

Frequently Asked Questions

FAQ

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These Frequently Asked Questions have been extracted from the chapters of the underlying report and are compiled here. When referencing specific FAQs, please reference the corresponding chapter in the report from where the FAQ originated (e.g., FAQ 3.1 is part of Chapter 3).

FAQ 3.1 | How Do We Know Humans Are Responsible for Climate Change?

The dominant role of humans in driving recent climate change is clear. This conclusion is based on a synthesis of information from multiple lines of evidence, including direct observations of recent changes in Earth's climate; analyses of tree rings, ice cores, and other long-term records documenting how the climate has changed in the past; and computer simulations based on the fundamental physics that governs the climate system.

Climate is influenced by a range of factors. There are two main natural drivers of variations in climate on time scales of decades to centuries. The first is variations in the sun's activity, which alter the amount of incoming energy from the sun. The second is large volcanic eruptions, which increase the number of small particles (aerosols) in the upper atmosphere that reflect sunlight and cool the surface—an effect that can last for several years (see also FAQ 3.2). The main human drivers of climate change are increases in the atmospheric concentrations of greenhouse gases and of aerosols from burning fossil fuels, land use and other sources. The greenhouse gases trap infrared radiation near the surface, warming the climate. Aerosols, like those produced naturally by volcanoes, on average cool the climate by increasing the reflection of sunlight. Multiple lines of evidence demonstrate that human drivers are the main cause of recent climate change.

The current rates of increase of the concentration of the major greenhouse gases (carbon dioxide, methane and nitrous oxide) are unprecedented over at least the last 800,000 years. Several lines of evidence clearly show that these increases are the results of human activities. The basic physics underlying the warming effect of greenhouse gases on the climate has been understood for more than a century, and our current understanding has been used to develop the latest generation climate models (see FAQ 3.3). Like weather forecasting models, climate models represent the state of the atmosphere on a grid and simulate its evolution over time based on physical principles. They include a representation of the ocean, sea ice and the main processes important in driving climate and climate change.

Results consistently show that such climate models can only reproduce the observed warming (black line in FAQ 3.1, Figure 1) when including the effects of human activities (grey band in FAQ 3.1, Figure 1), in particular the increasing concentrations of greenhouse gases. These climate models show a dominant warming effect of greenhouse gas increases (red band, which shows the warming effects of greenhouse gases by themselves), which has been partly offset by the cooling effect of increases in atmospheric aerosols (blue band). By contrast, simulations that include only natural processes, including internal variability related to El Niño and other similar variations, as well as variations in the activity of the sun and emissions from large volcanoes (green band in FAQ 3.1, Figure 1), are not able to reproduce the observed warming. The fact that simulations including only natural processes show much smaller temperature increases indicates that natural processes alone cannot explain the strong rate of warming observed. The observed rate can only be reproduced when human influence is added to the simulations.

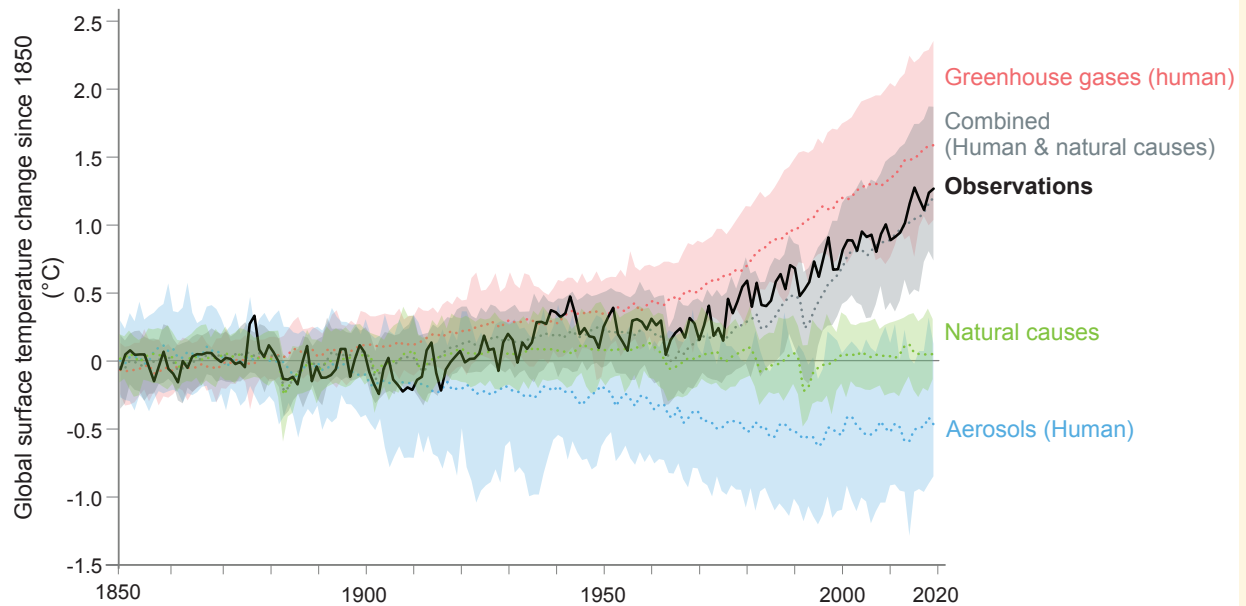
Moreover, the dominant effect of human activities is apparent not only in the warming of global surface temperature, but also in the pattern of warming in the lower atmosphere and cooling in the stratosphere, warming of the ocean, melting of sea ice, and many other observed changes. An additional line of evidence for the role of humans in driving climate change comes from comparing the rate of warming observed over recent decades with that which occurred prior to human influence on climate. Evidence from tree rings and other paleoclimate records shows that the rate of increase of global surface temperature observed over the past fifty years exceeded that which occurred in any previous 50-year period over the past 2000 years (see FAQ 2.1).

Taken together, this evidence shows that humans are the dominant cause of observed global warming over recent decades.

FAQ 3.1 (continued)

FAQ 3.1: How do we know humans are causing climate change?

Observed warming (1850-2019) is only reproduced in simulations including human influence.



FAQ 3.1, Figure 1 | Observed warming (1850–2019) is only reproduced in simulations including human influence. Global surface temperature changes in observations, compared to climate model simulations of the response to all human and natural forcings (grey band), greenhouse gases only (red band), aerosols and other human drivers only (blue band) and natural forcings only (green band). Solid coloured lines show the multi-model mean, and coloured bands show the 5–95% range of individual simulations.

FAQ 3.2 | What is Natural Variability and How Has it Influenced Recent Climate Changes?

Natural variability refers to variations in climate that are caused by processes other than human influence. It includes variability that is internally generated within the climate system and variability that is driven by natural external factors. Natural variability is a major cause of year-to-year changes in global surface climate and can play a prominent role in trends over multiple years or even decades. But the influence of natural variability is typically small when considering trends over periods of multiple decades or longer. When estimated over the entire historical period (1850–2020), the contribution of natural variability to global surface warming of -0.23°C to $+0.23^{\circ}\text{C}$ is small compared to the warming of about 1.1°C observed during the same period, which has been almost entirely attributed to the human influence.

Paleoclimatic records (indirect measurements of climate that can extend back many thousands of years) and climate models all show that global surface temperatures have changed significantly over a wide range of time scales in the past. One of these reasons is *natural variability*, which refers to variations in climate that are either *internally* generated within the climate system or *externally* driven by natural changes. Internal natural variability corresponds to a redistribution of energy within the climate system (for example via atmospheric circulation changes similar to those that drive the daily weather) and is most clearly observed as regional, rather than global, fluctuations in surface temperature. External natural variability can result from changes in the Earth's orbit, small variations in energy received from the sun, or from major volcanic eruptions. Although large orbital changes are related to global climate changes of the past, they operate on very long time scales (i.e., thousands of years). As such, they have displayed very little change over the past century and have had very little influence on temperature changes observed over that period. On the other hand, volcanic eruptions can strongly cool the Earth, but this effect is short-lived and their influence on surface temperatures typically fades within a decade of the eruption.

To understand how much of observed recent climate change has been caused by natural variability (a process referred to as attribution), scientists use climate model simulations. When only natural factors are used to force climate models, the resulting simulations show variations in climate on a wide range of time scales in response to volcanic eruptions, variations in solar activity, and internal natural variability. However, the influence of natural climate variability typically decreases as the time period gets longer, such that it only has mild effects on multi-decadal and longer trends (FAQ 3.2, Figure 1).

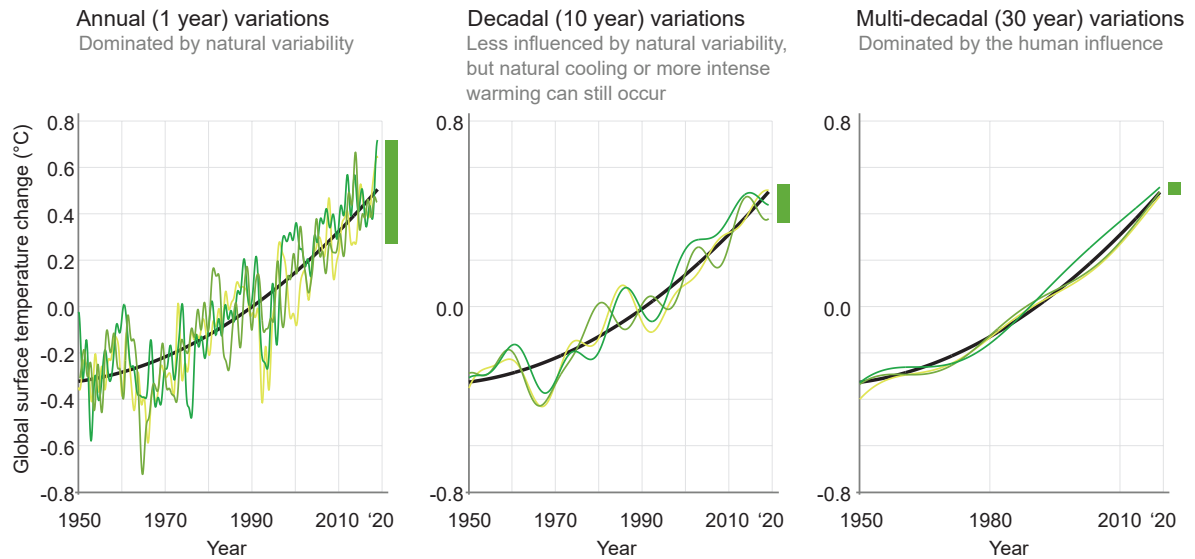
Consequently, over periods of a couple of decades or less, natural climate variability can dominate the human-induced surface warming trend – leading to periods with stronger or weaker warming, and sometimes even cooling (FAQ 3.2, Figure 1, left and centre). Over longer periods, however, the effect of natural variability is relatively small (FAQ 3.2, Figure 1, right). For instance, over the entire historical period (1850–2019), natural variability is estimated to have caused between -0.23°C and $+0.23^{\circ}\text{C}$ of the observed surface warming of about 1.1°C . This means that the bulk of the warming has been almost entirely attributed to human activities, particularly emissions of greenhouse gases (FAQ 3.1).

Another way to picture natural variability and human influence is to think of a person walking a dog. The path of the walker represents the human-induced warming, while their dog represents natural variability. Looking at global surface temperature changes over short periods is akin to focusing on the dog. The dog sometimes moves ahead of the owner and other times behind. This is similar to natural variability that can weaken or amplify warming on the short term. In both cases it is difficult to predict where the dog will be or how the climate will evolve in the near future. However, if we pull back and focus on the slow steady steps of the owner, the path of the dog is much clearer and more predictable, as it follows the path of its owner. Similarly, human influence on the climate is much clearer over longer time periods.

FAQ 3.2 (continued)

FAQ 3.2 What is natural variability and how has it influenced recent climate changes?

Natural variability can alter global temperature over short time scales (1 year to ~2 decades) but it has a minimal influence on longer time scales. Since 1850, **natural variability** (🌊 🟩) has caused between -0.23°C and 0.23°C of global temperature change, compared to the warming of about 1.1°C **observed** (📈) over that period.



FAQ 3.2, Figure 1 | Annual (left), decadal (middle) and multi-decadal (right) variations in average global surface temperature. The thick black line is an estimate of the human contribution to temperature changes, based on climate models, whereas the green lines show the combined effect of natural variations and human-induced warming, different shadings of green represent different simulations, which can be viewed as showing a range of potential pasts. The influence of natural variability is shown by the green bars, and it decreases on longer time scales. The data is sourced from the CESM1 large ensemble.

FAQ 3.3 | Are Climate Models Improving?

Yes, climate models have improved and continue to do so, becoming better at capturing complex and small-scale processes and at simulating present-day mean climate conditions. This improvement can be measured by comparing climate simulations against historical observations. Both the current and previous generations of models show that increases in greenhouse gases cause global warming. While past warming is well simulated by the new generation models as a group, some individual models simulate past warming that is either below or above what is observed. The information about how well models simulate past warming, as well as other insights from observations and theory, are used to refine this Report's projections of global warming.

Climate models are important tools for understanding past, present and future climate change. They are sophisticated computer programs that are based on fundamental laws of physics of the atmosphere, ocean, ice, and land. Climate models perform their calculations on a three-dimensional grid made of small bricks or 'gridcells' of about 100 km across. Processes that occur on scales smaller than the model grid cells (such as the transformation of cloud moisture into rain) are treated in a simplified way. This simplification is done differently in different models. Some models include more processes and complexity than others; some represent processes in finer detail (smaller grid cells) than others. Hence the simulated climate and climate change vary between models.

Climate modelling started in the 1950s and, over the years, models have become increasingly sophisticated as computing power, observations and our understanding of the climate system have advanced. The models used in the IPCC First Assessment Report published in 1990 correctly reproduced many aspects of climate (FAQ 1.1). The actual evolution of the climate since then has confirmed these early projections, when accounting for the differences between the simulated scenarios and actual emissions. Models continue to improve and get better and better at simulating the large variety of important processes that affect climate. For example, many models now simulate complex interactions between different aspects of the Earth system, such as the uptake of carbon dioxide by vegetation on land and by the ocean, and the interaction between clouds and air pollutants. While some models are becoming more comprehensive, others are striving to represent processes at higher resolution, for example to better represent the vortices and swirls in currents responsible for much of the transport of heat in the ocean.

Scientists evaluate the performance of climate models by comparing historical climate model simulations to observations. This evaluation includes comparison of large-scale averages as well as more detailed regional and seasonal variations. There are two important aspects to consider: (i) how models perform individually and (ii) how they perform as a group. The average of many models often compares better against observations than any individual model, since errors in representing detailed processes tend to cancel each other out in multi-model averages.

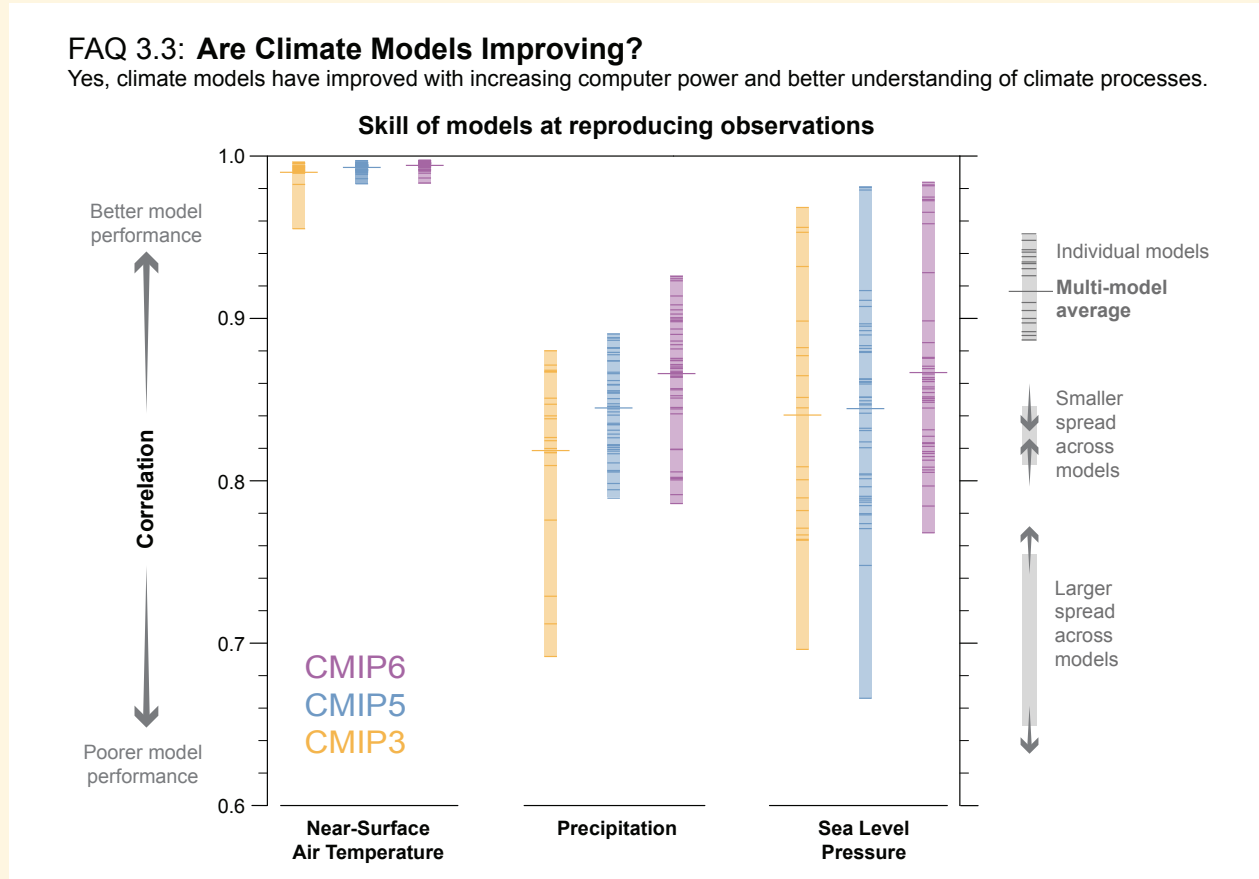
As an example, FAQ 3.3 Figure 1 compares simulations from the three most recent generations of models (available around 2008, 2013 and 2021) with observations of three climate variables. It shows the correlation between simulated and observed patterns, where a value of 1 represents perfect agreement. Many individual models of the new generation perform significantly better, as indicated by values closer to 1. As a group, each generation out-performs the previous generation: the multi-model average (shown by the longer lines) is progressively closer to 1. The vertical extent of the colored bars indicates the range of model performance across each group. The top of the bar moves up with each generation, indicating improved performance of the best performing models from one generation to the next. In the case of precipitation, the performance of the worst performing models is similar in the two most recent model generations, increasing the spread across models.

Developments in the latest generation of climate models, including new and better representation of physical, chemical and biological processes, as well as higher resolution, have improved the simulation of many aspects of the Earth system. These simulations, along with the evaluation of the ability of the models to simulate past warming as well as the updated assessment of the temperature response to a doubling of CO₂ in the atmosphere, are used to estimate the range of future global warming (FAQ 7.3).

FAQ 3.3 (continued)

FAQ 3.3: Are Climate Models Improving?

Yes, climate models have improved with increasing computer power and better understanding of climate processes.



FAQ 3.3, Figure 1 | Pattern correlations between models and observations of three different variables: surface air temperature, precipitation and sea level pressure. Results are shown for the three most recent generations of models, from the Coupled Model Intercomparison Project (CMIP): CMIP3 (orange), CMIP5 (blue) and CMIP6 (purple). Individual model results are shown as short lines, along with the corresponding ensemble average (long line). For the correlations the yearly averages of the models are compared with the reference observations for the period 1980–1999, with 1 representing perfect similarity between the models and observations. CMIP3 simulations performed in 2004–2008 were assessed in the IPCC Fourth Assessment, CMIP5 simulations performed in 2011–2013 were assessed in the IPCC Fifth Assessment, and CMIP6 simulations performed in 2018–2021 are assessed in this Report.

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