Safeguarding the Biosphere

John W. Purdie

June 3, 2021

Introduction

1. This is an analysis of the influence of atmospheric carbon dioxide on the global climate and possible effects over the long term. The current level of this gas in the atmosphere exceeds all previous records over the past 800,000 years. Although the immediate effect of this on the Earth's energy balance is well understood, the long-term effects on the climate are less clear. Reducing the level of CO_2 in the atmosphere would resolve the problem but the economic cost of doing so inhibits substantial action on this front. It is a problem of momentous importance as the Biosphere, which is essential to life on Earth, may be at risk if the situation is not corrected

Atmospheric Carbon Dioxide, (CO_2)

2. The level of carbon dioxide in the atmosphere over the past sixty years is displayed in Figure 1. It passed 410 parts per billion in 2019 and will continue to rise. The CO_2 level fluctuates with the growing season in the Northern hemisphere; it falls in summer as plants conduct photosynthesis. The level has been rising since the industrial revolution but especially over the past one hundred years.

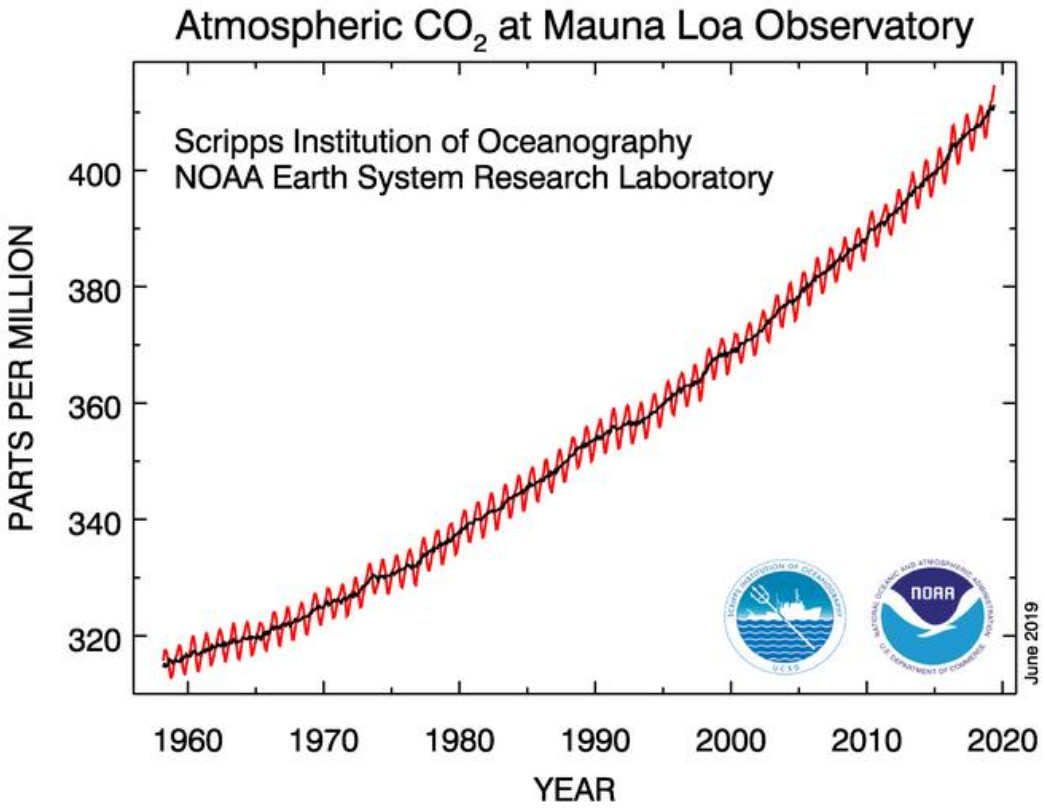

Figure 1: CO_2 in the atmosphere, parts per million

Ice core records of CO_2 and temperature

3. Historic levels of CO_2 in the atmosphere and temperatures have been determined by analysis of gas trapped in ice cores from Antarctica going back thousands of years. The carbon dioxide level rises and falls in step with temperature over ice ages and inter-glacial warm phases.

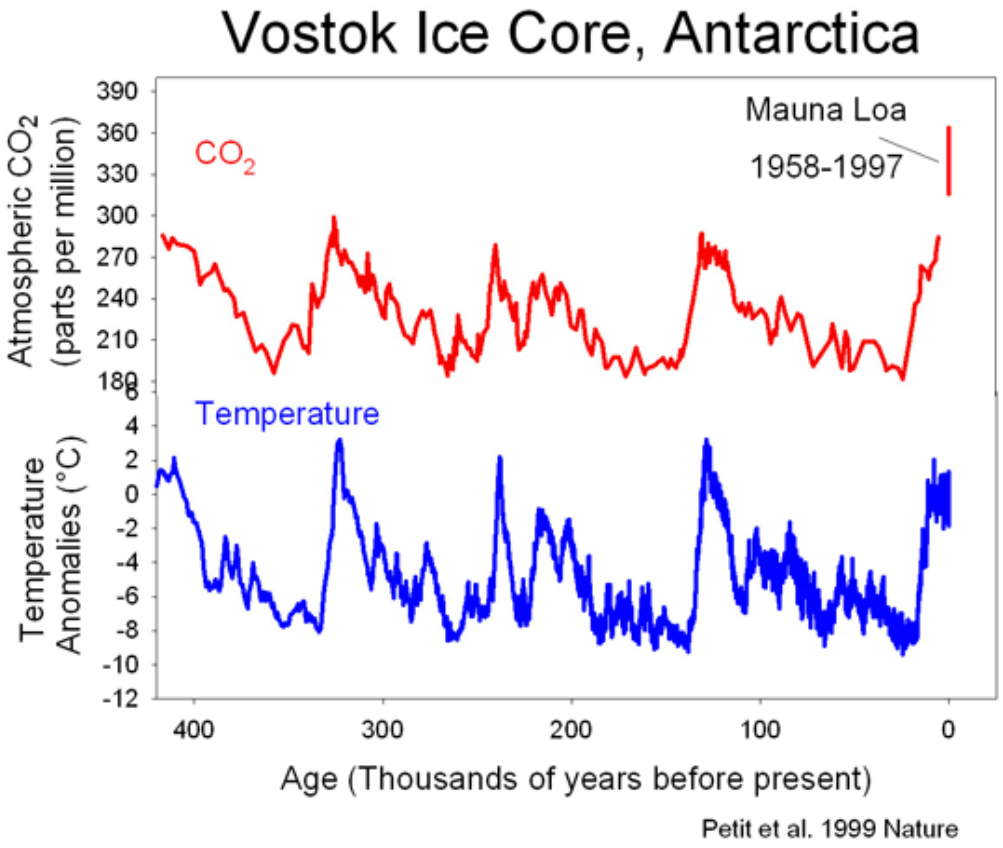

Figure 2. CO_2 and temperature records determined from ice cores.

Earth Energy Balance

4. The energy deposited by the sun is highest in equatorial regions. It is redistributed by three main processes: 1. Convection currents in the atmosphere, 2. Ocean currents, and 3. Radiation. Movement of heat by atmospheric convection currents occurs in three well recognized stages; the Hadley cell which carries energy to 30 degrees north and south, the Ferrel cell which circulates between 30 and 60 degrees, and the polar cells which continue the process to the poles. These circulation cells are driven by the movement of gas and are not significantly affected by greenhouse gases in the atmosphere. Ocean currents such as the Gulf Stream also transport energy away from warm regions and are not directly affected by greenhouse gases in the atmosphere.

5. Transfer of heat by radiation, on the other hand, is strongly affected by Greenhouse gases. Normally, infrared radiation moves energy from the Earth's surface into space. Carbon dioxide and other greenhouse gases in the atmosphere reflect infrared radiation back to Earth so some of it does not escape. Thus, as the amount of greenhouse gas in the atmosphere increases, removal of heat by radiation becomes less and less efficient. The result is general warming of the planet as energy is accumulated with a gradual increase in global average temperature. An additional effect of the reflected energy spreading out in a random pattern is that the Arctic and Antarctic regions receive more energy than would otherwise be the case and this promotes melting of polar ice caps.

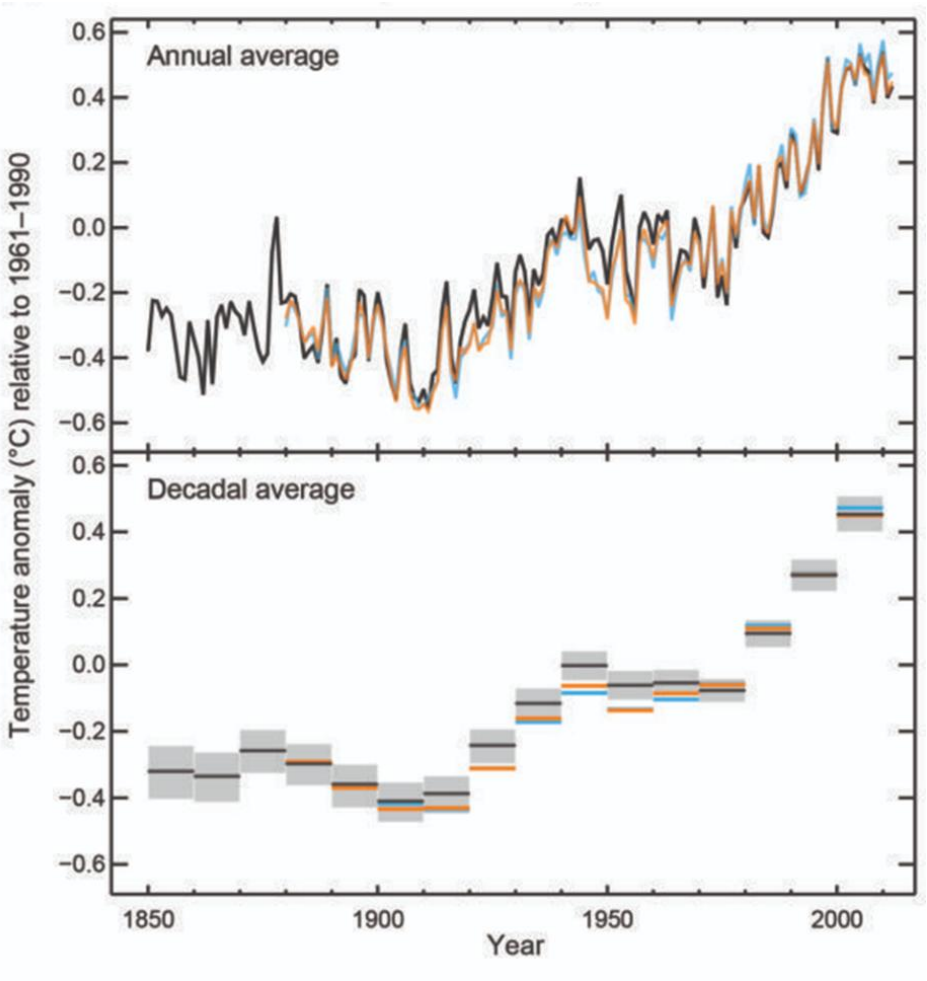

Figure 3. Global Average Temperature. (From; IPCC R5. Fig SPM. 1)

6. Global average temperatures fluctuate greatly; Figure 3. This graph from the Intergovernmental Panel on Climate Change (IPCC) uses averages over ten-year periods to smooth out the variations and better illustrate the increase over the past few decades.

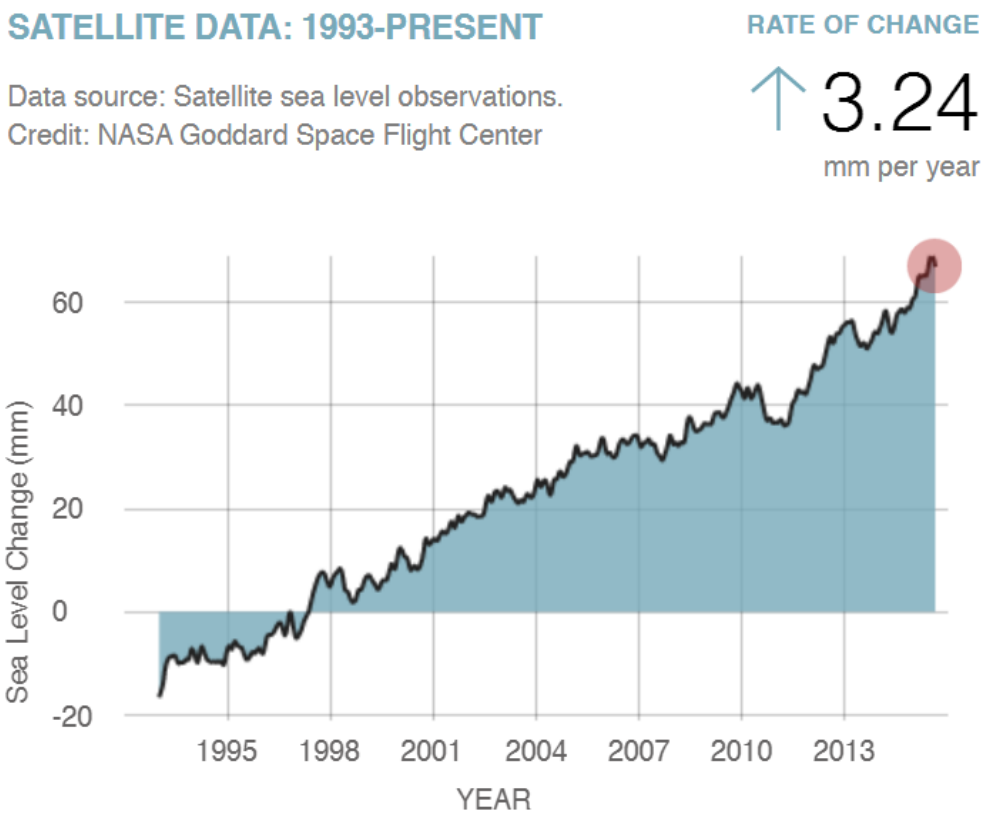

Figure 4. Sea Level Rise.

7. Warming of the Earth is also reflected in rising sea level. This is caused by land-based ice melting and sea water expanding and is less subject to regional variations, Figure 4. It demonstrates the steady increase in sea level due to increasing global heat since 1998. From the slope of the graph, it is possible to estimate that the increase will reach about one metre in 300 years. It is more instructive, however, to consider the graph prior to the present. It shows clearly that global warming has been going on since 1989 or earlier. The CO_2 in the atmosphere continues to rise so it must be concluded that global warming, and hence climate change, will also continue as long as an excess of the gas remains in the atmosphere.

Figure 5. Petrified Forest in Canadian high Arctic.

8. The photo in Figure 5 serves to illustrate that long warm periods have occurred in the Canadian high Arctic in the past. In this photo, Dr. Lillycrop is leaning against the petrified stump of a tree, part of a forest of meta-sequoia trees that grew on Ellesmere Island 43 million years ago. The wood has been converted to stone, petrified, by silicone replacing carbon in the structure over a long period of time.

Ellesmere Island is 500 miles (800 km) from the North Pole. Its position has not changed since then so the forest had to endure four months of darkness each year. In order for it to develop and grow there, the climate must have been warm for thousands, of years. That raises the question: Is the Earth now headed for a similar long hot spell and what will follow?

Curbing Climate Change

9. Attempts are being made to curb climate change by reducing emissions of Greenhouse Gas (GHG). The Paris Agreement on Climate Change, signed in 2016, is an attempt to prevent the global temperature from rising more than 2 ^{o}C above pre-industrial levels by reducing emissions. With 195 signatories it included almost all of the major emitting states. Each nation was required to determine its own non-binding contribution towards the overall goal of reducing GHG emissions. However, this is seen as the weak point in the Agreement. The withdrawal of the United States in November 2020, has been reversed but the long term success of the Agreement is not certain.

10. Carbon tax is used by some countries to achieve CO_2 reductions by making it more expensive burn fossil fuel. While this is useful to reduce the amount of gas that needs to be removed, it does not reduce the CO_2 already in the atmosphere. Reducing GHG emissions to zero could work in the very long run but it would take several thousand years for the atmospheric CO_2 to fall to a level that is safe from the point of view of climate. Further, there is a severe economic cost to doing so; the modern world thrives on abundant energy supplies. Thus, the current sources of energy based on fossil fuel would have to be completely phased out and replaced with clean energy supplies.

11. As climate change is being driven mainly by the carbon dioxide already in the atmosphere, the definitive way to curb it is to remove the excess of the gas from the atmosphere. Several companies are working on this, so called carbon removal, on a small scale. For example:

- Climeworks of Switzerland is extracting CO_2 from the air for direct sale and, more recently, for conversion to aviation fuel;
- Carbon Engineering of Canada is capturing CO_2 and converting it to clean fresh fuel;
- Deep Branch Biotechnology, UK, is developing a process to convert CO_2 to animal feed.

Incentives are also being offered for development of technology to remove CO_2:

- NRG COSIA XPRIZE; $20 million for development of technologies to convert CO_2 to valuable products.

Several other methods have been proposed for long term storage of captured CO_2 including:

- Pumping it into the ground in depleted oil and gas wells and other suitable geological locations;
- Growing a trillion trees: However, there is a risk of forest fires reversing the process as may have happened in prehistoric interglacial periods;

12. In a fresh initiative, the William and Kate Foundation in UK launched the “Earthshot” prize, a million-pound prize for ideas to “repair the Earth”. Of the five Earthshots announced so far only one is focussed on the climate. Hopefully it will include repairing the atmosphere in order to achieve that goal. Many more techniques for use or long-term storage of carbon dioxide will probably be developed but the important point is to remove the excess from the atmosphere.

13. In view of the large amount of fossil fuel consumed in the past, similar large amounts of CO_2 must be removed to restore the energy balance of the Earth. One product that could be used in billion-ton quantities is organic soil. CO_2 could be captured and converted to an organic soil amendment using biotechnology. Further, if soil type nitrogen is incorporated into this soil by means of the Maillard reaction, it would become a valuable product. Soils normally contain 1 to 10% organic matter but many have been depleted due to intensive agriculture. Thus, potentially, two problems could be solved at the same time.

<u>The Ice Man Cometh.</u>14.

A dramatic diagram published by NASA illustrates the degree to which the atmospheric carbon dioxide now exceeds all previously known levels, Figure 6. Historically the level of CO_2 in the atmosphere remained below 300 parts per million for eight hundred thousand years. The current level of 410 ppm, attained in 2019, will have a major impact on the Earth’s climate.

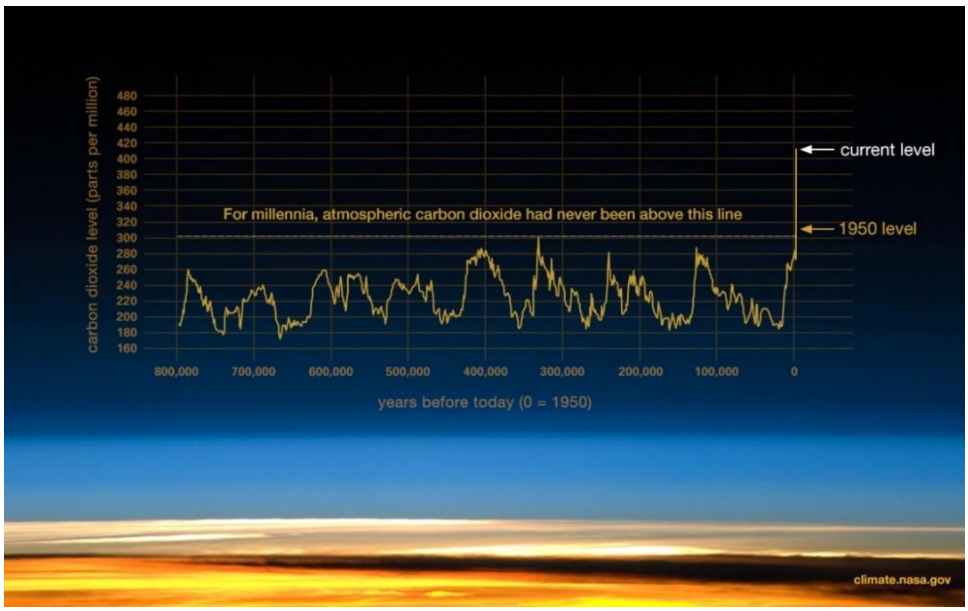

Figure 6. Long term CO_2 records.

15. The immediate effect is that more of the infrared radiating from Earth to space will be reflected back to the ground resulting in an accumulation of energy. This shows up as increasing global average temperature as illustrated in Figure 3 and rising sea level, Figure 4. The rise in temperature is more acute in Polar Regions and, if it continues, the polar ice caps will melt. Not only will this accentuate the sea level problem, but it will lead to major changes in the Earth's weather systems including precipitation patterns and ocean currents.

16. However, a more ominous effect will be a long-term change in reflectivity of the Earth as most of the snow and ice disappears. With less of the solar radiation reflected by snow and ice, the additional radiation being captured will gradually push the Earth to a higher orbit, further from the sun. As energy received is inversely proportional to the square of the distance, the planet will collect significantly less solar energy. The Earth will become progressively cooler and the climate will gradually shift towards an ice age. As illustrated in Figures 2 and 6, these changes normally take place over thousands of years but it will be accelerated by the high level of greenhouse gases now in the atmosphere. This process and past climates have been discussed by several authors including, for example, Graham Lawton, *Climate's future written in rocks*, New Scientist, July 6, 2019. Unfortunately, once set in motion, it would be very difficult if not impossible to reverse the trend. The effect of such an extreme climate change on the biosphere would be catastrophic.

Biosphere

17. Protecting the biosphere by reducing the amount of carbon dioxide in the atmosphere is imperative. It could be carried out over an extended period of time, say several hundred years, but less than one thousand years would be more prudent. The use of fossil fuels could be phased out completely as the removal of CO_2 progressed. Although the cost would be extremely high, the cost of destroying the biosphere is incalculable.

18. On a more positive note, if it can be done successfully, and an ice age averted, there are immense and far-reaching implications. It would mean that the Earth could be maintained in the "Goldilocks" zone, not too hot and not too cold, indefinitely by regulating the level of carbon dioxide in the atmosphere. In other words, it would break the cycle of ice ages and interglacial warm spells that has been a feature of the Earth's climate for at least a million years. Thus, developing technologies to control the amount of carbon dioxide in the atmosphere would have momentous long-term benefits.