Global and Planetary Change 254 (2025) 105038

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Research Article

A climate of conflict: How the little ice age sparked rebellions and revolutions across Europe

David Kaniewski [a,*,1], Nick Marriner [b,*,1], Frédéric Luce [a], Morgane Escarpe [a], Majid Pourkerman [c], Thierry Otto [a]

[a] Centre de Recherche sur la Biodiversité et l'Environnement (CRBE), Université de Toulouse, CNRS, IRD, Toulouse INP, Toulouse, France
[b] CNRS, ThéMA, Université Marie et Louis Pasteur, UMR 6049, MSHE Ledoux, 32 rue Mégevand, 25030 Besançon Cedex, France
[c] Research Institute of Earth Sciences, Geological Survey of Iran, Meraj Boulevard, Azadi Square, Tehran, Iran

ARTICLE INFO

Keywords:
Rebellions
Revolutions
Food resources
Climate change
Little Ice Age

ABSTRACT

The Little Ice Age (LIA) – lasting from ~1250 to ~1860 - was a long period of cooler, drier conditions, characterized by increased climate instability. The most significant climate extremes were more closely associated with interannual temperature variations or particularly severe, isolated cold spells than with prolonged cold spells lasting many years. During this pre-industrial phase of climate instability, many rebellions broke out, one of the most famous being the French Revolution of 1789. A key question, however, relates to the precise and often intricate role of climate in precipitating these widespread uprisings and rebellions that profoundly reshaped human institutions, particularly in the European context. Using data for solar activity, temperature, precipitation, volcanic forcing and the evolution of grain prices, we compared and contrasted the occurrence of rebellions and revolutions across a wide geographical area comprising Europe-Russia-Ottoman Empire with LIA climate and hazards. We find that climate change primarily affected people's livelihoods by reducing harvests, lowering food-resource availability and sharply increasing cereal prices. Climate therefore played a major role in heightening population vulnerability by exacerbating one of the greatest scourges: malnutrition. For the populace, this fuelled social anger towards political authorities for failing to mitigate the impact of climate change. This study primarily reveals that environmental causes did not generate social crises during the LIA but rather triggered a cascade of environmental and human events that interacted, ultimately leading to highly conflictual situations. The LIA serves as a warning to modern political systems, highlighting the necessity to anticipate the consequences of current climate change to mitigate its impact on societies and prevent social unrest and conflict.

1. Introduction

Historians have long observed the relationship between the environment and civilizations, particularly how environmental pressures have interacted with societies, sometimes acting as key forces that influenced or redirected their trajectory (e.g. White, 2011; Parker, 2013; Camenisch and Rohr, 2018). Past and present disasters such as droughts (Edwards et al., 2022), severe frosts (Camenisch et al., 2016), floods (Brázdil et al., 2010; Rohr, 2013; Kiss, 2018) or crop failures (Flückiger et al., 2017) have regularly plunged populations into uncertainty and chaos. Long-term shifts in the planet's climatic conditions, coupled with short-term extreme events, have driven flourishing societies to decline, wither or even collapse (Kaniewski et al., 2018, 2019). Climate is never an isolated factor, but when combined with social, political or even economic unrest, it can become a powerful catalyst for crises (Camenisch and Rohr, 2018).

A key example of the significant intersection between climate disruption and political upheaval is the period up to the French Revolution of 1789 (Doyle, 1990). Climate pressure appears to have been the spark that ignited the flames of the revolution. Around 1770, near the onset of the Dalton minimum (Ionita et al., 2021), a particularly cold period began in Europe (Wagner and Zorita, 2005), devastating agricultural production. In 1775, severe grain shortages in France, caused by successive years of poor harvests, triggered bread riots throughout the kingdom (the Flour War; Bouton, 1993). The eruption of the Laki volcano in Iceland in June 1783 compounded the situation (Brayshay and

* Corresponding authors.
E-mail addresses: david.kaniewski@univ-tlse3.fr (D. Kaniewski), nick.marriner@univ-fcomte.fr (N. Marriner).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.gloplacha.2025.105038
Received 28 March 2025; Received in revised form 19 August 2025; Accepted 19 August 2025
Available online 21 August 2025
0921-8181/

Grattan, 1999). Across northern Europe, the volcano radically modified the climatic conditions of the 1780s, making it extremely unstable. After a prolonged period of cooling, the summer of 1783 unexpectedly became the hottest on record (Edwards et al., 2022). The unusually warm weather triggered violent thunderstorms accompanied by hailstones. The scorching summer gave way to an equally extreme winter with severe frosts, followed by a warm spring that quickly melted the snow and ice, causing major flooding (Doyle, 1990). These extremes set the weather pattern for years to come: dry, scorching summers (Labuhn et al., 2016) interspersed with violent thunderstorms, followed by bitter winter cold, snowstorms and freezing temperatures. These fluctuations wreaked havoc on the lives of the French population, ruining harvests and creating a never-ending cycle of hunger, poverty, stress, fear and hardship (Camenisch and Rohr, 2018). The damage caused by these climatic hazards worsened the financial crisis that gripped the kingdom of France in the 1770s and 1780s (Doyle, 1990). The years of climatic stress, financial instability and political conflict brutally coalesced in 1788 and 1789. A severe drought in the spring of 1788 (Labuhn et al., 2016) devastated staple crops, leaving them crippled and withered. On July 13th, 1788, one of the most severe hailstorms in history struck France (Doyle, 1990). Grain shortages (an estimated 20 % drop compared to the harvest years 1774–1787; Labrousse, 1970; Neumann, 1977) sent prices skyrocketing. With all disposable income going towards bread (Lefebvre, 1954; Hufton, 1974), consumer demand for all other staples collapsed, sending the kingdom's already fragile economy into recession. In 1789, France was hit by the coldest winter in nearly a century (Labuhn et al., 2016). The harsh winter froze an already starving population. Winter's deathly grip lasted for months, exacerbating the growing social crisis (Doyle, 1990). In the summer, the frustrated and enraged populace rose up to storm the Bastille, marking the onset of the French Revolution. The same summer, the Great Fear (July 22nd-August 6th, 1789) that struck the French countryside was likely triggered by drought, storms and flooding that destroyed much of the harvest. Subsequently, vast areas of France were ravaged by rural rebellions. Mobs attacked castles and burned ancient feudal documents authorizing their work for the lords. The Great Fear is considered as a rebellion shaped by climatic stress (Lefebvre, 1973).

The French Revolution took place during the LIA, spanning roughly from 1250 to 1860, a period marked by a widespread temperature decline, evident from synchronous negative deviations across a number of temperature-sensitive proxy records from the Northern Hemisphere (Briffa, 2000; Jacobeit et al., 2001; Jones et al., 2001; Luterbacher et al., 2004; Meyers and Pagani, 2006; Osborn and Briffa, 2006; Kuhlemann et al., 2008; Richter et al., 2009; Wanner et al., 2022). However, this prolonged cooling was not consistent and uniform, as periods of extreme cold were interspersed with warmer phases. While the average summer temperature anomaly during this period is estimated to have been −0.36 ± 0.4 °C, colder anomalies ranging from −1 °C to −1.75 °C interspersed with warmer anomalies peaking at 0.56 °C (Luterbacher et al., 2016; Wanner et al., 2022). The average PDSI has been estimated at −0.47 ± 1.47, but with several values ranging from −3.0 to −4.5 (severe to extreme drought; Cook et al., 2015). Summer precipitation during the LIA shows strong variations, with the lowest values corresponding to a reduction of 25 % to 50 % (Cook et al., 2015) compared to the current situation (Marchi et al., 2020).

In Europe, the severe cold phases of the LIA significantly affected agriculture (e.g. Pfister and Brázdil, 2006; Holopainen and Helama, 2009), had deep societal impacts (e.g. Camenisch and Rohr, 2018), fuelled economic downturn (Collet and Schuh, 2018), favoured the spread of epidemic and epizootic diseases (e.g. Campbell, 2016) and altered human mentalities (e.g. Behringer, 1999). The LIA also revealed society's vulnerability to unpredictable events. Persecutions leading to lengthy witch hunts took place during this period, as a part of the society held witches directly responsible for the high frequency of climate anomalies and their consequences (Behringer, 1999; Oster, 2004; Pfister, 2007; Levack, 2015). The LIA clearly represents a period in which climate change and major socio-political crises intertwined over several decades.

Here, we focus on the rebellions and revolutions that took place in Europe-Russia-Ottoman Empire (ERO_E) during the LIA. We tested the impact of declining solar activity, volcanic forcing, climate change and shifts in bread prices as potential amplifiers of crises, in addition to socio-political upheavals. We focused on the period 1570–1860, a crucial era that saw 140 episodes of rebellion and revolution across the ERO_E, spanning from the end of the Renaissance to the rise of the Industrial revolution. The potential link between climate shifts, human institutions, and political, economic and social destabilization has emerged as a critical area of study. The United Nations has released an IPCC report described as a "code red for humanity". The report highlights that extreme weather, poor crop yields and low GDP are closely linked to an increase in violence (IPCC, 2021).

2. Methods

2.1. Rebellions and revolutions

The rebellions-revolutions in ERO_E were extracted from the abundant literature (see Dataset). The data considered in this study starts with the second rebellion of the Alpujarras (1569–1571, Spain; e.g. Domínguez Ortiz and Vincent, 1993) and ends with the Second Italian War of Independence (1859, Italy; e.g. Blumberg, 1990). We focused on the 1570–1860 period because all phases of rebellion or revolution are well documented in the literature, ensuring statistical robustness for the analyses. We used only the onset of each conflict as a reference point to establish a consistent framework for analysis. The initial dataset was then smoothed using a 20-yr moving average to highlight trends rather than individual conflicts. Long-term trends were also evaluated, using a 200-year moving average and a polynomial model ($P_{value} < 10^{-3}$; Fig. 1a) with a P_{value} based on a F test - two-tailed with no adjustment, to assess how rebellions and revolutions evolved over a longer time scale. These smoothed curves are crucial as they account for local factors, such as political and social parameters, which vary across different locations and countries. This approach moderates the emphasis on social causes behind the crises, allowing for a primary focus on the environmental factors that link the rebellions and revolutions together.

2.2. Solar activity

The solar activity dataset is the annual reconstructed sunspot numbers published by Solanski et al. (2004). Long-term trends were calculated for sunspot numbers using both a 20-year and 200-year moving average, along with a polynomial model (termed P. Model; $P_{value} < 10^{-3}$; Fig. 1a). Variations in the rebellions-revolutions were contrasted with the solar activity, using a Kernel density 2D model (with Gaussian as function). The two time-series were first transformed into z-scores (Fig. 1b). We used z-scores as variance reduction is crucial for comparing and contrasting different signals (such as solar activity and crises) on a consistent scale, enabling a clearer focus on trends.

2.3. Temperatures, Precipitation, Palmer Drought Severity Index and cereal prices

The temperature dataset derives from the tree ring-based reconstructions of central European summer temperature variability for the past 2500 years (Fig. S1a-b) published by Büntgen et al. (2011). The precipitation dataset was extracted from the tree-ring reconstructed summer wetness and dryness over Europe and the Mediterranean Basin during the Common Era (Cook et al., 2015; Fig. S2a-b). The Palmer Drought Severity Index (PDSI) is derived from summer reconstructions of the PDSI over Europe, North Africa and the Middle East (Cook et al., 2015; Burnette, 2021; Fig. S3a-b). The European cereal price (wheat and barley) dataset is based on numerous studies focused on four major

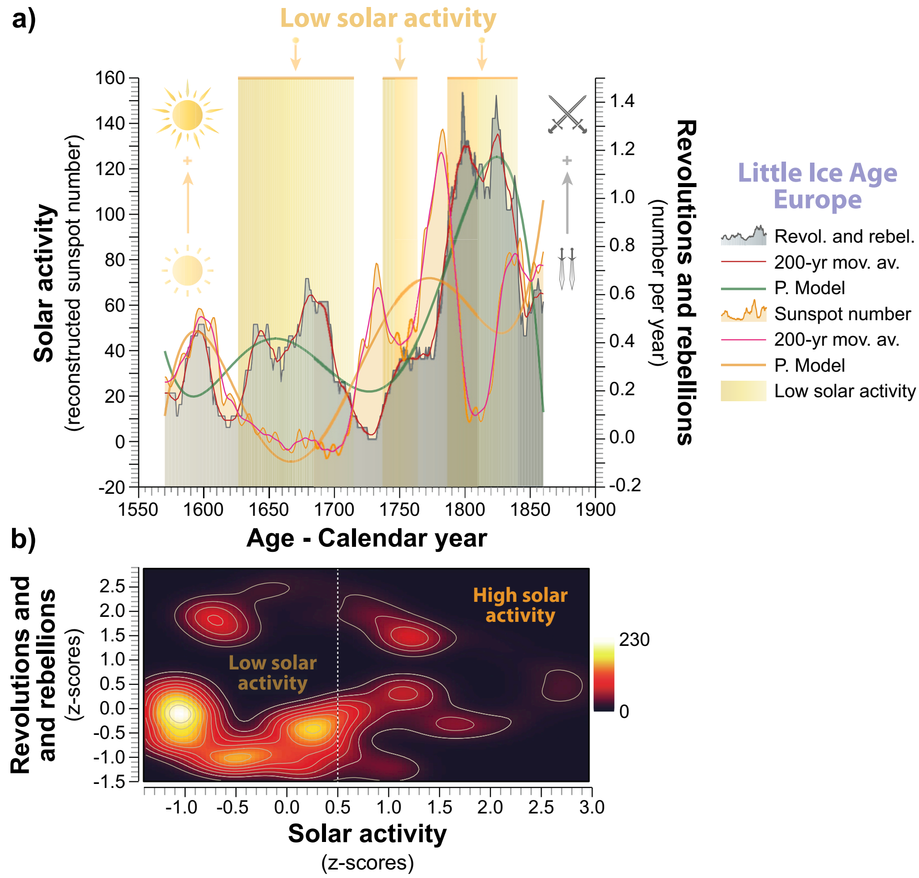

Fig. 1. Solar activity versus the number of rebellions-revolutions. (**a**) Annually reconstructed sunspot numbers plotted against the evolution of rebellions and revolutions. Long-term trends depicted using a 200-year moving average and a polynomial model (termed P. Model; P_{value} ⟨10^{-3}). The periods of low solar activity are highlighted in light orange. (**b**) Variations in the number of rebellions and revolutions compared with solar activity, based on a Kernel density 2D model (with Gaussian as function).

cereals (wheat, barley, oats and rye; compiled in Ljungqvist et al., 2022; Ljungqvist and Seim, 2024; Fig. S4a-b and Fig. S5a-b). A long-term trend was calculated for each time series, using a 200-year moving average.

2.4. Statistical analyses

A cluster analysis (descending type) was conducted to generate a dendrogram, with the branches representing the distances between the time series (Fig. 2a). The test was calculated using *Paired group* as an algorithm and *Correlation* as the similarity measure. All the time-series were first z-score transformed.

To create an integrative signal combining both environmental pressures and grain prices, a principal component analysis (PCA) was conducted. The first principal component (PCA-Axis 1), which captures the maximum variance, was extracted and termed *Environmental pressures and increase in cereal grain prices* (Fig. 2b). The harsh periods for populations - characterized by increasing cereal prices, falling temperatures, reduced precipitation, a high drought index and low solar activity - are associated with positive scores on PCA-Axis 1. In contrast, more favourable periods, marked by falling cereal prices, rising temperatures and precipitation, a lower drought index and more favourable solar activity are linked to negative scores (Fig. 2b). The long-term trend was calculated using a 200-yr moving average and a polynomial model (termed P. Model; $P_{value} < 10^{-3}$; Fig. 2b) with a P_{value} based on an F test - two-tailed, with no adjustment.

The relationship between each environmental-economic parameter and the rebellions-revolutions was carefully examined, comparing and contrasting each time series with the identified crises. The same process was applied to each parameter. The curves, showing the relationship between environmental-economic parameters and rebellions-revolutions, were first presented with a 200-yr moving average added for clarity. The link between each environmental-economic parameter and rebellions-revolutions was then tested, ranking the environmental-economic parameter values in ascending order and retaining the associated rebellion-revolution scores. Next, we added bar charts to explore the evolution of rebellions and revolutions at a defined study step for each environmental-economic parameter. A polynomial model (termed P. Model; $P_{value} < 10^{-3}$; Fig. 2b) with a P_{value} based on a F test - two-tailed with no adjustment, was then inserted. This process was applied for temperatures (Fig. S1a-b), precipitation (Fig. S2a-b), PDSI (Fig. S3a-b), wheat (Fig. S4a-b) and barley (Fig. S5a-b).

The time-series was then separated into «rebellions» and «revolutions» and z-score transformed. Each dataset was smoothed using a 20-yr moving average. The link between the environmental pressures - increases in cereal grain prices (PCA-Axis 1) and rebellions or revolutions (z-scores) was also tested, ranking the PCA-Axis 1 scores in ascending order and retaining the associated rebellion or revolution scores (Fig. 3a and b respectively). A 3-year moving average was first calculated for the rebellion and revolution time-series (termed trend). A linear model ($P_{value} < 10^{-3}$; Fig. 3a-b) was then calculated (with the associated R^2).

2.5. Volcanic forcing

The volcanic forcing dataset derives from the sulphate-sulphur dioxide concentration records (Fig. 4a-b) published by Kobashi et al. (2017) and Marshall et al. (2025). The two signals, deriving from different sources, were z-score transformed, averaged and smoothed using a LOESS approach to incorporate the 25th and 75th percentiles as

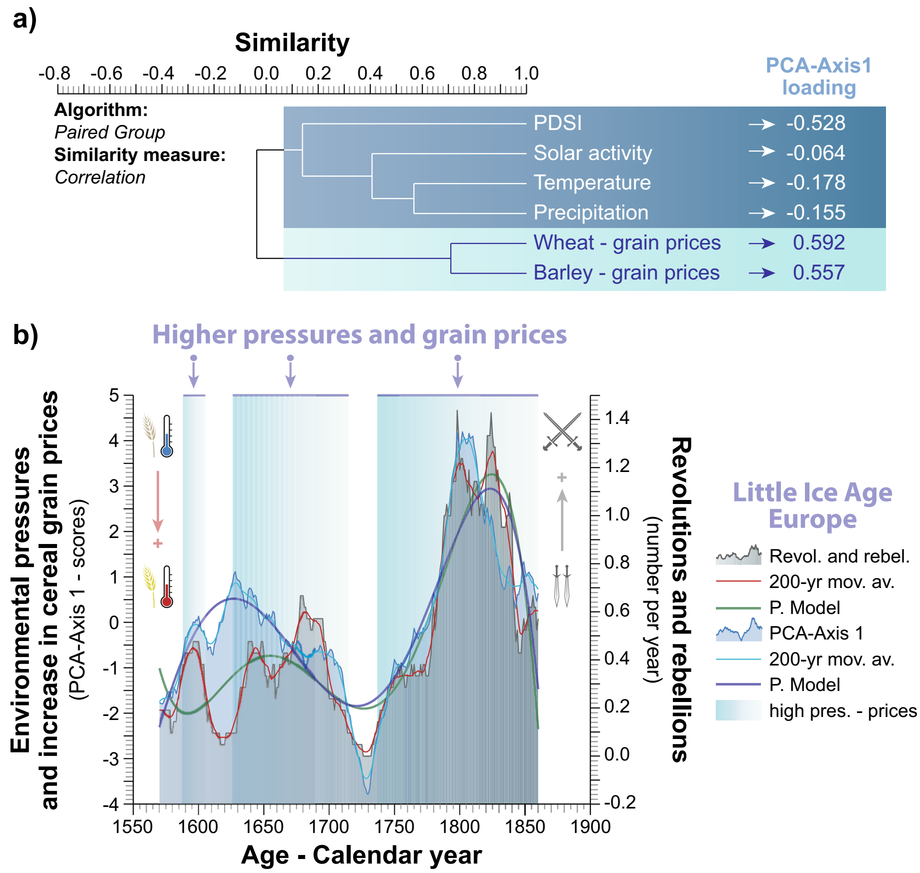

Fig. 2. An integrated signal combining both environmental pressures and grain prices. (**a**) Cluster analysis (descending type; Paired group as an algorithm and Correlation as the similarity measure) showing the statistical distances between each time series. The loading of each variable on PCA-Axis 1 (positive versus negative loadings) is shown on the graph. (**b**) PCA-Axis 1 scores plotted against the evolution of rebellions and revolutions. The long-term trend is shown as a 200-yr moving average and a polynomial model (termed P. Model; $P_{value} < 10^{-3}$). The periods of high pressures on populations (low solar activity, cooler temperatures, drought and high grain prices) are shown in light blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

indicators of maximum probability. The long-term trend was calculated using a 200-yr moving average and a polynomial model (termed P. Model; $P_{value} < 10^{-3}$; Fig. 4a) with a P_{value} based on an F test - two-tailed, with no adjustment. The signal was then compared and contrasted with the rebellion-revolution scores (Fig. 4a). The link between volcanic forcing (average scores) and rebellions-revolutions was then tested, ranking the volcanic forcing values in ascending order and retaining the associated rebellion-revolution scores. The resulting dataset was smoothed using a LOESS curve in order to incorporate the 25th and 75th percentiles as indicators of maximum probability (termed $\pm 1\sigma$; Fig. 4b).

2.6. Data availability

The data supporting our results are provided as Supplementary data to this article.

3. Results

3.1. A solar influence

The potential link between the number of rebellions and revolutions in the ERO_E and solar activity is crucial, as solar energy directly influences the Earth's climate. When the time series are juxtaposed, it becomes evident that periods of declining solar activity (1625–1715, 1737–1765, 1785–1840; Fig. 1a) are chronologically correlated with a strong increase in the number of rebellions-revolutions. The peaks in recorded conflicts occurred from 1789 to 1832 (with maximum values at 1.43–1.44 conflicts per year), a period when the sunspot number (annual value with a moving average of 20-year) dropped from 138 to 9 in less than 20 years (from 1784 to 1803). Analysing long-term trends, the two curves show an inverse evolution from 1570 to 1860, with this pattern becoming particularly pronounced between 1785 and 1840, suggesting a correlation between these two signals. This relationship is illustrated by the 2D Kernel density model, which shows that periods of lower solar activity (fewer sunspots) are associated with a high concentration of crises and vice versa.

3.2. Multiple sources of pressure

Key pressures such as temperature fluctuations, precipitation levels, drought periods and cereal price trends were considered as critical factors that probably had a significant impact on populations and could be quantitatively analysed. The first factor to consider is temperature as the LIA is defined by numerous episodes of severe cold. Three particularly cold phases appear to have been of major importance with regard to the evolution of rebellion-revolutions: (i) the 1587–1619 (called Cold Europe; Easton, 2021), (ii) 1665–1720 (Maunder Minimum; Usoskin et al., 2015) and (iii) 1789–1852 (the Dalton Minimum; Wagner and Zorita, 2005; Fig. S1a). During these three phases, the number of rebellion-revolutions increased significantly, with a very pronounced intensification during the Dalton Minimum. When the number of rebellions and revolutions is compared with temperature trends, a strong concentration of conflicts is observed during periods of pronounced negative temperature anomalies (substantial anomalies between −0.6 and − 0.7 °C are associated with an average of 0.72 ± 0.09 rebellions-revolutions per year; Fig. S1b). Focusing on precipitation (Fig. S2a)

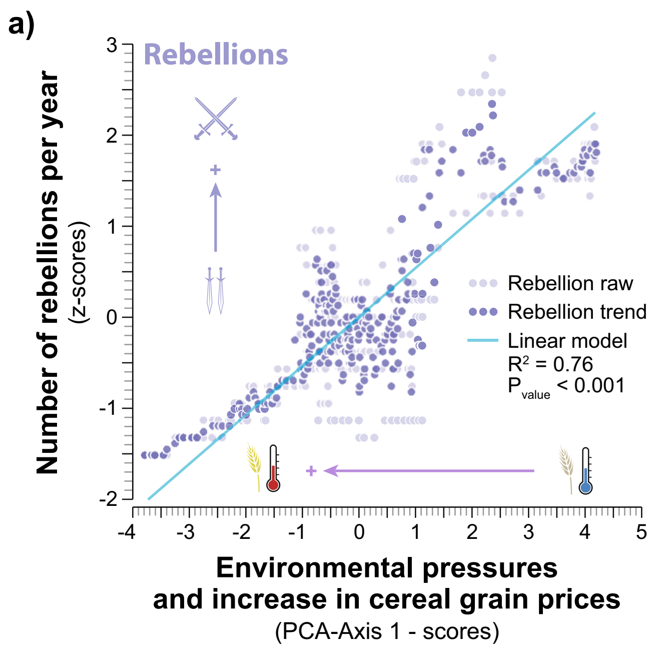

Fig. 3. Rebellions and revolutions versus environmental pressures and grain prices. (**a**) Number of rebellions plotted against the evolution of environmental pressures and grain prices (PCA-Axis 1 scores). The link is depicted by a linear model, with the R^2 indicated on the graph. (b) Number of revolutions plotted against the evolution of environmental pressures and grain prices (PCA-Axis 1 scores). The link is also depicted by a linear model, with the R^2 indicated on the graph.

and PDSI (Fig. S3a), although the correlation is less pronounced than with temperature, the data suggest an increase in rebellions and revolutions during periods of severe water deficits. The increase in the number of rebellions-revolutions seems clearly associated with a marked reduction in precipitation (Fig. S2b) as well as lower PDSI values (higher drought scores; Fig. S3b). Low April-to-June precipitation (150–200 mm) is linked to an average number of rebellions-revolutions of 0.63 ± 0.05 per year (Fig. S2b), negative PDSI (−0.6 to −0.5) to an average number of 1.2 ± 0.02 per year (Fig. S3b). Regarding the evolution of cereal prices (wheat and barley), the increase in conflicts appears to be closely linked to sharp fluctuations in the cost of living, particularly during periods of significant price surges. Whether for wheat (Fig. S4a) or barley (Fig. S5a), the prices of these two cereals, staples used for bread and food, have had a significant impact on populations. The highest average number of rebellions-revolutions is associated with elevated wheat prices (up to 1.16 ± 0.02 rebellions-revolutions per year; Fig. S4b) in addition to high barley prices (up to 0.95 ± 0.13 rebellions-revolutions per year; Fig. S5b).

The cluster analysis, which incorporates all the environmental and economic proxies, reveals two main groups (Fig. 2a). The first group includes temperature, precipitation, PDSI and solar activity. The second group is associated with cereal prices. This distribution is consistent with the cultivation of cereals. When solar activity, temperature, precipitation and PDSI increase, the cultivation of cereals is favoured, yields (supply) increases and therefore the price drops. Conversely, during harsh periods, the yields fall sharply and cereal prices increase significantly. When performing PCA on this dataset, the first group is characterized by negative scores on the first principal component (PCA-Axis 1), while the second group exhibits positive values (Fig. 2b). PCA-Axis 1 was then compared and contrasted with the number of rebellions-revolutions. The phases marked by an intensification of crises are all chronologically correlated with harsh climatic periods and high grain prices. The most severe environmental and economic conditions, which probably contributed to the significant rise in rebellions and revolutions, were recorded between 1775 and 1845, with peaks at 1.4 rebellions-revolutions per year (years 1798 and 1842; Fig. 2b). Focusing on the last part of the sequence (1830–1860), while environmental pressures and grain prices remained high and impacted the population, this period seems less marked by LIA climate-stress conflicts than by 19th century (liberal) ideological revolutions, even if climate had still a background misery effect.

3.3. Rebellions and revolutions

When rebellions and revolutions are separated into two datasets and their number compared and contrasted with environmental and economic data, a significant linear relationship emerges between the occurrence of more severe environmental and economic conditions and the increase in rebellions (Fig. 3a) and revolutions (Fig. 3b). PCA-Axis 1 scores are linearly correlated with the number of rebellions (R^2 of 0.76) and the number of revolutions (R^2 of 0.71), with the higher PCA-Axis 1 scores linked to the higher numbers of conflicts in both cases, even if the conflict corresponds to a violent protest demanding the restauration of previous, normal, conditions (rebellions) or a violent upheaval aimed at transforming the normal conditions (revolutions).

3.4. The role of volcanic forcing

As climate variability during the last millennium has been affected by the effects of large-magnitude volcanic eruptions, we compared the evolution of rebellions-revolutions with a volcanic proxy deriving from two datasets (Kobashi et al., 2017; Marshall et al., 2025). The three main phases of high rebellions-revolutions are recorded during periods when the influence of volcanic activity was enhanced (Fig. 4a). The highest peak in sulphate-sulphur dioxide concentration, recorded between June 1783 and February 1784 during the eruption of the Laki volcano (Brayshay and Grattan, 1999), coincides with the surge in crises that would later culminate from 1788 to 1798 (1 to 1.4 rebellions-revolutions per year). Each phase of increased rebellions and revolutions recorded since 1560 appears to be chronologically linked to volcanic activity, suggesting that volcanic eruptions have been a significant environmental forcing, intensifying political and social crises (Fig. 4a). When increasing concentrations of sulphate-sulphur dioxide are compared with the evolution of rebellions-revolutions, a correlation emerges between high concentrations and a significant number of conflicts (up to 1 conflict per year for the highest scores of the volcanic

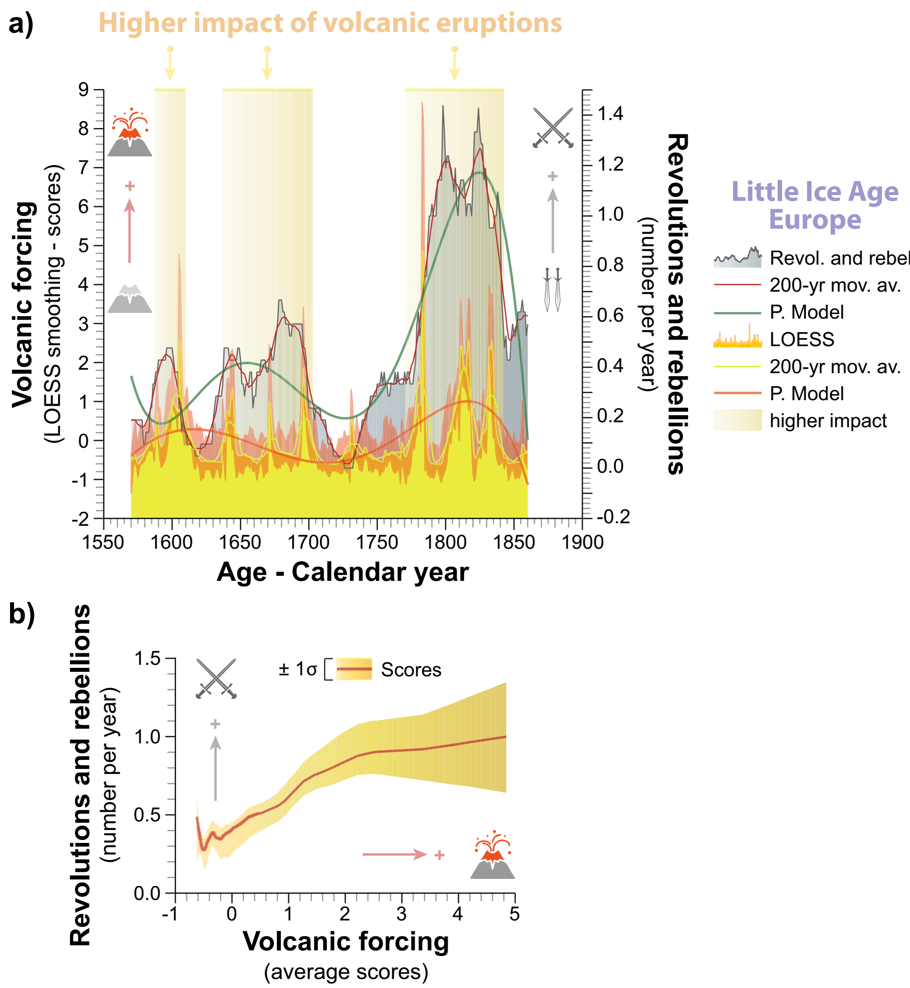

Fig. 4. Volcanic activity versus the number of rebellions and revolutions. (a) Sulphate-sulphur dioxide concentration (shown as a LOESS curve) plotted against the evolution of rebellions and revolutions. Long-term trends are shown as a 200-year moving average and a polynomial model (termed P. Model; $P_{value} < 10^{-3}$). The periods of high volcanic activity are underlined in light orange. (b) Relationship between volcanic forcing and rebellions-revolutions shown as a LOESS smoothing curve with maximum probability (termed ±1σ; dark orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

proxy; Fig. 4b).

4. Discussion

4.1. The interplay between social-political causes and environmental factors

While every rebellion or revolution is rooted in social and political causes, often shaped by decisions made by human institutions, environmental pressures appear to have played a crucial role in exacerbating crises over the past 500 years (Zhang et al., 2011). It has been suggested that the historical complexity and weak evidence of causality make it difficult to conclude that crises were, even partially, climate-induced (Butler, 2007; Salehyan, 2008). To address this issue, we focused not on a single conflict but on all the rebellions-revolutions that impacted the ERO_E. While each conflict is linked to local, regional or national historical and social causes, analysing these within a broader global framework allows us to better assess the human factors behind these rebellions and revolutions, focusing only on the elements that can affect populations on a large spatial scale. By focusing on long-term trends, environmental factors may seem decisive in triggering crises, even if they are not the origin of rebellions and revolutions, nor of their evolution.

4.2. Climate change impacts on societies

Climate change has long impacted populations with sometimes complex consequences, aggravated and amplified by human responses and local political structures and decisions (Slavin, 2016; Kaniewski and Marriner, 2020; Robbins Schug et al., 2023). Sometimes climatic pressures are such that humans, although endowed with behavioural elasticity, are unable to cope (deMenocal, 2001). As an example, over the past 800 years, the most severe drought in the southwestern United States lasted about 22 years, between 1572 and 1593 (Cook, 2000). These dry conditions persisted until the early 17th century, as far south as the Virginia coast (Stahle et al., 1998). Based on a 700-year tree-ring chronology from northeastern Virginia, the intervals 1587–1589 and 1606–1612 were identified as the driest periods of the past 700 years (Stahle et al., 1998; White, 2019). In 1587, the first English colonists arrived and settled in Virginia (Roanoke Island - Carolina Outer Banks). This group of settlers was nicknamed the Lost Colony because it had completely disappeared by the time the supply ships returned four years later. Initially attributed to poor planning and insufficient supplies, the failure of the colony is now explained by a severe drought, which began just as these settlers arrived (Stahle et al., 1998; White, 2019). In 1586, a settler described a drought that withered Native American maize. During the following year, colonists were unable to obtain maize from indigenous communities (by threats or barter), and they therefore suffered famine (White, 2019). A larger colony was then established in 1607 at Jamestown, Virginia, and the settlers were also severely affected. Within 25 years, more than 80 % of the population died, mainly from malnutrition (Stahle et al., 1998; deMenocal, 2001). In this particular case, drought acted as the trigger for the crisis, highlighting the vulnerability of these populations to this environment. Johnson (2011) also strengthened this observation. By contrasting natural disasters with the conventional chronology of socio-political and economic events in Caribbean colonial history, it emerges that certain key events can be seen as the consequences of the ecological crisis and measures for disaster relief. The widespread adoption of free trade in the Americas in 1778 was catalysed by the recognition of the harsh realities of food shortages and the needs of local settlers, who were reeling from a series of natural disasters. Climate-induced environmental crises and the slow response of imperial authorities played an inextricable role in the rise of revolutionary ideas in 18th-century Caribbean (Johnson, 2011).

4.3. Climate-induced malnutrition

In the ERO_E area, our study suggests that during the second half of the last millennium, climate played a key role in exacerbating political and social crises. Climate alone did not cause recurrent famines during the LIA, but rather it was the severity of food shortages, which evolved into famines based on decisions made by human institutions, as Slavin (2016) has suggested, in a different context. Temperature, particularly extreme cold weather, and long- to medium-term droughts are among the most critical factors affecting populations (McMichael, 2012). It has been shown that human health is modulated by climate change (Haines et al., 2006). Previous studies have moreover demonstrated that climate change has important health-related consequences because it can weaken afflicted populations by inducing food shortages, malnutrition and even starvation (Patz et al., 2000; Ben Ari et al., 2011). Chinese imperial archives documenting epidemics over the past eight centuries attest to the importance of climate in the mechanism of contamination. During the LIA, 881 epidemics were recorded in China. This database indicates that during colder periods (with temperatures below the 1300–1850 average), the probability of an epidemic or a major epidemic was respectively 35 % and 40 % higher than during warmer periods (McMichael, 2012). In the ERO_E area, the spread of plague has also recently been linked to climate instability during the LIA, when populations were already struggling with food shortages and malnutrition (Kaniewski and Marriner, 2020). Climate change did not directly trigger the emergence of the scourge but it facilitated subsequent outbreaks by weakening the ERO_E population.

The primary cause of the widespread weakening of populations, which led to most of the recorded revolts, was malnutrition, exacerbated by poor decisions made by human institutions under pressure from climate-related factors (cf. Chu and Lee, 1994; Pfister and Brázdil, 2006; Zhang et al., 2007; Degroot, 2018; Xiao et al., 2018). The weakening of populations also depends on how social relations and power dynamics shape human-climate interactions (Carey, 2012). In this context, during the LIA, successive episodes of food shortages were translated into famine (cf. Appleby, 1980; White, 2020), without the political powers taking effective measures (social and economic) to mitigate the impact of climate change on societies and help the population during the most difficult periods. Escalating grain prices due to climate-induced poor harvests, and the associated malnutrition (even blights), pushed rural-urban dwellers to revolt against the ruling institutions and political structures as attested by the French Revolution (Doyle, 1990). The devastating famine of the 1590s in northern Italy demonstrated that several consecutive years of harsh weather coupled with strong demographic pressure on limited resources, were the key drivers of the crisis (Alfani, 2011). Demographic trends are a crucial factor because the availability of food resources is directly tied to the number of people dependent on these resources (Slavin, 2016). Goldstone (1991) further suggested that revolutions were the result of ecological crises occurring when political, economic and social institutions remained inflexible and were overwhelmed by the cumulative pressure of population growth on limited available resources, emphasizing the necessary balance between consumption and resources.

Our study suggests that temperature and drought, both directly related to variations in solar activity and sometimes intensified by volcanic activity, were major drivers of crises. However, their primary impact was on the population's core resilience: agricultural harvests. By sharply driving up grain prices, this led to malnutrition and weakened populations, making them more vulnerable to plagues. This engendered social anger towards political authorities for not taking decisions to mitigate the impact of climate changes on populations. Crises during the LIA were not caused by a single environmental factor but rather by a cascade of environmental and human events that interacted cumulatively and generated highly conflictual situations. This study suggests that climate becomes a catalyst for chaos only when political powers respond incoherently to deteriorating living conditions, failing to make key decisions to support their populations. This, in turn, exacerbates social tensions and increases the number of vulnerable people during hardship.

In the context of the LIA, the term polycrisis (Lawrence et al., 2024) may be appropriate because rebellions and revolutions have occurred when rapid triggering events (here harsh climate and bad harvests) combined with slow-onset tensions (socio-political) and caused systems to deviate from their established equilibrium and plunge them into an unstable and detrimental state of disequilibrium. Three causal mechanisms can link conflicts during the LIA: (i) the existence of common tensions across a broad geographic scale, (ii) domino effects, and (iii) feedbacks related to a disruption of an initial socio-political system spilling over its boundaries and disrupting other systems. These three mechanisms have the capacity to connect multiple systems across the EROE and produce synchronized crises.

4.4. Why did England not experience a revolution?

England is an interesting counter example because it did not experience a revolution like those seen elsewhere in continental Europe during the late 18th and early 19th centuries. We posit that England's absence of a major revolution this time reflects a unique convergence of political, economic, social and geographical factors combined with an effective use of overseas colonies that served as safety valves for internal pressures.

First, politically, the constitutional settlements achieved after the revolutions of the 1640s and the Glorious Revolution of 1688–89 reconfigured state power by curtailing absolute monarchy and establishing parliamentary supremacy. These earlier revolutions, themselves shaped by external climatic stresses during the Little Ice Age (for instance, the severe conditions that affected the English Civil War and the "east wind" which enabled Price William's Dutch army to land safely in 1688) created an institutional framework in which dissent could be managed without a return to widespread insurrection (Pincus, 2009; Parker, 2013; Degroot, 2018). England had already curtailed royal power and established the supremacy of Parliament (Tridimas, 2021), unlike France which had an absolute monarchy until 1789 (Swann and Félix, 2013). This system of parliamentary government and constitutional monarchy allowed for some degree of political expression and reform. Furthermore, England generally tolerated a higher degree of freedom of the press and association (Ghanem, 2023), allowing discontent to be voiced and organized without necessarily escalating into revolutionary movements.

Second, economically and technologically, England lay at the heart of the Industrial Revolution and industrialized earlier than much of Europe (Wrigley, 2018). This process created new jobs, classes and wealth, reducing the likelihood of mass starvation or total economic collapse, which often fueled unrest elsewhere (Fagan, 2002). Furthermore, the 18th-century Agricultural Revolution (and associated its technological innovations) significantly improved food production and yields, and mitigated the worst effects of climate-related crop failures (Overton, 1996). Beyond these economic benefits, Davis and Feeney (2017) have stressed that England's stability was further secured by its overseas colonies. These colonies in North America, Australia, New Zealand and even Ireland helped to absorb excessive population growth and diffused elite competition by offering alternative opportunities in settlement, trade and colonial administration. The colonial dimension operated as an effective demographic and fiscal safety valve. Mass emigration not only relieved domestic labour market pressures but also provided pathways for elite ambitions to be channeled into administrative and military roles abroad. This dual function of emigration and settler-colonialism helped prevent the accumulation of pressures that could incite radical mobilization at home and contrasted sharply with the experience of continental European nations where lower emigration rates left domestic grievances to worsen. In this way, the expanding empire was not a mere byproduct of British power but an integral part of its strategy to manage internal stresses and preclude revolutionary outcomes.

Third, in the social realm, it could be argued that England offered greater opportunities for social advancement compared to the more rigidly stratified societies of continental Europe. Research suggests that the expansion of the middle class and increased opportunities in a rapidly industrializing economy fostered a greater degree of fluidity than in many continental counterparts, where traditional aristocratic structures remained more entrenched, leading to sentiments of resentment among the populace (Kaelble, 1984). Furthermore, wars with France (1790s-1815), particularly the Napoleonic wars, fostered patriotism and a desire to avoid internal division while facing a foreign enemy (Van Beurden, 2015).

Finally, the geography of the British Isles meant that England benefited from a geomorphological barrier against the rapid spread of revolutionary movements across borders, a "domino effect" that was frequently observed in continental Europe, such as during the 1848 revolutions (Rapport, 2008) or the recent Arab Spring of the early 2010s (Lynch, 2016). This isolation provided a degree of protection from revolutionary fervor that could easily spill over landlocked borders.

4.5. Lessons for the present

This study demonstrates that societies and institutions can be resilient in the face of climate insecurity if agricultural systems can adapt to emerging pressures and challenges (development of climate-resilient crops; Dhankher and Foyer, 2018; Kopéc, 2024), if health systems have the capacity to protect populations against climate risks (sustainable health-care facilities; Corvalan et al., 2020) and if urban development promotes planning and design of public spaces aimed at climate change mitigation and adaptation, resulting in multiple co-benefits for human health, while reducing social inequalities (Orsetti et al., 2022). The key is probably the implementation of effective governmental measures to help populations cope with climate insecurity (Termeer et al., 2011; Berrang-Ford et al., 2019). This would reduce the potential number of vulnerable people, mitigate associated crises and enhance resilience to the negative effects in many areas. Although the future evolution of climate remains uncertain, these measures would significantly benefit the population and may help prevent the risks of major social unrest, similar to those that played out during the LIA.

5. Conclusions

It seems rational to argue that climate change during the second half of the last millennium acted as a trigger for severe food shortages that directly affected populations. The severity of this impact varied depending on demographic pressure on food resources and the responses provided by political institutions. During the LIA, climate change caused a significant decline in harvests, leading to food shortages that directly impacted populations. The failure of institutions to respond adequately exacerbated the crises, transforming food shortages into famines, weakening populations and leaving them vulnerable to various scourges. It was this combination of factors, combined with pre-existing political and social tensions, that gave rise to rebellions and revolts. The LIA serves as a wake-up call, highlighting how inadequate adaptation to climate insecurity and the failure to mitigate the adverse effects of climate change can lead to uprisings up against governing bodies.

CRediT authorship contribution statement

David Kaniewski: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nick Marriner:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Frédéric Luce:** Writing – review & editing, Validation, Methodology, Investigation. **Morgane Escarpe:** Writing – review & editing, Investigation. **Majid Pourkerman:** Writing – review & editing, Validation, Investigation. **Thierry Otto:** Writing – review & editing, Validation, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by the Université de Toulouse - Paul Sabatier and by the CNRS.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloplacha.2025.105038.

Data availability

The data supporting our results are provided as Supplementary data to this article.

References

Alfani, G., 2011. The famine of the 1590s in Northern Italy. An analysis of the greatest « system shock » of sixteenth century. Hist. Mes. 26, 17–49.
Appleby, A.B., 1980. Epidemics and famine in the Little Ice Age. J. Interdiscip. Hist. 10, 643–663.
Behringer, W., 1999. Climatic change and witch-hunting: the impact of the Little Ice Age on mentalities. Clim. Chang. 43, 335–351.
Ben Ari, T., Neerinckx, S., Gage, K.L., Kreppel, K., Laudisoit, A., Leirs, H., Stenseth, N.C., 2011. Plague and climate: Scales matter. PLoS Pathog. 7, e1002160. https://doi.org/10.1371/journal.ppat.1002160.
Berrang-Ford, L., Biesbroek, R., Ford, J.D., Lesnikowski, A., Tanabe, A., Wang, F.M., Hsu, A., Hellmann, J.J., Pringle, P., Grecequet, M., Amado, J.C., Huq, S., Lwasa, S., Heymann, S.J., 2019. Tracking global climate change adaptation among governments. Nat. Clim. Chang. 9, 440–449.
Blumberg, A., 1990. A Carefully Planned Accident: The Italian War of 1859. Susquehanna University Press, Selinsgrove.
Bouton, C.A., 1993. The Flour War: Gender, Class, and Community in Late Ancien Régime French Society. Pennsylvania State University Press, Penn State University.
Brayshay, M., Grattan, J., 1999. Environmental and social responses in Europe to the 1783 eruption of the Laki fissure volcano in Iceland: a consideration of contemporary documentary evidence. Geol. Soc. Spec. Publ. 161, 173–187.
Brázdil, R., Demarée, G.R., Deutsch, M., Garnier, E., Kiss, A., Luterbacher, J., Macdonald, N., Rohr, C., Dobrovolný, P., Kolář, P., Chromá, K., 2010. European floods during the winter 1783/1784: scenarios of an extreme event during the "Little Ice Age". Theor. Appl. Climatol. 100, 163–189.

Briffa, K.R., 2000. Annual climate variability in the Holocene: interpreting the message of ancient trees. Quat. Sci. Rev. 19, 87–105.
Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.U., Wanner, H., Luterbacher, J., Esper, E., 2011. 2500 years of European climate variability and human susceptibility. Science 331, 578–582.
Burnette, D.J., 2021. The Tree-Ring Drought Atlas Portal: gridded drought reconstructions for the past 500-2000 years. Bull. Am. Meteorol. Soc. 102, 953–956.
Butler, D., 2007. Darfur's climate roots challenged. Nature 447, 1038. https://doi.org/10.1038/4471038b.
Camenisch, C., Rohr, C., 2018. When the weather turned bad. The research of climate impacts on society and economy during the Little Ice Age in Europe. An overview. Geograph. Res. Lett. 44, 99–114.
Camenisch, C., Keller, K.M., Salvisberg, M., Amann, B., Bauch, M., Blumer, S., Brázdil, R., Brönnimann, S., Büntgen, U., Campbell, B.M.S., Fernández-Donado, L., Glaser, R., González-Rouco, F., Grosjean, M., Hoffmann, R.C., Huhtamaa, H., Joos, F., Kiss, A., Kotyza, O., Lehner, F., Luterbacher, J., Maughan, N., Neukom, R., Novy, T., Pribyl, K., Raible, C.C., Riemann, D., Schuh, M., Slavin, P., Wetter, O., 2016. The 1430s: a cold period of extraordinary internal climate variability during the early Spörer Minimum with social and economic impacts in North-western and Central Europe. Clim. Past 12, 2107–2126.
Campbell, B.M.S., 2016. The Great Transition: Climate, Disease and Society in the Late Medieval World. Cambridge University Press, Cambridge.
Carey, M., 2012. Climate and history: a critical review of historical climatology and climate change historiography. WIRES Clim. Change 3, 233–249.
Chu, C.Y.C., Lee, R.D., 1994. Famine, revolt, and the dynastic cycle. J. Popul. Econ. 7, 351–378. https://doi.org/10.1007/BF00161472.
Collet, D., Schuh, M., 2018. Famines during the "Little Ice Age" (1300–1800). Socio-natural entanglements in premodern societies. Springer, Berlin.
Cook, E.A., 2000. Southwestern USA drought index reconstruction, international tree-ring data bank. In: IGBP PAGES/World Data Center for Paleoclimatology, Data Contribution Series #2000-053 (NOAA/NGDC Paleoclimatology Program, Boulder, CO, 2000). https://www.ncei.noaa.gov/pub/data/paleo/treering/reconstructions/swd_recon.txt.
Cook, E.A., Seager, R., Kushnir, Y., Briffa, K.R., Büntgen, U., Frank, D., Krusic, P.J., Tegel, W., van der Schrier, G., Andreu-Hayles, L., Baillie, M., Baittinger, C., Bleicher, N., Bonde, N., Brown, D., Carrer, M., Cooper, R., Čufar, K., Dittmar, C., Esper, J., Griggs, C., Gunnarson, B., Günther, B., Gutierrez, E., Haneca, K., Helama, S., Herzig, F., Heussner, K.U., Hofmann, J., Janda, P., Kontic, R., Köse, N., Kyncl, T., Levanič, T., Linderholm, H., Manning, S., Melvin, T.M., Miles, D., Neuwirth, B., Nicolussi, K., Nola, P., Panayotov, M., Popa, I., Rothe, A., Seftigen, K., Seim, A., Svarva, H., Svoboda, M., Thun, T., Timonen, M., Touchan, R., Trotsiuk, V., Trouet, V., Walder, F., Ważny, T., Wilson, R., Zang, C., 2015. Old World megadroughts and pluvials during the Common Era. Sci. Adv. 1, e1500561. https://doi.org/10.1126/sciadv.1500561.
Corvalan, C., Villalobos Prats, E., Sena, A., Campbell-Lendrum, D., Karliner, J., Risso, A., Wilburn, S., Slotterback, S., Rathi, M., Stringer, R., Berry, P., Edwards, S., Enright, P., Hayter, A., Howard, G., Lapitan, J., Montgomery, M., Prüss-Ustün, A., Varangu, L., Vinci, S., 2020. Towards climate resilient and environmentally sustainable health care facilities. Int. J. Environ. Res. Public Health 17, 8849. https://doi.org/10.3390/ijerph17238849.
Davis, D., Feeney, K.C., 2017. Explaining British Political Stability after 1832. Cliodynamics 8, 2. https://doi.org/10.21237/C7CLIO8237530.
Degroot, D., 2018. Climate change and society in the 15th to 18th centuries. WIRES Clim. Change 9, e518. https://doi.org/10.1002/wcc.518.
deMenocal, P.B., 2001. Cultural responses to climate change during the late Holocene. Science 292, 667–673.
Dhankher, O.P., Foyer, C.H., 2018. Climate resilient crops for improving global food security and safety. Plant Cell Environ. 41, 877–884.
Domínguez Ortiz, A., Vincent, B., 1993. Historia de los moriscos: vida y tragedia de una minoría. Alianza Editorial, Madrid.
Doyle, W., 1990. The Oxford History of the French Revolution. Oxford University Press, Oxford.
C. Easton. Les hivers dans l'Europe occidentale; étude statistique et historique sur leur température, discussion des observations thermométriques, 1852–1916 et 1757–1851, tableaux comparatifs, classifications des hivers, 1205–1916, notices historiques sur les hivers remarquables.
Edwards, J., Anchukaitis, K.J., Gunnarson, B.E., Pearson, C., Seftigen, K., von Arx, G., Linderholm, H.W., 2022. The origin of tree-ring reconstructed summer cooling in northern Europe during the 18th century eruption of Laki. Paleoceanogr. Paleoclimatol. 37, e2021PA004386. doi: https://doi.org/10.1029/2021PA004386.
Fagan, B.M., 2002. The Little Ice Age: how climate made history 1300–1850. Basic Books, New York.
Flückiger, S., Brönnimann, S., Holzkämper, A., Fuhrer, J., Krämer, D., Pfister, C., Rohr, C., 2017. Simulating crop yield losses in Switzerland for historical and present Tambora climate scenarios. Environ. Res. Lett. 12, 7. https://doi.org/10.1088/1748-9326/aa7246.
Ghanem, R., 2023. Freedom of expression, press, and censorship in 19th century Europe and the USA. Miskolci Jogtudó 2, 34–44.
Goldstone, J., 1991. Revolution and Rebellion in the Early Modern World. University of California Press, Berkeley.
Haines, A., Kovats, R.S., Campbell-Lendrum, D., Corvalan, C., 2006. Climate change and human health: impacts, vulnerability, and mitigation. Lancet 367, 2101–2109.
Holopainen, J., Helama, S., 2009. Little Ice Age farming in Finland: Preindustrial agriculture on the edge of the grim reaper's scythe. Hum. Ecol. 37, 213–225.
Hufton, O.H., 1974. The Poor of the Eighteenth Century, France 1750–1789. Clarendon Press, Oxford.
Ionita, M., Dima, M., Ngavciuc, V., Scholz, P., Lohmann, G., 2021. Past megadroughts in Central Europe were longer, more severe and less warm than modern droughts. Commun. Earth Environ. 2, 61. https://doi.org/10.1038/s43247-021-00130-w.
IPCC, 2021. Climate Change 2021 The Physical Science Basis Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport.pdf.
Jacobeit, J., Jönsson, P., Bärring, L., Beck, C., Ekström, M., 2001. Zonal indices for Europe 1780-1995 and running correlations with temperature. Clim. Chang. 48, 219–241.
Johnson, S., 2011. Climate and Catastrophe in Cuba and the Atlantic World in the Age of Revolution. The University of North Carolina Press, Chapel Hill.
Jones, P.D., Osborn, T.J., Briffa, K.R., 2001. The evolution of climate over the last millennium. Science 292, 662–667.
Kaelble, H., 1984. Eras of social mobility in 19th and 20th century Europe. J. Soc. Hist. 17, 489–504.
Kaniewski, D., Marriner, N., 2020. Conflicts and the spread of plagues in pre-industrial Europe. Humanit. Soc. Sci. 7, 162. https://doi.org/10.1057/s41599-020-00661-1.
Kaniewski, D., Marriner, N., Cheddadi, R., Guiot, J., Van Campo, E., 2018. The 4.2 ka BP event in the Levant. Clim. Past 14, 1529–1542.
Kaniewski, D., Marriner, N., Cheddadi, R., Morhange, C., Bretschneider, J., Jans, G., Otto, T., Luce, F., Van Campo, E., 2019. Cold and dry outbreaks in the eastern Mediterranean 3200 years ago. Geology 47, 933–937.
Kiss, A., 2018. Floods and Long-Term Water-Level Changes in Medieval Hungary. Springer, Berlin.
Kobashi, T., Menviel, L., Jeltsch-Thömmes, A., Vinther, B.M., Box, J.E., Muscheler, R., Nakaegawa, T., Pfister, P.L., Döring, M., Leuenberger, M., Wanner, H., Ohmura, A., 2017. Volcanic influence on centennial to millennial Holocene Greenland temperature change. Sci. Rep. 7, 1441. https://doi.org/10.1038/s41598-017-01451-7.
Kopéc, P., 2024. Climate change - the rise of climate-resilient crops. Plants 13, 490. https://doi.org/10.3390/plants13040490.
Kuhlemann, J., Rohling, E.J., Krumrei, I., Kubik, P., Ivy-Ochs, S., Kucera, M., 2008. Regional synthesis of Mediterranean atmospheric circulation during the Last Glacial Maximum. Science 321, 1338–1340.
Labrousse, C., 1970. L'expansion agricole : La montée de la production, sec. 3 : les oscillations courtes de la production agricole. In: Labrousse, E., Leon, P., Goubert, P., Bouvier, J., Carrière, C., Harsin, P. (Eds.), Histoire Economique et Sociale de la France. Tome 2 1660–1789. Presses Universitaires de France, Paris, pp. 417–471.
Labuhn, I., Daux, V., Girardclos, O., Stievenard, M., Pierre, M., Masson-Delmotte, V., 2016. French summer droughts since 1326 CE: a reconstruction based on tree ring cellulose $\delta^{18}O$. Clim. Past 12, 1101–1117.
Lawrence, M., Homer-Dixon, T., Janzwood, S., Rockstöm, J., Renn, O., Donges, J.F., 2024. Global polycrisis: the causal mechanisms of crisis entanglement. Glob. Sustain. 7 (e6), 1–16. https://doi.org/10.1017/sus.2024.1.
Lefebvre, G., 1954. Etudes sur la Révolution Française. Presses Universitaires de France, Paris.
Lefebvre, G., 1973. The Great Fear of 1789: Rural Panic in Revolutionary France. Random House Publishing Group, New York.
Levack, B.P., 2015. The Witch-Hunt in Early Modern Europe, 4th edition. Routledge, New York.
Ljungqvist, F.C., Seim, A., 2024. Reassessing grain price variability in early modern Europe (c. 1500-1800). Eur. Econ. Rev. 170, 104852. https://doi.org/10.1016/j.euroecorev.2024.104852.
Ljungqvist, F.C., Thejll, P., Christiansen, B., Seim, A., Hartl, C., Esper, J., 2022. The significance of climate variability on early modern European grain prices. Cliometrica 16, 29–77.
Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H., 2004. European seasonal and annual temperature variability, trends and extremes since 1500. Science 303, 1499–1603.
Luterbacher, J., Werner, J.P., Smerdon, J.E., Fernández-Donado, L., González-Rouco, F.J., Barriopedro, D., Ljungqvist, F.C., Büntgen, U., Zorita, E., Wagner, S., Esper, J., McCarroll, D., Toreti, A., Frank, D., Jungclaus, J.H., Barriendos, M., Bertolin, C., Bothe, O., Brázdil, R., Camuffo, D., Dobrovolný, P., Gagen, M., García-Bustamante, E., Ge, Q., Gómez-Navarro, J.J., Guiot, J., Hao, Z., Heger, G.C., Holmgren, K., Klimenko, V.V., Martín-Chivelet, J., Pfister, C., Roberts, N., Schindler, A., Schurer, A., Solomina, O., von Gunten, L., Wahl, E., Wanner, H., Wetter, O., Xoplaki, E., Yuan, N., Zanchettin, D., Zhang, H., Zerefos, C., 2016. European summer temperatures since Roman times. Environ. Res. Lett. 11, 024001. https://doi.org/10.1088/1748-9326/11/2/024001.
Lynch, M., 2016. The New Arab Wars: Uprisings and Anarchy in the Middle East. Public Affairs, New York.
Marchi, M., Castellanos-Acuña, D., Hamann, A., Wang, T., Ray, D., Menzel, A., 2020. ClimateEU, scale-free climate normal, historical time series, and future projections for Europe. Sci Data 7, 428. https://doi.org/10.1038/s41597-020-00763-0.
Marshall, L.R., Schmidt, A., Schurer, A.P., Abraham, N.L., Lücke, L.J., Wilson, R., Anchukaitis, K., Hegerl, G., Johnson, B., Otto-Bliesner, B.L., Brady, E.C., Khodri, M., Yoshida, K., 2025. Last millennium volcanic forcing and climate response using SO_2 emissions. Clim. Past 21, 161–184.
McMichael, A.J., 2012. Insights from past millennia into climatic impacts on human health and survival. Proc. Natl. Acad. Sci. USA 109, 4730–4737.
Meyers, S.R., Pagani, M., 2006. Quasi periodic climate teleconnections between northern and southern Europe during the 17th-20th centuries. Glob. Planet. Chang. 54, 291–301.
Orsetti, E., Tollin, N., Lehmann, M., Valderrama, V.A., Morató, J., 2022. Building resilient cities: climate change and health interlinkages in the planning of public

spaces. Int. J. Environ. Res. Public Health 19, 1355. https://doi.org/10.3390/ijerph19031355.
Osborn, T.J., Briffa, K.R., 2006. The spatial extent of 20th-century warmth in the context of the past 1200 years. Science 311, 841–844.
Oster, E., 2004. Witchcraft, weather, and economic growth in Renaissance Europe. J. Econ. Perspect. 18, 215–228.
Overton, M., 1996. Agricultural Revolution in England: The Transformation of the Agrarian Economy 1500–1850, 1st ed. Cambridge University Press. https://doi.org/10.1017/CBO9780511607967.
Parker, G., 2013. Global Crisis. War, Climate Change and Catastrophe in the Seventeenth Century. Yale University Press, New Haven.
Patz, J.A., Engelberg, D., Last, J., 2000. The effect of changing weather on public health. Annu. Rev. Public Health 21, 271–307.
Pfister, C., 2007. Climatic Extremes, Recurrent Crises and Witch Hunts: Strategies of European Societies in Coping with Exogenous Shocks in the Late Sixteenth and Early Seventeenth Centuries. J. Mediev. Hist. 10, 33–73.
Pfister, C., Brázdil, R., 2006. Social vulnerability to climate in the "Little Ice Age": an example from Central Europe in the early 1770s. Clim. Past 2, 115–129.
Pincus, S., 2009. 1688: The First Modern Revolution, the Lewis Walpole Series in Eighteenth-Century Culture and History. Yale University Press, New Haven, CT. https://doi.org/10.12987/9780300156058.
Rapport, M., 2008. 1848: Year of Revolution. Little, Brown, London.
Richter, T.O., Peeters, F.J.C., van Weering, T.C.E., 2009. Late Holocene (0-2.4 ka BP) surface water temperature and salinity variability, Feni Drift, NE Atlantic Ocean. Quat. Sci. Rev. 28, 1941–1955.
Robbins Schug, G., Buikstra, J.E., DeWitte, S.N., Baker, B.J., Berger, E., Buzon, M.R., Davies-Barrett, A.M., Goldstein, L., Grauer, A.L., Gregoricka, L.A., Halcrow, S.E., Knudson, K.J., Larsen, C.S., Martin, D.L., Nystrom, K.C., Perry, M.A., Roberts, C.A., Santos, A.L., Stojanowski, C.M., Suby, J.A., Temple, D.H., Tung, T.A., Vlok, M., Wtasoon-Glen, T., Zakrzewski, S.R., 2023. Climate change, human health, and resilience in the Holocene. Proc. Natl. Acad. Sci. USA 120, e2209472120. https://doi.org/10.1073/pnas.2209472120.
Rohr, C., 2013. Floods of the Upper Danube River and its tributaries and their impact on urban economies (c. 1350-1600): the examples of the towns of Krems/Stein and Wels (Austria). Environ. Hist. 19, 133–148.
Salehyan, I., 2008. From climate change to conflict? No consensus yet. J. Peace Res. 45, 315–326.
Slavin, P., 2016. Climate and famines: a historical reassessment. WIRES Clim. Change 7, 433–447.
Solanski, S.K., Usoskin, I.G., Kromer, B., Schüssler, M., Beer, J., 2004. Unusual activity of the Sun during recent decades compared to the previous 11,000 years. Nature 431, 1084–1087.
Stahle, D.W., Cleaveland, M.K., Blanton, D.B., Therrell, M.D., Gay, D.A., 1998. The lost Colony and Jamestown droughts. Science 280, 564–567.
Swann, J., Félix, J., 2013. The Crisis of the Absolute Monarchy: France from Old Regime to Revolution. Oxford University Press, Oxford.
Termeer, C., Dewulf, A., Van Rijswick, H., Van Buuren, A., Huitema, D., Meijerink, S., Wiering, M., 2011. The regional governance of climate adaptation: a framework for developing legitimate, effective, and resilient governance arrangements. Clim. Law 2, 159–179.
Tridimas, G., 2021. Constitutional monarchy as power sharing. Constit. Polit. Econ. 32, 431–461.
Usoskin, I.G., Arlt, R., Asvestari, E., Hawkins, E., Käpylä, M., Kovaltsov, G.A., Krivova, N., Lockwood, M., Mursula, K., O'Reilly, J., Owens, M., Scott, C.J., Sokoloff, D.D., Solanki, S.K., Soon, W., Vaquero, J.M., 2015. The Maunder minimum (1645-1715) was indeed a grand minimum: a reassessment of multiple datasets. Astron. Astrophys. 581, A95. https://doi.org/10.1051/0004-6361/201526652.
Van Beurden, K., 2015. 'No troops but the British': British national identity and the Battle for Waterloo (MPhil Thesis). The University of Queensland. https://doi.org/10.14264/uql.2015.1097.
Wagner, S., Zorita, E., 2005. The influence of volcanic, solar and CO_2 forcing on the temperatures in the Dalton Minimum (1790-1830): a model study. Clim. Dyn. 25, 205–218.
Wanner, H., Pfister, C., Neukom, R., 2022. The variable European Little Ice Age. Quat. Sci. Rev. 287, 107531. https://doi.org/10.1016/j.quascirev.2022.107531.
White, S., 2011. The Climate of Rebellion in the Early Modern Ottoman Empire. Cambridge University Press, Cambridge.
White, S., 2019. A comparison of drought information in early north American colonial documentary records and a high-resolution tree-ring-based reconstruction. Clim. Past 15, 1809–1824.
White, S., 2020. A Cold Welcome. The Little Ice Age and Europe's encounter with North America. Harvard University Press, Harvard.
Wrigley, E.A., 2018. Reconsidering the industrial revolution: England and Wales. J. Interdiscip. Hist. 49, 9–42.
Xiao, L., Fang, X., Zhao, W., 2018. Famine relief, public order, and revolts: interaction between government and refugees as a result of drought/flood during 1790-1911 in the North China Plain. Reg. Environ. Chang. 18, 1721–1730.
Zhang, D.D., Zhang, J., Lee, H.F., He, Y.Q., 2007. Climate change and war frequency in Eastern China over the last millennium. Hum. Ecol. 35, 403–414.
Zhang, D.D., Lee, H.F., Wang, C., Li, B., Pei, Q., Zhang, J., An, Y., 2011. The causality analysis of climate change and large-scale human crisis. Proc. Natl. Acad. Sci. USA 108, 17296–17301.