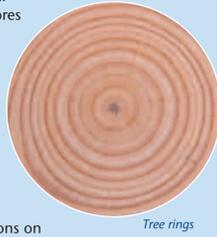


Then

We have a remarkably 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 (CO₂) and Earth's temperature.

In 1938, Guy Callendar (1898–1964), a British military engineer, first suggested CO₂ levels were rising due to fossil-fuel burning.

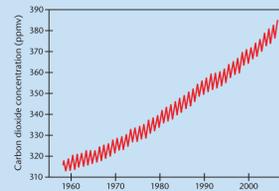


Ice cores after drilling

Now

The science of climate change has come a long way.

In 1958, Charles Keeling began making direct measurements of CO₂ in the atmosphere in Hawaii. These data are used today by climate scientists across the world and show a rapid rise in CO₂. Although the amount of CO₂ is different from season to season (there is less CO₂ in the air in the northern hemisphere in summer because increased vegetation growth absorbs CO₂) the annual CO₂ levels show a dramatic increase.



Atmospheric CO₂ 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 events like rain, sunshine and wind, which 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.

Underlying the variability, there are patterns in the climate. Some last a year or decade and others continue for hundreds or even thousands of years. For example, whereas seasons return yearly, ice ages occur around every 100,000 years and are followed by warmer periods, due to changes in Earth's tilt and orbit around the Sun.

Considering all this information, 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.



Ice skating on the Thames at Hoveley 1895

The enhanced greenhouse effect

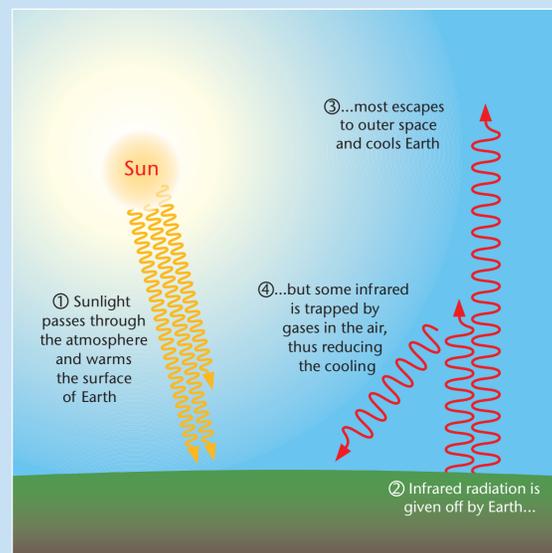
To understand how rising levels of CO₂ influence climate, imagine the atmosphere in terms of what happens in a greenhouse.

Energy from the Sun enters Earth's atmosphere in the form of shortwave radiation (sunlight). 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 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 warming the Earth.

Without the greenhouse effect most of the Sun's heat would escape to outer space and Earth would be at least 30 °C cooler than it is – too cold for human life.



The greenhouse effect

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How are humans causing climate change?

The main greenhouse gas responsible for recent climate change is CO₂. For hundreds of thousands of years the amount of this gas in the atmosphere has been 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 releases CO₂

Burning fossil fuels containing carbon, like coal and oil, releases large amounts of CO₂ into the atmosphere. Cutting down forests also leads to an increase in CO₂ because trees absorb CO₂ from the air. Fewer trees mean less CO₂ will be absorbed. As trees decompose, the carbon stored in them during photosynthesis (the process in which CO₂ 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.



Cutting down forests increases levels of CO₂



Cattle and landfill sites generate methane



Climate Change Science



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 future sea level rise.

Reflectivity

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

The measure of 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, land and ocean are exposed which are darker and less reflective because they have a lower albedo. This exposed surface absorbs more energy from the Sun which, in turn, warms the atmosphere even 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 the Archimedes' principle after the Greek mathematician, physicist, engineer, astronomer and philosopher who lived around 200 BC and 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.

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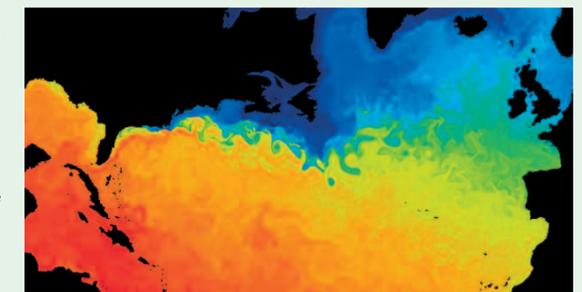
Interaction of ice and ocean

Oceans soak up and store more heat than the land and atmosphere, and so moderate the climate. Water takes longer to heat up than air, but retains the heat for longer. The mixing of ocean water carries heat to the depths of the ocean and helps keep the overall temperature of Earth's surface down. As glaciers and ice caps melt, freshwater is released and this can influence ocean currents and the world's climate.

A key element of the interactions between ice and ocean is an ocean current system called the 'Gulf Stream'. At present, warm water moves north from the Caribbean and Gulf of Mexico, crosses the Atlantic and travels past the

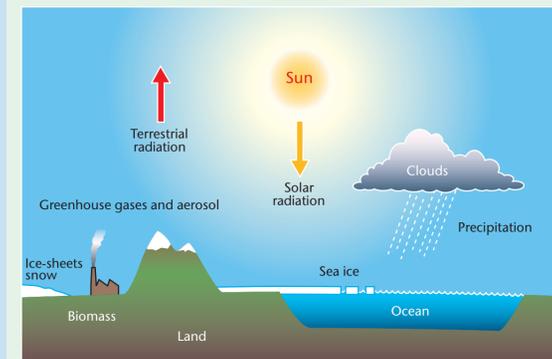
UK before flowing into the Arctic Ocean. Here, the cold, salty and dense water sinks to the bottom of the ocean and returns at depth to the Caribbean and Gulf of Mexico where it starts its journey again. Freshwater from melting Arctic ice mixes with the salty water reducing the density of the water and its ability to sink. This affects the flow of the Gulf Stream which currently keeps the climate of north-west Europe relatively mild.

An example of this is the contrast between the UK and Canada. Canada is as far north as the UK yet much colder in winter. It is possible that the Gulf Stream stopped during past ice ages, but it is unlikely to stop again before the year 2100 in response to future climate change.



Satellite image showing North Atlantic Ocean surface temperatures

Predicting future climate



The climate system

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, 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 and demonstrate how difficult it is to predict future climate. 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, especially at night. A warmer atmosphere evaporates more

moisture from the ocean and land and some of this water vapour forms clouds. High clouds tend to warm the planet, while low ones cool it down. Climate scientists are currently looking at how this will affect the future climate.

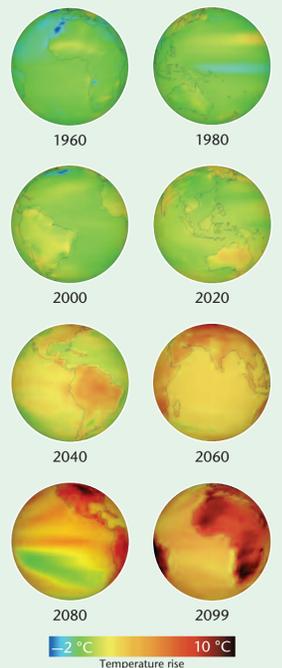


What if?

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? Climate scientists are confident in their forecasts of future global temperatures a century or more ahead. 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, but there is always uncertainty.

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 3.5 °C as we don't know how much greenhouse gas will be in the atmosphere. That depends on things like population levels and new technology. Although there are uncertainties in predictions, computer models provide the best method for predicting future climate and provide the best information as a basis for our response to climate change.



Global average temperature rise – high risk scenario

Maths and computing

To study climate change more closely, scientists have developed mathematical models of each part of the climate system and its actions and interactions. As many details as possible on the chemical and physical processes are fed into powerful supercomputers that do billions of calculations every second.