Climate Change Science

Met Office

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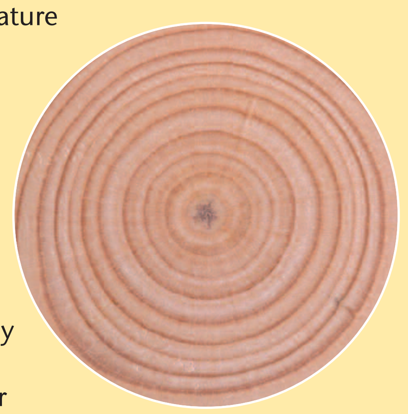
Then

We have a good understanding of what Earth's climate was like hundreds of thousands of years ago.

By analysing tree rings, air bubbles trapped in ice cores and the chemistry of ocean sediments, scientists can obtain information about the atmosphere and past temperatures.

In recent centuries, temperature measurements using thermometers have been made from weather stations on land, from ships and ocean buoys, and more recently using satellites.



Tree rings

Long-term data on the climate are relevant not only for understanding the past and present climate, but for what is likely to happen in the future.

Studying climate requires an understanding of the chemical and physical processes in the atmosphere.

In 1896, Svante Arrhenius (1859–1927), a Swedish chemist, linked the amount of greenhouse gases in the atmosphere, such as carbon dioxide (CO_2) and Earth's temperature.

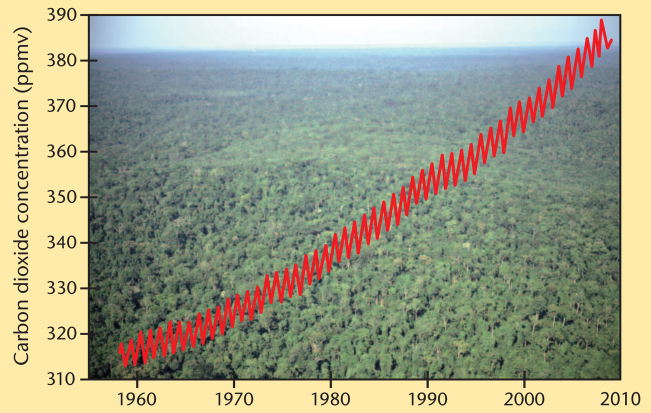
In 1938, Guy Callendar (1898–1964), a British military engineer, first suggested CO_2 levels were rising due to fossil-fuel burning.

Ice cores after drilling

Now

The science of climate change has come a long way.

In 1958, Charles Keeling began making direct measurements of CO_2 in the atmosphere in Hawaii. These data show a rapid rise in CO_2 and are used today by climate scientists across the world. Although the amount of CO_2 is different from season to season (there is less CO_2 in the air in the northern hemisphere in summer because increased vegetation growth absorbs CO_2) the annual CO_2 levels show a dramatic increase. We know the increase in CO_2 concentration is due to human activity.



Atmospheric CO_2 measured at Mauna Loa, Hawaii

Natural climate variability and change

To understand climate change, it is important to recognise the difference between weather and climate.

The weather is the state of the atmosphere around us. Temperature, rain, sunshine and wind change hour by hour and day by day. The climate is based on the average of these events over time, taking into account their variations.

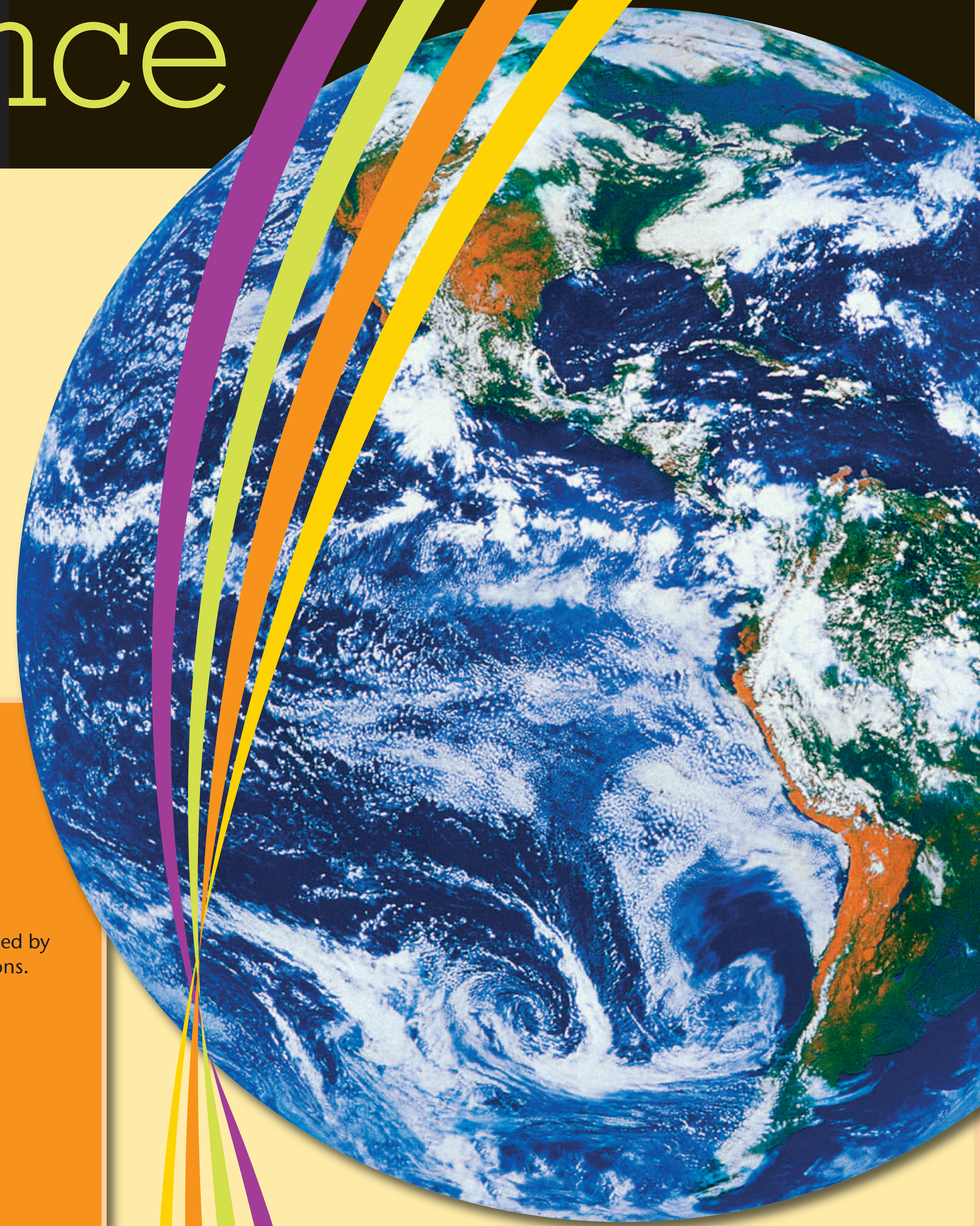
The climate differs around the world — for example, some areas are hot and humid while others are cold and dry. This depends on location. In the UK, some summers are hot, others cool; some winters colder and others warmer. This happens because of natural variability in Earth's climate.

In addition to natural variability, there are patterns in the climate. Some patterns are repeated yearly while others return after thousands of years. For example, whereas seasons return yearly, ice ages occur around every 100,000 years.

Ice ages are due to changes in Earth's tilt and orbit around the Sun.

Scientists are confident that the world has not been as warm as it is now for at least 1,300 years.

This rise in temperature cannot be explained by known natural forces such as solar variations. There is strong evidence that humans are responsible.



Some climate physics

There are many parts of the climate system. Here is a focus on just a few of the important physical principles that affect climate.

Thermal expansion

As water warms it expands and takes up more space. This is called thermal expansion and is an important factor affecting sea level rise.

Reflectivity

Snow and ice reflect the Sun's energy back into space, keeping Earth cooler than it would be otherwise.

A surface's reflectivity is called albedo.

Ice covers large areas of the Arctic, Antarctic and mountainous regions. As the climate warms, glaciers and ice caps around the world are melting at a rapid rate. As the ice melts, the land and ocean beneath are exposed. Because they are darker and less reflective (have a lower albedo) than ice they absorb more energy from the Sun, causing the atmosphere to warm further. This is like the difference between wearing a black jacket and a white jacket on a sunny day. We feel warmer in a dark jacket.

Displacement

When ice on the land melts it causes sea levels to rise, but when floating sea-ice melts there is no change to sea level.

This process is known as displacement or Archimedes' principle after the Greek mathematician, physicist, engineer, astronomer and philosopher who lived around 200 BC. He discovered the principles of density and buoyancy while taking a bath.

When icebergs or sea-ice melt there is almost no change in sea level, because the ice 'displaces' almost the same volume of water whether it is frozen or liquid. Try this experiment with ice cubes in a glass of water. However, when land ice melts (such as glaciers) sea level rises because more water is added to the ocean.

Just how much the sea level will rise in the future due to the melting of land ice is difficult to determine.

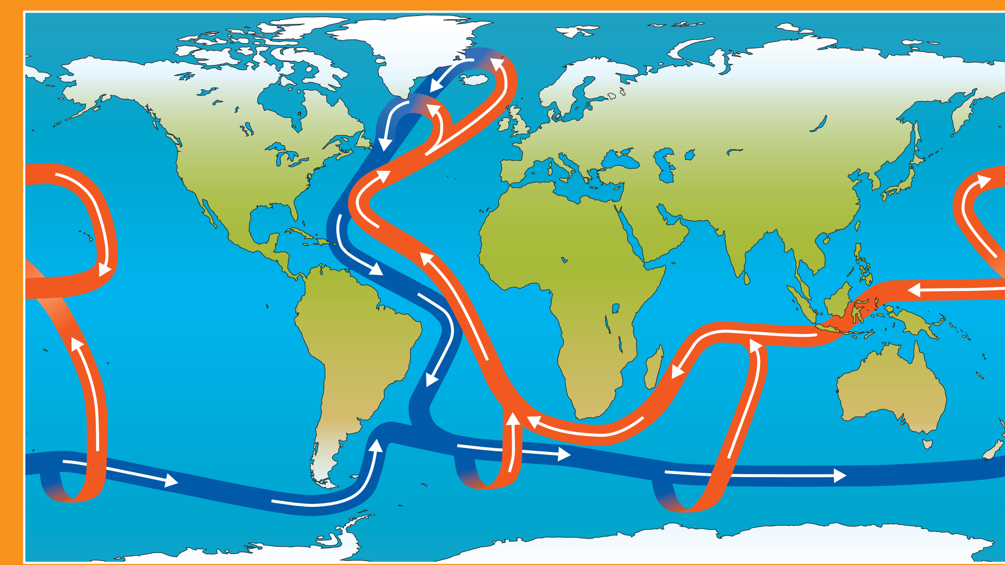
Interaction of ice and ocean

Oceans soak up and store more heat than the land and atmosphere, and so slow down the warming of the climate. The mixing of warm water currents at the sea surface and cold, deeper currents helps keep the overall temperature of Earth's atmosphere down.

These ocean currents, called the 'Ocean Conveyor Belt', transport heat around the world. At present, warm, salty water moves from the Gulf of Mexico and the Caribbean, northwards towards the UK and into the Arctic Ocean. Without this warm current, the UK would be much colder in winter.

As the warm, salty current moves north it gradually loses heat and cools to the temperature of the surrounding cold water of the Arctic. But because the current is saltier it is heavier than the surrounding water and sinks to the bottom of the ocean and then returns south as a cold current.

As Arctic glaciers melt and their freshwater flows into the salty ocean they can alter the Ocean Conveyor Belt and the climate. Freshwater is not as heavy as salty water so does not sink. This could slow down the ocean circulation and the movement of heat. Although it is thought that the circulation has stopped during past ice ages, it is unlikely that it will completely stop in the next 100 years in response to future climate change.



The 'Ocean Conveyor Belt' transports heat around the world. Red lines show warm surface water currents. Blue lines show cold deep water currents

The enhanced greenhouse effect

To understand how rising levels of CO_2 influence climate, imagine the atmosphere in terms of what happens in a greenhouse.

Energy from the Sun enters Earth's atmosphere in the form of shortwave radiation (sunlight). Where there are no clouds most of these rays pass through the atmosphere. On reaching Earth's surface they are absorbed and heat the land and sea.

As the land and sea warm they give off a different type of radiation, known as infrared. Infrared waves are invisible, longer and are absorbed by greenhouse gases in the atmosphere.

This heats the atmosphere. This natural process is known as the greenhouse effect because it is like the warming in a greenhouse. The atmosphere is similar to a blanket keeping Earth warm.

Without the greenhouse effect most of the Sun's heat would escape to space and Earth would be around 30 °C cooler than it is — too cold for most forms of life.

The main greenhouse gas responsible for recent climate change is CO_2.

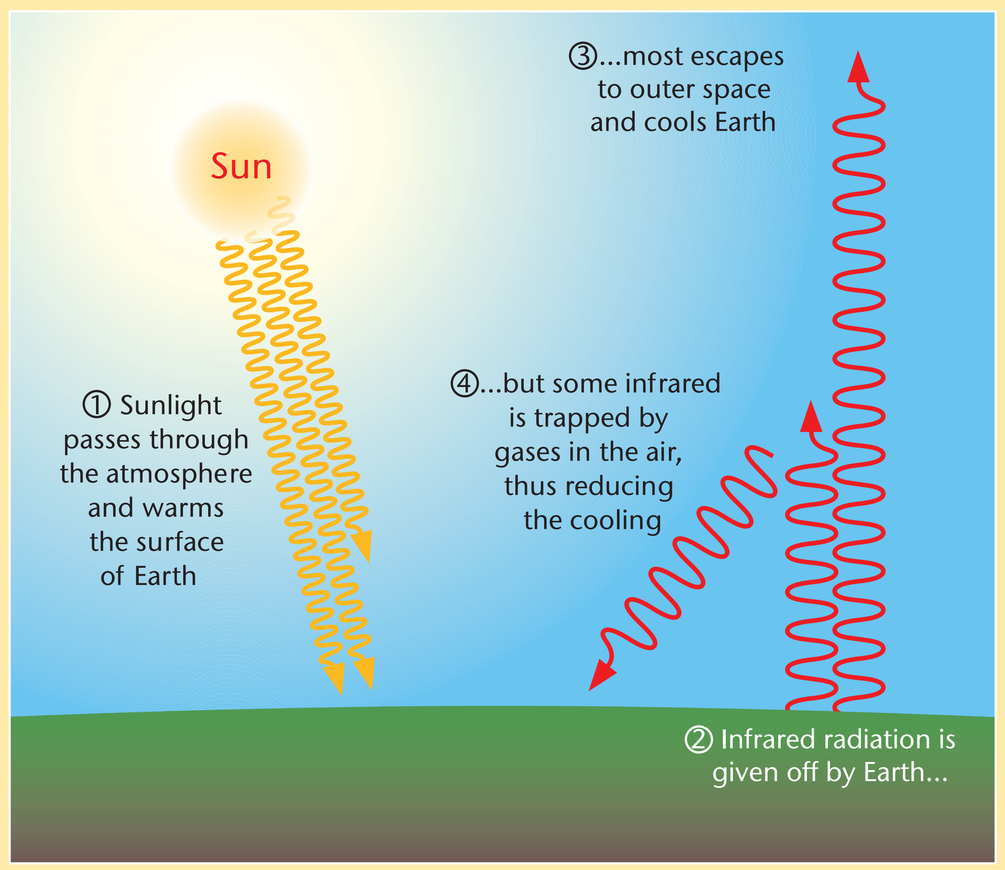
How are humans causing climate change?

For hundreds of thousands of years the amount of CO_2 in the atmosphere was much lower than it is today. Human activity has increased the amount of greenhouse gases and heat trapped in the atmosphere, enhancing the natural greenhouse effect. Scientists, politicians and the media often refer to the increase in temperature as 'global warming' or 'climate change'.

Burning fossil fuels containing carbon, like coal and oil, releases large amounts of CO_2 into the atmosphere. Cutting down forests also leads to an increase in CO_2 because trees absorb CO_2 from the air. Fewer trees mean less CO_2 will be absorbed. As trees decompose or are burnt, the carbon stored in them during photosynthesis (the process in which CO_2 is converted to plant material and oxygen) is released to the air.

The second most important greenhouse gas is methane, which is produced by bacteria that live in places like landfill sites, lakes, peat bogs and in the guts of animals like cows and sheep. Putting nitrogen fertiliser on to soils increases the amount of nitrous oxide in the air — another greenhouse gas.

High levels of greenhouse gases increase the temperature of Earth's atmosphere. CO_2 remains in the atmosphere for around 100 years before levels are reduced by being absorbed by the ocean and land vegetation. Some other greenhouse gases stay far longer. Because these gases stay around so long, reducing man-made emissions now will not be enough to stop climate change in the short-term, but will help to stabilise climate in the long-term.



The greenhouse effect

Burning fossil fuels releases CO_2

Cutting down forests increases levels of CO_2

Landfill sites and cattle generate methane

Predicting future climate

Predicting the future climate is important. We know from past and present temperature measurements that the world is warming, but how do we know what temperatures to expect in the future?

Scientists have a good idea of what influences the climate — the Sun, volcanic activity, greenhouse gases, small particles in the air (aerosols), clouds, ice, vegetation, land and the ocean. All these influences make up what is known as the climate system.

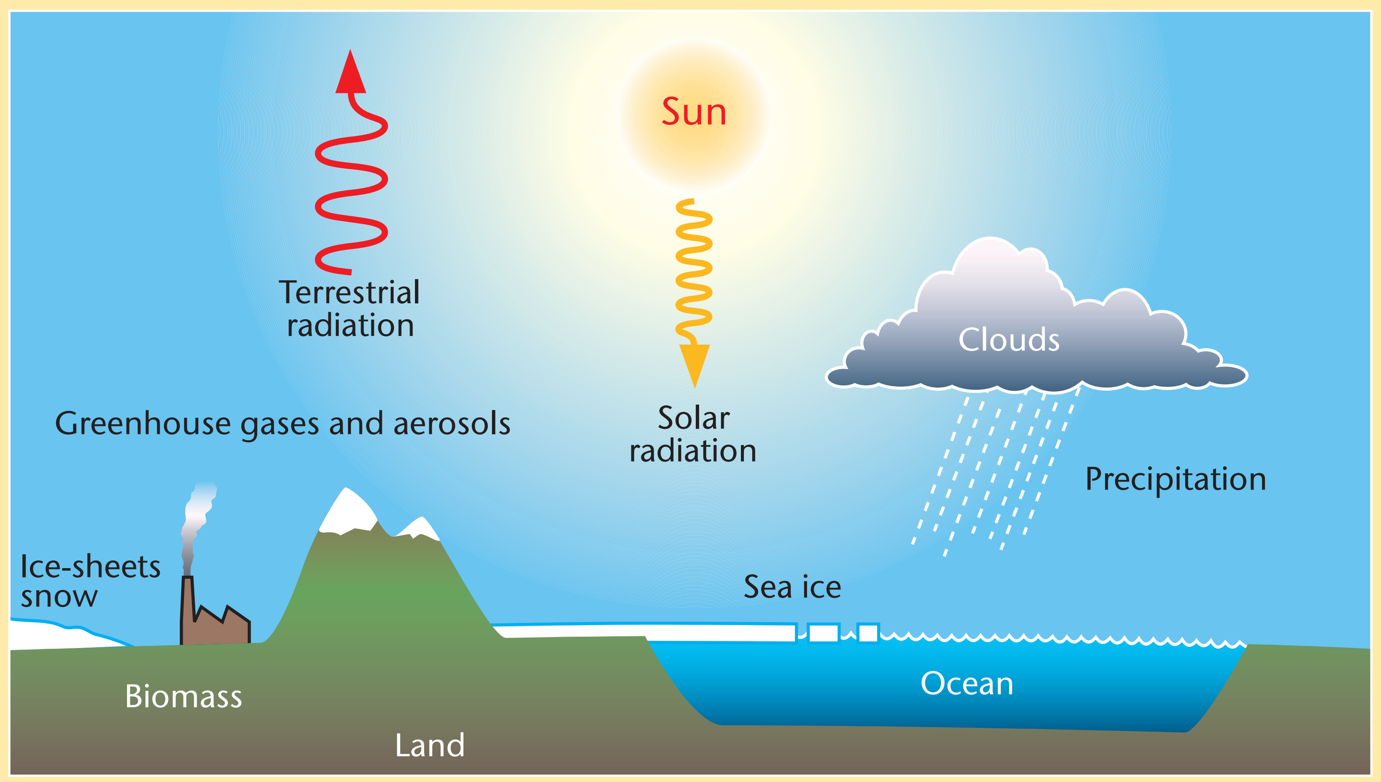
By considering all these factors, climate scientists can make predictions about climate change, enabling people, businesses and governments to make decisions about adapting as the climate changes.

Clouds

Clouds are a complex part of the climate system. They cool the planet down by shading Earth's surface from the Sun during the day. In contrast, they also insulate it by trapping heat that is trying to escape back into space, during both day and night. A warmer atmosphere evaporates more moisture from the ocean and land and some of this water vapour will turn into clouds. High clouds tend to warm the planet, while low ones cool it down. Climate scientists are currently looking at how changes to clouds will affect the future climate.

Maths and computing

To study climate change more closely, scientists have developed mathematical models of each part of the climate system and their interactions. Details of the chemical and physical processes are fed into powerful supercomputers that do billions of calculations every second.



The climate system

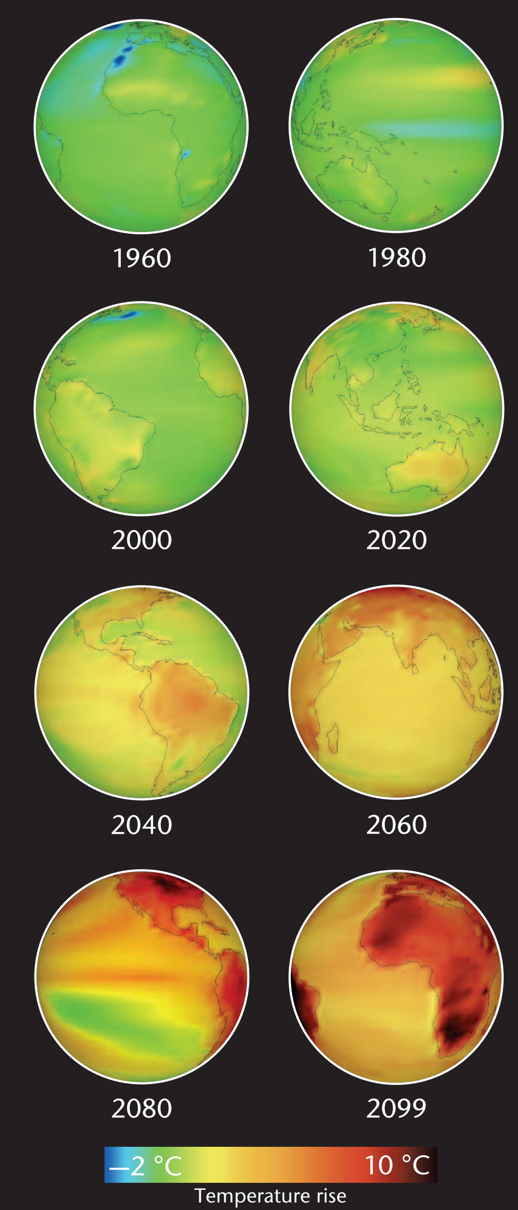
What if?

Predicting the future climate is complex and involves asking 'what if?'

For example, what will happen to the world's temperature if we continue to increase greenhouse gases? It is essential to have an idea of how things are likely to change in each country and region to prepare for the impacts on our lives and environment.

Climate scientists use different stories about the future known as scenarios (low, medium and high risk) to estimate how the climate might change.

The further into the future you look, the greater uncertainty there is. By 2080, the rise in UK temperature could be 2 °C or as much as 5 °C as we don't know how much greenhouse gas will be in the atmosphere. That depends on things like population levels and new technologies to reduce carbon emissions. Although there are uncertainties in predictions, computer models provide the best method for predicting future climate. They also provide the best information as a basis for our response to climate change.



Global average temperature rise — high risk scenario