MED-HYCOS CRP
IRD
BP 5045
AGROPOLIS
34032 - Montpellier
marc.morell@mpl.ird.fr

Climate changes

by Marc Morell

after "A Summary for Deciders" (2000, IGCC) and "Climates of the world" (1992, Bruno Voituriez)

January 2001

Summary

1. Introduction

Climate changes are currently the subject of intense scientific research and many questions are being asked by the general public, but on the other hand there is an obvious failure on the part of politicians to make decisions.

This is very strange since so many factors contribute to our awareness of the interactions that take place at planetary scale between physical environments (the oceans, the atmosphere, the continents), chemical environments (substances found in water, in the air, the soil, etc.) and living environments (florae and faunae) and to our ability to measure the impact of human activities on these environments.

While only a few decades ago, the world's seas and oceans were thought to be capable of absorbing all pollution created by human activities, today the degradation of marine environments is undeniable. And even a short time ago, the idea that humans could induce a change in the climate was a hypothesis that received little scientific support. Today no-one can deny climate changes and the fact that these changes are induced by man has been scientifically proved.

Will recent changes in our climate finally alert decision-makers to make these indispensable decisions before it is too late?

2. What is climate?

The climate of a region at any given time in the evolution of our planet can be defined by the values of variables that characterize the weather. The main variables are temperature, precipitation (rain, snow), and wind, plus atmospheric pressure, atmospheric humidity and sunshine.

2.1 Climate varies from one year to the next

Climate is defined as a norm that takes into account not only the mean values of climatic variables, but also their fluctuations over time. And it is true that the definition of one norm, commonly referred to as "seasonal weather" naturally implies deviations from this norm caused by, for example, an "abnormally" high daytime temperature, an "exceptionally" dry month, or a "particularly" cold winter.

The adverbs "abnormally", "exceptionally", "particularly" express a qualitative appreciation of the deviation from the mean value of a given parameter: mean daily temperature, mean monthly rainfall, the mean temperature of several winter months. Statistically we may refer to a daily temperature that is 5 degrees higher than is normal for the season, a rainfall deficit that occurs only once every 50 years, to a severe winter unlike any seen since 1956.

Thus, though the mean values of climatic variables (temperature, rainfall, etc.) are the main characteristics of the climate in a given region, the seasonal and multiyear variability of these variables also play an important role in defining climate.

Whereas climate refers to studies of the statistical distribution of climatic variables and analysis of the processes that control them, meteorology attempts to apprehend the weather at a given moment in time and, in addition, to forecast changes.

Climate can vary considerably in the same region over time, but there will be just as much variation at any given moment in time from one part of our planet to another.

2.2 Climate varies from one region to another

Climatic characteristics vary as a function of latitude from the equatorial zone to the polar regions, but significant differences can also be observed at the same latitude. These are linked to the geography of the region, for example, how far it is from the nearest ocean, relief, altitude, exposure to prevailing winds, possible influence on ocean currents and so on.

The mean temperature at the earth's surface is 15° Celsius. The main types of climate can be characterized as a function of mean regional temperatures.

Types of climate as a function of mean daily temperature

	Minimum temperature in ° C	Maximum temperature in ° C
Equatorial climate	26	32
Tropical climate	24	34
Desert climate	17	38
Steppe climate	17	38
Hot climate with dry winters	21	42
Hot climate with dry summers	17	31
Damp temperate climate with hot summers	8	31
Damp temperate climate with cool summers	4	20
Continental climate (cold winters)	-10	18
Climate with long, wet, very cold winters	-20	12
Climate with long, dry, very cold winters	-30	21
Tundra climate	-22	4
Polar climate	-28	-3

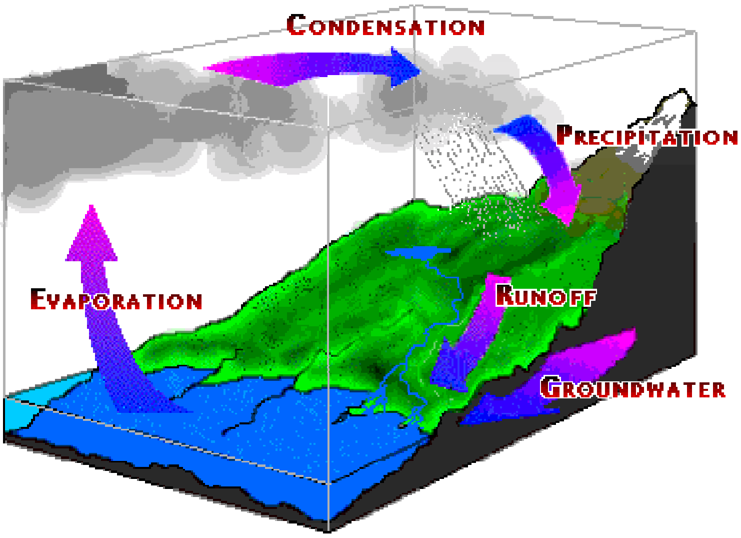
2.3 The climate system

The climate system is a thermal machine that converts and redistributes energy from the sun via the movements of the atmosphere and the oceans and exchanges between the different “compartments” of the system, of which the main vector is the water cycle.

The duration of time moisture remains in the different compartments of the cycle varies considerably with the compartment, on average, around one week in the atmosphere, from several days to several months in streams and rivers, around 30 centuries in the ocean and from hundreds to thousands of years in the water-bearing layers below the surface of the earth.

3. The water cycle

3.1 Water on the earth's surface



http://inspire.ospi.wednet.edu:8001/curric/weather/adptcty/watrcycl.html

Water is indispensable to every form of life on earth. It occupies around ¾ of the surface of our planet. It is also present in the atmosphere and deep under the earth's surface where it forms part of the composition of the earth's magma.

In nature, water exists in three different states: solid (glaciers, snow, hail), liquid (oceans, lakes, streams and rivers, in the soil), gas (water vapor in the atmosphere).

Water is the main component of our environment and undergoes successive transformations from one state to another:

- vaporization / condensation between liquid and gaseous states;
- sublimation / solidification between solid and gaseous states;
- fusion / solidification between solid and liquid states.

Total water reserves represent 1 342 409 250 km^3. 97% of the water present in our climate system is found in the oceans and the remaining 3% is fresh water.

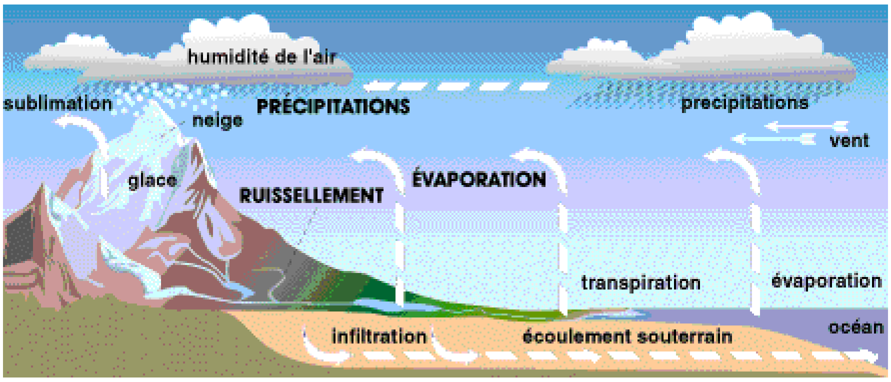
Fresh water is distributed in the following proportions: ice (77,2%), in the soil and sub-soil (22,5%), lakes, streams and rivers (0,3%) and in the atmosphere (0,03%).

The total volume (in km^3) of water in its different states is as follows:

- salt water: seas, oceans, lakes	1 304 000 000
- useable fresh water:	
glaciers and polar cap	29 500 000
sub-surface waters (up to 800m deep)	4 000 000
sub-surface waters (from 800m to 6000m deep)	4 600 000
soil humidity	66 000
streams and rivers	1 250 (35 000 per year)
lakes	124 000
atmospheric humidity	13 000

Mean annual precipitation is estimated at 870 mm for 970 mm evaporation over the oceans and 670 mm for 420 mm evaporation and 250 mm runoff over land.

3.2 The water cycle



atmospheric moisture / sublimation / precipitation / snow / wind / ice / runoff / transpiration / evaporation / infiltration / groundwater flow / ocean

The transformation of water from one state to another involves different processes in the water cycle :

- precipitation,
- interception,
- infiltration,
- evapotranspiration,
- surface runoff,
- groundwater flow,
- evaporation from the ocean
- condensation.

A certain proportion of the water resulting from precipitation is intercepted by the vegetation and subsequently returned to the atmosphere via evaporation.

The term evaporation describes water losses in the form of water vapor from open water surfaces (lakes, retaining reservoirs, ponds). Evapotranspiration combines losses due to absorption of soil water by plants or animals and the return of moisture to the atmosphere via transpiration.

Evapotranspiration is linked to a large number of parameters such as temperature, wind, humidity, sunshine etc.

Water that is not returned to the atmosphere migrates in the form of:

- Rapid surface runoff (streams and rivers), which sometimes passes through a natural storage area (lagoons, ponds) or an artificial storage facility (retaining reservoir, dam);
- Slow groundwater flow after infiltration; this water is often stored in deep reservoirs made up of porous and permeable rocks called aquifers.

If not used by humans, surface and underground water eventually ends up in the ocean.

Here the water cycle continues: via evaporation and evapotranspiration marine and earth environments humidify air masses transported by the wind. Clouds form due to condensation, and precipitation takes place over the continents and islands and of course, also over the oceans themselves.

3.3 Hydrological budget of a watershed

The determination of the water budget of a region for a given period implies being able to estimate the quantity of water than enters and leaves the different watersheds that make up the region concerned.

The watershed of a river is the zone within which water resulting from precipitation runs off and converges towards the river. The outflow of a watershed is that part of the river towards which all the water from that particular watershed flows.

The hydrological budget of a watershed can be expressed by the following equation:

$$dR = P - E - Q - I - U$$

where dR, P, E, Q, I, and U are the volumes of water that correspond to:

dR: variations in surface and underground reserves

P: precipitation minus interception

E: true evapotranspiration

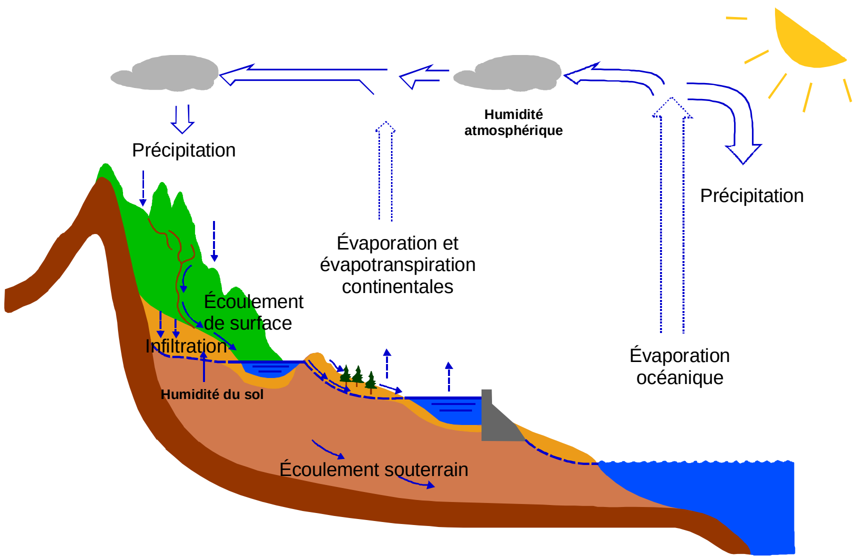
Q: runoff towards rivers

I: losses to deep infiltration

U: use by humans

Each of the factors used to describe a hydrological budget is naturally affected by various climatic and geographical parameters and the role it plays will thus vary with the region. Temperature is one of the main factors that govern atmospheric evaporation; relief affects the ability of clouds to precipitate, and the nature of the plant cover influences interception and transpiration phenomena.

LE CYCLE HYDROLOGIQUE



Hydrological cycle / Precipitation / Atmospheric humidity / Continental evapotranspiration and evaporation / Surface runoff / Infiltration / Soil water / Ocean evaporation / Groundwater flow

4. Why does climate change?

Different natural factures are responsible for changes in climate over the ages: solar activity, parameters of the earth's orbit, volcanic eruptions, and perhaps magmatic processes deep under the earth's surface, etc.

Human-induced factors are mainly linked to the increase in greenhouse gases released into the atmosphere and to physical and biological modifications of the environment (combustion, deforestation, pollution, etc.).

These natural and human-induced factors can each cause short-term climate disturbances over a period of a few years or a few decades, but when these two different types of factors are combined, they can influence long-term climate changes.

4.1 Solar activity

Solar energy is at the origin of water cycle mechanisms and of physical and energy phenomena that determine the climate. Solar activity is cyclic, each cycle corresponding to a period of 11 years.

The radiative effect due to changes that have occurred since 1750 in the energy emitted by the sun represents one fifth of that due to the increase in carbon dioxide over the same period. However it has been estimated that over the last two decades, the radiative effect linked to variations in solar energy was negative (i.e. resulted in global cooling), in contrast to the effect of greenhouse gases that resulted in global warming.

4.2 Volcanic eruptions

Stratospheric aerosols are minute particles suspended in the air that are emitted by major volcanic eruptions. They reduce the amount of solar energy received by the earth over a period of several years and thus facilitate a drop in temperature at the earth's surface. This phenomenon has been verified over the course of the last few decades, however it has very little impact on the mean temperature at the earth's surface.

4.3 Astronomical causes

The earth rotates around the sun following an ellipse whose shape varies over time in periodic cycles of 100 000 years. The total quantity of solar energy received by the earth thus varies by 1.2%. However, even though this percentage is very low, when combined with other factors it can influence climate changes.

The distance from the earth to the sun also varies during the course of its elliptical orbit. At the present time, the earth is closest to the sun in January (perihelion) and reaches its most distant position in July (aphelion). But these to relative positions are 21 000 years apart in time. In approximately 11 000 years the earth will be closest to the sun in July and most distant in January. At that time, the difference between winter and summer in the northern hemisphere will be greater than now.

The seasons are explained by the inclination of the axis of rotation of the earth to the perpendicular (23°27') with respect to its orbit around the sun. And in fact, over a period of approximately 40 000 years, inclination varies between 22° and 24°.

6 000 years ago, these three phenomena combined to produce a climatic optimum with a mean temperature 2°C higher than today. According to this theory, assuming there is no intervention by human beings, the cooling of the planet should continue until a new ice age occurs in 60 000 years.

4.4 Greenhouse gases

The main components of the atmosphere are nitrogen (77%) and oxygen (21%), neither of which absorb infrared rays emitted by the earth. Argon and water vapor make up the majority of the remaining 2%.

Greenhouse gases control the flux of energy by absorbing infrared rays emitted by the earth. The element that contributes most to the greenhouse effect is water vapor. Thus water vapor is mainly responsible for the additional 30°C that we benefit from on earth. Water vapour is characterized by positive feedback, i.e. the level of water vapour increases with an increase in the air temperature.

Traces of other gases are present in the atmosphere, for example carbon dioxide (0.035 %).

Carbon dioxide supplies the carbon required for photosynthesis. It plays a role in the natural cycle of carbon exchange between the different carbon reserves: the atmosphere, the oceans, sediments and living land and marine species.

The present level of atmospheric carbon dioxide (CO_2) is the highest in the last 420 000 years and probably in the last 20 million years. The concentration of CO_2 has increased by more than 30% since 1750, whereas the total rate of increase over the last 10 000 years was less than 10%. At the present time, the rate of increase in atmospheric CO_2 is around 10% every 20 years.

Carbon dioxide is now responsible for 60% of the increase in the greenhouse effect caused by human activities. Combustion of coal, petroleum and natural gas is responsible for two thirds of this increase, and deforestation, which results in the release into the atmosphere of carbon present in the trees, for the remaining third. Annual emissions of carbon are presently around 7 billion tons, i.e. almost 1% of the total mass of carbon dioxide in the atmosphere.

Other than the carbon dioxide that is naturally present in the atmosphere, other greenhouse gases are methane, nitrous oxide, chlorofluorocarbons (CFC) and ozone, whose concentration tends to increase with an increase in human activities.

The concentration of methane (CH_4) in the atmosphere, which is mainly due to rice cultivation and animal rearing, has doubled since 1750 and is continuing to increase. It has been estimated that methane is now responsible for 20% of the greenhouse effect linked to human activities. The remaining 20% is attributed to nitrous oxide, chlorofluorocarbons and ozone. Production of nitrous oxide, which has increased by 15%, is linked to increasingly intensive agriculture. Concentrations of CFC have stabilized since the beginning of the nineties, thanks to strict control of emissions. An increase of one third in tropospheric ozone explains the increase in the radiation effect of the sun equivalent to approximately 0.35 W per square meter.

4.5 Aerosols

Aside from volcanic eruptions, which are the primary natural source of aerosols, sulfur dioxide particles are mainly emitted by electric power stations and by the smoke that accompanies deforestation and also is produced when crop residues are burned. Although these particles disappear from the atmosphere in a few days, the quantities released are so large that they have a non-negligible effect on the climate by intercepting solar energy and returning it to the stratosphere. Aerosols thus have a cooling effect on the earth's climate.

5. Climates in the past

During the course of a period of observation ranging from a few years to a few decades, the climate in any given region will display irregularities from one year to the next. This type of irregularity is referred to as multiyear variation.

At a scale of from several decades to several centuries, changes in the climate can be observed that are linked to natural factors; to these natural factors we must add human-induced changes that have occurred since the beginning of industrial era.

5.1 Means of investigation

The progress that has been made in the investigation of past climates is due to studies by paleoclimatologists, oceanographers, atmospheric physicists, and others.

Paleoclimatology investigates ancient climates using observations made on ancient and more recent glaciers and on polar ice caps. The latter now only exist in Greenland in the northern hemisphere and in Antarctica in the southern hemisphere. These environments have conserved traces of climate fluctuations and particularly variations in the temperature of the planet over the last 400 000 years.

Coral reefs, which live at the sea surface, are also excellent indicators of sea level and of the variations in sea level that have occurred over the ages.

In the same way, marine sediments contain numerous microscopic remains of animals and plants (plankton) that lived at the surface of the sea and provide a wealth of information on the temperature of the planet's seas and oceans in the past.

Isotopic analysis of ice cores from polar ice caps provide exact information on the level of Oxygen 18, which an excellent tracer for atmospheric temperature, as well as for the volume of polar ice caps and as a consequence, sea level. Major climatic changes can also be identified by observing changes undergone by remains of species. Isotopic analysis allows precise dating of animal and plant remains trapped in the sediments (levels of carbon 14).

5.2 Past changes

For the last 900 000 years, the planet has been subjected to alternating hot periods (with temperature of 1 to 2 degrees above present mean temperature) and glacial periods, (with temperature 3 to 4 degrees below present mean temperature). The transition between a hot period and a glacial period lasted from several thousand years to several tens of thousands of years.

Nine major glacial periods have been identified during the last 730 000 years. The two most recent occurred 150 000 and 20 000 years ago respectively.

During the last 150 000 years, the sea level has only once been higher than today: 125 000 years ago it reached a level 6 meters higher than now. At that time the total quantity of ice on the continents was much smaller than today and temperatures in Europe and in North America were 1 to 4 degrees higher. The Sahara had a wet climate. Many of the species that now populate the intertropical zones inhabited Europe at that time.

From 20 000 years ago to 15 000 years ago the planet went through an ice age during which temperature was 3.5 °C below today's mean temperature. The northern parts of Europe and America were covered with a thick ice cap. Sea level was approximately 120 meters below today's level.

5 to 6 000 years ago, at the Holocene optimum, the temperature was 2 °C higher than today. More recently, just after the medieval optimum (+ 0.7 °C between the 10th and the 17th centuries) a short ice age occurred (- 0.5 °C between the 16th and the 17th century).

6. Tomorrow's climate

In order to be able to predict future climates we need a good knowledge of past climates, a thorough understanding of the processes that resulted in their successive modification and continual observation of the different factors that influence climate in general.

6.1 Modeling climate

To predict future climates, scientists have developed numerical models that simulate the dynamics of the atmosphere, the oceans, and energy exchange between atmosphere and continents on the one hand, and atmosphere and oceans and other open water surfaces on the other.

Some of these models help meteorologists forecast short-term changes; others are specifically designed to help climatologists predict long-term changes in climatic parameters under specific conditions (changes in land use, emission of greenhouse gases, etc.).

Considerable progress has been made in recent years in the understanding and modelling of water vapour, sea ice dynamics and energy transported by the oceans. The biggest remaining uncertainties concern the role of clouds and their interaction with the radiative effect and with aerosols, and the role of forests and oceans in the absorption of carbon dioxide.

6.2 Intergovernmental panel on climate change

The intergovernmental panel on climate change (IPCC) was created in 1988 by the World Meteorological Organization and the United Nations Program for the Environment. The IPCC is an international network of several hundred scientists who have been assigned the task of gathering state-of-the-art knowledge on the risk of climate change. Two reports have been published, one in 1990 and one in 1995. The final report was discussed in January 2001 and will be published sometime this year. A summary destined for decision-makers was made available to the general public in November 2000.

6.3 Recent observations

The November 2000 report revealed in particular that only the increase in man-made greenhouse gases has played a substantial role in the planetary warming observed over the last 50 years, though uncertainties remain concerning the effect of natural factors such as variations in the radiative effect and the presence of aerosols.

6.3.1 The energy balance

Emissions of greenhouse gases produced by human activities have already resulted in a change in the energy balance of the planet equivalent to 2.5 watts per square meter, which represents 1% of net solar radiation. This may not seem like much, but in fact it is the equivalent of 1.8 million tons of petroleum consumed per minute, or, in other words, more than one hundred times world energy consumption. Thus, consumption of energy linked to human activities has one hundred times more effect on natural flows of energy.

6.3.2 Changes in temperature

Since 1860, which is the first year for which scientists have sufficient data on the whole planet, the mean surface temperature has increased by 0.6 °C. Recent analysis shows that the 20th century probably witnessed the biggest rise in temperature in the northern hemisphere in the last thousand years. The 1990s and in particular the year 1998 were the hottest that have ever been observed.

6.3.3 Reduction in the ice and snow cover

In the northern hemisphere, the surface area of the ice sheet covering the sea has decreased by 10 to 15% since 1950, and the thickness of the ice pack has decreased by more than 40%. The surface area of the earth covered by snow has decreased by approximately 10% since the end of the sixties and the length of the period rivers and lakes are covered with ice shortened by approximately 2 weeks during the 20th century.

In contrast, the extent of the ice cover in the Antarctic shows no significant modification.

6.3.4 Rise in mean sea level

Mean sea level has risen 10 to 20 centimeters due to the expansion of seawater and melting ice. During the XX century the rate of the rise in the sea level was ten times higher than in the 3 preceding millenniums.

6.3.5 Ocean currents

The El Nino phenomenon is characterized by a rise in the surface temperature of the Pacific Ocean along the coast of South America (Peru). The El Nino occurs periodically every 4 to 7 years. IPCC experts have observed that the El Nino phenomenon has occurred more frequently since the middle of the seventies, with extreme phenomena occurring in 1983 and 1996.

6.3.6 Precipitation

In medium and high latitudes in the northern hemisphere precipitation increased by 0.5 to 1% per decade during the 20th century. It is probable that these regions were affected by more frequent extreme precipitation events.

During the same period, rainfall decreased by approximately 0.3% in the majority of intertropical regions in spite of a slight turn-around in recent years.

6.3.7 Cyclones

Tropical and extra-tropical cyclones – especially in their most extreme form as hurricanes - apparently do not occur significantly more frequently than previously.

6.4 Forecasts for the coming decades

The composition of the atmosphere will continue to change during the 21st century.

Future emissions of greenhouse gases will naturally depend on changes in life styles of human populations and also on the political decisions that are made to control these emissions.

Before the industrial revolution, the CO_2 concentration was approximately 280 ppm (parts per million). It is now 367 ppm. Models predict concentrations of between 540 and 970 ppm at the end of the 21st century. Even supposing the proportion of carbon dioxide emitted today as a result of deforestation is compensated for by intensive reforestation, this would only mean the CO_2 concentration would be reduced by 40 to 70 ppm.

The mean increase in surface temperature between now and the end of the 21st century is now estimated at from 1.5 to 6°C, whereas the previous estimate published by the IPCC (1995) was from 1°C to 3.5°C. Thus surface temperature all over the world will undergo an increase and particularly regions in North America and Asia (40% above mean changes). Warming will remain below the mean in southern and south eastern Asia in the summer and in South America in winter.

In the northern hemisphere, the snow cover and the ice shields covering the seas are expected to continue to shrink. Glaciers and the polar ice caps will continue their retreat, with the exception of those in Greenland and Antarctica. A rise in sea level of from 0.14 to 0.80 m is envisaged for the 21st century, which corresponds to a rate 2 to 4 times higher than in the 20th century. However, a major decrease in the Antarctic ice cap and a rapid rise in sea level are considered unlikely.

7. Questions

The latest report issued by the Intergovernmental panel on climate increased their previous estimate of the probable rise in temperature this century to between 1.5 and 6 °C from between 1°C and 3.5 °C in their previous estimate published in 1995. One may be justified in wondering, a little cynically, what the rise in temperature will be estimated to be in, say, 50 years, if 3°C are added to the top limit every five years? What is certain is that, far from limiting the maximum value published in 1995, it, in fact, considerably increased the degree of uncertainty. One may also question the adequacy of the method that led the panel to increase the range of uncertainty.

And finally, how useful are today’s estimates if they are so likely to be put into question tomorrow? In other words, if the upper limit of the mean rise in temperature at the earth’s surface was a short while ago not expected to go above 3.5°C, and today has already been moved up to 6°C, who is in a position to say whether the upper limit estimated in 5 years time might not reach 10°C? In such circumstances we are justified in asking the following questions:

- what will be the consequences for other characteristics of the climate (mean precipitation, frequency of drought and heavy rains, formation of cyclones, etc.) ?
- what will be the impact on the water cycle and the consequences for the distribution of water resources in different parts of the world ?
- what will be the consequences for predictions of a rise in sea level ?

Another point: estimates of the rise in mean temperature at the earth’s surface were made using a scenario to simulate the socio-economic development of countries that was based on our actual knowledge of the state of development in those countries, on population projections and on probable changes in their degree of industrialization and modes of life in the coming decades.

There is no irrefutable relation between a country’s contribution to the greenhouse effect and the wealth it produces (gross national product). The relation is closer if the degree of industrialization is taken into account. Nevertheless, this approach still requires fine tuning since the most developed countries usually dispose of the necessary means to reduce atmospheric pollution, which developing countries cannot afford.

Developing countries in the intertropical zone are often subject to large-scale deforestation, which, in the majority of cases, represents an irreversible loss in environmental and socio-economic terms. Deforestation apparently contributes little to the greenhouse effect and, in any case, deforestation cannot go on forever. In twenty years there will be no big forests left to cut down!

Thus there is every reason to think that it will be today's and tomorrow's industrialized countries who will be responsible for the majority of emissions of greenhouse gases into the atmosphere, although some uncertainty does remain in this connection.

One last question: who knows if future technologies will necessarily be less polluting and who knows what impact they will have on the fragile atmospheric equilibrium?

Faced with all these uncertainties, we would be well advised to proceed with the utmost caution.

8. In lieu of a conclusion

Looking beyond the provisional conclusions of the IPCC, in this last chapter we have considered possible future climate changes from the most unfavorable perspective.

But surely we do have an obligation towards future generations. Shouldn't maximum precautions be taken to avoid this 'worst possible scenario'? It may be unlikely to happen, but nevertheless it cannot be completely excluded.

All of which leads us to the conclusion – that should go without saying – that the peoples of the world and the politicians who represent them need to take immediate and draconian measures to reduce emissions of greenhouse gases into the atmosphere. After the failure of the Rio Protocol, recent negotiations (in The Hague in November, 2000) show we still have a long way to go to reach agreement.

The outright denial on the part of some of the most developed countries in the world, led by the United States, of the reality of climate changes and their causes and these countries' refusal to make the necessary decisions is not only a major failure, but also a warning about the attitude we can expect from other countries who choose to make economic development their absolute priority.

"Nous n'héritons pas de la terre de nos ancêtres, nous l'empruntons à nos enfants."

"We do not inherit the earth from our ancestors, we borrow it from our children".

(Antoine de Saint-Exupéry).