Climate Change Facts

Last Update: 16th May 2009 (last Section deleted Jan.2016)

Carbon Dioxide, the Atmosphere and Temperature Increase

- Fossil fuel burning puts 6.3 Gt of C into the atmosphere annually (23 Gt of CO_2)
- Carbon in the atmosphere is increasing at a rate of 3.2 Gt/yr (12 Gt/yr of CO_2 or an increase of 0.4% per year)

Annual Increases in Carbon, Gt (for CO_2 multiply by 44/12)

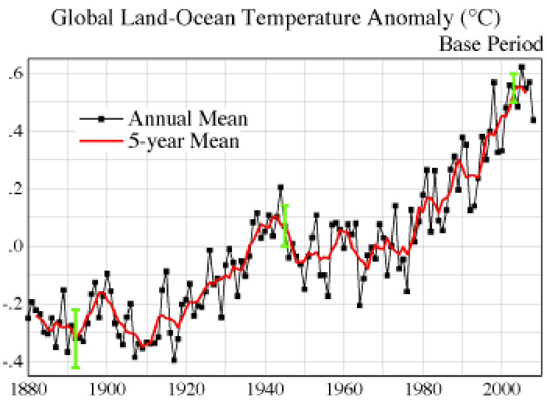
Atmosphere	Fossil Fuels	Changes in Land Use	Ocean Net Uptake	Missing Carbon Sink
3.2	6.3	2.2	-2.4	-2.9
±0.2	±0.4	±0.8	±0.7	±1.1

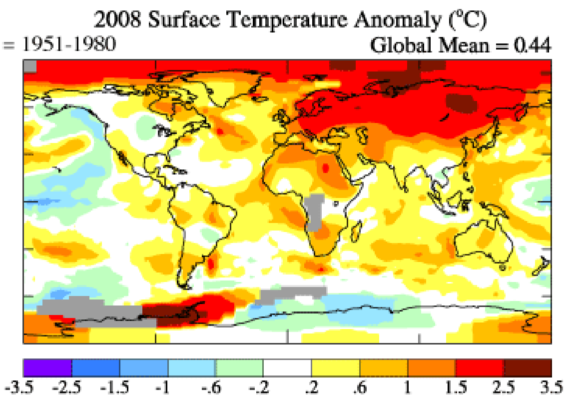
- The flow of carbon between the atmosphere and plants+soils is roughly 100 Gt/yr in both directions, the net effect being the result of a near cancellation. The contribution from decay is hotly debated.
- The flow of carbon between the atmosphere and the oceans is roughly 100 Gt/yr in both directions, the net effect being the result of a near cancellation.
- These observations show how hard it is to calculate the rate of increase of atmospheric CO_2 accurately, because it is the result of two delicate near-cancellations. However, we don't need to. It can be measured very accurately and is definitely increasing (see below).
- The "changes in land use" data in the above Table covers only human activity. For natural vegetation it is unknown whether photosynthesis is in balance with respiration/decay. This *could* be the missing carbon sink.
- Other possibilities for the missing carbon sink are the oceans via increased phytoplankton, or uptake by desert soils.
- Full grown forests are carbon neutral.
- Planting, or permitting, new forests provides a carbon sink. (Some sources claim that vigorous activity in this area could balance current fossil fuel burning).
- Some sources claim that tree biomass could be a net carbon sink due to the root systems left n the ground. (Usually biomass is claimed only to be carbon neutral). However, since the roots must rot this claim is suspect.
- Total carbon in the various sinks is as follows (for CO_2 multiply by 44/12):-

Sink	Gt of C	error
Atmosphere	745	±5
Surface of oceans	960	±60
Middle and deep oceans	36,000	±4,000
Vegetation	580	±30
Soil and detritus	1,390	±190
Coal and gas reserves	10,000	±?

- Mass of atmosphere is 5.2×10^{15} tonnes (1.8×10^{20} moles).

- Pre-industrial CO_2 concentration was ~280 ppm. Concentration increased from 315 ppm in 1958 to 385 ppm now (2009). (These ppm are by volume. Convert to ppm by mass of CO_2 by multiplying by 44/28.8, or to ppm by mass of C by multiplying by 12/28.8).
- Total world production of grains + cotton is 4.4 Gt/yr. Note that this is comparable with the net atmospheric carbon increase. This suggests that capture of the waste carbon (straw, chaff, etc), rather than allowing it to rot, could impact significantly on the rate of accumulation of CO_2 in the atmosphere. It has been suggested that the carbon could be captured by converting the waste to charcoal by low-oxygen combustion, followed by ploughing back into the soil.
- The habitability of the Earth results from the greenhouse effect, without which the average temperature would be perhaps -20°C or cooler. Whether there would be any regions with liquid water is unclear.
- The relative contributions of the various greenhouse gases is very uncertain (and made more so because their effect is not proportional to concentration) but a rough guide to within ±50% is,
    - Water vapour 64%
    - Carbon dioxide 22%
    - Methane 8%
    - Ozone 6%
- Atmospheric methane is increasing at ~1%/yr, and so it could have a comparable effect on temperature rise as CO_2 (which is increasing at ~0.4%).
- Direct observational evidence for global temperature increase:-





- Results of consensus climate change models for global average temperature increase,

IPCC 2007 Scenario	CO_2 ppm	Factor of increase in CO_2	ΔT (°C) IPCC 2007
Pre-industrial	280	0.73	-0.74
B1	600	1.55	1.8
A1B	850	2.20	2.8
A2	1250	3.25	3.6

The first line in the Table is a validation of the models, being comparable with the observations (Figure above).

- You can carry out a rough & ready climate change model yourself and confirm that doubling the CO_2 concentration leads to an increase in the average temperature of ~2°C. (See an example on this web site).
- Immediate cessation of all CO_2 production from burning fossil fuels would probably lead to an ***increase*** in temperature, of perhaps 2°C-3°C for the first few decades, due to the reduction in aerosol formation. Aerosols produced by burning fossil fuels currently provide a cooling effect of this magnitude. Eventually the CO_2 reduction would be beneficial, but only after several tens of years. We are, in effect, addicted to fossil fuel burning, and cannot stop suddenly. Not that this is likely.
- Atmosphere Facts:-
    - The troposphere (the weather region) extends to a height of 7 km at the poles and to 17 km at the equator. It contains 80% of the mass of the atmosphere;
    - 50% of the mass of the atmosphere is below (or above) 5.6 km;
    - The pressure decreases as $\exp\{-h/7.64\}$, where h is the height in km;
    - The lapse rate (decrease in temperature with height) is 6.5°C/km. This only applies in the troposphere. In the stratosphere the temperature levels off and then increases;
    - The layer of the atmosphere with an effective emissivity of unity (i.e. an optical depth of unity) is at a height of 6 km and a temperature of 254°K. This provides radiative heat balance with the incoming radiation from the Sun (assuming an albedo of ~0.3);
    - Global average surface temperature is perhaps ~14°C (though I have seen estimates up to ~20°C). This is an uncertain number and not terribly meaningful. The change in this average is far more accurately defined.

Effect on British/North Atlantic Climate: The Atlantic Conveyer

It is very difficult to judge the effect of global warming on the local climate. However, one threat of major climate change in Britain relates to the thermohaline circulation. Heat is transported from the equator polewards mostly by the atmosphere but also by ocean currents, with warm water near the surface and cold water at deeper levels. The best known segment of this circulation is the Gulf Stream, which transports warm water from the Caribbean northwards. A northwards branch of the Gulf Stream, the North Atlantic Drift, is part of the thermohaline circulation. This transports heat further north to the North Atlantic, where it contributes to warming Europe.

The evaporation of ocean water in the North Atlantic increases the salinity of the water as well as cooling it, both actions increasing the density of water at the surface. The formation of sea ice further increases the salinity. This dense water then sinks and the circulation stream continues at depth back in a southerly direction. Global warming could lead to an increase in freshwater in the northern oceans, by melting glaciers in Greenland and by increasing precipitation, especially through Siberian rivers. It is by no means clear that sufficient freshwater could be provided to interrupt thermohaline circulation. Climate models currently indicate not, but research continues. At the present time, however, we Brits need not panic about catastrophic climate change due to the shutdown of the Atlantic conveyer. This is fortunate. Given that Moscow and Glascow are at the same latitude, it would get very cold in Britain without the Atlantic conveyer.

Sea Level Rise and Melting Ice

- The current rate of rise of sea level is 3mm/yr based on satellite observations.
- Every year about 8mm of the oceans' surface falls on Greenland and Antarctica as snow. If these land ice sheets did not return ice to the oceans, the sea level would be *falling* by 8mm/yr (or, rather, a net fall of 8 - 3 = 5mm/yr). So those pictures you see of great chunks of ice falling off the ice shelves and into the sea should not (necessarily) be taken as a sign of anything abnormal. This is part of the normal water cycle.
- The arctic sea ice is melting more each year. The North-West Passage does now exist during part of the summer.
- The arctic sea ice will probably disappear completely in the summer months within about 20 years.
- In contrast, Antarctic sea ice is currently increasing, although there are substantial local differences between the east and west Antarctic. There is a net loss of ice from the west, but a greater gain currently in the east. This is believed to be due to the ozone hole, and hence is expected to reverse in ~10 years.
- Total melting of the Greenland ice sheet requires the global average temperature to increase by at least 3^{o}C (2007 IPCC report), and probably more like 6^{o}C (based on Bristol University research, 2009).
- Melting of the West Antarctica ice sheet requires a sea temperature rise of ~5^{o}C. Complete melting would cause sea level rise of up to 5m.
- However, the timescale for complete melting of the Greenland and Antarctic ice sheets is of the order of millennia.
- Therefore, some people have argued, the partial melting of the Greenland and Antarctic ice sheets will not contribute significantly to sea level rise by, say, 2100.
- But the complete melting of the Greenland ice sheet would raise sea level by ~6m, and complete melting of the Antarctic ice sheet by far more than that. So even a small proportion of this land ice melting be catastrophic.
- The level headed view (e.g. at the 2009 Copenhagen meeting) is an expected sea level rise by 2100 of about 0.8m. This corresponds to an average rise rate three times the current rate.
- Currently the most significant contribution of the Greenland and Antarctic land ice to rising sea level is not via melting but by calving of icebergs into the sea, thus displacing seawater.
- But the dominant cause of the *current* sea level rise is thermal expansion – because the seas are warming.
- Even by 2010 it is anticipated that thermal expansion will remain the dominant cause of sea level rise.

- Hence, the predicted acceleration in the rate of sea level rise is primarily a consequence of the predicted acceleration in global warming.

Ocean Acidification

Ocean acidification is an effect of rising concentrations of CO_2 in the atmosphere, and is not a direct consequence of global warming. The oceans soak up much of the CO_2 produced by living organisms, either as dissolved gas, or in the skeletons of tiny marine creatures that fall to the bottom to become chalk or limestone. Oceans currently absorb about one tonne of CO_2 per person per year. It is estimated that the oceans have absorbed around half of all CO_2 generated by human activities since 1800.

The increase in CO2 since the industrial revolution has already lowered the average pH of seawater by 0.1, to 8.2. Predicted emissions could lower the pH by a further 0.5 by 2100, to a level probably not seen for hundreds of millennia and, critically, at a rate of change probably 100 times greater than at any time over this period. There are concerns that increasing acidification could have a particularly detrimental effect on corals and other marine organisms with calcium carbonate shells. About 20% of the world's coral reefs have already died from bleaching caused by warm water. It is likely that a further large percentage will die as a result of the doubling of atmospheric CO_2 which is predicted by mid-century. This will have a major effect on the marine environment and biota in the affected areas. This could be exacerbated by the reduced amount of dissolved oxygen which is likely to accompany increased temperatures.

Global Temperature Positive Feedback Mechanisms

- Increasing temperatures will cause increased rates of evaporation and hence increasing atmospheric humidity. Since water vapour is a greenhouse gas this will cause accelerating warming.
- Higher temperatures lead to reduced ice coverage. Since ice is more reflective than other surfaces, reduced ice leads to a greater fraction of the sun's heat being adsorbed rather than reflected and hence a positive feedback mechanism.
- Reduced solubility of CO_2 at higher temperatures leads to release of dissolved CO_2 from the sea into the atmosphere – again a positive feedback mechanism.
- Methane release from melting permafrost peat bogs, e.g. in Western Siberia: The melting of its permafrost is likely to lead to the release, over decades, of large quantities of methane. As much as 70,000 million tonnes of methane, an extremely effective greenhouse gas, might be released over the next few decades, creating an additional source of greenhouse gas emissions
- Methane Clathrate is a form of water ice that contains a large amount of methane within its crystal structure. Extremely large deposits of methane clathrate have been found under sediments on the ocean floors. It has been postulated that rises in sea temperature could result in the sudden release of large amounts of methane from clathrate deposits (the "clathrate gun" hypothesis). This could cause a runaway greenhouse effect since methane is a much more powerful greenhouse gas than carbon dioxide
- Forest fires are likely to become more frequent in a hotter, drier climate, and hence also provide a source of increased carbon dioxide.

Global Temperature Negative Feedback Mechanisms

- The increased temperatures lead to increased rates of evaporation and higher humidity. This will lead to a higher fraction of cloud cover. Hence the Earth's albedo will increase, i.e., more of the Sun's energy will be reflected rather than transmitted to ground level. This is a cooling effect and hence provides negative feedback.
- Fossil fuel burning creates aerosols in the upper atmosphere. These aerosols increase the albedo and hence provide a cooling mechanism. It is estimated that the current aerosol concentration might account for 2^oC-3^oC of cooling. Strictly, this is not a negative feedback mechanism of warming itself, but a cooling effect of fossil fuel burning.
- The most significant negative feedback mechanism is the effect on the humans. The human population is likely to reduce significantly, perhaps to only one or two billion (although the most severe scenarios would suggest the human species could be threatened with extinction). Since humans are responsible for the increase in atmospheric CO_2 which is the cause of global warming, this will have a beneficial effect on reducing its rate of increase. Moreover, it is likely that the survivors will have an improved attitude towards husbanding the Earth.

Implications of the Expected Rise in Temperature over the 21st Century

This Section has been deleted because I no longer regard what I wrote in 2009 as sufficiently well founded. In truth I don't think we know what the effect of 2^oC or 4^oC global mean temperature increase would be.