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Excerpt
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1 Climate change and its impacts: a short summary

What is covered in this chapter?

The climate has changed. Human beings are responsible. And the climate will change further as energy use, agriculture, deforestation, and industrial production continue to increase. In the course of this century it could get up to 6°C warmer, with more heat waves, droughts, floods, and storms. As a result a wide range of impacts can be expected. Food production and water availability will diminish. Nature will suffer, with a large percentage of species threatened with extinction. New health problems will arise. Coastal areas and river deltas will face more floods. The overall effect of this will be devastating for poor countries, undermining their efforts to eradicate poverty. But even rich countries will see the costs of these impacts rise to significant levels.

The climate has changed

Climate can be defined as 'average weather', so it covers averaged temperatures, rainfall and wind direction and speed. Usually this is averaged over a period of 30 years. Let's have a look at how temperatures, rainfall, and wind have changed since 1850[1].

From the temperature measurements across the world (see Box 1.1) it is clear that global average surface temperatures have gone up about 0.8°C since the the pre-industrial era (or since about 1850). This happened in two stages, between 1910 and 1940 (about 0.35°C) and from the 1970s till the present (more than 0.55°C), with a period of slight cooling (0.1°C) in between. The change is getting faster over time (see Figure 1.1). Eleven of the twelve years in the period 1995–2006 belong to the warmest since the beginning of instrumental temperature measurements in 1850. It is likely that temperatures are now higher than in the last 1300 years.

Over the last 50 years there has been a significant decrease in cold days and cold nights and a significant increase in warm days and nights and heat waves. In Europe the summer of 2003 was exceptionally warm, with record temperatures. The summer was 3.8°C warmer than the 1961–1990 average and 1.4°C warmer than any summer since 1780[2]. This was well beyond what can be expected of extreme events in an unchanged climate.

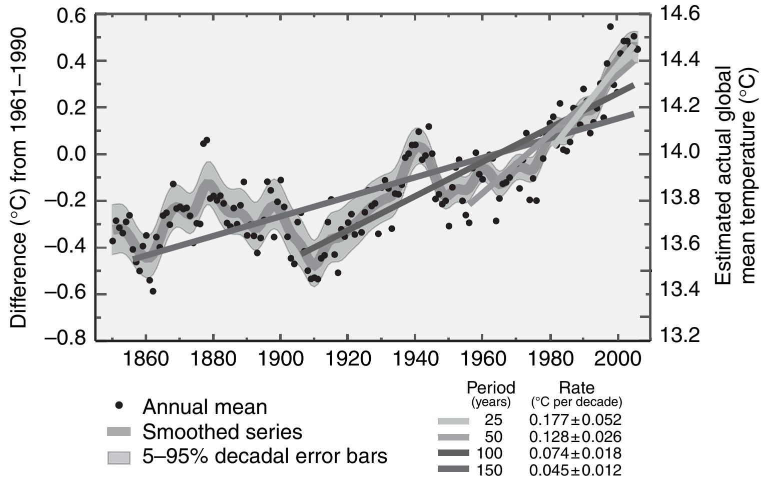


Figure 1.1 **Annual mean global temperatures 1850–2005 (dots and smoothed curve) and linear trends for the last 25, 50, 100, and 150 years (different lines).**
Source: IPCC Fourth Assessment report, Working Group I, figure TS.6.

Box 1.1 **Temperature measurements**

Average global surface temperatures are constructed from thousands of land based and ship based temperature measurements across the globe every day. They are corrected for additional urban warming (the so-called 'urban heat island effect'). Temperatures at higher altitudes are different. In the troposphere (up to 10 km) they are higher than at the surface. In the stratosphere (10–30 km) they are lower. This is exactly what the physical theory predicts. Satellites can measure the average over the whole atmosphere. Although there are uncertainties because of the integrated measurement and the fact that calibration of satellite instruments is complex, they are now fully consistent with the surface temperatures.
(Source: IPCC Fourth Assessment report, Working Group I, chapter 3, Frequently Asked Questions box 3.1)

Rainfall and snowfall (together: precipitation) patterns have also changed. On average precipitation has increased in Eastern North and South America, Northern Europe and Northern and Central Asia. In the Mediterranean, the Sahel, Southern Africa, and Southern Asia it has become drier. In addition heavy precipitation occurrences have increased in many areas, even in places where total amounts have decreased. This is caused by the higher amounts of water vapour in the atmosphere (the warmer the air, the more water vapour it can contain). Drought occurrences have increased as well in many areas as shown in Figure 1.2.

As far as wind is concerned, there is evidence that intensities of hurricanes in the North Atlantic have increased. The numbers of hurricanes have not increased. Wind patterns have also changed in many areas as a result of changes in storm tracks.

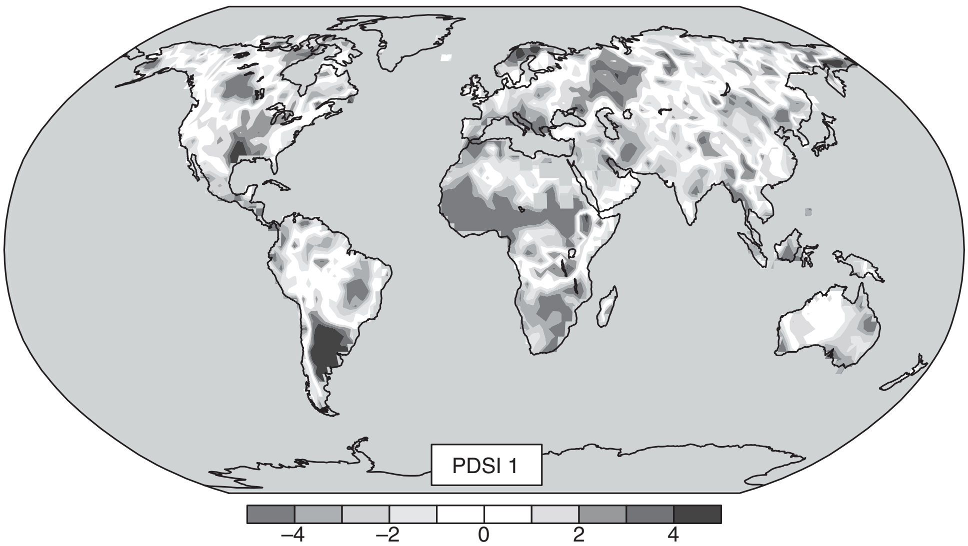


Figure 1.2 **Change in drought index between 1900 and 2002.**
Source: IPCC Fourth Assessment report, Working Group I, figure 1 from box FAQ3.2.
See Plate 1 for colour version.

Are ice and snow cover and sea level consistent with the temperature trends?

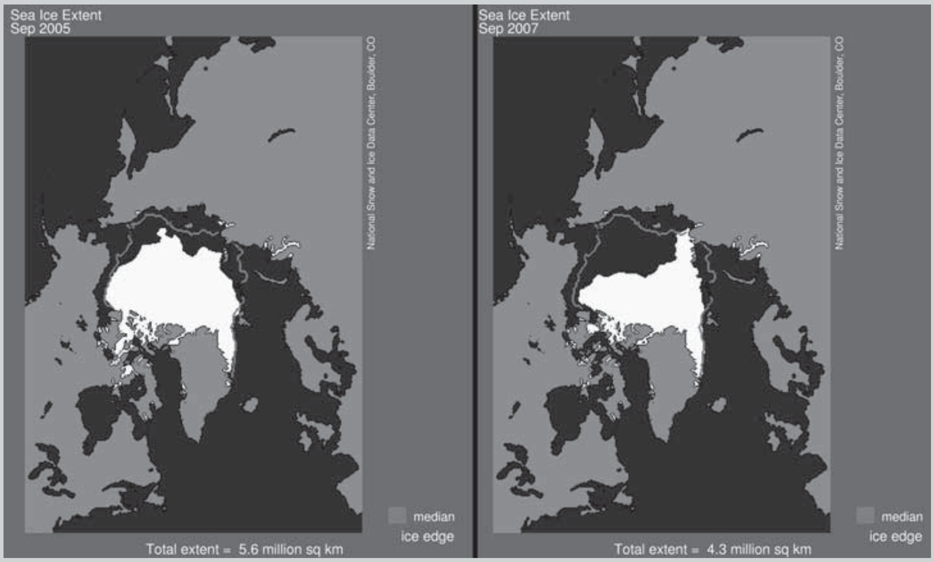
Trends in snow and ice cover are consistent with global average temperature increase. Most mountain glaciers are getting smaller. Northern Hemisphere snow cover in winter and Arctic sea ice cover (see Box 1.2) and area of frozen ground in summer are declining. Glaciers, as well as the Greenland ice sheet, are getting smaller, even while snowfall on top is higher than before. The Antarctic sea ice cover and the Antarctic ice sheet do not yet show clear trends (see Figure 1.3 for some of these trends).

Box 1.2 Sea ice and land ice: the difference

Melting sea ice does not increase sea level, because the ice floats and displaces the same amount of water (check it with an ice cube in a glass of water!). Melting land ice (the Greenland ice sheet for example) does increase sea level. In Antarctica large chunks of sea ice have broken off over the years. These large sea ice plates do however provide some support for the land ice. It is uncertain if land ice would move faster towards the sea in such places.

A reduction in sea ice also reduces the reflection of sunlight. So the more sea ice is disappearing, the more sunlight is absorbed by the oceans, which speeds up warming. This is one of the so-called feedback mechanisms in the climate system.

The figure below shows how much lower the Arctic sea ice cover in 2005 and 2007 was compared to the average over the 1979–2000 period.



Minimum summer sea ice cover in 2005 (left) and 2007 (right); dotted line is average extent of sea ice between 1979 and 2000.
Source: National Snow and Ice Data Center, Boulder, Colorado, USA, http://nsidc.org/arcticseaicenews/.
(Source: IPCC Fourth Assessment report, Working Group I, box 4.1)

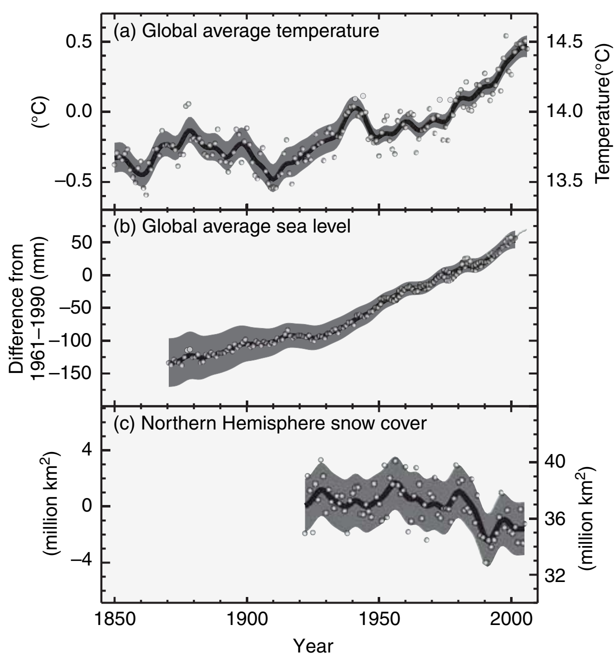


Figure 1.3 **Observed changes in (a) global mean surface temperature, (b) global average sea level, and (c) northern hemisphere November to March snow cover. All values are expressed as differences with the corresponding averages for the period 1961–1990. Shaded areas represent the uncertainty.**
Source: IPCC Fourth Assessment Report, Working Group I, figure SPM.3.

Sea level has been stable over the first 1900 years AD, but since 1900 it has been rising. Until 1990 this rise was about 1.7 mm per year, but since 1993 it has increased to 3 mm per year. Half this increase comes from melting of land ice (see also Box 1.2), the other half from expansion of sea water due to temperature increase (warmer water has a larger volume than cold water). This is fully consistent with the increase in global average temperatures. Annual fluctuations happen as a result of local weather conditions and human interventions in groundwater extraction and water storage reservoirs. Sea level rise is not the same everywhere, because of changes in ocean currents and local differences in ocean temperature and salinity. Rising or falling land can make a difference in specific locations.

Are observations of biological systems also consistent with the measurements of a changed climate?

Hundreds of studies were done on changes in fish, plankton, and algal populations, plants and trees, insects, and animals. Observations from these studies show a very strong correlation with the changes in climate that were discussed above[3]. Populations shift their ranges to areas where the climate has become favourable and disappear from areas where the climate is no longer appropriate. Often this means poleward movement of the ranges. Blooming occurs earlier. But it also means that mismatches are occurring between migratory bird breeding and availability of certain caterpillars or insects. The caterpillars or insects react to the higher temperatures by coming out earlier, but the migratory birds still arrive at the usual time and do not find the regular food for their young[4].

In agriculture changes have already occurred in terms of earlier planting, leading to a longer growing season, but also in the form of crop failures due to changing rainfall patterns. In forest management changes in pest invasions and patterns of forest fires show a clear correlation with the changed climate.

Are human activities responsible for this climate change?

The earth's climate is the result of a number of factors:

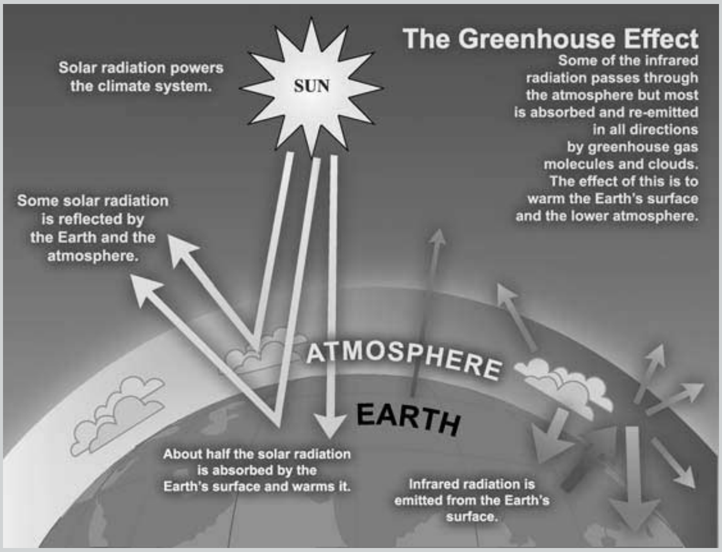
- the radiation from the sun and the position of the earth in relation to the sun (the changes in these two are responsible for the ice ages that the earth is experiencing every 100 000 years or so),
- the reflectivity of the earth (called albedo), as influenced by the vegetation and the ice and snow cover (this is influenced by human activities),
- the reflection of sunlight by clouds and fine particles in the atmosphere (from volcanic eruptions, sand storms, but also from coal burning and diesel vehicles), and
- last but not least by the presence of so-called greenhouse gases in the atmosphere, retaining some of the solar radiation.

Some of the factors have a warming, others a cooling effect. Natural greenhouse gases (water, CO_2, methane) are in fact responsible for making planet earth suitable for life (see Box 1.3). The problem arose when human activities (burning of fossil fuel, agriculture, cutting forests, industrial processes for making cement, steel, and other materials) added greenhouse gases to the atmosphere far beyond their natural levels, causing additional warming. So it is the enhanced greenhouse effect that is causing problems.

Box 1.3 The greenhouse effect

The earth is warmed by solar radiation. If no atmosphere would exist, the temperature would be minus 18°C and no life would be possible. But because of the atmosphere that has water vapour, methane, and CO_2, some of the radiation that is sent back into space by the earth is absorbed by the atmosphere and the clouds. This is the natural greenhouse effect. It brings the surface temperature to about 15°C.

Human activities have added greenhouse gases to the atmosphere: CO_2, mainly from deforestation and fossil fuel combustion, methane and nitrous oxides from agriculture and waste, and fluorinated gases from industrial processes. These additional greenhouse gases are responsible for the additional warming of the earth. This is the enhanced greenhouse effect.



Schematic diagram of the natural greenhouse gas effect.
Source: IPCC Fourth Assessment report, Working Group I, Frequently Asked Questions 1.3, figure 1
(Source: IPCC Fourth Assessment report, Working Group I, Frequently Asked Questions 1.3)

We can measure greenhouse gases in the atmosphere. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (N_2O) concentrations have gone up strongly since the beginning of the industrial revolution (see Figure 1.4). CO_2 levels are now about 30% higher than before 1750, N_2O about 50% higher, and CH_4 approximately doubled.

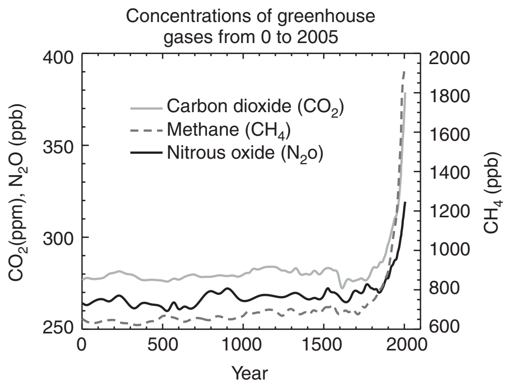


Figure 1.4 **Concentrations of the most important greenhouse gases in the atmosphere over the last 2000 years. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of a greenhouse gas per million or billion molecules of air.**
Source: IPCC Fourth Assessment report, Working Group I, figure 2.1.

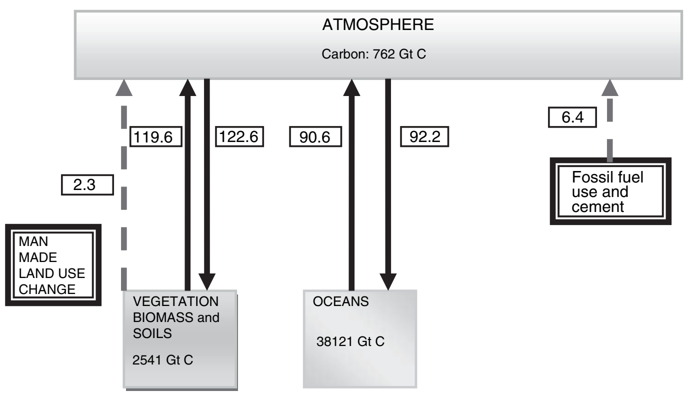


Figure 1.5 **Schematic diagram of global carbon cycle. Shown are stocks of carbon (in GtC) and fluxes (in GtC/yr). Dashed lines represent man-made fluxes of carbon form fossil fuel, cement and land use, change. Land use change numbers are corrected for peatland emissions (see Chapter 9).**
Source: IPCC Fourth Assessment report, Working Group I, figure 7.3 and Working group III, chapter 1.

Concentrations in the atmosphere are a result of emissions of these gases and processes that remove them. This includes natural and man-made emissions and removals. For CO_2 there are very large natural emissions and removals through vegetation and the oceans. Man-made emissions are relatively small compared to these.

Figure 1.5 gives a schematic overview of the natural and man-made emissions and sequestration of CO_2 (sequestration = absorption by growing vegetation). The natural fluxes to and from vegetation and the oceans are typically100 times larger than the man-made fluxes of CO_2. Nevertheless, the man-made fluxes are responsible for the increase in CO_2 emissions in the atmosphere. As the diagram shows, there is a net sequestration of CO_2 in the oceans and in vegetation and soils. That is the reason that only about half of the amount that humans are putting into the atmosphere is staying there.[5]

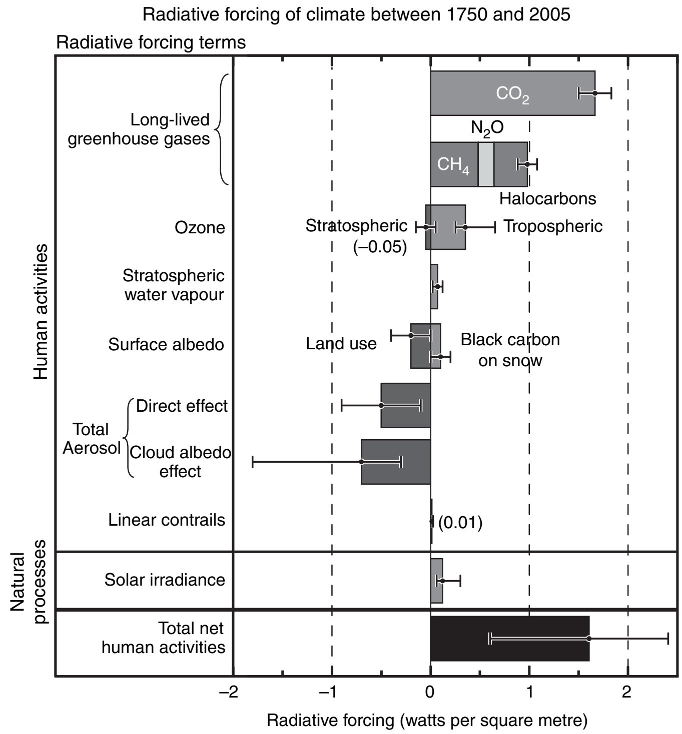


Figure 1.6 **Global average warming and cooling effect of greenhouse gases and other factors in 2005, compared to the situation in 1750. Warming and cooling effect is represented by so-called radiative forcing and expressed in Watt per square meter of the earth surface. Uncertainty ranges are shown with bars.**
Source: IPCC Fourth Assessment report, Working Group I, Frequently asked questions 2.1, figure 2.

The contribution of the various factors mentioned above to warming and cooling is fairly well known, although for some the uncertainties are high. Figure 1.6 gives an overview of the difference between the situation today and that in 1750. It shows significant warming from greenhouse gases (CO_2, CH_4, N_2O, but also fluorinated compounds and ozone) and small contributions to warming from black carbon particles that are deposited on snow and from increased solar radiation. Big cooling effects are caused by a wide range of particles (aerosols), directly through reflection of solar radiation and indirectly because these particles help cloud formation and clouds reflect sunshine. Some cooling has also occurred because the earth has become lighter due to loss of forest cover and reflects more sunshine (increased albedo). Aerosol effects are quite uncertain still. The impact of volcanic eruptions is not visible in Figure 1.6, because the dust and ash blown into the atmosphere by volcanoes disappears within several years. When a big volcanic eruption happens though (the last was Mount Pinatubo in 1991), the average global temperature goes down several tenths of a degree for a few years.

On average there is a clear warming effect. Natural causes (solar radiation, volcanoes) only make a very small contribution. Human beings are responsible; there is no escape from that conclusion. Over time however the relative contributions of human and natural factors changed. Until about 1940 natural forces were playing a big role, but over the last 50 years the human contribution is by far the most important.

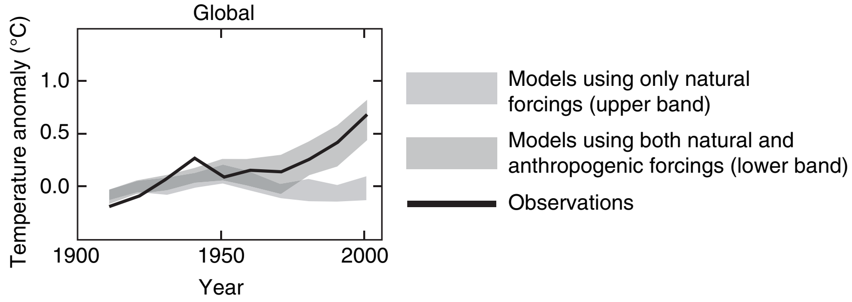


Figure 1.7 **Global average temperature changes compared to the average for 1901–1950. The black line indicates measured temperatures. The lower band indicates the climate model calculation with only natural factors included. The upper band indicates climate model calculations with the effect of greenhouse gases included also.**
Source: IPCC Fourth Assessment report, Working Group I, figure SPM.4.

There is another way to demonstrate that. Climate models have been developed to simulate climatic change, mainly to enable a prediction of future climates. These models have also been used to simulate the climate over the last 150 years. That would allow a comparison with the measurements. If these models are run with only the natural factors included, they do not come close to actual measurements of global average temperatures. When greenhouse gases are added to the calculations they do match the measurements quite well (see Figure 1.7).

How is the climate going to change further in the future?

Greenhouse gases only disappear very slowly from the atmosphere. If we keep adding them to the atmosphere at current rates, concentrations of greenhouse gas in the atmosphere will continue to rise. Without specific policies, emissions of greenhouse gases will continue to increase, so atmospheric concentrations will rise even faster. At the same time concentrations of aerosols tend to go down as a result of policies to clean up air pollution. So cooling forces (from aerosols) decrease and warming forces (from greenhouse gases) increase. As a result, further warming will occur.

Temperatures

Of course it is not precisely known how much warming will increase and by when. It depends on population growth, economic growth, and choices on energy, technology, and agriculture. To deal with this inherent uncertainty, scenarios are used to cover a range of plausible futures. Scenarios are sets of assumptions about the main factors driving emissions. (See Chapter 2 for a more detailed discussion about the causes of greenhouse gas emissions and scenarios.)

Figure 1.8 shows the IPCC SRES scenarios for greenhouse gas emissions (these scenarios also make assumptions on aerosol emissions) and the corresponding increase in the global

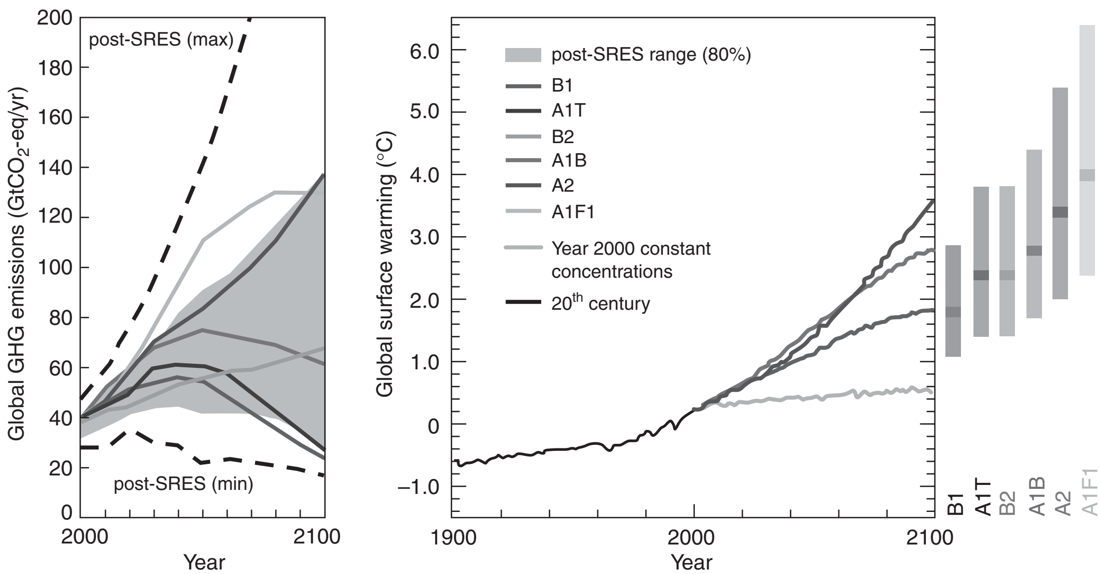


Figure 1.8 **(Left panel) Scenarios for global greenhouse gas emissions, according to IPCC; (right panel) projected global mean temperatures belonging to the scenarios in the left panel.**
Source: IPCC Fourth Assessment report, Synthesis Report, figure SPM.5. See Plate 2 for colour version.

average temperature till the end of this century. By the end of the century global average temperatures will be between 1 and 6.4°C higher than in the period 1980–1999, depending on the scenario (equal to about 1.5 to 6.9°C compared to pre-industrial temperatures).

Temperatures will change differently in different regions. Figure 1.9 shows the pattern that can be expected: stronger warming around the poles (particularly the North Pole) and less warming around the equator. This is caused by the atmospheric circulation patterns that transport heat towards the poles. For the mid range scenario used in this figure temperatures around the North Pole are predicted to be more than 7.5°C higher by the end of the century than in 1990, more than twice as high as the global average.

Other characteristics of the climate by the end of the century include:

- Reduced snow cover
- Widespread increase of summer thaw in permafrost areas
- Strong reduction in summer Arctic sea ice cover (some models predict complete disappearance by the end of the century)
- More heat waves and heavy precipitation
- Stronger tropical cyclones
- Movement of storm tracks towards the North, with changing wind patterns.

Precipitation

For precipitation the general picture is that dry areas will tend to become drier and wet areas wetter. Figure 1.10 shows the changes in precipitation for the December to February