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## Global Warming – Our Greatest Challenge

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The current state of Earth's climate is the result of a long-term and continuous development. It is like a mere snapshot from a lengthy film of the Earth's history that has lasted around 4.5 billion years and which is still running. Climate fluctuations are documented by geological findings (marine sediment cores: several million years; ice cores: 800,000 years), by tree rings (10,000 years), historical records (1000 years) and by modern instruments (e.g. thermometers and barometers, 250 years).

These data reveal pronounced changes to be a characteristic feature of Earth's climate, which extend over time scales ranging from months to millions of years. Short-term fluctuations of a few days within the atmosphere shape our weather, while long-term changes in the atmosphere on time scales of a month or more are considered climate fluctuations.

However, the causes of climate variations are not only to be found in the atmosphere, but also come about through the interaction of the atmosphere with the slow components of the climate system (ocean, ice, biosphere, lithosphere) and through external forcing (Fig. 1). In this context, the gas composition of the air plays an important role. Water vapour and carbon dioxide in the air are the largest contributors of the Earth's natural greenhouse effect, which raises the temperature at the Earth's surface from a hostile  $-18\text{ }^{\circ}\text{C}$  to a pleasant  $+15\text{ }^{\circ}\text{C}$ . Changes in these gaseous components of the air will therefore cause climate changes.

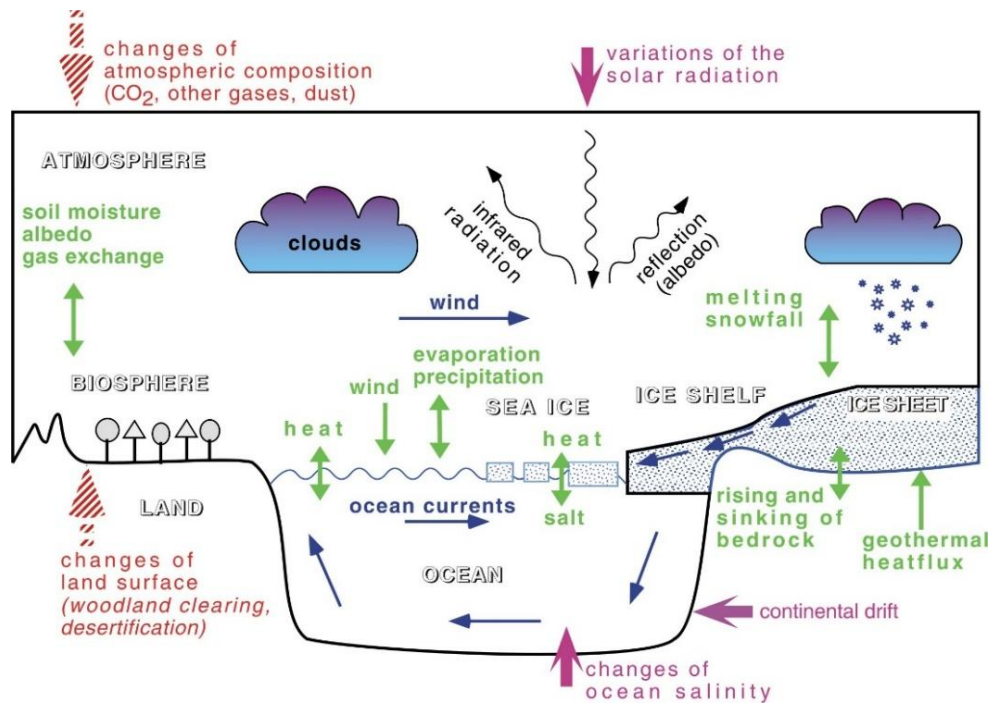


Fig. 1: Schematic depiction of the climate system. The thin black and blue arrows represent radiation and advection processes, respectively. Green arrows indicate interactions within the climate system. Bold magenta arrows show changes in external boundary conditions, with the effects of human activities shown in hatched red colour.

The Intergovernmental Panel on Climate Change (IPCC) regularly analyses the state of the climate system, its impact on nature and human societies, and discusses the options for political adaptation and mitigation measures. The first volume of the IPCC's Sixth Assessment Report [1] (The Scientific Basis) was published in August 2021. Volumes two (Impacts, Adaptation and Vulnerability) and three (Mitigation of Climate Change) were published in February and April 2022, respectively, and the final Synthesis Report was published in March 2023. In 2018 and 2019, the following reports were published by the IPCC: Special Report Global Warming of 1.5 °C (SR15 [2]), Special Report Climate Change and Land (SRCCL [3]) and Special Report Ocean and Cryosphere in a Changing Climate (SROCC [4]).

## 1. Causes of current climate change

The carbon dioxide content of the air has increased by 54 % since 1750 from 277 ppm to 427.4 ppm in 2025 (ppm = parts per million; ). The rate of increase over the last 10 years has been the highest for fifty years. Today's CO<sub>2</sub> level is by far the highest over the last 800,000 years, as measurements of air inclusions in ice cores from the Antarctic ice sheet show (Fig. 2). In the cold periods (glacials), the CO<sub>2</sub> content of the air was around 180 ppm and in the warm periods (interglacials) 280 ppm. In 2025, this value on Mauna Loa was 427.4 ppm.

This is the cause of our climate problem. By using fossil fuels, humankind has increased the CO<sub>2</sub> content of the air by more than 100 ppm over the past 60 years, which corresponds to the transition from a glacial to an interglacial period, which, however, took about 20,000 years in the natural climate cycle. Further investigations show that the current CO<sub>2</sub> concentration is higher than it has been for several million years.

Although the amount of CO<sub>2</sub> in the air is small, it plays the most important role in the greenhouse effect because nitrogen, oxygen and argon, which make up 99 % of the air, are not greenhouse gases. Greenhouse gases in the atmosphere absorb the heat radiation from the Earth's surface and send some of it back again, thereby additionally warming the Earth's surface.

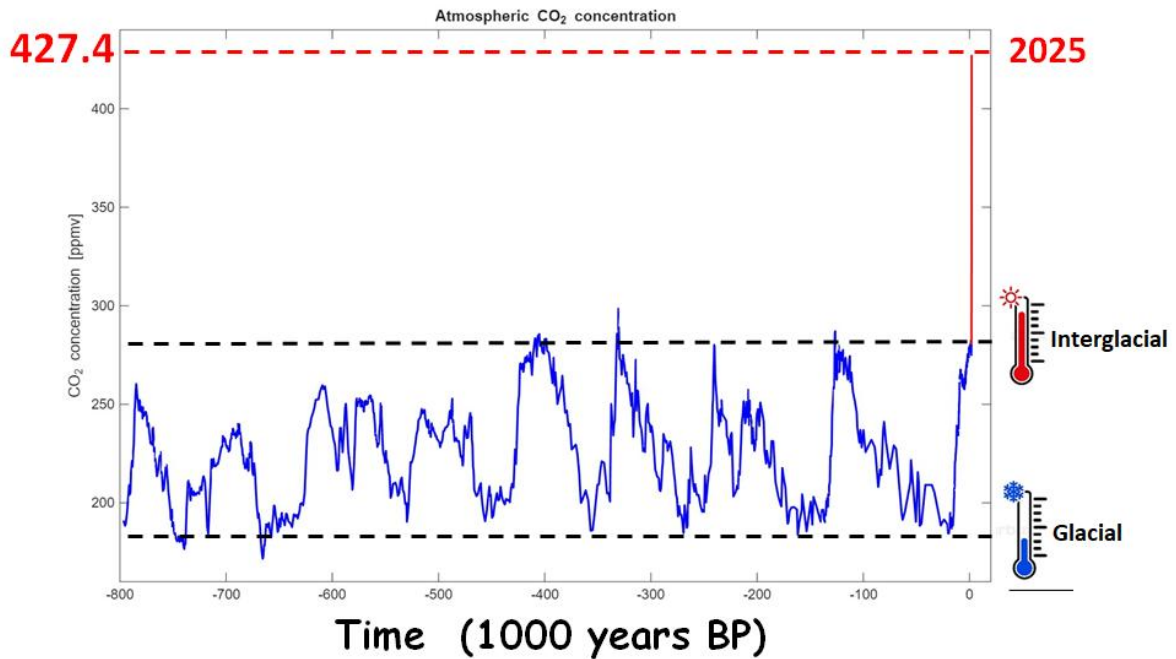
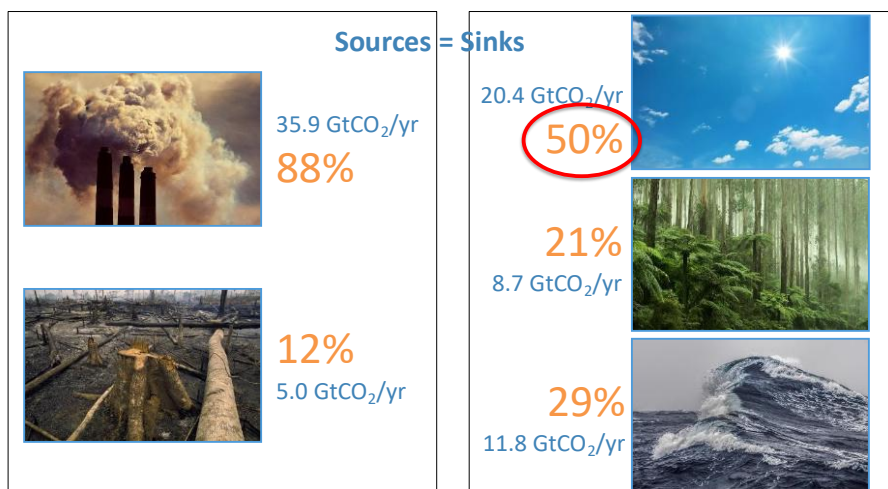


Fig. 2. Temporal development of the CO<sub>2</sub> content in the atmosphere over the past 800,000 years, determined from air inclusions in the EPICA Dome C (Antarctica) ice core (blue, Lüthi, D. et al., 2008 [5]) and direct measurements of air samples on Mauna Loa (since 1959, red, data source: <https://gml.noaa.gov/ccgg/trends/data.html>).

Of this increase, 90 % is due to the use of fossil fuels and 10 % to land use change (e.g. deforestation) (Fig. 3). The Earth System (essentially the biosphere and the ocean) cannot adapt to this high rate of emissions, therefore 48 % of emissions remain in the atmosphere, significantly increasing the natural greenhouse effect. It is getting warmer and we are probably heading for a super-warm interglacial. The biosphere takes up 29 % of the emissions (fertilisation effect due to the higher CO<sub>2</sub> content) and 26 % are absorbed by the ocean, resulting in higher acidification, with severe consequences for the marine ecosystem.



### Fate of anthropogenic CO<sub>2</sub> emissions (2015–2024)



Budget Imbalance: (the difference between estimated sources & sinks) <1%  
0.1 GtCO<sub>2</sub>/yr

Source: Friedlingstein et al 2025; Global Carbon Project 2025

Fig. 3: Sources and sinks of the anthropogenic CO<sub>2</sub> emissions in the Earth System (ocean, biosphere, atmosphere) in Gt CO<sub>2</sub> per year (1Giga tonne = 1 billion tonnes = 10<sup>12</sup> kg) (Friedlingstein et al., 2025 [6]).

Other important greenhouse gases such as methane and nitrous oxide, whose concentrations have also risen sharply since 1750, together account for slightly more than half of the climate impact of the increase in CO<sub>2</sub>, as they make up a much smaller percentage of the composition of the air. The changes in the radiation balance responsible for climate change (anthropogenic radiative forcing) are therefore primarily caused by changes in the carbon dioxide content.

The most effective greenhouse gas – water vapour – is not directly changed by humans. Furthermore, the water vapour content of the air cannot increase indefinitely. If the saturation value is reached, the water vapour condenses and it rains. It therefore does not play an important role in the current temperature trend. However, water vapour will play an amplifying role in the future, as its saturation value in the air increases with rising temperatures and allows a higher water vapor content.

Variations in solar radiation currently only have a minor influence on the Earth's temperature. The IPCC AR6 (2021, Table 7.8) puts this at approximately 0.01 W/m<sup>2</sup>, compared to the total anthropogenic radiative forcing of 2.72 W/m<sup>2</sup>.

## 2. Observed consequences of the increased greenhouse effect

The warming of the climate system is unequivocal. The global surface temperature has risen by around 1.25 °C since 1880. The trend over the last 60 years (0.19 °C/decade) is more than twice as large as the trend since 1880 (0.09 °C/decade), and the last ten years have been the warmest on record (Fig. 4). Meanwhile, the years 2011 to 2020 represent the warmest decade and 2024 the warmest year since 1880. The Arctic has warmed more than twice as much as the global average (<https://climate.copernicus.eu/climate-indicators>).

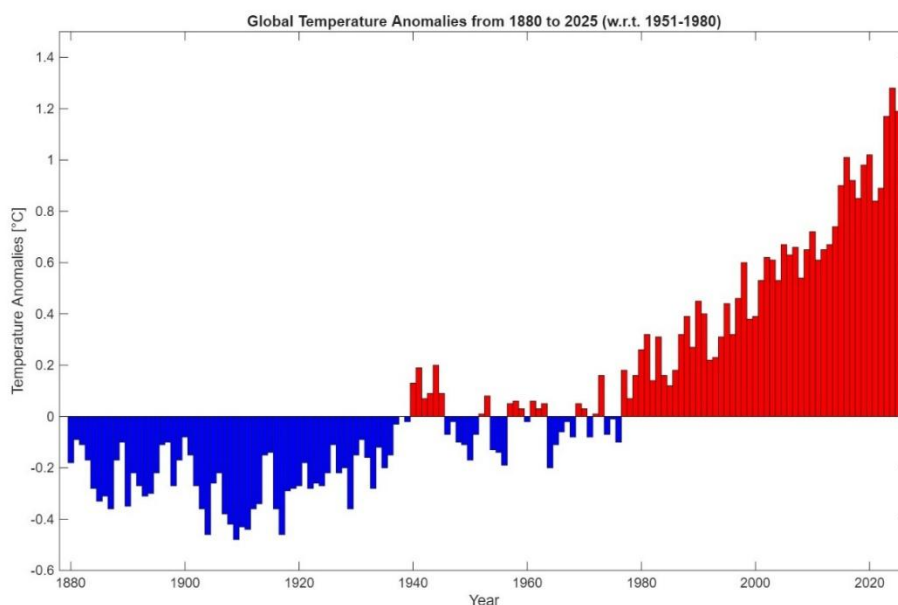
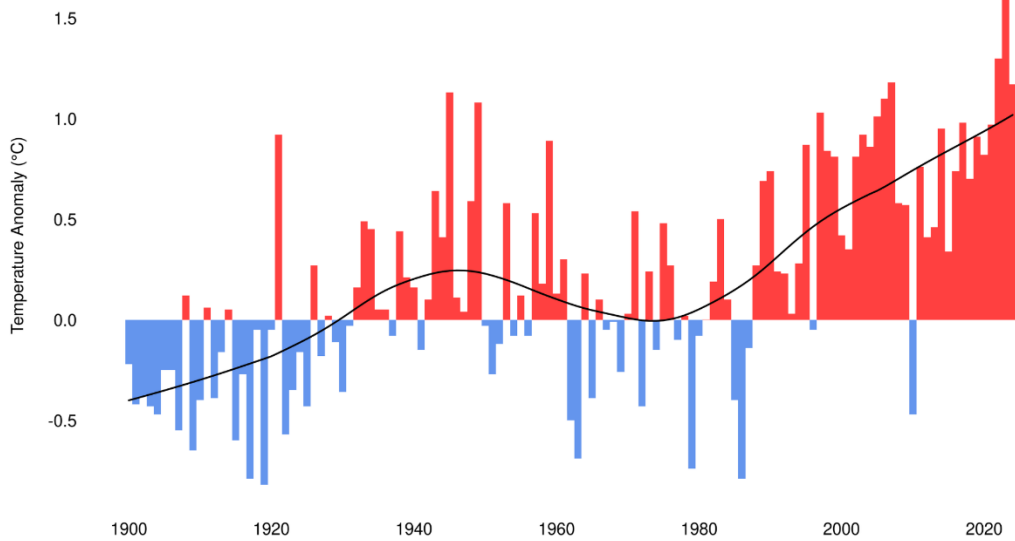


Fig. 4: Global surface temperature anomalies (w.r.t. 1951-1980; data source: <http://data.giss.nasa.gov/gistemp/>).

In contrast to continental Europe, where the warming trend is 2.4°C, Ireland has warmed up since 1900 by approximately 1°C, slightly less than the global trend (Fig. 5).

### Ireland Temperature Anomaly (1961-1990 baseline)



Met Éireann

Fig. 5: Ireland's temperature anomaly against the baseline period 1961-1990. The black line is a LOESS trendline, which uses a 42-year window to smooth out patterns in the data over time (<https://www.met.ie/climate/climate-change>).

Reconstructed data from observations and other sources, such as tree ring data, indicate that temperatures in the last 50 years have very likely risen more than in the last 2,000 years.

The snow-covered area in the northern hemisphere has decreased, most noticeably in March and April. Glaciers are shrinking worldwide and their meltwater is currently contributing 0.6 mm per year to sea level rise. Since 1979, the sea ice cover in the Arctic has decreased by 10 % in winter (March) and 53 % in summer (September, Fig. 6). Superimposed on the trend are strong natural variations. The reason for the sharp decline in summer is the strong thinning of the sea ice cover. No significant decline in Antarctic sea ice cover can be recognised.

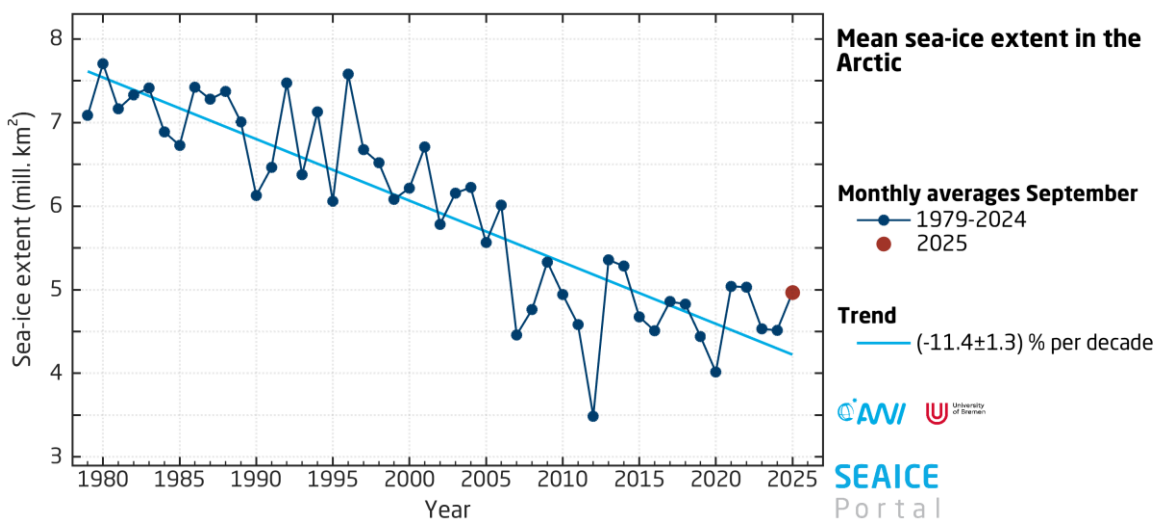


Fig. 6: Decline in summer sea ice extent in the Arctic ([www.meereisportal.de](http://www.meereisportal.de)).

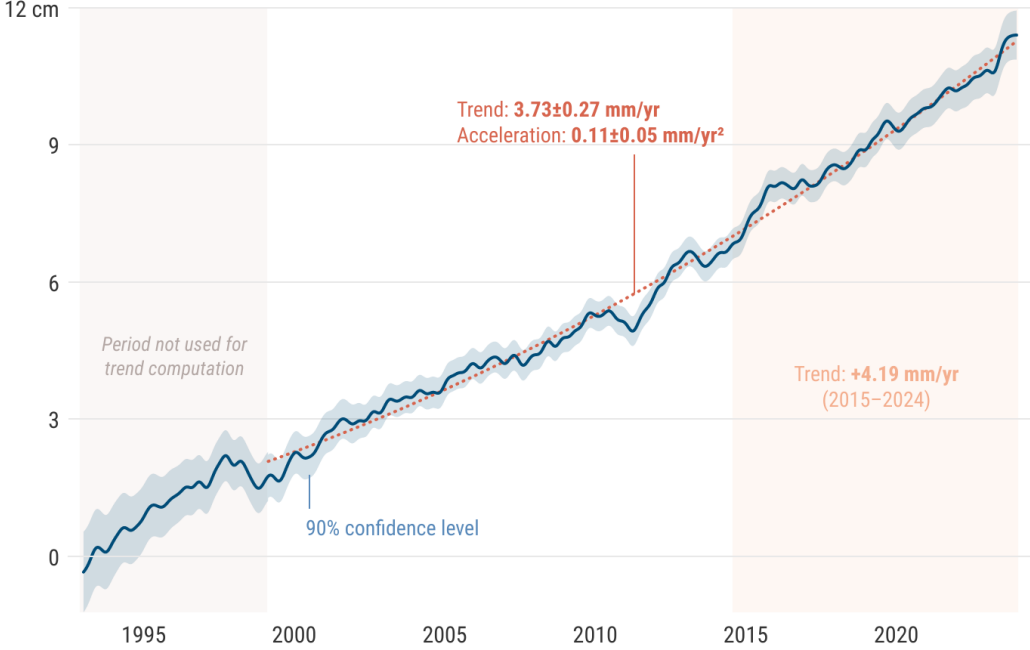
Temperatures in the upper layers of the permafrost soil in the northern hemisphere have warmed by 1 to 3 °C since 1980, and the extent of seasonally frozen ground has decreased by 7 % since 1900.

On a global average, the oceans have become warmer down to depths of 3000 metres. This warming has contributed to sea level rise. Global sea levels have risen by 17 cm in the 20th century. This is the highest rise in the past 3,000 years. Since 1993, global sea levels have risen by 3.4 mm per year. From 1999 to 2024, sea level rise averaged around 3.7 mm per year (Fig. 7). About half of this is caused by the meltwater of shrinking ice masses on the continents (glaciers 0.6 mm/year; Greenland Ice Sheet: 0.9 mm/year; Antarctic Ice Sheet 0.5 mm/year).

The total amount of meltwater is therefore 2.0 mm/year. The difference to the observed increase of 3.7 mm/year is due to the expansion of seawater as a result of warming (1.4 mm/year) and changes in the water balance of the continents (groundwater, reservoirs, etc., 0.6 mm/year) (IPCC, AR6, 2021 [1]). Although these individual estimates of sea level rise are somewhat higher in total than the measured rise, they demonstrate a good understanding of the processes that determine sea level. Meanwhile, sea levels have continued to rise by 4.2 mm per year between 2015 and 2024 (Fig. 7), meaning that sea level rise is accelerating.

A significant trend in the strength of the meridional overturning circulation in the Atlantic (often simplified but incorrectly referred to as the "Gulf Stream") cannot be derived from the available data.

### Daily change in global mean sea level



Data: CMEMS Ocean Monitoring Indicator based on the C3S sea level product • Credit: C3S/ECMWF/CMEMS



Fig. 7: Global Mean Sea Level from January 1993 to July 2024 (<https://climate.copernicus.eu/climate-indicators/sea-level>)

### 3. Projections of the future climate change

Climate models have been significantly improved over the past forty years as part of the World Climate Research Programme (<https://www.wcrp-climate.org/>), and they are certainly one of the best predictive tools available to our society. The models reproduce the observed patterns of the Earth's surface temperature and its trends over many decades on a continental scale, including the increased warming since the mid-20th century and the short-term cooling

immediately following large volcanic eruptions. These model calculations and their comparison with observations show that the warming of the last 50 years is very likely to have been caused mainly by anthropogenic greenhouse gas emissions (mainly carbon dioxide).

Climate projections for the next 100 years can therefore be convincingly simulated using climate models that are driven by greenhouse gas emission scenarios (Fig. 8). For these scenarios (Shared Socio-economic Pathway (SSP)), five examples of the possible development of human society in the future have been outlined. They range from a frugal and sustainable society that rapidly utilises only alternative energy sources to "business as usual". These scenarios for possible futures were sorted according to the amount of greenhouse gases still emitted by humans (SSP1 = small to SSP5 = very large). The number after the scenario abbreviation indicates the corresponding increase in additional radiative forcing due to greenhouse gases in W/m<sup>2</sup> (1.9 = small to 8.5 = large).

Climate models predict – depending on the energy use – a further increase in temperature and a significant rise in sea level by the end of the 21st century [1]. For the last two decades of the 21st century, the most likely value of global warming is 1.4 °C for the lowest scenario and 4.4 °C for the highest scenario, relative to the period 1850-1900 (see Table SPM B.1.2 in the Summary for Policymakers [1]). The greatest warming occurs in high northern latitudes. Accordingly, the sea level rise is 0.4 m for the lowest and 0.8 m for the highest scenario (based on 1850-1900; Table 9.10 in [1]).

For the next two to three decades, the projected warming depends only slightly on the assumptions about future emissions, and even if all emissions were to cease immediately, the inertia of the climate system would result in a further temperature rise of up to approx. 0.3 °C (Chapter 4 in [1]).

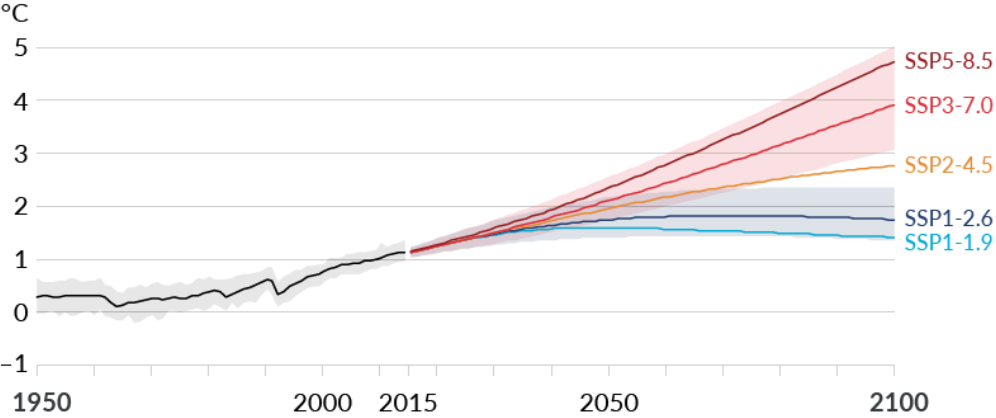


Fig. 8: Global surface temperature changes relative to 1850-1900 for various emission scenarios (Fig. SPM.8 in [1]). Shades represent uncertainty ranges.

Long-term projections show that the sea level will continue to rise for many centuries even after emissions cease completely, due to further slow warming of the deep ocean. However, there is considerable uncertainty regarding the further development of the Greenland and Antarctic ice sheets, where a higher contribution to the future rise cannot be ruled out. Model results suggest that a permanent warming of well above 3 °C would lead to a complete melting of the Greenland ice sheet, corresponding to a sea level rise of 7 metres. However, this melting would take many centuries.

It is likely that the meridional overturning circulation in the Atlantic will decrease by 15 to 30% over the course of the 21st century, depending on the energy scenario. Temperatures in the North Atlantic region will nevertheless increase, as the influence of global warming will predominate. However, it is unlikely that there will be an abrupt collapse of the meridional overturning circulation in the Atlantic in the 21st century.

Precipitation is very likely to increase in higher latitudes and in parts of the monsoon regions, while there will probably be a reduction in precipitation in areas of the subtropics (including the Mediterranean region).

Climate changes will be very noticeable in the future. It is clear that humanity has embarked on a gigantic experiment with the Earth and there are good reasons to take decisive action to counteract this. Humankind still has good opportunities to prevent major changes. However, limiting the global temperature rise to well below 2 °C by 2100 seems difficult.

In the IPCC's Fifth Assessment Report (AR5, 2013), it became clear that the total amount of global CO<sub>2</sub> emissions since the beginning of industrialisation largely and almost linearly determines the average global warming at the Earth's surface until the late 21st century and beyond. From the updated diagram in the latest IPCC Report (Fig. 9), it is now possible to extrapolate how much CO<sub>2</sub> humanity can still emit until the global surface temperature reaches 1.5 °C or 2.0 °C. For the lower limit (1.5 °C), the remaining budget (from 1 January 2020) is 500 Gt CO<sub>2</sub>, and for the upper limit (2.0 °C) 1350 Gt CO<sub>2</sub> (Table SPM2 in [1]). Considering that humans currently emit around 38 Gt of CO<sub>2</sub> every year, we only have 7 or 29 years from January 2026 until we have to achieve a CO<sub>2</sub> emissions freeze (net zero) across the entire planet if we continue as we have done so far. We can extend this time if we start to significantly reduce our CO<sub>2</sub> emissions now.

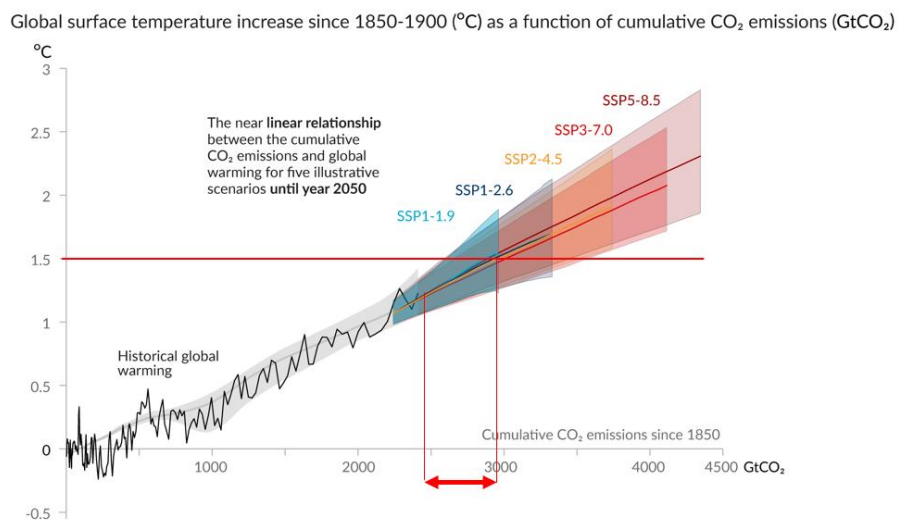


Fig. 9: Near-linear relationship between cumulative CO<sub>2</sub> emissions and the increase in global surface temperature ([1], Fig. SPM.10). The thin black line represents the observed global surface temperature increase since 1850-1900 as a function of historical cumulative CO<sub>2</sub> emissions in GtCO<sub>2</sub> from 1850 to 2019. The coloured central lines show the median estimate as a function of cumulative CO<sub>2</sub> emissions from 2020 until year 2050 for the set of illustrative scenarios. Shades represent uncertainty ranges

#### 4. Challenges arising from climate change

Our challenge is to adapt to the ongoing climate change and to limit the human impact on climate as far as possible through comprehensive mitigation measures.

Greenhouse gases emitted by humans (especially CO<sub>2</sub>) will remain in the atmosphere for decades to centuries even after emissions have been stopped and they will continue to determine the climate. The surface temperature will therefore remain at a high level for a long time to come, which is determined by the total amount of CO<sub>2</sub> emitted. The current nationally determined contributions (NDCs) to reduce greenhouse gas emissions point to a temperature

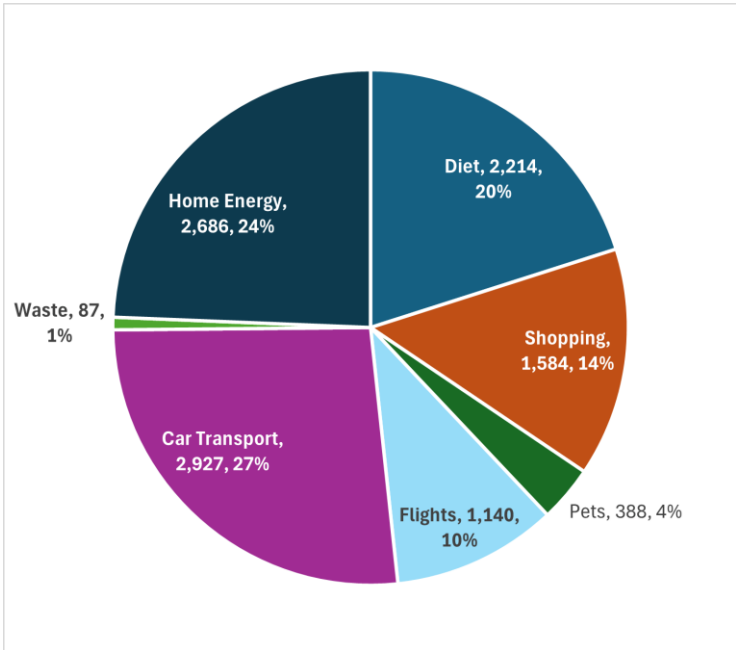
increase of around 2.6 °C. It will therefore not be possible to fulfil the Paris resolutions from 2015.

The result is an increase in extreme weather events, including in Germany. Examples include the floods in western Germany (particularly in the Ahr valley) in 2021, which caused many deaths and immense damage to the infrastructure of many villages and towns, and the drought in northern and eastern Germany in 2018, which resulted in major losses in agriculture. Adaptation measures to protect against the consequences of extreme weather events are becoming increasingly necessary, especially in the event of heavy rainfall, flooding, heatwaves and droughts.

In addition to these extreme events, sea level rise will be the biggest problem for humanity because more than 200 million people worldwide currently live below 5 metres above sea level. This figure is likely to double by the end of the 21st century. In many countries, the coasts are already threatened by flooding. As the deeper layers of the ocean are only warmed very slowly from the surface, the volume of the seas expands only very slowly. The sea level rises accordingly and will continue to do so for centuries after CO<sub>2</sub> emissions cease. In addition, the ocean will absorb the meltwater from glaciers and ice sheets. In the near future, dykes will have to be raised, but not all coastal countries will be able to afford this. In the long term, people in rich countries will also have to retreat to higher ground. The more climate change progresses, the more difficult adaptation measures will become.

Mitigation measures are therefore absolutely essential. They relate to investments in alternative energy and heating technologies, new CO<sub>2</sub>-emission-free transport systems and means of transport and new building materials. The federal, state and local authorities are called upon to create investment incentives for companies and private individuals.

A lot can also be done in the private sector. The per capita greenhouse gas emissions of around 11 tonnes per year in Ireland in 2024 clearly show where everyone can reduce their CO<sub>2</sub> emissions. Energy savings in electricity and heating and careful handling of food, around a third of which is thrown away and ends up in the rubbish bin in Western countries, would significantly reduce the carbon footprint. Even more can be saved in terms of mobility (driving fewer cars with combustion engines) and by limiting consumption (from T-shirts to smartphones), which accounts for 14% of the CO<sub>2</sub> emissions.



*Fig. 10: Greenhouse gas emissions per person in Ireland in 2024. (Source: <https://climateconnected.ie/carbon-footprint-tool/>)*

Science has recognised the problems and identified solutions. Solving the problem requires political, socio-economic and personal implementation. There are still major challenges to overcome in all three areas.

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