Global warming

Contributed by: AccessScience Editors

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Key Concepts

- Earth's atmosphere is warming because of increased levels of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere.
- Of all the greenhouse gases, CO_2 accounts for the largest share of radiative forcing.
- Concentrations of atmospheric CO_2 follow natural annual patterns of change. However, the ability of the oceans to take up excess anthropogenic CO_2 has been hampered by the rapid rate of atmospheric increase.
- Since the late 1800s, the global temperature has warmed roughly 0.85°C (1.53°F).
- Global warming has already had widespread impacts on human and natural systems.

The rise in the surface temperature of the Earth caused by increasing concentrations of greenhouse gases in the atmosphere. Although carbon dioxide (CO_2) is only the fourth most abundant gas in the atmosphere, it is vitally important in maintaining the Earth's surface temperature. Along with water vapor, CO_2 absorbs infrared (long-wave) radiation given off by the Earth, and reradiates this energy back to the Earth's surface, keeping our planet much warmer [average surface temperature of 15°C (59°F)]) than it would be otherwise. This trapping of incoming solar radiation is known as the greenhouse effect. *See also:* ATMOSPHERE; CARBON DIOXIDE; GREENHOUSE EFFECT.

Measurements of CO_2 concentrations in bubbles trapped in Greenland ice suggest that there has been a rise in atmospheric CO_2 beginning in the 1850s and starting from about 280 parts per million (ppm), which is referred to as the preindustrial CO_2 concentration. The concentration of atmospheric CO_2, as measured on Mauna Loa in Hawaii since the late 1950s, shows a sharp increase from 315 ppm in 1958 to 407 ppm in 2017 (**Fig. 1**). This CO_2 increase has been shown to be anthropogenic (human-caused), primarily a result of the burning of fossil fuels, including oil, natural gas, and coal. In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC)—a group of 1300 independent scientific experts from countries all over the world—concluded that there is a more than 95% probability that human activities over the past 50 years have warmed the Earth. *See also:* FOSSIL FUEL.

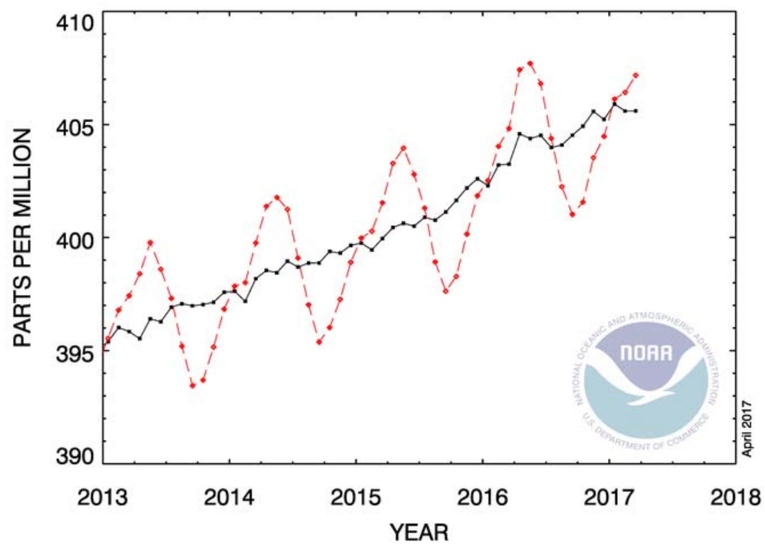

Fig. 1 **Monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii, as of April 5, 2017. March 2017: 407.18 ppm CO_2. March 2016: 404.83 ppm CO_2. (Credit: NOAA)**

Greenhouse gas increases

In addition to CO_2, concentrations of several other anthropogenically produced, yet naturally occurring, greenhouse gases have increased in the Earth's atmosphere, contributing to the phenomenon of global warming. Examples include methane (CH_4) and nitrous oxide (N_2O), whose atmospheric concentrations have also increased from fossil-fuel production and use, as well as agricultural practices, landfills, and biomass burning. *See also:* METHANE; NITROGEN OXIDES.

Fluorinated gases are another type of greenhouse gas. The four main types of fluorinated gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Their emissions result from a variety of industrial uses, as well as their use as refrigerants. Fluorinated gases have a characteristically long lifetime in the atmosphere, for example, 2600–50,000 years for PFCs. Fluorinated gases also have a much greater global warming potential because they trap more heat than CO_2. Global warming potentials allow the comparison of greenhouse gases relative to CO_2, the reference greenhouse gas, which is set as 1. For example, HFCs have a global warming potential of up to 14,800 times that of CO_2. Thus, fluorinated gases are very powerful greenhouse gases. *See also:* HALOGENATED HYDROCARBON.

Scientific evidence shows that changes in the global climate caused by increasing atmospheric concentrations of greenhouse gases are correlated with global warming. In 2016, for example, globally averaged temperatures were 0.99°C (1.78°F) warmer than in the middle of the twentieth century (**Fig. 2**). *See also:* CLIMATOLOGY.

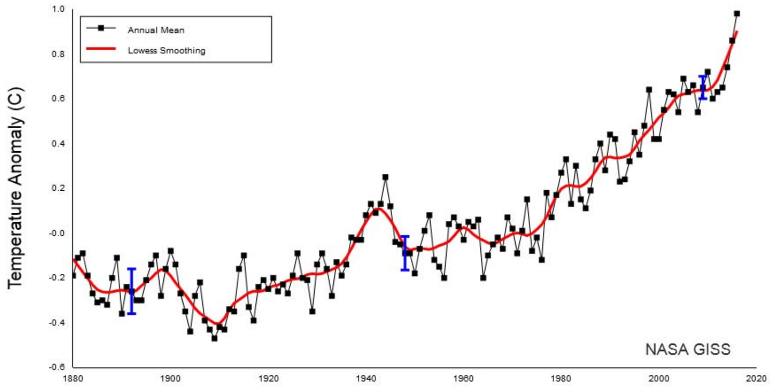

Fig. 2 **Global annual mean surface air-temperature change. Global mean estimates based on land and ocean data from 1880 to 2017, with base period 1951–1980. The solid black line is the global annual mean. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling. This is an update of Fig. 9a in Hansen et al., 2010 . (Credit: GISTEMP Team, 2017: GISS Surface Temperature Analysis (GISTEMP). NASA Goddard Institute for Space Studies. Dataset accessed 2017-05-01 at https://data.giss.nasa.gov/gistemp/)**

Radiative forcing

Climate experts often use the term radiative forcing to express changes caused by CO_2 and other gases and aerosols that cause global warming or cooling (**Fig. 3**). Radiative forcing is the change in average radiation at the top of the troposphere (lower atmosphere) because of a change in either solar or infrared (Earth) radiation. Radiative forcing represents the size of the energy imbalance in the atmosphere and is calculated in watts per square meter. *See also:* TERRESTRIAL RADIATION.

Changes in atmospheric aerosols have a strong effect on radiative forcing. Anthropogenic aerosols that affect global warming include sulfate aerosols, and organic and elemental carbon aerosols from biomass burning. Aerosols cause a direct cooling effect by absorbing and scattering solar radiation back to space. Sulfate aerosols are produced from sulfur dioxide (SO_2) released by fossil-fuel combustion. These aerosols cause a direct negative forcing. Biomass burning, particularly in the tropics, produces organic and elemental carbon aerosols that are also thought to produce negative radiative forcing. *See also:* AEROSOL.

In addition, aerosols have indirect effects on global warming, because they serve as nuclei for cloud droplets. Thus, aerosols affect cloud formation and cloud brightness, increasing the reflection of solar radiation towards the Earth. This indirect radiative effect of aerosols may also cause negative radiative forcing that may be similar in size to direct forcing by aerosols, but this effect is less well known. *See also:* ALBEDO; CLOUD; CLOUD PHYSICS.

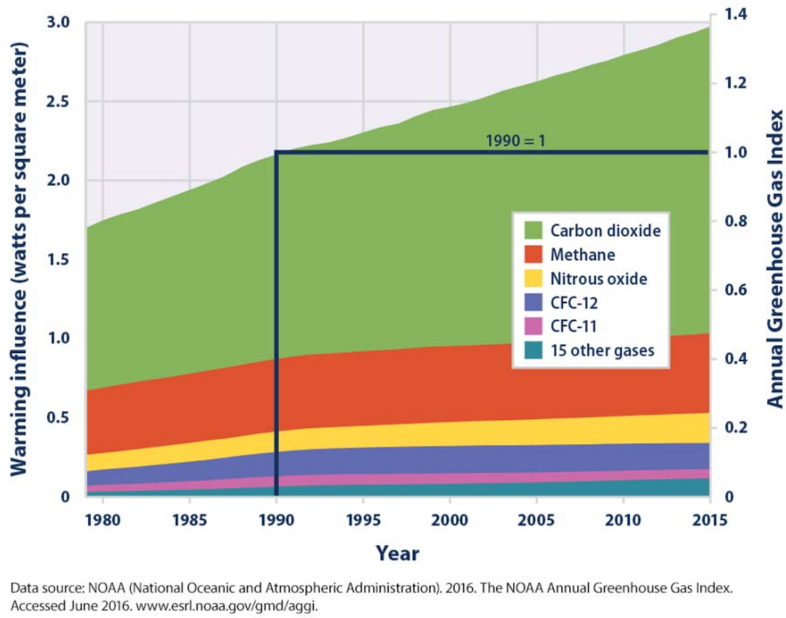

Fig. 3 Radiative forcing caused by major long-lived greenhouse gases, 1979–2015. This figure shows the amount of radiative forcing caused by various greenhouse gases, based on the change in concentration of these gases in the Earth's atmosphere since 1750. On the right side of the graph radiative forcing has been converted to the Annual Greenhouse Gas Index, which is set to a value of 1.0 for 1990. CFC-11 = Trichlorofluoromethane. CFC-12 = Dichlorodifluoromethane. (Credit: U.S. EPA)

Natural fluxes

Carbon dioxide contains carbon, the dominant element in life and in biogeochemical cycles on Earth. The concentration of atmospheric CO_2 has a conspicuous natural yearly oscillation (**Fig. 1**) because of its uptake due to excess photosynthesis and storage of carbon by plants during the growing season, and CO_2 release to the atmosphere when plant decay through respiration dominates. Plants plus the soil are an important reservoir of carbon on the Earth's surface. In fact, they are a much larger reservoir than atmospheric CO_2. *See also:* ATMOSPHERIC CHEMISTRY; BIOGEOCHEMISTRY; POTENTIAL OF SOILS FOR CARBON SEQUESTRATION.

Earth's largest reservoir of carbon is the oceans, where atmospheric CO_2 dissolves and is converted to inorganic bicarbonate (HCO_3^-), which is stored in seawater. The surface ocean (top 100 m) exchanges CO_2 with the atmosphere, and mixes the gas slowly within the deeper ocean over about 1000 years, which allows long-term carbon storage at greater depths. Thus, under natural conditions, the oceans would take up any excess atmospheric CO_2. However, since the Industrial Revolution, rising CO_2 levels in the atmosphere and increased absorption of CO_2 by the oceans have created an unprecedented ocean acidification phenomenon that is altering pH levels and threatening many marine ecosystems. *See also:* OCEAN ACIDIFICATION.

Global warming and climate change

Whereas global warming refers to the increase in the Earth's average surface temperature due to rising levels of greenhouse gases, the term "climate change" has a different connotation. Climate change refers to a long-term change in the Earth's climate, or of a region on Earth. *See also:* GLOBAL CLIMATE CHANGE.

Averaged over all land and ocean surfaces, global temperatures warmed by roughly 0.85°C (1.53°F) between 1880 and 2012. Because oceans tend to warm and cool more slowly than land areas, continents have warmed the most. IPCC scientists, after carrying out years of comprehensive research on global warming, have predicted that average global temperatures could increase between 1.4 and 5.8°C (2.5 and 10.4°F) by the year 2100.

Consequences of global warming

Temperature change by itself is not the most severe effect of global warming. Changes resulting from increasing temperatures are likely to have much greater impact on humans than higher temperatures alone. Such changes include rising sea levels due to melting of the polar ice caps, as well as an increase in occurrence and severity of storms and other severe weather events due to changes to precipitation patterns. In fact, global climate change has already had observable effects on the environment. Glaciers have shrunk, ice on rivers and lakes is breaking up earlier than normal, plant and animal ranges have shifted, and trees are flowering sooner. As global temperatures continue to rise, other effects may soon begin to show.

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Keywords

global warming; greenhouse gases; greenhouse gas; climate change; carbon dioxide; radiative forcing; global warming potential

Test Your Understanding

1. How have scientists determined the level of atmospheric carbon dioxide (CO_2) that was present in past centuries? How do those amounts compare to current CO_2 levels?
2. How does CO_2 in Earth's atmosphere interact with CO_2 in the oceans? How has that relation changed over time?
3. What is the difference between global warming and climate change?
4. Describe radiative forcing and how it has changed over the last 25 years.
5. Critical Thinking: What effect might a worldwide reduction in the levels of CO_2 and other greenhouse gases in the atmosphere have on Earth?

Additional Readings

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