Understanding Environmental Issues

Edited by

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Global Climate Change

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'Warming of the climate is unequivocal, as is now evident from observations of global average air and ocean temperatures, widespread melting of snow and ice and rising global mean sea-level'. (IPCC, 2007)

'The scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response'. (Stern Review, 2006)

Learning outcomes

Knowledge and understanding of:

- current trends in climate, and atmospheric gas concentrations
- the extent to which global warming is anthropogenically produced

Critical awareness and evaluation of:

- the reliability and accuracy of Global Climate Model (GCM) predictions
- the links between policy responses and the range of interests involved in these
- the unequal effects of climate change, at different scales, and at different times
- the relative merits of prevention, mitigation and adaptation of anthropogenic climate change

Introduction

In the last 250 years, humans have released ever greater quantities of carbon dioxide (CO_2), methane(CH_4), nitrous oxide (N_2O) and other greenhouse gases, into the Earth's atmosphere. CO_2 has risen from pre-industrial concentrations of 280 ppm to current values in excess of 380 ppm, and is currently rising by 1.9 ppm per year. There is a growing consensus among climate researchers that these greenhouse gases are causing the Earth's temperature to rise. Scientists have measured a temperature rise of 0.76 °C (with confidence intervals of 0.56 to 0.92 °C) between 1850 and 2005, as a result of increased radiative forcing from the increases in atmospheric greenhouse gases. (IPCC, 2007). Analysis of deep ice cores from Antarctica and Greenland reveal that the rise of atmospheric greenhouse gas concentrations, and the associated warming this generates, is occurring at a rate faster than any natural change seen in the last 650,000 years.

Despite such evidence, the wide-ranging and complex issues embedded in the climate change debate have vexed scientists, business representatives, environmentalists and politicians. Judgements and agendas permeate deeply controversial interest group biases and political approaches (O'Riordan and Jäger, 1996). This is, in part, due to the fact that, despite the annual cost of current climate change research being estimated at over three billion dollars (Stanhill, 2001), there are still large gaps in our understanding of the natural system and large inherent uncertainties in our predictions (Shackley et al., 1998). Indeed, the recent report from the Intergovernmental Panel on Climate Change (IPCC, 2007) excludes an estimate of sea-level rise produced by the melting of the ice sheets of Greenland and Antarctica, due to the current uncertainties within these systems. It is also hard to summarise complex climate research into easily digestible snippets for politicians and policymakers. Furthermore, the information available on climate change for policy-making purposes is plagued by large inherent uncertainties (Shackley et al., 1998).

This chapter will show how complex and uncertain climate change is, and some of the reasons behind this, including the methods, errors and outcomes associated with modelling the global climate. Prior to 2001, this complexity and uncertainty served to keep climate change low on the global political agenda, as different interest groups used this to avoid effective legislation. The current climate of political engagement is patchy at the global scale, as the chapter will show. O'Riordan (2004) argues that the 'target' of climate change is too nebulous to galvanise public interest, and renders people susceptible to negative 'sacrifice' discourses put forward by government and business. Other factors, as this chapter will also show, include the time and space dissonances which mean that the causes of global climate change are often distant from their effects. Commonly, the people or communities involved in producing the causes are not the same as those most affected by them with, arguably, the worst effects felt by communities least able to deal with them, a discussion which is also developed in Chapter 9 on natural hazards and elsewhere in the book.

The science of global warming will then be integrated into the policy interface by considering the role of the Intergovernmental Panel on Climate Change (IPCC) and other international institutions, which have largely set a global policy agenda to which individual states have had to respond. Moreover, strong political and economic interests hold powerful sway over national and international legislative bodies and affect their capacity to construct effective and just legislation.

Another factor making it difficult to gain a clear understanding of global climate change is that there is a lack of agreement on its importance as a critical global problem. While the European Union claims that global warming is the most serious international problem (eclipsing even terrorism in this era of post 9/11), to which the introduction to the book has already made reference, it is not only North Americans and Australians who disagree. Politicians and NGOs in the Global South challenge

Table 8.1 Greenhouse gases basketed under the Kyoto Protocol and their main generators (Note: greenhouse gases produced by air transport are exempt from the Protocol.)

Greenhouse Gas	Main Sources
Carbon dioxide (CO_2)	Fossil fuel combustion (e.g. road transport, energy industries, other industries, residential, commercial and public sector); forest clearing
Methane (CH_4)	Agriculture, landfill, gas leakage, coal mines
Nitrous oxide (N_2O)	Agriculture, industrial processes, road transport, other
Perfluorocarbons (PFCs)	Industry (e.g. aluminium production, semi-conductor industry)
Hydrofluorocarbons (HFCs)	Refrigeration gases; industry (as perfluorocarbons)
Sulphur hexafluoride ($SF/_6$)	Electrical transmissions and distribution systems, circuit breakers, magnesium production

Source: UNFCCC, 2003

this for very different reasons, citing the immediate problems facing their countries, whether this be HIV/AIDS, malaria, famine and malnutrition, lack of access to clean drinking water or effective sewage disposal. Such debates were fuelled at the turn of the 21st century by a book, *The Skeptical Environmentalist,* in which a Danish statistician, Bjorn Lomborg, argued at length that data forecasting global climate change is flawed (Lomborg, 2001). Unsurprisingly, given the ability of data to be forever manipulated, Lomborg's arguments and the data on which he bases them are also hotly debated. His more recent ranking exercise of global problems through the 'Copenhagen Consensus', and other controversies sparked by climate change sceptics, will be addressed later in the chapter. This chapter will conclude with possible responses to global warming, including issues of mitigation and/or adaptation, drawing on the Stern Review, commissioned by the UK Treasury to investigate the economics of climate change, but which has had far-reaching international effects.

While this chapter does not dwell on the anthropogenic causes of climate change, Table 8.1 offers a brief summary.

What is global warming?

Life on Earth is supported by a bubble of gas some 30 km thick, held in place by the gravitational pull of our planet. This atmosphere provides the oxygen we need to breathe and to protect us from the extremes of cold and some parts of the electromagnetic spectrum output by the sun, for example UV light, which is partly absorbed by ozone. Without the protection of the atmosphere, the surface of the Earth would be some 33 °C colder. Greenhouse gases, such as water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFC) and nitrous oxide (N_2O) trap heat in the atmosphere. In a stable climate, the concentration of greenhouse gases in the atmosphere will remain reasonably constant and play an important role in the Earth's energy balance (Figure 8.1a). Figure 8.1b illustrates the greenhouse effect.

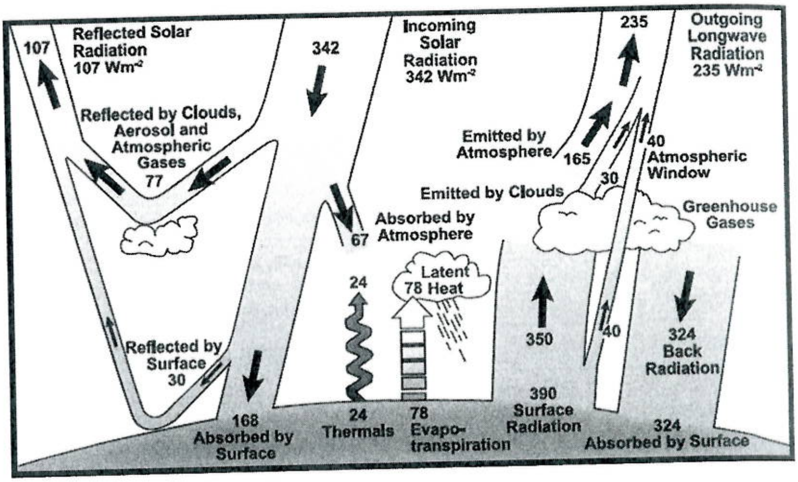

Figure 8.1a Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space.

Source: Kiehl and Trenberth, 1997 in IPCC, 2007

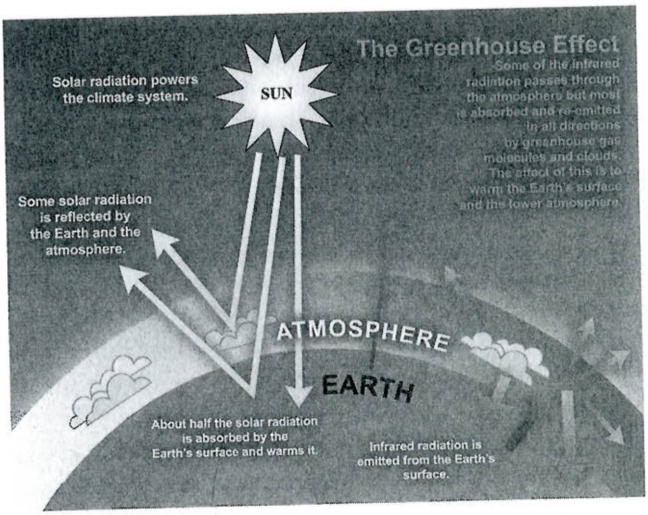

Figure 8.1b An idealised model of the natural greenhouse effect.

Source: IPCC, 2007

The link between increased concentrations of CO_2 in the atmosphere and climate change is only now becoming apparent at a global scale. Most scientists believe that proof exists of a steady warming, which can be linked to the increase in greenhouse gas concentrations, though the exact impact of such changes remains open to speculation.

Box 8.1 Scientific definitions

Climate change: any change in the global climate system, over time, whether due to natural variability or as a result of human activity.

Global warming: recent climatic amelioration, observed across the globe, believed to be a result of anthropogenic (human) forcing due to the increased release of greenhouse gases into the atmosphere.

Greenhouse gas: A gas that absorbs and emits radiative energy. The effects of the blanket of greenhouse gases making up our atmosphere are to trap heat at the Earth's surface, warming the Earth by some 33 °C.

Electromagnetic radiation: Energy generated by the interaction of electric and magnetic fields. Energy arrives at the outer edge of the Earth's atmosphere as short-wave radiation, centred in the visible part of the radiative spectrum. Energy leaves the Earth, primarily as long-wave radiation centred on the infrared band of the spectrum, though some long-wave light is reflected straight back to space. Greenhouse gases absorb long-wave radiation, re-radiating some of this back towards the Earth's surface, thereby warming the Earth.

Radiative forcing: a measure (in Watts per square metre (Wm^{-2})) of the influence of a factor that alters the balance of incoming to outgoing radiation from the earth. Greenhouse gases are a positive forcing, as they cause the Earth to warm.

El Niño southern oscillation: (ENSO or El Niño) is a natural variation in the Pacific ocean-atmosphere system. The coast of Peru is normally an up-welling region of cold, deep ocean water, which replaces surface water driven westward by the trade winds. During ENSO events, every 3–7 years, the trade winds weaken, reducing up-welling, resulting in warmer ocean temperatures and cloudiness across the central and eastern Pacific. ENSO is thought to result in: fewer Atlantic hurricanes; droughts in Brazil, Australia, Africa and Indonesia; and heavy rainfall on the arid coast of South America.

Observed changes in greenhouse gas concentrations and climate

Trends in greenhouse gas concentrations

Greenhouse gas concentrations in the atmosphere have been rising steadily since the beginning of human cultivation of crops in Asia, some 8000 years ago. This concentration has risen ever more rapidly since the beginning of the Industrial Revolution around 1750. For the last 150 years, earth scientists have been measuring the concentrations of greenhouse gases, and have established that the volume of CO_2 in the atmosphere has increased by more than a third since 1750. The present CO_2 concentration has not been exceeded during the past 420,000 years, while the present rate of increase is unprecedented during the last 20,000 years. Almost all this rise is attributable to anthropogenic emissions of CO_2, with 75 per cent thought to be due to fossil fuel burning, and the rest predominantly due to land use change, such as deforestation (IPCC, 2001).

CO_2 levels in the atmosphere, measured at Mauna Loa in Hawaii since 1957, show the recent steady rise in atmospheric CO_2 (Figure 8.2). Pre-industrial (1750) atmospheric concentrations were around 280 ppm, with 2005 values at 379 ppm (i.e. 379 molecules of CO_2 gas per million molecules of dry air). Current annual emissions, driving this rapid rise in CO_2 concentrations, are estimated to be in the region of 7.2 GtC (gigatonnes of carbon). The Mauna Loa curve shows that in 2001–2002 and

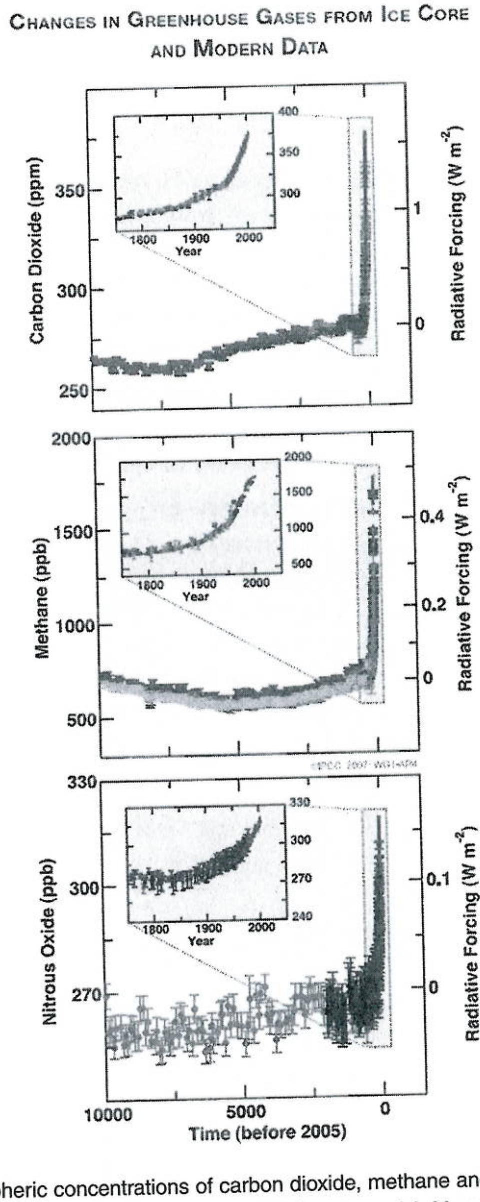

Figure 8.2 Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different shades of grey for different studies) and atmospheric samples. The corresponding radiative forcings are shown on the right-hand axes of the large panels

Source: IPCC, 2007

2002–2003, the concentrations of CO_2 rose by 2.08 ppm and 2.54 ppm respectively. This was the first recorded instance of a rise of more than 2 ppm for two consecutive years. Under normal conditions, significant rises in CO_2 levels in Hawaii are associated with El Niño years. The recent trend suggests that these patterns may be being overprinted by the signal from anthropogenic CO_2 emissions.

CO_2 is not the only important greenhouse gas to have seen rapid post-industrialisation rises in atmospheric concentration. Methane has increased from a pre-industrial value of around 715 ppb to a 2005 value of 1774 ppb. The IPCC (2007) states that this rise is predominantly due to agriculture and fossil fuel use, though sources are not well constrained and there is a suggestion in the recent record that emission levels may have stabilised during the 1990s. Nitrous oxide, predominantly released due to intensive agriculture, has also risen from 270 to 319 ppb between 1750 and 2005. These increased emissions have led to the IPCC (2007) stating that there is 'a very high confidence' that radiative forcing has risen by +1.6 (within the error bounds +0.6 to +2.4) Wm^{-2}, due to anthropogenic influences on the atmospheric system.

Trends in temperature

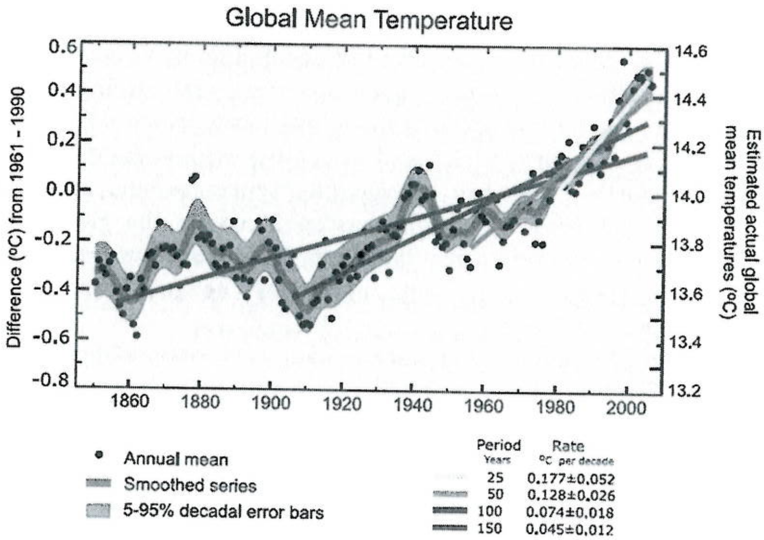

Figure 8.3 Annual global mean observed temperatures (black dots) with linear fits to the data. The left hand axis shows anomalies relative to the 1961 to 1990 average and the right hand axis shows the estimated actual temperatures both in °C. Linear trends for the last 25, 50, 100 and 150 years are shown as straight lines, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. Note that for shorter recent periods, the slope is greater, indicating accelerated warming. The thick grey curve is a smoothed series depiction to capture the decadal variations. To give an idea of whether the fluctuations are meaningful, decadal 5% to 95% (light grey band) error ranges about that line are given.

Source: IPCC , 2007

The general temperature curve seen in Figure 8.3 is made up of observational data showing changing global average temperatures over the last 150 years. Four stages can be identified within the overall trend:

1 A long, very irregular but generally cool period between 1860 and 1910.
2 A very rapid, regular and prolonged period of warming between 1910 and 1943.
3 An equally long period of small and irregular cooling between 1943 and 1975.
4 A rapid warming phase since 1975. Eleven of the twelve years between 1995 and 2006 rank among the 12 warmest years in the global instrumental temperature record which dates from 1850.

The overall trend suggests an average global temperature increase between the periods 1850–1899 and 2001–2005 of 0.76 °C (with confidence intervals 0.57 to 0.95 °C) (IPCC, 2007). Varying degrees of warming are recorded for every continent (with the exception of Antarctica where the instrumental record is inconclusive due to limited meteorological data), both on land and over the oceans. Temperature rises are also seen throughout the lower and mid-troposphere, the 11 km of the Earth's atmosphere nearest the surface.

What else might control the temperature curve?

If there were a direct link between greenhouse gas emissions and temperature, then the emissions and temperature curves would follow the same trend. Figure 8.3, showing the temperature record, while describing an overall increase, does not follow the clean trend of the emissions curves (Figure 8.2). This implies that either the climate system does not respond in a linear fashion to greenhouse gas forcing (making modelling more difficult – see below) or that there are other, natural cycles and variability within the climate system controlling the Earth's response to changing concentrations of greenhouse gases. Scientists and pressure groups, unconvinced by the global warming arguments, use the discrepancies between these curves to argue against the importance of greenhouse gas-induced climate change. So what else might control the climate's response?

Significant change in global temperatures can, with 'reasonable scientific certainty', be linked to three other causal mechanisms (see Houghton, 2004):

1 **Changes in solar radiation**: Solar intensity varies through the 11-year sunspot cycle by about 0.2–0.5 Wm^{-2}. There are known historic variations, such as the Maunder Minimum between 1650 and 1700 when there were no sunspots. This was the coldest period in Europe for the last 1000 years, and was the core of the Little Ice Age. Solar intensity can, therefore, control our climate, and produce significant temperature variations at short timescales. There is significant uncertainty in scientific measurements of sunspot activity and solar intensity before the 1970s, so there are only very limited usable historical data-sets. The proxy data indicating sunspot activity can explain over 60 per cent of climate variance prior to the 1970s. Recent research indicates that the observed rapid rise in global mean temperatures post-1985 cannot be attributed to solar forcing (Lockwood and Fröhlich, 2007).
2 **Volcanic eruptions**: The injection of sulphate aerosols and dust into the atmosphere during large volcanic eruptions will cool the climate. The 1991 eruption of Mount Pinatubo cooled the planet by 0.5 °C for several years. Large eruptions can cause a negative forcing of up to 3–5 Wm^{-2}. In extreme cases, scientists estimate this may be as large as 12 Wm^{-2}.

3 **Release of aerosols:** Anthropogenic sulphate aerosols are known to have a negative forcing on the climate system. The effect is also localised, so is often seen downwind of conurbations. The cooling forcing has risen from the early 1900s to account for around $-1\ Wm^{-2}$.

This suggests that CO_2 is significantly more important as a mechanism than short-term sunspot/solar radiation forcing, volcanic eruptions or aerosols. The problem for climate modellers and their attempted predictions of climate change is that the climate system is far more unpredictable than future CO_2 emissions trends.

Examples of change

Glaciers

The widespread 20th-century retreat of valley mountain glaciers in non-polar regions is well documented and is estimated to contribute 0.2 to 0.4 mm yr^{-1} of sea-level change. Any significant future rises in sea level will be determined by changes in the mass of the polar ice sheets in Antarctica and Greenland, which together hold some 33 million km^3 of ice, enough to raise global sea level by some 70 metres. The state (and fate) of these large ice sheets is less well understood than their valley glacier cousins. This is complicated, as the ice sheets are not only changing as a result of global warming, they are also undergoing long-term adjustments and are losing mass as a result of natural climate change since the last glacial maximum, 20,000 years ago. Box 8.2 presents a case study identifying some of the scientific uncertainties of dealing with risk, regarding the break-up of the West Antarctic Ice Sheet (WAIS).

Box 8.2 The complexity of predicting the behaviour of the West Antarctic Ice Sheet

The relationship between scientists and policymakers is often perceived as contentious. In part, this is because scientists work on detailed reports with discussions of errors and probability associated with any predicted impact or trend. For policymakers and the public, this must be condensed into usable sound bites. This example will show an attempt to provide policymakers with usable information on the possible future collapse of the West Antarctic Ice Sheet.

The Antarctic Ice Sheet stores 25.4 million km^3 of ice, equating to 90 per cent of the freshwater on Earth. The future of the ice sheet under climate change scenarios is unknown. This is because there are large uncertainties in accumulation (the addition of mass, primarily through snowfall) and ablation (the loss of mass, predominantly through iceberg calving) measurements, particularly as there is likely to be an increase in precipitation due to warming of the Southern Ocean.

Antarctica is made up of two large ice sheets, the East Antarctic Ice Sheet, grounded on bedrock above sea level, and thought to be stable and predictable in its response to climate change, and the West Antarctic Ice Sheet, grounded below sea level, and termed a marine ice sheet. Because of the marine base of WAIS, scientists have

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expressed concerns regarding WAIS and predicted possible rapid collapse of the ice sheet. In the media, this is often simplistically associated with the disintegration of ice shelves, such as the Wordie (see Figure 8.4) and Larsen Ice Shelves, in the Antarctic peninsula.

Figure 8.4 Icebergs in Wordie Bay produced by the break-up of the Wordie Ice Shelf on the Antarctic Peninsular

Source: author

Vaughan and Spouge (2002) define collapse as sea-level rise of 1 m per century or 4 m total. Significant sea-level rise is 0.2 m per century or >1 m in total. Vaughan and Spouge (2002) document three methods for estimating the risk of WAIS collapse:

1 Status of past behaviour of WAIS: WAIS has collapsed before but the evolution of WAIS is not well recorded, and atmospheric conditions are different today compared to those during the last collapse.
2 Risk estimate based upon model predictions: computer models of WAIS suggest instability but often fail to agree on the timing of any collapse.
3 Risk estimate using Delphi technique: this encapsulates the current state of expert opinion through a series of questions – respondents use model results, literature or gut feeling to make value judgements about risk.

Vaughan and Spouge conclude that the experts do not agree about when or whether WAIS will collapse. They find considerable benefit in the Delphi technique, as this methodology is understood by policymakers who often apply the technique of quantitative risk estimation and risk assessment. The process helps to rank particular issues in a debate and provides a measure of the degree of accord within the scientific community.

After questioning scientists, they estimate a 5 per cent probability of collapse and 30 per cent probability of significant sea-level rises in the next 200 years. This produces easily digestible information for policymakers. The scientists have helped digest the complex facts into a simple statement of possible risk. Policymakers can then decide where this risk fits within their assessment of environmental concerns.

Hurricanes

Media coverage often invokes large hurricanes, such as Katrina, as proof of global warming. Recent research, summarised in Shepherd and Knutson (2007), suggests that there has been a recent increase in both the intensity and activity of Atlantic hurricanes, mirrored by increases in tropical cyclone activity. As in other areas of earth system science, however, the problem is assessing and proving the link between hurricane activity and anthropogenic-induced global warming (the link between cause and effect). In order to generate a hurricane, six key atmospheric factors must usually be met: warm ocean waters (higher than 26.5 °C) through a sufficient depth of water; unstable atmospheric conditions; a moist mid-troposphere; sufficient distance from the equator to generate cyclonic behaviour; some form of near-surface disturbance to help generate the vortex, such as tropical easterly waves; and low values of vertical wind shear (changing wind speed with height). Which, if any of these processes are being significantly altered by climate change? The most plausible predictions indicate that any change in intensity and activity, as a response to warmer ocean temperatures, is likely to be locally variable, in response to changes in the larger atmospheric system. As Shepherd and Knutson (2007) conclude, 'significantly more research – from observations, theory and modelling – is needed to resolve the current debate around global warming and hurricanes'.

Box 8.3 Summary of IPCC observations of recent climate change

The 2007 IPCC report summarises the key scientific observations on climate change. It is impossible to replicate all observations in this chapter, so a summary of some key findings is given below.

There is high confidence that effects have been documented in the following systems:

- Snow, ice and frozen ground (including permafrost) with change exemplified by: retreating glaciers and Arctic sea ice; enlargement and an increased number of glacial lakes; increasing ground instability in permafrost regions; increasing rock avalanches in mountain regions; and increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers.
- Terrestrial biological systems, including such changes as: earlier timing of spring events, such as leaf-unfolding, resulting in earlier greening of vegetation; earlier bird migration and egg-laying; changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, with predators high in the food chain (such as polar bears) being affected around the world; pole-ward and up-ward shifts in ranges for plant and animal species, often linked to longer thermal growing seasons.
- Marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. Effects include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; range changes and earlier migrations of fish in rivers.

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There is a medium level of confidence that effects of temperature increases have been documented in the following:

- Agricultural and forestry management at northern hemisphere higher latitudes, resulting in earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests.
- Aspects of human health, such as heat-related mortality in Europe, infectious disease vectors in some areas, and allergenic pollen in northern hemisphere high and mid-latitudes.
- Some human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower elevation alpine areas (such as mountain sports).

Further, there are indications that:

- settlements in mountain regions are at enhanced risk to glacier lake outburst floods caused by melting glaciers
- in the Sahelian region of Africa, warmer and drier conditions have led to a reduced length of growing season with detrimental effects on crops
- in southern Africa, longer dry seasons and more uncertain rainfall are prompting adaptation measures
- sea-level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas.

Global Climate Models (GCMs)

What are GCMs?

The complexity of the climate system and the absence of definitive analogues for our evolving climate have led to the use of theoretical computer models known as global climate models (GCMs) to attempt to predict the future influence of greenhouse gases (MacCracken et al., 1991). GCMs predict climate based upon our understanding of the physical laws controlling the environment. These models represent what are believed to be the most important aspects of the atmosphere, ocean, cryosphere and biosphere, though they cannot yet simulate all aspects of the climate (IPCC, 2001).

GCMs divide the surface of the Earth into cells, usually some 100 km by 100 km in size. The resolution is important as, ideally, cell size would mirror land use on the ground surface. Clearly, this is not the case, as cell resolution is closely controlled by computer capability. Extra cells result in longer model runs and increase the number of links between cells, making the modelling process more complex. Once each cell area has been defined as a grid, a series of vertical layers are added to the model, creating boxes that represent the atmosphere. Near the ground surface, layers are small, often in the order of metres. This allows the boundary layer, the link between the ground surface and the atmosphere, to be modelled in significant detail. This is where the most important climatic interchanges take place, controlling moisture and heat transfer from the Earth's surface to the lower atmosphere. As elevation increases, layer depths become larger, as the relative importance of interactions decreases, and our ability to measure parameters as input to the models also decreases. GCMs then require each column of cells to be linked to the cells around them, so that transfer for heat and moisture can be modelled.

Such interactions are extremely complex, and must be carried out at every time interval for which the model is being run. Due to the significant changes in meteorological conditions throughout the day, it is common to run GCMs at hourly steps. This daily change is largely controlled by the primary input required to initiate a GCM, namely incoming solar radiation. This and other key controls are entered into the model, such as atmospheric gas concentrations and factors associated with the basic physics of the Earth, such as oceanic and atmospheric circulation patterns. The model then calculates for every vertical box, for every grid cell, and for every time-scale, the key meteorological parameters associated with wind speed, precipitation and temperature and so on. These calculations are parameterised (see Box 8.4 for an explanation of this term) against current known climatic conditions and variables. The next problem to be faced by modellers is what will happen in the future. Neither the Earth system nor the population that lives in it is static, so this dynamism must be factored into model scenarios.

Box 8.4 How big is a cloud?

Clouds are an important component of the atmosphere, as they have a direct effect on the temperature and moisture profile of the atmosphere and control the amount of incoming solar radiation that reaches the surface of the Earth. When including clouds in climate models, it is important to know the elevation and thickness of the cloud (low clouds tend to cool the system, while high clouds warm the atmosphere), the cloud type (the presence of water or ice in a cloud will control the cloud's optical properties) and, because clouds are forming at sub-grid scale, the percentage cover of clouds (individual clouds cannot be modelled by GCM) (Houghton, 2004). Small errors in calculating any of these controls have a disproportionate effect on the accuracy of a GCM. Unfortunately, many models make use of simplified parameters (numerical constants that constrain physical equations) when dealing with clouds:

'Many physical processes, such as those related to clouds, take place on much smaller time scales and therefore cannot be properly resolved and modelled explicitly, but their average effects must be included in a simple way by taking advantage of physically based relationships with the larger scale variables (a technique known as parameterization).' (IPCC, 1996)

Thus, it seems likely that important processes are often absent or highly simplified in ways that might affect model sensitivity. Models with different cloud parameterisation dramatically affect estimated sensitivity (MacCracken et al., 1991). Validation is weakened by poor observational data-sets of cloud feedback effects. The correct representation of clouds within GCM remains one of many difficult challenges facing climate scientists.

Emissions scenarios – the basis for predicting future climate change

In order to use a computer model to predict future climate change, modellers require clear statements regarding the future emissions of greenhouse gases expected over the coming century. The emissions of greenhouse gases are likely to depend upon complex economic and political issues, such as land use change, industrial development and global population dynamics. Since 1996, the IPCC has been developing new emission scenarios following four different narrative storylines. These are:

A1: Very rapid economic growth, a peak in global population by the mid-21st century, rapid development of more efficient technologies, with convergence between developed and developing regions. The A1 scenario is further subdivided into fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance across sources (A1B).

A2: A very heterogeneous world, with preservation of local identities. Economic development is locally focused, resulting in slower development but continuous population increases.

B1: A convergent world economy, similar to scenario A1, though with a heavy focus on clean and resource-efficient technologies, with an emphasis on global solutions to economic, social and environmental sustainability.

B2: Again, a heterogeneous world similar to A2, though with an emphasis on local solutions to economic development, social and environmental sustainability.

The combination of factors related to the four narratives result in 40 scenarios for the GCMs to model climate change. GCM outputs from different modelling groups can then be compared for each scenario. There is as much complexity in the development of the scenarios as there is in the models themselves.

How are the models tested?

Models can be tested against their ability to predict:

- The current climate – models are run against control data (meteorological records) in order to assess how well they reconstruct current climate. Parameterisation (the application of numerical constants to constrain physical equations) is applied to the model to increase its ability to predict current climate. Care must be taken to apply this parameterisation within the constraints of our understanding of the physical processes active within the environment. Climate change sceptics frequently cite model parameterisation as a key problem with GCM predictions, referring to this process as a 'fudge-factor'. Despite this, the current state-of-the-science GCMs, using well constrained equations, successfully recreate latitudinal and seasonal changes in climate.
- Recent climate change – models must be run for considerable time periods to reach steady-state conditions, that is to recreate current climate. Model results can be compared to known temperature trends for the last century, and are

able to recreate small climate changes, such as short periods of cooling due to volcanic activity, for example, the cooling effect of the eruption of Mount Pinatubo in 1991 (Houghton, 2004).

- Past Earth climates – models can also roughly explain (within the constraints of geological evidence) the changes in Earth's temperature throughout its geological history, as solar intensity has increased and atmospheric composition has changed (MacCracken et al., 1991).
- The climates of other planets in the solar system with known atmospheric conditions – using the same physical assumptions as applied to the Earth, models have successfully predicted the climates of other planets in the solar system, such as Venus and Mars.

The success of models to recreate current climate (short time-scales) and past climates (long time-scales) suggests that the basic physics applied in the models are reasonably well understood. Unfortunately, changes in greenhouse gases dominate the decadal-to-century time-scales and there are few appropriate tests for this (mid) time-scale (MacCracken et al., 1991). This limits our confidence in the ability of GCMs.

What limits confidence in the models?

'The limitations of computer modelling, the unrealistic nature of the basic assumptions made about future technological change and political value judgements have often distorted the scenarios presented to the public' (Lomborg, 2001).

Different models with differing parameterisation linked to 40 scenarios from four different narratives for predicting future change provides an extremely complex and challenging environment for climate change modellers, leaving many sceptical as to the usefulness of GCM predictions. In order to be convinced that the predictions provided by the models are believable, scientists must be satisfied that the models are comprehensive and correct. In order to make the models more acceptable and useful, they must be related to the scale of the process involved (see Box 8.4); represent sections of the Earth/atmosphere in as accurate a manner as possible; be as simple as possible; and have as few parameters as possible. MacCracken et al. (1991) suggest our confidence in the models is limited by a number of issues:

1. Many processes are not represented in the models. In part, this is a result of scale, with many meteorological phenomena and surface conditions being below the grid scale of the models. This is also a result of the incremental development of increasingly sophisticated GCMs. In the late 1990s, models failed to adequately incorporate the carbon cycle and non-sulphate aerosol calculations. It was only in the early 2000s that dynamic vegetation and coupled atmospheric chemistry components were added to GCMs.
2. Models are tuned (forced) to achieve improved agreement with observed climate.
3. There are limitations in observational data-sets with which to test the models, for example, the majority of meteorological records are for coastal areas, rather than the interior of the large continents, so we have only limited control over large spatial areas of the models. The old computer adage 'garbage in, garbage out' is only too true of GCM modelling.

4 The models assume that climate will change gradually (rather than in fits and starts) and also that the system is in equilibrium. In reality, the climate system is chaotic and inherently unpredictable at the small scale. An example of this is the problem of modelling the El Niño southern oscillations (ENSO), a chaotic and statistically random circulation phenomenon in the South Pacific. While Houghton (2004) states that some models are now capable of simulating some aspects of ENSO, many aspects are not well simulated in GCMs. If we don't fully understand ENSO, how do we force it to happen in the future, when we do not know how or if it will be generated?
5 There is insufficient data to adequately and simultaneously model non-greenhouse gas forcing (including solar variation, aerosol injections and oceanic circulation changes) in GCMs.
6 Model predictions do not always agree with observations. The weighting towards the influence of greenhouse gases results in models suggesting a more rapid and larger warming than has been observed to date, and irregularities such as the cooling events in the 1970s are not well modelled.

Current GCMs are become ever more sophisticated. Models are able to integrate more and more elements of the Earth's climate system and represent complexities in a more realistic way, thereby generating results comparable with expanding observational data-sets. Comparison between models is helping identify strengths and weaknesses, while nesting of models that run at different resolutions (such as local hydrological models coupled to GCMs) is assisting with problems associated with the scale of many processes within the climate system. Despite these huge advances in state-of-the-science computers and models, the use of computer models and the results they generate is not, and probably will never be, as conclusive as we would like.

Model predictions of future change in greenhouse gas concentrations and climate

February 2007 saw the agreement of the fourth assessment report of the IPCC. This report summarises the most likely future changes in climate as predicted by the range of greenhouse gas emission scenarios presented above. The following sub-sections highlight some key conclusions of the fourth IPCC report, while Box 8.5 reviews some of the results of climate change predicted by the IPCC.

Box 8.5 IPCC predictions for future change as a result of climate change

The IPCC report (2007) summarises the key scientific predictions resulting from climate change. Some of these observations are summarised below:

- **Fresh water resources and their management:** by mid-century, annual average river run-off and water availability are projected to increase by 10–40% at high latitudes and in some wet tropical areas, and decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics. Drought-affected areas will likely increase in extent. Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk. In the course of the century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability to one-sixth of the world's population.

- **Ecosystems:** the resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g. land use change, pollution, over-exploitation of resources). Approximately 20–30% of plant and animal species are likely to be at increased risk of extinction if the rise in global average temperature exceeds 1.5–2.5 °C. The progressive acidification of oceans due to increasing atmospheric carbon dioxide is expected to have negative impacts on marine shell-forming organisms, such as corals, and their dependent species.
- **Food and forest products:** crop productivity is projected to increase slightly at mid-to high latitudes though will decrease at lower latitudes, especially in seasonally dry and tropical regions. Globally, the potential for food production is projected to increase with rises in local average temperature over a range of 1–3 °C, but above this it is projected to decrease. Increases in the frequency of droughts and floods are projected to affect local production negatively, especially in subsistence sectors at low latitudes. Globally, commercial timber productivity will rise modestly with climate change in the short- to medium-term, though there will be large regional variability around the global trend.
- **Coastal systems and low-lying areas:** coastal systems are likely to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise. Increasing human-induced pressures on coastal areas will exacerbate the effect. Coastal wetlands, including salt marshes and mangroves, will be negatively affected by sea-level rise. Many millions more people are projected to be flooded every year, due to sea-level rise by the 2080s. Those densely populated and low-lying areas where adaptive capacity is relatively low, and which already face other challenges, such as tropical storms or local coastal subsidence, are especially at risk. The numbers affected will be largest in the mega-deltas of Asia and Africa while small islands are especially vulnerable.
- **Industry, settlement and society:** costs and benefits for this sector will vary widely by location and scale. The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources; and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring. Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas with limited adaptive capacities (see also Chapter 9 on natural hazards). Where extreme weather events become more intense and/or more frequent, the economic and social costs of those events will increase.
- **Health:** projected climate change-related exposures are likely to affect the health status of millions of people, particularly those with low adaptive capacity. This will occur through: increases in malnutrition and consequent disorders, with implications for child growth and development; increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts; the increased burden of diarrhoeal disease; the increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone related to climate change; and the altered spatial distribution of some infectious disease vectors.

Source: IPCC, 2007

Future changes in temperature

For the next two decades, a warming of 0.2 °C per decade is projected. Even if the concentrations of greenhouse gases and aerosols stabilised at 2000 values, a rise in temperature of 0.1 °C per decade would be expected. Over the longer term, projected, globally averaged, surface warming for the end of the 21st century (2090–2099) relative to 1980–1999 suggests a best estimate for the low scenario (B1) (see p. 188 for scenario descriptions) is a temperature rise of 1.8 °C (likely range 1.1 °C to 2.9 °C) and a worst estimate for the high scenario (A1F1) is a warming of 4.0 °C (likely range 2.4 °C to 5.8 °C). Warming is predicted to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic. Snow cover is projected to contract, and sea-ice is likely to shrink in both polar regions, with Arctic sea-ice almost disappearing by late summer by the latter part of the 21st century. There is also predicted to be an increase in hot extremes, i.e. heatwaves.

Future changes in precipitation and storminess

It is considered very likely that precipitation levels will increase at high latitudes while decreasing at lower subtropical regions (possibly by as much as 20 per cent in the A1B scenario). Heavy precipitation events will continue to become more frequent, and extra-tropical storm tracks are projected to move pole-ward, resulting in changes in wind, precipitation and temperature patterns. It is likely that tropical cyclones (typhoons and hurricanes) will become more intense, with stronger winds and more heavy precipitation, though there is a suggestion that they might decrease in number.

Predictions for sea-level rise

Over half the world's population live within 60 km of the coast (Holligan and deBoois, 1993). High-density populations on deltaic areas of the world are found in China, Bangladesh and Egypt, making them particularly susceptible to sea-level rise (Nicholls and Leatherman, 1995). Bangladesh, Senegal, Nigeria and Egypt appear particularly vulnerable – that is, they have the least ability to cope with sea-level rise, based on their existing physical and human susceptibility: large and expanding coastal populations and limited experience in adaptation techniques (see Chapter 9). Countries such as Senegal and Uruguay are among many countries threatened by sea-level rise for a very different reason – their economies are highly dependent on beach tourism (Nicholls and Leatherman, 1995). However, it is low-lying, small island developing states (SIDS) that are the greatest cause for concern, and this has been a contributory factor in a United Nations focus on SIDS in the World Summit on Sustainable Development Plan of Implementation (United Nations, 2002: Section VII).

Sea level is estimated to have risen at a rate of 1.8 ± 0.1 mm yr^{-1} over the last century (Douglas, 1991; IPCC, 2001). Estimates predict sea level will continue to rise at this rate, though may increase threefold, with total sea-level rise in 2090–2099 relative to 1980–1999 predicted to be 0.18–0.59 metres (IPCC, 2007). Table 8.2 sets out the main variables involved in sea-level change. These include:

- Thermal expansion of the oceans due to warming sea-surface temperatures – as the near-surface ocean water warms, the density of the water decreases, resulting in thermal expansion. Over decadal and millennial timescales, deep ocean water will also warm, as a result of thermal transfer and mixing due to ocean currents. Thus, even if temperature increases were stopped today, thermal expansion would continue far into the future.
- Change in the terrestrial storage of water – estimates of this reservoir from 1910–1990 are in the range −1.1 to 0.4 mm yr^{-1} of sea-level rise. Such discrepancy indicates the complexity of estimating this contribution, which includes change in soil moisture, reservoir storage, melting and consequent run-off from frozen ground in sub-Arctic areas, and changes in storage of water in vegetation.
- Contributions from glaciers and ice sheets that cover some 10 per cent of the Earth's land surface – as has already been identified, the widespread 20th-century retreat of valley mountain glaciers in non-polar regions is well documented and is estimated to contribute 0.2 to 0.4 mm yr^{-1} of sea-level change. Current estimates of the contribution (positive or negative) to sea-level change from the large polar ice sheets of Greenland and Antarctica are less well constrained.

Table 8.2 Estimated contributions to sea-level rise

Cause	20th-Century Contribution (mm yr^{-1})	Predicted 21st-Century Contribution (mm yr^{-1})
Thermal expansion	+0.3 – +0.7	+1.1 – +4.3
Melting of valley glaciers and ice-caps	+0.2 – +0.4	+0.1 – +2.3
Melting in Greenland	0.0 – +0.1	−0.2 – +0.9
Melting of Antarctica	−0.2 – 0.0	−1.7 – +0.2
Ice sheet adjustment since LGM	0.0 – +0.5	0.0 – +0.5
Changes in terrestrial storage of water	−1.1 – +0.4	−2.1 – +1.1
Sediment deposition	0.0 – +0.05	Small
Vertical land movements	Localised	Localised
IPCC total estimates	−0.1 – +1.9	+0.9 – +8.8

Source: IPCC, 2007

Unequal impacts of climate change

The previous section has highlighted the differences in projected impacts of the phenomenon that is global climate change, in which a 0.09–0.88 metre sea-level rise between 1990 and 2100 will have a much more dramatic impact on the population, geography and economy of a country in the Global South, such as Senegal or Bangladesh, compared to The Netherlands or Florida in the USA. An

Table 8.3 Impacts of the 2004 hurricane season in the Caribbean and south-east USA

Hurricane Event	Deaths	Insured Losses	Notes
Jeanne (USA, Haiti, Puerto Rico)	3034 (1700 in Haiti)	$4000 million	Haitian economy severely affected; social problems (e.g. looting)
Charley (USA, Cuba)	24 (none in Cuba)	$8000 million ($4.5 m worth of damage in Cuba)	In Cuba: 2 million people evacuated (17% of the population)
Frances (USA, Bahamas)	38	$5000 million	
Ivan (USA, Barbados, St Lucia, St Vincent, Grenada)	124	$11,000 million	Most costly insurance loss in 2004, including damage to oil rigs in the Gulf of Mexico

Source: SwissRe, 2006

indication of this can be seen in the string of hurricanes[1] affecting the Caribbean and south-east USA in the autumn of 2004. Table 8.3 shows the death toll and disruption caused by these events. Bearing in mind that the overall death toll in Florida for all four hurricanes was 113 and that no deaths occurred in Cuba (where two million people – 17 per cent of the population – were evacuated), you should be able to suggest both the nature of, and reasons for, these disparities.

Of course, these insurance losses were eclipsed in 2005 by Hurricane Katrina, which generated an estimated $45,000 million worth of insurance claims (SwissRe, 2006). This extreme event also drew attention to the fact that economic and social disparities do not just exist at the global level, but within countries also. The controversy over the disproportionate impact of Hurricane Katrina on poor, black communities in New Orleans is well known: with a pre-Katrina population of 485,000 in the city, around two-thirds were black. By the end of 2006, the city was half the size and only half the population was black, suggesting that African-Americans were most likely to have been affected, and not the first to return (see also pp. 227–229). In particular, the areas worst hit were low-lying neighbourhoods most at risk of flooding, and mostly inhabited by African-Americans. Chapter 9 on natural hazards develops these points. This draws attention to the fact that climate change impacts will affect individuals and communities, as well as states, in different ways.

There are many factors that contribute to such inequalities, the main one of which is poverty, but others include race, gender and age, as Chapters 2 and 3 have already illustrated with regard to environmental justice. Global and local income differentials (such as uneven terms of trade and uneven development) and their effects, such as poverty, need to be considered. Senegal and Bangladesh (and their neighbours in the Global South) have far fewer resources to mitigate climate change, or prevent it happening in the first place. For example, Haiti, which experienced the worst death toll of the 2004 Caribbean hurricane season, illustrated in Table 8.3 above, is one of the world's poorest countries, suffers badly from deforestation and has no disaster preparedness (Tearfund, undated). Such countries are poorly represented in organisations that are either controlled by the major contributors to global climate change (such as The World Bank and G8) or have the capacity to reduce its impact. Moreover, there are often irresistible pressures to develop in areas of vulnerability, which countries in the Global North are better equipped to avoid or to protect. A report commissioned by the new economics foundation has estimated that global warming will create 20 million environmental refugees a year, with 150 million people displaced by the impacts of global warming by 2050 (Conisbee and Simms, 2003), the overwhelming majority of whom will originate in the Global South. More recently, the Stern Review has presented research that calculates that climate change could generate as many as 150–200 million environmental refugees (that is, 2 per cent of the projected population) by the middle of the 21st century (Myers and Kent in Stern, 2006).

There are also differences in how effects of climate change may be experienced within countries: Box 8.6 explains the gender dimension of climate change which should get you thinking about how other groups (such as children, the infirm or disabled, as well as disadvantaged ethnic groups, as the New Orleans example above clearly illustrates) might experience this differently.

Box 8.6 Gender and climate change

In 1995, the United Nations 4th Conference on Women held in Beijing agreed that a 'gender perspective needed to be incorporated into all policies and programmes so that before decisions are taken, an analysis is made of the effects on women and men respectively'. This has been reiterated at a number of UN conferences subsequently and yet is a long way from being realised. As Box 8.7 below indicates, a recent Conference of the Parties to Kyoto has called for women to be nominated to sit on bodies established under the UNFCCC and the Kyoto Protocol. While women are very poorly represented on national governments and international bodies (mostly well below the 30 per cent required to create sufficient 'critical mass' to change policy in favour of women, Bhattar, 2001), they are frequently prominent among those who suffer the ill effects of climate change, or practices that exacerbate climate change. Consider the following:

- Women in the rural Global South are more likely than men to be in fuel poverty and, as deforestation gains pace, to have to walk increasing distances to collect fuel wood. This affects almost 40% of rural women in Latin America, almost 60% in Africa and nearly 80% in Asia (Bernstein, 2004).
- While there may be Western pressures on countries in the Global South to also reduce greenhouse gases, women in rural areas benefit significantly from having refrigerators and stoves, which respectively reduce disease, and the respiratory problems of cooking with wood, straw and husks (Bernstein, 2004).

(Continued)

- As climate change increases the likelihood of drought and endemic water shortage, this increases the time that women and girls spend on fetching water, which leads to girl children missing school (Denton, 2002).
- 80% of the global refugee community consists of women and children, and 75% of refugees from environmental and natural disasters are reported to be women and children. With increases in the refugee population as a result of environmental problems, this has a disproportionate impact on women and children. Women living in refugee camps are likely to spend an additional 20,000 extra woman hours a year over what they would have expected to spend at home, collecting water and fuel wood (Black, 1998; Stern, 2006).
- 90% of those who died in the 1991 cyclone in Bangladesh were women and children. This was largely as a result of their lack of education in disaster preparedness, and religious–cultural practices which isolated women from men (Fordham, 2003).
- Countries in Europe with greatest female political representation (such as Norway, Sweden and Germany) also tend to have the strongest environmental policies. The Chair of the Commission which investigated the relationship between environment and development (reported as Our Common Future in 1987) was the woman Prime Minister of Norway, Gro Harlan Brundtland. The European Commissioner for Environment in 1995–2004 was a Danish woman named Margaret Wallstrom (during a period in which the EU has taken a global lead on climate change negotiations).

Think about the possible reasons behind the practices illustrated by these statements, and identify some strategies that might mitigate the impacts of climate change without damaging women's lives disproportionately to men's.

The role of the IPCC and other institutions

While there now exists an intergovernmental framework for climate change (The United Nations Framework Convention on Climate Change – see Box 8.7), which has drawn up international legislation designed to reduce the production of greenhouse gases, the failure of the USA, Russia and Australia to ratify this meant that it was still not in force seven years after the Kyoto Protocol was agreed. Russia agreed to ratify the protocol late in 2004, which gave the protocol the number of states needed to bring it into force in February 2005. The path to getting to the situation, in which the necessary 55 per cent of UN member states have ratified the treaty, has been tortuous, and this can be followed from 1988 when the IPCC was set up to investigate climate change.

The drawn-out nature of coming to an agreement on modifying greenhouse gas emissions suggests that there are significant political ramifications. For example, the time period from the initial agreement to reduce greenhouse gases has seen four US national elections involving a change of government with somewhat different views on climate change from its predecessor. International politics may

Box 8.7 Climate change negotiations

Instruments/Dates	Achievements
1988 – Toronto Conference	Agreed 20% cut of greenhouse gases from 1988 levels by 2005. Intergovernmental Panel on Climate Change (IPCC) set up by UNEP and the World Meteorological Organization
1989 – 1st IPCC Assessment Report published	1st IPCC Assessment Report
1992 – United Nations Conference on Environment and Development, Rio de Janeiro	United Nations Framework Convention on Climate Change (UNFCCC) established and agreed to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Also agreed to use the 'precautionary principle'. Ratified in 1993 and annual Conference of the Parties established
1994 – 1st Conference of the Parties (CoP), Berlin	Agreed that firm, and tougher, reduction targets were needed
1996 – 2nd IPCC Assessment Report published	Acknowledged for the first time that human influence on climate change seemed likely
1997 – 3rd CoP, Kyoto	Kyoto Protocol identified what needed to be done to reduce human-produced greenhouse gases: to reduce global emissions by 5.2% of 1992 levels by 2008/12; to show improvement by 2005; Annex I countries must achieve an 8% reduction; established potential for emissions trading; must be ratified by 55 parties accounting for at least 55% of total CO_2 emissions for 1990
2000 – 5th CoP, The Hague	Agreed that mechanisms for action were necessary, although no agreement reached between the USA and Europe on mechanisms
2001 – 6th CoP, Bonn	Agreed on the mechanisms for action: carbon sinks; international carbon trading; technology transfer to less developed countries; plans and targets to be submitted to CoPs
2002 – 7th CoP, Marrakesh	Agreed the terms of implementation. Also, for the first time, invited parties to give consideration to the active nomination of women to any body established under the UNFCCC or the Kyoto Protocol. Agreed to a consultation on technology transfer
2004 – Russia ratifies Kyoto Protocol	Kyoto Protocol entered into force in February 2005
2006 – 12th CoP, Nairobi (2nd Meeting of the Parties, MoP)	Agreed the 'Nairobi Framework', by which six United Nations agencies have launched an initiative to help developing countries – especially in Africa – participate in the Kyoto Protocol's Clean Development Mechanism. First discussions about the shape of an agreement to replace the Kyoto Protocol that expires in 2012

also be a more potent factor than science in determining what action takes place. For example, the UK Chief Government Scientist, Sir David King, warned the American Association for the Advancement of Science that climate change causes a bigger global threat than terrorism, for which he was reprimanded by former Prime Minister Blair (O'Riordan, 2004), although Blair himself argued this line in 2005, as the book's introduction points out. O'Riordan, in discussing this, suggests that Blair's concern was motivated by the UK's relationship with the USA in election year, confirming the highly politicised nature of climate change.

The Conferences of the Parties identified in Box 8.7 have been used to thrash out a number of issues, often with very limited success. For example, in The Hague in 2000, a compromise between the USA (trying to avoid or at least limit international legislation) and the European Union (which has been in the vanguard of legislating for greenhouse gas reductions) failed over the US insistence on the use of 'carbon sinks'. Nevertheless, by the Bonn conference a year later, the EU had conceded the use of carbon sinks, at which point the USA and Australia (another legislation resister) negotiated not only for new plantings to count as action on climate change, but new management practices of existing forests, and changed farming practices. Ultimately, as is now famously recorded, the USA pulled out of the Kyoto agreements on the basis that American interests were not best served by it, and arguing that countries outside 'Annex I' (the signatory countries in the West), such as China and India, should be required to reduce their emissions. That this coincided with the new presidency of George W. Bush underlined the influence that the oil and automotive industries wield in American politics.

That the USA had still not signed the Kyoto Protocol by 2007 represents a major barrier to international achievements to reduce climate change and moves to a low-carbon economy. Ironically, however, a number of US states, including the New England states, and California and Oregon, utilising their power as federated states, have independently signed up to the protocol and are introducing measures aimed at reducing their carbon footprint. Opinion may be turning in the USA: in 2006, a Democratic Party, more sensitive to the need to legislate to mitigate climate change, won control of the Senate and House of Representatives. The film 'An Inconvenient Truth', in which the ex-vice president Al Gore campaigns to raise the awareness of the problems of climate change, also appears to have had an impact on public and some industrial opinion.

This change is mirrored in the UK with the publication of the Stern Review in late 2006, which unequivocally states that 'the evidence gathered by the Review leads to the simple conclusion: the benefits of strong, early action considerably outweigh the costs' (Stern, 2006: ii). The year 2006 appears to have been pivotal with regard to the acknowledgement of climate change as an overwhelmingly critical issue, and it is interesting to contemplate why this may be so. The publication of the Stern Review and the opening of 'An Inconvenient Truth' were both significantly heralded in the media. Politicians have been increasingly eager to align themselves with the issue: witness David Cameron, as leader of the Conservative Party, being filmed examining the retreat of Arctic glaciers in Norway ahead of the 2006 political party conferences, all of which held a 'Climate Clinic' fringe event, put together by an alliance of environmental groups in the UK (*The Independent*, 2006). 'Global warming' received an accolade of style in May 2006 when it hit the covers of *Vanity Fair* magazine as referred to in Chapter 3.

It is no longer surprising to hear business leaders express concern about climate change: from Richard Branson deciding to invest £3 billion in biofuel development for the airline industry (see Chapter 1) to the Confederation of British Industry launching a task force in January 2007 to discuss ways in which companies such as BT, Tesco and BA can tackle climate change, including methods such as carbon taxes and offsetting. According to BBC business editor Robert Peston, 'some of Britain's biggest companies are now admitting climate change is real, dangerous and partly their fault' (Peston, 2007). Despite this, however, national and international policy is still heavily influenced by the agendas of powerful commercial interests, which the next section addresses.

Box 8.8 Policy terms

Carbon sinks: these are biological resources that can absorb carbon, such as forests, grasslands and oceans. The burning of forests, therefore, not only produces CO_2 in its own right, but also reduces the capacity of nature to absorb CO_2.

Carbon taxes: taxes imposed on carbon producing activities. For example, in the UK, car tax is now scaled to the amount of CO_2 a vehicle emits. The owner of a low CO_2 emission vehicle will pay less than the owner of a higher emitting vehicle.

Carbon trading: this enables producers of CO_2 to trade their quotas; thus, one producer not wishing to reduce emissions may buy permits from another who is introducing cleaner technology to reduce its emissions. Trading can take place between industries (brokered through a 'carbon exchange' such as that in Chicago), between governments, or between individuals (see, for example, the RSA's campaign to introduce personal carbon trading).

Carbon offsetting: Defra (2007) describes this as involving a calculation of individual emissions and then purchasing 'credits' from emission reduction projects, which claim to prevent or remove an equivalent amount of carbon dioxide elsewhere, such as by investing in energy efficiency projects or afforestation programmes. These schemes are quite contentious with some environmental organisations, such as Friends of the Earth, suggesting that their value is limited, as they allow people to continue with their resource-intensive lifestyles, rather than change their behaviour to be more environmentally sustainable.

Clean development mechanism: under the Kyoto Protocol, the main formal channel for supporting low carbon investment in developing countries. Governments and the private sector can invest in projects that reduce emissions in fast-growing emerging economies.

Precautionary principle: a requirement on the polluter to take action to reduce likely pollution. This approach replaces an earlier approach that required those suffering pollution to prove its ill effects.

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Reinsurance: insurance companies are finding it increasingly difficult to survive the increasing number of extreme disasters that substantially increase the number of insurance claims. Reinsurance effectively insures the insurers, so that insurance companies can spread their risk. Consequently, when a big insurance claim hits an insurance company, it is able to meet its obligations because it has spread its own risk around a number of reinsurance companies, such as SwissRe and MunichRe.

Technology transfer: this involves the sharing of technology developed in Annex I countries, which will enable less developed countries to introduce clean technology. Agreed under the Marrakesh Accords (see Box 8.7), the UNFCCC has agreed a framework to assess technology needs, establish a technology information system, create environments for technology transfer, provide the capacity building necessary to enable the transfer and provide funding to implement the framework.

Sceptics or visionaries?

Who pays for the research? Can researchers be bought? Are there controls on what researchers are allowed to research into and publish? Climate change science is a social construction that cannot be disentangled from political biases, interpretations and expectations of funders and regulators (Jasanoff, 1990; Wynne, 1994). Both scientific research and monitoring, let alone the integrated assessment process, are triggered by political values and ideological conflict (Jäger and O'Riordan, 1996).

It will come as no surprise, therefore, that business interests collude to finance scientific interpretations that are contrary to established IPCC viewpoints. The American Petroleum Institute, for example, has cooperated with the coal industry to review and critique global circulation models (O'Riordan and Jäger, 1996), while the Global Climate Coalition, set up in 1989 primarily by the oil industry, was formed to provide an alternative view on climate change which would favour the fossil fuel industry, and this has lobbied governments to develop policy sympathetic to its concerns. Another example of the power of industrialists is found in Exxon-Mobil which succeeded in having the chair of the Intergovernmental Panel on Climate Change (IPCC) replaced by someone they found more amenable to the oil and gas industry (O'Riordan, 2004).

In January 2007, Chrysler's chief engineer, Van Jolissant, described climate change as 'way way in the future, with a high degree of uncertainty'. A spokesman from DaimlerChrysler was then reported in the media as stating that 'while the science of climate change remained "uncertain", the company supported concurrent advances in climate science to ensure a fuller understanding of the controversies surrounding this issue and to avoid inappropriate responses by government or private sector' (BBC, 2007).

This tension between the different viewpoints and their supporters was thrown into relief by the broadcasting of 'The Great Global Warming Swindle' in the UK and Australia in 2007, in which a group of climate change sceptics claimed that scientists were at best wrong, or at worst lying, about the extent of anthropogenic climate change. The film provoked heated debate, and was much criticised by eminent panels of scientists in both countries, on the basis of poor evidence underpinning the programme, scientific errors and editorial bias (Climate of Denial, 2007; Jones et al., 2007). The only climate change scientist recruited to the programme claimed that he had been misrepresented, and the programme's director has a record of producing misleading environmental broadcasts that have had to be retracted later (Monbiot, 2007).

Another exercise which has attracted controversy has been the 'Copenhagen Consensus' organised by Bjorn Lomborg (author of *The Skeptical Environmentalist* referred to at the beginning of the chapter), in which he assembled 'eight of the world's most distinguished economists' (Copenhagen Consensus, undated) to rank a range of global problems including climate change, by their responsiveness to investment. Climate change was ranked last. This exercise begs a number of questions which could include: the basis on which the problems were ranked and which eight of the 'world's most distinguished economists' were selected. The criteria for ranking was a cost–benefit rationale, which Chapter 4 has already identified as being problematic for a range of reasons, and when the backgrounds of the economists are considered, it is notable that there is a strong free-trade/libertarian bias and no ecological economists. For example, Vernon Smith is a fellow of the right-wing American 'Cato Institute' which is committed to 'libertarianism, individual liberty, free markets and peace' (Cato Institute, 2007); Jagdish Bhagwati is an advocate of free trade; Thomas Schelling is on record as believing that climate change is an exaggerated threat for the USA (although of serious consequence for the developing world); and Robert Fogel is well known for a controversial analysis of antebellum slavery in the USA, which claimed it was 'a lucrative, robust and rational economic system . . . 35 per cent more efficient than Northern family farms' (Gibson, 2007) – a conclusion which arguably points up the limitations of cost-benefit analysis. The Copenhagen Consensus, then, is a good example of the need to examine the provenance of ideas and claims concerning climate change, and a caution against accepting such claims at face value.

Dealing with the problem

Ultimately, there are two key ways of dealing with the problem of climate change – mitigating against future change or adapting to the resultant change.

Mitigation

Mitigation initiatives approach the problem of climate change by reducing emissions of greenhouse gases, such that likely future rises in greenhouse gases' atmospheric concentrations will be reduced, or reversed. As stated in Article 3.3 of the Framework Convention on Climate Change: 'The parties should take precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects' (UNFCCC, 1994). These analyses depict mitigation efforts as a type of insurance against potentially serious future consequences. A weak version of this precautionary principle is the idea that, in the presence of uncertainty, it may be prudent to engage in policies that provide insurance against some of the potential damages from climate change. In its stronger form, the precautionary principle stipulates that nations should pursue whatever policies are necessary to minimise the damages under the worst possible scenario. This stronger form assumes extreme risk-aversion, since it focuses exclusively on the worst possible outcomes (Lyon, 2003). Such principles can take the form of voluntary or regulated actions.

Lyon (2003) classifies voluntary programmes into three broad categories: unilateral initiatives, negotiated agreements and public voluntary agreements (PVAs). Unilateral initiatives by industry are sometimes referred to as self-regulation and are typically seen as attempts to ward off regulatory threats. They may also produce a range of ancillary benefits, however, including wooing environmentally sensitive consumers and investors, and influencing future regulatory programmes. Self-regulation can avoid the costly process of passing legislation and implementing regulations, and give industry the flexibility to meet environmental goals in a cost-efficient manner. Negotiated agreements are also a means of averting a regulatory threat, but the government, by participating in the negotiation process, can make a clear policy statement and can push industry to go beyond what it would have done on its own. Finally, PVAs are programmes involving government provision of technical assistance in meeting environmental goals, government-sponsored publicity for firms with outstanding environmental records, and information sharing between participating firms. Often, this will result in government agencies including environmental statements in tenders, ensuring environmental goals are met through the economic process.

A plethora of local government initiatives and legislation is attempting to change consumer attitude, such that emissions are reduced at an individual level as well as at the corporate level. For example, mitigation options in the automotive sector include: more fuel-efficient vehicles; the development of alternative fuel sources such as biofuels, and electric and hybrid vehicles with more powerful and reliable batteries; taxation or road tolling for high carbon-emitting cars; lower road taxes for energy-efficient cars; investment in rail and inland waterway shipping to produce a shift away from road use; and encouragement to move from low-occupancy to high-occupancy passenger transportation through the provision of higher-standard, mass transport options.

Adaptation

Many early impacts of climate change can be effectively addressed through adaptation. The array of potential adaptive responses available is very large, ranging from purely technological (e.g. sea defences), through behavioural (e.g. altered food and recreational choices) and managerial (e.g. altered farm practices), to policy (e.g. planning regulations). Many social and economic systems, including agriculture, forestry, settlements, industry, transportation, human health, and water resource management, have evolved to accommodate some deviations from 'normal' conditions. This adaptation rarely includes the extreme events predicted with climate change. Adaptation is also often reactive (undertaken after impacts are apparent) rather than anticipatory (undertaken before impacts are apparent).

Early planning for the impacts of climate change is likely to bring considerable advantages. Many decisions made today will have consequences for decades. It is cheaper, for example, to design new housing or infrastructure to cope with a future climate than to retrofit later. A systematic approach to adaptation planning, such as risk management, will help identify information needs (IPCC, 2007).

The options for successful adaptation diminish and the associated costs increase with increasing climate change. At present, we do not have a clear picture of the limits to adaptation, or the cost, partly because effective adaptation measures are highly dependent on specific, geographical and climate risk factors, as well as institutional, political and financial constraints. As for mitigation, a wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change, and adaptation alone is not expected to cope with all the projected effects of climate change.

It is noteworthy that the Stern Review referred to earlier has concluded that the human and economic costs of adaptation are of such consequence that mitigation '... – taking strong action to reduce emissions – must be viewed as an investment, a cost incurred now and in the coming few decades to avoid the risks of very severe consequences in the future' (Stern, 2006: i).

Summary

This chapter has illustrated some of the uncertainties behind the science of climate change: the inevitable incompleteness of scientific knowledge; the complexity of the very many components in climate change; and the unpredictability of these components, and even more of the synthesis of these components. It has also explored the nature of political and business interests that seek to influence any attempt to regulate factors contributing to climate change, in order to protect their own interest.

As this chapter was being written, there have been a number of claims that climate change is becoming increasingly out of control (McGuire 2004), and concerns expressed that it is of a completely different magnitude compared to other problems facing humanity (Monbiot, 2007). On the other hand, as the chapter has already illustrated, the Copenhagen Consensus has dismissed climate change as 'the least important of the world's immediate problems' and as such not worthy of investment.

What is clear and unarguable is that whatever effects are being felt, and their relative importance or unimportance, these effects are unevenly spread both at the macro (global) and at the micro (as in the community) level. Moreover, there is a clear inverse relationship between those contributing the most to anthropogenic climate change and those experiencing most of the negative effects. What should be done about this is the debate that is laboriously being worked out at the national and global level, and it is a position that a student of environmental issues in general, and climate change in particular, should consider.

At the time of this book's publication, there appears to be an increasing agreement that climate change is, indeed, a major world problem, demanding attention and action. The reasons for this change in perspective are not entirely clear, but are likely to include the nature of the data itself; the high profile of key authorities and their champions, including media stars; the work of high-profile NGOs on climate change (such as Friends of the Earth and Greenpeace); the increasing availability of alternatives to fossil fuels (such as wind and solar power, biofuels and hydrogen), which become more economically feasible and offer profitable opportunities for business; and the high profile of extreme events which, while their link with climate change might not be scientifically conclusive, are persuasively linked to climate change in people's minds.

Note

1. While these severe weather events – creating the highest insured damage of any hurricane season to that date – have been linked to global warming in the popular media, there is debate over the extent to which they are linked, as this chapter has already indicated. However, it is interesting to note that SwissRe, the reinsurance company from which the data is drawn, is now suggesting a link between climate change and severe weather events; likewise, the Stern Review proposes that 'extreme weather events are likely to occur with greater frequency and intensity in the future, particularly at higher temperatures' (Stern, 2006: 132)

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