Our future climate

World Meteorological Organization

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CONTENTS

FOREWORD

Each year, World Meteorological Day is celebrated worldwide to commemorate the coming into force of the Convention of the World Meteorological Organization (WMO) in 1950. For each anniversary, WMO selects a theme, which highlights the contribution of meteorology and operational hydrology to an issue of importance to humanity. For the year 2003, the theme is *Our future climate*.

The theme is particularly propitious in the light of the outcome of the United Nations World Summit on Sustainable Development (Johannesburg, South Africa, 2002) in which concern was expressed about change in the Earth's climate and its adverse effects and in which was reaffirmed a commitment to the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system…". This reaffirmation is based on the work of the WMO/United Nations Environment Programme (UNEP) Intergovernmental Panel on Climate Change (IPCC).

The IPCC assessed that continued increase of greenhouse gases will cause the global mean temperature to rise by 1.4 to 5.8°C and the sea level to rise by 9 to 88 cm by the end of the century compared to 1990 levels. The projected changes are expected to significantly affect weather and climate systems.

In this regard, the unprecedented weather- and climate-related extreme events such as floods, droughts and tropical cyclones in various parts of the world are viewed with concern.

The last decade of the 20th century and, in particular, the year 1998, have been the warmest since instrumental records began some 140 years ago. The 20th century has also been the warmest of the last millennium.

Such knowledge of our past climate and its future state has been possible through WMO's historic and pioneering work in monitoring and research. In 1929, WMO's predecessor, the International Meteorological Organization, established a Commission for Climatology. In 1976, WMO issued the first authoritative statement on the potential impact of the increase in greenhouse gases on the climate.

Subsequently, in 1979, the Organization convened the First World Climate Conference, leading to the establishment of the World Climate Programme (WCP) and its component parts, and invited other organizations such as UNEP and the International Council for Science to collaborate with WMO in their implementation.

Since then, WCP has been the mainstay of all climate-related activities, strategies and policies. It benefits synergistically from WMO's basic observational systems, including the World Weather Watch, the Global Atmosphere Watch and the hydrological observing networks. WMO also contributed to the negotiations and implementation of the United Nations Framework Convention on Climate Change.

As in the past, WMO's expertise and networks of National Meteorological and Hydrological Services (NMHSs), scientists and centres of excellence in climate monitoring, research and applications place it in a foremost position to project the future state of our climate. These will also contribute to assessing the impacts of climate change and in addressing climate-related challenges of the future, including the implementation of the various environment-related conventions such as those on climate, desertification, biodiversity and ozone. In these undertakings, the contributions of NMHSs remain vital.

Many of the issues relating to our future climate are highlighted in this brochure. I wish to thank Mr Y. Boodhoo, the President of the Commission for Climatology, and Mr M. Crowe, a former member of the Commission, for preparing the manuscript. I hope that the information provided and the activities of World Meteorological Day will serve to draw further the attention of governments, the public and the media to the contributions of WMO and NMHSs and on the need to act now to protect our climate as a vital resource for future generations.

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

INTRODUCTION

Europe's recurring and intensifying floods are but one example of extreme climate events experienced worldwide in recent years (Direzione Servizi Tecnici de Prevenzione, Regione Piemonte)

Can you imagine a world in which droughts are longer lasting and floods more prevalent; where islands are becoming submerged; where some of our coastal cities are in danger of flooding; where tropical diseases are found at increasingly higher latitudes; where heatwaves have increased in frequency and severity and more and more people in urban areas are succumbing to them; where exposure to sunlight may have deadly consequences; where the crops tended by today's farmers have been supplanted by completely different crops more attuned to warmer conditions; and where a large fraction of the glaciers are disappearing?

Such a world may be awaiting our children if human-induced (also called anthropogenic) change to our climate is not brought under control.

We are experiencing glimpses of these extreme events today. Floods of rare magnitude in the summer of 2002 in Europe — extending from the United Kingdom to Romania and Bulgaria — left hundreds dead and billions of dollars worth of damage. In Asia, the Republic of Korea had to mobilize troops to battle downpours after deluges dumped two-fifths of the average annual rainfall of the country in a single week. In China, many tens of millions of people were affected amidst torrential rain and flooding of historic magnitude. During the same period, parts of Asia, the United States and Australia experienced droughts severe enough to threaten harvest failures. In Southern Africa, nearby 13 million people were threatened by severe droughts.

Weather, the day-to-day manifestation of climate, plays a decisive role in food production and the availability of freshwater, in ensuring our well-being, in energy production and usage, in industrial, transport, leisure and other economic activities. Climate information is instrumental in decision-making about all of them. Climate even affects the mood of people, moulds their character and governs their ways of thinking. Climate is increasingly recognized as one of the most precious resources on Earth.

Climate varies, and has always varied, from time to time as a result of natural causes. However, it is now also being influenced as a result of human activities. When WMO discerned signs of this influence on the climate system, it reinforced the already existing mechanism for the systematic collection, dissemination and analysis of climate data throughout the world. It coordinated the establishment of a network of specialized global and regional measuring stations, and the infrastructure needed to support them. These enable the collection of data and information about the physical characteristics of the Earth's environment.

The monitoring initiated by WMO showed disturbing signs of human (anthropogenic) interference with the climate system. This interference has mostly occurred through the injection of massive amounts of carbon dioxide and other gases into the atmosphere. These findings were presented and discussed at the First World Climate Conference organized by WMO in 1979. This Conference established the World Climate Programme to undertake scientific monitoring and study of the climate. Through sustained actions by WMO, leaders of all nations slowly, but surely, took stock of the fragile climate, its change and the potential societal and economic impacts. In 1990, WMO hosted the Second World Climate Conference, which brought together scientists and political leaders. One major outcome of the conference was the establishment of the Global Climate Observing System, which works to improve observations of climate and coordinate their collection and use in climate change studies.

Amid growing concerns about continued anthropogenic impacts on global climate, in 1988 WMO and UNEP established the Intergovernmental Panel on Climate Change (IPCC). In 2001, this body issued its extensive Third Assessment Report on the state of the global climate. Some of the major landmarks in the study of the climate are given on **page 30.**

The Intergovernmental Panel on Climate Change (IPCC)

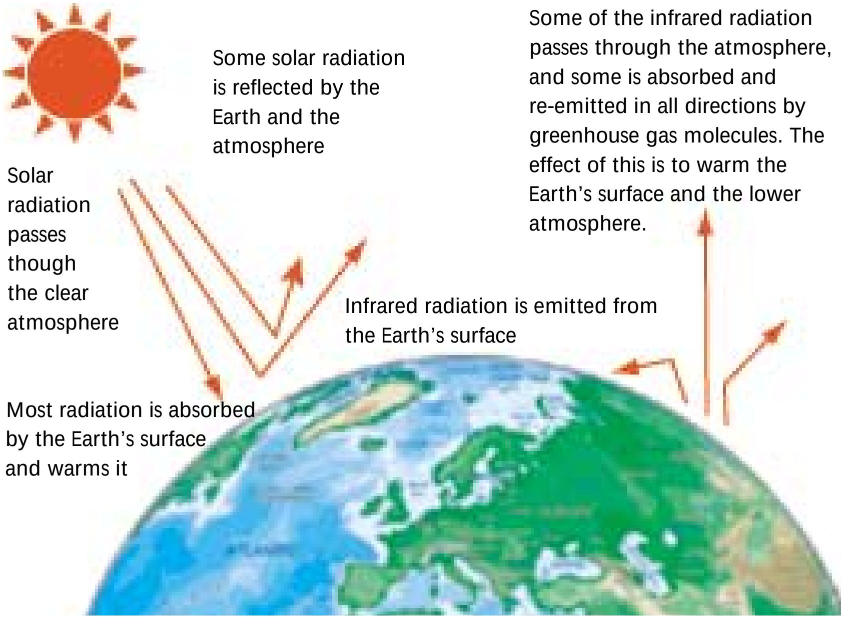
The Intergovernmental Panel on Climate Change (IPCC) was jointly established by WMO and UNEP in 1988. Its terms of reference include: (i) to assess available scientific and socio-economic information on climate change and its impacts and on the options for mitigating climate change and adapting to it and (ii) to provide, on request, scientific/technological/socio-economic advice to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). Since 1990, the IPCC has produced a series of Assessment Reports, Special Reports, Technical Papers, methodologies and other products that have become standard works of reference, widely used by policy-makers, scientists and other experts. Its Third Assessment Report, comprising the contributions of Working Groups I, II and III and the Synthesis Report, including the Summaries for Policymakers and Technical Reports, was produced in 2001.

CLIMATE

The greenhouse effect plays a crucial role in maintaining a life-sustaining environment on Earth

To understand climate change, we must start with an explanation of the Earth's climate system. We are able to live on Earth because of energy radiated by our Sun and a phenomenon known as the greenhouse effect, in which gases such as water vapour and carbon dioxide retain a certain amount of the energy radiated back from the Earth's surface. This allows the temperature of the Earth to remain within bearable limits for humankind. As we shall see, the effects of intensive human activity are increasing the concentrations of some of these gases and thus further enhancing the greenhouse effect.

Climate is defined as the average state of the atmosphere taken over a given period of time (months to years) for a particular geographical location. The climate is characterized by a wide range of meteorological parameters; the most common of which are temperature, precipitation, atmospheric pressure, duration of sunshine and wind. Other elements may include humidity, cloudiness, extreme weather such as thunderstorms, and even the type of soil (dry, arid, desert). Often, climates are given descriptions, such as tropical, subtropical, middle-latitude, high-latitude, maritime, cold, dry, moist or savannah.



The climate system

The Earth's climate system includes the atmosphere, ocean, land, cryosphere (snow and ice) and biosphere. Descriptors of this complex system include temperature, precipitation, atmospheric and soil moisture, snow cover, cloud cover, extent of land and sea ice, sea level, extreme weather and climate events, atmospheric and oceanic large-scale circulation, and habitats of plants and animals. The science of describing climate must take into account the measurements and interrelationships among these descriptors.

Linkages between the components of the climate system

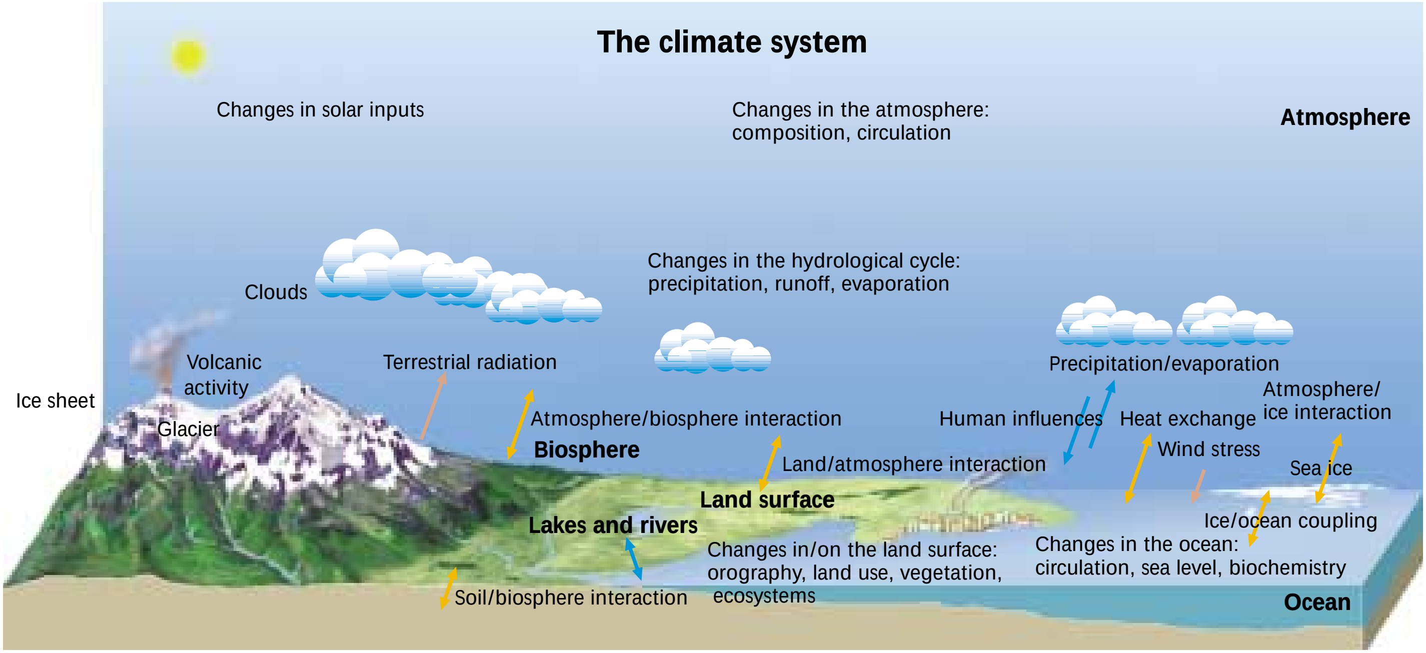
The global climate, biological, geological and chemical processes and natural ecosystems are closely linked with one another, and changes in any one of these systems may affect the others, which could result in consequences detrimental to humans and other living organisms on Earth. Gaseous and particulate matters produced by humans and emitted into the atmosphere have modified the energy balance in the atmosphere and thus affect interactions among the atmosphere, hydrosphere and biosphere.

The importance of the oceans and their currents in maintaining a climate balance and regional climatic differences is becoming ever better known. One remaining uncertainty, though, is the potential influence that climate change may have on ocean circulation patterns.

Feedback mechanism within the climate system

Feedback within the climate system is just one facet of its complexity, but helps to underscore the difficulty in describing its present condition, and more so the forecasting of future conditions. Changes in part of the climate system can have influences which tend to increase over time. For example, a decrease in snow cover, due to increased temperature, can reduce the reflection of solar energy back into the atmosphere thus increasing the energy absorbed by the Earth's surface. This then can lead to higher temperatures and hence greater melting — an example of positive feedback.

There are also negative feedback processes within the climate system. An increased amount of cloudiness, possibly caused by higher temperatures, for instance, reduces the amount of solar radiation reaching the ground and eventually decreases temperatures near the surface.



EVOLUTION OF THE GLOBAL CLIMATE

Climate change and variability

Studies have shown that the Earth's climate has never been static. It is dynamic, subject to variations on all timescales ranging from decades to millennia to millions of years. Among the most prominent variations is the cycle, over about 100 000 years, of glacial periods when the Earth's climate is mostly cooler than at present followed by warmer interglacial periods. These cycles occurred as a result of natural causes.

Since the industrial revolution, change in climate has been occurring at an accelerated rate as a result of human activities. This change, which is superimposed on natural climate variability, is attributed directly or indirectly to human activity that alters the composition of the atmosphere.

Ice cores

Researchers in the United States bored over 3 km, representing 200 000 years of climate history of the Earth, to the very bottom of the Antarctic ice sheet. This is one of the longest environmental records ever observed from an ice core.

These cores show the sharp change from clear to silty and clear ice followed by progressively siltier ice until contact with the bedrock at 3053.51 m.

J.S. Putscher/NGDC/NOAA

The past climate

Numerous anthropological studies undertaken have shown evidence of past climate change. For example, cave paintings, estimated to have been drawn several thousand years ago and discovered in the Sahara desert, depict animals that can only survive in climates with plentiful water. Excavations in Egypt have yielded bones of elephants and remains of other animals that are present elsewhere but are at present non-existent in Egypt. This bears testimony to greener periods in the past compared with present-day desert conditions. Several other discoveries in arid areas provide evidence that these were once lush with green vegetation and water.

Other studies, based on paleo-climate or proxy data, such as tree rings, ice cores, lake sediments and coral reefs, show that climate has, in fact, been subject to changes in the past. Some of these changes have occurred over relatively short time periods.

Rapid climate transitions

For some time now, it has been known that, since the icecaps withdrew for the last time from Central Europe, there have been two phases of remarkable, rapid, natural warming. The first occurred around 14 700 years ago at the end of the last Ice Age during the transition to what is called the Late Glacial. The second period was some 3 200 years later (about 11 500 years ago), during the transition from the last cold periods of our climate (the Younger Dryas period) to our present warm climate (Holocene).

The rate of change since the Industrial Revolution appears to be analogous to the rapid changes of the Younger Dryas and Holocene periods. Average global temperature fell over the previous 10 000 years due to intense volcanic activities or other natural climate forcings then rose abruptly, especially since the early 1900s.

For several thousand years prior to the 1850s, the amount of atmospheric greenhouse gases had remained relatively steady. Today, much of the concern regarding climate is that humans are pumping unprecedented amounts of greenhouse gases, such as carbon dioxide and methane, into the atmosphere and this is causing a marked change in the chemical composition of the atmosphere. This change is affecting the global climate. If the tendency continues, the climate is projected to continue to change, though not by the same magnitude in all regions of the world. In fact, some regions are more susceptible to the influence of climate change than others. For example, the land areas of middle and high latitudes have shown the greatest increase in temperature during the last 100 years, while some other areas have exhibited some cooling.

Findings from icecaps

Research on the Greenland Icecap revealed that both climate transitions in Central Europe (14 700 and 11 500 years ago) occurred very rapidly, over a few decades at most (and clearly without significant anthropogenic input). These offer sufficient possibilities for comparing the climate processes that occurred then with the current evolution of the climate. Combining geological and ecological data in numerical models, quite accurate estimates of the magnitude of the climate changes, as well as their rapidity and geographical trends, are obtained. Such analyses have revealed some of the major forces driving climate change and the sensitivity of the climate to certain environmental factors, such as sea temperature. Observations and numerical modelling allowed quantitative reconstruction of climate changes, and provided an assessment of the importance of the forces that drove the changes.

B. Pikhanov

CAUSES OF CLIMATE CHANGE

Natural

Natural factors which alter the climate include shifts in the Earth's orbit and tilt, the relative position of its axis, changes in solar activity, volcanic eruptions and changes in the distribution of naturally-occurring atmospheric aerosols.

Volcanic eruptions

Emissions following volcanic eruptions inject significant amounts of particles and gases into the atmosphere. These particles are carried by tropospheric and stratospheric winds over large areas of the globe and shield part of the incoming solar radiation. Any alteration in the

Emissions following volcanic eruptions, such as Mount Etna's spectacular eruption in Sicily in October 2002, inject significant amounts of particles and gases into the air, destroying stratospheric ozone and affecting climate (NASA)

Examples of temperature drops after volcanic eruptions

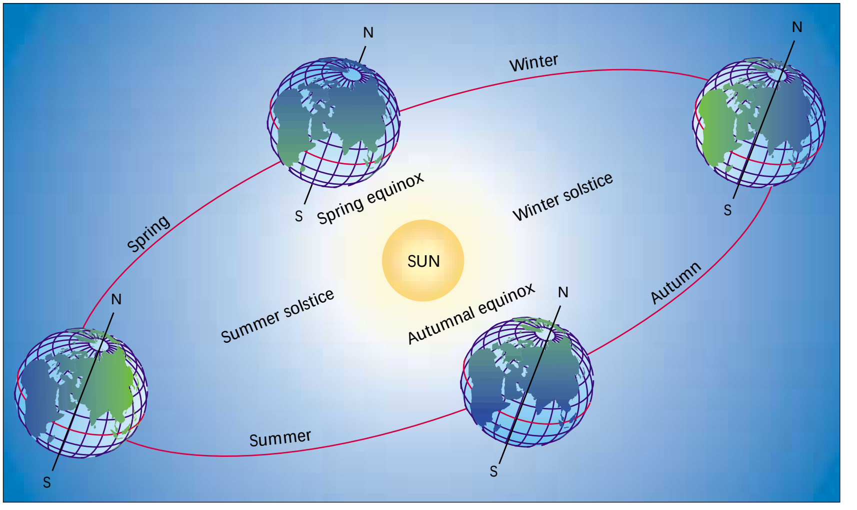
The major eruption of the Santorini volcano in the Mediterranean about 1600 BC, which may have lead to the fall of the Minoan Empire, seems to have produced a significant cooling of the atmosphere. Very narrow tree growth rings and indications of frost rings are dated to the time of this eruption. The same eruption has also left traces in ice cores in Greenland.

Global temperatures dropped by as much as 3°C during the years following the eruption of Mount Tambora in Indonesia — the deadliest volcano in recorded history — in 1815. The following year was, in parts of Europe and Northern America, known as 'the year without a summer'.

The eruption of Mount Pinatubo in the Philippines in 1991 — one of the largest in the past 100 years — injected enormous clouds of volcanic ash and acid gases to heights of 35 km into the atmosphere. The ash cloud was carried by upper level winds and circled the globe in 22 days. The net radiation at the top of the atmosphere was estimated to have decreased by 2.5 W/m^2, equivalent to a global cooling of at least 0.5 to 0.7°C.

incoming solar radiation is bound to alter the regularity, pattern and location of the rising and sinking air motions and cause changes to the prevailing climate, including temperature. However, the changes are not long lasting.

In addition to changes in the temperature regime, volcanic eruptions also destroy stratospheric ozone. For example, the impact of the El Chichon eruption in Mexico in 1982 depleted ozone by about 10 per cent in the following three to four years. In 1991, the eruption of Mount Pinatubo in the Philippines provoked a 15 per cent decrease, over several years, and is believed to have caused an increase in the size of the ozone hole over Antarctica.



The elliptical orbit of the Earth alters its proximity to the Sun and thus the amount of solar radiation it receives

The solar cycle and the Earth's orbit

The ultimate source of energy that drives the climate system is radiation from the Sun. Its output is known to vary within certain relatively small limits. While direct measurements of the Sun's output have only been available for the past 25 years or so, indirect evidence, such as sunspot activity, has long been used to estimate solar radiation changes.

In addition to changes in the energy output of the Sun, the Earth receives differing amounts of solar radiation as its elliptical orbit alters its proximity to the Sun. During the past one million years or so, glacial and interglacial periods have alternated as a result of variations in the Earth's orbit. There have been fewer orbital variations during the past ten thousand years, a period over which the climate has been relatively stable. If the climate is to remain stable, the solar energy reaching the surface of the Earth must be balanced by outgoing radiation. Any change in the incoming solar radiation can profoundly change the Earth's weather and climate. The energy distribution within the atmosphere and its impact on the climate are dependent on factors such as albedo, clouds, aerosols and gases, as is the portion of energy re-radiated back into space from the Earth's surface. Some of these factors result from, or are influenced by, human activities.

Human-induced (anthropogenic) greenhouse gases

Atmospheric concentrations of key anthropogenic greenhouse gases such as carbon dioxide, methane, nitrous oxide and tropospheric ozone increased continuously for the most part during the 20th century. Halocarbons are the exception, as their concentration increased until approximately 1990 and then stabilized when restrictions on the use of these compounds were put into effect by the Montreal Protocol on Substances that Deplete the Ozone Layer. The changes in greenhouse gases were due primarily to the combustion of fossil fuels, increased agricultural and land-use changes. Carbon dioxide concentrations have increased from 280 parts per million (ppm) in pre-industrial times (1750s) to 370 at present and it is estimated that, with the present trend, *Energy distribution within the Earth–atmosphere system; at the top of the atmosphere, the incoming radiation from the Sun equals the reflected solar radiation and the outgoing long-wave radiation; the major transfer processes include absorption, reflection, emission, direct transmission and evapotransportation*

the concentration will range between 540 and 970 ppm in the year 2100. These gases have a long lifetime in the atmosphere. Evaluations show that half of all CO_2 emissions end up in the atmosphere and stay there for between 50 and 200 years, while the other half are absorbed by the oceans, land and vegetation. With changes in land use and further deforestation, the proportion of CO_2 in the atmosphere is expected to increase.

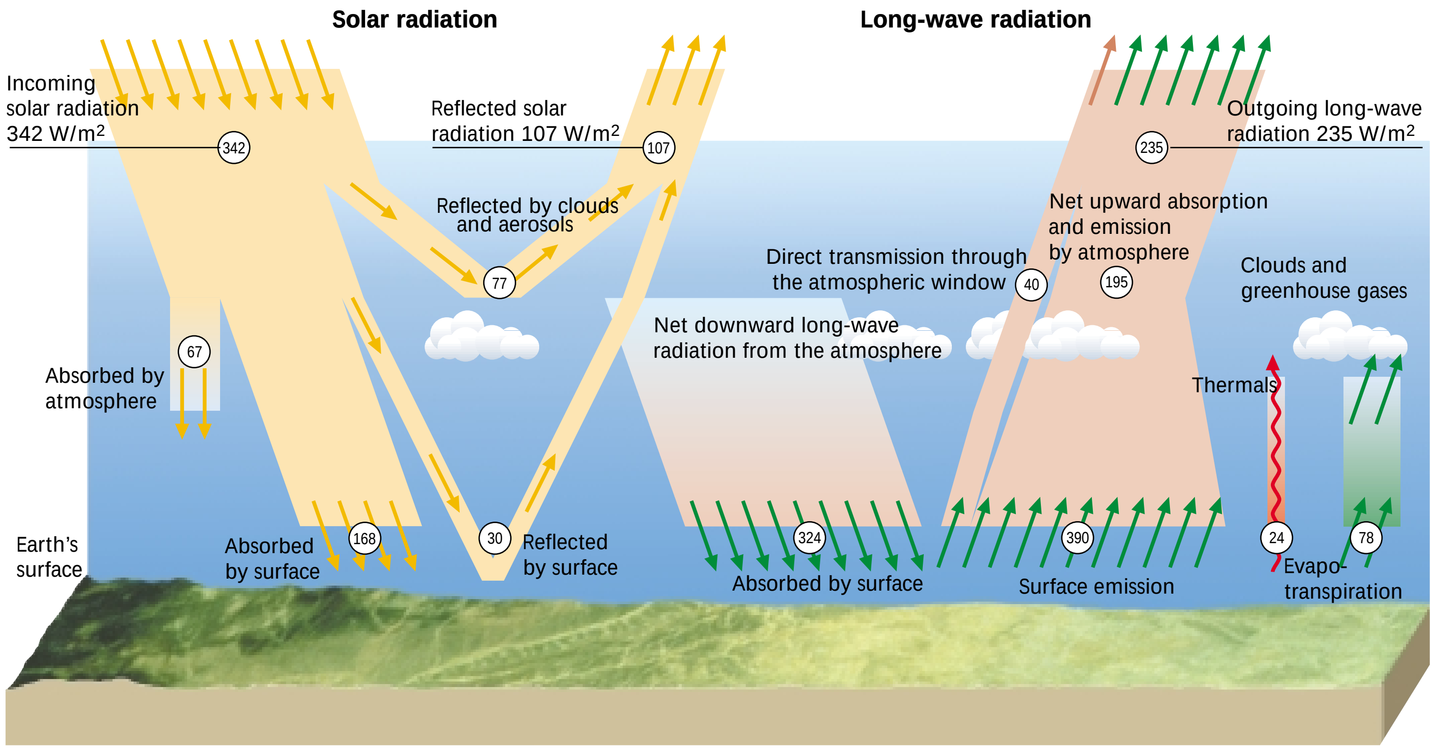
Aerosols

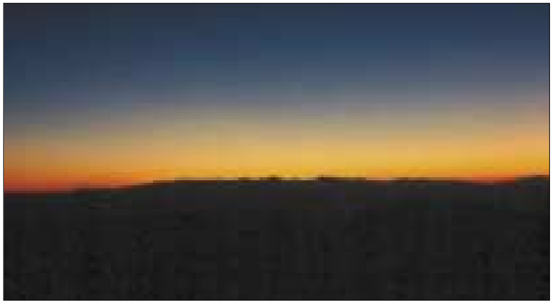
Aerosols are small dust particles that float in the atmosphere. They result mostly from chemical reactions between gaseous air

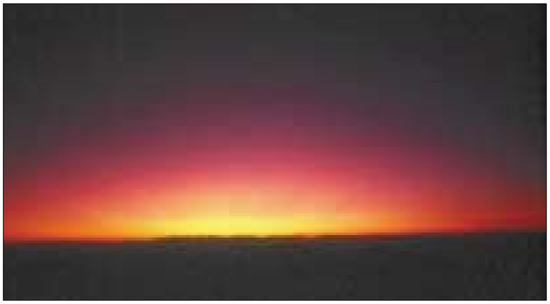
Some of the important greenhouse gases

Naturally occurring greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases.

Greenhouse gases that are not naturally occurring include chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).







The effects of aerosols in the atmosphere after a major volcanic eruption create remarkable sunsets, such as changing the evening sky (left) after the eruption (right) of El Chichon in Mexico (© Grant W. Goodge/ NCDC (retired))

pollutants, rising sand or sea spray, forest fires, agricultural and industrial activities and vehicle exhausts. Aerosols form a turbid layer in the troposphere, the lowermost 10 km of the atmosphere. They may also occur high in the atmosphere after a volcanic eruption, even in the stratosphere at an altitude of about 20 km. On cloudless days they make the sky a less perfect blue, and rather whitish (especially in the direction of the Sun). Aerosols have the most visible effects during sunrise and sunset when the rays from the sun travel through a greater depth of atmosphere to reach the surface of the Earth.

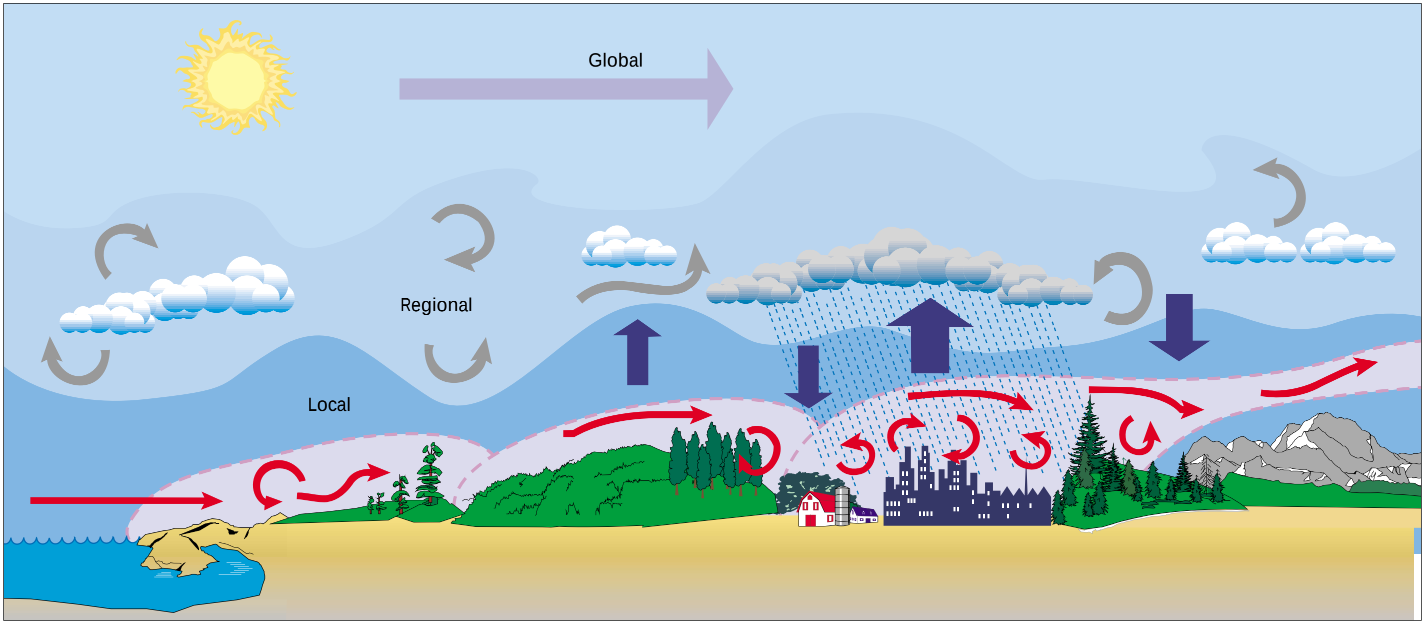
Aerosols are highly efficient at scattering sunlight, as they typically have a size of a few tenths of a micron. Some aerosols (such as soot) also absorb light. The more they absorb, the more the troposphere is warmed and the less solar radiation can reach the Earth's surface. In this way, the temperature of the atmosphere near the ground can be reduced by aerosols.

Large amounts of aerosols can thus lead to a cooling of the climate, which offsets to a certain degree the warming influence of the increase in greenhouse gases. Aerosols also have an additional indirect cooling effect through their ability to help increase cloud cover. The lifetime of dust particles in the atmosphere is much shorter than that of greenhouse gases, as they may be removed by precipitation within a week. The effects of aerosols are also much more localized than the wider-spread influence of greenhouse gases.

Change in land use

With the increase in the world population, pressure to increase the land area under cultivation has increased many fold. Intensive farming, pasture and extensive depletion of

Climate change is an additional pressure on ecosystems, which are subject to many pressures, including grazing by livestock and natural climate variability (Essa Ramadan/ Kuwait Meteorological Department)



Local, regional and global influences on the climate

underground water for irrigation have degraded the soil in several areas. Almeria, in southern Spain, is one of the many examples where the land is threatened by desertification. Changes in land use affect the climatic parameters, such as temperature and humidity, of the region which, in turn, have impacts on the regional and global climate.

Since the industrial revolution green forests all over the globe, at present largely in the tropical rain belt, have been replaced by cash crops and other cultivation. Humans also alter the environment by raising livestock, which increases water demand. In addition to grazing by wildlife, humans have substantially changed the frequency, intensity and extent of grazing through domesticated livestock. In fact, efforts to contain the spread of deserts in the Sahel regions and elsewhere have been hampered by overgrazing by cattle and felling of trees for firewood.

Urbanization

Urbanization has been seen to contribute to climate change. At the dawn of the present century urban dwellers comprised almost half of the world's population. A city of one million inhabitants is estimated to generate 25 000 tons of carbon dioxide and 300 000 tons of waste water every day. The concentration of activities and emissions suffices to modify the local atmospheric circulation around cities. These modifications are so significant that they change the regional circulation, which in its turn affects the global circulation. If this influence continues the long-term effect on the climate will become palpable.

SIGNIFICANT CHANGES OBSERVED

Over the last decades, there has been growing evidence of climate change based on changes to the physical characteristics of the atmosphere and in fauna and flora of various parts of the world.

One of the most compelling arguments concerning climate change is that so many independently-measured observations confirm that over the last century global rise in surface temperature has increased by 0.6°C. Since the industrial revolution, atmospheric carbon dioxide has continued to increase at an accelerated rate.

Both maximum and minimum average daily temperatures are increasing, but minimum temperatures are increasing at a faster rate than maximum temperatures.

Surface, balloon and satellite temperature measurements show that the troposphere and the Earth's surface have warmed and that the stratosphere has cooled.

Increased evidence from paleoclimate records indicates that it is likely that the rate and duration of the warming of the 20th century is larger than at any other time during the last 1 000 years. The 1990s are likely to have been the warmest decade of the millennium in the Northern Hemisphere. The year 1998 was the warmest on record with 2001 the second highest.

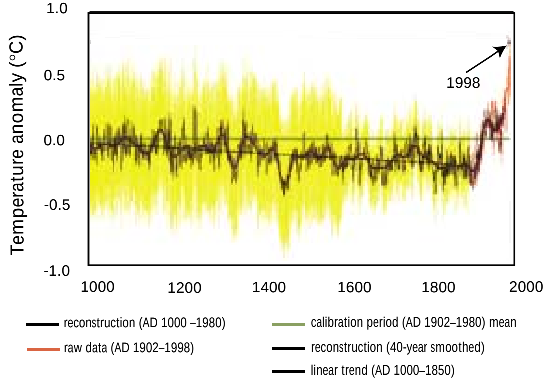
Annual land precipitation has continued to increase in the middle and high latitudes of the Northern Hemisphere, except over Eastern Asia. Floods have appeared even where rain is normally a rare event.

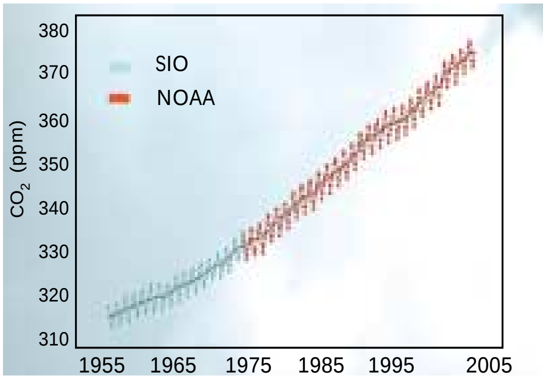
Cloud cover has increased by about 2 per cent over Northern Hemisphere middle- and high-latitude continental regions since the beginning of the 20th century.

Decreasing snow cover and land-ice extent continue to be positively correlated with increasing land-surface temperature.

The amount of sea ice in the Northern Hemisphere is decreasing, but no significant trends in Antarctic sea-ice extent are apparent.

Over the past 45–50 years, Arctic sea ice in late summer to early autumn appears to have thinned by about 40 per cent.





Temperature anomaly over the last 1 000 years (left) and monthly mean carbon dioxide in the atmosphere as observed by the Mauna Loa Observatory (right) (right: NOAA)

Some consequences of regional climate change

Recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems. Examples include:

- Lengthening of middle- to high-latitude growing seasons;
- Declines of some plant and animal populations;
- Declines and shifts of plant and animal ranges toward the poles and higher altitudes;
- Decreasing snow cover and land-ice extent which is positively correlated with increasing land-surface temperature;
- Later freezing and earlier break-up of ice on rivers and lakes;
- Thawing of permafrost;
- Shrinkage of glaciers.

Natural systems, such as animal and plant populations, are vulnerable to climate change because of factors that include decreasing snow cover and land-ice extent, coral bleaching due to warmer seas and forest fires due to increasing droughts (Top photos: NOAA; bottom: Liz Roll/ FEMA Photo News)

The rate of global mean sea-level rise during the 20th century is in the range of 1.0 to 2.0 mm/yr. These increases are greater than those of the 19th century, although there are few records that far back. The 20th century rise may be as much as ten times the average increase of the last 3 000 years.

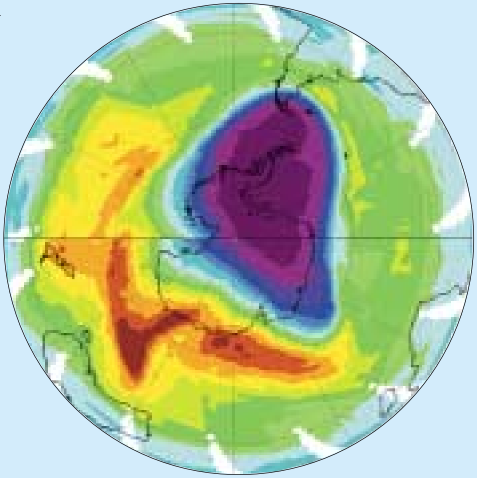
The behaviour of the El Niño/Southern Oscillation (ENSO) has been unusual since the mid-1970s compared with the previous 100 years. Floods and droughts, often accompanied by crop failures and forest fires, have become more frequent, although the overall land area affected increased relatively little.

There have been pronounced increases in heavy and extreme precipitation events.

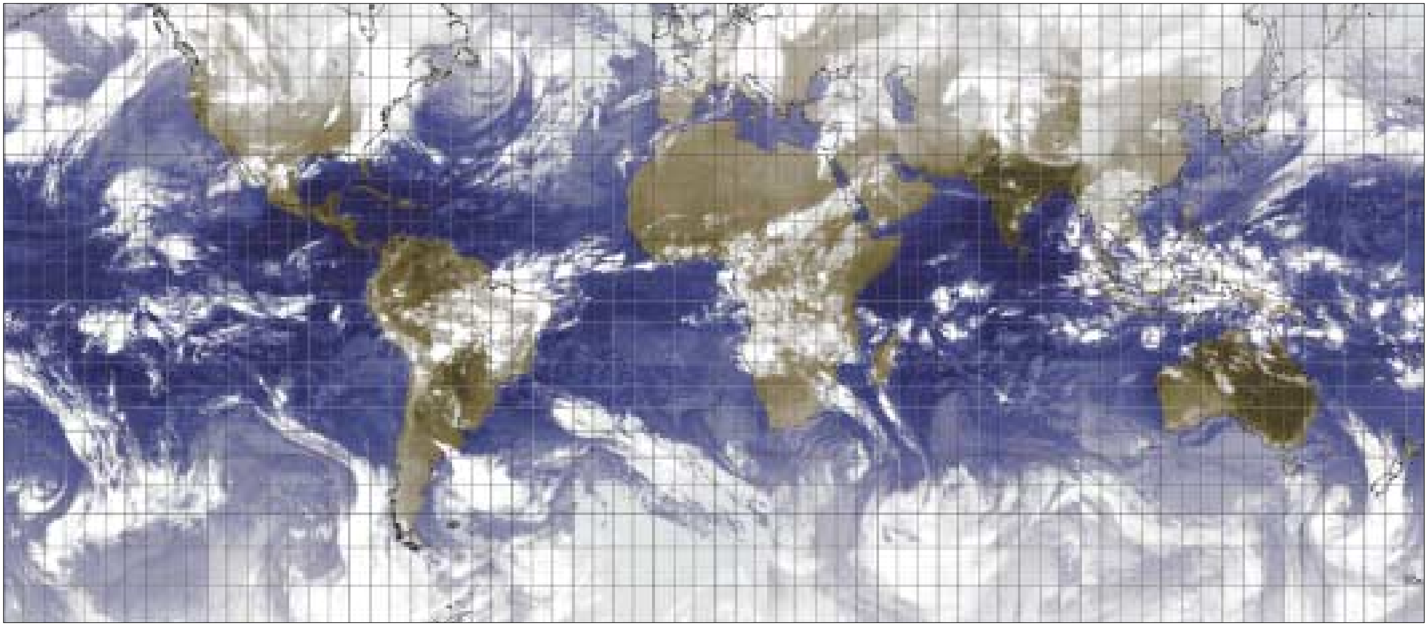
Over the 20th century there were relatively small increases in global land areas experiencing severe drought or increased wetness, although some regions have exhibited changes.

Some impacts of ozone depletion

Monitoring led by WMO provided information on the thinning of the life-protecting ozone layer and on the “ozone hole”. The potential dangers arise from an increase in incoming ultraviolet radiation. Direct effects attributed to such an increase on the surface of the Earth include an increase in cases of skin cancer and eye cataracts, and damage to crops and the aquatic ecosystem including ocean plankton. The Vienna Convention for the Protocol of the Ozone Layer (1985) and the Montreal Protocol on Substances that Deplete the Ozone Layer and its Amendments commit Parties to protect human health and the environment from the effects of ozone depletion.



Devastating floods in Mozambique following Cyclone Eline *in 2000 and the destruction following a tropical cyclone in India show both the human and socio-economic impacts of tropical storms*
(Left: UMC Mozambique; right: IFRC)



Global mosaic of infrared images constructed from data from five satellites: 2 × GOES, 2 × Meteosat and one GMS (Planeta)

There is no compelling evidence to indicate that the characteristics of tropical and extra-tropical storms have changed.

There is also emerging evidence that some social and economic systems have been affected by the recent increasing frequency of floods and droughts in some areas. However, such systems are also affected by changes in socio-economic factors such as land use and it is difficult to quantify the impact of changing climate alone.

Natural systems, such as glaciers, coral reefs, atolls, forests, wetlands, etc., are vulnerable to climate change. Some experts estimate that more than a quarter of the world's coral reefs have been destroyed due to the warming seas. They warn that unless urgent measures are taken, most of the remaining reefs could be dead in 20 years. In some of the worst hit areas, such as the Maldives and the Seychelles in the Indian Ocean, up to 90 per cent of coral reefs are estimated to have been bleached over the past two years.

Damage to the ozone layer

The discovery of the "ozone hole" above Antarctica in the mid-1980s led to intensive research into the chemistry and transport in the stratosphere. Stratospheric ozone makes up about 90 per cent of all the ozone in the atmosphere while the remaining 10 per cent is found in the troposphere, the lowest layer of the atmosphere with a thickness of 10 km at the poles and 16 km in the tropics.

OUR FUTURE CLIMATE

Predictability of climate

The Earth's climate system is chaotic, limiting predictability of the detailed evolution of weather to about two weeks. However, the predictability of climate is not so limited because of the systematic influences of the more slowly varying components of the climate system on the atmosphere. Reliable climate projections are made starting with different initial states and using different global models of the atmosphere.

Climate processes and modelling

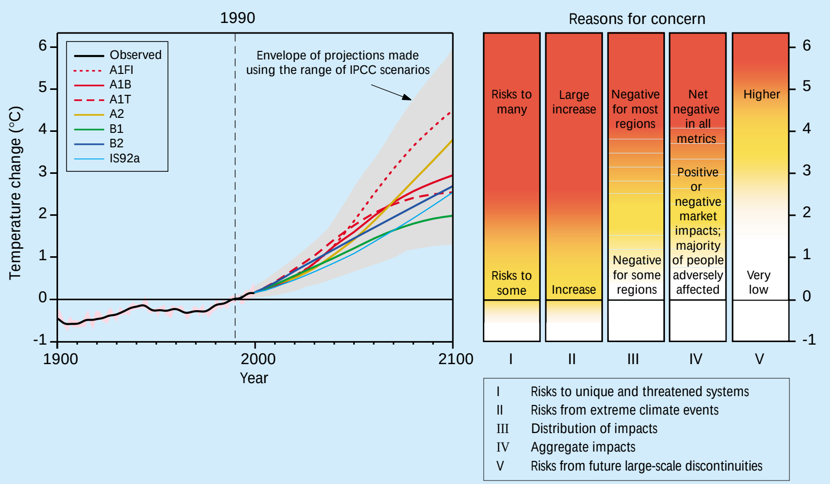
Studies of past and present reactions of our environment and society to climate changes, coupled with projections of climate models, provide us with numerous examples and tools that enable us to predict the future climate with some confidence.

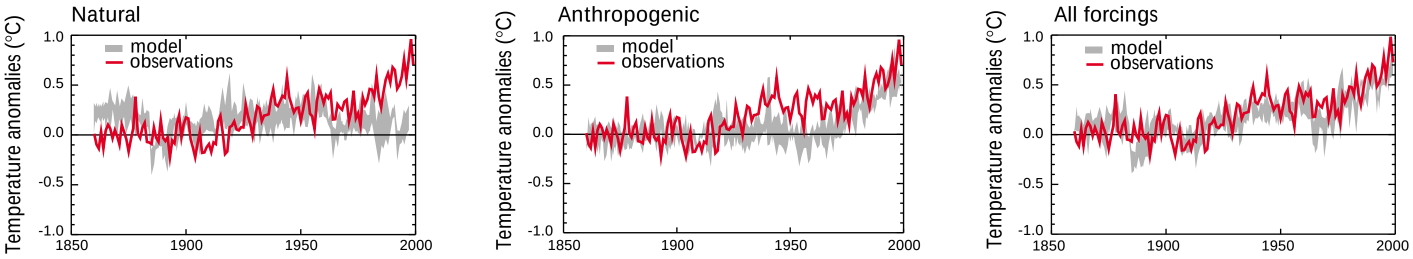
Comprehensive climate models are based on physical laws represented by mathematical equations. For climate simulation, the major components of the climate system (atmosphere, ocean, land surface, cryosphere and biosphere) are presented along with the processes that go on within and between them. Quantitative projections of future climate change require the models to simulate all the important processes governing the future evolution of climate. A great deal of effort has been expended by the climate modelling community to develop robust models that integrate all the components of the climate system.

However, in view of certain uncertainties, modellers will have to address more fully the dominant processes (such as ocean mixing) and feedbacks (e.g. from clouds and sea ice) in the atmosphere, biota, land and oceans (both on the surface and deep down). It is also important to understand the long-term natural variability patterns in the climate system and to expand the emerging capability of predicting patterns of organized variability, such as ENSO.

Understanding of climate processes and their representation has improved. Several climate models have been able to reproduce the observed warming trend in surface air temperature that has occurred during the 20th century. One model was able to predict global temperature variations between the time of the eruption of Mt Pinatubo in June 1991 to the end of 1994. Such agreement increases confidence in the ability of models to predict the future climate.

Outputs of climate models are often reconciled with observations, which increases the confidence in these models to project the climate of the 21st century.





Comparing simulations of the Earth's annual global mean surface temperatures with measurements can provide insight into the underlying causes of major changes; adding the calculated effects of human-induced and natural forcings mimics actual observations (IPCC, 2001)

Projections of the future climate

As CO_2 remains in the atmosphere for up to 200 years, stabilizing its emissions at near-current levels is not expected to lead to rapid stabilization of its concentration (or of its effects on the temperature). On the other hand, stabilization of emissions of shorter-lived greenhouse gases such as methane could lead, within decades, to stabilization of their atmospheric concentrations.

Surface air temperature is projected to continue to rise by a few tenths of a degree per century for a century or more because of the long life of some major greenhouse gases in the atmosphere. At the same time, sea level is projected to continue to rise for many centuries. The slow transport of heat into the oceans and slow response of ice sheets means that long periods are required to reach a new climate system equilibrium.

Some changes in the climate system, plausible beyond the 21st century, would be effectively irreversible. For example, major melting of the ice sheets and fundamental changes in the ocean circulation pattern could not be reversed over a period of many human generations.

Future climate change is determined by historic, current and future emissions. It is evident that the greater the reduction in emissions and the earlier they are introduced, the smaller and slower the projected warming and the rise in sea level.

Each successive IPCC assessment report has been more definite in its assertions that global warming and other associated changes during the last 35–50 years have been the result of human activities. The conclusions have been reached through the science of climate change, observing past and present climate, developing climate models based on the physical laws and observations, and comparing their outputs to observations and to results of other models starting with different forcing factors (such as greenhouse gas and aerosol concentrations and volcanic activity). The best agreement between model simulations and observations over the last 140 years

Reasons for concern

Shown are reasons for concern about projected climate change impacts. At far left are various scenarios (A1FI, A1B, etc.) of greenhouse gases and other human related emissions, along with the IS92a scenario used in the previous IPCC projections. The scenarios take into account varying economic and population growths and efficient technologies.

The risks of adverse impacts from climate change increase with the magnitude of climate change. The figure at far left displays the observed temperature increase relative to 1990 and the range of projected temperature increase after 1990 as estimated by IPCC for a range of emissions scenarios. The figure at left displays conceptualizations of five reasons for concern regarding climate change risks evolving through 2100. White indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems or low risks, and red means negative impacts or risks that are more widespread and/or greater in magnitude.

has been found when all anthropogenic and natural forcing factors are combined.

Model projections of the future climate and extreme events

Models have projected a variety of changes that can describe our future climate. Some are listed below and some of the major consequences are described in the next section.

- Global average surface temperature is projected to increase by 1.4 to 5.8°C by the end of the present century. This warming is much larger than changes observed during the 20th century and is very likely unprecedented during the last 10 000 years.
- Sea level is expected to rise 0.09 to 0.88 m from the 1990 level by the end of this century.
- Globally averaged water vapour, evaporation and precipitation are projected to continue to increase. At regional scales, increases and decreases in precipitation are projected in different regions.
- More hot days and heatwaves are very likely to occur over nearly all land areas. Increases in the heat index, which reflects a combination of temperature and humidity, are expected. Frost days and cold waves are very likely to become fewer.
- Precipitation extremes are projected to increase more than the average and so is the intensity of precipitation events.

There is little certainty concerning future changes in middle-latitude storm intensity, frequency and variability. Nor is there consistent evidence that shows changes in the frequency of tropical storms. However, there is some evidence concerning increases in their intensities.

Climate models are unable to simulate such small-scale storms as thunderstorms and tornadoes, so there is no projection on changes in these phenomena.

What is an El Niño event?

An El Niño event occurs when the sea surface temperature (SST) over a large area of the central and eastern equatorial Pacific becomes warmer than normal. At the same time, a number of concurrent changes occur in the normal pattern of winds blowing across the broader tropical regions of the Pacific. An El Niño event, however, is only one stage of a characteristic cycle of changes that occur in this region that also can be likened to a pendulum, in this case an irregular one.

There are three main stages of an El Niño cycle: the presence of an El Niño event; normal or intermediate conditions; and the presence of a La Niña event, which occurs when the pendulum has swung furthest away from El Niño conditions. These represent systematic patterns of change in both the atmosphere and ocean between the three stages. Perhaps the most important point is that the main centre of convective activity moves eastward or westward along the equator according to which stage is dominant at any time.

The changes observed in the atmosphere over many years were independently given the term Southern Oscillation since they were typically recorded by calculating the difference between the atmospheric pressures in Darwin, Australia and the Pacific island of Tahiti (both in the Southern Hemisphere). Around 20 years ago, when meteorologists and oceanographers gathered to examine and compare what was happening in their respective domains, they soon realized that what they had been observing independently was in fact an intimately connected set of processes. In a true spirit of cooperation, they then joined forces to study what has become known in scientific circles as the El Niño/Southern Oscillation phenomenon, or simply ENSO.

Warm episodes of the ENSO phenomenon have been more frequent, persistent and intense since the mid-1970s compared with the previous 100 years. However, there is some indication of decreases in some of the large-scale ocean and atmosphere circulation systems. Among possible effects is an expected increase in the variability of precipitation associated with the Asian monsoon. There is, however, disagreement among the climate models on the degree of change.

SOME CONSEQUENCES OF PROJECTED CLIMATE CHANGE

Coping with the projected changes in climate and some of the associated extreme events mentioned in the previous section will not be an easy task. It will necessitate considerable readjustments in infrastructure, habits, life style and, most important of all, in economic planning. The consequences are therefore far-ranging. In spite of many studies on climate change impacts, there still is substantial uncertainty about how effective adaptation will be (and could be) in reducing the negative impacts of climate change and taking advantage of its positive effects.

Food security

There are many social, economic and environmental factors that influence agricultural, horticultural and livestock productivity. Climate change represents an additional pressure on the world food supply system. The most probable effect of a significant increase in global temperature will be a general reduction in potential crop yield in most tropical and subtropical regions. In addition, if the average annual temperature rises by more than a few degrees there will be a general reduction, with some variation, in potential crop yields in most

Climate change adds pressure on the world food supply system; and may affect dryland ecosystems leading to permanent degradation of productive potential (Clockwise from near-right: WMO/B. Genier; USDA/Tim McCabe; FAO; WFP/W. Othman)

regions in middle latitudes. Models do show, however, that a modest temperature rise can increase potential crop yields in some middle-latitude regions.

Arid lands may be the first regions in which ecosystem dynamics are affected by global environmental changes, as the vegetation there is sensitive to small changes in climate. Even such small changes in climate may intensify the already high natural variability of dryland ecosystems and lead to permanent degradation of their productive potential. Over-exploitation by expanding human populations puts arid and semi-arid lands in an ever more precarious situation, which may lead to further dramatic ecological change.

There will be losses of habitats for some cold-water fish, but gain in habitat for warm-water fish. The higher range of increased temperatures might halve the Southern Ocean's krill, the tiny planktonic crustaceans that are the planet's most abundant animal. Krill, the keystone of the Antarctic ecosystem and food for seals, penguins, and whales, need ice for sanctuary and algae for food. The geographical extent of the damage or loss will increase with the magnitude and rate of climate change. Scientists predict a 15 per cent drop in total global marine phytoplankton production by the end of the century because of slowing ocean circulation resulting from global warming and change in atmospheric circulation.

Water resources management

Under our future climate it is predicted that precipitation will increase (typically by 5–10%) over high-latitude regions in both summer and winter. Increases are also projected over northern middle latitudes, tropical Africa and Antarctica in winter, and in southern and eastern Asia in summer. On the other hand, consistent decreases in winter rainfall are predicted for Australia, Central America and southern Africa. Larger year-to-year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected.

However, it is foreseen that even less water will be available for populations in many water-scarce regions, particularly in the subtropics. Mid-continental areas are likely to be even drier during summer periods, leading to an increase in droughts.

Human health

Our future climate will render us more vulnerable to threats from diseases and pests. Climate change will affect human health directly. The greatest effect of heat stress will be felt in the urban areas which will continue to grow and harbour increasingly higher percentages of the Earth's population. Urban areas are

With ever-larger numbers of people migrating to heavily-populated areas, urban heat islands, which affect human health and energy demand, will keep on growing and in turn continue to influence global land-temperature trends (Susan Blackmore/ DHD Photo Gallery)

Left: Some areas could become increasingly vulnerable to flooding as a result of the rise in the number of extreme rainfall events or the rise in sea level (Essa Ramadan/ Kuwait Meteorological Department)

Right: Many countries are facing the increased risk of widespread erosion of their beaches and coastlines, especially the small island states that depend on their natural resources for economic livelihood (Y. Boodhoo)

generally warmer than rural areas due to the heat-retaining properties of buildings and streets. The increase in temperatures will render urban dwellers, principally those in older age groups and the urban poor, more vulnerable to heatwaves. On the positive side, increased winter-time temperatures should result in reduced winter mortality in middle and high latitudes.

Climate change will also have far-ranging indirect effects, including changes in the ranges of disease vectors, such as mosquitoes, and water-borne pathogens; poorer water quality, air quality, food availability and quality (e.g. decreased protein content in some cereals); and probably through population displacement and economic disruption.

The actual impacts will be strongly influenced by local environmental conditions and socio-economic circumstances. For each anticipated adverse health impact there is a range of social, institutional, technological and behavioural adaptations that could lessen the impact. Adaptations could, for example, strengthen the public health infrastructure and the provision of appropriate medical care.

Impacts of sea-level rise

Projections of sea-level rise for the 21st century, mainly from the thermal expansion of the oceans, lie in the range of 0.09 to 0.88 m. The central value of predicted rise is about half a metre, which corresponds to an average rate of about two to four times the rate over the 20th century.

A rise in the higher end of the range would cause a widespread increase in the risk of flooding for many human settlements from both sea level and an increase in heavy precipitation. At sea levels approaching 88 cm above the present, many coastal infrastructures would be in danger, giving rise to other problems such as drinking water salinization. Large populations would have to be moved inland.

Many human settlements are already facing increased risk of coastal flooding and erosion, which could be exacerbated by sea-level rise and storm surges. Tens of millions of people living in deltas, low-lying coastal areas, and on small islands will face the risk of displacement and loss of infrastructure, despite substantial efforts and costs to protect vulnerable coastal areas. Resources critical to island and coastal populations such as freshwater, fisheries, coral reefs and atolls, beaches and wildlife habitat would also be at risk. The predicted future climate will place these populations, especially those on small islands, at particular risk of severe social and economic effects.

Some of the areas with populations at risk are southern Asia and southeast Asia, with lesser but significant increases in eastern Africa, western Africa, and the Mediterranean from Turkey to Algeria. Significant portions of many highly populated coastal cities are also vulnerable to more frequent coastal flooding, or even permanent land submergence if the sea level rises. The problems could well be exacerbated in some areas by more frequent or intense storms and associated surges.

Attempts to mitigate impacts of sea-level rise

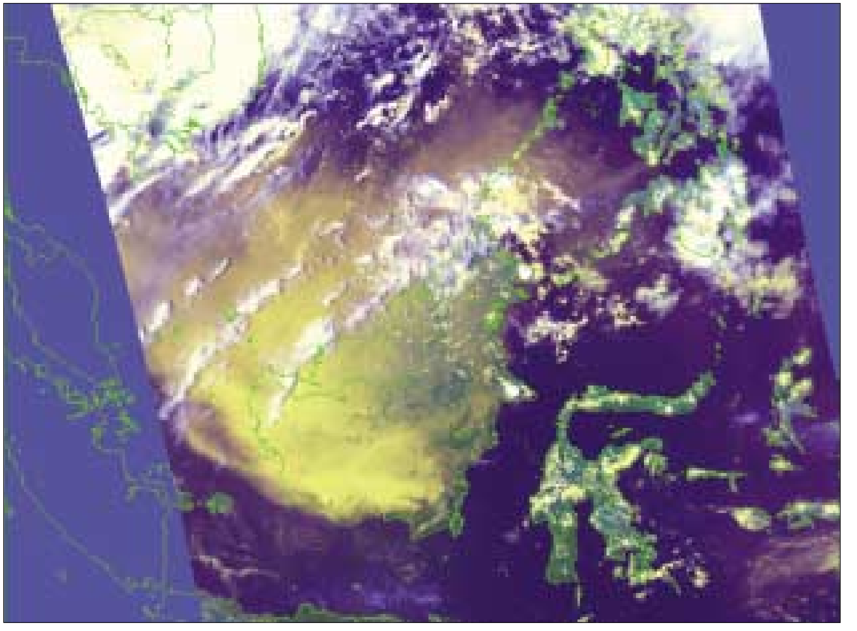
The fluctuations in extreme climate events in the last decade have caused concern in many nations. Thus countries, especially small island states, have started to implement tangible action to mitigate the erosive effect already taking place and which could worsen with climate change.

Air quality

Climate change is projected to exacerbate local and regional air pollution and delay the recovery of the stratospheric ozone layer. Local and regional air pollution, stratospheric ozone depletion, changes in ecological systems and land degradation would, in turn, affect the Earth's climate by changing the sources and sinks of greenhouse gases, radiative balance of the atmosphere and surface albedo.

Actions by some island states to mitigate impacts of sea-level rise

Maldives: Structures of steel and reinforced concrete are being placed as artificial coral reefs.
Mauritius: Gabions or pebbles are being laid along portions of the coasts.
Seychelles: Land reclamation plans have been revised to include the 88 cm sea-level rise predicted.
South Pacific: Resettlement of inundated islanders to safer islands is being considered.



The NOAA-14 Polar Orbiting Environmental Satellite (POES) image of huge fires on the island of Borneo on 22 September 1997 shows the extensive range of area affected beyond the island itself

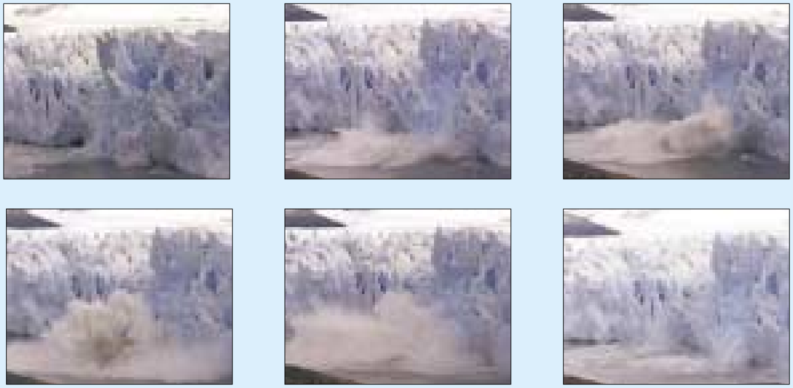
Ecology

Some natural systems such as glaciers, coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands and native grasslands, may undergo significant and irreversible changes. Significant disruptions of ecosystems from disturbances, such as fire, droughts, floods, pest infestation, invasion of species, storms and coral bleaching events are expected to increase. Land degradation and problems related to freshwater quantity and quality could occur at a faster rate.

Increases in the occurrence of heavy precipitation events will most likely lead to increased

Retreat of glaciers

In the last 100 years many glaciers have retreated extensively. This sequence shows the Argentinian Petito Moreno Glacier calving.



(Martin Clark/NSIDC, UCB)

flood, landslide, avalanche and mudslide damage.

The increased amount of carbon dioxide indicates a potential for an increase in global timber supply from appropriately managed forests.

The overall impact on wild plants and animals is not immediately evident. While some species may increase in abundance or range, climate change will increase existing risks of extinction of some more vulnerable species and lead to a consequent loss of biodiversity.

Glaciers and ice

There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. It is likely that Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15 per cent from the 1950s to the year 2000; that Arctic sea ice has thinned by about 40 per cent during late summer and early autumn in the last three decades of the 20th century; and that the annual duration of lake and river ice cover in the middle and high latitudes of the Northern Hemisphere has been reduced by about two weeks over the 20th century. While there is no change in overall Antarctic sea-ice extent from 1978 to 2000 in parallel with global mean surface temperature increase, regional warming in the Antarctic Peninsula coincided with the collapse of the Prince Gustav and parts of the Larsen ice shelves during the 1990s, but the loss of these ice shelves has had little direct impact on the sea level.

Glaciers and ice caps will continue their widespread retreat during the 21st century and Northern Hemisphere snow cover and sea ice are projected to decrease further. A possible alarming feature caused by extensive global warming is the melting of the polar ice packs.

The Antarctic ice sheet is likely to gain mass because of greater precipitation, while the Greenland ice sheet is likely to lose mass. However, beyond the 21st century, if the globe continues to warm, it is quite possible that large sections of the West Antarctic ice sheet may be vulnerable.

WMO'S ACTIONS: PRESENT AND FUTURE

Over the years, WMO has taken a lead role in the monitoring of the climate system and in the prediction of its future state.

Reducing uncertainties

Developing scenarios for future climates and the wide range of impacts these climates may cause is extremely complex. Much work is being done to reduce uncertainties concerning the description of past climates, the monitoring and description of our present climate, the modelling of future climates and the assessment of human influence on climate change. Attention is also being paid to the assessment of the spectrum of possible impacts from global climate change, both globally and on specific regional or local bases, and to the continuing refinement of adaptation strategies to mitigate the predicted impacts.

WMO continues to work in all these crucial areas through an ever-expanding framework of cooperation among National Meteorological and Hydrological Services (NMHSs). However, the challenge imposed by global climate change will put increasing pressure on resources available for environmental work. Some of the future tasks that need to be accomplished are described below.

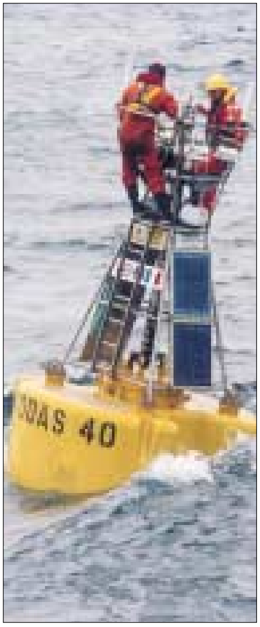
Improved observations and analysis of weather and climate

Advances in observing the environment from satellites have not entirely compensated for a degradation of observational networks in many parts of the world. These networks need significant improvement, to provide essential climate monitoring in many areas of the globe.

Climate and environmental change investigations and projections as well as climate change detection depend on accurate, long-term data with expanded temporal and spatial coverage. Data from the present and recent past, climate-relevant data for the last few centuries and for the last several millennia are all needed. There is a need for more data from polar regions and for better quantitative assessments of extremes on a global scale.

Major landmarks in the study of the climate

1929	Commission for Climatology created
1950	The Commission for Climatology re-established
1957/58	International Geophysical Year
1969-74	Sahel Drought
1975	Ozone Alert
1976	Climate Change Alert
1978/79	First Global GARP (Global Atmospheric Research Programme) Experiment
1979	First World Climate Conference, which led to the establishment of the World Climate Programme
1985	Vienna Convention on the Protection of the Ozone Layer
1985	The Vienna Conference on Greenhouse Gases
1988	Creation of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC)
1990	Second World Climate Conference, which initiated GCOS
1992	United Nations Conference on Environment and Development
1994	United Nations Framework Convention on Climate Change
1996	United Nations Convention to Combat Desertification
1997	Kyoto Protocol adopted
2001	IPCC Third Assessment Report
2002	World Summit on Sustainable Development



Data collected from oceanographic measurements and meteorological and hydrological observations form part of the long-term data needed for climate and environmental change investigations and projections, as well as climate change detection; WMO facilitates international cooperation of NMHSs in the establishment of networks of stations for making these and other observations
(From left: Météo-France; WMO; BOM, Australia)

WMO has responded by initiating, over the past decade, the Global Climate Observing System (GCOS) which is built on the existing WMO observing systems, primarily the World Weather Watch (WWW), Global Atmosphere Watch (GAW) and hydrological observing systems. It addresses the total climate system including physical, chemical and biological properties and coordinates with the WMO World Climate Programme (WCP), particularly the World Climate Data and Monitoring Programme. The role of satellites, both polar and geostationary, will continue to increase through the greater use of vertical profilers of the atmosphere, higher resolution instruments and the development of climate-related products.

WMO is participating with the Intergovernmental Oceanographic Commission (IOC of UNESCO) in the ARGO Programme under which a global array of 3 000 ocean buoys to sample the temperature and salinity of the upper layers of the oceans will be launched by 2005. This is one component of an integrated *in situ* ocean observing system. Interaction and cooperation among NMHSs and regional data processing centres will increase to allow for improved exchange of data and the expanded usage of sophisticated climate-related products.

WMO established the Atmospheric Research and Environment Programme (AREP), and particularly GAW, which has matured considerably during the last few years. Presently GAW consists of many coordinated components that have been designed to provide accessible, high quality atmospheric data, such as chlorofluorocarbon (CFC), ozone and greenhouse gas concentrations, to the scientific community. These components include measurement stations, calibration and data quality centres, data centres and external scientific groups for programme guidance.

In future GAW will improve:

- Its measurements programme for better geographical and temporal coverage;
- Its capacity for near-real-time monitoring, improve quality assurance systems and the availability of data;
- Communication and cooperation between all GAW components, NMHSs and the scientific community.

At present, through the World Climate Research Programme (WCRP), a number of activities are under way to better understand environmental processes and increase prediction capability. The Climate Variability and Predictability (CLIVAR) project, following on the Tropical Ocean and Global Atmosphere (TOGA) project, is collecting data and modelling both ocean conditions and the interaction between the oceans and the atmosphere with a view to further improving our understanding of the oceans' role in climate and climate prediction. The project benefits from the recently concluded World Ocean Circulation Experiment (WOCE). CLIVAR is the main focus in WCRP for studies of climate variability, extending effective predictions of climate variation and refining the estimates of anthropogenic climate change. CLIVAR is attempting particularly to exploit the "memory" in the slowly changing oceans and to develop understanding of the coupled behaviour of the rapidly changing atmosphere and slowly varying land surface, oceans and ice masses as they respond to natural processes, human influences and changes in the Earth's chemistry and biota.

To help in the understanding of polar conditions and processes, WMO has initiated the Arctic Climate System Study (ACSYS), concentrating on the understanding of Arctic ocean variability and change including sea-ice processes. This will be expanded into the Climate and Cryosphere (CLiC) initiative investigating the role of the entire cryosphere for global climate and as an early indicator of change.

WMO is supporting the National Hydrological Services (NHSs), river basin authorities and other institutions responsible for water management in a wide range of activities through its Hydrology and Water Resources Programme (HWRP). The Programme facilitates the collection and analysis of hydrological data as a basis for assessing and managing freshwater resources. This includes water for human consumption, sanitation, irrigation, hydropower production and water transport. Support for the development and application of flood forecasting systems and prediction of droughts provides an important contribution to reduce water-related disasters. The data can also be used in climate change assessments.

The World Hydrological Cycle Observation System (WHYCOS) is a component of HWRP

As well as facilitating the analysis of climate change data, computers are used for extensive climate modelling that can provide a much clearer picture of long-term changes, and also allow the dissemination of information from major centres to local centres and those who need to use climate data for making effective management and other decisions
(P. Mosley)

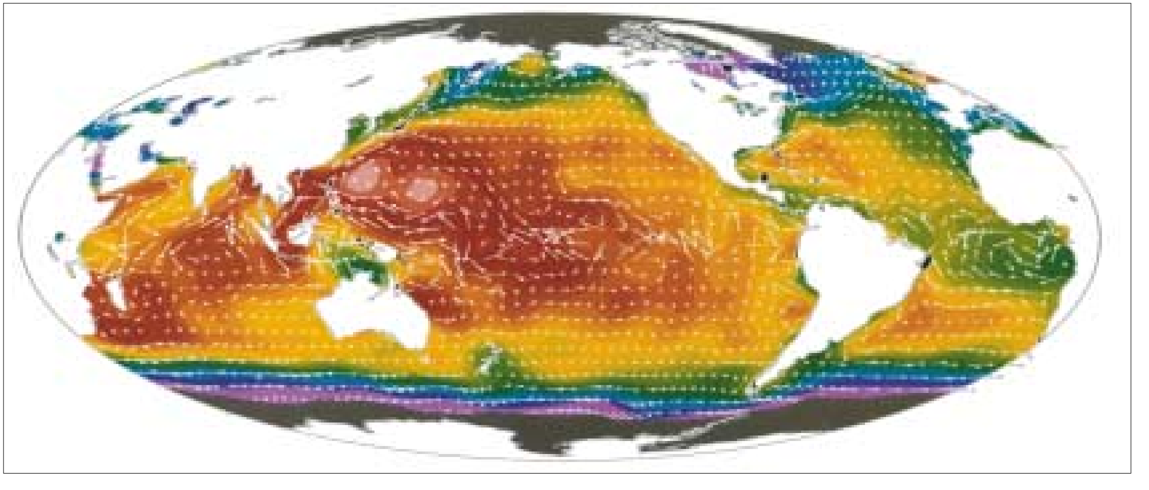
and is structured to supply reliable water-related data to resource planners, decision makers, scientists and the general public. Regional (HYCOS) components of WHYCOS are presently being developed and implemented in the Mediterranean Basin, Southern Africa, Western and Central Africa, Asia and the Caribbean. Linkage between water and climate issues is provided by the World Climate Programme–Water (WCP–Water) within HWRP in collaboration with UNESCO. HWRP also cooperates actively with other United Nations organizations in the field of water as well as international non-governmental organizations such as the Global Water Partnership.

As part of its capacity-building activities, which includes guidance in the organization and management of Hydrological Services, HWRP provides for the exchange of know-how and technology through its Hydrological Operational Multi-purpose System (HOMS).

The WCP Climate Information and Prediction Services (CLIPS) system is designed to assist countries in using past climate data to aid in the development of various economic sectors such as agriculture and water resources and to make use of seasonal forecasts in water management, agriculture, disaster mitigation and other sectors. With projected advent of climate change, these activities will become even more valuable to WMO Members.

Renewable energy

The Kyoto Protocol has recommended reductions in greenhouse gas emissions to below the 1990 level. This implies greater efficiency in the use of fossil fuel for energy generation. However, a nominal reduction is difficult to attain with the development of nations and the need to attend to the aspirations of their peoples for a better living standard coupled with a wider range of amenities. Therefore, any drastic reduction in the use of fossil fuel will slow down economic progress and have an impact on the development of societies. It is therefore imperative that alternative energy forms be developed. This strategy will also help nations meet the goals of the United Nations Framework Convention on Climate Change.



Satellite observations of the elevation of the world's oceans can be analysed to provide a measure of surface currents; colour is used to show ocean topography and arrows show the speed and direction of ocean currents; this map shows how currents move clockwise around higher regions in the ocean in the Northern Hemisphere

Renewable energy from sun, wind and water is clean, free and abundant and will last as long as the sun will shine. The United Nations World Summit on Sustainable Development, held in Johannesburg, South Africa in 2002, formulated proposals to encourage the use of renewable energy. The Global Environment Facility has committed funds for projects aimed at creating sustainable markets for solar energy systems in Africa, Asia and South America. It aims to provide energy to one billion of the world's poor by 2015.

The United Nations World Energy Assessment asserts that solar thermal power plants covering just one per cent of the world's deserts could meet the entire planet's current energy demands. Wind energy technology is developing at a fast rate and its developers are gaining considerable confidence. It is estimated that the entire present energy needs of the whole of Africa corresponds to the potential in hydro-power of the Zambesi River only.

Societal benefits

Models of climate and biogeochemical systems need to be linked more precisely with models of the human system to provide the basis for expanded exploration of possible cause-effect patterns linking human and non-human components of the Earth system.

In this aspect, WMO has always been keenly interested in the effects of weather and climate on the human condition. Agenda 21 of the 1992 United Nations Conference on Environment and Development (UNCED) included the guaranteed quality of global commons — oceans and atmosphere — and the guaranteed provision of adequate food security, through the sustainable management of agriculture, forestry, fisheries and land use. Clearly, all these aspects depend fundamentally on climate and weather services. Moreover, work has been accomplished through WMO Programmes to improve meteorological and hydrological early warning systems to reduce the loss of life and property to severe weather, flood and drought. These will be expanded during the 21st century and the International Strategy for Disaster Reduction will be associated in this effort.

Alternative energy forms, such as solar energy systems, should be further encouraged, developed and utilized to assist in the mitigation of climate change impacts (Y. Boodhoo)

Steps for adaptation strategy

Step 1: Establishment of a National Climate Committee (NCC), wherever this has not been done, to supervise and coordinate the development of a climate plan.
Step 2: Formulation of a national climate-oriented policy.
Step 3: Inventory of natural, biological and human resources, and determination of financial and legal constraints.
Step 4: Implementation of the climate plan.
Step 5: Development of multi-level educational and training programmes.

International framework

To assist in understanding climate change, there must be a strengthening of the international framework in the coordination of national and institutional efforts so that research, computational and observational resources may be used to the greatest overall advantage.

WMO has worked for years with other bodies such as the International Council for Science (ICSU), UNESCO and its IOC. The findings of IPCC assessment reports is one example of the fruits of this coordination. In 1999, WMO issued the Geneva Declaration, which calls upon WMO Members to support NMHSs in their mission of understanding weather and climate and in providing necessary services. WMO will continue to work closely with the other agencies in the international system to provide an increasingly effective infrastructure that will allow for a synthesis of the climate-related activities which are undertaken in different countries.

National responsibilities

Set against a background of tightening legislation on emissions and widening political support for international trading schemes, it has become imperative for business strategies to get educated and get involved.

Public awareness and education material needs to be developed, distributed and incorporated into an education campaign. This needs to be developed concurrently with the NMHSs, and relevant national institutions and authorities.

State initiatives are vital. Governments could proceed to formulate mitigation plans with respect to climate change related impacts. The essential elements to consider in the formulation of these plans may be presented in a multi-step process.

Public awareness and technical development

Climate affects us all. Every country needs qualified communicators to diffuse information to the general public. As well as its vital role in disseminating appropriate technology, WMO takes the lead in training meteorologists and media personnel in the art of communicating climate and weather information.

Météo-France

CONCLUSIONS

Greater emphasis on assessing regional impacts of climate change and appropriate mitigation and adaptation strategies need to be given. This task will be undertaken by the IPCC for the Fourth Assessment Report that is planned for completion in 2007.

The struggle to redress the climate has to be tackled on several grounds and in such a way as to ensure stability among all the climate systems. Industries will have to be more efficient and adopt cleaner methods of production. Fossil fuel will need to be supplemented in a greater proportion by renewable energy forms. Our land must be better managed. For carbon sequestration, reafforestation and other policies must be adopted. Effluents from industries need to be eliminated and oceans kept clean. Our huge fleet of vehicles needs redesigning to run on other forms of fuel

Most importantly, however, we must change our attitudes and agree to live in a way that will ensure the well-being of all nations while ensuring the protection of climate, all for the sake of our future climate.

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