GLOBAL WARMING: IS IT REAL? DOES IT MATTER?

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Abstract – Global warming and climate change are topics that are regularly covered in the media. However, there are varying opinions on what has caused the observed global warming and whether it is important. Using the latest international assessment of climate change, these questions are answered. This issue can be used to stimulate students' interest in mathematics. Some applications of simple mathematics to this issue are illustrated and a wide range of on-line material, suitable for classroom use, is described.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme because of the considerable government and public interest in climate change and its possible impacts. Its objective was to undertake assessments of the science of climate change, its impacts, and approaches to mitigate and adapt to climate change. The IPCC First Assessment Report was completed in 1990 (IPCC, 1990), its Second Assessment Report in 1995 (IPCC, 1996) and its Third Assessment Report was completed last year (IPCC, 2001).

There has been considerable media attention on global warming, its possible causes, and the chances of significant climate change in the future. This has probably occurred for a number of reasons, including the potential significant impacts on society, the possible very high costs associated with mitigating climate change by reducing fossil fuel use, but also because some scientists have argued that the observed climate variations are just due to natural causes.

In the next section, a brief summary is presented of the scientific assessment of climate change recently completed by the IPCC (IPCC, 2001). Given the considerable public interest in climate change, some ways that this issue can be used in the classroom to demonstrate some simple mathematical concepts are described in the final section. In addition, several helpful web sites and on-line resources are described.

The IPCC Scientific Assessment of Climate Change

The following summary is heavily based on the *Summary for Policymakers* from IPCC (2001). This report is available on the web (HREF1). Quotation marks are not used in the text below, but much of it is taken verbatim from IPCC (2001).

Observations show that the Earth's surface is warming

The global average surface temperature has increased over the 20^{th} century by about 0.6°C, as shown in Figure 1. Air temperatures over land and sea surface temperatures have increased in both hemispheres. There has been widespread retreat of mountain glaciers, increase in global ocean heat content, and reduction in Northern Hemisphere snow cover and ice extent. Globally, the 1990s are very likely the warmest decade in the instrumental record. New analyses of data from tree rings, corals, ice cores and historical records indicate that the increase in temperature in the 20^{th} century is likely to have been the largest of any century during the past 1,000 years, at least for the Northern Hemisphere.

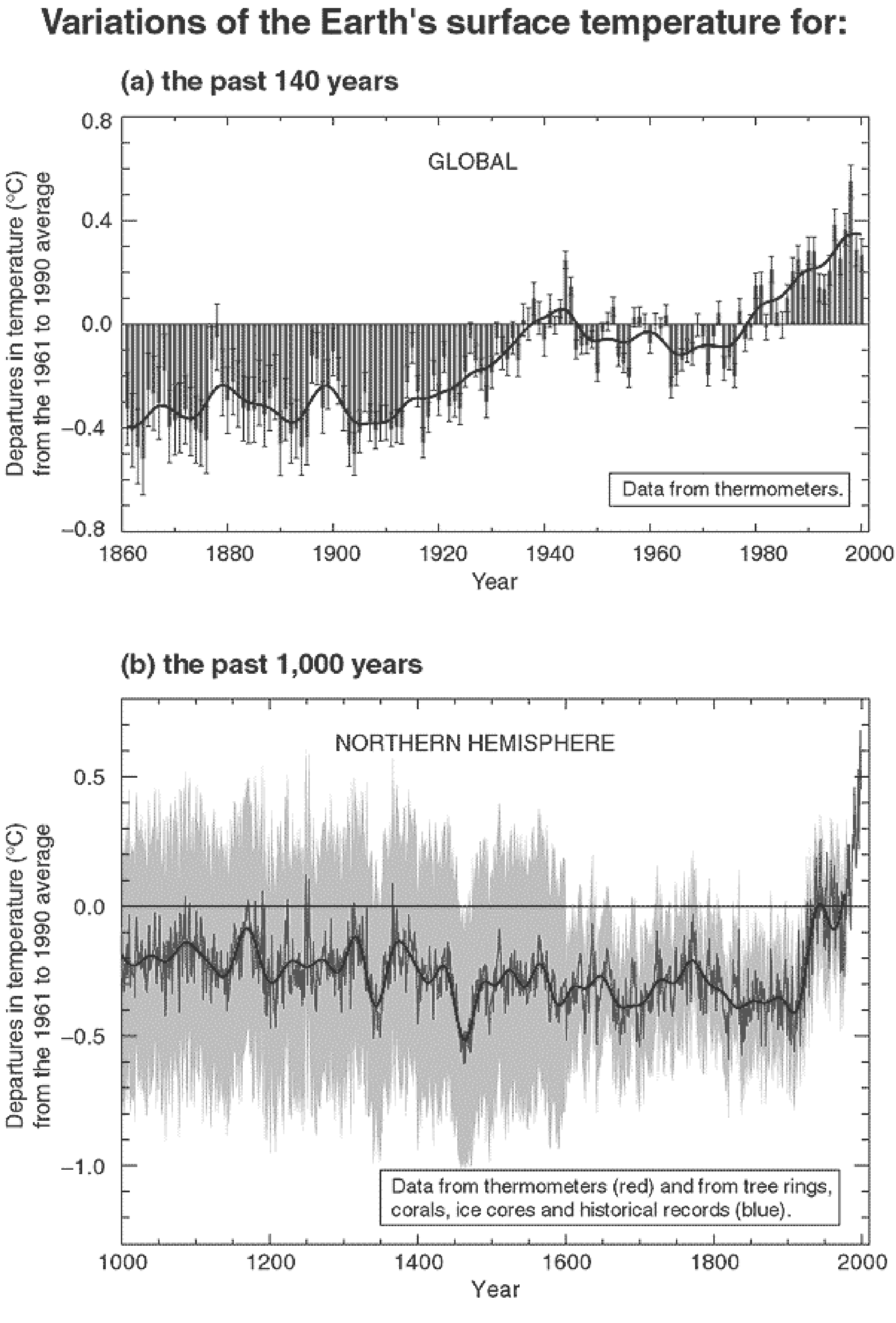

Figure 1. *Variations of the Earth's temperature over the last 140 years and the last millennium.* (a) The Earth's surface temperature from instrumental observations is shown year-by-year (thick vertical bars) and decade by decade (thick line). The uncertainties in the annual data (due to data gaps, instrumental errors, and adjustments for urbanization, etc) are shown by the thin whisker bars (representing the 95% confidence range). Over the last 100 years, the global average surface temperature has increased by 0.6 ± 0.2°C. (b) In addition, the year-by-year and 50-year average variations of the surface temperature of the Northern Hemisphere for the past 1000 years have been constructed from 'proxy' data calibrated against thermometer data. The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times. Nevertheless, the rate and duration of warming in the 20th century have been much greater than in any of the previous nine centuries. It is likely that the 1990s have been the warmest decade and 1998 the warmest year of the millennium. Reproduced from IPCC (2001).

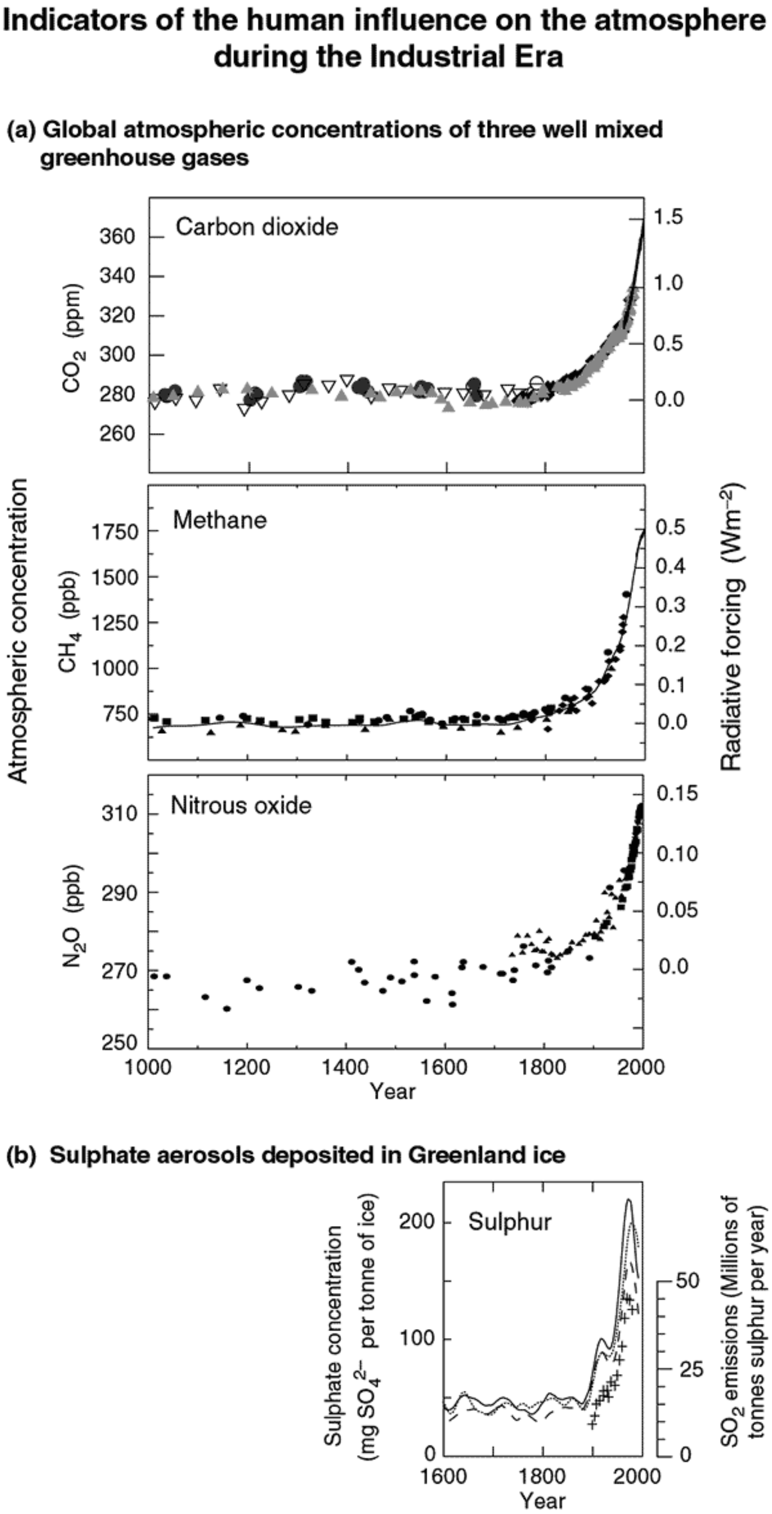

Figure 2. *Long records of past changes in atmospheric composition provide the context for the influence of anthropogenic emissions.*

(a) shows changes in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) over the past 1000 years. Ice core data from several sites in Antarctica and Greenland (shown by different symbols) are supplemented with data from direct atmospheric samples over the last few decades (shown by the thin lines). Since these gases have atmospheric lifetimes of a decade or more, they are well-mixed and their concentrations reflect emissions from sources throughout the globe. (b) shows the influence of industrial emissions on atmospheric sulphate concentrations, which cool the climate. This record shows the large growth in sulphur emissions in the Northern Hemisphere over the last 200 years. Reproduced from IPCC (2001).

Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect climate

Changes of climate occur as a result of internal variability within the climate system and external factors (both natural and anthropogenic. The influence of external factors on climate can be broadly compared using the concept of radiative forcing. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface. A negative radiative forcing, which can arise from an increase in some types of aerosols (microscopic airborne particles), tends to cool the surface. Characterisation of these climate forcing agents and their changes over time, such as shown in Figure 2, is required to understand past climate changes in the context of natural climate variations.

Atmospheric concentrations of the main anthropogenic greenhouse gases have increased substantially since 1750 (CO_2 by 30%, CH_4 by 150%, and N_2O by 17%), as in Figure 2. The present CO_2 concentration has not been exceeded during the past 420,000 years and likely not for the past 20 million years. . About three-quarters of the anthropogenic emissions of CO_2 are due to fossil fuel burning, with the rest due mainly to land-use change, especially deforestation. The ocean and land together take up about half the anthropogenic emissions. Some greenhouse gases (CO_2 and N_2O) have long atmospheric lifetimes.

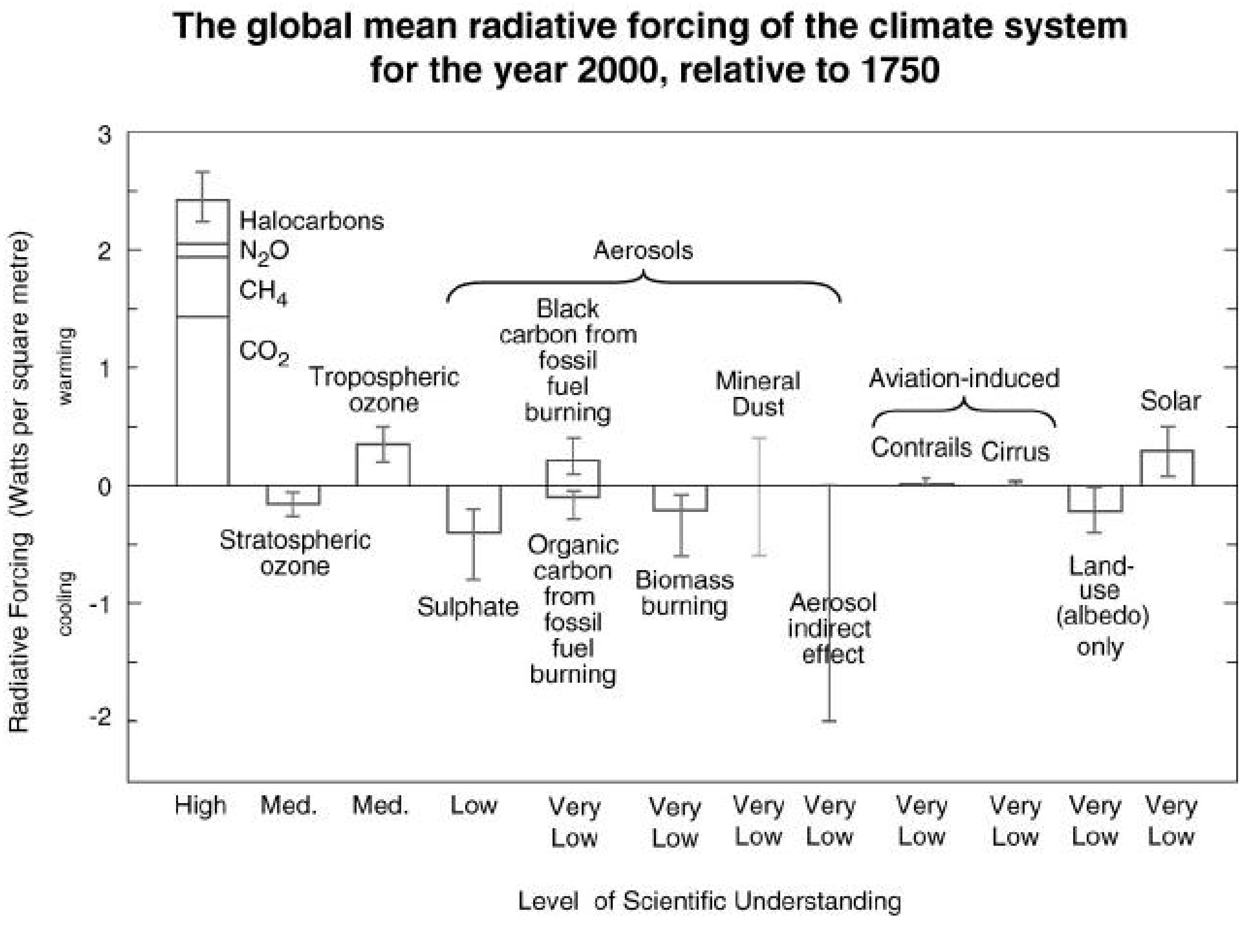

Figure 3. *Many external factors force climate change*. These radiative forcings arise from changes in the atmospheric composition, alteration of the surface reflectance by land use , and variation in the output of the sun. Except for solar variation, some form of human activity is linked to each one. The rectangular bars represent the contributions of these forcings – some of which give warming (positive radiative forcing) and some cooling. The indirect effect of aerosols is associated with their effect on clouds. The vertical line about the rectangular bars is an estimate of the uncertainty of the forcing. A vertical line without a rectangular bar denotes a forcing for which no best estimate can be given due to large uncertainties. The overall level of scientific understanding of the different forcings varies considerably, as shown. The net effect of these forcings is likely to have warmed the globe since 1750. Reproduced from IPCC (2001).

Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing, as shown in Figure 3. The major sources of anthropogenic aerosols are fossil fuel and biomass burning. There is much less confidence in the ability to quantify the magnitude of the direct influence of aerosols on climate and its evolution over time, than that for the anthropogenic greenhouse gases. Aerosols also have an indirect influence on climate through their effects on clouds. There is now more evidence for this indirect effect, which is negative, although very uncertain in magnitude.

Natural factors (solar variations and volcanic eruptions) are estimated to have made small contributions to radiative forcing over the past century.

There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

Simulations of the response to natural forcing alone, such as shown in Figure 4, do not explain the observed warming in the second half of the 20th century. In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.

Future increases in global average temperature and sea level can be expected as a consequence of continued emissions of carbon dioxide and other greenhouse gases.

The IPCC Special Report on Emissions Scenarios (SRES) produced a set of future emission scenarios based on a range of differing assumptions about population, energy sources and socio-economics. Under all of these scenarios, as shown in Figure 5, CO_2 concentration grows in the atmosphere, reaching 540 to 970 ppm by 2100 (compared to a pre-industrial level of 280 ppm and a present level of 367 ppm). Taking into account the range of emission scenarios and the differing results of current global climate models, global mean warming is projected to range from 1.4 to 5.8°C by the year 2100, relative to 1990. These projected warmings are higher than earlier IPCC estimates, primarily because of reductions in the projected increase of sulphate aerosols. Climate modelling results also indicate that the warming will be more rapid over land and in the higher latitudes. Precipitation is projected to increase in the global average and in the mid to high latitudes, but in lower latitudes, models give areas of both increase and decrease. Increases in rainfall are associated with more intense rainfall events. Increases in temperature are associated with increases in the frequency of hot days, and decreases in cold extremes.

The projected temperature increases are likely to lead to a global average rise of sea level over the period 1990 to 2100 of 30-50 cm, with a full range of uncertainty across all models and greenhouse gas scenarios of 9-88 cm. It is very likely that the 20th century warming has contributed significantly to the observed rise, through thermal expansion of the ocean and the widespread loss of land ice. The future rise in sea level will continue long after greenhouse gas concentrations have stabilised.

Key uncertainties

- the magnitude and character of natural climate variability;
- climate forcings due to natural factors (solar and volcanic) and anthropogenic aerosols (particularly effects on clouds);
- assumptions underlying the large range of plausible future emissions of greenhouse gases and sulfate aerosols, relating to economic growth, population growth and technological progress;
- factors associated with climate model projections, in particular climate sensitivity and feedback processes, especially those involving water vapour, clouds and aerosols;
- relating regional trends to anthropogenic climate change.

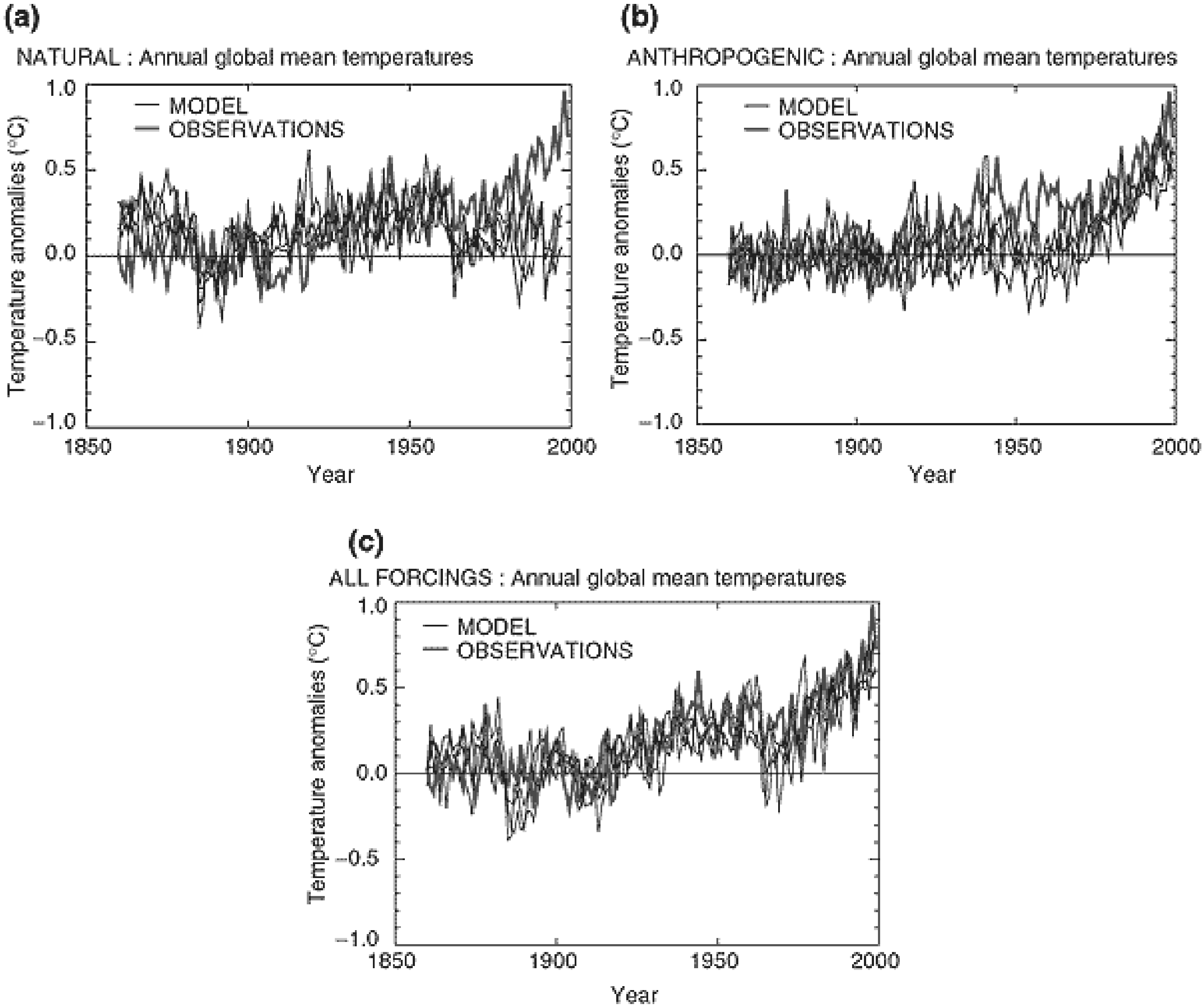

Figure 4. *Simulations of the Earth's temperature variations, and comparing the results to measured changes, can provide insight into the underlying causes of the major changes*. A climate model can be used to simulate the temperature changes that occur both from natural and anthropogenic causes. The simulations represented by the thin lines in (a) were done with only natural forcings: solar variation and volcanic activity. Those shown by the lines in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulphate aerosols, and those shown in (c) were done with both natural and anthropogenic forcings included. From (b), it can be seen that inclusion of anthropogenic forcing provides a plausible explanation for a substantial part of the observed global temperature increases over the past 50 years, but the best match with observations is obtained in (c) when both natural and anthropogenic factors are included. The four lines shown for the model are four simulations from the same model with the same forcing but differential initial conditions, showing the chaotic nature of climate and the uncertainty in the simulation of annual mean temperature. Reproduced from IPCC (2001).

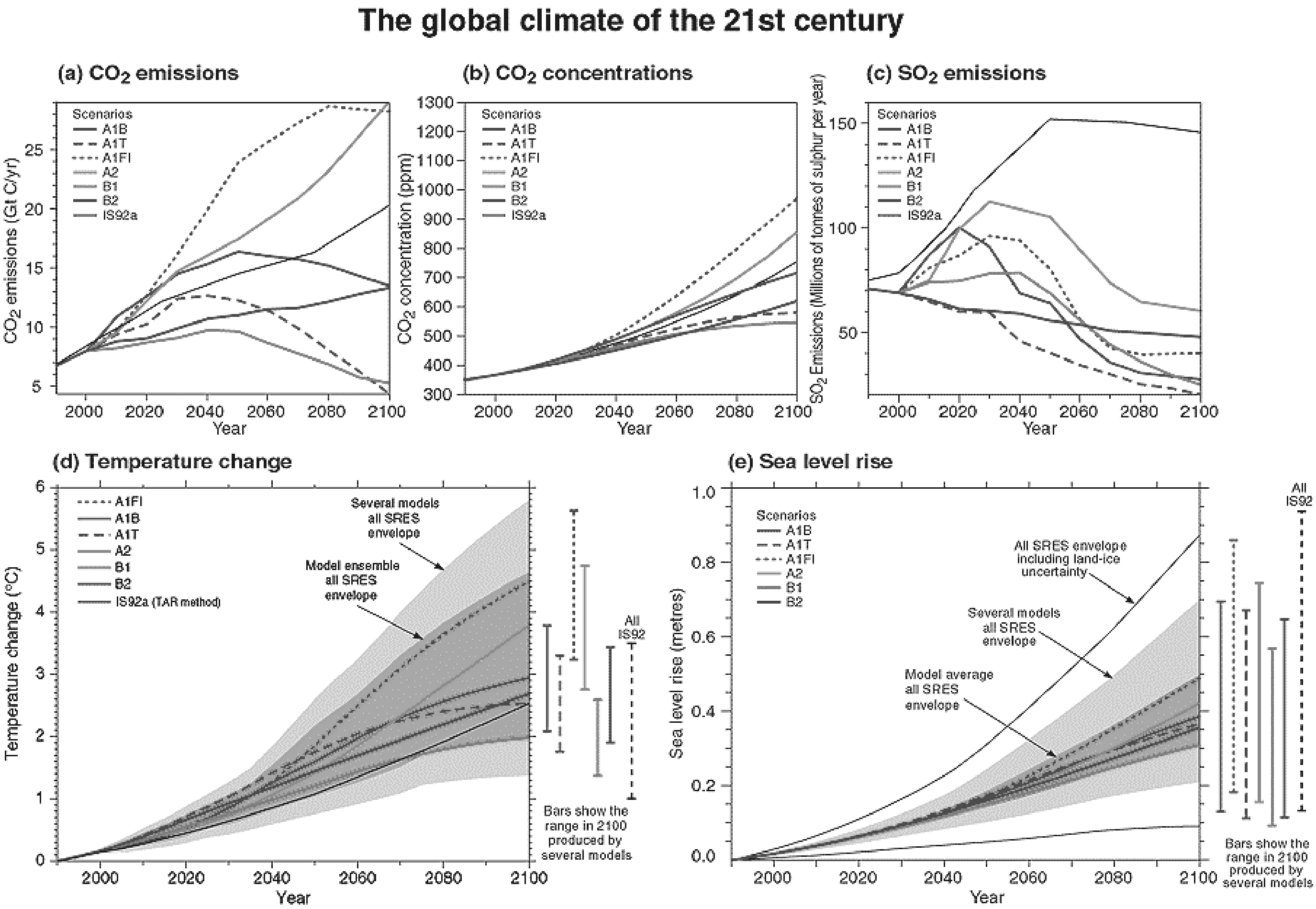

Figure 5. *The global climate of the 21st century will depend on natural changes and the response of the climate system to human activities.* Climate models project the response of many variables, such as increases in global surface temperature and sea level, to various scenarios of greenhouse gas and other human-related emissions. (a) shows the CO_2 emissions for six illustrative SRES scenarios. (b) shows the resulting projected CO_2 concentrations. (c) shows the anthropogenic SO_2 emissions. (d) and (e) show the projected temperature and sea level rise respectively. Note that the warming and sea level rise from these emissions would continue well beyond 2100.

Some classroom activities

The analysis of large climate datasets and the development of climate models involve complex mathematics that is beyond the scope of the classroom. However, there are many simple mathematical and statistical concepts that can be illustrated using aspects of climate change.

Variability and change

The assessment of whether climate variations are due to natural variability or are associated with longer-term changes is a question of time scales and variability (noise). For example, in Figure 1, it is difficult to see the longer-term changes if short intervals, of about 20 years only, are considered. Over such short intervals, the year-to-year variability is large relative to any longer-term changes expected from the effects of increasing greenhouse gases. A 20-year window can be superimposed on Figure 1 to see over which, if any, intervals a significant climate change might be identified (data available from HREF2). This is really an exercise in comparing a climate change signal to climate noise. The noise can be estimated by calculating the standard deviation of the year-to-year temperature variations. Using longer time averages reduces the noise and makes it clearer to see the longer-term trends, as shown by the decadal average line in Figure 1. A similar comparison can be made for Australian mean temperatures (available from the Bureau of Meteorology, HREF3). In this case, the natural variability of Australian mean temperatures is higher than for the global mean temperatures (where the global average has reduced the variability), and it is harder to detect the significant trend in the Australian mean temperatures, even though it is a similar magnitude trend to that in global mean temperature. It is even more difficult to identify real trends due to climate change at an individual station, such as temperatures in Melbourne, because the natural variability is even larger.

Compound and linear growth

The growth of the concentrations of greenhouse gases in the atmosphere, shown in Figure 2, is an example of exponential growth, similar to compound interest. Due to increasing energy use and increasing population, the concentration of CO_2 in the atmosphere has grown at a rate of between 0.2% and 0.6% per year since about 1800. It is very easy for students to use a spreadsheet, like Excel, to show the effects of different compound growth rates for CO_2 from its preindustrial concentration of 280 ppm (parts per million) to its current concentration of about 370 ppm. This compound growth can be contrasted to the effects of the addition of a constant emission of CO_2 into the atmosphere each year, which would lead to a linear growth in CO_2 concentrations. Similar exercises can be carried out for methane and nitrous oxide, which have different compound growth rates.

On-line resources

There are many useful on-line resources which can provide additional background information and data on climate change. Some of these include:

Intergovernmental Panel on Climate Change (HREF1, HREF4)
Australian Bureau of Meteorology (HREF3, HREF5)
CSIRO Atmospheric Research (HREF6)
Nova site on global warming and the greenhouse effect (HREF7)

References

IPCC (1990) *Climate Change: The IPCC Scientific Assessment – Report of IPCC Working Group I.* Cambridge University Press, Cambridge UK, pp ??

IPCC (1996) *Climate Change 1995: The Science of Climate Change*. Contribution of Working Group I to the IPCC Second Assessment Report. Cambridge University Press, Cambridge UK, pp ??

IPCC (2001) *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the IPCC. [J T Houghton, et al. (eds)] Cambridge University Press, Cambridge UK, pp ??

HREF1 www.grida.no/climate/ipcc_tar/ The IPCC Third Assessment Report. Click on the report you want to view to see an index to the full text and diagrams, which can be downloaded.

HREF2 www.cru.uea.ac.uk/cru/data/temperature/ Annual mean global mean temperatures available from the Climatic Research Unit, University of East Anglia, UK.

HREF3 www.bom.gov.au/climate/change/amtemp.shtml Annual mean temperatures averaged over Australia, available from the Bureau of Meteorology.

HREF4 www.ipcc.ch The IPCC web site

HREF5 http://www.bom.gov.au/lam/climate/index.htm Bureau of Meteorology climate education site. Includes information about climate and climate change in Australia and globally. Also includes student experiments and worksheets.

HREF6 http://www.dar.csiro.au/information/greenhouse.html CSIRO Atmospheric Research site on the greenhouse effect.

HREF7 http://www.science.org.au/nova/016/016key.htm Australian Academy of Science Nova site for students on the greenhouse effect.