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# ON THE CLIMATE HISTORY OF CHACO CANYON

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Notes on Chaco Canyon history in connection with the presentation
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## On the Involvement of the Sun in Chaco Canyon Climate History

Tree-ring research since A.E. Douglass and E. Schulman has brought great benefits to the archaeology of the Southwest. It has become possible to reconstruct the climate narrative in some detail. The appropriate field of study is termed “dendroclimatology,” which is focused on the information contained in the growth of a given set of trees. The term harks back to the intent of the pioneer, the solar astronomer Douglass, who worked early in the 20th century. Since that time the study of tree rings has become a respected branch of Earth Sciences, with well-defined objects and methods (Hughes et al., 1982; Fritts, 1991).

Douglass spent great efforts on documenting a role for the sun in climate change. Studies relating climate to solar variation have multiplied since. As yet, a focus on solar activity encounters much skepticism among climate scientists (see, e.g., Hoyt and Schatten, 1997). The expert’s skepticism has several causes. One is that the direct evidence for 11-year solar cycles within tree rings remains rather weak, for many or most of the records studied. In other words, the 11-year cycles are usually hard to see, when analyzing the records using standard statistical techniques. The second is that no one knows why the sun’s output of energy should fluctuate in the manner observed. The third is that there is no agreed-on cause-and-effect path from observed solar variability to observed climate fluctuation. Given the existing lack of knowledge about solar physics (sun cycles have not been successfully predicted) and given the lack of knowledge about possible effects of changing solar brightness on climate, statements regarding the matter face much distrust.

Given great uncertainty, ignoring the issue at hand is a common strategy. Before one invests any effort in thinking about cause-and-effect, one would like to be reasonably sure that the phenomenon to be explained in fact exists. Evidently, establishing the reality of the phenomenon is a task for climate historians. Indeed, research on the topic is proceeding; it involves astronomers, physicists, anthropologists, tree-ring experts, and oceanographers (Eddy, 1976; Jirikow and Damon, 1994; Davis, 1994; Dean, 1994; Petersen, 1994; Cook et al., 1997; Bard et al., 2000; Bard and Frank, 2006; Beer et al., 2000; Berry and Hsu, 2000). As indicated below, there is indeed evidence for a solar influence but not necessarily in the manner expected.

Regarding a direct effect on climate from the sun, it has been suggested that the Chacoan peak activity period (ca. 1050-1100) benefited from an unusually active (and hence bright) sun. A bright sun, presumably, brings additional warmth, for a longer growing season, and additional rain (from a stronger monsoon).  In particular, Jeffrey Dean of the Laboratory of Tree Ring Research in Tucson suggested increased overall moisture and an elevated water table on the southern Colorado Plateau for a period of about 250 years centered on 1150 (Dean, 1994, p. 228). More specifically, a link is seen to European climate history, as follows:  “The zenith of Anasazi Pueblo Indian occupation in the northern Colorado Plateau region of the southwestern U.S.A. coincides with the Little Climatic Optimum or Medieval Warm Period (A.D. 900-1300), and its demise coincides with the commencement of the Little Ice Age.” (Petersen, 1994, p. 243). In turn, the Little Ice Age has been linked to a dimming of the sun (Eddy, 1976, and many others since).

Such proposals can be tested against the record. If the inferred relationship exists, we should see a coincidence between reconstructed solar brightness and the record of precipitation, as reflected in the tree-ring based drought record. To make the comparison, we first obtain a record of precipitation for northwestern Mexico (available from the NOAA data bank, citing the work of Cook et al., 2004).

The precipitation history is given in terms of the “Palmer Drought Severity Index,” an index that is zero for “normal” or “average” precipitation, positive for precipitation higher than normal, and negative for anomalously low values of precipitation (that is, drought). In what follows, I refer to this measure as “drought index.”

The drought index for Chaco Canyon, for the relevant time span, is assumed to be identical to the compound index (based on the processing of numerous tree-ring records) of a site not far away, at 107.5ºW and 35.0ºN (Site 119 in the NOAA data bank). I take the “zenith” of Chaco occupation as identical with the building boom in Chaco Canyon, as seen in the peak building activity reconstructed by Lekson (in Lekson et al., 2006). The boom lasted from roughly 1050 to 1110; it arose at the end of a period of severe drought that left its maximum in 1040, and ended with a drought centered on 1100 (Figure 1). The intervening favorable (non-drought) period (labeled “A” in Figure 1b) holds the most intense building activity. (Plotting drought indices in terms of “look-back” takes account of what matters to a farming community: summing indices for the previous three years reflects the amount of corn in storage; summing indices for the previous twenty years reflects whether springs are running and whether there is water behind dams.)

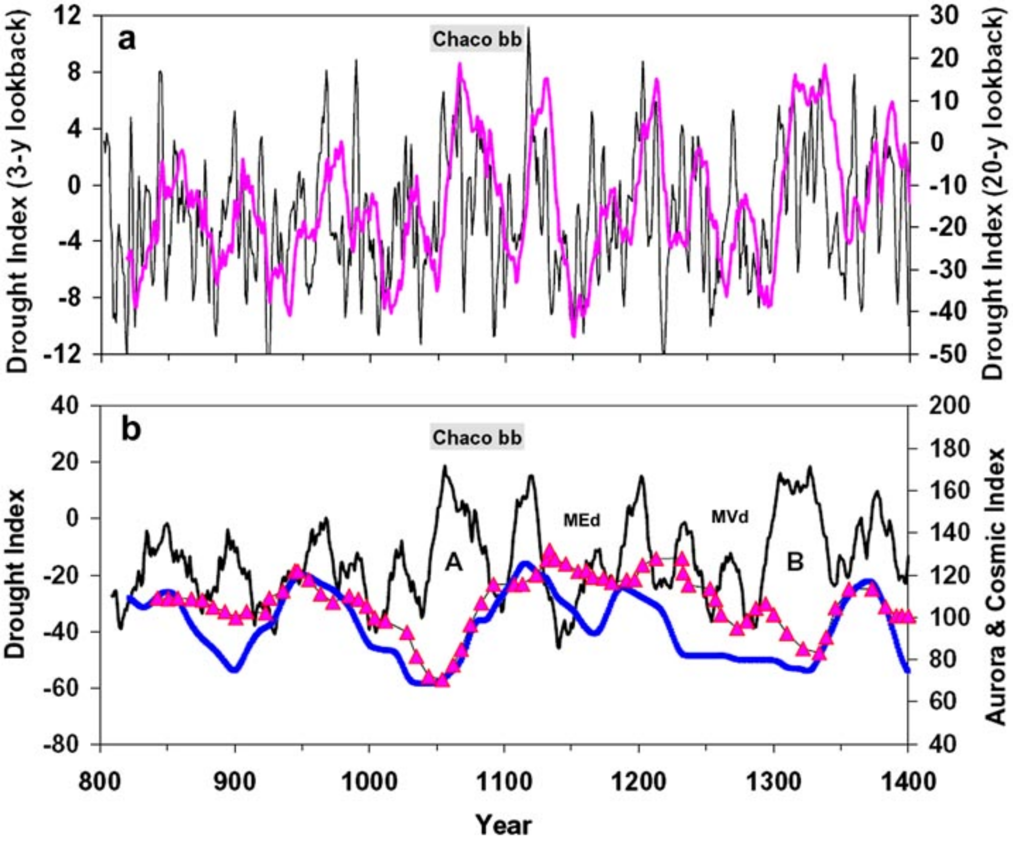

Figure 1. Drought narrative in Chaco Canyon, and comparison with the reconstruction of long-term solar activity. (**a**) Drought as seen by a farming community, with 3-year (black line) and 20-year look-back (pink line). (**b**) Drought history (20-y average) and solar activity from aurora abundance (triangles) and cosmic isotope assessments (blue). (Auroras: Schove, 1964; Isotopes: Bard et al., 2000). "Chaco bb," Chaco building boom (1050-1100); A and B, non-drought periods; Med and MVd, periods of drought (within McElmo and Mesa Verde phases).

Regardless of the precise relationship between building activity and precipitation (Figure 1a), inspection of the comparison between the drought index (and derivatives) and indices of solar activity shows that valid relationships are difficult to find (Figure 1b). In other words, there is no clear evidence for the notion that a brighter sun was responsible for favorable conditions during the Chaco period, on the time scale considered (centuries). If such a relationship exists it is of a tenuous nature and difficult to define. The two major favorable climate periods (labeled A and B in Figure 1b) obviously owe nothing to a brighter sun, as far as this can be ascertained.

The time between periods labeled A and B, which includes the artifact phases termed “Classic Bonito,” “McElmo,” and “Mesa Verde” in archaeological sequencing, does include two periods of increased precipitation (the first centered on 1120, the second near 1200). The lack of drought in these intervals provides support for the suggestions of Dean (1994) and Petersen (1994). In fact, a case might be made (Figure 1b) that the sun is unusually active during those particular periods. On the whole, however, the sun seems an unreliable guide to climate on the time scale of centuries.

Of course, this analysis leaves unexamined the question of whether circa-11-year solar cycles are contained in the climate record. It is a question that requires the application of more advanced statistical techniques. Results of such studies suggest that the sun is indeed present (as discussed in the section that follows); but there is as yet no agreement on the matter among climate scientists.

The single most important aspect of such studies is the link of precipitation in the western U.S. to ocean oscillations. It is a subject that has engendered an impressively long list of contributions (e.g., Namias and Cayan, 1981; Ropelewski and Halpert, 1986; Cayan and Peterson, 1989; Cayan and Webb, 1992; Cayan et al., 1998; D’Arrigo and Jacoby, 1991; Cole and Cook, 1998; McCabe and Dettinger, 1999; Rajagopalan et al., 2000; Barlow et al., 2001; Gray et al., 2003; Hidalgo et al., 2003; Hoerling and Kumar, 2003; McCabe et al., 2004; Seager et al., 2005; Herweijer et al., 2006; McCabe et al., 2007). As far as the possibility of a solar effect on drought cycles, therefore, what needs to be established is whether the sun is involved in the great oceanic oscillations, such as the El Niño – Southern Oscillation (ENSO). At this point, no one knows for sure. Indications are that both sun and moon can be found in the precipitation cycles on land (Currie, 1984; Cook et al., 1997), which suggests that both solar variation and tides influence the ocean oscillations driving drought (as claimed by Fairbridge, 1990, and elaborated in Berger, 2008).

## On the Cyclicity of Drought in Chaco Canyon

The compilation of drought runs in northwestern New Mexico (that is, the number of years with drought, in look-back fashion) that is shown in Figure 2a (AD 800 to 1400) suggests the presence of cycles, of length between a century and 50 years. The suggestion is readily tested, using standard techniques in converting a time series into a “spectrum;” that is, a graph showing the relative importance of periods contained in the series. When doing this with the series shown in Figure 2a, we find that it is dominated by cycles with periods of 67 years and 30.4 years (Figure 3). The origin of these cycles is obscure; they may involve beating between competing ocean oscillations, or similarly complicated means of cycle generation, including interference between solar and lunar (that is, tidal) cycles (as suggested in Cook et al., 1997, for bi-decadal drought cycles; see the peak near –1.3 in Figure 3.).

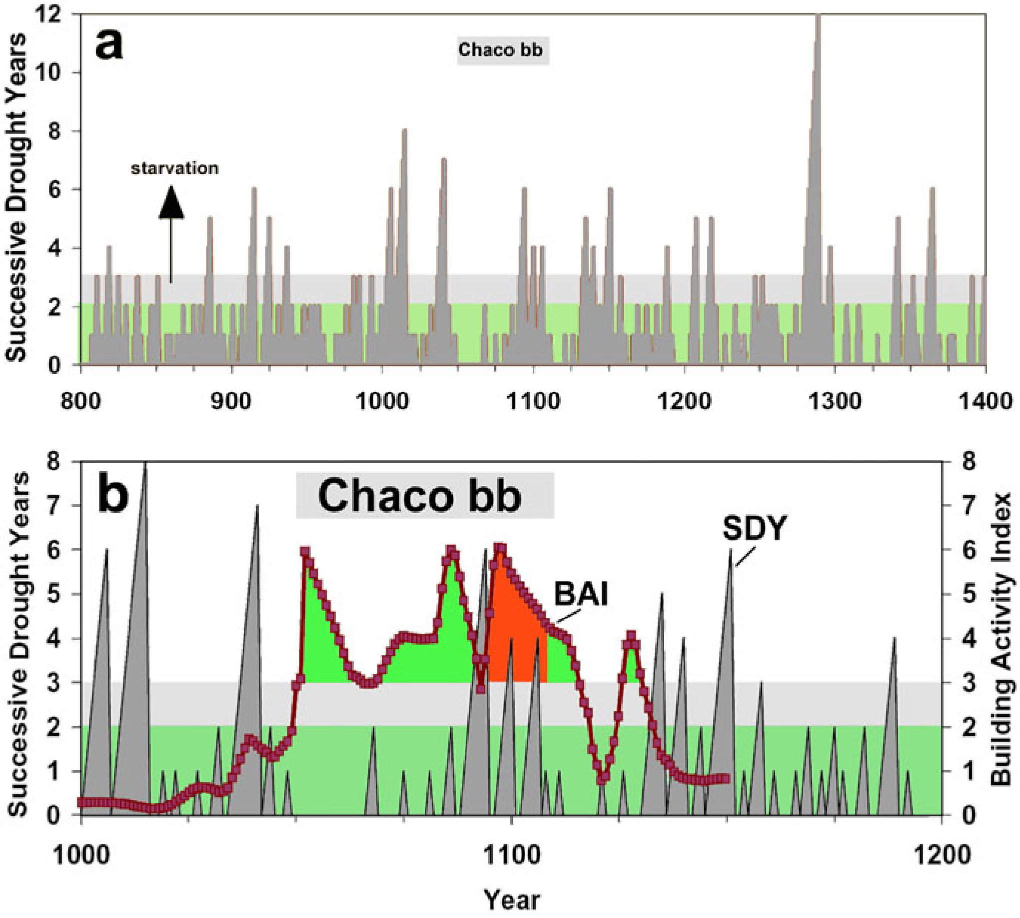

Figure 2. Comparison of the drought narrative of northwestern New Mexico with the building boom in Chaco Canyon. (**a**) Dark gray spikes: successive drought years, ranging from 1 to 12 years (maximum at end of 13th century), with position of boom time (Chaco bb). Drought is defined as PDSI ≤ -1. Danger of starvation sets in when a drought run exceeds 2 years. (**b**) Close-up of boom time (peaking from 1050 to 1110). SDY, successive drought years; BAI, building activity index, based on labor hours in Lekson et al. (2006). Green zone: harvests are satisfactory; red zone: building activity is out of phase with drought. Gray spikes show drought runs (as in upper panel).

Interestingly, among the cycles less than 15 years long ("multiannual cycles" in Figure 3), a period near 11 years is dominant. Because solar activity has a quasi-11-year cycle, this coincidence suggests that drought cycles in Chaco Canyon do reflect solar activity to some degree, as first suspected by Andrew Ellicot Douglass, the astronomer who pioneered tree-ring studies.

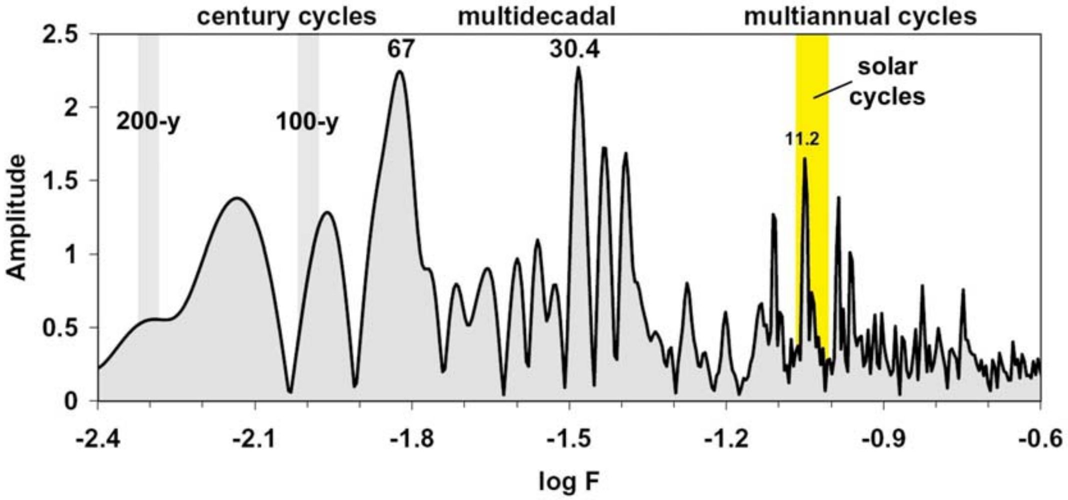

Figure 3. Spectrum of the drought run series shown in Figure 2a. The two dominant cycles have periods of 67 years and 30.4 years. The sharply defined cycle at 11.2 years (which is dominant within the band of multiannual periods) is within the band of solar cycle activity.

Remarkably, within the spectrum of drought runs there is no evidence for a century-long cycle (what is seen near log F = –2 is closer to 90 years). Neither is there evidence for a 200-year cycle (log F = -2.3) (as might be expected, following Schimmelmann et al., 2003, and Rapopov et al., 2008). What is seen is a broad cycle peaking in the range 133 to 137. Of course, it should be kept in mind that the record is in fact too short to exclude the presence of cycles of a length of 200 years or longer.

[Note regarding method in constructing Figure 3. The spectrum is based on the drought run series shown in Figure 2a, based on the number of successive drought years (years with PDSI values of –1 or less). The spectrum was calculated in two steps, as follows: (1) The input series was converted to an autocorrelation series, by sliding an exact copy along the original, starting at one end and ending at the other. The correlation coefficients were weighted with the overlap (unity for 100% overlap), thus tapering the resulting autocorrelation series. (2) Fourier analysis was then applied to the tapered autocorrelation series, starting with a period of length of the series, and continuing with periods each one percent shorter than the previous one. This differs from the classic stepwise analysis, for which successive periods are defined in terms of division by [n+1]. The procedure here adopted does not produce a reversible listing of cosine and sine values (as does the classic Fourier decomposition) but does result in equal resolution between neighboring bins for power within the spectrum on a log scale. By plotting log F as x-axis, the distance between lines describes the factors by which lines differ (which is deemed more instructive than the usual habit of plotting along a 1/n axis). Intervals shown on the x-axis correspond to a factor of two.]

## On Shifts in Climate History

The interpretation of the climate record in the context of the cultural history of Chaco Canyon (Figure 2) is clearly fraught with difficulties. But regardless of how one wishes to proceed in this matter, the data are readily available in a fashion unprecedented in archaeological study anywhere else. This is so because of the dedicated work at the Laboratory for Tree-Ring Research in Tucson and other tree-ring laboratories elsewhere in the U.S. (Hughes and Funkhouser, 1998; Stahle et al., 2000; Cook et al., 2004; Meko and Woodhouse, 2005; Salzer and Kipfmueller, 2005; Meko et al., 2007). As a result of these labors, we can now confidently plot the course of precipitation and harvest success for Chaco time, and link these items to the various cultural phases commonly listed in the archaeological literature (Figure 4).

When this is done, it becomes possible to test the idea that the boundaries between such cultural phases reflect events of severe drought or else marked shifts in climate (as seems reasonable). In addition, we can (in principle) check the concept that differences in precipitation between adjacent regions might have encouraged back-and-forth migration (or in any case influenced trade and cultural hegemony). When comparing the precipitation history of northwestern New Mexico (i.e., Chaco Canyon) with that of southwestern Colorado (i.e., Mesa Verde), we note that the southern area was favored during much of the time, in the time span before 1090, but not after that date (Figure 4b). A shift in the amount of precipitation, just before 1100, would surely support the notion that center activities were moved northward around that time (as emphasized by Lekson, 1999). In addition, the decision to move would have been seen as wise, and favored by the spirits.

## On the Abandonment of Chaco Canyon

The change in overall precipitation patterns that set in around 1090 (Figure 4b) has to be considered when contemplating the question why the Great Center (of ritual activity) was moved northward to Salmon and Aztec (near today’s Farmington) *before* the great post-Chaco drought set in at 1130. It appears that the great drought of 1130 to 1180 (mostly in the “McElmo” phase) did not necessarily close down the Chaco Great Center, but may have simply ensured that the Center could not recover from its earlier abandonment. Also, the McElmo-phase drought may have effectively terminated the Aztec Great Center (where leaders lost credibility, being unable to produce rain). (The name McElmo refers to an area just north of Mesa Verde, where distinct types of pottery were being produced, and which found their way into Chaco Canyon; see section on ceramics.)

Armed with the various simple concepts regarding the meaning of tree-ring data for the needs of farmers (Figure 2), let us return to a question of central importance: Why was Chaco Canyon abandoned around A.D. 1115, rather than with the onset of the great drought of the McElmo phase (which began around 1130)?

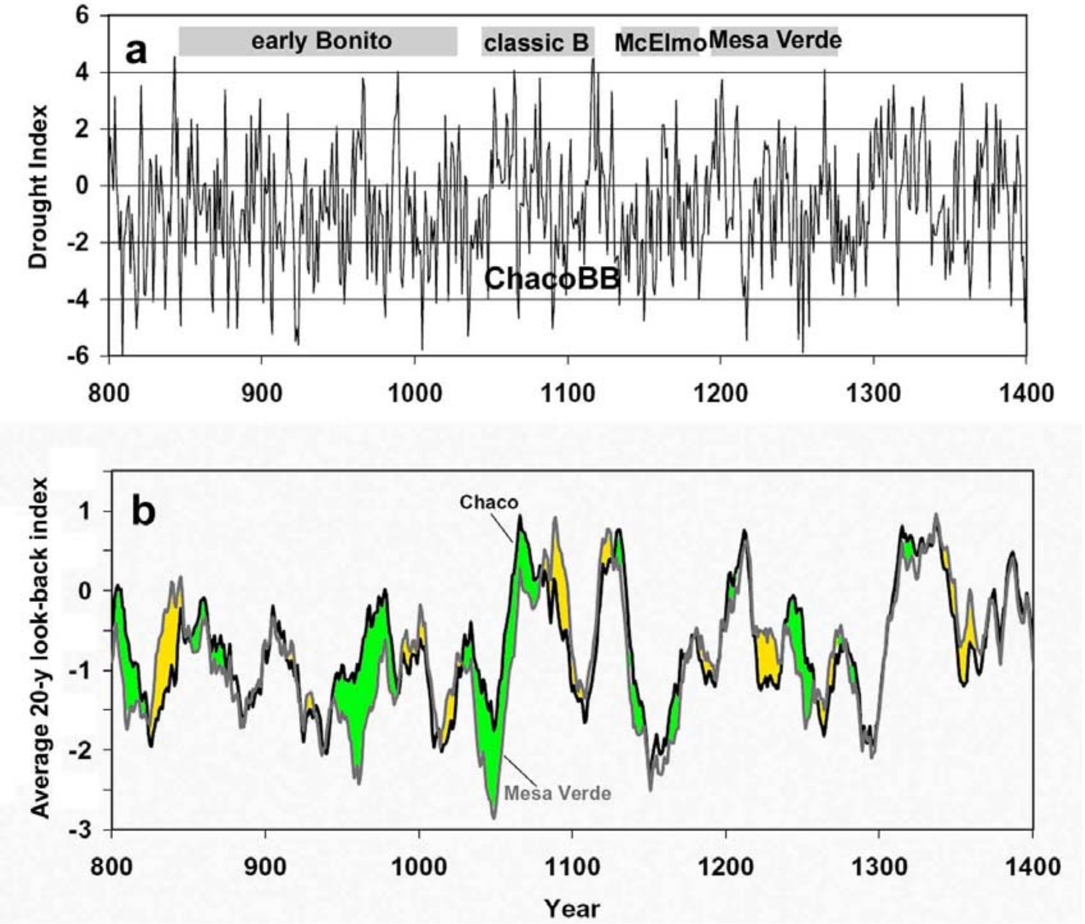

Figure 4. Drought narratives in a cultural context. (**a**) Year-by-year record of rainfall ("drought index") compared with archaeologically defined "phases" of cultural development in Chaco Canyon. Phases ("early Bonito", etc.) based on ceramics. "Chaco BB", Chaco Building Boom. (**b**) Comparison of 20-year average index values for northwestern New Mexico ("Chaco") and southwestern Colorado ("Mesa Verde"), plotted in "look-back" fashion. Green: Chaco wetter than Mesa Verde; yellow: Chaco drier than Mesa Verde. Climate data from NOAA (Cook et al., 2004).

In addition to a shift in climate, we have to consider the importance of trust in leadership, which is always in jeopardy when harvests fail. (The modern version of this situation, focused on the economy, is presumably familiar to the reader.) Also, we note the fact that building activity continued almost unabated despite serious drought in the late stage of the Chaco building boom (Figure 2b), suggesting that the leadership made decisions guided by wishful thinking. (Again, modern analogs are not difficult to envision.)

The fact remains, regardless of one's interpretations of the interactions between decision-making and reality, that the building activity index was largely decoupled from the drought index (that is, from food supply) after 1090 (Figure 2b, red field). It is reasonable to assume, therefore, that the building boom, set in motion at a time of good harvests (Figure 2b, first peak of green field), could not be stopped when environmental conditions deteriorated (after 1090). The resulting social stress level may be estimated by adding drought intensity (that is, food shortage) to intensity of building activity (that is, the need for labor and food). The overall stress level (indicated by the broad reddish band on top of the solid red line in Figure 5) is seen to have risen from 1050 to 1100, when it reached a maximum. At that point, there was a decision to move the Great Center to Aztec, a move that was carried out around 1100 (Lekson, 1999, pp. 108-112).

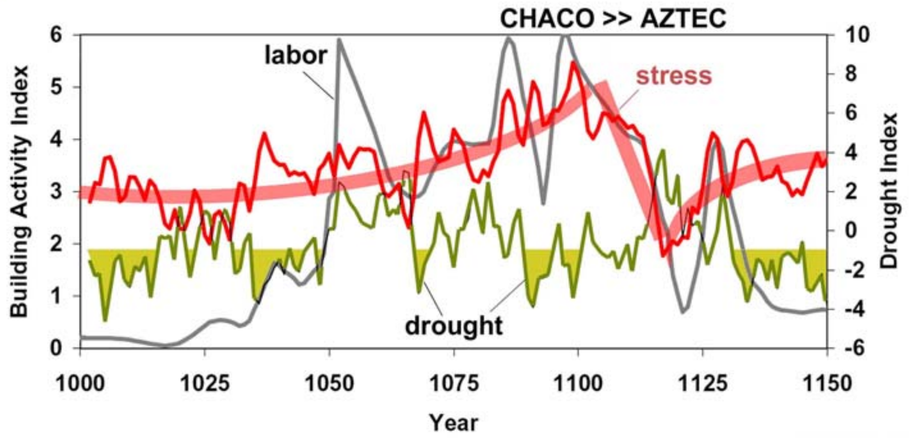

Figure 5. Reconstructed social stress level in Chaco Canyon resulting from adding building activity and inferred food shortage. Index scales are arbitrary. The inferred food supply is a function of the drought narrative; it is plotted as "drought index" (gray line at bottom, axis to right). Times of food shortage are indicated in yellow and labeled "drought." The Building Activity Index (gray line on top) is based on a reconstruction by S. H. Lekson; it reflects the building boom between 1050 and 1110 (see Figure 2). The stress level (red line) results from summing the two; the broad reddish line is a generalization of the red line).

After the move, Chaco lost its prominence. To quote the archaeologist Stephen Lekson who emphasized the importance of the Great Move (1999, p. 112): "Whatever Chaco had been, it was something else – something *less* – after 1125. Aztec, from 1100 to 1275, was huge. Chaco and Aztec were sequential, not contemporary.” Of course, the leaders’ decision to move had to be made several years before the actual move; that is, it was made in the 1090s.

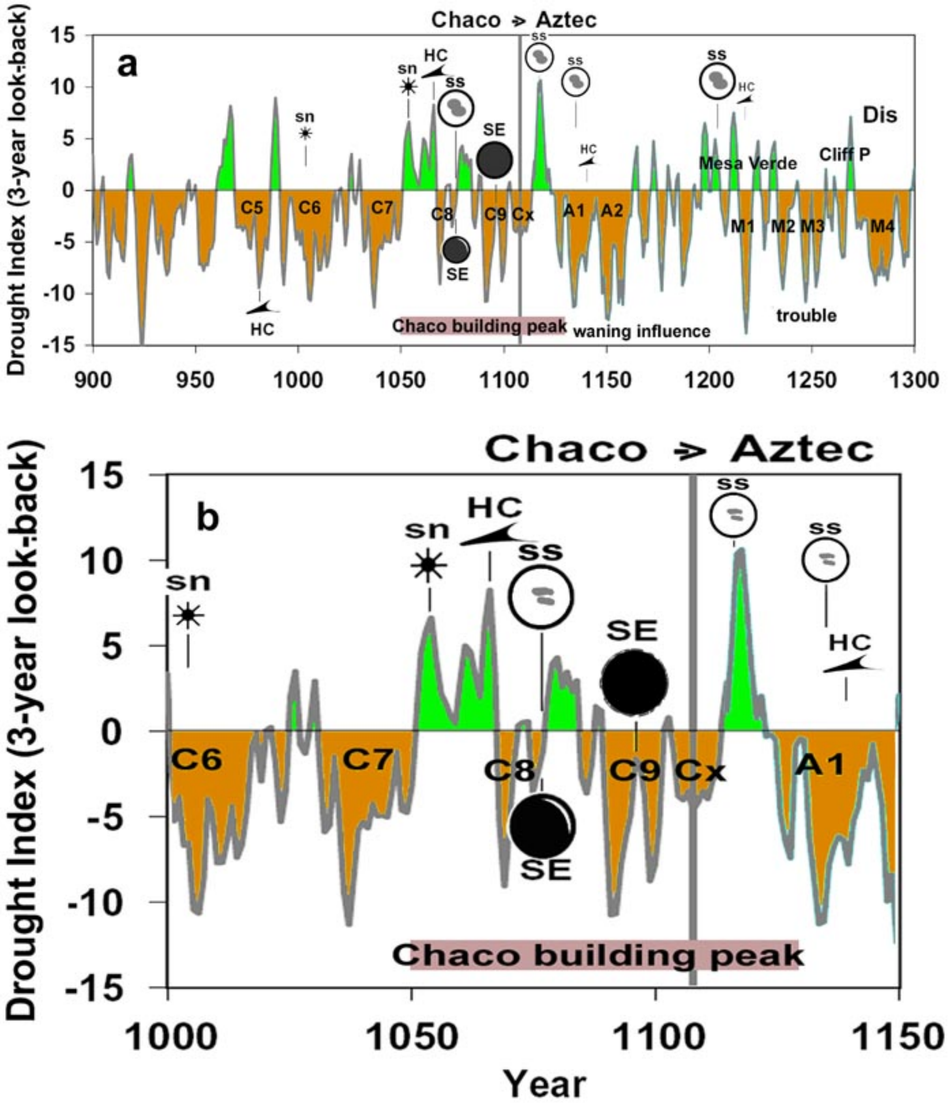

Figure 6. History of celestial phenomena visible in Chaco Canyon, A.D. 900 to 1300, in the framework of drought history. (**a**) Entire period. (**b**) Detail: 1000 to 1150. Symbols in order of appearance in (**a**): HC, Halley’s comet; sn, supernova (the second in 1054); HC, comet prominent; SE, partial eclipse; ss, large sunspots and red aurora; SE, total eclipse; ss, sunspots and auroras, prominent near 1200. Green and brown fields: relatively wet (good) and dry (bad) times. Drought periods are labeled for reference in the text (C6, C7, C8, C9, Cx, A1, etc.); “waning influence” refers to Chaco Center traditions; “trouble” refers to violence. Sources of astronomical data: Malville and Putnam (1993) and various astronomical handbooks.

It appears likely that the timing of that decision owed something to the history of astronomic events, notably a total eclipse in 1097 (Figure 6). At the time, presumably, a total eclipse was understood as a message from the spirit world; one that pressed a warning, making it necessary to think hard about business-as-usual. Given the high prevailing stress level, the solution (to move north toward flowing water with the opportunity for irrigated farming) may have readily offered itself to the leaders in charge.

How reliable is this conclusion that drought alone did not result in the termination of the Chaco Great Center? Quite good. Archaeological research (that is, the reconstruction of the building activity from the tree-ring dates of beams and logs within the buildings) suggests that major construction terminated in the 1120s. As Lekson et al. (2006, p. 100) point out: “We have devoted far more time and energy to Chaco’s origins than its end. A big drought from 1130 to 1180 pretty much explains everything, yes? Things were probably more complicated than that. The shift from Chaco to Salmon and Aztec predates that final drought by decades …” Evidently, Lekson et al. (2006) believe that it would be a serious mistake to focus solely on climate change as the ultimate driver of cultural history at the expense of considerations of internal dynamics. It would seem that their attitude is eminently reasonable. People react to climate change according to their worldview, and this reaction informs their decisions. Whether such decisions address the problem in the most rational manner is another matter, and fundamentally beside the point.

Fortunately, there is no necessity to adopt an attitude of externally forced response *versus* internally mediated reaction to change. Instead, there is room for invoking both climate change and societal dynamics concurrently, as illustrated in Figure 5. The suggestion is that building activity started in response to greatly improved conditions and that it subsequently developed a dynamics of its own, becoming largely detached from the reality of the underlying environmental economics. Thus, there is certainly room for internal dynamics.

Using the concept of dual stress (natural and social), we can guess at the historical evolution of social tensions. Such tensions, in essence, would parallel the sum of water shortage and building indices, properly weighted. The weights are unknown. For the purpose of stress reconstruction (Figure 5), I have given equal weight to the two factors related to farming and to use of labor. Different weighting (and including human impact on the environment) produces similar conclusions (albeit with different arbitrary index values).

The exercise suggests that stress level (red line in Figure 5) decreased during the earliest phase of building due to increased precipitation, but increased steadily after that, till it reached an unacceptable threshold. Building ceased and the center activities moved to the north (to Salmon and Aztec). In these more northerly sites, where impressive Great House complexes were erected beginning with the 12th century, there was flowing water (at Salmon, the San

Juan River; at Aztec, the Animas River). The drought that followed the Great Move North prevented recovery in Chaco Canyon, and the Move itself made it unlikely, even though stress levels had dropped sufficiently for additional building to occur.

The stress-level exercise illustrated in Figure 5 is highly hypothetical, of course. But it does support the possibility that there were factors at work other than the drought itself. The memories of a society tend to be generational (the Elders claiming that what they did when younger worked well). However, when drought cycles approach generational cycles (say, three decades; Figure 3), there is then an opportunity for the advice of the Elders being quite out of phase with the changing reality of the situation. What is being remembered as working in the past becomes precisely the wrong expectation. That is when the specter of “collapse” arises. It would be wrong to attribute such calamity to a societal “choice” between different options. More realistically, it is a failure of traditional coping mechanisms.

The ultimate mechanism to cope, in the Chacoan world, was to move away from a place that provided insufficient support, and to migrate to places (preferably settled by kinfolk or fellow clan members) where such support was still accessible. The topic of large-scale migration dominates discussions regarding the end of the Chacoan period, at the end of the 13th century. At that time, pervasive drought combined with warfare and strife to encourage large-scale abandonment of the vast ancient homelands surrounding Chaco Canyon.

## On the Gradients of Climate Change in the Chaco Region

Regardless of the validity of the speculations about stress levels proposed in Figure 5, the one thing we can be sure of is that the availability of water was central to human existence and activities in the drylands of the Southwest, all through history. Another thing we can be reasonably sure of is that precipitation in Chaco Canyon was intimately linked to climate change in the surrounding regions and indeed in much of North America (Woodhouse and Overpeck, 1998). In fact the precipitation history in Chaco Canyon was linked even to changes far away on the northern hemisphere (e.g., Cayan et al., 1998). Thus, we should not be surprised if strange parallelisms arise in the rates of change of historical narratives between unrelated and faraway cultures.

Of course, this large-scale climatic connectedness (which is a result of the grand hemispheric patterns of air pressures and resulting wind fields) is not the only thing that matters when discussing the climate history of Chaco Canyon. There are strictly local effects as well; effects that have to do with the location of seeps and springs, and the opportunities for damming seasonal flow in tributary canyons, as aids to irrigation. In fact, there is evidence that during the early stages in the settlement of Chaco Canyon there was a natural dam across the wash, in the west, a sand dune that created an area of wetlands. A breaching of that dam (around A.D. 900) obviously had adverse consequences, regarding groundwater level and other water issues, problems that were alleviated a century later by building an artificial barrier at the site (Force et al., 2002; Judge in Noble, 2004). Presumably, that dam too eventually was breached in a great flood, and the timing of such breaching would have been crucially important for understanding the history of settlements in Chaco Canyon. Absent surviving wooden elements of a broken dam, any such event is very difficult to reconstruct, although remnant lake sediments or similar deposits might also provide some clues.

Restricting our focus to the more general climate developments in northwestern New Mexico and the Four Corners region, we might reasonably ask whether there were differences in the rainfall narratives of neighboring population centers, differences that would have conceivably influenced decisions about directions of migration whenever such migration occurred. It turns out, when studying the issue, that the narratives of precipitation are fairly similar for the adjacent areas in northwestern New Mexico, eastern Arizona, southeastern Utah, and southwestern Colorado. However, there are indeed noticeable differences between the histories that might be of interest in the context of migration or of shifts of economic power, or both. For example, it is just at the time (a few years before 1100) when the decision was made to move the Great Center from Chaco to Aztec that differences in rainfall of the northern San Juan Basin and the central Basin changed in favor of northern regions (see Figure 4b, green switching to yellow).

We do not know whether that change in rainfall patterns in favor of northern areas was a crucial datum in the making of the decision to move out of Chaco Canyon to Salmon and Aztec. We do know, based on decades of archaeological research, that there was much exchange between Chaco proper and the regions to the north; that is, with Aztec, Mesa Verde, and McElmo. The latter two areas provide names for phases within the Chaco period (Figure 4a).

By plotting the drought narratives as shown in Figure 4b, we obtain a guide to any differences in rainfall on a generational time scale (the scale that seems relevant in the context of motivation for migration). Such plots are readily provided for neighbors not just to the north, but also to the east, to the south, and to the west (Figure 7). Changes in gradient are strongest between Chaco and the northern neighbors, presumably favoring motivations for migration in a north-south direction, north of Chaco Canyon. Other large changes are with the western neighbors, but only in the early part of the Chaco period. Apparently, Chaco would have looked very attractive to people to the west for several decades, starting around 950 (Figure 7, bottom panel).

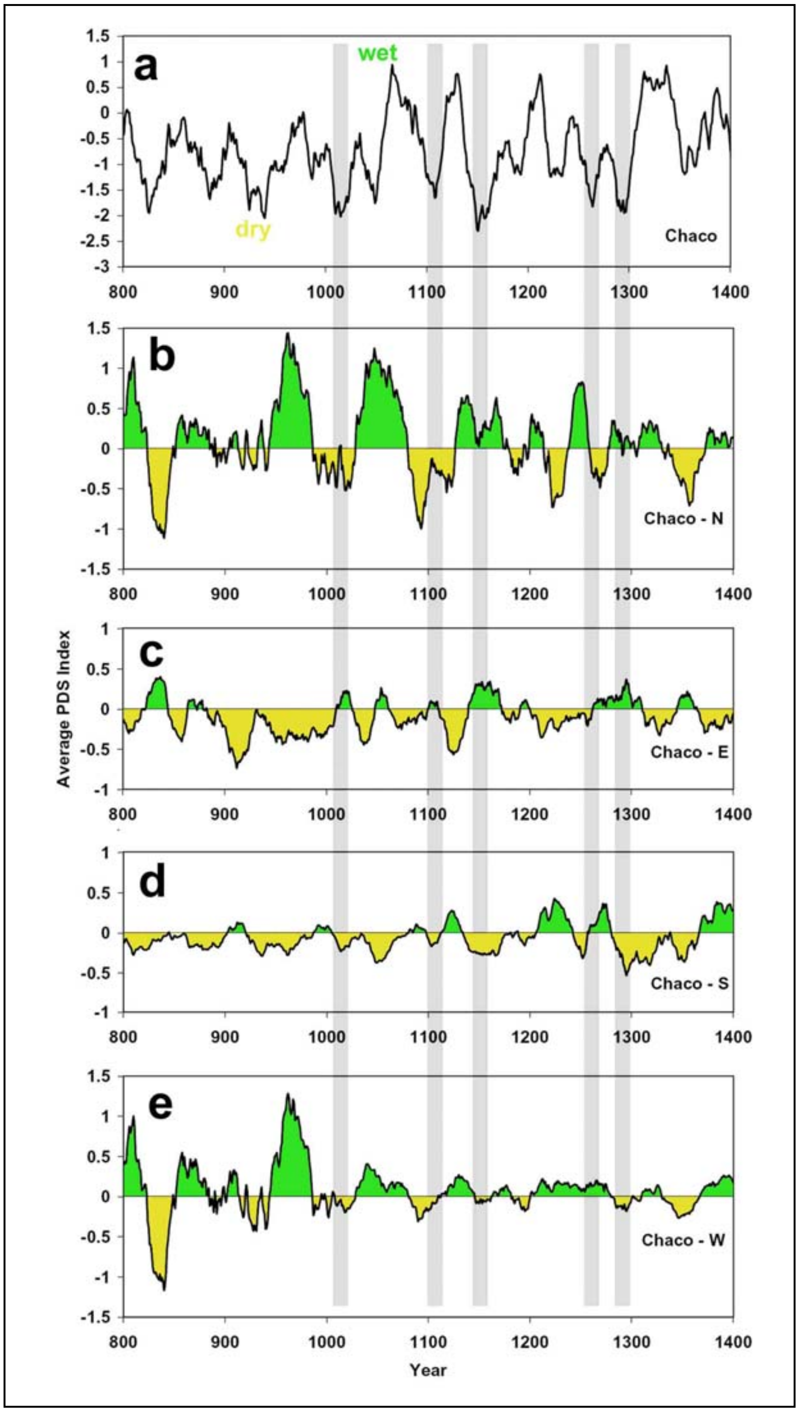

Figure 7. Rainfall in NW New Mexico (**a**) and differences in rainfall between Chaco and neighbors to the north (**b**), to the east (**c**), to the south (**d**) and to the west (**e**). Positive index (green): Chaco had more rain than the neighboring area. Otherwise: yellow. Shaded: times of drought (top panel). Data from NOAA data bank. Site of "Chaco": Point 119, northwestern New Mexico.] "PDS," Palmer Drought Severity, a measure of rainfall. The period of averaging is 20 years.

Gradients with eastern and southern neighbors are weak throughout the time interval in question. With regard to the time of dispersion late in the 13th century, there is no indication for incentives for eastward or southward migration from the drought index record. Thus, migrations east and south were based on other factors, such as the knowledge of trade routes and the location of kinfolk or fellow clan members in areas favorable for farming.

As emphasized throughout this essay, drought is not the only external factor that needs to be considered when contemplating motivations for migration. Temperature (that is, the strength of winters and the changing length of growing seasons) is undoubtedly important as well. A host of non-climate factors of a sociological nature must be considered also. We cannot be sure what such factors were and whether they involved significant violence (e.g., raids by neighbors or by nomadic tribes) but we can be quite sure that any sociological factors will be much more difficult to reconstruct and quantify than those related to climate. Many, perhaps most, of the sociological factors of change in Chaco Canyon were related to the ritual aspects of the culture, including a strong link to the spiritual forces in heaven and inside the earth (Malville and Putnam, 1993; Sofaer, 2008).

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