CHAPTER 3

# Archives of Nature and Archives of Societies

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## 3.1 Introduction

Paleoclimatology and historical climatology share the common goal of reconstructing climates before regular instrumental records. However, these two disciplines work with two different sets of evidence. Paleoclimatologists work to reconstruct the past from physical traces in the cryosphere, hydrosphere, biosphere, and lithosphere that record the influence of climates centuries and millennia ago.[1] By contrast, historical climatologists reconstruct the past from written records and human artifacts, which may range from direct descriptions of weather to indirect indicators of climatic and meteorological impacts.

This volume distinguishes between these two sets of evidence as the *archives of nature* and the *archives of societies*. Both archives require some of the same techniques and pose some similar methodological and conceptual challenges. Their periods of coverage and of spatial and temporal resolution overlap. As described below, both often involve working with "proxies" rather than direct representations of past weather and climate.

Nevertheless, these two archives also present distinct issues. The archives of nature tend to be more homogeneous, continuous, and precisely located, and in some cases can reach very far back into the past. The archives of societies, on the other hand, tend to be more heterogeneous, and their data is

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often scattered over time and space. Yet they can often provide more precise information, reaching back centuries or even millennia, revealing those climatic and meteorological events most relevant to human history. Moreover, as explained in this volume, diligent research and appropriate methods can overcome some of their apparent shortcomings for climate reconstruction. Climate history necessarily requires research in both kinds of archives.

This chapter first provides a brief introduction to the archives of nature and the archives of societies, and then outlines some of the common techniques and challenges in working with proxies from each. The chapters in Part I of this volume explain in more detail the use of evidence and the creation of climate reconstructions from the archives of societies. For further information about climate reconstruction from the archives of nature, we refer readers to Raymond Bradley, *Paleoclimatology. Reconstructing Climates of the Quaternary* (3rd ed., 2015) and to Neil Roberts, *The Holocene: An Environmental History* (3rd ed., 2014).

## 3.2 The Archives of Nature

The Earth's climate influences physical, chemical, and biological processes taking place over the planet's land, water, and ice, and in its living creatures. Variations in temperature and precipitation (and sometimes in sunshine, sea ice, and other such variables) produce corresponding variations in all sorts of natural developments: the build-up of snow and ice over glaciers, the accumulation of lake deposits, the ratios of stable oxygen isotopes in precipitating water, the blooming of certain species of algae and plankton, the growth of shells in marine life or the rings of tree trunks, and so on. In some cases these processes leave behind physical remnants that preserve these variations in such a way that scientists can study them in order to reconstruct past climates. The storage mediums of these processes, such as ice, peat bogs, stalagmites, or tree trunks, are named archives of nature.

Researchers extract information from these archives through different methods of sampling, such as coring ice or drilling trees. Depending on the sensitivity to local conditions, they create time series of measurements from either a single sample or by averaging several samples (often called "composite" records). The analysis of each archive requires specific scientific skills related to the underlying physics, chemistry, or biology of the process captured in the archive and how it relates to past climates.

The archives of nature now include a remarkable variety of records, as researchers have developed ingenious ways of extracting ever more climate information from different physical remains. The most useful records are those where some process that is highly sensitive to a specific climate variable has left some very regular and well-preserved sequence. Some of the best-known and most widely used examples include growth rings in trees, variations in oxygen isotopes in ice cores, and pollen types in sedimentation layers ("varves") at the bottom of lakes and estuaries. However, new techniques have been continuously developed in order to extract more climate data from more parts of the world. Keeping up with those techniques and that data remains an essential task of



climate history. Examples of different proxies (ring width, oxygen isotope ratios, varve thickness, and sulfate and lead concentrations) from different archives (tree rings, ice cores, stalagmites, sediments, and peat bogs) are shown in Fig. 3.1.[2]

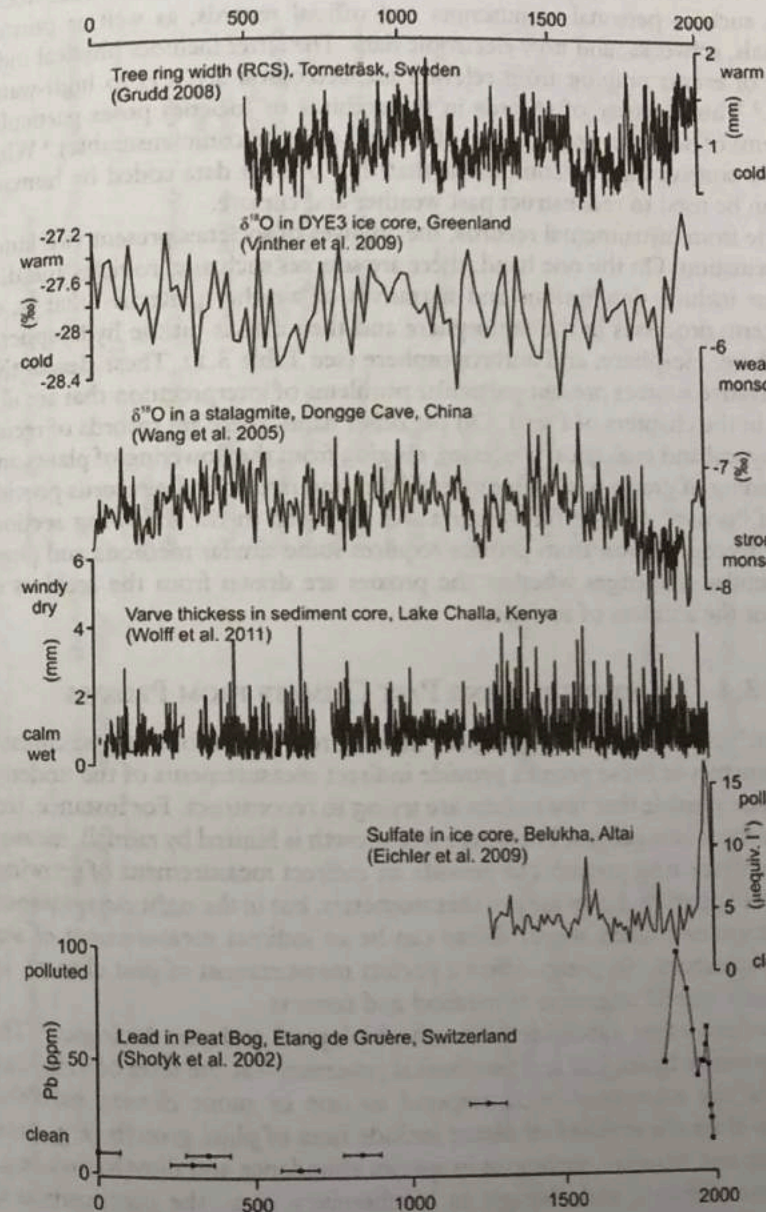


Fig. 3.1 Examples of time series over the past 2000 years drawn from the archives of nature, along with the authors' interpretation (from the National Oceanic and Atmospheric Administration paleoclimatology website)

## 3.3 The Archives of Societies

The term "archives of societies" is used here in a broad sense to refer to both written records and evidence preserved in the built environment that can help researchers reconstruct past climate and weather. The former includes documents such as personal manuscripts and official records, as well as printed materials, artworks, and now electronic data. The latter includes physical indicators of events ranging from relevant archaeological artifacts to high-water marks.[3] This diversity of records in the archives of societies poses particular problems of homogenization (i.e., of making them all commensurable).[4] What all these sources have in common is that they present data coded by humans that can be used to reconstruct past weather and climate.

Aside from instrumental records, the archives of societies present two kinds of information. On the one hand, there are sources such as chronicles and diaries that include descriptions and narratives of weather patterns—that is, of short-term processes in the atmosphere and their effects on the hydrosphere, cryosphere, biosphere, and anthroposphere (see Table 3.1). These descriptive and narrative sources present particular problems of interpretation that are discussed in the chapters of Part I. On the other hand, there are records of recurring physical and biological processes, ranging from the flowering of plants and the ripening of grains to the freezing of lakes and rivers. These records provide sorts of "proxy" climate information. As discussed in the following section, climate reconstruction from proxies requires some similar methods and poses some similar challenges whether the proxies are drawn from the archives of nature or the archives of societies.

## 3.4 Reconstructing Past Climate from Proxies

"Proxies," as their name suggests, are indirect representations of past climate. Measurements of these proxies provide indirect measurements of the underlying climate variable that researchers are trying to reconstruct. For instance, tree trunks are not rain gauges, but where tree growth is limited by rainfall, measuring annual tree-ring growth can provide an indirect measurement of growing-season precipitation. Lakes are not thermometers, but in the right circumstances the duration of a lake's winter freeze can be an indirect measurement of seasonal temperature. No proxy offers a perfect measurement of past climate. Its use requires careful attention to method and context.

Proxies are often subdivided into the biological and non-biological. The former preserve biological and biophysical processes—at the level of individual species or the ecosystem—that respond to one or more climate variables. Examples from the archives of nature include rates of plant growth (e.g., tree-ring width and density), variations in species abundance and distribution (e.g., pollen assemblages), and changes in biochemistry (e.g., the composition of



**Table 3.1** Examples of evidence from archives of nature and archives of societies (T = temperature; P = precipitation; p = air pressure)

| *Archives of nature (nature-generated data)* | | | | | *Archives of societies (anthropogenic data)* | | | |
|---|---|---|---|---|---|---|---|---|
| *Archive* | *Proxy* | *Climate variables* | *Time resolution* | *Temporal range* | | *Climate variables* | *Time resolution* | *Temporal range* |
| *Weather* | | | | | **Narrative** | | | |
| | | | | | (Weather) chronicles | Weather, impacts | Hours to seasons | >5 centuries |
| | | | | | Weather diaries | Weather, impacts | Hours to seasons | 5 centuries |
| | | | | | Ships' logbooks | Wind, weather | Hours to days | 3 centuries |
| | | | | | Weather reports | Weather, impacts | Days to months | >5 centuries |
| | | | | | **Art** | | | |
| | | | | | Paintings, literature, poems, etc. | Weather, impacts | Days to weeks | Centuries |
| | | | | | **Instrumental** | | | |
| | | | | | Instrumental measurements | T, P, p, etc. | Secs to days | 1–3 centuries |
| *Climate* | **Biological proxies** | | | | **Biological proxies** | | | |
| Tree rings | Ring width | T, P | Seasons | Centuries | Plant observations | T | >1 month | Centuries |
| | Maximum late wood density | T | | | Time of agricultural work | T | >1 month | Centuries |
| | Oxygen isotopes | T | | | Agricultural production | T, P | >1 month | Centuries |
| Lake sediments | Pollen assemblages | T, P | Annual | Millennia | | | | |
| | Chironomids | T | | | | | | |
| Corals | Oxygen isotopes, Sr/Ca ratio | T, Salinity | Seasons | Centuries | | | | |
| Peat bogs | Trace chemicals | Pollutants | | | | | | |

*(continued)*

**Table 3.1** (continued)

| *Archives of nature (nature-generated data)* | | | | | *Archives of societies (anthropogenic data)* | | | |
|---|---|---|---|---|---|---|---|---|
| *Archive* | *Proxy* | *Climate variables* | *Time resolution* | *Temporal range* | | *Climate variables* | *Time resolution* | *Temporal range* |
| | **Non-biological proxies** | | | | **Non-biological proxies** | | | |
| Ice cores | Oxygen isotopes | T | | >100 kiloyears | Freezing of water bodies | T | >1 month | Centuries |
| | Accumulation | P | | | | | | |
| | Air bubbles | Trace gases | | | Snow cover | T, P | Days to months | Centuries |
| | Snow chemistry | Aerosols | | | Floods | P, T | Days to weeks | Centuries |
| Lake sediments | Grain size | T, Floods, Wind | | | | | | |
| Speleothems (stalagmites) | Thickness, oxygen isotopes | P, T | | | | | | |
| Glaciers | | T, P | Years | Millennia | | | | |



shells from marine creatures such as foraminifera). Examples from the archives of societies include grape harvest dates and data on the time of cultural activities such as the Cherry Blossom Festival in Japan.[5] Since various life forms in diverse environments react to changes in climate, biological proxies cover a range of regions.

Non-biological proxies preserve physical processes in the environment that respond to climate variables. Examples from the archives of nature in this case include precipitation chemistry (e.g., the snow composition of firn), the sedimentation process (e.g., grain size or abundance of sediments at the bottom of lakes), and isotope fractionation (e.g., the stable oxygen isotope ratio $\delta^{18}O$ of water ice in ice cores). Examples from the archives of societies include written and visual records of glacier movements and records of ingoing and outgoing ships in ports, revealing the length of the winter freeze.[6]

The first challenge of proxy-based climate reconstruction, whether from the archives of nature or the archives of societies, comes in establishing properly dated measurements. With respect to the archives of nature, the most precise and reliable dating often comes from stratigraphy—that is, the counting of layers, as in the growth rings of old trees or the visible layers in some ice cores. However, most natural records do not preserve dates so clearly. In these cases, paleoclimatologists may make use of specific markers in the record (e.g., sulfur from volcanic eruptions, or radioactive fallout from nuclear tests) and/or by using radiocarbon dating, which dates buried materials according to the decay of the radioactive $^{14}C$ isotope. Once they have established a few dates using these methods, paleoclimatologists may then model an "age-depth curve" to provide an approximation of dates in the rest of the sample, such as in a sediment core. The choice and accuracy of dating methods will vary according to the archive in question, and the accuracy of dates usually deteriorates farther back in time. The resolution (precision) of dating can vary from several months (e.g., tree rings and corals) to centuries or millennia (e.g., ocean sediment cores).

Records from the archives of societies are usually dated at least by their year, and in most cases by their season, month, or day. Nevertheless, these records also present dating challenges. Historical climatologists must first determine whether the author of a document really witnessed the events described, or whether they are dealing with an (error-prone) copy. For instance, the new Euro-Climhist database of European climate and weather observations has systematically labeled all non-contemporary sources in order to alert researchers to this problem.[7] Dating styles vary according to era and country (e.g., Julian vs. Gregorian) as well as culture and religion (e.g., solar calendars in Europe vs. lunar calendars in China and the Islamic world, see Chap. 17). Similar to the archives of nature, the accuracy of written records usually deteriorates farther back in time. Manuscript sources pose uncertainties in data extraction: handwriting may be difficult to read, the ink may fade, or the paper may become damaged. Prior to the late nineteenth century, records were often written in older forms of languages or in regional dialects, and the meanings of terms have changed over time.[8] Table 3.1 outlines some of the most common proxies from the archives of nature and the archives of societies, along with their temporal range and resolution.

The second challenge of proxy-based climate reconstruction comes in establishing the association between the proxy and the past climate. This process usually involves establishing a statistical relationship between measurements of the proxy and some climate variable or variables. Usually this relation, termed a "transfer function," needs to be calibrated. For some proxies, calibration may be achieved by experimental or laboratory measurements. More often, statistical methods are used, working from some period of overlap between proxy measurements and the instrumental climate record (see Chap. 10). The application of a transfer function relies on the concept of stationarity—that is, the assumption that the relationship between the proxy and the climate was the same in the past as it is in the present (or in the period of overlap). This assumption may be questionable in some cases, and it can create uncertainty.

Proxy-based climate reconstructions try to isolate the relevant climate "signal" in their proxy measurements from the "noise" of other factors. For example, although tree growth reacts to climate everywhere, tree rings are best sampled near a growth limit, such as at a mountain tree line (for temperature) or a desert margin (for precipitation). Even in the best circumstances, no proxy measurement will produce a pure signal from only one climate variable: other climatic and non-climatic factors will always influence proxy measurements, whether taken from the archives of nature or the archives of societies.

To put this relationship in perspective, many climate reconstructions work with proxy measurements that have correlation coefficients of around 0.5–0.6 with the climate variable they are trying to reconstruct—or about the same as the correlation coefficient between the height and weight of adult men. Just as some men might be short and fat while others are tall and skinny, not every thin tree ring reflects a cold or dry season and not every wide ring records a warm or wet one. (This is one reason why proxy-based reconstructions often show moving averages instead of, or in addition to, annual values.) Further sources of error come from uncertainties in measuring proxies, and the possibility of non-linear relationships between climates and proxies. For proxies from the archives of societies, researchers also need to carefully establish the context in which records were created in order to assess any possible human bias.

Nevertheless, these difficulties do not undermine the validity of proxy-based climate reconstructions, nor their usefulness in climate history. Many reconstruction techniques have proven to be remarkably robust, producing well-verified results that strongly agree with each other and with historical descriptions. While discrepancies and disagreements persist, one of the great achievements of climate history comes from the way that diverse physical and written records so often complement each other and create a more complete and reliable picture of the past.[9]



## 3.5 Conclusion: Combining the Archives of Nature and Society

This handbook focuses on reconstruction techniques from the archives of societies and from early instrumental records. Whereas research in the archives of nature has produced a voluminous literature of review articles and textbooks, this volume is the first of its kind to provide a complete introduction to historical climatology. Nevertheless, we stress that climate history requires a judicious use of all available evidence, from natural as well as human records. As Christian Pfister has explained,

> "The objectives of palaeoclimatologists and historical climatologists are similar to the extent that both attempt to reconstruct climate for the period prior to the creation of national meteorological networks from the mid-nineteenth century. To that extent, data from Archives of Nature and Society to some extent complement each other. Where anthropogenic data are fragmentary or lacking, longer-term temperature or precipitation trends may be drawn from evidence contained in the Archives of Nature. In cases where it is important to establish the nature and severity of extreme conditions, anthropogenic data are temporally higher resolved, more differentiated and case-specific."[10]

Part III of this volume (Climate and Society) therefore considers both physical and written records of past climate, and Part IV (Case Studies) provides illustrations of how climate historians can combine research in the archives of nature and society in order to achieve the most complete reconstructions of climate and weather at the level of human experiences and impacts.

## Notes

1. Masson-Delmotte et al., 2014.
2. For a regularly updated database of paleoclimate reconstruction relevant to human history, see http://www.climatehistory.net/bibliography/ (last accessed April 8, 2016).
3. Brázdil et al., 2010.
4. Ayre et al., 2015.
5. Aono and Saito, 2010; Daux et al., 2012.
6. Leijonhufvud et al., 2010.
7. Pfister and Rohr, 2015.
8. Pfister et al., 2008.
9. Büntgen et al., 2015; Pfister et al., 2015.
10. Pfister, 2015.

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CHAPTER 4

# Evidence from the Archives of Societies: Documentary Evidence—Overview

*Christian Pfister*

## 4.1 Introduction

When dealing with archives of societies, researchers need to distinguish between sources and data. A climate historical source is a unit of information coded by humans which refers to weather and climate, usually from the viewpoint of individuals. Data are found within these sources, and their interpretation is content-specific. Human archives contain three kinds of data: instrumental measurements, narrative data providing direct weather information, and observations of climate proxies providing indirect data.[1] This documentary-based proxy evidence includes both plant- and ice-phenological data as well as historical hydrology, which aims at "reconstructing temporal and spatial patterns of runoff conditions as well as extreme hydrological events (floods, ice damming, hydrological droughts) for the period prior to the creation of national hydrological networks."[2] We can further classify these archives by their authors and circumstances of production. This chapter distinguishes between documents produced by members of official bodies (institutional sources) and those produced by individual amateur observers (personal sources), although some source types may belong to both categories (see Table 4.1). To assess and interpret these sources, researchers need to know who produced them, why, and how they recorded meteorological conditions and their human consequences.[3]

Communicating climate risk through narratives of extraordinary events dates back to early civilizations, including the Assyrians, Babylonians, Egyptian

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**Table 4.1** Major categories of climate and weather sources from the archives of societies discussed in this handbook

| *Data* | *Sources* | |
|---|---|---|
| | *Personal* | *Institutional* |
| Instrumental | Measurements by individual observers | Measurements within meteorological networks |
| Direct: narrative or visual | Chronicles<br>(Weather) diaries<br>Newspapers<br>Letters<br>Scientific journals<br>Broadsheets, etc.<br>Visual art, photographs | Manorial audits<br>Mandatory reports<br>Rogation ceremonies<br>Damage reports<br>Ships' logbooks<br>Reports on crop development |
| Indirect: proxy | Plant-phenological observations<br>Ice-phenological observations<br>Flood and low water marks | Time of harvest (grain, grapes)<br>Wage accounts<br>Flood marks<br>Agricultural production<br>Port records |

pharaohs, Chinese emperors, and Aztec kings, who recorded these events, whether in chronicles or pictograms written on clay tablets, in birch-bark, parchment, or in the Nilometer.[4] However, this section focuses on the medieval and (early) modern eras. In addition to presenting an overview of different types of source, this chapter discusses guidelines on dating applicable to all kinds of evidence.

## 4.2 Institutional Sources

Institutions are here defined as bodies in charge of performing official functions including taxation, law, war, and pastoral care, whether as states, municipalities, armies, or navies. Regulations determined who was in charge of keeping these records, how frequently, and often in what form. Beginning in the later Middle Ages, some institutions began keeping records in the same places for several centuries using more or less standard formats and bureaucratic practices. In agrarian societies the timing of most agricultural activities, receipts, and expenditures varied with the weather in some way, which was usually reflected in institutional documents. Of course, the officials in charge could not know that their records would be used as raw material for climate reconstruction in some distant future. It is up to the researcher to investigate whether there is really a relationship between the assumed indicator and some feature of climate, how strong that relationship is, and whether it changes over time. In the best case, the researcher may establish continuous, multi-centennial, quantified time series of temperature or precipitation indices, akin



to those from natural archives. Chapters 5 and 6 will describe these sources and their use in more detail.

Among the earliest and best-known institutional sources are vintage (grape harvest) dates. To prevent theft or tax evasion, local officials had to decide on a single day each year to start this important event in the life of rural communities.[5] Daily wage accounting records can serve the same purpose. In late medieval England, estate managers noted down daily wage and food expenditures for harvesters, and so the date of each year's first payment indicates the beginning of the harvest.[6] Long series of grain harvest dates are available for Switzerland and Czech lands.[7] Andrea Kiss and colleagues provided a May to July temperature reconstruction of Budapest based on five vine- and grain-related historical phenological series from the town of Kőszeg in west Hungary.[8]

Customs fees paid from incoming and outgoing ships serve as a proxy for winter and spring temperatures in harbors where the sea regularly freezes, as series from Tallinn and Stockholm demonstrate.[9] Moreover, some official accounts reference extreme weather when justifying extraordinary expenses. For example, weekly account books kept in the town of Louny in northwest Bohemia in the Czech Republic from the mid-fifteenth century list infrastructure maintenance expenses such as clearing the snow from roads.[10] In the city of Wels in Upper Austria the office of the bridge master was responsible for bridge repairs in case of flood damage. Weekly account books registered workers' wages and timber costs, which researchers can use to reconstruct the frequency and severity of river floods.[11] Likewise, governors in Venetian possessions of the Adriatic and the Eastern Mediterranean had to report annually to their superiors about events that affected income and expenditure in their territories, such as storms that damaged port installations or droughts that ruined the harvest.[12]

Ships' logbooks provide a unique source of weather information for the world's oceans. The English Admiralty obliged all officers of the Royal Navy to keep a logbook in which the wind and weather had to be recorded daily if not hourly, as did the admiralties of other naval powers.[13]

Chinese emperors ordered provincial administrators to keep detailed weather records related to the development of crops.[14] Bishops in Spain and in the Spanish world used to schedule rogation ceremonies to assist people in coping with meteorological stress such as droughts (Pro Pluvia Rogations) or excessive rain (Pro Serenitate Rogations).[15]

## 4.3 Personal Sources

Personal sources refer to those created by individuals rather than institutions. These present certain characteristics that can complicate their use. They usually suffer from gaps, their time of reporting is rather short (several decades at best), and they necessarily end with the death of the author. Observers often moved during their lifetime, and they frequently focused on a personal field of experience and activity, usually agriculture, meaning that we get somewhat different, but still usually meteorologically coherent, information from vine growers, cereal growers, and herdsmen. Issues of language, particularly old dialects, can create almost insurmountable barriers to interpretation. They often present difficult handwriting, although numbers remain universally comprehensible.

Until the late eighteenth century, meteorology dealt primarily with weather narratives. From the point of view of climate reconstruction, the language used to describe these events and the focus of the narrator can render the narratives subjective and difficult to compare. On the other hand, they shed light on the interplay of different weather elements, such as temperature, precipitation, snow cover, cloud cover, and wind, and they often include conditions in the surrounding area. The observations were made by humans for humans, thereby linking natural phenomena and human experiences. They describe, for example, the impact of destructive weather on crops and infrastructure, and they lay down social and cultural information about weather perceptions and discourse.[16] In doing so, storytelling also addresses people's emotional side.

Within scientific journals, however, the narrative approach gradually disappeared. In 1787

> the Irish chemist Richard Kirwan introduced a tradition which would persist until our own time [...] He distinguished between the "Empyric" method—vague and uncertain—and "Scientific," still in its infancy, but "grounded on a long series of observations accurately taken of all the changes of the atmosphere, from whence some general law may at length be deduced."[17]

This tendency became dominant during the nineteenth century, and soon observers stopped keeping records of phenological observations and natural disasters such as floods, windstorms, and avalanches. The First International Meteorological Congress in Vienna, 1873, started work on standardized instructions and procedures for land observations. In the years that followed, member states stopped publishing narrative observations in their yearbooks altogether in favor of bare instrumental observations. Narratives even disappeared from newspaper weather reports for some time, at least in Switzerland. More research is needed about this "quantitative turn" in meteorology.

*Systematic weather diaries* contain short, dry weather notes, often in the form of hardly legible abbreviations. From these, historical climatologists can derive some quantitative information by counting the frequency of binary meteorological phenomena (e.g., days with/without precipitation, snowfall, or frost).[18] Most European weather diaries come from Germanic, English, and Slavic countries. In France, family account books (*livres de raison*) handed down from one generation to the next occasionally included notes on the weather. Weather diaries have also been identified for China (Chap. 17), India and Japan (Chap. 18), North America (Chap. 24), and Latin America (Chap. 19).



*Chronicles* refer to a broad category of medieval and modern works, whose common denominator is that they list important events in chronological order. Depending on the interest of the authors, weather usually makes up only a small part of the information found in them. Some chroniclers noted the weather frequently and quite systematically, although not on a daily basis, while others just reported disasters and extreme events. Some noticed only local conditions, while others included a variety of regional events. The merchant Philippe de Vigneulles (1471–1527), for example, paid great attention to weather relevant to the development of vines and the sugar content of grapes around his native town of Metz in France because his income depended on it.[19]

Most chroniclers wrote about extreme anomalies with serious human consequences. In the same way, some clergymen noted extreme events and those memorable for their communities in their church registers. The more outstanding an event the more chroniclers usually went into detail. For example, the eleven-month-long heatwave and drought of 1540 in Europe, a disaster of unspeakable dimensions, is described in hundreds of chronicles.[20] The "domestic colouring" of such reports, as Theodore Feldman remarked, shows how much their authors were at home in the weather, how much it formed part of their daily lives, and how little able they were to objectify the weather for the purpose of analysis.[21]

*Newspapers and early scientific journals and papers* are goldmines for weather observations and early instrumental measurements in many parts of the world. For example, in the absence of instrumental observations, Maria Prieto and colleagues gathered information about climate in the Argentinian and Chilean Andes from newspapers from 1885 to 2000 (see Chap. 19).[22] Likewise, newspaper reports were crucial for reconstructing weather series for Australia since its first European settlement (Chap. 21). In Europe, newspaper information remains important for reconstructions of natural disasters, including hailstorms and the freezing over of lakes and rivers.[23]

*Travelers' journals* provide important climate-related reports in areas without permanent settlement or with few endogenous records, such as parts of Africa (see Chap. 20).

*Broadsides and pamphlets* were short publications often inspired by nature-induced disasters and meteorological anomalies, describing the events in detail, and sometimes placing them in the context of earlier analogous disasters. Likewise, secular or religious authorities published their views of meteorological events, often in the form of exhorting sermons, as in the case of the disastrous European ice floods in spring 1784 (see Chap. 34).[24]

*Paintings, etchings, and early photographs* of historical glaciers provide among the most impressive evidence of climatic change. Together with written evidence, they make it possible to reconstruct the position of well-documented glaciers with remarkable precision over the last 400 to 500 years, including examples in Norway, the Gorner and Lower Grindelwald

Glaciers in Switzerland, and the Mer de Glace in France (see Chap. 8).[25] Paintings of winter landscapes from the Netherlands during the Little Ice Age, such as *The Return of the Hunters* (ca. 1565) by Pieter Bruegel the Elder, make the viewer feel the coldness of this period—although such images need to be interpreted carefully before being taken as evidence of actual weather conditions.[26]

With regard to *early instrumental observations*, the earliest instruments and networks date back to the seventeenth century (see Chap. 7). Barometers and thermometers sold by traveling salesmen became increasingly fashionable in better-off households from the early eighteenth century onwards. In England "by the 1790s, for instance, the barometer was said to be a widely owned piece of furniture, and often used as nothing more than a toy."[27] Most amateur observers ignored the problems of standardizing instruments, units of measurements, and observational techniques such as the location of instruments and schedule of readings. Thus using their early instrumental measurements in climate reconstruction requires an understanding of the instruments themselves, how the measurements were taken, and whether their data display artificial breaks and trends (see Chap. 9).[28] Outside the world of professional scientists, instrumental readings went hand in hand with narrative weather reports.

From the Middle Ages onwards, chroniclers increasingly cared for intergenerational comparability by referring to quasi-objective climate indicators in the human and natural environment. These include the level of bridges to indicate the magnitude of a flood, the absence or duration of snow cover, the freezing of bodies of water, the appearance of spring flowers, and the advance or delay of agricultural work.[29] Such objective observations may be compared to parallel cases in the instrumental period. Of course, in order to properly interpret sporadic climatic indicators, the researcher needs to become familiar with similar data from the instrumental period. In some cases, such as Norway, farmers regularly noted certain agricultural activities in their diaries such as the start of the cereal harvest, and this data has been used to reconstruct rising seasonal temperatures.[30] High-water marks on the walls of public or private buildings visually represent the frequency and severity of disaster over time, in a manner akin to actuarial data.[31]

## 4.4 Dating

Globally, there have been two major systems of calendars: solar calendars based (approximately) on the revolution of the Earth around the sun, and lunar calendars based on the orbit of the moon. The former have historically been used in Europe (and its colonies), India, and Iran, while lunar calendars were historically used in the Islamic world and imperial China.[32]

It should be noted that the meaning of terms—for example those of the seasons—may have been different in the past. In continental Europe, for example, "winter" could be equated with the duration of snow cover, which often included March, whereas "Herbst" (autumn) indicated the period of grape harvest. In (medieval) England, "summer" was equivalent to the period from May to July, and "autumn" to August and September. In the tropics, what mattered was the alternation between dry and wet seasons.



It is also important to distinguish between Julian ("old style") and Gregorian ("new style") dates. Roman emperor Julius Caesar first introduced his calendar in the first century BC. As time went on, astronomers discovered that each Julian year was 11 minutes and 10 seconds too long. In 1582, under the auspices of Pope Gregory XIII, most Catholic territories corrected this error by skipping ten days, in order to bring the calendar date back in line with the solar year. However, most Protestant territories waited until 1701 to adopt the Gregorian calendar; England (including the colonies) waited until 1752; and Russia until 1917. In many cases, this difference in dating will make little or no difference in climate reconstructions. In other cases, failure to correct for this change can introduce serious errors, as becomes apparent when comparing an uncorrected grape harvest series with a corrected one (see Fig. 4.1).

In medieval and early modern Europe, the calendar year did not necessarily begin on January 1. To make matters worse, most medieval and many early modern writers were silent about which dating system they used. This fact can produce puzzling results, particularly with regard to winters. Today, winters

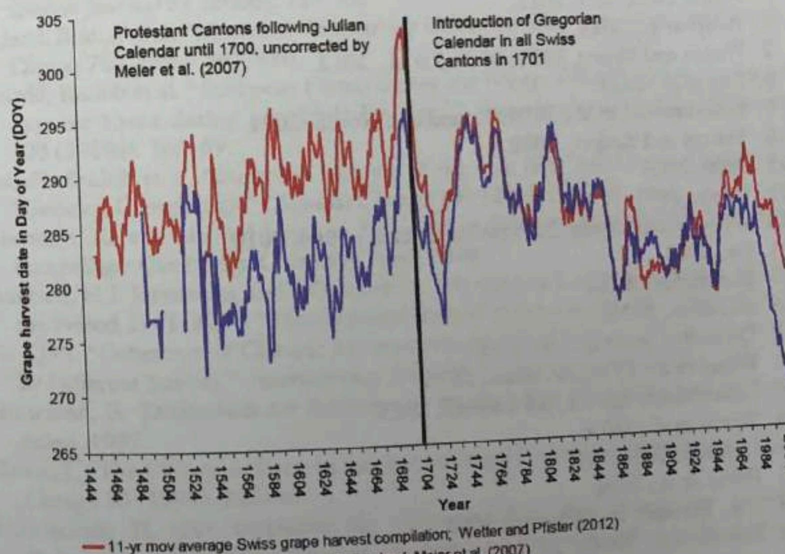


**Fig. 4.1** A comparison between a grape harvest date series that has not corrected its dating for the switch from the Julian to Gregorian calendar (Meier et al. 2007) and a series that has corrected for this change in dating. (Image reproduced without changes from O. Wetter and C. Pfister, "An Underestimated Record Breaking Event. Why Summer 1540 Was Likely Warmer than 2003," *Climate of the Past* 9 (2013): 41–56, doi:10.5194/cp-9-41-2013., under a CC-BY 3.0 license: https://creativecommons.org/licenses/by/3.0/.)

are usually dated by the year in which January falls. However, in calendar systems in which the new year begins on March 25, the meteorological winter (December to February) falls in the previous calendar year. Sources using different calendar styles may thus refer to the same winter under two different dates.[33]

Individual dates were long named after religious feasts, such as Easter, or after saints. Some conventional handbooks on chronology offer catalogues of saints' days together with their corresponding Gregorian dates.[34] Most research by non-specialists has failed to observe that saints' days in the Julian and in the Gregorian calendars correspond to different (Gregorian) dates. This section has highlighted only the most important pitfalls. For further information about how to grapple with medieval and early modern European dating, see E.G. Richards, *Mapping Time: The Calendar and its History* (Oxford University Press, 1998).

## Notes

1. Pfister, 1984; Brázdil et al., 2005, 2010a, 2010b; Ge, 2008.
2. Brázdil and Kundzewicz, 2006.
3. Bell and Ogilvie, 1978.
4. Schwemer, 2001; Seidlmayer, 2001. See also Chaps. 17 and 19.
5. Wetter and Pfister, 2011.
6. Pribyl et al., 2012.
7. Wetter and Pfister, 2011; Možný et al., 2012.
8. Kiss et al., 2011.
9. Leijonhufvud et al., 2010; Tarand and Nordli, 2001.
10. Brázdil and Kotyza, 2000.
11. Rohr, 2013.
12. Grove, 1995.
13. Wheeler and Pfister, 2009; Wheeler et al., 2006, 2010.
14. Ge, 2008.
15. Barriendos, 2005.
16. Adamson, 2015.
17. Quoted in Janković, 2001, 154.
18. Pfister et al., 1999; Adamson, 2015.
19. Litzenburger and Le Roy Ladurie, 2015.
20. Wetter et al., 2014.
21. Janković, 2001, 34.
22. Prieto et al., 2001.
23. E.g., Franssen and Scherrer, 2008.
24. Brázdil et al., 2010a, 2010b.
25. Nesje et al., 2008; Zumbühl et al., 2008; Holzhauser, 2010.
26. Behringer, 2010, 139–40.
27. Janković, 2001, 34.
28. Janković, 2001, 122.
29. Wegmann, 2005.
30. Nordli, 2001.



31. Pfister, 2011.
32. Richards, 1999.
33. Rohr, 2015.
34. E.g., Grotefend, 1997; Cheney and Jones, 2000.

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