Chapter 2
The Science of Climate Change

2.1 Assessing Climate Change: Difficulties and Limitation

Climate change is not an easily understood concept, especially since it is often defined differently by researchers and misunderstood by the popular media. The phrase "climate change" can mean a multitude of things. To understand variations in climatic conditions, there are several aspects that need to be understood, such as the scale of time being used, the length of time for which it has been monitored, and the measures that are being used to identify the changes. This is accomplished by investigating whether or not there is a perceived shift in weather patterns over the past few decades or whether the change being measured has lasted much longer. What exactly are researchers measuring to determine that there is a shift in the climate (e.g., temperature, precipitation, sunlight, or something else)? Are they looking at the changes in climate on a regional or worldwide scale? These are important questions because climate change is often proposed as if the term were universally known and accepted, but the reality is that very few of us understand what climate is and how we track its changes. The purpose of this section is to introduce the reader to the term "climate"means, how we go about measuring its fluctuations, and what, if any, effect it has on human populations when it varies.

The term "climate," as it is presented in many introductory textbooks, is simply defined as the environmental conditions of a particular area over a long period; typically, at least 30 years (Gabler et al. 2007, p. 110). This definition is important because it differentiates climate from the concept of weather. Weather is what is happening in the environment of a region at a particular moment. Thus, weather can change from day to day or even from hour to hour, while climate is the average of the weather in a region over several decades.

One complication with this definition is that it makes it seem as if the average estimation of weather is an impartial estimate. According to Lucarini (2002), there are some major limitations associated with the estimation of climate that are often not discussed. First, the climatic indicators being compared are average fluctuations of multiple indicators of weather that are highly variable at any given time.

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Depending on when they are measured and how often, the estimated climate might be fairly representative or it might not. Second, different researchers collect climate data using different methods, so data compared over a region or over multiple regions may be incongruent.

As Lucarini (2002, p. 414) states, "Due to the complexity of the system, climate dynamics is chaotic and is characterized by a large natural variability on different temporal scales that would cause non-trivial difficulties in detecting trends in statistically relevant terms, even if the observational data were absolutely precise." He cautions, however, that this does not mean that climatic science is a flawed science, but that as with any other science (e.g., bioarchaeology), it is important to recognize the limitations that may be associated with the findings.

Recognizing the limitations of the definition and estimation of climate, another issue that is essential to address is the concept of climate change itself. The term "climate change" is typically associated with the notion of global warming, which has come to be shorthand for the recent and future changes in the climate that are resulting in higher average temperatures worldwide. This typically involves focusing on mapping shifts in anthropogenic (human) activities (e.g., the Industrial Revolution, the development of the automobile industry, or globalization) and the impact these activities have on long-term changes in the weather conditions of a particular area. However, there are a number of ways in which researchers attempt to understand the relationship between humans and their environment. For example, some scientists map climate change by evaluating historic measurements of weather conditions and how the shifts in weather over time (i.e., climate) affected human productivity. Other researchers, compare aspects of the ancient environment against modern conditions to show major shifts or climate events, such as the Last Glacial Maximum, Younger Dryas or Medieval Warm Period, and Little Ice Age.

2.2 Measuring Climate Change

In looking to reconstruct past climates to study the changes over vast periods of time, scientists use various techniques to obtain ancient or paleoclimate data. However, researchers measuring climate in the past (paleoclimate) are not able to directly measure the specific climatic conditions of an area, but instead, rely on either mathematical projections of what was likely or use what are called proxy data. In terms of mathematical modeling, most of the data are based on astronomical changes of the Earth in relation to other objects in space.

2.2.1 Types of Data

There are three ways in which the Earth changes to cause a shift in the climate: eccentricity, obliquity or tilt, and axial precession or procession of the equinox.

Together, these processes create what are known as the Milankovitch cycles (Snyder 2010, p. 414). Eccentricity is the fluctuation of the Earth's orbit around the Sun in relation to how far apart they are at different times of the year. The distance varies as the orbital trajectory alternates between being more circular or elliptical (Rohli and Vega 2012, p. 278; Desonie 2008, pp. 25–26). The second process Milankovitch found was the changes in obliquity, a gradual shifting in the tilt of the Earth over time; it can vary between 2.4° and 2.6° (Rohli and Vega 2012, p. 278; Desonie 2008, p. 26). The final process is the axial procession, which is typically described as the process where the rotation of the Earth is said to wobble like a spinning top (Rohli and Vega 2012, p. 279; Desonie 2008, p. 26). The wobbling or deviation away from a perfect rotation is the result of the gravitational pull of the Sun and the Moon (Freedman et al. 2011, p. 34). The importance of the Milankovitch cycles is that they have been suggested to be the cause of major climate change events, such as the Pleistocene or Quaternary ice ages (see Fig. 2.1) (Desonie 2008, pp. 27–28; Hays et al. 1976, p. 1131).

The problem with using the Milankovitch cycles to explain climate change is that these are slow events that span tens to hundreds of thousands of years. So, it is difficult to identify precise climate conditions of a region at a specific time. Additionally, there is the problem of how these cycles affected a group's lived experience. Were they even aware of the shifting cycles of the Sun? Looking at populations in the US Southwest, it could be argued that people in the past were aware of at least some aspects of the Milankovitch cycles.

Among the Ancestral Pueblo associated with the Four Corners region of the US Southwest, there is evidence that astronomical events were especially important to the people. A number of sites were constructed with a cosmological orientation focused on the solstice and cardinal directions (Lekson 1999; Munro and Malville 2011; Sofaer 2007; Sofaer et al. 1989). The earliest and the largest of these sites are located in Chaco canyon in North Central New Mexico. One site in particular is noteworthy for its astronomical alignment, Pueblo Bonito, which is the largest architectural building in the canyon that was initially constructed around A.D. 860 (Lekson et al. 2006; Windes 2003; Windes and Ford 1996).

Symbolism is extremely important at Chaco canyon as it seems to be at the heart of the road system and is reflected in the fact that many of the sites and structures are aligned along astronomical and cardinal orientations (Sofaer 1997, 2007). Munro and Malville (2011) argue that the importance of the astronomical alignment was that it was a means for the elite to demonstrate their ability to predict the movements of the heavens above them, and that the architecture built on the landscape may have functioned as a form of veneration. Yet, it may be that while these other functions were important, the Pueblo people could also have been tracking and attempting to understand changes in the seasons. It has been proposed that other past cultures, like the Maya, may have developed a complex means of tracking changes in the Milankovitch cycles (Melchizedek 2012, pp. 32–33). It is possible that the drought-prone people of the Southwest may have been interested in mapping these cycles as well because their livelihood was tied to tracking their local climate conditions.

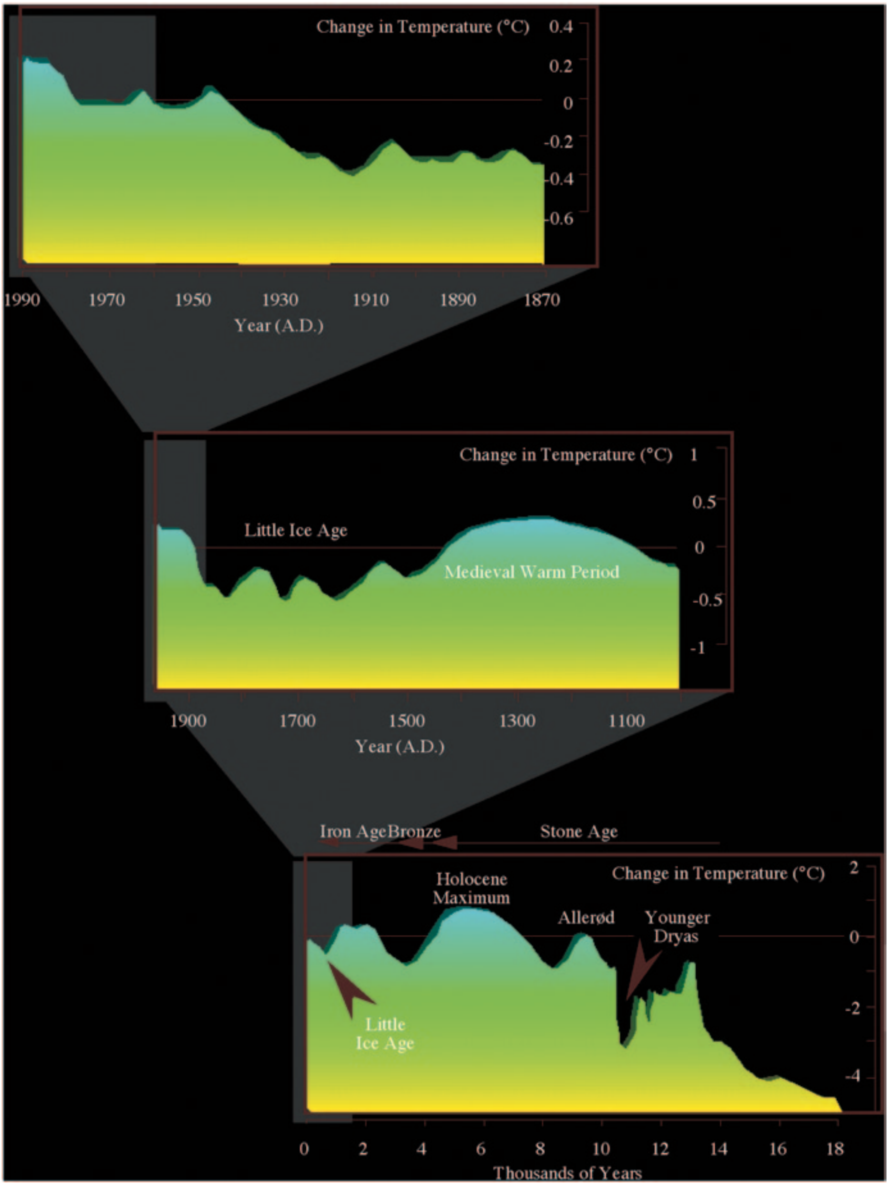

Fig. 2.1 Climate change and ice ages. Modified from Wikimedia Commons (Webb 1991)

Yet, despite attempts to predict the astronomical cycles and their potential impacts, these changes are unlikely to have affected the day-to-day lives of people in the past. What is more pertinent is the impact of catastrophes like earthquakes, volcanoes, and cycles of changes to the environment. To reconstruct these types of changes in the past requires the use of proxy data.

Proxy data includes using both the abiotic (all nonliving aspects that make up a particular environment) and biotic (plant and animal life) characteristics of the landscape. The most common proxies utilized to track changes in the climatic conditions of a region are the differences in tree-ring size (i.e., dendrochronology), and the variance in the isotopic signatures derived from ice cores, lake sediments, shell, and animal or human bones.

Speer (2010, p. 2) suggests that dendrochronology is the most accurate of the proxy data used to record climate change (e.g., ice cores, lake sediment, and pollen). Dendrochronology is the science of recording annual shifts in precipitation within a region by measuring the diameter of new tree growth as evidenced by a series of concentric rings. According to Martinelli (2004, p. 129), the reason why dendrochronology is the preferred proxy measure of climate change is that it provides both short- and long-term intervals of change. Given dendrochronology is one of the earliest and most reliable proxies for reconstructing past climates it has become a cornerstone of much of the archaeology that has been and is being, conducted in the US Southwest. Beginning with the work of Douglass at the turn of the twentieth century, dendrochronology was applied at a multitude of archaeological sites in the US Southwest (Douglass 1929). By dating the timber used in the construction of the multiroom architecture, researchers are able to recreate the environmental conditions around the time when there was an increase or decrease in construction at sites. For nearly half a century, most climate reconstructions in the US Southwest have relied on shifts in precipitation, typically using the Palmer Drought Severity Index. The result is that the Ancestral Pueblo is one of the best climatically documented cultures in the world with reference to precipitation. In fact, it has been suggested that modern climate models based on precipitation can be improved by using the dendrochronological reconstructions in the US Southwest, such as the North American monsoon and its long-term effects (Leavitt et al. 2011).

According to Burke et al. (2009), however, there are problems with simply analyzing precipitation alone. They argue that it is a growing trend in modern climate studies to focus on proxies beyond precipitation, and of particular interest are those measures that identify variations or fluctuations in temperature. The reason for the shift from precipitation to temperature is twofold. First, it is less complicated to model temperature changes in the future and more accurate than predicting shifts in rainfall or cycles of oscillation, allowing for the development of more precise models of climate change (Burke et al. 2009). Second, the effects of precipitation changes in a particular area are variable depending on other geomorphological features of the landscape, and as a result, the impact of precipitation is highly unpredictable.

The fact that precipitation is variable is problematic not only because it is difficult to find patterns but also because cultures tend to adopt ways of dealing with mild and moderate fluctuations in rainfall and runoff. Wolf et al. (2003, p. 6) argue that "the entire causal relationship between hydroclimatology and water-related political relations, however, is certainly complex and strongly dependent on socioeconomic conditions and institutional capacity as well as the timing and occurrence of changes and extremes in a country and basin." The reality is that there is no simple relationship between the presence or absence of water and violence, and instead a researcher must consider many other factors that could correlate with how a culture will react (i.e., violence) to a change in the climate. The logic for questioning any explanation that relies solely on drought is best articulated by Wills (2009), who says there are inherent problems with correlating the fine chronological sequence provided by paleoclimatological measures with the more abstract, archaeologically obtained chronologies.

There are problems with all estimates of climate change because most mathematical models are too broad, and despite the fact that proxy data can reveal climatic conditions, they are also potentially affected by other variables. Buchdahl (2010) describes the limitation of these proxies using the analogy of a signal and the noise, suggesting that while proxy data provide a signal, this signal is often hard to discern because of the noise that is associated with it. Besides the other factors that could potentially be contributing to the changes in proxy data, Moberg et al. (2006) argue that proxy measures often only represent specific climate areas and not the entire region. The unique geomorphology of each area within the larger region could potentially have a number of other factors that are contributing to the climate. The problem is that the research focuses solely on indicators of climate and does not look at all of the other aspects of the environment that people interact with and are affected by, which results in either overlooking or ignoring of other indicators.

One approach is to use multiple proxies that measure changes of different aspects of the climate (i.e., precipitation and temperature) to establish the broader, more inclusive baseline for the region. There are, however, researchers who argue that there are inherent limitations to constructing models that incorporate multiple proxies as well. According to Bürger and Cubasch (2005), one limitation of utilizing multiple proxies is that it increases the error rate of the climate estimates due to calibration issues. However, they note that this is something that can be overcome by utilizing precise mathematical methods and regularization schemes to reduce the error rate (Bürger and Cubasch 2005). The best approach to recreating the climate of a particular region is to use multiple proxies and accurate modeling of the geomorphology of the region under study (e.g., topography, elevation, and vegetation). This has been demonstrated in the US Southwest by Benson et al. (2013), who found that to accurately reconstruct the maize productivity of a particular region, it is imperative to understand the role of soil productivity and depth, elevation, and the growing season in addition to the traditional temperature and precipitation reconstructions.

As Benson's study suggests, climate is just one of the many features of a particular environment and ecology. The environment and ecology describe the physical landscape and climatic pattern of a region. Additionally, environment and ecology can also be utilized to explore the role of the humans in the environment.

> 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. (Berger 2009, p. 14)

2.2.2 Looking Beyond Climate to Understand the Environment

Even with the exclusion of the most unpredictable factors, humans and their cultural innovations, it is very difficult to accurately recreate the environment of a particular region. It requires an understanding of variations in other factors beyond the climate that also play a role, such as elevation, geomorphology of the landscape, vegetation, and latitude. Mapping periods of violence against all of these other factors, makes it more difficult to map human behavior over large geographical regions. Environmental factors are typically separated into two categories: abiotic and biotic features of the landscape.

Biotic factors include all of the living things on a landscape. Abiotic features are the nonliving aspects of a particular environment including climate, geomorphology, and soil type and distribution. Geomorphology is defined as "the study of the classification, description, nature, origin, and development of landforms and their relationships to underlying structures, and the history of geologic changes as recorded by these surface features" (Bates and Jackson 1984, p. 208). Geomorphology is crucial because shifts in climate within a region differ according to changes in the terrain. In fact, the interaction between the landscape and climate is crucial to the development of biotic communities. The geomorphology of the landscape directly affects the vegetation as a result of differential interactions between annual precipitation and soil accumulation, and the type of vegetation determines animal populations found in the region.

The impact of vegetation on the carrying capacity of a region is especially crucial to understanding when the role humans play in the modification of the environment is considered. Even in the past, there is evidence of humans significantly modifying their natural environment. In the US Southwest, for example, Pool (2013) looks at the Classic Mimbres culture to argue that cultural practices were increasing the effects of climate change. His research shows that in the past, agricultural societies were probably having an impact on their environment; they did so, by engaging in intensive agriculture that resulted in changes to the ecological nature of the landscape. One possible human-caused change that could have happened in these cultures, according to Pool, was that there was a loss of nutrients and minerals in the soil as well as extensive soil erosion. With intensive agriculture in ancient societies, crop rotation and movement of fields was not always practiced. These findings are supported by Minnis and Sandor (2010), whose analysis of soil productivity in the Mimbres Valley over the past 1,000 years revealed evidence that the soil has yet to fully recover from being overused by the Mimbres culture in prehistory.

2.3 Summary

The intent of this chapter is to illustrate that measuring and identifying the effects of climate change can be an arduous endeavor, and despite the scientific nature of the findings, interpretation is not always a straightforward process. Even when humans are taken out of the picture, it can be difficult to know exactly what happened in a particular environment and to determine how these changes may have necessarily impacted the ecological context. Yet, there is a wealth of information that can be generated by carefully scrutinized climatic data that, in conjunction with archaeological reconstructions, can provide important information on the interactions between the natural and cultural environment in the past. In fact, this collaborative work has important implications for understanding the role of humans in climate change events. Because of the long periods of time that archaeologists work with, long chronological sequences of climate data can be used to reconstruct human activities before, during, and after events such as long droughts, volcanic eruptions, or periods of cold and dry weather, all of which affected the various cultures living in the US Southwest.

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