Global climate change

Activity:
This is not an activity in itself. We have simply provided references to existing resources, with brief summaries of them. Teachers may wish to use these resources to amplify or to balance the materials which they have located elsewhere, or which feature in the standard student textbooks. Research into the topic is happening so quickly that teachers will do well to use the most recent resources, abstracted from the internet.

Student Learning Outcomes:
Students will be able to:

- explain that the topic is complex and that there is considerable controversy about the interpretation of data;
- explain that the best way to obtain up to date information about this fast-moving topic is to use the media and websites.

Student practical or teacher demonstration:
Background notes for teachers

Resources:
See the accompanying sheets.

Ideas for leading into the activity:
Show students *The E-Carbon PowerPoint* © presentation, to help them to realise the many ramifications of the carbon cycle, and particularly to note the importance of the lithosphere as a sink for carbon, which is frequently omitted in simple versions of the cycle.

Ideas for following up the activity:
Use the activity *A year in the dome* to establish ideas of balance in the carbon cycle.

Use the practical activity *Melting ice and sea level change* to enable students to appreciate the science behind this topic and to realise that media reports of the effects of melting ice are sometimes in error.

Source of activity:
Earth Science Education Unit.

Resources on global climate change for teachers

Widespread public awareness of global warming is a relatively recent thing. During the teaching careers of the authors of this activity, the emphasis has changed from discussing the probability that the world was heading towards another ice age to the exact opposite. The concern about resources of oil, natural gas and coal was that they would run out within a few decades (in the context of the decline of industry unless resources were conserved), and not because of any warming effect that their combustion might be having.

By the very nature of their education, geologists tend to take the long term view and would point out that the world has seen many periods of heating and cooling, long before humans appeared on the scene. Thus any measurable global warming that was detected might be natural. For this reason some geologists were slow to believe that human activity could be having any appreciable effect. A key piece of scientific information that triggered a change in view of many geologists was the publication of the 'hockey stick graph' in 1999, since updated several times (as shown below). Geologists have now realised that the events of the past can be used to model climate change in an attempt to predict the future. This forms an interesting variant on Lyell's dictum, (in the 19th Century), that "the present is the key to the past", as scientists now attempt to use the idea that 'the past is the key to the future'.

The economic, environmental, social and political implications of global warming are profound, and this has encouraged the sceptics to attempt to deny that emissions of greenhouse gases are having any effect on world climates, realising that attempts to reduce greenhouse gas emissions will be costly.

In an effort to clarify the science, in order to aid the world's political leaders in their decisions, the United Nations set up the Intergovernmental Panel on Climate Change, composed of scientists from many nations. The Panel has produced a series of reports, the latest of which (the 4th) appeared in February 2007 and is summarised below.

A former Co-Chairman of the IPCC, Sir John Houghton, has written an influential book on the subject, which was updated again after the 4th Report and is also summarised here.

The 4th report of the IPCC attracted much publicity and prompted considerable debate in the media. It was followed on 8th March 2007 by a programme on Channel 4, entitled *The Great Global Warming Swindle*. This purported to show that changes in temperature are due mainly to variations in solar radiation, and are not connected to greenhouse gas emissions.

The programme succeeded in confusing the general public, most of whom do not know enough science to be able to evaluate the evidence. A flurry of correspondence ensued. Some of this is also outlined below. (Channel 4 was subsequently reported as distancing itself from the makers of the programme, WAG TV).

There is clearly much scope here for teaching "scientific literacy" and for examining the influences that may impact on the work of scientists as well as the ways that the work of scientists impacts on others!

The' hockey stick' graph' of reconstructions of Northern Hemisphere temperatures for the last 600 or 1,000 years. The name comes from the similarity of the shape of the graph to an ice hockey stick lying on its back.

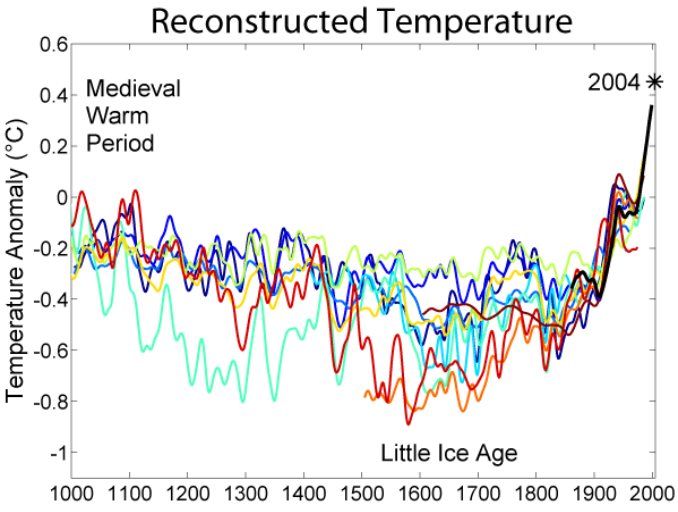

Image by Global Warming Art, http://en.wikipedia.org/wiki/File:1000_Year_Temperature_Comparison.png

1. The U.N. Intergovernmental Panel on Climate Change (I.P.C.C.)

Climate change 2007: The Physical Science Basis. Summary for Policymakers
The above part of the Fourth Assessment Report of the IPCC appeared in February 2007 and is available at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-introduction.html

Some of the main findings of the Report (quoted verbatim) are:

Human and natural drivers of climate change

- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.

- The understanding of anthropogenic (i.e. of human origin) warming and cooling influences on climate has improved since the Third Assessment Report, leading to *very high confidence* that the globally averaged net effect of human activities since 1750 has been one of warming… ("*Very high confidence*" is defined by the IPCC as a 90% chance that human influence is responsible for the underlying science being correct).

Direct observations of recent climate change

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global air and ocean temperature, widespread melting of snow and ice, and rising global mean sea level.
- Numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather, including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.
- However some aspects of climate have not been observed to change. These include Antarctic sea ice, which shows considerable variation in extent from year to year, but no statistically significant trends.

A palaeoclimatic perspective

- Palaeoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time that the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise.

Understanding and attributing climate change

- Most of the observed increase in globally averaged temperatures since the mid-20th Century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. (>90% probable, up from >66% in the previous Report).
- Analysis of climate models, together with constraints from observations, enables an assessed likely range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing.

Predictions of future changes in climate

- For the next two decades a warming of about 0.2^{o}C per decade is projected for a range of SRES emission scenarios…. (SRES = IPCC Special Report on Emission Scenarios, 2000. These provide calculations for different scenarios of world population and industrial activity etc and are summarised on page 14 of the 2007 Report).
- Continued greenhouse gas emissions at or above current rates would cause further warming and would induce many changes in the global climate system during the 21st Century that would *very likely* be larger than those observed during the 20th century.
- There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice.
- Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilised.

Further notes:

- Please refer to Figure SPM-2 on page 16 of the IPCC Report .
  This diagram shows that many anthropogenic influences can add to positive radiative forcing (the difference between incoming and outgoing radiation), but that others have a negative effect. Thus rising concentrations of carbon dioxide and methane add to positive radiative forcing, but aerosols such as sulfates subtract from it. Ironically, sulfates are discharged from power station chimneys as well as carbon dioxide, but the installation of scrubbers in recent years has reduced the output of sulfates.

- Please refer to Table SPM-1 on page 5 of the IPCC Report. The table shows that the observed rate of global sea level rise has increased from 1.8 $\pm$ 0.5mm per year between 1963 and 2003 to 3.1$\pm$ 0.7mm per year between 1993 and 2003. This is likely to be due to the melting of continental ice and the expansion of warming ocean waters. It is, however, uncertain as to whether this is variability on a 10-year scale or an increase in the long tem trend.

- Making predictions about future average global warming and sea level rise depends upon the scenario used in calculating the model. Figure 1 below shows calculated rises in average global warming and sea level, by the end of the 21st Century, for seven of the IPCC's scenarios (see the Report page 14 for details of these).

	Temperature change (^{o}C at 2090 - 2099 relative to 1980 - 1999)		Sea level rise (m at 2090 - 2099 relative to 1980 - 1999)
Case	Best estimate	Likely range	Model-based range*
Constant year 2000 concentrations	0.6	0.3 – 0.9	N/A
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1F1 scenario	4.0	2.4 – 6.4	0.26 – 0.59

Figure 1. Average surface warming and sea level rise at the end of the 21st Century for different model cases, projected globally (based on Table SPM-2, page 11 of the IPCC Report)

*But note that this takes no account of rapid dynamical changes in ice flow on the continents (The British Antarctic Survey is convinced that this should be allowed for, resulting in an increase in sea level of up to one metre by 2100). This also takes no account of uncertainties in carbon cycle feedbacks, because the IPCC argues that there is insufficient published literature on this feedback cycle.

Ice core data from Antarctica have played a major part in understanding the relationship between former temperatures and the concentration of greenhouse gases.

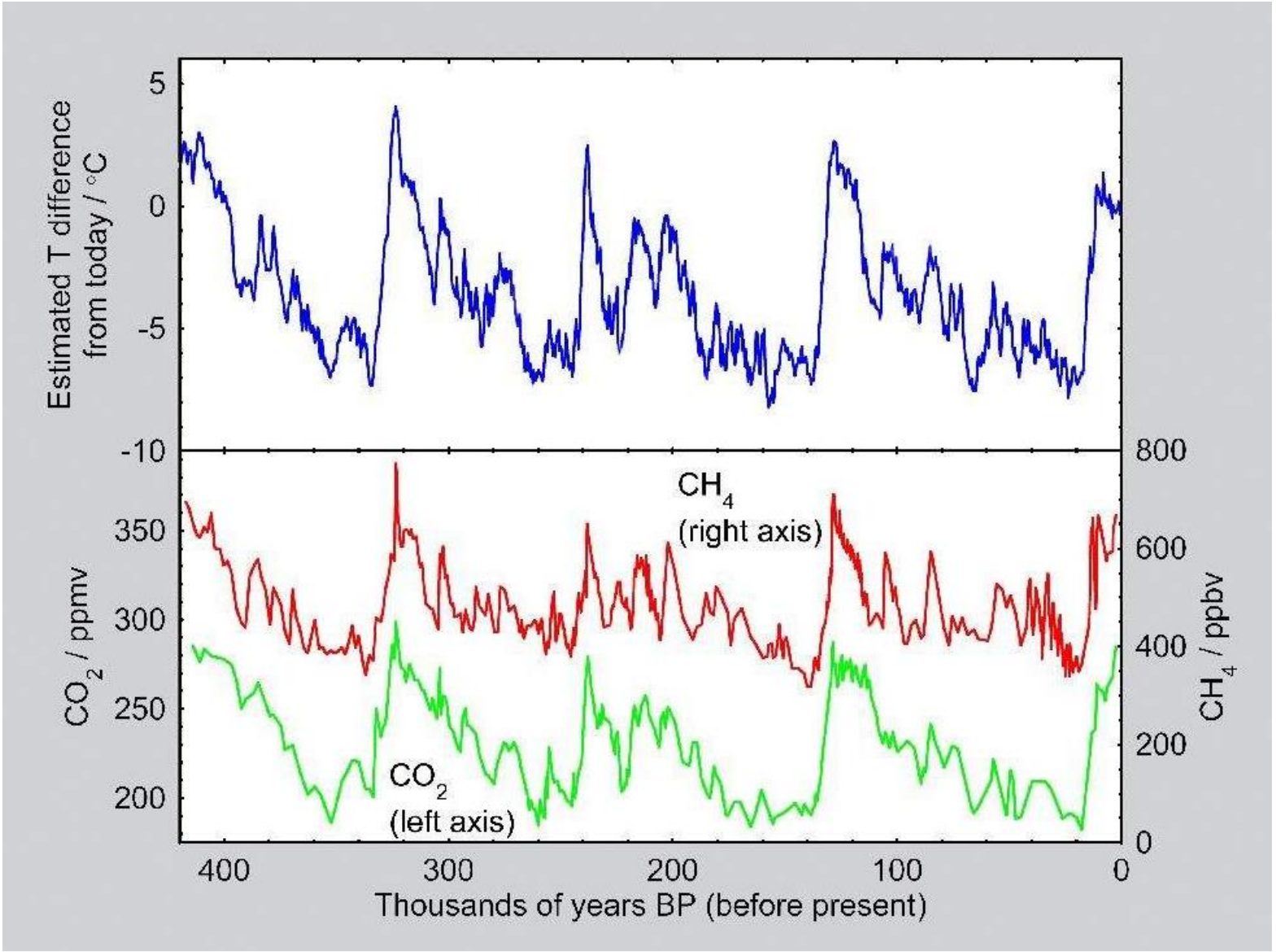

Figure 2. The correlation between ancient temperatures and the concentrations of carbon dioxide and methane in ice cores from East Antarctica (By kind permission of the British Antarctic Survey).

2. *Global Warming: the complete briefing*, a book by Sir John Houghton, 4th edition, 2009, Cambridge University Press, ISBN 978-0-521-70916-3.

Sir John Houghton is a former Director of the Meteorological Office and a former Co-Chairman of the IPCC. His book was updated shortly after the appearance of the IPCC 4th Report. The book states that "Illustrations are available on line". Cambridge University Press state that these are accessible to purchasers of the book as follows: "http://www.cambridge.org/gb/knowledge/isbn/item2327011/?site_locale=en_GB

You need to create an account, following the instructions there, so you can be authenticated as a lecturer. Please follow the procedure on the webpage so the web team can grant you access to the locked end-of-chapter answers."

The following notes are an attempt to summarise each of the main chapters.

1. General introduction:
The 1960s were colder than average, so a return to an ice age was more discussed than global warming.
The eruption of Mt Pinatubo 1991 released 20 Mtonnes of sulfur dioxide (SO_2) into the stratosphere, which lowered temperatures by 0.25^{o}C in 1992/3.
It is estimated that global temperatures would rise by 3^{o}C per century (unless we curb emissions). NB There is only a 5-6^{o} difference in mean world temperatures between an ice age and an interglacial!

2. Greenhouse effect:
Carbon dioxide etc absorbs radiation from the Sun that has been re-emitted from Earth.
However, the greenhouse effect is essential – the average temperature of the Earth would be -6^{o}C without it. The average world temperature today is +15^{o}C.

3. Greenhouse gases:
The following have a positive radiative forcing effect: carbon dioxide, methane; nitrous oxide, chlorofluorocarbons (CFCs), ozone etc. (Also water vapour, but this is balanced by natural processes, so is not counted).
Factors providing a negative forcing include sulfates, particles in the atmospheres from human activity and land use albedo (changes in land use, which increase the reflectivity of the Earth's surface).

4. Climates of the past:
Data are obtained from: instrumental measurements; historical records; ice cores; tree rings; corals; use of $^{16}O/^{18}O$ ratios in ocean floor microfossils.
James Croll and then Milutin Milankovitch predicted that variations in global temperatures were based on variations in three factors: the eccentricity of Earth's orbit (periodicity of 100 thousand years (100kA)); the orientation of the Earth's spin axis between 21.6^{o} and 24.5^{o} (periodicity of 41kA,); the longitude of the perihelion i.e. the time of year when Earth is closest to the Sun (periodicity of 23kA). The beginning of the next ice age, according to these variations, is predicted in about 50000 years (this is longer than usual, because of relatively small solar radiation variations this time round. Note that the text on page 87 gives 50kA, but the Summary on page 91 gives at "least 30kA").
Milankovitch published in the early 1940s but his hypothesis could not be tested until the 1970s, when deep-sea drilling enabled the recovery of dateable cores of sediment, where variations in global ice cover could be calculated from ratios of ^{16}O and ^{18}O in microfossils. The current observed rate of rise in global average temperatures cannot be explained by Milankovitch theory alone.

5. Modelling the climate:
Houghton emphasises that there is a need to model climatic changes over the globe and not just world average temperatures. Huge computing capacity is needed, which has only become available in recent years. Models match actual changes quite well, including the influence of El Nino events and volcanic eruptions, giving more confidence for future predictions. "The modelling of cloud feedback processes remains the source of the largest uncertainty".

6. Climate change in the 21st Century and beyond:

The *Special Report on Emission Scenarios,* IPCC, 2000 (p117) gives 35 scenarios, in four different "story lines" – A1, A2; B1, B2. Also story line IS92 (from 1992 = "business as usual")

"The increase in greenhouse gases is by far the largest of the factors that can lead to climate change in the 21st Century.

The rate of change is likely to be larger than any seen by Earth in past 10000 years.

The greatest impact will be on the frequency, intensity, and location of climatic extremes, especially droughts and floods.

There is enough fossil fuel to keep increasing the burning rate throughout the 21st Century.

7. The impacts of climate change:

- Sea level rise is due to thermal expansion of water as well as the melting of ice caps.
- Gas hydrates (frozen deposits of a methane/water compound trapped in oceanic sediments) could be released, emitting methane (a powerful greenhouse gas).
- Ocean currents would change in speed and direction, with major effects on climate.
  The following could all occur: more extremes of weather; flood; drought; water shortage; soil erosion; large scale migration, e.g. as the delta of the Ganges/Brahmaputra river floods; malaria in the UK, etc. Lord Stern's Review, "The economics of climate change", Cambridge University Press, 2007, has endeavoured to estimate the economic impact of climate change and to assess the significance of regional variations across the world.

8. Why should we be concerned?

- Humans have special responsibility and are stewards of Earth (Houghton is unusual for a science writer in presenting human responsibility for the world in a spiritual perspective, referring to the standpoint of the world's major faiths).
- It is wrong to harm the environment.
- We should have shared values and take responsibility for one another.
- "Humility before the facts" Thomas Huxley.
- Politicians leave problems to the next lot!
- Houghton refers to James Lovelock's Gaia Theory (this indicates that the Earth has self- balancing effects due to the life on Earth, rather like homeostasis in the body).

9. Weighing the uncertainty:

Houghton lists the IPCC's reasons for uncertainty – concerned with sources and sinks of greenhouse gases, clouds, oceans and ice sheets. The four IPCC Assessments (1990, 1995, 2001 and 2007) have provided increasingly accurate and detailed information about the climate change occurring now and likely future changes. The 3rd and 4th IPCC Assessments have refined the presentation of uncertainty in terms of statistical probability, e.g. the term *very likely* indicates a 90% probability of any predicted outcome.

10. Strategy for action to slow and stabilise climate change:

The Montreal Protocol 1987, required replacement for CFCs (this has already reduced the hole in the ozone layer).

The Rio Summit in 1992 paved the way for cooperation between nations on environmental issues, and established the principle that the polluter pays.

Kyoto 1997 – most (but not all) delegate countries agreed to stabilise emissions, to liaise with others to develop clean technology, and to trade emissions. The Protocol was largely ratified and came into force in 2005, agreeing that CO_2 emissions should be 5% below 1990 levels by the year 2012. Many experts argue for a target of no more than a 2^oC rise in world average temperatures compared to pre-industrial levels.

11. Energy and transport for the future

The main approaches suggested include improving energy efficiency; developing renewable energy sources; continuing with electricity from nuclear fission, whilst actively researching nuclear fusion as a possible future source of energy.

Technology should be shared between countries.

Carbon dioxide emissions could be stored underground, a process known as carbon capture and storage (CCS), or sequestration. Houghton states, "...carbon capture and storage (CCS) must be installed aggressively and urgently in new power stations and retrofitted where possible in existing stations" p383. Page 327 shows a photograph of the Sleipner Gas Platform T, in the Norwegian sector of the North Sea, where one million tonnes of carbon dioxide are currently being sequestered annually.

12. The global village:
Global warming must be put into the wider context of global pollution, sustainability and population growth. All sections of the community are challenged - scientists, technologists, politicians, economists, educators, aid agencies, individuals – all are responsible. Page 401 lists the things that individuals can do. (School pupils are often fired up with the desire to save the planet, but how do you persuade them to turn off the lights in their bedrooms when they are unoccupied?! PK).

Edmund Burke, (early 19th Century) said, "No-one made a greater mistake than he who did nothing because he could do so little".

3. The great global warming swindle (WAG TV for Channel 4, 8th March 2007) and the response from the mainstream

We have not attempted to obtain a transcript of the programme, but the main topics may be judged from the responses posted on the web by mainstream scientists and the media at the time.

http://www.antarctica.ac.uk/about_bas/news/news_story.php?id=178

http://www.monbiot.com/archives/2007/03/13/channel-4s-problem-with-science/

http://www.belfasttelegraph.co.uk/features/daily-features/article2715156.ece

Some of the assertions in the TV programme are claimed to be untrue: others give some of the science but not all of it, e.g. the role of sulfate aerosols in reducing temperature rise is not mentioned: temperature fluctuations are mainly quoted for the U.K., yet this is not typical of the world as a whole, etc.

Perhaps the most difficult data to interpret objectively are the ice core results. The graph from the British Antarctic Survey shown above demonstrates an astounding correlation between palaeotemperatures and levels of carbon dioxide and methane trapped in the ice. However, as shown in the TV programme, when examined on a larger scale graph, the rise of temperature seems to precede the rise in levels of greenhouse gases by several decades.
This is accepted by the mainstream scientists. To quote from the DEFRA website, "It is true that temperature changes appear to have preceded CO_2 changes through glacial-interglacial cycles in the distant past. However, this just suggests that CO_2 was not the initial driver of the glacial cycles. The evidence suggests that CO_2 levels rose as a result of warming, possibly as the surface of the ocean warmed. As CO_2 has a warming effect on the climate, it would then act as a feedback – stimulating additional warming. Now human emissions are causing the rise in CO_2 levels, and therefore, the resulting warming of the climate".

4. Correspondence

- Some of the confusion engendered in the general public may be judged from the following letter, published in the free Metro newspaper on 20th March 2007:

"Am I the only person who watched The Great Global Warming Swindle on Channel 4? It produced convincing evidence that humans are not the cause of global warming, yet people still think changes to our lifestyles will halt it. As the biggest culprits are the oceans, volcanoes and rotting vegetation, there is no point in altering our lifestyles. Temperatures have always fluctuated. The Thames regularly froze over 200 years ago. During the Medieval Warm Period, Britain was as hot as Spain. Why did this happen? I'm pretty sure it wasn't the fault of gas-guzzling 4x4s.
Sam Gardiner, Manchester."

- In May 2007, many mainstream scientists appealed for the withdrawal of plans to publish the Channel 4 programme as a DVD. Quoted in the Baptist Times (May 4th 2007), Sir John Houghton said, "I don't want to stifle proper scientific discussion and debate, but the public expects standards of honesty and truth, which this programme blatantly broke. The material that was presented was clearly doctored to lead to the conclusions they wanted."

5. Ongoing research and actions

This continues apace, and teachers should keep up to date through the scientific literature and the media, sometimes in obscure places! Examples include:

- "An increase in winds over the Southern Ocean, caused by greenhouse gases and ozone depletion, has led to a release of stored carbon dioxide into the atmosphere, and is preventing further absorption of the greenhouse gas. The Earth's carbon sinks – of which the Southern Ocean accounts for 15% - absorb about half of all human carbon emissions. With the Southern Ocean reaching its saturation point, more CO_2 will stay in our atmosphere". (Corinne Le Quere of UEA and the British Antarctic Survey, published in *Science* May 2007 and quoted in the Falkland Islands' Penguin News).
- It has been demonstrated recently that solar radiation has decreased in recent years, yet temperatures have continued to rise. This implies that temperature is not dependent on solar radiation alone as claimed by the Channel 4 programme. **(**BBC Today programme, 11th July 2007).
- BBC Radio 4 reported in May 2011 that Brazil and Indonesia?? had agreed to reduce rates of deforestation, to help slow the rate of global warming.
- In his blog of 21st May 2011, (http://www.bbc.co.uk/blogs/paulhudson/) Paul Hudson, a BBC weather forecaster, drew attention to an academic paper published in April/May 2011 by Dr James Hansen ("a passionate advocate of man-made global warming"). Hansen felt that the influence of aerosols of human origin has not been sufficiently taken into account by the IPCC. Aerosols generally lower global temperatures (e.g. following the eruption of Mt Pinatubo). Thus it could be argued that the IPCC had overestimated global temperature rise in its Reports. However, Hudson states that "IPCC models could be at the same time understating global warming because they may overestimate ocean heat uptake. Combined, the result could be that these two model errors largely cancel each other out - and when treated together, and not in isolation, the overall impact could be neutral, and so IPCC projections would not as a consequence of these two model errors be too high". See the following for Hansen's complete paper: http://www.columbia.edu/~jeh1/mailings/2011/20110415_EnergyImbalancePaper.pdf
- In a Shell Lecture at the Geological Society on 15th June 2011, it was stated that, "The British Government predicts that Carbon Capture and Storage could become an industry the size of present day North Sea oil and be worth £2-4 billion a year by 2030, sustaining 50,000 jobs", so it's not all bad news!

Conclusion – Watch this space!