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World Meteorological Organization

REDUCING VULNERABILITY TO WEATHER AND CLIMATE EXTREMES

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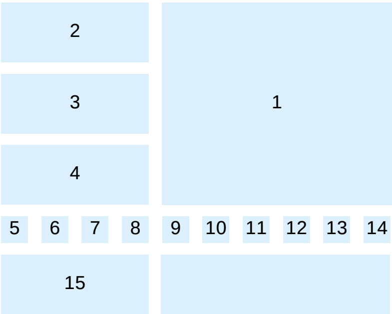

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FOREWORD

On 23 March of each year, the World Meteorological Organization (WMO) commemorates the coming into force of its Convention in 1950 by celebrating World Meteorological Day with focus on a theme of interest to humanity. For 2002, the theme "Reducing vulnerability to weather and climate extremes" has been chosen to recognize the engagement of WMO and the National Meteorological and Hydrological Services (NMHSs) in preparedness and prevention against weather-, water- and climate-related extremes and of their adverse consequences for human safety and sustainable development.

Human beings have a great capacity to adapt to varied climates and environments but remain vulnerable to marked changes in weather and climate conditions. Global statistics highlight the increasing number of people affected by hydrometeorological disasters that account for over 90 per cent of those killed. Over the 1991–2000 decade, those persons affected averaged 211 million per year, seven times those affected by conflict. Moreover, 98 per cent of the people affected are in developing countries.

In assessing the sensitivity and vulnerability of communities to weather and climate hazards, long-term climate records and related sectoral information are of vital importance. Such records are also essential for preparedness planning and response strategies that build resilience for coping with extreme events. Otherwise, each extreme event will cause destruction and set back development, in some cases for many years. The most effective measures for preparedness require a well-functioning early warning system.

Advances in science and technology have significantly enhanced the early warning capabilities of NMHSs. This is further reinforced by WMO's network of Regional Specialized Meteorological Centres that provide advisories against tropical cyclones, floods, droughts and other extreme events, and by its promotion of free and unrestricted exchange of meteorological and hydrological data and products.

Over the years, the close collaboration between NMHSs, other related institutions, decision makers, the media and non-governmental organizations has led to a marked reduction in the loss of life. This has also been due to the increasing capability of people at risk to assess and understand the information provided, personalize the risks and respond in a timely manner. To enhance such synergy, WMO provides the international framework for disaster mitigation efforts, encourages the exchange and transfer of know-how and technology in disaster reduction activities, and contributes to the development and implementation of regional and global initiatives such as the International Strategy for Disaster Reduction (ISDR).

I hope that World Meteorological Day will draw the attention of those involved in the welfare of local communities, including governments, the media and local authorities, to the major role WMO and the NMHSs play in contributing to a safer world for present and future generations.

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

INTRODUCTION

Extreme weather events can cause damage and destruction to housing and public infrastructures, leaving communities unprotected to the weather, with food and water shortages, and with loss of their livelihoods.

Society is vulnerable to extreme weather and climate events that occur on all scales. Tornadoes and hailstorms are small-scale weather systems that last only a few minutes and extend over a few hundred metres but are intensely destructive. Gales and floods accompany storm systems that extend over hundreds of kilometres with durations from hours to days. Climate anomalies, such as those producing drought, last for seasons and longer.

The impacts of extreme weather and climate events vary, the most devastating being the loss of life. Many of the impacts are long-lasting and complex, and can include homelessness, polluted water and contaminated food supplies that lead to health problems, and the loss of business and commerce on which livelihoods depend. Every step toward reducing the impacts of extreme meteorological and hydrological events is a step toward reducing vulnerability and achieving sustainable development.

Understanding both the short-term and longer-term sensitivity and vulnerability of communities to weather and climate hazards calls for multidisciplinary studies using climate records and related sectoral information. Long climate records make it possible to estimate the magnitude and frequency of extreme events, and to quantify the potential hazard of each. Using this information, planning guidelines and response strategies can be developed to build resilience for coping with future extreme events. Without such resilience each extreme event will cause destruction and set back development, in some cases for many years.

Sensitivity and vulnerability of societal systems

Each locality has its own climate, described by characteristic seasonal temperatures, rainfall, wind, etc. In many places, the climate is far from ideal: at one extreme there are prolonged dry periods leading to drought and at the other there is recurring rain that causes waterlogging of soils and increases the risk of flooding and landslides.

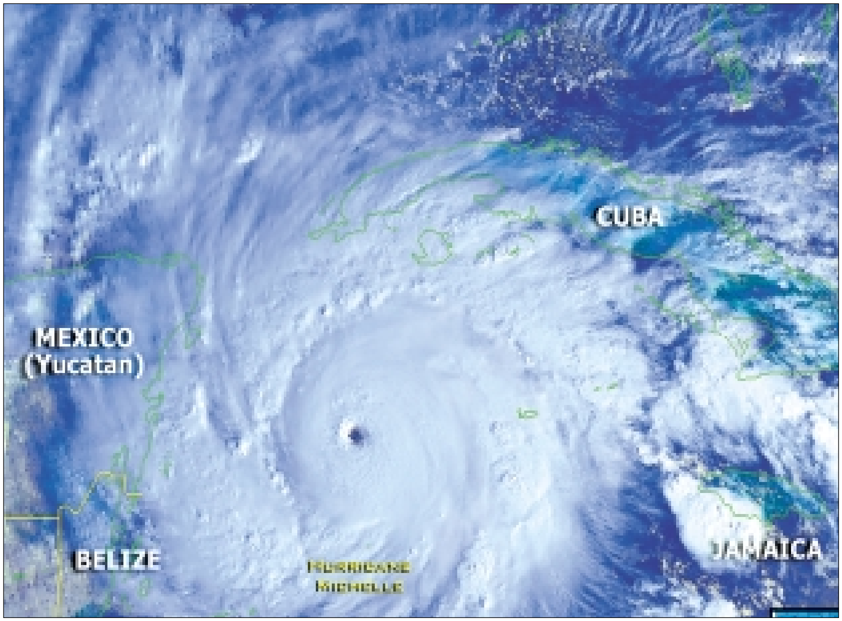
The aftermath of extreme weather events such as flooding includes damaged or destroyed infrastructure on which commerce depends and contaminated water and food supplies that lead to health hazards (FEMA News Photo – left: A. Booher; right: L. Roll)

Well-established communities have built up their infrastructures and prospered within a general pattern of local climate to which they have adapted. However, meteorological and hydrological events with intensities outside that general pattern can cause catastrophic failures of environmental, economic and social systems. A few examples include:

- Strong winds that impose exceptional loading (or pressure) on buildings causing structural failure;
- Heavy rainfall that leads to flooding, accompanied by erosion that undermines structures and inundation that destroys crops, drowns stock, contaminates freshwater supplies and isolates communities;
- Hot dry winds that promote the rapid spread of wildfire leading to destruction of native and farmed vegetation and farm and urban buildings;
- Prolonged dry periods, leading to drought with its associated dust storms, and erosion and crop failure;
- Ice loading that can lead to broken power and other overhead cables.

The impacts of extreme climate events are felt across environmental, social and economic sectors as losses of crop production; reduced availability and quality of freshwater; deterioration of riverine, estuarine and coastal waterways; and the increased incidence and spread of a range of diseases. Communities and their economic and social activities generally tolerate a range of year-to-year variability of the local climate. However, when a season is significantly different from the expected pattern for an extended period, then the consequences can be severe.

The assessment of weather and climate hazards requires data and knowledge about potentially damaging phenomena that occur in the region. In many parts of the world, the systematic collection and archiving of weather data over long periods permit the local climate to be quantified. Such records are used for the planning of weather-sensitive activities. Elsewhere, where records are incomplete, there is only qualitative understanding of the local weather and climate hazards. Sometimes, although the risk of certain hazards is recognized, they occur so infrequently that planners become complacent. In the absence of prior planning and adequate emergency response procedures, the impact of an extreme event can be devastating.



Tropical cyclones (also known as hurricanes or typhoons) are a well-known hazard in the tropics; satellite monitoring, such as that for Hurricane Michelle *in 2001, can assist in preparedness measures* (National Oceanic and Atmospheric Administration, USA)

Hazard assessment, vulnerability analysis, risk assessment and prevention and preparedness measures

The first step in risk analysis is to identify and assess the hazards. The degree of danger is determined by the maximum threat involved. The concept of hazard includes the probable range of intensity of the event and the probability of its occurrence.

Following hazard assessment, the second part of a risk analysis is vulnerability analysis. Vulnerability is evaluated by the damage that can arise as a result of the extreme event. Damage can be caused to the population (life, health, well-being, etc.), to property (buildings, infrastructure, etc.) and to natural resources. Potential damage is recorded on vulnerability maps.

Hazard and vulnerability are aggregated into risk. Risk can be seen subjectively or objectively. A subjective risk is the risk perceived by the people affected which determines their willingness to accept a potential hazard. The decision to accept a potential risk is crucial, for example, when choosing to move into an area that is prone to earthquakes or to flooding. For moderated damage levels, risk is objectively defined by the predicted damage and probability of its occurrence per year. In the case of very extreme events and a very high level of damage, such as a dam break or nuclear power plant accident, the risk is the number of persons affected (victims, injured, etc.) and/or the damage in monetary terms that can be expected on average per year.

Both structural and non-structural measures can be applied to disaster prevention. Structural measures include, for example, building protection and the creation of harbours. Ideally, buildings and the infrastructure around them should be designed to withstand the rigours of all extreme phenomena that might occur. Hence, one of the most important non-structural measures is drawing up appropriate regulations and codes of practice for the various threats facing a specific region. These can constitute a significant contribution to disaster prevention. Other non-structural measures for disaster mitigation include development planning, urban and land-use planning (for example, indicating especially endangered areas on land use plans or using areas prone to flooding for temporary purposes such as sports fields or pasture). Insurance measures that encourage policyholders to make their own provisions, i.e. by appropriate design of policies, can also contribute. This may not prevent disasters but it does limit their consequences.

Experience has shown that one of the most effective preparedness measures for damage reduction in the case of extreme events is a well-functioning early warning system. In 1970, a violent tropical cyclone in Bangladesh cost 300 000 lives. With improved warning systems, similar cyclones resulted in 13 000 and 200 lives lost in 1992 and 1994, respectively. The early warning process can be split into three related phases, namely forecast,

Well-designed public infrastructures, for example this bridge over the Una River in Brazil, will withstand extreme weather and climate events and ensure that economic and social activities can be quickly resumed (Jaqueline Maia/Diário de Pernambuco, courtesy of INMET, Brazil) warning and reaction. Improved forecasts followed by long lead time of warnings and early reaction are essential for success in disaster mitigation. The reaction phase is dominated by the reliability of the forecast and its credence as well as by social dimensions – the "human factor" in risk perception and decision-making.

Integration of weather and climate information in planning mitigation strategy

In many regions, mitigation of the effects of weather- and climate-related natural hazards has been achieved through planning and implementation of robust infrastructures and resilient societal systems that take full account of information about such hazards. A quantitative understanding of the local climate regime and the nature of hazards is critical in the development of a mitigation strategy. Local climate data are the basis for effective standards, planning controls and other regulations that ensure buildings and structures can withstand specific hazards and can provide safety for occupants and contents. The importance of local climate data is underscored by the history of disasters where buildings without design standards, or buildings meeting imported but climatically unrepresentative standards, have failed during extreme conditions.

Attention to planning and building design is not always sufficient to fully protect communities from the most extreme events. Strength and robustness add significantly to the cost of structures, particularly if they are to withstand relatively rare but extremely intense events. Also, many communities have evolved in geographic locations, such as river flood plains and coastal deltas, that are the source of their livelihood but, by their very nature, are vulnerable to specific weather hazards. In these naturally hazardous locations some communities have developed resilience against extreme events through the implementation of integrated plans that have, as their focus, the protection of lives, vital infrastructure and essential resources. Although there is an expectation of significant material loss and damage, lives are saved; and essential public infrastructures and resources, including food and water reserves, are protected as far as possible to provide community resilience.

Emergency response plans, where actions are taken within a predetermined decision framework, also enhance the mitigation of loss associated with extreme and episodic events. In the simplest models a warning of an extreme weather event triggers action to seek shelter. Communities and their infrastructure are now very complex and officials in different sectors have responsibilities for decisions

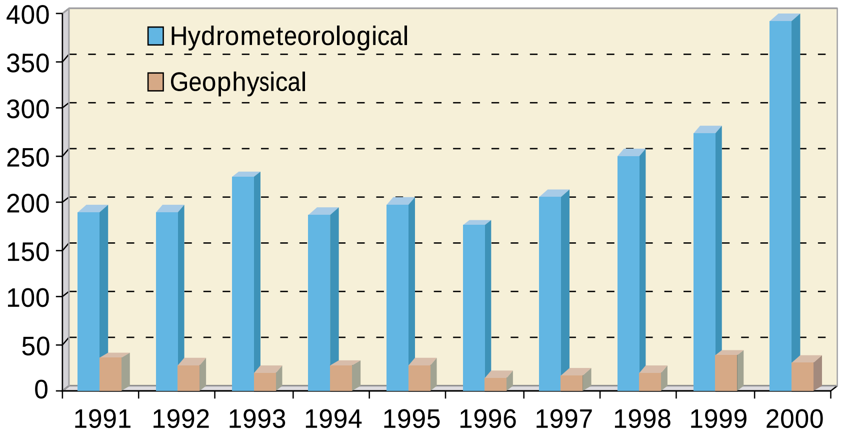
In a well-coordinated emergency response plan, early warning will trigger response actions so that, when notified, people can quickly evacuate a threatened region or seek refuge in specially-built shelters such as this cyclone shelter in Bangladesh (D. Pitchford)

Ideally, buildings should be built to withstand the rigours of weather phenomena occurring in the region, like this typical Vietnamese house built to accommodate heavy rains that can have immediate impact through damage to structures and possible injury and death (J. Stickings)

relating to various aspects of public safety. A predetermined community plan, based on early warning and follow-up monitoring information, will ensure that decisions are timely and effective. Similar information made available to all officials and the public will ensure that decisions of all agencies are mutually supportive. Also, the public will be well informed about the hazard and their expected response. The integration of weather- and climate-related information into community-based emergency response plans to reduce the vulnerability of communities and effects of hazards as diverse as tropical cyclones, floods, wildfires and drought is now a well-established practice in many countries. There is, however, a continuing need to upgrade these plans in line with advances in science and technology. Other countries, though, still need to establish plans in a more formal setting.

WEATHER AND CLIMATE HAZARDS

During the decade 1991–2000 more than 90 per cent of people killed by natural hazards lost their lives as a consequence of severe meteorological and hydrological events (see table below and figure at right). Over the period, the numbers of meteorological and hydrological disasters, including droughts, floods and wind storms, gradually increased. Asia was the continent most frequently hit by disasters (see table below), registering 43 per cent of the total number of events, and 80 per cent of the people killed (it occupies about 33 per cent of the world's land area and accommodates 61 per cent of its population).



Number of reported disasters during the 1991–2000 period

	Total number of reported disasters	Total number of people killed by disasters	Total number of people affected by disasters	Total amount of estimated damage (US$ billion)
Disaster				
Avalanches/landslides	173	9 550	2 150	1.7
Droughts/famines	223	280 007	381 602	30.5
Earthquakes	221	59 249	17 023	239.6
Extreme temperatures	112	9 124	6 065	16.7
Floods	888	97 747	1 442 521	272.8
Forest/scrub fires	123	626	3 422	26.3
Volcanic eruptions	54	942	2 157	0.8
Wind storms	748	205 635	252 401	198.1
Other natural disasters	25	2 718	60	0.3
Continent				
Africa	804	38 078	130 598	2.3
Americas	1 057	78 041	47 893	212.9
Asia	2 035	598 290	1 888 224	403.5
Europe	664	34 495	23 239	179.3
Oceania	143	3 617	18 071	11.8

Disaster information by type of phenomenon and by continent during the 1991–2000 period (University of Louvain, Belgium, 2001)

An increasing number of people are being affected by such disasters. It is therefore necessary to understand and record the most common weather and climate hazards and to map the vulnerability of communities or geographical zones to these phenomena. Every improvement in the lead time and risk analysis in the affected area contributes to reducing vulnerability.

Severe thunderstorms spawn a number of potentially destructive short-lived weather phenomena, including tornadoes with winds that can reach 500 km/h
(National Oceanic and Atmospheric Administration, USA)

Severe thunderstorms

Small-scale severe weather phenomena, including severe thunderstorms with related phenomena such as tornadoes, lightning, hailstorms, wind, dust storms, waterspouts and downpours, occur widely but are often short-lived and local in extent. This makes it difficult to study them and establish their climate patterns.

It is known that a combination of warm moist low-level air, which is the source of energy, and cool dry air in the upper atmosphere frequently provides the highly unstable conditions that are necessary for generating the most severe thunderstorms. In the USA, tornadoes spawned from such thunderstorms most frequently strike between April and June, but can occur at any time of year. Tornadoes produce the strongest winds observed on the surface of the Earth with speeds reaching 500 km/h. Although they are most common in the south central part of North America, tornadoes have been observed and have killed people on every continent except Antarctica. They are also particularly damaging in parts of northern India and in Bangladesh where over 400 people have been killed in each of three severe tornadoes since 1989. They are also quite frequently recorded in Japan, Australia, northern Argentina and parts of northern Europe.

Severe thunderstorms can cause damage of the same order of magnitude as moderately intense tornadoes. Windspeeds can reach and even exceed 150 km/h near the ground and are an especially serious hazard in the vicinity of aircraft take-off and landing operations. Strong winds associated with thunderstorms are known to have caused several fatal accidents involving large commercial aircraft. Severe thunderstorms often lead to flash flooding which catches people unprepared and is estimated to cause more deaths than tornadoes.

Large hailstones can reach diameters of over 10 cm and can fall at speeds of over 150 km/h. Worldwide losses to agriculture in a typical year are more than US$ 200 million. Individual hailstorms have also caused great damages to cities. Storms in Sydney, Australia in 1999, Dallas-Fort Worth, USA in 1995 and Munich, Germany in 1984 each caused damages of more than US$ 500 million. Eight people were killed and 160 injured during a 1976 hailstorm in Zejiang Province, China where hailstones "the size of eggs" occurred over an area of 7 km by 2–3 km.

In a typical year in the USA, lightning kills more people than hurricanes, tornadoes and winter storms combined. Worldwide, summer lightning is also a significant factor in starting wildfires in forests and grasslands.

Mid-latitude storms

Low pressure systems, or mid-latitude cyclones, occur throughout the middle latitudes. They are generally most frequent and intense during winter, with gales lasting for up to several days and extending for distances of more than 1 000 km. They have the potential to cause widespread property damage and death through wind damage and flooding. At sea, gale force wind and wind-generated waves associated with these storms are a danger to shipping and their cargoes. Along the coast, storm surges generated by the winds and breaking waves are a major threat.

The strength of mid-latitude westerly winds and the frequency of storms in the winter half of the year exert a profound influence on the climate of northern Europe. Also, over the eastern half of North America many of the most damaging winter storms involve heavy snowfall, most frequently affecting the Maritime Provinces of Canada. Farther south, once or twice each decade, an intense low pressure system will run up the East Coast of the United States drawing cold air down from Canada in its train and dump anything from 30 to 75 cm of snow on the major cities of the region. The combination of heavy snow, strong winds and plummeting temperatures paralyses the worst hit cities and towns. Similar weather events occur in other mid-latitude regions of the world.

Mid-latitude storms are a primary source of beneficial mid-latitude rainfall but can lead to floods and severe winter storms affecting people's daily lives
(Royal Netherlands Meteorological Institute (KNMI))

Tropical cyclones, hurricanes and typhoons

The warm tropical oceans spawn the most formidable storms on the planet. They evolve from clusters of thunderstorms called tropical disturbances, the majority of which do not develop any further. On average, though, 80 develop into fullblown tropical cyclones each year. The strongest tropical cyclones have sustained winds greater than 195 km/h and wind gusts greater than 280 km/h; they produce widespread destruction. Some tropical cyclones can grow to a radius of more than 300 km before they decay, over either land or cooler water. Tropical cyclones often sweep out of the tropics to higher latitudes, and continue to have the potential to leave a swathe of destruction from both strong winds and heavy rainfalls.

At sea, the high winds and waves pose a major threat to shipping and coastal fishing fleets. As the storm comes near to the shore, the waves pile up ahead of the hurricane forming a storm surge in the region of the strongest winds. Also, the sea level is higher in the eye of the storm where the atmospheric pressure is lowest. This wall of water can do great damage when hurricanes strike the shoreline, especially if it coincides with a high tide. In 1999, a tropical cyclone struck the Indian State of Orissa and swept inland with 300 km/h winds and a seven-metre tidal surge that caused devastation to a distance of 20 km and left more than 40 000 people dead. Tropical cyclones have been recorded in all tropical oceans except the South Atlantic Ocean.

The fierce winds of tropical cyclones can destroy all but the best engineered structures, as shown by the destruction wrought by Hurricane Mitch *in Tegucigalpa, Honduras in 1998* (P. Jeffrey/CCD)

Floods

Floods are among the most common natural disasters and, in terms of economic damage, the most costly. Several types of weather systems lead to flooding. These include mid-latitude storms, tropical cyclones, monsoons and El Niño events. In addition to the direct impacts of loss of life and property damage, there are indirect impacts such as increased exposure of survivors to other hazards such as contaminated water supplies and landslides, and the disruption of traffic and trade. The indirect impacts are quite numerous and often difficult to quantify.

Droughts

The primary cause of any drought is deficiency of rainfall and, in particular, the timing, distribution and intensity of this deficiency in relation to existing reserves, demand and water use. Temperature and evapotranspiration may act in combination with reduced rainfall to aggravate the severity and duration of the event. In most cases, droughts are recognized as such too late for emergency measures to be effective.

A prolonged period of relatively dry weather leading to drought is a widely recognized climate anomaly. Drought can be devastating to some communities as water supplies dry up, crops fail to grow, animals die, and malnutrition and ill health become widespread. These effects are exacerbated in many tropical regions as smoke from uncontrolled wildfires in the dry vegetation causes respiratory and other health problems. In today's global society, financial mechanisms and international aid can provide relief and limit the famine, starvation, malnutrition, disease and widespread deaths that typically occurred with historical drought. However, the environmental impacts of drought, including salinization of soil and groundwater, increased pollution of freshwater ecosystems and regional extinction of animal species, continue to weigh on affected communities well after relieving rains occur. Unless protective measures are taken during periods of drought, ongoing grazing and cropping will lead to degradation of land and water resources, which can ultimately lead to desertification, especially in less well-developed regions.

Human factors that influence drought include demand for water through population growth and agricultural practices, and modification of landuse that directly influences the storage conditions and hydrological response of a catchment and thus its vulnerability to drought. As pressures on water resources grow so does vulnerability to meteorological drought.

Monsoons

The term monsoon refers to a seasonally steady wind. Monsoon winds and rainfall peaks in summer are a feature of many tropical land areas including East Asia, Australia, the Americas and West Africa. For example, the basic driving force for the Indian monsoon is the heating up of the Asian landmass with approaching summer, especially the warming of the Himalaya Mountains and the Tibetan Plateau. This has the effect of drawing huge quantities of moisture northwards from the tropical Indian Ocean. In any one year, the movement of moist air up across the Indian subcontinent takes place in fits and starts. Similar conditions are responsible for monsoonal conditions in other parts of the world. Periods of torrential rain are followed by days of sunny weather. More importantly, from year to year the timing of the start and end of the monsoon rains varies greatly. Late arrival, early departure or protracted breaks without rainfall all affect the growing season.

The year-to-year variability of the tropical monsoon circulation is not yet well understood but the impacts can be devastating. Years with heavy monsoon rain bring flooding while a shortened or weak monsoon will cause water shortages and can result in crop failures. The El Niño/Southern Oscillation (ENSO – forced by changing sea surface temperature patterns of the equatorial Pacific Ocean) and the Quasi-Biennial Oscillation (QBO) of winds in the equatorial high atmosphere are factors that have been identified as contributing to year-to-year variability of tropical rainfall. The depth and extent of snow cover over the Tibetan Plateau are also considered to be contributing factors in the case of the Asian monsoon.

Drought can be devastating as water supplies dry up, crops fail to grow, animals die and malnutrition and ill health become widespread; in addition, its environmental impacts continue to weigh on affected communities well after relieving rains occur (FAO)

Heatwaves

High temperatures are experienced in many areas of the world but heatwaves are generally most deadly in mid-latitude regions where they concentrate extremes of temperature and

Heavy summer rains are the basis for agriculture in many tropical areas; however, excess rainfall or serious rainfall deficiencies can result in ruined crops (FAO/I. Velez)

humidity over a period of a few days in the warmer months. The oppressive air mass that settles across an area, especially in urban environments, can result in many deaths through a wide variety of health-threatening conditions and situations.

A severe heatwave struck Shanghai in August 1998 and the average daily deaths increased by more than 300 per cent. Medical researchers concluded that the heatwave caused much more loss of life in Shanghai than any other single natural disaster during that year. The direct causes of death associated with the heatwave included circulatory and respiratory diseases, neoplasm, mental disorder and endocrine diseases. Public disorder, accidental injury and poisoning are other related outcomes. A heatwave in New York City in 1966 was accompanied by a striking increase of 139 per cent in the number of homicides committed.

Cold spells

It is estimated that the number of deaths during the winter period of 1997–2000 exceeded the number of deaths in comparable summer periods by 165 000. Of these, 90 per cent were people aged over 60 years. Most of these extra deaths were not caused by hypothermia but by cold aggravating circulatory diseases (leading to strokes and heart attacks), and respiratory diseases such as bronchitis and pneumonia. In Mongolia in January 2001, blizzard conditions with winds of more than 100 km/h froze 12 herders to death, contributed to the death of 467 000 animals and drove another 33 000 away onto the steppes.

Oscillations

Statistical analyses of pressure, temperature and precipitation patterns have identified various recurring patterns, termed oscillations, over large areas of the globe. In addition to the widely-known El Niño/Southern Oscillation of the Asia-Pacific region, operating on approximately interannual time scales, there are longer-lasting North Atlantic and North Pacific oscillations.

The strongest year-to-year fluctuations of climate are linked to the ENSO phenomenon. An ENSO event originates in the equatorial Pacific Ocean but affects climate conditions over many parts of the world, bringing heavy rain and flooding to some and drought to others. Through its Tropical Ocean Global Atmosphere (TOGA) project and now the Climate Variability and Predictability (CLIVAR) study, WMO's World Climate Research Programme (WCRP) has played a key role in developing the understanding of this linkage and the means of predicting an ENSO event.

The North Atlantic Oscillation (NAO) is a measure of the surface westerly winds across the Atlantic. Positive winter values of the NAO

El Niño/Southern Oscillation (ENSO)

El Niño is the term now used for an extensive warming in the surface layers of the equatorial eastern Pacific Ocean lasting three or more seasons. When this oceanic region switches to below normal temperatures, it is called a La Niña event. These events, via air-sea energy exchange, cause changes in the atmospheric pressure patterns across the Asia-Pacific region known as the Southern Oscillation (SO). Because the SO and El Niño are so closely coupled they are collectively known as the El Niño/Southern Oscillation (ENSO) phenomenon. Through 'teleconnections' the increased convection over the eastern equatorial Pacific Ocean produces large-scale waves in the upper atmosphere that extend into mid-latitudes and alter the winds, including the jet streams; they also shift storm tracks, altering weather patterns farther afield in middle and high latitudes.

The system swings between warm (El Niño) conditions and cold (La Niña) conditions in a wide-ranging periodicity from two to seven years.

As the pressure distribution across the equatorial Pacific, and the associated movement of sea level and sea surface temperatures (SSTs), swing back and forth, major changes occur in global weather patterns. An ENSO event is the primary reason for seasonal droughts or periods of unusually heavy rainfall that occur from time to time in many parts of the world.

During an El Niño event countries bordering the western Pacific Ocean often experience drought conditions with wildfires (such as shown here in Indonesia) common in the dry equatorial forests (FAO/P. Johnson)

(with stronger-than-average westerlies) are associated with cold winters over eastern USA and Canada and mild winters over Europe, as well as wet conditions from Iceland through Scandinavia and drier winter conditions over southern Europe. A negative index indicates weak westerlies, a more meandering circulation pattern and cold winters over Europe. Over the past 20 years or so, the pattern of wintertime atmospheric circulation over the North Atlantic has shifted. A sharp reversal of the index set in around 1980 and the NAO has tended to remain in a highly positive phase.

Over the North Pacific an effective measure of climate variability is the intensity of the semi-permanent low-pressure system near the Aleutian Islands (the Aleutian Low). This low became deeper than normal after about 1976, especially during the winter half of the year (November to March), and the westerly winds across the central North Pacific have been stronger than they have been previously.

Atmospheric ozone

Ozone occurs naturally near the Earth's surface in small concentrations. It is also a by-product of many industrial processes and is formed in photochemical smog. A characteristic property of ozone is that it accelerates corrosion and

The ozone layer provides a level of protection against harmful UV radiation and its destruction increases the exposure of humans and other species (S. Béliveau/WMO)

early deterioration of many substances and has a harmful impact on health. Meteorological conditions that promote the formation of photochemical smog are a serious hazard.

However, the maximum concentrations of naturally occurring ozone are in the stratosphere. At these high altitudes, ozone provides protection against ultraviolet-B (UV-B) radiation which causes damage to skin tissue and has other dangerous health effects. Any depletion of the ozone layer increases the surface exposure to harmful UV-B radiation. Chlorofluorocarbons (CFCs), chemical compounds originally thought to be inert and consequently widely used in industry, were identified in 1974 as a source of stratospheric chlorine that is particularly active in the destruction of ozone. The formation of an "ozone hole" (unusually low concentrations of stratospheric ozone) during the Antarctic spring caused by the buildup of CFCs and other ozone-depleting substances was first detected in the early 1980s.

The 1985 Vienna Convention for the Protection of the Ozone Layer and its subsequent 1987 Montreal Protocol and its Amendments are aimed at phasing out all CFC production and consumption, thus reducing the UV-B radiation hazard.

The changing climate

Knowledge of climate and its extremes is necessary for the development of economic and social systems for a sustainable future. However, human activities affect the climate system and produce shifts in local, regional and global weather patterns and characteristics. At the local and regional levels:

- Modern building materials change the surface thermal properties and urbanization leads to local warming;
- Land clearing generally reduces the surface evapotranspiration and increases the proportion of sunlight reflected back to space; land clearing also speeds the rate of local runoff from rainfall which results in a drier and warmer climate.

On a wider scale, the so-called 'greenhouse gases', including carbon dioxide, methane, oxides of nitrogen and ozone, in the atmosphere retain heat and thus keep the Earth's temperature higher than it would otherwise be. They all

The IPCC-projected sea-level rise would increase the impacts of natural disasters and be disastrous to communities living in low-lying coastal areas and small island states (S. Béliveau/WMO) occur naturally, but their concentrations in the atmosphere have been significantly altered by human activity. Industrial processes also create other greenhouse gases not previously present in the atmosphere and their concentrations are increasing as well. The global annual emission of carbon dioxide from burning fossil fuel and other industrial processes has been estimated to have increased from about 0.1 Gigatonnes of carbon (GtC) in 1860 to near 10 GtC by the end of the 20th century. Over the same period, the atmospheric concentration of carbon dioxide has increased from about 280 parts per million by volume (ppmv) to about 369 ppmv and the global temperature of the Earth has increased by about 0.6°C.

The most recent assessment of the Intergovernmental Panel on Climate Change (IPCC) is that, globally averaged, the surface temperature of the Earth is projected to increase by between 1.4°C and 5.8°C over the period 1990 to 2100 as a result of human activities. Over the same period, an associated rise in global mean sea level of between 9 to 88 cm is projected.

The 1992 United Nations Framework Convention on Climate Change (UNFCCC), including its Kyoto Protocol, is aimed at stabilizing human-induced greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system.

Human activities affect climate, including through urbanization that changes land-surface processes, and through industrial and transport activities that emit gases and aerosols into the atmosphere and change the radiative properties (www.freeimages.co.uk)

REDUCING VULNERABILITY

To deal with meteorological and hydrological hazards requires information collected over many years and spanning countries and continents.

A community's vulnerability to meteorological and hydrological hazards is reduced through assessment of the local risk from potential hazards, through planning and implementing appropriate community response strategies should a hazard occur, and through developing the best possible early warning capabilities. A long history of local observations is essential to determine the frequency and intensity of potentially hazardous events (i.e. the climate risk) and to develop effective mitigation strategies. Comprehensive observations of the global climate system are the basis for monitoring, prediction and early warning. Clearly, a local meteorological and hydrological observing programme and the management of a climate archive are an essential basis for risk assessment and development of plans for disaster reduction.

The World Weather Watch (WWW), established by WMO in 1963, is a comprehensive programme of observations, and the exchange of such data along with forecasts and warnings derived from them. It is organized and coordinated by WMO to ensure that every country has access to data and information necessary to provide weather forecasts and warning services on a day-to-day basis, especially in support of safety of life and property. The basic infrastructure established through the WWW delivers the data and products essential for predicting and providing early warning of severe weather and monitoring the climate system.

An artist's impression of WMO's Global Observing System, which comprises observing facilities on land, at sea, in the air and in outer space (Australian Bureau of Meteorology)

Risk assessment

Data held in national climate archives are the basis for defining the local climate, including the frequency and intensity of hazardous events, and for assessing vulnerability.

Local climate archives, built up from systematic observations over a long period, contain the essential data for estimating the frequency and intensity of local weather and climate events likely to be dangerous to life and destructive to property. Used in combination with other socio-economic and environmental data, much can be learned about the sensitivity of societal systems to weather and climate extremes. (See box opposite.)

Monitoring for hazardous events

The Global Observing System (GOS) coordinates millions of observations from a variety of instruments on land, water, in the air and in space, which measure the characteristics of the atmosphere and the oceans and monitor weather and climate patterns. Timely collection and analysis of these data provide the first indications of the formation of weather and climate phenomena likely to be dangerous to life and property. More localized monitoring systems, including those on upstream reaches of rivers, provide input that permits the forecasting of downstream floods.

State of the atmosphere

The backbone of atmospheric monitoring continues to be some 10 000 stations on land from which observations at or near the Earth's surface are made at three-hourly intervals. Over recent years there has been a move to replace manual observing instruments with automated systems and this has involved a radical change to instrument sensors. An advantage of automated weather stations is that observations can be made more frequently, particularly overnight and during normal holiday periods, and the systems can take measurements untended in remote locations, thus significantly increasing the frequency and geographical coverage of observations. It is important, however, that the basic standards of the traditional methods are

AMDAR systems fitted to commercial aircraft provide air temperature, pressure, wind and turbulence data during ascent and descent and during level flight over regional and intercontinental routes (Boeing/SAS)

Observations of surface climate carried out under similar conditions for more than a century assist in assessing local climate and identifying the magnitude of global climate change (Meteorological Service of Canada) maintained through careful calibration procedures on an increasingly diverse range of sensors.

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, humidity and pressure. These data continue to be essential for analysing the circulation of the atmosphere and for more detailed assessments, such as the characteristics of individual storms and identifying when conditions for severe thunderstorms might be developing. There is now a global network of about a thousand stations providing at minimum daily soundings of the atmosphere from radiosondes.

National climate archives

Basic climate observations continue to be recorded in traditional forms but most countries now enter the observations into national computer archives and prepare standard summaries and statistics as part of their climate information service. The benefits of a computer-based climate archive are the ready access to the data and the ability to quickly carry out complex analyses of risks, and to update previous analyses using more recent data.

WMO has coordinated a very successful technology transfer project (called CLICOM) to bring climate computers and data management software to developing countries. More than 130 developing countries use CLICOM packages for managing their national climate archives. Many are now benefiting from upgraded database management software to provide more efficient and effective climate data management and for allowing more powerful applications, including those related to disaster mitigation. Plans are being formulated to assist developing countries migrate their data to the new climate database management systems.

Although current data are now largely managed using computers, there are enormous amounts of historical data that were collected and stored in early years which are still in manuscript form. These data are effectively unavailable for most purposes and the manuscript media are deteriorating with a risk of permanent loss. Under the WMO-supported Data Rescue (DARE) project many early records from developing countries have been transferred to microfilm. Many records from periods prior to the formation of NMHSs are held in public and other archives and the joint WMO/UNESCO Archival Climate History Survey (ARCHISS) project attempts to locate and catalogue these. The challenges are to process these early records to the national computer archives as a major expansion of the knowledge base essential for understanding and reducing local and regional weather and climate hazards.

National climate archives contain the essential data for planning cities that are safe and amenable, and for understanding local climate hazards as the basis for developing effective emergency response (L. Le Blanc)

International exchange of data and products

The first comparisons of climates from different parts of the world were based on the voluntary exchange of data between countries. Global and regional datasets have proven crucially important for research into the climate system, climate processes, climate variability and climate change.

The international exchange of data and the production of regional and global datasets and climate atlases continue to be fundamental for application of climate information in related socio-economic and environmental applications, early warning and risk assessment.

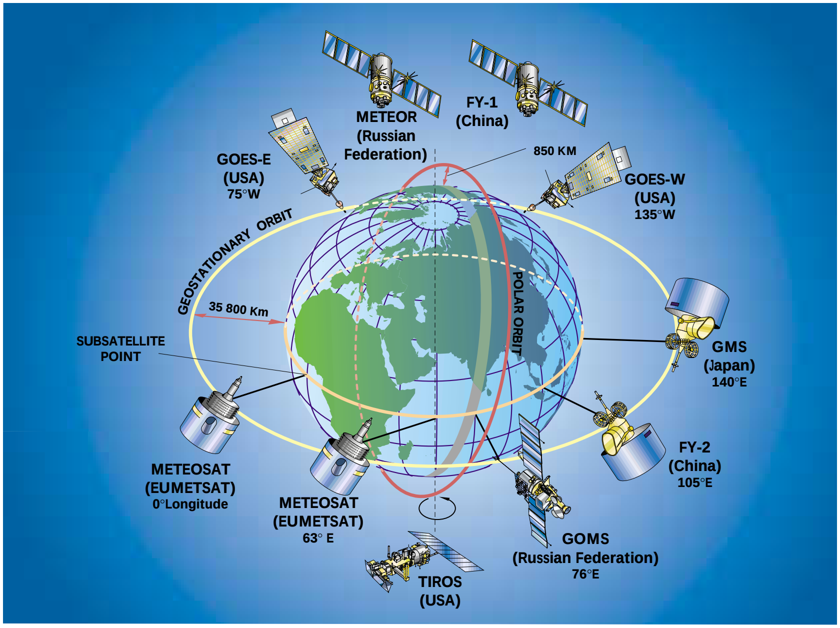
WMO and its predecessor, the International Meteorological Organization (IMO), established as a non-governmental organization in 1873, have coordinated the collection and publication by the World Data Center for Meteorology in Asheville, USA, of climate datasets. The first Standard Climatological Normals of basic climatological statistics covered the period 1901–1930. Subsequent Standard Climatological Normals have been produced for the 1931–1960 and 1961–1990 periods. In addition, the World Weather Records of monthly means and totals have been published in decade intervals since the first period covering data available to 1920. These data are now also available in electronic format. The Standard Climate Normals and World Weather Records, especially when used in multidisciplinary studies, provide essential data for risk assessment of weather and climate hazards in different parts of the world.

Over recent decades, instrument packages have been developed to provide frequent observations from commercial aircraft while in flight. Sensors measure the outside temperature, pressure and turbulence while from the aircraft inertial navigation system location, height and wind velocity are calculated. Advances have also been made by measuring humidity with improved aircraft meteorological data and relay (AMDAR) systems. There are now more than 300 AMDAR systems fitted to aircraft flying regional and intercontinental routes. The AMDAR systems provide valuable data over many oceans and other sparsely populated land areas.

Monitoring the oceans

The meteorological instruments developed to make land-surface measurements are also carried on ships. Today there are more

New systems, such as the TAO-TRITON moored buoys of the equatorial Pacific Ocean, are expanding knowledge of the ocean to improve prediction of extreme climate events such as ENSO (National Oceanic and Atmospheric Administration, USA)



Meteorological and environmental satellites of the space-based subsystem of GOS provide the 'eye-in-the-sky' to monitor weather and provide early warning of potentially dangerous systems

than 5 500 Volunteer Observing Ships of the international commercial fleets making and transmitting regular meteorological observations.

To fill in the gaps in data between the main shipping routes, the WMO-sponsored World Climate Research Programme (WCRP), through its Tropical Ocean and Global Atmosphere (TOGA) project, played a prominent role in introducing observations of tropical drifting buoys that float around the ocean's surface and regularly make and transmit a range of observations important for monitoring weather and climate. Of particular importance are the measurements of sea and air temperature and air pressure. At any time there are approximately a thousand buoys drifting around the world's oceans regularly providing these data.

Expendable bathythermograph (XBT) instrument packages dropped from ships provide measurements of temperature and salinity at depth. A number of the Volunteer Observing Ships that operate regularly on cross-ocean routes have been recruited to deploy XBT and this network is a primary source of information about subsurface ocean conditions.

Buoys moored in the coastal margins and on continental shelves measure offshore wave and swell characteristics to assist marine navigation in the shallow approaches to harbours and to give quantitative early warning of sea and swell conditions dangerous for offshore bulk loading of minerals, oil and gas. Buoys with meteorological and oceanographic instruments moored across the equatorial Pacific Ocean provide information to depths of 500 metres and at the surface. Implemented primarily to study the El Niño phenomenon, the array of 70 buoys (now called TAO-TRITON) was completed in 1994 and was crucial for the early detection and monitoring of the devastating 1997/1998 El Niño event. The array is being extended to the equatorial Atlantic Ocean and there are plans for a similar array across the equatorial Indian Ocean.

Satellite monitoring

Weather forecasters were among the first to make use of satellites on a regular basis. Satellites provide images of the Earth and graphically portray the changing cloud patterns of the whole globe.

Now, four near-polar-orbiting and six geostationary satellites make up the space-based component of the WWW. The complex array of satellite-borne instruments provides global coverage for a variety of measurements, including those for temperature and humidity profiles of the atmosphere, extent of sea ice and snow cover, cloud-drift atmospheric winds, ocean wave heights and associated ocean surface winds, changing sea surface topography, and estimation of precipitation rates. These instruments have enormously expanded the volume and coverage of observations but are crucially dependent on *in situ* measurements for their calibration. Satellites are an important part of the Global Observing System and also provide a range of climate-related environmental variables, including the growth rate of vegetation over the land and biological activity in the surface waters of the oceans. Increasingly relevant data from environmental satellites is being used for monitoring hazardous weather phenomena.

Radar surveillance

Since the middle of the 20th century, radar has become the cornerstone on which observations of extreme weather events in severe thunderstorms, including tornadoes, are made. More advanced Doppler radars analyse the signal to determine the speed of movement of the cloud particles carried in the storm's circulation. Radar can now give a very detailed picture of the three-dimensional structure of a storm system, including the strength of its wind field, the presence of damaging ice and the rates of precipitation. Radar is essential to monitor and provide early warning of the development and movement of severe storms, especially for tornadoes and for dangerous winds near airports.

Gauging for flood forecasting

Flood forecasting systems have been deployed over many river catchments to give early warning to downstream communities of flood events. The systems are often made up of a network of rain and stream gauges across the catchment linked to a central computer. Analyses of the flow of data, in particular intense precipitation, snowmelt and rising stream levels, are monitored at critical locations. Radar, supported by a network of raingauges, is also used to make quantitative assessments of the accumulation of rainfall over catchments and the likelihood of flooding.

As rivers rise during major rainfall events the information from stream gauges is sent to flood warning centres for assessment of danger and possibly issuing of necessary warnings (WMO Archive)

Atmospheric constituents

Human activities affect climate in many ways but particularly through emission of pollutants and aerosols. Twenty-two global and over 300 regional observatories have been established to provide data and other information on chemical composition and related physical characteristics of the atmosphere and their trends. The observatories monitor greenhouse gases, ozone concentration, aerosols (particularly those involved in acid deposition) and ultraviolet radiation.

Weather and climate prediction

The computer models used for numerical weather prediction calculate the formation, growth, movement and decay of the large-scale systems within which weather events, including severe weather, are embedded. The models are complex and integrate fluid motion, thermodynamics and radiation on a rotating globe that includes topography, land and sea differences and the seasonal cycle. In addition, mathematical schemes for representing very small-scale processes, such as clouds and turbulence, are included.

Comprehensive and accurate global data are necessary to start a weather forecast. Errors in the initial representation will expand as errors in the forecast. The accuracy of models has improved as more powerful computers have become available to process the global data quickly and to perform many more computations on higher resolution representations of the atmospheric system. Not only are these models now more skilful in the short-term but skill is maintained for a week and more. Numerical weather prediction models are providing earlier and more accurate warning of dangerous weather events.

Climate models have been developed from the original weather forecast models. In addition, they take account ocean influences and changing land characteristics including wetness of the soil, seasonal changes in vegetation characteristics and the advance and recession of snow and ice fields. Because of their additional complexity, climate models have to compromise with lower spatial resolution. Already the global climate models use the most powerful supercomputers available and as computers become more powerful the physical processes and spatial resolution will be improved to make the models more accurate. These better climate models are necessary to refine future climate scenarios, particularly those related to increased concentrations of greenhouse gases and potentially dangerous climate change.

The ENSO phenomenon has clearly demonstrated how changing sea surface temperature patterns (or ocean forcing) can affect seasonal weather patterns around the globe. Global climate models have been developed to reproduce the ocean forcing of the atmospheric circulation and to make seasonal predictions in terms of probabilities of regional drought or flooding rain.

Although still in the early stages of development, these climate-forecasting models are expected to improve on current statistical techniques and give early warning of significant climate events that are important for vulnerability analysis, risk assessment, prevention and preparedness for community welfare.

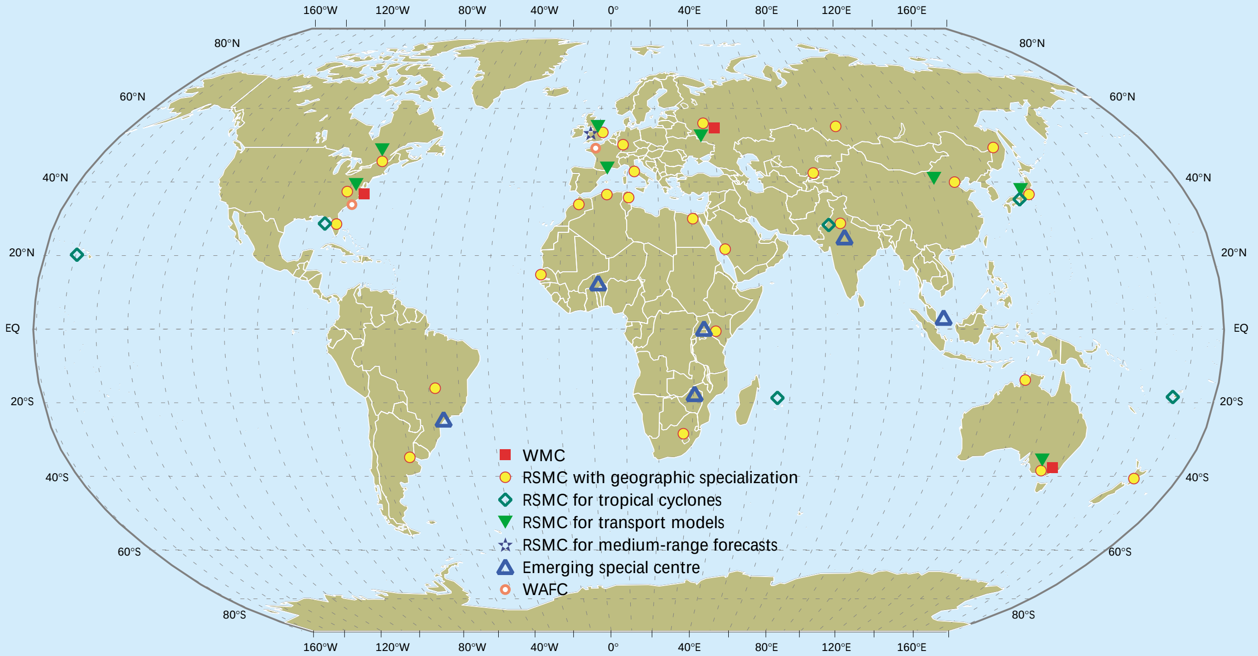
Numerical weather prediction models are computer-based systems to integrate data from around the world, produce a picture of the current motions of the atmosphere and simulate how those motions will change over the coming days, including what dangerous weather systems might develop (National Oceanic and Atmospheric Administration, USA)

The WMO Global Data-processing System

The WMO Global Data-processing System (GDPS) is a cooperative hierarchical network of centres carrying out weather analysis and prediction to ensure that all NMHSs have timely access to the data and products necessary for them to provide early warning of potentially dangerous weather events. It is a three-level system of centres operated by WMO Members made up of:

- Three World Meteorological Centres (WMCs);
- Forty Regional Specialized Meteorological Centres (RSMCs); and
- The National Meteorological Centres (NMCs) of each country.

WMO has supported the establishment of cooperative regional data-processing and forecasting centres as an initiative to assist developing countries to better utilize regional and global products. Through capacity building activities significant progress has been made. The Regional Specialized Meteorological Centres in Miami (USA), Nadi (Fiji), Réunion (France), New Delhi (India), Tokyo (Japan) and Honolulu (USA) provide advisories for tropical cyclones. The African Centre of Meteorological Applications for Development (ACMAD) in Niamey, Niger, the Association of South-East Asian Nations (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 RSMCs, generate regionally focused products for various phenomena including droughts, forest fires and seasonal forecasts.



The Mt Kenya station is one of 22 WMO GAW global stations that monitors the changing concentrations of atmospheric gases and aerosols, which is vital to anticipate human-induced changes in the climate and its impact on the frequency and intensity of severe weather events (WMO Archive)

Prediction and early warning

The timely collection and processing of observations and the distribution of forecasts are essential for effective early warning of dangerous meteorological and hydrological events. Today, an increasing number of countries integrate their computers and telecommunications facilities into the global infrastructure for monitoring and early warning of weather and climate events likely to endanger life and property.

A dedicated global system for exchange of data and products

The WMO Global Telecommunication System (GTS) is the dedicated high-speed communications link that is essential for collecting observations from around the globe and giving a complete picture of the pattern of weather systems. It is an integrated network comprising terrestrial and satellite telecommunications links and provides for timely and reliable exchange of observational data between NMHSs and for distribution of processed information (i.e. meteorological analyses, forecasts and warnings). The GTS ensures that all countries have access to regional and global data, products and information necessary to meet their operational and research needs as well as for disaster mitigation. Particular efforts are being made to strengthen the GTS where it is weak or deficient, especially in developing regions and other areas with limited communications infrastructure.

Integrated system for data analysis

It is neither feasible nor practical for every country to acquire the supercomputers and develop the specialized expertise that are currently necessary to run global numerical weather prediction and climate models that are vital for early warning over various time and space scales. Major meteorological processing centres share a worldwide coordinated responsibility for providing forecast products for different geographic areas and different specific purposes. (See box opposite.)

Weather and climate research

International cooperation in research has been essential for advancing the frontiers of climate science.

Advancement of knowledge about the climate system has been achieved through dedicated research based on programmes of systematic observations and their collection and analysis. Early studies were about local phenomena but the scope expanded as first regional and then

Future observing systems

The value of space-based observations for weather and climate monitoring was established during the Global Weather Experiment of 1979. The operational system is now an integral part of the WWW and supports weather and climate research and the operational needs of numerical weather prediction, including early warning of severe weather events.

The Global Observing System is being modernized to meet the needs of the 21st century. The role of satellites will continue to increase through the greater use of soundings of the atmosphere and imagery over the whole globe. Both polar-orbiting and geostationary satellites will provide user-oriented space-based products, as well as more reliable data collection and transmission services for early warning of severe weather events. Recently, it was decided to add research and development (R&D) satellites to the space-based GOS.

global data became available through international cooperation. International data exchange and the cooperative research programmes ensure that the advances in meteorological and hydrological knowledge and their applications, especially for the assessment of risk and vulnerability to dangerous events, are available to all countries.

Advances in atmospheric and environmental research

The advancement of atmospheric sciences assists NMHSs in providing better meteorological, hydrological and environmental services.

The WMO World Weather Research Programme (WWRP) has its origins in the belief that it is possible to substantially improve weather forecasting performance and provide major economic and societal benefits, particularly through early warning of potentially dangerous meteorological and hydrological events. The programme integrates recent advances in scientific understanding of relevant physical processes with parallel technological advancements, such as in computing, communications and observational technologies, to develop new forecasting capabilities within the NMHSs.

For example, strong emphasis is placed on understanding and predicting the nature and movement of tropical cyclones, but studies of the monsoon circulations and their variability and prediction on regional and seasonal scales, especially as they influence tropical drought, are also emphasized. Better understanding of the behaviour of tropical weather systems and further improvements in forecasting of tropical cyclones will give more timely and accurate early warning and help reduce the loss of life and social disruption arising from severe tropical weather and climate events.

The Tropical Meteorology Research Programme is aimed at promoting and coordinating the international research activities of NMHSs in the high-priority area of tropical meteorology.

Special programmes of observations, and a strong research component in the field of the atmospheric environment, comprise the WMO Global Atmosphere Watch (GAW) established in 1989. The main research objective is to

Observing the global climate

The Global Climate Observing System (GCOS) is to be capable of providing the comprehensive observations required for climate purposes.

The GCOS builds on the WWW observing system for the atmosphere but expands the coverage of observations to include the oceans and the land surface. It addresses the total climate system including physical, chemical and biological properties.

In general, ocean observing networks, are not as developed as atmospheric networks and large and significant gaps in coverage exist, especially over the Southern Hemisphere. Recent developments in technology have made possible important advances to *in situ* ocean observing capabilities. The Argo Programme will ultimately introduce a global array of some 3 000 sophisticated ocean buoys to undertake large-scale sampling of the temperature and salinity of the ocean from the surface to a depth of down to/up to 2 000 metres.

The understanding of ocean dynamics and the capacity to predict ocean and climate variations and monitor climate change have been greatly improved by the availability of precise measurements of changing ocean surface topography from space. Such information is essential for projecting the future climate of the planet and the extreme events.

Past climates are being reconstructed using data from deep polar ice cores, drilling the ocean floor, and analysis of the growth patterns of trees and corals (National Oceanic and Atmospheric Administration, USA)

improve understanding of the atmosphere and its interactions with the oceans and the biosphere.

Climate research

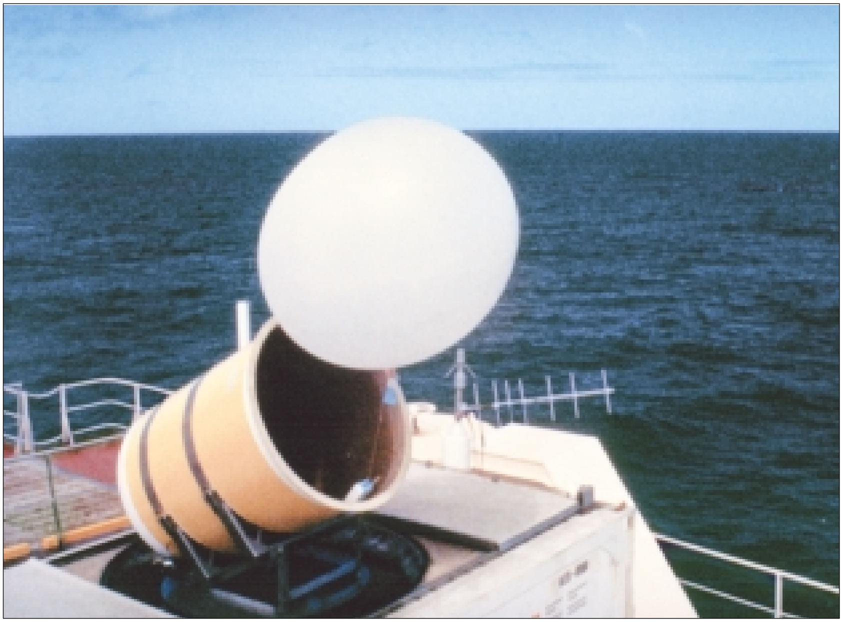
To what extent can climate be predicted, and what is the extent of human influence on climate?

An important thrust of international climate research has been to understand and predict year-to-year climate variability. The world-wide impacts of climate extremes during the 1982/1983 El Niño event in the tropical Pacific Ocean gave impetus to climate research.

Current studies are specifically directed at providing scientifically-founded quantitative answers to the questions being raised on climate and the range of natural climate variability. Objectives are to establish the basis for predictions of global and regional climate variations and of changes in the frequency and severity of extreme events.

A number of global broadly-based multi-disciplinary science strategies offering the widest possible scope for investigation of all physical aspects of climate and climate change have been formulated within the context of the WMO-sponsored World Climate Research Programme (WCRP).

The development of global climate models is an important unifying component of the WCRP that builds on scientific and technical advances in the more discipline-oriented studies. These models are the fundamental tools for understanding and predicting natural climate variations and providing reliable estimates of anthropogenic climate change and disaster mitigation based on projections of the future state of the atmosphere.



The World Climate Research Programme encompasses studies into the processes linking to the air, the land, the sea and ice in order to study the climate system and its variability; these studies depend on observational data, such as from this ship radiosonde launch as part of the Automated Shipboard Aerological Programme (ASAP) (WMO Archive)

COORDINATION FOR A SAFER WORLD

The management of weather and climate risk is multi-dimensional and involves close coordination between international organizations and government agencies.

International coordination

At the global and regional levels WMO, through its networks of NMHSs, World Meteorological Centres and Regional Specialized Meteorological Centres, ensures effective coordination in the making of meteorological, hydrological and related geophysical observations, the processing and rapid exchange of such data and products for various socio-economic activities and, in particular, for early warning and disaster preparedness and prevention.

WMO is also a partner, with other United Nations system organizations as well as regional and international organizations, in the development and implementation of disaster mitigation strategies. In particular, WMO participated actively in the implementation of the International Strategy for Disaster Reduction (ISDR), which follows and builds on the successful International Decade for Natural Disaster Reduction (IDNDR). WMO has also entered into partnership with other UN system organizations in specific sectors such as health, agriculture and forestry, water resource management and tourism. The organizations cooperate through building multidisciplinary approaches to integrate scientific knowledge about physical, chemical and biological processes of the Earth system with impact assessments, and to develop preparedness and response strategies for a range of extreme meteorological and hydrological events. The assessments of the Intergovernmental Panel on Climate Change (IPCC) established by WMO and the United Nations Environment Programme (UNEP) in 1988 have been a catalyst for, and have stimulated, multidisciplinary studies that have identified potential impacts of climate extremes across sectors. All these contribute to vulnerability assessment and disaster mitigation on different time and space scales.

Beach reinforcement at Bandos Island (Maldives South Ari Atoll) due to sea-level rise and the potential for severe weather and climate events; local weather and climate information and the deliverance of early warning are crucial to the effectiveness in reducing vulnerability to such hazards (Marcel & Eva Malherbe)

National coordination

Reduction of vulnerability requires that there is assessment of the risks, formulation of strategies for mitigation and coordination of emergency response plans.

Role of NMHSs in risk assessment

NMHSs, as providers of meteorological and operational hydrological services, have an important national role in risk assessment and vulnerability reduction. A coordinated approach involving NMHSs and other appropriate agencies will ensure that:

- The collection of meteorological and related information and its ongoing management are appropriate to support studies of community sensitivity and vulnerability;
- Multidisciplinary studies are carried out to establish national risk and vulnerability at the community level;
- Appropriate national planning policies and response strategies that give weight to vulnerability reduction are formulated;
- The meteorological and related information and early warning services required in support of the national plans are timely and available to those agencies for decision-making.

A nationally coordinated strategy to reduce vulnerability ensures that science and technology are integrated into planning and decision-making processes at all levels and across all sectors. Government support is essential to ensure that the scientific and technological infrastructures for the delivery of services are in place.

Early warning services

The NMHSs support natural disaster reduction by providing early warnings of severe meteorological and hydrological events and ongoing information about the extent and severity of climate anomalies.

An appropriate national scientific and technological infrastructure underpins services that reduce vulnerability. The infrastructure is the basis for systematic observations of the local climate, for maintaining national climate archives, for monitoring prevailing anomalies of the local climate, and for providing early warning of weather and climate events, especially of extreme events likely to threaten life and property.

NMHSs assist in reducing vulnerability

Meteorological and hydrological information services underpin risk assessment, mitigation strategies and early warning. For this reason it is important that there are strong links between NMHSs and agencies of government with special responsibilities for infrastructure planning, disaster mitigation and emergency response. Inter-agency cooperation and coordination will ensure that the potential for planning and early warning are realized, that information and service needs are identified, and that the format, content and timing of warning services to decision makers are of maximum benefit.

Accessing international data and products

Through WMO, the NMHSs are the national focal points for intergovernmental cooperation and coordination of meteorology and hydrology.

The global infrastructure for meteorological and related scientific operations is supported by each of the 185 Member States and Territories of WMO. In addition to their own national observing and data-processing systems, all countries have access to the data and prediction products generated by the cooperative Global Observing System and the network of World and Regional Meteorological Centres. The integration of national, regional and global information and products is essential for the early warning of severe weather and climate events.

The services provided by the NMHSs are dependent both on:

- The national data generated through their own observing and data-processing infrastructure;
- The global and regional monitoring and prediction products that are generated within the framework of the WWW.

WMO assists NMHSs with their service responsibilities, especially in the areas of early warning and natural disaster reduction. Its objective is to ensure that NMHSs have access to, and fully benefit from, the international exchange of data and processed products, particularly of forecasts and warnings relating to extreme weather events. Tropical cyclones pose a particular danger to low-lying coastal and small island developing states. Regionally coordinated activities ensure that NMHSs are better able to provide tropical cyclone and related flood and storm-surge forecasts and warnings.

Technical cooperation

Technological advances continue to enhance the overall global meteorological infrastructure for operations and service delivery. Miniaturization, automation, high-speed communication and computers have enabled provision of new products from the WWW and the potential for delivery of better services by NMHSs. As a consequence, there are new community capabilities for planning and early warning that are saving lives and making public infrastructures more robust and resilient against the impacts of extreme meteorological and hydrological events.

A major challenge is to ensure that the potential benefits from the new capabilities are fully realized. WMO endeavours to ensure, through the collaborative efforts of Members and for their mutual benefit, the enhancement and development of the capabilities of all NMHSs. The objective is for all NMHSs to contribute to, and participate fully in, the implementation of WMO programmes for the good of the global community and in support of sustainable national social and economic development.

WMO training and technical cooperation programmes assist developing countries to ensure that they have the appropriate scientific and technical capabilities to engage in the World Weather Watch and deliver quality services (J.-P. Gaucher/Météo-France)

Local disaster preparedness structures

The success of efforts at international, regional and national levels in disaster mitigation also rests on:

- Strengthening the underlying institutional and legal conditions of local disaster preparedness organizations, including non-governmental organizations, within the policy framework of governments and local authorities;
- Uniting local disaster preparedness structures with regional and national activities as well as with neighbouring countries in the event of cross-border risks, and with international structures of organizations such as WMO;
- Providing training and integrating aspects of disaster mitigation in schools and in various fields of disaster preparedness for experts/specialists working at the local and national levels;
- Initiating self-help activities.

SUMMARY

Global statistics continue to highlight that an increasing number of people are affected by hydrometeorological disasters. Over the 1991–2000 decade, the figure averaged 211 million persons per year, seven times the number affected by conflict. Moreover, 98 per cent of the people affected by meteorological and hydrological disasters are in developing countries.

Community preparedness is the only practical solution for countries that are at high risk to extreme weather and climate events. The global, regional and national layers of the scientific and technological infrastructure that make up the World Weather Watch provide an array of information for managing climate risk and reducing vulnerability to meteorological and hydrological hazards. It is critical that each NMHS is effective and is capable of delivering timely and accurate information and early warning services for the protection of life and property.

WMO has taken special note of the widening gap that exists between the level of relevant services provided by the developed countries and the developing countries. It reaffirmed that the disparity was a matter of major concern for all WMO Members because of their high level of interdependence. WMO stressed that it is of crucial importance that governments provide appropriate funding for their respective NMHSs in support of basic national meteorological and hydrological infrastructures and the delivery of services, especially for the reduction of vulnerability to extreme events.

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