

SUMMARY: Warning Signals from Climate

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Everyone knows that the atmosphere, with its sometimes dramatic weather, is one of the most decisive factors affecting humankind. The present atmosphere has developed over hundreds of million of years, and one of the most important events was the increase in oxygen concentration due to photosynthesis by primitive cells. This gas was a prerequisite for the development of life at the Earth's surface because it allowed the formation of the stratospheric ozone layer (see Fig. 5.1), which has an essential role as a filter for the harmful short-wavelength parts of ultraviolet radiation from the sun.

The familiar term »weather« taken in its strictest sense means the current status of the atmosphere. It is also the collective name for all atmospheric processes occurring within a time frame up to a few weeks, and which in principle are predictable in a weather forecast based on a precise measurement of the initial state. Processes of longer time scales are known as »climate«. We currently define the term climate as the synthesis of weather over a time period long enough to allow the estimation of certain statistical characteristics, such as the mean value, the standard deviation and the probability for extreme values. These statistics can be estimated for all properties which determine the state of the atmosphere. It is essential that under no circumstances should the term climate be restricted only to the mean value.

Our changing climate

The climate system of the Earth consists of five components: the atmosphere, the hydrosphere (oceans, lakes, rivers), the cryosphere (ice and snow), the lithosphere (soils and the Earth's crust), and the biosphere. These components react with each other and react to external influences on largely different timescales (see Chart 1). The key factor that controls the climate system is the input of solar radiation. The uneven distribution of the sources and sinks of heat (with warming in the tropics, and cooling in the polar zones) gives rise to the global circulation patterns observable in the atmosphere and in the oceans, and also causes the formation of different climate zones.

The mean surface air temperature of about 15 °C is due to the natural greenhouse effect caused by water vapour and carbon dioxide as well as some more trace gases in the atmosphere. These gases strongly absorb thermal radiation leaving the Earth's surface (see Chart 2). Without the greenhouse effect, the mean temperature of the Earth would be around 30 °C lower than observed.

At the core of the present-day climate problem is the fact that during the past 100 years mankind has been

emitting increasing quantities of carbon dioxide, methane and other greenhouse gases, thus enhancing the greenhouse effect. This alone, along with feedbacks within the climate system, will lead to a mean global temperature above the present one, and consequently to a regionally very different sort of climate.

The ocean is of great importance within the climate system. The great heat capacity of sea water and the physics of its heat balance dampen the yearly course of temperature, and lead to maritime climate zones. The ocean and the general circulation of the atmosphere contribute in equal measure to the meridional exchange of heat between the higher and lower latitudes. When warmer water arrives in the cold areas of higher latitudes, transfer of heat to the atmosphere cools the water (this is how the climatic effects of the Gulf Stream originate). The cooled water, if denser, sinks to deeper layers. The further polewards this convection reaches, the stronger is the cooling and the larger is the amount of sea ice formed. In this way, deep water is continuously formed, creating a global abyssal circulation. A gigantic oceanic water cycle is set in motion, in the form of an »oceanic conveyor belt«, whose circulation time is up to approx. 1,000 years. Disturbances of the forcing of this cycle, especially in the North Atlantic Ocean, and depending on their intensity and duration, can cause long-lasting climatic variations for large areas. The ocean has not only an important thermal effect on the climate, but has also a key role in the extensive biogeochemical cycles of the planet, especially that of carbon.

Causes of Climate Change

A realistic prediction of future changes in climate is hardly feasible without knowledge of the history of climate. The characteristics of past climates are stored in places such as terrestrial and marine sediments, the large ice-sheets of Antarctica and Greenland, as well as in biological records such as pollen, tree rings, coral reefs, and ancient natural boundaries. Additionally, human reports have recorded the climate of recent times. The quaternary ice age of the last 1.5 million years is particularly well documented, with sediment and ice records showing a sequence of warm and cold periods. These distinctive climatic shifts are mainly controlled by long-term variations in the orbit of the Earth around the Sun, which alter the distribution of solar radiation on Earth. A further cause of long-term and short-term climatic changes is alteration in the intensity of the solar radiation itself. The most well known expression of the changing solar activity is the number of sunspots, which

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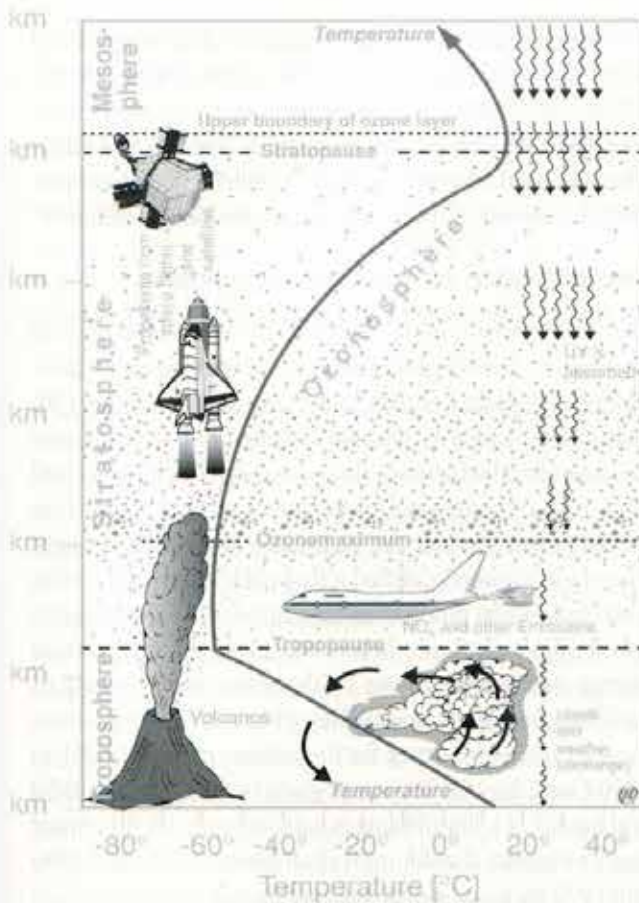


Fig. 5-1: Vertical layers of the atmosphere.

have been observed by astronomers for many centuries. Since the middle of the 19th century the climate has been in a phase of warming, but this was preceded by the so-called »Little Ice Age« which began in the 13th/14th century. Low numbers of sunspots predominantly characterised this period.

Strong volcanic eruptions such as that of Mt. Pinatubo in 1991 can influence today, just as in former times, the regional and global climate for periods of at least several years. The cause for this is the build-up of an aerosol layer consisting essentially of sulphuric acid droplets in the stratosphere, which develop from the sulphur dioxide in the fumes of the volcano. This sulphuric acid droplet layer alters the radiation balance of the atmosphere in such a way that on average a warming occurs in the area of the aerosol layer, but a cooling occurs at the Earth's surface.

A short-term and irregular climatic variation is the El Niño-phenomenon, which occurs on average about every four years, and is caused above all by internal interactions in the climate system. During the one-to-two year lifetime of an El Niño event, large-scale warming of the tropical eastern Pacific Ocean occurs. This causes circulation anomalies in the atmosphere, and a number of distinct climatic anomalies in many tropical, but also temperate regions.

Influence of climate on the history of Humankind

The first recognisable signs of human settled society are dated to about 12,000 years before present (BP). At that time, the last ice age (the Weichselian Ice Age in Europe) had ended, and humankind began to describe its own surroundings and history using cave paintings. Since large water masses during the ice age were trapped in the form of ice, whose rests partly still exist today in the polar regions, the mean sea level lay about 120 m deeper than at present. Land bridges were present for example between Siberia and Alaska and between Central Europe and England, which facilitated an exchange of both people and wildlife.

The sea level has been rising since the beginning of the Holocene warm period and coastlines have receded world-wide. The warming continued up until 6,500–5,000 BP (see Chart 4), and during the Atlanticum (between 9,200 and 6,200/5,700 BP) the air temperature was probably higher than today. The Earth was then only thinly populated. By migration, areas with unfavourable climate could be avoided. During this time the area of rainfall also occurred in the Sahara, which is today the largest desert in the world, and the amount of rain was sufficient for the formation of a savannah-type habitat. As testified by rock paintings from this time, elephants, rhinos, hippopotami and other tropical species were found in abundance. The Atlanticum was followed by another phase of slight cooling and glacial expansion. So, the Holocene period is generally characterised by a sequence of moderately warmer and colder climates. Around the year 870, the retreat of sea ice enabled the Vikings first to reach Iceland, then Greenland, and later America too. As the ice in the 15th century again advanced, the Vikings did not adapt to the colder climate, in contrast to the Inuit in Greenland.

During the warm phase in the Medieval Age, the mean air temperatures were similar to those found at present. Important technical progress was made during this time of expanding agriculture and rapidly increasing populations. Wine was grown in the south of England, and in Norway the cultivation of grain was possible as far north as Trondheim. In the subsequent »Little Ice Age«, which lasted up to the middle of the 19th century, the climate of central and northern Europe was characterised by the frequent occurrence of cold winters and wet summers, which triggered or at least favoured economic decline, migrations and wars. The economic development and the increase of world population in the industrial age are not only founded on technical progress but also on the predominantly favourable climatic conditions in the middle latitudes.

Consequences and intensification of the El Niño- and La Niña-phenomena

Natural climatic variations occur in numerous forms and patterns. There are many far-reaching changes that last for millennia, as well as shorter perturbations, which last only a few years. Spatially, either the whole Earth or only certain regions may be affected by such changes. Among the short-lived phenomena are the El Niño events, which denote the irregularly occurring, but persistent (lasting ~1–2 years) large scale warming of the equatorial eastern Pacific Ocean. In normal years, cool upwelling water is found off the west coast of the equatorial South America. An anomalous cooling of the coastal waters sometimes follows an El Niño-event; this is the situation known as La Niña. Continuous temperature measurements in the equatorial Pacific Ocean are presented in *Fig. 1* (page 12). From this, it seems that the successive positive and negative anomalies (deviations from the mean value of the reference period) are becoming stronger and more frequent. But only time will tell whether this is a real trend, connected to anthropogenic climate change.

The natural atmospheric phenomenon connected with El Niño and La Niña is part of a global, and in particular tropical and subtropical, cycle in the atmosphere and oceans. This cycle arises presumably within the climate system itself, but, as mentioned above, there may also be external influences that force it. The subtropical anticyclone in the south-eastern tropical Pacific Ocean and the Indonesian equatorial low vary in strength depending on the temperature differences between these zones. The air pressure differences between the south-eastern tropical Pacific (Tahiti) and the easternmost Indian Ocean (Darwin in Australia) is called the Southern Oscillation, and the combined effect is known as ENSO (El Niño/Southern Oscillation). The result in the atmosphere is a large change in the prevailing wind systems and altered weather conditions over extensive areas, depending on whether cooler or warmer, wetter or drier air masses prevail. Therefore it is no surprise that during ENSO, wide parts of the world experience persistent weather anomalies, which often lead also to extreme events such as heat waves and cold spells, droughts or floods.

Climatologists have succeeded in the past few years to forecast elements of the ENSO-cycle up to one year in advance. The El Niño 1997/98 was predicted, and the affected countries were warned of the consequences to be expected. However, an important question to be answered is, how will ENSO be affected by anthropogenic climate change? First model results indicate that with generally rising sea surface temperatures, ENSOs will in future occur more frequently. The typical consequences of El Niño, including extreme weather events, would follow more often as well.

We have to find out the extent to which natural and anthropogenic changes in the climate system are connected. And we must note that not all weather extremes and not all anomalies of weather result from ENSO. There are also other interactions, which can cause comparably strong variability in the meteorological conditions.

The influence of man on the climate

Due to the world-wide observations of meteorological parameters, we are quite reliably able to review the development of global climate since the middle of the 19th century (see *Chart 3*). Despite a background which shows considerable fluctuations, this period can be characterized by a trend of increasing mean annual global near-surface air temperatures since the beginning of the 20th century. The warming trend reached a first peak during the 1940s. Then followed a phase of relatively constant temperature, and a slight decrease, before the mean air temperature started rising again in the 1970s. Since the beginning of the 1980s, the values recorded have been increasingly above the average temperature for the reference period 1961 to 1990 (see *Chart 3*). The mean global warming since 1850 is about 0.7 °C. This finding is valid not only for the annual mean value but also for individual months. Between 1990 and 1999 the mean global near-surface air temperature was lower in only 15 months (or 12.5% of all values) than the 1961–1990 reference values, and in most cases the negative deviations were only small. To date, the warmest year since the beginning of observations was 1998 (approx. 0.6 °C higher than the reference value). The curve presented in *Chart 3* should not mislead to the conclusion, that the temperature change is spatially homogeneous. Only the trends for the northern and southern hemisphere are similar and of equal magnitude. The strongest warming has been observed over the continents in the latitude zone between 40° and 70° N (between Central Spain and Northern Norway), in winter and spring. There is a tendency for the temperature increase to be higher in the winter than in the summer. Areas with a decreasing trend in temperatures were found in the north-west Atlantic Ocean and in the middle latitudes of the North Pacific Ocean. However, a warming of the whole troposphere (*Fig. 5-1*) has been shown by analysis of temperature profiles throughout the atmosphere. These more precise measurements, with good spatial coverage, first began at the end of the 1950s. Measurements in the lower stratosphere verify a cooling trend, a finding which is compatible with the assumption of a strengthening of the greenhouse effect as well as of a decrease in the concentration of stratospheric ozone.

It has been shown by various methods that the increase of the global mean near-surface air temperature can not be attributed to natural causes alone, but is at least in parts due to the anthropogenic changes in the composition of the

atmosphere. Further causes of the observed warming trend are an increased solar variation, and internal climatic effects such as El Niño. In the last decades, however, these contributions to the observed temperature change are rather low compared with the anthropogenic influence. Thus, the Intergovernmental Panel on Climate Change stated in its Second Assessment Report (IPCC 1996) when interpreting the observed development, that more arguments exist for than against an anthropogenic influence on contemporary climate.

The anthropogenic greenhouse effect

The globally averaged radiation fluxes at the Earth's surface and at the top of the atmosphere as part of the global energy budget are shown schematically in *Chart 2*. Particularly striking are the high values for the fluxes of thermal radiation at the Earth's surface. The thermal radiation flux (counter-radiation of the atmosphere) which arises from the absorption of greenhouse gases and is directed towards the Earth's surface, has far-reaching consequences for climate. The amount of heat energy which is directly lost into space from the surface is the small difference between the two thermal radiation fluxes. To obtain a balance between the average absorption of solar radiation by the Earth and the average emission of thermal radiation, the surface (as well as the lower atmosphere) must become warmer. The natural greenhouse effect is responsible for a warming of approx. 33 °C. The contribution of the individual gases to this total are: water vapour with about 20,6 °C, carbon dioxide (CO₂) with 7,2 °C, ozone (O₃) with 2,4 °C, dinitrogen oxide (laughing gas, N₂O) with 1,4 °C, methane (CH₄) with 0,8 °C and the remaining greenhouse gases with 0,6 °C. All these gases together represent only 3 thousandth of the mass of the atmosphere, but they are nevertheless highly effective for our climate. The concentration of all these gases, with the exception of stratospheric ozone, has increased drastically since the beginning of industrialization about 130 years ago (CO₂: 280 to 370 ppm; CH₄: 0,7 to 1,75 ppm; N₂O: 0,275 to 0,312 ppm). The mean partial volume of atmospheric carbon dioxide alone has shown an increase of 31,4% (*Fig. 5-2*). The primary cause of this increase is the use of fossil fuels, from which about 22 Gt (Gigatons) CO₂ per year are emitted. The consumption of fossil fuels is still increasing at an annual rate of approximately 1% despite of efforts for climate protection and collapse of industry in the former East Block. New greenhouse gases like chlorofluorocarbon (CFC) have also been added in the course of technical development (see *Table 2.2-1*). *Chart 7* shows the primary sources of greenhouse gases.

Main sources of greenhouse gas emissions

The primary cause for the observed increases in greenhouse gas concentrations is the use of fossil fuels, which are

responsible for 50% (see *Chart 7*). A further 20% of the entire world-wide output comes from chemical industry. Of great importance are the new greenhouse gases such as the chlorofluorocarbons (CFC). A new high effective anthropogenic CFC-gas (trifluormethyl-sulphurpentafluoride, SF₅CF₃) have been discovered.

A further important source is the intensive agriculture which accounts for 15% of the emissions. The destruction of forests adds a further 15% to the total emissions (see *Table 2.8-3*). Forest clearance has been in progress since the introduction of extensive agriculture and cattle-breeding, and was also necessary to create areas for settlements and to obtain wood as a building material. Previously, about a third of the land surface of the Earth, about 46 million km², may have been forested. Today there are still about 36 million km² with intact or partly-intact forests. While on the one side the forests are dependent on climate, they influence on the other side the climate, e.g. as storage for carbon.

Deforestation results not only in the loss of trees, but may also cause the entire remaining vegetation to partially break down. Moist areas are drained and the organic matter (e.g. humus) bound in the soil decomposes more easily. All these processes release CO₂ and CH₄. Since 1850 there has been a world-wide release of some 20% (117 Gigatons C) of carbon which was locked up in vegetation. Simultaneously, valuable CO₂-sinks such as wetlands have been lost. Agriculture and intense cattle breeding are also important sources of CO₂, CH₄ and N₂O. Methane is formed by microbial action not only in the soils, moist areas and shallow waters, but also in the rumen of ruminant animals. Methane is also released during the storage of animal excrements. Since food production will increase, owing to the growing world population, the further increase of emissions from agriculture is almost unavoidable.

Cattle breeding has quadrupled in the last century and the number of sheep has doubled. The number of animals in agriculture is estimate to double again up to the year 2100. For the same reasons as for wet areas and shallow waters, the cultivation of rice contributes considerably to the release of methane too. In the last 40 years the area of rice fields has increased by only about 17%, but the yield of rice has increased by around 41% owing to technical improvements. Nitrous oxide also emerges as a by-product of microbial transformation of inorganic nitrogen compounds in waters and above all in soils. N₂O is also formed during combustion of organic material (as with slash-and-burn agriculture and savannah fires). A fraction of the gas is transported into the atmosphere, where it remains on average for about 120 years. Although there are still many unsolved questions in connection with the formation of N₂O from the different nitrogen compounds, a proportional dependence has been recognised between the

N_2O -rise and increased use of fertilizers. World-wide intensification of agriculture will therefore cause a further increase of N_2O in the atmosphere. The changed energy fluxes at the surface of the Earth which are caused by alterations of land use like clearing, irrigation, and urban building have hardly been mentioned in the current debate on the anthropogenic climatic variations. This man-made influence on the climate has been present for thousands of years, but it is however even more difficult to determine than the influence of the trace gases, because the fluxes of radiation and heat may be either increased or decreased depending on the type of human activity. Examples for this are the clearing of forests and the irrigation of arid zones. A sufficiently spatially-resolved climate model, taking into account changed land surface characteristics, is still under development.

In the course of technical development new substances have been produced by the chemical industry, some of which also accumulate in the atmosphere as trace gases. Many of these have a very strong greenhouse potential and destroy at the same time the stratospheric ozone layer. The production of some of these substances has been forbidden world-wide as the result of an international conference in Montreal 1987 (and of following conferences). But, as shown in *Table 2.2-1*, these substances have a very long life-time and a residence time in the atmosphere of many decades. Thus, the ozone layer will remain depleted for several decades despite the ban on the gases responsible. The agreement of Montreal shows that a protection of our environment is possible, if politicians are sufficiently moved by public opinion.

Up to now, about three quarters of the emissions have come from the industrialized countries, in which only 25% of the world population live (*Chart 6*). The share of the developing countries will however increase in the next decades with the acceleration of economic growth.

The climate of the 21st century: changes and consequences

To predict the climate of the future is one of the greatest challenges for science. Global climate models have been developed to do this. They are able to realistically simulate the essential components of the climatic system. Because computer capacity is limited, the relatively low horizontal and vertical resolution of such models and the necessary simplification of mathematical descriptions of complicated atmospheric and oceanic processes produce unavoidable errors and inaccuracies. To provide a climate forecast, it is necessary to estimate parameters for extreme influence during the period of time covered by the prediction. Such estimates are based on assumptions of future emissions of greenhouse gases into the atmosphere, which will depend upon changes in the world economy and the success or

failure of policies designed to protect the climate. It is plausible that even an ideal model might not provide a correct prediction if the assumptions made are not correct. Numerous changes predicted by climate models have already occurred, such as the mean warming, the shift in the precipitation zones, the rise of the sea level and the shrinking of the glaciers. For example, the glaciers on the Alps have been reduced by more than half since 1850, and the sea level is rising annually about 2 mm. The observed and modelled findings, which are regularly evaluated by scientists in the IPCC, are the basis for international climate policies. According to the Framework Convention on Climate Change (FCCC), accepted by the world summit in Rio in 1992, climate policies have the goal to stabilise the concentration of greenhouse gases at a level that will not cause dangerous interference with the climatic system. This goal must be reached fast enough to allow the ecosystems to adapt to climatic change naturally, to prevent threats to the production of food, and to permit economic development in a sustainable manner. The successes of climate policies have thus far been very modest. The resolutions of the Kyoto conference, constituting the first binding agreements set forth in December 1997, must still be ratified. What consequences for the climate should be expected for an increase in global mean air temperature by 1.5 to 4.5 °C (*Fig. 3.3-1*)? This temperature range indicates the degree of uncertainty concerning the change to be expected due to a doubling of carbon dioxide content of the atmosphere.

Global temperature change

Fig. 3.3-1 shows the possible alteration in the mean global temperature if the output of greenhouse gases continues at its present rate. In addition, sulphate aerosols have been included in the projections. They have a direct effect by causing back-scattering of solar radiation and an indirect effect by increasing the number of droplets in clouds, which also increases back-scattering. If anthropogenic activities increase the greenhouse effect still more, warming will continue. The 20th century has been the warmest for at least 1,000 years, and no century has seen such a rapid change. In the 21st century, this trend will probably be accelerated, so humankind will live in the warmest climate ever experienced. The consequences for nature and society are diverse and still not fully perceived.

Regional temperature changes

Warming was not equal in all places. In some regions, such as north-western Canada, Siberia, and the Alps, the temperature increase has been much greater than the global average. In the Alps (Switzerland), it has reached a mean of almost 1°C (see *Fig. 3.16-1*), and at individual sites, it has been nearly 2 °C. Investigations in Austria and

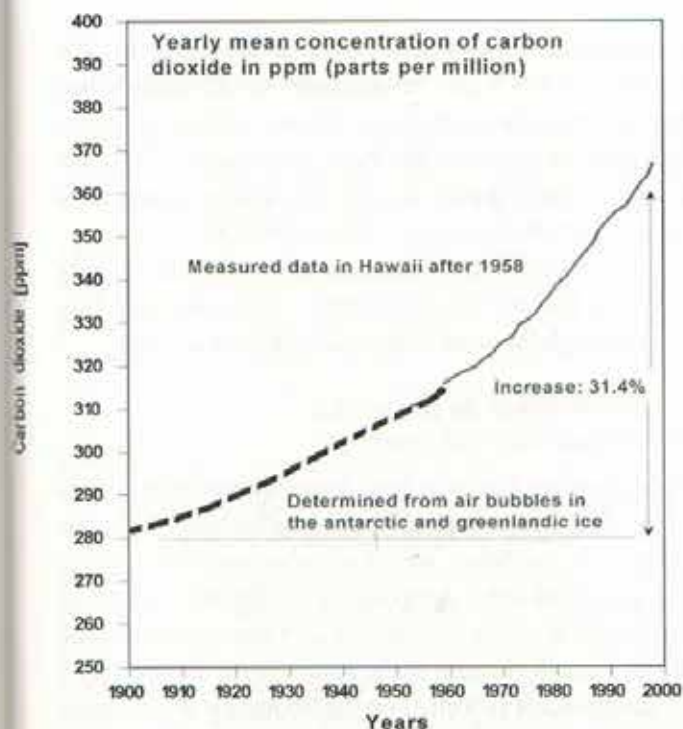


Fig. 5-2: Yearly means of CO₂ concentration in the atmosphere after measurements in Hawaii (Mauna Loa) since 1958 (Source: Scripps Institution of Oceanography).

Southern Germany have yielded similar results. Mountainous regions play an important role in the hydrological cycle, since they are the sources of large river systems. They are also of great socio-economic importance for adjacent regions. Because of their steep slopes and potential for strong erosion, mountains are very sensitive to climatic variations. Negative changes not only affect the people living there but also the plants and animals which occur there in relatively great diversity.

Changes in sea level and coastal regions at risk

Because of global warming, an increase in the mean sea level of about 5 mm per year is predicted during the coming decades. With a slow increase in the volume of the Antarctic ice and a somewhat quicker reduction in that of the Greenland ice sheet, the IPCC attributes the increase in sea level mainly to the thermal expansion of the upper layer of the ocean and to the melting of mountain glaciers (Fig. 5-3). In coastal areas, not only valuable ecosystems are found but also over 50% of the world population, which will be exposed to natural hazards, such as storms, floods, coastal erosion, and incursions of salt water. By the year 2100, a general sea level increase to about 50 cm above the present mean level is expected. Not all coastal and island countries will be able to protect their coastal zones effectively.

Changes in the large ice sheets

The ice sheets of Antarctica and Greenland have a great influence on global climate. If they were to melt completely,

a sea level increase of about 70 m would occur. In the case of a general warming, more snow could be expected in Antarctica, and its inland ice cover could increase. Because of its geographical location, the air temperature in Greenland is about 10–15°C higher than in Antarctica. Thus, with progressive warming of the northern hemisphere, a massive decrease in the size of the Greenland ice sheet can be expected. More will thaw than will be added as snow.

Consequences for agriculture

Agriculture is the segment of the economy most sensitive to climate. As many investigations have already shown, there will be considerable variation in the effects on the crops grown by different people and the yield risks, according to the region and the kind of land being cultivated. It is estimated that if atmospheric CO₂ reaches a concentration double that of the pre-industrial world, which is expected to occur by the middle of the 21st century if no measures are taken to prevent it, the global average for production of cultivated plants will essentially remain the same. Shifts in the locations of the climatic and vegetation zones toward higher latitudes and elevations, however, will demand considerable regional adaptations, especially in transitional areas. In the arid zones of the Earth, the risk of malnutrition will probably increase since the requirements for adaptation, such as changing the crops, water engineering, and land improvement, cannot generally be met. The current investigations seek to determine the growth-promoting effect of higher atmospheric carbon dioxide concentrations. It will be very difficult to estimate the future requirements for controlling pests and plant diseases, which are also influenced by climate. Crops depend not only on the mean climatic conditions but also on the characteristic weather processes that occur during the course of the growing season, including the normal variability of meteorological parameters. Thus, the nature and fluctuations of the components of the annual climatic cycles play an important role. The growing dates for some crops will be shortened by about three to four weeks at some locations but increased at others. Both the time of harvest and the seasons for the individual stages of crop development will be changed. Almost all current investigations fail to consider the frequency of extreme weather conditions in the future, which will be produced by the intensification of the hydrological cycle. Thus a relatively unendangered agriculture may be altered to a strongly affected one. It should also be mentioned that agriculture itself contributes a significant 15% of the anthropogenic greenhouse gas (Chart 7).

Intensification of the hydrological cycle

The mean rates of evaporation and precipitation will increase by about 3% to 15%, which will lead to a

considerable intensification of the hydrological cycle. According to modelling results, the surplus of precipitation will be considerably different in various regions of the world. The increase is expected mainly in areas in the tropics and at high latitudes, where sufficient precipitation already falls. In other regions, such as some arid subtropical zones, the precipitation will decrease, amplifying the contrast between arid and humid climatic regions. In large parts of Europe, more precipitation can be expected in the winter and less in the summer. The frequency of heavy rainfall and the number of days without precipitation should increase, creating a tendency toward increasing the frequency of weather extremes.

Availability and shortage of water

The looming global climatic variations will influence the water supply primarily by changes in precipitation and evapotranspiration. However, the consequences can still not be predicted precisely on a regional basis. In some parts of the world, people already suffer from acute water scarcity, which will often be intensified by the future climate and spread to many new regions. More than 20% of the world population already lack sufficient access to clean drinking water (see Fig. 5-4). This endangers the food supply and public health. A result can be political crises and mass flight from the affected areas.

The example of Africa

In February and March of 2000, Mozambique, with a mean annual *per capita* income of about 80 US \$, and Madagascar, where it is about 230 US \$, were subjected to extensive flooding over a long period of time. This took a high toll in human lives and material goods. Heavy damage to the natural environment and infrastructure were caused. After first being subjected to heavy precipitation, the lands were inundated by tropical cyclone originating in the Indian Ocean. This produced the catastrophe. In contrast, a famine

occurred in Ethiopia, where the annual *per capita* income is about 120 US \$ and an unusually severe drought had been occurring for several years. In other african countries ecological destruction has been continuing. Thus, the desertification is greatly accelerating in Mauritania, where the average annual income is about 500 US \$.

In view of all these events, has climate change already become a fact on this continent? We cannot yet affirm this, although there are many indications that it has.

When will there be proof that the climate has changed?

Those disasters that have been described and many others can be attributed to expanded and long-persistent climatic and weather anomalies, which are, when considered over a long period of time, components of climatic variability. Therefore, the strong El Niño and La Niña events have had effects through changes in the atmospheric circulation on the temperatures as well as on the frequency and intensity of precipitation in the tropics and subtropics. The area in which the Northeast and Southeast trade winds converge, called the innertropical convergence zone, belongs to the sites of most precipitation on Earth. It is usually centred somewhat to the north of the equator especially over the oceans and it oscillates during the course of the year over about 10 to 20 degrees of latitude. If the rhythm of this oscillation is disturbed, however, the precipitation zone shifts with the large-scale air flow. If this occurs, areas with tropical rain climates become dry zones for relatively long periods, while other areas can receive considerable damage from surplus rain. Depending on the frequency of such shifts, the climatic averages will change in the areas affected, reflecting the increased climate variability. Before we can declare with certainty that this has already occurred, decades of careful observation must be completed. This dilemma of the climatologists can not be solved by additional short-term observations. Thus we have to follow the precautionary principle and start measures now.

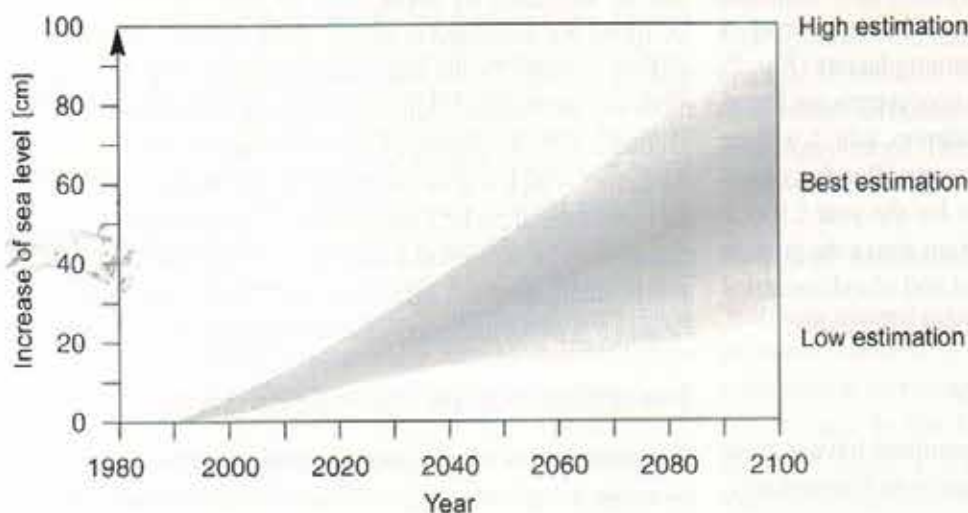


Fig. 5-3: Increase of the sea level (From IPCC 1996).

Those responsible often will not bear the consequences

There is more to the African problem. Africa has only about 14% of the world population and is responsible for only 3.2% of the global CO₂ output. On March 18, 2000, the executive director of UNEP, Klaus Töpfer, said in Berlin, that the true causes of the African disasters are to be sought in the industrialised countries, where the annual *per capita* income averages almost 20,000 US \$. These emit the lion's share of greenhouse gases. He called this »ecological aggression«. The consequences of climatic anomalies occurring irregularly from year to year or one decade to the next that might become even greater in the future, are manifold because social and economic problems complicate them. A still growing inequality exists in the economic relationships between developing and industrialised countries, that encourages ecologically poor methods of management in developing regions. The growth of population, which is largely offsetting the progress in agriculture or other fields of economy, makes it more difficult to provide appropriate education for all and also makes it almost impossible to block the spread of the acquired immune deficiency syndrome, AIDS. Population growth is also related to low economic performance. The progressive destruction of tropical rain forests and the degradation of soils are further grave problems. Attempts to lower the difficulties, beyond outside control, are often wars and genocide, which further weaken the economy, damage the environment, and make help from outside much more difficult. From the example of Africa, the complexities of estimating the consequences of a changing climate and finding ways to mitigate them become evident. Success will also depend on the number and quality of scientific institutions being supported in countries dealing with these problems. They will have to effectively use seasonal

forecasts of the occurrence of climatic anomalies under the particular conditions in the country being investigated. Skilful forecasts of the probability of a poor or good rainy season exist mainly for tropical areas affected by the ENSO phenomenon, e.g. Southern and Eastern Africa. Similar problems, just as serious as those in Africa, also exist in other regions of the world, such as parts of Central and South America.

Global changes in vegetation

Major climatic changes, such as the alternations between ice ages (glacials) and the warm interglacial periods during the Pleistocene, have led again and again to the displacement of vegetation zones. Preliminary estimates to identify the regions in which plant communities can be affected by climate change have been provided by biosphere models. Computations have shown that a doubling of the CO₂ concentration in the atmosphere would very likely cause the tundra, taiga, warm temperate deciduous forests, and warm temperate evergreen forests to move as much as 600 km toward the poles. The tropical rain forests could probably cover a larger area than now. This would be possible only in regions where the development of the vegetation could take place undisturbed.

However, it is still not clear how the vegetation in the regions affected will actually adapt. If accelerated warming causes the vegetation zones to shift their positions too quickly, then plants would not have time to adapt, and the structure of the plant communities would change. But a rising CO₂ concentration in the atmosphere has also a direct effect on plants. Therefore, the impact of climate at elevated CO₂ levels on plants is very complex. It encompasses an increase in the decomposition of organic material in soils and changes in evapotranspiration, i.e. the evaporation from the soil and from the vegetation together.

Expansion of deserts

It is estimated that up to 20 million km² on the continents have already experienced desertification, primarily due to improper agricultural and water engineering practices. This is an area as large as the USA and Canada combined. More cautious estimates give about 10 million km². The annually expansion rate of deserts in Central Asia, north-western China, North Africa, and the Sahel zone estimated to between 0.5 to 0.7%. At 0.5%, an area of 80,000 km² becomes desert each year. This corresponds to about half the area of Tunisia. If desertification continues unchanged, all land areas in the arid and semi-arid zones will be affected during the 21st century. This will endanger about a one billion people, who will lose the basis of their existence. The future changes in climate will probably accelerate the

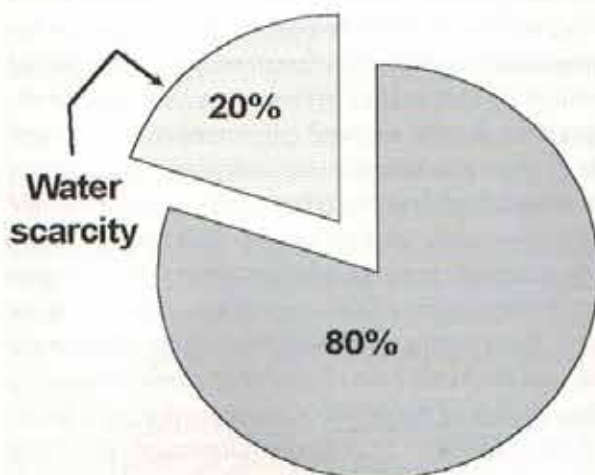


Fig. 5-4: Already about 20% of the people in the world are affected by water scarcity today.

spread of deserts because precipitation in dry areas will rather decrease than increase as the temperature increases in already arid zones.

Retreat of mountain glaciers

Mountain glaciers react to climatic changes more quickly than large ice sheets. They are therefore good indicators of altered energy balances. The nearly world-wide retreat of glaciers is also among the clear signals that the climate of the Earth has already changed strikingly since the end of the »Little Ice Age«. Not only the glaciers in the Alps but also those of the Andes and the Rocky Mountains have been greatly reduced, while some in Norway have advanced massively due to strongly increased snowfall in winter. The losses in the Alps between about 1850 and the 1970s have already reduced the ice covered area by a third and half of the ice mass has been lost (see *Charts 9 and 10*). Since 1980, another 10% to 20% of the glacier area has disappeared. It is likely that in the first third of the 21st century, a strikingly accelerated glacier loss will occur in the Alps. By about 2035, half of the present glaciers might have disappeared, and by the middle of the century, the losses may amount to three quarters.

Influence on human health

Climatic variations caused by the global environmental change are expected to have a significant, negative influence on human health. More frequent and intense heat waves, especially those in the urban heat islands of the uncontrollably growing megacities, together with other kinds of weather extremes, have already been identified as the causes of an increase in deaths. Because the distribution of infectious tropical diseases, such as malaria, depends on climate, its relationship with climatic change is particularly clear. About 45% of the world population already inhabit areas in which malaria occurs. By the year 2080, 260 to 320 million additional people will be exposed to the disease because of the expansion of its range. In Central Europe, infectious diseases carried by ticks could increase in importance. The vulnerability of the population, which depends upon both its sensitivity and ability for precautionary or reactive adaptation, differs greatly from country to country. It depends greatly on socio-economic conditions. In order to protect public health, remedial measures must be taken even before all of the uncertainties have been resolved.

Consequences for the economy

The frequency and scope of damage from natural catastrophes have dramatically increased throughout the world during the last decades. In the 1990s, the number of such catastrophes has tripled in comparison to the 1960s,

and the damage to national economies, corrected for the inflation rate, has grown eightfold and with insured damage even sixteenfold. The vast majority of these disasters and their corresponding damage have been caused by weather extremes. There are indications that global warming and the resulting rise in sea level, regional intensification of storms, and increased heavy rainfall events already noticeably contribute to the catastrophes, which are also augmented by other important factors, such as population growth, a strong increase in insured values, urbanisation, and growing vulnerability of modern civilisations. This trend will become more distinct in the future. The total national economic costs of the expected climatic change that will result from a doubling of the atmospheric CO₂ concentration is estimated to be several hundred billion U.S. \$ per year or about 1% to 2% of the annual gross national product (GNP). However, they could exceed 10% in certain countries with coastlines threatened by sea level rise. In its own interest, the insurance industry must definitively assist in developing protective measures and in influencing events through decisions on their investments. It can also reduce harmful environment influences arising from the business activity of the individual companies and real estate that they own. In addition, the insurance companies can motivate their customers through the services they provide and government authorities to take more precautions to limit the damage by their own changed activities. Only in this way will the industry succeed in maintaining the present acceptable costs for insurance against natural disasters.

These examples should suffice to make clear that the far-reaching climatic change in progress at the beginning of this century will become the environmental problem number one throughout the world. Climate research must improve the understanding of the climatic system and provide more comprehensive models that make the conditions of the change substantially clearer. We should not speak of a climate catastrophe. Of course, the consequences in some regions will be catastrophic, but in other, they will be tolerable or even positive. However, the most threatening aspect is the alteration of the atmospheric composition by humankind without even considering the consequences for the natural environment and human society. It is unquestionably the merit of international climate research to bring anthropogenic climate change to the attention of the general public. This resulted in the adoption of climate policies, which attempt to put a stop to the unrestrained abuse of the atmosphere. Limitations on emissions, forest management with protection of the climate in mind, and the further development of climate research, including studies of the possible consequences of climate change and education to promote adaptation, are some main projects designed to comply with the convention to protect climate. This will also help to approach to sustainable development."