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The Waning of the Little Ice Age: Climate Change in Early Modern Europe

Adjectives such as "important," "epochal," "acute," and "dramatic" usually accompany descriptions of the European Little Ice Age (LIA). An enormous literature attests to the LIA's symptoms and consequences. This article examines the statistical and anecdotal evidence for an LIA in Europe but finds little sign that any such event occurred. Looking at all of the available statistical reconstructions of European temperature during the last millennium, we find that annual winter and summer temperatures from the late Middle Ages to the end of the nineteenth century appear to be almost independent within a distribution that has a constant mean and variance. We find no statistical evidence of any major breaks, trends, or cycles in European weather of the sort that one could associate with an LIA. Moreover, we also find that the anecdotal evidence usually adduced to demonstrate that episodes of marked cooling occurred between the fourteenth and nineteenth centuries—for instance, the freezing of the Thames and the disappearance of grape growing in England—admits of simpler explanations.[1]

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1 For useful surveys of an extensive literature, see John A. Matthews and Keith R. Briffa, "The 'Little Ice Age': Revaluation of an Evolving Concept," *Geografiska Annaler,* LXXXVIIA (2005), 17–36; Michael E. Mann, "Little Ice Age," *Encyclopedia of Global Environmental Change. I. The Earth System: Physical and Chemical Dimensions of Global Environmental Change* (Chichester, 2002), 504–509; Mann, Raymond S. Bradley, and Malcolm K. Hughes, "Northern Hemisphere Temperatures during the Past Millennium: Inferences, Uncertainties, and Limitations," *Geophysics Review Letters,* XXVI (1999), 759–762. A new, posthumous edition

The idea that human history is driven by fluctuations in climate is tenacious; the collapse of most civilizations from the Roman to the Maya have been attributed at one time or another to diminishing resources caused by worsening weather. However, the implicit view of human beings as passive victims of meteorological circumstance, bereft of any capability to adapt to changing conditions—combined with an uneasiness about deterministic, mono-causal explanations in general—has led many mainstream historians to be skeptical of such climatic stories. An exception is Parker, who links most of the major historical events in the mid-seventeenth century, from the Irish Catholic uprising to the Mughal civil war, to a supposed worsening of weather in the Northern Hemisphere, although we will see below that the climatological bases for this argument are at best exiguous.[2]

Estimates of annual winter and summer temperature exist for Central Europe since 1500, for the Netherlands since 1201, for Switzerland since 1525, for England since 1660, and for Germany since 1000. These reconstructions, assuming that they are reliable, offer the potential to assess the size and timing of major swings in European climate since the Middle Ages. To assess the accuracy of the earliest and, presumably, most conjectural reconstructions, a comparison of known English wheat prices with the Dutch estimates from 1211 to the beginning of the price revolution in 1500 finds a close match (see Figure 1).[3]

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of Jean M. Grove's useful *The Little Ice Age* (London, 1988) appeared as *Little Ice Ages: Ancient and Modern* (London, 2004).

This journal has a long tradition of publishing work on climate history. The special issue, "History and Climate: Interdisciplinary Explorations," *Journal of Interdisciplinary History,* X (1980), 583–858, remains a highly useful introduction to an earlier literature. Most recently, see Michael McCormick et al., "Climate Change during and after the Roman Empire: Reconstructing the Past from Scientific and Historical Evidence," *ibid.,* XLIII (2012), 169–220.

2 See Joseph A. Tainter, *The Collapse of Complex Societies* (New York, 1988), for a skeptical survey. Jan de Vries, "Measuring the Impact of Climate on History: The Search for Appropriate Methodologies," *Journal of Interdisciplinary History,* X (1980), 599–630; Emmanuel Le Roy Ladurie, *Times of Feast, Times of Famine: A History of Climate since the Year 1000* (New York, 1971); Geoffrey Parker, "Crisis and Catastrophe: The Global Crisis of the Seventeenth Century Reconsidered," *American Historical Review,* CXIII (2008), 53–79.

3 For the temperature estimates, see Petr Dobrovolnā et al., "Monthly, Seasonal and Annual Temperature Reconstructions for Central Europe Derived from Documentary Evidence and Instrumental Records since AD 1500," *Climatic Change,* CI (2009), 69–107. Aryan F. V. van Engelen, Jan Buisman, and Vorstgetal van F. IJnsen, "A Millennium of Weather, Winds and Water in the Low Countries," in Philip D. Jones et al. (eds.), *History and Climate: Memories of the Future?* (Boston, 2001) (also available at http://www.knmi.nl/kd/daggegevens/

From the perspective of a European LIA, the statistical behavior of these temperature reconstructions comes as a surprise. In each case, the mean and variance of the series remained almost constant until around 1900 when temperatures, particularly winter temperatures, started to rise steadily. In no case do we find evidence of auto-correlation (one year's temperature helping to predict temperature in the following year), trends, or structural breaks in mean temperature. Although sustained shifts in climate do not appear to have occurred in Northern Europe since the late Middle Ages and, more tentatively, since 1000, we can identify decades of noticeably poor summer weather—in particular, the 1690s (the "Seven Lean Years" of 1693 to 1699 when Scotland experienced almost continual harvest failure) and the 1810s (when a fall in temperature preceded the eruption of Tambora in 1815 and the following "Year without a Summer"). None of the European series, or recent temperature reconstructions for the Northern Hemisphere, shows any evidence of decline from 1635 to 1665, a period that Parker claims to have had unusually bad weather.

Given the lack of evidence of any sustained declines in European temperatures before 1900, how are we to account for the belief among reputable climatologists that Europe experienced an LIA? The answer probably lies in the climatological practice of smoothing data in accord with some sort of moving average before analyzing it. If the data being smoothed are random, as European temperatures appear to be, smoothing them will give the spurious appearance of irregular oscillations—what statisticians call a Slutsky effect (see Figure 2).[4]

Not only do statistical reconstructions show no evidence of an LIA in Europe, most of the anecdotal evidence for worsening cli-

antieke_wrn/millennium_of_weather.pdf); Christian Pfister, "Monthly Temperature and Precipitation in Central Europe 1525–1979," in Bradley and Jones (eds.), *Climate Since A.D. 1500* (London, 1992), 118–142; Gordon Manley, "Central England Temperatures: Monthly Means 1659 to 1973," *Quarterly Journal of the Royal Meteorological Society,* C (1974), 389–405; Rüdiger Glaser and Dirk Riemann, "A Thousand Year Record of Climate Variation for Central Europe at a Monthly Resolution," *Journal of Quartenary Science,* XXIV (2009), 437–449. Glaser and Riemann describe years as good, average, or bad.

4 Mann, "Little Ice Age," 504–509; Matthews and Briffa, "'Little Ice Age,'" 17–36; Mann et al., "Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly," *Science,* CCCXVI (2009), 1256–1260; Eugen Slutsky "The Summation of Random Causes as the Source of Cyclic Processes," *Econometrica,* V (1937), 105–146; Vincent Barnett, "Chancing an Interpretation: Slutsky's Random Cycles Revisited," *European Journal of the History of Economic Thought,* XIII (2006), 411–432.

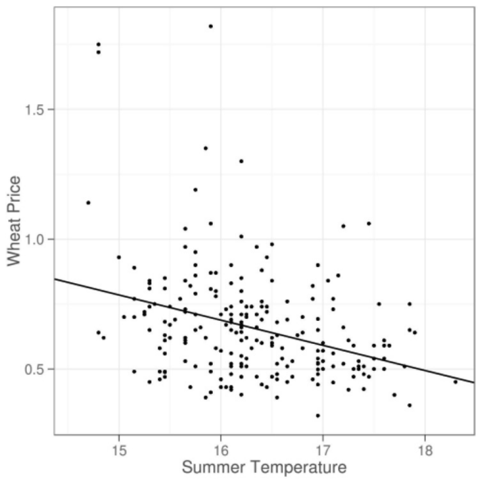
mate after the high Middle Ages also looks decidedly shaky. Our focus will be on the following well-known images, all directly linked to climate change: the demise of grape-growing in southern England in the late medieval era; the vogue for the Dutch winter landscape paintings of Pieter Bruegel the Elder (1525–1569) and others; the collapse of Greenland's Viking colony; the periodic "frost fairs" on London's Thames, ending in 1814; and, as the LIA waned, the contraction of Europe's Nordic and Alpine glaciers. Note that our six types of evidence include one that is demographic (Viking Greenland), one that is artistic (Dutch paintings), one that is social (London frost fairs), one that is economic (medieval vineyards), one that is agricultural (wheat yields), and only one (glaciers) that actually rests on an attempt to measure the effects of climate directly. Our review finds that the evidence of these images is less supportive of an LIA than has been claimed, or else that non-meteorological explanations for them are equally or more persuasive.

RECONSTRUCTING EUROPEAN WEATHER Because instrumental records of weather go back only to the late seventeenth century, earlier European weather must be reconstructed from a variety of documentary sources. The temperature reconstruction for the Low Countries by van Engelen, Buisman, and IJnsen runs almost continuously from 1301, although the records for the earlier years tend to be fragmentary; this reconstruction is based largely on records that note the length of time for which river tolls could not be collected or water mills not used during each year because rivers were frozen in winter or too low in summer.[5]

We can gauge the reliability of this reconstruction by comparing it with records of English wheat prices in 1211 from the other side of the North Sea, compiled by Clark. Because wheat could be stored for a year, prices reflected the current and previous harvest, permitting a comparison between prices and weather estimates for the previous two years. Figure 1 shows the strong relationship between these wheat prices (ending in 1500 before the start of the price revolution) and average summer temperatures. Regressions

5 Although tree rings might seem like a more systematic source, annual-growth rings only reflect weather for trees at the edge of their geographical ranges that are under stress from cold or arid conditions, which is not the case for most of Europe.Van Engelen et al., "Millennium."

Fig. 1 English Wheat Prices versus Average Dutch Summer Temperature for the Previous Two Years, 1211–1500

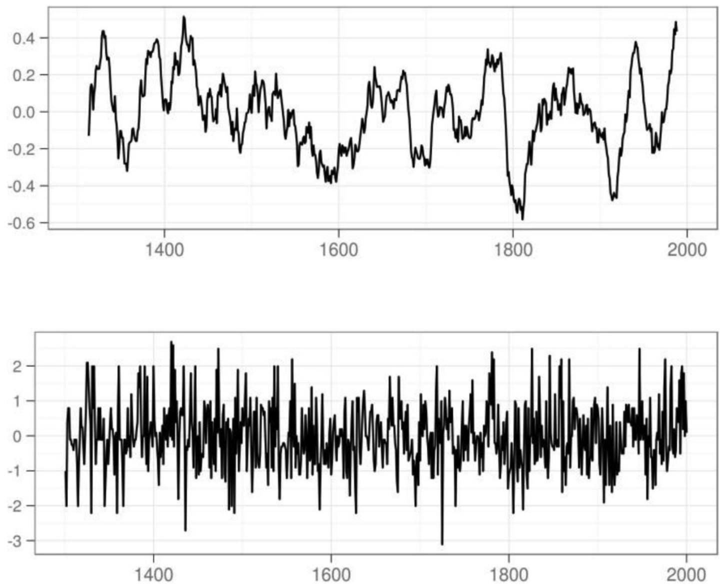


again reveal that winter temperature had no impact, but that a rise in summer temperature of one degree reduced wheat price in the same and following year by 5 percent. In a working paper of 2012, we show that the Dutch series also predicts wheat yields on English manors from 1270 to 1450; a rise in summer temperature of one degree increased them by 5 percent. Hence, the temperature reconstruction for the Low Countries appears to be reliable based on its ability to predict medieval prices, apparently offering a conclusive way to assess the timing and magnitude of the LIA in northern Europe.[6]

The top panel of Figure 2 shows summer temperature in the Low Countries from 1301, smoothed using a twenty-five year moving average. The LIA is immediately evident as a declining trend between the mid-fifteenth and the early nineteenth centuries, with markedly cold episodes in the late sixteenth, late seventeenth, and early nineteenth centuries. However, the unsmoothed graph of summer temperature in the panel below gives an impres-

6 Gregory Clark, "The Price History of English Agriculture, 1209–1914," *Research in Economic History,* XXII (2004), 41–123; Kelly and Ó Gráda, "Change Points and Temporal Dependence in Reconstructions of Annual Temperature: Did Europe Experience a Little Ice Age?" working paper 2012/10 (University College Dublin Centre for Economic Research, 2012), available at www.ucd.ie/economics/research.

Fig. 2 The LIA as Slutsky Effect: Low Countries Summer Temperature, 1301–1980

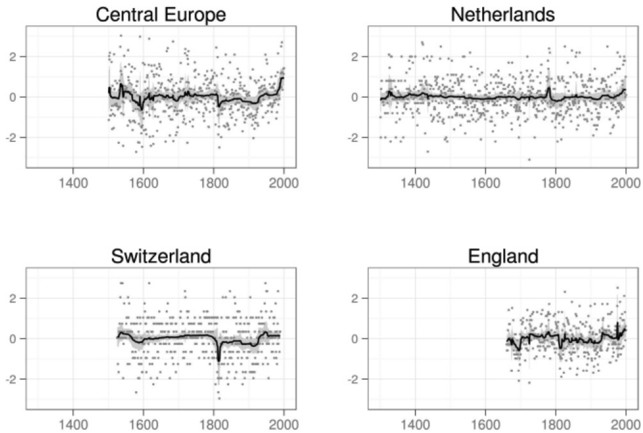


NOTE The top panel, which shows the data smoothed with a twenty-five year moving average, gives the appearance of marked cold episodes between the fifteenth and nineteenth centuries. The lower panel shows the actual data, which are almost entirely random with a constant mean and variance.

sion of randomness, without any major trends, cycles, or breaks. This impression of statistical randomness turns out to be correct. Using an array of statistical tests, we show that annual summer and winter temperatures for the Low Countries, Central England, Switzerland, and Central Europe before 1900 (when temperatures started to trend upward) behave almost discretely within a distribution providing a constant mean and variance.

Given these results, the general belief in an LIA can derive only from mistaken attempts to smooth data that are, on closer inspection, random. The top panel of Figure 2 shows a white noise series—independent selections from a normal distribution with mean 0 and variance 1. The lower panel shows that smoothing this series with a twenty-five-year moving average or with a more sophisticated loess (locally weighted sum of squares) smoother and a

Fig. 3 Historical Series of Central European, Dutch, Swiss, and English Summer Temperatures, Smoothed Using a Bayesian Change Point Procedure



span of one-third generates artificial peaks and troughs. The reason for the appearance of these spurious cycles when random series are smoothed (the Slutsky Effect) is straightforward. Random series present occasional runs of unusually high or low values; these outliers distort the smoothed average, giving the appearance of irregular oscillations.

Kelly and Ó Gráda show that one smoothing technique that performs well (avoiding the distortion caused by outliers but detecting short changes in series) is the Bayesian Change Point procedure of Barry and Hartigan. Figure 3 shows the mean values of summer temperature estimated by this procedure (the corresponding winter series are entirely flat until around 1900 when they start to trend upward). These figures show, even in the absence of the sustained changes in European weather since the late Middle Ages that an LIA would create, individual decades with notably cold summers. Since grain was rarely stored for more than a year, two or more years of harvest failure were potentially catastrophic. The Dutch and English series both clearly show the "seven ill years" from 1693 to 1699 when poor weather caused a succession of poor harvests in Scotland. Other notably poor decades were the 1590s and the 1810s, although the mid-seventeenth century, which

Parker claims to be the nadir of the LIA, does not emerge as unusual in any of the weather series.[7]

Glaser and Riemann reconstructed annual German temperatures back to 1000, categorizing each one as either good, average, or bad. Looking at these data by half-century, Kelly and Ó Gráda find that since the proportion of good and bad years has remained constant, as has the probability of two good or bad years in a row, the Medieval Warm Period may turn out to be just as illusory as the LIA.[8]

THE LIA, AN ELASTIC CONCEPT Although it amounts to academic heresy to question or deny the existence of an LIA, considerable imprecision about its chronology, geography, and impact remains. Originally applied to an era spanning several millennia in California's Sierra Nevada, the term "Little Ice Age" now usually refers instead to a global climatic shift toward colder weather in northwestern Europe during the second millennium. Estimates of the timing of the LIA's onset range from the ending of a warm phase—the so-called Medieval Warm Period or Medieval Climatic Anomaly—that "had already passed its peak in Greenland in the twelfth century [but] broadly continued in Europe until 1300 or 1310," to an "abrupt beginning" in the late sixteenth century. Moreover, although Le Roy Ladurie referred to the cold 1850s as "the final sigh of the LIA," others have found little evidence of an

7 Kelly and Ó Gráda, "Change Points and Temporal Dependence"; Daniel Barry and J. A. Hartigan, "A Bayesian Analysis for Change Point Problems," *Journal of the American Statistical Association,* LXXXVIII (1993), 309; Alex J. S. Gibson and T. Christopher Smout, *Prices, Food, and Wages in Scotland, 1550–1780* (New York, 1995), 170–171. The most widely used series of temperature reconstructions for the northern hemisphere—Mann et al., "Proxy-Based Reconstructions of Hemispheric and Global Surface Temperature Variations over the Past Two Millennia," *Proceedings of the National Academy of Sciences,* CV (2008), 13252–13257—finds that the mid-seventeenth century stands out as a local maximum of temperature rather than the supposed Parkerian minimum. In assessing local conditions, these hemispheric reconstructions are, however, problematical for two reasons: first, the low correlation of weather across even small geographical areas (an unusually cold period in one place can be normal or warm in other areas), and, second—as indicated in Blakeley B. McShane and Abraham J. Wyner, "A Statistical Analysis of Multiple Temperature Proxies: Are Reconstructions of Surface Temperatures over the Last 1000 Years Reliable?" *Annals of Applied Statistics* (forthcoming)—the poor statistical fit of weather proxies (usually tree rings) to instrumentally recorded temperature, raising questions about the validity of climate reconstructions based on physical records. These criticisms do not apply to the documentary-based reconstructions used herein.

8 Glaser and Riemann, "Thousand Year Record"; Kelly and Ó Gráda, "Change Points and Temporal Dependence."

end to it before the twentieth century. Even Hubert Lamb, the English climatologist who was one of the main popularizers of the LIA, conceded the imprecision of the dating. The chronology of the preceding Medieval Warm Period, identified by Lamb in 1965, is equally elastic. Some of the uncertainties may stem from genuine regional differences in climate. Within large, hemispheric areas, climate can enter "anomalous" phases that are not necessarily the same everywhere. A single forcing factor (for example, changing solar irradiance) can result in markedly different regional effects; advocates of an LIA, by implying a simple single-sign direction of change, fail to capture this point.[9]

Consensus has also been lacking about the LIA's geographical reach. The Intergovernmental Panel on Climate Change's *Third Assessment Report* emphasizes the variations in climate change across regions and the possible independence of such variations to the extent that it deems the term "Little Ice Age" a misleading guide to *global* temperature changes in the past. Even though the period from 1500 to 1900 in the Northern Hemisphere stands out, agreement about the extent to which temperatures dropped there is lacking. The modest declines proposed by some scholars sit uncomfortably with the rhetoric of, say, Fagan ("a climatic seesaw that swung . . . in volatile and sometimes disastrous shifts. . . , growing season was about five weeks shorter") or Steckel ("pack ice surrounded Iceland. . . , havoc in northern Europe. . . , glaciers advanced significantly"; "cool temperatures and temperature variability were bad for health"). More recent assessments also reckon

9 For an early use of the term "Little Ice Age" in a European context, see Manley's comment on Hans W. Ahlmann, "The Present Climatic Fluctuation," *Geographical Journal,* CXII (1948), 193. François E. Matthes, "Report of the Committee on Glaciers," *Transactions of the American Geophysical Union,* XX (1939), 518–523; Hubert H. Lamb, *Climate, History and the Modern World* (London, 1995; orig. pub. 1982), 181; Pier Paolo Viazzo, *Upland Communities:* Environment, Population and Social: Structure in the Alps since the Sixteenth Century (New York, 1989), 133; Bradley and Jones, "When Was the 'Little Ice Age'?" in Takehiko Mikame (ed.), *Proceedings of the International Symposium on the "Little Ice Age" Climate* (Tokyo, 1992), available at http://www.geo.umass.edu/faculty/bradley/bradley1992c.pdf; Gifford Miller et al., "Abrupt Onset of the Little Ice Age Triggered by Volcanism and Sustained by Sea-Ice/ Ocean Feedbacks," *Geophysical Research Letters,* XXXIX (2012), available at http://nldr.library.ucar.edu/repository/assets/osgc/OSGC-000-000-010-465.pdf. Emmanuel Le Roy Ladurie, *Histoire humaine et comparée du climat. II. Disettes et révolutions, 1740–1860* (Paris, 2006); Lamb, *Climate, History,* 318; *idem,* "The Early Medieval Warm Epoch and Its Sequel," *Palaeogeography, Palaeoclimatology,* Palaeoecology, I (1965), 13–37; Bradley, Malcolm K. Hughes, and Henry F. Diaz, "Climate in Medieval Time," *Science,* CCCII (2003), 404–405.

the "Medieval Warm Period" to have been only moderately milder than the cooling period that followed.[10]

How does the statistical skepticism toward the LIA offered herein leave the combination of vivid images invoked by Lamb and Le Roy Ladurie and popularized by Fagan and others that link the LIA firmly to key trends and events in European history? We exclude from this analysis links that certain scholars have proposed between the LIA and events as disparate as witch burning during the Renaissance and the "general crisis" of the seventeenth century. Instead, our focus is on the familiar images directly linked to climate change. The evidence of these images is either less supportive of an LIA than their proponents claim, or nonmeteorological explanations for them are equally or more persuasive.[11]

WINE IN MEDIEVAL ENGLAND Since vintage and wine quality are sensitive to weather, the concern about wine cultivation that the prospect of further global warming in the present century has created is hardly surprising. The same process in reverse, whereby late medieval England suffered the collapse of its grape cultivation and wine production due to cooling temperatures, is one of the most resonant pieces of evidence adduced for the LIA.[12]

10 Estimates of temperature range from the modest 0.1–0.2° C implied by several meteorological reconstructions, through the 1.7° C employed by Richard H. Steckel in a recent anthropometric analysis, to the "about 7° C cooler than during the Medieval Warm Period" claimed by Brian Fagan. See Johannes Oerlemans, *Glaciers and Climate Change* (Rotterdam, 2001); Fagan, *Little Ice Age: How Climate Made History, 1300–1850* (New York, 2000); Steckel, "The Little Ice Age and Health: Europe from the Early Middle Ages to the Nineteenth Century" (2011), available at www.econ.ucla.edu/workshops/papers/History/Steckel.pdf. For a modest decline, see Oerlemans, "Extracting a Climate Signal from 169 Glacier Records," *Science,* CCCVIII (2005), 675–677; Michael H. Zemp et al., "Extending Glacial Monitoring into the Little Ice Age and beyond," *PAGES News,* 19[2] (2011), 67–69. Steckel, "Health and Nutrition in the Pre-industrial Era: Insights from a Millennium of Average Heights in Northern Europe," in Robert C. Allen, Tommy Bengtsson, and Martin Dribe (eds.), *Living Standards in the Past: New Perspectives on Well-being in Asia and Europe* (New York, 2005), 227–253; Intergovernmental Panel on Climate Change, *Climate Change 2001, Third Assessment Report: Working Group I: The Scientific Basis,* Section 2.3.3, available at http://www.grida.no/publications/other/ipcc_tar/ .

11 Wolfgang Behringer, "Climatic Change and Witch-hunting: The Impact of the Little Ice Age on Mentalities," *Climatic Change,* XLIII (1999), 335–351; Emily Oster, "Witchcraft, Weather and Economic Growth in Renaissance Europe," *Journal of Economic Perspectives,* XVIII (2004), 215–228; Parker, "Crisis and Catastrophe"; David D. Zhang et al., "The Causality Analysis of Climate Change and Large-scale Human Crisis," *Proceedings of the National Academy of Sciences* (2011), available at http://www.pnas.org/content/early/2011/09/29/1104268108]. Compare Tainter, *Collapse of Complex Societies,* 44–50.

12 Isabelle Chuine et al., "Grape Ripening as a Past Climate Indicator," *Nature,* CDXXXII (2004), 289–290; Valérie Daux et al., "Température et dates de vendanges en France," paper

The area reserved for grapes in pre-Norman England must have been meager. The forty-five vineyards recorded in the Domesday Book (1086) were for the most part recently planted, small in size, and aimed mainly at the requirements of the Anglo-Norman nobility and the Church. The only yield reported in Domesday refers to the vineyard at Rayleigh, Essex, where six *arpents* yielded twenty *modii* in a good year (*si bene procedit*). Assuming that the Domesday *modius* was the same as the Roman measure, this yield would imply about 30 litres per arpent. An average vineyard of 5 arpents (about five acres) implies a rough aggregate estimate of about 7,000 litres and, given a population of about 1.6 million at the time, a miniscule per capita consumption.[13]

The production of wine did not cease altogether in late medieval and early modern England. However, as Rogers, a nineteenth-century historian/politician, noted, there was less of it than frequently imagined. The trouble was that the Latin word for a fishpond (*vivarium*) was often inaccurately transcribed as vineyard (*vinarium*). Referring to the post-Black Death era, Dyer notes the "surprisingly large number of vineyards" found in "unlikely locations, because the Latin word for a fishpond, *vivarium,* was read as *vinarium.*" The widespread presence of fishponds in the medieval English landscape reflected the importance of freshwater fish in the diets of the rich and famous. One of five examples of a fishpond apparently masquerading as a vineyard was in the parish of Sherborne, Dorset (1377): "John Uphull and John Mulleward hold a piece of meadow lying next to a long "vinarium"; between their meadow on the south side is a water course which acts as a boundary; pays six shillings per annum and increasing to seven shillings per annum" (authors' translation). This "vineyard" is most likely one of several in the parish belonging to Richard Mitford, successively

presented at the Conference "Réchauffement climatique, quels impacts probables sur les vignobles?" March 28–30, 2007, University of Burgundy, Dijon, available at http://www.u-bourgogne.fr/chaireunesco-vinetculture/Actes%20clima/Actes/Article_Pdf/Daux.pdf; Orley Ashenfelder and Karl Storchmann, "Using Hedonic Models of Solar Radiation and Weather to Assess the Economic Effect of Climate Change: The Case of Mosel Valley Vineyards," *Review of Economics and Statistics,* XCII (2010), 333–349; Lamb, *Climate, History;* Fagan, *Little Ice Age; idem, The Great Warming: Climate Change and the Rise and Fall of Civilizations* (New York, 2008); Steckel,"Health and Nutrition," 243.

13 John H. Round, "Essex Vineyards in Domesday," *Transactions of the Essex Archaeological Society,* VII (1903), 249–251; Henry C. Darby, *The Domesday Geography of Eastern England* (New York, 2007; orig. pub. 1951), 372.

bishop of Chichester and Salisbury, as well as a royal favorite, who "obtained fish from his pools at Sherborne (Dorset)."[14]

The quality of England's medieval vineyards is no more likely to have matched that of the continental vineyards of the time than are today's. England's Norman rulers would not have been content with a mediocre variety that, according to Peter of Blois, Henry II's Latin secretary, had to be drunk "with closed eyes and tense jaws." Indeed, such was the low quality of English "wine" that some of it was consumed instead as verjuice.[15]

Before the conception of the LIA, comparative advantage had long been the traditional explanation for the decline in English wine production. In the wake of Henry II's annexation of the wine-rich regions of Anjou, Poitou, and Gascony in the 1150s, "that fondness for French wines which then came upon us" led to the neglect of England's vineyards. Although still costly to ship, English imports of Angevin (and, later, Gascon) wine grew steadily thereafter until interrupted by the Hundred Years' War. The Anglo–Gascon wine trade reached a peak in 1303, when 20,000 tons were imported (at 232 gallons or 1,040 litres per ton); imports were only half that 150 years later at the end of the Hundred Years' War (1336–1453).[16]

Such an "economic"—as distinct from a "meteorological"—interpretation is also consistent with the much higher price of wine relative to beer in England than in France during the Middle Ages. In late thirteenth- and early fourteenth-century England, a gallon

14 J. E. Thorold Rogers, *A History of Agriculture and Prices in England* (Oxford, 1885), I, 18; Christopher Dyer, "The Value of Fifteenth-Century Inquisitions Post Mortem for Economic and Social History," in Michael Hicks (ed.), *The Fifteenth-Century Inquisitions Post Mortem: A Companion* (Woodbridge, 2012), 98; Frederic W. Weaver and Charles H. Mayo (eds.), *Notes & Queries for Somerset and Dorset* (London, 1912), 73; Dyer, *Everyday Life in Medieval England* (London, 1994), 107. According to the *Oxford Latin Dictionary* (New York, 1982), II, 2081, "*Vivarium*" could also mean a game enclosure or "a place where living creatures are kept."

15 Yves Renouard, "The Wine Trade of Gascony in the Middle Ages," in Rondo Cameron (ed. and trans., with the assistance of Franklin F. Mendels and Judith P. Ward), *Essays in French Economic History* (Homewood, Ill., 1970), 67. Verjuice is a flavor-enhancing, acidifying liquid made from a variety of white grape. See John Willoughby, "Power Ingredients: Verjuice Makes Sour Grapes a Good Thing," *New York Times,* 27 Oct. 2010.

16 Morgan O'Doherty, "Remarks on Henderson the Historian," *Blackwood's Edinburgh Magazine,* XVI (1824), 6; Renouard, "Wine Trade"; Henry J. Chaytor, *The Troubadours and England* (Cambridge, 1923), 26–27; Margery K. James, "The Fluctuations of the Anglogascon Wine Trade during the Fourteenth Century," *Economic History Review,* IV (1951), 170–196; review of James and Elspeth M. Veale, *Studies in the Medieval Wine Trade,* by Sylvia L. Thrupp, *Speculum,* XLVIII (1973), 369–370.

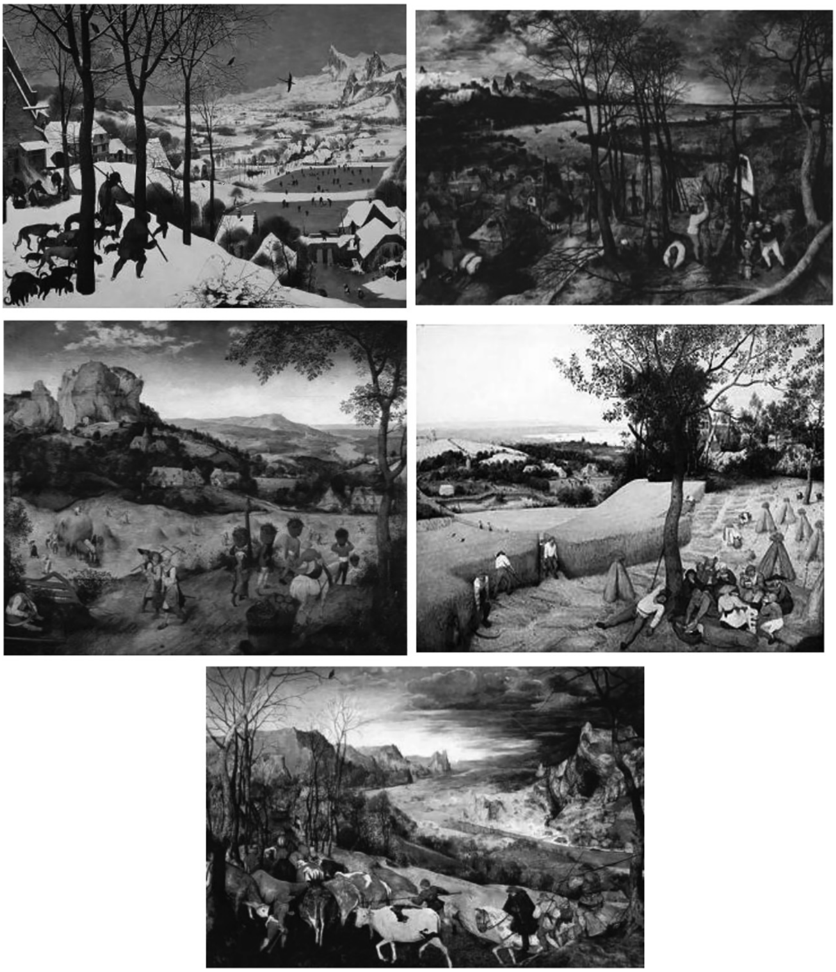
of the cheapest wine cost about five times as much as a gallon of the cheapest ale, whereas the ratio for first-quality wines and ales was seven to one. In medieval France, however, beer cost about twice as much as ordinary wine by volume.[17]

Admittedly, the lack of distinct time-series evidence about cultivated acreages, foreign trade, and relative prices makes the role of comparative advantage in reducing English wine production impossible to prove conclusively. But even on the basis of the available evidence, comparative advantage offers just as compelling an argument for the "disappearance" of England's vineyards as does climate change.

LIA LANDSCAPES Thanks largely to Lamb, Pieter Bruegel the Elder's "The Hunters in the Snow" (1565), one of the masterpieces of the northern Renaissance, has attained iconic status in both academic and popular accounts of the LIA. However, few of those who agree with Lamb about Bruegel's famous oil-on-wood landscape supporting an LIA note that it is just one of a cycle of six paintings describing the different seasons of the year. Four of the other five survive, including the equally well-known "The Harvesters," which is now in New York's Metropolitan Museum of Art. Less familiar are "The Gloomy Day" and "The Return of the Herd" (both in Vienna's Kunsthistorisches Museum) and "The Hay Harvest" (in Prague Castle). Taken as a group, these five paintings by Bruegel make a less-than-convincing case for an LIA (see Figure 4). Although "Hunters in the Snow" may have been painted in the wake of what van Engelen, Buisman, and IJnsen reckon was the coldest winter in the Low Countries be-

17 Compare Dyer, *Standards of Living in the Later Middle Ages: Social Change in England c. 1200–1520* (New York, 1989), 58, 62; Alec R. Myers, *London in the Age of Chaucer* (Norman, 1972), 192; Richard Unger, *Beer in the Middle Ages and the Renaissance* (Philadelphia, 2004), 74–77. A quarter litre of beer cost a denier, whereas a *pinte* (roughly 1 litre) of wine cost 1 to 2 deniers. See http://medieval.mrugala.net/Commerce%20et%20l'argent/Prix%20au%20moyen%20age%20-%20ordre%20chronologique.htm. Lamb's linking of Germany's decline in grape cultivation to the LIA does not readily square with the dynamism of German viticulture after the ravages of the Thirty Years' War, even in such northern regions as the Ahr valley. See Jancis Robinson (ed.), *The Oxford Companion to Wine* (New York, 2006; orig. pub. 1994), 304–308. However, German vineyard owners might have learned to reduce the effect of temperature on yields as did twentieth-century French owners. See Jean-Michel Chevet, Sébastien Lecocq, and Michael Visser, "Climate, Grapevine Phenology, Wine Production, and Prices: Pauillac (1800–2009)," *American Economic Review: Papers & Proceedings,* CI (2011), 142–146.

Fig. 4 Pieter Breugel's "The Months" (1565): "The Hunters in the Snow," "The Gloomy Day," "The Hay Harvest," "The Harvesters," "The Return of the Herd"



tween 1435 and 1684, "The Harvesters," painted in the same year, is evocative of a warm summer and a bountiful harvest.[18]

Bruegel started a fashion for winter landscapes in the Low Countries. Other painters of such scenes included Hendrick Avercamp (1585–1634), Gillis Mostaert (1534–1598), Lucas van Valck-

18 Lamb, "Britain's Changing Climate," *Geographical Journal,* CXXXIII (1967), 445–466; *idem, Climate, History,* 233–234; John E. Thornes, *Constable's Skies: A Fusion of Art and Science*

enborch (1530–1597), Jacob Grimmer (c. 1525–1590), and Pieter Bruegel the Younger (1564/5–1636). Avercamp was the best known, but whereas Bruegel the Elder depicted his returning hunters in the snow as weary and disappointed, Averkamp favored lively works, mostly of people enjoying themselves on the ice. It remains unclear whether the lack of low cloud and sunshine in Avercamp's landscapes reflected actual climatological conditions or simply an inability to "portray a high-albedo surface in the sun." Not all of the northern artists of the era adhered to the vogue for snow-and-ice scenes. Other better known sixteenth- and seventeenth-century Dutch landscape artists, such as Aelbert Cuyp (1620–1691) or Jan van Goyen (1596–1656), rarely produced them, and Rembrandt van Rijn (1606–1669) has only one surviving winter landscape.[19]

In an analysis of more than 12,000 works held in dozens of art galleries, painted between 1400 and 1967, Neuberger, a meteorologist, believed that he had detected the LIA by changes in cloud patterns and coloring. Dividing the data into three periods—1400 to 1549, 1550 to 1849, and 1850 to 1967—he found that darkness and cloudiness peaked in the middle period. However, Neuberger attributed the fact that patterns in the third period were uncomfortably similar to those detected in the second to fashion (especially the movement of Impressionism) and the atmospheric pollution associated with the Industrial Revolution.[20]

Burrough's study of the link between trends in art and climate, published a decade after Neuberger's, was more circumspect, allowing a greater role to changing tastes. Burroughs dated the decline of winter landscapes as a theme in Dutch painting from c. 1660, awkward timing from the standpoint of LIA historiography. The part that the vagaries of artistic fashion played in this develop-

(New York, 1999), 160–162; Jenny L. Chapman and Michael J. Reiss, *Ecology: Principles and Applications* (New York, 1999), 98; Fagan, *Little Ice Age,* 48; Jonathan Jones, "Into the White," *The Guardian,* 18 Dec. 2006; Wikipedia, "Little Ice Age" (http://en.wikipedia.org/wiki/Little_Ice_Age). Breugel's masterpiece also features in the text and on the dust jacket of Behringer's interesting *Cultural History of Climate* (New York, 2009). Van Engelen, Buisman, and IJnsen's data are available at www.knmi.nl/kd/metadata/nederland_wi_zo.html.

19 The highly derivative character of Bruegel the Younger's work renders it unlikely to represent contemporary climatic conditions. See William J. Burroughs, "Winter Landscape and Climate Change," *Weather,* XXXVI (1981), 352–357; Peter J. Robinson, "Ice and Snow in Paintings of Little Ice Age Winters," *ibid.,* LX (2005), 38.

20 Hans Neuberger, "Climate in Art," *Weather,* XXV (1970), 46–66.

ment prompted Burroughs to urge caution in drawing inferences about historical trends from art. More cautious still is Robinson's 2005 analysis of the link between the LIA and the varieties of landscape painting. Leaving room for both meteorological and cultural interpretations, Robinson conceded (1) that both "decreasing winter severity" and the strong influence of Italian styles could explain the lack of snowy landscapes between c. 1420 and the 1560s, (2) that Rembrandt's sole winter landscape is not "meteorologically completely convincing," and (3) that van Ruisdael's thirty winter landscapes might give a "somewhat biased" impression of weather conditions in the late seventeenth century.[21]

Robinson also noted that the precipitous drop in Dutch landscapes painted after c. 1675 owed more to fashion than to changing climate, as the purchasing public increasingly preferred representations of "sunlit sunny days." In the late eighteenth and early nineteenth centuries, ice scenes sought to reflect Dutch heroism rather than adverse weather. Moreover, depictions of sunlight and more realistic cloud formations in the nineteenth century reflected the Romantic movement, and the Impressionist landscapes of the following generation might have captured "short-term synoptic situations." In sum, although trends in early modern landscape art may have been influenced by the weather to some extent, they can hardly be represented as a faithful impression of its evolution.[22]

GREENLAND'S VIKINGS AND THE NORDIC COUNTRIES In accounting for the collapse of Greenland's small Norse colony in the fifteenth century, recent scholarship has tended to de-emphasize the role of climate, proposing several potential competing explanations instead. As a warning against simplistic assertions that the Norsemen simply "got cold and then died," McGovern and others pointed to archaeo-faunal and ice-core evidence that the Norsemen had shown signs of successfully adapting to periods of extremely cold weather before the fifteenth century,[23]

Alternative explanations for the demise of the colony include

21 Burroughs, "Winter Landscape"; Robinson, "Ice and Snow," 37–41.

22 Robinson, "Ice and Snow," 38, 39–40. We defer to Robinson's judgment about "sunlit sunny days," despite the skepticism of one referee who protested that the buying public might have grown weary of gloomy paintings precisely because the weather was worsening at this time!

23 Thomas H. McGovern, "Climate Correlation and Causation in Norse Greenland," *Arctic Anthropology,* XXVIII (1991), 77.

competition for resources with the indigenous Inuit; the decline of Norwegian trade in the face of an increasingly powerful German Hanseatic League; the diversion of English fishing vessels from Greenland to Labrador and Newfoundland during the fifteenth century; the increasing availability of African ivory as a cheaper substitute for walrus ivory, one of the settlers' major resources; an ill-fated westward migration by Greenland colonists after the discovery of Labrador and Newfoundland; and soil erosion caused by the overgrazing and tree felling that an inflexible social structure encouraged.[24]

Emigration by Greenlanders to Iceland, which faced its own problems—mainly poor soils and soil management, rather than climatic deterioration—could also have played a role in the Norse colony's demise. The opportunity for the cheap land and high wages that the Black Death presented on Iceland after the pandemic's belated sojourn on the island from 1402 to 1404 might have been attractive to Greenlanders. The Black Death killed two-thirds of the population on Iceland; whether it ever spread as far as Greenland is not known.[25]

Clearly, the number of alternate explanatory hypotheses is in inverse proportion to the available evidence. But the sheer size of the colony has to be taken into consideration. If, as Lynnerup reckoned, the population of Greenland's Norse colony never exceeded 2,250, even a steady trickle of migrants would eventually have reduced numbers to below sustainable size. Hence, apart from any meteorological threat, in Nørlund's words, "the little colony was

24 Dale Mackenzie Brown, "The Fate of Greenland's Vikings," *Archaeology,* February 28, 2000, available at http://www.archaeology.org/online/features/greenland/; Niels Lynnerup, *The Greenland Norse: A Biological-anthropological Study: Man & Society Number 24* (Copenhagen, 1998); Else Roesdahl, "L' ivoire de morse et les colonies norroises du Groenland," *Proxima Thule: Revue d?Études Nordiques,* III (1998), 9–48; Kirsten A. Seaver, "Desirable Teeth: The Medieval Trade in Arctic and African Ivory," *Journal of Global History,* IV (2009), 271–292; Alastair G. Dawson et al., "Greenland (GISP2) Ice Core and Historical Indicators of Complex North Atlantic Climate Changes during the Fourteenth Century," *The Holocene,* XVII (2007), 427–434; Orri Vésteinsson, McGovern, and Christian Keller, "Enduring Impacts: Social and Environmental Aspects of Viking Age Settlement in Iceland and Greenland," *Archaeologia Islandica,* II (2002), 98–136; Joel Berglund, "Did the Medieval Society in Greenland Really Fail?" in Patricia A. McAnany and Norman Yoffee (eds.), *Questioning Collapse* (New York, 2010), 45–70, blames a combination of climatic and institutional factors.

25 Ian S. Simpson et al., "Soil Limitations to Cultivation in Premodern Iceland," *Human Ecology,* XXX (2002), 423–444; Richard F. Thomasson, "A Millennium of Misery: The Demography of the Icelanders," *Population Studies,* XXXI (1977), 410.

too remote to stay permanently strong and healthy. Half a millennium it endured. All honour to it for that."[26]

If, however, the LIA led to the collapse of Greenland's Viking colony, the presumption is that it should also have had a negative, if less extreme, effect on Europe's colder northern regions. Yet demographic trends there between 1500 and 1800 indicate no such effect. The populations of the Nordic countries—and of Switzerland—would presumably have been more vulnerable to global cooling than those of Europe as a whole. But as Table 1 shows, both regions increased their estimated populations relative to the rest of Europe during the early modern era, confirming the claim that the decline of wheat and rye cultivation in Norway from the fourteenth century onward owed more to lower German cereal prices than to any temperature change; as markets developed, Norwegians concentrated more on fish and butter.[27]

CEREAL YIELDS IN ENGLAND A likely corollary to the scenarios described in the previous section is that the LIA led to a contraction of wheat cultivation in Europe's uplands and its northern fringes. Fagan argues that because a deteriorating climate compromised the cultivation of wheat (always a risky crop in cooler climates), by the late seventeenth century, the growing season in England (Fagan is silent about trends elsewhere) was about five weeks shorter than it is today. Lamb had anticipated this claim five years earlier: "The growing season was presumably shortened on the long-term average (30–50 years) by about 5 weeks in comparison with the warmest decades of the twentieth century."[28]

Such a truncation in the growing season should have left its mark on crop mixes and crop yields, particularly in marginal regions. Tillage should have retreated at the expense of pasture and, given its relative sensitivity to cold weather, wheat at the expense of sturdier cereal crops. The hard, definitive evidence concerning

26 Lynnerup, "Palaeodemography of the Greenland Norse," *Arctic Anthropology,* XXXIII (1996), 133; Andrew J. Dugmore, Keller, and McGovern, "Norse Greenland Settlement: Reflections on Climate Change, Trade, and the Contrasting Fates of Human Settlements in the North Atlantic Islands," *Arctic Anthropology,* XLIV (2007), 12–36. The Nørlund quotation (1928) derives from Lynnerup, *Greenland Norse,* 120.

27 Gustav Utterström, "Climatic Fluctuations and Population Problems in Early Modern History," *Scandinavian Economic History Review,* III (1955), 3–47; Harry A. Miskimin, *The Economy of Early Renaissance Europe, 1300–1460* (New York, 1975), 59.

28 Fagan, *Little Ice Age,* 113; Lamb, *Climate, History,* 232.

Table 1 Nordic, Swiss, British, and European Populations, 1500–1820 (1,000s)

COUNTRY	1500	1600	1700	1820
[1] Finland	300	400	400	1,169
[2] Norway	225	400	500	970
[3] Sweden	550	760	1,260	2,585
[4] Denmark	570	650	700	1,155
[5] Switzerland	562	905	1,200	1,986
[6] Europe	48,192	62,580	68,796	114,571
[1]–[4] as % [6]	3.42	3.53	4.16	5.13
[1]–[5] as % [6]	4.59	4.97	5.90	6.86

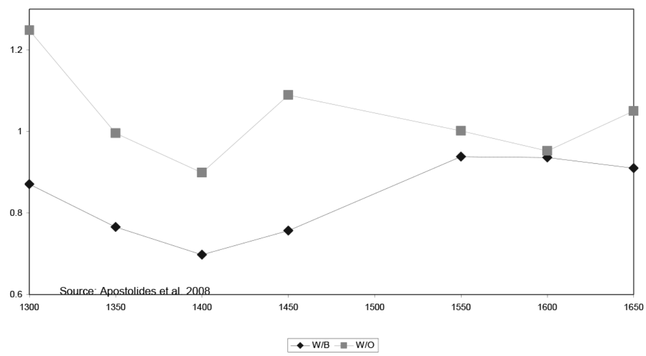
SOURCE Derived from data in Angus Maddison, *Statistics on World Population, GDP and Per Capita GDP, 1–2006 AD,* available at http://www.tacitus.nu/historical-atlas/population/scandinavia.htm; Markus Mattmueller, *Bevolkerungsgeschichte der Schweiz. Teil 1: die fruhe Neuzeit, 1500–1700* (Basel, 1987), 2 v.

grain acreages and yields required to test this claim are lacking. *Faute de mieux,* however, data about output and productivity trends in early modern agriculture in England as a whole are available. They imply that total arable acreage grew between 1380 and 1700 and that the share of wheat in the total cereal acreage held its own, falling marginally from 21 percent of all arable land in 1300 to 18 percent in 1420 before reaching 21 percent again in 1600 and 1700. Furthermore, as Figure 5 reports, net wheat yields per acre also kept pace with those of oats and barley during the same period.

The Lamb–Fagan claim that cooler temperatures led to a shrinking growing season does not sit comfortably with the available evidence—admittedly tentative and contestable—that the number of days worked per household in English agriculture rose by more than half between 1450 and 1600. Such evidence does not disprove the presence of an LIA—after all, an advocate might insist that more working days were required precisely because the working season was shorter (poor climatic conditions reduced labor productivity)—but it indicates that the economic consequences of any such LIA for English agriculture, abstracting from other possible influences, were modest at most.[29]

29 Alexander Apostolides et al., "English Gross Domestic Product: Some Preliminary Estimates" (2008), Tables 4A, 4B, 15, available at http://www2.warwick.ac.uk/fac/soc/economics/staff/faculty/broadberry/wp/pre1700v2.pdf]; Bruce M. S. Campbell and Ó Gráda," Harvest Shortfalls, Grain Prices, and Famines in Preindustrial England," *Journal of Economic History,* LXXI (2011), 859–886.

Fig. 5 Relative Wheat Yields, 1300/1350–1650/1700

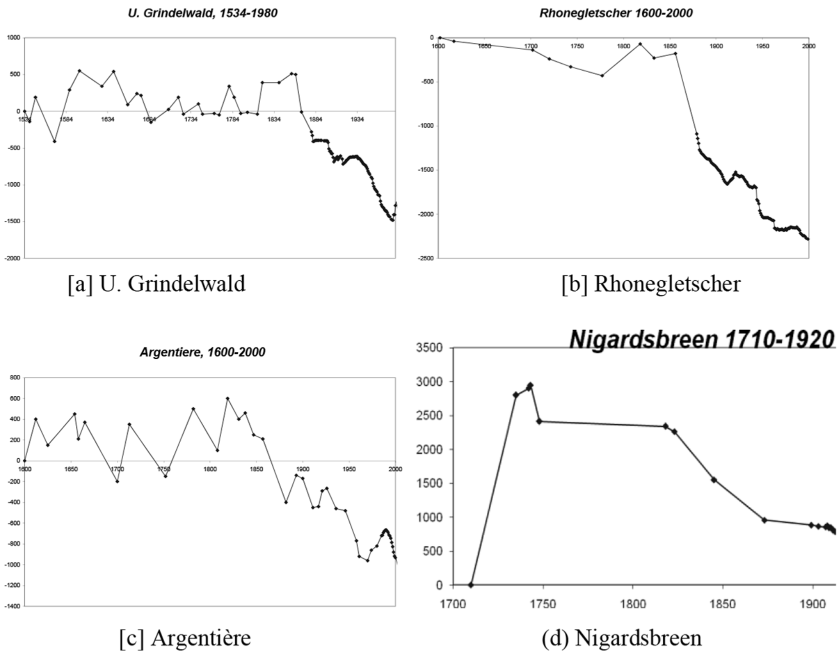


GLACIERS Matthes' linking of his original "Little Ice Age" to the growth of Sierra Nevadan glaciers following a mid-Holocene thermal maximum prompted others to reconstruct historical glacier lengths. Glacial retreat since the late nineteenth century has become one of the hallmark images of global warming. Glaciers expand and shrink in response to temperature and snowfall, although in Europe, rising temperature rather than reduced precipitation is deemed to be the dominant influence. Today, scientists attribute the retreat of glaciers in northern Europe and their virtual disappearance in the Pyrenees to global warming. Similarly, Le Roy Ladurie's much-reproduced images of retreating Alpine glaciers are resonant of the LIA, although they describe the eighteenth century and later refer only to the *dénouement* of that episode. Comparable illustrations of the same glaciers from an earlier period would be more telling. In their stead, we present some statistical evidence of the length of a small number of glaciers during a longer period.[30]

Figures 6[a]–6[c] describe the computed lengths of three Alpine glaciers at various dates extending back to the sixteenth and seventeenth centuries. Figure 6[a] reveals an increase in the length of Lower Grindelwald glacier in the Bernese Alps between the

30 Grove—in "The Little Ice Age in the Massif of Mont Blanc," *Transactions of the Institute of British Geographers,* XL (1966), 129–143—was one who followed Matthes' lead in reconstructing historical glacier lengths. Maurizio d'Orefice et al., "Retreat of Mediterranean Glaciers since the Little Ice Age: Case Study of Ghiacciaio del Calderone, Central Apennines, Italy," *Arctic, Antarctic, and Alpine Research,* XXXII (2000), 197–201; Oerlemans, *Glaciers and Climate Change; idem,* "Extracting a Climate Signal"; McCormick et al., "Climate Change," 213–214; Ahlmann,"Present Climatic Fluctuation"; Le Roy Ladurie, *Times of Feast.*

Fig. 6 Glacier Lengths, 1500–2000



1550s and the 1630s, but this gain disappeared in the following half-century; the glacier was roughly as long in the mid-nineteenth century as it had been in the mid-sixteenth. Rhonegletscher, a glacier located at the source of the Rhone (Figure 6[b]), lost length between 1600 and 1780, and the Argentière glacier in southeast France (Figure 6[c]) oscillated until the early nineteenth century, when it began a retreat that has continued to the present. The recent reconstruction of fluctuations in the length of the Mer de Glace in the Mont Blanc massif by Nussbaumer, Zumbuehl, and Steiner implies no sustained change between the early seventeenth and the late nineteenth centuries. Again, Vatnajoküll glacier in southeast Iceland hardly grew between the late seventeenth and late nineteenth centuries, though it has shrunk considerably since.[31]

The pattern on Nigardsbreen glacier in southwestern Nor-

31 We are grateful to Johannes Oerlemans and Paul Leclerq for the data described in Figure 6. Oerlemans, *Glaciers and Climate Change.* Samuel U. Nussbaumer, Heinz J. Zumbuehl, and D. Steiner, "Fluctuations of the Mer de Glace (Mont Blanc area, France) AD 1500–2000: An Interdisciplinary Approach Using New Historical Data and Neural Network Simulations," *Zeitschrift für Gletscherkunde und Glazialbiologie,* XL (2005/2006), 1–183.

way—a dramatic expansion of 2.8 km between c. 1710 and c. 1740, followed by a decline that has accelerated since the late nineteenth century—has raised questions about the determinants of glacier length (see Figure 6[d]). Nesje and Dahl argue that Nigardsbreen's advance was caused by higher winter precipitation rather than by colder summers. The startling implication that mild and humid winters were responsible for the advance, which is consistent with other measures of weather at the time, means that the connection between glacier length and climate change is less straightforward than traditionally assumed in the climate-history literature. A recent temperature reconstruction based on available Alpine glacier data implies little change between 1600 and 1750, a drop of about 0.1 °C between 1750 and 1800, and a 0.2 °C rise within the following century. Overall, such trends are also more consistent with stasis than the dramatic cooling often associated with the LIA.[32]

LONDON'S FROST FAIRS The river Thames above old London Bridge froze solid at least twenty-three times between 1400 and 1814—twice in the fifteenth century, five times in the sixteenth, nine times in the seventeenth, six times in the eighteenth, and once in the nineteenth. The freezes gave rise to carnival-like "frost fairs" on the Thames, some of which lasted for several weeks. Lamb and others have interpreted the seventeenth-century peak in freezes, as indicated by the presence of a frost fair, as a product of the LIA. The argument is plausible, but the likelihood of the river turning to ice under given weather conditions varied over time. Frost fairs were much more likely during cold winters in the two centuries after 1600 than in the preceding or following centuries. Using estimated central England temperatures as a guide, between

32 Gunnar Østrem and Nils Haakensen, "Glaciers of Europe: Glaciers of Norway," in Richard S. Williams and Jane G. Ferrigno (eds.), *Satellite Image Atlas of Glaciers of the World,* Fact Sheet 2005–3056, available at http://pubs.usgs.gov/fs/2005/3056. Compare Zemp et al., "Extending Global Monitoring." Atle Nesje and Stein Olaf Dahl, "The 'Little Ice Age'—Only Temperature?" *The Holocene,* XIII (2002), 139–145. See also Matthews and Briffa, "'Little Ice Age.'" For the more straightforward version of glacial length and climate change, see Le Roy Ladurie, *Times of Feast.* The distinction between popular accounts that continue to insist on a connection between temperature and glacier length and the more nuanced specialist literature (for example, Matthews and Briffa, "'Little Ice Age'") is well worth making. We are grateful to a referee for insisting on this point. For a recent temperature reconstruction based on available Alpine glacier data, see Oerlemans, "Extracting a Climate Signal." Compare Zemp et al., "Extending Global Monitoring."

1660 and 1699 the river froze hard enough to allow for a frost fair during four of the fourteen winters when mean temperatures dropped below 2.3°C; from 1700 to 1799, the ratio was five years out of thirteen; in 1800 to 1899, it was one out of thirteen; and in 1900 to 1980, it was zero out of seven.[33]

Alternatively, the following logit regression runs the occurrence of a frost fair in any given year on the Thames (*FROST*) against the Dutch winter temperature series of van Engelen, Buisman, and IJnsen (*TEMP*) and dummy variables for the seventeenth and eighteenth centuries (*C17, C18*). *T*-statistics are in parentheses:

$$\underset{}{\text{FROST}} = \underset{(-8.87)}{3.19} - \underset{(-6.71)}{0.10}\,TEMP + \underset{(3.03)}{1.54}\,C17 + \underset{(2.78)}{1.62}\,C18$$

$N = 571$; Pseudo $R^2 = 0.315$;
Log Likelihood Ratio $= -76.58$

The higher probability of frost fairs in the seventeenth and eighteenth centuries, after controlling for temperature, is confirmed.[34]

Until 1750, Old London Bridge was the only bridge linking the city with its south bank. Even after the removal of its shops and houses from 1758 to 1762, it remained a cumbersome structure. Simond's account of London Bridge in 1815 suggests one plausible explanation for the temporal pattern of frost fairs: "Nothing can be uglier than London bridge; every arch is of a size different from its next neighbour; there are more solid than open parts; it is in fact like a thick wall, pierced with small holes here and there, through which the current, dammed up by this clumsy fabric, rushes with great velocity, and in fact takes a leap, the difference between high and low water being upwards of 15 feet."[35]

This description is consistent with the claim that what brought the frost fairs on the Thames to an end was not climate warming but the replacement, in 1831, of the medieval twenty-arched London Bridge—plus waterwheels—and its big protective platforms

33 Lamb, *Climate, History;* Fagan, *Little Ice Age,* 197; Manley, "Central England Temperatures."

34 Van Engelen, Buisman, and IJnsen, "Millennium." *TEMP* lacks some observations for the early years.

35 Louis Simond, *Journal of a Tour and Residence in Great Britain during the Years 1810 and 1811 by a French Traveller* (Edinburgh, 1815), II, 262–263. Compare Patricia Pierce, *Old London Bridge: The Story of the Longest Inhabited Bridge in Europe* (London, 2001).

by a new five-arched granite bridge that allowed a much freer flow of water. Two other factors unrelated to climate change may have eased the flow: first, the employment, beginning in 1775, of convict labor to dredge sand and silt from the river's bottom to keep the main channel clear, and, second, the increase in the city's population from about 1 million c. 1800 to more than 6 million c. 1900, which may have produced what a Londoner in the 1810s called an "urban heat island" effect, whereby urban development was accompanied by the rapidly increasing use of heat-maintaining materials.[36]

Extreme weather events clearly mattered in the past. Campbell carefully documented their consequences for the late medieval period, as Utterström and Cullen did for the 1690s and Pfister and Brádzil did for the 1770s. Scholars have also associated the European famines of 1709/10, 1740/41, 1782/83 and 1816–1818 with severe frosts, cold summers, or volcanic eruptions. Moreover, Kelly and Ó Gráda's statistical analysis points to the periods from 1591 to 1598, 1687 to 1698, and 1809 to 1817 as intervals when temperatures were below average every year. More controversial is the attempt to make climate a causal explanation for such political crises as those of the 1640s in Europe, highlighted by Parker as "an excellent example of the role of climate in producing catastrophe." Yet although such events have been linked to long-run climate shifts such as the LIA, they would not be inconsistent with a stationary climate during the centuries when they occurred.[37]

This article's skepticism toward the idea of a European LIA is twofold. First and foremost, any convincing reassessment of the concept must address the evidence supplied in the numerous quantitative palaeoclimatic reconstructions of the region. Our analysis

36 Luke Howard, *The Climate of London, Deduced from Meteorological Observations, Made at Different Places in the Neighbourhood of the Metropolis* (London, 1818–1820), 2 v.

37 Marcel Lachiver, *Les années de misère: la famine au temps du Grand Roi* (Paris, 1991); John D. Post, *The Last Great Subsistence Crisis of the Western World* (Baltimore, 1977); Ó Gráda, *Famine: A Short History* (Princeton, 2009), 17–18; Campbell, "Nature as Historical Protagonist: Environment and Society in Pre-Industrial England," *Economic History Review,* LXIII (2010), 281–314; Utterström, "Climatic Fluctuations"; Karen Cullen, *Famine in Scotland: The "Ill Years" of the 1690s* (Edinburgh, 2010), 31–53; Pfister and Rudolf Brádzil, "Social Vulnerability to Climate in the 'Little Ice Age': An Example from Central Europe in the 1770s," *Climate of the Past Discussions,* II (2006), 123–155, available at http://www.clim-past-discuss.net/2/123/2006/cpd-2-123-2006-print.pdf; Kelly and Ó Gráda, "Change Points and Temporal Dependence"; Parker, "Crisis and Catastrophe," 1074.

of a range of reconstructed and instrumental series covering several centuries offers no indication of long swings or sustained structural breaks in weather series before c. 1900, although occasional extended periods of notably cold summer weather undoubtedly occurred. The "climatic seesaw" highlighted by Lamb, Fagan, and others is a statistical mirage, an artifact caused by what is known in the statistics literature as the Slutsky effect. Secondly, several of the oft-recycled "stories" that add rhetorical power to the claim for an LIA have more or less plausible alternative or complementary interpretations that do not rest on climate change.[38]

Finally, the agnosticism expressed herein about an LIA defined by a prolonged period of significant temperature cooling does not entail a denial of either important changes in climate or the role that human activity may play in these changes. Le Roy Ladurie's once provocative, if now old-fashioned, inference from the LIA that "in the long term the human consequences of climate seem to be slight, perhaps negligible, and certainly difficult to detect" does not apply to the current era of global warming. On the contrary, the apparent absence of any major secular fluctuations in climate during the period from 1200 to 1800 makes the rise in temperatures from the late nineteenth century through the twentieth century stand out as more of a structural than a cyclical phenomenon.[39]

38 William F. Ruddiman, "The Early Anthropogenic Hypothesis: Challenges and Responses," *Reviews of Geophysics,* XLV (2007), RG4001, links falling post-1500 temperatures to the demographic consequences of the *Conquista* and the consequent reforestation of formerly cultivated land and extraction of carbon dioxide from the atmosphere. The simulations of Robert Dull et al., "The Columbian Encounter and the Little Ice Age: Abrupt Land Use Change, Fire, and Greenhouse Forcing," *Annals of the Association of American Geographers,* C (2010), 755–771, available at http://westinstenv.org/wp-content/Annals_2010_Dull_et_al.pdf, 3, 10, find that the shock was responsible for 6 to 25 percent of LIA-induced cooling. Their results assume modest cooling (−0.1 C), however. Massimo Livi Bacci, *Conquest: The Destruction of the American Indios* (Malden, Mass., 2008), implies that population decline and resultant reforestation were less drastic than assumed in these studies.

39 Le Roy Ladurie, *Times of Feast,* 119.