Chapter One

The Mediterranean Climate

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Formation and structure of the Mediterranean climate system

The Mediterranean is the remnant of the Mesozoic and Cenozoic Tethys ocean (about 250–35 million years ago), which bounded the ancient land masses that geologists call Laurasia and Gondwanna. As the African plate moved northward into the Eurasian plate and the mountain ranges that stretch along the southern rim of the Eurasian continent—the Alps, Dinarides, Carpathians, Taurus, Alborz, and others—were lifted up, the connections between the western part of this ocean and the Indian ocean, as well as those with the shallow sea (the Paratethys) that covered a basin reaching from north of the Alps to the area of the Aral sea, gradually narrowed and at last, about 11 million years ago, closed off. This left behind a string of inland seas, the Black, Caspian, and Aral to the east, and to the west an inland sea whose only (intermittent) connection to the world's oceans was through the narrow and relatively shallow straits of Gibraltar.

What one normally understands as "the Mediterranean climate" with its relatively wet winters and dry summers does not go back to this very early date. It emerged between 7000 and 5000 years ago, around the middle of what geoscientists call the Holocene, the period since the end of the last ice age, when the Mediterranean reached its modern high stand and changes in the forest cover near its shores produced environments favorable to human agricultural and pastoral settlements (Robinson *et al.*, 2006; Perez-Obiol *et al.*, 2011). Nevertheless, the very early geological history is essential to understanding the broader framework within which this late-Holocene climate evolved. The shrinking of the shallow Paratethys changed the Eurasian climate from oceanic to continental conditions, with colder winters and hotter summers. At the same time, the slow closing of the connection to the Indian Ocean led to drier conditions in Anatolia, the Arabian peninsula, and North Africa. All of these set the fundamental conditions for fresh water flows into the emerging Mediterranean, just as the narrowing of the western straits set those for oceanic flows (Lionello, 2012: 18–47). They also set the conditions for the complex seasonal atmospheric flows.

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As an inland sea the Mediterranean is dominated by three atmospheric systems, with their pressure ridges and troughs and the storm systems associated with them. The first, and most important, is the flow coming across the north Atlantic, whose strength and direction is determined by the relative strengths of the low pressure system west of Iceland and the high pressure system south of the Azores. The variation in this system is known as the North Atlantic Oscillation (NAO). When in its "negative" state, with a relatively weak pressure gradient, the westerly jet stream and its attendant storm centers (cyclones) flow along a southern route, commonly over Scotland and Denmark. Along with the wintertime Siberian high, this can push cold, wet winter storms as far south as Italy (as it did, for example, in 2000). In its "positive" state, with a steep pressure gradient, the jet stream travels further north, bringing milder winters to western and central Europe and drier winters to the Mediterranean (Pavan, 2008; Martin-Puertas *et al.*, 2010). The second flow is the African monsoon, originating in the Intertropical Convergence Zone (the climatic equator), whose seasonal movement north brings late-summer precipitation to the sources of the Nile in the Sahel and the Sudan as it encounters the return flow of winds from the Indian monsoon. The latter, known locally as the "Etesian" winds, blowing off the Anatolian plateau bring arid summer weather to the Levant (Raicich *et al.*, 2003). The winds from the African monsoon also blow Saharan sand over the North African coastal plain and dust as far as Iberia and France. There they encounter cold from the North Atlantic and may "seed" hail storms, such as the historic storm of July 13, 1788, the final blow to the northern French grain harvest that year and the antecedent to the bread riots that touched off the Revolution (Le Roy Ladurie, 1971: 76; Lionello, 2012: lxxii).

Over the very long term, millennial and pluri-millennial, these atmospheric flows have been strongly affected by changes in the amount of incoming solar energy, changes caused by complex variations in the earth's orbit. On a shorter term, they also appear to be affected by sun-spot cycles and other variations in solar energy, as well as by random events on earth, such as volcanic eruptions—the "years without a summer" in 536 and 1816 CE, for example (Robock and Free, 1996; Gunn, 2000; Larson *et al.*, 2008; McCormick *et al.*, 2007 and 2012). Very recent changes in the climate have been caused by human activity that has pumped greenhouse gases into the atmosphere. Whether or not there were past changes in climate due to human activity in Mediterranean lands remains a subject of debate.

Because air and moisture flow over continental land masses before reaching the Mediterranean they form very different regional micro-climates. What is familiarly thought of as "the Mediterranean climate" of wet winters and hot, dry summers—the climate of the Costa Brava, the Côte d'Azur, and the Greek islands, the lands of olive and vine that fires the imagination of northern tourists and was lyrically evoked by Braudel—is only one of many surrounding the inland sea. Among them are the subtropical and mid-latitude steppe of south-western Iberia, western North African coastal areas, parts of Greece and Anatolia, the maritime and humid temperate zones in the Balkans, and the subtropical desert of North Africa (Lionello, 2012: map xl). Winter rainfall is heaviest around the Gibraltar strait, on parts of the Algerian and Tunisian coast, Calabria, the eastern Adriatic, Ionia, and the Syrian–Lebanese–Israeli coast, while in some areas not far inland amounts can drop by half. The Alps generate a year-round low-pressure region in the gulf of Genoa, which makes the eastern Alps and the eastern Adriatic one of the wettest zones. During the winter these storms can track as far as the Ionian coast. At the same time, the winds off Anatolia can create another low-pressure center east of Crete, bringing winter rains to the Levantine coast. Meanwhile, from Morocco to Syria, the desert is everywhere close at hand. As anyone who has stood on Mount Scopus, north-east of Jerusalem, has seen, the line between vegetation and the desert can be as sharp as a knife's edge. Summer mean temperatures reach 30 °C from Tunisia eastwards to Syria, 25 °C in southern Iberia and along the Moroccan-Algerian coast as well as along a narrow coastal band of France, Italy, Greece, and Turkey, while inland temperatures drop to means common to all of western Europe, and the cool of the Alps, the Dinarides, and Anatolia are not far away.

These air, heat, and moisture flows also generate the winds whose names and force have been legendary since antiquity: the easterly Levante and the westerly Ponente blowing through the Strait of Gibraltar; the Mistral, whose force can reach 90 km per hour in the Rhone valley and often be felt as far as the African coast; the Bora from the eastern Alps blowing down the Adriatic, flooding the lagoon of Venice, and influencing weather east to the Aegean during the winter; further east, the Etesian, already mentioned; and finally, from the south, especially in fall and spring, comes the Sirocco, stirred up by North African highs.

In the sea itself, alterations of temperature and salinity create two major basins, west and east, and a number of sub-basins within them. From the Atlantic and, in much lesser amounts, from the Black Sea, precipitation, and rivers, come fresher, colder water. Winter-time cold and dry winds from the north and summer-time heat cause evaporation. The result is a flow of relatively less salty surface water eastward along the African coast becoming increasingly salty as it moves in a counter-clockwise (cyclonic) gyre through the Tyrrhenian. Some of that west basin water flows through the Sicilian strait and rapidly becomes yet saltier and warmer than in the west, reaching its highest salinity between Cyprus and the Levantine coast, about 9% saltier than the water coming through the straits of Gibraltar and 13% saltier than the average of the world's oceans (Rohling, 2001). Only the north-eastern Aegean, freshened by water flow from the Black Sea, has a salinity level as low as that just south-east of Gibraltar. As the surface saltiness gradient runs west to east, the surface temperature gradient runs north to south, cooled by winds off the European continent and thus coldest in the Gulf of Lion, the northern Adriatic, and the northern Aegean, and warmest along the Syrian–Lebanese–Israeli coast.

These two gradients create the basic vertical movement of waters (and thus also of oxygen) within the two basins. The flow of surface water eastward would tend to sink were it not for its increasing temperature which keeps it lighter than the deeper waters. In the winter, however, as those surface waters are cooled, in particular by the winds blowing off the Anatolian plateau, they lose their relative buoyancy and sink, mixing with the waters below, carrying with them both oxygen and nutrients. Near the Sicilian "sill," these lower lying waters (in technical terms Levantine Intermediate Water) mix with others stirred up and cooled by winds blowing from the Alps onto the Adriatic, forming the deepest strata of the sea, the Western Deep Water. To the west, winter winds also churn up currents in the Gulf of Lion. In both regions this mixing brings the oxygen and nutrients in the deeper water flowing from the Levant up to levels where light can penetrate, thus bringing together the three factors necessary to support plant and animal life. The same up-welling is found in shallow coastal areas of the northern Aegean, enriched by the inflow from the Black Sea; off the coast of Catalonia, enriched by nutrients from the Ebro river; and in the Alboran Sea just west of Gibraltar. These are the richest fishing grounds in a sea that, compared to the major fishing grounds of the world's oceans, is relatively poor in plant and animal productivity (Lionello, 2012). That productivity was, furthermore, significantly reduced after 1964 by the construction of the Aswan Dam, which cut off the flow of nutrients from the upper Nile to the sea.

All of these—winds, salinity and temperature differences that cause vertical exchanges within the various basins of the sea, all the various land masses around and islands in the sea, as well as the varied topography of the sea bottom—create the complex surface currents of the Mediterranean: the counter-clockwise circulations in the western and eastern basins and the various eddies that form both permanently and seasonally in both of them. It is also important to note that the conditions creating equilibria in these various flows remain in part unknown, and the consequences climate change might have for them are thus difficult to predict (technical details in Robinson *et al.*, 2001).

Climate variability since the mid-Holocene

A half-century ago the title of this section would have been met with raised eyebrows, if not dismissed out of hand. The dominant view at that time was still that climate has not changed—apart from minor fluctuations—since temperatures reached their maximum after the last ice age about 9000 years ago. Because climate did not vary significantly, it could therefore be ignored in the analysis of historical events, short-term or even long-term.

"Minor," as in "minor fluctuations," is of course a matter of scale. Project the size of human population since 100 000 years ago onto a graph, with time as the horizontal axis, and the sudden and huge demographic rise since the mid-eighteenth century will make it appear that there were no "significant" variations before then: the required size of the vertical axis reduces earlier rises and falls to changes invisible to the naked eye. Project European population from around 1000 to 1750 and the change in the dimension of the vertical axis will make the great demographic wave of the central Middle Ages and the trough that begins with the great famine of 1314–1315 and plunges with the onset of the plague in 1348 all too clear. To those who lived through these events they were not "minor fluctuations." And so with climatological data. A number of Arctic and Antarctic ice cores go back through the last glacial period and a handful to the glacial period before that (Bradley, 1999: 126). When one of the paleoclimatological "proxies" from those cores is graphed—for example changes over time in the relative concentration of oxygen isotopes reflecting changes in temperature—the difference between the temperatures at the glacial minimum and those at the Holocene maximum are so great that even major Holocene cold events, such as the one that occurred about 8200 years ago (the "8.2 ka BP event" in paleoclimatologist shorthand), are reduced to what looks like a minor blip in a nearly straight line. In that very long view the climate has been "relatively stable." But we must remember that the creation of all of what we think of as human civilization—the domestication of plants and animals, the building of permanent settlements and the social organizations that developed within and around them—occurred since the mid-Holocene, and the agriculture on which it has depended is itself critically dependent on a narrow range of temperature and water supplies, "narrow" in comparison to the wide swings from glacial to inter-glacial. It is therefore to those "minor" variations during the Holocene that historians of human communities must pay attention.

As recently as the 1960s relatively little was known about those variations, and historians were generally skeptical even about inquiring into what they might have been. At the beginning of the twentieth century the geographer Ellsworth Huntington, contemplating the vanished cities in the deserts of the eastern Mediterranean, argued that

> unfavorable changes of climate have been the cause of depopulation, war, migration, the overthrow of dynasties, and the decay of civilization; while favorable changes have made it possible for nations to expand, grow strong, and develop the arts and sciences. (Huntington, 1913: 223, citing 1911: 251)

But his theory of worldwide climatic "pulses" and his strong climate determinism were enough for his contemporaries and generations of successors to put him on the shelf of science fantasy, along with his exact contemporary, Alfred Wegener and his theory of continental drift. There the subject of climate change would long remain. Braudel could consider the idea of an extended period of colder climate as the source of problems in the later sixteenth century to be but one speculative hypothesis among many (Braudel, 1972–3: 272–275).

In retrospect, Braudel's caution is hardly surprising. In 1962, the meteorologist Reid Bryson, in his introduction to a summary of findings of an international paleoclimatology conference, had been unsparing in his evaluation of most current work:

> [There is] too much theorizing about the causes of climatic change without a firm factual basis as to the nature of the change, and … for one reason or another the study of climatic change [is] plagued with an inordinate amount of mediocrity. (Bryson and Julian, 1962: 1)

That situation was about to change, to a large extent as a consequence of that conference and the work of the geologists, biologists, anthropologists, meteorologists, and historians who attended it. The sixteenth century was set as one focus for these scholars, and the data they shared amply demonstrated the beginning of a long cold period over Europe, as well as related changes elsewhere in the northern hemisphere, beginning around the middle of that century. What Braudel considered speculation was shown to be an identifiable period of modern climate history, soon to be known as the Little Ice Age or simply the LIA (Le Roy Ladurie, 1971). For the eleventh century, the other conference focus, the specialists concluded that the available data were insufficient to judge whether that was also a period of climatic "anomaly" (a deviation from a set of mean values) in the opposite direction, a warming period. The British meteorologist H.H. Lamb, who had been arguing forcefully for such a conclusion (Lamb, 1959 and 1968), must have been disappointed. The recognition of the Medieval Warm Period would take longer, but in time would also become part of the standard schema of the climate history of the last millennium (Jones *et al.*, 2001; Osborn and Briffa, 2006).

More significantly, the assembled specialists envisaged the kinds of data they hoped to see collected and the scientific problems that would have to be addressed. They also called for continued cooperation and sharing. The seeds were planted that would soon grow into the flourishing field of paleoclimatology, with its research centers, its journals, its intergovernmental committees, such as the Intergovernmental Panel on Climate Change (IPCC), and its international programs, such as MedCLIVAR (Mediterranean Climate Variability), which brought together 134 scientists to produce the massive survey *The Climate of the Mediterranean Region: from the Past to the Future* (2012).

Although North American anthropologists–archaeologists participated in the 1962 conference, Old-World archaeologists were not invited. The reason was simple: in Western Europe, archaeology did not go beyond the classical period. Even late antique remains were commonly ignored. Only in Eastern Europe and Scandinavia did practitioners pay attention to material from the first millennium CE, as part of the "late Iron Age." Elsewhere, "Christian archaeology," as it was then sometimes called, was largely confined to the study of church buildings. That too was about to change.

In 1969 the then young archaeologist and geoscientist Claudio Vita-Finzi brought attention to the alluvial soil that had buried Roman-era waterworks in North Africa, associating this alluvium with what he termed the "younger fill," low terraces in river valleys around the Mediterranean, from Spain and Morocco to the Peloponnese and the Jordan rift. In some cases, such as Olympia in Greece, this fill covered whole cities. Given the dating of this fill, and above all its composition everywhere it is found, Vita-Finzi argued that one of the causes of the extensive erosion to which it testified was an important change in rainfall patterns, whose beginnings he dated to late antiquity (Vita-Finzi, 1969). Thus began a debate that still continues: was erosion around the Mediterranean caused by human "degradation" of the land by clearing, plowing, and putting animals to graze, or by climate change? Out of this debate has come extensive research by hydrologists, soil scientists, and archaeologists on kinds of erosion and the soil types, vegetation, and precipitation patterns that promote them.[1] Vita-Finzi has been shown to be at least partially correct, and studies of erosion have contributed in a major way to identifying yet another major climate anomaly of the most recent two millennia: the fifth to the seventh century (for example Constante *et al.*, 2011).

Sources of data

Although paleoclimatology is now a highly technical scientific enterprise, at its most basic the kinds of questions its practitioners ask are similar to those that all scholars face who attempt to understand the past. All start with objects the vanished past has left behind. The first question they must answer is: from when do they date? Then, why do they have their particular form, language, and content? Only then can they turn to the ultimate task, constructing a plausible narrative to make sense of what they have found and filtered. In the case of human history (in the older and now outdated sense that distinguishes "history" from "pre-history"), the source materials have traditionally been written documents—newspapers, chronicles, laws, land titles, letters, literature. The questions about form and language will ask, for example, why particular words are used and what they meant at the time they were used; why a document has its particular shape and content and what clues this might give to understanding what it tells and what it may occlude. The narrative will be a story of human thought and action, thus with a time scale gauged by human life spans. In archaeology the materials will be potsherds and bones, standing or buried buildings, or sometimes only dark stains in the soil that reveal ancient ditches or post-holes. The questions will be first of all about the particular form of those materials and what they may reveal about such things as food sources, commerce, wealth, and social organization. The narrative will again be about human actions, though the actors will most often be anonymous or collective, and the time scale will run from generations to centuries.

In paleoclimatology the source material for very recent periods is instrumental data. In the Mediterranean region, continuous series go back to the early nineteenth century, but other discontinuous records go back as far as the seventeenth. These, of course, must be recalibrated to match modern measurements. In addition, many other sources of information can be exploited, though converting them into normalized series presents its own set of problems. There are ships' log books which record wind speeds and directions, as well as a multitude of other kinds of individual records made for professional reasons (for example, by military officers, shipping companies, botanic gardens) or simply out of curiosity. These add to what is available for the last 300 years (Brázdil *et al.*, 2010; Camuffo *et al.*, 2010; Lionello, 2012: 92–98).[2] Chronicle mentions of unusual or extreme weather events start to become voluminous in the fourteenth century (Alexandre, 1987). Records of the date of grape harvests (reflecting summer temperatures) have been reconstructed with increasing density from the fifteenth century on, and comparisons of variations in these dates with instrumental data from the eighteenth and nineteenth century show a strong correlation (Le Roy Ladurie, 1971 and 2011). By the eighteenth century, the indirect consequences of weather variation is increasingly reflected in records of local food supplies found, for example, in parish tithe records and the registers of towns and cities concerned with feeding their populations. These series can, likewise, be correlated with weather data (Pfister, 1984–1985; Frenzel *et al.*, 1992). In the eastern Mediterranean, Byzantine and Arab narrative sources as well as the letters of the Cairo Geniza, likewise sometimes mention extreme weather events, and compilers from the fourteenth century onwards report the height of the Nile floods back to the beginning of the Islamic period (Stathakopoulos, 2004; Ellenblum, 2012). The recovery and correlation of this non-instrumental data has barely begun, however. One can only dream of what may still be hidden, for example, in the Venetian and Ottoman archives.

To study climate before the advent of instrumental records, paleoclimatologists turn to what they call "proxies." These are physical deposits that in some way reflect changes in precipitation and temperatures over time and thus stand in for instrumental data. The great advances in the discipline since the 1970s have been, first, discovering what such deposits might be, and what about them might reflect changes in the ambient atmosphere in a measurable way; second, learning how to date such deposits more accurately; and, finally, developing statistical operations that can turn this data into meaningful narratives. The time scales of these narratives (most commonly in the form of graphs) may, in rare cases, be as short as decades or even years, but far more often they are centuries or even millennia. Everything depends on the proxies being measured and the techniques of analysis and correlation.

In terms of time scales, proxies are either low resolution or high resolution, depending on the nature of the evidence, or sometimes on the interests of the research team publishing the results. Low temporal resolution proxies are those that register changes datable to centuries or millennia. Such are the data extracted, for example, from micro-fossils taken from the bottom of the sea. The profile of species populations and the oxygen isotopes in their shells can reveal changes over time in sea surface temperature and the oxygenation of water at different depths, and therefore, by implication, changes in air temperature and rainfall. Similar kinds of data have been drawn from analyses of sea bottom sediments as well as sediments from lakes. More recently, work has been directed at extracting information from corals on long-term changes in water temperature, nutrient content, and water circulation. As we shall see, this research has raised important questions about the conditions in which Neolithic cultures developed in the eastern and southern regions of the Mediterranean basin. Because of the time it takes for bodies of water to respond to atmospheric changes and then for the populations of aquatic plants and animals to respond to changes in their environment, the dating of such changes must necessarily be quite broad. It is the same for other physical processes that change slowly over long periods of time: the accumulation of soil in ditches and alluvial fans, the alterations in regional plant populations, the rise and fall of lake levels which leave their marks in shore-line terraces, the uncovering of former moraines as glaciers retreat.

Very different are physical, chemical, and biological processes that respond quickly to changes in temperature and precipitation: the seasonal growth of plants, the sediments that mark river floods, annual layers in accumulated arctic and antarctic ice, even the growth rings of speleothems in limestone caves. Tree rings in a few species can be dated to the year (and thus to the growth season) as series have been reconstructed going back 5000 years or more (Büntgen *et al.*, 2011). With somewhat less precision, the varves of lake sediments can be counted back from the present, thus dating the plant and micro-faunal remains in them as well as changes in their mineral content.

What we might think of as medium-term resolution dates are provided by radioactive isotopes, most commonly C^{14} from organic material from the Holocene, whose dates are then calibrated using standardized curves (available from Cologne University at www.calpal-online.de).[3] Other isotopes are used for deposits further back in time. Because the confidence range of such dates may be rather wide (a century or more), proxies dated in this manner are only congruent with geographic or economic changes occurring over an equally long period of time. Their temporal uncertainty is increased as the dates of strata in between those dated by C^{14} must be interpolated by assuming even sedimentation.

Once proxies are dated, it remains to find the “signal” of climate variability in what one is measuring. For, unlike instruments, proxies do not directly measure the properties of climate. In their formation, temperature and precipitation are mediated by complex physical, biological and chemical processes. Whether one is measuring changes in the width of tree rings, oxygen isotopes in the carbonate of mollusc shells, the silicates in lake sediments, or some other physical feature, climate variations are only a part of the complex physical systems that shape them. Other aspects of those physical systems, some of which may be quite random (that is, unspecifiable), may also be reflected in what one is measuring. They are the “noise” that one must somehow filter out to identify and measure the climate "signal." Meeting this challenge is a constant preoccupation in the scientific analysis of paleoclimatological proxies. It is also one of the reasons why practitioners look for climate signals in a variety of different proxies. One hopes that the sources of noise in the measurement of one proxy are different from those in another. If this is the case, and the climate signal one has discovered in one proxy conforms to that in separate studies of others, together they increase confidence in the results. Paleoclimate research is, above all, cumulative.

To find the climate signal, paleoclimatologists calibrate recent changes in the particular material they are analyzing with instrumental weather records over the last 100 years or so registered nearby. Thus they assume that the biological and chemical processes in the plants or animals being studied have not changed over millennia. This, however, is the only way to measure mathematically what portion of the change they have detected comes from climatic variations. The need for nearby weather records also presents particular problems for Mediterranean research, for while there are many such weather records around the northern shores of the Mediterranean, around the southern shores they are rare, save in Tunisia, the Nile valley, Israel, and Cyprus.

Of the proxies listed above, there are relatively numerous low-resolution examples available for the Mediterranean (Lionello, 2012: table 1.1 and 58–86) which present interesting questions especially for eastern regions from the early Holocene through the Bronze Age. Of high-resolution proxies for the most recent two millennia, however—the kind that would be of interest to most historians of the ancient, medieval and modern periods—written, archival evidence is potentially the richest source. Of physical evidence, only river flood records are at the moment sufficiently numerous and sufficiently lengthy: Tiber records, for example, go back to antiquity (Aldrete, 2007). More importantly, records are available for both western (Spain, France, Italy, Tunisia) and eastern (Greece, Turkey, Israel) river systems. Although some published studies have only centennial or longer-period resolution, others identify individual flood events on annual or decadal scales (Lionello, 2012: 108–112).

In contrast, at the time of writing, there are only a handful of published tree-ring-based Mediterranean temperature and precipitation series reaching back more than 600 years, and the only one that includes the first millennium CE is from the Austrian Alps (Lionello, 2012: 99). Tree-ring research has focused primarily on high-altitude sites, where growth is particularly sensitive to temperature fluctuations and to early summer rainfall (May, June, July)—not the relevant season for Mediterranean agriculture. Furthermore, the published studies reflect only century to multi-century variability. Thus tree-ring studies at the moment have relatively limited usefulness for historians of Mediterranean societies, but this could potentially change.

Given the prevalence of karst areas and limestone caves around the Mediterranean, speleothems are also potentially a rich source for Mediterranean climate data, multi-millennial records with annual or even sub-annual resolution. Very few, however, have yet been published or analyzed for periods prior to the beginning of instrumental weather records (Lionello, 2012: 103–108).

In interpreting almost all physical proxies around the Mediterranean, the most serious problem, the most serious source of "noise" in the data, is the long history of human settlements. It was eastward of the Mediterranean's most eastern shore that the Neolithic package of domesticated einkorn and emmer, chickpeas and barley, goats, sheep, pigs, and cattle, first appeared. With these came fixed settlements, fields, and pastures. Does the development of soil and deposition in the form of river terraces and alluvial fans reflect this human activity? Or does it reflect periods of increased rainfall? Or some mix of both (Bintliff, 1992 and 2005)? Does the abandonment of settlements reflect increased aridity, soil depletion, warfare, or social and political disruption? So likewise, do changes in plant or wild animal populations over time reflect changes in climate or selective cutting and hunting, planting and breeding by human beings? These have been major issues in the historiography of Mediterranean climate.

In addition to collecting data on past variations in the earth's climate, one ultimate goal of paleoclimatologists is to understand that climate as a system, that is, how changes in one aspect of climate in one region results in changes in aspects of climate in other regions, for example, how changes in the El Niño Southern Oscillation (ENSO) in the Pacific are related to changes in the North Atlantic Oscillation (NAO) or the Arctic Oscillation (AO). Since, as we have seen, Mediterranean climate is governed in different parts of the basin by three different atmospheric sub-systems, the North Atlantic, the African monsoon, and the Indian monsoon, and by their interactions, only when we understand the connections among these systems (and their connections to the hemispheric system) will we understand some peculiarities of the Mediterranean-wide climate. One of the most important of these is the east-west climate "see-saw," evident, for example, in the developing aridity in the Levant from the seventh century CE onward, at the same time that anomalous wet conditions, already evident two centuries earlier, prevailed in the West (Martin-Puertas *et al.*, 2010; Bakker *et al.*, 2012). At other periods, strong Saharan winds may have given southern Iberia a very different climate than other regions of Mediterranean Europe (Nieto-Moreno *et al.*, 2011). Correlating changes in temperature and rainfall over the entire Mediterranean basin has barely begun. For the moment there are still too many unknowns. We do not yet have the ability to "retrodict" the predominant weather patterns in, let us say, the Nile delta when we know the climatic patterns in southern France. Eventually, climate models may allow this, but not yet. For this reason it may be beside the point to refer to the Medieval Warm Period or the Little Ice Age, identifiable in a European context, when we talk of events in the eastern Mediterranean.

Linking climate variations to the events of human history

What is required to connect the history of climate to the story of human actions? Since Ellsworth Huntington's assertion that the ancient powers of the Fertile Crescent were brought low by climate change, to connect climate change to the fall of empires or civilizations has never been far below the surface of even the most scientific of paleoclimate studies, and even now occasionally surfaces without apology in plain sight. It is the not-so-hidden dream (McCormick *et al.*, 2012). How can it be done?

Coincidence is not causation. That simple rule is sometimes forgotten. Coincidence, at most, suggests a question; by itself it does not give an answer. And so, to connect climate variation to other historical phenomena, one must proceed link by link. Apart from sudden natural disasters, hurricanes, tsunamis, floods, volcanic eruptions, which can wipe out whole cities and destroy the livelihoods of large populations (and whose frequency may or may not be related to climate change), climate change will first of all have consequences, positive or negative, on food production. This, in turn, may have an impact on human fertility and mortality rates, again either positive or negative.

In exceptional cases, famine may lower tax revenues or spark food riots, with consequences for political stability. But such results can only be demonstrated by analyzing and testing all the intermediate stages. In this, the historian differs from the paleoclimatologist: the latter seeks to identify the climate signal in an undifferentiated body of noise, the former to separate the varying strands of noise to see if climate has any identifiable role at all, and if so, exactly what it may be.

The first question will therefore be what were the demands for water and warmth over the growing season of staple crops? What would have been the consequences for growth and productivity of too much or too little of either at different times of the year? Likewise, how did too much or too little water affect the availability of nutrients in the soil, above all nitrogen? How did the commonly available technologies manage variations in water supply, heat, and fertility? For different crops as for different societies there will be different answers. Too much or too little water when seed is germinating may be more critical than temperatures, while at ripening time, temperature may be determinant. Thus much may depend on water management, which in turn may depend on labor availability and thus on factors other than climate. Through erosion, flooding, or aeolian drift, once fertile soils may become marginal. Each agricultural system will have its own labor demands, its own provisions for storage of grain and seed, its own distribution strategies, especially for times of crop failure. All of these will buffer, or amplify, the consequences of climate change (or any other change that affects population), and possibly drive the entire agricultural system to a very different equilibrium state (Borsch, 2004).

Thus, the historian's objective must be to work out as fully as possible the ways in which a particular society at a particular time mobilizes its necessarily limited resources to sustain itself. Only then can the consequences of climate change begin to be defined and measured. In the early modern period, when records begin to grow voluminous in parts of Europe, many of the links can be worked out in detail. Christian Pfister's study of a group of Swiss cantons over more than three centuries is a model example (Pfister, 1984–1985). In places and times less well documented, more will have to be left open to hypothesis or supposition, but, as Haas, for example, has shown, many of these complexities can be approximately assessed even for a period with as limited documentation as the second and third century CE (Haas, 2006).

The model of inquiry should hold even for changes over long periods of time, or when climate data is of relatively low temporal resolution. Shifts in the sites of settlements and crop production from lowlands and valley bottoms to uplands and hilltops, from heavy soils to lighter, or vice versa, may be in part a response to climate changes that turn marginal what had been usable soil (see also Bintliff, this volume). Such changes would be most evident in regions that are marginal even under favorable conditions and are then abandoned, or again, vice versa. Other alterations that mark major shifts in an agricultural economy—between mono- and poly-cultures, between exchange-orientated and "autarchic," between demographic expansion and contraction—at the very least show a move to a new equilibrium state in which climate change may have played a role.

One can certainly argue for millennial-scale climatic change in the transformation of what is now the northern and eastern Sahara. Before the mid-Holocene (around 7000 to 5000 years ago) there was sufficient rainfall here to allow big game and domestic cattle to flourish. Thousands of years later, Hannibal's elephants were drawn from a relict "Tunisian" population of this ancient fauna. It also seems more plausible to associate the abandonment of the Neolithic settlements at Çatalhöyük in south-east Anatolia and Jerico in the Jordan valley with what paleoclimatologists call the 8.2 ka BP event, a sudden hemispheric cooling caused by the flooding of cold fresh water into the North Atlantic, rather than the common (and unprovable) explanation of land degradation caused by over-exploitation (Cunliffe, 2008; Barber *et al.*, 1999; Kobashi *et al.*, 2007; Maher *et al.*, 2011). Another major transition, the late-Bronze-Age crisis around 3200 BP, marking the end of major east-Mediterranean civilizations amidst the turmoil induced by mysterious raiding "sea peoples," has been shown to coincide with an abrupt onset of extended drought in the region (Kaniewski *et al.*, 2013). Almost all proxies, eastern and western Mediterranean alike, point to more benign conditions between about 500 BCE and 100 CE (usually referred to as the Roman Warm Period), the necessary precondition for feeding the great cities of antiquity as well as the armies that created the Roman Empire (Finne *et al.*, 2011).

As climate changes are integrated into the history of human societies around the Mediterranean, the major challenge for historians will continue to be identifying, amidst the "noise" of complex social and economic changes, exactly where the "signal" of climate change may be found. Not an impossible task, but one that will invite historians and archaeologists to venture far deeper into the landscape and the lives of the many anonymous men and women who drew their sustenance from that landscape than they have been wont to do.

Endnotes

1 Among the varied studies, particularly from the Mediterranean region: Bintliff, 1992; Berger, 1997 and 2003; Butzer, 2005; Constante *et al.*, 2011 with bibliography.

2 Collection and calibration of Mediterranean data is being done under the auspices of the World Meteorological Organization at www.omm.urv.cat/MEDARE (accessed June 30, 2013).

3 Raw C^{14} dates are usually given "BP," for "before the present" with the "present" defined arbitrarily as 1950 CE; calibrated dates are commonly identified as such. Calibration gives a mean with dates of one and two standard deviations (68% and 95% confidence).

References

Aldrete, G.S. (2007) *Floods of the Tiber in Ancient Rome*, Baltimore: Johns Hopkins University Press.

Alexandre, P. (1987) *Le climat en Europe au moyen âge*, Paris: EHESS.

Bakker, J., Kaniewski, D. and Verstraeten, G. *et al.*, (2012) Numerically derived evidence for Late-Holocene climate change and its impact on human presence in the southwest Taurus mountains, Turkey. *Holocene*, 22 (4): 425–438.

Barber, D.C., Dyke, A. and Hillaire-Marcel, C. *et al.* (1999) Forcing of the cold event 8,200 years ago by catastrophic drainage of Laurentide lakes. *Nature*, 400 (6742): 344–348.

Berger, J.F. (2003) Les étapes de la morphogenèse holocène dans le sud de la France, in *Archéologie et systèmes socio-environnementaux: études multiscalaires sur la vallée du Rhône dans le programme ARCHAEOMEDES* (eds S. Van der Leeuw, F. Favory, and J.-L. Fiches), Paris: CNRS, pp. 87–167.

Bintliff, J.L. (1992) Erosion in the Mediterranean lands: A reconsideration of pattern, process and methodology, in *Past and Present Soil Erosion* (eds M. Bell and J. Boardman), Oxford: Oxbow, pp. 125–131.

Bintliff, J.L. 2005. Human impact, land-use history and the surface archaeological record: a case study from Greece. *Geoarchaeology* (special issue: Landscape and Land Use: Geoarchaeological Approaches to Human Impact), 20 (2): 135–147.

Borsch, S.J. (2004) Environment and population: The collapse of large irrigation systems reconsidered. *Comparative Studies in Society and History*, 46 (3): 451–468.

Bradley, R.S. (1999) *Palaeoclimatology: Reconstructing Climates of the Quaternary*, San Diego: Harcourt/Academic Press.

Braudel, F. (1972–3) *The Mediterranean and the Mediterranean World in the Age of Philip II*, London: Collins.

Brázdil, R., Wheeler, D. and Pfister, C. (2010) Special issue: European climate of the past 500 years based on documentary and instrumental data. *Climatic Change*, 101 (1–2).

Bryson, R.A. and Julian, P.R. (1962) Proceedings of the Conference on the Climate of the Eleventh and Sixteenth Centuries, Aspen, Colorado, June 6–24. Boulder, CO: High Altitude Observatory, National Center for Atmospheric Research.

Büntgen, U., Tegel, W. and Nicoluss, K. *et al.* (2011) 2500 years of European climate variability and human susceptibility. *Science*, 331 (6017): 578–582.

Butzer, K.W. (2005) Environmental history in the Mediterranean world: Cross-disciplinary investigation of cause and effect for degradation and soil erosion. *Journal of Archaeological Science*, 32: 1773–1800.

Camuffo, D., Bertolin, C., Barriendos, M. *et al.* (2010) 500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. *Climatic Change*, 101 (1–2): 169–199.

Constante, A., Peña, J.L., Muñoz, A. and Picazo, J. (2011) Climate and anthropogenic factors affecting alluvial fan development during the late Holocene in the Central Ebro Valley, Northeast Spain. *Holocene*, 21 (2): 275–286.

Cunliffe, B. (2008) *Europe Between the Oceans*, New Haven: Yale University Press.

Ellenblum, R. (2012) *The Collapse of the Eastern Mediterranean: Climate Change and the Decline of the East, 950–1072*, Cambridge: Cambridge University Press.

Finné, M., Holmgren, K. and Sundqvist, H.S. *et al.* (2011) Climate in the Eastern Mediterranean, and adjacent regions, during the past 6000 years—A review. *Journal of Archaeological Science*, 38 (12): 3153–3173.

Frenzel, B., Pfister, C. and B. Gläser (eds) (1992) *European Climate Reconstructed from Documentary Data: Methods and Results*, Stuttgart, New York: G. Fischer.

Gunn, J.D. (ed.) (2000) *The Years without Summer: Tracing A.D. 536 and its Aftermath*, Oxford: Archaeopress.

Haas, J. (2006) *Die Umweltkrise des 3. Jahrhunderts n. Chr. im Nordwesten des Imperium Romanum*, Stuttgart: F. Steiner.

Huntington, E. (1911) *Palestine and its Transformation*, London and Boston: Constable and Houghton Mifflin.

Huntington, E. (1913) Changes of climate and history. *American Historical Review*, 18 (2): 213–232.

Jones, P.D., Osborn, T.J. and Briffa, K.R. (2001) The evolution of climate over the last millennium. *Science*, 292 (5517): 662–667.

Kaniewski, D., Van Campo, E., Guiot, J. *et al.* (2013) Environmental roots of the late Bronze Age crisis. *PLOS ONE* 8 (8): e71004. DOI:10.1371/journal.pone.0071004 (last accessed September 28, 2013).

Kobashi, T., Severinghaus, J.P., Barnola, J.M. *et al.* (2007) Precise timing and characterization of abrupt climate change 8200 years ago from air trapped in Polar ice. *Quaternary Science Reviews*, 26 (9–10): 1212–1220.

Le Roy Ladurie, E. (1971) *Times of Feast, Times of Famine*, New York: Doubleday.

Le Roy Ladurie, E., Rousseau, D. and Vasak, A. (2011) *Les fluctuations du climat, de l'an mil à nos jours*, Paris, Fayard.

Lamb, H.H. (1959) Our changing climate, past and present. *Weather*, 14: 299–318.

Lamb, H.H. (ed.) (1968) *The Changing Climate: Selected Papers*, London: Methuen.

Larson, L.B., Vinther, B.M., Briffa, K.R. *et al.* (2008) New ice core evidence for a volcanic cause of the A.D. 536 dust veil. *Geophysical Research Letters*, 35 (L0478): 5 pp.

Lionello, P. (ed.) (2012) *The Climate of the Mediterranean Region: From the Past to the Future*, Amsterdam: Elsevier.

Maher, L.A., Banning, E.B. and Chazan, M. (2011) Oasis or mirage? Assessing the role of abrupt climate change in the prehistory of the Southern Levant. *Cambridge Archaeological Journal*, 21 (1): 1–30.

McCormick, M. and Büntgen, U. *et al.* (2012) Climate change during and after the Roman Empire. *Journal of Interdisciplinary History*, 43 (2): 169–220.

McCormick, M., Dutton, P.E. and Mayewski, P.A. (2007) Volcanoes and the climate forcing of Carolingian Europe. *Speculum*, 82: 865–895.

Martín-Puertas, C., Jiménez-Espejo, F. and Martínez-Ruiz, F. *et al.* (2010) Late Holocene climate variability in the Southwestern Mediterranean region: An integrated marine and terrestrial geochemical approach. *Climate of the Past*, 6 (6): 807–816.

Nieto-Moreno, V., Martínez-Ruiz, F. and Giralt, S. *et al.* (2011) Tracking climate variability in the Western Mediterranean during the Late Holocene: A multiproxy approach. *Climate of the Past*, 7: 1395–1414.

Osborn, T.J. and Briffa, K.R. (2006) The spatial extent of 20th-century warmth in the context of the past 1200 years. *Science*, 311: 841–44.

Pavan, V. (2008) Large-scale atmospheric circulation and the Mediterranean climate. 1st ESF MedCLIVAR Summer School for Post-Graduate Students on Climate Variability over the Mediterranean area: Atmospheric and Oceanic Component: www.medclivar.eu/schooldocs/lectures/LectureA5_Pavan_outline.pdf (accessed June 30, 2013).

Pérez-Obiol, R., Jalut, G. and Julià, R. *et al.* (2011) Mid-Holocene vegetation and climatic history of the Iberian peninsula. *Holocene*, 21 (1): 75–93.

Pfister, C. (1984–1985) *Das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft*, Bern: P. Haupt.

Raicich, F., Pinardi, N. and Navarra, A. (2003) Teleconnections between Indian monsoon and Sahel rainfall and the Mediterranean. *International Journal of Climatology*, 23: 173–186.

Robinson, A., Leslie, W. and Theocaris, A. *et al.* (2001) Mediterranean Sea circulation, in *Ocean Currents: A Derivative of the Encyclopedia of Ocean Sciences* (eds J.H. Steele, S.A. Thorpe, and K.K. Turekian), Waltham MA: Academic Press, pp. 1689–1705.

Robinson, S.A., Black, S., Sellwood, B.W. *et al.* (2006) A review of Palaeoclimates and Palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: Setting the environmental background for the evolution of human civilisation. *Quaternary Science Reviews*, 26 (13–14): 1517–1541.

Robock, A. and Free, M. (1996) The volcanic record in ice cores for the past 2000 years, in *Climatic Variations* (eds P.D. Jones, R.S. Bradley, and J. Jouzel), Heidelberg and New York: Springer, pp. 533–546.

Rohling, E.J. (November 2001) (last updated January 7, 2002) *The Dark Secret of the Mediterranean: A Case History in Past Environmental Reconstruction*: www.noc.soton.ac.uk/soes/staff/ejr/DarkMed/dark-title.html#ref (accessed June 30, 2013).

Stathakopoulos, D. (2004) *Famine and Pestilence in the Late Roman and Early Byzantine Empire*, Aldershot, Ashgate.

Vita-Finzi, C. (1969) *The Mediterranean Valleys: Geological Changes in Historical Times*, London: Cambridge University Press.

Further Reading

Bradley, R.S. (1999) *Palaeoclimatology*, San Diego: Academic Press.

A standard technical introduction to the field of historical climatology.

Grove, A.T., and Rackham, O. (2001) *The Nature of Mediterranean Europe: An Ecological History*, New Haven: Yale University Press.

A lively and copiously illustrated introduction to the region's geology, climate, and flora.

Harvard University (2010) Digital atlas of Roman and medieval civilization. Accessed June 30, 2013, http://darmc.harvard.edu/icb/icb.do. Contains among its data links, M. McCormick, K. Harper, A.M. More and K. Gibson. "Geodatabase of Historical Evidence on Roman and Post-Roman Climate 2012."

Jones, P.D., Ogilvie, A.E.J., Davies, T.D. *et al.*(eds) (2001) *History and Climate: Memories of the Future*, New York: Springer.

Contains essays on more recent climatic events, though not focusing on the Mediterranean.

Lamb, H.H. (1995) *Climate, History and the Modern World*, 2nd edn, London and New York: Routledge.

A good general introduction to how climate systems work.

Lionello, P. (ed.) (2012) *The Climate of the Mediterranean Region: From the Past to the Future*, Amsterdam: Elsevier.

Contains highly technical summaries of current knowledge as well as very full bibliographies.