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Climate of the Past Discussions

Climate change and the demise of Minoan civilization

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Abstract

Climate change has been implicated in the success and downfall of several ancient civilizations. Here we present a synthesis of historical, climatic, and geological evidence that supports the hypothesis that climate change may have been responsible for the slow demise of Minoan civilization. Using proxy ENSO and precipitation reconstruction data in the period 1650–1980 we present empirical and quantitative evidence that El Niño causes drier conditions in the area of Crete. This result is supported by modern data analysis as well as by model simulations. Though not very strong, the ENSO-Mediterranean drying signal appears to be robust, and its overall effect was accentuated by a series of unusually strong and long-lasting El Niños during the time of the Minoan decline. We show that a change in the dynamics of the El Niño/Southern Oscillation (ENSO) system occurred around 3000 BC, which culminated in a series of strong and frequent El Niños starting at about 1450 BC and lasting for several centuries. This stressful climatic tend, associated with the gradual demise of the Minoans, is argued to be an important force acting in the downfall of this classic and long-lived civilization.

1 Introduction

The Minoan civilization was a prominent Bronze Age society which flourished from approximately 2700 to 1450 BC on Crete, Greece (Fig. 1). The Minoans developed splendid architecture, a complex language, and a written script that is still not understood. They built a significant naval power and coexisted with neighboring civilizations as the dominant influence in the region (apparently without being significantly threatened). Contact with Egypt and Mesopotamia influenced their culture, as the Minoan civilization evolved to become the forerunner of Greek civilization; thus Minoan society is generally regarded as the first European civilization. Following its regional predominance for more than an millennium, Minoan civilization slowly withered until it disappeared around 1200 BC.

There are essentially two main theories that have been invoked to explain the demise of Minoan civilization, but neither matches the observed gradual decline that took place. One is the explosion of the volcano in Thera and the other is invasion and occupation by the Mycenaeans. The former was suggested by Marinatos (1939). This catastrophic theory argues that earthquakes destroyed the palaces, tsunamis obliterated the fleet and peers of the Minoans, and the volcanic ash of Thera covered the whole island destroying crops and killing animals. This view was initially supported by geologists who agreed that the Thera eruption was of a colossal scale, and such effects were possible. However, in 1987 studies conducted at the Greenland ice cap dated frozen ash from the Thera eruption and concluded that it occurred in 1645 BC (Hammer et al., 1987); a result which has been confirmed by subsequent studies (Friedrich et al., 2006; Manning et al., 2006) and placing the event several hundred years before the destruction of the Minoan palaces around 1450 BC and the final disappearance of Minoans around 1200 BC.

Minoan society faced many problems and physical disasters throughout its history but it rebounded to elevate its culture to high levels. So why did it not recover after the destruction of 1450 BC? An explanation is provided by the hypothesis that an invasion by the Mycenaeans was responsible for the destruction of the palaces and their subsequent occupation contributed to the demise of Minoan civilization. However, archeological evidence to support this idea is either contradictory or lacking. For example, skeletal remains consistent with an invasion pattern have never been found (Callender, 1999). Indeed in the palaces the dead were neatly buried in well preserved burial sites, a pattern inconsistent with an invasion scenario. The fact that the Mycenaeans did not establish themselves in nearby and more vulnerable Crete as they did in mainland Greece is also not consistent with ambitious military conquest, even though Mycenaean culture was clearly influential in mainland Greece at this time. Questions regarding the demise of the Minoan civilization remain unanswered as the historical and physical records fail to provide definitive answers.

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2 The climate connection

Climate has played a significant role in the disappearance of several cultures on Earth. A recent study (Sandweis et al., 2009), for example, reviews evidence of how environmental changes induced by earthquakes and El Niño flooding contributed to the demise of the early Supe settlements in Peru. Another example is the disappearance of the Mayans. Around 800 AD, the Mayans were at the peak of civilization with a population of about 15 million occupying the area from Mexico's Yucatán peninsula to Honduras, before they ultimately and rather suddenly disappeared. In addition to hypotheses concerning epidemic disease as the agent, evidence has emerged that a long period of dry climate, punctuated by three intense droughts, may have contributed to the end of Mayan society (Haug et al., 2003). Here we examine multiple and consistent evidence to suggest that climate played a central role in the downfall of Minoan civilization and that the ultimate mechanism was a fundamental change in the dynamics of El Niño/Southern Oscillation (ENSO).

ENSO is a phenomenon that takes place in the Pacific Ocean. During normal conditions the westward surface winds in the tropical Pacific sweep and accumulate over time warm surface water to the west. This leaves the surface eastern tropical Pacific with colder upwelling water. Thus during normal conditions (often referred as La Niña) there are cold surface temperatures in the eastern Pacific and warm in the western Pacific. The continual accumulation of warm water in the west increases the surface elevation and eventually the warm pool of surface water sloshes back to cover all tropical Pacific. We now have an El Niño, which is characterized by a large warm spot over the tropical Pacific Ocean. This surface warming is large enough to interact with the atmosphere, which is then modified and brings significant weather changes all over the world. These ENSO teleconnections are established via complex mechanisms involving El Niño and its effect on the North Pacific area, and the subsequent result of this effect on the wave structure of Northern Hemisphere circulation. The north Atlantic and the stratosphere may also be key players in establishing El Niño teleconnections

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(Mokhov and Smirnov, 2006; Ineson and Scaife, 2009).

Figure 2 shows the correlation between the cold season (DJF) Nino3 index (Mann et al., 2000) and the seasonal (DJF) precipitation reconstruction over Europe (Pauling et al., 2006; Mitchell and Jones, 2005). The Nino3 data cover the period 1650–1980 AD and the gridded precipitation data the period 1500–2000 AD. The correlation is based on the data in the period 1650–1980 AD. Most correlations are small but what is important (especially with nonlinear interactions such as ENSO and precipitation teleconnections) is emerging patterns. Here a very coherent and non-random spatial structure is evident suggesting a significant precipitation signal of El Niño over Europe. The map indicates drier conditions over Northern Africa and part of the Mediterranean (a direct result of the cyclone track shifting northward during El Niño; Bronnimann, 2007), wetter conditions over most of Europe and drier conditions in Scandinavia. Even though it is only represented by two grid points, Crete is located in the drier belt. For the area of Crete we find that the fractional change of precipitation between El Niño and La Niña years to be around 10%. This result, as well as the correlation structure in Fig. 2, is consistent with results using rainfall station data in the period 1880–1980 (Fraedrich and Muller, 1992; Bronnimann, 2007).

The El Niño signal on precipitation on Crete appears to be weak but as confirmed by modeling results it is a robust phenomenon and as we will see below during the time of the Minoans this signal may have been 2–3 times stronger. Figure 3 is based on model simulations and also indicates that precipitation in the area of interest is reduced on the average during El Niño events and increased during La Niña events. Note that the El Niño OND and JFM maps are in very good agreement with the spatial structure in Fig. 2 and is reversed during La Niña years (from Bronnimann, 2007). This consistency suggests that the El Niño signal in the area of Crete is robust. Parenthetically we point out the exceptional pattern on Cyprus actually adds to our argument about climate effects. Cyprus even though relatively close to Crete appears to be wetter during El Niño years. This is clear in Fig. 2 and in the model simulation (Fig. 3). Interestingly, at the time when the Minoans were in decline the Cypriots were apparently not suffering the same fate. This special case is reassuring however raises the question as to whether during the period from 1450 to 1200 BC El Niño activity was sufficiently unusual, broad and long-lasting to produce a strong enough signal to cause the gradual decline of the Minoans.

A recent study (Moy et al., 2002) documented the variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch (Fig. 4; adapted from Moy et al., 2002). This is a proxy record based on the distribution of inorganic clastic laminae in a core retrieved from Lake Laguna Pallcacocha in Ecuador. The laminae are deposited during ENSO-driven episodes of alluvial deposition in the Laguna Pallcacocha drainage basin. These laminae are mixed with dark-colored organic-rich silt. The surface of the core sections was scanned and the intensity of the red color was used to generate the proxy record. In general higher intensity values correspond to El Niño and lower values to La Niña. This record has been extensively analyzed and recent results (Moy et al., 2002; Tsonis, 2008) suggest a change in the dynamics at around 3000 BC. It appears that around that time a bifurcation occurred in the ENSO system causing the attractor of the underlying dynamical system to become higher dimensional with less stable behavior (Tsonis, 2008). As a consequence the system switched from a dynamics where the normal La Niña condition was the dominant mode to a dynamics where El Niños became more frequent and stronger. Changes in boreal summer insolation or slow changes in ocean dynamics (which are known to be affected during interglacial events) have been suggested as possible mechanisms for this bifurcation (Tsonis, 2008). This scenario is consistent with geoarchaeological evidence form Peru, which also suggests absence of El Niño before 5000 BP (3000 BC) and its onset after that (Sandweis et al., 1996). Additional support for the Ecuador ENSO proxy record is provided by a recent study of hurricane events (Donnelly and Woodruff, 2007). It is well known that ENSO affects hurricane activity in the Atlantic Ocean and that this activity is reduced during El Niño years. That study shows that a proxy record of hurricane activity over the past 5000 years obtained from sediment cores in Vieques, Puerto Rico is well correlated with the Ecuador ENSO proxy record. In addition, precipitation inferred from

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sediment cores from Lake Ossa in West Cameroon (an area where ENSO's effect on precipitation is well known) also correlates well with the Ecuador ENSO proxy record. According to Fig. 4, a series of intense El Niño events (high red color intensity) begins at about 1450 BC that will last for centuries. In that period normal (La Niña) conditions have but disappeared. For comparison, the very strong 1998 El Niño event scores 89 in red color intensity. During the time when the Minoans were fading, El Niño events reach values in red color intensity over 200. Figure 5 shows a comparison between the two proxies for ENSO used here. It shows El Niño frequency in a 50-year moving window. The top panel shows that the two proxies are in good agreement and the bottom panel that the El Niño events in the coral record (Fig. 4) starting at about 1450 BC are much stronger than in the last three hundred years (by a factor between two and three). This will indicate that the El Niño signal may have been much stronger at the time of the Minoans. Thus, it is highly probable that the area of Crete experienced drier conditions from 1450 to 1200 BC and even later. For communities that strongly depended on water and agriculture in order to survive, the cumulative effect of these drier conditions could have been devastating and may have led to a slow decline bringing the population below a critical threshold that will allow it to exist and thrive. The above results and observations are also supported by an O^{18} analysis (Magill et al., 2005) of a core obtained from the Limnes depression, a small sinkhole located within the Akrotiri Peninsula, Crete (close to the palace of Knossos and other important outlets of the Minoans). This analysis indicates that wetter conditions during the middle Holocene were followed by drier conditions and that around 1450 BC a long stretch of drier conditions commenced ending around 1200 BC. Additional sediment support for drier conditions after 1450 BC is provided by a pollen core obtained from Lake Kournas in Crete. In that core *Tilia* (a temperate European tree) pollen, while present before 1400, has but disappeared in the period 1400–1000 BC. This suggests that annual drought levels reached levels beyond which the tree could not survive (Moody, 2005). Indeed, the tree does not anymore grow naturally in Crete.

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3 Conclusions

We have presented a synthesis of historical, climatic, and geologic evidence which supports the hypothesis that climate change instigated by an intense El Niño activity contributed to the demise and eventual disappearance of the Minoan civilization The North Atlantic Oscillation (NAO) in its positive phase may also bring dry conditions in the Mediterranean (Luterbacher and Xoplaki, 2003). This effect, however, cannot be assessed in the second millennium BC as no proxy NAO data extend that far. Nevertheless, El Niño has been linked to NAO activity (Ineson and Scaife, 2009; Huang et al., 1998; Wang et al., 2009) and this possibility could have accentuated the dry conditions. Climate change and its associated effects will always influence our lives. While nobody anymore expects any civilization to get extinct because of climate, it is becoming clear that convergent events such as earthquakes and volcanic activity in synergy with climate anomalies may produce significant stress to contemporary populations vis-a-vis their social and economic development (Moseley, 1999). It is thus important that we understand how the evolutionary trajectory of early civilizations was disrupted and that even today we may not be completely immune to hazardous stress induced by natural catastrophes.

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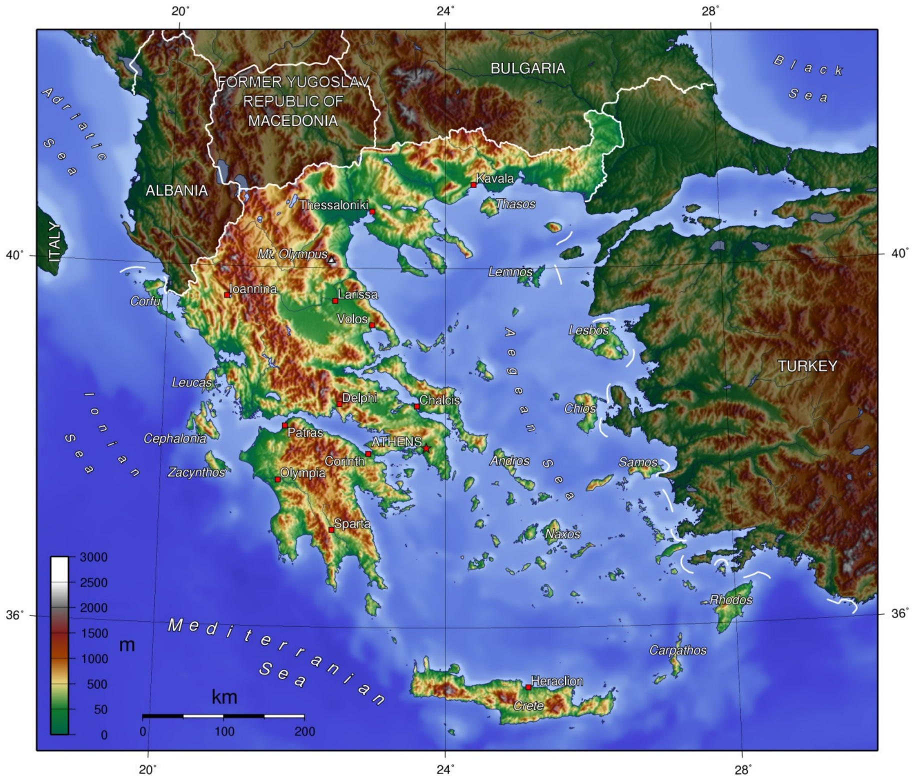

Fig. 1. A map of eastern Mediterranean with Crete on the bottom. Used with permission from the Free Software Foundation.

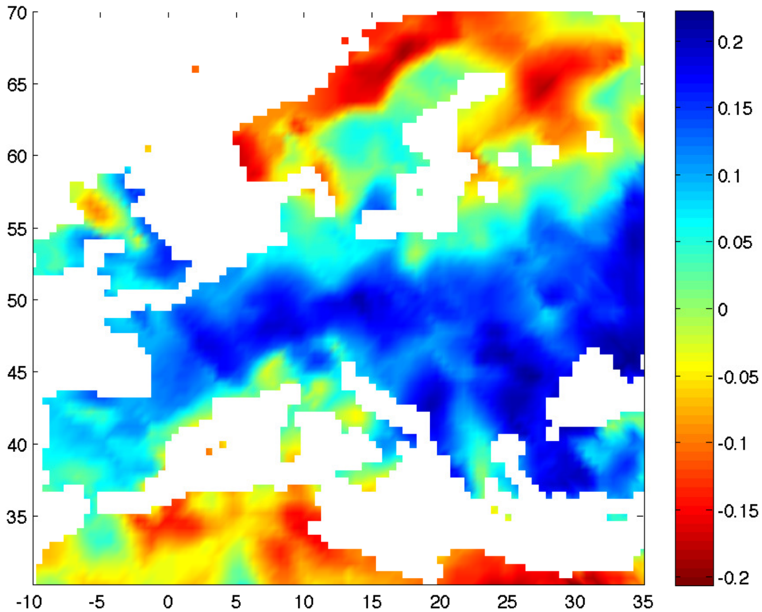

Fig. 2. Correlation between the cold season (DJF) Nino3 index (Mann et al., 2000) and the seasonal (DJF) precipitation reconstruction over Europe (Pauling et al., 2006; Mitchell and Jones, 2005). Red indicates negative correlations corresponding to drier conditions and blue positive correlations associated with wetter conditions. While correlations may be weak the spatial structure is nevertheless non-random. Positive correlations correspond to wetter conditions and negative correlations to drier conditions.

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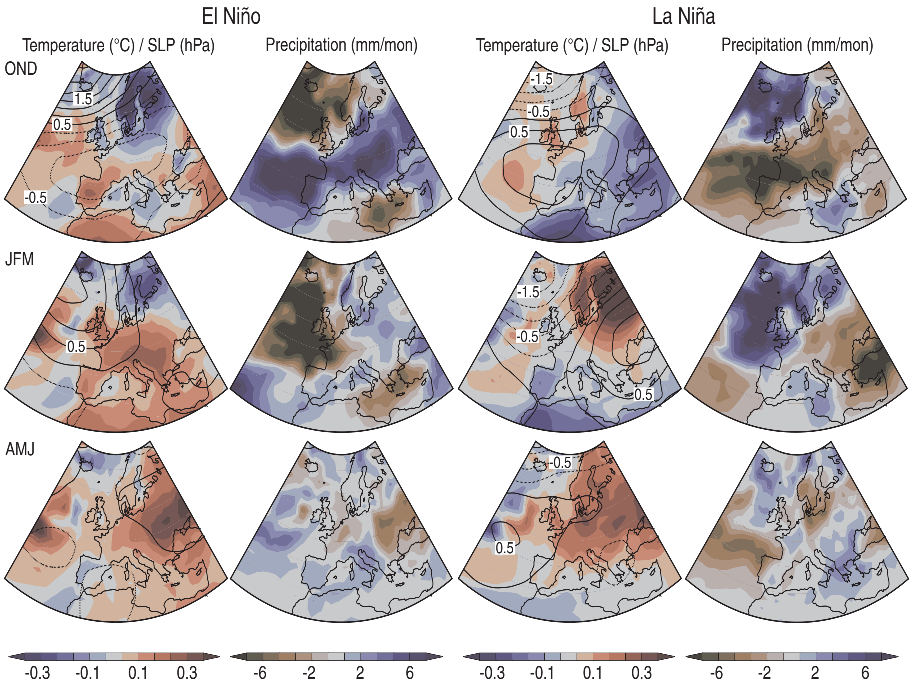

Fig. 3. Anomaly fields of temperature, SLP (contours), and precipitation for strong El Niño and strong La Niña events in 540 years of the control run b30.009 of version 3 of the Community Climate System Model (CCSM3) for different seasons. Strong events are defined when the September-to-February average of Nino3.4 index was outside 1 standard deviation. In the precipitation maps blue corresponds to above normal precipitations and brown to below normal precipitation. In the temperature maps blue indicates below normal values and red above normal values. Consistent with observations, this simulation suggests that by and large the area surrounding Crete, will experience drier and warmer conditions during El Niño (from Bronnimann, 2007; figure courtesy of Stefan Bronnimann).

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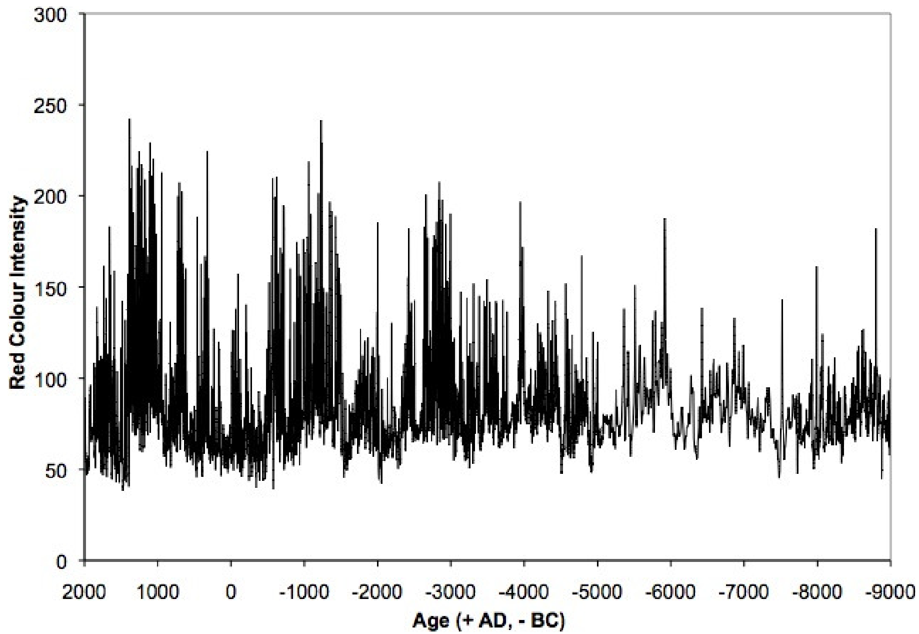

Fig. 4. El Niño proxy reconstruction from Lagune Pallcacocha, Ecuador. High red color intensity indicates an El Niño event. At about 1500 BC a series of strong El Niño events begins that lasts for centuries (adapted from Moy et al., 2002).

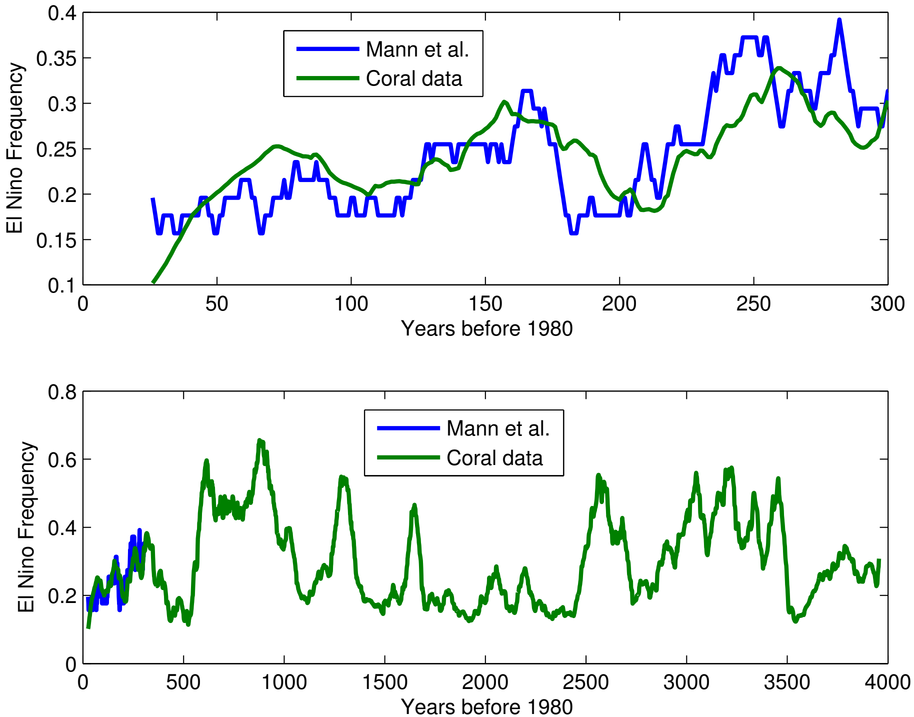

Fig. 5. Comparison between the two ENSO proxies used here during common years. The agreement between the two records is rather good. Moreover, the bootom panel indicated that the intensity of the strech of El Niño events starting at about 1450 BC is much larger than that observed in the last 350 years. This would suggest that the El Niño signal may have been much stronger at the time of the Minoans.

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