1 · *Birds and climate change*

1.1 Introduction

This book is about the impact of global climate change on birds, especially on their populations and conservation status, and what can be done about it. Birds are widespread in their distribution and occur in almost all environments. People enjoy watching them and many are easy to observe. As a result, they have long been studied by both amateur naturalists and professional scientists and they are amongst the best understood group of organisms. Data exist on the migration of birds from ringing (banding) studies and the direct observation of arriving and departing individuals, on their historical distribution from museum specimens, archaeology, literary and other sources, and on the timing and success of their breeding from nest recording that span many decades, or in the case of museum specimens, over a century. More recently, quantitative counting and mapping techniques have provided up to 50 years of standardised population and distribution data collection (Møller & Fiedler 2010). The internet is now being used to collect millions of sightings from bird watchers every year, whilst recent technological advances allow almost real-time tracking of migrating birds. These data provide an unparalleled opportunity first to understand the relationship between climate and species distributions and populations, and second to document changes in those distributions and populations occurring as a result of climatic change. Critically reviewing and documenting these kinds of evidence and what they tell us about the impacts of climate change on birds is one of the main purposes of this book, covered in Part 1.

Unfortunately, popular as they are, many bird species and populations are under threat. Of the 10 064 bird species identified around the world, some 13% are regarded as threatened by extinction within the next 100 years. Another 880 species are near-threatened (BirdLife International 2012a). Populations of habitat-specialists and shorebirds are in particular decline (Butchart *et al.* 2010). The threat of extinction which these species face is a real one; 103 species have been lost forever during the last 200 years. There is an urgent need for effective bird conservation to halt these trends. Whilst there have been significant conservation successes, these have only slowed, rather than halted, global rates of biodiversity loss (Butchart *et al.* 2010; Hoffman *et al.* 2010). Conservationists are winning occasional battles, but seem to be losing the war.

Although the majority of threats facing bird populations are attributed to habitat loss and degradation, exploitation and impacts of invasive species (BirdLife International 2000), climate change is regarded as likely to become an increasingly significant threat to birds and other biodiversity during the course of this century (e.g. Thomas *et al.* 2004, Bellard *et al.* 2012, Warren *et al.* 2013). In the second part of the book, we therefore use our knowledge of the effects of climate change on birds to suggest how conservationists should respond. We also consider some of the potential indirect effects of climate change on birds mediated through human responses to the threat, such as through the expansion of renewable energy generation, and how best to minimise these effects. However, before we immerse ourselves in bird biology, in this introductory chapter we aim to set the scene by briefly summarising the most relevant parts of what is now known about the climatic change that we currently appear to be facing.

For more than a decade, of the many environmental issues of concern, the issue of climate change has most captured the attention of the public and policy-makers. Whether someone is persuaded by the science, or is a climate change sceptic, almost everyone has something to say about the matter. We come from the UK, where the temperate oceanic climate means that the weather varies so much from day to day and year to year that talking about it is a famous national foible. Global climate change now gives such conversations an extra edge. Not surprisingly, given the potentially huge impacts of climatic change on human beings and the economic consequences of efforts to limit them (Stern 2007), many of these conversations are about whether rapid global climatic change is really happening and, if so, whether it is driven by human activity. At least part of the reason for this debate is that climate change can be difficult for us as individuals to perceive. How do we know that the climate is changing?

1.2 Climate change observed from close up

The question is a challenging one for us to answer from our own personal experience. So much of our understanding of the world is based upon recent perception compared to an imperfectly remembered or recorded past. This makes it very difficult for us to grasp long-term trends in the climate hidden within the short-term fluctuations of our weather. Hence, measurements of climatic conditions with scientific instruments, such as thermometers, are of great importance. The longest running direct temperature measurement time series in the world comes from England and stretches back to 1659 (Figure 1.1). This graph of annual averages illustrates these fluctuations from one year to the next, which sometimes exceed 3 °C in magnitude. However, when running averages are used to smooth the graph, we can begin to see patterns emerging. The Little Ice Age during the seventeenth century, when temperatures were consistently 1 °C lower than the 1961–1990 average, can be identified. During the nineteenth century there were periods of several years with unusually cold conditions in England: sufficient for the River Thames in London to freeze in winter, which it has hardly ever done during our lifetimes. Most striking of all, though, is the recent warm period since about 1985, which is warmer than any other period since measurements began. Is this enough to convince us of a recent unusually rapid and sustained increase in average temperature in England?

Not really, because the graph shows other periods with consistent sustained trends as well as this one, such as very rapid warming at the end of the Little Ice Age, when the temperature rose by in excess of 1 °C during 10 years. We cannot be sure what is happening from this information alone, long-term and detailed though it is. We need to take a bigger view, and can do that in two ways. We first need to examine a much wider area than just England, even though the weather-obsessed British have the longest

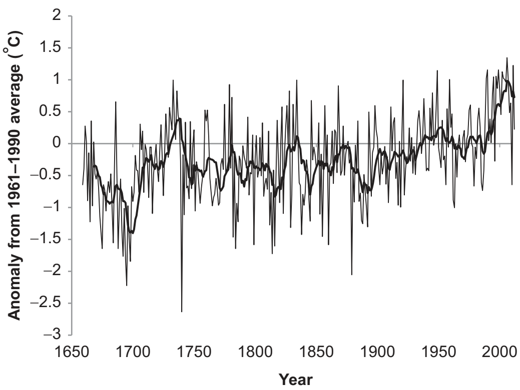

Figure 1.1 Annual variation in the average temperature in Central England, UK, 1659–2010, as measured as an anomaly relative to the 1961–1990 mean (thin line), alongside a 10-year running mean (thick line). Data from www.metoffice.gov.uk/hadobs as published by Parker *et al.* (1992).

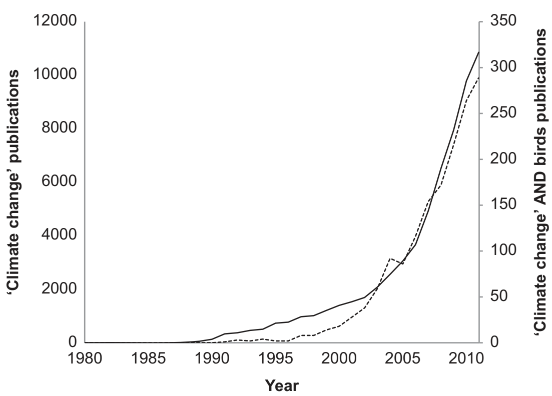

Figure 1.2 Annual variation in the number of scientific papers that have 'climate change' as a keyword (solid line, y-axis) compared to those which additionally include 'bird' as a keyword (dashed line, z-axis).

run of measurements. We also need to look further back in time than 1659. Although this is difficult, as it pre-dates the thermometer record, it is not impossible. We will have considerable help in doing this. As illustrated by a rapidly rising, almost exponential growth in the numbers of peer-reviewed scientific articles published annually about climate change (Figure 1.2), there has been an unprecedented global scientific effort, stimulated, supported and summarised since its establishment in 1988 by the Intergovernmental Panel on Climate Change, to take both the wider and the longer views.

1.3 A wider view of climate change

The equivalent graph of instrumentally measured global average temperature on land (Figure 1.3) to that for central England only starts in 1850 but demonstrates that recent rapid warming is not just local but also a global phenomenon (Brohan *et al.* 2006). Both

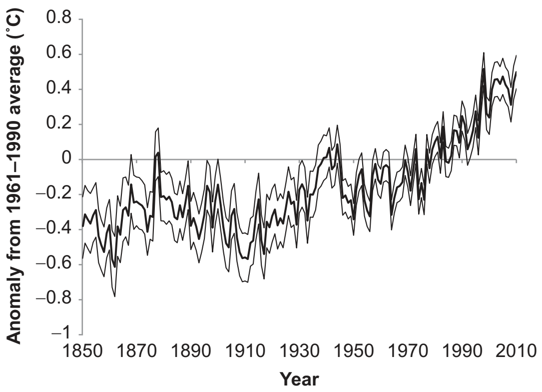

Figure 1.3 Time series of global temperature, 1850–2010 (thick line) based on analyses of data from a range of recording stations, alongside with 95% confidence intervals (thin lines). As in Figure 1.1, temperature is presented as an anomaly relative to the 1961–1990 average. Note the contraction in the level of uncertainty (confidence intervals) through time as the number of recording stations has increased. Data from www.metoffice.gov.uk/hadobs as published by Brohan *et al.* (2006).

the English and global time series show a strong upturn in temperature during the 1980s. Both graphs also suggest the rate of warming may have slowed recently, in response to changing solar insolation, a change in the Southern Oscillation and increasing sulphur emissions (Kaufmann *et al.* 2011), or because more heat is being absorbed by the oceans (Otto *et al.* 2013). Mean global surface temperature is now about 0.7–0.8 °C warmer than it was a century ago (IPCC 2007b). Despite considerable annual fluctuations in the record, 13 of the 14 warmest years in the 160-year time series have occurred since 1995. Sea-surface temperature has increased by 0.7 °C over the same period (Rayner *et al.* 2006).

As a result of changes in atmospheric and oceanic circulation, rates of temperature increase have not been uniform (Figure 1.4). The most rapid temperature increases have occurred at high latitudes in the Northern Hemisphere, particularly in northern Canada and Scandinavia, and around parts of the Antarctic, although there is greater uncertainty associated with these high-latitude trends than for other global trends because they are based upon data from a small number of isolated stations (IPCC 2007b). They are supported by sea surface warming trends, which have been greatest in the north Atlantic, particularly since the mid 1980s, and the north Pacific, associated with phase shifts in ocean circulation (Baines & Folland 2007).

Warming at the poles has occurred particularly during the respective winter periods in each hemisphere (December–February in the Arctic and June–August in the Antarctic; Figure 1.5), which is at least partly related to a positive feedback loop known as Arctic amplification (Serreze & Francis 2006). As the amount of winter sea ice decreases, less incoming radiation is reflected back into space. Heat absorption by the Arctic Ocean is thereby increased, so that ice formation in the autumn, which normally insulates the Arctic Ocean, is delayed. This promotes continued upwelling of warm water to the surface, thus heating both the sea surface and the lower troposphere. The associated reduction in snow cover on the land further reduces albedo and increases heat absorption. This warms the lower atmosphere further, exacerbating the loss of sea ice.

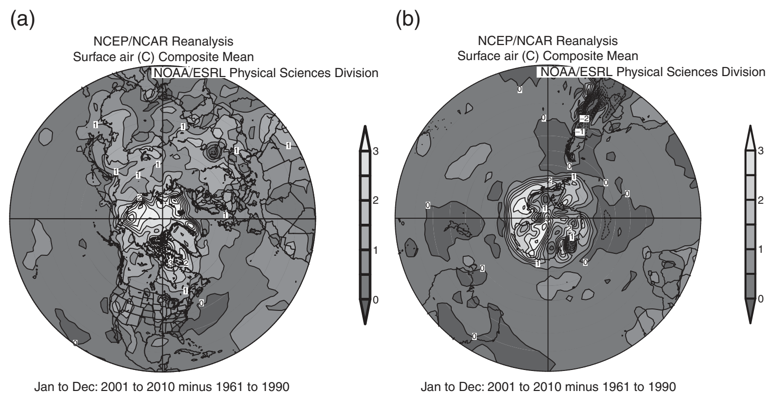

Figure 1.4 Spatial variation in mean annual temperature (2001–2010) relative to the 1961–1990 global average across the Northern Hemisphere (a) and Southern Hemisphere (b). Light areas indicate the areas of greatest warming. Contours denote 0.5 °C intervals. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website at http://www.esrl.noaa.gov/psd/ and based on Kalney *et al.* (1996).

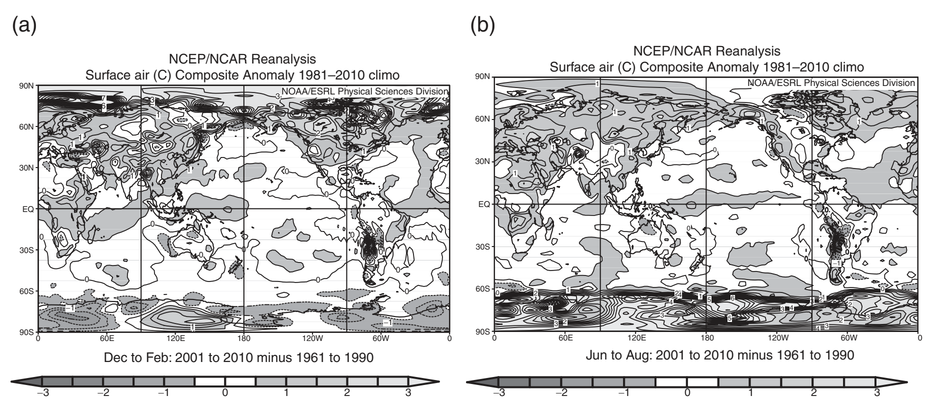

Figure 1.5 Spatial variation in December–February warming (a) and June–August warming (b) as indicated by the (2001–2010) anomaly of mean temperature relative to 1961–1990. White areas indicate stable climates (< 0.5 °C change). Light grey indicates increasing levels of warming, whilst dark grey colours indicate cooling. Contours denote 0.5 °C intervals. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website at http://www.esrl.noaa.gov/psd/ and based on Kalney *et al.* (1996).

Summer warming in the Northern Hemisphere has been greatest in Europe and North Africa, Mongolia and eastern Siberia, Alaska and north-eastern Canada. These trends have led to increased frequency of heat waves, for example in China (Wang *et al.* 2012), the Mediterranean (Kuglitsch *et al.* 2010) and southern states of the USA (Gershunov *et al.* 2009). Temperature increases in the Tropics and Southern Hemisphere have been more moderate, but they are still statistically significant in many areas (IPCC 2007b).

As a result of increasing temperatures, there have been significant reductions in the extent of snow and ice cover in the Northern Hemisphere where a 5% reduction in cover

Cambridge University Press & Assessment
978-0-521-11428-8 — Birds and Climate Change
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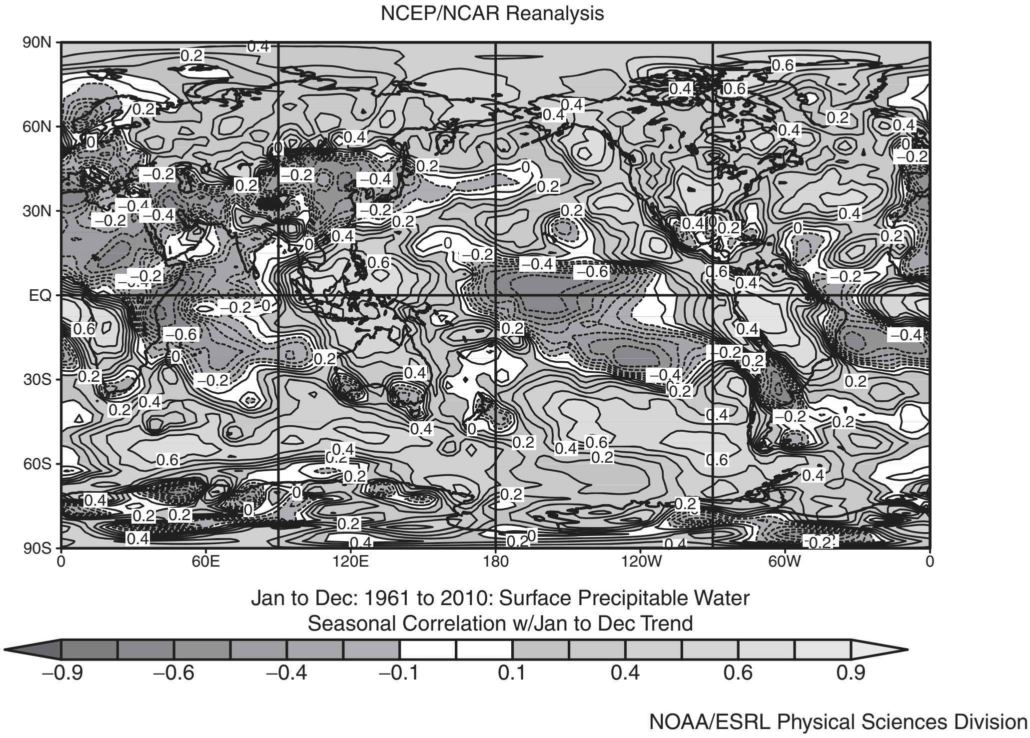

Figure 1.6 Spatial variation in the strength of the correlation between annual variation in precipitation and year, 1961–2010 as a measure of trend. Areas in white show little trend ($-0.1 > r < 0.1$). Annual precipitation increased in light grey areas, but declined in dark grey areas. Contours indicate intervals of $r = 0.1$. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado, from their website at http://www.esrl.noaa.gov/psd/ and based on Kalney *et al.* (1996).

has occurred since the late 1980s. The extent of ice in glaciers and ice caps has also reduced over the same period, particularly in Patagonia, Alaska, the Rocky Mountains and the Himalayas, whilst tropical glaciers have declined in extent by 80% or more since 1900. This has had significant impacts on flow rates in ice-fed rivers (Sorg *et al.* 2012). Arctic sea ice has contracted in extent by 2.4% per decade from 1978 to 2004, although no overall change in Antarctic sea ice extent has occurred over the same period. Here, the rate of warming has been limited by strong circumpolar winds which reduce the transfer of heat from the tropics to the poles. Largely as a result of the thermal expansion of seawater associated with warming, there has been a 7.5 cm rise in mean sea level between 1961 and 2003 (IPCC 2007b; Hurrell & Trenberth 2010; Serreze 2010).

Although there have been no strong trends in global precipitation during the last century, there have been fluctuations between wet decades such as the 1950s and 1970s and dry decades such as the 1990s. There has also been considerable regional variation in precipitation trends (Figure 1.6). Western Amazonia, south-east Asia, equatorial West Africa and much of North America have experienced significant increases in precipitation over the last 50 years (IPCC 2007b). Conversely, a continuous band from the Mediterranean and North Africa, through central Europe, the Middle East, East Africa,

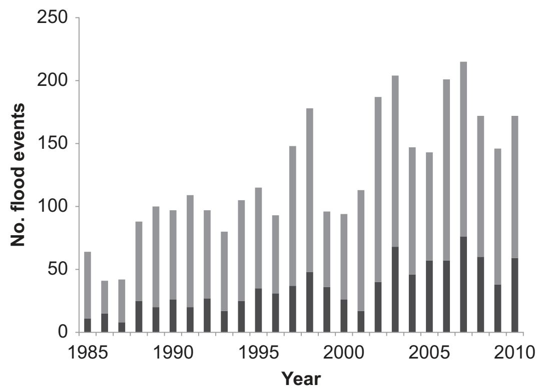

Figure 1.7 Increases in the frequency of severe (grey bars) and very severe (dark grey bars) floods in recent years. Flood magnitude is calculated from a severity class (based on the likely recurrence interval and equals 1 for events with a 10–20 year interval, 1.5 for a 20–100 year interval and 2 for a > 100 year interval), duration (days) and the size of the affected area (km^2). Magnitude = Log (severity*duration*area). A flood with an M>4 is listed as severe, and an M>6 is very severe. These data were collated by the Dartmouth Flood Observatory (Brakenridge 2012).

southern India and China has suffered significant reductions in precipitation levels, which can be linked to changes in tropical sea-surface temperatures (Dai 2010). Combined with the increases in temperature, these changes mean that areas of drought have increased significantly, with central North America, the Cerrado of Brazil, the Mediterranean, Central Africa, the Middle East, China and Western Australia having experienced higher frequencies of drought in the last decade, relative to 1961–2000 (IPCC 2007b).

Given that the water holding capacity of the atmosphere increases by 7% for every 1 °C rise in temperature (the Clausius–Clapeyron relation), increased global temperature has led to more intense precipitation events when they occur. As a result, there have been increases in the frequency of heavy precipitation events that have contributed to a rise in severe flood events around the world during the last 25 years (Figure 1.7). Related to this, there has been a significant increase in the intensity and duration of tropical storms since the 1970s, although such storm events are strongly related to El Niño fluctuations. Thus, there has been a 75% increase in the number of category 4 and 5 hurricanes, particularly in the North Atlantic, Indian and south-west Pacific oceans (IPCC 2007b). Although there has been no overall trend in the frequency of extreme snowfall events, there have been some significant regional trends, with increases in heavy snowfall in parts of northern and eastern United States (Kunkel *et al.* 2009), northern and eastern China (Sun *et al.* 2010) and Europe, which appear to be related to declining Arctic sea ice (Liu *et al.* 2012).

To conclude, warming has been widespread both on land and at sea, and particularly apparent at high latitudes, resulting in significant changes in ice extent, most obviously in the Arctic. There have been significant and interrelated changes to ocean and atmospheric circulation systems which influence the spatial pattern of warming and precipitation change. The main change at lower latitudes has been an increased frequency of drought risk, particularly in the Mediterranean and parts of northern and east Africa and the Middle East. Other parts of the globe have suffered an increased risk of severe rainfall events causing flooding and increased frequencies of tropical storms. The climate has changed in our lifetimes, but is this change significantly different from what has occurred before?

1.4 A longer view of climate change

The idea of past large cyclical changes in global mean temperature, including cold ice ages of global scope, was first proposed in 1837 by the Swiss scientist Louis Agassiz, as a consequence of his geological observations. Since then, much remarkable evidence has been amassed about their magnitude, frequency and causes, which lie in cyclic variations in the Earth's orbit and rotation, amplified by changes in greenhouse gas concentrations. If large changes in global mean temperature have occurred in the past, then perhaps the recent increase in global mean temperature does not require any special explanations or warrant concern.

To place the directly measured changes in global mean temperature of recent centuries into a longer term context at first seems impossible because thermometers were not invented until the sixteenth century. However, palaeoclimatologists have found a wide variety of proxies for air and water temperatures that allow the temperature record to be constructed back in time over thousands and sometimes millions of years. Some of these involve studies of the growth rates of living organisms or the evidence of growth left within their fossilised remains, that can be related to temperature, such as growth lines in trees and marine corals. Variation in the growth of plankton populations can also be related to temperature and measured by the thickness of annually deposited layers in sediments. Alternatively, modern data linking the geographical distribution of different closely related species to temperature can again be used to infer long-term temperature records from the identification of the most prevalent species amongst the remains of pollen, plankton or midge mouthparts preserved in bog, lake or marine sediments.

The validity of these reconstructions depends upon the critical assumption that the biotic relationships with temperature that we measure now have not changed from those in the distant past. Although apparently reasonable, we cannot be certain of this due to potential effects of other environmental changes upon these species, or evolutionary adaptation altering the physiological and ecological responses of species to temperature. To guard against this, proxies of many different types are often used, since it is unlikely that very different types of organisms would all change their responses in similar ways.

An even better method is to use proxies that depend upon chemical or thermodynamic principles that do not change over time. Some of these also involve living organisms. Proportions of different stable isotopes of oxygen incorporated into the skeletons of planktonic foraminifera and marine corals vary with temperature because of well-established effects of temperature on isotope ratios in the water around the living organisms as they grow. By measuring the isotopic composition of preserved remnants of the skeletons, past temperatures can be estimated. However, the best known palaeoclimatic temperature reconstructions do not involve living things at all. Proportions of the different stable isotopes of oxygen and hydrogen in annually deposited layers of ice drilled from the ice caps of Greenland and Antarctica provide information on the temperature of the seawater that gave rise to the vapour that eventually became the snow that fell onto the ice cap. Painstaking measurements of isotope ratios from ice cores and dating of the layers from which the samples came allows a biology-free proxy record of past temperatures to be constructed. In the case of the EPICA ice core from Antarctica, this record extends back 800 000 years before the present (Lambert *et al.* 2008). Combined, these records of the palaeoclimate indicate that temperatures in the past few decades are high relative to any other period in recent centuries (e.g. Alley *et al.* 2010). In the Northern Hemisphere, for which temperature reconstructions are best developed, it is likely that the average temperature in the last 50 years is higher than in any other 50-year period in the last 1300 years (IPCC 2007b).

Looking further back, during the last interglacial (130 000–116 000 years ago; Kulka *et al.* 2002), the Earth may have been warmer than at present. As a result, there was also probably less glacial ice then than there is now (Stirling *et al.* 1998). While the rate of current climate change during the twentieth century was thought likely to be ten times greater than the 4–7 °C warming which occurred at the end of the Last Glacial Maximum (21 000 years ago; IPCC 2007b), more recent evidence suggests that this may not be the case. High-resolution ice-core data from Greenland suggests temperature changes occurred at a rate of 2–4 °C per year during this period also, leading to a shift in polar atmospheric circulation in less than 4 years (Steffensen *et al.* 2008; see also Brauer *et al.* 2008; Bakke *et al.* 2009).

Change has therefore long been a feature of our planet's climate. Previous climates have been warmer than at present, and may also have warmed at least as rapidly at present. What then is unique about our current 'climate change'? The answer is the origin of the recent warming. There is considerable evidence to suggest that the change that we are currently experiencing is anthropogenic in origin. We are warming the planet, and therefore if such warming continues, there is considerable potential for future climate change to be much greater than experienced in the recent past, or even in the palaeological past. For example, a further 2 °C rise in global temperature would mean that world climate would be warmer than that experienced for 2.5 million years (Williams *et al.* 2007).

1.5 The causes of recent rapid global climate change

To understand the causes of recent global change, we need to first understand the tools used by climatologists to answer this question and examine what is known as attribution, the process of establishing the most likely causes of change. In particular, climatologists use detailed computer models of the atmosphere, oceans and, increasingly, also the biosphere, to examine the extent to which predictions from their current understanding match the changes which have been observed. Based on a good understanding of the mechanisms responsible for our weather and climate, built up over decades of observation and research, these General Circulation Models (GCMs) seek to incorporate, at as fine a spatial scale as computer power permits, the physical processes which drive global climate and as many of the interactions between those processes as possible. The main elements of a GCM are therefore an atmospheric model coupled with models of ocean circulation, the land surface and sea ice. The validity of the model is then rigorously tested by examining how well it can reproduce both the instrumental record of recent climate and the palaeoclimate proxies of past millennia. Different research groups have developed

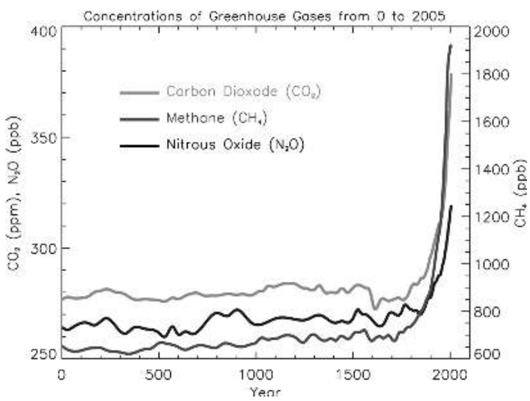

Figure 1.8 Atmospheric concentrations of important long-lived greenhouse gases over the last 2000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. The figure is taken from *Climate Change 2007: The Physical Science Basis*. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ 2.1, Figure 2. Cambridge University Press (IPCC 2007b).

different GCMs and often each has several variants. None of the models describe (retrodict) observed climate or proxies perfectly, and they can vary considerably in the ways in which they fail to match observations. To allow for these differences, a frequently used approach is to average results from several GCMs with contrasting assumptions. This 'ensemble' approach to modelling means that the extent of agreement between outputs of the different models can be used to assess the probability that a particular outcome is robust.

Having developed models with outputs that approximate observed past climatic change reasonably well, they can then be run with different levels of various potential drivers of climate change in order to attribute the most likely cause of the recent warming observed. Special attention has been given to the effects of changes in the concentrations of greenhouse gases. It is well known that increased concentrations of a greenhouse gas in the atmosphere lead it to absorb more of the infrared radiation that is emitted from the surface of the Earth, and that would otherwise be lost to space. Hence, the atmosphere becomes warmer. Careful long-term measurements of greenhouse gases in the atmosphere show that concentrations of carbon dioxide (CO_2) have increased by 38% over the last 150 years, levels of methane (CH_4) by 148% and nitrous oxide (N_2O) by 9% (Figure 1.8). These changes are far in excess of the natural variability in these concentrations measured in bubbles of air trapped in Greenland and Antarctic ice over the last 20 000 years, and are in large part due to human actions. Carbon dioxide has increased because it is released by the burning of fossil fuels and the clearing and burning of forests; methane because of increased rice cultivation and livestock production; and nitrous oxide because of vehicle exhausts and fertiliser application to farmland.

The greenhouse gases vary in their initial concentrations and tendency to absorb radiation, so the scale of the increases does not on its own tell us the likely impacts on