Environmental Studies
FACT SHEET
www.curriculum-press.co.uk Number 072

The Science of Climate Change

This Factsheet provides a comprehension exercise on the science of climate change. It is based upon the Executive Summary of the Stern Report, published in December 2006.

Overwhelming scientific evidence now clearly indicates that the Earth's climate is rapidly changing, mainly as a result of increases in greenhouse gases caused by human activities. The irony is that the greenhouse effect is a natural process that keeps the Earth's surface around 30°C warmer than it would be otherwise. Without this effect, the Earth would be too cold to support life.

However, since pre-industrial times (around 1750), carbon dioxide concentrations have increased by just over one third from 280 parts per million (ppm) to 380 ppm today, predominantly as a result of burning fossil fuels, deforestation, and other changes in land-use. This has been accompanied by rising concentrations of other greenhouse gases, particularly methane and nitrous oxide.

In total, the warming effect due to all (Kyoto) greenhouse gases emitted by human activities is now equivalent to around 430 ppm of carbon dioxide (CO_2e) and rising at around 2.3 ppm per year. Current levels of greenhouse gases are higher now than at any time in at least the past 650,000 years.

Fig 1 shows the warming effect of greenhouse gases (the 'radiative forcing') in terms of the equivalent concentration of carbon dioxide (a quantity known as the CO_2 equivalent). The (dashed) line shows the value for carbon dioxide only. The (solid) line is the value for the six Kyoto greenhouse gases (carbon dioxide, methane, nitrous oxide, PFCs, HFCs and SF_6) and the (x-x) line includes CFCs (regulated under the Montreal Protocol).

The uncertainty on each of these is up to 10%. The rate of annual increase in greenhouse gas levels is variable year-on-year, but is increasing.

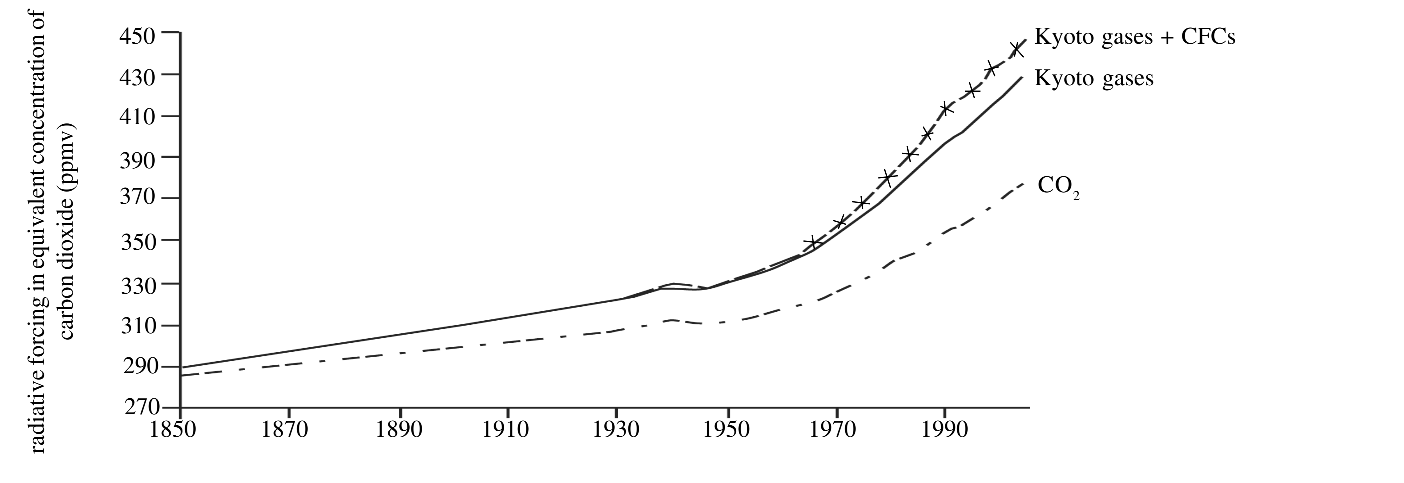
Most climate models show that a doubling of pre-industrial levels of greenhouse gases will increase the amount of infrared radiation (heat energy) trapped by the atmosphere resulting in a rise of between 2 – 5°C in global mean temperatures. This level of greenhouse gases will probably be reached between 2030 and 2060.

A warming of 5°C on a global scale would be far outside the experience of human civilisation and comparable to the difference between temperatures during the last ice age and today. Several studies suggest up to a 20% chance that warming could be greater than 5°C.

If greenhouse gas emissions remained at the current level, concentrations would be more than treble pre-industrial levels by 2100, committing the world to 3 – 10°C warming, based on the latest climate projections. Analysis of warming events in the past indicates that some impacts of climate change itself may amplify warming further by triggering the release of additional greenhouse gases.

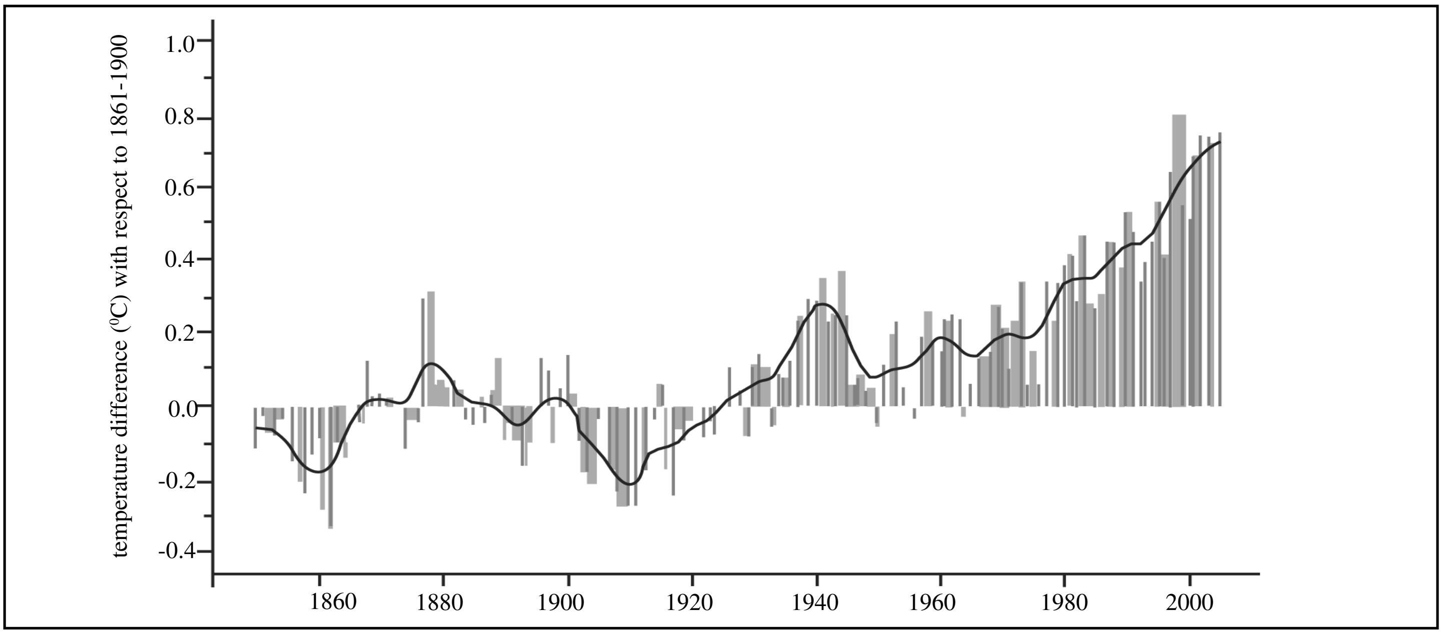
This creates a real risk of even higher temperature changes. The main positive feedback comes from water vapour, a very powerful greenhouse gas. Evidence shows that, as expected from basic physics, a warmer atmosphere holds more water vapour and traps more heat, amplifying the initial warming.

Fig 1. Warming effect of greenhouse gases



The Earth has warmed by 0.7°C since around 1900 (Fig 2). This is an average figure over both space (globally across the land-surface air, up to about 1.5 m above the ground, and sea-surface temperature to around 1 m depth) and time. This warming does not occur evenly across the planet.

Fig 2. Global average near-surface temperatures 1850-2005



Over the past 30 years, global temperatures have risen rapidly and continuously at around 0.2°C per decade. All of the ten warmest years on record have occurred since 1990.

The first signs of changes can be seen in many physical and biological systems. For example many species have been moving poleward by 6 km on average each decade for the past 30 – 40 years. Another sign is changing seasonal events, such as flowering and egg - laying, which have been occurring 2 – 3 days earlier each decade in many Northern Hemisphere temperate regions.

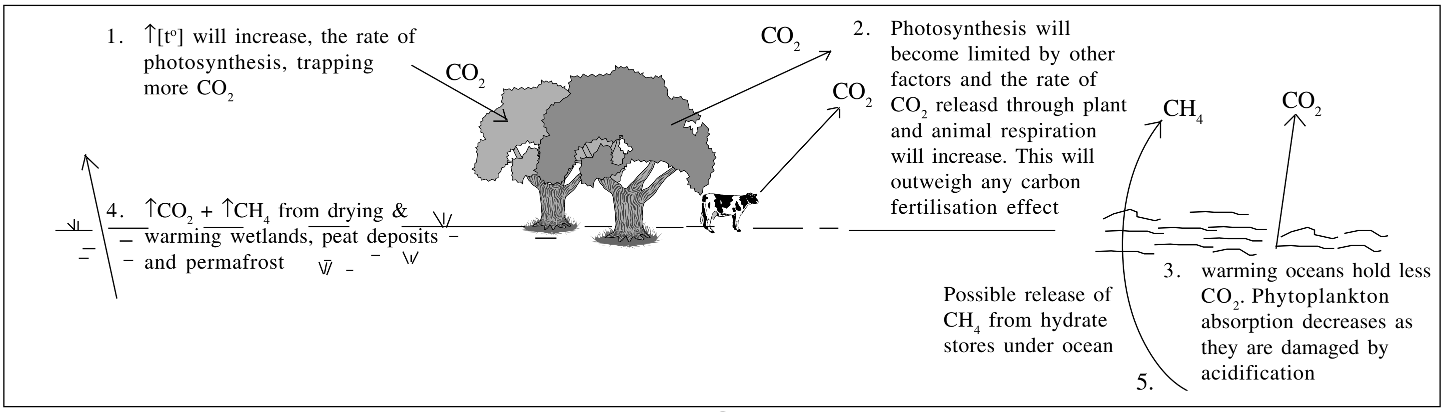
Widespread thawing of permafrost regions is likely to add to the extra warming caused by weakening of carbon sinks. Large quantities of methane (and carbon dioxide) could be released from the thawing of permafrost and frozen peat bogs. Together, wetlands and frozen lands store more carbon than has been released already by human activities since industrialisation began. Substantial thawing of permafrost has already begun in some areas; methane emissions have increased by 60% in northern Siberia since the mid-1970s. Studies of the overall scale and timing of future releases are scarce, but initial estimates suggest that methane emissions (currently 15% of all emissions in terms of CO_2 equivalent) may increase by around 50% by 2100.

Fig 3 summarises the expected effect of warmer temperatures on key greenhouse gas sinks.

Warming is very likely to intensify the water cycle, reinforcing existing patterns of water scarcity and abundance and increasing the risk of droughts and floods.
Rainfall is likely to increase at high latitudes, while regions with Mediterranean-like climates in both hemispheres will experience significant reductions in rainfall. Preliminary estimates suggest that the fraction of land area in extreme drought at any one time will increase from 1% to 30% by the end of this century. In other regions, warmer air and warmer oceans are likely to drive more intense storms, particularly hurricanes and typhoons.

As the world warms, the risk of abrupt and large-scale changes in the climate system will rise. Changes in the distribution of heat around the world are likely to disrupt ocean and atmospheric circulations, leading to large and possibly abrupt shifts in regional weather patterns. If the Greenland or West Antarctic Ice Sheets began to melt irreversibly, the rate of sea level rise could more than double, committing the world to an eventual sea level rise of 5 – 12 m over several centuries.

Fig 3. The effect of warming on greenhouse gas sinks



Practice Questions

(a) Explain how the natural greenhouse effect keeps the earth 30°C warmer than it would otherwise be. (4)

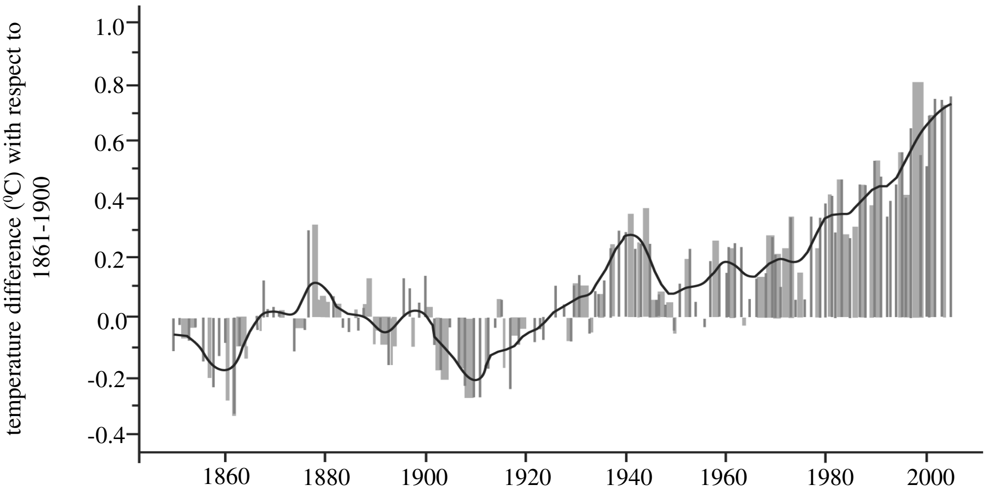
(b) Outline how human activities have increased the concentration of greenhouse gases in the atmosphere. (4)

(c) What evidence is there that increasing atmospheric concentrations of carbon dioxide are in fact due to human activity and not natural causes? (2)

(d) Explain why it is useful to convert the concentration of all greenhouse gases into carbon dioxide equivalents (1)

(e) Outline one:
(i) negative feedback effect that may result from increased average global temperature;
(ii) positive feedback effect that may result from increased average global temperature; (6)

(f) The graph shows global average near-surface temperatures 1850 – 2005.



Explain why, for many years, some scientists used this type of data to argue **against the idea** that global climate change was really happening. (3)

Answers

(a) atmosphere transparent to incoming/shortwave radiation;
Radiation warms land surface;
Land surface emits infra red radiation;
some of which is trapped by carbon dioxide/water vapour etc;
Converted to heat/idea of warming; Max 4

(b) Fossil fuel combustion;
Ploughing soils;
Deforestation;
Reduction of vegetation/named land use change;
Creation/release of CFCs; Max 4

(c) Analysis of gases/isotopes trapped in ice cores/ sediments/ corals;
show that carbon dioxide concentrations have fluctuated over thousands of years;
but current levels not matched to any other known cause;
solar intensity/volcanic eruptions cannot explain upturn in 20th century;
emissions since industrial revolution can be seen in trapped gases/tree ring data; Max 2

(d) different gases exert different radiative forcing effects/ are not equally powerful greenhouse gases/ allows easier quantification of warming effect/ allows easier representation in graphs etc;

(e) (i) increased temperature increases rate of photosynthesis;
so more carbon dioxide absorbed;
temperature decreases;

(ii) increased temperature leads to warmer oceans;
solubility of gases decreases as temperature increases so more carbon dioxide released/less absorbed;
temperatures increase further;
or

increased temperatures increase evaporation;
increased water vapour in atmosphere;
a greenhouse gas;

(d) relatively short time period shown;
hockey-stick effect may be within natural variability;
some years show lower than average temperatures;
average figures of air and water may be unreliable; Max 3

Acknowledgments: This Factsheet was researched and written by Kevin Byrne. *Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU*
Environmental Science Factsheets may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. **ISSN 1351-5136**