The Societal Relevance of Paleoenvironmental Research

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1.1 Introduction

As the third millennium opens, it is clear that human beings are having a discernible impact on global climate. Profound changes are underway, but their attribution to specific causes poses a problem. What fraction can be assigned to human activities? Can we be sure that human impacts are not subordinate to natural variability? How can we gauge the severity, likely long-term effects and possible consequences of changes that we are inducing? Part of the answer lies in the exploration of the past. By understanding how climate has varied naturally in geologically recent times, we enhance our ability to peer into the future. This objective, simply stated, belies a remarkable complexity in the climate system and its linkages with other environmental systems. This book addresses the challenge posed by this complexity with a view to shedding light on current and future changes.

The meaning of the term 'global change' has become somewhat narrowed in recent literature. Increasingly, it has become linked exclusively to the major changes to the earth system that are currently underway. More often than not, the term is used to denote the inferred consequences of human actions. Here, we give the term its literal meaning without restriction to the most recent times, and without prejudgment with regard to underlying causation. Thus the shifts in climate that took place at the end of the last glacial period, as well as the biospheric responses to these shifts, are just as much examples of global change as are contemporary anthropogenic changes such as greenhouse gas concentration increases in the atmosphere, water and land degradation, and declining biodiversity.

The dominant theme of this book is past climate change and its links to other environmental systems at both global and regional scales. The book presents a synthesis of research in a broad, interdisciplinary field, the scope of which is defined by the major goals of the IGBP Past Global Changes (PAGES) project (Oldfield 1998, Alverson et al. 2000). The overriding concern of the research community contributing to the PAGES project has been to provide a quantitative understanding of the climate and environment in the geologically recent past and to define the envelope of natural variability alongside which anthropogenic impacts on the earth system may be assessed. Within this almost boundless remit, focus has been achieved by concentrating on those aspects of past environmental change that most affect our ability to understand and, wherever possible, predict and respond to future changes.

The 'raw material' available for this task includes:

- a wide variety of archives, both natural (ice and sediment cores, tree-rings, corals for example) and documentary;
- an even greater range of 'proxy' signatures decipherable within these archives using techniques such as microfossil, sedimentological, geochemical and stable isotope analysis;
- a range of dating techniques involving methods as diverse as layer counting and radioisotope decay series; and
- numerical models used to reconstruct past climates within the bounds of known dynamical constraints.

The main focus of the research summarized in this volume is on continuous paleoenvironmental records, with annual to decadal time resolution over the last few millennia, and mainly with decadal to century scale resolution, spanning the last several hundred thousand years. In order to document both lower frequency variability and the full range of transient extreme events recorded within the present interglacial, it is necessary to study the variability of the entire Holocene, which began with the dramatic transition out of the Younger Dryas cold period around 11.5k BP. Figure 1.1 shows how rapidly ice accumulation rates and oxygen isotopes in ice (a complex proxy of temperature) changed in Central Greenland at this time (Dansgaard et al. 1993). This remarkable climatic shift, recorded in many high resolution archives, was a rapid warming event felt over much of the earth's surface and is a striking example of global change by any definition. As is clear from the preceding part of the record, also in Figure 1.1., it was by no means unique.

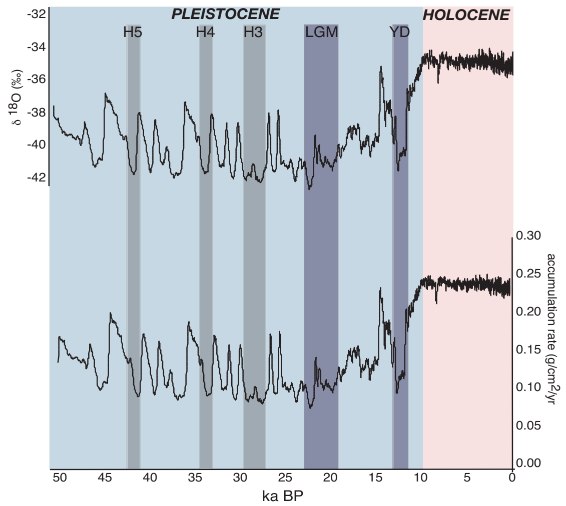


Fig. 1.1. Accumulation and isotopically inferred temperature over the past 50,000 years as measured in Greenland ice cores (Dansgaard et al. 1993).

Paleo-reconstructions of lower temporal resolution may be equally valuable in terms of their location and quantitative implications. Temperatures during glacial times reconstructed from noble gas ratios in ground water archives (Stute et al. 1995, Stute and Talma 1998, Weyhenmeyer et al. 2000) and temperatures of the last millennium reconstructed from bore-hole temperature inversions (Huang et al. 1996, Huang et al. 2000) are but two such examples.

The rationale for emphasizing past climate change rests on the following propositions:

- Climate has varied continuously on all timescales. Irrespective of the extent to which human activities lead to changes in the global climate system, it will continue to vary in the future. This is unquestioned; doubts surround only the nature of future variability and the degree to which the consequences of human activities will influence or perhaps even dominate it. Documenting past variability therefore has a vital role to play in understanding the present climate and predicting future change.
- Climate change affects human societies both directly and indirectly. Although the nature of the interaction between climate and human society is mediated by a wide range of cultural processes and varies greatly for different types of biophysical environment and social organization, the socio-economic impact of climate variability is substantial.
- Increasingly, policy development in virtually every sphere of life, from sustainable subsistence agriculture to infrastructure insurance in technological societies, rests, in part, on scenarios of future climate based on models that require empirical refinement and validation. An essential component of this validation consists of providing accurate reconstructions of past conditions.
- Part of the basis for understanding and predicting the course of future climate change lies in increasing our knowledge of the spatial and temporal patterns, causes and consequences of past variability.

Figures 1.2 and 1.3 show highly condensed impressions of temperature and hydrological variability respectively over a range of timescales. Figure 1.2 shows, from top to bottom, temperature variability associated with glacial cycles as inferred from $\delta^{18}O$ measurements in the Vostok ice core (Petit et al. 1999), millennial scale temperature variability during the last glacial period and the Holocene as inferred from $\delta^{18}O$ in Greenland ice cores (Dansgaard et al. 1993), and Northern Hemisphere average temperature over the last millennium as estimated from a network of multiproxy reconstructions and instrumental data (Mann et al. 1999). Figure 1.3 presents examples of past hydrological variability on three different timescales as derived from paleoproxy measurements. Sea level variability associated with glacial cycles (Waelbroek et al. 2002), lake level changes in Lake Abhé, Ethiopia during the Holocene (Gasse 2000) and lake level changes in Lake Naivasha, Kenya over the last millennium (Verschuren et al. 2000).

These figures illustrate several noteworthy points:

- climate variability is not just reflected in temperature – extreme hydrological variability, which is often of much greater importance to human populations, has been documented on all timescales in the past.
- underlying *global* climate change are very diverse *regional* variations which reflect the mechanisms responsible for the global change.
- although major, abrupt transitions, reflecting reorganization of the global system are most evident during glacial periods, they are not absent in the Holocene, especially in regional hydrological variability at lower latitudes.
- during the late Holocene, although natural forcings and boundary conditions were similar to those operating today, climate variability

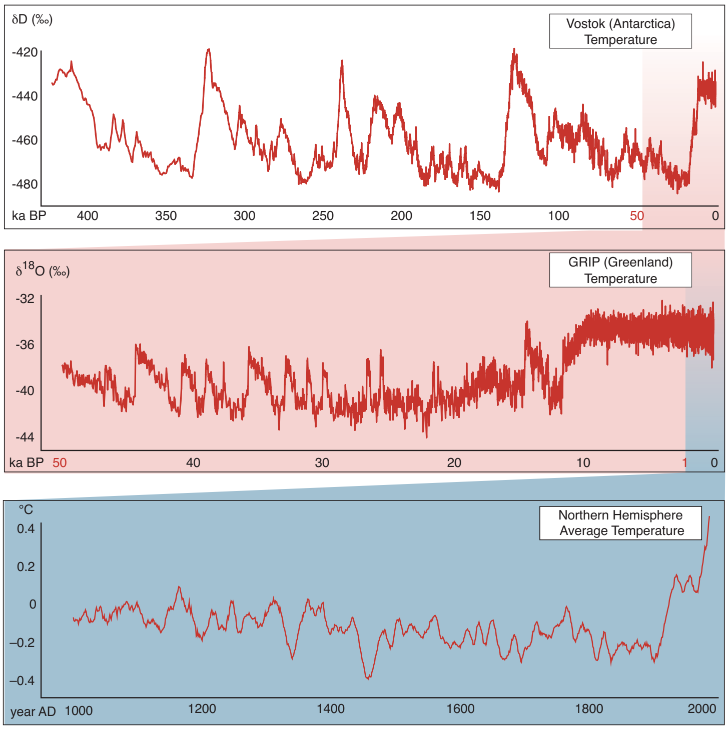
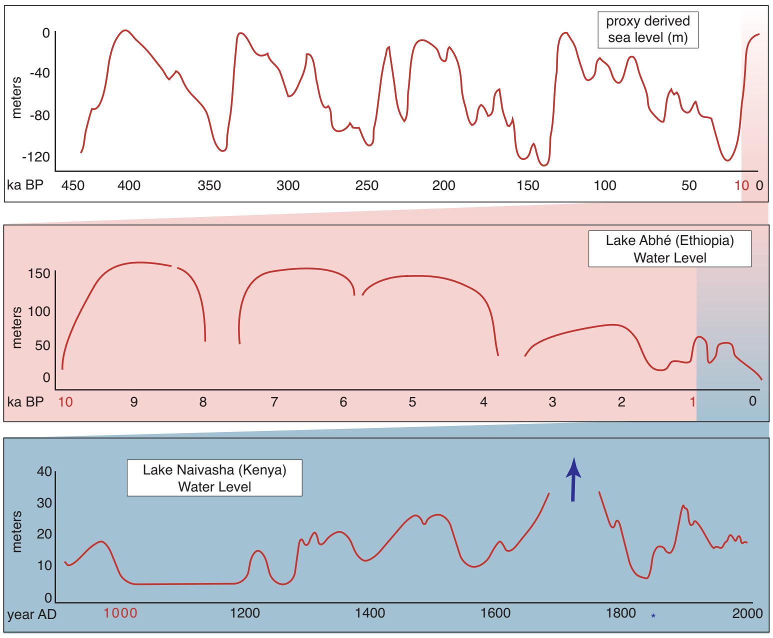


Fig. 1.2. Examples of past temperature variability on three different timescales as derived from paleoproxy measurements. Temperature variability associated with glacial cycles as inferred from δD measurements in the Vostok ice core (Petit et al. 1999), millennial scale temperature variability during the last glacial period and the Holocene as inferred from $\delta^{18}O$ in Greenland ice cores (Dansgaard et al. 1993), and Northern Hemisphere average temperature over the last millennium as estimated from a network of multiproxy reconstructions and instrumental data (Mann et al. 1999).



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often greatly exceeded anything that is seen in modern instrumental records.

Irrespective of any evaluation of the effects of human activities, natural climate variability alone is thus of vital concern for the future. When we set this observation alongside the projected impact of anthropogenic forcing, and consider natural and anthropogenic factors together, several important questions arise:

- How does the paleo-record improve our understanding of earth system function and climate variability?
- What can reconstructions of past climate contribute to the detection and quantification of human impacts on climate?
- What does the past record tell us about the global and regional implications of potential future climate change for ecosystems and human societies?

1.2 A paleo-perspective on earth system function

Although past changes in climate could be described without reference to other aspects of earth system history, this would give no sense of the processes and functional linkages that are crucial for understanding and prediction. Climate variability reflects complex interactions between external forcing, ocean-atmosphere-biosphere-cryosphere dynamics and a range of environmental feedbacks. Among the relevant external forcing mechanisms, those operating on the longest timescales reflect the astronomical cycles that modulate the pattern of solar energy impinging on the earth and provide the chronometer for the onset of successive major glacial episodes in the geologically recent past. At the other extreme are the transient effects of major volcanic eruptions that impact climate primarily through the effects of atmospheric aerosols they produce. Between the two are changes in solar irradiance operating on decadal to millennial timescales. A wide range of internal modes of variability arises from feedbacks and system responses to external forcing. Among these are components of the earth system that operate on millennial timescales with a potentially high degree of hysteresis such as the deep ocean and the Antarctic ice sheet. Other parts of the earth system have more rapid characteristic response times. Many processes within the terrestrial biosphere and upper ocean for example operate over years, decades or centuries.

One effect of the interactions between external forcings and internal system dynamics is that at any point in time the state of the earth system reflects both contemporary processes and those that are inherited from the past. This highlights the need for an understanding of earth system function that is firmly rooted in knowledge of the past. Furthermore some the processes that crucially modulate current modes of climate variability have undergone major rearrangements in the past and we do not yet know why.

These issues are addressed in the chapters that follow. Chapter 2 focuses on the history of atmospheric trace gases and aerosols on timescales ranging from the last millennium to the last four glacial cycles. Special attention is devoted to the role of changes in trace gas concentrations associated with periods of rapid climate change both within and at the end of glacial periods. Chapter 3 explores dynamical processes operating on timescales from decades to hundreds of millennia. Both data and model examples are used to explore past millennial scale climate variability, rapid changes, and glacial cycles. The carbon cycle is the main theme of chapter 4, though other chemical species critical to the functioning of the earth system and its living components are also considered. An overview of the history of marine and terrestrial sources and sinks of carbon and changes in the fluxes between various reservoirs is provided. Further consideration is given to the terrestrial biosphere in chapter 5, which deals with both its responses to climate change and the role it has played in modulating climate. The chapter also provides a paleo-perspective on future management and conservation issues. Chapter 6 highlights and analyzes the changes in climate that have occurred during the last thousand years, with a view to evaluating the relative importance of different forcing and feedback mechanisms, outlining patterns of natural climate variability over this time interval, and providing a dynamic baseline against which to assess anthropogenic greenhouse gas forcing. Reconstructions of the changing patterns of forcing and climate response through time help to identify the causal mechanisms for recent climate variability. They also provide strong evidence for a significant anthropogenic influence on global climate over the last few decades (Mann et al. 1998, Crowley and Kim 1999, Mann et al. 1999, Crowley and Lowery 2000, Stott et al. 2000, Stott et al. 2001). This approach complements studies that seek to detect anthropogenic climate change through a ‘fingerprinting’ approach (Forest et al. 2002). Paleoclimatic reconstructions therefore make a distinctive contribution to the often highly politicized debate about the causes of the recent warming trend and the extent to which increased greenhouse gas concentrations are contributing to it. Chapter 7 is concerned with the role humans have played as past drivers of change in terrestrial and aquatic ecosystems. Timescales of transformation resulting from human impact range from millennia to the last few decades. Human activities must be considered alongside natural environmental changes and the relation between the two is shown to be an interactive one. The final chapter aims to draw these many themes together and provides an integrated account of the main insights set out in the book, to identify the main implications for human societies and to propose research priorities for the future.

In seeking to gain a preliminary view of future climate change impacts, one of the most striking perspectives arises from comparing the range of predicted future changes in global temperature with estimates of the changes that occurred during the last millennium (Figure 1.4, see also Chapter 6, Section 6.3). At the global level, the most dramatic of these past changes were far below even the lowest predictions of future climate change. Yet this same period included major regional climate changes that were of great human significance in the past and would undoubtedly have dramatic consequences for present day societies. This brings us to a fuller consideration of the interactions between climate variability and human societies.

1.3 Past climate variability, human societies and human impacts

Studies of the relationship between past climate variability and human societies have often been marked by antithetical perceptions within the social science and physical science communities. Archaeological and anthropological research encompasses interpretations of socio-economic and cultural change, resource use and subsistence practices (Pringle 1997, Redman 1999), but the direct evidence for potentially damaging climate change is usually derived independently from different archives and lines of evidence (Cullen et al. 2000, Hodell et al. 2001). As a result, even where temporal correlations can be proposed between major societal changes and shifts in climate, they could be viewed as little more than coincidences. Taken to its extreme, the 'cultural' view attributes major changes in past societies, even the collapse of ancient civilizations, entirely to human actions. Although human actions are clearly important, too one-sided an interpretation is not supported by research which ascribes the collapse of civilizations as diverse as the classic Akkadian (Cullen et al. 2000, DeMenocal et al. 2000), Mayan (Hodell et al. 1995, Hodell et al. 2001) and Anasazi (Dean et al. 1985, Dean et al. 1999) cultures to abrupt and persistent climatic changes (Figure 1.5, see also Chapter 7, Section 7.8). Such studies do not discount the role of societal factors, but assert that, at times, climate variability has been a critical factor influencing societal stability.

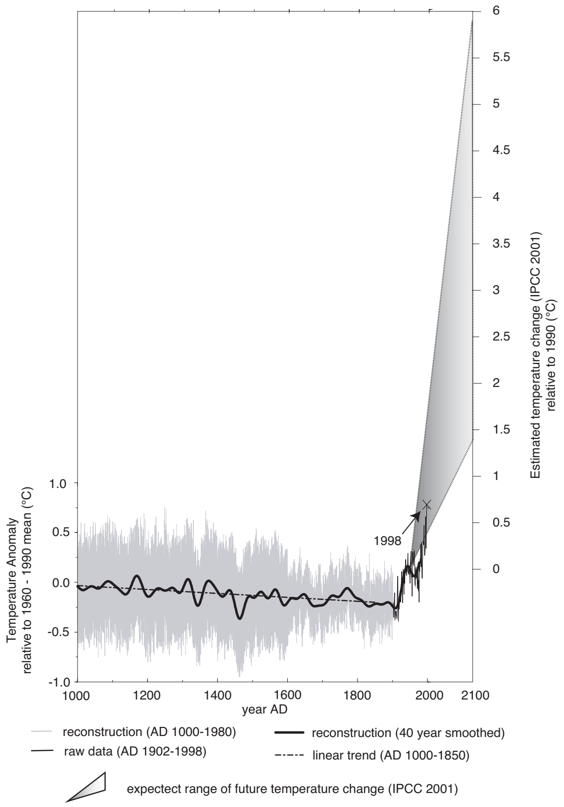

Fig. 1.4. A multiproxy reconstruction of mean annual Northern Hemisphere temperature (Mann et al. 1999) extrapolated to the range of IPCC estimates for the year 2100 (Houghton et al. 2001). A statistical confidence interval for the reconstruction is also shown.

1.3.1 The Anthropocene

Acknowledging the strong dependence of human-environmental interactions on socio-economic variables raises a further issue. The interaction between natural processes and human activities is complex. Moreover, the balance between the two has shifted dramatically (Vitousek et al. 1997, Meybeck et al. 2001), for the effects of human activities, especially during the last two centuries, have led to transformations much more significant than those resulting from climate change over the same period.

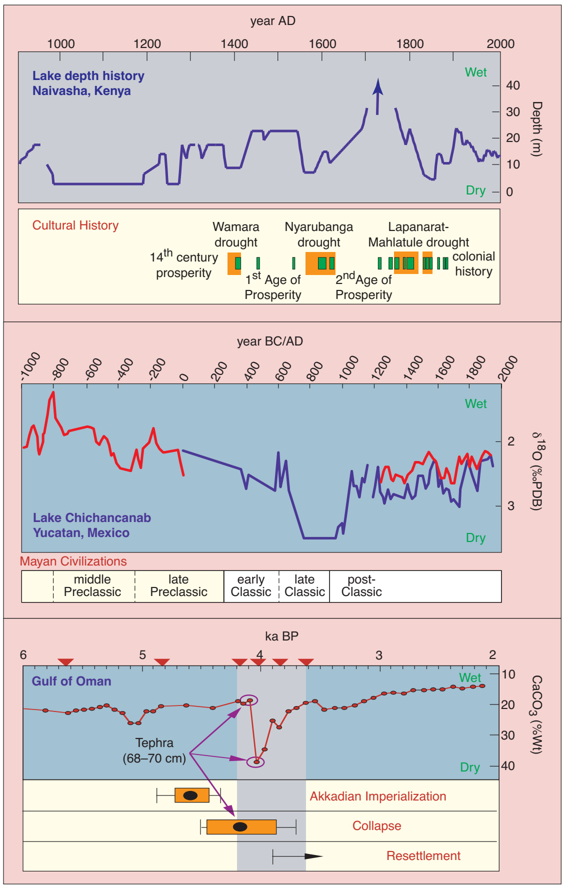

Fig. 1.5. Three examples of paleo-records where the combination of environmental and cultural history, coupled with rigorous chronological constraints, points to a strong link between the incidence of drought and the collapse of human cultures. In the upper panel, changing lake level in Lake Naivasha, Kenya as inferred from the sediment record is superimposed with a rough reconstruction, based on oral histories, of societal prosperity in the region (Verschuren et al. 2000). In the middle panel, drought in Yucatan, Mexico inferred from changes in the stable isotope ratios in two species of ostracod (red and blue lines) is shown to coincide with the collapse of Mayan Civilization (Hodell et al. 2001). In the lower panel a steep fall in carbonate percentage in a marine sediment record from the Gulf of Oman, representing a major episode of dust deposition, is directly linked to drought conditions associated with the demise of the Akkadian civilization (Cullen et al. 2000). This figure is reproduced from Alverson et al. (2001).

They have brought us into what may realistically be termed the "Anthropocene" (Crutzen 2002) and in so doing, endowed us with a 'no-analogue' biosphere as the canvas upon which future climate changes and human activities will interact. Moreover, the contemporary, no-analogue Anthropocene biosphere is now the initial condition on which changes related to increasing greenhouse gas concentrations will be superimposed. The Anthropocene is also marked by greenhouse gas levels well outside the range of at least the last 400,000 years (Figure 1.6, see also Chapter 2, Section 2.6) and global average temperatures that are the warmest for at least the past millennium (Figure 1.4, see also Chapter 6, section 6.6). At the same time, the pace of population growth, the level of technology and the degree of globalization of the world economy have endowed us with 'no-analogue' patterns of global and regional social organization. Does this imply that the insights to be gained from a deeper understanding of past human-environment relations are irrelevant for the future? Certainly they must not be overstated, but there are at least three important considerations that merit attention (1.3.2 to 1.3.4).

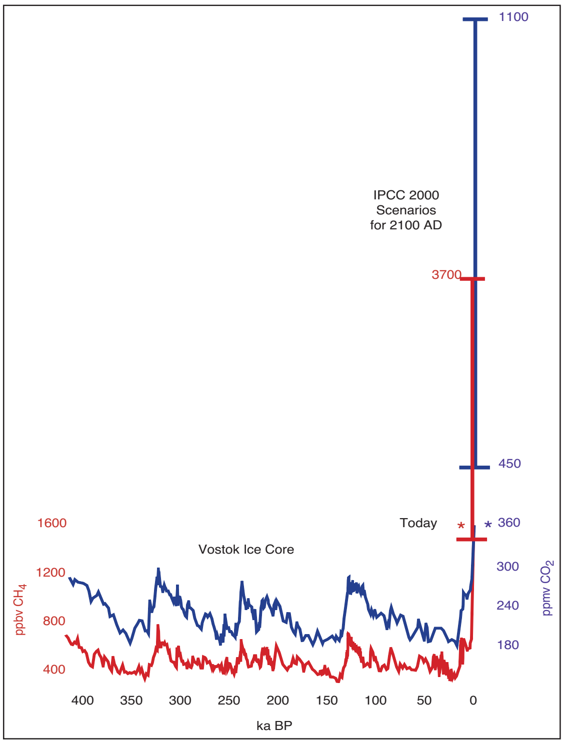

Fig. 1.6. Greenhouse trace gas (CO_2 and CH_4) changes over the last four glacial as recorded in the Vostok ice core (Petit et al. 1999) extrapolated to present day values and compared with the range of IPCC scenarios for the year 2100 (Houghton et al. 2001). This figure is reproduced from Alverson et al. (2001).

1.3.2 Societal responses to past climatic change

Over the last few years, paleoenvironmental, documentary, archaeological and anthropological approaches have begun to overcome the antagonism between dogmatic or over-mechanistic interpretations. The results reveal the complex nature of the relationship between environmental change and socioeconomic structures over longer time spans and during large or rapid environmental changes

(Chapter 7, Section 7.8). The insights obtained are particularly valuable with regard to contemporary societies whose patterns of social organization and resource use are most comparable to the earlier societies, and whose potential adaptation or mitigation strategies are most similar to those employed in the past.

1.3.3 Decadal-centennial modulation of modes of climate variability

One of the most striking successes in climate prediction has stemmed from the growing ability to anticipate the onset of El Niño. Although ENSO is one of the best known modes of interannual climate variability, with major implications for human activities, it is not the only one. The economic costs of El Niño events can be large (US$$10^{10}$) (Cane et al. 2000), as can ecosystem responses (Mantua et al. 1997, Hare and Mantua 2000). Its predictability is recognized to be dependent on understanding, among other things, the interplay between ENSO and longer, decadal to century scale modes of variability such as the Pacific Decadal Oscillation. One of the essential roles of paleoclimate research is to explore the variability of ENSO and especially changes in its teleconnections with a view to understanding their physical basis (Moore et al. 2001, Villalba et al. 2001). In this way, ENSO predictability under the changed conditions implied by future climate scenarios may be improved. The same applies to other modes of climate variability.

1.3.4 Vulnerability to extreme events

The impacts of extreme climatic events on even the most technologically advanced modern human societies are often severe. The period of instrumental records is too short to indicate the full range of hydrological and ecological stresses that will occur in the future. Even where relatively well informed planning is possible, decisions are necessarily based on assumptions about magnitude frequency relationships. As climatic boundary conditions change and as patterns of variability shift into different modes, these assumptions are compromised (Schrott and Pasuto 1999, Brown et al. 2000, Knox 2000, Messerli et al. 2000).

Figure 1.7, for example, shows the frequency of floods along the Colorado River drainage in the Southwest United States reconstructed for the past several thousand years (Knox 2000). The dramatic increase in flood frequency in the last few centuries is certainly not a simple expression of natural variability. However, looking further back to times well before substantial human influence could have occurred, it is clear that flood magnitude and frequency statistics can change substantially on centennial timescales.

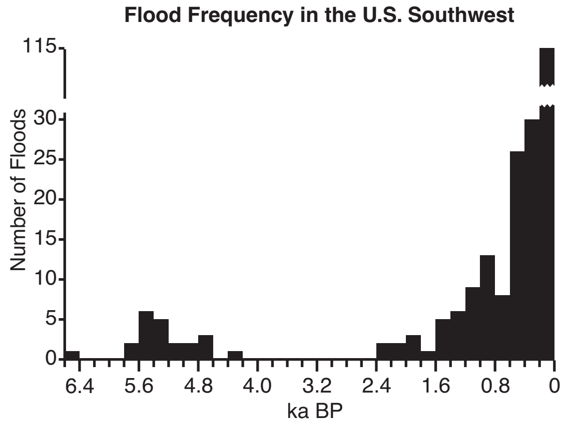

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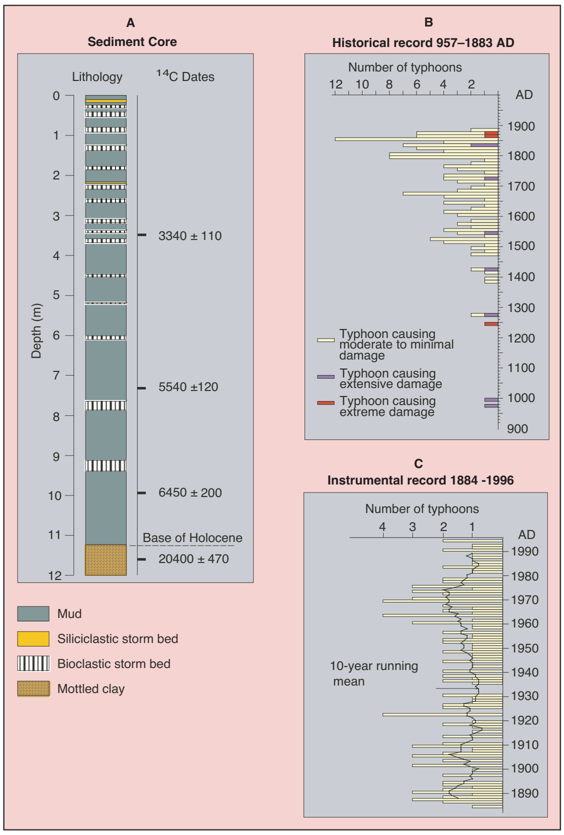
Figure 1.8 shows one example of an attempt to quantify the record of extreme events, in this case typhoons in the northern South China Sea (Huang and Yim 2001). Here typhoon frequency is reconstructed over three different timeframes using instrumental, documentary, and sedimentary records. Unfortunately, in this case there is little overlap between the time periods that these records cover, making cross validation difficult. Nonetheless, the records indicate that there is substantial natural variability in the frequency and magnitude of typhoons.

1.4 Hydrological variability

The most severe impacts of climate variability on human populations are often due to extreme drought, storm and flood events. Many environmental archives, as well as early documentary records provide clear evidence of such extremes. Persistent droughts, well beyond the range of those recently experienced, have been common in the past (Swetnam and Betancourt 1990, Gasse 2000, Verschuren et al. 2000) suggesting a high probability of occurrence in the future. Responsible planning must recognize this and allow for future environmental impacts associated with the wider range of hydrological variability documented in the past.



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A common theme implicitly linking many environmental and human concerns is that of the quality and availability of fresh water. The paleorecord highlights enormous variability in water resources in many parts of the world where population pressure and demands for water are currently rapidly increasing. Availability of clean fresh water is already a dominant concern in many areas of the world and one likely to be greatly exacerbated in the future. In this regard, the course of environmental change in mountain regions is of special significance, since they provide a high percentage of the water used in many densely populated parts of the world (Loaiciga et al. 1996, Beniston 2000, Meybeck et al. 2001).

Groundwater is a major human resource. Under favorable conditions, it also acts as an archive of climatic and environmental change, through information obtained from conservative chemical species, noble gas ratios and isotopic signatures (Gasse et al. 1987, Fontes et al. 1993, Stute and Talma 1998, Edmunds et al. 1999). The groundwater paleoarchive not only helps to quantify source contributions, ground water age, recharge rates and the future consequences of extraction, but also the effects of diffuse and point source contamination. Such considerations are of vital human importance especially in semi-arid areas where finite aquifers are being ‘mined’ much faster than they can be replenished. Rapidly falling water tables in such regions presage severe societal stress. The exhaustion of groundwater in some regions, for example Gujarat State, NW India, has already eliminated the principal buffer that could have been used to blunt the impact of potential future drought. In other regions, such as the mid-western United States similar depletion of groundwater is underway.

Documenting and better understanding the basis for the full range of potential climate driven hydrological variability is thus one of the most urgent and significant tasks for paleoscience. It is important to recall in this context that even the most sophisticated numerical climate models do not yet provide a realistic representation of precipitation patterns or amounts at regional scales.

1.5 Ecosystem processes

As the foregoing discourse shows, the human rationale for PAGES science extends into the area of past changes in the entire biosphere, whether as a result of climate change, human activities or the interaction between the two. Any consideration of human impacts on the biosphere entails an involvement with those aspects of global change that are, in terms of the distinctions made by Turner et al. (1990) ‘cumulative’ rather than ‘systemic’ (Chapter 7, Table 7.1). Such changes have, so far, had a much greater impact on hydrology, soils, vegetation and renewable resource systems over the last 150 years than have changes in climate. This is true despite the fact that over roughly the same time period, the change from the end of the Little Ice Age (ca. AD 1850) through to the last decade of the 20th century has, in many areas, already been one of the greatest climate changes recorded during the late Holocene (Bradley 2000).

Two main challenges arise from the above. The first is to reconstruct changes in ecosystems and hydrological regimes during the period of human impact. The second is to understand the consequences of these changes, especially those affecting gas and energy exchanges between the terrestrial biosphere and the atmosphere. For example, there is growing evidence from models, present day observations and paleodata/model comparisons (Ganopolski et al. 1998, Brovkin et al. 1999, Kleidon et al. 2000) that feedbacks to the atmosphere from land cover changes play an important role in modifying regional climate.

Even within the limited time-frame of the last two centuries, paleoscience has played a major role in documenting and improving our understanding of many environmental systems and processes (Battarbee 1990, Appleby and Oldfield 1992). This reflects, in part, the importance of decadal and century timescales for understanding the interaction of the many environmental processes upon which ecosystem function depends. Significant human impact on the environment and especially on terrestrial ecosystems did not begin two centuries ago; in many parts of the world, it began many millennia before present. On these longer timescales, the paleoperspective also provides an important complement to studies based on present day observations and modeling.

1.6 Landcover change

The present day landscape that forms the canvas upon which human endeavors and climate play out their counterpoint is itself the product of that counterpoint. Consider regions where soils are degraded, nutrient status diminished, organic matter content depleted or moisture retaining capacity is reduced. It is important to know, before modeling such systems or adopting the present day conditions as some kind of baseline, the extent to which current conditions are the product of current practices, or an inheritance from the past. Equally, it is important to explore the extent to which prevailing conditions reflect processes that are easily reversible or remediable, or are the product of past, non-linear shifts in ecosystem function that are much less tractable. The historical record is rich in examples of persistently reduced productivity arising from the transgression of thresholds in, for example, nutrient cycling or moisture retention (Bahn and Flenley 1992). Such switches have occurred in different parts of the world over at least the last six thousand years. It is often impossible to establish the relative importance of climate variability and human activity in driving systems over a given threshold since the two are interactive and can be mutually reinforcing in their effects.

Land cover changes brought about by human activity have a major influence on the impacts of climate variability, especially extreme events. Land cover modulates the expression of floods, their geomorphological impact (Starkel 1987, Eden and Page 1998) and the human hazards to which they give rise. There are many examples of how landcover changes, such as urbanization, deforestation and agriculture, have totally transformed downstream hydrological and sediment regimes. In many parts of the world, the period of direct observation and monitoring is not long enough to capture the full interaction of these processes. It is thus essential to build knowledge of past land cover change into the any evaluation of flood hazard based on magnitude/frequency statistics. The Yangtze River floods of 1998 that displaced in excess of 200 million people are a classic example of extreme climatic conditions exacerbated by land cover change, in this case deforestation in the watershed and loss of flood storage capacity downstream as a result of wetland reclamation for agriculture.

The past provides essential evidence for understanding the nature of human-environment interactions and optimizing them for the future. To consider the complex and rapidly changing scheme of human-environment interaction without regard to its antecedents is not a realistic enterprise. Human activities are as much drivers of contemporary and future environmental change as are anticipated changes in climate. The interplay between the two types of forcing is of vital concern and the history of their interaction is an important component in assessing future impacts.

The cumulative effects of land cover changes have global significance; they respond to and interact with the systemic changes currently under way. Even so, it is often most profitable to examine them within a more limited spatial framework since they are strongly differentiated regionally and it is at the regional level that their human implications are most evident. Global syntheses of such processes thus embrace representative case studies and recognize their diversity, rather than agglomerate them into global generalizations. It is through their effects on environmentally dependent resource systems that future changes in climate will most often impact human activities.

1.7 Biodiversity

The biodiversity that we now value is as much a product of environmental history as is any other aspect of the biosphere. Past interactions between climate variability and human activities (Chapter 7, Section 7.6) have served both to create and to jeopardize much of the biodiversity that is of vital concern at the present day. One of the key elements in any appraisal of biodiversity must be an understanding of the processes that have allowed for its development in the first place, its persistence, and finally those processes that threaten the survival of key taxa and habitats (Chapter 5, Section 5.4). This applies at all spatial scales from localized hotspots of high endemic diversity to major biomes such as the dwindling areas of equatorial rainforest. These historical aspects of biodiversity, though often neglected, pose a vital challenge to paleoenvironmental scientists at the present day.

1.8 Testing climate models with paleodata

Scenarios of how climate will vary in the future are dependent on model simulations. In order to be accepted as credible indicators of future conditions, such models must also be shown to be capable of reproducing conditions known to have occurred in the past. Models thus form one of the major links between past global change and decision making, which is inherently oriented towards the future. Subsequent chapters in this book include numerous examples of the interdependence of modeling and paleoreconstruction for model validation and process understanding. Paleostudies, for example, have played a major role in demonstrating the importance of terrestrial biosphere feedbacks on climate. Paleostudies also provide a basis for evaluating the dynamics of known past examples of abrupt climate change and exploring their potential relevance to the future (Claussen et al. 1999, De Menocal et al. 2000). One example is the possibility that future warming could lead to a decrease or shut down of North Atlantic Deep Water formation. The human consequences of any 'surprise' such as this are not well known but some of the physical and environmental consequences can be estimated by analogy with past periods when they are known to have occurred.

The emphasis in paleoclimate modeling is shifting towards transient experiments and regional simulations. Another technique, relatively new to paleo studies but long used in operational weather forecasting is inverse modeling, which allows known uncertainties in both data and model dynamics to be explicitly accounted for when addressing questions of model-data comparison (LeGrand and Wunsch 1995, LeGrand and Alverson 2001). These new modeling directions point towards a change in the interplay between models and data, with more emphasis on process understanding. Many concerns about future environmental change are rooted at the local level and this is precisely where paleodata can make the strongest contribution to placing contemporary or model predicted variability in a longer term perspective. The trend towards regional model simulations will further reinforce the relevance of paleoresearch in decision making, provided quantitative regional reconstructions are available. At present regional model output based on various downscaling techniques remains highly uncertain. With this degree of uncertainty likely to remain within the near future, it is worth tapping the potential of paleorecords for climate change impact assessment studies. It is possible to generate scenarios for future change based on a range of variability reconstructed from proxy data. Of course this approach has limitations, since future forcing may generate variability outside the range of past extremes.

Moreover, a strong case can be made for using paleodata qualitatively to assess system predictability. In the case of well buffered systems that have not exhibited catastrophic responses to extreme events in the past, predictability may be relatively high. By contrast, there are also systems that have clearly shown repeated non-linear responses to high magnitude events. For these systems future behavior will remain extremely difficult to model or predict.

1.9 A paleoperspective on future global change

The scope of this book is wide-ranging. Drawing out the main conclusions from themes that are as diverse as ocean biogeochemistry, atmospheric physics, terrestrial paleoecology and environmental archaeology is a formidable task. The final chapter seeks to do this with an eye on those processes and interactions that are most significant for the future of human societies. The past does not provide a prescriptive guide to the future, but analyzed and interpreted with sufficient insight, it does inform evaluation of present day trends, future probabilities and likely human consequences.

The following are some of the key points to emerge from the present introduction:

- ongoing natural climate variability has affected every part of the earth system on all timescales
- the past range of climate variability exceeds that captured by the short period of instrumental observations
- atmospheric greenhouse gas concentrations

have varied in parallel with temperature throughout the last four glacial cycles

- current levels of greenhouse gas concentrations in the atmosphere are well above the upper limit of natural variability for at least the past 400,000 years
- understanding of the nature of the link between greenhouse gas concentrations and temperature in the past is a prerequisite for evaluating the consequences of recent increases
- understanding past ecosystem processes improves our ability to predict the likely effects of future global change
- in the past, areas that are today densely populated have experienced droughts and floods that would have disastrous consequences in the future
- the paleorecord is rich in examples of climate change coinciding with major changes in human societies
- humans have long had impacts on environmental processes with a range of consequences for ecosystems and sustainability
- the paleorecord can help to disentangle the natural climate variability and human activities as drivers of environmental change and to evaluate their interactions.
- studies of the past are an essential component of global change research which is otherwise limited by the short period of direct observations

Kenneth Boulding (1973) aptly describes the challenge we face:
"*…whereas all experiences are of the past, all decisions are about the future… it is the great task of human knowledge to bridge this gap and find those patterns in the past which can be projected into the future as realistic images…*"
Clearly, the paleorecord provides essential insight into past earth system variability. Without this perspective a full understanding of how the system works and why it has changed (an elusive goal even wearing the rosiest of glasses) would be unattainable. Attempts to anticipate future changes will inevitably fail without considering these past experiences. By synthesizing the evidence from the past and tying it to human concerns, this volume stands as a PAGES response to Boulding's challenge.

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