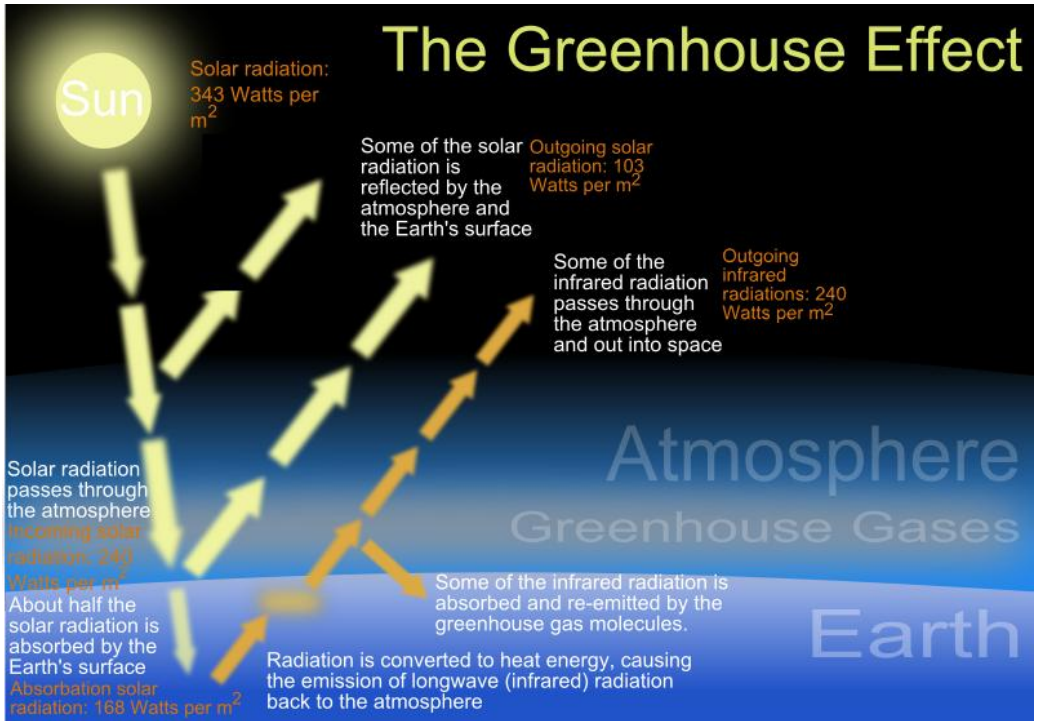
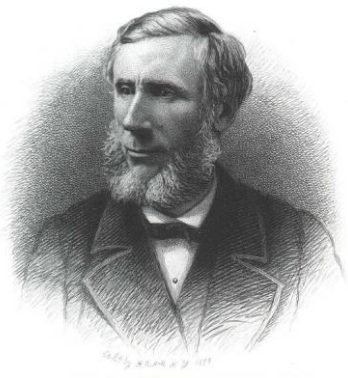
# Chapter 2 – Climate Science

*The Climate*.

- *Greenhouse gas effect*. The greenhouse effect is the heating of the surface of the planet due to the presence in the atmosphere of gases that absorb and emit infrared radiation. Thus, greenhouse gases trap heat within the surface-troposphere system.




- The greenhouse effect was discovered by Joseph Fourier in 1824, first reliably experimented on by John Tyndall in 1858, and first reported quantitatively by Svante Arrhenius in 1896.

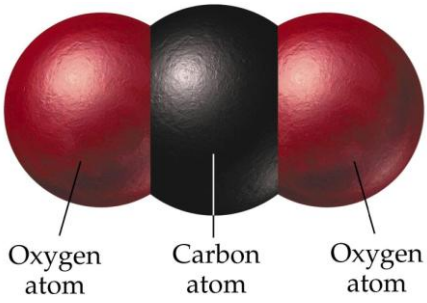




In the absence of the greenhouse effect and an atmosphere, the Earth's average surface temperature of 14 °C could be as low as −18 °C, the black body temperature of the Earth. Anthropogenic global warming, a recent warming of the Earth's lower atmosphere, is believed to be the result of an "enhanced greenhouse effect" mainly due to human-produced increases in atmospheric greenhouse gases.

The Earth receives energy from the Sun mostly in the form of visible light. About 50% of the sun's energy reaches the Earth and is absorbed by the surface.


Like all bodies with a temperature above absolute zero the Earth's surface radiates energy in the infrared range. Greenhouse gases absorb infrared radiation and pass the absorbed heat to other atmospheric gases through molecular collisions. The greenhouse gases also radiate in the infrared range. Radiation is emitted both upward, with part escaping to space, and downward toward Earth's surface. The surface and lower atmosphere are warmed by the part of the energy that is radiated downward, making our life on earth possible.

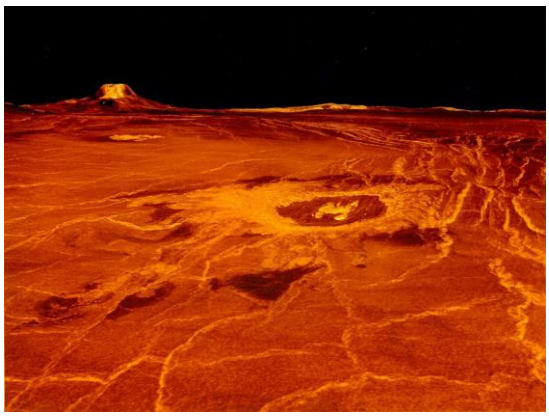
Carbon dioxide is the main gas given off when carbon fuels burn. The effect of combustion-produced carbon dioxide on the global climate is a special case of the greenhouse effect first described in 1896 by Svante Arrhenius.




Because it is a greenhouse gas, elevated $CO_2$ levels will contribute to additional absorption and emission of thermal infrared in the atmosphere, which contributes to net warming.

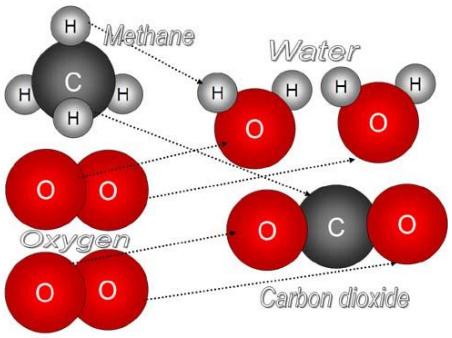
In fact, according to the opening statement of the Fifth Assessment Report from the Intergovernmental Panel on Climate Change "*Human interference with the climate system is occurring*".

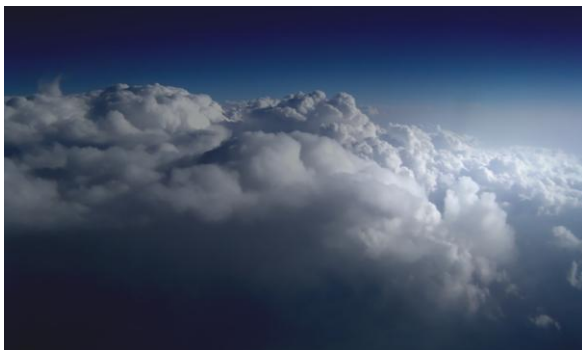
Over the past 800,000 years, ice core data shows unambiguously that carbon dioxide has varied from values as low as 180 parts per million (ppm) to the pre-industrial level of 270ppm. Certain paleoclimatologists consider variations in carbon dioxide to be a fundamental factor in controlling climate variations over this time scale.



A runaway greenhouse effect occurs if positive feedbacks lead to the evaporation of all greenhouse gases into the atmosphere. A runaway greenhouse effect involving carbon dioxide and water vapor may have occurred on Venus.

- *$CO_2$. Methane. Water vapour. Sulphur dioxide. CFCs.*



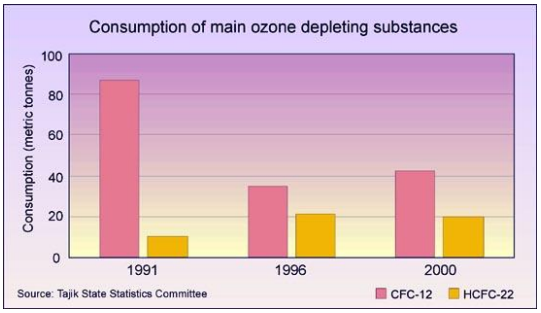



The following greenhouse gases have a contribution to the greenhouse effect: water vapor, which contributes 36–72%, carbon dioxide, which contributes 9–26%, methane, which contributes 4–9% and ozone, which contributes 3–7%. The major non-gas contributor to the Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on radiative properties of the atmosphere.

Carbon dioxide is the human-produced greenhouse gas that contributes most of radiative forcing from human activity. $CO_2$ is produced by fossil fuel burning and other human activities such as cement production and tropical deforestation. Measurements of $CO_2$ from the Mauna Loa observatory show that concentrations have increased from about 313 parts per million in 1960 to about 383 ppm in 2009. The current observed amount of $CO_2$ exceeds the geological record maxima (~300 ppm) from ice core data.

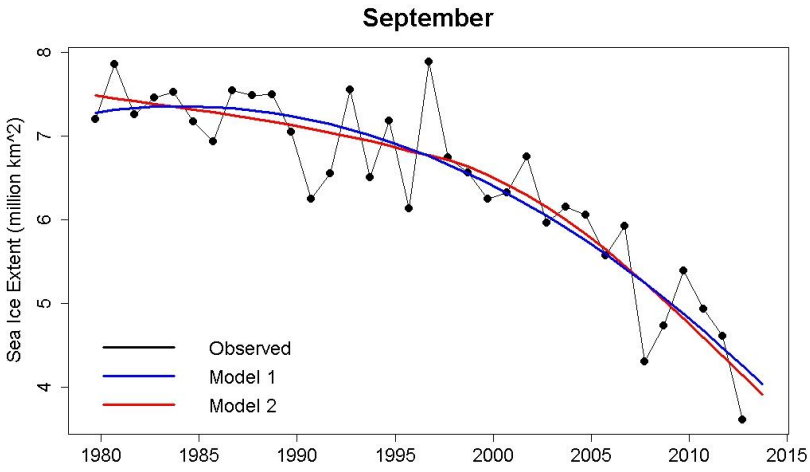
There are 3 teratonnes of carbon dioxide in the atmosphere and 50 times more in the oceans. Methane ($CH_4$), which is the fuel of natural gas, is 22 times more potent than carbon dioxide as a greenhouse gas, but is under 2 ppm of the atmosphere compared with 387 ppm for carbon dioxide. Water vapour also acts as a greenhouse gas

contributing 36-72% of radiative forcing, but in daytime the presence of cloud reflects sunlight. Sulphur dioxide, which can be given off when coal burns, which contributes to 50% of global emissions – this was the source of smog in London in the 1950s – has a cooling effect as a greenhouse gas. It comprises 0.001 ppm of the atmosphere. When the Mt Pintubo volcano in the Philippines erupted in 1991, the sulphur dioxide given off cooled the planet by 0.5 °C between 1991 and 1993. Roughly half of the carbon dioxide stays in the atmosphere when emitted for over 100 years, but $CO_2$ has a variable atmospheric lifetime that cannot be specified precisely. The corresponding figure for methane is 7 years.



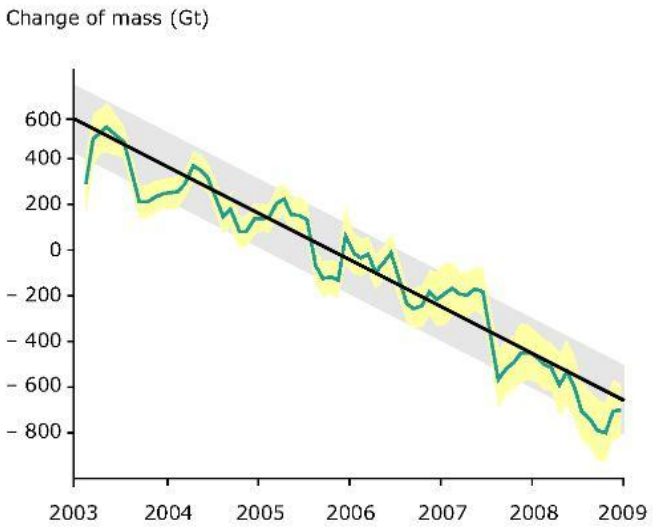

CFCs (chlorofluorocarbons), which were used as refrigerator coolants and in cans of hair spray until they were abolished by the Montreal Protocol in 1989, depleted the ozone layer (which prevents dangerous ultraviolet radiation reaching the ground) above the Arctic and Antarctic leaving the largest ozone hole in the winter of 2006. The situation has now greatly improved and is expected to recover by 2050.

- *The Arctic and Antarctic. Greenland and ice-melt.* Shown below is the Artic sea ice between 1979 and 2014.




The GRACE satellites have measured the melting of Greenland ice from the effects of the mass of the ice on their polar orbits. If the entire 2,850,000 $km^3$ (684,000 cu mi) of ice were to melt, global sea levels would rise 7.2 m (24 ft). Recently, fears have grown that continued climate change will make the Greenland Ice Sheet cross a threshold where long-term melting of the ice sheet is inevitable. Climate models project that local warming in Greenland will be 3 °C to 9 °C during this century. Ice sheet models project that such a warming would initiate the long-term melting of the ice sheet, leading to a complete melting of the ice sheet (over centuries), resulting in a global sea level rise of about 7 metres (23 ft). Such a rise would inundate almost

every major coastal city in the world. How fast the melt would eventually occur is a matter of discussion. According to the IPCC 2001 report, such warming would, if kept from rising further after the 21st Century, result in 1 to 5 meter sea level rise over the next millennium due to Greenland ice sheet melting. However, in a study published in *Nature* in 2013, 133 researchers analyzed a Greenland ice core from the Eemian interglacial. They concluded that Greenland ice sheet had been 8 °C warmer than today for 6000 years. The large and long-lasting warming had a modest effect on the ice sheet, leaving it largely intact.




Some scientists have cautioned that these rates of melting are overly optimistic as they assume a linear, rather than erratic, progression. James E. Hansen has argued that multiple positive feedbacks could lead to nonlinear ice sheet disintegration much faster than claimed by the IPCC. According to a 2007 paper, "we find no evidence of millennial lags between forcing and ice sheet response in paleoclimate data. An ice sheet response time of centuries seems probable, and we cannot rule out large changes on decadal time-scales once wide-scale surface melt is underway."

- *Rise in temperature – the model* A1FI. The climate model A1FI is a business as usual carbon dioxide emissions model. However, the projections for business as usual under this model have already been exceeded.