Holocene Climates of Anatolia: as Simulated with Archaeoclimatic Models

Holosen'de Anadolu'nun İklim Türleri: Arkeoklimatik Modellerle Yapılan Kurgulama

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Keywords: Paleoclimate, Site-spesific models, Paleoclimatic maps, Anatolia, Archaeoclimatology
Anahtar Sözcükler: Paleolitik Dönem iklimi, Belirgin yerleşme modelleri, Paleolitik Dönem iklim haritaları, Anadolu, Arkeoklimatoloji

Yenilerde gelişen makrofizik Paleolitik iklim örnekleme yöntemlerinin kullanımı sayesinde bugün artık belirli yerleşme modellerinde çeşitli iklim ögelerinin (yağış, ısı, buharlaşmanın yeterliliği v.s. gibi) aylık dağılımlarını 14 C yılıyla M. Ö. 14 000 yılına kadar 200 yıllık aralıklarla götürmek mümkündür. Yaklaşım, bu parametrelere zaman ve mekân içinde kuvvetli değerlendirmeler getirme ve kültürel dinamiklerin biçimlenmesinde çevresel değişimlerin rolünün incelenmesine ayrılan geçici çözümleri sağlama avantajına sahiptir. Bu metodla zaman ve mekân içinde gerçekleştirilen bölünmenin arkeolojik sorgulamaya uygun olmasından dolayı bu metodu "Geçmiş dönemlerin iklim bilimi" diye adlandırıyoruz.

Bu tipteki çeşitli bireysel modeller, sözü geçen metodu tanıtmak için ortaya konmuştur ve Anadolu'nun önemli yerleşmelerinin Holosen'deki kayda değer iklim değişikliklerine ışık tutmaktadır. Bölgenin tümüne yayılan yaklaşık 60 yerleşme yerine ait model sonuçları birleştirilerek 100 km^2 lik bir alanda mekân çözümleri ile çevre haritaları ortaya çıkarılmıştır. Bu haritalar, bölgenin iklimsel tarihinin coğrafi olarak bir bütünlük göstermediğini ispat etmiştir. Topografik olarak dağlık olan ve modern iklimde çok çeşitlilik gösteren bu yerde alınan sonuç, bir sürpriz oluşturmamaktadır.

Introduction

Based on the results of analyses of paleoenvironmental proxy data there is by now little doubt that the climate of Anatolia has changed rather dramatically since the last glacial maximum. Despite considerable study of these data, however, the exact nature and geographical extent of these changes remain a matter of debate. This situation has made it difficult to determine what effect, if any, paleoclimatic change has had

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2. Since it may be readily shown that the equator-to-pole (meridional) temperature gradient is proportional to the hemispheric temperature, the dynamics elucidated by Smagorinsky (1963) may be used to calculate the equatorward edge of the westerlies on a monthly basis at the same time intervals as before. This process defines the latitude at which the atmospheric westerlies become dynamically unstable and break off into the very large eddies called the "subtropical anticyclones" located in particular longitudinal zones. Since the main jetstream is near the outer edge of the westerlies, its latitude may also be estimated for each zone. In this way the past positions of the major circulation features can be calculated.

3. In general, if the latitude of the jetstreams and the locations of the subtropical anticyclones can be determined over time, then these and other major atmospheric circulation features (formerly called "centers of action") can be used to model local rainfall and precipitation over the same period. This is accomplished through application of the techniques of synoptic climatology, by which the behavior of a climatic element is explained in terms of atmospheric circulation patterns, particularly the positions of the major features.

Indeed, in many ways archaeoclimatic modeling can be thought of as synoptic paleoclimatology. This is based on the reasonable premise that, for any particular place, the relationship between the monthly positions of the "centers of action" and monthly precipitation (or temperature) has remained essentially constant through the very late Pleistocene and Holocene. In other words, it is assumed that the physics of the situation has remained the same over this period. This relationship can be determined through modern synoptic climatology and calibrated by the multiple regression, not necessarily linear, of the current (i.e., observed) precipitation against the current locations of the pertinent circulation features. It then becomes possible to calculate past monthly precipitation from the modeled past positions of the centers of action. Other climatic elements, such as temperatures, evapo-transpiration, rainfall intensity, etc., can be similarly modeled.

These steps can clearly be done sequentially, obviating the necessity of using an expensive iterative model on a mainframe computer. The climatic simulations in this paper were all calculated using a personal computer. Indeed, in developing the model one of the considerations was to produce a technique within the typical financial resources of the individual archaeologist, namely, very little.

The synoptic features important to the climate of Turkey are primarily the location of the Mediterranean branch of the jetstream, and the location of the semi-permanent anticyclones. Climatically, the rains associated with storms in the westerlies are distributed systematically with respect to the position of the jetstream. The intertropical convergence and other features related to the monsoon are of no importance to Turkish climate because the season of monsoon rains farther south is the dry season in Anatolia, and what summer rains there are in a few parts of Turkey are apparently related to synoptic influences on the less stable air of summer. For the location of the pertinent synoptic features see the airstream analysis of LaFontaine et al. (1990)

A significant feature of the synoptics that has not yet been elucidated is the mechanism involved in the splitting of the main Mediterranean storm track north and south of Turkey. Storms that go along the southern coast and past Cyprus are the major source of winter precipitation all across Mesopotamia, along the Mekran coast, and into the northwestern part of the Indian sub-continent. Nevertheless, the rains of that area can be fairly well simulated using synoptic climatology.

Site-Specific Archaeoclimatic Models

One of the more interesting sites for demonstrating the application of an archaeoclimatic model is Hattuşaş, the Hittite capital. This site is quite close to the modern village of Boğazköy but there is no weather station there to provide a record of the present day seasonal distribution of precipitation or other climatological elements. Thus we will assume here that the climate at Hattuşaş can be represented by the climate at the recording station in Yozgat, which lies a few miles to the south. These data are necessary to develop the algorithms relating the seasonal positions of the pertinent circulation features with the seasonal distribution of, for instance, precipitation.

This region, like all of the Mediterranean, has a climate dominated by winter rains associated with cyclonic storms moving along the track indicated by the Mediterranean branch of the jetstream. It is far enough north and away from the Mediterranean towards the Black Sea to have some of the summer rains of the interior. The relationship of the rain amount to the latitude of the jet axis is non-linear, as in other parts of the world, approximating a nearly Gaussian distribution, but located nearly entirely north of the axis of the jetstream. That is, the amount of rainfall at a particular location in any given month is related to its distance north of the latitude of the jetstream core at that time.

Figure 1. Modeled annual precipitation history of Yozgat since 5000 B.P.

The modeled annual precipitation at Yozgat for the last 5000 years is shown in Figure 1 as sequential 200 year averages. Examination of the model reveals more rainfall during the period of Hittite ascendancy and a sharp decline in precipitation just prior to the prolonged drought and famine reported in Egyptian and Hittite documents written at the end of the 13th century BCE . As seen in Figure 2, the modeled temperature rose significantly at the same time as this drought. This change would increase evapo-transpiration and exacerbate the effect of the drought (Figure 3). Thus one can see that while the water supply, precipitation, decreased about 8%, the environmental water demand also increased 23%. These are significant changes, if correct, when one remembers that they represent two-century averages. It is also likely that this relatively conservative modeling methodology underestimates the variance of the climatic elements to some extent. With the economy already in a deep crisis due to endless wars, it should come as no great surprise that the Hittite capital was abandoned at this time.

Figure 2. Modeled temperature history of Yozgat since 5000 B.P.

The other time in the last half of the Holocene that conditions of precipitation, temperature, and potential evapo-transpiration resembled that of the Hittite florescence and collapse was in the approximate 500 BCE to 400 CE (2400-1600 B.P.) period. These two periods appear world-wide as anomalies in the climatic proxy data. In the models used here they are driven by global bursts of volcanic activity which have been shown to decrease hemispheric surface temperatures, in this case driving the jetstream farther south in the Mediterranean area and increasing the winter precipitation of Turkey. We have named the earlier event that centers about 3800 B.P. the Indus Event, using the momentous events at that time in the Indus Valley as the reason for using it as a type locality.

The second of these two periods we have named the Vandal Event because the cold seems to have been a factor in the southward movement of the Vandals, Goths, and others in late Roman times. These two events appear in all models of past Turkish climates but with varying expression from place to place.

Figure 3. Modeled potential evapo-transpiration history of Yozgat compared to its precipitation history since 5000 B.P.

The modeled climatic history of Hattusas, as represented by Yozgat, appears to be consistent with the ascendance and decline of the Hittites. Considering the whole of the Holocene at Yozgat (not pictured here), we see a more dramatic event in the decline of annual precipitation from 8000 B.P. to 6000 B.P. This is also a hemispheric phenomenon which varies in intensity from place to place. The decline after roughly 8200 B.P. is also evident at Konya (Fig. 5) where the decline appears to have been completed earlier than at Yozgat. This decline would seem to be significant in the history of Çatal Hüyük.

Figure 4. Modeled precipitation and potential evapo-transpiration history of Konya, used as representative of the Çatal Hüyük area.

The modeled rainfall prior to 11,000 B.P. is several hundreds of millimeters per year more than the estimated evapo-transpiration, then from 10,000 to 8000 B.P. about equal, then rapidly changes to nearly the present condition. One could interpret this as meaning that the region was probably forested before 10,000 B.P., then a rich savanna suitable for grazing as well as browsing animals, then a change to the present rather dry state. This viewpoint, of course, is roughly the opposite of the orthodox interpretation of the palynological records from the Konya Basin.

The growth of the "city" at this site appears to have been entirely during the rather stable climatic regime which lasted from about 10,000 B.P. to about 8000 B.P. During this time, the shoreline of the large lake near the site was also undoubtedly quite stable except for the progradation of the nearby delta of the Çarşamba River. This favorable location on the lake-land ecotone meant that the resources of the lake, the marshy shores, and of the land were all available.

Circa 8000 B.P., the conditions at Çatal Hüyük estimated by the model (Figure 5) started to change rapidly with a sharp decrease in average rainfall, rising temperatures, and sharply increased evaporative stress. This change would stress the agriculture, reduce the availability of fresh water locally, and, perhaps most of all, cause the lake to rapidly shrink. Çatal Hüyük was then many kilometers from the shore, not on the ecotone, and the quantity and variety of the resources was reduced. Perhaps this climatic change was involved, at least in part, in the abandonment of the site within a few centuries. At any rate, the modeled climatic history for Çatal Hüyük appears to be consistent with the history of the settlement and the history of the lake .

In the far northeast of Turkey, where the precipitation is largely concentrated in summer, the same major events appear that are seen in the models for the winter-precipitation regions: the sharp decline after 8000 B.P., the Indus event, and the Vandal event. This is shown in Figure 6, the modeled precipitation history for Kars.

Here however, the decline of precipitation at 8000 B.P. is about 35%, a very important change, and is combined with an equally large increase in evaporative stress as modeled. The modeled pattern for Doğubayazıt, although not shown here, is similar. In both cases a truly significant impact on the environment should be evident in the field data, if the models are indeed correct.

Figure 5. Modeled Holocene precipitation and evapo-transpiration history for Kars.

Regional Perspectives

There have now been enough individual Turkish sites modeled (about 60 stations altogether) to begin to map the climatic elements with a space resolution of about 100 kilometers or so. The locations for which climatic histories have been calculated are displayed in Figure 6. With a few more months of effort one person with a personal computer could increase the detail to produce significantly finer resolution.

Even given the present coverage, a number of important aspects of the past climates of Anatolia come to light when the modeled precipitation data are presented in the form of contour maps. Three examples must suffice to illustrate the spatial patterning of the past climate here. In Figure 7 the percent change in modeled mean annual precipitation between 8200 and 7200 B.P. is presented. It may be observed in Figures 4 and 5 above that this was a period of extreme change in precipitation regimes in Anatolia. The modeled position of the jetstream had shifted northward, thus substantially reducing the amount of winter rainfall in most of Anatolia. Figure 7 demonstrates, however, that the modeled reduction in precipitation was not uniform nor continuous across the entire region and in fact precipitation increased during this period at several stations in the northwest and along the coast in the extreme southwest. The lack of uniformity seen in these models relates almost entirely to the way in which regional geography and local topography significantly influence the local expression of large scale changes in atmospheric circulation. This influence is among the most important reasons why it is inappropriate to consider individual paleoclimatic proxy records as representative of conditions over wide geographical areas.

Figure 7. The percentage change in modeled mean annual precipitation between 8200 and 7200 B.P. The contour interval is 5%.

Figure 8 presents the percentage difference between modern observed mean annual precipitation and that modeled for 1800 B.P. (i.e., roughly at the time of what we have termed the "Vandal Event"). In this case the map suggests that conditions throughout Anatolia were wetter at 1800 B.P. than they are today but, once again, the difference is not uniform across the entire region. The majority of the reduction to modern precipitation levels was accomplished by 500 A.D. in virtually all of the individual models compiled to develop this contour map.

Figure 8. The percentage difference between modeled mean annual precipitation at 1800 B.P. (roughly at the time of the "Vandal Event") and observed modern values. The map contour interval is 2%.

Figure 9. The percentage difference between modeled mean annual precipitation at 6000 B.P. and observed modern values. The map contour interval is 2%.

Third, the percentage difference between modeled mean annual precipitation at 6000 B.P. and observed modern levels is seen in Figure 9. Once again the pattern which emerges is one of regional differences within Anatolia as a whole. It may further be noted that the differences portrayed in Figure 9 are not as significant as those seen in Figure 7 but not much different from those seen in Figure 8. What this suggests is that the temporal resolution of our paleoclimatic models and proxy records is critical in determining whether we will be able to detect periods of significant climatic change and if so, whether those changes will be accurately dated. It is clear that the 3000 year intervals applied in most General Circulation Models do not provide sufficient resolution.

Concluding Remarks

Macrophysical paleoclimatic modeling (or "Archaeoclimatology") offers a means of developing robust, site-specific estimates of paleoclimatic change with a temporal resolution on human scales. The hypotheses so generated can be tested with carefully analyzed field data and then used in studies aimed at assessing the role of environmental change during specific periods of cultural dynamics. These models are not seen by the authors as an alternative to the analysis of paleoclimatic proxy records. Because it is based on models of the past locations of major circulation features, this approach is viewed instead as a logical means of extending our knowledge of modern synoptic climatology back into the past.

This methodology has several distinct advantages. First, it is site-specific by virtue of the manner in which the observed seasonal distribution of precipitation and other climatic elements are used to calibrate the relationship between those elements and the seasonal locations of major circulation features. This approach thus takes into account the way in which regional and local topography create unique local responses to large scale climatic changes. Particularly in mountainous terrain, these responses are not always of the same magnitude nor even of the same sign at locations in relatively close proximity to one another.

Secondly, the past monthly distributions of several different climatic elements may be modeled, following essentially the same methodology. In the above descriptions of the modeled climates of several interesting specific locations in Anatolia (Yozgat, Konya, and Kars), we have given examples of the importance of changes in evapo-transpiration considered in conjunction with precipitation changes. We believe that a meaningful discussion of past environments as they impacted the food supply must include consideration of both components of the water stress.

This paper represents the first time that the results of a sufficiently large number of site-specific archaeoclimatic models have been combined to produce a meaningful view of paleoclimatic change across an area the size of Anatolia. This geographical coverage has the advantage of not masking the diversity of local climatic histories and may prove useful in understanding interregional cultural dynamics which have environmental elements.

Finally, this methodology allows the estimation of monthly values of various climatic elements with a present temporal resolution of 200 year intervals back to 14,000 B.P. Our continuing research includes efforts to improve this resolution although even the current scale allows the detection and relatively precise dating of paleoclimatic events taking place over short time periods. We feel that understanding these periods is crucial to understanding what role, if any, has been played by a changing environment in the shaping of cultures. This is nowhere more important than in an area with the rich cultural heritage of Anatolia.

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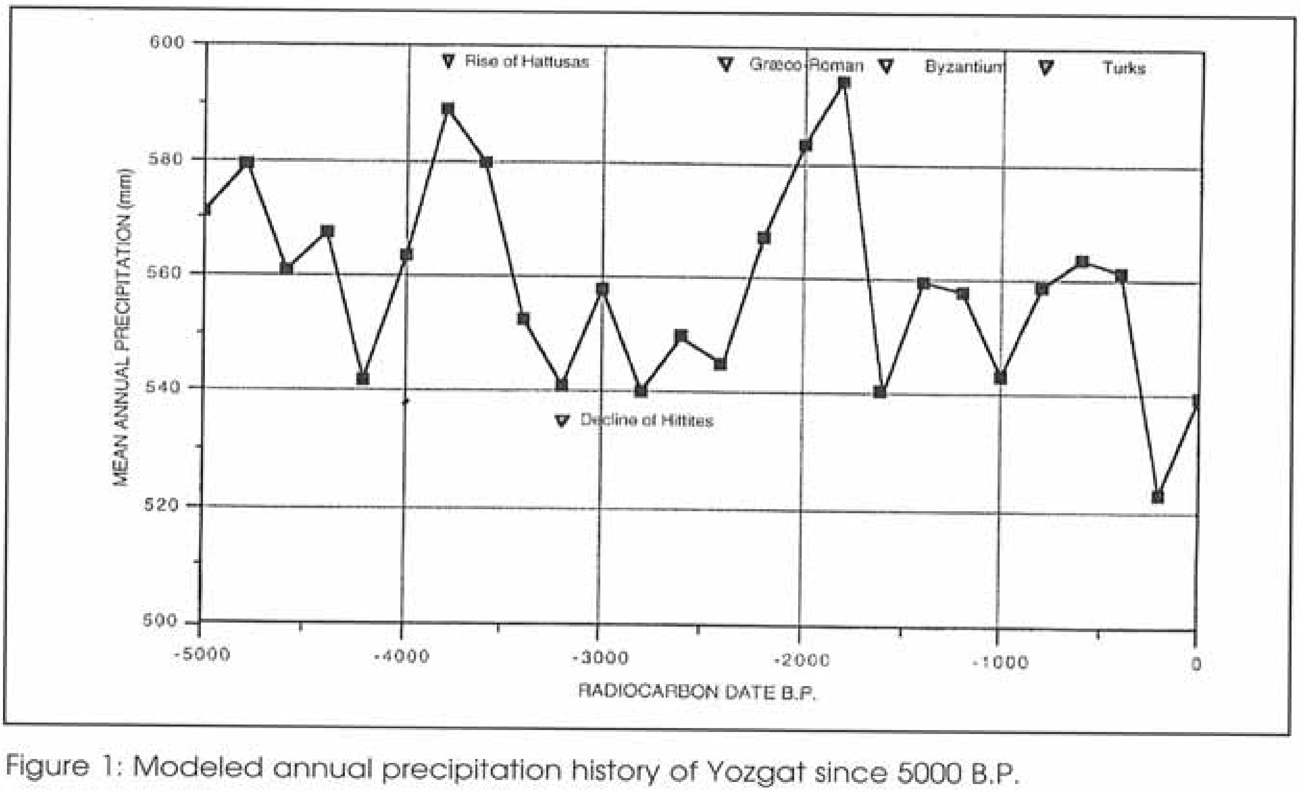

Figure 1: Modeled annual precipitation history of Yozgat since 5000 B.P.

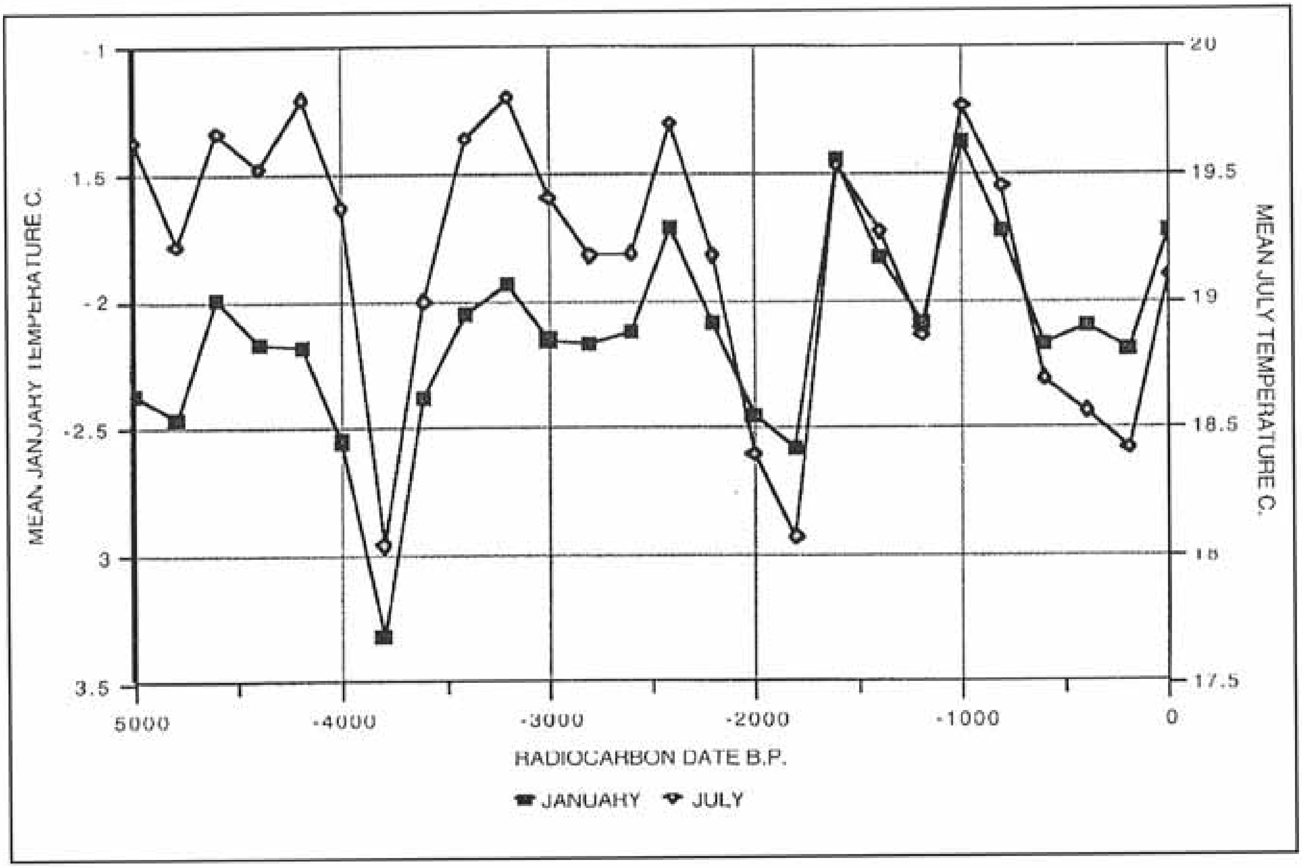

Figure 2: Modeled temparature history of Yozgat since 5000 B.P.

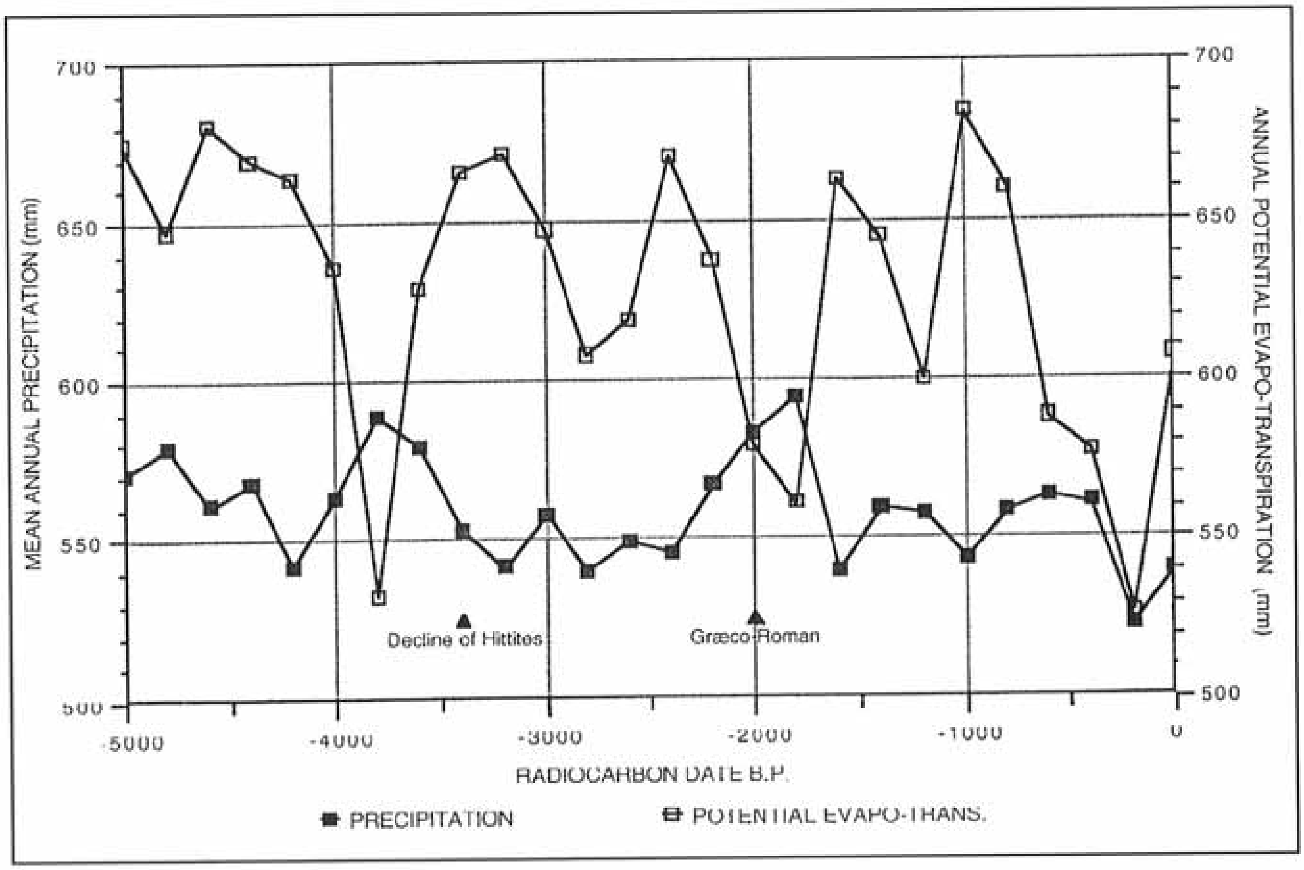

Figure 3: Modeled potential evapo-transpiration history of Yozgat compared to is precipitation history since 5000 B.P.

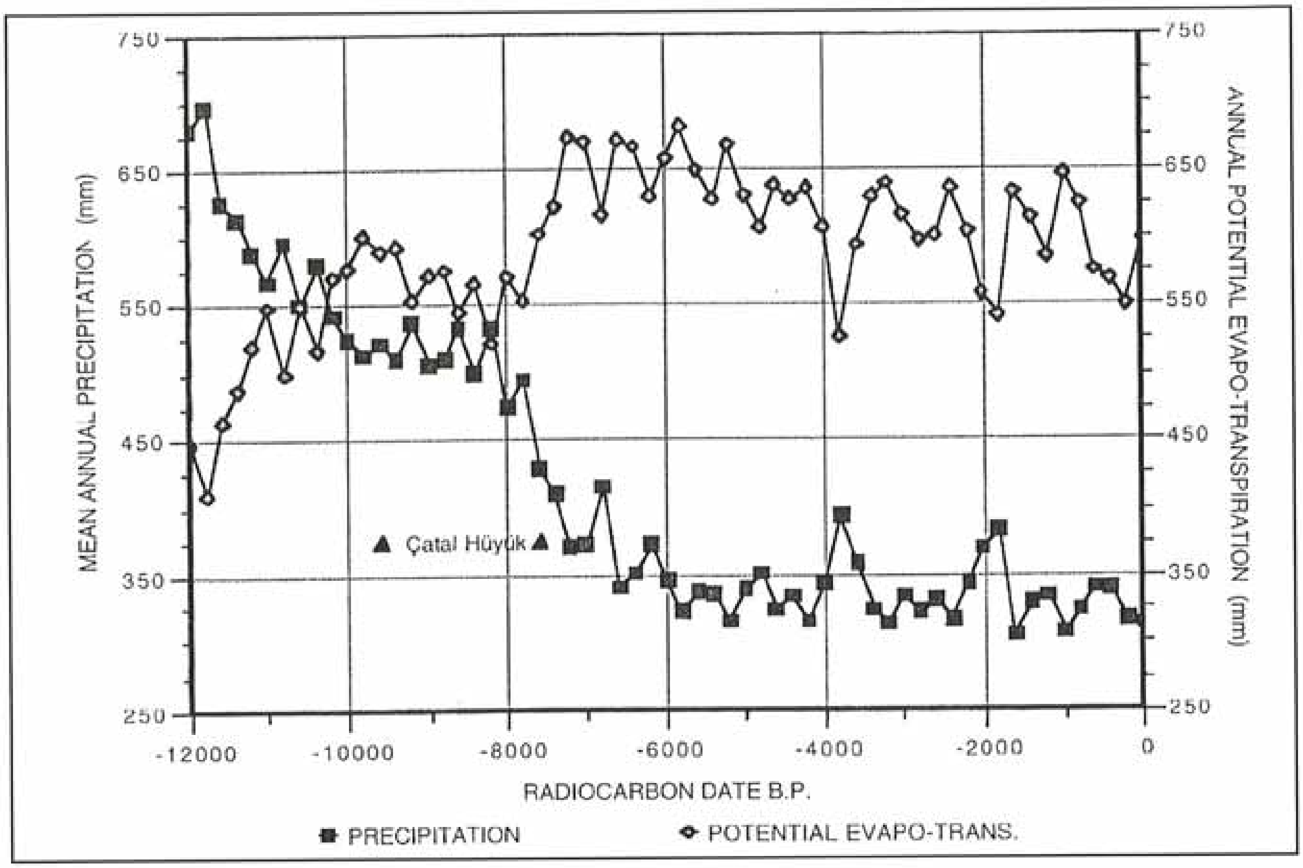

Figure 4: Modeled precipitation and potential evapo-transpiration history of Konya, used as representative of the Çatal Höyük area.

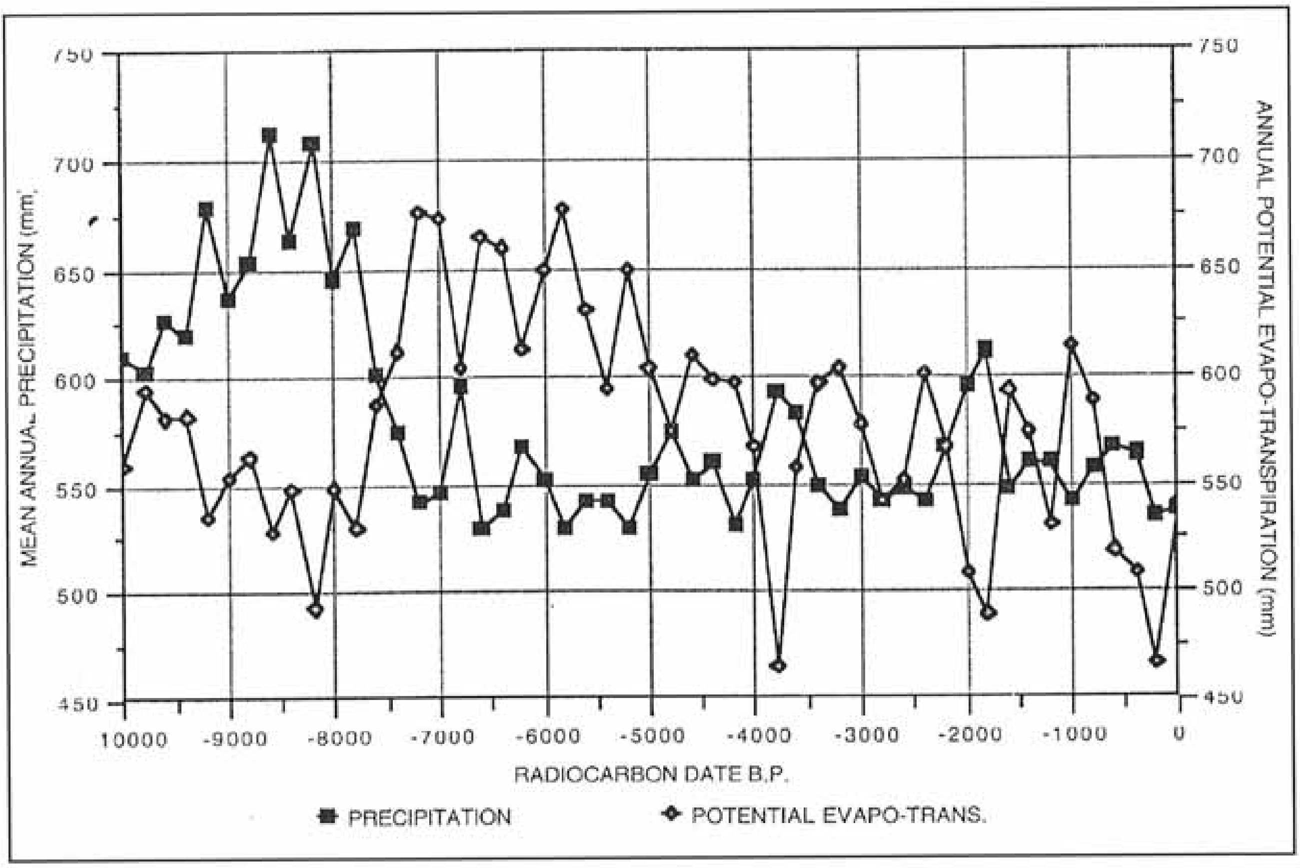

Figure 5: Modeled Holocene precipitation and evapo-transpiration history for Kars.

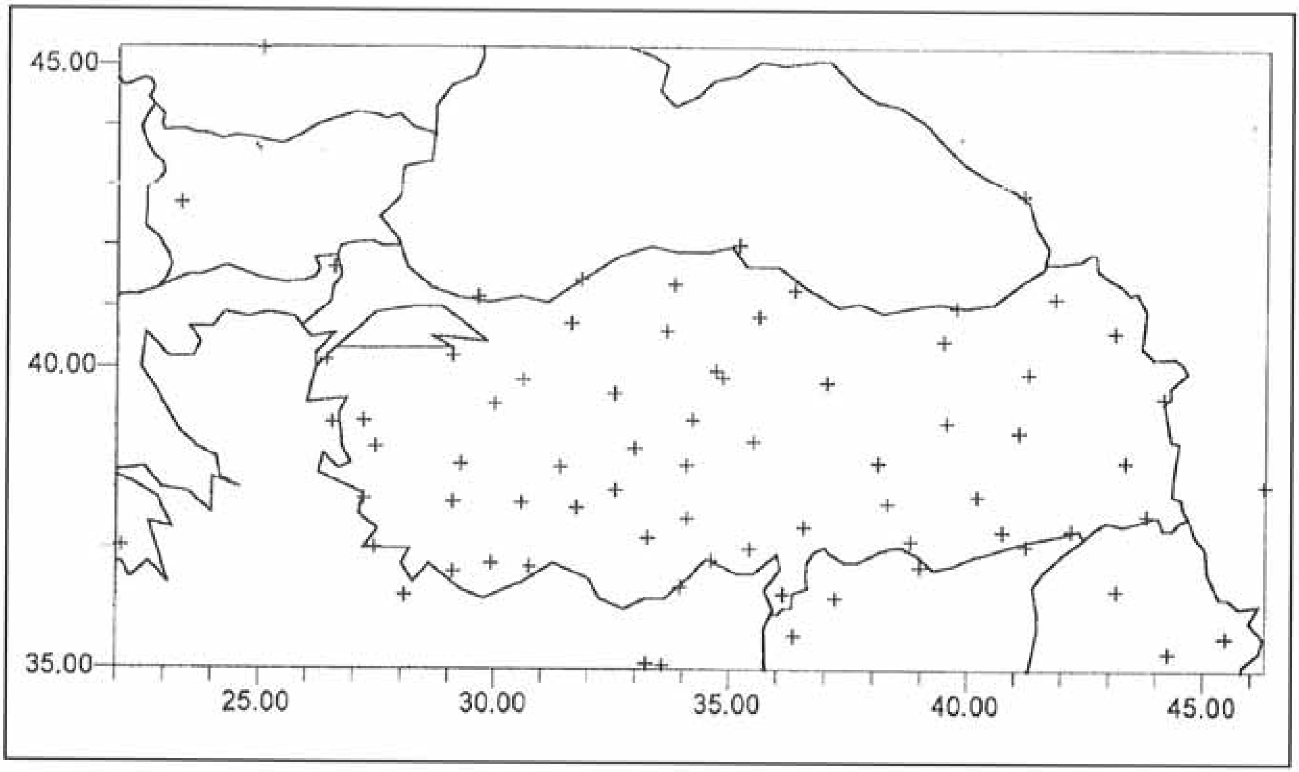

Figure 6: The locations of the recording stations for which archaeoclimatic models were created for purposes of this study are shown with a+ symbol on this map.

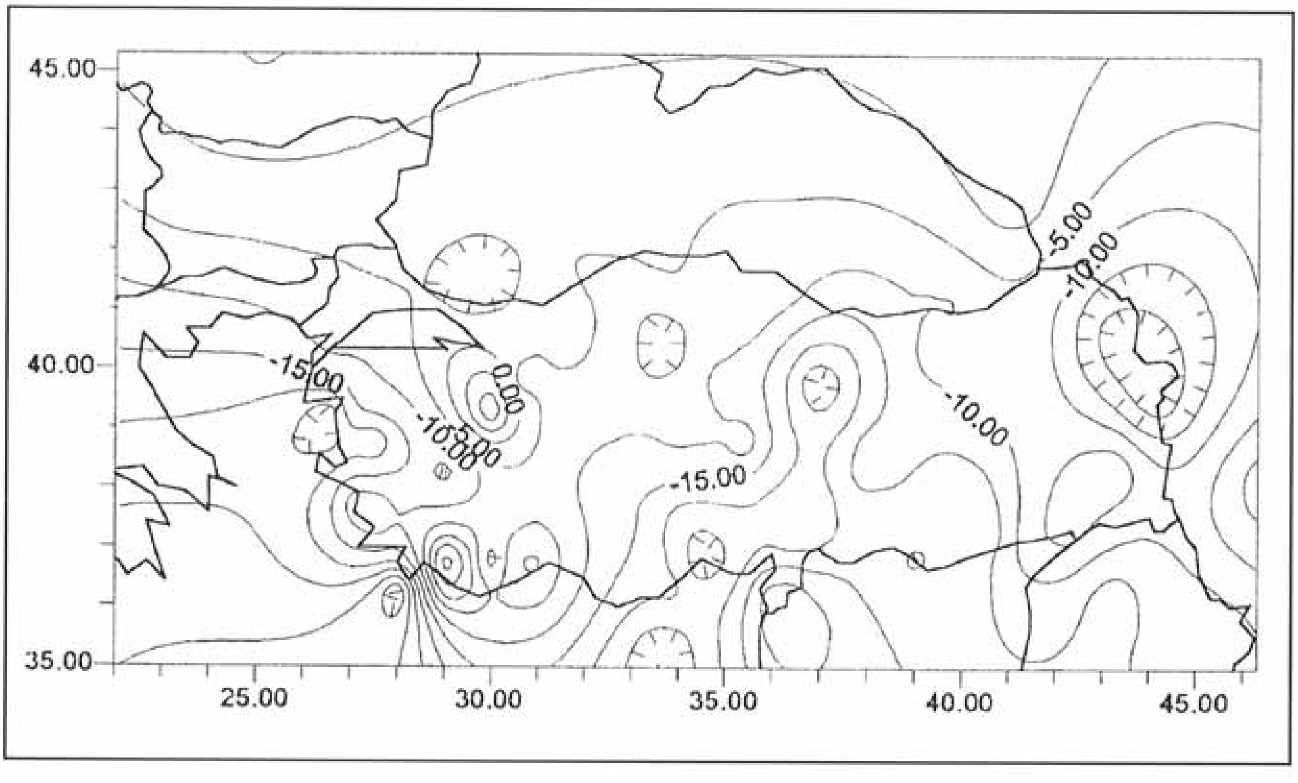

Figure 7: The percentage change in modeled mean annual precipitation between 8200 and 7200 B.P. The map contour interval is 5%.

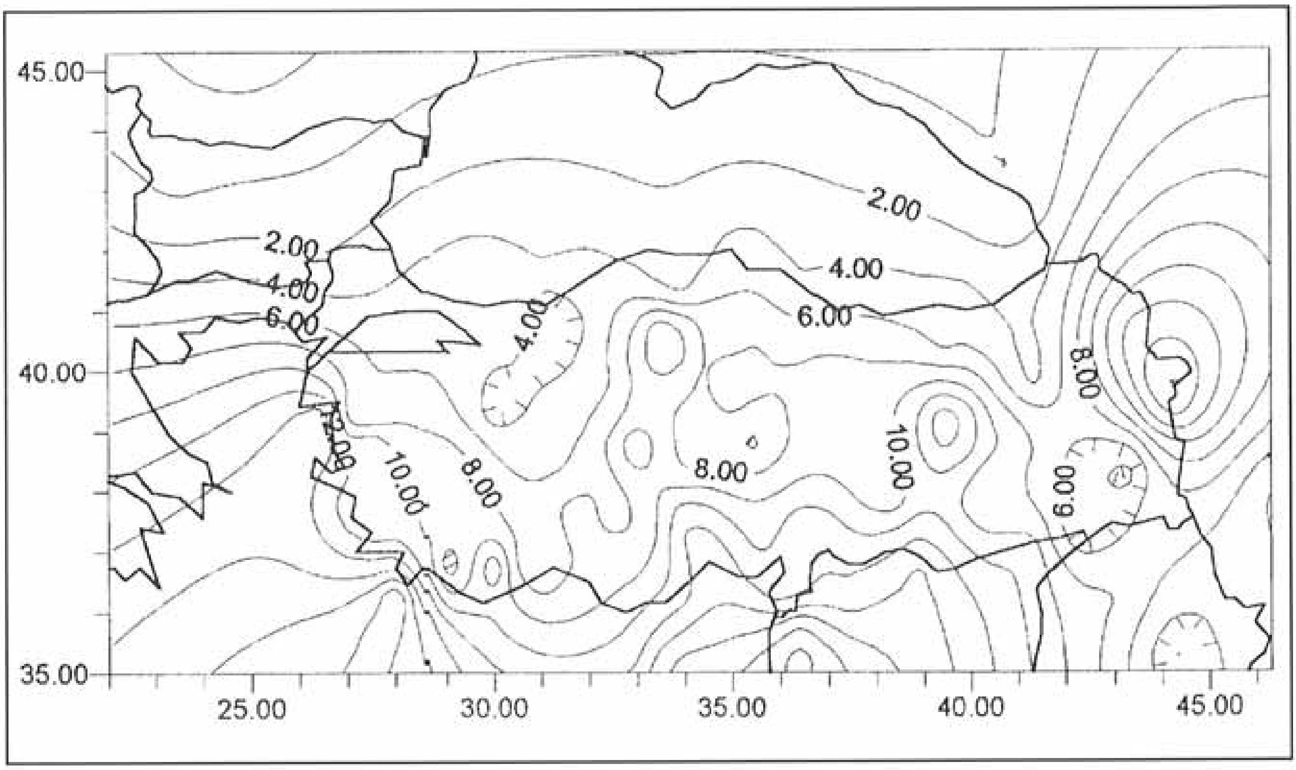

Figure 8: The percantage difference between moddeled mean annual precipitation at 1800 B.P. (roughly at the time of the "Vandal Event") and observed modern values. The map contour interval is 2%.

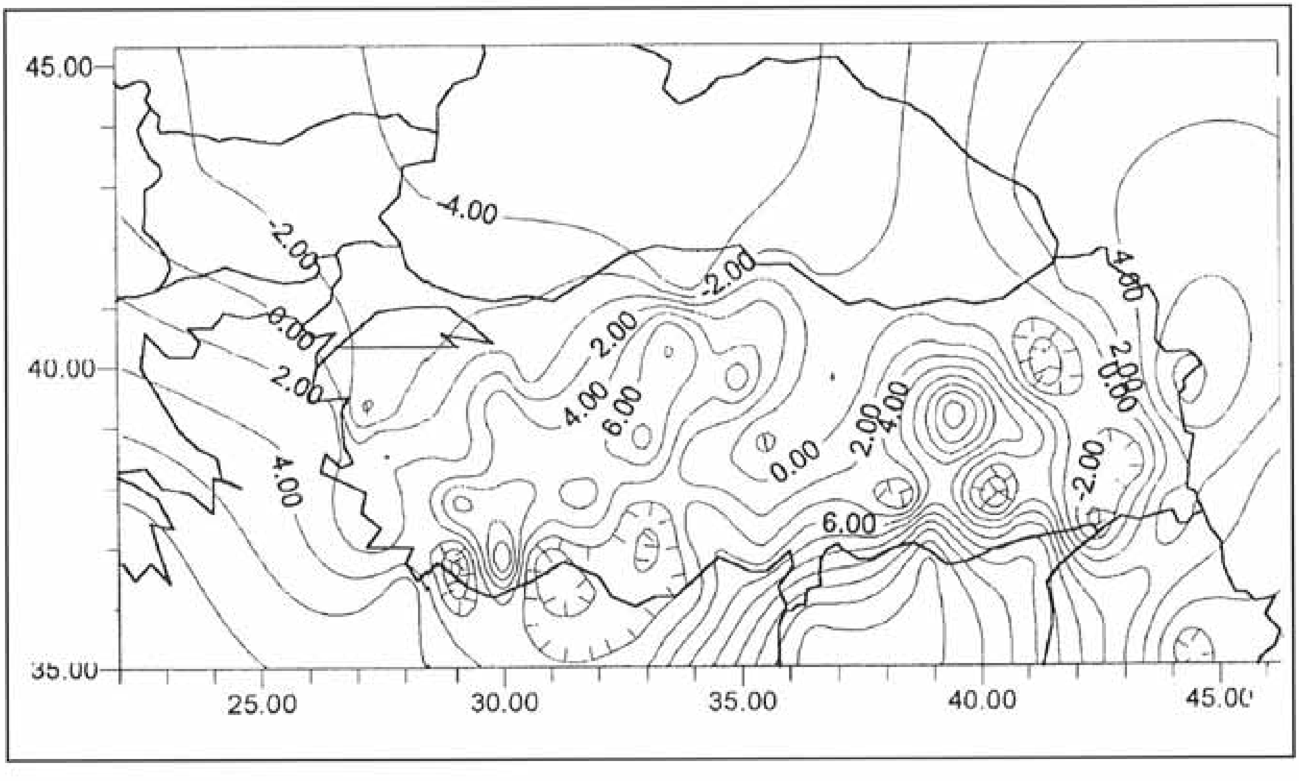

Figure 9: The percantage difference between moddeled mean annual precipitation at 600 B.P. and observed modern values. The map contour interval is 2%.