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On Integrating Climatic Change and Culture Change Studies

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In the last few decades, advances in understanding and modeling climate have paralleled the growth of an impressive log of radiocarbon dates and quantitative analyses of climatic indicators including pollen, tree rings, and lake levels. At the same time, archeological research has given us an impressive assemblage of cultural information. We also have the tools for sorting out the diverse sources of variance in our datasets. The time has come to begin to integrate these lines of scientific endeavor to produce a mutually coherent picture of at least one of the mechanisms that have affected the history of humankind, and one that undoubtedly will affect the future as well.

KEY WORDS: climate change; culture change; models.

INTRODUCTION

A number of possible mechanisms for culture change in relation to climate change have been presented in isolation in this volume. A characteristic of both paleoclimatology and culture history is that they are multicausal. This, then, requires that some mechanism be developed for integrating the effects of each variable into a coherent picture, as well as sorting out the various cause–effect relationships. An attempt to do that in a preliminary fashion will be assayed below. The focus will be on those culture changes that appear to be coincident with climatic changes, and that appear to be globally synchronous. Those changes that are internal to a culture or local in origin should not be globally synchronized. Climate, on the other hand, is part of a totally interlocked global system. It has not been shown that there is such a thing as a purely local climatic change.

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Even the local urban heat islands of today enter into the global heat balance that drives the climate in general.

The literature, both popular and scientific, is currently charged with discussions of the putative effects of a carbon dioxide-induced warming of the earth. Every few years, following a major volcanic eruption, there is discussion of the consequent climatic change and its impact. It hardly seems likely that climatic changes of the past, related to these two forcing mechanisms, would have had no impact on cultures given their greater reliance on local and regional resource bases than those of today.

There has also developed a consensus that the variation in irradiance, first intensively studied as a climatic forcing mechanism by Milankovitch, is indeed the clock that times the advances of the great continental glaciers. The work of Kutzbach and others has also shown that this variation, responsive to changes in the eccentricity of the earth's orbit, the inclination of the axis, and the precession of the equinoxes, also produces climatic variations on a time scale of interest to students of human history (Davis, 1985; Bryson and Goodman, 1986; Bryson, 1988, 1989, 1992; Kutzbach and Guetter, 1986). The modeling of climate, which requires an understanding of the controlling mechanisms, is progressing rapidly, but has not yet reached the point where credible maps of all the pertinent climatic parameters can be produced for any given century. Still it is possible to make some general calculations on the time-scale of centuries that should be pertinent to questions of change in the economic base of past cultures, and that might provide some insight into at least one source of change.

In the following paragraphs a generalized climate model for the Northern Hemisphere will be described, as a preliminary guide to the climatic mechanisms which appear to produce realistic results, as judged by the match of the output of the model with the field data. It will also provide a crude guide to when climatically-induced cultural changes might be expected. In the concluding paragraphs a suggestion will be made as to how the output of climatic models might be tested in the archeological context.

A GLACIATION MODEL

In northern Canada, in the District of Keewatin where the last remnants of the central ice of the last major glaciation stood, there are snowbanks that last until the last week of July (personal field observations). The first snowfall in this area north of Baker Lake can be expected any day after the middle of August. Shortening the summer by three or four weeks would result in new snow falling on old snow, the necessary condition for the onset of continental glaciation. One might reason that much heavier snowfall in winter would leave larger residual snowbanks that would last longer.

Since snowy winters in those far north areas where glaciation began require that the storms also be farther north than usual, one might reason that relatively mild winters in general would produce more snowfall in the far north, while cool summers would mean less wastage of the snow and earlier snow in the fall (or late summer in Keewatin). Modeling of the climate at specific times in the past carried out by Kutzbach and his collaborators has shown the inverse, colder winters and warmer summers, were characteristic of the interval between 15,000 BP and 6000 BP, a time of rapid wasting of the continental glaciers. At least the models used, which employed the observed distribution of glaciers and the sea temperature and ice distribution calculated from climate-sensitive plankton records, gave results consistent with the above hypothesis and a great deal of other field data as well (Kutzbach and Guetter, 1986).

A central element in this modeling effort was the use of the Milankovitch approach, as modified and updated by Berger (1978) and Hopkins (1985), to calculate the irradiance on the earth. The irradiance values have little variance at the less-than-millennium time scale, so many efforts have been directed toward a search for causal mechanisms that operate at a shorter time scale. A prime candidate for this second mechanism that meets the test of having a sound physical cause and effect basis as well as field measurements of the intermediate physics is volcanism. To test the hypothesis, a search of the literature for a suitable volcanic history was made. About the only time series related to the variation of volcanic activity found for the Holocene was the record of acidity of the layers in the Greenland ice cap (Hammer et al., 1980). This probably is biased toward the nearby Icelandic volcanos.

As a substitute, a count of all radiocarbon dated volcanic events was made, and reduced to eruptions per century. Radiocarbon dating limits this chronology to the past 40,000 years. The number rapidly diminishes into the past because erosion and deposition reduce the available exposures. Thus, the data were normalized by fitting a power law curve to the raw data, and expressing the data as the anomaly from this curve divided by the value of the curve at that date, plus one. The resulting volcanicity chronology is shown in Fig. 1. This radiocarbon chronology correlates with the Greenland acidity record at about 0.60. Which of the two chronologies best describes the course of global volcanism will have to be resolved by further work. The approach used here will be to apply the test of utility. The radiocarbon chronology will be combined with the irradiance calculations to provide a basis for a climate model for the Northern Hemisphere. If this model agrees with the field data, it will be assumed that the chronology is

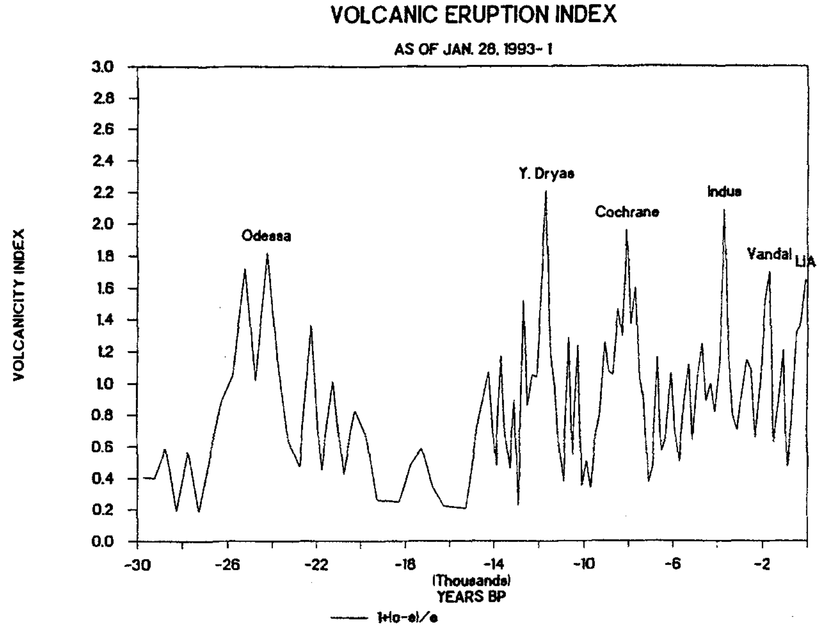

Fig. 1. Chronology of volcanic eruption frequencies over the past 30,000 years expressed as an index. The trend towards fewer and fewer dated eruptions as one goes back in the record was removed by fitting a power-law curve to the raw number of eruption dates per century, expressing the departures from this "expected" value as a ratio to the expected value, and then adding one to the ratio to make the index zero when no eruptions were recorded. The scale changes from average counts per century averaged over two centuries to average eruption rates per century over five centuries for dates before 13,900 BP. Significant events are named.

adequate for a first exploration of the centuries to millennium modeling problem.

However, for such a model to be realistic, the reflectivity of the snow and ice cover of the earth must be included. Hence the first step, if possible, must be to model the area of glaciation in the hemisphere. It has been shown by Bryson and Goodman that this may be done by integrating the seasonality of the irradiance (Bryson and Goodman, 1986). The rationale is simply that the accumulation rate and the wastage rate are proportional to mild winters and hot summers, respectively. Including the integrated effect of volcanic aerosols in modulating the incoming radiation, one may model the glacial volume with the short-term variations due to volcanic forcing included (Fig. 2, from Bryson, 1988). Converting the modeled gla-

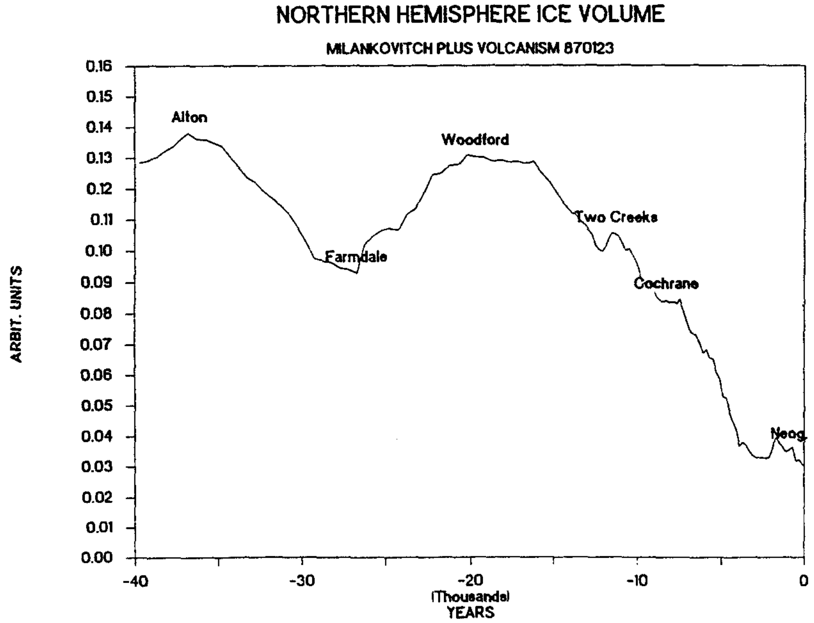

Fig. 2. Modeled history of ice volume in the Northern Hemisphere using Milankovitch variations in irradiance seasonality modulated by volcanicity. Individual well-known North American glacial events are indicated. It is not likely that the peak of glaciation about 37,000 BP was as large as modeled, but if the unknown constant of integration were larger than used in the model the peak would be that near 20,000 BP.

cial volume into an equivalent ice area, modeling the climate of the hemisphere is then possible.

A SIMPLE HEMISPHERIC CLIMATE MODEL

Using the energy budget model of Bryson and Dittberner (1976), the winter and summer half-year temperatures for the past 40,000 years were calculated, at 200-year intervals back to 13,900 years BP and at 500-year intervals for earlier times (Fig. 3). One cannot, of course relate the short-term climatic events reconstructed by the model to local and regional climates directly, because the pattern of climate is related to the hemispheric climate in a complex fashion. Some local areas warm when the hemisphere cools, and other areas are relatively insensitive.

In essence, the model used assumes that the incoming radiation from the sun is reduced by the volcanic aerosol present in the atmosphere, and then a certain part is lost by reflection from the surface, especially the snow and ice, which have a higher reflectivity (albedo) than other surfaces. The remaining energy is then absorbed by the surface to be reradiated, warm the air, or evaporate water. The particular formulation used in the present model is insensitive to cloud amount, and the evaporation is taken to be dependent on the general temperature of the hemisphere.

As a test of the model, the temperatures calculated with a much more sophisticated general circulation model (which does not, however, consider volcanic aerosols) are given, when available, in Fig. 3.

Of particular interest in the present context are the major short-term events that are modeled. To illustrate these, the last 13,900 years of the modeled climate are shown in Fig. 4, along with the times of globally synchronous biogeological and cultural changes given by Wendland and Bryson

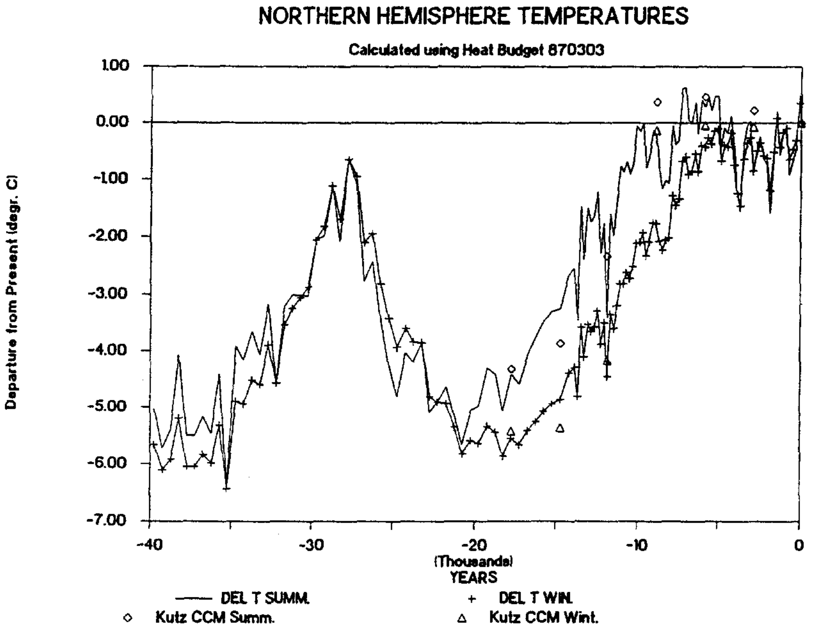

Fig. 3. Modeled history of Northern Hemisphere winter and summer temperatures compared to those obtained by Kutzbach (personal communication) using a large general circulation model. The hot summers and cold winters of the "Altithermal" are evident in the output of both models. The temperature is expressed as departures in degrees Celsius from the present modeled value in the case of Kutzbach's results and as departures from the actual present value for the model described here.

(1974) as modified by Bryson (1978). In that work they statistically analyzed the composite of all radiocarbon dated changes in biological and geological indicators of climate in the literature that were so identified by the initial investigators, and the globally significant concentrations of breaks in cultural continua. These should be the cultural change times most likely to be related to climatic change. Those cultural changes related to other causes probably should not be concentrated at particular times. Certain large-scale events that are recognized globally are also named in the figure, such as the "Little Ice Age," the Cochrane glacial stillstand, the Atlantic interval, and the Two Creeks-Valders or "Younger Dryas" events (indicated by the name Valders). Some events are named here for the first time in order to identify the event being discussed, such as the Mazama, Indus, and Vandal events. Since the events on the century to millennium timescale are driven by the global level of volcanicity, one would expect to see similar, but not identical, events in the climatic history of the Southern Hemisphere as modeled.

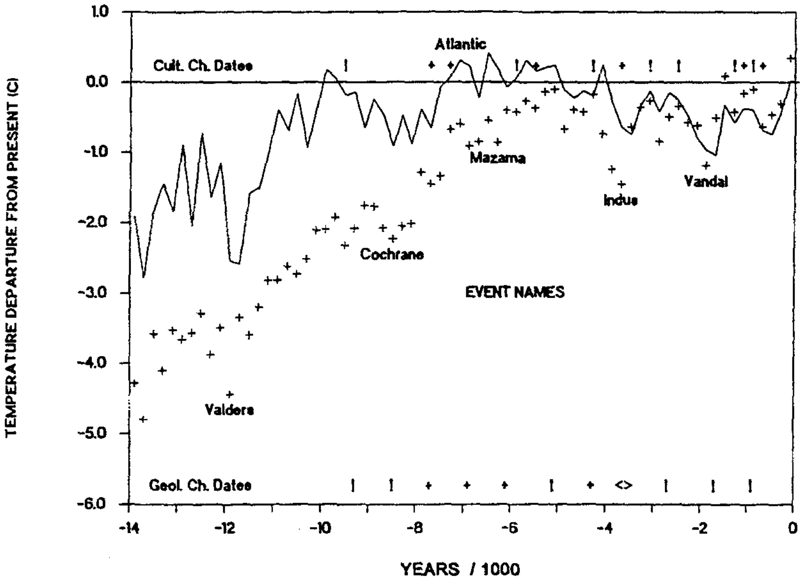

Fig. 4. Modeled Holocene temperature departures from the present for the summer (solid line) and winter (symbols) half-years. Significant episodes of a century or more in length are indicated with "event names." At the top and bottom are times of important geological change and cultural change as identified by Wendland and Bryson (1974). Exclamation points indicate major changes, plusses indicate less important times of change, and arrows indicate a change which seems to be rather broad in time.

CLIMATIC AND CULTURAL EVENTS

The Neo-Boreal Episode (the so-called "Little Ice Age"), and the preceding medieval warm period are particularly interesting in that they are modeled on the basis of the best known part of the volcanic record. If one accepts "Occam's Razor" as a valid scientific precept, then one must assume tentatively that a sufficient cause of the widespread cold period and the preceding well-documented warmer period was a little volcanic activity followed by a burst of volcanism greater than in the middle of the present century. The attribution of the "Little Ice Age" to a minimum of solar output is not needed to explain the event, though if a credible record of variation in solar output could be constructed it might add useful detail to the general picture of the event (Eddy, this volume). To be sure, the timing of the event calculated here is crude because of the two century grouping of eruptions. The "Vandal" event is named here for the *Volkerwanderung* of the time, amply documented around the end of the Roman Era. One must caution, however, that this may have been an event of shorter duration than depicted, because the uncertainty in radiocarbon dates may make the burst of volcanic activity at that time appear longer than it actually was.

It seems well-documented that the amount of rainfall in the northwestern part of India is inversely related to the temperature of the hemisphere, so the cold event modeled between about 4000 and 3500 years ago should have been a period of intense drought in northwest India, and such appears to have been the case (Bryson and Swain, 1981).

The Atlantic interval, long recognized by European palynologists and often loosely called the "Hypsithermal" or "Altithermal" starts and stops abruptly at the usually recognized times. However, as shown by Kutzbach and associates, it does not appear to have been a period of year-round warmth but rather a period of warmer summers and colder winters. This suggests that another factor must be taken into account in understanding the transition from Paleoindian to Archaic and to later cultures. Even within the Atlantic interval there should have been changes in the character of the seasons due primarily to the precession of the equinoxes (Davis and Sellers, this volume). Within the Atlantic period there is modeled a short period of colder than usual temperatures, labeled the Mazama event because the author recognized it first in a reconstruction of summer temperatures in Minnesota.

Since, in the interior, summer climates are largely radiation driven rather than the consequence of atmospheric flow patterns, one might expect that a modulation of sunlight from a continuing large volcanic event to the west would be important. Such was the interpretation obtained objectively and quantitatively from the Minnesota pollen record, coincident with the major eruption that produced Crater Lake, Oregon. The event modeled here is not the result of Mazama alone, for there were a number of other eruptions about the world near that time (Bryson and Goodman, 1980).

The Cochrane and Valders events are best seen in terms of the associated glacial events depicted in Fig. 2.

Along the top and bottom of Fig. 4 are a series of symbols indicating the globally synchronous times of rapid change as given by Wendland and Bryson (1974). It will be noted that there is a very good match between these times and the times of rapid climatic change, more particularly the immediately preceding change in the case of cultures. Streuver and Vickery (1973) have shown that these times appear to be valid specifically for the east-central U.S. One should not assume that the apparent relationship is one that involves temperature alone, however, for the precipitation changes appear to have been related to the temperature changes both through the direct effect of radiation on evaporation rates and the more complex change of circulation regimes associated with the energy supply change. Fortunately, it is possible to model the precipitation falling on the hemisphere, seasonally, using the energy partitioning method of Lettau (e.g., Lettau, 1977).

MODELING THE PRECIPITATION

Driving the Lettau climatonomic model with the radiation retained at the surface as modeled above, one can obtain the hemispheric evaporation rate month by month. Because of the short retention time of the atmosphere, this can be taken as an approximation of the monthly hemispheric precipitation. Additionally, one may model the wind direction in the northern Arabian Sea with the aid of a few additional reasonably well-based assumptions. These assumptions are that the west component of the wind is proportional to the south-to-north temperature gradient, which is an application of the thermal wind equation, and that the south component is a function of the seasonal temperature contrast, in turn derived from the usual explanation of the monsoon circulation. The modeled January and July precipitation is shown in Fig. 5, and the modeled wind direction is shown in Fig. 6. For comparison the maxima and minima of summer monsoon precipitation obtained by using transfer functions on pollen assemblages in northwest India are shown with "D" for dry and "W" for wet in Fig. 6.

As also found by Kutzbach and Guetter (1986), the Atlantic interval was modeled as a time of wetter winters than the present and drier summers. Such a contrast is also indicated in Fig. 5. This indicates that the "Altithermal," often characterized as "hotter and drier," should only be so

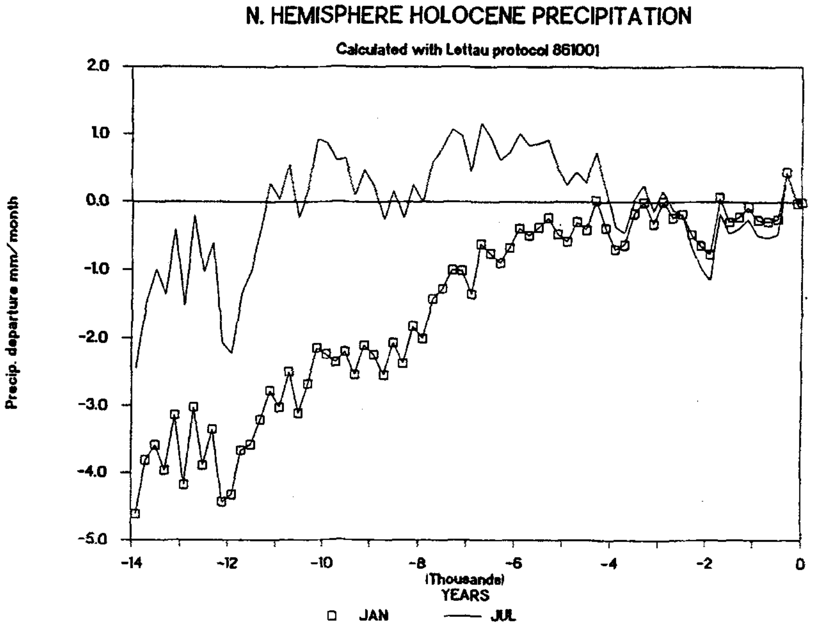

Fig. 5. Calculated January and July departures, in mm/month, in hemispheric precipitation expressed as departures from the present. The "Altithermal," viewed hemispherically, appears to have had wetter summers and drier winters.

characterized for the summer. They also found the Indian summer monsoon to be stronger around 9000 BP and weak around 15,000 and 18,000 BP. When the wind in the Arabian Sea is westerly, northwest India and Pakistan are in the rain shadow of mountainous Baluchistan and southerly winds are needed to carry moisture effectively into the Rajasthan area. The simple model used as the basis of Fig. 6 agrees, in most details, with the field data insofar as the relatively crude time scales allow.

DISCUSSION

Models of climate do not prove that a particular climate was experienced by a particular culture at a given time. They do provide a hypothetical basis for the design of field experiments, however, an approach espoused by Gunn and Crumley (1991). An example of the use of a model to design a field experiment is the study by Baerreis and Bryson of the environmental changes during the time of the Mill Creek people of northwest Iowa (1967). On the basis of a simple model of expansion of the cir-

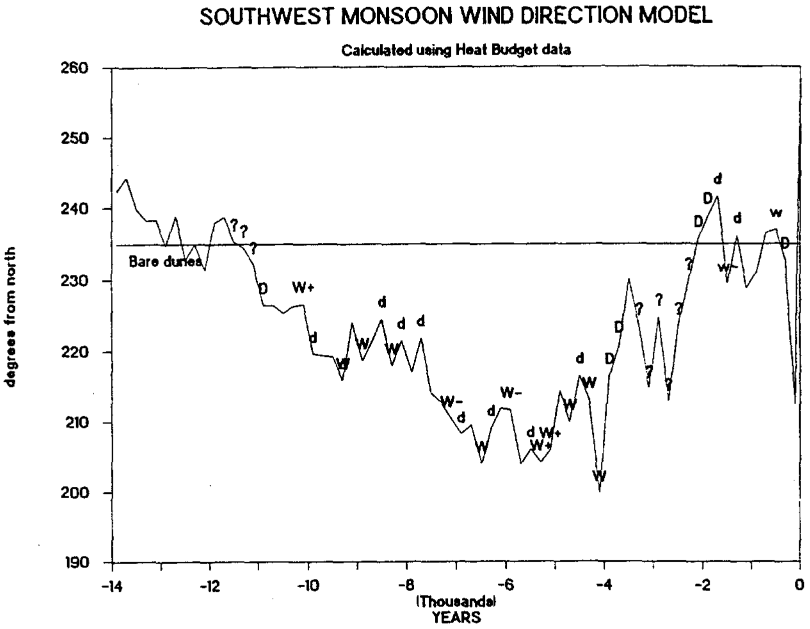

Fig. 6. Modeled wind direction in the Northern Arabian Sea derived from the present model results, expressed as the standard "degrees from north, clockwise." W and D represent relatively wetter and drier extrema found by Bryson and Swain (1981) by quantitative analysis of the pollen record from Rajasthan. Lower case letters indicate less pronounced maxima and minima. Dates do not correspond exactly, but are within the limits of dating accuracy.

cumpolar vortex during cold intervals in the Northern Hemisphere, they concluded that there should have been stronger westerlies across the northern United States starting between 1150 and 1200 AD. In turn, they reasoned, there should have been a rather severe dry period starting at that time, with dry Pacific air descending the high plains rather than the present day summer intrusion of moist Tropical air. Using modern data, it was found that stronger westerlies produced maximum drought in northwestern Iowa, roughly on the short grass-tall grass prairie ecotone. From the literature it was determined that there were sites in that area, poorly dated, which appeared to be in the right time span by comparison with other foci. The initial fieldwork then verified that the environmental changes were indeed those that would be expected with the onset of a drier regime, and there were concomitant changes in the culture as well. As with most investigations the field work raised additional problems and subsequent work showed the environmental situation to be more complex than originally thought. A similar approach was used to test the validity of climatic change as a factor in the interpretation of the Panhandle Aspect of Texas and Oklahoma (Baerreis and Bryson, 1966).

A carefully worked out glacial model with somewhat finer chronological resolution would provide a detailed model of eustatic sea-level changes in the tropics with which one might formulate a field experiment to test Folan et al.'s (1987) suggestion that sea-level changes might have been important in Mayan history.

Similarly, a Southern Hemisphere reconstruction could be tested against the Quelccaya ice cap record of Peru (Thompson et al., 1994) and the cultural sequences of Paulsen (1976). Since the global volcanicity drives the short-term variations in both hemispheres, one could even now begin the experiment. Preliminary modeling efforts suggest that there have been significant Southern Hemisphere climatic changes in synchrony with those of the Northern Hemisphere within the time range of archeological interest.

It will probably be some time before it will be possible to model local, or even regional, climates with enough time resolution to throw much light on the problems of the Greenland Viking colonies as discussed by McGovern (1993) especially in view of the mountainous and coastal terrain. However, there are still field techniques independent of the cultural data that can be used.

Throughout the climate modeling work discussed above and the supporting studies done by the author's students (most notably Goodman, 1984), it has been evident that the general level of volcanic activity was a good indicator of the level of volcanic aerosols in the atmosphere. The use of radiocarbon dated eruptions has a major problem in relatively recent centuries, however. That is a bias on the part of investigators against spending good money to date an eruption that was recorded historically, or was obviously some time in a particular century from the historical evidence. Thus we must rely on careful scholarship to document the most recent part of the volcanic sequence. It is clear, however, the cultural impact of volcanism is not entirely in its devastating local effect, for there is a global climatic signal as well. Perhaps it was the prolonged episode of globally enhanced volcanism around 4000–3700 BP that "did in" the great Indus Culture, even though there were no local eruptions.

CONCLUSION

I believe that Environmental Archeology is on the threshold of a new maturity. The gestation period of quantitative field methods for reconstructing the environments of the past, both climates and ecosystems, is well along. Our understanding of the forcing functions and processes is rapidly advancing, and before long we will be able to formulate quantitative *a priori* hypotheses for sound testing rather than producing *ad hoc* rationalizations of adventitious bits and pieces of field data. This will require, I believe, an enhanced collaboration of scholars from a number of disciplines, and the development of a new breed of integrative scientists as well. It is to the credit of the American Anthropological Association and the organizers that they have sponsored a "Symposium on the mechanisms of culture change and climate change." The level of sophistication of the work reported is considerably higher than at a few similar symposia 15 years previously. The will to move ahead is evident, and the future appears bright with new insights into the most intriguing of all subjects—the lives and times that make up the story of humankind.

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