Science Topic 09-11-24

Update in newsletter: Jun 2025

CliSciPol

Climate Science and Policy for Nonscientists

One picture is worth a thousand words.

CO2 FACTS AND HISTORY

In the world there are massive amounts of naturally occurring CO2. Presently in the atmosphere there are stored about 850 petagrams of CO2. A petagram equals one billion metric tons. In the oceans are stored about 38,000 pgs. But most CO2 is stored in the earth's crust, about 100,000,000 pgs., mostly in the form of rocks, such as limestone. Human emissions per year from burning fossil fuels are about 10 petagrams, which is trivial in relation to the amount of natural occurring CO2 stored in the earth's crust or in the oceans.

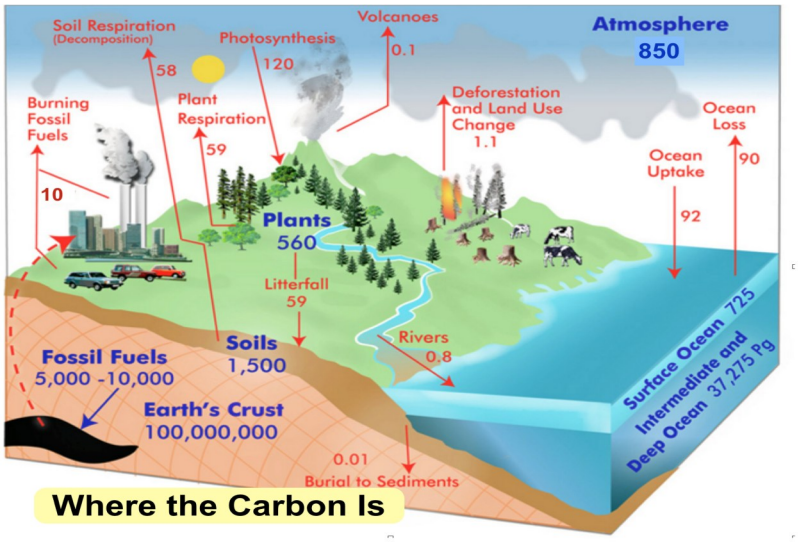
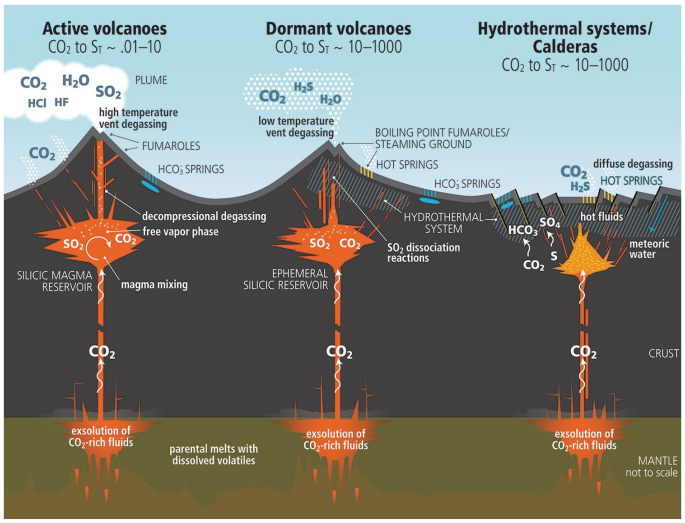
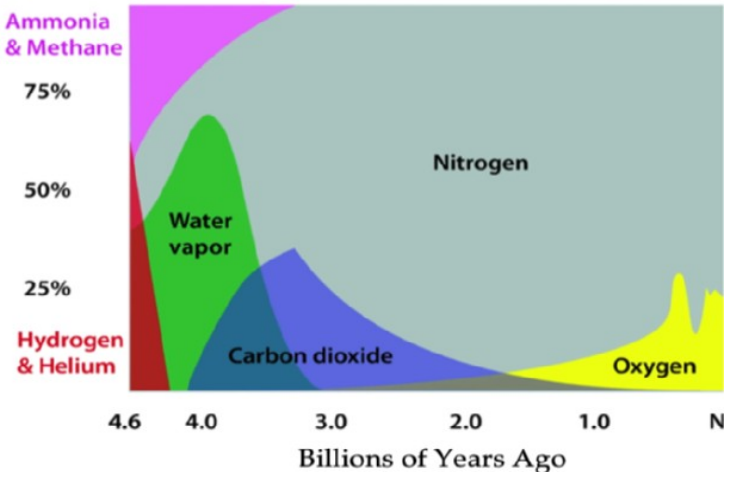


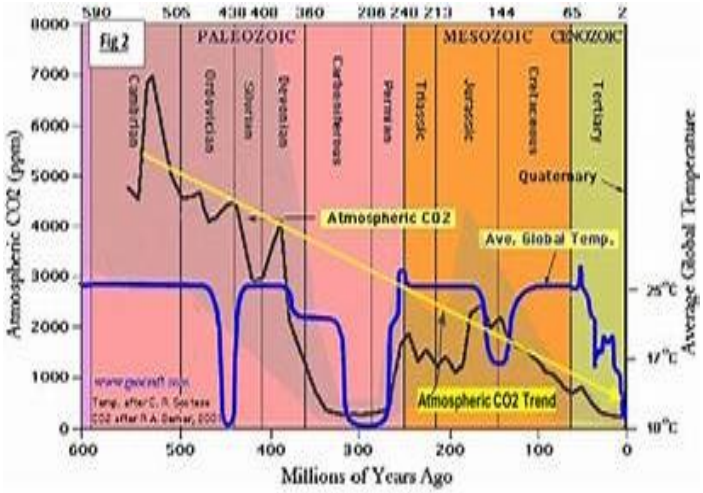
Figure 3. Depiction of the global carbon budget in Gt of carbon. Values in blue are stocks of carbon while values in red are annual flows. Note that the ocean contains nearly 50 times as much carbon as the atmosphere does, and the ocean and atmosphere are in constant flux.[17]



Historically the principal way that CO2 is released into the atmosphere is via volcanic eruptions. Limestone (CACO3), for example, is formed by the combination of a molecule of calcium oxide (CaO) and of CO2. When limestone is melted by the heat in the earth's core, it breaks down, releasing the CO2, which then is released into the atmosphere when a volcano erupts.

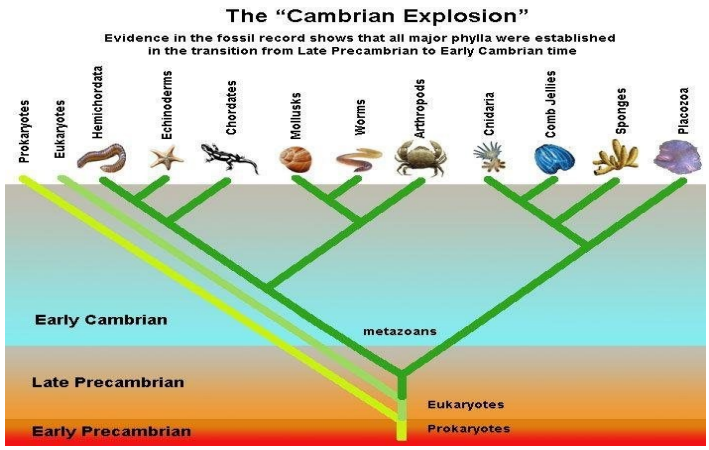
The percentage of various gases in the atmosphere has varied greatly over earth's lifetime. For a period of time about 3 billion years ago CO2 was over 25% of the atmosphere. This percentage then declined steadily over the following 2 billion years.

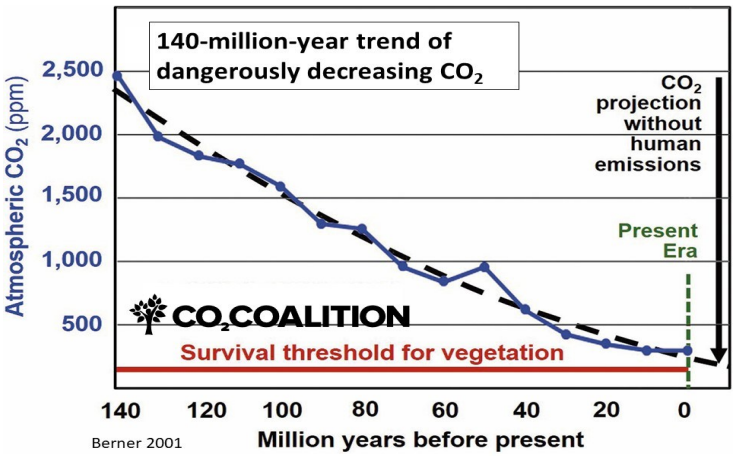




Since 600 million years ago, CO2 has continued its downward trend in the atmosphere with some significant variation from period to period. The present CO2 level in the air is 420 parts per million (ppm), which is less than half of one tenth of one percent (less than 1 part per 2,000). For most of the last 600 million years CO2 levels have been much, much higher than today (average about 2,500 ppm), and world temperature has been much higher than today.

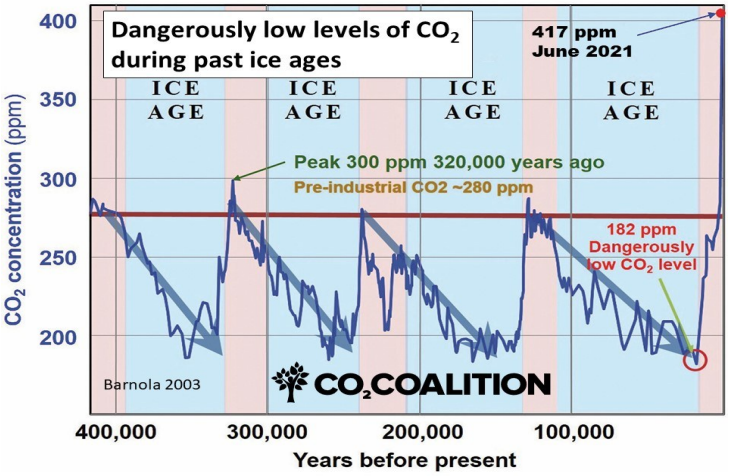
During the Cambrian, when CO2 spiked to 7,000 ppm, and when world temperatures were much higher than today, the earth experienced an extraordinary blossoming of life and of biodiversity known as the Cambrian Explosion. There was a sudden radiation of complex life, and practically all major animal phyla started appearing in the fossil record. In earth's history warm periods tend to be associated with growth and diversification of life. Cold periods tend to be associated with extinctions.





Over the last 140 million years the CO2 decline has been almost linear. CO2 is plant food, and the levels reached in recent years have been so low as to threaten plant starvation. CO2 levels decline, because of natural processes that remove CO2 from the atmosphere., e.g. plants eating CO2.

During the 4 recent glaciations (the most recent about 20,000 years ago) atmospheric CO2 levels fell to around 190 ppm, a level at which plant life is seriously impaired with widespread plant death occurring at around 150 ppm. The lowest CO2 level ever in earth's history was 182 ppm, which occurred about 14,000 years ago. At that time many areas that are now productive farmland had no plant life and were racked by violent dust storms.



From about 25,000-13,000 years ago the Arctic ice cap covered all of Canada and significant parts of the US, Europe, and Russia. Much of the world was frozen, cold, dusty, and barren.

From 14,000 years ago up to the end of the preindustrial period (about the year 1800), CO2 levels rose from 182 ppm to 280 ppm due to natural causes. Temperatures rose dramatically from about 15,000 to 10,000 years ago, causing the Arctic ice sheet to retreat to its present extent. Some scientists believe that temperatures have been declining slightly since that time, as shown, but this is disputed.

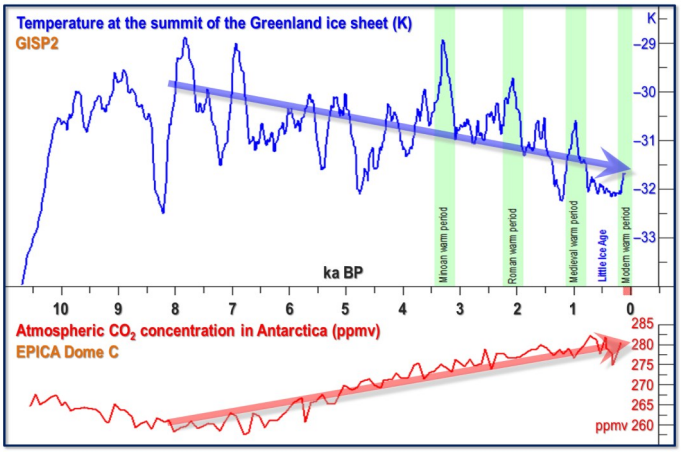


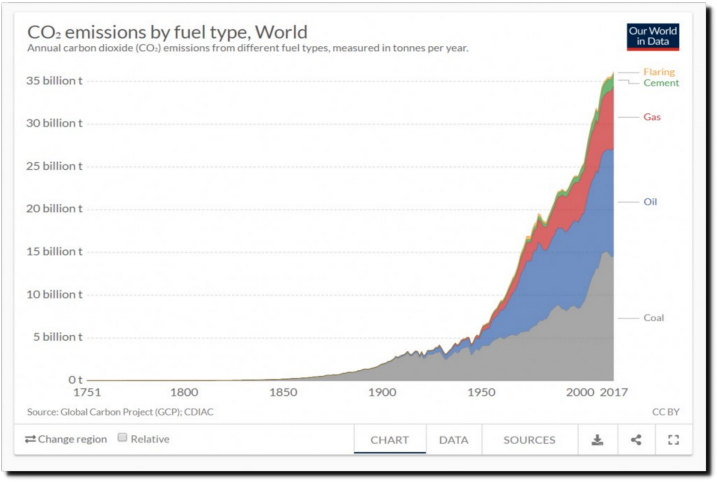
Figure 7. Reconstructed Greenland mean temperature anomalies (top) and Antarctic CO_2 concentration (bottom). Halving the temperature anomalies to allow for polar amplification gives a reasonable approximation of global temperature change in the Holocene. Since the Holocene Optimum began about 9,000 years before present (ka BP), global temperature has fallen by ~1°C, though CO_2 concentration rose throughout.[34]

CHANGING ATMOSPHERIC CO2 LEVELS

Preindustrial CO2 level	**280 ppm**
Present CO2 level	**420 ppm**
Human contribution	**140 ppm**
Natural CO2 in the air	**280/420 = 67%**

Since the preindustrial level of about 280 ppm in the year 1800, CO2 levels have risen to about 420 ppm. The human contribution is debated with some studies concluding that only about 20% of the 140 ppm is human caused. But assuming that the increase is totally due to human emissions, still about 2/3ds of the CO2 in the air today is due to natural causes (the preindustrial level) and only 1/3d is due to human activity.

Human emissions were relatively insignificant until the 1950s when they dramatically spiked upwards. They have been rising at a significant and roughly linear rate ever since.



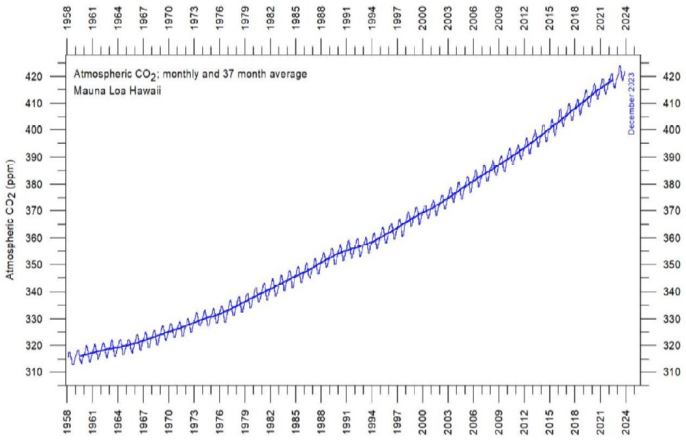
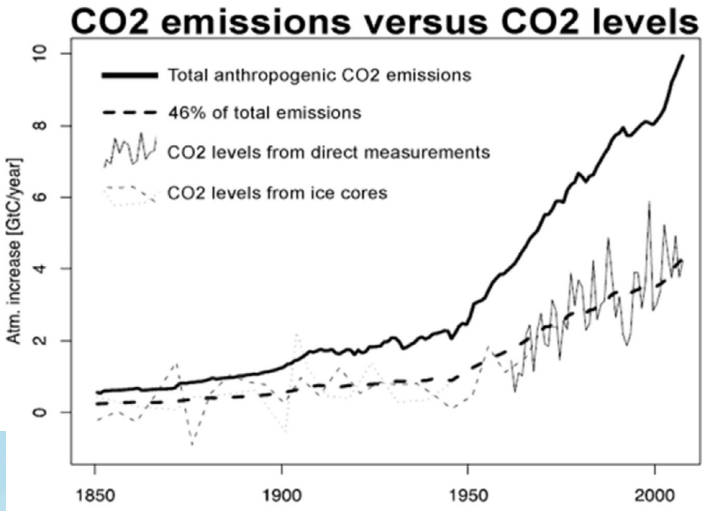
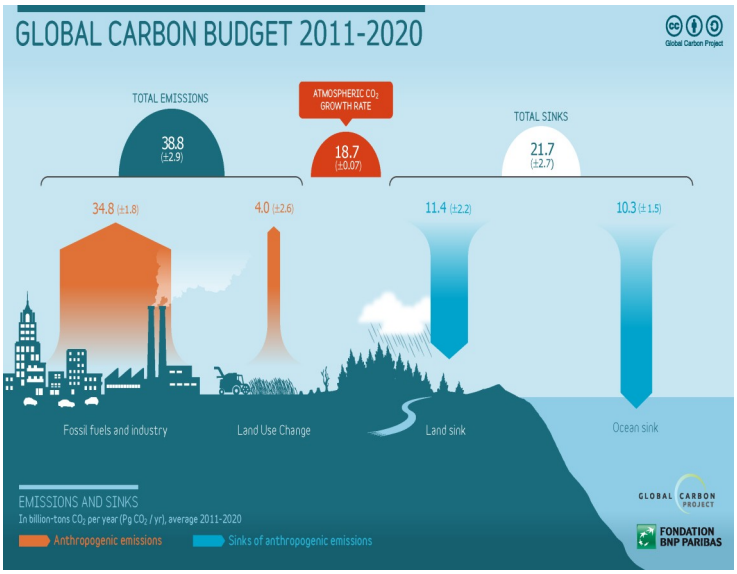


FIGURE 25: Monthly amount of atmospheric CO_2 since March 1958, measured at the Mauna Loa Observatory, Hawaii. The thin line shows the monthly values, while the thick line is the simple running 37-month average, nearly corresponding to a running 3-year average.

The atmospheric CO2 concentrations have been rising also at a roughly linear rate, but at a significantly slower rate than total human emissions, because human emissions have been significantly smaller than the naturally occurring CO2 already in the atmosphere (280 ppm). The maximum human addition has been 140 ppm.

Natural processes, such as plants eating CO2, remove a significant amount of CO2 from the air each year. This particular study concluded that only about 46% of human emissions actually remain in the air to contribute to an increase in the atmospheric concentration.





This analysis concluded that of 38.8 gigatons of CO2 emitted per year, 18.7 gigatons, or 48%, remained in the atmosphere to contribute to CO2 growth.

The absolute rate of atmospheric CO2 increase has been rising slightly over the years and is now about 2.5 ppm per year.

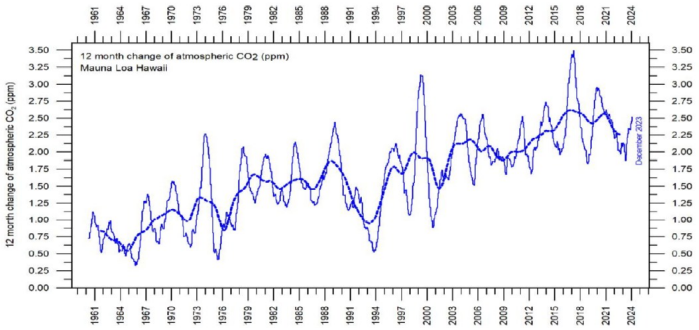
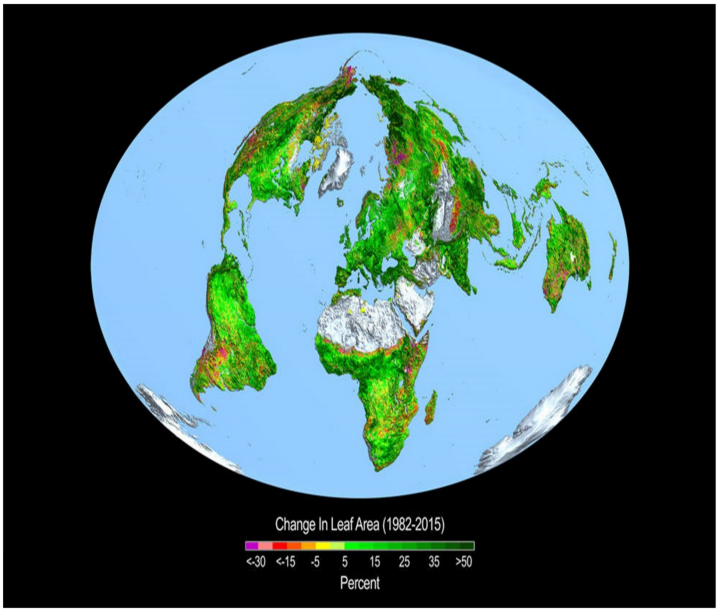


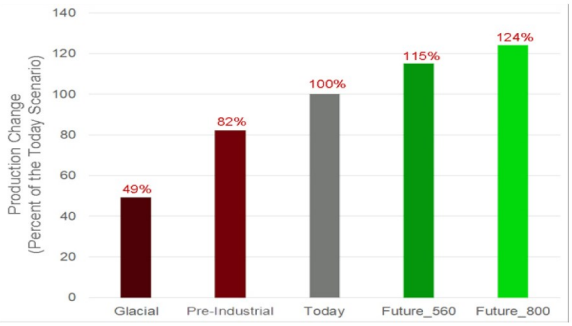
FIGURE 26: Annual (12 month) growth rate (ppm) of atmospheric CO2 since 1959, calculated as the average amount of atmospheric CO2 during the last 12 months, minus the average for the preceding 12 months. The graph is based on data measured at the Mauna Loa Observatory, Hawaii. The thin blue line shows the value calculated month by month, while the dotted blue line represents the simple running 3-year average.



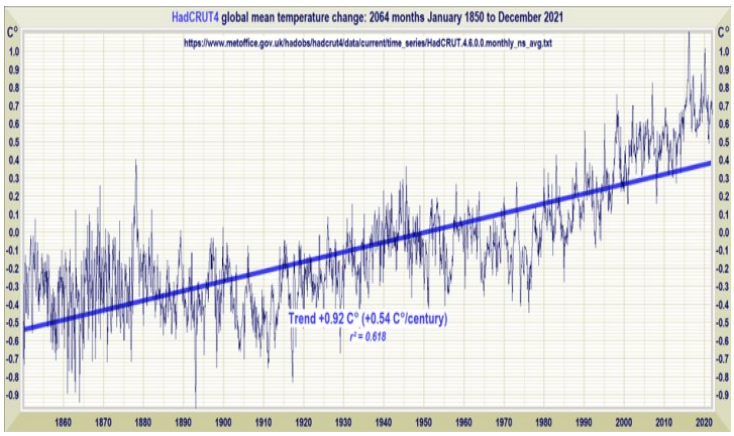
As a result of the rising CO2 levels (plant food) and the rising world temperature, the world is greening, as concluded by a recent massive study organized by NASA (data collected by satellite). The study found that from 1982 to 2015 from a quarter to half of Earth's vegetated lands showed significant greening. Leaves on plants and trees increased equivalent in area to two times the continental US. The study attributed 70% of the greening to rising CO2 levels and 30% to rising temperatures.

Rising CO2 levels and temperatures also improve crop yields per acre. The IPCC repeatedly acknowledges this positive effect of rising CO2 levels. [AR6 WGI pps. 6, 82, 292, 365-6, 1057, and 1062 (2021)] (For further discussion see CLISCIPOL Science Topic: Greening World). Yields for major crops 2024-2025 are expected to be at record levels.

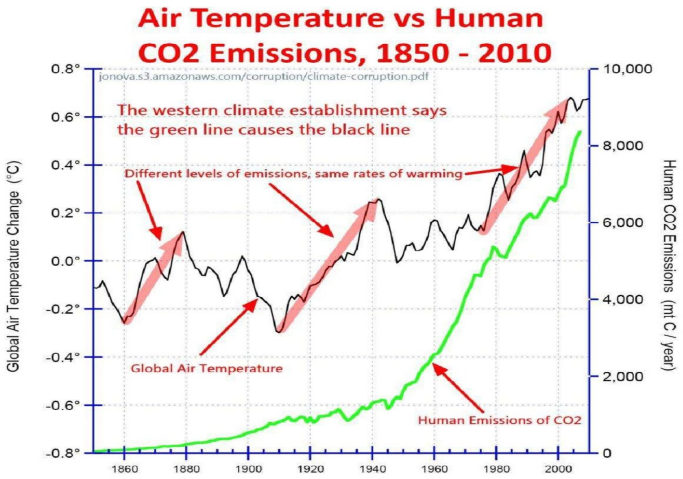
Percent change in the combined production of wheat, maize, rice, and soybean under five temperature and CO_2 scenarios



Columns from left to right are five climate scenarios: Glacial, 180 ppm CO_2 and -6°C relative to Today; Pre-Industrial, 280 ppm CO_2 and -1°C relative to Today; Today, 400 ppm CO_2; Future_560, 560 ppm CO_2 and +2°C relative to Today; and Future_800, 800 ppm CO_2 and +4°C relative to Today. *Source:* Mariani, 2017.

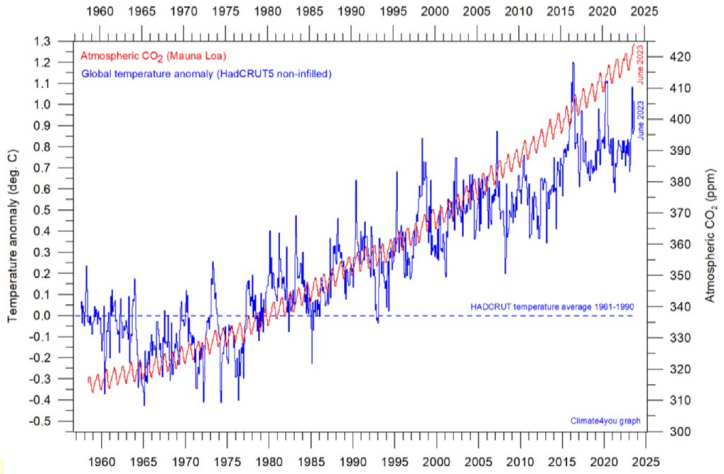


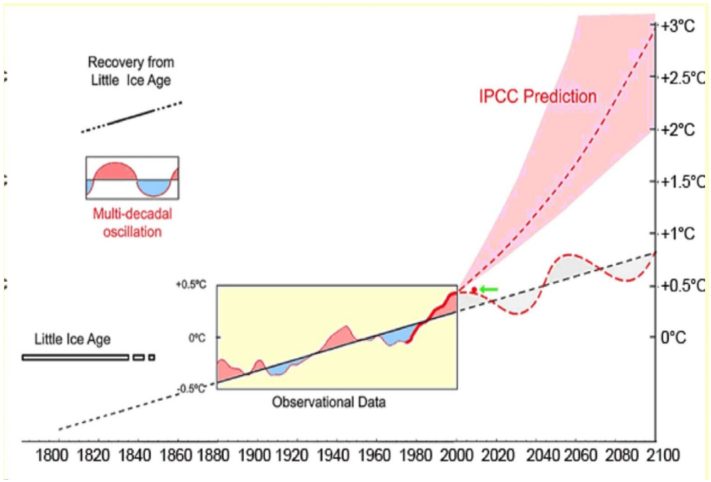
The IPCC concludes that the world has warmed about 1.1 C from the preindustrial period, 1850-1900, to 2010-2020. [AR6 WGI p. 5 (2021)]. The warming has been roughly linear, and the rate of warming has been about 1 C per century.



CO2 is a greenhouse gas, and increasing atmospheric levels of CO2 cause some amount of temperature rise. But the amount of recent warming caused by rising CO2 levels is disputed. There was a significant temperature rise from 1910-1940 that can not be reasonably attributed to CO2. But there is a strong correlation between rising CO2 levels and the rising temperatures after 1975.

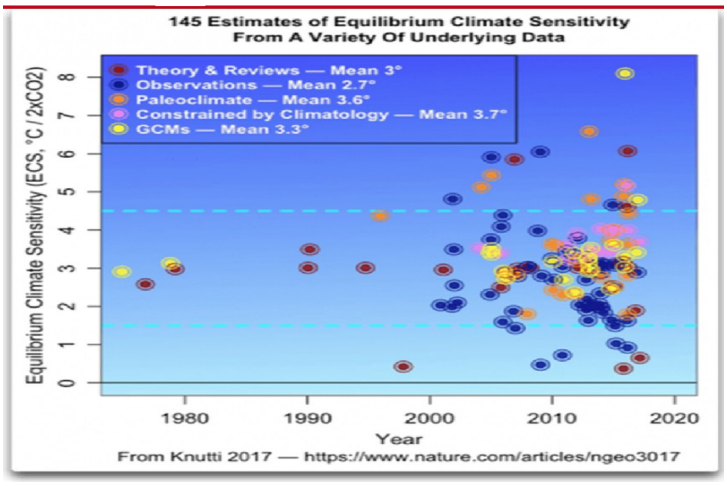
This more detailed image shows that from 1960 to 2023 the increase of world temperature closely tracked (but perhaps slightly lagged behind) the rising CO2 level. The IPCC describes the temperature increase as "unprecedented" but makes no claim that the increase is accelerating. [AR6 WGI p.5-6 (2021)]





A key issue is how much more the world will warm in the next 100 years as CO2 levels continue to rise. A projection based on the trend line shows a further linear rise of 1 C , which is generally considered to be moderate, i.e. a concern but not a serious concern. The IPCC uses models to predict much higher temperature rises that could be catastrophic.

A key unknown is what scientists call "Sensitivity." This is a measure of the strength of CO2 as a greenhouse gas. For example, CO2 has been increasing in the atmosphere at a rate of 2.5 ppm per year. If it increases by 25 ppm over a 10 year period, how much will the earth warm? No one has been able to measure S, so scientists are forced to estimate S, and the results are widely scattered, as shown in the image. There is no agreed number.



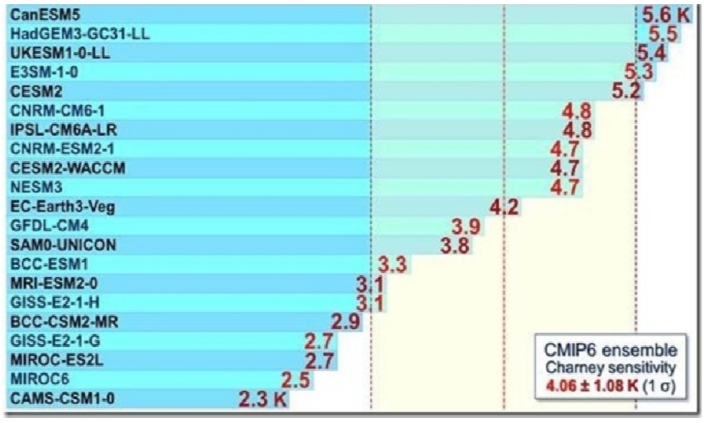


Figure 8. Climate sensitivity values used by various global climate models.

To predict a temperature rise every model must start with an assumption of the correct value of S. The image shows the S value assumed by each of an ensemble of models that submitted results for the most recent IPCC Assessment Report, AR6. S values ranged from 2.3 to 5.6.

Backcasting shows that CMIP6 models predict twice the actual warming. This overprediction was so large that the IPCC was forced to concede the models' failure. [AR6 WGI p.444 (2021)]. The IPCC acknowledged that uncertainty with respect to S was the "dominant" source of uncertainty in temperature projections. (AR6 WGI p. 93, 95) , and that the "very likely" range of S was 2.0 to 5.0, an extraordinarily wide range of uncertainty. (AR6 WGI p. 93, 1007). The IPCC concluded that 3.0 was the "central value" for S. (AR6 WGI p. 93, 1007).

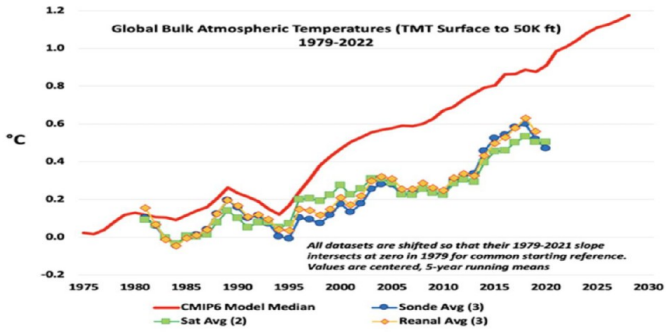


Figure 1: Comparison of global warming trends from 1979 to 2022 between CMIP6 climate models (median of all models in red) compared to average of satellite derived temperature measurements (green), average of weather radiosonde balloons (blue), and reanalysis of average surface temperature measurements (orange). Note the red line indicating climate model temperatures has rates of warming that are nearly double that of actual measurements in 2022. Graph by John Christy, PhD.

CONCLUSION

S is defined as the amount of temperature rise if atmospheric CO2 concentration is doubled from its preindustrial level of 280 ppm, so doubling will occur when the CO2 level reaches 560 ppm. CO2 concentration today is 420 ppm and is rising at 2.5 ppm per year, so, at that rate, 560 will be reached in 56 years (56 x 2.5 = 140), which would be the year 2080 (2024+56).

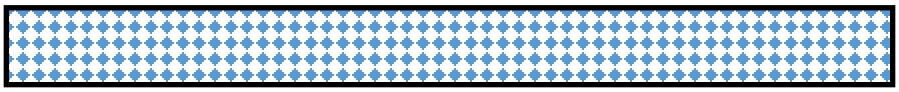
The world warmed 1.1 C from the preindustrial to 2010-2020 (AR6 WGI p.5), and it has probably warmed another 0.1 C to 2024, for a total of 1.2 C warming to date since the preindustrial period.

So, if S = 3.0 (the IPCC central value), from the present the world will warm another 3.0 - 1.2 = 1.8 C by 2080, which is a rate of warming of 1.8 x 100 / 56 = 3.2 C per century, which is more than 3 times the actual rate of warming measured over the last century.

If the present rate of moderate warming (1 C per century) continues, then over the 56 years (2024 to 2080) the world will warm 0.56 C or about 0.6 C, which means that S = 1.2 + 0.6 = 1.8.

There is significant disagreement among scientists as to how much global warming will be caused by rising CO2 levels over the next century. The trend line projection suggests that the warming will continue to be moderate, but many scientists use other methods to predict much greater warming.

The optimum atmospheric CO2 level for plant growth and crop yields appears to be in the range of 1,500-2,000 ppm, versus the current level of 420 ppm.



Work Cited

Intergovernmental Panel on Climate Change Assessment Report 6, Working Group I, The Physical Science Basis (2021) (AR6 WGI)