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 9.1 | Can Continued Melting of the Greenland and Antarctic Ice Sheets Be Reversed? How Long Would It Take for Them to Grow Back?

Evidence from the distant past shows that some parts of the Earth system might take hundreds to thousands of years to fully adjust to changes in climate. This means that some of the consequences of human-induced climate change will continue for a very long time, even if atmospheric heat-trapping gas levels and global temperatures are stabilized or reduced in the future. This is especially true for the Greenland and Antarctic ice sheets, which grow much more slowly than they retreat. If the current melting of these ice sheets continues for long enough, it becomes effectively irreversible on human time scales, as does the sea level rise caused by that melting.

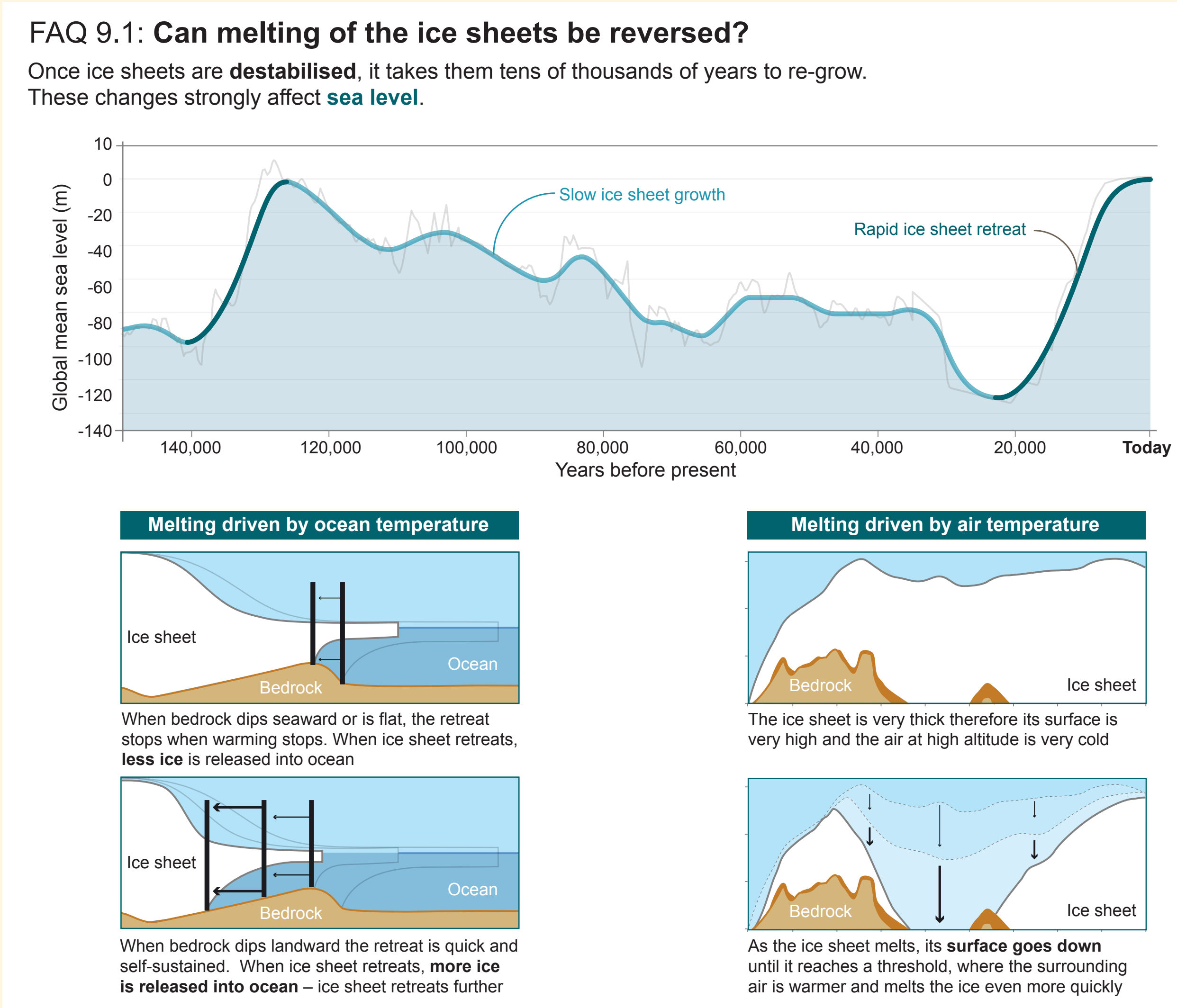
Humans are changing the climate and there are mechanisms that amplify the warming in the polar regions (Arctic and Antarctic). The Arctic is already warming faster than anywhere else (see FAQ 4.3). This is significant because these colder high latitudes are home to our two remaining ice sheets: Antarctica and Greenland. Ice sheets are huge reservoirs of frozen freshwater, built up by tens of thousands of years of snowfall. If they were to completely melt, the water released would raise global sea level by about 65 m. Understanding how these ice sheets are affected by warming of nearby ocean and atmosphere is therefore critically important. The Greenland and Antarctic ice sheets are already slowly responding to recent changes in climate, but it takes a long time for these huge masses of ice to adjust to changes in global temperature. That means that the full effects of a warming climate may take hundreds or thousands of years to play out. An important question is whether these changes can eventually be reversed, once levels of greenhouse gases in the atmosphere are stabilized or reduced by humans and natural processes. Records from the past can help us answer this question.

For at least the last 800,000 years, the Earth has followed cycles of gradual cooling followed by rapid warming caused by natural processes. During cooling phases, more and more ocean water is gradually deposited as snowfall, causing ice sheets to grow and sea level to slowly decrease. During warming phases, the ice sheets melt more quickly, resulting in more rapid rises in sea level (FAQ 9.1, Figure 1). Ice sheets build up very slowly because growth relies on the steady accumulation of falling snow that eventually compacts into ice. As the climate cools, areas that can accumulate snow expand, reflecting back more sunlight that otherwise would keep the Earth warmer. This means that, once started, glacial climates develop rapidly. However, as the climate cools, the amount of moisture that the air can hold tends to decrease. As a result, even though glaciations begin quite quickly, it takes tens of thousands of years for ice sheets to grow to a point where they are in balance with the colder climate.

Ice sheets retreat more quickly than they grow because of processes that, once triggered, drive self-reinforcing ice loss. For ice sheets that are mostly resting on bedrock *above* sea level – like the Greenland Ice Sheet – the main self-reinforcing loop that affects them is the 'elevation–mass balance feedback' (FAQ 9.1, Figure 1, right). In this situation, the altitude of the ice-sheet surface decreases as it melts, exposing the sheet to warmer air. The lowered surface then melts even more, lowering it faster still, until eventually the whole ice sheet disappears. In places where the ice sheet rests instead on bedrock that is *below* sea level, and which also deepens inland, including many parts of the Antarctic Ice Sheet, an important process called 'marine ice sheet instability' is thought to drive rapid retreat (FAQ 9.1, Figure 1, left). This happens when the part of the ice sheet that is surrounded by sea water melts. That leads to additional thinning, which in turn accelerates the motion of the glaciers that feed into these areas. As the ice sheet flows more quickly into the ocean, more melting takes place, leading to more thinning and even faster flow that brings ever-more glacier ice into the ocean, ultimately driving rapid deglaciation of whole ice-sheet drainage basins.

These (and other) self-reinforcing processes explain why relatively small increases in temperature in the past led to very substantial sea level rise over centuries to millennia, compared to the many tens of thousands of years it takes to grow the ice sheets that lowered the sea level in the first place. These insights from the past imply that, if human-induced changes to the Greenland and Antarctic ice sheets continue for the rest of this century, it will take thousands of years to reverse that melting, even if global air temperatures decrease within this or the next century. In this sense, these changes are therefore irreversible, since the ice sheets would take much longer to regrow than the decades or centuries for which modern society is able to plan.

FAQ 9.1 (continued)



FAQ 9.1, Figure 1 | Ice sheets growth and decay. (Top) Changes in ice-sheet volume modulate sea level variations. The grey line depicts data from a range of physical environmental sea level recorders such as coral reefs while the blue line is a smoothed version of it. **(Bottom left)** Example of destabilization mechanism in Antarctica. **(Bottom right)** Example of destabilization mechanism in Greenland.

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FAQ 9.2 | How Much Will Sea Level Rise in the Next Few Decades?

As of 2018, global average sea level was about 15–25 cm higher than in 1900, and 7–15 cm higher than in 1971. Sea level will continue to rise by an additional 10–25 cm by 2050. The major reasons for this ongoing rise in sea level are the thermal expansion of seawater as its temperature increases, and the melting of glaciers and ice sheets. Local sea level changes can be larger or smaller than the global average, with the smallest changes in formerly glaciated areas, and the largest changes in low-lying river delta regions.

Across the globe, sea level is rising, and the rate of increase has accelerated. Sea level increased by about 4 mm per year from 2006 to 2018, which was more than double the average rate over the 20th century. Rise during the early 1900s was due to natural factors, such as glaciers catching up to warming that occurred in the Northern Hemisphere during the 1800s. However, since at least 1970, human activities have been the dominant cause of global average sea level rise, and they will continue to be for centuries into the future.

Sea level rises either through warming of ocean waters or the addition of water from melting ice and bodies of water on land. Expansion due to warming caused about 50% of the rise observed from 1971 to 2018. Melting glaciers contributed about 22% over the same period. Melting of the two large ice sheets in Greenland and Antarctica has contributed about 13% and 7%, respectively, during 1971 to 2018, but melting has accelerated in the recent decades, increasing their contribution to 22% and 14% since 2016. Another source is changes in land-water storage: reservoirs and aquifers on land have reduced, which contributed about an 8% increase in sea level.

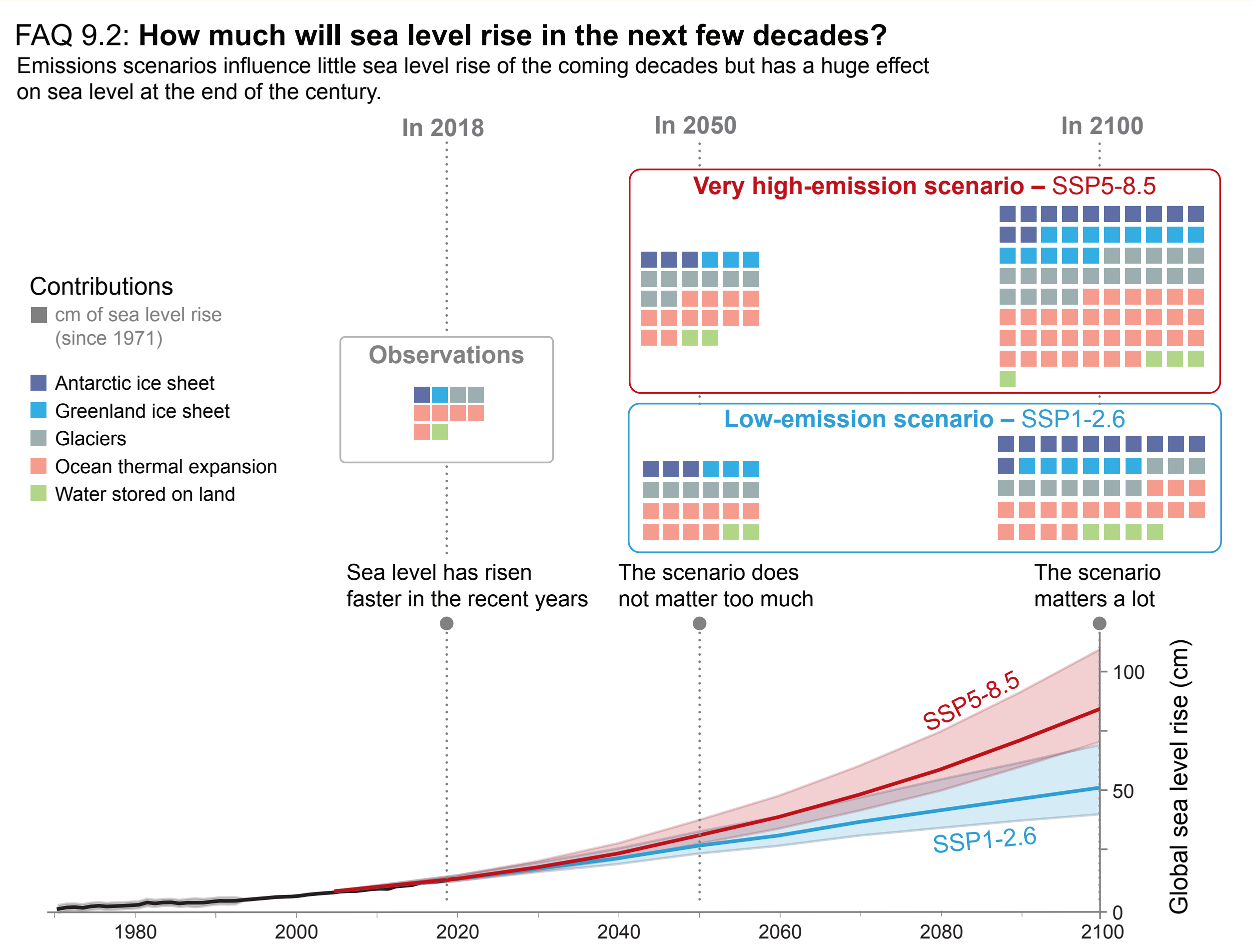
By 2050, sea level is expected to rise an additional 10–25 cm whether or not greenhouse gas emissions are reduced (FAQ 9.2, Figure 1). Beyond 2050, the amount by which sea level will rise is more uncertain. The accumulated total emissions of greenhouse gases over the upcoming decades will play a big role beyond 2050, especially in determining where sea level rise and ice-sheet changes eventually level off.

Even if net zero emissions are reached, sea level rise will continue because the deep ocean will continue to warm and ice sheets will take time to catch up to the warming caused by past and present emissions: ocean and ice sheets are slow to respond to environmental changes (see FAQ 5.3). Some projections under low emissions show sea level rise continuing as net zero is approached at a rate comparable to today (3–8 mm per year by 2100 versus 3–4 mm per year in 2015), while others show substantial acceleration to more than five times the present rate by 2100, especially if emissions continue to be high and processes that accelerate retreat of the Antarctic Ice Sheet occur widely (FAQ 9.1).

Sea level rise will increase the frequency and severity of extreme sea level events at coasts (see FAQ 8.2), such as storm surges, wave inundation and tidal floods: risk can be increased by even small changes in global average sea level. Scientists project that, in some regions, extreme sea level events that were recently expected once in 100 years will occur annually at 20–25% of locations by 2050 regardless of emissions, but by 2100 emissions choice will matter: annually at 60% of locations for low emissions, and at 80% of locations under strong emissions.

In many places, local sea level change will be larger or smaller than the global average. From year to year and place to place, changes in ocean circulation and wind can lead to local sea level change. In regions where large ice sheets, such as the Fennoscandian in Eurasia and the Laurentide and Cordilleran in North America, covered the land during the last ice age, the land is still slowly rising up now that the extra weight of the ice sheets is gone. This local recovery is compensating for global sea level rise in these regions and can even lead to local decrease in sea level. In regions just beyond where the former ice sheets reached and the Earth bulged upwards, the land is now falling and, as a result, local sea level rise is faster than the global rate. In many regions within low-lying delta regions (such as New Orleans and the Ganges–Brahmaputra delta), the land is rapidly subsiding (sinking) because of human activities such as building dams or groundwater and fossil fuel extraction. Further, when an ice sheet melts, it has less gravitational pull on the ocean water nearby. This reduction in gravitational attraction causes sea level to fall close to the (now less-massive) ice sheet while causing sea level to rise farther away. Melt from a polar ice sheet therefore raises sea level most in the opposite hemisphere or in low latitudes – amounting to tens of centimetres difference in rise between regions by 2100.

FAQ 9.2 (continued)



FAQ 9.2, Figure 1 | Observed and projected global mean sea level rise and the contributions from its major constituents.

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FAQ 9.3 | Will the Gulf Stream Shut Down?

The Gulf Stream is part of two circulation patterns in the North Atlantic: the Atlantic Meridional Overturning Circulation (AMOC) and the North Atlantic subtropical gyre. Based on models and theory, scientific studies indicate that, while the AMOC is expected to slow in a warming climate, the Gulf Stream will not change much and would not shut down totally, even if the AMOC did. Most climate models project that the AMOC slows in the later 21st century under most emissions scenarios, with some models showing it slowing even sooner. The Gulf Stream affects the weather and sea level, so if it slows, North America will see higher sea levels and Europe's weather and rate of relative warming will be affected.

The Gulf Stream is the biggest current in the North Atlantic Ocean. It transports about 30 billion kilograms of water per second northward past points on the east coast of North America. It is a warm current, with temperatures 5°C to 15°C warmer than surrounding waters, so it carries warmer water (thermal energy) from its southern origins and releases warmth to the atmosphere and surrounding water.

The Gulf Stream is part of two major circulation patterns, the Atlantic Meridional Overturning Circulation (AMOC) and the North Atlantic Subtropical Gyre (FAQ 9.3, Figure 1). The rotation of the Earth causes the big currents in both circulations to stay on the western side of their basin, which in the Atlantic means the circulations combine to form the Gulf Stream. Other large currents contribute to gyres, such as the Kuroshio in the North Pacific and the East Australian Current in the South Pacific, but the Gulf Stream is special in its dual role. There is no comparable deep overturning circulation in the North Pacific to the AMOC, so the Kuroshio plays only one role as part of a gyre.

The gyres circulate surface waters and result primarily from winds driving the circulation. These winds are not expected to change much and so neither will the gyres, which means the gyre portion of the Gulf Stream and the Kuroshio will continue to transport thermal energy poleward from the equator much as they do now. The gyre contribution to the Gulf Stream is 2 to 10 times larger than the AMOC contribution.

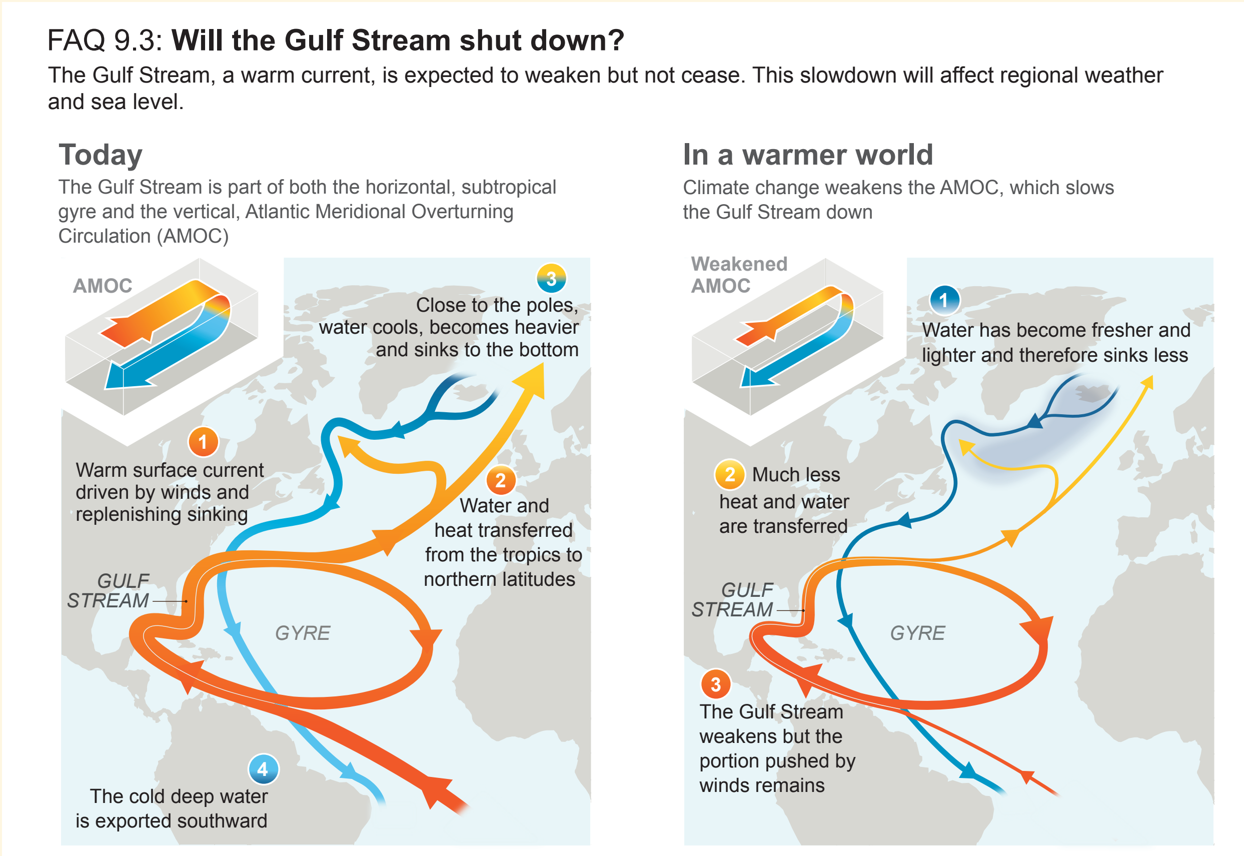
The Gulf Stream's role in the AMOC is supplying surface source water that cools, becomes denser and sinks to form cold, deep waters that travel back equatorward, spilling over features on the ocean floor and mixing with other deep Atlantic waters to form a southward current at a depth of about 1500 metres beneath the Gulf Stream. This overturning flow is the AMOC, with the Gulf Stream in the upper kilometre flowing northward, and the colder deep water flowing southward.

The AMOC is expected to slow over the coming centuries. One reason why is freshening of the ocean waters: by meltwater from Greenland, changing Arctic sea ice, and increased precipitation over warmer northern seas. An array of moorings across the Atlantic has been monitoring the AMOC since 2004, with recently expanded capabilities. The monitoring of the AMOC has not been long enough for a trend to emerge from variability and detect long-term changes that may be underway (see FAQ 1.2). Other indirect signs may indicate slowing overturning – for example, slower warming where the Gulf Stream's surface waters sink. Climate models show that this 'cold spot' of slower-than-average warming occurs as the AMOC weakens, and they project that this will continue. Paleoclimate evidence indicates that the AMOC changed significantly in the past, especially during transitions from colder climates to warmer ones, but that it has been stable for 8000 years.

What happens if the AMOC slows in a warming world? The atmosphere adjusts somewhat by carrying more heat, compensating partly for the decreases in heat carried by AMOC. But the 'cold spot' makes parts of Europe warm more slowly. Models indicate that weather patterns in Greenland and around the Atlantic will be affected, with reduced precipitation in the mid-latitudes, changing strong precipitation patterns in the tropics and Europe, and stronger storms in the North Atlantic storm track. The slowing of this current combined with the rotation of the Earth means that sea level along North America rises as the AMOC contribution to the Gulf Stream slows.

The North Atlantic is not the only site of sensitive meridional overturning. Around Antarctica, the world's densest seawater is formed by freezing into sea ice, leaving behind salty, cold water that sinks to the bottom and spreads northward. Recent studies show that melting of the Antarctic Ice Sheet and changing winds over the Southern Ocean can affect this southern meridional overturning, affecting regional weather.

FAQ 9.3 (continued)



FAQ 9.3, Figure 1 | Horizontal (gyre) and vertical (Atlantic Meridional Overturning Circulation, AMOC) circulations in the Atlantic today (left) and in a warmer world (right). The Gulf Stream is a warm current composed of both circulations.