Chapter 19

Climate Change – Past, Present and Future: A Personal Perspective

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The record of instrumental temperature measurements clearly documents a systematic rise in global temperatures since the mid-19th century. However, there are insufficient data to say if this warming is part of a longer-term trend, a quasi-periodic oscillation or even if it is quite unusual. In order to answer such questions, we must place the relatively short instrumental record in a longer-term perspective, and to do that we must rely on palaeoclimatic information. Palaeoclimatic archives are natural phenomena that have in some way recorded in their structure a record of past climate. They are a treasure trove of the climatic and environmental history of the planet.

Important palaeoclimatic archives include tree rings, ice cores, lake and ocean sediments, cave deposits (speleothems) and banded corals. The climatic signal in these archives is often embedded in a lot of non-climatic "noise", and the task of the palaeoclimatologist is to extract a meaningful climatic history from the material. This may involve detailed geochemical studies (for example, examining isotopes in corals as an index of past sea-surface temperatures) or taking measurements of specific physical characteristics (such as tree ring widths, or wood density changes). These measurements are calibrated with overlapping instrumental records to develop equations that can then be applied to periods for which we have no instrumental data. In this way, a picture of past climate variability (temperature, rainfall conditions, etc.) can be built up.

Some palaeoclimatic archives can also provide information about factors that may have directly influenced climate variations in the past ("forcing factors"). For example, ice cores record variations in atmospheric chemistry that track the past history of explosive volcanic eruptions, many of which had significant impacts on global temperatures. Ice cores have also provided records of past variations in the cosmogenic isotope ^{10}Be, which varies in response to changes in solar activity. Studies of ^{10}Be show that it tracks sunspot variations and thus provides an index of solar irradiance changes over time. Ice cores may also yield samples of the Earth's atmosphere from the past, trapped in bubbles within the ice. These have provided remarkable insights into variations of important greenhouse gases (such as carbon dioxide, methane and nitrous oxide) and reveal how far beyond the limits of natural variability atmospheric conditions now are as a result of recent anthropogenic activity.

Palaeoclimatic records thus tell us about conditions in the past before we had instrumental records, enabling us to build up a much longer perspective on the climatic and environmental history of the Earth. They unlock a world that humans experienced but no longer remember. And they provide a salutary warning that our recent experiences are but a small sample of the full range of natural variability. They also help us to understand the mechanisms that cause climate to change, and provide a framework for us to assess the nature of future changes that we are likely to experience as greenhouse gases continue to accumulate in the atmosphere.

Ironically, many of the archives that are necessary to achieve these goals are currently under threat from human activities and the very climatic changes that we need to better understand. It is alarming to see so many of these unique records disappearing at a dramatically increasing rate, before we have had the opportunity to sample them and so preserve a record of the past. Throughout the world we see old growth trees being cut, corals being dynamited for marine developments, or eroding away following bleaching episodes associated with record high ocean temperatures, tropical glaciers and ice caps melting. There is an urgent need to establish a programme to recover these archives, and to study the records they contain before they are lost forever. They are part of our history, just as much as the Pyramids, the Sistine Chapel in Rome or the terracotta soldiers in the Tomb of Emperor HuangTi in Xi'an. Would we seriously contemplate such treasures of our past being removed by purposeful acts, or even by benign neglect? Such destruction of our cultural archives would be accompanied by an international outcry, and we must recognise that the loss of the Earth's natural archives is no less of a tragedy, requiring international attention. There is an urgent need for an international programme to recover, calibrate and analyse these unique and rapidly disappearing archives. Such an effort should be carried out in parallel with the implementation of the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System

(GTOS). GCOS, GOOS and GTOS will shed light on how climate changes in the future, but without the perspective of the past, they will have limited value.

19.1 Lessons from the Past

Drought reconstruction from networks of trees in the USA shows that periods of drought occurred in the past that were far beyond recent experience. In the 16th century, droughts in the southwestern United States were longer, more extreme and geographically more extensive than anything registered in the instrumental period. In fact, for part of the time, such a drought spread across the USA, and was in part responsible for the demise of the early colonial settlement at Jamestown, Virginia. If similar droughts occurred today across this important agricultural region in an area of fast-growing population, the results would be devastating. Interestingly, the drought pattern is similar to that we often see associated with La Niña conditions. Could the prolonged droughts in the 16th century be a reflection of a different mode of El Niño activity in the past? Unfortunately, our understanding of sea surface temperature variations associated with the quasi-periodic shift from El Niño to La Niña conditions is very short – less than a century of spotty observations. But isotopic records from banded corals in the Pacific can provide a longer perspective on these variations. For example, spectral analysis of ^{18}O (a proxy for sea surface temperatures) in the carbonate of corals from Maiana Atoll in the central equatorial Pacific shows that in the mid to late 19th century, sea surface temperatures varied on longer time scales than have been observed during the period of instrumental records. Thus, the palaeoclimatic evidence suggests that the ENSO system may indeed have oscillated at longer periods than our recent experience suggests, leading to more persistent anomalies than anything experienced in the 20th century.

Other evidence also points to conditions in the recent past that were quite different from modern conditions. For example, studies of lake sediments in the upper Midwest of the United States reveal that the relatively moist conditions that this region experiences today may be atypical of what prevailed before AD 1200. This information is obtained from variations in the type of diatoms found in the sediments. These indicate changes in water chemistry that reveal the past history of water balance in the region. In the first millennium, much drier conditions prevailed. If these conditions were to return, it would have an enormous impact on agricultural productivity of the region, and the resulting economic disruption would ricochet through the region and far beyond.

Some of the most remarkable palaeoclimatic records have come from ice cores, taken in both north and south polar regions, as well as from high elevation tropical ice caps. High resolution ice core records can reveal important insights into past climate variations that (if they occurred again today) would have catastrophic consequences. One such record, recovered from over 7 000 m at the crest of the Himalayas, registers monsoon precipitation variations, and clearly reveals a sequence of monsoon failures in the late 18th century, as recorded by dust and chloride levels in the ice. Nothing like this has occurred in the last 180 years of instrumental records from this region, but the lesson from the ice core is that it happened not long before instrumental records began – and it could happen again. We need to understand what caused these anomalies, because in 1792, at least 600 000 people died in just one region of northern India from the droughts associated with this event. Considering that the population in this region today is hundreds of times greater than it was in the late 1700s, a recurrence of this kind of anomaly would be nothing short of catastrophic.

19.2 Global Temperature Change

Networks of palaeo-data can also be used to reconstruct large-scale temperature changes. By combining the best temperature-sensitive records from around the globe, several studies have used palaeoclimate proxies to reconstruct past temperature variations. Figure 19.1a shows one example, a record of mean annual temperatures, averaged over the Northern Hemisphere, from Mann et al. (1999). The record, expressed as anomalies from the 1901–1980 average, is shown in *black*, with low-frequency changes in *purple* and estimated statistical uncertainties in *yellow*. The long-term perspective provided by this study indicates that temperatures slowly declined over the last millennium, but this trend was abruptly terminated at the start of the 20th century. Superimposed on the long-term millennial-scale trend are century to multi-decadal-scale fluctuations and high frequency (inter-annual to multi-year) variations. Modelling studies using realistic estimates of various forcing factors over the last millennium suggest that much of the variability of the record can be explained by past changes in solar irradiance and by large-scale explosive volcanic eruptions. But the temperature change in the 20th century can not be explained by such factors, and it appears that it is largely the result of accumulating greenhouse gases in the atmosphere, as a consequence of human activities.

There are now several other studies that generally confirm these findings (Fig. 19.1b). Differences relate to the fact that some studies have reconstructed a particular season of the year, rather than mean annual temperature, or the precise geographical domain of the study in question is less than hemispheric in scale. Nevertheless, they all show a cooling trend from the early part of

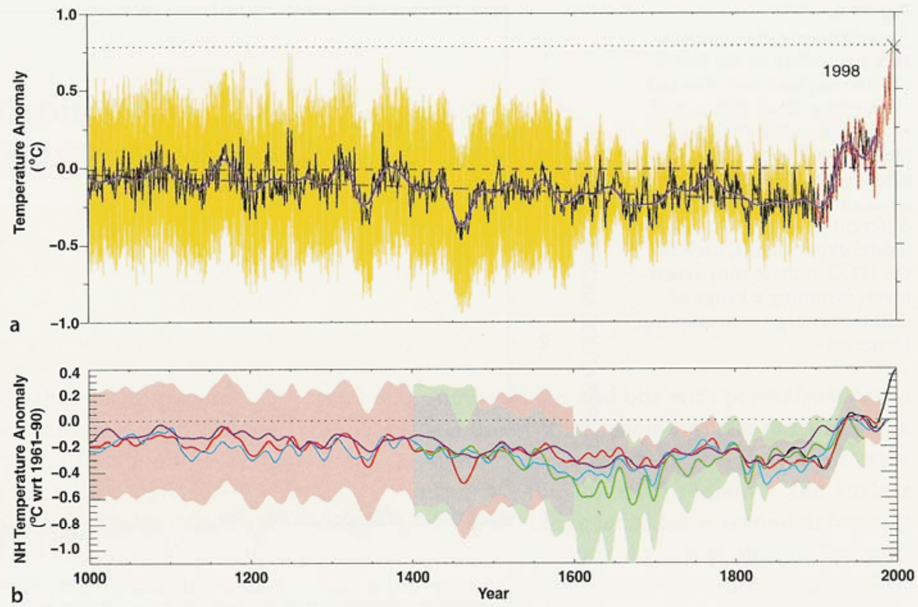

Fig. 19.1.
Top: Temperature variability of the Northern Hemisphere over the last 1 000 years (from Mann et al. 1999) (*yellow shading* indicates statistical uncertainty; *black line* shows interannual variability with low frequency changes superimposed (*purple line*); *red line* is calibration period, 1901–1980, followed by the instrumental record from 1980–1998) (© American Geophysical Union).
Bottom: Estimates of long-term temperature changes from various sources (only low frequency variations shown). *Blue line* is the low frequency record from the upper figure (from Briffa et al. 2001) (© American Geophysical Union)

the millennium, to lowest temperatures in the 16th to 19th centuries – the so-called "Little Ice Age" – followed by the dramatic warming of the 20th century, which is unprecedented in rate and amplitude in the entire one thousand-year record.

19.3 The Future in Perspective of the Past

It is instructive to compare the variability reconstructed for the last millennium, with that expected in the future, as projected by IPCC under different energy use and population growth scenarios (Fig. 19.2). All of them are far outside the range of natural variability on the time scale of the last 1 000 years. But will a change of a few degrees make much of a difference? It is important to recognise that the changes shown here are *hemispheric* or *global* averages. One should superimpose on these projections higher frequency variability of the sort that is shown for the last millennium in Fig. 19.1a. As an example, the interannual range for the last thousand years amounted to ~3 times the variability over 50 year periods. So individual years over the next century will be both considerably warmer and colder than these averages suggest. Furthermore, general circulation models, running for periods of ~1 000 years, show that regional-scale changes are larger than hemispheric changes by a factor of 3–5. This means that areas about the size of Montana, or Poland, (i.e., a typical GCM grid box) could expect to experience anomalies on a scale that could significantly amplify the overall hemispheric changes. Of course, regional impacts related to changes in rainfall patterns may be more important economically and ecologically than temperature changes, but such changes are extremely difficult to predict. The bottom line is that the climate variability that all regions have experienced in the last millennium is unlikely to capture the variability we can expect in the future, which should give us cause for concern. These changes will be a direct consequence of the unprecedented increase in greenhouse gas levels in the atmosphere, together with associated feedbacks.

Ice cores reveal that CO_2 levels have generally varied over glacial to interglacial time scales from ~180 ppmv to ~275 ppmv. CO_2 levels today at ~370 ppmv have far exceeded anything that the Earth has experienced for millions of years, and the growth rate has been unprecedented. But such long-term views are sometimes hard to grasp. What is the time scale relevant for society today? Perhaps it is more instructive to consider just the period over which civilisation has developed, from the time when the first cities were established around 6 000 years ago. If we consider this in terms of the minute hand on a clock, with time ticking away as we approach the present, each minute represents a century (Fig. 19.3). 6 000 years ago, CO_2 levels were around 270 ppmv. When the first writing was developed around 3 800 years ago (20 minutes to the hour in terms of the "civilisation clock") CO_2 levels were still close to 280 ppmv … and they remained at this level throughout most of our history – throughout Egyptian and Chinese, Incan and Mayan dynasties, all through the Crusades, the Inquisition, the Renaissance and the period of European settlement of the New World. But things began to change significantly following James Watt's invention of the steam piston engine 250 years ago, and Karl Benz and Gustav Daimler's introduction of the first petrol-driven internal combustion engines in 1886 – a little over 100 years ago and only 2 or 3 minutes ago on our clock of civilisation. As we began this process of industrialisation, CO_2 levels were 275 ppmv … but today they have reached 360 ppmv and are rising rapidly. Thus, on the time scale of this clock of civilisation, it's the last

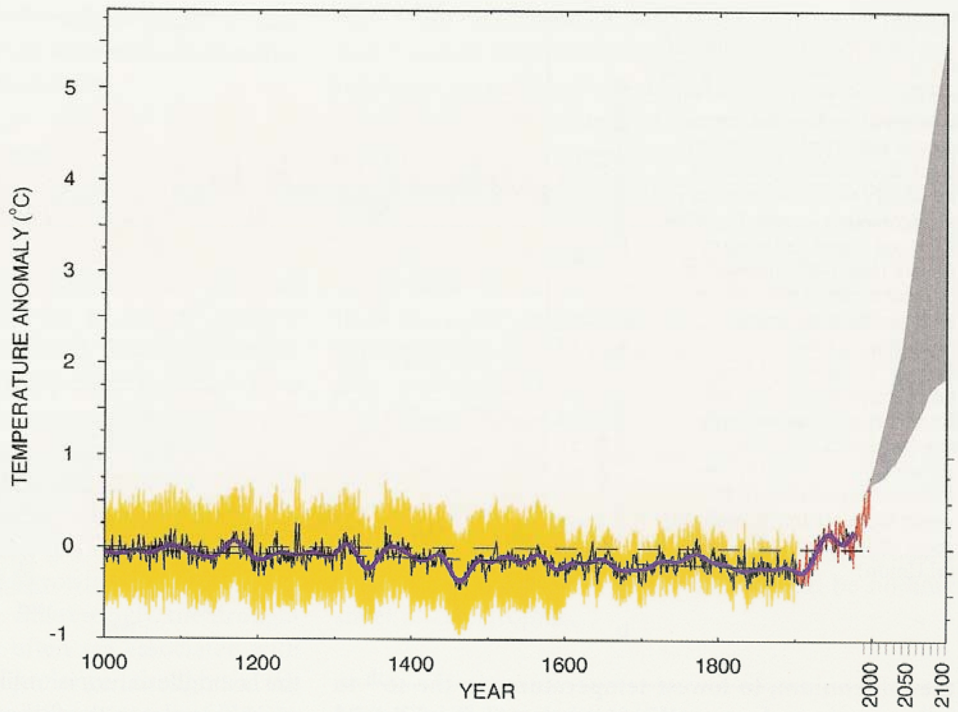

Fig. 19.2. An estimate of the temperature variability of the Northern Hemisphere over the last 1000 years (from Mann et al. 1999), and of the changes in mean *global* temperature that might occur in the next millennium, according to several different general circulation model experiments, used by the IPCC in their 2001 assessment, assuming a range of different energy consumption scenarios

2 minutes where things have gone badly wrong on a global scale … and it's in the "next minute" – that is, within this century – that we must fix the problem. We cannot mindlessly hand it off to our children and to future generations as yet unborn, with the hope that something will turn up – some technological fix, some magic solution that may relieve us of this burden. We cannot ruthlessly pin our hopes in unsupported speculation that feedbacks will bring these unprecedented and incredibly rapid changes into balance. And we cannot rely on alternative energy systems which produce waste products that need to be isolated from living things for a hundred thousand years – 15 times longer than the entire history of our civilisation. What an appalling legacy that would be. What right do we have to burden future generations with this responsibility?

This is not merely an issue of scientific importance – it's an ethical and moral issue. We who are the inheritors of all that civilisation has provided, of all the wisdom accumulated in our literature and science, all the beauty in art and music handed down for generations – *we* have to fix this problem. And we must act quickly, within the next "one minute" on the time scale of our civilisation's development.

Civilisation implies civility – the development of a society that is caring and respectful of its citizens *and* its environment. Sadly, we have diverted from such a trajectory. The abuses our civilisation have heaped on the world in "the last couple of minutes" will require a major effort to resolve, particularly given the expected further growth in world population. There will be 50% more people on Earth within this century. Morally, ethically

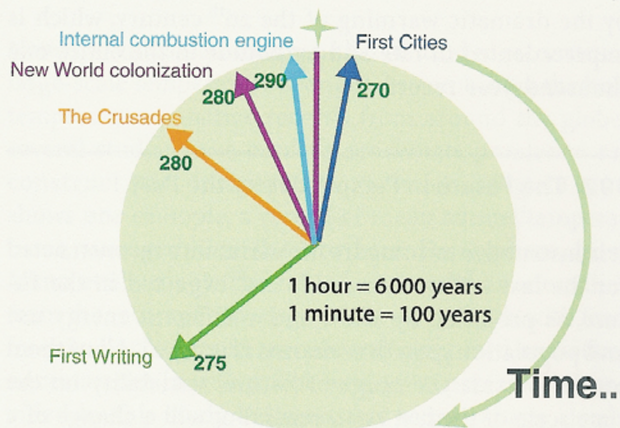

Fig. 19.3. The "clock of civilization"; assuming the first cities (~5700 years ago) mark the start of modern civilization, each minute represents 100 years. CO_2 levels at various times are shown in *black* (based on ice core measurements)

and scientifically we have no choice but to act boldly, and quickly, *as a global community*, to resolve these global-scale problems – our heritage from civilisations in the past, and our obligations to civilisations in the future require that we deal with these issues now.

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