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A FRAMEWORK FOR THE MIDDLE-LATE HOLOCENE TRANSITION: ASTRONOMICAL AND GEOPHYSICAL CONDITIONS

Joel D. Gunn

The Middle-Late Holocene transition around 2,500 B.C. is one of the defining episodes of regional landscape changes in the Southeastern United States area and throughout the world. Coeval cultural and climatic changes are recognized locally and worldwide. Analyzing local cultural change records while incognizant of the shifts in global scale context can lead to misunderstandings of the reasons for changes. Studies of the global climate processes suggest that climate differences between the Middle and Late Holocene could emanate from astronomical and geophysical influences. The influences include variations in the earth's rotational tilt, solar emissions, global-scale volcanism, and atmospheric chemistry. How do these quantities affect watershed-sized landscapes? Resolving this question requires a landscape-oriented analysis of global climate forces. A "looking-up" perspective on global climate is proposed that is compatible with the needs of archaeological analysis, and which supplements the "looking down" emphasis of climatology. The looking-up perspective takes advantage of the variability and long term cyclicity of global climate. Regional climate impacts of global change are modeled using modern climate processes to test for sensitivity of regional hydrology to global change, especially seasonality of precipitation. Landscape impact hypotheses are suggested in anticipation of further study.

Approximately 4,500 radiocarbon years ago (3,300 B.C. calibrated radiocarbon/calendar[1]) was a profound transitional episode in prehistory and history. About the same time a widely recognized paleoclimatological boundary between the Middle and Late Holocene, or the Altithermal and the Mesothermal, has been detected (Antevs 1948; Gunn 1994a; Wendland and Bryson 1974). The transformation of cultures in many regions of the world was so dramatic that it can be questioned as to which consequences, cultural or paleoclimatic changes, led to the recognition of the other. Wendland and Bryson (1974), in their seminal analysis of globally synchronous Holocene transitions, found it to be one of three most important moments of change both in the botanical and cultural domains. Wendland and Bryson's hypothesis appears to be enduring the test of time. White et al. (1994) found three spikes of elevated atmospheric CO_2 during the Holocene: 12,800, 10,000, and 4,400 B.P. radiocarbon years. The earlier two spikes represent well known events of rapid transition that changed the atmospheric chemistry and climate of the ecosphere (Broecker and Denton 1990). That the third is the Middle-Late Holocene transition places it in an equivalent class of highly significant global-scale transitions.

That the Middle-Late Holocene transition episode is also a momentous cultural milestone is quite clear, as the examples in Table 1 illustrate. In the Near East, it literally marks the boundary between prehistory and history. After functioning for perhaps 7,000 years as symbolic clay tokens used by seasonally migratory herdsmen, around 2,500 B.C. these ancient symbols emerged in a new format appearing as a syllabic alphabet. They were converted to phonetic characters that could be arranged according to grammatical rules interpretable to modern scholars (Kramer 1991:xxi; Schmandt-Besseratte 1978; after 2,900 B.C. according to Wenke 1980:410). Their new utility was recording the complex transactions of long distance commerce and local food storage transactions.

Parallel and equally momentous cultural milestones were attained in other parts of the world within the range of a few hundred years. The Bronze Age in Europe saw the intensification of far reaching trade relations (Crumley and Marquardt 1987:242; Earle 1982), fortified settlements, woolen clothing replaced flax, and status hierarchies that included domesticated horses and status tombs appeared (Champion et al. 1985:203-209). Marginal lands farmed in the Neolithic may have been over exploited and abandoned because of the demands imposed by the production of prestige goods (Champion et al. 1985:208). In Egypt, the Old Kingdom united upper and lower Egypt into a single polity and was accompanied by the construction of the Great Pyramid at Giza (Hassan 1994; Wenke 1980:475). In Harappan, India and Lungshan, China, highly organized urban centers were designed and built. In both the Near East and China, extensive fortified cities were constructed (Wenke 1980:327).

In the Western Hemisphere, the episode signals the advent of sedentary communities in Peru, even though plants had been domesticated two or three millennia earlier (Wenke 1980:631). In Mesoamerica, domesticated plants appear in the southwestern Maya lowlands shortly after 3,000 B.C.; around 2,000 B.C. Proto-Olmec became clearly identifiable in the archaeological record (Gunn and Folan 1995); plants had been domesticated

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Table 1. Middle-Late Holocene Cultural Chronologies from Eight Areas of the World.

Date BP Uncal.	Date BC Uncal.	Date BC Cal.	Europe	Egypt	Near East	China	Mayan Lowlands	South America	Gulf Coast	Atlantic Slope
3500	1550	1900								Stallings abandoned
3600	1650	2035								
3700	1750	2160								
3800	1850	2350								
3900	1950	2455								
4000	2050	2595	Wool				Proto Olmec			
4100	2150	2755	Horse							
4200	2250	2910								
4300	2350	3030			Sargon					
4400	2450	3175				Lungshan forts				
4500	2550	3310	Bronze					Settled coast		
4600	2650	3430		Giza						
4700	2750	3530			Writing					
4800	2850	3635								
4900	2950	3730								
5000	3050	3835								
5100	3150	3935								
5200	3250	4040								
5300	3350	4160	Calcolithic							
5400	3450	4325								
5500	3550	4410								

in the highlands for millennia. The Gulf Coast of the United States experienced enhanced growth in monumental mound building traditions that had been practiced for 2,000 years (Gibson 1974; Russo 1994; Sassaman 1995:192). This was accompanied by a pan-Southeastern exchange-trade sphere focused on steatite bowls, axes, and other investment-intensive objects (Gibson 1994; Johnson 1994; Sassaman 1995; Saunders 1996). On the Atlantic coast, Stallings ceramics appeared along with giant shell midden rings, indicating a more settled existence and perhaps monumental intentions (Claassen 1991; Russo 1994; Sassaman 1995). Joyce (1988:203-204), in an extensive review of eastern United States Middle Holocene paleoecology, finds that a Middle Holocene period of river channel stability spans 8,500-4,500 B.P. The collapse of this Middle Holocene regime occured abruptly and was accompanied by widespread biotic change.

These cultural reorientaiions generally suggest movement toward broader (interregional) and deeper (hierarchical) organizations such as empires and trading spheres. The common underlying cultural theme seems to be one of new prominence for long existing but little used cultural practices, and the muting of traits that had long been prominent.

In the case of the Near East, these developments are even more intriguing if one considers the suggestion of Settegast (1987). She believes that civilization, after propitious beginnings in the eighth and seventh millennia B.C. at sites such as Catal Huyuk, had been held in abeyance for 4,500 years, a pause as long as the interval of Late Holocene momentum toward civilization and urbanization. What were the conditions that stemmed the momentum of the march of civilization, and what revived it? What spurred the Late Holocene transition to larger and more complex, and in many cases more combative, social orders worldwide?

This article outlines the global context of the Middle-Late Holocene transition. Whatever events and processes carried such a worldwide state of change, they were as important to the builders of monumental shell middens on the Southeastern Atlantic Slope as they were to priests of Uruk who were at the same time organizing the first complex city states. The era marks a fundamental change in the global climate processes that interact with cultures, whether they were Southeastern hunters and gatherers or Sumerian city states. How important were these modified environments to regional cultures?

Looking Up—Landscape Studies and Tropospheric Climate

Over the past half dozen years I have become increasingly aware that most if not all regional landscapes have a global-scale environmental context that must be understood before any meaningful analysis of culture change can be undertaken. This context minimally includes astronomical, geophysical, and atmospheric-oceanic conditions (Gunn 1996). Without being aware of this context, proceeding to causes rooted in human agency and historical trends is almost certain to produce misunderstanding of culture change. The most interesting case of this misascription problem I have encountered involves events following the year A.D.

536. It has been understood for decades that something very unusual transpired in A.D. 536 (Stothers 1984). Because it falls in the historical period, it provides a clear illustration of the misascription problem. The destruction and plague that following A.D. 536 (Crumley 1987) event have traditionally been attributed to Justinian who was bent on rejoining the western Roman Empire to the Eastern Empire. However, recent research has shown that the event was not limited in scope to the Mediterranean, but in fact was a part of a worldwide calamity possibly precipitated by a meteor (Baillie 1994, 1995; Gill 1995; Rasmussen et al. 1995).

Understanding the impacts of global change on local landscapes requires an amalgamation of climatological and archaeological concepts and analytical tools. Climatologists, by the nature of their practical interests, discuss top-down models of atmospheric circulation (Kutzbach and Webb 1991), while archaeologists prefer bottom-up investigations (Kowalewski 1995:149). That is not to say that there is a fundamental level of investigation. Rather archaeologists and climatologists need to actively exchange information and concepts to achieve effective results, namely an improved understanding of landscape formation processes.

Students of prehistoric and historic landscapes are well aware that regional culture change should be viewed in a local geophysical, historical, and climatic matrix (Crumley and Marquardt 1987; Gunn, Folan et al. 1995; Stine et al. 1993). However, the structuring of global-scale contexts for landscape studies is a relatively new undertaking in any realistic sense. In a general fashion, efforts to understand global-regional influences such as Antevs' (1948) concept of the Altithermal could be considered early attempts, but the idea of a global ecology (Budyko 1977; Lovelock 1979, 1989; McMenamin and McMenamin 1994) with feedbacks between the human and global scales has only recently emerged. It was brought forth as a pressing issue as it has become evident that human actions impact the ecosphere as well as vice-versa. As understanding of global climate has developed, it has become increasingly clear that for archaeologists to proceed with landscape analysis, systematic linkages need to be made between the local and global scales.

Climatology is a necessary source of principles for understanding these linkages. Thermodynamics and chemistry of the oceans and atmosphere form the building blocks of any analysis of climate change (Gunn 1994b). However, most climatological research focuses at spatial scales and ranges of variation that are not directly applicable to human adaptation. Climatologists have only recently turned to the issue of global-local linkages through global teleconnections such as El Niño effects (Cubasch and Cess 1990:73, 85-86). These are generally pursued as interactions between the El Niño and continental-scale land surfaces. At that scale, teleconnections provide limited insight into the small watershed venue of most landscape studies. It is not just the global atmospheric circulation that affects the climate of a watershed. Also important are the aspect, proximity to sea, geology, and other variables (Gunn and Folan 1995; Gunn, Folan et al. 1995). Further, many climatological models focus on internal oscillations in the earth system that provide little relevant insight into the long-term nature of climate change; they lack precise pacemakers. Without obvious pacemakers, there is no means to correlate and cross check climate patterns and cultural chronologies at high temporal resolutions.

The seasonal distribution of moisture usually guides human adaptations. While addressing some effects of changes in astronomical and geophysical boundary conditions on the general global circulation, climatology typically avoids more precise questions of the causes of global stability and instability over the long term. Climatology does not typically attempt to explain decades and centuries of relative calm or disruptions by brief extreme events. It does not examine episodes of stable, as opposed to unstable, conditions spanning decades and centuries (see Mitchell et al. 1991:152 for discussion). The divergence of goals and foci between archaeology and climatology have their understandable roots in professional utility. One is basically a concept for forecasting weather and the other looks for human interactions with century-scale climate.

While small-scale regional variation and long term climate processes probably have little utility for meteorologically oriented atmospheric science, it is of ultimate importance for archaeologists and paleoclimatologists. Processes involving stability at decadal to century time scales are generally understood among prehistorians to be at the root of much of the physiological and cultural change observed within the human species in the Quaternary, although detailed causal accounts of the links between the global ecology and local biocultures are also frequently inadequate or absent (see Anderson et al. [1995], Gunn and Crumley [1991], and Gunn, Folan et al. [1995] for examples of construction of causal accounts).

An interesting parallel case to archaeological requirements can be found with agronomy. County soil surveys report on a social community-sized block of interaction between climate, geology, soils, and crop production. Early and mid-century Soil Conservation Service county soils surveys defined climate in terms of means; more recently the emphasis has shifted to tables that describe variability through the frequency of drought years per decade. Archaeologists have attempted to address the variability issue by methods such as tree-rings or geomorphology (see Anderson et al. 1995; Brakenridge 1980; Dean et al. 1985; Gunn, Folan et al. 1995; Gunn and Grzymala-Busse 1994).

To be useful for landscape and cultural change studies, atmospheric conditions must be viewed through combinations of lenses that include, but see beyond, the concerns of climatology with its focus on atmospheric thermodynamic and fluid dynamic processes (see Barry and Chorley 1992; Budyko 1977). It should encompass not only focused attention on how global change impacts regions, but also must address the long durations of paleoclimate (see Peregrine 1995:259-260 for relevant discussion of time scales). In short, a *landscape climatology* would attempt to understand effects on local conditions of long-term shifts in global boundary conditions imposed by changes in the rotational wobble of the earth on its axis, variability in solar emissions, and geophysical effects such as volcanism. Landscape climatology should define processes by which the changes in global conditions are reflected in regional patterns of precipitation, especially seasonality of precipitation, since this is the critical variable in most subsistence systems (Gunn and Crumley 1991; Gunn 1992; Gunn, Folan et al. 1995). In a sense, while climatology looks down on the atmosphere, landscape climatology looks up at it from a regional perspective. Everything in which climatologists invest their time is only the beginning of the tale for the landscape climatologist.

Building a landscape climatology requires viewing global climate through measurements of past climate that can be compared to other archaeological time scales such as cultural chronologies and fluvial chronologies. In the following sections I will highlight four hypotheses that have recently appeared in various literature. They outline a possible system of causes and effects of global conditions and their regional impacts. I will then discuss the availability of documentation of each of these influences on global conditions of the past and their serviceability to the landscape study community. Ultimately the outcome will be an understanding of the impact on landscapes of the Middle-Late Holocene transition alluded to above. This article attempts to define the global-scale forces that drive climate and the reactions of the global life envelope to the changing configuration of those forces. Some hypotheses for local impact will be suggested, but detailed analysis will be carried forward.

I emphasize that this is not a review of the climatological literature or an attempt to provide a balanced perspective of consensus opinions on the causes of climate changes. At least two perspectives on the causes of climate changes have emerged among climatologists: some favor internal oscillations in the earth system as the dynamic of climate changes while others register changes in terms of external forcing of the ecosphere. As noted above, internal oscillation-based models provide limited purchase for understanding the timing and magnitude of global climate changes. That is not to say that internal oscillations do not account for some proportion of the sum of global climate changes. They do not, however, account for that portion of global climate variation that provides a serviceable backdrop for cultural change studies. Without specific knowledge of their time and magnitude of occurrence, internal oscillations become a part of the background noise, the durable harrier of students of cultural change.

Astronomical and Geophysical Influences on Tropospheric Climate

To understand the processes that govern global-regional climate, including those in the distant past, it is sometimes useful to investigate the most recent past. Doing so establishes a dialectic in which the recent past illuminates the distant past and vice-versa. By "most recent past," I mean the period of intensive instrumental observation, the nearly four decades since the International Geophysical Year (IGY). Beginning in 1957-1958, the IGY, standards were defined and observation stations established worldwide (see Angell and Korshover 1983 and Keeling 1979 for examples) to measure temperature, moisture, and chemical parameters of global environmental change. These observation stations have been maintained consistently for nearly 40 years and thus provide longitudinal observations on the state of the earth system. The stations are generally ground based because of the era during which they were established. Space based satellite observations provide more detail and hold great promise, but it will be a few years before they provide the duration of observation necessary to analyze the effects of influencing variables on the Earth's environment.

A shorthand for "Earth's environment" is the tropospheric average temperature. This is because the atmosphere and oceans are a thermodynamic system whose overall structure is a function of its temperature (Budyko 1977; see Gunn 1994a for a year-by-year account). In its simplest form from the on-the-ground perspective of a resident of temperate latitudes, storm tracks under the jetstream are moved toward the poles by global warming. Fortunately, accurate measurement of the global temperature from the surface to the limits of the atmosphere on a daily basis was one of the major thrusts of the global observation programs. Atmospheric CO_2 (Keeling 1979) and incoming solar radiation (Dutton et al. 1985) were also measured at the greatest accuracy feasible.

Studying the tropospheric average temperature as a function of astronomical and geophysical variables (Gilliland 1982; Gunn 1991; Gunn and Grzymala-Busse 1994; Schneider 1994; Schneider and Mass 1975) has shown that tropospheric average temperature varies with the input from solar emissions, atmospheric aerosols such as debris from volcanoes, trace gases, and the El Niño. (The troposphere is the lower atmosphere below about 30,000 feet. The upper atmosphere, or stratosphere, is above 30,000 feet.) These influences appear to account for 70 percent of the change in the tropospheric average temperature between 1958 and 1994

(Table 2) (Gunn 1991; Gunn and Folan 1995; Gunn and Grzymala-Busse 1994).

The amount of movement in the tropospheric average temperature in any given year depends on the status of the influencing variables. The sun drives the earth system. Its influence varies over an eleven-year emissions cycle (Willson et al. 1986), and over longer periods as well (Dean et al. 1996; Eddy 1977; Landscheidt 1987; Lean et al. 1992; Stuiver et al. 1995; Thomson 1995). Solar emissions are thought to vary enough to account for part of the change in global temperatures through the Little Ice Age (Lean et al. 1992). The Intergovernmental Panel on Climate Change admitted to this possibility four years before it acceded to the potential for CO_2 warming (Shine et al. 1990:61-63). Incident heating and drying of the surface in some regions (Davis 1984; Mitchell et al. 1979), suntans, and skin cancers (Eddy 1994), and the discharge volumes of some rivers (Gunn and Crumley 1991; Gunn, Folan et al. 1995) follow its pattern. By multiple regression analysis, I find that since 1958, variation of solar emissions has accounted for the fourth largest portion of change in the tropospheric average temperature following El Niño variation and carbon dioxide variation (see Table 2). Thomson (1995) found evidence that before 1922 the solar emission cycle was the dominant seasonal pace setter, while after 1922 carbon dioxide assumed the preeminent role. This finding appears to be supported by analysis of the last millennium from the GISP2 ice core. Stuiver et al. (1995:349) discovered that the correlation between ^{18}O values and the 11-year solar cycle dwarfed the other influences although "the physical mechanism for a substantial amplification of the small change in solar constant has not been identified." Varves from the North American Midwest and Plains reveal dominant solar periodicities at 200, 44, and 22 years pacing drought and moisture (Dean et al. 1996). While the amplification mechanisms are still a matter of concern, there appear to be a growing number of researchers who detect cyclical patterns in global change that reasonably fit solar emissions parameters. I suggest the following amplification mechanisms.

Energy from the sun enters the global life envelope (the lower atmosphere) through at least two energy gateways or paths (Gunn 1994a). One is the sun-ocean path, a focus of energy entry because of the great capacity of the oceans to absorb, store, and release energy on a revised schedule. In doing so, they amplify or diminish tropospheric temperature at their pace. The El Niño is the most prominent example of this process, though not the only one. During the twentieth century, the El Niño followed a quasi-periodic cycle of about four years. It acts as a capacitor, storing the sun's energy and eventually releasing it as circumstances dictate (Cane and Zebiac 1985; Handler and Andsager 1994; Rasmusson 1985). The magnitude of the El Niños varies considerably as does its period. The 1983 El Niño following the El Chichon eruption was a so-called mega El Niño. It pumped warm water north and south from the equator disrupting life systems from southern Chile to Alaska. Nine feet of rain fell on the Peruvian coast where there is normally no precipitation. Such events have occurred periodically in premodern times (Gunn 1991; Meggers 1994). Since the IGY, El Niños (the amount of heat stored in the tropical Pacific Ocean) are the second largest effect on tropospheric temperature (see Table 2).

The second energy path is the sun-upper atmosphere path. Debris (aerosols) in the upper atmosphere injected there primarily by volcanoes, and occasionally meteors (Baillie 1994, 1995; Rasmussen et al. 1995), modify the amount of energy coming into the life envelope. Volcanoes since the IGY have been irregular in their influence on the tropospheric temperatures, but had the third largest impact (see Table 2). Volcanologists have been concerned that the effects seem to be smaller than might be anticipated (Rampino and Self 1982). However, there is evidence that when volcanoes coincide with favorable conditions for El Niño, they trigger El Niños by reducing westerlies along the equator (Handler and Andsager 1994). The release of stored energy nullifies some of the volcanic depression of tropospheric temperature. This relationship is probably responsible for low amounts of variance accounted for by volcanoes. However, it is clear that in the past volcanoes have disturbed the atmospheric temperature significantly. An example is Krakatoa (1883) and its accompanying decade of volcanism (Figure 1; Folland et al. 1990:217). A more interesting case is the 1815 Mount Tambora eruption and the subsequent year without summer (Stommel

Table 2. Multiple Regression Model of Astronomical, Geophysical, and Anthropogenic Influences on Tropospheric Average Temperatures (see Gunn 1991 for discussion of variables and analytical methods).

Years	Solar Emissions	Upper Atmos. Aerosols	El Niño	CO_2 Residual	CO_2 Trend	Unknown
1958-1994	.32	.24	-.39	.44	.10	30%

R^2=.70; Adjusted R^2=.66; F=14.7; p<.001

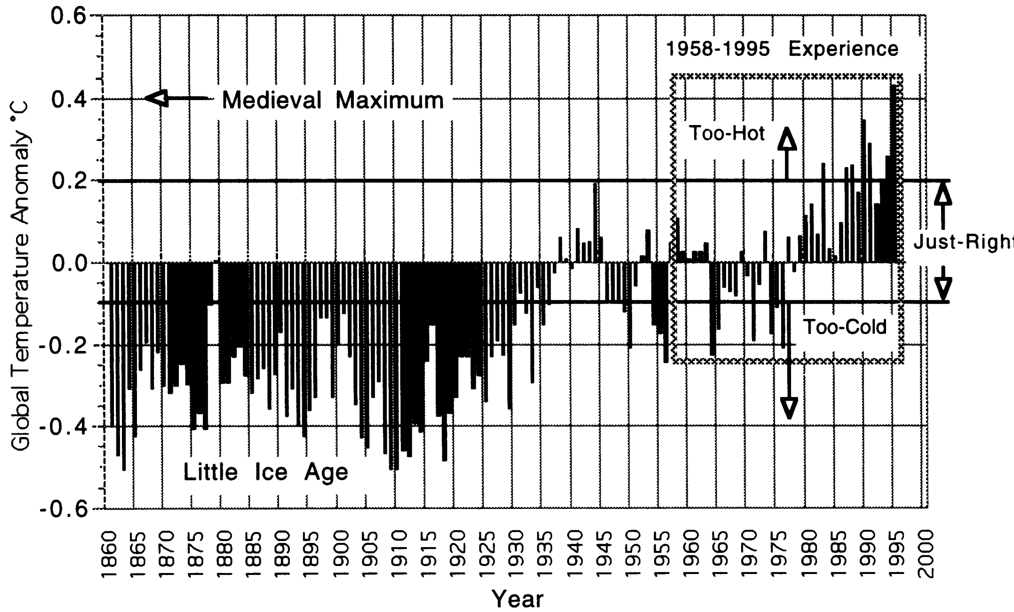

Figure 1. Global temperatures from 1861 to 1995 (WMO 1996).

and Stommel 1979, 1983). A model useful to landscape studies would account for this apparent discrepancy between past and present impacts of volcanoes on regional environments; I will return to this later.

The impact of anthropogenic trace gases on tropospheric average temperatures is still very much under study and discussion. During 1995, however, the IPCC officially recognized measurable anthropogenic warming of the atmosphere. The thermodynamic character of the atmosphere suggests that trace gases must have some impact. It is unclear if these impacts are canceled or amplified by other influences such as dust, clouds, and sulfur in the lower atmosphere. For the present, to be meaningful in terms of the past, this influence must be considered. It is known from ice core studies (Neftel et al. 1982) and lichen studies (White et al. 1994) that carbon dioxide, the principal greenhouse gas after water vapor, has varied in past millennia.

In the long term, there may be other important relationships between the astronomical and atmospheric/oceanic subsystems. Landscheidt (1987) has suggested a link between solar emissions and volcanism through solar flares. Solar flares not only precipitate polar auroras, an upper atmosphere phenomenon, but also change the rate of rotation of the earth and threaten or disable electrical utility grids. Landscheidt believes that these rotational anomalies generate volcanism by rocking continental plates. The grinding of plate edges causes friction, heat, and eruptions. Supporting this contention is the fact that the last four solar maxima were followed by major eruptions that recognizably altered atmospheric processes. Should this solar-geophysical link be confirmed, there would, in effect, be a geophysical antidote to excessive solar emissions with respect to effects on atmospheric temperatures. Such a link would also mean that Bryson and Goodman's (1980) Holocene volcanism index discussed below has significance beyond simply cataloging episodes of geophysical disturbance. It also reflects anomalies in solar emissions and the general state of the solar-geophysical system. In the next section I will attempt to link these quantities into a model of global climate change that will benefit landscape studies.

Integrating the Atmospheric Influences into a Three State System

For studies of global temperature, I have used Northern Hemisphere tropospheric temperature because tropospheric circulation and moisture influence cultures directly; it is the life envelope of terrestrial biota. A study of the movements in tropospheric average temperatures using rule based artificial intelligence methods (Gunn and Grzymala-Busse 1994) shows that there are three states that the global environment takes, too hot, too cold, and just-right (warm-cool in the original article), a sort of three bears outlook on global living conditions. Between 1958 and 1994, the hot (n=5) and cold (n=7) world years were relatively infrequent, while the just-right (n=20) condition dominated (Figure 2).

Gunn and Grzymala-Busse (1994) have argued that the just-right regime represents a complex system in which all of the players—sun, volcanism, El Niño, and greenhouse gases—are actively cycling through their amplitudes. Chances are that they will cancel each other in a given year preventing movement into the too hot or too cold ranges. This imparts a broadly stable condition to tropospheric temperatures. It also favors broadening of the annual and interannual storm track

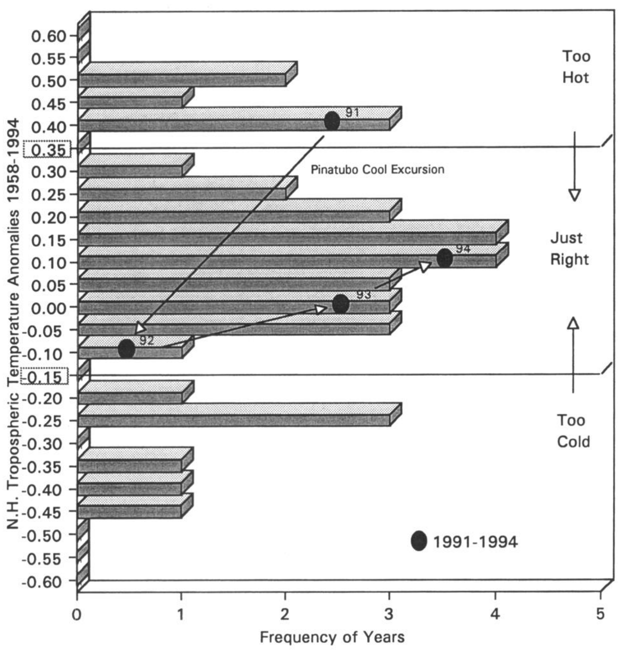

Figure 2. Average northern hemisphere tropospheric temperature (C) annual frequency distribution for 1958-1994.

latitudes by frontal bumping the jetstream north and south; this creates a relatively wide, moderately moist temperate zone favorable to agriculture. The temperature anomalies in Figure 2 are deviations from the 1958-1970 mean (Angell and Korshover 1977). The just-right world condition prevails when most years fall between -0.10 and +0.30 C° of the 1958-1978 mean tropospheric temperature. The tendency for cycling influences to prevent the tropospheric temperatures from moving outside these boundaries creates a gap in the frequency distribution between the just-right years and the too-hot and too-cold years. I will refer to this as the "seizing range" of the just-right complex atmospheric system. The movements of the tropospheric temperature following the Mount Pinatubo eruption (1991-1994) illustrates the ability of one influence to seize the temperate and pull it back into the just-right range.

The too-hot and too-cold tropospheric temperature conditions appear when more than one of the influencing variables is stalled at high or low levels. Thus, if greenhouse gases are high, and solar emissions cycle through their high phase, one could anticipate a sustained increase in tropospheric temperatures such as occurred in the 1980s. This was only briefly interrupted by the eruption of Mt. Pinatubo in 1991 (British Meteorological Office, see Figure 2). On the other hand, if solar emissions are low, and carbon dioxide is at preindustrial levels, as in the 1600s, then cold tropospheric temperature conditions can be anticipated such as occurred during episodes of the Little Ice Ages.

It is clear from measurement of global temperatures for the last 136 years (see Figure 1) that the 1958-1990 period exhibits a wide range of variation in global temperatures. Though not as far ranging as depressed temperatures in the Little Ice Age, or as elevated as the inferred temperatures of the Medieval Maximum, they do extend into the range of those periods. If the 1958-1990 tropospheric temperature variability is used as a guide to Holocene climate processes, they suggest that too-cold tropospheric temperature conditions appear when the average tropospheric temperature falls -0.20 C° below the 1958-1970 mean. Too-hot tropospheric temperature conditions appear as annual temperatures rise +0.40 C° above the 1958-1970 mean. While we can observe little of the impacts of too-hot and too-cold tropospheric temperatures from the data of the twentieth century because there are no multidecade runs of such years, we can theorize that movements between the three tropospheric climates are made simply based on the frequency of temperature years (Figure 3). If the just-right tropospheric temperature complex system succeeds in maintaining just-right conditions for most years over a run of decades, then the just-right world climate accrues with infrequent excursions into the too-hot and too-cold ranges; this is as it has been during recent decades, and perhaps during the Roman Optimum (300 B.C.-A.D. 200) (Figure 3B). Should the majority of years fall into the too-cold range (Figure 3C),

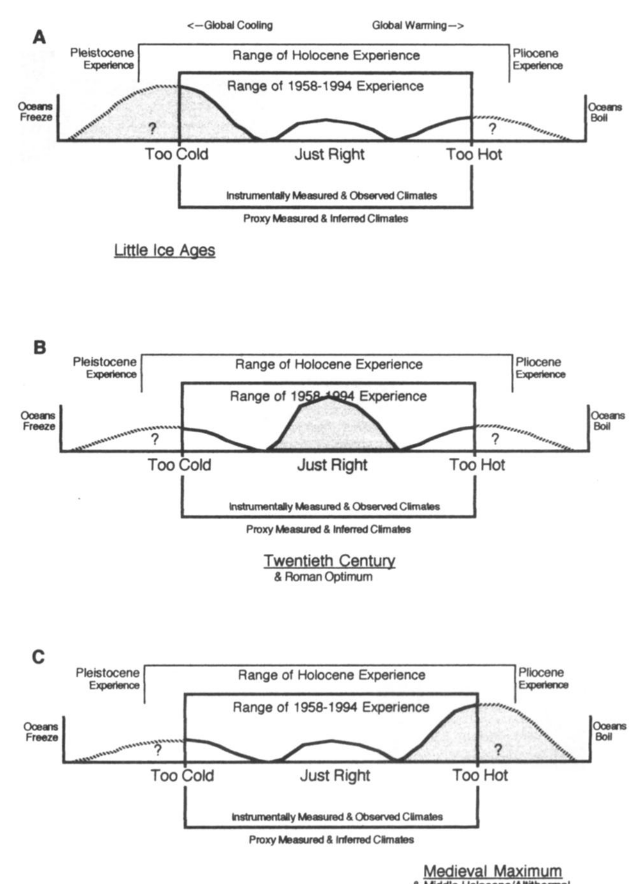

Figure 3. Theoretical frequency distributions of (A) too cold, (B) just right, and (C) too hot worlds for three decades.

the climate will be too-cold for a majority of the years, and biocultures will adjust to those conditions within their regions. Agricultural societies generally function on a success rate of about 3-4 years out of five (Parry 1978). Should the majority of temperatures exceed the too-hot criterion (Figure 3A), then the too-hot tropospheric climate appears.

Modern climatologists, or even paleoclimatologists, probably know little about the exact ramifications of the too-hot and too-cold tropospheric temperatures. Archaeologists can provide understanding of how hot tropospheric temperature conditions, such as those of the Middle Holocene and Medieval Optimum, impact human societies. I suspect that this three state perspective on tropospheric climate will aid both archaeologists and climatologists in an understanding of those conditions by defining the thermodynamic boundaries of global climatic variability within a manageable number of states.

El Niño-Volcanism Sliding Scale

In the introduction, I suggested that there are variations through time in the amount of influence volcanism and El Niño bring to bear on atmospheric temperatures. Since understanding the character of variations is the substance of climate impacts on culture change, I will now consider a possible cause of this variation.

If the three states are valid, and their implied processes as observed in the modern atmosphere apply across the Holocene (except during extreme events such as A.D. 536 or the Tambora eruption), one can describe a model of past interactions of the astro-geo-eco-system for different episodes at higher and lower tropospheric temperatures. It has been suggested from paleoenvironmental studies that the Middle Holocene and Medieval Maximum were warmer than the present century. These would have been episodes during which too-hot conditions prevailed. The Little Ice Ages, which have been particularly characteristic of the Late Holocene (see Bradley and Jones 1992; Denton and Karlen 1973; Williams and Wigley 1983), were cooler than present. The Little Ice Ages episodes probably represent the dominance of the too-cold state.

Too-cold

Because of the low frequencies of the too-hot and too-cold conditions since the IGY, the modern atmosphere only hints at their overall characters. Geological, paleoenvironmental, and paleocultural data may provide additional reach for our understanding of those states. Conditions in the last millennium suggest that there must be a sliding scale of relationships between El Niño and volcanic influences on tropospheric temperature across the three tropospheric temperature states. During too-cold conditions, volcanoes have greater influence; during warmer conditions, solar emissions have greater influence. This sliding scale relationship is supported by geological evidence from coastal Peru which suggests that during cold episodes the El Niño is nonexistent or much diminished in magnitude (see Gunn 1991 for discussion of sources). This is probably because there is too little surplus energy in the oceans to disperse to the atmosphere when the energy demands of sudden tropospheric cooling appear, as following an eruption (see Broecker 1995 for discussion of ocean cooling, including the tropics).

Students of global climate assume that because of their ability to disperse heat to the atmosphere, the oceans act as a stabilizing influence on climate, the flywheel of global climate. Oceanographic measurements since the IGY indicate that the deep Atlantic has obtained energy at 1.0°C per century (Parrilla et al. 1994). Thus, the deep oceans are a century-scale flywheel while the El Niño, which is confined to the upper 100 meters, acts at a time scale of about half a decade. In the very long-term perspective, these tandem energy reservoirs have successfully shielded the world from excessive temperature fluctuations for billions of years—oceans have never frozen or boiled away. However, it is reasonable to assume that the ability of the oceans to buffer changes in atmospheric temperatures depends on the reservoir of heat they possess at any given time. Recent investigations summarized by Broecker (1995) propose that, contrary to previous opinions, oceans temperatures, including tropical oceans, change from period to period. This position is supported by findings from low latitude glacier cores (Thompson et al. 1994; Thompson et al. 1995) and ground water (Stute et al. 1995).

Without the subdecade buffering of the El Niño, the tropospheric temperature can fluctuate wildly with extreme events such as volcanoes. An excellent example can be seen in the acutely unstable centuries during the globally cold decades of the European Early Middle Ages (Gunn, Crumley et al. 1995). This includes the aftermath of A.D. 536. Inherently unstable, too-cold world conditions would explain unusual events such as frequent cold winters between A.D. 764 and 860; most notable was A.D. 829 during which the Nile froze (Lamb 1977:427).

Because of oceans performing a key role in atmospheric temperature maintenance, sea level is a sensitive indicator of the long-term conditions of the earth system. Tanner's (1993) sea-level curve for the Middle and Late Holocene is therefore an important guide to the state of the life envelope and provides a Holocene-scale empirical perspective on tropospheric temperature. It, for example, shows a 200-300-year decline in sea level following A.D. 536. The decline in sea level is paralleled by falling European temperatures (see Lamb 1977:Figure 16.23; Crumley and Marquardt 1987:238).

I have selected Tanner's curve for this purpose because of its resolution of 50 years duration reaching back past the Middle Holocene, and because the methods of its derivation allow it to detect both high and low sea stands; this is not a characteristic of all such curves. The issue of sea level as an indicator of world conditions will be further addressed in the next section.

Too-hot

As the tropospheric temperature increases to the just-right condition, El Niño possesses enough energy so that it counteracts most short-term global cooling events. Through this system of heat emission by the sun and storage by El Niño, relatively flat tropospheric temperatures may be sustained for periods of up to centuries. An example is the approximately 500 years of the Roman Optimum. With yet more tropospheric warming to hot conditions, El Niño becomes a permanent state with sufficient energy to subvert all but the largest negative impacts on tropospheric average temperature. With the oceans permanently hot, any downward disturbances such as eruptions would be immediately subverted by release of heat by the El Niño. Hot oceans, then, are the flywheel of global climate.

If oceans are hot, nullifying variation from volcanoes (and similar negative impacts), the dominant variability remaining in the system could be the solar emissions cycle. Tropospheric temperature would follow the solar cycle without constraints from the other influencing variables. This would create a super-annual seasonality. We can guess at this point that the super-annual cycle probably would be summer-like weather spanning the half dozen years of high solar emissions and a spring-fall like condition in the half dozen low years, but this requires investigation. However, as discussed above, there are numerous lines of research that detect climatologically significant variations in solar emissions. If variable solar emissions drive seasonality during hot world conditions, super-annual seasonality may explain why populous, complex urban civilizations paused in their development during the Middle Holocene. Highly productive monocrops upon which mass population aggregates depend (Crumley 1994) would have been tenuous in a super-annual seasonality environment.

Mobil hunters and gatherers, on the other hand, would have survived with facility. Mobility, of course, is the hallmark of many Middle Holocene populations including those of the Southeast (Sassaman 1995). Tanner's (1993) sea-level change oscillates through a cycle of approximately 200 years in the middle Holocene. If this is equivalent to the 200-year solar cycle in lake varves (Dean et al. 1996), it will constitute powerful support for the hot-world solar seasonality hypothesis.

Examining the Middle to Late Holocene Transition

There is a tendency to treat the earth as a target of the astronomical and geophysical forces that shape climate of the life envelope. In this section, I examine the effects of the broad-scale parameters as they might affect the life envelope, and ultimately, local landscapes. This requires a different analogy from that of the shooter and target. The life envelope is a bio-geological organism with its own velocity and mass (McMenamin and McMenamin 1994:5). At least since the Gondwanan Ice Age, vascular plants have played an important role in balancing carbon dioxide in the atmosphere and maintaining tropospheric temperature in a range tolerable to terrestrial life (McMenamin and McMenamin 1994:31). Water, atmosphere, and life forms interact to modulate tropospheric temperature. Astronomical influences, powerful as they are, can be significantly and even surprisingly modified by the response characteristics of the life system component. To accommodate the biological mass and velocity during interpretation, the world needs to be viewed using a medical analogy. This will be an analogy in which changing conditions, analogically a disease, has precondition (acute=events) and post-condition (chronic=episodes) stages, and symptomologies. Lovelock (1989) has suggested "geophysiology" for this perspective and notes that its roots date to the Enlightenment. While a quantitative time-series analysis would be useful as a means to examine this pattern of interaction, its complexity suggest a graphical comparison for a first approximation effort such as this. Following this scheme, I will examine how the influencing variables change between the Middle and Late Holocene, and use sea levels as an indicator of life system responses to external forces. Then the impacts on landscapes will be suggested.

The influences that have been quantified for the last 6,000 years are illustrated in Figure 4 (Gunn, Folan et al. 1995). The solar variable is drawn from the work of Landscheidt (1987). He calculates the magnitude of solar emissions based on the angular momentum of the planets. The validity of Landscheidt's model can be verified by testing it against independently observed empirical phenomena; these are only two among many favorable comparisons that can be made; they are the least remote in time and therefore most verifiable. Landscheidt's solar emissions trajectory shows elevated emissions during the Medieval Maximum (A.D. 900-1250). This corresponds with Eddy's (1994) findings from historical observations of auroras. Landscheidt's model projects low emissions for the seventeenth century. This compares favorably with the much-studied Maunder Minimum (Eddy 1977; Lean et al. 1992). Following the suggestions of these test cases, I assume that the remainder of the trajectory correctly estimates solar emissions for less well-understood episodes of the more remote past. Dean et al. (1996) and other research-

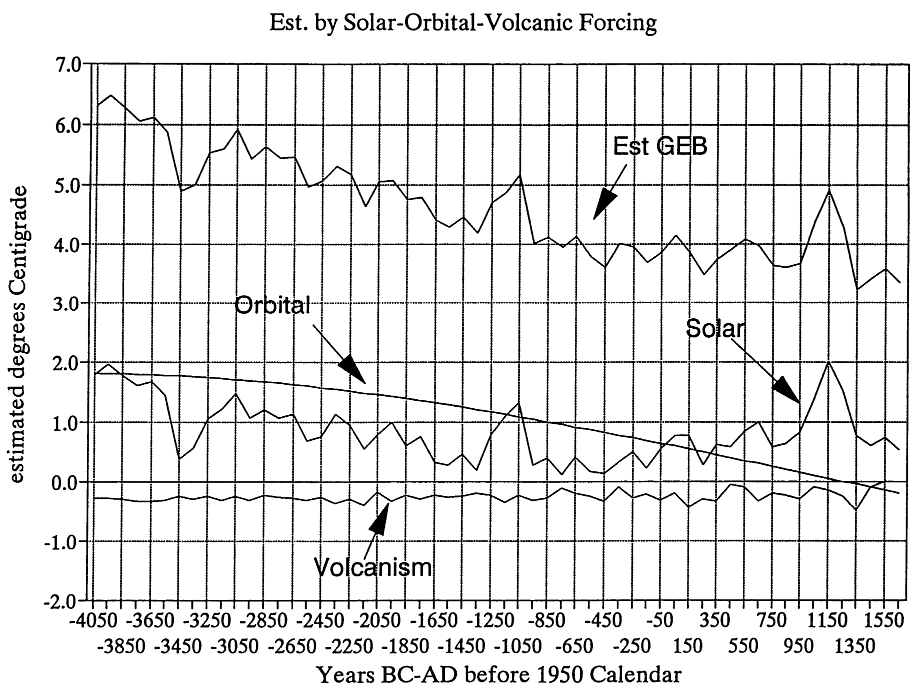

Figure 4. Middle and Late Holocene solar emissions, volcanism, and rotational tilt (October precession) and estimated tropospheric temperature.

ers have used ^{14}C correction data as a solar indicator. This is probably an acceptable alternative. I prefer the Landscheidt approach in principle because it is derived independently of the life envelope and is therefore less susceptible to modification by feedbacks. Broecker (1995) discusses the feedbacks between the oceanic maritime conveyor system and atmospheric ^{14}C.

Landscheidt's solar emissions model finds sustained, elevated solar emissions during the Middle Holocene, but only brief comparable episodes in the Late Holocene. Thus, it can supposed that one of the differences between the Middle and Late Holocene is a reduction in solar emissions. Solar emissions during the Late Holocene were also more variable.

In addition to the variables observable in the modern system, the tilt of the earth's axis exerted a different influence on temperatures during the Middle Holocene (Broecker and Denton 1990; Thomson 1995). The rotational configuration of the earth was such that the Northern Hemisphere tilted further toward the sun in summer and further away in winter than at present (Bryson 1994; Davis 1984; Davis and Sellers 1994; Kutzbach and Guetter 1986). This increased the amount of insolation in the Northern Hemisphere during summer by seven percent and reduced it by seven percent in winter. Thus, to the observer in the Northern Hemisphere, summer days were longer and brighter and winter days were shorter and dimmer. This probably produced more extreme summers and winters than those of the present (Bryson 1994), especially since it was reinforcing elevated radiation in summer. (Davis [1984] discusses impacts of variation in incident heating through the Holocene. See Eddy [1994] and Handler [1985] for genetic damage of high solar emissions.) Summers would have been long, hot, and dry in most nonmountainous regions at midlatitudes. In watersheds with favorable topography and atmospheric characteristics, moisture would fall as summer monsoons. On the Atlantic Coastal Plain, summer monsoons have been modeled for the Middle Holocene, and that along with frequent fires generated by lightening, encouraged pine dominance (Kutzbach 1987; Sassaman 1995:182). Winters would have been long and cold. There would have been relatively large amounts of moisture in the atmosphere because of high evaporation in a hot world, so cold winters may have been snowy winters; this would recharge perched water tables and provide for living in uplands during part of the year. There may have been relatively little intervening time for spring frontal precipitation, criticial for upland temperate vegetation.

Much of this simply characterizes subtropical climate that displaces temperate zone storm tracks northward; much of the difference between the Middle and Late Holocene can be explained as the subtropics moving north to encompass the Southeast earlier in the year and reducing spring precipitation. As with the Pleistocene, however, we probably have no direct analogy to Middle Holocene conditions because of the differences in rotational tilt between then and now and the sustained elevated radiation.

The alternative Late Holocene tilt configuration would have reduced incident radiation. Since no key variables are permanently high, just-right or too-cold conditions would have become possible.

Turning from the astronomical scale to the upper atmosphere, the volcanism trajectory for the period of study is developed from Bryson and Goodman's (1980) work. The magnitude of the influences is calculated from their relative contribution to global temperature during the period since the IGY using beta values like those in Table 1 (see Gunn, Folan et al. 1995). The volcanism contribution is the fourth largest (see Table 2). However, as was discussed above, volcanism and El Niño appear to share their influence on tropospheric temperature in a sliding scale relationship. Thus the regression model (see Table 2) used to scale the relative contributions of the influences is relatively simple for the whole system. Researching the aforementioned sliding scale for the non-just-right states is an urgent issue. For now, it is worth noting that volcanism in the Middle Holocene was relatively diminished compared to that of the Late Holocene. The Late Holocene has pronounced episodes of volcanism compared with the Middle Holocene. (The volcanism values in Figure 4 are negative because volcanism subtracts from the tropospheric temperature. See also absolute frequencies of volcanic radiocarbon dates at the bottom of Figure 5.) Some of the episodes of volcanism appear to be lengthy and were compounded at times by low solar emissions. This would have permitted too-cold conditions or little ice ages.

A summary of the combined astronomical and geophysical forces projects a potent hot world condition for the Middle Holocene. For the Northern Hemisphere, there was not only additional solar radiation, but also more exposure from longer days and a more direct incidence angle of sunlight. This tendency toward higher radiation exposure was capped, or more accurately uncapped, by reduced protection from upper atmospheric debris. All of the indications are reversed for the Late Holocene.

Middle Holocene

Given the differences in energy inputs, Middle Holocene landscapes could have differed substantially from those of the Late Holocene. With energy from multiple reinforcing sources, vegetation could have been bizarre by present-day Carolinian standards. Active sand blowouts appeared in elevated archaeological sites (Gunn and Foss 1992) and dunes in the Cape Fear flood-

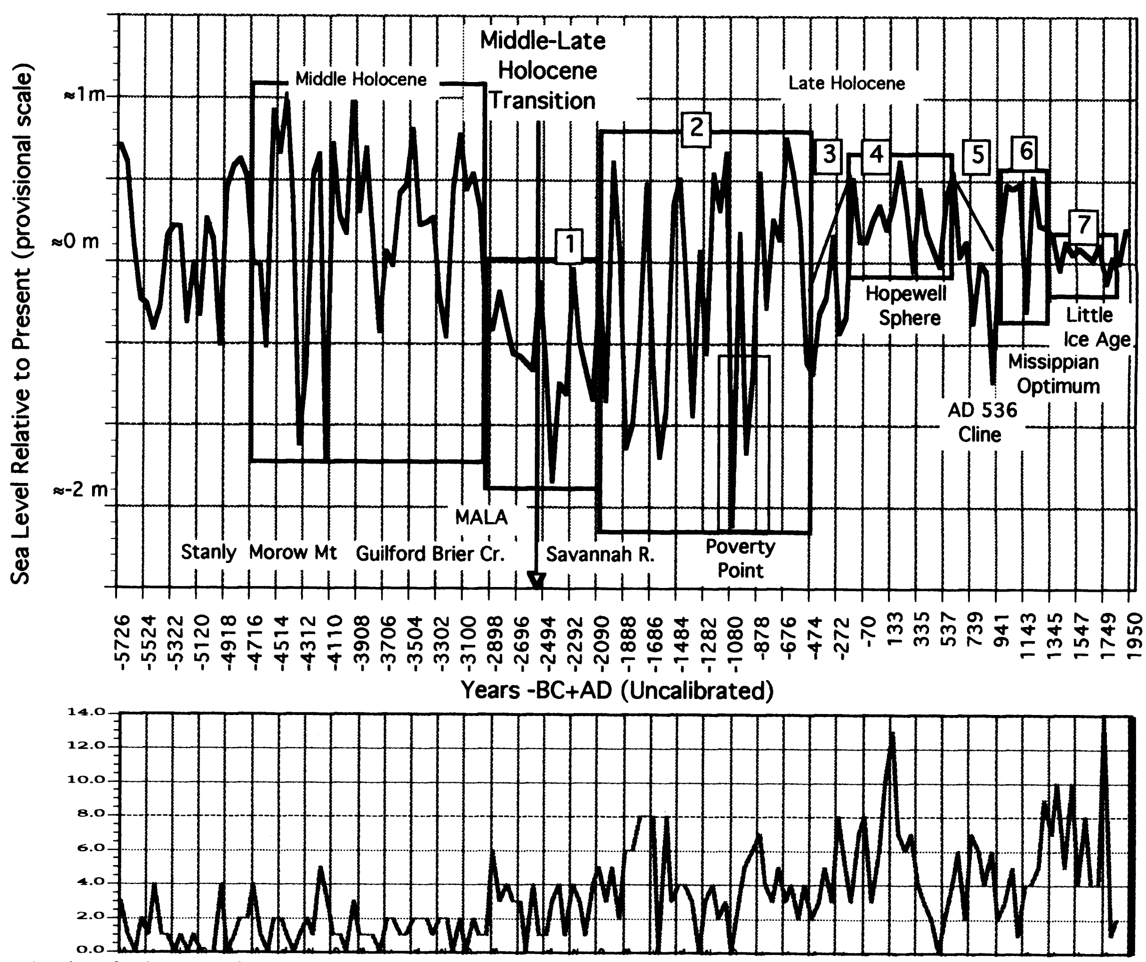

Figure 5. Middle and Late Holocene sea level at 50.5 year resolution and volcanism frequencies.

plain (5,700 to 3,720 B.C.) (Soller and Mills 1991). Rovner (1995) and Carbone (1977) identified a shift from Festucoid (cool moist) to Panicoid (warm moist) grasses in archaeological sites in the North Carolina Piedmont, the Shenandoah Valley of Virginia, and the Susquehanna Valley in Pennsylvania. West of the Appalachians, Whitehead and Sheehan (1982) studied pollen on the Tombigbee River and found that nearby uplands gave rise to scrub oak savanna.

Midwestern dunes were active at the same time (Dean et al. 1996). While the dunes and phytolith studies suggest similar developments east of the Appalachians, definitive resolution of the landscape configuration remains elusive. It is important that the Panicoid grasses only appear in Middle Archaic levels, perhaps indicating a drier upland environment, but there are no desertic Chloridoid grasses. Remnants of such a biome remain in the Piedmont as little blue stem grass and a now-endangered sunflower species that survives in powerline clearcuts (Tippitt and Moss 1996). It is certain that valleys were choked with sediments, vegetation, and teaming with aquatic life on both sides of the mountains (Bense 1982; Brakenridge 1980; Brooks et al. 1986; Claggett and Cable 1982; Leigh and Feeney 1995). Scrub savannas combined with dense floodplain vegetation are called "gallery forests" and are common in subtropical savannas. In some aspects, the contrast with the Late Holocene may have been as significant as between the Pleistocene and the Late Holocene, at least from the perspective of human beings. It is interesting to note that both generated highly mobile hunting ways of life—Paleoindian and Morrow Mountain. Worldwide it was an unfavorable climate for glaciers. Tanner (1993) finds higher sea levels (see Figure 5) than at present between 4,800 and 3,000 B.C.

The widespread, long enduring Morrow Mountain folk adapted to this Plains-like environment concentrating in the Piedmont (Elliot and Sassaman 1995:29-31; Sassaman and Anderson 1994:106, 124). Within the Piedmont, they retreated from the sediment choked streams and congregated on hill tops. These sites may have been utilized to avoid infestations during some seasons (Gunn and Wilson 1993). They appear as upland lithic scatters near spring heads. That spring heads were habitable during the Middle Holocene indicates precipitation during some part of the year to recharge perched water tables. Monsoons and tropical storms too late in the year to support temperate vegetation would have served this purpose. The relatively rare lowland occupations are on rivers that head in mountains as at Doerschuk on the Yadkin (Coe 1964) because they were scoured by free running water (Gunn and Foss 1992; Gunn and Wilson 1993). There were no large population aggregations except on the Gulf Coast (Russo 1994). Villages appeared in pine forested parts of the Coastal Plain adapting to a summer monsoonal biome (Sassaman 1995). In parts of the world where antecedent cultural developments would have led to large population aggregates, as in the Near East, it was delayed to the Late Holocene. Rather, village based Neolithic farming dominated settlement patterns.

If, as discussed above, Middle Holocene climate invoked a seasonality of precipitation crossing years rather than months, high mobility would have been the most reasonable adaptation in nonforested regions. This was a seasonality pattern to which urban aggregates, or even villages in the Southeast (see Sassaman 1995 for exceptional subregions), could not adjust given existing technology, modes of transportation, and trade practices. Highly mobile hunters and gatherers, as in the Piedmont, however, could have accommodated such conditions as a matter of course.

A lanceolate point tradition (Guilford, Brier Creek, and MALA) appeared just before or at the end of the Middle Holocene (Elliot and Sassaman 1995; Sassaman and Anderson 1994). The dating of these phases is still imprecise. At Copperhead Hollow there were slight adjustments in prevailing wind direction and possibly some stabilization of the sand blowout (Gunn and Foss 1992). That all three phases have been discussed as intrusive suggests their association with some sort of transitional event at the end of the Middle Holocene.

Transitional Late Holocene

The Late Holocene witnessed a turn to more equitable seasonal insolation as the tilt of Earth's axis equalized energy input during Northern Hemisphere winters and summers. Volcanism and solar-emissions variations became pronounced, generating a punctuated rather than gradualist character to the climate trajectory. The decline of sea level at 3,000 B.C. marks the threshold of collapse of the Altithermal regime (see Figure 5, box 1).

Persistent low sea levels between 3,000-2,000 B.C. suggest an optimal condition for little ice ages-like mountain glaciers (Figure 5, box 1) and greater global ice volume (Brooks et al. 1986; Colquhoun and Brooks 1986; Tanner 1992, 1993). This is probably a global transitional state between the Middle Holocene—too-hot for glaciers—and the most recent Late Holocene—too-cold and unstable for glaciers. (Bryson [1989; Bryson and Goodman 1986:25] suggests a curvilinear relationship between ice volume and global temperatures.) Although a global cooling must be indicated, the increase in ice volume could be symptomatic of still-hot oceans sustaining atmospheric water vapor in a then-colder world climate. The duration of about 1,000 years approximates the lag time estimated for deep ocean temperature adjustments.

The transitional episode corresponds with the Savannah River and Broad Spear phases. It was in most regions an unusually moist and populous period. There was a shift from the upland mast harvest preoccupation of the Middle Holocene to a riverine subsistence orientation (Sassaman 1995). These populations are signaled by the intrusive appearance of Middle/Late Archaic (MALA) and Brier Creek points on the south Atlantic Slope Savannah River region. As with MALA, Guilford appears, perhaps intrusively (Elliot and Sassaman 1995; Gunn and Wilson 1993), in the northern Piedmont. Similar riverine reorientation can be seen at the same time on the northern Atlantic Slope as documented on the Rappahanock River in Virginia (Mouer 1991). During this period, coasts were favored areas of occupation as indicated by the giant ring middens along the South Carolina and Georgia coast (Trinkley 1989). Some of the sites of this period are now submerged (Blanton 1993; Brooks et al. 1986; DePratter and Howard 1980; Walker et al. 1994). Permanent settlement of the coastal zone suggests reduced tropical storm frequency. This would be a logical product of continuous depletion of ocean heat.

Early Late Holocene

The second regime of the Late Holocene begins about 2,000 B.C. and continues to 600 B.C. Sea level and tropospheric climates began an approximately 200 year cycle of change. Apparently the oceans, now depleted of Middle Holocene heat, no longer buffered tropospheric temperature movements. Accompanying episodes of volcanism and/or solar emissions may be responsible for the periodicity (see Figure 5).

The return to higher sea levels following 2,000 B.C. (Figure 5, box 2) does not indicate a return to persistent hot tropospheric conditions of the Middle Holocene. Presumably the now-cooled oceans no longer freely fed the glaciers—a true dry cold. I suggest that the glaciers did not fare well during century-scale global instability and thus the tendency toward higher sea level. Instability not only implies cold episodes that may have expanded glaciers, but also brief hot episodes that diminished them. The instability became progressively more erratic through the period as though a second oscillation was being overlaid on the first. Thus, the post 2,400 B.C. period, the Late Holocene, is one of adaptation to relatively unstable, century scale oscillations.

This period of global, century-scale instability is also the period of the cycles of civilizations. The Egyptian Kingdoms rose and fell with the rhythm of Nile flood volumes (Hassan 1994), and Mesopotamia (Hole 1995; Issar 1995; Weiss et al. 1993) and Indus (Bryson and Murray 1977) civilizations experienced uneven climates. It may indicate that civilizations are one of the possible antidotes to century-scale instability.

Research on Hilton Head Island (Gunn, Lilly et al. 1995) indicates that a small increment of sea level change affects ground surface conditions at far greater elevations and inland distances than might be anticipated. Osprey Marsh, three meters above current sea level, became only marginally habitable with one meter of sea-level rise. Brooks et al. (1986) found that changes in river base levels affected sediment deposition over 100 miles inland as far as the fall line. Such sea-land interactions may account for the southern Atlantic Slope coastal zone settlements being less important. During the Early Woodland, the great coastal shell mounds were abandoned and settlements tended to focus inland toward the fall line. This may suggest a return of greater tropical storm frequency. During this era of cyclical climates, Eastern North Americans joined in widespread trading spheres. The Poverty Point Trading Network is the best documented (Anderson 1994; Gibson 1994; Sassaman 1995). It is known that durable goods such as lithics and copper were transported by water; perhaps the shipment of foodstuffs by water was also practiced (Kowalewski 1995; Peregrine 1995).

Widespread interregional networks likewise appeared in other parts of the world after 2,400 B.C. and in unprecedented configurations. The means by which historical cultures in the Old World adapted to long-term instability varied from region to region depending on previous cultural status. City states joined into empires to buffer inter annual instability. Sargon's Akkadian Empire and its descendent form, the Roman Empire, appear to be excellent examples of this strategy to reduce risk (see Gunn, Crumley et al. 1995; Tainter 1988). Other empires such as those of India and China may reflect similar circumstances and decision-making processes.

Late Late Holocene

Following the episode of cycles (Figure 5, box 2), the sea level changes assume a different character with episodes of relative stability (Figure 5, box 4, 6) being separated by clines (Figure 5, boxes 3, 5, 7). Why the change in changes? Human intervention in the temperature of the atmosphere may have begun as early as 3,000 years ago. During Classical times, pollen diagrams and other evidence indicates deforestation from Poland to tropical Africa for charcoal used in iron manufacture (Schmidt 1994). The Romans made massive numbers of bricks and smelted silver and other metals (Tainter 1988; see Hong et al. 1996 for ancient copper industry and other citations). Similar deforestation activities were under way in the tropical New World for making plaster (Hanson 1995; Scarborough and Gallopin 1991). Were these carbon releases sufficient to modify the atmospheric greenhouse gas composition and stabilize tropospheric temperatures?

Returning to the question posed at the beginning of the article relative to the social consequences of the Middle-Late Holocene transition, why was it so notable in many parts of the world? Are there sufficient data here to suggest reasons? As discussed in the introduction, around 2,500 B.C. there were many indications that pending Late Holocene cultural strategies were present and awaiting conditions favorable for their application. The most observable of these in the Southeastern seaboard is the turn to valley-oriented settlement by previously nomadic upland foragers. Thus began the manufacture of ceramics and the creation of huge coastal shell mounds or ring middens on the South Carolina and Georgia coasts (Sassaman 1995). In Virginia, substantial villages appeared on floodplains (Mouer 1991). One suspects a relationship but, as is frequently said, correlation does not equal causation. A causal account of environmental and cultural linkages will be the work of coming years. For now I can suggest some potentially productive hypotheses of impacts on southeastern landscapes.

Conclusions

We can draw at least six conclusions about the astronomical and geophysical context of the Middle-Late Holocene transition and its local ramifications.

1. From episode to episode, global climate processes shifted significantly. To understand causes of regional cultural change, the local impacts of these process shifts need to be considered. Since many of the global-scale shifts are products of cyclical changes in the astronomical and geophysical domains, they are most easily studied before turning to changes whose cause resides in human agency and historical forces.

2. Global climate processes appear to take at least three states. The just-right state, a medium tropospheric temperature range, is a complex system with some ability to maintain itself at the expense of the other states. It is characterized by the absence of any key variable held permanently high or low. It sponsors a broad, moderately moist temperate zone. This seems to favor agriculture and large, complex social organizations.

3. Variability processes during the too-hot and too-cold world states need urgently to be studied as they have been infrequently observed since the IGY. They may be dominantly ascribable to solar emissions and volcanism respectively. On a sliding scale, El Niño diminishes the effects of volcanism in a warmer world by substituting ocean heat reserves for blocked solar energy. Too-hot and too-cold episodes are probably relatively unstable, or have other characteristics such as super-annual seasonality. They discouraged the development of complex urban population aggregates. They may encourage mobility as a subsistence solution, as in the New World, or dispersed settled populations, as in the Old World Neolithic. They can be studied for the most part through paleoecological investigations.

4. There are measurable effects of solar emissions, volcanic dust, El Niño, and carbon dioxide variations on tropospheric temperature, and through tropospheric temperature on regional climates. Studying the interactive processes of these forces can be used to determine regional sensitivity to global change and construct models of regional climate change.

5. To understand regional climate changes, it is necessary to gauge the sensitivity of landscapes to disturbances in the global climate. This can be accomplished with modern climate data using them to discover the processes of global-regional linkage. These processes are then further linked to regional subsistence customs.

6. The research to understand the linkages between global-scale climate changes and regional climate change is just beginning. Shifts in seasonality of precipitation forced by Middle Holocene global warming appear on the surface to explain known conditions such as the appearance of grasslands on elevated landforms. The Piedmont of the Atlantic Slope is a possible example. On the Atlantic Slope, as well as in other areas of the world, many of the cultural traits that characterized the Late Holocene were present in the Middle Holocene as marginal practices. The shift from Middle to Late Holocene climate apparently played a role in galvanizing the old marginal traits into a new suite of dominant customs, including abandonment of mobility for sedentism and a constellation of accompanying practices such as stone and ceramic containers. The shapes of these interactions, and accompanying landscape changes, will be the subject of a subsequent study.

Notes

[1] Calibrated using Stuiver and Riemer (1993) CALIB 3.0 program.

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