Chapter

# Climate Stability and the Origin of Agriculture

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## Abstract

Although modern man had developed long before the migration from Africa began ~ 55,000 years ago, no agricultural societies developed until about ~ 10,000 years ago. But in the next 5000 years, agricultures developed in several unrelated regions of the world. It was not a chance occurrence that new agricultures independently appeared in the same 5000 years. The question is what inhibited agriculture worldwide for 44,000 years and what changed ~ 10,000 years ago? We suggest that a major factor influencing the development of agricultural societies was *climate stability*. From the experience of several independent cultures, we estimate that the development of agriculture needed about 2000 years of climate free from significant climate variations on time scales of a few centuries.

**Keywords:** origin of agriculture, climate stability, paleoclimate data, younger Dryas

## 1. Introduction

One of the most important events in human history was the establishment of agriculturally based societies, that is, societies with fully developed agriculture. Modern human beings (*Homo sapiens sapiens*, Hss) had developed in East Africa by about 195,000 ybp (years before present) [1]. [Note that the dates throughout the chapter are the calibrated by $^{14}C$ years before 1950.] However, no agriculture appeared during the first 100,000 years after the development of modern man [2]. Even after migrations out of Africa began about 55,000 years ago, no agricultural societies developed during the next 44,000 years. Although before 20,000 ybp, the cave walls in the south of France were being painted so beautifully that we can understand the art [3], there was no agriculture. But then around 10,000 ybp agricultural societies were independently established in many regions during the same few thousand years.

The relationship between climate and the development of agriculture has been widely discussed for many years by both the anthropology and climate scientific communities. Many competing views have been developed primarily based on studies of the archeology of the Near East (for a review see [4]). For example, it had been suggested [5] that agriculture appeared as a result of technological advances that gradually increased man's ability to exploit the environment after man had occupied vast areas of the Earth. Certain conditions were found necessary for the development of agriculture [4] such as the technology for collection, processing, and storage of agricultural products and the presence of potential domesticates in the local environment. Examples included development of improved hunting technology by one group and perhaps experimentation with agriculture by another. The increased efficiency of hunting failed as a survival technique, but the experimenting with agriculture may have had more success, and when the stresses of the YD were removed, agricultural development was accelerated. Bar-Yosef [6] emphasized that the initiating event in this view was a response to the environmental stress during the YD. This same idea has been applied to the development of agriculture in China [7].

Here, we discuss a different explanation for the origin and development of agriculture. We examine the proposition that the agricultural development depended on the stability of the climate. It was the decrease of climate variability at the Pleistocene/Holocene boundary (i.e., at the termination of the YD) that allowed the establishment of societies fully based on agriculture [8, 9]. Paleoclimate data from Greenland ice cores and ocean climate proxies show that the last glacial climates were extremely unfavorable for development of agriculture-dry, low in atmospheric $CO_2$ [8], and extremely unfavorable for development of agriculture on short time scales. We hypothesize that agriculture was impossible under the last glacial conditions. The quite favorable for agriculture climate conditions appeared in the Holocene. Note that Rehfeld et al. [10] argued that although glacial-interglacial changes in variability have been quantified for Greenland, a global view may remain elusive. However, the Greenland ice core records faithfully reflect the timing and relative magnitudes of climate variability before and after the start of Holocene and, we believe, still can be used for the study of culture development such as the origin of agriculture.

The current consensus is that agriculture arose independently in several regions of the world located in Asia, South America, Europe, and the Fertile Crescent (an area near the Tigris and Euphrates rivers that spans modern-day Iraq and Syria) after the termination of the YD [11–13]. A probability that agriculture would appear by chance in these independent regions during the same 5000-year period after man left Africa is very small [9]. The first factor is the time when human evolution had progressed to the point where mankind was essentially the same as we are now, that is, the point at which Hss almost certainly had the mental and physical capabilities required for agriculture. A conservative time estimate may be made by considering the Aurignacian people who drew pictures of horses on the walls of the Chauvet cave in Southern France 30,000 ybp (see **Figure 1**) [2]. These ancestors of modern Europeans [14] not only produced art but also were apparently highly organized socially. Since then,there have been roughly six periods of 5000 years each, it is certain that the development of so many independent agricultures in the same 5000-year period did not occur by chance. There must have been something special about that period of time. It seems implausible that it was the release of the stress of the YD and the sudden increase in global mean temperature because during the last 40,000 years, there have been nine sudden increases in temperature, in so-called Dansgaard-Oeschger (DO) events, in addition to the YD termination [15–17], but agriculture developed only after the most recent one, that is, after the transition to the Holocene.

The question is what prevented agriculture for more than 40,000 years after the exodus of man from Africa and what changed after YD about 11,000 years ago? We propose that until the end of the last Ice Age, frequent climate change inhibited the transition from the hunter-gatherer way of life to an agricultural way of life, which became possible due to more stable climate conditions after the end of the YD [8, 9]. We will first give four examples of plant domestication that took place early in that transition (see the next section). Then, we estimate the time required for the transition to be completed based on the information on the most extensively investigated case, the Levant. The paleoclimate data lead us to suggest that transition from a hunter-gatherer-based society to the agriculture-based society required an extended period of the climate stability on characteristic times of centuries. The Greenland ice core sodium ion and oxygen isotope climate proxy records for the wind and temperature from 50,000 ybp until the present show that the climate

**Figure 1.**
*Chauvet cave (35,000–22,000 ybp). Panel of the four horses [3].*

variability changed when the Younger Dryas cold period ceased at 11,570 ± 200 ybp [18] and the magnitude of the climate variations on time scales relevant to the development of agriculture decreased markedly. The same conclusion is supported by an analysis of a lower latitude climate proxy data set record taken from the Cariaco sea sediment.

Richerson et al. [8] pointed out to another factor the plant productivity limited by lower atmospheric CO2 during the last glacial that may prevented the development of agriculture, because the CO2 content of the atmosphere was only about 190 ppm during the last glacial, compared to about 250 ppm at the beginning of the Holocene (c.f. http://cdiac.essdive.lbl.gov/trends/co2/ice_core_co2.html).

## 2. First steps toward agricultural societies

Let us briefly describe the current state of knowledge about the earliest domestication of plants focusing on the four best-studied examples of agricultural societies that had developed independently: the Levant (Middle East), China, MesoAmerica, and the Andes-Amazon area of America.

## 3. The Levant

The first definite evidence of cultivated cereals in the Levant has been dated to about 10,600–10,000 ybp [19, 20]. Wild cereals were extensively gathered even before domestication took place; their remains are found at various settlement sites. In order to properly date the time of domestication, a distinct marker is needed to distinguish domesticated plants from their wild progenitors. In the case of cereals, such as the wheat, domesticated in the Levant, there are such distinguishing characteristics [19]. For example, in the wild cereals, the seeds ripen over a period of time and leave stems when ripe. In domesticated cereals, all seeds ripen at the same time and are retained on the stems until harvested, which is necessary if a farmer wants to have control of the crop. For dating the onset of agriculture, grain has the advantage that the plant material is not easily destroyed; both wild and domesticated remains of wheat have been recovered from ancient sites in the Levant. The wild grain inadvertently goes via genetic changes required for the domestication. The estimated time required for these changes is of the order of a few centuries [19]. Hence, the climate must remain stable on time scales of a few centuries for even the first step in the development of an agricultural society to take place.

## 4. China

The main plant in this case is rice. Various types of wild and domesticated rice have a wide distribution in Asia and beyond. Domesticated rice is descended from the wild plant *Oryza rufipogon*, and at least two major types of cultivated rice, *Oryza sativa Japonica* and *Oryza sativa indica*, are currently major crops in Asia, although it is still unknown whether or not these crops are due to one or separate domestications (c.f. [21]). Many authors suggested the sites of domestication in Asia (see [22] and references there in). The best-studied and oldest rice known is from the middle Yangtze Basin from the Diaotonghuan Cave in that region [20]. The time to be assigned to the domestication of the rice is also uncertain and depends on the definition of “domestication.” The presence of the double-peaked glume is a good characteristic distinguishing between domesticated and wild rice [20]. Wild rice grew in the Yangtze Basin and was harvested by local people by ~12,000 ybp, that is, before the climate emergence from the Younger Dryas. Domesticated rice is dated to 9000–10,000 ybp. If this latter date is correct, then the remains found in the Diaotonghuan Cave site were the earliest domesticated rice remains found to date. This time agrees with the termination of the YD (see [22] and references therein). As in the case of the Levant, although the wild cereal grain was clearly being utilized before the sudden end of the YD, the evidence for the domesticated counterpart seems to appear shortly after the YD ended.

## 5. MesoAmerica

Three major crops were domesticated in the early history of agriculture in MesoAmerica: the maize, the common bean, and the squash. The cultivation of maize was widespread, and it exhibits a very large morphological and genetic diversity. Maize samples were studied from its entire pre-Columbian range, which is extending from eastern Canada to northern Chile [23]. From the genetic makeup of these samples, Matsuoka et al. [23] constructed a map showing the relation of the maize types in North and South America and concluded that all of the many types of maize were derived from a single domestication of the wild grass *Teosinte* in the highlands of Mexico about 9000 years ago. Their molecular data are consistent with the date of 6250 ybp for the oldest known fossil maize [13] and with archeological estimates that crop domestication in Mexico did not precede 10,000 ybp. There is some evidence that squash (*Cucurbita pepo*) was also domesticated in the Mexican highlands between 10,000 and 8000 ybp [24].

## 6. Andean-Amazon region of America

A recent study of domestication of plants in the Andean-Amazon region indicates that squash and gourds were domesticated there very early [25] and

| Region | Domesticated plant | Dates of the oldest remains |
|---|---|---|
| Levant | Wheat (emmer and einkorn) | 10,600–10,000 ybp |
| China | Rice (*Oryza sativa japonica*) | 10,000–9000 ybp |
| MesoAmerica | Maize | ~ 9000 ybp |
| Andean-Amazonian | *Cucurbita pepo*<br>*Cucurbita* | 9000–7000 ybp<br>10,000–9000 ybp |

**Table 1.**
*Early domesticated plants.*

independently from their domestication in Mexico. *Phytoliths* recovered from two sites in southwest Ecuador have been dated to 10,100–9300 ybp [25]. As in the cases of wheat, rice, and maize, there is evidence that the wild precursors were exploited earlier. The highly cultured societies, which were present when the Europeans arrived, were strongly dependent on the cultivation of the potato in the Andean highlands. The research, which indicates that Peru was the only site of potato domestication [26], gives no reliable time estimate for the development of that crop.

**Table 1** gives the cited regions, the domesticated plants, and the time known for domestication.

**Table 1** indicates that the initial domestications in the four regions took place in the same period. The development of independent agricultures in these regions must have been due to something that occurred in each of the regions at the same time, which we identify with the onset of relative stability in the climate. Climate instability can be expected to strongly inhibit agriculture since agricultural societies are dependent on a relatively few species compared to simple foraging societies. For example, six species of large prey animals have been reported in the Levant before the termination of the YD ([27] but only sheep and goats are domesticates). As far as plants are concerned, each plant, whether domestic or wild, thrives best in a specific growing environment. If the environment changes so that it becomes too far from the plant's required conditions, the crop fails. For an agricultural society, this can be catastrophic because of the limited number of plants utilized and the permanence of the settlement site. It is interesting to note that the plants domesticated differed from region to region and the climates of the four regions differed widely. This supports a hypothesis that it was not the specific values of the local climate parameters (annual rainfall or mean temperature) that were of foremost importance in the inhibition of agriculture but the stability of these parameters.

## 7. Time required for establishing an agricultural society: the Levant

The regions listed in **Table 1** went on to complete the establishment of the four independent agricultural societies [28] are compared in **Table 2**. Some of the main changes to be accomplished to become an established agricultural society are listed in **Table 3**.

The independence of the four agricultures is borne out by the diversity of species involved in each case as shown in column 2. Each area developed its own distinct constellation of domesticated species. The last column gives the date at which the complex agriculture-based society appears to have been well established and shows that they were all established within the same 5-millennium time period.

Each of the changes indicated in **Tables 2** and **3** has its own problems, and the order in which they are accomplished may differ from place to place, but all of them must be carried out to complete the development of an agricultural way of life. In

| Location | Species | Development accomplished |
|---|---|---|
| Levant | Wheat, barley, chickpeas, flax, sheep, goats | ~ 9000 ybp |
| China | Rice, millet, pigs, silkworms | by 9000 ybp |
| Mesoamerica | Corn, beans, squash, turkey | by 5500 ybp |
| Andean-Amazonian | Potato, manioc, guinea pig, llama | by 5500 ybp |

**Table 2.**
*Four agricultural societies developed independently.*

| Item | Hunter-gatherers | Agricultural society |
|---|---|---|
| Food plants | Wild grains, fruit, tubers | Domesticated counterparts |
| Animals | Many species of wild prey | A few domesticated species |
| Clothing | Wild animals, vegetable fibers | Domesticated counterparts |
| Tools | Projectiles and traps | Farming tools, cereal preparation, food storage techniques |
| Housing | Temporary, easy to erect | Permanent structures |
| Settlement patterns | Small bands | Villages, towns |

**Table 3.**
*Main steps in transition from hunter-gatherer to agricultural societies.*

addition to the genetic changes required to produce a domesticated plant or animal, fundamental changes in technology and social structure are needed. Although the time to domesticate one particular plant may be of the order of a few centuries [19], the total time it takes to change from a hunter-gatherer society to an agricultural one is much longer. Here, we estimate this time scale for the best-studied case, the Middle East, using archeological investigations and studies of wild progenitors of cultivated plants [19]. There is also information on animal domestication that comes from bones found in archeological sites [4, 29]; housing, tool development, and settlement patterns are also available from archeological studies [4, 20]. However, much of the material from earlier archeological studies, while provocative, is of limited use because reliable dating methods are still not perfect.

The earliest agricultural society was developed in the southern Levant, an area that includes southern Syria and Lebanon, Israel, Palestine, Jordan, and the Sinai Peninsula during the cultural-historical time known as the Pre-Pottery Neolithic (PPN) that spanned the years between about 11,700 and 8250 ybp [6]. In the well-studied Israeli section of the Levant, much of the area was an open grassland with wild cereals and pistachio trees [6]. Local Levant climate history has been derived from speleothems in Israeli caves (at 32°N) [29] that have recorded a proxy signal of the Eastern Mediterranean region. An analysis of the data since 18,000 ybp shows several markedly different climates. The most interesting time for our purposes is the ~3000-year period that has a rainfall of 675–950 mm, almost twice the present-day values, and the Dead Sea reached its maximum level. The onset of this wet episode determined within the accuracy of the time determinations corresponds to the end of the YD. After 8000 ybp, the temperature and rainfall in the Levant became more similar to the current values. The plant remains were combinations of cereals, pulses, and flax and were similar to the plants that appeared later all over the Near East. Three cereals were cultivated: emmer wheat, einkorn wheat, and barley. Cereals alone, however, do not provide all of the nutrition required by man. In the case of the Levant, the cereals were added by legumes (lentils, peas, bitter vetch, and chickpeas) [20]. Sheep and goats were also domesticated and replace gazelles, and other wild games have previously been hunted [19]. During the PPN, the size and complexity of settlements increased by a factor of 14 [20], but the earliest of the PPN sites show some cultural continuity with the preceding final phase of the preagricultural Natufian period (12,500–12,000 ybp). The agriculture was not brought to the region by an invading force due to total absence of evidence for interpersonal or intercommunity aggression or violence during the PPN.

The earliest evidence of cultivated cereals in the Levant has been dated to ~ 10,600–10,000 ybp when the remains of emmer and einkorn wheats show the telltale signs of domestication. The fact that such remains were found in several sites during this period implied that the actual beginning of wheat cultivation in this area was earlier, perhaps as early as the first part of the Pre-Pottery Neolithic (PPNA) (11,700–10,500 ybp) [6]. Kislev et al. [30] presented evidence that during this same period figs appear to have been gathered from trees grown intentionally from planted branches. The development of agriculture so soon after the termination of the YD-led Bar-Yosef et al. [6] to suggest that the first experiments in systematic cultivation may have occurred during the YD which ended abruptly ~11,750 ybp. However, they report that no remains of domesticated plants have yet been recovered from the YD itself [6]. Although there is some uncertainty in the date of the beginning of wheat farming, ~11,000$ ybp is a reasonably conservative estimate of that date.

Thus, the development of the earliest agricultural societies would be encouraged by the absence of large century-scale climate variability during a period of at least 2000 years.

## 8. When climate was stable on these time scales

Here, we discuss the variations in the Earth's climate derived from two of climate proxy records (CPR): the polar ice cores in Greenland and the sea sediments from the Cariaco Basin of the Northern coast of South America.

The best and the most discussed of these data banks is from the polar ice cores in Greenland, which contains climate memory of diverse climate variables [31]. The oxygen isotopes in snow characterize temperatures [16, 32], while the dust blown from the deserts and the sea salt blown from the ocean characterize the atmospheric wind.

The records from the Greenland Ice Sheet Project 2 (GISP2) cover the time period from 110,000 ybp to the present, although with differing sampling rates and accuracy. The variability found in these records indicates a nonlinear nature of the climate variations. For example, using a composite of the time series of the Ca, Na, Cl, $SO_4$, K, and Mg ions and a narrowband filtering technique, Mayewski et al. [31] found that between 110,000 and 11,000 years ago there was a variation with a persistent period of 1450 years but with time-varying amplitude.

To take into account the nonstationary and nonlinear character of the climate paleo records, we apply the empirical mode decomposition (EMD) techniques [33], which are especially designed for analyses of nonlinear and nonstationary time series. The EMD represents the data as the sum of a small number of empirical orthogonal modes that have time-variable amplitudes and instantaneous frequencies capturing the nonstationary spectral content of the data. This method employs empirical basis that is changing in time to adapt to the actual variability of the data so that the selection of the modes is equivalent to locally adaptive filtering of the signal. The lack of leakage from one power to another in the EMD method presents an advantage over narrowband filtering and many other techniques. A set of the EMD modes that have mean periods in the range shorter than about 300 years provides a detailed characterization of the climate variability in the frequency range relevant to the development of agriculture.

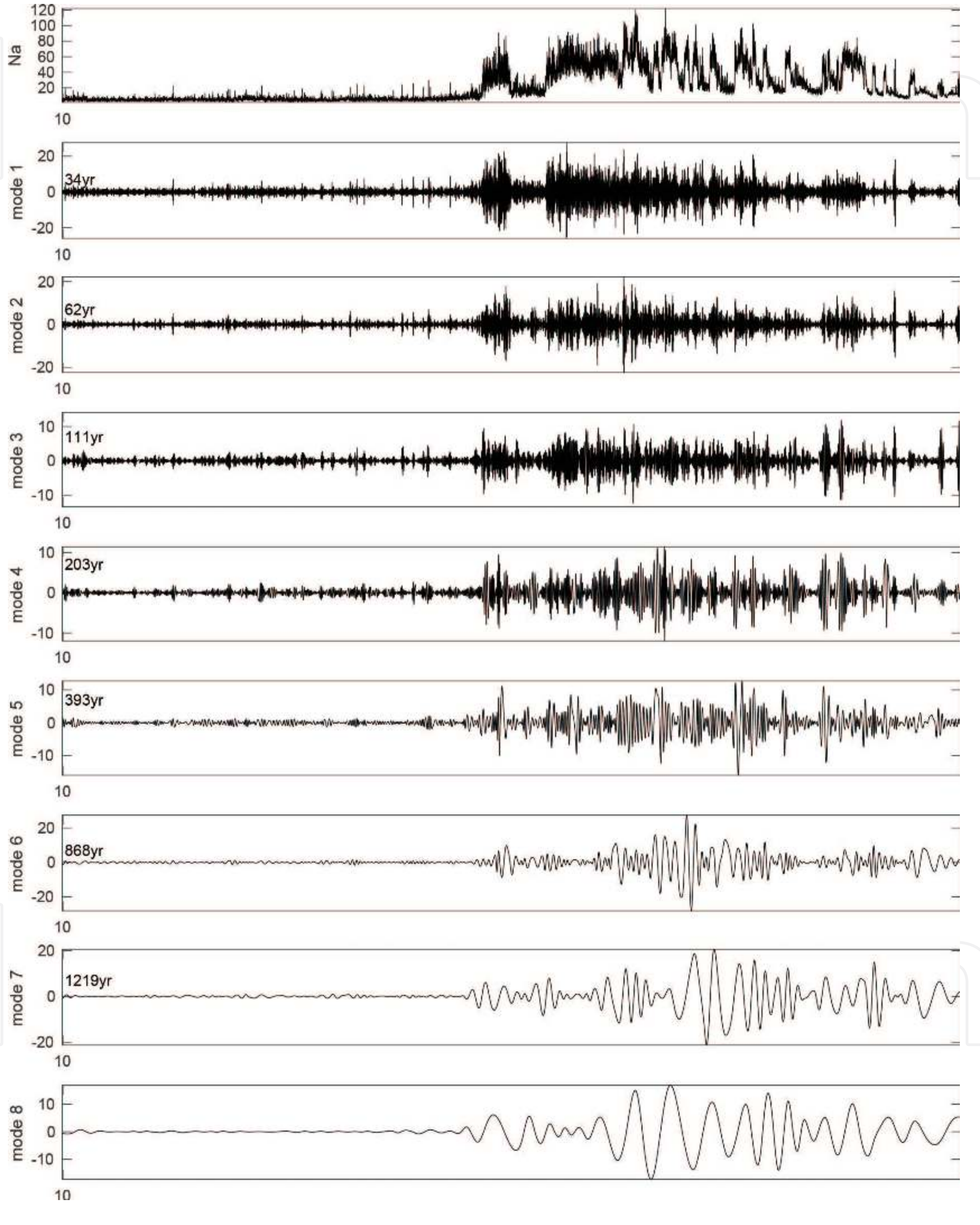


**Figure 2.**
*The GISP2 ice core data for the Na ion (upper panel). To obtain a uniformly sampled Na data set, we interpolated between the gaps in the original GISP2 unevenly spaced data and resampled with a time cadence of 10 years using the piecewise cubic Hermite interpolating polynomial, which preserves the shape of the data and respects monotonicity. This procedure works well for the most recent 50,000 years of the data set because there are no large unevenly spaced data gaps. The eight lower panels show the decomposition of the data variations into EMD modes. Each EMD mode varies in amplitude (seen in this figure) and frequency (can be estimated by the inverse quasi-period between zero crossings). The inverse frequencies of the EMD modes are shown in the left upper corner for each mode. At any given time, the sum of these modes equalizes the data. The mode amplitudes are scaled to the maximum of the data. The decrease in the amplitudes of variations at about 11,000 ybp is evident in all panels.*

First, we apply the EMD to analyze the behavior of the concentration of the Na ion, which characterizes the meridional winds transporting ions toward the North pole [31, 34]. The resulting data time series is shown in the top panel of **Figure 2**.

**Figure 2** clearly shows strong variations in all of the modes between 50,000 ybp and 11,000 ybp (with the possible exception of a short period at about 44,000 ybp). There is a sharp decrease in the amplitude of all modes at the termination of the Younger Dryas.

To characterize the Greenland temperature (**Figure 3**), we use the GISP2 bi-decadal $^{18}$O record based on measurements done at the Quaternary Isotope Laboratory, University of Washington, and the calibration given in Ref. [34]:

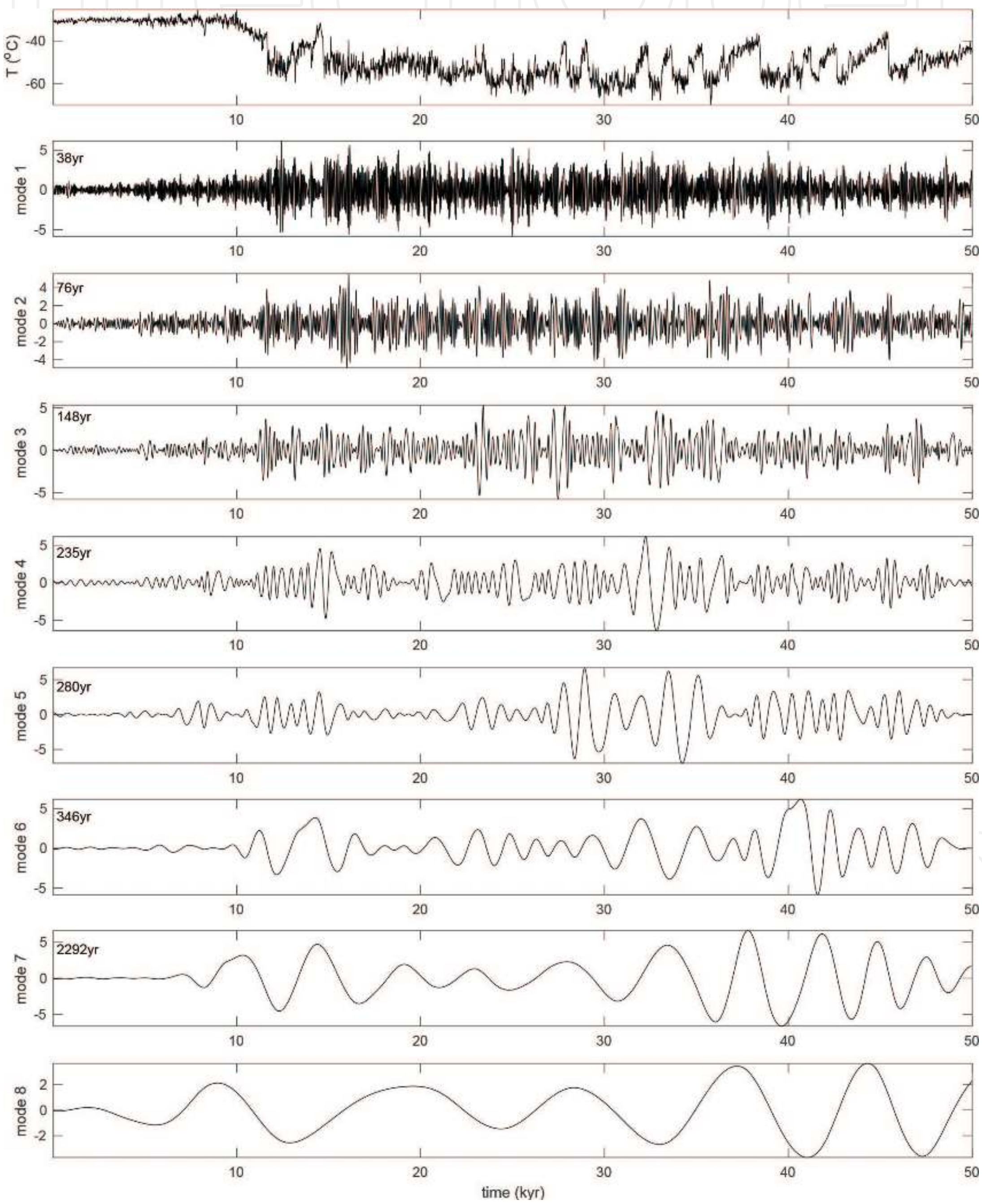


**Figure 3.**
*(Upper panel) The air temperature estimated from the GISP2 Δ$^{18}$O data. The evolution of the temperature, which is given at a 20-year cadence, its EMD modes in the relevant frequency range, and the characteristic quasi-periods are shown (see the upper left side of the figure). In accordance with the results for the Na ion shown in **Figure 2**, we see that the amplitudes of the variations of temperature were much greater before the Holocene. The warming at the termination of the YD was very abrupt and may have been accomplished in only a single decade at 11,570 ± 200 ybp [18].*

$$T = a\Delta^{18}O + b \tag{1}$$

where (a,b) = (2.15, 43.4) for t < 0.5 kyr, (a,b) = (3.99, 108.0) for 0.5 < t < 3 kyr, (a,b) = (3.98, 207.7) for 3 < t < 8 kyr, and (a,b) = (3.05, 75.4) for t > 8 kyr.

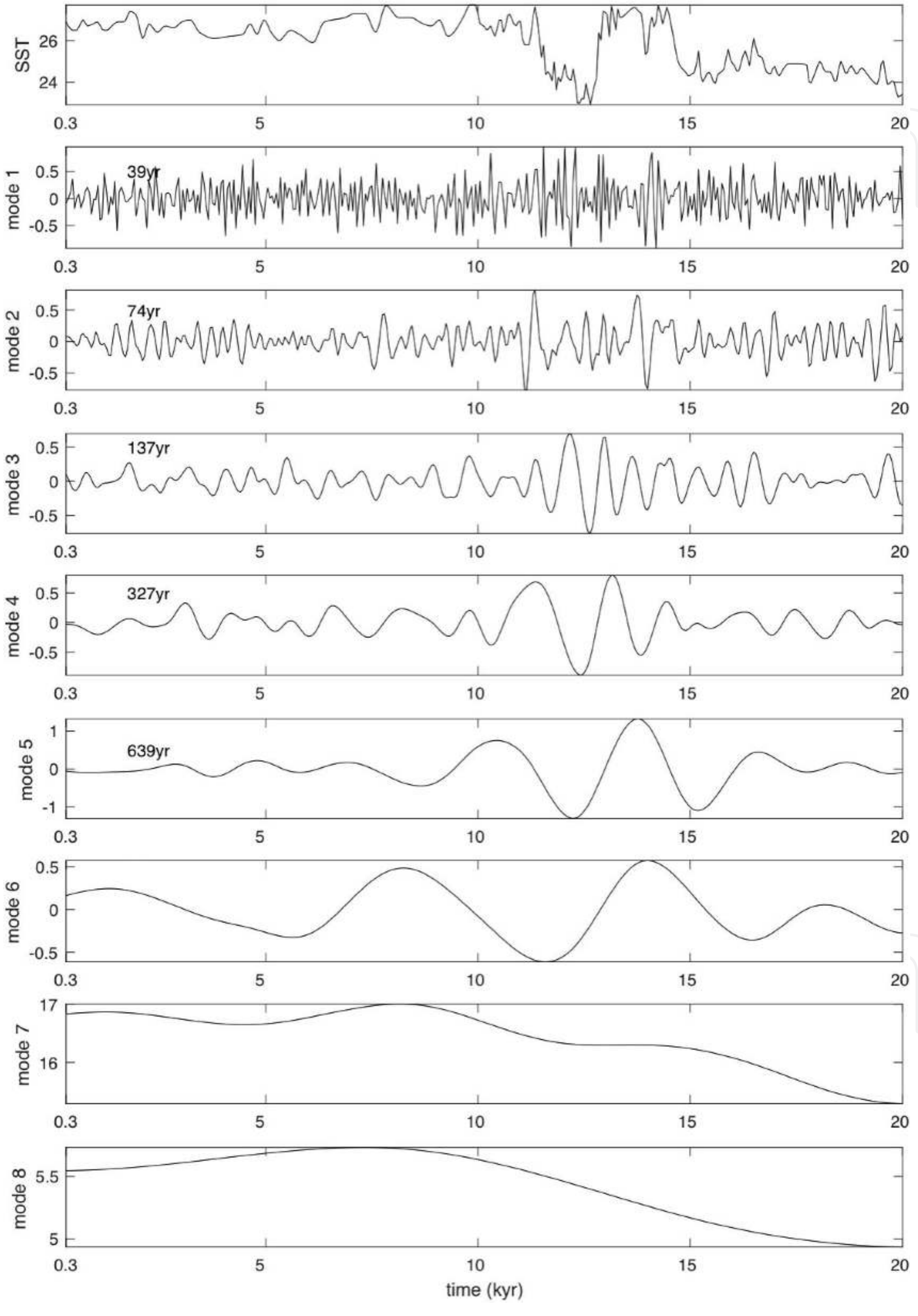


**Figure 4.**
*(Left rows) Top most panel shows the SST data in the Cariaco Basin, and the lower panels show the amplitudes of the EMD modes with the mean quasi-periods marked on the left side. Compared with GISP2 (see **Figures 2** and **3**), these data have lower resolution, and the time interval without major data gaps is more limited. We interpolated the data with a 50-year time cadence in the time interval from 300 ybp to 20,000 ybp. Note the presence of ~1500-year period in these data as well as in the GISP2 data. The amplitudes of all modes are large before and during the YD and decrease when the YD ends.*

Thus, in from 50,000 ybp until the recovery from the YD ~11,500 ybp, there were always (except perhaps about 44,000 ybp) large amplitude variations in both the winds and the temperature. The high amplitude of the variations continued throughout the YD, but the amplitude dropped precipitously at the end of that period. The figures also show that data meet the stability requirements we indicated above in our discussion of the development of agriculture (i.e., 2000 years of stability against variations with periods ≤300 years) after the YD termination and not before.

As an example of climate variability found at low latitudes, we show the EMD (**Figure 4**) of the sea surface temperature (SST) from sediments of the Cariaco Basin (~10°N) off the coast of Venezuela [35]. This record shows essentially the same variations as the $\Delta^{18}O$ from the GISP2 record [35, 18] and directly characterizes the MesoAmerican climate during the summer and early fall [56]. Compared with GISP2, these data have lower resolution than the GISP2 data, and the time interval without major data gaps is more limited. The data from 300 to 20,000 ybp are utilized here. We interpolated the data with a 50-year time cadence. Note that the ~1500-year period is present in these data as well as in the GISP2 data. The amplitudes of all modes are large before and during the YD and decrease when the YD ends. We also found that the spectral content of the EMD modes obtained from Cariaco data resembles the content of the modes obtained from Greenland ice core data smoothed with similar 50-year cadence in that both data sets show large high-amplitude, high-frequency changes in climate when there was no agriculture and that these variations became much smaller before agriculture appeared.

## 9. On relationship between climate variability found in widely separated regions

Current studies show that climate variations recorded in geographically widely separated regions are strongly interrelated. In addition to the climate records analyzed above, there are many other climate proxy records (CPR) obtained from widespread regions of the Earth including coral cores from several oceans [36] and stalagmites from Soreq caves in the area of the ancient Levant [29]. Many CPR have been intercalibrated to obtain well-dated records of tracers of worldwide patterns in climate change [36, 32]. Comparisons of these records demonstrate the Northern Hemisphere wide extent of both millennium scale [38] and more rapid climate changes [39]. Thus, the abrupt termination of the YD cold-dry period has been detected throughout the Northern Hemisphere in Greenland, Western Europe, North America, and Central America, off the Venezuelan coast, in the Middle East, with some evidence from Central Africa and the Indian Ocean [35, 40–42].

The agreement of the climate variability found from the GISP2 data and the Cariaco data is an example of the climate tele-connections between distant regions of the Earth [43, 31] that have been demonstrated by ocean and atmospheric observational and modeling studies for both the Pleistocene [44] and Holocene [45]. Intercomparison of data shows that climate variations in the Arctic are linked to variations in Antarctic and to lower latitudes [37, 39, 46]. Here are some examples: Grootes and Stuiver [16] compared the ice core records with the deep ocean $\Delta^{18}O$ records from Atlantic and Pacific Oceans and with tree-pollen land records in North America and Europe; Bond et al. [47] established correlations between climate records from North Atlantic Ocean and Greenland ice; Barlow et al. [34] established a link between stable isotope ratios (for deuterium) found from GISP2 ice cores data and the North Atlantic Oscillation (NAO) for the time period 1840–1970; and Wang et al. [48] linked the Asian monsoon in Southern China with the climate in the North

Atlantic. Century-scale temperature variations in the Greenland Ice record [17] have also been related to the NAO [49]. The NAO is associated with a sea surface temperature anomaly having a meridional average tripole pattern: cool north of 55°N, warm in 20°–55°N latitudinal band, and cool south of 20°N in the positive phase of the NAO [50]. The Red Sea coral cores in an area close to the initial domestication of wheat also currently reflect variations in the North Atlantic Oscillation [36]. The Cariaco Basin data directly reflect the MesoAmerican rainfall during the summer and early fall in the Yucatan peninsula [50] near where corn was first domesticated. The NAO is one of several large-scale climate circulation patterns (such as Pacific Decadal Oscillation, Northern Annular Mode, Aleutian-Iceland Seesaw, and Cold Ocean-Warm Land patterns) that can be expressed as made up of different combinations of the current first and second Empirical Orthogonal Functions of the Northern Hemisphere winter sea-level pressure [45]. In these large-scale patterns, a climate variable, such as temperature, is above its mean value in one area of the coherent climate pattern and below its mean value in another geographically remote part of the pattern (and vice versa). The global mean is only weakly, if at all, affected, and the pattern temperature variability is not necessarily related to a change in global temperature. The pattern variability sometimes manifests itself as a prolonged statistical preference of one of the two basic states. For example, during the Little Ice Age, the temperature pattern tended to be in a state with a cold northern Eurasia more frequently than during more recent times [51, 52].

Studies such as these indicate that the climate variations observed in the GISP2 and Cariaco data reflect worldwide patterns that mankind would have experienced during the Pleistocene as well as the Holocene. It is not important for the development of agriculture, if these Pleistocene patterns are exactly the same as those we are familiar with from the Holocene. In fact, modeling suggests that they were not identical, but that the large-scale worldwide coherence was maintained [29, 42]. The large-scale coherence is an important feature because it strongly implies that the century-scale variations seen in Greenland and Cariaco Basin are parts of interrelated worldwide climate variations.

## 10. Conclusion

When an agricultural society is developing, it may not be important if the local climate tends to be colder or warmer and dryer or wetter. What is important is that the local climate remains stable enough so that the crops and the livestock being domesticated continue to thrive.

It appears that from the time man left Africa about 50,000 ybp until 11,750 ybp there was essentially continuous climate variability in the period range of a century to a few centuries and no agriculture-based societies developed. These climate variations quieted at the beginning of the Holocene after the Younger Dryas terminated and were quickly followed by the development of several agricultural societies. It was the intense Pleistocene *climate variability* that prevented agriculture from developing until the onset of the relatively stable Holocene [8, 9]. This suggestion is supported by studies of the responses of already well-established agricultural societies to the relatively mild periods of climate variability that have taken place during the Holocene. For example, there was a weakly variable climate event at about 4000 years ago. This event strongly disrupted the Neolithic culture of Central China [48] as well as destroying the Egyptian Old Kingdom circa 4250–3950 ybp [53] and Akkadian in Mesopotamia 4170 ± 150 ybp [54]. A later period of climate variability observed in the Cariaco Basin sediments was accompanied by the fall of the classical Maya civilization in the Yucatan during the ninth century [55].

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We argued that the conditions required for the development of agricultural societies include about a millennium or more periods during which there are no large-century-scale climate variations. We have presented evidence that this has been the case in the Northern Hemisphere since the end of the Younger Dryas but not during the last several tens of millennium of the preceding Pleistocene and suggested that this resulted in the failure to develop agricultural-based societies until after the termination of the Younger Dryas. We conclude that there is considerable evidence that climate variability inhibited the development of agriculture until ~11,000 ybp when relative climate stability was established and many independent agricultural systems were developed.

## List of abbreviations

| | |
|---|---|
| ~ | approximate |
| ybp | year before present (1950) |
| Hss | *Homo sapiens sapiens* |
| YD | younger Dryas |
| DO events | Dansgaard-Oeschger climate events |
| PPN | pre-pottery neolithic |
| CPR | climate proxy records |
| GISP2 | Greenland Ice Sheet Project 2 |
| EMD | empirical mode decomposition |
| SST | sea surface temperature |
| NAO | North Atlantic Oscillation |

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