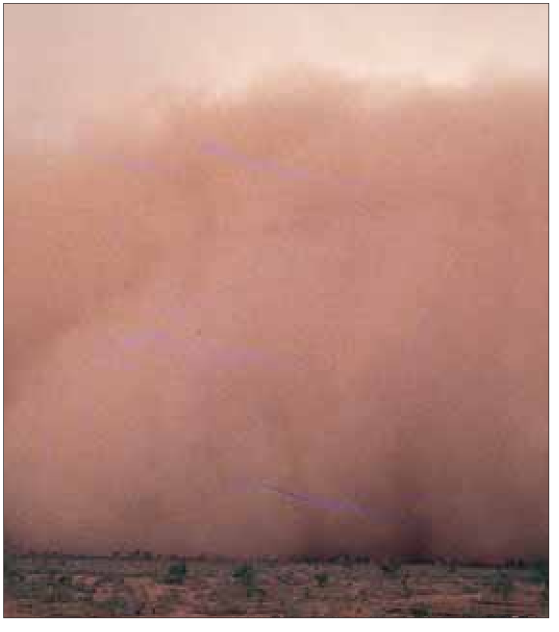
Wind storms and dust storms

Wind erosion, the removal of soil by wind, is one of the most damaging effects of wind in many parts of the world. This is a major problem in regions with a strongly marked annual dry season and thus is a potential hazard in all dry environments. The occurrence of wind erosion at any place is a function of weather events interacting with soil and land management through its effect on soil structure, tilth and vegetative cover. Little attention has been given to this environmental degradation affecting the drylands — covering approximately a third of the world continental area — because wind erosion is a low-grade, insidious-onset, long-term, cumulative process. As with water erosion, the most severe form of wind erosion comes from relatively rare, severe events.

According to the United Nations Foundation, of the reported 850 catastrophes with a natural trigger in 2000, wind storms accounted for more than 300 events and for 73 per cent of the insured losses.

Floods

Two of the principal hydrometeorological events that often have deleterious effects on agriculture are flooding and heavy rainfall. Floods also have temporal characteristics; those that occur in a short period of time, or come quickly, are called flash floods. The interaction between spatial and temporal scales is important in determining impacts. A



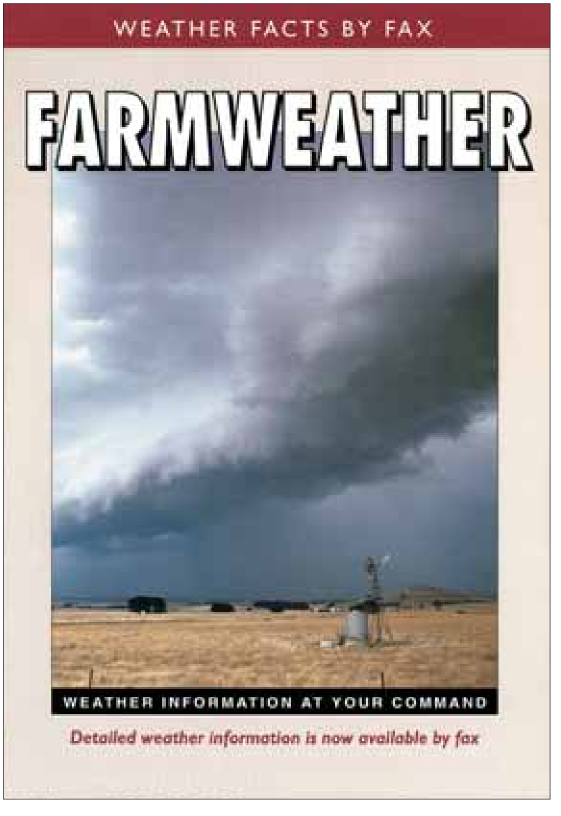
Wind erosion on light sandy soils can provoke severe land degradation (left) and sand deposits on young seedlings can affect crop establishment (right) (WMO/M.V.K. Sivakumar) very intense (extreme) rainfall can result in catastrophic flood damage even though it occurred for a relatively short period of time, and/or at the proper location, at the proper time of year, etc. Flash floods and landslides in Venezuela in December 1999 caused 30 thousand deaths. The direct and indirect costs of the floods in Mozambique caused by tropical storms *Elyne* and *Gloria* in February and March 2000 are estimated at US$ 1 billion, as compared with the country's export earnings of US$ 300 million in 1999.

The effects of floods on agriculture can be classified as direct or indirect. Direct effects are those that regard the property and income of individuals, enterprises and the public sector. Indirect effects are slower and often more widespread (geographically, economically, etc.) than direct effects, and are the result of decreased income, environmental degradation and other factors. In general, direct effects are much easier to quantify, while estimates of indirect effects are often incomplete due to their complicated impacts throughout society.

In the Sahel, flash floods on sandy soils can cause land degradation and affect crop productivity (WMO/M.V.K. Sivakumar)

WEATHER AND CLIMATE RELATED TO FOOD SECURITY — CONTRIBUTIONS OF WMO

Few countries or communities are immune from extreme weather events and climate extremes. Some communities are more vulnerable to particular events and suffer more frequently than others. Notwithstanding the climatological risk that is related to geography, the extent to which an extreme meteorological event becomes a natural disaster has much to do with planning, early warning, protective measures taken and the resilience of a community, including its ability to recover after an extreme weather event.



Provision of weather information to farmers through Agrometeorological Advisories is essential for operational decisions in crop management (Bureau of Meteorology, Australia)

WMO is the United Nations specialized agency responsible for meteorology and operational hydrology. WMO provides support to the National Meteorological and Hydrological Services (NMHSs) of its 185 Member States and Territories in their respective missions of observing and understanding weather and climate and providing meteorological and related services in support of national needs. These needs especially relate to protection of life and property, safeguarding the environment and contributing to sustainable development.

The scientific programmes of WMO have been vital in expanding knowledge of the climate system. The systematic observations carried out 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 observations, including those for chemical constituents of the atmosphere and characteristics of the oceans and their circulations, have led to a better understanding of interactions between the domains of the climate system (the atmosphere, the oceans, the land surface and the cryosphere) and of climate variability and change.

Early warning systems

The enhanced application of science and technology, including prediction and early warning with good lead-time about impending weather and climate hazards, provides the best solution

Climate Prediction Services (CLIPS)

Prediction on seasonal and longer time scales, as a basis for warning, is a developing community service. WMO believes that the progress being made in climate research, where appropriate, should be translated into forms that will elevate the socio-economic well-being of humanity. In 1995, the WMO Twelfth World Meteorological Congress endorsed the Climate Information and Prediction Services (CLIPS) project to build on research achievements and provide information, including expectations of future conditions, to improve economic and social decisions. This has come at a time when there is a growing public awareness of possible human-influenced changes in climate, and the impact on society of variations in climate, such as those caused by El Niño. An important feature of CLIPS is analysis of the past and contemporary climate and integration with near-future climate predictions.

One of the immediate tasks of the CLIPS project has been to assist in developing the capability of NMHSs to receive and utilize the global climate information and prediction products which are currently being produced by several major climate centres around the world. Climate information and prediction services are frequently aimed at alleviating or mitigating negative impacts of extreme climate conditions or anomalies, and also at taking advantage of any positive impacts. For a number of years, El Niño predictions have been used by several countries to provide early warnings and in disaster preparedness. WMO has been coordinating the activities of various interested groups through the co-sponsorship of workshops, seminars and conferences, and the organization of special training events on El Niño.

In collaboration with partner institutions, WMO has organized several Regional Climate Outlook Fora (RCOF) in many parts of the world. The fora have enabled researchers from various advanced climate prediction centres, regional operational climate centres and experts from NMHSs to develop consensus or consolidated climate outlook guidance products, together with guidance on interpretation, for dissemination to users. The RCOF proved to be a very effective capacity-building mechanism for the NMHSs in terms of the transfer of knowledge of the current state of development and limitations of seasonal climate prediction science. The fora were therefore used to enhance the regional and climate outlooks and associated impact projections during El Niño events.

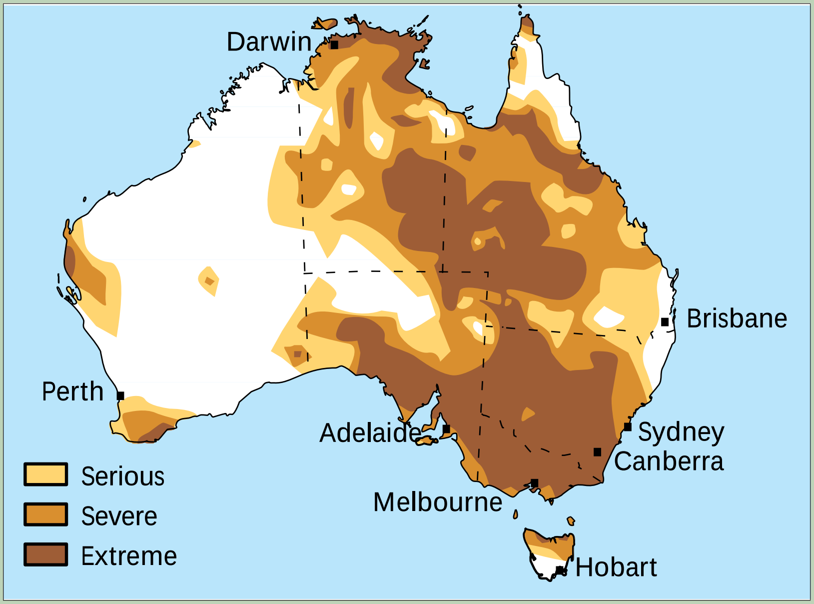
Some examples to illustrate the use of El Niño predictions to provide early warning include:

- Peru, where the El Niño information has been used for sustainable agricultural production through the alternation of crops, for example rice and cotton, during dry years;
- In Brazil, enhanced agricultural production is reflected when El Niño information was used in making specific agricultural decisions when the El Niño events took place in the last two decades;
- Too much or too little rainfall, which is common in some regions during warm and cold El Niño phases, has been associated with various vector-borne and food-related diseases. In Colombia, linkages between El Niño and malaria cases were established.

An important component of the CLIPS project is in the area of training and technology transfer. The objective is to

Cost/loss table for an adverse weather event		IS THE EVENT FORECAST?	
		YES	NO
DID THE EVENT OCCUR?	YES	HIT Financial losses occur but are mitigated through taking appropriate protective action	MISS Full losses occur, as no protective action is taken
	NO	FALSE ALARM Costs of protection are borne, but protection is not required	CORRECT REJECTION No losses; no costs; outcome is that expected from normal activities without the event

(After *Foresight*, Department of Trade and Industry, UK)



The Drought Watch Service of the Bureau of Meteorology of Australia provides information on the severity of El Niño conditions (Bureau of Meteorology, Australia)

ensure that NMHSs have access to the regional and global climate monitoring products that are routinely generated in support of the World Climate Programme (WCP) and that the staff of NMHSs have the necessary training to provide services in support of community decision-making. The CLIPS project is closely linked to the WMO Agricultural Meteorology Programme and the Hydrology and Water Resources Programme to build on existing linkages with community managers in the land and water resource areas.

to minimize loss of life and property damages caused by natural disasters. Prediction and early warning information and products are vital in enhancing food and agricultural production as well as in the utilization and management of fresh water, energy and other natural resources that are sensitive to extreme weather and climate events.

In order to improve on the lead-time of prediction and early detection of extreme meteorological and hydrological events, and of climate variability and change, proper understanding of the processes that control global weather and climate systems is required. These processes include weather prediction research at all time scales and modelling capacity, especially the potential to improve the prediction of climate variability or change at local or regional levels. WMO provides an international framework for collaboration in all meteorological and hydrological research areas that are of national, regional and global interest.

Over the last several decades, major advances have been made in weather forecasting, that is, up to about a week for mid-latitudes, but the understanding of El Niño represents the first major breakthrough in the prediction of the longer-term climate. Over the last decade, a new era has emerged for climate prediction. A new generation of coupled climate models, which can be nested with high-resolution regional models, is now available. Some of these coupled models can now be used to provide climate outlooks at multi-seasonal to interannual time scales. For example, it is now possible to predict El Niño-related sea-surface temperature anomalies, in a time-span ranging from seasons to over one year in advance. Recent researches have also shown consistent worldwide anomalies in the occurrence of floods, hurricanes, severe storm activities, and many other extreme climate

Agricultural Meteorology Programme of WMO

The purpose of the Agricultural Meteorology Programme of WMO is to support food and agricultural production and activities. The main long-term objectives are:

- To promote economically viable and high-quality production so that it can be sustainable and environment-friendly by strengthening Members' indigenous capabilities to provide relevant meteorological services to agricultural and other related sectors;
- To foster a better understanding by farmers and other end-users in the agricultural, forestry and related sectors of the value and use of meteorological (including climatological) information in planning and operational activities.

The following projects are being implemented by the Agricultural Meteorology Programme during the period 2000–2003.

Agrometeorological Applications

To promote further development and application of basic knowledge on relationships between meteorological factors and agricultural production including its quality and protection of the agricultural resource base and the output for sustainable management of farming systems, forestry and livestock in line with the World Food Summit Plan of Action.

Use of Climate Forecasts in Operational Agriculture

To promote more active use of seasonal to interannual climate forecasts and current weather advisories in agricultural planning and operations in active collaboration with the CLIPS project.

Agrometeorological Data Management

To provide Members with techniques and methods to observe, register, collect, manage, store and exploit ground-based, radar and remotely-sensed meteorological, climatological and agronomic data in the most timely and personnel-efficient manner.

Communication of Agrometeorological Information

To develop methods, procedures and techniques for the dissemination of agrometeorological information with the full involvement of users.

Agrometeorology for Extreme Events

To focus on studies and applications of agrometeorological information needed to cope better with droughts and desertification, flooding, tropical cyclones, storm surges, locust invasions, and other spreading and intensifying environmental hazards.

Agrometeorological Adaptation Strategies to Climate Variability and Climate Change

To develop agrometeorological adaptation strategies to climate variability and climate change especially in the vulnerable regions where food and fibre production is most sensitive and vulnerable to climatic fluctuations.

anomalies associated with El Niño. Early warning of any impending El Niño phenomenon, one or several seasons in advance, is now being used in disaster preparedness in those parts of the world where El Niño signals are strong.

The use of predictions of El Niño a year or more in advance, such as the early warning of unusual rainfall and drought patterns, therefore has significant economic benefits in various regions. Socio-economic losses cannot be entirely eliminated, but timely and appropriate mitigation measures can certainly reduce the impacts. In fact, early information on El Niño episodes allows for advanced national planning, with considerable advantages in many sectors of the economy such as agricultural production, water resources management and fisheries. In the case of the 1997/98 El Niño event, advances in El Niño-related science and in monitoring the sea-surface temperatures in the Pacific Ocean enabled scientists in the NMHSs to predict its formation longer in advance than all the previous events. With recent developments in communication technology, including the use of Internet, information on El Niño was rapidly and timely disseminated throughout the world. These developments enabled many governments to take appropriate measures, and stimulated international cooperation and integrated efforts to address the associated impacts.

About 80 tropical cyclones form annually over tropical oceans. They have a lifetime varying from days to a week or two, sometimes longer. A particular important aspect of tropical cyclones, which is distinct from some of the other natural hazards, is the worldwide availability of early warning systems as a basis for preparedness action and, hence, disaster mitigation. As a result of international cooperation and coordination, and with the aid of meteorology and modern technology, such as satellites, weather radars and computers, all tropical cyclones around the globe are now being monitored from their stages of formation throughout their lifetime by designated Regional Specialized Meteorological Centres (RSMCs) located in Miami, Nadi (Fiji), New Delhi, Tokyo and La Réunion, as well as by other centres of NMHSs. These centres provide forecasts on the behaviour of tropical cyclones, their movement and changes in intensity, and on associated phenomena, mainly storm surges and floods. They issue timely warnings to all those who are threatened. The activities of the centres are coordinated at the global and regional levels by WMO through its World Weather Watch (WWW) and Tropical Cyclone Programmes.

A good example of how an appropriate satellite-based early warning system can help countries reduce human and economic losses is that of Bangladesh. After the killer cyclones

Making users aware of the value of weather information promotes improved applications of weather and climatic information at the field level
(WMO/M.V.K. Sivakumar)

of 1971 (300 000 deaths, 1.3 million homeless) and 1991 (138 000 deaths), the government put in place an early warning system. When another devastating cyclone of equivalent intensity struck in 1994, the ultimate impact was many times less — 250 deaths, 0.5 million homeless — compared to the disastrous 1971 and 1991 events.

Reducing vulnerability

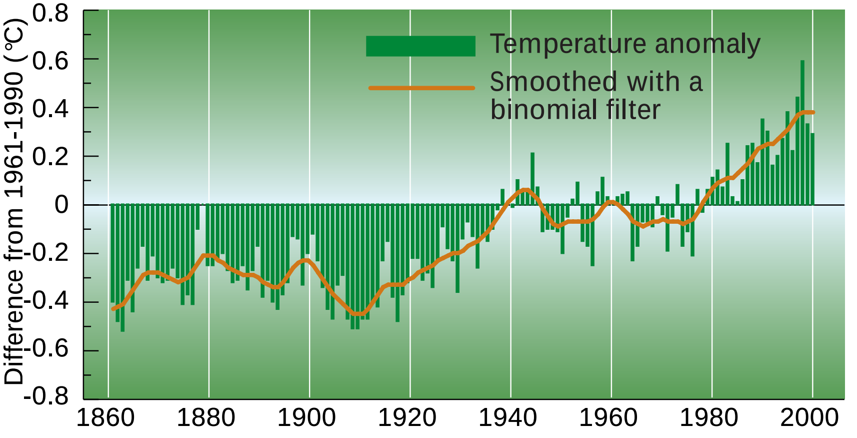
Due to globalization, population pressures and urbanization, many farmers, particularly in developing countries, are being forced out of their traditional cropping systems and into adopting systems and crops expected to be more productive and more relevant to market-related economies. Also, cropping and herd grazing have expanded into marginal lands to further increase overall output. The economic vulnerability of many traditional and subsistence farmers has therefore increased markedly due to the introduction of unfamiliar crops and farming techniques, their new exposure to market forces, the use of marginally productive lands and the impacts of global and local climate variability.

There have been unintended consequences to new land-use patterns in some regions that will reduce the long-term sustainability of the system. Water logging and increased salinity are problems associated with both clearing of forests for dryland farming and the introduction of irrigated farming. Expansion or intensification of dryland cropping and herd grazing can increase susceptibility of soils to wind erosion.

A range of agrometeorological services is available to assist in evaluation of new cropping strategies and the sustainability of new cropping regimes within the context of the local climate. WMO, through its Agricultural Meteorology Programme, works with the Food and Agriculture Organization of the United Nations (FAO) to address regional land-use problems and in assisting NMHSs in introducing services that support sustainable land-use practices.

Understanding climate change and impacts

Concern about climate has touched communities in all parts of the globe. As communities have adapted to their local climate, they are sensitive to its variations, and many are threatened by climate change. The WMO/United Nations Environment Programme (UNEP) Intergovernmental Panel on Climate Change (IPCC) assessments have shown that the observed increases in atmospheric greenhouse gases (GHGs) may lead to global warming, sea-level rise and space-time changes in the normal patterns of hydrometeorological parameters. Based on evidence from climate models together with observations from instrumental and other available records, the IPCC Third Assessment Report (2001) concluded that: “There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities”. Human influences will continue to change atmospheric composition throughout the twenty-first century. By 2100, the concentration of CO_2 is expected to increase from the present figure of 370 ppm to 540–970 ppm. Over the period 1990 to 2100, it is projected that the average global air temperature will increase by 1.4 to 5.8°C and global mean sea level will rise by somewhere between 9 cm and 88 cm. According to that reported in the IPCC assessments, recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems.



Combined annual land-surface air and sea-surface global temperatures from 1860–2000, relative to 1961–1990 (Climatic Research Unit, University of East Anglia, and Hadley Centre, The Met. Office, UK)

Based on experimental research, crop yield responses to climate change vary widely, depending upon species and cultivars; soil properties; pests and pathogens; the direct effects of carbon dioxide on plants; and the interactions between CO_2, air temperature, water stress, mineral nutrition, air quality and adaptive responses. It is noted that those countries with the fewest resources have the least capacity to adapt to climate change and thus are the most vulnerable.

For example, the adaptive capacity of human systems in Africa is low due to the lack of economic resources and technology and to greater vulnerability due to frequent droughts and floods, poverty and the heavy reliance on rain-fed agriculture. Grain yields are projected to decrease, diminishing food security, particularly in small food-importing countries. Desertification would be exacerbated by reductions in average annual rainfall, runoff and soil moisture. Significant extinction of plants and animal species is projected and would impact rural livelihood.

In Asia, the adaptive capacity of human systems is also low and vulnerability is high in the developing countries of the region. Extreme events, including floods, droughts, forest fires and tropical cyclones, have increased in temperate and tropical Asia. Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise and extreme events would diminish food security in many countries. Climate change would exacerbate threats to biological diversity due to land-use and land-cover change and population pressure in Asia.

Similarly, in Latin America, the adaptive capacity of human systems is low, particularly with respect to extreme climate events, and vulnerability is high. Yields of important crops are projected to decrease in many locations. Subsistence farming in some regions could be threatened. The rate of biodiversity loss would increase.

AGROMETEOROLOGICAL ADAPTATION STRATEGIES TO INCREASING CLIMATE VARIABILITY AND CLIMATE CHANGE

The agricultural community can receive useful assistance from agrometeorologists in developing strategies to adapt to climate variability and climate change, which should be validated on-farm for improved extension advisories, together with the farmers. The increased frequency and magnitude of extreme events have been frequently mentioned as potential characteristics of future global climate. Even small changes in the frequency of extreme events have a disproportionate effect. For instance, the life cycle of perennial plants changes drastically if the frequency of extreme events increases, because seedling establishment and the mortality of these plants are highly sensitive to extremes. Both the stability or forage supply and the balance between temperature and subtropical species are largely controlled by the frequency of extreme climatic events and thus are easily subject to change in a CO_2-warmed climatic change scenario. One important aspect of short-term extreme events is the apparent randomness and abruptness with which they arrive.

The agricultural sector must react to the demands of reducing its contributions to possible global warming, which asks for changes in production methods, and must be better prepared to react to the (increasing) variabilities and extremes, and prepare scenarios for possible lasting change. The character of this need to adapt is determined initially by worsening limiting factors of agricultural production and the vulnerability of farming systems. The rate of required adaptation to climate variability and climate change as well as the impact on the disruptions resulting from other socio-economic or environmental changes have to be taken into account. Easy access to developed and well-tested technology is important for many countries, however local innovations should not be neglected.

Agroforestry plays an important role as do other afforestation techniques, with an additional role as CO_2 sink. There are numerous drought adaptation measures: these range from time of planting, practising water conservation techniques, using crops with very extensive and deep rooting systems to planting drought-resistant varieties. Simple agrometeorological techniques exist to improve water use efficiency of crops in drylands, for example tillage in the fallow period, mulching, soil moisture management with adapted fertilization, crop rotation and multiple cropping.

To ensure food security, an effective response strategy to climate variability and climate change should pay adequate attention to the possibilities of linking response options with responses to socio-economic transition phenomena. Some agrometeorological adaptation strategies include:

- *Regular weather advisories on farming, production and cropping systems, in accordance with the possibilities for change in the different farming communities. This applies to techniques of using inputs, soil conditions and planting densities, choices of cropping systems and varieties, applications of (improved) protection strategies in crop/tree space and applications of other multiple cropping microclimate management and manipulation techniques;*
- *Dissemination of information through on-line current advisories, on time scales and in*

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

(IPCC, 2001)

Examples of Agrometeorological Applications

Five-day weather forecast by telefax for agriculture in Switzerland

In 1994, the Swiss Meteorological Institute developed a forecast for a five-day period especially for agricultural establishments, its upstream and downstream enterprises, as well as for further outdoor activities. The forecast has been produced daily since 1 March 1995. Clients can call it in by telefax whenever they wish to do so, against a corresponding charge. The five-day forecast for agriculture contains a forecasting part in the form of a text and ‘particularities’, such as recommendations (for example weather for hay harvest), warnings (for example frost warnings) and climate values (for example information on decades, months or seasons). In addition, listed is some agricultural work which can be better planned and carried out because of the forecasts (for example sowing bed preparation, frost protection measures, irrigation management, optimization of plant protection measures, optimization of stock transport facilities, or optimization of crops (date or period), purchases, sales, quantities and qualities).

Relationship between weather and sheep feeding in China

The efficiency of animal husbandry in the Inner Mongolia area of China is very low. The main problem is that the winter is so cold that all grass withers. Animals only grow in the warmer half of the year, with their weight decreasing in winter; some years, weak animals even die in the spring. Therefore, herders usually make hay in the summer, from 10 July to 20 August, and feed sheep in winter. But the hay season is also the rainy season. The weather forecast service therefore is very important to herders. Agrometeorologists in Inner Mongolia have studied the relationship between weather and the hay harvest and have developed an index of the best haying time: no rain for more than three days, mean daily humidity less than 75 per cent, mean air temperature above 20°C and wind velocity above 3 m/s. Under these conditions, the water content of hay will decrease to below the safe index of 18.5 per cent in two to three days. Agrometeorologists also determined the quantity of hay (kg) required for sheep feeding according to body weight (kg) and mean daily temperature (°C). This technique has become popular in many counties of Inner Mongolia and herders had an increased profit of 14 yuan per sheep.

FAO/A. Odoul

- *spatial scales as required. Examples are: weather and climate forecasts; and timely advice on farm operations such as sowing dates, weeding, fertilizer application, spraying, integrated pest management, harvesting and drying;*
- *Promoting the more active use of seasonal to interannual climate forecasts and of current climate bulletins in agricultural planning and operations.*

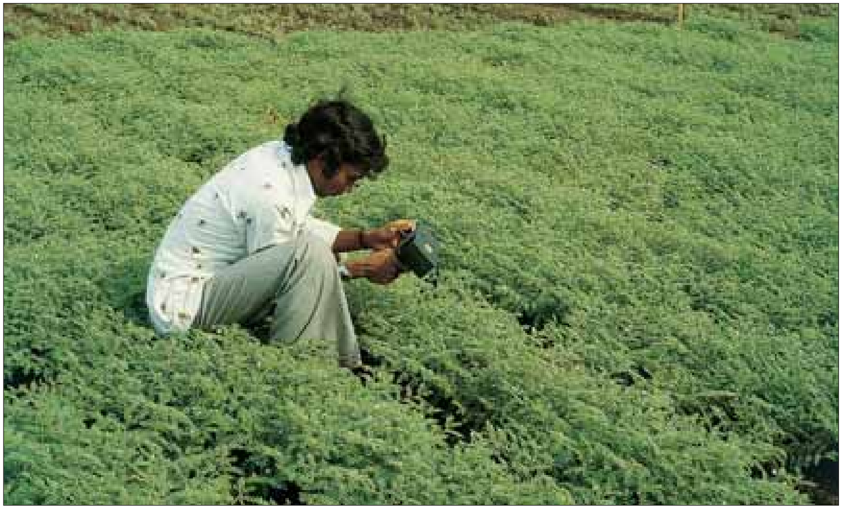
Flood management

Flood management is a broad concept that focuses on coping with flood hazards through the combination of policy, institutional, regulatory and physical measures such as replanting upstream catchment areas, while recognizing that floods can never be fully controlled.

WMO's long-standing activities in the areas of flood risk assessment and flood forecasting have recently been enhanced by a joint initiative with the Global Water Partnership, namely the Associated Programme on Flood Management for which a technical support unit located within WMO Headquarters is providing the global coordination.

The Terrestrial Observation Panel for Climate (TOPC), sponsored by the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS), has recognized the critical need for improved availability and access to global hydrological data, information and products for climate and hydrological research and applications to quantify key environmental change processes, identify significant trends, assess variability and develop response strategies.

In a joint effort, WMO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) have restructured the World Climate Programme—Water (WCP–Water) identifying three main areas of work, namely: variability and trends in water resources availability; water climate and health; and water, climate and agriculture. A strong expression of interest is now required by organizations and agencies to contribute within the framework of the Programme.

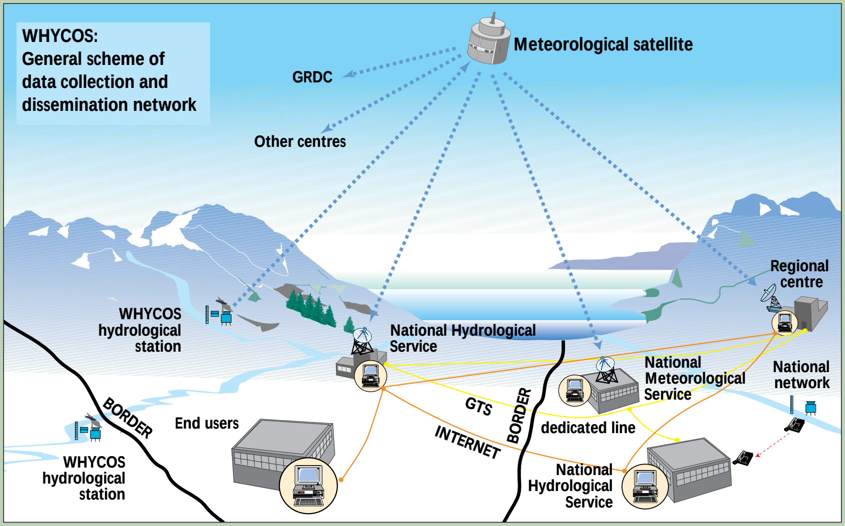


Understanding crop response to enhanced temperatures is crucial to develop agrometeorological adaptation strategies to climate change
(WMO/M.V.K. Sivakumar)

World Hydrological Cycle Observing System (WHYCOS)

Everyone agrees that fresh water is a critical resource, but much remains to be done to ensure that all the world's population has equitable access to sufficient water to meet even basic needs. The *Comprehensive Assessment of the Freshwater Resources of the World* showed that 40 per cent of the world's population today lives in countries which have medium-to-high water stress, and it is expected that by 2025 two-thirds of the population will do so. Demand for water can only increase, but growing pollution is likely to reduce the available quantity of suitable water. Irrigated agriculture and hydroelectric power generation compete with other uses for limited water within national boundaries. At the same time, maintaining the health of aquatic ecosystems is increasingly accepted as an essential concern. There are about 300 river basins and numerous aquifers, which are shared among two or more nations; competition for water among nations could become a potential source of conflict.

Adequate information is essential for wise management of water resources. Sadly, at the global scale our ability to provide information about the status and trend of water resources is declining. Many developing countries are unable to maintain their systems for acquiring water-related data, and for disseminating them to decision makers, engineers, resource managers and the public. To counter these trends, an essential goal of WMO is to assist its Members in maintaining and improving their information systems. The Organization uses such means as technology transfer and training, collaboration among National Meteorological and Hydrological Services, and international exchange of data and information.



The World Hydrological Cycle Observing System (WHYCOS) has been developed to contribute to this goal. WHYCOS, composed of regional systems (HYCOSs) implemented by cooperating nations, will complement national efforts to provide the information required for wise water resource management. Modelled on WMO's World Weather Watch, and using the same information and telecommunications technology, WHYCOS will provide a vehicle not only for disseminating high-quality information, but also for promoting international collaboration. It will build the capacity of National Hydrological Services (NHSs), so that they are ready to face the demands of the twenty-first century. It will provide a means for the international community to monitor more accurately water resources at the global level, and to understand the global hydrological cycle.

Climate Prediction and Agriculture (CLIMAG)

As the gains of the green revolution start to plateau, the impacts of climate-driven interannual variability in crop production become significant in the overall economies of farming. The question of interannual variability was investigated by the Tropical Ocean and Global Atmosphere (TOGA) programme established 15 years ago by the World Climate Research Programme (WCRP) by building on the partnership between the meteorological and oceanographic communities. By any measure, TOGA is one of the most successful international programmes ever undertaken. Not only did it greatly enhance the scientific understanding of interannual variability, it also established the observing system needed to support operational prediction of seasonal variability. Perhaps the most significant consequence is that TOGA has led to a change in the way climate is perceived by society. In most countries, the El Niño or ENSO phenomenon is recognized as a cause of interannual variability of climate. The CLIVAR programme on climate variability and predictability is the current programme following on from TOGA.

Major advances in the capability to predict the interannual variability of climate, especially in the regions affected by the El Niño phenomenon, suggest that it should be possible to enhance crop productivity at the farm level by improving farm management decisions based on better knowledge of climate in the seasons ahead. In March 1996, the Joint Scientific Committee for the WCRP initiated a programme in cooperation with the International Geosphere–Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and the Global Change System for Analysis Research and Training (START) aimed at applying the potential benefits of seasonal prediction to agricultural production.

At a joint workshop in Bogor, Indonesia in February 1997, the basic goal and direction of a programme on Climate Prediction and Agriculture (CLIMAG) was formulated. A task group set up by START developed a strategic implementation plan for CLIMAG. As per the recommendations of the task group, an International Workshop on CLIMAG was held at WMO in September 1999. The workshop agreed that end-to-end demonstration projects could be developed in Africa, Asia–Pacific and the Americas from existing activities. CLIMAG projects are currently being implemented in South Asia and West Africa by multidisciplinary teams (natural and social scientists) bringing together expertise in climate, crop and economic modelling, as well as agronomic expertise. CLIMAG projects involve the following activities:

- Determining the baseline relationship between climate variability and crop production in the specified region;
- Establishing awareness in the region of the potential for climate predictions to be used to increase crop yield;
- Identifying agricultural practices in the region that must be modified through knowledge of future climate variations;
- Conducting trials with farmers over a number of years where climate information is used to modify agricultural practice;
- Quantifying the impact of the changes in the agricultural practice through use of appropriate methodologies;
- Analysis and dissemination of the results of the trial.

The CLIMAG Task Force, established to coordinate the planning and implementation of the demonstration projects, is also ensuring that global research programmes (WCRP, IGBP, IHDP) take up the strategic research challenges posed by CLIMAG. It is recognized that advances in strategic science need to be made in order for climate predictions to be used routinely in agriculture decision-making. These issues include improvements in both climate and crop models, as well as better techniques to link climate and crop models.

COLLABORATION AND PARTNERSHIPS

Professor G.O.P. Obasi, Secretary-General of the World Meteorological Organization (left), and Professor Peter Tyson, Chairman of the START Scientific Steering Committee, at the opening of the CLIMAG workshop in Geneva

The provision of weather, water and climate information and services by the NMHSs to meet national requirements and international commitments has relied and will continue to rely on international cooperation. In the twentieth century, WMO as well as its predecessor, the International Meteorological Organization (IMO), have promoted and facilitated worldwide cooperation in meteorology, hydrology and related sciences for the benefit and safety of humankind.

Under WMO leadership and within the framework of its Programmes, NMHSs have played and will continue to play an increasing role in serving humanity. The establishment of NMHSs charged with systematic monitoring of atmospheric and related environmental conditions and the provision of scientifically-based forecasting and warning services has enabled the governments of virtually every nation in the world to forewarn and protect their national communities from the threat of tropical cyclones, floods, droughts, forest fires, severe storms and other weather-induced natural disasters; enhance the reliability and productivity of agriculture and the availability of food and fibre; manage their water, energy and other resources in an efficient manner; underpin the safety and efficiency of travel by air, land and sea; and anticipate and move to avert or minimize the impacts of desertification, ozone layer depletion, acid rain and climate change and other threats to the global environment.

These and many other benefits which modern society derives from meteorological, hydrological and related sciences and services have been made possible through a unique system of international cooperation among nations which dates back to the nineteenth century. At the international level, WMO collaborates with a number of organizations and institutions in the areas of climate, food security, water resources and disaster mitigation. These include, *inter alia*, FAO, the International Council for Science (ICSU), UNEP, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the World Health Organization (WHO), the World Bank, the United Nations Development Programme (UNDP) and the International Strategy for Disaster Reduction (ISDR). Information and scientific advice provided by WMO played a vital role during the negotiations and the implementation of the various conventions and protocols initiated to protect the environment. These include the United Nations Framework

Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD).

WMO also promotes collaboration at the regional level having established, together with its Member countries, a regional cyclone body for each of the five tropical cyclone ocean basins of the world, and a number of climate/ drought monitoring centres. These include the African Centre of Meteorological Applications for Development (ACMAD); the Association of South-East Asian Nations (ASEAN) Regional Specialized Meteorological Centre in Singapore; the European Centre for Medium-range Weather Forecasts (ECMWF) based in Bracknell, United Kingdom; and the Instituto Nacional de Pesquisas Espaciais (INPE) in Brazil.

During the twenty-first century, one of the greatest challenges for humanity is to protect and sustainably manage the natural resource base on which food and fibre production depend, while feeding and housing an ever-growing population. The strengthening of agrometeorological activities will continue to be required within NMHSs and WMO, in close collaboration with FAO, the institutes of the Consultative Group on International Agricultural Research (CGIAR) and relevant national and regional institutions.

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