RECONSTRUCTING ENVIRONMENTS

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Contents

Summary

The most common sources of data for reconstructing past climate include ice cores, long, narrow cylinders of ice drilled from an icecap, and sediment cores, cylinders of mud and other matter drilled from the floors of oceans and lakes. Other sources of information are the fossilized remains of plants and animals; samples from coral reefs; plant remains obtained from peat bogs; and the growth rings of trees. By studying these kinds of evidence, researchers have been able to reconstruct a timeline of the prehistoric climate of Earth. Knowledge of past climatic fluctuations has helped to explain ice ages, changes in sea level, famines, migrations, and societal collapse. Increasing evidence indicates that human impact on the environment is causing local and perhaps worldwide changes in climate.

1. Introduction

In trying to understand changes in the archaeological record, archaeologists have long been interested in understanding the climatic conditions that may have affected prehistoric peoples coincident with the changes. However, there are few direct records of palaeoclimate so one must rely on proxies—measurable parameters that provide quantitative information about variables such as temperature, rainfall, or ice volume—to reconstruct it. The elements of climate change vary through time as well as from place to place. Indirect evidence of climatic trends in the distant past is revealed in fossils, lake and ocean beds, peat bogs, glacial deposits, and soils. Widths of annual growth rings in trees correlate with temperature and rainfall fluctuations, especially along the drier margins of forests. Archaeological remains and written history offer clues to climatic conditions during the human era. Modern instrument records provide direct evidence of climatic change.

As a factor in the natural environment, climate not only affects world patterns of vegetation, soils, and water resources, but also directly or indirectly influences every human endeavor. Climate determines an area's suitability for settlement and for agriculture, manufacturing, transportation, and other economic activities. The climate changes from the recent past—such as drought—can help in understanding potential impact on societies.

Drought often conjures up images of the Dust Bowl drought in the United States, which lasted approximately six years (1933–1938) and resulted in one of the most devastating and well-documented agricultural, economic, and social disasters in the history of the United States. The drought was triggered by large and widespread reduction in rainfall across the American West, particularly across the northern Great Plains. It displaced millions of people, many of who moved to the western U.S., including California, in search of jobs and better living conditions. Many sought to continue farming—the way of living they were most familiar with. This drought episode cost over $1 billion (in 1930s U.S. dollars) in federal support and contributed to nascent economic collapse.

Global climate usually changes little over the course of a human lifetime, but a large and rapidly growing body of research has begun to reveal just how variable global climate is on longer timescales. Three hundred and fifty years ago, the world was in the depths of a prolonged cold spell called the "Little Ice Age," which lingered for nearly half a millennium. Fifty thousand years ago, in the middle of the last glacial period of a global ice age, large continental ice sheets covered much of North America, Northern Europe, and Northern Asia. This was a time when *Homo sapiens* was expanding into southern Europe.

How fast can climate change? How drastic are the swings? What parts of the world will be hit with typhoons or drought? To answer questions like these, climate scientists look at records of the past. Humans have noted aspects of climate change for about 1000 years, in historical records of cherry blossoms in Japan and grape harvests in Europe, and Egyptian hieroglyphs tell of 4000-year-old droughts. But a wealth of natural data is being examined to gather evidence of past climatic conditions and subsequent changes in those conditions. Annual records of climate are preserved in tree rings, locked in the skeletons of tropical coral reefs, frozen in glaciers and ice caps, and buried in the sediments of lakes and ocean. Heightened interest in global climate change has come about in recent years because of growing concern that the earth's climate may be getting warmer possibly due to human activities such as the burning of fossil fuels (coal, oil, and natural gas). Knowledge of past changes in climate can give a perspective on how much of a warming trend may be part of the normal cycle of change in the climate system and how much can be blamed on human activities.

2. What is Climate, Weather?

Climate is the general state of the atmosphere over a long period of time. Whereas weather is the expression of day-to-day conditions, climate is a composite of averages and extremes during a specified number of years. Like weather, climate results from energy and mass exchanges within the atmosphere and between the atmosphere and the earth's surface. The study of climate is ancient. Greek philosophers replaced supernatural explanations with a concept of climate based on latitude and the inclination of the earth's axis. The Greek word *klima* means the slope of the earth with respect to the sun and approximates the modern concept of latitude.

3. Why Climates Differ

Incoming solar radiation, or insolation, is the basic source of energy for atmospheric processes. The earth's orbital revolution around the sun and its rotation on a tilting polar axis produce seasonal and daily changes in the amount of insolation. Gases, clouds, and suspended particles in the atmosphere scatter and reflect about 26% of insolation into space. The earth's surface reflects another 4%, although the proportion varies with the angle of the sun and the reflectivity of different materials. The atmosphere and the earth's surface together absorb about 70% of insolation, which is converted to the heat and kinetic energy that create weather and climate. Absorption by the atmosphere of energy emitted from the earth's surface delays the energy's return to space, creating a greenhouse effect. Eventually all absorbed solar energy returns to outer space as long-wave radiation, maintaining a long-term global energy balance and a nearly constant average global temperature.

The actual energy budget and resulting effects on climate at a given place depend on additional factors. Latitude determines the duration of daylight as well as the angle of the sun's rays, which are more effective when the sun is near the zenith. Altitude is also a factor in climate, because air temperature normally decreases with elevation at a rate of about 6°C/1000 m. General atmospheric and oceanic circulation systems redistribute heat and moisture, helping to prevent overheating in the tropics and intense cold near the poles. Prevailing winds, especially trade winds and westerlies, transfer temperature and moisture properties between the continents and the oceans. Because water is slower to heat and cool than land and affords a ready supply of moisture, regions downwind from oceans usually have more moderate temperatures and more precipitation than do the interiors of the continents. This maritime influence is marked in middle latitudes. Ocean currents and drifts further promote the transfer of heat.

Areas lying in the paths of cyclonic storms are subjected to the associated variability of winds, temperature, and precipitation. Where prevailing winds, air masses, and traveling storms encounter mountains the barrier effect retards movement, often forcing air to rise. This orgraphic effect causes cooling as the air expands and may induce greater precipitation on windward slopes, whereas the leeward slopes experience a rain shadow effect. Mountain barriers can also slow the passage of cold, stable air masses, thereby protecting regions to the leeward. Local relief features and differences in slope or exposure affect the receipt of insolation, water runoff, and wind conditions.

Daily differences in heating and cooling generate local mountain and valley winds and land-sea breezes. Monsoons develop as a result of changing patterns of atmospheric pressure caused by the varied heating and cooling rates of continental landmasses and oceans. Summer monsoons are like a giant sea breeze. The faster warming of the land than sea on a summer day induces a sea breeze at the beach because warm air rises over the land and draws in moist air from the sea. In the case of the monsoon, the direction of the monsoon wind during the warm season is from the cooler ocean to the warmer land and the greater the temperature contrast between the continental landmass and ocean the stronger the monsoon. Under these conditions, large amounts of precipitation can be transported inland. If the direction of the monsoon wind is from the cold interior towards the relatively warmer ocean (a winter phenomena) there is wind but no moisture transport. Inland bodies of water also can create daily breezes as well as influence temperature and humidity in their vicinity owing to the lake effect.

4. Palaeoclimatology

The study of ancient climates is known as palaeoclimatology. We only have about a 150-year perspective on the variability of the climate system as a whole based on instrumental records for the measurement of temperature, precipitation, sea level pressure, and wind speed and direction. For longer periods, palaeoclimatologists use natural environmental (or "proxy") records to infer past climatic condition. In much the same way as some researchers study the prehistoric past by examining fossils and other physical clues, palaeoclimatologists study several types of evidence in an attempt to understand what Earth's climate was like in the past and how—and why—it has changed. The more scientists learn about how the climate has varied over the past several million years the better their predictions about future changes will be.

Several such proxy climate records are discussed below. The dating of tree rings, ice cores, and corals is accomplished by counting the annually deposited growth ring, ice layer or growth bands. Other methods depend on the use of radiocarbon dating back to 40 000 years or so or the decay of other radioactive elements such as uranium (U) and thorium (Th), which can be used to date material back hundreds of thousands to millions of years. Yet other methods correlate stable isotopes to regular changes in Earth's orbit going back millions of years.

4.1. Tree Rings

Annually, trees put on a growth ring that represents the stored food surpluses. Tree rings are valuable sources of proxy climatic data because they are continuous in nature (allowing for precise dating), and research has shown that tree-ring widths or density can provide estimates of climatic conditions. Work by the Laboratory of Tree-Ring Research at the University of Arizona indicates that there is a relationship between tree growth, as manifested in the annual tree rings, and the stored food reserves. The amount of food manufactured and stored by a tree (rather than residual soil moisture) seems to be the main link between the environment and tree growth. At low-elevation locations, the amount of food manufactured and stored by a tree for the winter is directly related to the amount of moisture available during the current growing season as well as the amount of food held over to be consumed at that time. On the other hand, high-elevation trees near the upper limits of their ranges are not usually limited by moisture, but by temperatures during the current growing season as well as the amount of food reserves available for consumption. Therefore, depending on the location of the tree, narrow rings form when precipitation and/or temperature during the previous year were not conducive to the production and storage of adequate reserves, coupled with insufficient moisture (low elevations) or low temperature (high elevations) during the current growing season.

Thus, tree rings have been used to provide information on temperature and rainfall, even seasonal changes from ring width and density. Tree-ring records contain patterns of cycles such as El Niño and the Pacific decadal oscillation of sea surface temperatures. Ring scars can be used to reconstruct the frequency and area of fire or severe frosts.

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Biographical Sketch

Kenneth Lee Petersen I received my B.A. (1970) in Anthropology from the University of Utah, Salt Lake City, and my M.A. (1975) and Ph.D. (1981) in Anthropology from Washington State University, Pullman. I am currently working in the Office of the Vice President of Academic Affairs, University of Utah. In addition to training as an archaeologist, I was trained as a palynologist—a researcher who reconstructs climate by using pollen. My earliest exposure to studies of climate and humankind interactions occurred in the mid 1960s while working on high elevation game drive systems and Holocene cirque glaciation in the Colorado Front, above Boulder, Colorado. Since then I have expanded my studies to include most of the Western United States and Egypt, even looking to the future by examining the potential impact of future climate change as it relates to nuclear waste disposal.