

Introduction: A Perspective from the Humanities—Science Boundary

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Abstract

The articles in this special issue range across such influences on climate as solar emissions, orbital precession, atmosphere, oceans, and precipitation, and generally approach, each in some context, human implications of these phenomena. The common underlying theme of all of the papers is the effect the phenomena have on radiation balance as measured by global average temperature. This introductory paper undertakes a formulation of radiation balance theory that makes it serviceable to students of regional science. The objective is to go beyond inference of cause and effect by correlation to causal accounts of cause and effect through regional climatic and cultural processes. This is accomplished primarily by revisualization of the energy system with regions as dependent spatiotemporal entities, and temporally through a protocol for regional episode definition. **KEY WORDS:** climate change; episodes; radiation balance; global change; historical ecology.

Article:

INTRODUCTION

Practically anyone alive in 1950, humanist or scientist or mix of the two, would have viewed the future in terms of science and technology, some more enthusiastically than others. The eleventh edition of *Encyclopedia Britannica* (1910-1911) is taken by many to mark the onset of the age of technology. It was the last issue with a major emphasis on history and literature. Subsequent editions emphasized science and technology. Ironically, by the last decade of the twentieth century, scientists had discovered that historical processes influence many astronomical, geophysical, and life functions, both in the solar system and the earth system. In this issue of *Human Ecology*, we attempt to recognize this synthetic state of relations between history and science, heritage and process, by examining an issue squarely on the boundary between the two, the effects of global climate change on regional scale cultures. Regions are taken to be relatively small geographical units possessing demonstrably coherent but constantly varying complexes of climatic, geological, biological, and cultural phenomena. In this introduction, we will attempt to provide a communication protocol for the as yet uneasy relationship between mathematical precision and historical interpretation as relates to global climate processes. The vehicle selected to enable us to implement cooperative investigation is regional climatic episodes of a few decades or centuries duration. Episodes already have some standing in the literature. Here we attempt to formally implement episodes as an analytical concept.

GOALS OF THE ISSUE

The articles in this issue engage questions of change in the global climate and its impacts on regional biocultural systems. Fundamentally, they all address the question of causes of variation in global average temperature. They document how global climate is produced, modulated, and measured (Fig. 1). They also attempt to point out possible cultural and historical implications of these conditions for regional cultures with the understanding that these formulations are hypotheses that will be addressed and elaborated with and/or by those with specific regional interests in social processes. Extensive discussions of the biocultural aspects of global-regional climate are presented by Crumley (1993) and contributors. This volume is a companion to that work.

This introduction gathers key elements of a working model of global climate change as it affects regional life systems. The character of that model is intended to be a common conceptual workplace for those involved in the impacts of global change on regional conditions, including social scientists, physical scientists, and humanities scholars. Thus, the model must be acceptable to those involved in atmospheric and related research, but comprehensible and manipulable to a more general public. Climatic episodes appear to be the concept most widely held in common. More than one of the contributors has made significant contributions to defining episodes. The key properties of the model are that it is fundamentally verbal and typological, but amenable to refinement by scientific study of past and present conditions through modeling, historical documentation, data gathering, and analysis. We will return to the structure of the episode-driven model at the end of the introduction. First, some principles by which the global climate functions will be discussed. In this context, a scheme will be

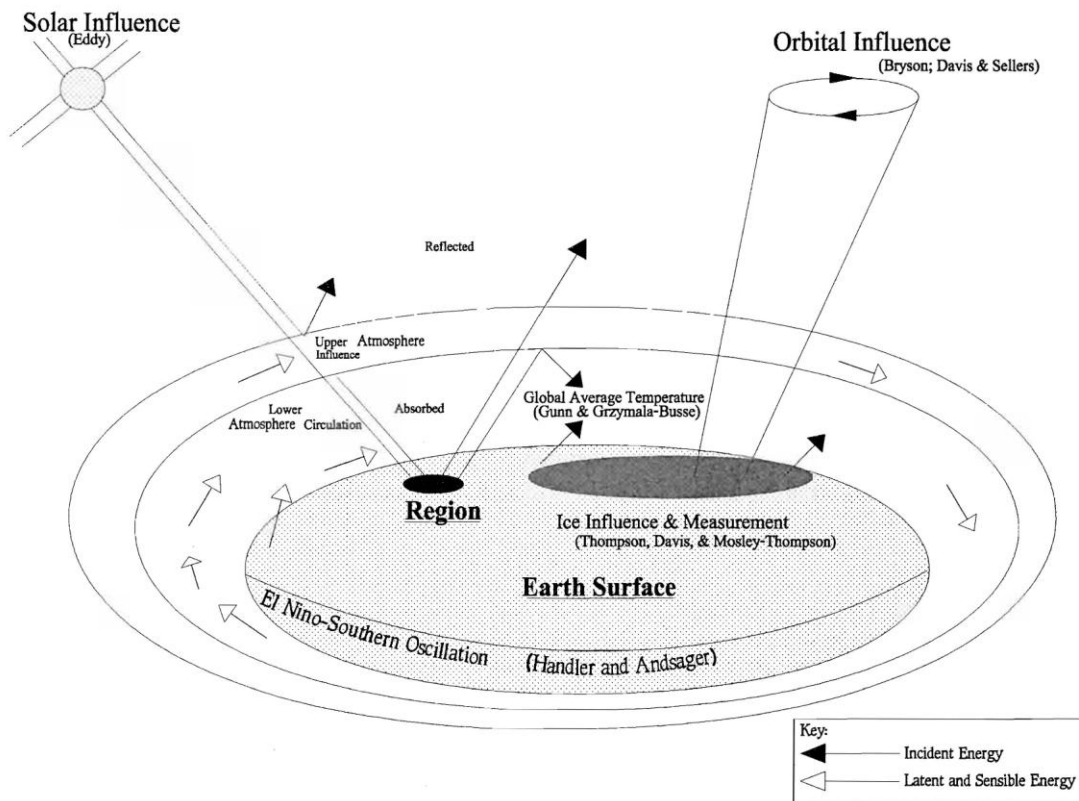


Fig. 1. Textbook view of the global energy stream showing key influences on global average temperature and relationships of the articles in this issue.

formulated to show how global climate affects regional conditions and life systems. At appropriate points during this presentation of principles are brief introductions to the articles. Related readings are appended.

A REGIONALIST'S OVERVIEW OF GLOBAL CLIMATE CHANGE

Of first importance to global-regional analysis is a somewhat adjusted view of the global energy system (Fig. 2). The dynamo that drives global climate is incoming solar radiation that is captured and stored in the atmosphere and oceans. One of many useful methods of measuring the status of that energy reservoir is global average temperature of the atmosphere. Global temperature has great utility in this context because it constitutes a shorthand for the global climate system as a whole, and for the atmospheric flow patterns which mold climate on the earth's surface. The global temperature directs the flow of air, clouds, and precipitation in the atmos-

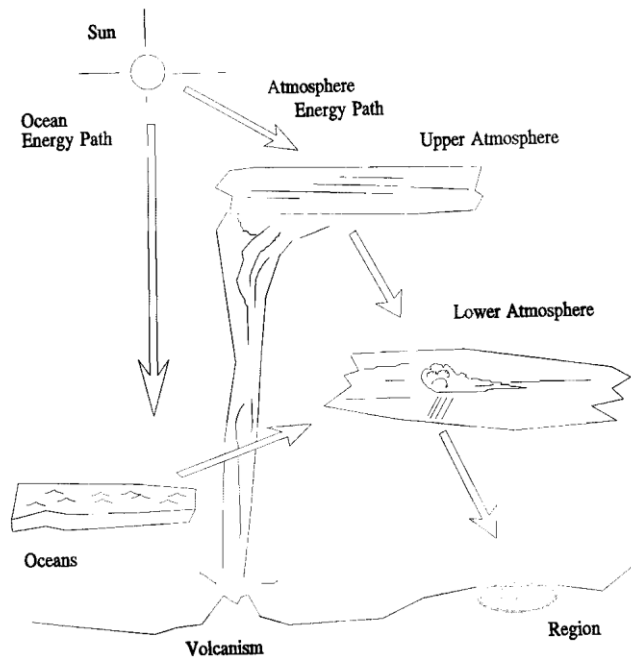


Fig. 2. Regionally adjusted view of global energy stream. All influences are causally prior to regional climate.

phere through the thermodynamics of fluids, a principle that has been understood since shortly after the turn of the century (see Gunn, 1994). We observe this process through the cycle of seasons each year as changing hemispheric temperature drives the Arctic airmass north each summer. Seasons are in some aspects brief rehearsals of climate changes. The flows, or airstreams, determine which portions of the earth's surface are dry and which are moist, and they are the single most important influence on the density and quality of biocultural populations. The publication of E. R. Reiter's book *Jet Stream Meteorology* in 1963 marks the advent of intensive study of the thermodynamics of the atmosphere. However, the study of the impacts of global effects on regions, communities, watersheds, etc., has been given little attention until recent years. Its importance became apparent when the super computers of the late 1980s clearly could not calculate climatic effects at socially and biologically meaningful scales. A review of the existing literature on regional impacts is provided in Gunn et al. (1993).

Study of global climate was once predominantly the domain of meteorologists interested in predicting weather. However, with the realization of the earth system as a single fully mobilized entity, understanding shifts in atmospheric flows is no longer the exclusive concern of the sciences; it has, or will become, an important factor for research in the social sciences and scholarly disciplines. Humanistic scholars, especially historians, folklorists, and classical/biblical scholars are benefitting as they turn their attention to the study of the earth system of the past. Global climate is now a concern to diverse audiences, including archeologists, who study long past civilizations, and present-day policymakers, who fear damage or demise of our own civilization because of carelessness with the global environment.

Lacking to date has been an effort to study the earth system in a theoretical context friendly to all parties interested in regional impacts. To remedy this we propose, as a working model, that the region of study in any given undertaking be viewed as causally dependent on the conditions of the global system. The textbook concept of global climate views energy as passing through the earth system (see Fig. 1). However, as a special case of that system, the dynamic the global average temperature brings to the earth system is registered in a region as climates. Regional climates change with the global temperature. The climates determine regional precipitation and temperature characteristics (see Fig. 2). The global average temperature is measured as the

tropospheric average temperature of the hemisphere under study. The troposphere, or lower atmosphere below about 30,000 feet, contains the moisture and temperature that influences living organisms.

One very important modulator of the global temperature that has received much attention recently is the El Niño-Southern Oscillation. In this process, solar energy accumulates in the water of the equatorial Pacific, and then is suddenly released around Christmas time after about 4 years. In this sun-ocean energy path, the sun and the tropical Pacific work in concert to change the global temperature and modify regional terrestrial conditions.

There is also a sun-stratosphere energy path. The upper atmosphere, or stratosphere, acts as a somewhat independent influence in conjunction with the sun and volcanism. Significant changes have been noted in the upper atmosphere as a result of increases in solar energy emissions. Also, geophysical conditions related to plate tectonics produce volcanoes that eject debris into the upper atmosphere. Since there is no moisture in the upper atmosphere to wash the debris away immediately, silicon dust and sulfur compounds remain aloft for years following eruptions. This debris blocks some of the incoming radiation, preventing it from warming the lower atmosphere, thereby modifying the global temperature and regulating atmospheric flow patterns. Thus, two somewhat independent energy paths operate to modify global climate and produce regional consequences.

There is yet another atmospheric energy modulator that involves humans. It is now realized that humans may have significant effects on the global temperature. Burning of fossil fuel increases gases that capture radiation in the lower atmosphere, preventing it from escaping into space. In addition, other anthropogenic chemicals have reduced the ozone in the upper atmosphere; this is expected to permit more radiation to enter the lower atmosphere further increasing global temperature. It is possible that human activities have modified atmospheric composition for thousands, if not tens of thousands, of years through the use of fire. For example, during the period usually termed classical Mediterranean civilization, including the Roman Empire, much of Europe from Poland in the north to tropical Africa in the south was largely deforested. This was the result of burning wood to obtain charcoal to process iron. This suggests that the so-called Roman Optimum could be the first incident of anthropogenic global warming. During the twentieth century, atmospheric chemistry has been radically altered and the consequences are not understood, either as transitive processes or ultimate outcomes. Given the gravity of the potential consequences, the situation suggests that all possible avenues of investigation should be pursued to achieve appropriate understanding. That the condition of the global system is as much an historical outcome as it is a deterministic one emphasizes this urgency.

If we take global temperature as an index of global climate, it immediately becomes clear that any influence on global temperature is germane to understanding global climate change. A brief examination of modern global climate will serve to illustrate the interactive nature of the influences on global temperature. In a study of the effects of variable sun, El Niño, volcanism, and atmospheric carbon dioxide on global temperatures, I have shown the degree to which each of these influences makes a contribution, given currently available measurements. A map of the expected and observed global temperatures since the International Geophysical Year during 1957-1958 appears in Fig. 3. We can use this map to test whether global temperature behaves as an index of global climate. The map shows that beginning in 1958 (the first two characters at each point is the year) the

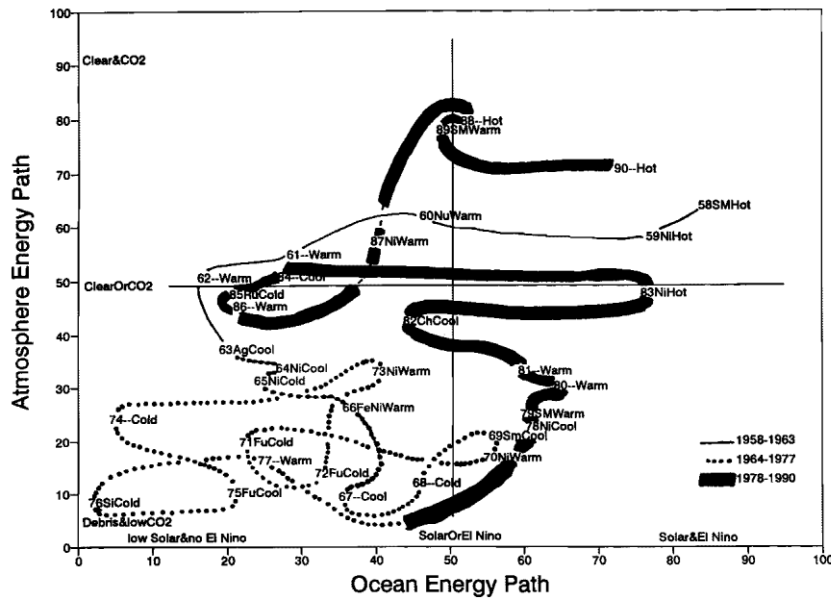


Fig. 3. Global energy map 1958–1990. To investigate relationships between global energy path expectations and observed global temperatures, energy path values were mapped in a phase space. The energy paths in this figure are mapped according to expectations from solar energy, El Niño, volcanism, and atmospheric carbon dioxide. To construct the expected values for the energy paths, a regression equation was calculated for the effect of these influences on global temperature. Global average temperature was represented by the average annual temperature of the Northern Hemisphere troposphere (850–300 mb, see Angell and Korshover, various). The data values for each influence were converted to percentiles. The standardized regression coefficients were used as weights by multiplying them by the percentiles. Solar and El Niño weights were summed to obtain the ocean energy path value. Upper atmosphere debris was quantified as atmospheric apparent transmission, or optical depth, at Mauna Loa, inverted. CO₂ was represented by the summing Trend and Residual weights. Apparent transmission and CO₂ weights were summed to obtain the atmosphere energy path values. This creates a combined geophysical (stratospheric volcanism) and anthropogenic (tropospheric trace gases) atmospheric energy path value.

world should have been hot because of high solar energy output combined with an El Niño energy release. Special events influencing the global temperature, such as solar maxima (SM) and El Niño (Ni) are indicated by the middle two characters at each location (Table I). Following the years like an energy road map, the theoretical ocean energy path values declined from 1958 through 1962. During 1963 Mount Agung (Ag) erupted, which should have cooled global temperatures along the atmosphere energy path. The remainder of the 1960s and the early 1970s remained low on both the ocean and atmosphere energy paths except for a minor solar maximum in 1969 and an El Niño in 1970. The 1978 El Niño, and the 1979 solar maximum, initiated a warming that continued until 1981. During 1982 the El Chichon (Ch) eruption should have cooled the global temperature. However, it also unleashed the largest El Niño the last 500 years during the subsequent 1982-1983 winter; this produced an expected warming during 1983. It is marked by a sharp excursion to the right (warmer) between 1982 and 1983. After the El Niño energy reservoir was expended, the years 1984 to 1986 should have been cooler. Following 1986, El Niño and solar maximum, coupled with clear upper air and increased CO₂, should have combined to move the global temperatures upward.

The actual global temperatures measured by balloon releases each day are shown as the last characters at each year. They are displayed as cold, cool, warm, or hot. In this ocean-atmosphere energy field, or phase space, the world should be hot when both energy paths are high; it should be cold when both are low. This in fact is the case; all hot years are in the upper right and all cold years are in the lower left. In general, what should have happened did. In the midst of these overall positive findings there are years that appear to be out of place relative to the actual global temperature measurements. The year 1977, for example, should have been cold, or at least cool, but it was, for some reason yet to be understood,

Table I. Key to Global Energy Map^a

| | |
|----|------------------------------|
| — | No event |
| SM | Major solar maximum |
| Sm | Minor solar maximum |
| Ni | El Niño |
| Ag | Mount Agung eruption |
| Ch | El Chichon eruption |
| Ru | Ruiz eruption |
| Nu | Maximum nuclear testing |
| Si | Year of the Siberian express |

^aThe events are discussed more thoroughly elsewhere (Gunn, 1991).

warm. However, while there are apparently influences yet to be defined, overall the expected effects on global temperature materialized as anticipated.

The implication of this is that there is no single cause of global climate. All contributing factors must be given due consideration if the past and future of global climate is to be understood. This of course presents a complex interpretive problem. Further compounding the bases of understanding are rapidly evolving notions of how the universe is constituted and how humans comprehend it. We will briefly attempt to introduce these factors next.

FOUNDATIONS OF A NEW EPISTEMOLOGY

The articles in this issue document variation in the source of energy and its modulation by astronomical, geophysical, and anthropogenic influences. In addition to presenting state-of-the-art points of view on the constituent controls on global average temperature, the co-occurrence of these articles implies a change of attitude and priorities in the study of both life and physical processes. Since the 1950s, consideration of these issues has moved from a disciplinary isolationist approach to one in which the parts are understood to be of a whole earth system, even the solar system. This implies not only conceptual wholeness, but temporal wholeness as well; outcomes are a product of historical forces as well as physical processes. Even processes once considered completely deterministic such as planetary orbits are now known to be unstable, or "chaotic," in the sense of nonlinear systems. The planets of the solar system influence not only each other's routes but the behavior of the sun as well. In other words, even the position and behavior of the sun and the planets are products of initial conditions and historical processes as are our everyday lives. To study this world, data and history must be joined with calculation to acquire redundant observations of trends in global environmental change. Even these efforts cannot assure against surprise outcomes.

Planetary and interplanetary interaction and integration requires a style of research and presentation of results that accommodates broad interdisciplinary cooperation. Facile use of disciplinary jargon must give way to explicit and sympathetic development of concepts before consequences are discussed. Discussions of the outcome of these investigations appear to be more related to flow of consciousness literature than to the sound-bite staccato of disciplinary discourse. In the introduction and integration of the articles in this issue, we will attempt both to view historical developments in human understanding of the global environment and to introduce the special issues discussed in the articles. Since we, as a small group, cannot encompass all of the integrative issues, we will also touch on related influences that the contributors might have hoped to see discussed along with their own topics.

The development of present understanding of global climate evolved on at least two fronts over the last 40 years. In the first, observation of the global system was undertaken in the context of a new determination to measure global conditions accurately. This resulted in much rethinking of environmental processes. In the second, concerns for the future lead to investigations ever deeper into the past. The interplay of modern, precisely observed climate and ancient, more highly variable climate became the subject of intense scrutiny. To accommodate these developments requires a new epistemology of the earth system and the political forces that influence it. This new perspective requires a general recognition of the co-evolution and co-function of the elements of the earth system.

FROM GUESTIMATION TO MEASUREMENT

The evolution of understanding of the earth as a habitat over the last half century has moved at such an aggressive pace that it leaves one who has watched the whole process out of breath. I generally count the beginning of the present age of understanding as 1958 because of the International Geophysical Year (IGY). This was the year that observations of global temperatures and related conditions were standardized and implemented all over the world. Scientists and policymakers seriously undertook measuring what the earth was about, both in terms of its systemic character and the change of that character through time. The critical step was taken by the United States of establishing a global atmospheric observatory on Mauna Loa, an extinct volcano in Hawaii. Keeling (1979, p. 37) notes "The IGY, which began in 1957, offered scientists for the first time an organizational setting for study of atmospheric CO₂ on a global scale. In view of the importance of knowing whether airborne CO₂ was rising worldwide, such a study was long overdue."

Since 1958, technological developments have entrained with the attitude of measurement, adding new dimensions of thought about the physical environment. Space technology has not only provided the much-discussed platform for a new perspective of spaceship earth, but also a platform from which the status of spaceship earth can be measured broadly and with precision. In this new milieu, observation and measurement presaged most theoretical developments, sometimes antedating understanding by decades. In this respect, this age resembles that of Copernicus, whose precise observations of the movements of the planets during the sixteenth century eventually led to a reconsideration of the solar system as heliocentric rather than geocentric.

An important element of the old science that stymied the study of climate change was an idea that the sun produced a constant amount of energy. Like Copernicus, John Eddy, who contributes an article to this issue on the effects of solar variability, was not the first to suggest that the energy output of the sun varied over time. Through the 1970s, however, he was persistent in documenting indications of this variation through the study of historical records, and pointing out that these variations corresponded to known changes in global scale climate. Finally, the first satellite-based measurements of solar output in the early 1980s showed in a few months that the solar energy emanating from the sun was indeed variable.

In spite of Eddy's efforts and the requisite measurements, arguments against solar variation having effects on global climate continued. Counter-arguments from the old physics generally evolved around the small magnitude of the changes in solar energy as compared to the great amount of energy needed to induce change in the global average temperature. Typical of this new age of Copernicus, former traditional constraints were ignored and solutions were sought by bold thinkers, many of whom turned to long neglected ideas. Researchers suggested that it was not the output of the sun alone that generated global climate change, but rather a combination of multiplying mechanisms within the earth system that gathered the relatively small emanations of the sun and made them into formidable climatic forces. One of these mechanisms is certainly the now universally discussed El Niño-Southern Oscillation phenomenon which, acting as a capacitor, stores solar energy in the tropical Pacific for years, and then suddenly releases it in a few months.

Another modulator of solar energy at a much longer time scale, 1000s of years, is the earth's orbital wobble. Measurement during the 1970s appeared to confirm long standing theories that wobble is the clock that drives the ice ages. The north pole of the earth wobbles like a top every 23,000 years. This causes the Northern Hemisphere to incline toward the sun during part of the cycle and may from it during the other. Since the wobble imparts a different pattern of incoming energy to each month of the year (see Davis and Sellers, this issue) as it cycles through its 23,000 year period, scientists began to look at these different monthly patterns as sources of global climate change. In 1975, George Kukla of the Lamont-Doherty Earth Observatory noted that patterns of glaciation and non-glaciation closely matched the October wobble. He, therefore, suggested that the first snows of fall, whether they were melted as the Northern Hemisphere wobbled toward the sun, or persisted because it wobbled away from the sun, were the major mechanism that drove the ice ages. If the snows persisted, they reflected heat from the earth's surface, deepening the ice age; if they melted, the surface absorbed October heat, moving the system toward a warmer non-glacial condition. Satellite measurement of global snow

cover supported this perspective. Kukla has since documented a complementary warming during the spring months that assists the October glacial clock. In this issue, Reid Bryson, and Owen Davis and William Sellers examine different months to find various effects in regional environments.

Geophysical mechanisms also appear to actively modulate global climate. It is fairly clear that earth goes through periods of unsettled geological conditions about every 1000 years (see Bryson, this issue). Resulting earthquakes and volcanism, both related to plate tectonics, produced effects on the ground and in the upper atmosphere. After a major volcanic eruption, effects on the global average temperature appear within a month. Paul Handler and Karen Andsager discuss some of the mechanisms of this effect in the modern atmosphere. The effects of volcanism are not yet fully understood. Technically, their impact on global temperature appears to be rather small. On the other hand, some of the great human tragedies and triumphs of all time have co-occurred with global scale volcanism. During the last few years a number of unanticipated effects of volcanoes have been detected by the global remote sensing network of surface, atmosphere, and space-based instruments. Paul Handler and Karen Andsager discuss these findings in their article on the effects of volcanic eruptions on El Niño and on crop productivity. The interactive effects of El Niño and volcanoes are further analyzed by Gunn and Grzymala-Busse in a chapter on analysis by rule induction and artificial intelligence. All of these studies suggest interactive effects about which much remains to be learned.

Simultaneously with the revolution of thinking brought about by new measurements of the earth system, technology brought a revolution to the mathematics of the solar system and earth system as well. Compared to what is known now, in 1958, understanding of the world and its place in the solar system was based on fragile assumptions, the proverbial mathematical scatchings on the backs of envelopes. In theory, it was a safe and simple world. A physics ill-equipped to comprehend the complexity of the earth system wrapped the world concept in a blanket of oversimplification. Since that time, the study of nonlinear systems (sometimes referred to as chaos theory), made possible by cheap and plentiful computers, facilitated exploration beyond the edges of the former envelope. It suggested that the solar system is not so safe, or even predictable. Rather it is a system in which extraterrestrial trash (meteors, comets) can be expected to crash into the earth in the future as they apparently have done in the past. Furthermore, Theodore Landscheidt found that the angular momentum of the planets fuses with solar emissions, causing them to vary. Even the progress of the seasons is no longer inviolate. If the earth did not have a moon of such great size as to be nearly a companion planet, it would wobble so freely that the poles would turn toward the sun every few million years and the planetary environment would probably be too unstable for life. In a new theoretical environment freed of absolute determinism, measurement could proceed to clearly historical conclusions.

These three quantities of science, measurement, multiplying mechanisms, and in a sense a new measurement of mathematics, have disrobed thinking about the earth system from a theoretical straight jacket and finessed a new working garb. The final design is yet to be seen, but it is being designed.

FROM PAST TO FUTURE

As science and policy joined forces to investigate the global climate, realization also dawned that prehistory and history could play a role in understanding the future of climate. The warmest global temperatures in the accessible past occurred between about 4500 and 7500 years ago. Those millennia would be the most useful of any for understanding conditions in a hot world. Eddy's historical observations document changes in solar energy output for the last millennium. Bryson and Murray's book *Climates of Hunger* also made a great range of historical information on climate change and its affects on culture accessible. However, history can only carry this method of discovery so far into the past, perhaps a thousand years before the present in Europe, two thousand years in the Far East, and three thousand years in the Near East. During the historical period there were hot world episodes that can be used as analogues for the future, but they are not as hot as those of the prehistoric past. The study of global warming therefore could benefit from the insights of prehistory in order to anticipate the effects of the greater extremes of global climates. Steve Schneider and Londer summarize much of this information in their book *The Coevolution of Climate and Life*.

The stage was set for studies of past climates by current events. As the 1980s developed ever warmer years, questions appeared that were posed by possible threats to the very creators of history, historical observation and measurement began to show that sun, atmosphere, and oceans were not the only actors in the unfolding drama of global climate change. As a part of the growing awareness of the state of the world, it became possible to think of humans as contributing a substantial increment to climatic change. By dispersing various gasses into the atmosphere, humans were thought to be altering the atmospheric chemistry, which before industrialization biological forces alone had been regulating. These alterations, for the most part, were expected to increase the global temperature. Carbon dioxide, which absorbs rebounding solar energy, was increased by the burning of fossil fuels. Added to this was a depletion of upper atmospheric ozone, which blocks incoming solar radiation. Ozone is decreased by catalytic interaction with chlorine-bearing molecules introduced to the atmosphere almost exclusively by humans. During the 1980s repeated record annual global temperatures rapidly generated international concern. Scientists and policymakers took a hand in turning the light of investigation onto the problem as individuals raised the question of shifting patterns of precipitation and their effects on human population stability and movement. There were at least two notable landmarks that focused scientific and public attention on global climate. The first was the publication of an article in *Science* on the effects of increasing carbon dioxide by Glen Hanson of the National Oceanic and Atmospheric Administration in 1981. The other was the great Midwestern U.S. drought of 1988 which appeared to suggest confirmation of general circulation model forecasts of the effects of global warming. Because of the double threat of global warming and exposure to life-destroying ultraviolet radiation, international accords were signed in 1989 to reduce use of ozone depleting chemicals. By 1990 the United Nations and the World Meteorological Organization were stimulating worldwide interest through publications by the Intergovernmental Panel on Climate Change and through global-scale international conferences.

Since the increase in carbon dioxide and other gases has been projected to augment the global temperature as much as 4°C, examining the most extreme past global temperatures became important. The last time the world was 1°C warmer than at present was the Medieval Optimum (AD 900-1250). The last time the earth was 2°C warmer was during the Middle Holocene Optimum (7500-4500 BP). This was well before any record keeping that would lend itself to the study of solar activity and related influences.

For prehistory, scientists turned to indirect observation through cores from bogs, ice, sea sediments, trees, and cave deposits. Some indirect understanding of solar activity in the long past can be gained from tree rings. However, since trees are within the earth system, their measurements of the earth system are part of the mutual influences exchanged between all denizens of the surface. A better solution would be a method of determining solar emissions apart from the earth system. Calculating solar energy output became possible during the 1980s in part because of the space program requiring information on dangerous solar flares. These calculations of the solar emissions during the Middle Holocene Optimum provide a workable model against which to test paleoclimatic data. Thus, while historical observation displaced oversimplified mathematical estimates of the solar system in the early part of the process of understanding solar effects, the latter returned as the need for understanding climate variations extended beyond the scope of historical observation and methods of calculation improved. My colleagues and I have recently taken these calculations of solar emissions and added them to Bryson's index of volcanism with convincing results in a study of global climate and regional culture change in the Maya lowlands (Gunn et al., 1993).

In a conceptual world in which measurement often presages theory, concepts extending the envelope of measurement have become an important matter. In addition to the time depth component discussed above, the envelope has a precision dimension. Measuring past climate at 1 year precision is a desirable goal since most organisms adapt to that cycle. Annual tree rings provide a few thousand years of annual measurements of condition of the earth when they are collected from certain high altitude and well-placed trees. However, the greatest extension of the envelope into the past has come in recent years through ice cores. For example, ice cores have revealed major swings in global climate in less than a decade 10,000 years ago. In this issue, Lonnie Thompson, Mary Davis, and Ellen Mosely-Thompson discuss the breadth of information that can be gathered from ice cores on an annual basis for many thousands of years across all of the times in the recent past when the

world was warmer than at present, even the last interglacial about 110,000 years ago when the world was perhaps 3°C warmer than at present. These measurements, it is expected, will provide an accurate understanding of observed and calculated past conditions.

FROM EPISODE TO EPISODE: AN EPISODE-DRIVEN RESEARCH DESIGN

As measurement assumed an important role in reformulating theory, and concern for the future compelled investigation of the past, yet another trend emerged that moved toward a historical bent. At the beginning of the latter half of the twentieth century, physics held sway over an orderly world that was simply calculated out of necessity, and not well integrated in its physical, social, and biological parts. This lack of integration was in part a function of the beliefs of the mid-twentieth century. Much of the character of the new world was not easily calculated, if it could be calculated at all. However, nonlinear physics began to suggest that mathematical predictability only extends in runs separated by jumps in the condition of the solar system, the atmosphere, the oceans, and in biological, psychological, and cultural subsystems. In this world, measurement of current and past circumstances is often equally rewarding as long term projections by mathematical means. The analytical context of global climate has become more like the social scientist's measurement-and-data challenge than like the mathematical scheme of the old physics. The new scientist must be in part a historian, the new historian in part a scientist. Generally, human limitations suggest partnerships to meet these demands.

This brings us to the matter of a model that will facilitate a research partnership across physical and historic investigations. We suggest that the appropriate vehicle for cooperation is a common vocabulary structured to insure that all parties can work productively within its context. The concepts associated with the structure must be dynamic and flexible enough so that communication is achieved while remaining responsive to new findings from all fields of research.

For purposes of this model, we will focus on global climate changes of the last 13,000 years. These are the years of the domestication of plants, the birth of cities, the rise of civilizations, and of most accessible and numerous historical and paleo-environmental records. Since the 1940s, that time has been divided by climatologists into four periods at a scale of thousands of years, the latest Pleistocene (13,000-10,000 BP), the Early Holocene (10,000-7500 BP), the Middle Holocene (7500-4500 BP), and the Late Holocene (4500 BP to the present). These terms have utility at a general level and reflect broad, global scale conditions mostly resulting from declining Pleistocene ice volume and rising sea levels, largely a function of the rotational wobble and varying global temperatures discussed earlier. Because these Holocene periods are so general, it is relatively easy to characterize their global climates. As Bryson points out in the issue, however, there are still important new insights to be gained even concerning these long-recognized periods.

For studies of regional ecological systems, the Holocene periods have some limited utility. However, considerable study of human cultures suggests that civilizations, in fact many of them, came and went during any given Holocene period. Wendland and Bryson (1974) likewise found that biological regimes changed more frequently than Holocene periods would suggest. The Holocene periods are, therefore, useful as a general backdrop for the understanding of global climate and its effects. Civilizations, however, adapt to shorter time intervals and many can be shown to have succumbed or changed radically after only a few tens or hundreds of years. Also, although broadly similar in rhythm of change, they vary in time of onset and termination from region to region. Dividing time into lengthy theoretical periods, which are presumably characterized by broadly similar conditions, distracts attention from the more immediate concern for viability of biocultural entities within regions as they struggle with varying environments. A better solution is a more flexible time segmentation scheme which is less rigidly bounded either temporally or spatially.

Of the methods of time segmentation that are being currently used, what could be called episode-driven research appears to present the most realistic engagement of the time segmentation problem, and the most promising cross-disciplinary communications forum. An ad hoc vocabulary has arisen to designate episodes. We have already spoken of the Medieval Optimum (AD 900-1250), and Little Ice Ages (AD 1250-1920).

Theoretically episodes occur because global climate tends to be relatively stable for tens or hundreds of years, then changes suddenly into another condition. Wendland and Bryson documented this phenomenon in the 1970s and Bryson (1988; 1994) continues this research to the present. As new episodes with coherent characteristics are discovered, terms have been added (Table II). Generally, the terms defined to date recall events of European history. This gives a Eurocentric appearance to the vocabulary. However, John Kutzbach and Reid Bryson found in an analysis of world data that the landmasses around the North Atlantic are one of the areas of the world most sensitive to global climate change. The application of European names may not, therefore, be completely inappropriate in the case of many episodes. It should be kept in mind, however, that the terms are meant to refer to episodes of global climate stability, and researchers should not hesitate to apply terms from other parts of the world. It would be heuristically useful for the terms to be applied from parts of the world where the evidence for global effects is strongest. The Indus civilization, for example, collapsed precipitously around 1800 BC. We can suppose that this was in

Table II. Commonly Recognized Episodes^a

| | | |
|---------------------------|---------------|-------------------------|
| Little Ice Ages (min/opt) | AD 1920–1250 | Eddy, 1977 |
| Medieval opt | AD 1250–900 | Eddy, 1977 |
| | AD 940–1140 | Hood et al., 1990 |
| Vandal min | AD 750–350 | Bryson, 1988 |
| Roman opt | AD 300–300 BC | Denton and Karlen, 1973 |
| | AD 350–500 BC | Bryson, 1988 |
| Greek min | 460–260 BC | Landscheidt, 1987 |
| Homeric min | 860–600 BC | Landscheidt, 1987 |
| Egyptian opt | 900–1200 BC | Gunn et al., 1993 |
| Egyptian min | 1400–1200 BC | Landscheidt, 1987 |
| Indus opt | 2200–1800 BC | Bryson, 1988 |
| Sumarian min | 3390–3190 BC | Landscheidt, 1987 |
| Worley opt | 7500–7800 BC | Gunn, 1992 |

^aSee Eddy, 1977; Bryson, 1988a and b; Davis et al., 1992 for general discussions of episodes.

part the result of global effects because it was at this same time that Egyptian civilization recessed into the second intermediate decline and similar effects can be observed in other parts of the world. Bryson recently added the term Indus from 2200-1800 BC to the list of global climate episodes.

For purposes of ongoing research it is important, however, that the temporal bounds of the episodes be fuzzy, in the sense of fuzzy sets. The duration of an episode varies from region to region because changes in global temperatures bear differently on atmospheric flow patterns depending on latitude and other factors. Effects of a global climate episode can be completely opposite in different parts of the world. For example, during the first millennium AD, the globally cool Vandic episode wrought havoc with European civilization while civilization in the Maya Lowlands of Mexico flourished, all for very explainable reasons. Cool global climate brings dank, moist climate to Europe which leaches soil nutrients and impedes harvests of grain crops. On the Yucatan Peninsula, globally cool climate fosters ideal agricultural conditions for corn (Gunn and Adams, 1981; Gunn et al., 1993).

For those inclined to a scholarly approach, episodes are defined by anecdotal evidence from diaries, folklore, histories, photographs, paintings, and many other sources. These sources have been exploited to demonstrate lengthy periods of climatic stability, or in some cases, climate that is distinctly deviant from conditions observed during the twentieth century. Because of long written records, Europe and China are the centers of this genre of research.

For those with interests in formal methods, a global climate episode is a period in which similar processes are active in the global system. Solar emissions, volcanism, El Niño activity, global ice volume, etc., may be high or low, active or inactive, or any combination of those attributes. The definition of the processes of the episode will indicate seasonality and location of precipitation. Statistical methods may apply within episodes but not across boundaries between episodes because of changing processes that generate inappropriate statistical distributions. In this volume Grzymala-Busse and I investigate the potential of rule-based expert systems to

decipher influences independent of jumps in global temperature. Alternatively, an episode can be thought of as an object, in the programming sense, with its own suite of processes and its test data.

The most important property that an episode possesses is that it is amenable to refinement. This implies, minimally, that its boundaries are adjustable as it competes with adjacent episodes for "territory" on the global climate timeline within a region. Since episode boundaries will probably be defined relative to specific research questions, part of the episode's climatic algorithm would be to test the internal stability of its segment of the global climate timeline. Thus, the precise boundaries could be set according to the relatively narrow tolerance of an insect in one study, and the broader tolerance of a large mammal in another. The outcome would be a hypothesis of the length of the episode based on tolerance of the study subjects. In effect, the outcome is an estimate of boundaries of the episode. Multispecies tolerance tests could be designed. Cultural algorithms could also be devised based on tolerance of technologies and other aspects of cultural adaptive systems. An hypothesis I would like to test would determine which are more sensitive to climatic change, hunter—gatherers bands or civilizations. It is my suspicion that civilizations, contrary to broadly held beliefs, are more sensitive to climatic disturbance.

Second, the internal structure of an episode is subject to subdivision (Fig. 4). For example, it is fairly well understood that there was a temperature dip in the otherwise globally hot conditions of the Medieval Optimum around A.D. 1100. This dip divides the Medieval Optimum into sub-episodes, two hot, one cool. To our knowledge, no one has attempted to analyze the global scale characteristics of the intervening cool sub-episode. There is plenty of anecdotal and quantitative evidence for it, as well as many possible historical impacts. At some future time, the early, middle, and late phases of the Medieval Optimum will be analyzed to determine their causes and implications. At that time, the definition of the Medieval Optimum will be enriched, extended, and incorporated into the vocabulary of that episode.

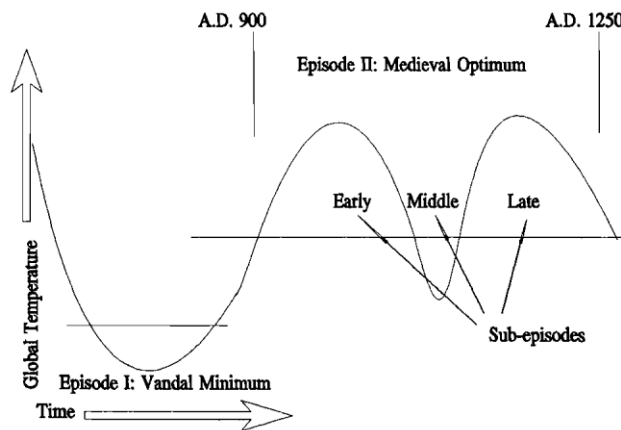


Fig. 4. Episode refinement.

Perhaps the most important contribution we can make here is to define a protocol identifying the basic description of an episode. The following summarizes the arguments made in this introduction.

1. A global climate episode should have a type region, preferably selected from a part of the world in which impacts are most clearly observed.
2. It should have an average (mode) time during which it was most characteristically identifiable. This modal time should be measured chronometrically (corrected dates if by radiocarbon) and/or historically. It should have astronomical, geophysical, atmospheric, and biocultural parameters. The latter will probably include literature, and folkloric and historic documentation.

3. It should have flexible temporal and spatial boundaries. In a given region, spatial boundaries will vary with time; around a given modal time, temporal boundaries will vary with species and cultures. Mechanisms that transform global climate to regional climate should be defined.
4. It should have a global average temperature mean and standard deviation.
5. High variability or relative stability of the episode should be identified.

Examples of the latter case are the Roman Climatic Optimum and the Vandal Minimum. The issues involved were not so much that one was warm (Roman) and the other cool (Vandal). Rather, the dynamic effects on civilization resulted in the Roman Optimum being characterized by relatively long and stable sub-episodes that fostered city-state expansion into nations and empires in all parts of the world. The subsequent Vandal episode encompassed a number of short sub-episodes that prevented time-ingrade development of hierarchical civilization, and thus was characterized by small polities that endured for brief periods of time.

Table II lists many of the commonly recognized Holocene episodes along with their hypothesized span and documentation. It represents a list of episodes that should be extended, contracted, elaborated, and modified by all involved researchers. A central clearinghouse for assessing the list by all involved researchers. A central clearinghouse for assessing the list and maintaining the pertinent literature needs to be established.

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