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Global Warming, Local Causes

The world is getting warmer. Eleven of the 12 warmest years on record in the whole world have occurred in the past 12 years.[1] Sea levels are rising, ice sheets and glaciers are melting, and between 15 and 37 percent of all species that live on land could be committed to extinction in the next 50 years as a result of climate change.[2]

What is causing this? Is it due to human activity or just natural variability in the Earth's climate? And does it matter anyway? In this chapter we explore the facts about global warming and its causes. We show that unsustainable consumption of the Earth's resources lie at its root. Finally, we discuss why global climate change and sustainable lifestyles are so important to a world facing other major problems such as water quality, sanitation, famine, and flood.

The Greenhouse Effect

The temperature at the surface of the Earth, averaged across the entire globe over a long period such as a decade, is about 14°C. It is this equable temperature that makes human life possible: if it were less than 0°C the entire surface would be an icy waste; if more than 100°C all the water would have boiled off. The surface temperature is dependent on the balance between incoming energy from the Sun, which acts to warm the surface of the Earth and the atmosphere, and the outgoing loss into space of infrared radiation from the Earth and atmosphere, which acts to cool the Earth. There must be a long-term balance between the incoming and outgoing radiation, otherwise the Earth would inexorably heat up or cool down.

The amount of energy reaching the Earth from the Sun is huge. At the equator, when the Sun is directly overhead, every square meter receives 1370 watts. At higher latitudes the Earth's surface is oblique to the Sun, so the average input from the Sun across the whole globe is rather less, averaging 342 watts for every square meter (this is equivalent to the heat output from nearly 4,000 electric fires in an area the size of a soccer field). It would rapidly get extremely hot if this energy were not reradiated back to space. However, there is one important change when the energy is reradiated. The incoming energy from the Sun is largely in the form of visible sunlight. But energy emitted from the soil and plants at the surface of the Earth is in the form of invisible infrared radiation. Infrared radiation carries just as much heat, as anyone who has used an infrared electric cook top will know, but is invisible to the human eye.

The significance of the change in the form of energy (technically known as the wavelength) between incoming and outgoing radiation is that it allows the greenhouse effect to operate. The gases in the atmosphere that envelops the Earth act as a blanket to keep the surface of the Earth warmer than it would otherwise be because they absorb infrared radiation but are transparent to the Sun's incoming radiation. The glass in a greenhouse has similar properties, which is why this phenomenon is known as the greenhouse effect (Figure 1.1). The glass in a greenhouse transmits almost unimpeded the incoming Sun's radiation in the visible spectrum, which warms up the soil and plants inside. The soil and vegetation then emit that energy in the infrared spectrum. Since the glass absorbs infrared radiation and re-emits some of it back into the greenhouse, the inside of the greenhouse warms up.[3]

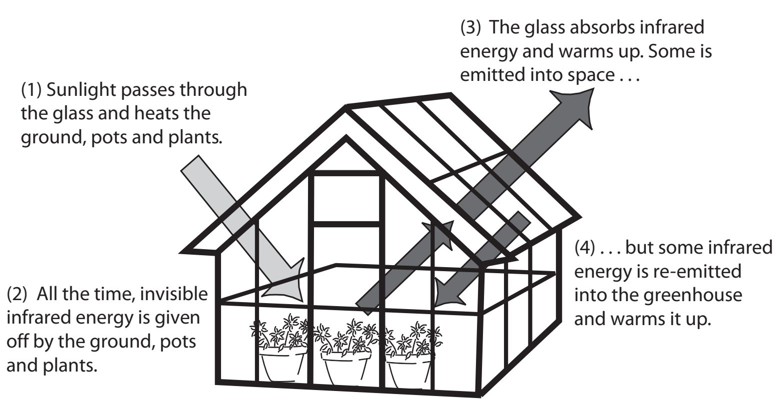

Figure 1.1 Illustration of the greenhouse effect

This effect was first recognized by the French scientist Jean-Baptiste Fourier in 1827. Around 1860 a British scientist, John Tyndall, measured the absorption of infrared radiation by water vapor and carbon dioxide and suggested that a decrease in the greenhouse effect of carbon dioxide might be a cause of the ice ages. In 1896 a Swedish scientist, Svante Arrhenius, calculated the effect on the global temperature of increasing the concentration of carbon dioxide: he estimated that doubling the atmospheric concentration would increase the global average temperature from 5 to 6°C. That value is not so far from our present estimates using complex computer simulations.[4] So the basic mechanism of the greenhouse effect has been understood for over a century, and it was worked out, appropriately enough, by international scientists.

The atmospheric gases that cause the greenhouse effect are not static like the glass in a greenhouse, so a more rigorous explanation is required to show why an increase in the concentration of greenhouse gases causes an increase in global temperature. As more greenhouse gases are pumped into the atmosphere, they thicken the layer of the blanketing gases. So just as adding an extra blanket or duvet on your bed increases the temperature in it, so too does thickening the layer of greenhouse gases cause an increase in the temperature at the surface of the Earth.

The bulk of the atmosphere is made up of oxygen and nitrogen which neither absorb nor emit thermal radiation. So if they were the only constituents of the atmosphere, there would be no greenhouse effect and the average temperature at the Earth's surface would be about 30°C lower, or -16°C, well below the freezing point of water, and the Earth would be uninhabitable. Fortunately, the atmosphere contains several natural greenhouse gases, including water vapor (which condenses to form clouds), carbon dioxide, ozone, methane, and nitrous oxide. Of these, the largest greenhouse effect comes from water vapor, which accounts for about two-thirds of the greenhouse warming. Carbon dioxide is the next most important greenhouse gas. Human activity is not directly increasing the water vapor content of the atmosphere, but, as we shall see later in this chapter, humankind is dramatically and very rapidly increasing the carbon dioxide content: carbon dioxide has already increased by about 38 percent (equivalent to 600,000 million tons of carbon) in the last two centuries. It is this that is beginning to cause a major change in the global climate systems, with an overall increase in surface temperature—global warming.

Greenhouse Gases

Which greenhouse gases should we worry about most? Since the concentration of water vapor in the atmosphere is mainly controlled by the temperature of the sea, in the long term human activity will affect the amount of water vapor indirectly, via global warming. This may amplify the global temperature increase by as much as 40 to 50 percent. However, over the last 200 years it is the increase in carbon dioxide which has contributed most to enhancing the greenhouse warming effect of the atmosphere, accounting for about 70 percent of the warming since pre-industrial times.

Most of the increases in greenhouse gases have been caused by burning fossil fuels (coal, oil, and gas). A smaller, but significant component is due to the destruction of forests, particularly in tropical areas. A surprisingly large percentage of the effect of global greenhouse gases—18 percent, which is more than the entire transport sector—comes from the 1.7 billion cows in the world: each animal releases about 500 liters of methane per day, which accounts for more than one-third of all methane caused ultimately by human activity.[5]

The long-term impact of a greenhouse gas on climate depends on two main factors: how long it stays in the atmosphere (the longer it stays, the more time it has to exert a warming influence), and its potency in absorbing outgoing infrared radiation. If the extra gases emitted by human activity into the atmosphere were all absorbed back immediately into the oceans, or into vegetation (which are the two main repositories of carbon on Earth), then there would be little long-term effect. But unfortunately the Earth reacts on a much longer timescale. Carbon dioxide stays in the atmosphere for up to 100 years, while some gases, like nitrous oxide, remain in the atmosphere for much longer than that.

In order to compare the capacity of different greenhouse gases to cause global warming, a useful measure is to calculate the future warming effect of the gas emitted today over the next 100 years, compared to the effect of the same amount of carbon dioxide. This is known as its Global Warming Potential (GWP). Current estimates are listed in Table 1.1: they vary from 1 for carbon dioxide (by definition) to more than 22,000 for sulphur hexafluoride. What this means is that even tiny amounts of sulphur hexafluoride would have enormous long-term effects on the climate. Fortunately, concentrations of sulphur hexafluoride are extremely low, so we do not have to worry about it as much as we do about carbon dioxide.

Gas	*Main sources*	*Effective lifetime in atmosphere*	*Global Warming Potential*
Carbon dioxide	Fossil-fuel burning, land-use changes	Approx. 100 years	1
Methane	Natural gas extraction, agriculture	12 years	23
Nitrous oxide	Fossil-fuel burning, fertilizer use	114 years	296
Chlorofluorocarbons	Refrigerators, aerosol sprays	100–200 years	7,300
Sulphur hexafluoride	Industrial processes	>1,000 years	22,200

Table 1.1 Global warming potentials of 1 kg of a range of greenhouse gases relative to 1 kg of carbon dioxide for a time horizon of 100 years

Source: Data from IPCC 2001: Climate Change 2001: The Scientific Basis, Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. T. Houghton et al., eds. (Cambridge University Press, 2001).

Although carbon dioxide is the least potent of the greenhouse gases, it is the most important one produced by human activity. This is because such huge quantities are being pumped into the atmosphere. Burning fossil fuels accounts for three-quarters of the total carbon dioxide production by humans, while land-use change (mainly deforestation) accounts for most of the remainder.

The main contributor to global warming over the next 100 years, accounting for nearly two-thirds of the effect, will be carbon dioxide (Figure 1.2, see next page). Methane, although much smaller in quantity, makes up for that with its greater global warming potential, producing about one-quarter of the total warming. Nitrous oxide accounts for about 10 percent, with all other greenhouse gases adding up to only a minor contribution. In order to provide a simple measure of the effect of all greenhouse gases in the atmosphere, sometimes they are lumped together into a single measure known as the carbon dioxide equivalent. When targets for concentrations in the atmosphere of greenhouse gases are set, for example by governments, it is important to be clear as to whether they refer to carbon dioxide alone or to carbon dioxide equivalent. If the target is set as a carbon dioxide equivalent, then of course the actual carbon dioxide concentration target will be lower.

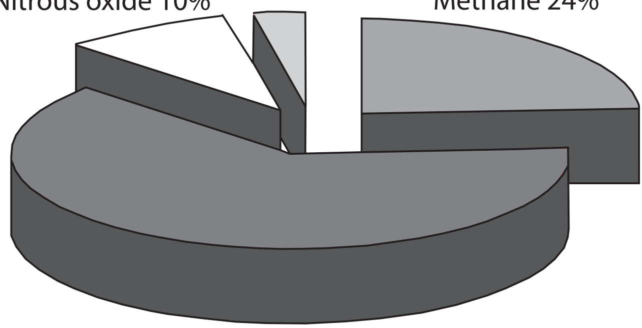

Figure 1.2 Effect of current greenhouse gas emissions as contributors to global warming over the next 100 years

Source: Data from IPCC 2001: *Climate Change 2001: The Scientific Basis,* Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. T. Houghton et al., eds. (Cambridge University Press, 2001).

Before we move to contemporary issues, it is relevant to see how the Earth's temperature has changed in the past, and how this might compare with what we are likely to face in the coming decades.

Climate on Earth: The Geological Perspective

One of the most striking features of the Earth is that it has maintained a surface temperature favorable to life throughout almost all its history. This certainly requires temperatures to remain above the freezing point of water, 0ºC, and lower than its boiling point of 100ºC, although for life as we know it to thrive the temperatures need to remain in a rather narrower band toward the bottom end of this range.

Scientists date the Earth at 4,566 million years old, a figure considered accurate to within a few million years.[6] Scientists find evidence from carbon isotopes indicate forms of life existing on Earth around 3,850 million years ago. Life was present on Earth almost as soon as the environmental conditions made it possible. Microbial fossils have been found from 3,500 million years ago. The Earth has maintained a temperature suitable for life ever since then, despite the solar output of the Sun having risen by about 30 percent over the same period. No other planet has fared this well. For example, our nearest planetary neighbor, Venus, has an atmosphere with a massive amount of carbon dioxide as its main constituent. This results in a surface temperature of about 500°C—red hot. Venus is much nearer the Sun than is the Earth, and the huge greenhouse effect of the carbon dioxide caused all the water vapor to boil off into space.

On a longer timescale there are well-documented cyclic changes in the global temperature of the Earth of about 9°C. The primary cause of these temperature changes is regular variations in the orbit of the Earth about the Sun, coupled with precession of the tilted axis of rotation of the Earth relative to the plane of its orbit around the Sun. Regular climatic cycles have been identified ranging from 19,000 years to 413,000 years in duration. The effects of these cyclic global temperature changes can be recognized from sediments dating back more than 30 million years.[7]

Global temperature changes of up to 9°C through the last eight ice ages have been estimated by sampling the isotopic composition of bubbles of air trapped in ice recovered from cores drilled through thick ice accumulations in continental interiors such as the Greenland and the Antarctic ice caps. In Greenland an ice core has penetrated back to 123,000-years-old ice, while in the Antarctic a core has reached ice some 740,000 years old.[8]

Average temperature changes of about 5°C are sufficient to switch between an ice age and an interglacial temperate period such as we now enjoy. The last ice age, which ended some 12,000 years ago, was about 9°C colder than at present. In the absence of any human influence, the next ice age resulting from orbital changes would not be expected for some 50,000 years. So we certainly cannot rely on these long-term changes either to explain the current rapid global temperature change or to counteract the effects of human-induced temperature increases. Another striking feature of the climate changes found between ice ages is that they are much greater than those caused by solar radiation changes resulting from variations in the Earth's orbit around the Sun. They also require enhancement of the temperature changes, possibly by interactions between the concentration of carbon dioxide and biological processes.

All of these changes are on far longer timescales than that of human civilization. Scientists find evidence of communities of humans existing since 8000–9000 BC. But the large temperature variations evidenced, for example, by the ice ages and intervening temperate periods serve to demonstrate that the Earth can, and

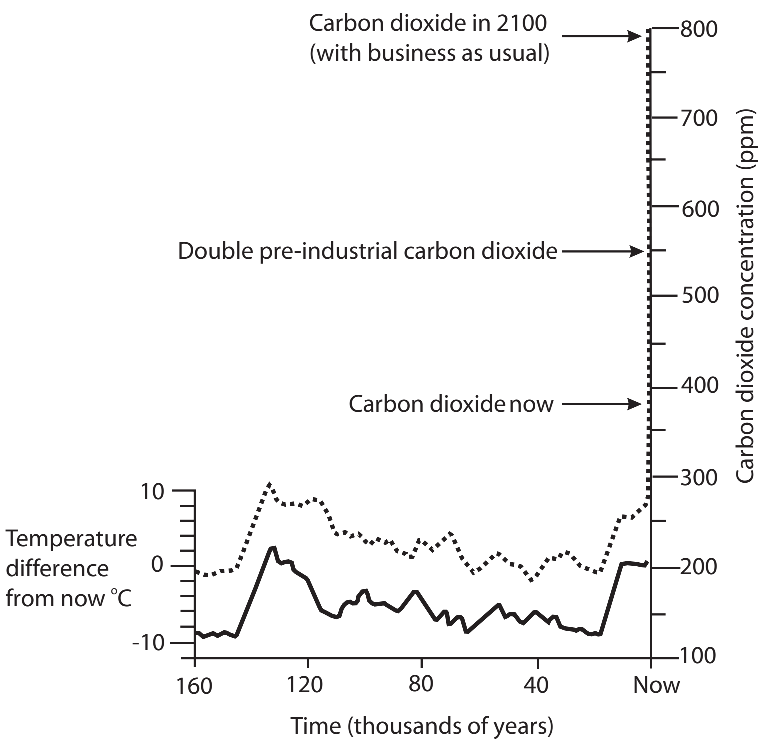

Figure 1.3 Variations of polar temperature and atmospheric carbon dioxide concentrations

Continuous line: variations of polar temperature. Broken line: atmospheric carbon dioxide concentrations.

Source: From D. Raynaud et al., "The Ice Core Record of Greenhouse Gases," *Science* 259 (1993), pp. 926–34.

frequently has, experienced major changes in temperature and climate. We should expect the same to happen again if we dramatically change the volume of greenhouse gases in the atmosphere. The only difference now is that humans are causing climatic change at a speed unmatched in the history of humankind on Earth—and it is that very rapidity which is the crux of the problem, since we now live on an extremely densely settled Earth with limited room for maneuver without megascale human disruption. And we are starting our experiment in global warming from an interglacial warm period where the Earth's climate is already far warmer than the average over the past 600,000 years.

Climate on Earth: The Historical Perspective

The last ice age began about 120,000 years ago and ended some 12,000 years ago. Analysis of air trapped in bubbles in an ice core from the Antarctic over the past 160,000 years shows a close correlation between carbon dioxide concentrations and surface temperatures inferred from the concentration of deuterium, a heavy form of hydrogen (Figure 1.3). Perhaps the most striking point to be made from Figure 1.3 is the unprecedented rapid rise of carbon dioxide in the last two centuries: on the timescale of the graph they appear to be rising almost vertically, just as is the global population shown in Figure 1.4 (see next page). Already carbon dioxide concentrations are 38 percent higher than in pre-industrial times and are higher than at any time in the past 650,000 years. Yet they are certain to rise much higher in the future, as we discuss later.

Carbon dioxide content in the atmosphere was constant at about 280 ppm (parts per million) for 800 years (and probably more) prior to 1800. The carbon dioxide level in 2007 was 384 ppm and is currently increasing at nearly 2 ppm every year.[9] Other greenhouse gases show similar increases since pre-industrial times: methane has more than doubled; nitrous oxide up by 15 percent; and ozone in the lower atmosphere up by about 3 percent.

If we zoom in on the last century and a half, the period of most intense industrial activity by humankind, sufficient direct measurements of surface temperatures are available to make meaningful

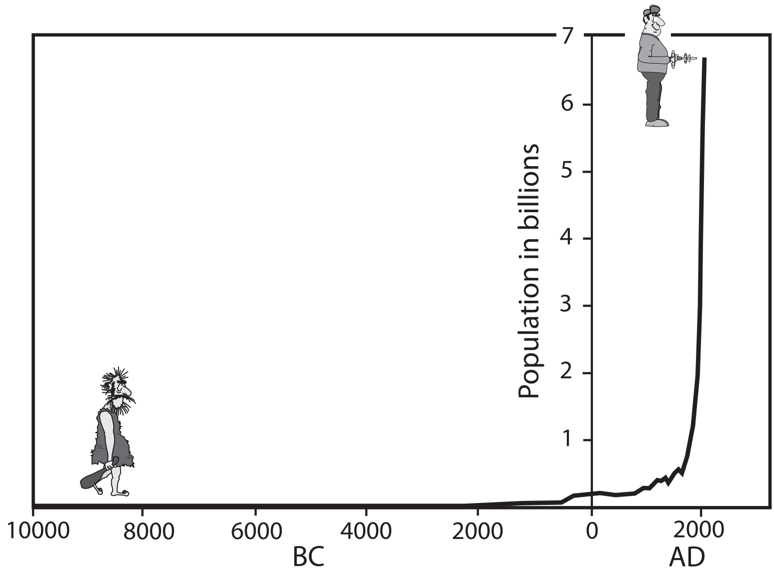

Figure 1.4 Global human population

Source: Values from United Nations Population Division.

global averages (Figure 1.5). Although there is considerable year-to-year variability in the annual-mean global temperature, a clear upward trend can be seen. Some of the variability is natural within the complex climatic system of the Earth; other is due to additional consequences of human activity. For example, atmospheric pollution caused by sulphates and particles, either from burning fossil fuels or from biomass burning, actually causes global cooling because the particles reflect some of the incoming solar radiation before it reaches the surface of the Earth. Similarly, the destruction of natural vegetation and of forests causes the land surface to be more reflective, again leading to a small overall cooling effect. But the addition of greenhouse gases far outweighs any cooling effects. Ironically, as industry in the high-income nations is quite properly required to clean up its emissions, the overall warming trend becomes still more dominant. Pollution from the expansion of heavy industry in the decades following 1940 probably caused the dip in temperatures shown in Figure 1.5. The resumption of an upward trend in temperature from 1970 accompanied the implementation of clean air legislation.

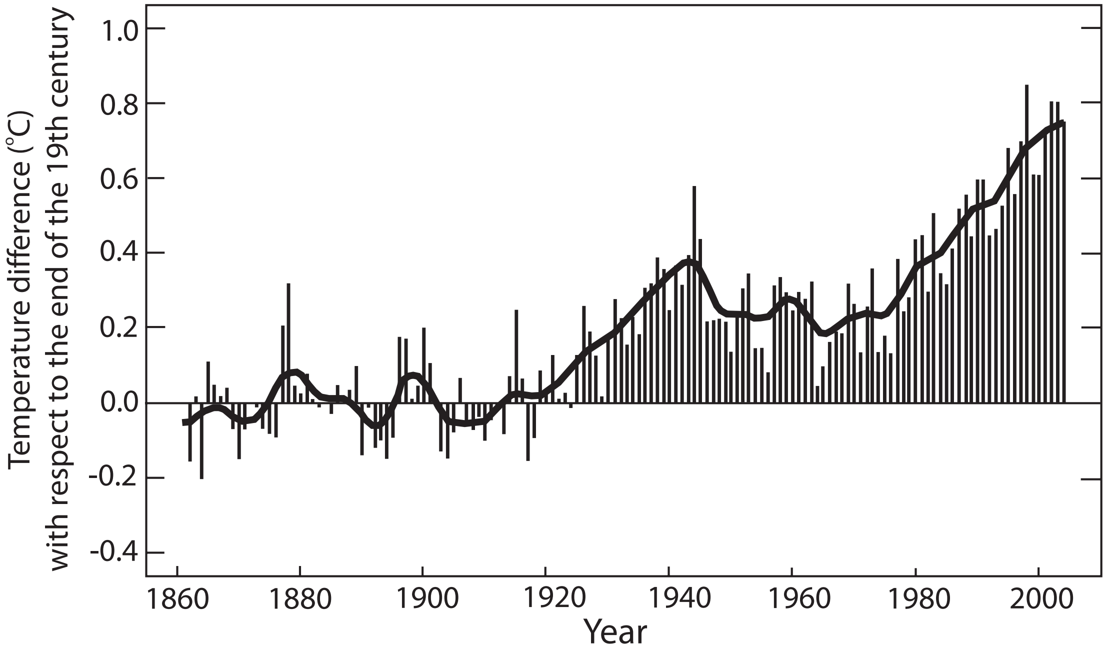

Figure 1.5 Changes in global average surface temperature from 1861 to 2004

Individual annual averages are shown by vertical lines, with the solid line showing the smoothed trend.

Source: Based on C. K. Folland et al., "Global Temperature Change and Its Uncertainties since 1861," *Geophysical Research Letters,* 28 (2001), pp. 2621–24. Updates available from the Meteorological Office Hadley Centre Web site at www.metoffice.gov.uk/climatechange/.

The take-home message is that global warming is real and unequivocal, and is caused by humans.[10] Not only was 1998 the hottest year on record globally, but strikingly, each of the first eight months set temperature records for that month. Successive years, such as 2006 and 2007 have vied for the record. Although the average mean temperature increase so far is less than 1°C, it is sufficient to be noticeable in North America by changes in flowering times for plants and the earlier arrival of spring migratory birds.[11] In our polar regions, such as Alaska and northern Canada, the effects are more dramatic. Over the past 50 years, temperatures have risen by twice the global average. Arctic sea ice has been melting inexorably over the last 30 years, losing about 1 million square kilometers, or 2.5 percent of its area per decade. Summer sea ice was predicted to disappear by the end of this century,[12] but this may occur much faster as seen by the unprecedented melting during 2007.

Effects have reached far beyond retreating glaciers, polar bears, and walrus to disturbing human lives, ecosystems, and the economy. For example, approximately 184 native Alaskan communities are at risk from flooding and erosion due to melting sea ice. Some villages that have been settled for hundreds of years will have to relocate or slip into the sea. Forty-five percent of Yukon River salmon have become infected by a parasite not known prior to 1985, a result of 10°F warming of the river. Four million acres of mature forest were destroyed by the world's largest outbreak of the spruce bark beetle. Warmer temperatures allowed the beetle to mature faster, survive the winter, and devastate trees already stressed by heat and drought.[13] Canada's forests, which cover almost half of the landmass and are a crucial part of their economy, are expected to be the most vulnerable in the world. It is estimated that 80 percent of the mature pine forest of British Columbia is predicted to be destroyed by the mountain pine beetle over the next decade, again the result of warmer winters.[14]

Can we be sure about the scientific story presented above? The answer is that we can be very sure: it is based on work by many thousands of scientists from numerous different disciplines and over 100 different countries. No assessments on any other scientific topic have been so thoroughly researched and reviewed as has the question of global climate, through the Intergovernmental Panel on Climate Change (IPCC). In June 2005, 11 leading academies of science from around the world (the G8 plus India, China, and Brazil) issued a statement unequivocally endorsing the IPCC's conclusions.[15] The IPCC was set up in 1989, and since then has issued four authoritative assessments of climate change, in 1990, 1995, 2001, and 2007,[16] together with many other specialist reports. As each report has been issued the evidence for climate change has become stronger, and the models for expected future changes better constrained with reduced uncertainty.

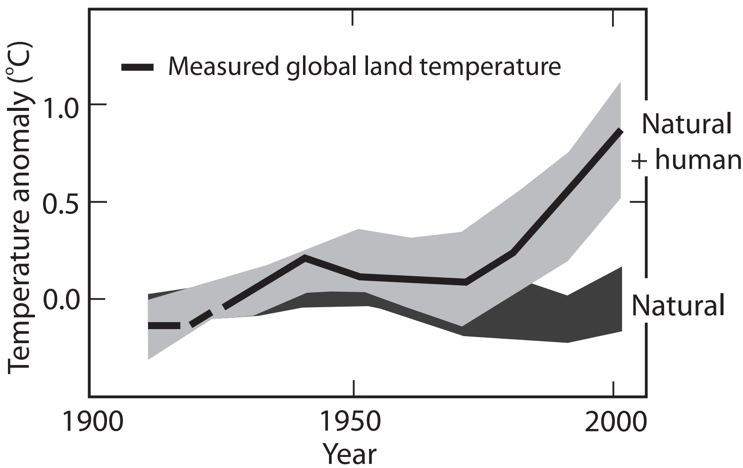

Figure 1.6 Measured global temperature variation over land in the twentieth century, compared to the results of multiple computer simulations of climate change using both natural and nonnatural greenhouse gas emissions

Dark-shaded band: results of multiple computer simulations of climate change using only natural factors. Light-shaded band: simulations using both natural and nonnatural greenhouse gas emissions.

Source: Redrawn from IPCC, *Climate Change 2007: The Physical Science Basis, Summary for Policymakers* (2007).

Could the observed climate change be due to natural variations rather than human causes? Figure 1.6 shows the observed global temperature variation over land in the twentieth century (solid black line), compared to the results of numerous computer simulations of climate change using only natural factors (dark-shaded band). It is clear that although the natural factors produce small variations in global temperature, they do not begin to match the observed temperature increase. However, once the effects of greenhouse gas emissions by humans are included (light-shaded band) the predictions match the observations well.

Unfortunately, there are strong vested interests that have spent tens of millions of dollars on spreading misinformation about the climate change issue.[17] They first denied the scientific evidence and have argued more recently that its impacts will not be large, that we can "wait and see" and that in any case we can always "fix" the problem if it turns out to be substantial. The scientific evidence cannot support such arguments.

Future Projections

The response of the surface temperature of the Earth to a sudden injection of greenhouse gases into the atmosphere is complex and generally sluggish. This means that even if humans completely stopped emitting any more greenhouse gases with immediate effect, we have already committed the Earth system to wide-ranging changes in climatic patterns, to overall global warming and to sea level rises, which will take centuries to work through. This is partly due to the long periods over which greenhouse gases remain in the atmosphere before being removed into the oceans or the vegetation and soils of the land (Table 1.1 [see p. 15]), and partly due to the huge thermal inertia of the ocean systems. It takes several decades to transfer heat from a warmed atmosphere to the surface waters of the oceans, and then many centuries to spread that heat through the deep ocean circulation system. To add to this complexity there are likely to be a wide variety of biological, chemical, and physical feedback systems that may dampen, or more likely amplify, the global warming effect of the greenhouse gases. For example, once large regions of snow-covered areas or glaciers decrease as a result of melting caused by global warming, the highly reflective snow cover is replaced by less reflective land, so less energy is reflected directly back to space. This leads to yet further global warming.

More difficult to predict are changes to the oceanic circulation system that might be caused by the global warming. For example, the Gulf Stream (or, as it is more properly called, the North Atlantic Drift), carries a huge amount of heat northwards, keeping the British Isles much warmer than, for example, those parts of western Canada at the same latitudes. If it were not for this ocean circulation, the average temperatures in the UK would be from 3 to 5°C cooler. Could global warming cause the North Atlantic Drift to switch off, as has happened more than once in the past? In principle it certainly could because several mechanisms associated with global warming could cause a decrease in density of the surface waters in the northern North Atlantic, which could then reduce and eventually switch off the ocean circulation system.[18] Fortunately for those in the United Kingdom, current models for realistic future scenarios suggest that although the Atlantic Ocean circulation is likely to decrease in strength from 15 to 25 percent by 2100, the decrease in heat carried by the Gulf Stream would be more than offset by direct greenhouse warming.

Despite the complexities of climate models, and the range of uncertainty in some of the feedback mechanisms, continuing improvements in the power of computers used for modeling, plus continual improvements in the long-term measurements relevant to global warming collected worldwide is leading to improved confidence in the predictions. More difficult to quantify is the likely future behavior of humanity. At one extreme is the "business as usual" response, which ignores any possible damaging effects of our behavior on others; at the other extreme would be the unrealistic scenario of a complete stop in the production of greenhouse gases. In the middle lie a range of realistic responses, such as attempting to stabilize global atmospheric carbon dioxide equivalent between 450 to 550 ppm; this represents a range of 400 to 490 ppm in terms of carbon dioxide alone, the lower limit of which will be reached within a decade. The upper limit would cause an estimated average temperature increase of about 3 °C,[19] although the uncertainties in predictions of the future and of feedback mechanisms that might operate mean that the temperature might still rise much more, even in this optimistic case. But at least there would be a limit to it, and appropriate adaptation procedures for the worst effects could be put in place.

The IPCC spent a considerable amount of effort outlining a range of realistic scenarios,[20] and in the following sections we will use their results to outline likely consequences of our behavior. What emerges is that our behavior thus far has already led to irrevocable effects on the Earth's climate.

Fossil Fuel Supply

There are still enormous quantities of fossil fuels available underground, and unless concerted action is taken to reduce or mitigate the effects of their consumption the likelihood is that we will keep extracting them. To date we have used about half the easily available oil. Although experts disagree whether or not we have already passed "peak oil," the year with the highest rate of oil extraction, they are all agreed that, even if we haven't done so already, we shall do so within a decade or thereabouts.[21] After that the rate of oil production will decrease. We have used less than half of the natural gas and there are massive amounts of coal still available (see Figure 1.7). On present rates of usage, oil would last another 40 years, gas well into the latter third of the twenty-first century and coal for another 150 to 250 years.[22] This is without even considering unconventional sources of oil such as oil sands and oil shales, or the production of coal bed methane gas. These latter are all much "dirtier" than oil and would have a much greater greenhouse effect on the Earth than burning oil. Coal already accounts for 40 percent of all electricity generated worldwide, and is the biggest single source. In China, in 2008, a new 1 Gwatt low-technology coal-fired power station was commissioned every five days, so it is likely that coal will remain a widely used fuel through the twenty-first century.

It is not only the consumption of fossil fuels, but the extraction process as well, that contributes to climate change, both through the destruction of natural carbon sinks and direct greenhouse gas emissions. Alberta Canada's oil sands contain the second largest source of petroleum in the world, behind those of Saudi Arabia. The open pit mining technique required to extract this resource destroys the boreal forest and natural muskeg of the area. While oil companies are required to restore the land after mining, they are not required to restore it as forest, so much has been converted to pasture. It is estimated that for every barrel of oil produced from the oil sands, 80 kg of greenhouse gases are emitted into the atmosphere, three times the amount resulting from the production of oil by conventional methods. Yet this resource has the potential to satisfy the world's oil needs for several hundred years. Alberta's oil sand production has become Canada's fastest growing source of carbon dioxide emissions.[23]

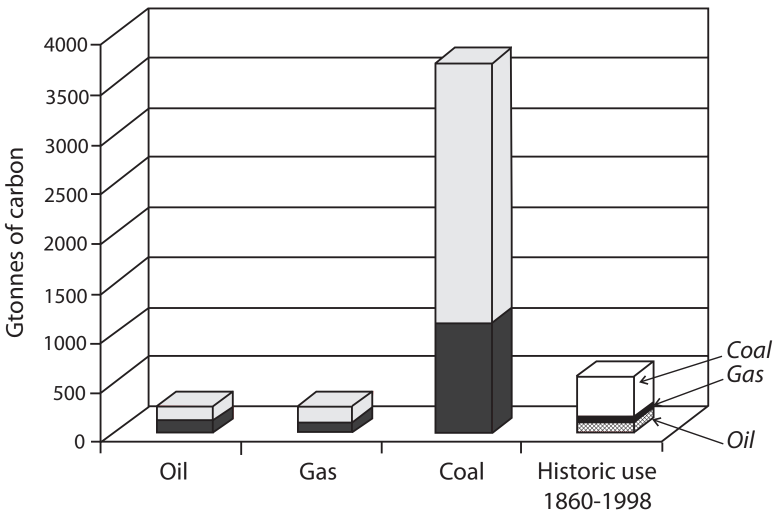

Figure 1.7 Estimated reserves of fossil fuels with upper limits and amount of fossil fuel burnt to date

Estimated reserves of fossil fuels with upper limits (light shading). Right-most column shows amount of fossil fuel burnt to date.

Note: Figures are from www.ipcc.ch and do not include unconventional sources of oil such as oil sands and oil shales or unconventional gas resources such as coal bed methane, which would treble the total oil and gas resources that could potentially be extracted. For approximate conversion from tonnes of carbon to tonnes of carbon dioxide, multiply these figures by 3.2.

There is little doubt that if humanity chose to do so, it could readily burn all this fossil fuel and overheat the planet. It does not make much difference whether we slow the rate of usage or use it as fast as possible: the end result would be much the same because the main greenhouse gases remain in the atmosphere for around a century. The problem is not one of insufficient supply of fuel: rather it is whether we choose to use it at all, or at least whether we choose to allow the carbon dioxide that results from burning it for energy to enter the atmosphere.

Figure 1.8 (see next page) shows three representative scenarios for the future projection of carbon dioxide emissions from burning fossil fuels.

- A—continuing much as at present, with high carbon dioxide emissions resulting from rapid economic growth and use of fossil fuels, and continued growth in world population which peaks in the mid twenty-first century;

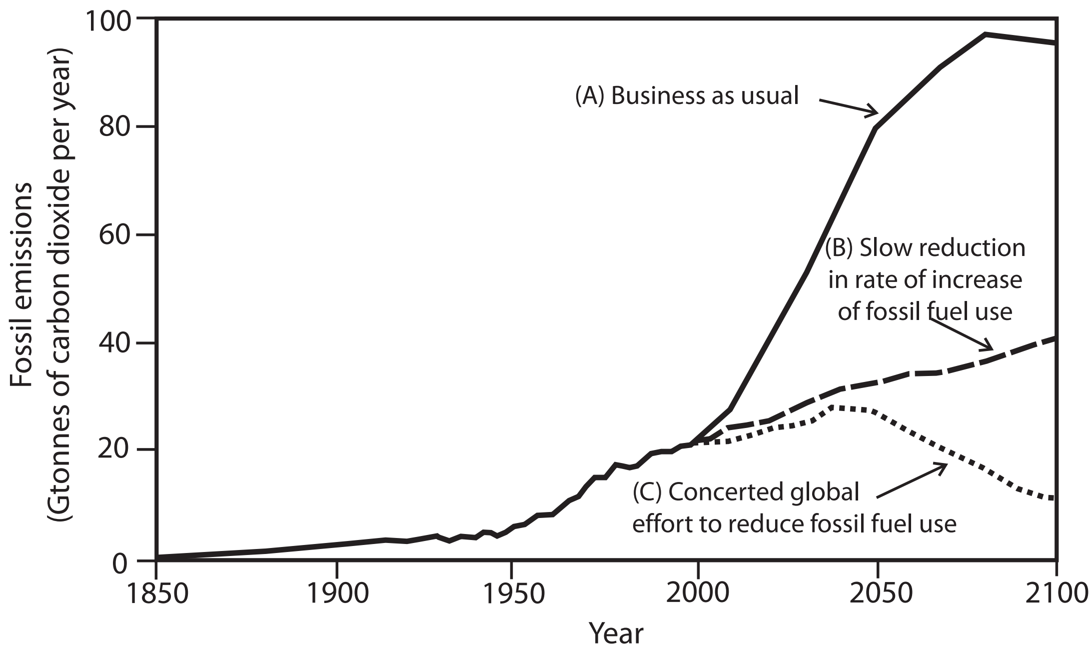

Figure 1.8 Projections of the amount of carbon dioxide produced per year from human activity for the three scenarios outlined in the text

Source: These scenarios are taken from a suite of 35 scenarios investigated by the Intergovernmental Panel on Climate Change, *Special Report on Emissions Scenarios: A Special Report of Working Group III of the IPCC,* N. Nakicenovic et al., eds. (Cambridge University Press, 2000).

- B—medium to low carbon dioxide emissions by lowering the rate of increase of usage of fossil fuels and emphasizing local solutions to social, economic, and environmental sustainability;
- C—low carbon dioxide emissions, with the same population growth as in A, but with a rapid and concerted effort to reduce carbon dioxide pollution through the introduction of sustainable energy.

It is the latter two scenarios with the assumption of a move toward sustainable consumption that we hope will be attainable. However, even the best attainable scenario is likely to lead to considerable global temperature increase.

The worst case (A), where little serious attempt is made at carbon dioxide reduction, causes a fivefold increase in the rate of production of carbon dioxide over present levels during the twenty-first century, and by the end of the century the total amount of carbon dioxide in the atmosphere would reach over 900 ppm, more than three times its pre-industrial level. The two cases that move towards manageable long-term stability of the global climate require either slowly lowering the annual rate of increase of carbon dioxide production below the rate of increase in the latter half of the twentieth century (case B) or, in the best outcome, a decrease in the amount of carbon dioxide generated worldwide back to 1970 levels (case C). Even in the best-envisaged case, the atmospheric concentration of carbon dioxide continues rising long after the rate of increase has been cut back, due to the long period it stays in the atmosphere (as shown in Table 1.1; see p. 15). If we make the most aggressive measures for cutting back carbon dioxide production, we could aim for a global concentration of carbon dioxide in the atmosphere that eventually flattens out at something less than twice its pre-industrial level. And this, like the other even less palatable scenarios, would have multiple effects.

Temperature Increases

The consequences of the carbon dioxide increase for global warming are shown in Figure 1.9 (see next page). All the scenarios, including the most optimistic, predict continuing and large

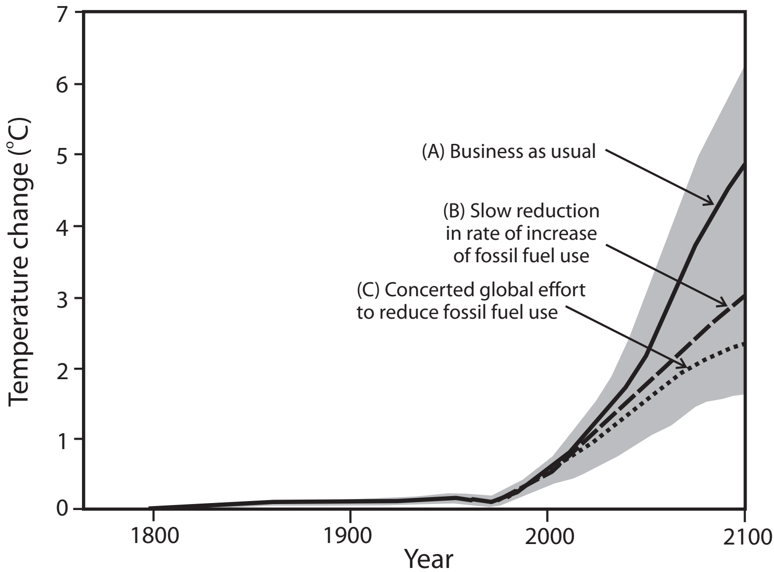

Figure 1.9 Predicted change in global average temperature for the three scenarios shown in Figure 1.8

Shading shows the range of predictions for these models with realistic estimates of the uncertainties.

temperature increases. By the year 2100 we should expect increases of at least 2°C above "normal" pre-industrial temperatures even if humanity cooperates to achieve the best of the modeled scenarios. If they don't, then increases of up to 5°C are very likely. Although these may sound relatively small temperature increases, we need to bear in mind that the most extreme global average temperature changes sustained by the Earth over the past million years are of a similar size—and they occurred between the depth of an ice age and the warmest interglacial period. Since our baseline pre-industrial temperature is already that of a warm interglacial period, these projected global temperature increases will take the Earth well above anything it has experienced in its recent geological history, and at a rate of change far greater than that imposed by "natural" processes.

Human activity has already committed the Earth to considerable long-term temperature change. Figure 1.10 shows predicted global average temperatures if we were able to stabilize greenhouse

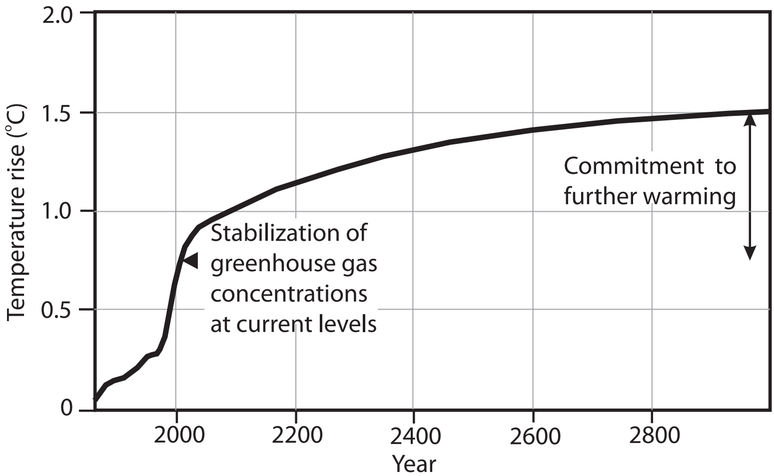

Figure 1.10 Global future temperature rise that would occur even if greenhouse gases were stabilized at today's levels

This shows that even if greenhouse gases could be stabilized immediately at today's levels, the global temperature would keep rising and eventually warm the Earth a further 1°C, or almost twice the global warming already produced.

Source: Diagram from Hadley Centre, *Climate Change and the Greenhouse Effect* (December 2005).

gases at today's levels—in practice, an almost impossible task. As can be seen, the consequences of human behavior to date will persist for hundreds of years to come and in the long term will cause temperature increases almost double those that have already been produced. The larger the temperature increases and the further into the future we try to look, the more uncertainty there is. This is because there is nothing with which to compare such massive changes to the Earth's climate and we cannot be certain of all the consequences of global warming on the climate system. To take but one biological example, an increase in atmospheric carbon dioxide may speed up the growth of some land plants, and thus in the short term remove more carbon than expected from the atmosphere, while the same increase may acidify the surface water of the oceans and inhibit carbon take-up by marine organisms. There may be other sudden and dramatic changes when a particular threshold of temperature increase is crossed such as switching off the North Atlantic Drift, as discussed earlier, which could cause extremely abrupt climate changes.

Irrespective of these uncertainties, the overall message is clear: what humankind does now will have serious long-term consequences on the global atmospheric temperature.

Climatic Patterns and Extreme Weather Events

So far we have only discussed global average temperatures. But what affects individuals most is the day-to-day climate in the region where they live. Two main conclusions have emerged from climate modeling. First, there will be regional variations that are very different from the average. For example, in North America the greatest temperature increases are projected to be in Alaska and northwestern Canada, with substantial warming in the interior of the continent, more modest changes in the southeastern United States and slight cooling in eastern Canada. Globally rainfall is likely to increase in mid to high latitudes, while droughts will become more common in lower ones. Africa is likely to fare particularly badly. This pattern can also be seen across the United States with decreased precipitation in the already arid southwest, but increases over the rest of the country.[24] Second, it is likely that extreme weather events—typhoons, hurricanes and storms causing floods and landslides, and extreme temperatures causing heat waves—will become on average more intense.

Because the land surface heats up and cools down much more rapidly than ocean areas, the surface temperature just above the land is likely to experience 40 percent greater warming than ocean areas. Model projections suggest that there will be a large increase in the number and severity of extremely hot summer days, coupled with a decrease in the daily variability of winter temperatures. By late in the century Chicago will experience 25 percent more heat waves annually, and heat wave days will increase in Los Angeles from 12 to between 44 and 95.[25] Heat waves are particularly hard in large cities and on vulnerable populations where heat stress can double or triple the normal death rate. In 2006, record heat persisted across most of the United States and Canada for over a month, resulting in hundreds of heat-related deaths.[26] Record high temperatures that in many places rose above 40°C during a heat wave in Europe in summer 2003 caused over 20,000 additional deaths.[27] The warm summers also caused great losses in agricultural productivity in southern Europe.[28]

In the absence of any human modification of climate, the European heat wave of 2003 could have been as rare as a one-in-a-million year event.[29] But human-produced greenhouse gases have already doubled the probability of another such event. And as the prediction of the increase in summer temperatures in Europe over the twenty-first century shows (Figure 1.11), by the 2040s a 2003-type summer will be about average, and by the 2060s it would typically be the coldest summer of the decade.

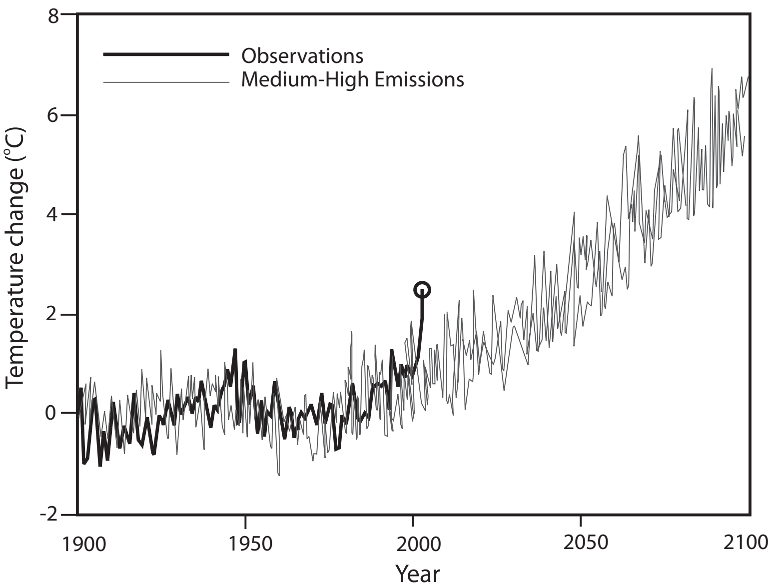

Figure 1.11 Measured average summer temperatures in southern Europe up to 2003, compared to predictions of past and future temperatures from several computer models

Several different model predictions (in fine lines) to show the range of likely increases in summer temperatures over southern Europe from an increase in carbon dioxide similar to case (A) of Figure 1.8. Heavy line shows actual temperatures. The models reproduce well the observations from 1900 to 2003 except for the summer of 2003 which was much hotter than either the model simulation or the normal climate. By the mid twenty-first century, the heat wave of 2003 will become the norm.

Source: Modelling by Hadley Centre, reported in *Climate Change and the Greenhouse Effect* (December 2005).

However, the greatest impact of global warming is likely to be a large increase in the intensity of rainfall from storms. Although there is no evidence that the number of storms will increase, there is both observational data and scientific reasons for a marked increase in the *intensity* of storms as a result of global warming.[30] For example, the total power dissipated by tropical storms has nearly doubled over the past 30 years.[31] The reason for this is that the volume of moisture drawn into a storm's circulation rises as the sea temperature rises, and the energy released as the water vapor condenses in clouds increases the wind speed. Computer simulations suggest that doubling the carbon dioxide in the atmosphere leads to an increase of between 5 to 10 percent in the peak wind intensities and an increase of about 30 percent in the peak rainfall. In 1998, Hurricane Mitch stalled over Central America as a relatively weak storm, but nevertheless, killed over 11,000 people from rainfall alone.[32] 2007 marked the first year that two hurricanes, Dean and Felix, made landfall as Category 5 storms during the same season, both striking Central America.

Deaths as a result of flooding and cyclones are humankind's worst natural disasters, accounting for two-thirds of deaths from all forms of natural disaster including earthquakes and volcanic eruptions. This is partly because settlements are usually in river valleys near a source of water. The worst known flooding disaster was on the Huang He (Yellow) River in China in 1931, when it was estimated that from 1,000,000 to 3,700,000 people died. Nor was this an isolated incident: in 1887 from 900,000 to 2,000,000 people died in floods of the same river. The worst death toll caused by a hurricane was on 13 November 1970 in Bangladesh when more than 500,000 people living in low-lying areas perished in a single day. In the last part of the twentieth century, floods affected 100 million people per year. The United Nations estimates that by 2025 half the world's population will be living in areas at risk from storms and other weather extremes.

Accompanying the human misery associated with deaths from floods are huge economic losses that add to the long-term suffering caused by the flood events. Moreover, the disease and famine that follow floods often cause more deaths than the floods themselves. So the increase of extreme storms are a real and frightening by-product of global warming, particularly since they will increase in intensity over coming decades and centuries.

Ironically, some areas with naturally low rainfall will become drier still. This is because the more intense cycling of water between the sea and the atmosphere as a result of climate change will cause a bigger proportion of the rain to fall in the more intense events. So although more water will be carried further upward into the atmosphere where air is rising, the areas where air is sinking will become drier. In the naturally dry areas of the world, the total rainfall will become less, and the number of rainy days will become substantially fewer, with more chance of prolonged periods with no rainfall at all—in other words, much more chance of drought. Adding to these woes, the higher temperatures will cause increased evaporation, thus reducing still further the amount of moisture available at the surface and deepening the drought conditions. Sub-Saharan Africa, already struggling with famines caused by drought, will suffer particularly badly. It is estimated that today 2 percent of the world's land area is suffering extreme drought, a doubling since 20 years ago. By 2050 this is expected to rise to between 10 to 12 percent of the land area.

Sea-Level Rise

As the global temperature rises, so the oceans will warm up. In doing so the water expands slightly, thus resulting in global sea-level rise. An additional, though smaller contribution to sea-level rise comes from melting of continental ice and snow masses—if the entire Greenland ice cap were to melt, for example, the extra water released into the oceans would raise sea level globally by about 7 meters, although this is predicted to take several centuries. Over the twenty-first century, melting of glaciers and part of the Greenland ice sheet are expected to contribute to about one-third of the total sea-level rise, but most will come from thermal expansion of the oceans.

We have already seen that the full effect of global warming lags behind the release of greenhouse gases into the atmosphere: translation of increased surface temperatures into sea-level rise takes even longer, due to the relatively slow circulation patterns of the ocean currents. But it is inexorable. By our actions to date we have already committed the world to steady sea-level rise for hundreds of years into the future. So at any time, the human-produced greenhouse effect carries with it a commitment to an additional, inescapable rise in sea level many times larger than at present. Generations following us will suffer the effects of what we are doing now.

The average global sea-level rises over the twenty-first century from the range of likely greenhouse gas scenarios vary from 0.1 meter to 0.9 meter. The central value is about 0.5 meter. This expected sea-level rise is about three times that which occurred in the twentieth century. As with global average temperature rises this may not at first sound like a huge problem, until one remembers that 15 million people live within one meter of sea level in Bangladesh or that many Pacific islands have only a few meters of freeboard. So for those people their homes will become literally uninhabitable. But, more importantly, there are likely to be regional variations in the size of the sea-level rise by a factor of two or so, depending on local ocean heat uptake and changes in atmospheric pressure and currents. Such regional variations are hard to predict which makes them even more problematic.

Almost half of the United States, twenty-four states, face the Atlantic or Pacific Oceans, the Gulf of Mexico, or are along tidal rivers. Eighty percent of the nation's shoreline is formed by bays or estuaries. While the potential flooding of New York City is dramatic, sea level rise has more subtle consequences. Marshes and wetlands along these shallow waters purify water, buffer and protect shorelines, and are nurseries for numerous species of fish and shellfish. Low-lying off-shore islands protect the coast from storms. As development has increased along the coasts, space for marshes and wetlands to migrate with the rising water has disappeared or declined.[33]

Some areas such as Maryland and the delta of the Mississippi are at greater risk from sea level rise because the land itself is subsiding. Between 2000 and 2100 up to 21 percent of the remaining wetlands in the Mid-Atlantic will likely be flooded. In low lying areas, such as the Chesapeake Bay, farmland has been lost as sea water has gradually infiltrated inland making the soils too salty for agriculture.[34] Fifty percent of the US population lives within 50 miles of the coast. For every 1-foot rise in sea level, 100 to 200 feet of shoreline is likely to erode. In a state like California where 85 percent of the population lives in coastal counties, the effects can be profound. By 2050, California expects a 1-foot rise in sea level; by 2100 the increase could be 3 feet. Not only will this change the shoreline and inundate homes close to the sea, but each rise in sea level increases the energy from wave actions by the square of the wave height. For instance, a 2-foot wave has four times the power of a 1-foot one.[35]

On top of the average sea-level rise, the biggest problem local populations face will be an increase in extreme high-water levels resulting from the increased intensity of storm surges. Much of Hurricane Katrina's devastation along the US Mississippi coast was a result of the record 27-foot storm surge. New Orleans was not on the coast, and Katrina had weakened to a Category 3 storm by the time it passed the city. But years of flood control practices that had stopped the river sediments from rebuilding the delta, the loss of vast areas of wetlands as the Gulf of Mexico crept further inland, and the building of navigation channels through the marshes allowed the force of the storm surge to reach further inland. Water broke through a weakened levee system, and large parts of the city were destroyed and are unlikely to ever be rebuilt. Some regions of the world have begun adapting to projected increased sea level rise and storm surges. For example, it is predicted that by the 2080s, with a medium to high greenhouse gas scenario generating a 0.3 meter average global sea-level rise, the average high-water levels in the southern North Sea and Thames Estuary are likely to be more than a meter above present levels, three or four times higher than the average. They will also happen more frequently: extreme high-water events that currently occur on average once every 100 years will instead occur as often as once every seven years in the 2080s. London already has a protective Thames Barrage which is raised when high tides threaten: it is likely that this defense will have to be substantially enhanced to protect against extreme future events caused by human-created global warming.

Food, Water, and Health

Social consequences of global climate change are more difficult to predict than is the physical response of the Earth's environment to temperature changes because they are dependent on the complexities of human and societal response as well as on the changes in the physical environment. But in general it is clear that high-income countries will have more freedom to respond and to adapt to changing circumstances, for example, by building higher sea barriers in response to sea level rise, than will low-income countries. So the deleterious effects will have a greater impact on the populations that are already marginalized or with low incomes, such as those in sub-Saharan Africa. As a general rule, human communities have adapted their lives over long periods to existing normal climate patterns, and most rapid climate changes are likely to produce adverse effects. Since settled human societies jealously guard their territory, and indeed most wars are fought over territorial rights, it is likely that large numbers of environmental refugees could in the future lead to widespread unrest or even war.

It is estimated that already, by the beginning of the twenty-first century, the approximately 20 million environmental refugees forced to leave their homes because of deteriorating environmental conditions exceed all other refugees from war and political repression combined. By 2050 there could be from 150 to 200 million refugees as a result of global warming.[36] In a world where the population has quadrupled in the twentieth century, land is increasingly at a premium. So huge numbers of stateless people will provide both a humanitarian and a political challenge.

The *global* capacity of agriculture to feed the world's population may not initially change greatly as a result of climate change. The mid to high latitudes will in general initially become slightly more favorable for agriculture, with a longer growing season and warmer temperatures, although further global warming would remove this advantage. The low latitudes, where there are already stresses on the food supply due partly to drought and partly to inept political management, will probably become still more stressed. Climate change is likely to produce more extreme events than at present, droughts that last several years, or floods that are more ferocious, and this is likely to be a bigger problem for agriculture than is the average temperature change. The problem is made more acute by environmental degradation already produced by human activity—loss of soil through poor agricultural practice, overextraction of groundwater and damage due to acid rain will only be made worse by the impact of global warming. But the problem is more than physical: already many millions of people die of famine in one part of the world while elsewhere there is an overabundance of food to the extent that large percentages of the population are clinically obese with all the attendant health problems that go with that. This is a significant issue of justice and sharing of resources, to which Christianity speaks powerfully. And as with many of the effects consequent on climate change, it is the poor and the marginalized who will suffer most, indeed who are already suffering, and who have the least resources to enable them to adapt to the changes forced on them.

Sustainable fresh-water supplies are crucial for human life to flourish, both for direct use and for agriculture. It is estimated that by 2050 some 100 million people will be living in areas with extreme water stress caused by climate change alone.[37] Much of the American and Canadian west is dependent on water supplied by snow melt fed river systems such as the Columbia or Colorado, or drawn from underground aquifers which are recharged by rainfall. Intense competition for water use between agriculture, energy production, industry, human consumption, and even care for endangered species has characterized this region and may become more intense over the next decades. By 2020, 41 percent of southern California's water supply will be affected by the decline in the snow pack in the Sierra Nevada and Colorado watersheds.[38] Glacier National Park, which drains into the Columbia River, has lost approximately 80 percent of its glaciers since 1850 with the rest expected to disappear by 2030.[39] Loss of glaciers, diminished snowfall, and earlier snow melt affect the timing and availability of water, especially for the summer months when demand increases. A 2.5°C warming is predicted to decrease the recharge ability of the Ogallala aquifer by 20 percent. This vast underground aquifer underlies eight of the most agriculturally productive states in the United States, from North Dakota to Texas.[40]

The impact of global warming on human health is more uncertain since health is so strongly tied to living conditions and is dependent on the income available to provide medical care to counter poor living conditions. Again it is the poor people and the low-income countries that are likely to suffer most. Even today, lack of clean drinking water can be linked to roughly 250 million cases annually of water-related diseases and between 5 and 10 million deaths worldwide. Increased spread of insect-borne diseases, such as malaria, is also likely in a warmer world. We have already discussed the increased incidence of deaths due to extreme high temperatures that will become more frequent and more widespread, especially in urban populations. Although highly uncertain, one estimate suggests that human-produced climate change over the past 30 years already claims over 150,000 lives annually and that the excess risk of climate-induced health problems may more than double by 2030.[41]

Global Population

At the beginning of the nineteenth century there were only one billion people on this planet; the six billion mark was passed before the end of the twentieth century. Population studies show that as life expectancy and individual wealth increase, the birth rate drops. The United Nations predicts that on present evidence the world population will not continue rising indefinitely, as it has hitherto (Figure 1.4, see p. 20), but will stabilize at between 9 and 11 billion by the middle of this century. That is still nearly double the present population; but it is not beyond the capacity of this Earth to provide sufficient food, water, and energy for everyone, provided it can be equitably distributed. It does, however, mean that we can no longer treat our local environment, including the atmosphere, as an inexhaustible sink for our waste products. Rather we will have to manage both our use of finite supplies and our disposal of waste products, including greenhouse gases, in a way which can be sustained in the long term.

The importance of global population to climate change is that as the number of people increases so do the greenhouse gas emissions. Perhaps even more pertinently, the largest rates of population increases are in Asia. India passed one billion inhabitants early this century, and China is already well over that size. Asia contains more than half the world's population, yet its current production of carbon dioxide per person is among the lowest on Earth (Figure 1.12). It is the high-income societies, who have built their wealth and their lifestyles on the back of technology, who are by far the worst polluters. So as the prosperity of Asian countries increases, as it is doing now, the generation of greenhouse gases globally will increase massively, far faster even than the rate of population increase.

Are Other Issues More Urgent than Global Warming?

The long-term consequences of climate change are serious and potentially disastrous. Notwithstanding the complexity of the systems involved and resultant level of uncertainty over the consequences, it is beyond serious doubt that the lives, health, security, and happiness of millions of people are threatened.

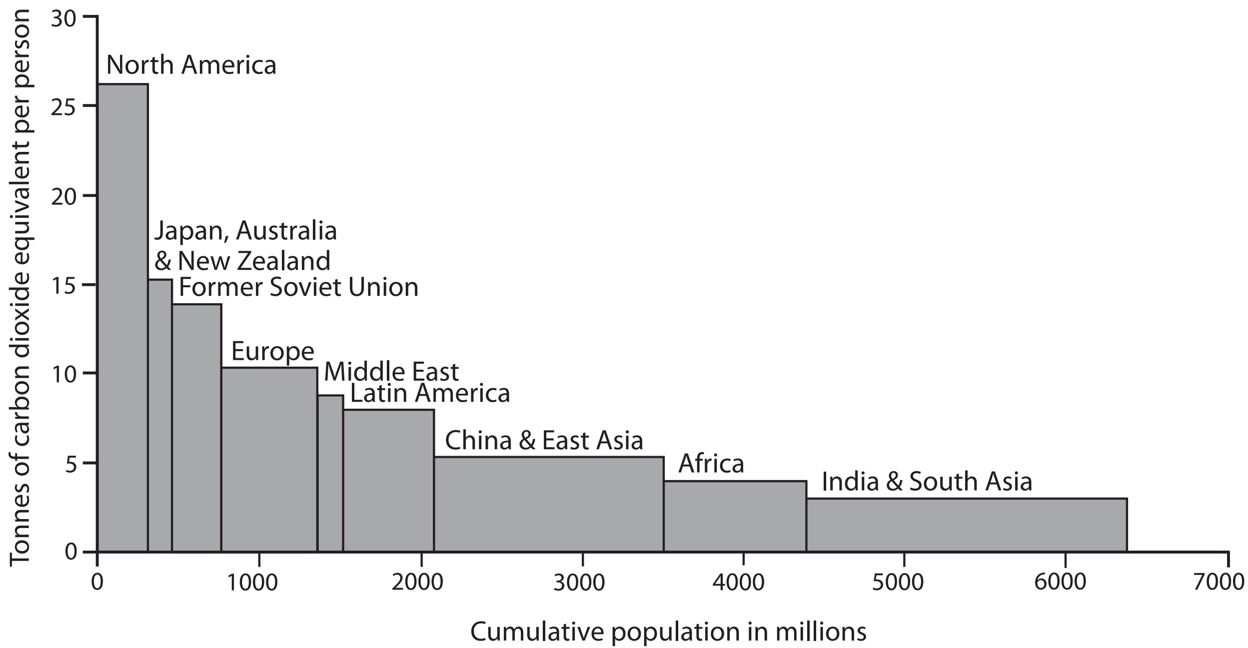

Figure 1.12 Carbon dioxide emissions in 2000 from different countries expressed per person plotted against their population

Source: From M. Grubb, "The Economics of the Kyoto Protocol," *World Economics* 4 (2003), p. 145.

But the lives, health, security, and happiness of millions are also threatened by many other factors, such as HIV/AIDS or a lack of clean drinking water. Should we invest money and energy in trying to reduce long-term global warming when there are many seemingly more pressing issues for the Christian commanded to love his or her neighbor? What of more traditionally Christian priorities, such as the breakdown of family life? And more obviously spiritual ones, such as the importance of proclaiming the gospel and seeking to bring unbelievers to a salvation faith?

The answer, of course, is that the Christian has to be concerned about, and responsive in an appropriate way, to all these issues. A lack of access to clean water and sanitation, for example, is a daily crisis for millions of people. Dirty water claims more lives through disease than any war claims through guns. Some 1.8 million children die each year as a result of diarrhea caused by unclean water and poor sanitation. The United Nations estimate that 1.1 billion people live without access to adequate clean water. The majority of those use only 5 liters (1.1 gallons) per day, about one-tenth of the average daily amount used in rich countries to flush toilets.[42] One part of the world sustains a designer bottled-water market that generates no tangible health benefits while another part suffers acute health risks because people have to drink from contaminated drains or lakes and rivers.

As the United Nations Development Programme reports, there is more than enough water in the world for domestic purposes, for agriculture, and for industry. The problem is that the poorest people tend to be systematically excluded from access to clean water by their poverty, by their limited legal rights, or by public policies that restrict access to the infrastructures that provide water. In other words, the solution lies primarily in the social and political structures in the countries where they live. Water governance must improve if poor people's health and livelihoods are also to improve, and therefore responses that push for structural change as well as improved service delivery are vital. Given the current scale of the problem, it is a sobering thought that, as our climate changes, the situation is actually likely to get worse.

Global climate change has a major impact on the hydrological cycles that determine the availability of water. It is clear from modeling that the consequences of climate change at the local level are complex and depend on local microclimates. But one thing seems certain: there is likely to be an increase in local variability and extreme events, of temperature, droughts, and floods. Many of the world's water-stressed areas will get less water, and water flows will become less predictable and more subject to extreme events. It is these aspects that make tackling global climate change, and damping the rate of climate change, such a crucial objective. All countries also need to improve their water governance and ensure that fair and open processes are put in place to decide who is entitled to use existing resources so that, if water scarcity increases, the poor are not marginalized further.

Then there are the problems of famine and disease that often accompany issues of water. Global communications mean that images of emaciated and starving people are beamed by TV direct into our living rooms. They cannot be ignored. Surely we need to respond to such desperate need?

Provision of emergency medical, food, and relief supplies are a crucial immediate response to famine and disease, as too is helping to create a sustainable infrastructure for agriculture and rural development. But beyond this short-term response, many of the factors governing stable food supply in an area are dependent on the consistency of the climate. So just as with the provision of adequate water, one of the main threats to agriculture, particularly in areas of subsistence farming, is rapid climate change and the associated increased variability and occurrence of extreme events. It is crucial to address climate change and to attempt to reduce rapid changes in it in order to guarantee the long-term stability of the food supply and to reduce the malnutrition that provides a fertile breeding ground for disease.

Though the high-income countries, such as those in North America and the European Union, comprise only one-sixth of the world's population, they produce 55 percent of the greenhouse gases responsible for global warming. In contrast, the poorest sixth of the world's population produce less than 3 percent of the global carbon dioxide. And yet it is this poorest segment of the world's population that does not have the economic or technical resources to counter the effects of global warming such as changes in rainfall and temperature, or rising sea levels. So they will pay for it by increased death rates from famine or disease, or by displacement from their homelands. Since we all live on one small globe and the circulating atmosphere carries the pollution that causes global climate change around the whole world in a matter of days, then no one can avoid responsibility for the effects their actions will have on others.

People in high-income countries who have benefited historically from the burning of fossil fuels have a particular responsibility to deal with the results of their actions. And they can hardly claim to love their (global) neighbor when the consequences of their lifestyles may lead to suffering and an increased probability of an early death by people elsewhere. To refuse to consider the physical and social welfare of others when the consequences of our actions are already clear is not only reckless but at root selfish. And selfishness is nothing less than sinfulness, of putting oneself first. If our daily actions are at root an expression of sinfulness then we need not only to repent of that but also to change our behavior.

Summary: Global Warming, Local Causes

Global warming caused by human activity is real, and we now understand the main causes of it. Most prominent is the injection of massive amounts of carbon dioxide into the atmosphere from the indiscriminate burning of fossil fuels—oil, gas, and coal. The Earth has seen temperature swings of up to 10°C in the geological past, and there is no doubt that, by continuing our present behavior, humans would cause exactly the same sort of temperature changes again. The significant difference is that the present rates of change forced on the planet by human activity are at least 30 times faster than anything the Earth has suffered before. The consequences of this are likely to include massive ecological disturbance and loss as natural ecosystems fail to respond sufficiently quickly to the rapidly changing environment.

But more significant still are the likely consequences on a planet crowded by more humans than it has ever supported before and where one-quarter of the population live in poverty, with a marginal lifestyle that is extremely vulnerable to changes caused by drought or flooding, by the failure of agricultural crops, or by rising sea levels. To continue our present reckless experiment with the Earth's future climate would be a morally gross failure both towards those who are less fortunate than ourselves in their material resources and towards future generations.

There are many other issues that press equally hard for attention, and Christians need to be able to respond to all of them as appropriate. However, the sheer scale and impact of climate change makes it a priority. Global temperature increases, extreme weather patterns, rising sea levels, desertification, drought, flooding, water crises, and health scares will affect billions of people. Global warming demands a response.

That sheer scale also, however, makes the issue appear rather daunting to us, leaving individuals feeling distinctly powerless, unable to do anything meaningful by way of response. That feeling is misleading however, as climate change may be a global problem but it has distinctly local and human causes. It is to these we now turn.