# Climate Change 2021: Summary for All

INTERGOVERNMENTAL PANEL ON climate change

WORKING GROUP I TECHNICAL SUPPORT UNIT

Version 2 - 15 November 2022.

This document has not been the subject of IPCC review.

## Weather, Climate and the IPCC

No matter where we live, we all experience weather: how the conditions of our atmosphere change over minutes, hours, days, weeks. We also all experience climate: the weather of a place averaged over several decades. Climate change is when these averaged conditions start to change and its causes can be either natural or caused by human activities. Rising temperatures, variations in rainfall, increased extreme weather events are all examples of climate changes, but there are many others.

Back in 1990, the first report by the Intergovernmental Panel on Climate Change (IPCC) concluded that human-caused climate change would soon become apparent but could not yet confirm that it was already happening. Now, some 30 years later, the evidence is overwhelming that human activities have changed the climate.

Hundreds of scientists from all over the world come together to produce IPCC reports. They base their conclusions on several kinds of scientific evidence, including:

- Measurements or observations, sometimes spanning more than a century back in time;
- Paleo (very old) climate evidence from thousands or millions of years ago (for example: tree rings, rock or ice cores);
- Computer models that look at past, current and future changes (see box *What are climate models?* on page 9);
- Understanding of how the climate works (physical, chemical and biological processes).

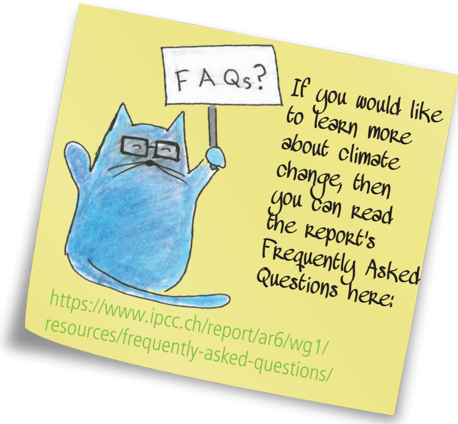
Since the IPCC first started, we now have much more data and better climate models. We understand more now about how the atmosphere interacts with the ocean, ice, snow, ecosystems and land of the Earth. Computer climate simulations have considerably improved and now provide past change and future projections that are much more detailed. Plus, we have now had decades more greenhouse gas emissions, making the effects of climate change more apparent (see box *What are greenhouse gases?* on page 6). As a result, the latest IPCC report is able to confirm and strengthen the conclusions from previous reports.

What's covered in this summary?

- Climate Change Today: what changes have already occurred and how we know humans are responsible;
- Our Future Climate: what changes could happen in the future depending on the actions we take;
- Limiting Future Climate Change: what is required to stop global temperature from continuing to rise.

# Climate change today

## Global warming has already caused widespread, rapid and intensifying changes. Some changes are unprecedented in thousands or even millions of years




Climate change is more than simply the world getting hotter; we are experiencing widespread changes across the atmosphere, land, ocean and ice regions. The list below and Graphic A give an overview of climate changes we are observing across the globe.

### Atmosphere

- The average temperature of the Earth's surface between 2011 and 2020 was 1.1°C (2°F) warmer than the average temperature in the late 19th century (before the industrial revolution) and warmer than at any time in the last 100,000 years.
- Each of the last four decades has been warmer than any previous decade since 1850. The world is warming faster than at any time in at least the last two thousand years.
- The levels of greenhouse gases in the air are continuing to rise because of our emissions. Carbon dioxide concentrations are at their highest in at least the last 2 million years. Methane and nitrous oxide concentrations are at their highest in at least 800,000 years (see box *What are greenhouse gases?* on page 6).

### Land

- Rainfall over the land has increased since the 1950s. In the tropical regions, it is raining more during wet seasons and raining less during dry seasons.
- Many plant species and animal species have moved closer to the poles and to higher elevations, to follow the shifts in climate zones.
- For some Northern Hemisphere plant species, the growing season has become longer (up to 14 days longer since the 1950s) and, overall, the surface of the land has become greener since the early 1980s.

### Ice

- Many of the frozen parts of the Earth are rapidly melting or thawing (defrosting). Overall, snowfall is decreasing. The widespread retreat of glaciers since 1950 has not been seen in at least 2000 years.
- The area of the Arctic Ocean covered by sea ice in the summer is now 40% smaller than in the 1980s. It is the smallest it has been for at least one thousand years.
- Snow cover in the Northern Hemisphere has decreased since the late 1970s, and some of the ground areas usually frozen all year round have warmed and thawed (defrosted).

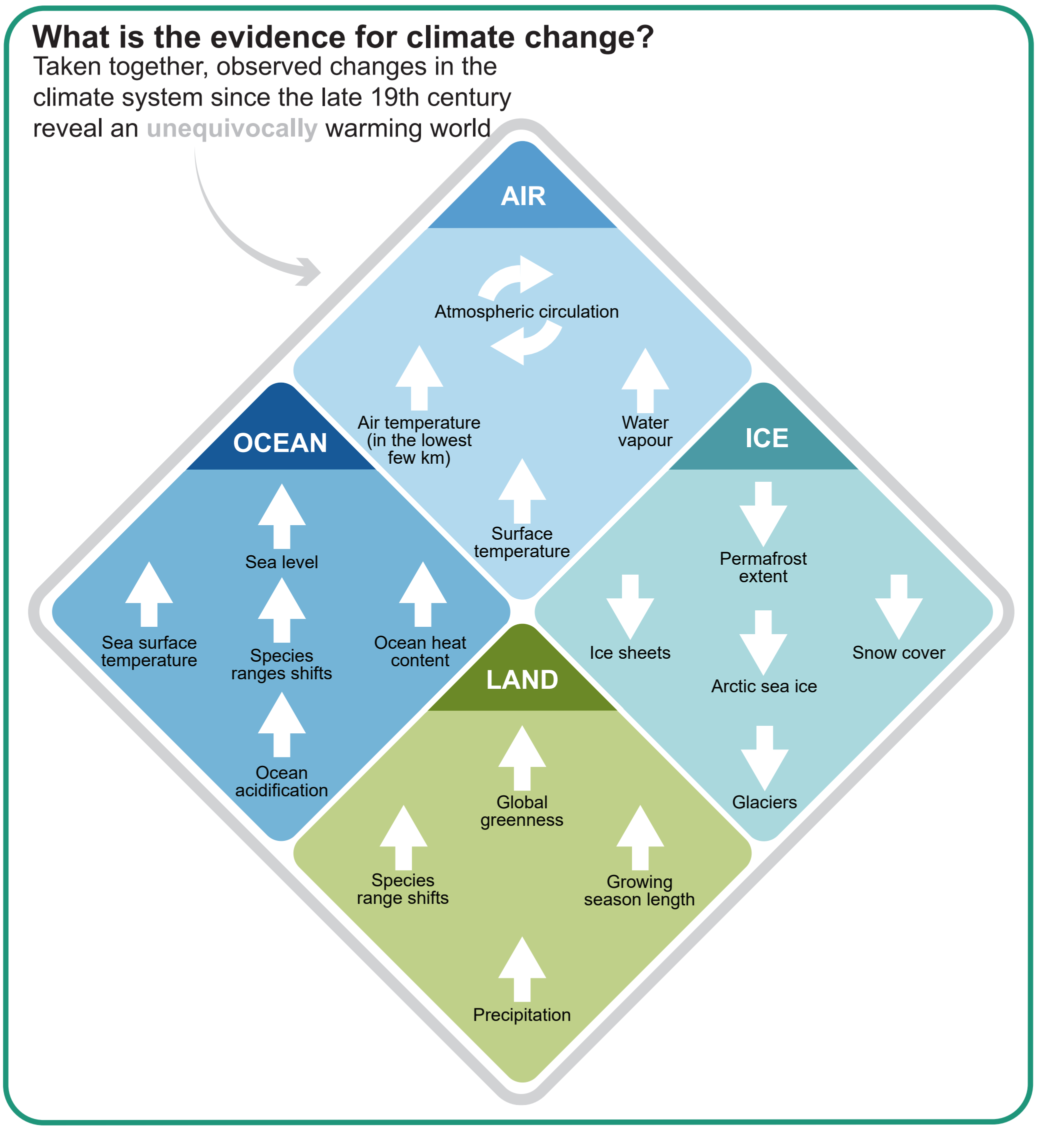
- The Greenland and Antarctic ice sheets are shrinking, as are the vast majority of glaciers worldwide, adding huge quantities of water to the oceans.

## Ocean

- 90% of the extra heat associated with global warming has been taken up by the ocean (see box *What are greenhouse gases?* on page 6). The ocean is now warming faster than at any time in at least 11,000 years.

- Sea level has risen globally by about 20 centimetres (approximately 8 inches) since 1900. It is rising faster than at any point in at least 3000 years, and this speed is accelerating.

- By absorbing carbon dioxide from the atmosphere, the ocean is becoming more acidic. The surface water of the ocean is now unusually acidic compared with the last 2 million years.



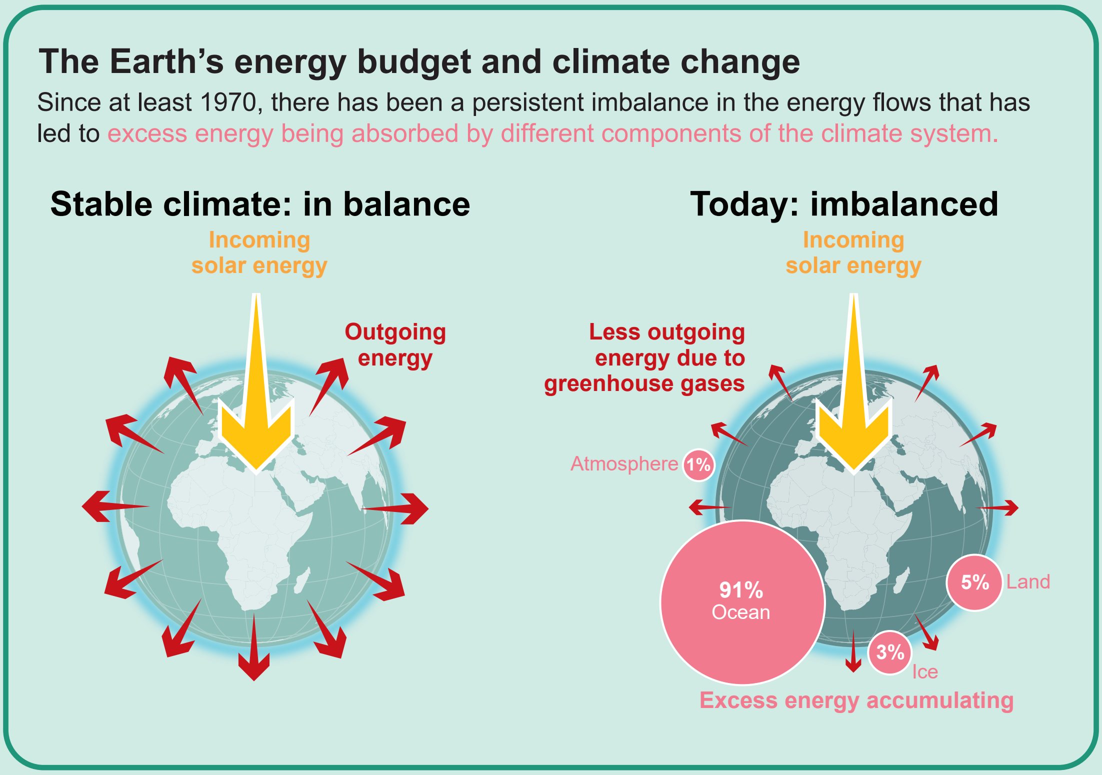

**Graphic A • Global warming has triggered widespread changes across the entire climate system.** The four main parts of the climate system – the air, the ocean, the land and the ice regions – are all experiencing widespread changes. Km = kilometres. Graphic adapted from IPCC AR6 Working Group I FAQ 2.2, Figure 1 in Chapter 2. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-2/

## What are greenhouse gases?

Some gases in our atmosphere – such as carbon dioxide, methane and nitrous oxide – act like an insulation blanket for the Earth. They warm the Earth by making it harder for heat to be released into outer space. Much like adding a blanket around your body heats you up and keeps you warm, or the walls of a greenhouse help keep the air inside warmer than its surroundings.

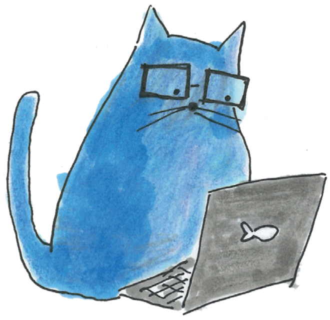
This effect is called the greenhouse effect, and these heat-trapping gases are called greenhouse gases. The greenhouse effect is a natural process that makes the Earth liveable for humans: without the natural greenhouse effect, the global average temperature would be about 33°C (59°F) colder. However, human activities since the 19th century have emitted more and more greenhouse gases into the atmosphere, mostly from burning fossil fuels (coal, oil and gas), but also from agriculture and cutting down forests. These actions have added to the greenhouse effect, causing global warming.

The excess energy is taken up by different parts of the Earth (Graphic B): 91% is absorbed by the oceans, 5% is absorbed by the land, 3% is absorbed by the ice. Only 1% of the extra heat is absorbed by the atmosphere. This warming has caused changes in many aspects of climate.



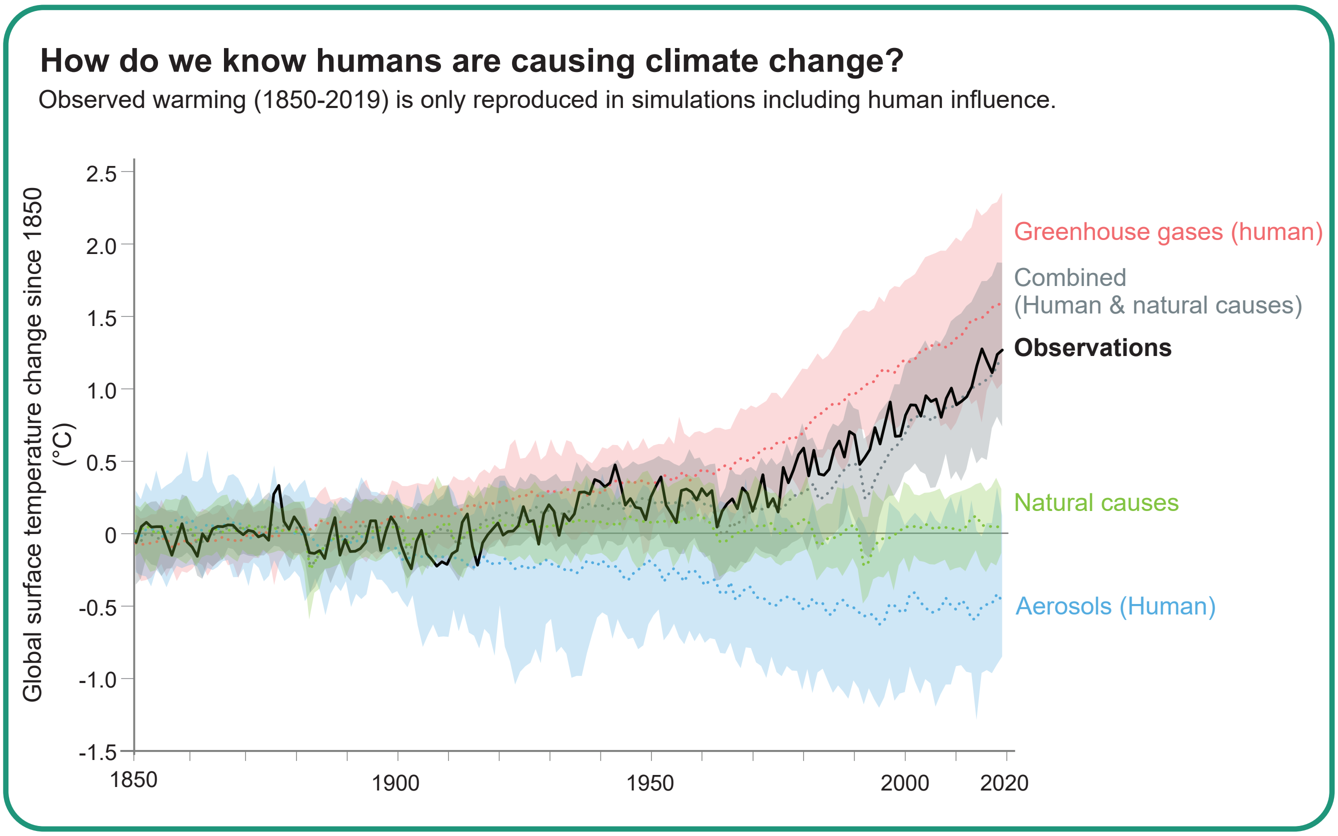

**Graphic B • The Earth's energy budget compares the flows of incoming and outgoing energy that are relevant for the climate system.** Since at least the 1970s, less energy is flowing out than is flowing in, which leads to excess energy being absorbed by the ocean, land, ice and atmosphere.
Graphic adapted from IPCC AR6 Working Group I FAQ 7.1, Figure 1 in Chapter 7.
https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-7/

## We are certain that humans are warming the climate



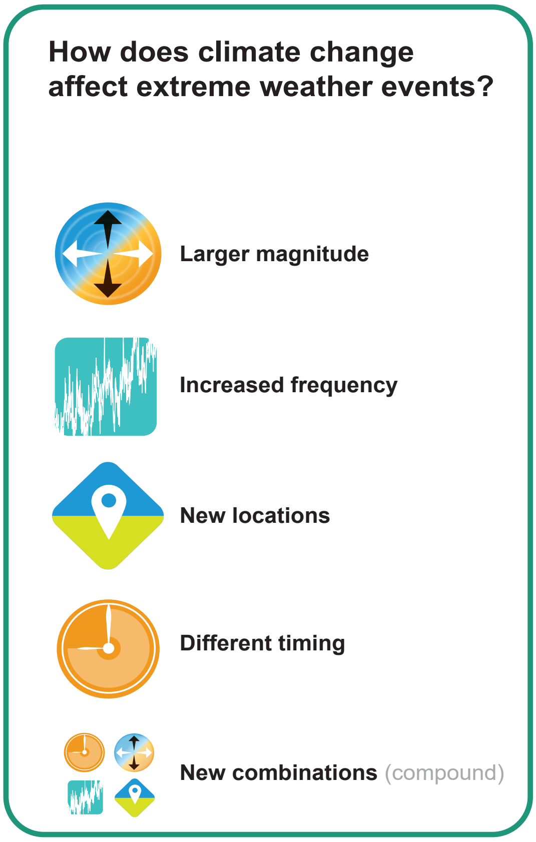
All of the observed warming (1.1°C/2°F) we have seen since the pre-industrial era is a result of human activities. In fact, greenhouse gas emissions from human activities would have warmed the Earth even more, by about 1.5ºC (2.7°F) in total, but their warming effect has been partly counteracted by emissions of air pollutants called aerosols, which have an overall cooling effect. Carbon dioxide is the greenhouse gas that contributes the most to the warming, followed by methane and then nitrous oxide.

How do we know global warming is not naturally caused? Natural causes of climate change that affect global temperature on short time scales (years to decades) haven't significantly affected global temperatures since the pre-industrial era. A large volcanic eruption is an example of a natural variability, which can cool global temperatures for a few years but doesn't alter temperatures on much longer time frames. Graphic C shows how greenhouse gases, air pollutants (aerosols) and natural causes have affected global temperatures since 1850. It is only when climate model simulations include human-caused greenhouse gases that they can recreate temperature observations. This is one of the ways we know that humans are responsible for warming the climate.




**Graphic C • Humans are responsible for warming the climate.** Climate model simulations (coloured shading) can only reproduce observed change in global temperature (black) when they include human-caused emissions. This graphic shows how global temperatures change when using climate model simulations that include: greenhouse gases only (red band); or aerosols (air pollutants) and other human drivers only (blue band); or natural causes only (green band); or when all causes are included (grey band). **Combined** = **natural** + **aerosols** + **greenhouse gases**. Solid/dashed coloured lines show the average of all models and shading shows the uncertainty ranges of the simulations.
Graphic adapted from IPCC AR6 Working Group I FAQ 3.1, Figure 1 in Chapter 3. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-3/

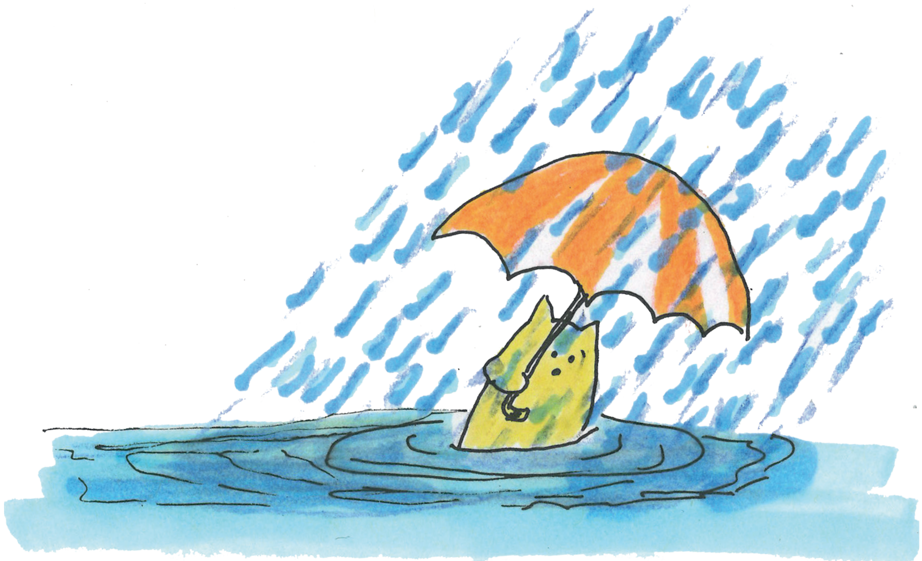
## Human-caused climate change is making extreme events more frequent and severe




**Graphic D • Human-caused climate change can affect extreme weather events in multiple ways.**
Graphic adapted from IPCC AR6 Working Group I FAQ 11.2, Figure 1 in Chapter 11. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/

All the regions of the world must now deal with extreme events (such as heatwaves, droughts and heavy rainfalls) that are generally more severe and happening more often. Each region experiences different types of extreme events. Since the 1950s, all inhabited regions have seen more frequent and more intense heatwaves, and fewer and milder cold extremes. Many regions have seen heavier and more intense rainfall events (which can fuel floods). The soils of some regions have become much drier, leading to more severe droughts that negatively impact agriculture, people and nature. In the tropics, the strongest tropical cyclones – also called typhoons or hurricanes – have become more intense. Global warming has also caused some extremes to reach places where they were not previously common (for example, tropical cyclones and extreme heatwaves).

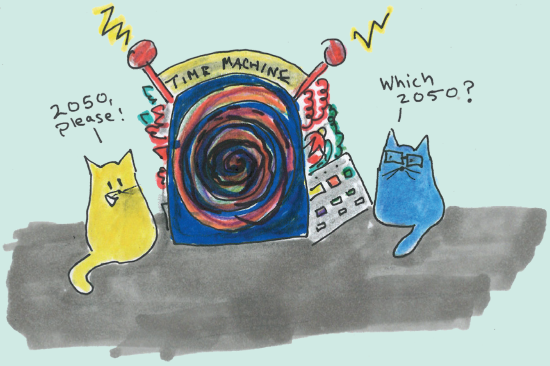
Human-caused climate change has increased the chances of seeing multiple extreme weather events occurring at the same time or soon after each other; these are called compound events. Compound events can have even bigger impacts on nature and people than if they happened individually. For example, a drought along with extreme heat will increase the risk of wildfires, death of livestock, or crop failure. With a higher average sea level, a severe storm will increase the risk of simultaneous extreme sea level and heavy rainfall, and thus coastal flooding.



### What are climate models?

Climate models are computer tools that scientists use for understanding past, present and future climate changes. They are computer programs that simulate the Earth's climate, based on fundamental laws of physics, chemistry and biology of the atmosphere, ocean, ice and land. Some models include more processes, complexity and detail than others. So, the resulting simulated climates can vary between models. That is why the IPCC always looks at results from many climate models to understand which findings we can be more certain about.

Scientists test climate models by comparing their results with past observations and paleo (very old) evidence. If models accurately simulate the changes we have observed on the Earth in the past, this gives us confidence that they capture the most important climate processes. The models can then be used to identify what has caused these past changes, and also to explore how the climate could change in the future, depending on our actions.




Of course, there is no way to know exactly how human-caused emissions of greenhouse gases and air pollutants will change in the future. But scientists can explore different possibilities: for example, by modelling futures where emissions of greenhouse gas are strongly reduced or, alternatively, futures where greenhouse emissions remain high. They can explore how these futures would affect things like sea level rise, extreme events and air pollution, among many others.

# Our future climate

*In order to be prepared for the future, we need to understand how climate will continue to change. Our future is not set in stone: it will depend on many choices we make now and in the coming years.*

## Global warming will continue until at least about 2050 before temperatures can stabilize

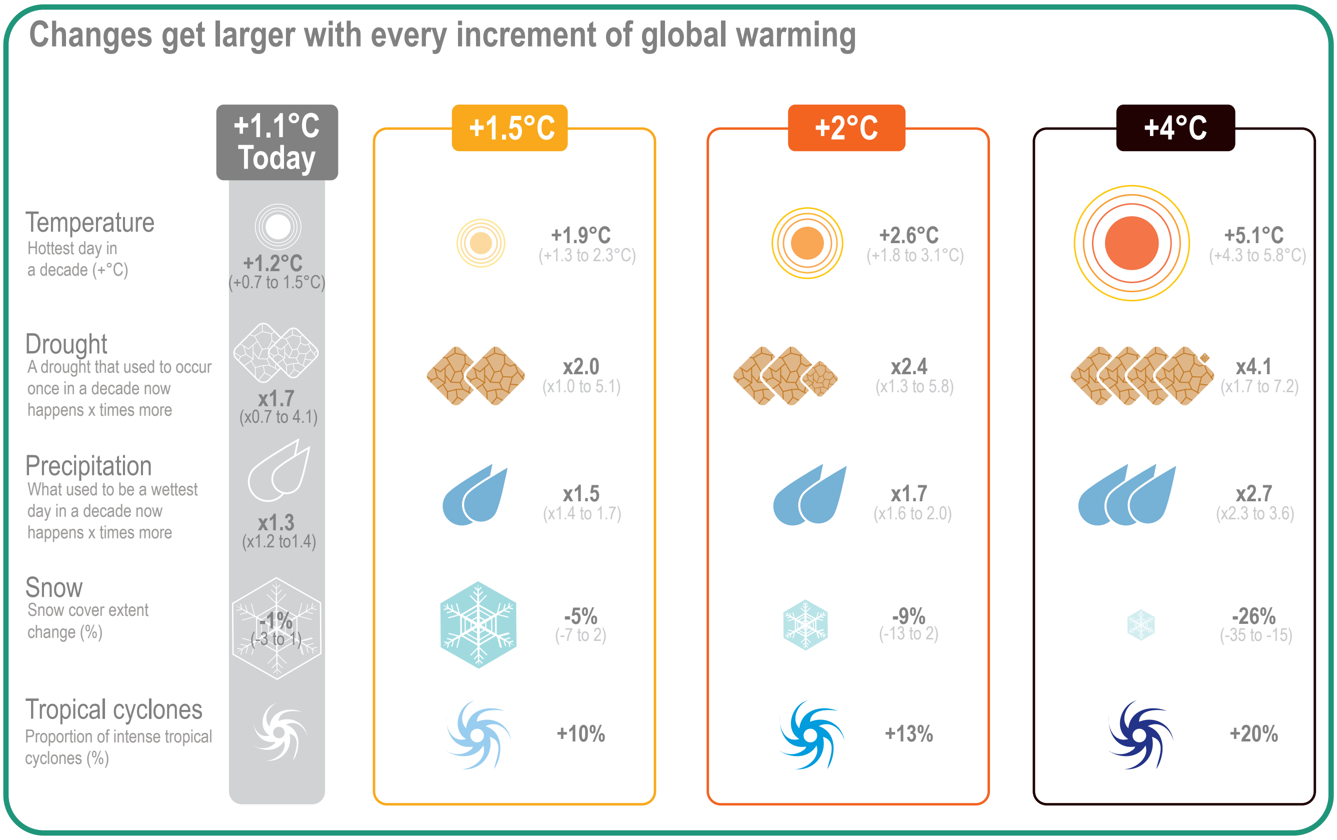
Climate models show that, even if we strongly reduce greenhouse gas emissions starting now, warming won't be halted until at least the 2050s. This is because the human activities that cause greenhouse gas emissions cannot stop immediately; it takes time to implement actions to reduce greenhouse gas emissions (even if done ambitiously). Strong reductions in greenhouse gases starting now would slow and reduce this amount of warming.

After the 2050s, climate models show very different levels of warming, depending on the actions we take in the near future. For example, if we strongly and rapidly reduce carbon dioxide emissions starting now and throughout the 21st century, warming would be halted by around the middle of the century, reaching around 1.5°C (2.7°F) or 2°C (3.6°F) by the end of the century in these scenarios. On the other hand, if emissions remain the same or increase, temperatures will continue to rise. In climate models that look at very high levels of greenhouse gas emissions, warming reaches around 4.5°C (8°F) by the end of the century. See also the section later in this summary titled *Global temperatures will only stabilize when we stop adding more carbon dioxide to the atmosphere* on page 13.

The world will most likely reach 1.5°C (2.7°F) global warming in the period 2021–2040 (we reached 1.1°C/2°F already in the last decade). But unless there are rapid, strong and sustained reductions in greenhouse gas emissions, limiting warming to 1.5°C (2.7°F) or even 2°C (3.6°F) will be impossible.

## Extremes will get worse. The water cycle will intensify and be more variable

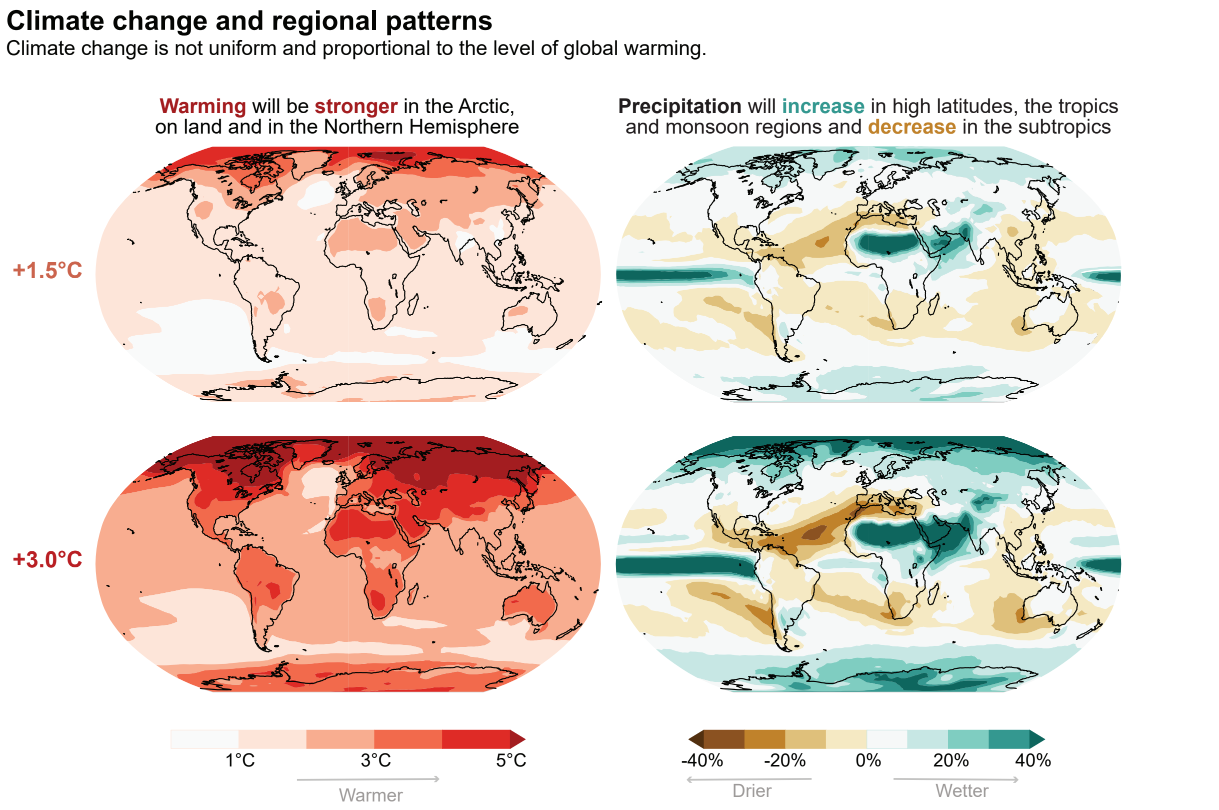
Many aspects of climate change will continue to increase as the Earth becomes warmer (see Graphic E). Heatwaves, heavy rainfall and droughts will continue to become more severe and more frequent. Rainfall over land, including monsoon rainfalls, will become more variable and intense: some areas will get drier, others will get wetter. Further warming will also amplify the thawing (defrosting) and melting of many frozen parts of the world, such as snow cover, glaciers, frozen ground and Arctic sea ice. For instance, it is estimated that the Arctic Ocean will be effectively free of sea ice at its lowest point in summer (September) at least once before 2050. Tropical cyclones will get stronger. Graphic E shows how some climate changes will become more severe at 1.5°C (2.7°F), 2°C (3.6°F) and 4°C (7.2°F) global warming.




**Graphic E • Climate changes become more severe with every increment of global warming.** How temperature extremes, droughts, heavy rainfall (precipitation) events, snow cover and tropical cyclones change at different levels of global warming compared with the late 19th Century (1850–1900). Today here is the average over 2011–2020. For example, the hottest day in a decade now is already +1.2°C (2.2°F) hotter than compared with the hottest day in a decade before the industrial revolution. By 1.5°C (2.7°F) global warming, it would be around +1.9°C (3.4°F) hotter, by 2°C (3.6°F) global warming it would be around +2.6°C (4.7°F) hotter and by 4°C (7.2°F) global warming it would be around +5.1°C (9.2°F) hotter.
Graphic adapted from IPCC AR6 Working Group I Infographic TS.1 in the Technical Summary. https://www.ipcc.ch/report/ar6/wg1/figures/technical-summary/ts-infographics-figure-1

## All regions of the world will experience further climate changes

Warming will continue to be different around the globe, being stronger over the land compared to over the ocean and strongest in the Arctic. Each region is unique and affected by climate change in its own way. The greater the warming, the larger and more widespread the climate changes are in each region. Graphic F shows how temperature and rainfall will change at 1.5°C (2.7°F) and 3°C (5.4°F) global warming. As a result, extreme weather events will more likely occur together, worsening the overall effect. For instance, heatwaves and droughts can occur at the same time or shortly after each other. In the IPCC Interactive Atlas, you can explore the different climate changes in your region: https://interactive-atlas.ipcc.ch/




**Graphic F • All regions of the world will experience further climate changes, and these changes will be different depending on where you are.** Changes in annual average temperatures and rainfall (precipitation) at global warming of 1.5°C (2.7°F) and 3°C (5.4°F) compared with the late 19th Century (1850–1900). The colour scales at the bottom of the graphic show the size of these changes as percentages. Some changes may be relatively large in terms of percentage even if the actual change is relatively small. For example, in very dry areas like the Sahara, even a small increase in actual precipitation shows as a relatively larger percentage increase.
Graphic adapted from IPCC AR6 Working Group I FAQ 4.3, Figure 1. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-4/

## Climate will always be affected by natural variability on time frames of years to decades

There are natural factors that affect global temperature on relatively short time scales (years to decades, see Graphic C). These normal variations in climate, known as natural variability, will continue in the future, as they have done in the past.

When combined with human-caused climate changes, the consequences of natural variability can either be larger or smaller than projected. An example of natural variability is a phenomenon found in the tropical Pacific called the El Niño–Southern Oscillation, or ENSO. This is a climate pattern that changes every two to seven years, and can (among other things) alter the chances of wildfires and heavy rainfall in many regions of the world for several months. For those affected regions, ENSO can make the human-caused changes to rainfall and wildfires a bit larger, or smaller, for that short period of time.

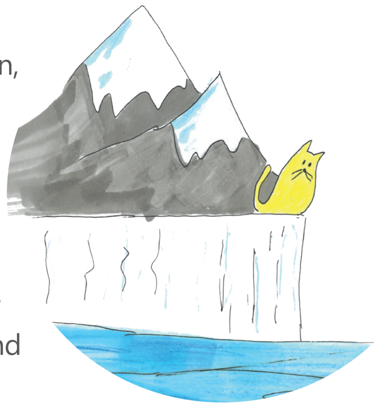
It is important for communities to consider natural variability when preparing for future climate changes over short time scales. There's always a chance that future changes could be a bit stronger (or a bit weaker) than projected – but these natural factors will have little effect on long-term trends.

## Many changes will continue for hundreds or thousands of years

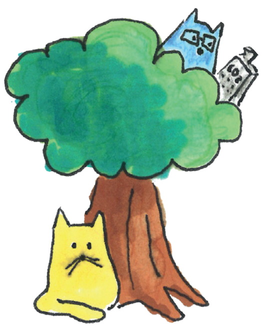
The atmosphere warms relatively quickly in response to greenhouse gas emissions, but some elements of the climate system react very slowly to a warming world. Changes like deep ocean warming, Greenland and Antarctica ice sheet melting, and sea level rise are slow to respond to the atmosphere warming but will continue to change for centuries, if not millennia. These changes are called irreversible because they would continue to change even if greenhouse gases or global temperatures were brought back down again. Taking sea level rise as an example: even if we stabilize global warming to 1.5°C (2.7°F), sea level would still rise 2–3 metres (7–10 feet) over the coming 2000 years and 6–7 metres (20–23 feet) over the coming 10,000 years.

## Low-likelihood outcomes are climate changes that we think are not likely to happen, but we cannot rule them out

There are some climate change events that we think are not likely to happen, or their likelihood is hard to know, but we cannot entirely rule them out. If they do occur, the consequences would be very serious. Those events are called low-likelihood, high impact outcomes and include the collapse of the Earth's ice sheets (causing much larger, faster sea level rise) or massive forest dieback (that would release a large amount of carbon dioxide to the atmosphere and reduce the amount being removed by nature). Given their huge potential consequences, it is important to keep those outcomes in mind when planning for the future.



## Nature will remove relatively less of our carbon dioxide from the atmosphere in the future compared to the past, unless we reduce our emissions



The land vegetation and ocean remove roughly half of the carbon dioxide that humans emit to the atmosphere. This fraction of carbon dioxide removal has not really changed over the past 60 years – human activities have emitted more and more carbon dioxide into the atmosphere but the land vegetation and ocean have also removed more carbon dioxide. This is why the oceans have become more acidic, because when carbon dioxide dissolves in water, it reacts to make the seawater more acidic.

However, climate modelling shows that if we carry on emitting more and more carbon dioxide into the atmosphere, the relative amount being naturally removed by the land vegetation and ocean would decline. So, what does this mean? The bottom line is that nature helps us less when we emit more carbon dioxide compared to if we reduce our emissions.

# Limiting future climate change

*This summary only covers how to limit further climate change from a physical science perspective because it is based on the IPCC report that looks at the science behind climate change (Working Group I: https://www.ipcc.ch/report/ar6/wg1/). The IPCC report on adaptation (Working Group II: https://www.ipcc.ch/report/ar6/wg2/) describes how climate changes affect humans and other species and the options to adapt to these changes. The report on emissions reductions and other mitigation efforts (Working Group III: https://www.ipcc.ch/report/ar6/wg3/) describes our options to limit or reverse future climate change.*

## Global temperatures will only stabilize when we stop adding more carbon dioxide to the atmosphere

Carbon dioxide remains in the atmosphere for a very long time – some of it for centuries to millennia. Adding more carbon dioxide to the atmosphere will cause further warming (See box *What are greenhouse gases?* on page 6). So, to stop temperatures from increasing even more, we need to either stop all carbon dioxide emissions from human activities or reach a point where any remaining emissions of carbon dioxide are balanced by activities that remove and store carbon dioxide for a very long time. This is called net-zero carbon dioxide emissions.

If our future emissions of carbon dioxide are very small but still larger than the amount we remove from the atmosphere, then the world will still continue to warm, albeit at a slower rate. But if carbon dioxide emissions and removals are balanced (i.e., net-zero) then global temperatures will stabilize.

Of course, carbon dioxide is only one of the human-caused greenhouse gases that cause global warming.

## Strong, rapid and sustained reductions in other greenhouse gases like methane and nitrous oxide are also needed to limit climate change

If this can be achieved then global temperatures can be stabilized. However, this would not mean that global temperatures go back down to previous levels. This is why many of the climate changes that have happened already cannot be reversed, only stopped, slowed, or stabilized.

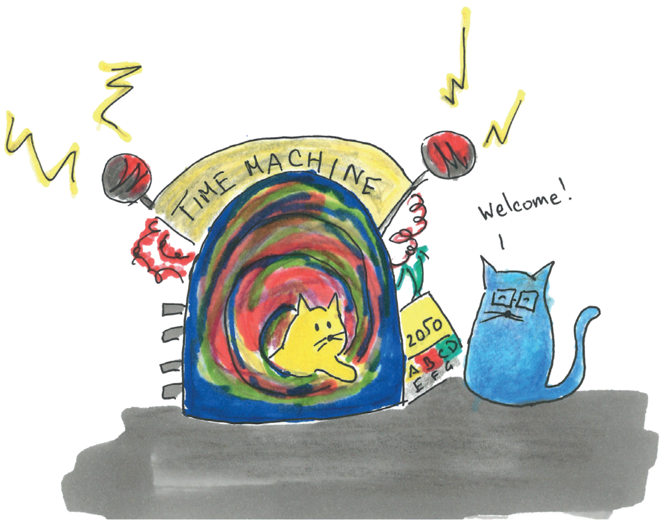
The amount of carbon we can release into the atmosphere and still keep global temperature to around 1.5°C (2.7°F) global warming is small compared to what we have already released: about 500 $GtCO_2$ (calculated starting from 2020) compared to the approximately 2500 $GtCO_2$ that we have emitted already (1 Gt = 1 gigaton = 1 billion tons). This is roughly equal to only a few years left of current emissions.

## Reducing greenhouse emissions would also improve air quality

Air pollution leads to millions of premature deaths and poorer health worldwide every year. Climate change and air quality are closely connected, because many of the human activities that produce greenhouse gases also emit air pollutants. Therefore, if we take action to reduce greenhouse gas emissions then we often also reduce emissions of other substances (like aerosols) that cause air pollution. So, strong actions to reduce climate change would also improve air quality.

## With rapid and sustained reductions in greenhouse emissions, we would clearly see the effect on global temperature in 20 years

Immediate and sustained reductions of greenhouse gas emissions would slow down global warming within a decade, but it could take twenty years or so before we would clearly see temperatures stabilize. This slowdown of warming would initially be masked by natural variability (see section *Climate change will always be affected by natural variability on time frames of years to decades* on page 11). And, because it takes time, the longer we wait to take action, the longer it will be before we see the benefits of those actions.



## About this summary

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body that produces scientific reports on our current understanding of climate change. It contains three main Working Groups that cover different topics of climate change: Working Group I looks at the physical climate changes, Working Group II looks at the impacts these changes have on people and ecosystems, as well as how we can adapt to our changing climate, and Working Group III looks at how climate change can be reduced or stopped (mitigation). The Working Groups publish climate change reports about once every 8 years. The IPCC doesn't do its own research but bases its reports on the published scientific evidence (scientific literature, datasets, etc).

This document is a plain-language summary of the IPCC Working Group I climate change report released in August 2021. It was written by members of the Working Group I Technical Support Unit (WGI TSU) and several authors of the report. Additionally, many volunteers offered feedback and guidance along the way. It has *not* undergone the same approval process that official IPCC documents undergo, such as the Summary for Policymakers.

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