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).

Frequently Asked Questions

FAQ 7.1 | What Is the Earth's Energy Budget, and What Does It Tell Us About Climate Change?

The Earth's energy budget describes the flow of energy within the climate system. Since at least 1970 there has been a persistent imbalance in the energy flows that has led to excess energy being absorbed by the climate system. By measuring and understanding these energy flows and the role that human activities play in changing them, we are better able to understand the causes of climate change and project future climate change more accurately.

Our planet receives vast amounts of energy every day in the form of sunlight. Around a third of the sunlight is reflected back to space by clouds, by tiny particles called *aerosols*, and by bright surfaces such as snow and ice. The rest is absorbed by the ocean, land, ice and atmosphere. The planet then emits energy back out to space in the form of thermal radiation. In a world that was not warming or cooling, these energy flows would balance. Human activity has caused an imbalance in these energy flows.

We measure the influence of various human and natural factors on the energy flows at the top of our atmosphere in terms of *radiative forcings*, where a positive radiative forcing has a warming effect and a negative radiative forcing has a cooling effect. In response to these forcings, the Earth system will either warm or cool, so as to restore balance through changes in the amount of outgoing thermal radiation (the warmer the Earth, the more radiation it emits). Changes in Earth's temperature in turn lead to additional changes in the climate system (known as *climate feedbacks*) that either amplify or dampen the original effect. For example, Arctic sea ice has been melting as the Earth warms, reducing the amount of reflected sunlight and adding to the initial warming (an amplifying feedback). The most uncertain of those climate feedbacks are clouds, as they respond to warming in complex ways that affect both the emission of thermal radiation and the reflection of sunlight. However, we are now more confident that cloud changes, taken together, will amplify climate warming (see FAQ 7.2).

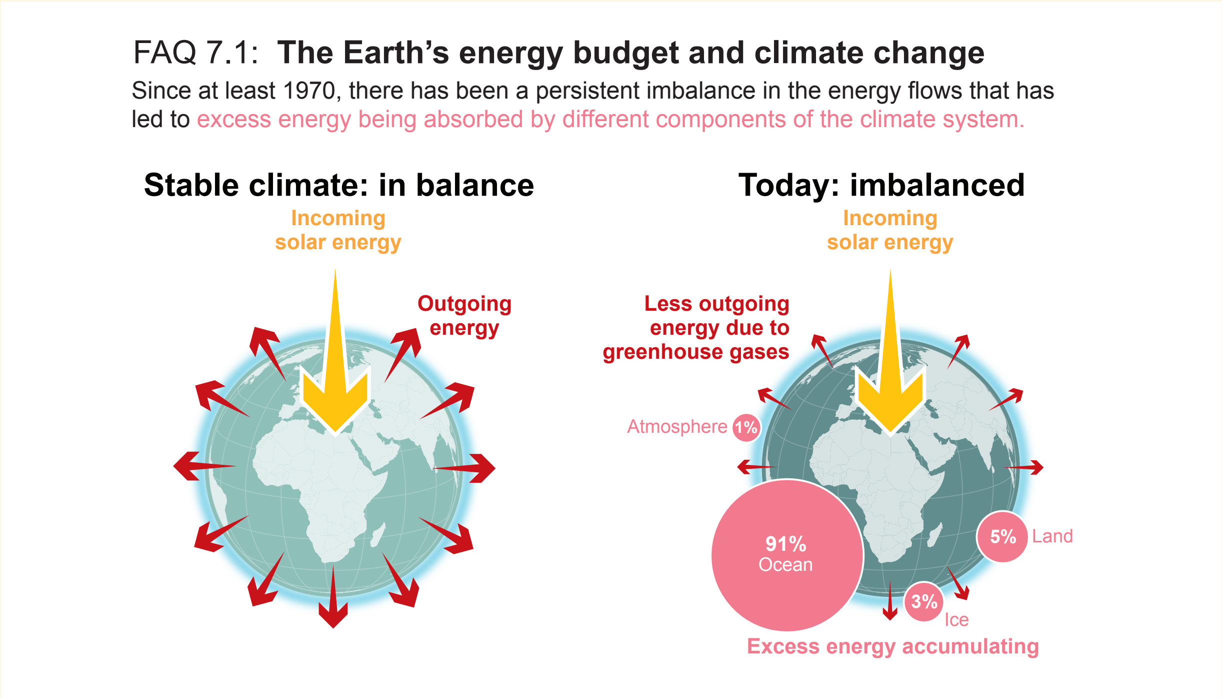
Human activities have unbalanced these energy flows in two main ways. First, increases in greenhouse gas levels have led to more of the emitted thermal radiation being absorbed by the atmosphere, instead of being released to space. Second, increases in pollutants have increased the amount of aerosols such as sulphates in the atmosphere (see FAQ 6.1). This has led to more incoming sunlight being reflected away, by the aerosols themselves and through the formation of more cloud drops, which increases the reflectivity of clouds (see FAQ 7.2).

Altogether, the global energy flow imbalance since the 1970s has been just over half a watt per square metre of the Earth's surface. This sounds small, but because the imbalance is persistent and because Earth's surface is large, this adds up to about 25 times the total amount of primary energy consumed by human society, compared over 1971 to 2018. Compared to the IPCC Fifth Assessment Report (AR5), we are now better able to quantify and track these energy flows from multiple lines of evidence, including satellite data, direct measurements of ocean temperatures, and a wide variety of other Earth system observations (see FAQ 1.1). We also have a better understanding of the processes contributing to this imbalance, including the complex interactions between aerosols, clouds and radiation.

Research has shown that the excess energy since the 1970s has mainly gone into warming the ocean (91%), followed by the warming of land (5%) and the melting of ice sheets and glaciers (3%). The atmosphere has warmed substantially since 1970, but because it is comprised of thin gases it has absorbed only 1% of the excess energy (FAQ 7.1, Figure 1). As the ocean has absorbed the vast majority of the excess energy, especially within its top two kilometres, the deep ocean is expected to continue to warm and expand for centuries to millennia, leading to long-term sea level rise – even if atmospheric greenhouse gas levels were to decline (see FAQ 5.3). This is in addition to the sea level rise expected from melting ice sheets and glaciers.

Understanding the Earth's energy budget al.o helps to narrow uncertainty in future projections of climate. By testing climate models against what we know about the Earth's energy budget, we can make more confident projections of surface temperature changes we might expect this century and beyond.

FAQ 7.1 (continued)



FAQ 7.1, Figure 1 | The Earth's energy budget compares the flows of incoming and outgoing energy that are relevant for the climate system. Since at least the 1970s, less energy is flowing out than is flowing in, which leads to excess energy being absorbed by the ocean, land, ice and atmosphere, with the ocean absorbing 91%.

Frequently Asked Questions

FAQ 7.2 | What Is the Role of Clouds in a Warming Climate?

One of the biggest challenges in climate science has been to predict how clouds will change in a warming world and whether those changes will amplify or partially offset the warming caused by increasing concentrations of greenhouse gases and other human activities. Scientists have made significant progress over the past decade and are now more confident that changes in clouds will amplify, rather than offset, global warming in the future.

Clouds cover roughly two-thirds of the Earth's surface. They consist of small droplets and/or ice crystals, which form when water vapour condenses or deposits around tiny particles called *aerosols* (such as salt, dust, or smoke). Clouds play a critical role in the Earth's *energy budget* at the top of our atmosphere and therefore influence Earth's surface temperature (see FAQ 7.1). The interactions between clouds and the climate are complex and varied. Clouds at low altitudes tend to reflect incoming solar energy back to space, creating a cooling effect by preventing this energy from reaching and warming the Earth. On the other hand, higher clouds tend to trap (i.e., absorb and then emit at a lower temperature) some of the energy leaving the Earth, leading to a warming effect. On average, clouds reflect back more incoming energy than the amount of outgoing energy they trap, resulting in an overall net cooling effect on the present climate. Human activities since the pre-industrial era have altered this climate effect of clouds in two different ways: by changing the abundance of the aerosol particles in the atmosphere and by warming the Earth's surface, primarily as a result of increases in greenhouse gas emissions.

The concentration of aerosols in the atmosphere has markedly increased since the pre-industrial era, and this has had two important effects on clouds. First, clouds now reflect more incoming energy because cloud droplets have become more numerous and smaller. Second, smaller droplets may delay rain formation, thereby making the clouds last longer, although this effect remains uncertain. Hence, aerosols released by human activities have had a cooling effect, counteracting a considerable portion of the warming caused by increases in greenhouse gases over the last century (see FAQ 3.1). Nevertheless, this cooling effect is expected to diminish in the future, as air pollution policies progress worldwide, reducing the amount of aerosols released into the atmosphere.

Since the pre-industrial period, the Earth's surface and atmosphere have warmed, altering the properties of clouds, such as their altitude, amount and composition (water or ice), thereby affecting the Earth's energy budget and, in turn, changing temperature. This cascading effect of clouds, known as the *cloud feedback,* could either amplify or offset some of the future warming and has long been the biggest source of uncertainty in climate projections. The problem stems from the fact that clouds can change in many ways and that their processes occur on much smaller scales than global climate models can explicitly represent. As a result, global climate models have disagreed on how clouds, particularly over the subtropical ocean, will change in the future and whether the change will amplify or suppress the global warming.

Since the last IPCC Report in 2013 (the Fifth Assessment Report, or AR5), understanding of cloud processes has advanced with better observations, new analysis approaches and explicit high-resolution numerical simulation of clouds. Also, current global climate models simulate cloud behaviour better than previous models, due both to advances in computational capabilities and process understanding. Altogether, this has helped to build a more complete picture of how clouds will change as the climate warms (FAQ 7.2, Figure 1). For example, the amount of low-clouds will reduce over the subtropical ocean, leading to less reflection of incoming solar energy, and the altitude of high-clouds will rise, making them more prone to trapping outgoing energy; both processes have a warming effect. In contrast, clouds in high latitudes will be increasingly made of water droplets rather than ice crystals. This shift from fewer, larger ice crystals to smaller but more numerous water droplets will result in more of the incoming solar energy being reflected back to space and produce a cooling effect. Better understanding of how clouds respond to warming has led to more confidence than before that future changes in clouds will, overall, cause additional warming (i.e., by weakening the current cooling effect of clouds). This is called a *positive net cloud feedback*.

In summary, clouds will amplify rather than suppress the warming of the climate system in the future, as more greenhouse gases and fewer aerosols are released to the atmosphere by human activities.

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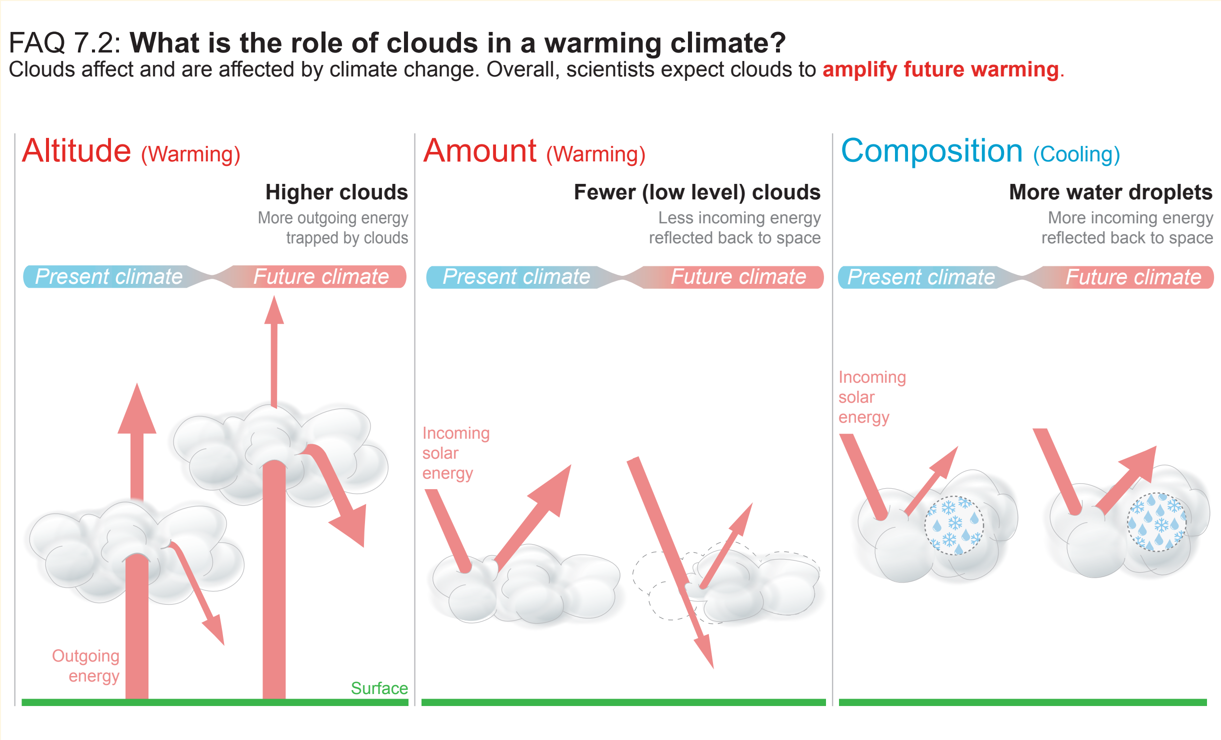
FAQ 7.2 (continued)



FAQ 7.2, Figure 1 | Interactions between clouds and the climate, today and in a warmer future. Global warming is expected to alter the altitude **(left)** and the amount **(centre)** of clouds, which will amplify warming. On the other hand, cloud composition will change **(right)**, offsetting some of the warming. Overall, clouds are expected to amplify future warming.

FAQ

Frequently Asked Questions

FAQ 7.3 | What Is Equilibrium Climate Sensitivity and How Does It Relate to Future Warming?

For a given future scenario, climate models project a range of changes in global surface temperature. This range is closely related to equilibrium climate sensitivity, or ECS, which measures how climate models respond to a doubling of carbon dioxide in the atmosphere. Models with high climate sensitivity project stronger future warming. Some climate models of the new generation are more sensitive than the range assessed in the IPCC Sixth Assessment Report. This leads to end-of-century global warming in some simulations of up to 2°C–3°C above the current IPCC best estimate. Although these higher warming levels are not expected to occur, high-ECS models are useful for exploring low-likelihood, high-impact futures.

The *equilibrium climate sensitivity* (ECS) is defined as the long-term global warming caused by a doubling of carbon dioxide above its pre-industrial concentration. For a given emissions scenario, much of the uncertainty in projections of future warming can be explained by the uncertainty in ECS (FAQ 7.3, Figure 1). The significance of equilibrium climate sensitivity has long been recognized, and the first estimate was presented by Swedish scientist Svante Arrhenius in 1896.

This Sixth Assessment Report concludes that there is a 90% or more chance (*very likely*) that the ECS is between 2°C and 5°C. This represents a significant reduction in uncertainty compared to the Fifth Assessment Report, which gave a 66% chance (*likely*) of ECS being between 1.5°C and 4.5°C. This reduction in uncertainty has been possible not through a single breakthrough or discovery but instead by combining evidence from many different sources and by better understanding their strengths and weaknesses.

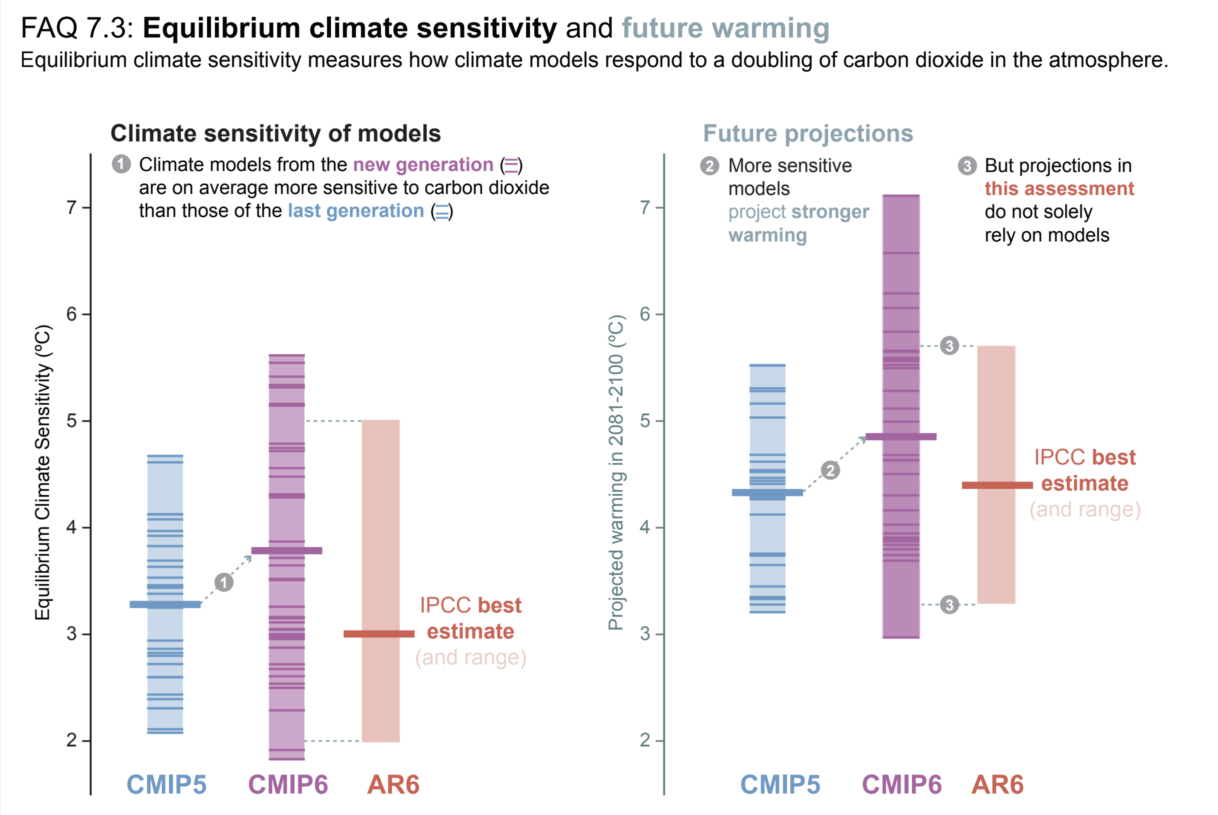
There are four main lines of evidence for ECS.

- The self-reinforcing processes, called *feedback loops*, that amplify or dampen the warming in response to increasing carbon dioxide are now better understood. For example, warming in the Arctic melts sea ice, resulting in more open ocean area, which is darker and therefore absorbs more sunlight, further intensifying the initial warming. It remains challenging to represent realistically all the processes involved in these feedback loops, particularly those related to clouds (see FAQ 7.2). Such identified model errors are now taken into account, and other known, but generally weak, feedback loops that are typically not included in models are now included in the assessment of ECS.
- Historical warming since early industrialisation provides strong evidence that climate sensitivity is not small. Since 1850, the concentrations of carbon dioxide and other greenhouse gases have increased, and as a result the Earth has warmed by about 1.1°C. However, relying on this industrial-era warming to estimate ECS is challenging, partly because some of the warming from greenhouse gases was offset by cooling from aerosol particles and partly because the ocean is still responding to past increases in carbon dioxide.
- Evidence from ancient climates that had reached equilibrium with greenhouse gas concentrations, such as the coldest period of the last ice age around 20,000 years ago, or warmer periods further back in time, provide useful data on the ECS of the climate system (see FAQ 1.3).
- Statistical approaches linking model ECS values with observed changes, such as global warming since the 1970s, provide complementary evidence.

All four lines of evidence rely, to some extent, on climate models, and interpreting the evidence often benefits from model diversity and spread in modelled climate sensitivity. Furthermore, high-sensitivity models can provide important insights into futures that have a low likelihood of occurring but that could result in large impacts. But, unlike in previous assessments, climate models are not considered a line of evidence in their own right in the IPCC Sixth Assessment Report.

The ECS of the latest climate models is, on average, higher than that of the previous generation of models and also higher than this Report's best estimate of 3.0°C. Furthermore, the ECS values in some of the new models are both above and below the 2°C to 5°C *very likely* range, and although such models cannot be ruled out as implausible solely based on their ECS, some simulations display climate change that is inconsistent with the observed changes when tested with ancient climates. A slight mismatch between models and this Report's assessment is only natural because this Report's assessment is largely based on observations and an improved understanding of the climate system.

FAQ 7.3 (continued)



FAQ 7.3, Figure 1 | Equilibrium climate sensitivity and future warming. (left) Equilibrium climate sensitivities for the current generation (Coupled Model Intercomparison Project Phase 6, CMIP6) climate models, and the previous (CMIP5) generation. The assessed range in this Report (AR6) is also shown. **(right)** Climate projections of CMIP5, CMIP6 and AR6 for the very high-emissions scenarios RCP8.5, and SSP5-8.5, respectively. The thick horizontal lines represent the multi-model average and the thin horizontal lines represent the results of individual models. The boxes represent the model ranges for CMIP5 and CMIP6 and the range assessed in AR6.