

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 1850¹.

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 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 1780². This was well beyond what can be expected of extreme events in an unchanged climate.

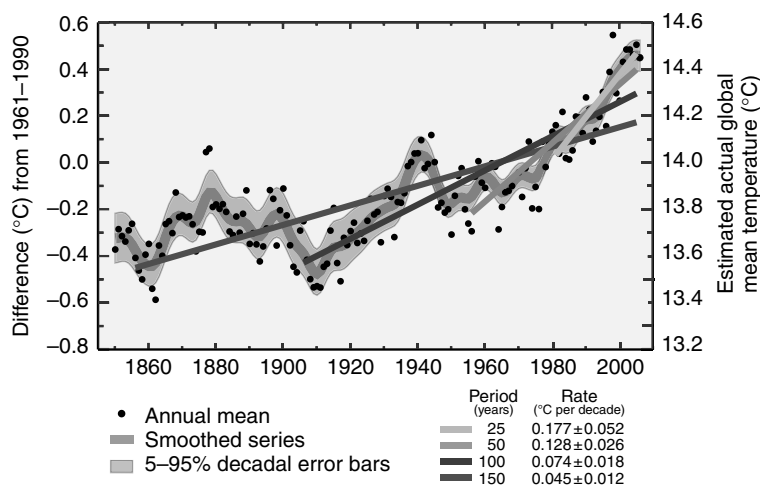


Figure 1.1

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

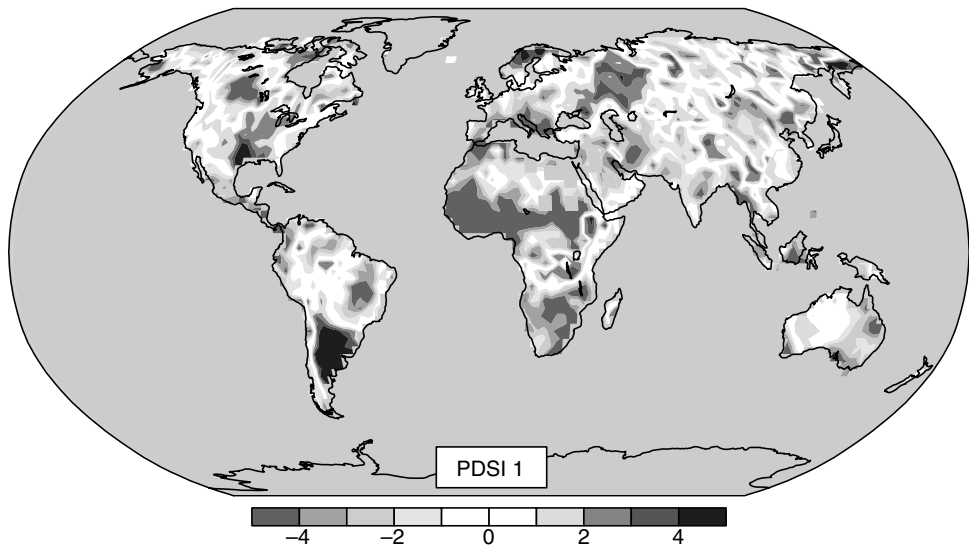
Temperature measurements

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 10km) they are higher than at the surface. In the stratosphere (10–30km) 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).

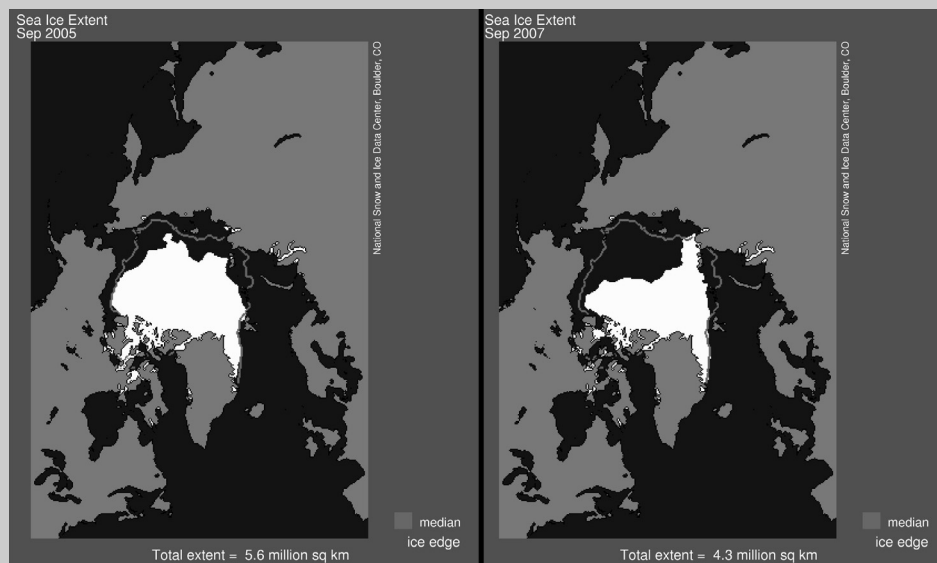
Box 1.2

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)

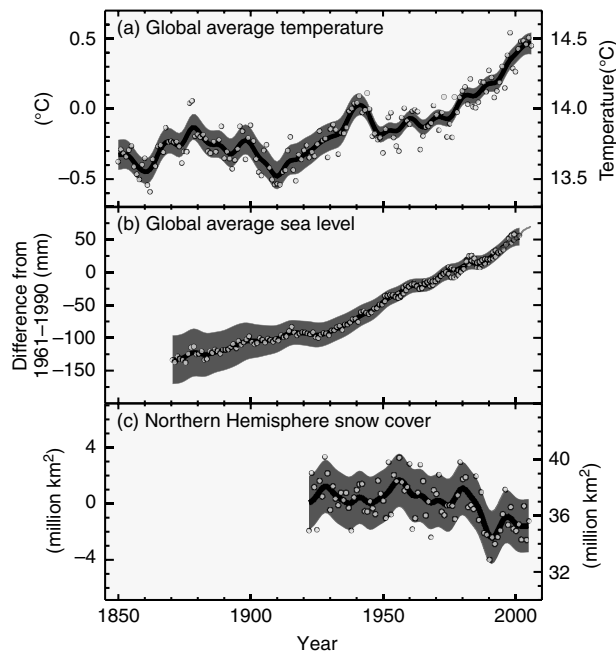


Figure 1.3

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 above³. 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 young⁴.

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.

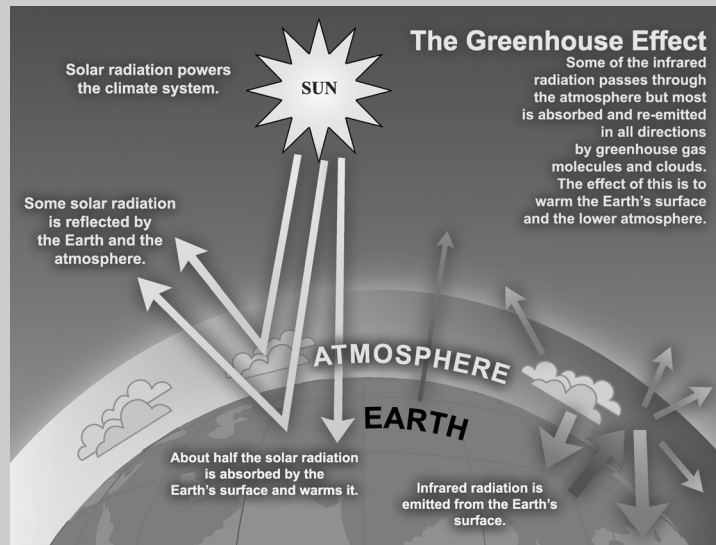
Some of the factors have a warming, others a cooling effect. Natural greenhouse gases (water, CO₂, methane) are in fact responsible for making planet earth suitable for life (see Box 1.3). The problem arose when human activities (burning of fossil fuel, agriculture, cutting forests, industrial processes 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 CO₂, 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: CO₂, 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 (CO₂), methane (CH₄), and nitrous oxides (N₂O) concentrations have gone up strongly since the beginning of the industrial revolution (see Figure 1.4). CO₂ levels are now about 30% higher than before 1750, N₂O about 50% higher, and CH₄ approximately doubled.

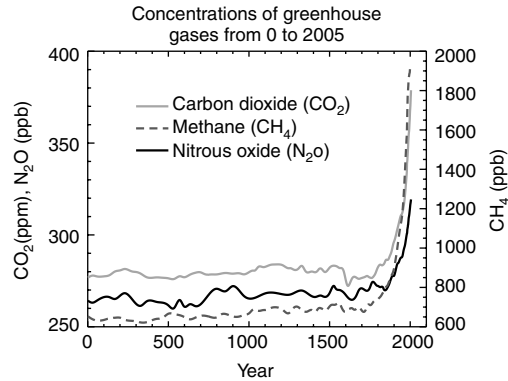


Figure 1.4 Concentrations of the most important greenhouse gases in the atmosphere over the last 2000 years. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of a greenhouse gas per million or billion molecules of air.

Source: IPCC Fourth Assessment report, Working Group I, figure 2.1.

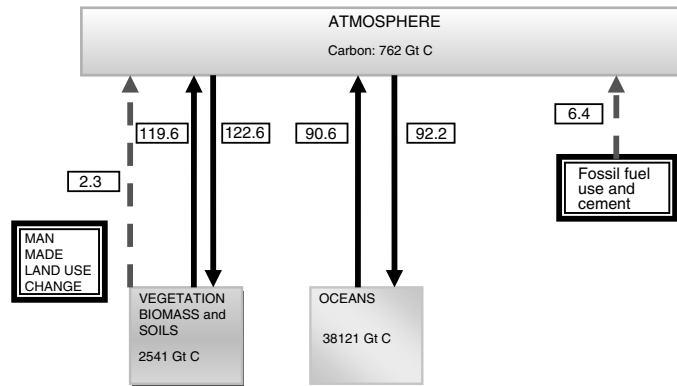


Figure 1.5 Schematic diagram of global carbon cycle. Shown are stocks of carbon (in GtC) and fluxes (in GtC/yr). Dashed lines represent man-made fluxes of carbon from fossil fuel, cement and land use, change. Land use change numbers are corrected for peatland emissions (see Chapter 9).

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 typically 100 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

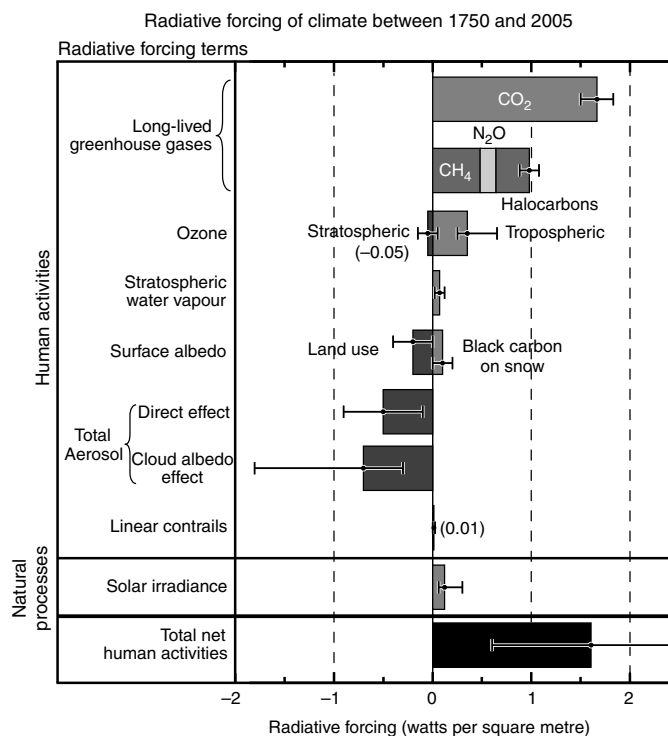


Figure 1.6

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 (CO₂, CH₄, N₂O, 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.

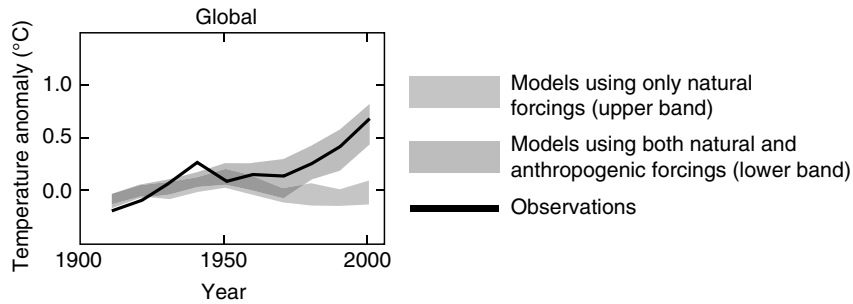


Figure 1.7 Global average temperature changes compared to the average for 1901–1950. The black line indicates measured temperatures. The lower band indicates the climate model calculation with only natural factors included. The upper band indicates climate model calculations with the effect of greenhouse 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).

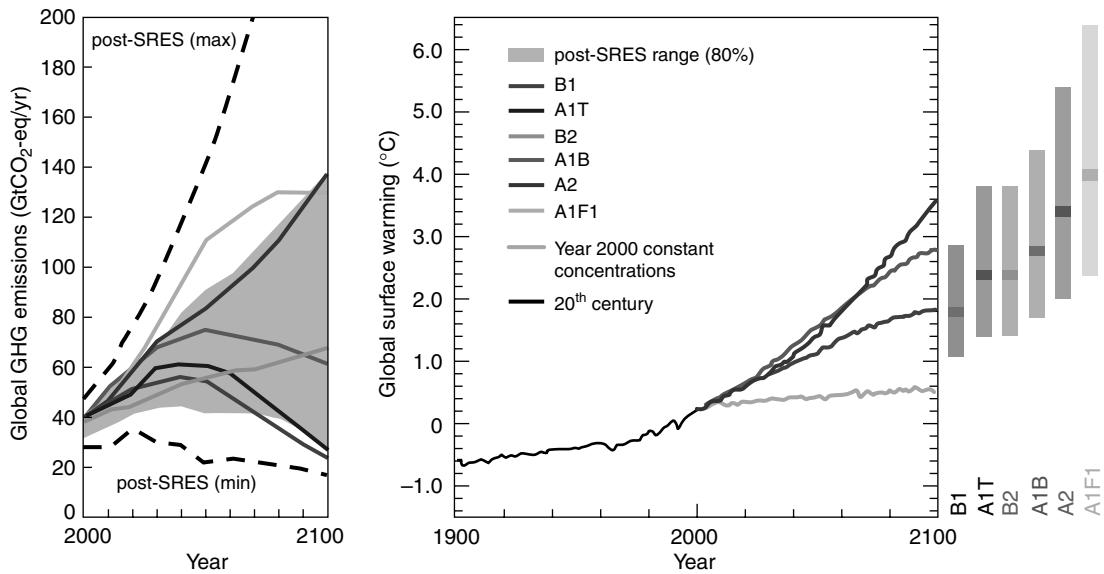
How is the climate going to change further in the future?

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).

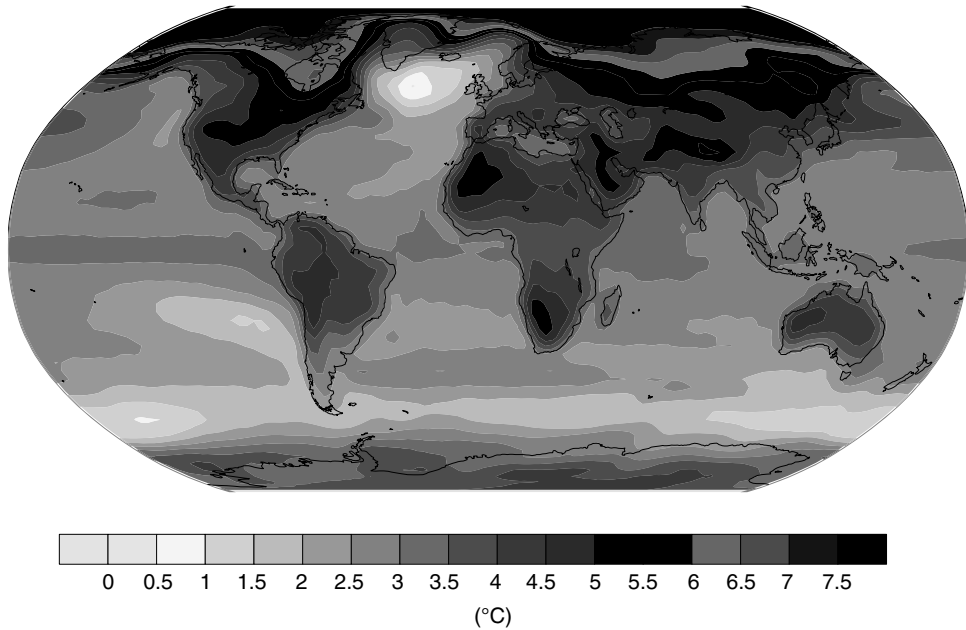
Temperatures will change differently in different regions. Figure 1.9 shows the pattern that can be expected: stronger warming around the poles (particularly the North Pole) and less warming around the equator. This is caused by the atmospheric circulation patterns that transport heat towards the poles. 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.

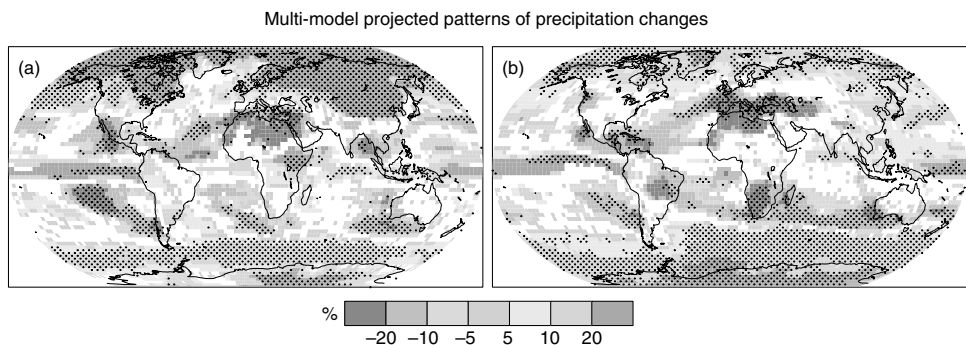
Precipitation

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

**Figure 1.9**

Projected surface temperature changes for the period 2090–2099, compared to 1980–1999. The average of different models is shown for the IPCC SRES A1B scenario (a middle of the range one).

Source: IPCC Fourth Assessment report, Synthesis Report, figure SPM.6. See Plate 3 for colour version.

**Figure 1.10**

Relative change in precipitation for the period 2090–2099, compared to 1990–1999. (a) December to February. (b) June to August. Model averages are shown for the IPCC SRES A1B scenario (a middle of the road one). White areas are where less than 66% of the models agree about increase or decrease. In stippled areas more than 90% of the models agree.

Source: IPCC Fourth Assessment report, Synthesis Report, figure 3.3. See Plate 4 for colour version.

and for the June to August period around 2095, compared to the situation in 1990 for a mid range scenario. In most subtropical areas rainfall decreases by up to about 30%, while in high latitudes increases in precipitation of more than 20% can be expected. More pessimistic scenarios regarding greenhouse gas emissions can give even bigger changes.

Sea level rise

Sea levels will rise as a result of warming. As discussed above it is the result of expansion of ocean water and of melting of land ice. It is a slow process. By the end of this century sea level rise is expected to be 20–60cm compared to 1990. But it does not stop there. Even if, through a miracle, concentrations of greenhouse gases in the atmosphere could be kept at the current level, sea level will continue to rise by about 1 meter. And with the sharply increasing concentrations expected over the course of this century, we could be heading for several meters of sea level rise over the next few hundred years. These numbers do not include melting of the large land ice masses in Greenland and Antarctica. The Greenland ice sheet is most at risk of melting. Our current knowledge says that for global temperature increases of 2–4.5°C (well within the range we will see in the course of this century, if no action is taken) the Greenland ice will melt. This will take somewhere between a few hundred to a few thousand years, but total melting means 7 metres of additional sea level rise. This is comparable to the situation on earth about 125000 years ago, when temperatures in Greenland were about 4°C higher than today, a large part of the Greenland ice sheet had melted, and the sea level was 4–6 meters higher than today⁶. Recent observations of ice flow in Greenland suggest that the process of melting could be much faster than climate models have assumed so far. Melt water seems to go down crevices to the base of the ice sheet, where it acts as a lubricant, moving the ice faster out to sea. If this mechanism is the dominant one, complete disintegration and melting could happen in a few hundred years. Our current knowledge is insufficient however to be certain about that⁷.

Climate models

Climate change projections are the result of climate change model calculations. Climate models describe in mathematical equations the incoming solar radiation, the retention of energy by greenhouse gases and reflection of radiation by clouds and aerosols, the circulation of air across the globe, the interaction of the atmosphere with the oceans, rainfall, the formation of ice, and many more processes that determine the earth climate. Different models give different outcomes, because of the many assumptions made about the various processes that determine the climate.

One of the most difficult problems is how to describe the different feedback mechanisms in the earth climate system. Water for instance is a powerful greenhouse gas. When the air warms it can contain more water vapour, which strengthens the warming. It also forms clouds that can either have a cooling or a warming effect, depending on the type, height, and structure of the clouds. It is difficult to determine how much additional warming will be the result of this. Other feedback mechanisms are the reflection of ice and snow. More ice and snow means more reflected radiation and cooling. Disappearing snow and ice means warming, which will reduce snow and ice further.

Together these uncertainties are captured in the so-called “climate sensitivity”, the warming that occurs for a doubling of CO₂ concentrations in the atmosphere compared to its pre-industrial concentration. The most recent estimate of climate sensitivity is 3°C, with a probability of 66% that it lies between 2 and 4.5°C. That is a big uncertainty. And there is a chance the climate sensitivity is even higher. In other words, when calculating the warming as a result of increases in greenhouse gas concentrations in the atmosphere using the best estimate of climate sensitivity (the 3°C value used in most calculations), actual warming could be twice as small or twice as big. See also Box 1.4.

Box 1.4**How reliable are current climate model predictions?**

Although models have their limitations, there is considerable confidence in their predictions of future climate change. This confidence is based on the fact that the descriptions of the various processes is based on generally accepted principles of physics, and from their ability to reproduce observed changes in current and past climates. Models can reproduce climate change over the past 150 years pretty well (see Figure 1.5 above), including the short term effect of volcanic eruptions. They also have been able to reproduce the climate over the past 20000 years (including part of the last ice age) reasonably well. Confidence in model predictions is higher for temperatures than for precipitation, although temperature extremes are still difficult. Confidence in model results for large areas is much higher than for smaller regions.

The fact that weather forecasting models become very unreliable beyond periods of a few days does not mean that they cannot be used for climate forecasting. On the contrary, their reliability increases when applied over longer periods of time, when average weather (= climate) is the desired outcome.

(Source: IPCC Fourth Assessment Report, Working Group I, Frequently Asked Questions 8.1)

What will be the impact of future climate change?

Human and natural systems will be exposed to climate change. If the affected people, infrastructures, human activities, or nature are sensitive to climate change, then an impact occurs. We speak about vulnerability to climate change if the capacity to adapt is also taken into account: a system may be sensitive, but if it can adapt easily to the new climatic condition, then it is not vulnerable. The capacity to adapt depends on a range of social and economic factors (see Figure 1.11). In practice the distinction between impact and vulnerability is not always clearly made. In the discussion below the two are separated where possible.

First, the most important impacts will be discussed on a sectoral basis: water, food, nature, health, and infrastructure and human settlements. Then the impacts are grouped together on a regional basis and also vulnerabilities are considered. Finally an overall assessment is made of the most important vulnerabilities.

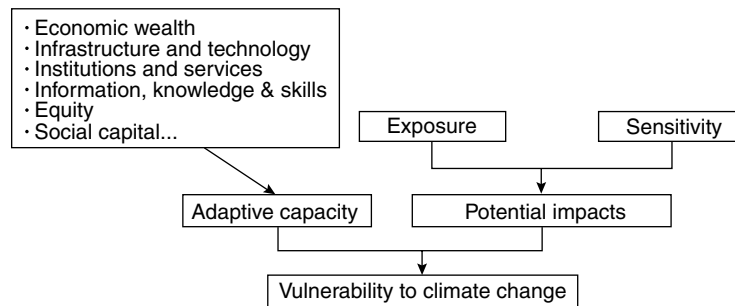


Figure 1.11

Definition of and factors contributing to vulnerability to climate change.

Source: Stern review, chapter 4.

Water⁸

Freshwater is vital for human health, food production, forests and ecosystems, cooling water for power plants and industries, and hydropower. Too much water means floods and mud slides, crop failure, and threats to hydropower dams. Too little water means lack of drinking water, crop failure, forest die-back, ecosystem loss, and severe constraints on shipping, industrial production and electricity generation. Sea level rise will mean salt intrusion in fresh groundwater, making it no longer suitable for drinking or agriculture. Increased temperatures and drought periods will make water pollution more serious, so that it can no longer be used for producing drinking water or for irrigation.

Changes in rainfall or snowfall, melting of glaciers, and increasing temperatures (that lead to more evaporation of water) will lead to significant changes in available freshwater. Generally speaking the pattern is similar to the one for changes in precipitation shown in Figure 1.9 above. Wet areas (northern latitudes, tropics) will have more available water, while dry areas (subtropics, in particular Mediterranean and North Africa, Southern Africa, Western Australia, Amazon) will have less water available. By the end of this century water availability in some areas could be 30–50% lower than today, and in others up to 50% higher.

The scale of problems that can be expected with freshwater availability is enormous. Almost 20% of the world's population live in areas where glaciers or snow feed the rivers, which will be affected by glacier melting. Furthermore 20% live in river basins that are likely to have increased risk of flooding by the end of the century. The total number of people that will face increased problems with water availability will be about 2–3 billion by 2080. Pressure on ecosystems will strongly increase. And all of this is in addition to increasing scarcity of freshwater due to population growth, increased wealth, and more agriculture, energy and industry needs.

More specifically, by 2020 75–250 million people in Africa will have to face increased water scarcity. By 2030 water availability in large parts of Australia and New Zealand is

going to cause problems. By 2050 freshwater availability in large parts of Asia is going to decline, particularly in large river basins. There is the threat that by mid-century the Amazon forest will be turned into a dry savannah landscape due to drying out of soils. In other parts of Latin America drinking water scarcity and constraints on agriculture and hydropower can be expected. By mid-century fresh groundwater in many small low-lying islands will seriously diminish due to salt water intrusion. In the American West more winter flooding and summer droughts are expected. In Southern Europe water scarcity could reduce hydropower capacity by more than 25% by 2070. And in terms of the impact of flooding, in Bangladesh annual floods will cover 25% more land in the course of this century, where pressure on agricultural land and land for human settlements is already high and the population is still growing.

Food⁹

Increasing temperatures will increase productivity of some crops such as wheat and maize in temperate regions, provided there is enough water. Above a 3°C increase however crop productivity will decline. In tropical and subtropical areas even moderate temperature increases of 1–2°C will reduce crop productivity of most cereal crops that form the basic food of people, such as rice, maize, and wheat. This means increased risk of malnutrition and hunger. Although total global food production could increase up to a warming of 3°C, food scarcity in poor countries is a real danger even at much lower temperature increases. The recent explosion of food prices and the reactions from exporting nations to ban exports of rice and wheat show how fragile the world food market is. Regional scarcity and high prices often mean poor people will not get the food they need. Above 3°C, total food production will decrease, making poor countries and poor people even more vulnerable to hunger. This effect counters the expected improvement in food security as a result of increasing incomes. In addition to the effects of temperature and average rainfall, food production will suffer from irregular rainfall patterns and extreme weather events, such as heat waves, extended droughts, heavy precipitation, and cyclones.

In parts of Africa (Sahel, East Africa, and southern Africa) yields from rain-fed agriculture could be reduced by 50% as early as 2020. Given the strong dependence of many African economies on the agricultural sector (10–70% of GDP earned there), this is not only threatening food security, but will also seriously affect the economy as a whole. In southern and eastern Australia, one of the major exporting areas of wheat, droughts are expected to reduce crop yields. In southern Europe crop yields are primarily affected by water availability. Enhanced irrigation could keep productivity up, but water availability is a problem. In Latin America temperate region crops such as soybeans will do better with moderate temperature increases, but rice production in subtropical and tropical areas is expected to suffer. Productivity in the poultry and cattle industries, which are strong in Latin America, will go down as well. Natural grazing lands will partly suffer from

drought, and overgrazing may happen in areas that have water. Both will have a negative influence on pastoral populations.

Fishery will also be affected. Sensitivity to ocean temperatures is well known. The El Nino cyclical movement of warm water across the Pacific Ocean towards South America strongly reduces fish catch along the coast of Peru. With a changing climate movement of fish to different areas, changes in available food, and spreading of diseases to new areas and to fish farms (now about half of the total wild catch) off the coast all may have negative consequences. Higher fish growth rates are unlikely to compensate for this. Climate change impacts come on top of heavy overfishing in many parts of the oceans as well as disturbance or loss of breeding grounds in mangrove forest, coral reefs, and tidal areas. Local fishing communities will suffer from these changes.

Nature¹⁰

Nature is formed by all the ecosystems on earth. Ecosystems form the backbone of the earth's ability to provide habitable conditions. They consist of webs of plants, animals, insects, and bacteria that interact with each other to create a living system. They provide invaluable services to the global economy via the provision of clean water, shelter, food, building materials, medicines, recreation, and tourism¹¹. They also capture large amounts of CO₂ from the atmosphere and reduce the amounts that stay in the atmosphere (they are 'net sinks' of CO₂). Ecosystems are under enormous pressure already. Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period in human history. This has resulted in a substantial and largely irreversible loss in the diversity of life on earth. Climate change impacts are going to be added to this.

Ecosystems are very much adapted to climatic conditions. They are optimized to the climate we had for the last thousands of years. Slow changes, i.e. changes over periods of thousands of years, can usually be accommodated by natural ecosystem adaptation. Rapid changes as we are facing now, i.e. where we see significant changes over a period of 100 years or so, are too fast for many species to adapt to. Within this century ecosystems will see the highest CO₂ concentrations in at least the last 650000 years, the highest temperatures in at least the last 740000 years, and the most acid ocean waters in more than 20 million years. Natural adaptation is further threatened by man-made and natural obstacles for migration of animals and plants (roads, towns, rivers, mountains).

The threats from climate change do not only come in the form of higher temperatures, heat waves, and changes in precipitation. Wildfires as a result of drought, explosions in insect numbers as a result of changing climate, and more acid ocean water as a result of CO₂ dissolving in sea water, all contribute to the impacts on ecosystems. Impacts on ecosystems are often of the so-called 'threshold' type. Above a certain level of temperature or acidity or drought one or more species can no longer survive (which can easily lead to extinction for species that are unique to certain areas) and with the decline in those species ecosystems as a whole may collapse.

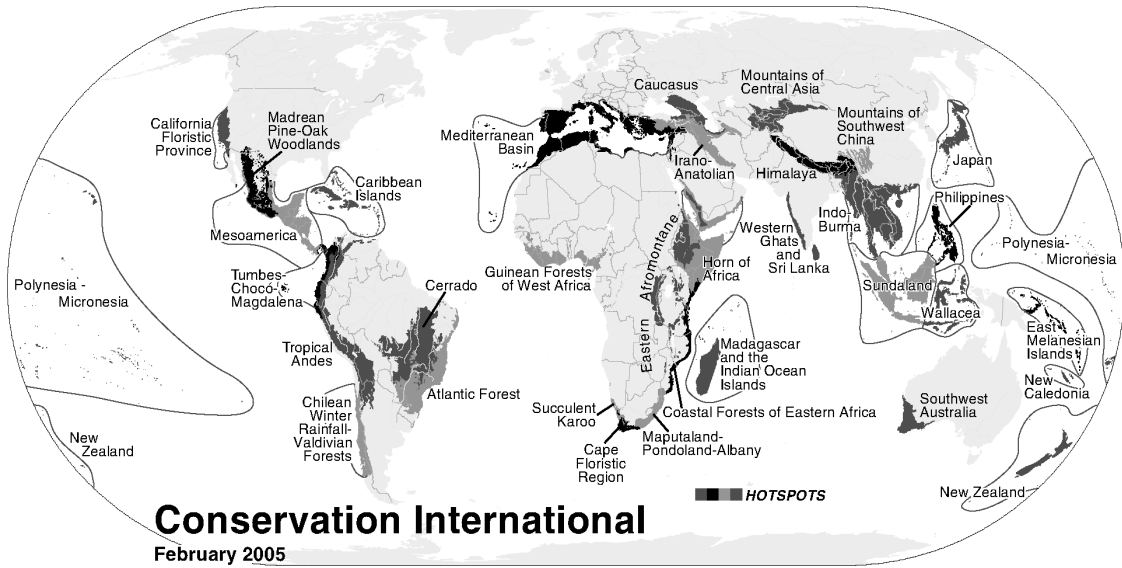


Figure 1.12

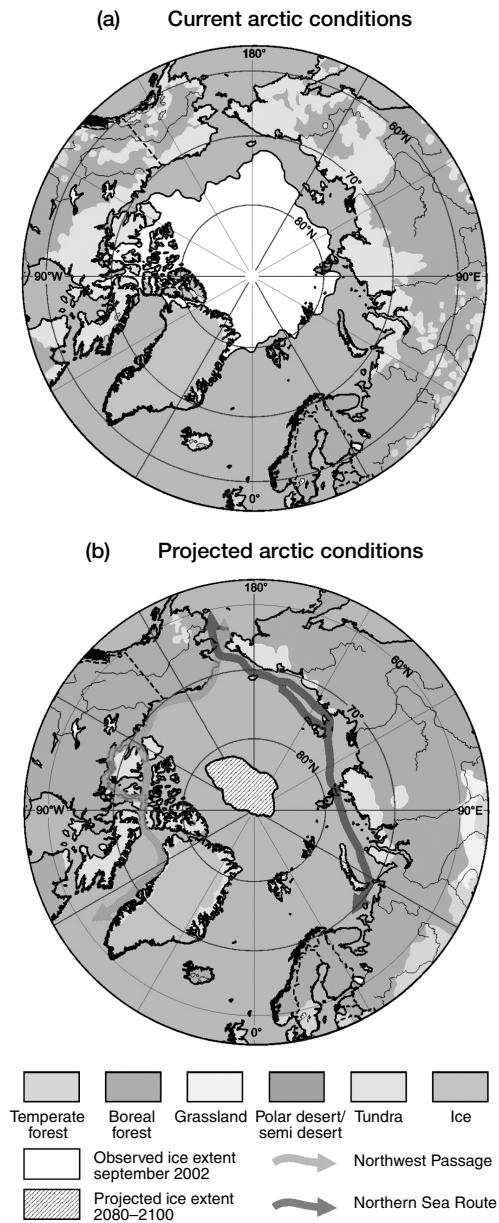
Biodiversity hotspots.

Source: Conservation International, www.biodiversityhotspots.org. See Plate 5 for colour version.

The scale of the threat of climate change to nature is extremely large. For global average temperature increases of 1–2°C above what they were around 1990 (1.5–2.5 °C above the pre-industrial era) many sensitive and unique ecosystems are threatened with extinction. This includes ecosystems in many of the 34 areas with high concentrations of unique species that are seriously threatened (so-called ‘biodiversity hotspots’) that have been identified¹² (see Figure 1.12). At 1–3°C warming of sea water, coral reefs, currently already affected by warming, will face widespread bleaching and die off. At 1.5 to 2.5°C warming 20–30% of all species for which research was done are likely to be faced with extinction. For temperature increases beyond that many more species will face extinction.

In addition, some ocean organisms that form shells are going to be negatively affected by the increasing acidity of ocean water. Some form an important part of plankton and their disappearance could have major impacts on the food chain and on reflection at the surface and cloud formation above oceans. With higher temperatures the decomposition of plant material increases and as a result the capture and sequestration of CO₂ (the ‘net carbon sink’) has a good chance of changing into a net source of CO₂ before the end of this century.

Latin America is particularly under threat when it comes to ecosystems. All of its seven biodiversity hotspots are impacted by climate change, in addition to the threat to the Amazon forest. In Australia a number of very important ecosystems, including the Great Barrier Reef, are going to be negatively affected. In the Alps in Europe up to 60% of mountain plants face extinction by the end of the century, because it is no longer possible for these plants to move up the mountain to cooler areas. Polar bears have been declared a “threatened species” by the US government recently¹³ because the continuing loss of

**Figure 1.13**

Arctic sea ice and vegetation of Arctic and neighbouring regions. (a) 2005 conditions. (b) Projected for 2090–2100 under an IPCC IS92a scenario. Note the sharp decline in sea ice and tundra area.

Source: IPCC Fourth Assessment Report, Working group II, figure TS.16. See Plate 7 for colour version.

sea ice as a result of climate change is a serious threat to their survival (see Figure 1.13 and Box 1.5). Forest fires are likely to increase strongly in the big Northern forests of Siberia and Canada. Tundra areas will shrink causing loss of nesting areas for the several hundred million migratory birds that fly to the Arctic in summer¹⁴ (see also Figure 1.13).

Box 1.5**Polar bears threatened with extinction**

Polar bears are good swimmers, but they need sea ice to hunt for seals that live on the ice. Sea ice also gives them a way to move from one area to another. With more and more sea ice melting in summer their food supply will be in danger. Given that they give birth in winter and do not eat for 5 to 7 months in that period, having ample food in spring and summer is critical to them and their cubs. And that depends completely on the ice conditions. Signs of declining conditions for bears are already visible in the southern most ranges in Canada. Breeding success is already going down. Only if polar bears can adapt to a land-based summer lifestyle is there hope for their survival. Competition with brown and grizzly bears will be a big obstacle however.



Polar bear in arctic, 1999. Greenpeace/Daniel Beltrá.

Source: Greenpeace, <http://www.greenpeace.org/international/photosvideos/photos/polar-bear-in-arctic>.

(Source: Arctic Climate Impact Assessment, Synthesis Report, and IPCC Fourth Assessment Report, Working group II, box 4.5)

Health

Human health will be affected negatively by climate change. As a result of food scarcity malnutrition will increase. More frequent and intense extreme weather events (floods, storms, fires, droughts, heat waves) will lead to injuries and death. The heat wave of 2003 in Europe that caused an additional 35000 deaths could be a regular phenomenon by the end of the century. Higher temperatures and longer droughts will increase the risk of water pollution and food poisoning, leading to an increase in diarrhoea. Some mosquito-borne diseases like dengue fever and malaria will spread to some areas where they are not occurring now.

There are some positive effects as well, mainly the reduction of cold-related deaths and disappearance of malaria from some areas. On balance the negative effects clearly dominate (see Figure 1.14).

	Negative impact	Positive impact
Very high confidence		
Malaria: contraction and expansion, changes in transmission season	←	→
High confidence		
Increase in malnutrition	←	
Increase in the number of people suffering from death, disease and injuries from extreme weather events	←	
Increase in the frequency of cardiorespiratory diseases from changes in air quality	←	
Change in the range of infectious disease vectors	←	→
Reduction of cold-related deaths		→
Medium confidence		
Increase in the burden of diarrhoeal diseases	←	

Figure 1.14

Selected health impacts of climate change.

Source: IPCC Fourth Assessment Report, Working group II, figure TS.9.

Poor and elderly people, children, small farmers, and people in coastal areas will face the biggest impacts of these health risks because they are more exposed to climate change impacts, and they also do not have access to good health services.

Infrastructure and human settlements

The biggest risk for infrastructure and human settlements comes from coastal and river flooding as a result of increased precipitation and sea level rise¹⁵. With river deltas and coastal areas having enormous concentrations of people, impacts can be very serious, particularly in South-East Asia and Africa. Without adaptation more than 100 million people could face coastal flooding every year by the end of the century¹⁶. Millions of people could be permanently displaced in major coastal delta regions as a result of sea level rise alone (see Figure 1.15). Low-lying coastal urban areas, especially those that also undergo natural land subsidence and are in cyclone prone areas, such as Bangkok, New Orleans and Shanghai, face the risk of great damage. Low-lying small islands may even have to be abandoned. In the Caribbean and Pacific more than 50% of people live within 1.5km from the shore.

At present about 120 million people are exposed annually to tropical cyclones and on average more than 10000 people were killed every year between 1980 and 2000. Impacts from more intense tropical cyclones will lead to greater damage, particularly in coastal areas.

Very different risks are faced in permafrost (permanently frozen ground) areas. Melting of frozen ground in summer will happen in many areas where the ground is frozen year round (see also Figure 1.13). Roads, buildings, pipelines, and high voltage electricity lines may be seriously damaged and expensive reconstruction needed¹⁷.

**Figure 1.15**

Vulnerability of coastal river delta areas. Dots represent potential number of displaced persons due to sea level rise in combination with erosion and reduced sediment deposition from rivers in 2050. Extreme = more than 1 million; high = 50000 to 1 million; medium = 5000 to 50000.

Source: IPCC Fourth Assessment Report, Working Group II.

What is the combined effect of these impacts regionally?

The magnitude of climate change varies from region to region. Impacts from climate change are manifold and they come on top of other stresses. Table 1.1 gives an overview of the most prominent risks for each region.

In some areas the capacity to adapt to climate change is more limited than in others, usually because of poverty. That brings us to vulnerability: low adaptive capacity means a high vulnerability. In terms of the most vulnerable regions, the Arctic stands out because of the high rates of change and the big impact on ecosystems and human communities. Africa is particularly vulnerable because of its lack of adaptive capacity. Small islands and low-lying river deltas in Asia and Africa face the biggest risk of mass migration.

How can we characterize the overall vulnerability to climate change?

An overall picture of vulnerability to climate change cannot be captured in one indicator. The IPCC has used a set of five indicators that reflect the range of vulnerabilities that are relevant:

Table 1.1. Examples of some projected regional impacts

Africa	<ul style="list-style-type: none"> • By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change • By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition • Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5–10% of gross domestic product (GDP) • By 2080, an increase of 5–8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS)
Asia	<ul style="list-style-type: none"> • By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease • Coastal areas, especially heavily populated megadelta regions in South, East, and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers • Climate change is projected to add to the pressures on natural resources and the environment, associated with rapid urbanization, industrialization, and economic development • Disease and death due to diarrhoeal disease associated with floods and droughts are expected to rise in East, South, and South-East Asia due to projected changes in the hydrological cycle
Australia and New Zealand	<ul style="list-style-type: none"> • By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites including the Great Barrier Reef and Queensland Wet Tropics • By 2030, water security problems are projected to intensify in southern and eastern Australia and in northern and eastern New Zealand • By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions • By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding
Europe	<ul style="list-style-type: none"> • Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods, and more frequent coastal flooding and increased erosion (due to storminess and sea level rise) • Mountainous areas will face glacier retreat, reduced snow cover, and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080)

Latin America	<ul style="list-style-type: none"> • In Southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism, and, in general, crop productivity • Climate change is also projected to increase the health risks due to heat waves, and the frequency of wildfires • By mid century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid land vegetation • There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America • Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; <i>medium confidence</i>) • Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture, and energy generation
North America	<ul style="list-style-type: none"> • Warming in western mountains is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources • In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5–20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilized water resources • During the course of this century, cities that currently experience heat waves are expected to be further challenged by an increased number, intensity, and duration of heat waves during the course of the century, with potential for adverse health impacts • Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution
Polar regions	<ul style="list-style-type: none"> • The main projected biophysical effects are reductions in thickness and extent of glaciers and ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals, and higher predators • For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed • Detrimental impacts would include those on infrastructure and traditional indigenous ways of life • In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered
Small Islands	<ul style="list-style-type: none"> • Sea level rise is expected to exacerbate inundation, storm surge, erosion, and other coastal hazards, thus threatening vital infrastructure,

settlements, and facilities that support the livelihood of island communities

- Deterioration in coastal conditions, for example, through erosion of beaches and coral bleaching is expected to affect local resources
- By mid century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low rainfall periods
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands

Unless stated explicitly, all entries are from WGII SPM text, and are either very high confidence or high confidence statements reflecting different sectors (Agriculture, Ecosystems, Water, Coasts, Health, Industry, and Settlements). The WGII SPM refers to the source of the statements, timelines, and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emission scenarios, development pathways, and adaptation.

Source: IPCC Fourth Assessment Report, Synthesis Report, Table SPM.2.

Unique and threatened systems

As discussed extensively above, many ecosystems (coral, polar, mountain, and other systems) are vulnerable to increases in temperature of a few degrees centigrade. They typically have very little room to adapt to new circumstances.

Extreme weather events

Many of the more serious impacts are not caused by a gradual change of the climate, but by the extremes in temperature, precipitation, or wind speed. Table 1.2 gives an overview of these.

Distribution of impacts and vulnerabilities

Vulnerability is not about global averages. It is about the weakest people, the most sensitive coastal areas, and the most vulnerable infrastructure. When low-lying islands and coastal areas have to be abandoned, while other parts of the world face only minor problems, this cannot be averaged out. A chain is as strong as the weakest link. Africa, polar regions, and Asian megadelta regions were identified above as the most vulnerable.

Aggregate impacts

An obvious aggregation of impacts is the value of lost food production and damage to infrastructure and other market systems. Aggregating other non-market impacts such as species loss or loss of human life is much more difficult to quantify in monetary terms. As

Table 1.2.

Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column 2 relate to the phenomena listed in column 1

Phenomenon and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement, and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increased over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related deaths, especially for the elderly, chronically sick, very young, and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young, and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land	Adverse effects on quality of surface and groundwater; contamination of water supply; water	Increased risk of deaths, injuries, and infectious respiratory skin diseases	Disruption of settlements, commerce, transport, and societies due to flooding; pressures on urban and

Table 1.2. (cont.)

Phenomenon and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement, and society
Area affected by drought increases	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	scarcity may be relieved More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	rural infrastructures; loss of property Water shortage for settlements, industry, and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops and trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases	Disruption by flood and high winds; loss of insurance in vulnerable areas; potential for population migrations, loss of property
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Salt water intrusion in irrigation water, estuaries, and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries; migration-related health effects	Costs of coastal protection versus costs of relocation; potential for movement of populations; also see tropical cyclones above

Source: IPCC Fourth Assessment Report, Synthesis Report, Table SPM.3.

will be discussed below, total costs can go up to 5–20% of global GDP, with higher costs for very vulnerable countries. Other quantifications, for instance millions of people affected by certain impacts, are often even more useful to reflect the magnitude of the aggregated impacts.

Large-scale irreversible events

Some impacts are irreversible. When a plant or animal species becomes extinct, it is gone forever. When glaciers and ice sheets melt, they cannot be reconstructed. When sea levels rise metres as a result of that, it means much of the inundated land can no longer be reclaimed. When ocean circulation changes, there is no way to bring it back to its original state and it will have large impacts on fisheries and ocean ecosystems. It could trigger big changes in regional climate.

When melting permafrost generates large methane emissions from the new swamps that develop, that leads to a self-reinforcing warming. As indicated above, species extinction is likely to happen on a large scale in the course of this century if no action is taken. The other big and irreversible impacts probably will not occur this century, because more drastic warming is needed than what can be expected this century. With uncontrolled climate change however these conditions may well exist beyond 2100. The level of warming above which such irreversible processes occur are called ‘tipping points’.

Overall picture

Compared to the previous IPCC assessment, when knowledge about vulnerabilities was more limited, the picture has become more pessimistic. Vulnerabilities are more serious now for a given level of warming and the confidence in the findings is higher¹⁸.

What does this mean for development?

From the discussions above it is clear that climate change impacts are wide ranged and affect many people and important economic sectors, directly or indirectly. The total impact will be bigger than the sum of the individual impacts. Developing countries are the most vulnerable because of their much greater reliance on climate sensitive economic sectors such as agriculture, their low incomes, poor health systems, rapid population growth, and limited protection against extreme weather events. In addition, for many developing countries these impacts come on top of many other problems like poverty, lack of food security, environmental degradation, loss of biodiversity, and natural hazards. Achieving progress in key development areas, as for instance covered under the Millennium Development Goals, will be made much more difficult. Climate change can become a major obstacle for the elimination of poverty. Achieving real sustainable

development will become impossible for countries facing large climate change impacts, while this development is critical to increasing their adaptive capacity to reduce vulnerability to climate change.

How would this affect the economy? The broader social, economic, and environmental impacts that are discussed above reflect quite well the seriousness of the threats. However, economic aspects are so prominent in decision making that the impact on a country's GDP is providing useful information.

Calculating economic costs of impacts is very problematic (see Chapter 3 for a more in-depth discussion). A whole range of impacts needs to be quantified in monetary terms. Some affect goods that have a market value, in which case calculating the costs is relatively straightforward. Others affect health or nature, which does not have a market value and must therefore be quantified in indirect ways, for instance by asking people how much they are willing to spend to protect endangered species. Quantifying the value of a human life is particularly sensitive. This is the first source of uncertainty and of differences in outcomes from different studies.

Then there are other problems: how to compare costs made in the short term with costs to be made in the distant future when people might have become much richer? This is the so-called discount rate problem. And there is the problem of adding up all costs across countries with very different incomes. And how far do we go in looking into the future? Do we stop at impacts that are likely to happen this century or are we looking much further into the future with more corresponding serious climate change impacts? And do we use only average impacts or do we take into account low probability events that may have catastrophic consequences? All these things matter enormously when calculating the damages from climate change¹⁹.

How much does climate change cost? The range of costs found is 1–5% of global GDP for global average temperature increases of about 4°C, going up in some studies to 10% for 6°C warming. In developing countries costs are generally above average. The Stern review got even higher numbers when looking at per capita consumption: 5–20% of GDP, when the future is weighed heavily, impacts on poor people are counting more than impacts on rich people and by taking the low probability, high risks into proper account.

The conclusion must be that development, particularly in poorer countries, can be seriously undermined by climate change impacts.

Notes

1. For a more detailed discussion see IPCC Fourth Assessment Report, Synthesis Report, chapter 1 and Working Group I, chapters 3 and 4.
2. IPCC Fourth Assessment Report, Working Group I, box 3.6.
3. IPCC Fourth Assessment Report, Working Group II, chapter 1.4.
4. IPCC Fourth Assessment Report, Working Group II, chapter 4.4.10.
5. See IPCC Fourth Assessment Report, Working Group I, chapter 7.3 for a more detailed description of the carbon cycle.
6. IPCC Fourth Assessment Report, Working Group I, chapter 6.4.1.2.
7. IPCC Fourth Assessment Report, Working Group I, box 4.1.

8. See for an in-depth discussion IPCC Technical Paper on Water, 2008.
9. See for an in-depth discussion IPCC Fourth Assessment Report, Working Group II, chapter 5.
10. See for an in-depth discussion IPCC Fourth Assessment Report, Working Group II, chapter 4.
11. Millennium Ecosystem Assessment, Synthesis Report, <http://www.millenniumassessment.org/en/synthesis.aspx>.
12. A biological hotspot is defined by two criteria: (1) it is a region that contains at least 1500 plant species, unique for that area or ecosystem, and (2) it has already lost 70% or more of its original area. Collectively, 25 areas in 1999 held no less than 44% of the world's plants and 35% of terrestrial vertebrates in an area that formerly covered only 12% of the planet's land surface. The extent of this land area had been reduced by almost 90% of its original extent, such that this wealth of biodiversity was restricted to only 1.4% of land surface. There are now 34 of these hotspots identified. See <http://www.biodiversityhotspots.org>.
13. On 15 May 2008 the polar bear was declared a "threatened species" under the US Endangered Species Act; see <http://alaska.fws.gov/fisheries/mmm/polarbear/issues.htm>.
14. See Arctic Climate Impact Assessment, Synthesis report, page 45.
15. See for an in-depth discussion IPCC Fourth Assessment Report, Working Group II, chapter 6.
16. IPCC Fourth Assessment Report, Working Group II, chapter 6.2 and box 6.3.
17. Arctic Climate Impact Assessment, Overview Report.
18. IPCC Fourth Assessment Report, Synthesis Report, chapter 5.2.
19. See IPCC WG II, 2007, chapter 20.6 for an in-depth discussion.