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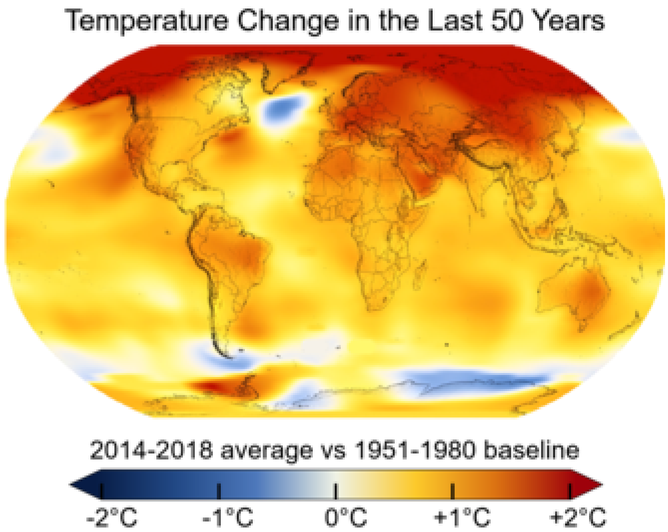
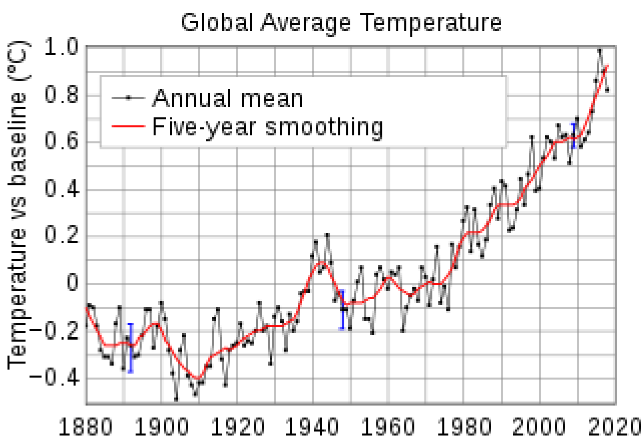
Global warming

"Climate change" redirects here.

Global warming is the long-term rise in the average temperature of the Earth's climate system. It is a major aspect of **climate change** and has been demonstrated by direct temperature measurements and by measurements of various effects of the warming.[5][6] *Global warming* and *climate change* are often used interchangeably.[7] But more accurately, *global warming* is the mainly human-caused increase in global surface temperatures and its projected continuation,[8] while *climate change* includes both global warming and its effects, such as changes in precipitation.[9] While there have been prehistoric periods of global warming,[10] many observed changes since the mid-20th century have been unprecedented over decades to millennia.[5][11]



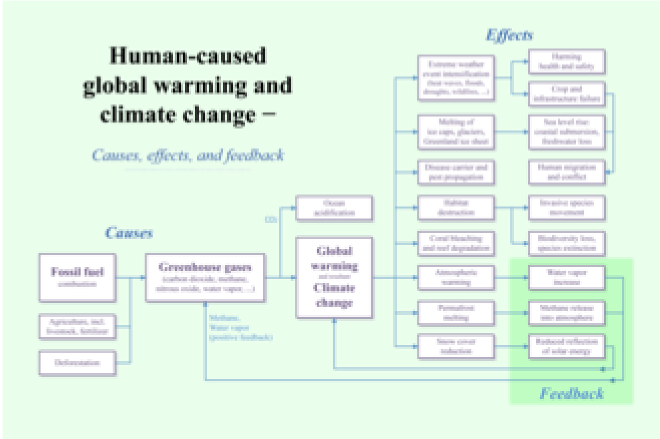
Average global temperatures from 2014 to 2018 compared to a baseline average from 1951 to 1980, according to NASA's Goddard Institute for Space Studies



The average annual temperature at the earth's surface has risen since the late 1800s, with year-to-year variations (shown in black) being smoothed out (shown in red) to show the general warming trend.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded, "It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century".[12] The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. Climate model projections summarized in the report indicated that during the 21st century the global surface temperature is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) in a moderate scenario, or as much as 2.6 to 4.8 °C (4.7 to 8.6 °F) in an extreme scenario, depending on the rate of future greenhouse gas emissions and on climate feedback effects.[13] These findings have been recognized by the national science academies of the major industrialized nations[14] and are not disputed by any scientific body of national or international standing.[15][16]

The effects of global warming include rising sea levels, regional changes in precipitation, more frequent extreme weather events such as heat waves, and expansion of deserts.[17] Ocean acidification is also caused by greenhouse gas emissions and is commonly grouped with these effects even though it is not driven by temperature. Surface temperature increases are greatest in the Arctic, which has contributed to the retreat of glaciers, permafrost, and sea ice. Overall, higher temperatures bring more rain and snowfall, but for some regions droughts and wildfires increase instead.[18] Climate change threatens to diminish crop yields, harming food security, and rising sea levels may flood coastal infrastructure and force the abandonment of many coastal cities.[19] Environmental impacts include the extinction or relocation of many species as their ecosystems change, most immediately the environments of coral reefs,[20] mountains, and the Arctic.[21]



Scientists have determined the primary causes[1] and the wide-ranging effects[2][3] of global warming and resulting climate change. Some effects constitute feedback mechanisms that intensify climate change in the direction of climate tipping points.[4]

Societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, and possibly climate engineering. Countries work together on climate change under the umbrella of the United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994 and has near-universal membership. The ultimate goal of the convention is to "prevent dangerous anthropogenic interference with the climate system".[22] Although the parties to the UNFCCC have agreed that deep cuts in emissions are required[23] and that global warming should be limited to well below 2 °C (3.6 °F) in the Paris Agreement of 2016,[24] the Earth's average surface temperature has already increased by about half this threshold[25] and current pledges by countries to cut emissions are inadequate to limit future warming.[26]

Contents

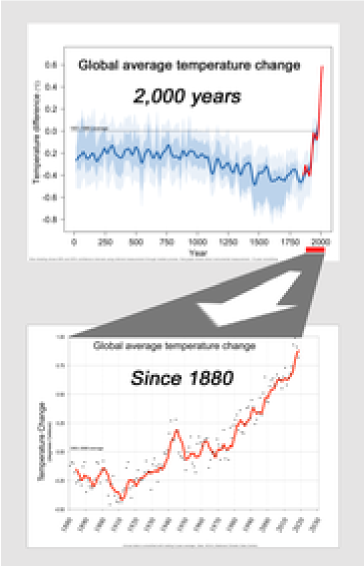
Observed temperature rise

Climate proxy records show that natural variations offset the early effects of the Industrial Revolution, so there was little net warming between the 18th century and the mid-19th century,[27][28] when thermometer records began to provide global coverage.[29] The IPCC has adopted the baseline reference period 1850–1900 as an approximation of pre-industrial global mean surface temperature.[27]

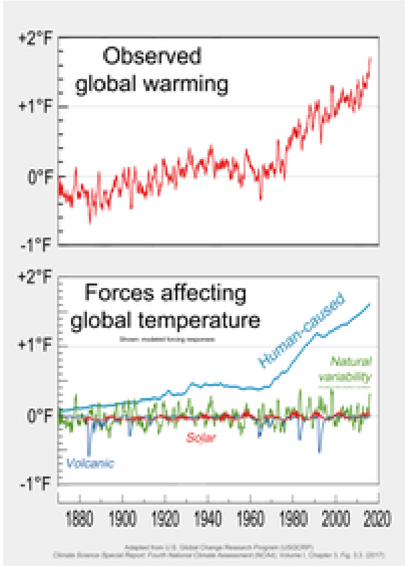
Multiple independently produced instrumental datasets confirm that the 2009–2018 decade was 0.93 ± 0.07 °C warmer than the pre-industrial baseline (1850–1900).[30] Currently, surface temperatures are rising by about 0.2 °C per decade.[31] Since 1950, the number of cold days and nights have decreased, and the number of warm days and night have increased.[32] Historical patterns of warming and cooling, like the Medieval Climate Anomaly and the Little Ice Age, were not as synchronous as current warming, but may have reached temperatures as high as those of the late-20th century in a limited set of regions.[33] Past examples of climate change provide insight into modern climate change.[34]

Although the most common measure of global warming is the increase in the near-surface atmospheric temperature, over 90% of the additional energy stored in the climate system over the last 50 years has warmed ocean water.[35] The remainder of the additional energy has melted ice and warmed the continents and the atmosphere.[36]

The warming evident in the instrumental temperature record is consistent with a wide range of observations, documented by many independent scientific groups;[37] for example, in most continental regions the frequency and intensity of heavy precipitation has increased.[38] Further examples include sea level rise,[39] widespread melting of snow and land ice,[40] increased heat content of the oceans,[41] increased humidity,[42] and the earlier timing of spring events,[43] such as the flowering of plants.[44]



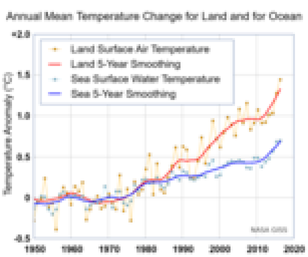
Global average temperatures declined for thousands of years, until fossil fuel-based industrialization beginning roughly 200 years ago reversed the decline. Global warming has intensified in recent decades.



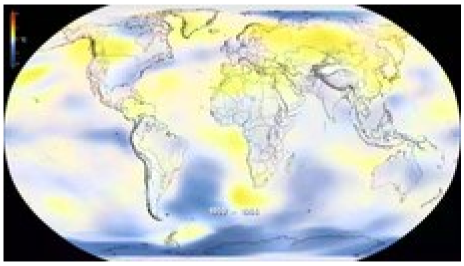
Scientists have investigated many possible causes of global warming, and have found that accumulation in the atmosphere of greenhouse gases, especially those resulting from humans burning fossil fuels, is the predominant cause.

Regional trends

Global warming refers to global averages, with the amount of warming varying by region. Since the pre-industrial period, global average land temperatures have increased almost twice as fast as global average temperatures.[45] This is due to the larger heat capacity of oceans and because oceans lose more heat by evaporation.[46] Patterns of warming are independent of the locations of greenhouse gas emissions because the gases persist long enough to diffuse across the planet; however, localized black carbon deposits on snow and ice do contribute to Arctic warming.[47]



Average annual temperature has risen faster on land than on the ice-free surface of the sea.



NASA animation of annual average temperature maps dating from the late 1800's to modern times.

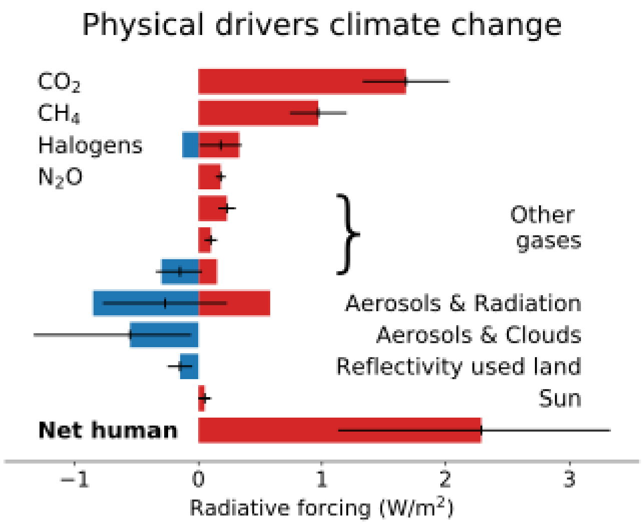
The Northern Hemisphere and North Pole have warmed much faster than the South Pole and Southern Hemisphere. The Northern Hemisphere not only has much more land, but the arrangement of land masses around the Arctic Ocean has resulted in the maximum surface area flipping from reflective snow and ice cover to ocean and land surfaces that absorb more sunlight and thus more heat.[48] Arctic temperatures have increased and are predicted to continue to increase during this century at over twice the rate of the rest of the world.[49] As the temperature difference between the Arctic and the equator decreases, ocean currents that are driven by that temperature difference, like the Gulf Stream, are weakening.[50]

Short-term slowdowns and surges

Because the climate system has large thermal inertia, it can take centuries for the climate to fully adjust. While record-breaking years attract considerable public interest, individual years are less significant than the overall trend. Global surface temperature is subject to short-term fluctuations that overlie long-term trends, and can temporarily mask or magnify them.[51] An example of such an episode is the slower rate of surface temperature increase from 1998 to 2012, which was dubbed the global warming hiatus.[52] Throughout this period ocean heat storage continued to progress steadily upwards, and in subsequent years surface temperatures have spiked upwards. The slower pace of warming can be attributed to a combination of natural fluctuations, reduced solar activity, and increased volcanic activity.[53]

Physical drivers of recent climate change

By itself, the climate system experiences various cycles which can last for years (such as the El Niño–Southern Oscillation) to decades[54] or centuries.[55] Other changes are caused by *external forcings*. These forcings are "external" to the climate system, but not always external to the Earth.[56] Examples of external forcings include changes in the composition of the atmosphere (e.g. increased concentrations of greenhouse gases), solar luminosity, volcanic eruptions, and variations in the Earth's orbit around the Sun.[57]

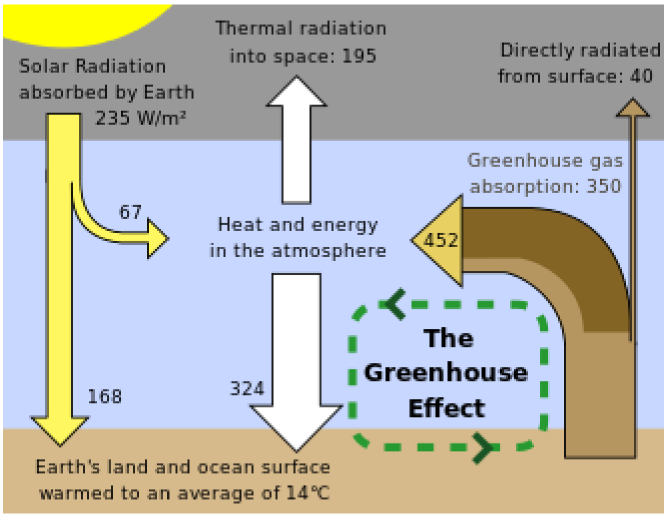


Radiative forcing of different contributors to climate change in 2011, as reported in the fifth IPCC assessment report. For the gases and aerosols, the values represent both the effect they have themselves and the effect of any chemical compound they get converted into in the atmosphere.

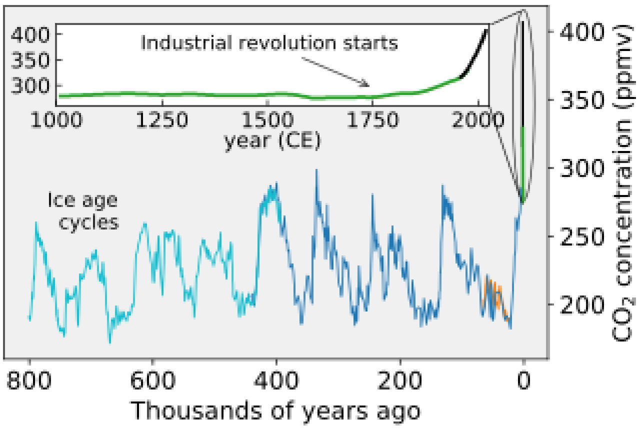
Attributing detected temperature changes and extreme events to human-caused increases in greenhouse gases requires scientists to rule out known internal climate variability and natural external forcings. Therefore, a key approach is to use physically or statistically based computer modelling of the climate system to determine unique fingerprints for all potential causes. By comparing these fingerprints with observed patterns and evolution of climate change, and the observed evolution of the forcings, the causes of the observed changes can be determined.[58] Scientists have determined that the major factors causing the current climate change are greenhouse gases, land use changes, and aerosols and soot.[59]

Greenhouse gases

Greenhouse gases trap heat radiating from the Earth to space.[60] This heat, in the form of infrared radiation, gets absorbed and emitted by these gases in the atmosphere, thus warming the lower atmosphere and the surface. Before the Industrial Revolution, naturally occurring amounts of greenhouse gases caused the air near the surface to be warmer by about 33 °C (59 °F) than it would be in their absence.[61] Without the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water.[62] While water vapour (~50%) and clouds (~25%) are the biggest contributors to the greenhouse effect, they increase as a function of temperature and are therefore considered feedbacks. Increased concentrations of gases such as CO_2 (~20%), ozone and N_2O are external forcing on the other hand.[63]

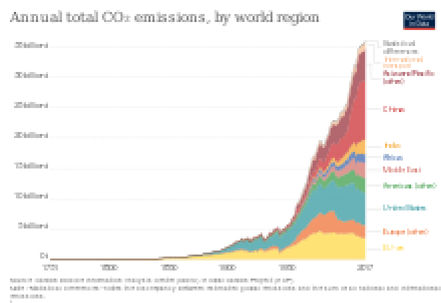


Greenhouse effect schematic showing energy flows between space, the atmosphere, and the Earth's surface. Energy exchanges are expressed in watts per square meter (W/m^2).



CO_2 concentrations over the last 800,000 years as measured from ice cores (blue/green) and directly (black)

Human activity since the Industrial Revolution has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from CO_2, methane, tropospheric ozone, CFCs, and nitrous oxide. As of 2011, the concentrations of CO_2 and methane had increased by about 40% and 150%, respectively, since pre-industrial times.[64] In 2013, CO_2 readings taken at the world's primary benchmark site in Mauna Loa surpassing 400 ppm for the first time.[65] These levels are much higher than at any time during the last 800,000 years, the period for which reliable data have been collected from ice cores.[66] Less direct geological evidence indicates that CO_2 values have not been this high for millions of years.[67]



Global CO2 emissions by world region since 1750 – visualization by Our World in Data

Global anthropogenic greenhouse gas emissions in 2010 were equivalent to 49 billion tonnes of carbon dioxide (using the most recent global warming potentials over 100 years from the AR5 report). Of these emissions, 65% was carbon dioxide from fossil fuel burning and industry, 11% was carbon dioxide from land use change, which is primarily due to deforestation, 16% was from methane, 6.2% was from nitrous oxide, and 2.0% was from fluorinated gases.[68] Using life-cycle assessment to estimate emissions relating to final consumption, the dominant sources of 2010 emissions were: food (26–30% of emissions);[69] washing, heating, and lighting (26%); personal transport and freight (20%); and building construction (15%).[70]

The 10th Emissions Gap Report issued by the United Nations Environment Programme (UNEP) predicts that if emissions continue to increase at the same rate as they have in 2010–2020, global temperatures would rise by as much as 4° by 2100.[71]

Land use change

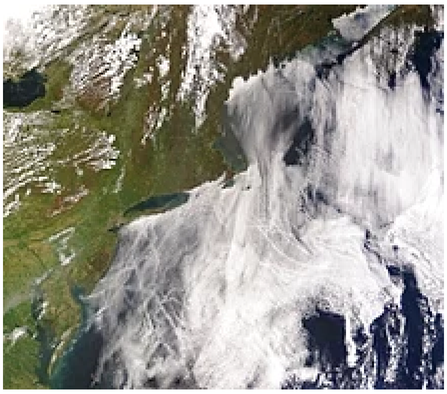
Humans change the land surface mainly to create more agricultural land. Today agriculture takes up 50% of the world's habitable land, while 37% is forests,[72] and that latter figure continues to decrease,[73] largely due to continued forest loss in the tropics.[74] This deforestation is the most significant aspect of land use change affecting global warming. The main causes are: deforestation through permanent land use change for agricultural products such as beef and palm oil (27%), forestry/forest products (26%), short term agricultural cultivation (24%), and wildfires (23%).[75]

Current patterns of land use affect global warming in a variety of ways. While some aspects cause significant GHG emissions, other land use processes act as a significant carbon sink for CO2, more than offsetting these GHG sources. The net result is an estimated removal (sink) of about 6 billion tonnes annually,[76] or about 12% of global GHG emissions. The land acts as a carbon sink via carbon fixation in the soil and increased photosynthesis.

Land use changes also affect global warming through a variety of other chemical and physical dynamics. Changing the type of vegetation in a region impacts the local temperature by changing how much sunlight gets reflected back into space, called *albedo*, and how much heat is lost by evaporation. For instance, the change from a dark forest to grassland makes the surface lighter, causing it to reflect more sunlight. Deforestation can also contribute to changing temperatures by affecting the release of aerosols and other chemical compounds that affect clouds; and by changing wind patterns when the land surface has different obstacles.[77] Globally, these effects are estimated to have led to a slight cooling, dominated by an increase in surface albedo.[78] But there is significant geographic variation in how this works. In the tropics the net effect is to produce a significant warming, while at latitudes closer to the poles a loss of albedo leads to an overall cooling effect.[77]

Aerosols and soot

Solid and liquid particles known as *aerosols* – from volcanoes, plankton, and human-made pollutants – reflect incoming sunlight, cooling the climate.[79] From 1961 to 1990, a gradual reduction in the amount of sunlight reaching the Earth's surface was observed, a phenomenon popularly known as *global dimming*,[80] typically attributed to aerosols from biofuel and fossil fuel burning.[81] Aerosol removal by precipitation gives tropospheric aerosols an atmospheric lifetime of only about a week, while stratospheric aerosols can remain in the atmosphere for a few years.[82] Globally, aerosols have been declining since 1990, removing some of the masking of global warming that they had been providing.[83]



Ship tracks can be seen as lines in these clouds over the Atlantic Ocean on the East Coast of the United States as an effect of aerosols.

In addition to their direct effect by scattering and absorbing solar radiation, aerosols have indirect effects on the Earth's radiation budget. Sulfate aerosols act as cloud condensation nuclei and thus lead to clouds that have more and smaller cloud droplets. These clouds reflect solar radiation more efficiently than clouds with fewer and larger droplets.[84] This effect also causes droplets to be of more uniform size, which reduces the growth of raindrops and makes clouds more reflective to incoming sunlight.[85] Indirect effects of aerosols are the largest uncertainty in radiative forcing.[86]

While aerosols typically limit global warming by reflecting sunlight, black carbon in soot that falls on snow or ice can contribute to global warming. Not only does this increase the absorption of sunlight, it also increases melting and sea level rise.[87] Limiting new black carbon deposits in the Arctic could reduce global warming by 0.2 °C by 2050.[88] When soot is suspended in the atmosphere, it directly absorbs solar radiation, heating the atmosphere and cooling the surface. In areas with high soot production, such as rural India, as much as 50% of surface warming due to greenhouse gases may be masked by atmospheric brown clouds.[89]

Minor forcings: the Sun and short-lived greenhouse gases

As the Sun is the Earth's primary energy source, changes in incoming sunlight directly affect the climate system.[90] Solar irradiance has been measured directly by satellites,[91] and indirect measurements are available beginning in the early 1600s.[90] There has been no upward trend in the amount of the Sun's energy reaching the Earth, so it cannot be responsible for the current warming.[92] Physical climate models are also unable to reproduce the rapid warming observed in recent decades when taking into account only variations in solar output and volcanic activity.[93] Another line of evidence for the warming not being due to the Sun is how temperature changes differ at different levels in the Earth's atmosphere.[94] According to basic physical principles, the greenhouse effect produces warming of the lower atmosphere (the troposphere), but cooling of the upper atmosphere (the stratosphere).[95] If solar variations were responsible for the observed warming, warming of both the troposphere and the stratosphere would be expected, but that has not been the case.[96]

Ozone in the lowest layer of the atmosphere, the troposphere, is itself a greenhouse gas. Furthermore, it is highly reactive and interacts with other greenhouse gases and aerosols.[97]

Climate change feedback

The response of the climate system to an initial forcing is increased by self-reinforcing *feedbacks* and reduced by balancing feedbacks.[99] The main balancing feedback to global temperature change is radiative cooling to space as infrared radiation, which increases strongly with increasing temperature.[100] The main reinforcing feedbacks are the water vapour feedback, the ice–albedo feedback, and probably the net effect of clouds.[101] Uncertainty over feedbacks is the major reason why different climate models project different magnitudes of warming for a given amount of emissions.[102]


The dark ocean surface reflects only 6 percent of incoming solar radiation, whereas sea ice reflects 50 to 70 percent.[98]

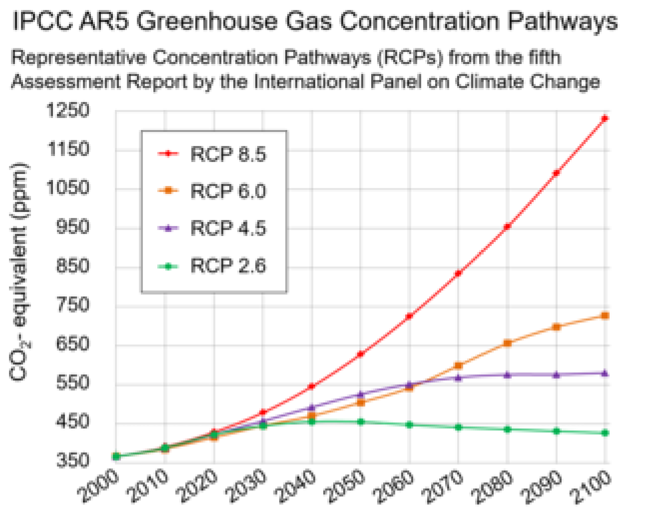
As air gets warmer, it can hold more moisture. After an initial warming due to emissions of greenhouse gases, the atmosphere will hold more water. As water is a potent greenhouse gas, this further heats the climate: the *water vapour feedback*.[101] The reduction of snow cover and sea ice in the Arctic reduces the albedo of the Earth's surface.[103] More of the Sun's energy is now absorbed in these regions, contributing to Arctic amplification, which has caused Arctic temperatures to increase at more than twice the rate of the rest of the world.[104] Arctic amplification also causes methane to be released as permafrost melts, which is expected to surpass land use changes as the second strongest anthropogenic source of greenhouse gases by the end of the century.[105]

Cloud cover may change in the future. If cloud cover increases, more sunlight will be reflected back into space, cooling the planet. Simultaneously, the clouds enhance the greenhouse effect, warming the planet. The opposite is true if cloud cover decreases. It depends on the cloud type and location which process is more important. Overall, the net feedback over the industrial era has probably been self-reinforcing.[106]

Roughly half of each year's CO_2 emissions have been absorbed by plants on land and in oceans.[107] Carbon dioxide and an extended growing season have stimulated plant growth making the land carbon cycle a balancing feedback. Climate change also increases droughts and heat waves that inhibit plant growth, which makes it uncertain whether this balancing feedback will persist in the future.[108] Soils contain large quantities of carbon and may release some when they heat up.[109] As more CO_2 and heat are absorbed by the ocean, it is acidifying and ocean circulation can change, changing the rate at which the ocean can absorb atmospheric carbon.[110]

A concern is that self-reinforcing feedbacks will lead to a tipping point, where global temperatures transition to a hothouse climate state even if greenhouse gas emissions are reduced or eliminated.[111] A 2018 study tried to identify such a planetary threshold for self-reinforcing feedbacks and found that even a 2 °C (3.6 °F) increase in temperature over pre-industrial levels may be enough to trigger such a hothouse Earth scenario.[112]

Models and projections

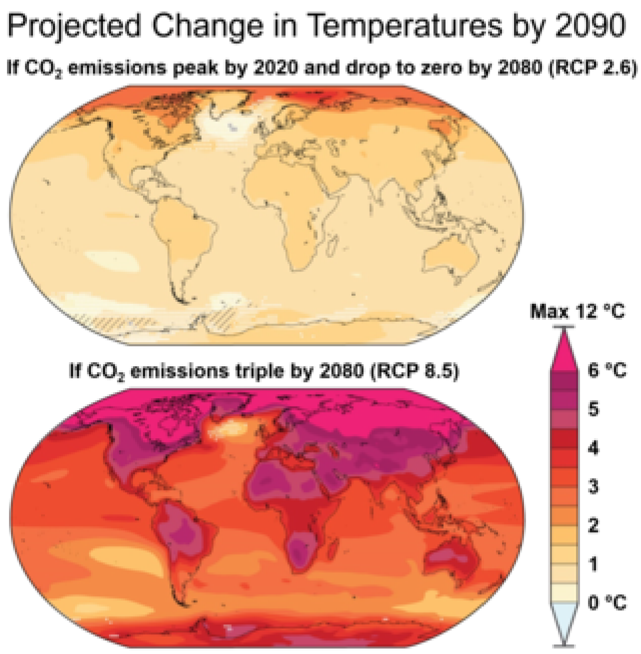


Future CO_2 projections, including all forcing agents' atmospheric CO_2-equivalent concentrations in parts-per-million-by-volume (ppmv) according to four RCPs (Representative Concentration Pathways)

A climate model is a representation of the physical, chemical, and biological processes that affect the climate system.[113] Computer models are run on supercomputers to reproduce and predict the circulation of the oceans, the annual cycle of the seasons, and the flows of carbon between the land surface and the atmosphere.[114] There are more than two dozen scientific institutions that develop climate models.[115] Models not only project different future temperature with different emissions of greenhouse gases, but also do not fully agree on the strength of different feedbacks on climate sensitivity and the amount of inertia of the system.[116]

A subset of climate models add societal factors to a simple physical climate model. These models simulate how population, economic growth, and energy use affect – and interact with – the physical climate. With this information, scientists can produce scenarios of how greenhouse gas emissions may vary in the future. Scientists can then run these scenarios through physical climate models to generate climate change projections.[117]

Climate models include different external forcings for their models.[118] For different greenhouse gas inputs four RCPs (Representative Concentration Pathways) are used: "a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG [greenhouse gas] emissions (RCP8.5)".[119] Models also include changes in the Earth's orbit, historical



Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean projections (i.e., the average of the model projections available) for the 2081–2100 period under the RCP 2.6 and RCP 8.5 scenarios for change in annual mean surface temperature. Changes are shown relative to the 1986–2005 period. Data from the IPCC Fifth Assessment Report.

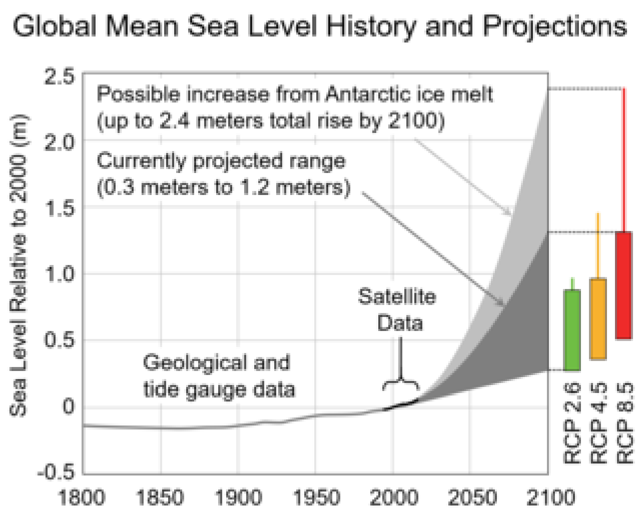
changes in the Sun's activity, and volcanic forcing.[120] RCPs only look at concentrations of greenhouse gases, factoring out uncertainty as to whether the carbon cycle will continue to remove about half of the carbon dioxide from the atmosphere each year.[121]

The physical realism of models is tested by examining their ability to simulate contemporary or past climates.[122] Past models have underestimated the rate of Arctic shrinkage[123] and underestimated the rate of precipitation increase.[124] Sea level rise since 1990 was underestimated in older models, but now agrees well with observations.[125] The 2017 United States-published National Climate Assessment notes that "climate models may still be underestimating or missing relevant feedback processes".[126]

Effects

Physical environment

The environmental effects of global warming are broad and far-reaching. They include effects on the oceans, ice, and weather and may occur gradually or rapidly.



Historical sea level reconstruction and projections up to 2100 published in January 2017 by the U.S. Global Change Research Program for the Fourth National Climate Assessment.[127]

Between 1993 and 2017, the global mean sea level rose on average by 3.1 ± 0.3 mm per year, with an acceleration detected as well.[128] Over the 21st century, the IPCC projects that in a very high emissions scenario the sea level could rise by 61–110 cm.[129] The rate of ice loss from glaciers and ice sheets in the Antarctic is a key area of uncertainty since this source could account for 90% of the potential sea level rise:[130] increased ocean warmth is undermining and threatening to unplug Antarctic glacier outlets, potentially resulting in more rapid sea level rise.[131] The retreat of non-polar glaciers also contributes to sea level rise.[132]

Global warming has led to decades of shrinking and thinning of the Arctic sea ice, making it vulnerable to atmospheric anomalies.[133] Projections of declines in Arctic sea ice vary.[134] While ice-free summers are expected to be rare at 1.5 °C degrees of warming, they are set to occur once every three to ten years at a warming level of 2.0 °C[135] increasing the ice–albedo feedback.[136] Higher atmospheric CO_2 concentrations have led to an increase in dissolved CO_2, which causes ocean acidification.[137] Furthermore, oxygen levels decrease because oxygen is less soluble in warmer water, an effect known as *ocean deoxygenation*.[138]

Many regions have probably already seen increases in warm spells and heat waves, and it is virtually certain that these changes will continue over the 21st century.[139] Since the 1950s, droughts and heat waves have appeared simultaneously with increasing frequency.[140] Extremely wet or dry events within the monsoon period have increased in India and East Asia.[141] Various mechanisms have been identified that might explain extreme weather in mid-latitudes from the rapidly warming Arctic, such as the jet stream becoming more erratic.[142] The maximum rainfall and wind speed from hurricanes and typhoons are likely increasing.[143]

Long-term effects of global warming: On the timescale of centuries to millennia, the magnitude of global warming will be determined primarily by anthropogenic CO_2 emissions.[144] This is due to carbon dioxide's very long lifetime in the atmosphere.[144] The emissions are estimated to have prolonged the current interglacial period by at least 100,000 years.[145] Because the great mass of glaciers and ice caps depressed the Earth's crust, another long-term effect of ice melt and deglaciation is the gradual rising of landmasses, a process called *post-glacial rebound*. This could be facilitating seismic and volcanic activity in places like Iceland.[146] Tsunamis could be generated by submarine landslides caused by warmer ocean water thawing ocean-floor permafrost or releasing gas hydrates.[147] Sea level rise will continue over many centuries.[148]

Abrupt climate change, tipping points in the climate system: Climate change could result in global, large-scale changes.[149] Some large-scale changes could occur abruptly, i.e. over a short time period, and might also be irreversible. One potential source of abrupt climate change would be the rapid release of methane and carbon dioxide from permafrost, which would amplify global warming.[150] Another example is the possibility for the Atlantic Meridional Overturning Circulation to slow or shut down (see also shutdown of thermohaline circulation).[151] This could trigger cooling in the North Atlantic, Europe, and North America.[152]

Biosphere


The U.S. Geological Survey projects that reduced sea ice from climate change will lower the population of polar bears by two-thirds by 2050.[153]

In terrestrial ecosystems, the earlier timing of spring events, as well as poleward and upward shifts in plant and animal ranges, have been linked with high confidence to recent warming.[154] It is expected that most ecosystems will be affected by higher atmospheric CO_2 levels and higher global temperatures.[155] Global warming has contributed to the expansion of drier climatic zones, such as, probably, the expansion of deserts in the subtropics.[156] Without substantial actions to reduce the rate of global warming, land-based ecosystems risk major shifts in their composition and structure.[157] Overall, it is expected that climate change will result in the extinction of many species and reduced diversity of ecosystems.[158] Rising temperatures push bees to their physiological limits, and could cause the extinction of bee populations.[159]

The ocean has heated more slowly than the land, but plants and animals in the ocean have migrated towards the colder poles as fast as or faster than species on land.[160] Just as on land, heat waves in the ocean occur more due to climate change, with harmful effects found on a wide range of organisms such as corals, kelp, and seabirds.[161] Ocean acidification threatens damage to coral reefs, fisheries, protected species, and other natural resources of value to society.[162] Higher oceanic CO_2 may affect the brain and central nervous system of certain fish species, which reduces their ability to hear, smell, and evade predators.[163]

Humans

The effects of climate change on human systems, mostly due to warming and shifts in precipitation, have been detected worldwide. The future social impacts of climate change will be uneven across the world.[165] All regions are at risk of experiencing negative impacts,[166] with low-latitude, less developed areas facing the greatest risk.[167] Global warming has likely already increased global economic inequality, and is projected to do so in the future.[168] Regional impacts of climate change are now observable on all continents and across ocean regions.[169] The Arctic, Africa, small islands, and Asian megadeltas are regions that are likely to be especially affected by future climate change.[170] Many risks increase with higher magnitudes of global warming.[171]

A helicopter drops water on a wildfire in California. Drought and higher temperatures linked to climate change are driving a trend towards larger fires.[164]

Food and water

Crop production will probably be negatively affected in low-latitude countries, while effects at northern latitudes may be positive or negative.[172] Global warming of around 4 °C relative to late 20th century levels could pose a large risk to global and regional food security.[173] The impact of climate change on crop productivity for the four major crops was negative for wheat and maize, and neutral for soy and rice, in the years 1960–2013.[174] Up to an additional 182 million people worldwide, particularly those with lower incomes, are at risk of hunger as a consequence of warming.[175] While increased CO_2 levels help crop growth at lower temperature increases, those crops do become less nutritious.[175] Based on local and indigenous knowledge, climate change is already affecting food security in mountain regions in South America and Asia, and in various drylands, particularly in Africa.[175] Regions dependent on glacier water, regions that are already dry, and small islands are also at increased risk of water stress due to climate change.[176]

Health and security

Generally, impacts on public health will be more negative than positive.[178] Impacts include the direct effects of extreme weather, leading to injury and loss of life;[179] and indirect effects, such as undernutrition brought on by crop failures.[180] Temperature rise has been connected to increased numbers of suicides.[181] Climate change may also lead to new human diseases. For example, while ordinary temperatures usually kill off the yeast *Candida auris* before it infects humans, three strains have recently appeared in widely separate regions, leading researchers to postulate that warmer temperatures are driving it to adapt to higher temperatures at which it can more readily infect humans.[182] Climate change has been linked to an increase in violent conflict by amplifying poverty and economic shocks, which are well-documented drivers of these conflicts.[183] Links have been made between a wide range of violent behaviour including fist fights, violent crimes, civil unrest, and wars.[184]

Livelihoods, industry, and infrastructure

Aerial view over southern Bangladesh after the passage of Cyclone Sidr. The combination of rising sea levels and increased rainfall from cyclones makes countries more vulnerable to floods, impacting people's livelihoods and health.[177]

In small islands and mega deltas, inundation from sea level rise is expected to threaten vital infrastructure and human settlements.[185] This could lead to homelessness in countries with low-lying areas such as Bangladesh, as well as statelessness for populations in island nations, such as the Maldives and Tuvalu.[186] Climate change can be an important driver of migration, both within and between countries.[187]

The majority of severe impacts of climate change are expected in sub-Saharan Africa and South-East Asia, where existing poverty is exacerbated.[188] Current inequalities between men and women, between rich and poor and between people of different ethnicity have been observed to worsen as a consequence of climate variability and climate change.[189] Existing stresses include poverty, political conflicts, and ecosystem degradation. Regions may even become uninhabitable, with humidity and temperatures reaching levels too high for humans to survive.[190]

Responses

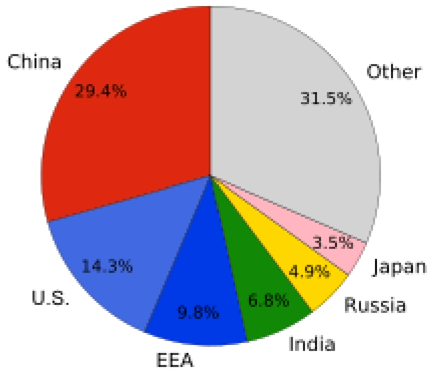
Mitigation of and adaptation to climate change are two complementary responses to global warming. Successful adaptation is easier if there are substantial emission reductions. Many of the countries that have contributed least to global greenhouse gas emissions are among the most vulnerable to climate change, which raises questions about justice and fairness with regard to mitigation and adaptation.[191]

Mitigation

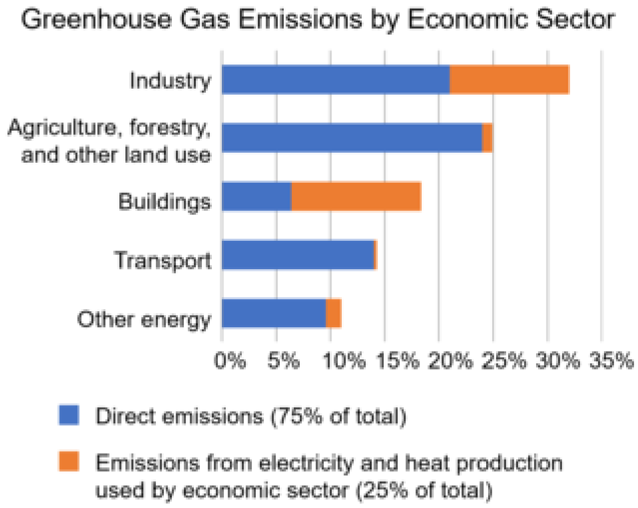
Climate change can be mitigated through the reduction of greenhouse gas emissions or the enhancement of the capacity of carbon sinks to absorb greenhouse gases from the atmosphere.[192] There is a large potential for future reductions in emissions by a combination of activities, including energy conservation and increased energy efficiency; the use of low-carbon energy technologies, such as renewable energy, nuclear energy, and carbon capture and storage; decarbonizing buildings and transport; and enhancing carbon sinks through, for example, reforestation and preventing deforestation.[193] A 2015 report by Citibank concluded that transitioning to a low-carbon economy would yield a positive return on investments.[194]

Drivers of greenhouse gas emissions

Over the last three decades of the twentieth century, gross domestic product per capita and population growth were the main drivers of increases in greenhouse gas emissions.[195] CO_2 emissions are continuing to rise due to the burning of fossil fuels and land-use change.[196] Emissions can be attributed to different regions. The attribution of emissions from land-use change is subject to considerable uncertainty.[197]



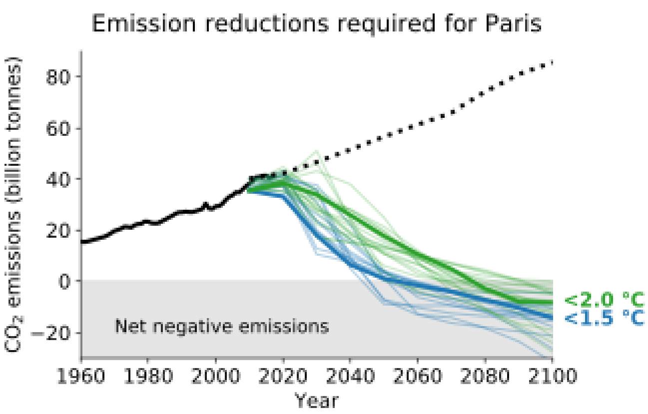
Global carbon dioxide emissions by country in 2015



Annual greenhouse gas emissions attributed to different sectors as of 2010. Emissions are given as a percentage share of total emissions, measured in carbon dioxide-equivalents, using global warming potentials from the IPCC Fifth Assessment Report.

Emissions scenarios, estimates of changes in future emission levels of greenhouse gases, depend upon uncertain economic, sociological, technological, and natural developments.[198] In some scenarios emissions continue to rise over the century, while others have reduced emissions.[199] Fossil fuel reserves are abundant, and will not limit carbon emissions in the 21st century.[200] Emission scenarios can be combined with modelling of the carbon cycle to predict how atmospheric concentrations of greenhouse gases might change in the future.[201] According to these combined models, by 2100 the atmospheric concentration of CO_2 could be as low as 380 or as high as 1400 ppm, depending on the Shared Socioeconomic Pathway (SSP) the world takes and the mitigation scenario.[202]

Reducing greenhouse gases



The graph shows multiple pathways to limit climate change to 1.5 °C or 2 °C. All pathways include negative emission technologies such as afforestation and bio-energy with carbon capture and storage.

Near- and long-term trends in the global energy system are inconsistent with limiting global warming to below 1.5 or 2 °C relative to pre-industrial levels.[203] Current pledges made as part of the Paris Agreement would lead to about 3.0 °C of warming at the end of the 21st century, relative to pre-industrial levels.[204] To keep warming below 2 °C, more stringent emission reductions in the near-term would allow for less rapid reductions after 2030.[205] To keep warming under 1.5 °C, a far-reaching system change on an unprecedented scale is necessary in energy, land, cities, transport, buildings, and industry.[206] A report, published just before the 2019 UN Climate Action Summit, says that the full implementation of all pledges taken by international coalitions, countries, cities, regions and businesses (not only in the Paris Agreement) would be sufficient to limit temperature rise to 2 °C but not to 1.5 °C.[207] All the information about the pledges is added to the UNFCCC Global Climate Action portal. The scientific community is checking their fulfilment.[208]

Co-benefits of climate change mitigation may help society and individuals more quickly. For example, bicycling reduces greenhouse gas emissions while reducing the effects of a sedentary lifestyle at the same time.[209] The development and scaling-up of clean technology, such as cement that produces less CO_2,[210] is critical to achieve sufficient emission reductions for the Paris agreement goals.[211] Many integrated models are unable to meet the 2 °C target if pessimistic assumptions are made about the availability of mitigation technologies.[212]

It has been suggested that the most effective and comprehensive policy to reduce carbon emissions is a carbon tax[213] or the closely related emissions trading.[214]

Individual action on climate change to reduce a person's carbon footprint include: limiting overconsumption,[215] living car-free,[216] forgoing air travel[217] and adopting a plant-based diet.[218]

Adaptation

Climate change adaptation is "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities".[219] Examples of adaptation are improved coastline protection, better disaster management, and the development of more resistant crops.[220] The adaptation may be planned, either in reaction to or anticipation of global warming, or spontaneous, i.e. without government intervention.[221]

The public sector, private sector, and communities are all gaining experience with adaptation, and adaptation is becoming embedded within certain planning processes.[222] While some adaptation responses call for trade-offs, others bring synergies and co-benefits.[223] Environmental organizations and public figures have emphasized changes in the climate and the risks they entail, while promoting adaptation to changes in infrastructural needs and emissions reductions.[224]

Adaptation is especially important in developing countries since they are predicted to bear the brunt of the effects of global warming.[225] The capacity and potential for humans to adapt, called *adaptive capacity*, is unevenly distributed across different regions and populations, and developing countries generally have less capacity to adapt.[226] In June 2019, U.N. special rapporteur Philip Alston warned of a "climate apartheid" situation developing, where global warming "could push more than 120 million more people into poverty by 2030 and will have the most severe impact in poor countries, regions, and the places poor people live and work".[227]

Climate engineering

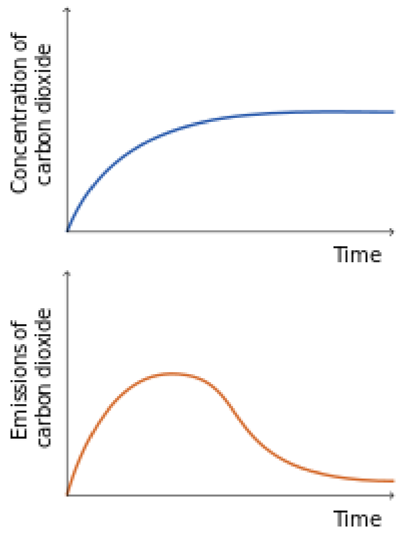
Climate engineering (sometimes called *geoengineering* or *climate intervention*) is the deliberate modification of the climate. It has been investigated as a possible response to global warming by groups including NASA[228] and the Royal Society.[229] Techniques studied fall generally into the categories of solar radiation management and carbon dioxide removal, although various other schemes have been suggested. A study from 2014 investigated the most common climate engineering methods and concluded that they are either ineffective or have potentially severe side effects and cannot be stopped without causing rapid climate change.[230]

Society and culture

Political response

UN Framework Convention

As of 2020 nearly all countries in the world are parties to the United Nations Framework Convention on Climate Change (UNFCCC).[233] The objective of the Convention is to prevent dangerous human interference with the climate system.[234] As stated in the Convention, this requires that greenhouse gas concentrations are stabilized in the atmosphere at a level where ecosystems can adapt naturally to climate change, food production is not threatened, and economic development can be sustained.[235] The Framework Convention was agreed on in 1992, but global emissions have risen since then.[236] Its yearly conferences are the stage of global negotiations.[237]



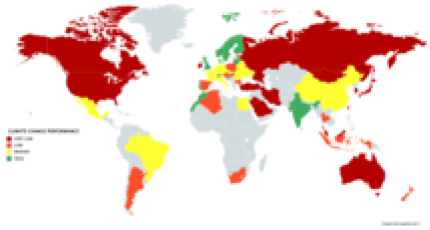
Article 2 of the UN Framework Convention refers explicitly to "stabilization of greenhouse gas concentrations".[231] To stabilize the atmospheric concentration of CO_2, emissions worldwide would need to be dramatically reduced from their present level.[232]

During these negotiations, the G77 (a lobbying group in the United Nations representing developing countries)[238] pushed for a mandate requiring developed countries to "[take] the lead" in reducing their emissions.[239] This was justified on the basis that the developed countries' emissions had contributed most to the accumulation of greenhouse gases in the atmosphere, per-capita emissions were still relatively low in developing countries, and the emissions of developing countries would grow to meet their development needs.[240]

This mandate was sustained in the 2005 Kyoto Protocol to the Framework Convention.[241] In ratifying the Kyoto Protocol, most developed countries accepted legally binding commitments to limit their emissions. These first-round commitments expired in 2012.[242] United States President George W. Bush rejected the treaty on the basis that "it exempts 80% of the world, including major population centres such as China and India, from compliance, and would cause serious harm to the US economy".[243] In 2009 several UNFCCC Parties produced the Copenhagen Accord,[244] which has been widely portrayed as disappointing because of its low goals, leading poor nations to reject it.[245] Parties associated with the Accord aim to limit the future increase in global mean temperature to below 2 °C.[246]

In 2015 all UN countries negotiated the Paris Agreement, which aims to keep climate change well below 2 °C. The agreement replaced the Kyoto Protocol. Unlike Kyoto, no binding emission targets are set in the Paris Agreement. Instead, the procedure of regularly setting ever more ambitious goals and reevaluating these goals every five years has been made binding.[247] The Paris Agreement reiterated that developing countries must be financially supported.[248] As of November 2019, 194 states and the European Union have signed the treaty and 186 states and the EU have ratified or acceded to the agreement.[249] In November 2019 the Trump administration notified the UN that it would withdraw the United States from the Paris Agreement in 2020.[250]

Other policy



Countries by Climate change performance Index

In 2019, the British Parliament became the first national government in the world to officially declare a climate emergency.[251] As at September 2019, nine countries including the United Kingdom, France and Argentina have made national declarations of a climate emergency. Climate emergency declarations have been made in 983 separate jurisdictions and local governments in 18 countries covering 212 million citizens.[252]

In November 2019 the European Parliament declared a "climate and environmental emergency".[253]

While the ozone layer and climate change are considered separate problems, the solution to the former has significantly mitigated global warming. The estimated mitigation of the Montreal Protocol, an international agreement to stop emitting ozone-depleting gases, is estimated to have been more impactful than the Kyoto Protocol, which was specifically designed to curb greenhouse gas emissions.[254] It has been argued that the Montreal Protocol, may have done more than any other measure, as of 2017, to mitigate climate change as those substances were also powerful greenhouse gases.[255]

Scientific discussion

In the scientific literature, there is an overwhelming consensus that global surface temperatures have increased in recent decades and that the trend is caused mainly by human-induced emissions of greenhouse gases.[256] No scientific body of national or international standing disagrees with this view.[257] Scientific discussion takes place in journal articles that are peer-reviewed, which scientists subject to assessment every couple of years in the Intergovernmental Panel on Climate Change reports.[258] The scientific consensus as of 2013, as stated in the IPCC Fifth Assessment Report, is that it "is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century".[259]

National science academies have called on world leaders for policies to cut global emissions.[260] In November 2017, a second warning to humanity signed by 15,364 scientists from 184 countries stated that "the current trajectory of potentially catastrophic climate change due to rising greenhouse gases from burning fossil fuels, deforestation, and agricultural production – particularly from farming ruminants for meat consumption" is "especially troubling".[261] In 2018 the IPCC published a Special Report on Global Warming of 1.5 °C which warned that, if the current rate of greenhouse gas emissions is not mitigated, global warming is likely to reach 1.5 °C (2.7 °F) between 2030 and 2052, risking major crises. The report said that preventing such crises will require a swift transformation of the global economy that has "no documented historic precedent".[262] In November 2019, a group of more than 11,000 scientists from 153 countries named climate change an "emergency" that would lead to "untold human suffering" if no big shifts in action takes place.[263] The emergency declaration emphasized that economic growth and population growth "are among the most important drivers of increases in CO2 emissions from fossil fuel combustion" and that "we need bold and drastic transformations regarding economic and population policies".[264]

Public opinion and disputes

The global warming problem came to international public attention in the late 1980s.[265] Significant regional differences exist in how concerned people are about climate change and how much they understand the issue.[266] In 2010, just a little over half the US population viewed it as a serious concern for either themselves or their families, while 73% of people in Latin America and 74% in developed Asia felt this way.[267] Similarly, in 2015 a median of 54% of respondents considered it "a very serious problem", but Americans and Chinese (whose economies are responsible for the greatest annual CO_2 emissions) were among the least concerned.[266] Worldwide in 2011, people were more likely to attribute global warming to human activities than to natural causes, except in the US where nearly half of the population attributed global warming to natural causes.[268] Public reactions to global warming and concern about its effects have been increasing, with many perceiving it as the worst global threat.[269] In a 2019 CBS poll, 64% of the US population said that climate change is a "crisis" or a "serious problem", with 44% saying human activity was a significant contributor.[270]

Protesters for climate action at the 2017 People's Climate March


September 2019 climate strike in Sydney, Australia

Due to confusing media coverage in the early 1990s, issues such as ozone depletion and climate change were often mixed up, affecting public understanding of these issues.[271] Although there are a few areas of linkage, the relationship between the two is weak.[272]

Controversy

From about 1990 onward, American conservative think tanks had begun challenging the legitimacy of global warming as a social problem. They challenged the scientific evidence, argued that global warming would have benefits, warned that concern for global warming was some kind of socialist plot to undermine American capitalism,[273] and asserted that proposed solutions would do more harm than good.[274] Organizations such as the libertarian Competitive Enterprise Institute, as well as conservative commentators, have challenged IPCC climate change scenarios, funded scientists who disagree with the scientific consensus, and provided their own projections of the economic cost of stricter controls.[275]

Global warming has been the subject of controversy, substantially more pronounced in the popular media than in the scientific literature,[276] with disputes regarding the nature, causes, and consequences of global warming. The disputed issues include the causes of increased global average air temperature, especially since the mid-20th century, whether this warming trend is unprecedented or within normal climatic variations, whether humankind has contributed significantly to it, and whether the increase is completely or partially an artifact of poor measurements. Additional disputes concern estimates of climate sensitivity, predictions of additional warming, what the consequences of global warming will be, and what to do about it.[277] One suggestion is that the best individual actions include having fewer children[278] but some disagree with encouraging people to stop having children, saying that children "embody a profound hope for the future", and that more emphasis should be placed on lifestyle choices of the world's wealthy, fossil fuel companies, and government inaction.[279]

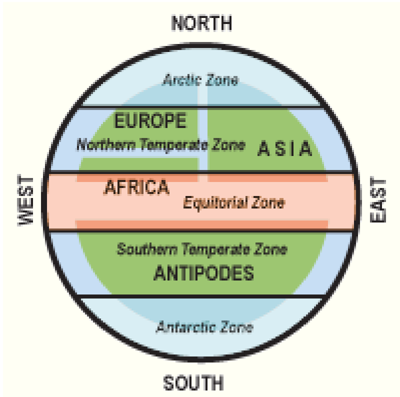
In the 20th century and early 2000s some companies, such as ExxonMobil, challenged IPCC climate change scenarios, funded scientists who disagreed with the scientific consensus, and provided their own projections of the economic cost of stricter controls.[280] In general, since the 2010s, global oil companies do not dispute that climate change exists and is caused by the burning of fossil fuels.[281] As of 2019, however, some are lobbying against a carbon tax and plan to increase production of oil and gas,[282] but others are in favour of a carbon tax in exchange for immunity from lawsuits which seek climate change compensation.[283]

Protest and litigation

Protests in favour of more ambitious climate action have increased in the 2010s in the form of fossil fuel divestment,[284] worldwide demonstrations,[285] and a school strike for climate.[286] Mass civil disobedience actions by Extinction Rebellion and Ende Gelände have ended in police intervention and large-scale arrests.[287] Litigation is increasingly used as a tool to strengthen climate action, with governments being the biggest target of lawsuits demanding that they become ambitious on climate action or enforce existing laws. Cases against fossil-fuel companies, from activists, shareholders and investors, generally seek compensation for loss and damage.[288]

History of the science

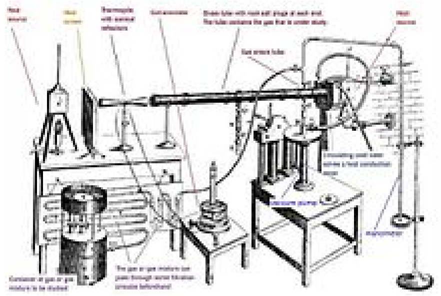
In Greco-Roman geography, climate was thought to be simply set by *klima*, the angle of the midday sun defining bands of latitude which suited different peoples. Theophrastus thought agriculture caused local climate changes. Colonists expected North American weather to match latitudes, but found winters unexpectedly harsh. 18th century naturalists, starting with Du Bos in 1719, said millennia of farming had given Europe the temperate climate needed for civilisation, and cultivation could bring rapid climate improvements to America. Thomas Jefferson and others sought evidence of this warming.[289] Savants thought the earth had cooled from incandescent origins; in 1778 Buffon proposed climatic Epochs of diminishing warmth, shown by tropical fossils in the north.[290]



Aristotle's five zones of climate

Following from Mariotte's 1681 demonstration that glass, though transparent to sunlight, obstructs radiant heat,[291] de Saussure showed that non-luminous warm objects emitted "obscure" (infrared) heat, and in 1774 measured heat from the sun with a thermometer in a glass-topped insulated box exposed to sunlight for an hour.[292] In an innovative 1824 memoir summarising research into heat transfer, Joseph Fourier assessed sources heating the globe, and the balancing emission of infrared radiation. He proposed, by analogy with de Saussure's device, a simple formulation of what was later called the greenhouse effect; transparent atmosphere lets through visible light, which warms the surface. The warmed surface emits infrared radiation, but the atmosphere is relatively opaque to infrared and slows the emission of energy, warming the planet.[293]

In detailed research starting in 1859,[294] John Tyndall established that nitrogen and oxygen (99% of dry air) are transparent to infrared, but water vapour and traces of complex molecules (significantly methane and carbon dioxide) both absorb infrared and, when warmed, emit infrared radiation. His 1861 paper proposed changing concentrations of these gases could have caused "all the mutations of climate which the researches of geologists reveal" and would explain ice age changes.[295] By then, as Humboldt noted in 1850, decades of climate measurements showed stability in North America rather than the expected improvement, though popular belief that rain follows the plow continued.[296]



Tyndall's sensitive ratio spectrophotometer measured the extent to which infrared radiation was impeded by various gases filling its central tube.

Svante Arrhenius noted that water vapour in air continuously varied, but carbon dioxide (CO_2) was determined by long term geological processes. At the end of an ice age, warming from increased CO_2 would increase the amount of water vapour, amplifying its effect in a feedback process. In 1896, after laborious calculations, he published the first climate model of its kind, showing that halving of CO_2 could have produced the drop in temperature initiating the ice age. His source for geology, Arvid Högbom, had estimated industrial carbon output, and Arrhenius calculated the temperature increase expected from doubling CO_2. Other scientists highlighted flaws; Ångström said that saturation of the greenhouse effect meant adding more CO_2 made no difference. Experts thought climate would be self-regulating.[297][298] From 1938 Guy Stewart Callendar published evidence that climate was warming and CO_2 levels increasing,[299] but his calculations met the same objections.[297]

1950s military research found less saturation of the greenhouse effect at high altitudes. Earlier calculations treated the atmosphere as a single layer, Gilbert Plass used digital computers to model the different layers and found added CO_2 would cause warming. Hans Suess found evidence CO_2 levels had been rising, Roger Revelle showed the oceans would not absorb the increase, and together they helped Charles Keeling to begin a record of continued increase, the Keeling Curve.[297] Revelle, Plass and other scientists alerted media to press for government attention,[300] the dangers of global warming came to the fore at James Hansen's 1988 Congressional testimony.[301] Scientific research on climate change expanded, and the Intergovernmental Panel on Climate Change, set up in 1988 to provide formal advice to the world's governments, has spurred unprecedented levels of exchange between different scientific disciplines.[302]

Terminology

Research in the 1950s suggested that temperatures were increasing, and a 1952 newspaper used the term "climate change". This phrase next appeared in a November 1957 report in *The Hammond Times* which described Roger Revelle's research into the effects of increasing human-caused CO_2 emissions on the greenhouse effect: "a large scale global warming, with radical climate changes may result". A 1971 MIT report referred to the human impact as "inadvertent climate modification", identifying many possible causes.[303]

Both the terms *global warming* and *climate change* were used only occasionally until 1975, when Wallace Smith Broecker published a scientific paper on the topic, "Climatic Change: Are We on the Brink of a Pronounced Global Warming?". The phrase began to come into common use, and in 1976 Mikhail Budyko's statement that "a global warming up has started" was widely reported.[304] An influential 1979 National Academy of Sciences study headed by Jule Charney followed Broecker in using *global warming* to refer to rising surface temperatures, while describing the wider effects of increased CO_2 as *climate change*.[305]

There were increasing heatwaves and drought problems in the summer of 1988, and NASA climate scientist James Hansen's testimony in the U.S. Senate sparked worldwide interest.[301] He said, "Global warming has reached a level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and the observed warming."[306] Public attention increased over the summer, and *global warming* became the dominant popular term, commonly used both by the press and in public discourse.[305] In the 2000s, the term *climate change* increased in popularity.[307]

In technical sources, the term *climate change* is also used to refer to past and future climate changes that persist for and extended period of time, and includes regional changes as well as global change.[308] People who regard climate change as catastrophic, irreversible, or rapid might label climate change as a *climate crisis* or a *climate emergency*.[309] One newspaper, *The Guardian*, has embraced this terminology (as well as *global heating*) in their editorial guidelines.[310] In a statement explaining the paper's policy editor-in-chief, Katharine Viner said "We want to ensure that we are being scientifically precise, while also communicating clearly with readers on this very important issue".

Oxford Dictionary chose *climate emergency* as the word of the year 2019 and defines the term as "a situation in which urgent action is required to reduce or halt climate change and avoid potentially irreversible environmental damage resulting from it". Usage of the term soared more than 10,000% between September 2018 and September 2019.[311]

See also

- Anthropocene – proposed geological time interval for a new period where humans are having significant geological impact
- Global cooling – minority view held by scientists in the 1970s that imminent cooling of the Earth would take place
- Holocene extinction
- Planetary boundaries – climate change is one of them

Notes

1. NASA: The Causes of Climate Change 2019.
2. NCA4: Climate Science Special Report 2017.
3. IPCC SROCC Summary for Policymakers 2019, p. 6.
4. NASA: The Study of Earth as an Integrated System 2016.
5. IPCC AR5 WG1 Summary for Policymakers 2013, p. 4: Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased

6. "Myths vs. Facts: Denial of Petitions for Reconsideration of the Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act" (https://www.epa.gov/ghgemissions/myths-vs-facts-denial-petitions-reconsideration-endangerment-and-cause-or-contribute). U.S. Environmental Protection Agency. 25 August 2016. Retrieved 7 August 2017. "The U.S. Global Change Research Program, the National Academy of Sciences, and the Intergovernmental Panel on Climate Change (IPCC) have each independently concluded that warming of the climate system in recent decades is "unequivocal". This conclusion is not drawn from any one source of data but is based on multiple lines of evidence, including three worldwide temperature datasets showing nearly identical warming trends as well as numerous other independent indicators of global warming (e.g. rising sea levels, shrinking Arctic sea ice)."
7. Shaftel 2016: " 'Climate change' and 'global warming' are often used interchangeably but have distinct meanings. .... Global warming refers to the upward temperature trend across the entire Earth since the early 20th century .... Climate change refers to a broad range of global phenomena ...[which] include the increased temperature trends described by global warming."
8. IPCC AR5 SYR Glossary 2014, p. 124: Global warming refers to the gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions.; IPCC SR15 Ch1 2018, p. 51: "Global warming is defined in this report as an increase in combined surface air and sea surface temperatures averaged over the globe and over a 30-year period. Unless otherwise specified, warming is expressed relative to the period 1850–1900, used as an approximation of pre-industrial temperatures in AR5.".
9. Shaftel 2016; Associated Press, 22 September 2015: "The terms global warming and climate change can be used interchangeably. Climate change is more accurate scientifically to describe the various effects of greenhouse gases on the world because it includes extreme weather, storms and changes in rainfall patterns, ocean acidification and sea level.".
10. IPCC AR5 WG1 Ch5 2013, pp. 389, 399–400: "5: Information from Paleoclimate Archives: The PETM [around 55.5–55.3 million years ago] was marked by ... global warming of 4 °C to 7 °C ..... Deglacial global warming occurred in two main steps from 17.5 to 14.5 ka [thousand years ago] and 13.0 to 10.0 ka.
11. IPCC AR5 SYR Summary for Policymakers 2014, p. 2: SPM 1.1 .... Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (medium confidence).
12. IPCC AR5 WG1 Summary for Policymakers 2013, p. 17.
13. IPCC AR5 WG1 Technical Summary 2013, p. 57.
14. Joint science academies' statement 2005.
15. "Scientific consensus: Earth's climate is warming" (https://web.archive.org/web/20180628042920/https://climate.nasa.gov/scientific-consensus/). *Climate Change: Vital Signs of the Planet prevent dangerous anthropogenic climate change*. NASA. Archived from the original (https://climate.nasa.gov/scientific-consensus/) on 28 June 2018. Retrieved 7 August 2017.
16. "List of Organizations" (https://web.archive.org/web/20170807111205/https://www.opr.ca.gov/s_listoforganizations.php). The Governor's Office of Planning & Research, State of California. Archived from the original (https://www.opr.ca.gov/s_listoforganizations.php) on 7 August 2017. Retrieved 7 August 2017.
17. IPCC AR5 WG2 Technical Summary 2014, pp. 44–46; D'Odorico et al. 2013.
18. National Geographic 2019; NPR 2010.
19. Campbella et al. 2016; National Research Council 2012, pp. 26–27.
20. Knowlton 2001.

21. EPA (19 January 2017). "Climate Impacts on Ecosystems" (https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-ecosystems_.html#Extinction). Archived (https://web.archive.org/web/20180127185656/https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-ecosystems_.html#Extinction) from the original on 27 January 2018. Retrieved 5 February 2019.
22. UNFCCC 1992, Article 2, "Objective".
23. Decision 1/CP.16, paragraph 4 (http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2), in UNFCCC: Cancun 2010: "deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels".
24. CNN, 12 December 2015; The Guardian, 12 December 2015; Paris Agreement 2015, Article 2, Section 1(a).
25. IPCC SR15 Ch1 2018, p. 51,
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External links

- Official list of United Nations Framework Convention on Climate Change members (https://treaties.un.org/Pages/ViewDetailsIII.aspx?src=IND&mtdsg_no=XXVII-7&chapter=27&Temp=mtdsg3&clang=_en)

Research

- NASA Goddard Institute for Space Studies (http://www.giss.nasa.gov/) – Global change research
- Climate Change at the National Academies (http://dels.nas.edu/Climate/Climate-Change/Reports-Academies-Findings) – repository for reports
- Met Office: Climate Guide (http://www.metoffice.gov.uk/climate-guide) – UK National Weather Service
- Educational Global Climate Modelling (http://edgcm.columbia.edu/) (EdGCM) – research-quality climate change simulator

Educational

- NRDC Guide: Global Warming 101 (https://www.nrdc.org/stories/global-warming-101)
- NASA: Climate change: How do we know? (https://climate.nasa.gov/evidence/)
- Global Climate Change Indicators (https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php) – NOAA
- Skeptical Science: Getting skeptical about global warming skepticism (http://www.skepticalscience.com/)
- Climate change tutorial by Prof. Myles Allen (Oxford), March 2018: Parts 1 (https://www.youtube.com/watch?time_continue=8&v=CqjbTMz5Hro), 2 (https://www.youtube.com/watch?time_continue=104&v=Tqx99ea-DrM), 3 (https://www.youtube.com/watch?time_continue=13&v=2Hh8iurCvcA), 4 (https://www.youtube.com/watch?time_continue=3&v=QFlcmsFOv6Y), 5 (https://www.youtube.com/watch?time_continue=2&v=aMjzpaNLQ0Y) (45 min. total); background & slide deck (http://www.eci.ox.ac.uk/news/2018/0410.html)
- Result of total melting of Polar regions on World (https://www.nationalgeographic.com/magazine/2013/09/rising-seas-ice-melt-new-shoreline-maps/) – (National Geographic Society; 2013)
