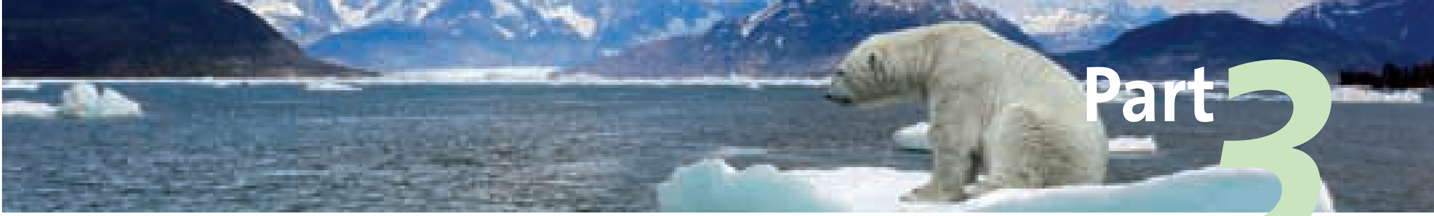

Part 3

The causes of climate change

There is no single cause of climate change. On the very long timescales of glacial to interglacial cycles, the most common explanation is the variation in the Earth's orbit around the Sun. On medium timescales of hundreds to thousands of years, variations in the Sun's solar output may fit the observed trends. The warming that the Earth has experienced in the last few decades (known as global warming) is seen increasingly as being driven by atmospheric pollution by humans (known as anthropogenic warming). In the IPCC's AR4 (2007) it is stated that: 'The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (2001) leading to very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming.' It also stated that 'most of the warming is very likely (odds 9 out of 10) due to greenhouse gases'.

Astronomical forcing

Milutin Milankovitch developed the theory of astronomical climate forcing in 1924. He argued that the surface temperature of the Earth changes over time because the orbit and axis tilt of the Earth vary over time. These variations lead to changes in the amount and distribution of solar radiation received by the Earth from the Sun. Over a timescale of 100 000 years, the Earth's orbit changes from circular to elliptical and back again. This affects the amount of radiation received from the Sun. On a timescale of 41 000 years, the Earth's axis tilts from 21.5° to 24.5° and back again. This changes the seasonality of the Earth's climate. The smaller the tilt, the smaller is the difference between summer and winter. In addition, on a 22 000-year timescale, the Earth's axis 'wobbles' and this changes the point in the year when the Earth is closest to the Sun.

In support of Milankovitch's theory is the fact that ice ages (glacials) have occurred at regular 100 000-year intervals. However, the actual impact of orbital changes on amount and distribution of solar radiation is small — probably only enough to change global temperature by 0.5°C. It is known from the evidence of past climate change that ice ages were about 5°C colder than interglacials.

Many scientists argue that **Milankovitch cycles** may have been enough to trigger a major global climate change, but that other mechanisms are needed to sustain it.

These mechanisms are known as 'feedback' effects. For example, small increases in snow and ice on a surface raise the **albedo** (the proportion of heat reflected) of that surface. More solar energy is reflected back by the white surface, contributing to further cooling, which in turn may encourage more snowfall. A small change therefore has an ever increasing effect.

Changes in solar output

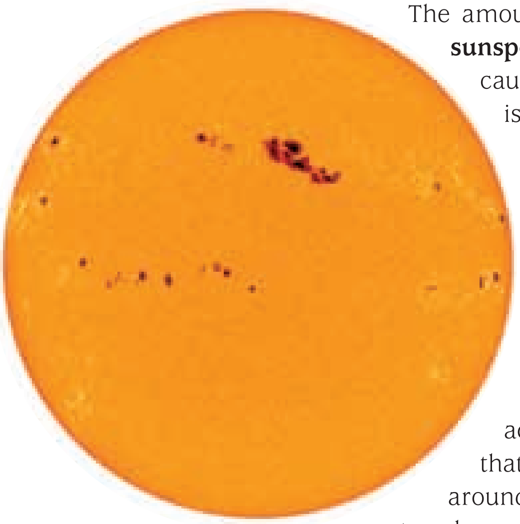

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Figure 3.1
Sunspots

The amount of energy emitted by the Sun varies as a result of **sunspots**. These are dark spots that appear on the Sun's surface, caused by intense magnetic storms. The effect of sunspots is to blast more solar radiation towards the Earth. There is a well-known 11-year sunspot cycle, as well as longer cycles. The total variation in solar radiation caused by sunspots is about 0.1%. Sunspots have been recorded for around 2000 years and there is a detailed record for around 400 years.

A long period with almost no sunspots occurred between 1645 and 1715, and this is linked to the Little Ice Age. Prior to that there was more intense sunspot activity, which could have led to the warmer conditions that existed at that time. Some scientists have suggested that around 20% of twentieth-century warming could be attributed to solar output variation.

The greenhouse effect

The **greenhouse effect** is a natural phenomenon. Atmospheric gases in the troposphere allow incoming short-wave radiation from the Sun to pass through and warm the Earth. Some of this radiation is reflected back at a longer wavelength from the Earth's surface into space. Greenhouse gases in the troposphere, such as water vapour and carbon dioxide, absorb some of this long-wave radiation and radiate it back again to the Earth's surface. This trapping of heat is known as 'the greenhouse effect' and is part of the natural process of heat balance in the atmosphere. It is essential for life on Earth. Temperatures are raised to a global average of 15°C; without the greenhouse effect the planet would be about 30°C colder. The greenhouse gases responsible for trapping heat include carbon dioxide, chlorofluorocarbons (CFCs), methane, water vapour, nitrous oxide and ozone.

Provided the amount of carbon dioxide and water vapour in the atmosphere stay the same and the amount of solar radiation is unchanged, then the temperature of the Earth remains in balance. However, this natural balance has been influenced by human activity. The atmospheric concentration of carbon dioxide has increased by about 15% in the last 100 years and the current rate of increase is estimated to

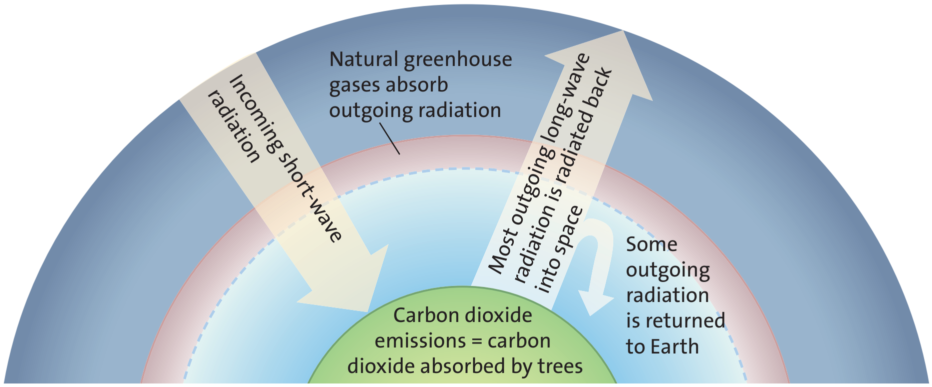

Figure 3.2
The greenhouse effect

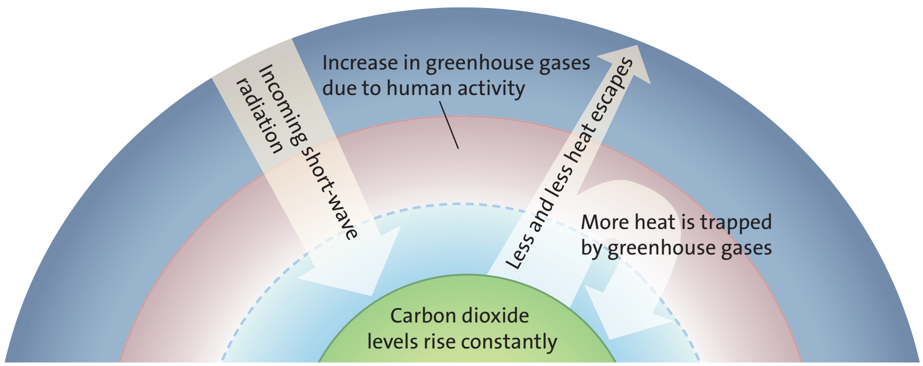

Figure 3.3
The enhanced greenhouse effect

be 0.4% per year. This, together with increases in levels of other greenhouse gases, such as methane and nitrous oxide, has upset the natural balance and led to global warming. Some scientists refer to these increased levels of greenhouse gases as the enhanced greenhouse effect.

In general, it is agreed that these continuing atmospheric changes will lead to a further rise in temperature. However, it is difficult to predict the extent or speed of change. If carbon dioxide levels double, then temperatures could rise by a further 2–3°C, with greater rises at higher latitudes, perhaps in the order of 7–8°C. It is believed that this warming will cause sea levels to rise.

One of the main reasons for the increase in atmospheric carbon dioxide has been the burning, in the industrialised nations of the world, of fossil fuels such as coal, oil and natural gas, which contain hydrocarbons. Developing countries (and some countries such as China are now well established) are beginning to generate energy as cheaply as possible. At the present time this means consuming huge quantities of fossil fuels, thereby adding to the problem.

Deforestation has also been linked to global warming. The rainforests of the world act as a 'carbon sink' because trees are a major store of non-atmospheric carbon. The more vegetation there is, the more carbon dioxide that can be processed by trees and other plants. The tropical rainforests are diminishing rapidly due to the demand for space and resources created by economic development in many countries — for example Brazil. Continued deforestation will, therefore, contribute to the build-up of carbon dioxide in the atmosphere. Large-scale pastoral farming, where huge herds of domestic cattle are reared for meat in areas cleared of forest, has been found to result in increased emissions of methane gas. Ironically, where the rainforests have been flooded to create reservoirs for the production of hydro-electric power (a form of renewable energy), decomposing vegetation within the lakes adds to carbon dioxide levels.

Other possible causes of climate change

Volcanic activity can alter global climate. Major eruptions eject material into the stratosphere where high winds distribute it around the world. Volcanoes eject huge volumes of ash, sulphur dioxide, water vapour and carbon dioxide. High in the atmosphere, sulphur dioxide forms a haze of sulphate aerosols that reduces the amount of sunlight received at the surface, thereby lowering temperatures. These changes are short lived as the sulphur aerosols persist for only 2 to 3 years.

Global dimming is a new phenomenon that has entered the debate. Atmospheric pollutants consisting of suspended particulate matter and sulphur dioxide reflect solar energy back into space and so have a net cooling effect. So, with the green-house effect having a warming effect, it is possible that human-created pollution is both warming and cooling the planet at the same time and that some pollutants are reducing the full impact of global warming. In both North America and Europe, soot and sulphur dioxide pollution has fallen dramatically since 1990 as a result of attempts to reduce acid rain. Could this have a link to the global warming trend that has accelerated since that time?

Case study 4 THE EL NIÑO SOUTHERN OSCILLATION (ENSO)

The Pacific Ocean contains large circulations of warm and cold water. El Niño and La Niña are linked to changes in these circulations, which in turn are linked to changes in atmospheric processes. This continually oscillating climatic pattern is known as the El Niño Southern Oscillation (**ENSO** — see Figure 3.4).

In a normal year, transfers of heat energy take place in the usual way between the equator and the subtropical high pressure zone and there are east-to-west surface circulations of warm air and water, called Walker circulations. The normal Walker circulation produces easterly trade winds between South America and Indonesia/Australia, taking warm water in a westerly direction and allowing cold water to move north along the Pacific coast of Peru.

Every few years this Walker circulation breaks down. The easterly trade winds decline and warm water moves eastwards across the Pacific to shut off the cold Peru ocean current and produce a warm ocean current (El Niño, 'the Christ child') off the South American coast. The high pressure which normally forms over the cold ocean is replaced by low pressure over the warmer ocean, which can have a temperature

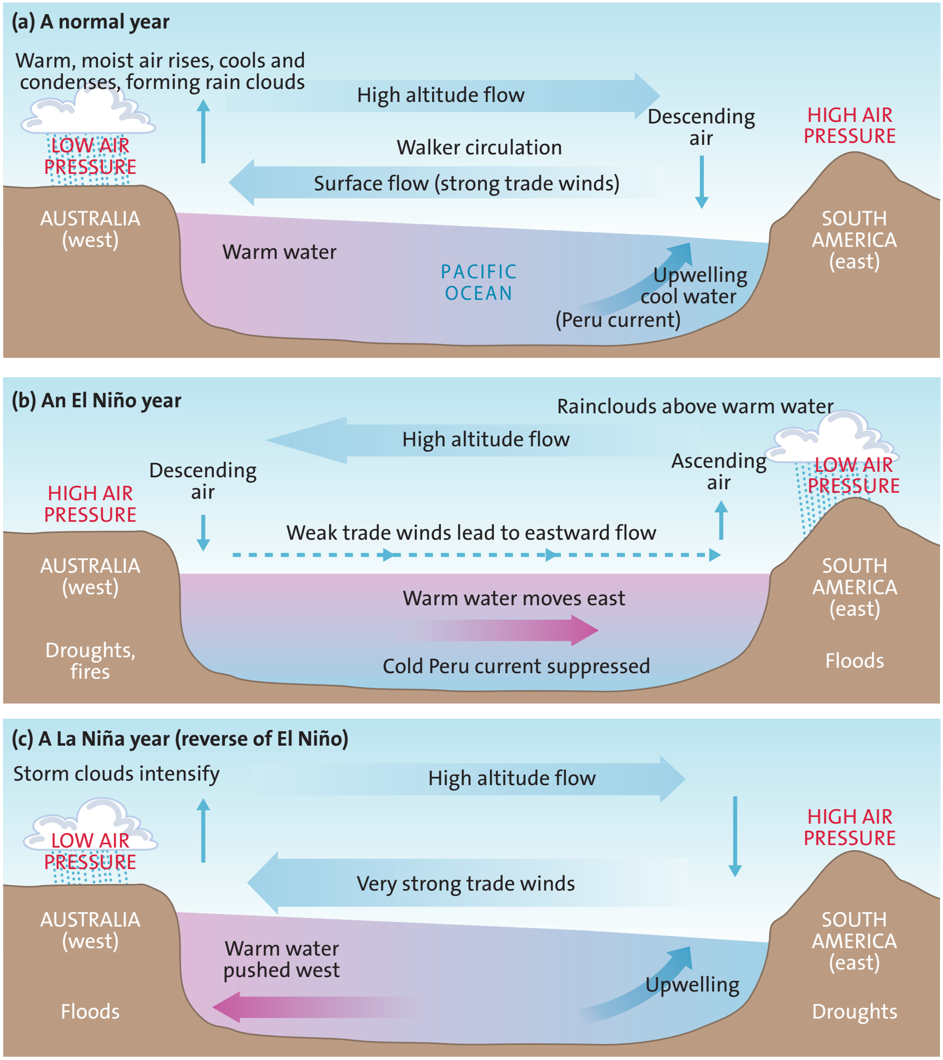

Figure 3.4
El Niño Southern Oscillation

6–10°C above normal. This produces heavy rainfall on the usually arid coastline of Peru and brings natural hazards, such as flooding. The change in circulation can have an effect elsewhere: the effect on the route of the jet stream can produce drought in other areas and even affect climatic events in the northern hemisphere, bringing increased snow and floods to North America. Conversely, the number of hurricane events in the Caribbean tends to be reduced in El Niño years.

Under the effects of the normal Walker circulation, the easterly trade winds cause warm water to build up in the area of the Coral Sea (between Australia and Indonesia). Sea levels rise and can cause ecological and economic damage to low-lying islands within the region. Recent research in Australia indicates that even a well-developed Walker circulation can cause extreme problems. With unusually strong easterlies, the cool water off South America can be moved northwards across the central Pacific, lowering ocean temperatures, pushing the warm water even further west and changing atmospheric pressure patterns to produce higher than average rainfall and cyclone intensities in a zone extending from Australia through Indonesia to Bangladesh. This is termed a La Niña event.

These changes to the normal circulation are not annual events; they occur at intervals of 2 to 7 years, although El Niño seems to have operated more regularly in recent years, with several in the early 1990s and a particularly catastrophic event in 1997–98. It is not known if these events are also linked to global warming, although it is believed that increased global warming could increase the variation attributed to ENSO. On the other hand, ENSO is regarded as a distinct phenomenon, and hence not all extreme weather events can be attributed to global warming.

Table 3.1
Effects of El Niño and La Niña events

During an El Niño event	During a La Niña event
Rainfall is reduced in southeast Asia, New Zealand, Australia and India leading to drought, crop failure and wildfires	Rainfall is higher than normal in Indonesia and the Philippines and lower than normal on the west coast of South America
Heavy rain in California, Mexico and the coasts of Peru and Ecuador often results in flooding and mudslides	Southern Africa and southeast Australia may experience floods
Suppression of the cold current in the east Pacific devastates fish catches off the west coast of South America	North eastern Africa, California and western South America may experience drought
Unusually strong winds in the Atlantic shear off the tops of clouds preventing convection cells forming, so there are fewer severe hurricanes in the USA and Caribbean	There are more hurricanes in the Caribbean and the southern USA
Tornadoes in the USA are reduced There are more cyclones in Hawaii and Polynesia, but fewer in northern Australia Southern Africa may experience drought while there may be floods in east Africa	

4 *Using case studies*

Question

Describe the varying effects of the El Niño and La Niña events both on the immediate areas affected and also on the global scale.

Guidance

The reasons for the ENSO (El Niño Southern Oscillation, including the event known as La Niña) are not yet understood fully, although their effects are described in many geographical texts. It would not be appropriate therefore to ask a question on their causes. However, one interesting aspect of this area of work is that both El Niño and La Niña affect not only their regional areas, but are also thought to affect weather and climate on a much bigger scale. This introduces another element of synopticity — the ability to see connections between different *scales* of effects: regional and global.

A response to this question should focus on the effects on two scales. For example, for La Nina:

Regional scale In northeastern Australia, there are warmer temperatures, lower atmospheric pressure, windier conditions, heavier rainfall, flash floods.

Global scale Rainfall is higher in Indonesia and lower on the west coast of South America; higher levels of rainfall on the eastern coast of southern Africa; lower levels of rainfall in northeastern Africa, California and western South America. Some people believe that hurricanes are more frequent in the Caribbean and southern USA.