GLOBAL CHANGES OF THE PAST

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Records of Past Global Changes

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Introduction

The earth is constantly changing, never static: a dynamic system in which all parts interact, at some scale, with all other parts. Involved are all components of the earth system—the atmosphere, geosphere, cryosphere, hydrosphere, and biosphere, including mankind. The goal of global change research is to understand how these complex coupled systems interact, to identify the important linkages among them, and to better understand the earth system as a whole. Ultimately, this research may provide the basis for anticipating future global or large-scale environmental changes and their consequences for mankind.

To forecast environmental changes of the future, or even to understand our contemporary environment, requires a perspective that can only be obtained from a better knowledge of the past. Our present environment is a transient condition that has resulted from an entire spectrum of factors (both natural and anthropogenic) interacting in time and space. To understand our contemporary environment and how it may change in the future thus requires an assessment of conditions that *preceded* the present, a perspective that can only be gained by studies of the past. Such research focuses both on the time evolution of relevant processes (which may operate on time scales from many millennia to a few decades) and on their interactions through time. It may shed light on the linkages between biogeochemical processes and the physical aspects of climate, enabling causes and effects to be isolated and assessed. Studies of the past also reveal how quickly earth systems have responded to particular forcing factors, which is of critical importance in anticipating and planning for future environmental changes. Finally, a better understanding of environmental conditions in the past is invaluable for testing numerical models of atmospheric and oceanic circulation, biospheric dynamics, and environmental processes, by providing a data base of environmental conditions in the past which were quite different from those of today.

It is important to recognize that it is not possible to specify precisely *which* period in the past is of most relevance to understanding future global changes. Changes in climate and environment over the last century must be viewed in the context of how contemporary climatic conditions have evolved over varying time scales. In the last few centuries, many regions of the world experienced the so-called Little Ice Age; is the 20th-century warming no more than a natural recovery from that cold episode? To answer that question, we need to know what caused the Little Ice Age and, perhaps more importantly, what caused it to end. Some have argued that the Little Ice Age was one of a series of quasi-periodic episodes which may return again in the future. To assess that, we need to know the time evolution of climate over many millennia, i.e., over a period considerably longer than the length of the recurring period itself. Past records reveal many episodes of abrupt climatic change with dramatic environmental consequences, yet the causes of such events remain elusive. Studying these periods, many of which are in the distant past, is necessary to understand the reasons for such changes and their relevance to society today. Thus, studies of past global changes cannot be constrained to focus on only the most recent period of time, but must reach back in time to include those periods that are most significant to contemporary environmental problems.

Reconstruction of Past Global Changes

For the period before the introduction of instrumental records, all evidence of environmental change comes from natural phenomena which have preserved a record of former conditions. These "natural archives" or "proxy records" provide a wealth of information about paleoenvironmental conditions, including, *inter alia*, records of past atmospheric composition, tropospheric aerosol loads, explosive volcanic eruptions, air and sea temperatures, paleowind and precipitation patterns, ocean chemistry and productivity, sea level changes, former ice sheet extent and thickness, and variations in solar activity. Table 1 summarizes some of the primary characteristics of these records of the past.

In all cases, the ability to date these records accurately is of critical importance. Without accurate dating it is impossible to determine whether events occurred synchronously or certain events led or lagged others. This is a fundamental requirement if we are to understand the nature of global changes of the past. Accurate dating is required in any assessment of the rate at which past environmental changes occurred, particularly when considering high-frequency, short-term changes in climate. Indeed, the duration of such events may be shorter than the normal error associated with many dating methods. However, the more widespread application of accelerator mass spectrometer (AMS)–^{14}C dating in paleoenvironmental research promises to greatly expand our understanding of past environmental changes and their causes, at least for the last 30–40,000 years. As more and more samples are dated by the AMS method, it will become easier to determine whether past events

Table 1: Characteristics of natural archives

Archive	**Best Temporal Resolution***	**Temporal Range (yr)**	**Information Derived**
Historical records	day/hr	10^3	T,H,B,V,M,L,S
Tree rings	season/yr	10^4	T,H,C_a,B,V,M,S
Lake sediments	yr to 20 yr	10^4–10^6	T,H,C_w,B,V,M
Ice cores	yr	10^5	T,H,C_a,B,V,M,S
Pollen	100 yr	10^5	T,H,B
Loess	100 yr	10^6	H,B,M
Ocean cores	1000 yr	10^7	T,C_w,B,M
Corals	yr	10^4	C_w,L
Paleosols	100 yr	10^5	T,H,C_s,V
Geomorphic features	100 yr	10^7	T,H,V,L
Sedimentary rocks	yr	10^7	H,C_s,V,M,L

*Minimum sampling interval in most cases.
T = temperature
H = humidity or precipitation
C = chemical composition of air (C_a), water (C_w), or soil (C_s)
B = biomass and vegetation patterns
V = volcanic eruptions
M = geomagnetic field variations
L = sea levels
S = solar activity

were truly synchronous and global in extent, or whether different parts of the earth system responded more rapidly than others. AMS dating can provide a hitherto unattainable perspective on the time evolution of earth system responses to particular forcing factors, enabling cause and effect to be documented and analyzed.

Modeling in Paleoenvironmental Research

In addition to studies of natural archives, paleoenvironmental research also involves numerical models of environmental processes. These models are necessarily based on studies of the contemporary environment, but are applied to those periods in the past when boundary conditions were different from today's. This provides a test of the model's ability to simulate distinct environmental states. For example, general circulation models have been used to produce large-scale paleoenvironmental reconstructions for particular periods in the past which can be verified (or nullified) by research on natural archival materials. Models are also used to test hypotheses about the causes of past environmental changes, to quantify the relative importance of different factors, and to examine the sensitivity of the system to forcing.

Models and field data are used interactively to stimulate new hypotheses about the nature and causes of environmental change, and to assess their validity. As an example of this evolving process of data collection and model building, consider recent developments in studies of environmental changes on glacial to interglacial time scales. It has long been postulated that orbital variations were primarily responsible for the onset and cessation of the major glaciations of the late Quaternary. However, modeling studies suggest that the changes in solar radiation produced by orbital variations were insufficient, by themselves, to produce the observed environmental changes. Other processes or feedbacks were evidently involved. Recent studies of polar ice cores have revealed significant changes in CO_2, atmospheric aerosols, and CH_4 from interglacial to glacial periods. CO_2 and CH_4 levels were much lower during the last glaciation, and the tropospheric aerosol load was much greater. Models have been used to assess the relative importance of these factors in the growth and decay of continental ice sheets, to provide *quantitative* estimates of their significance. However, these results have raised new questions about the processes involved in such dramatic environmental changes: What changes occurred first? Was there a primary triggering factor? What caused the changes in atmospheric composition? Are there critical thresholds in earth systems which, once crossed, lead to new and different quasi-stable environmental states? As the following chapters demonstrate, much new research has been fueled by such questions, and so the search for more information and better understanding continues. This is not an irrelevant academic exercise. Changes in atmospheric CO_2 and CH_4 levels experienced in the geologic past were of the same magnitude as changes wrought by human activities over the last century. Thus, paleoenvironmental data and modeling can together help us to evaluate known changes in the past, and to comprehend the feedbacks and system responses that are of direct relevance to understanding the future impact of greenhouse gases.

Many of these, and other, topics are discussed in the chapters that follow. The objective is not to provide a detailed review of research on any one topic, but to identify areas where further understanding is needed, and to assess the major uncertainties in each field. In this way, directions for future research are outlined. Major recommendations are given in the Working Group Reports, focusing on high-resolution records of the last 2000 years, past changes in the biosphere, and environmental change during the late Quaternary. Subsequent chapters then address topics of particular importance in each of these areas. Overall, the chapters which follow provide a broad "status report" on our current understanding and pointers as to where further efforts are likely to yield important advances in the study of global changes of the past.