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White, Sam

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New perspectives on historical climatology

Sam White[1] | **Qing Pei**[2] | **Katrin Kleemann**[3] | **Lukáš Dolák**[4,5] | **Heli Huhtamaa**[6,7] | **Chantal Camenisch**[6,7]

[1]Faculty of Social Science, University of Helsinki, Helsinki, Finland

[2]Department of Social Sciences, Education University of Hong Kong, Ting Kok, Hong Kong

[3]German Maritime Museum Leibniz/Institute for Maritime History, Bremerhaven, Germany

[4]Department of Geography, Masaryk University, Brno, Czechia

[5]Global Change Research Institute CAS, Brno, Czechia

[6]Institute of History, University of Bern, Bern, Switzerland

[7]Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

Correspondence

Sam White, Faculty of Social Sciences, University of Helsinki, Helsinki, Finland.
Email: samuel.white@helsinki.fi

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Abstract

Historical climatology is an interdisciplinary field of research encompassing the reconstruction of past climate and weather from written sources and artifacts, as well the application of climate reconstructions to the study of human history. Historical climatology has grown in recent years, and this growth has brought both insights and challenges. Research has expanded into new regions and periods and diversified into novel sources, methods, and interdisciplinary collaborations. At the same time, the heterogeneity of evidence and approaches has complicated the integration of multiple climate and weather reconstructions. Moreover, the diversity of disciplinary perspectives, terminologies, and perspectives can create miscommunication among scholars in the field, particularly on issues of historical knowledge and causation. Innovative approaches in the field, including Bayesian methods, may help address these challenges.

This article is categorized under:

Climate, History, Society, Culture > Disciplinary Perspectives
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KEYWORDS

climate history, historical climatology, methodology

1 | INTRODUCTION

Historical climatology is here defined as an interdisciplinary field of research encompassing both the reconstruction of past climate and weather from "archives of societies" (written sources and artifacts) and the application of climate reconstructions to the study of human history. It incorporates qualitative and quantitative analysis and methods from the humanities, social sciences, and natural sciences. It forms an integral part of the wider field of "climate history," which also includes cultural histories of climate and the history of climate science (White et al., 2018).

Historical climatology has grown and diversified in recent years, incorporating new sources and methods and reaching in to new regions and eras. This growth has brought insights but also challenges. The number and variety of new studies exceed the capacity of researchers to keep up with the latest findings. The heterogeneity of data and methods exacerbates problems of integrating results from different studies and furthering their use in climate reconstruction. Divergent vocabularies and concepts among sub-fields and disciplines have engendered miscommunication and misunderstanding rather than productive diversity and debate, particularly on questions of causation. Different regional source bases, languages, and traditions of scholarship have widened these rifts and impeded collaboration.

Therefore, this article provides a critical analysis of the recent growth in historical climatology, its emerging challenges, and some initiatives to overcome them. It begins with a brief background to the field (Section 2) and a review of recent directions in research (Section 3). We then turn to the intersections among disciplines (Section 4) and recent efforts to review, criticize, and synthesize the field (Section 5). We argue that this turn to self-reflection and criticism reflect challenges of holding the field together during its current growth and diversification, and the article reviews two principal issues: the integration and comparison of reconstructions from multiple, heterogeneous sources (Section 6) and clashing frameworks of historical knowledge and causation regarding climate in human history (Section 7). Finally, this article considers two recent directions in research that could help address these issues: the use of Bayesian methods (Section 8) and more careful analysis of historical knowledge and causation, including explicit contrast sets in causal claims (Section 9). We conclude with a list of four key recommendations for future projects in the field (Section 10).

2 | BACKGROUND

As explored in past reviews, the earliest precursors of historical climatology go back to theories of climate and its influence on societies proposed by classical authors and debated during the Enlightenment (Mauelshagen, 2010; Rohr, 2017). Other precedents may be found in ideas about climate and race formed in the context of European overseas expansion and colonial empires, which resurfaced in the climate determinist theories of early 20th-century geographers (Mahony & Endfield, 2018). Once modern climate science took shape in the late 19th century, and "climate" acquired its sense of "average weather," climatologists such as Eduard Brückner examined correlations between climate and social statistics (Brückner, 1895). Yet the modern origins of the field in the West are usually traced to the mid-20th-century work of meteorologists such as Hubert Lamb and historians such as Emmanuel Le Roy Ladurie. Meanwhile, research in historical climatology emerged more or less independently among geographers in China and other world regions (Le Roy Ladurie, 2013; Pfister et al., 2018).

For much of the late 20th century, researchers focused primarily on testing and improving temperature and precipitation reconstructions. They developed approaches such as the index method (or "Pfister indices") to convert diverse qualitative sources into quantitative measures. Schools of historical climatology formed around influential scholars of different world regions, including central and western Europe, China, and Japan. Claims of climate's historical impacts were often tempered, whether for lack of firm evidence or concerns about climate determinism. Nevertheless, scholars established central research questions regarding climate in human history, including the influence of climate variability and extreme weather on food prices and mortality. By the end of the century, rising concerns over global warming and expanding paleoclimate research had widened the scope of the field. Recognition of climate change and extreme weather impacts in the 21st century also invited stronger interest in topics of historical impacts, adaptation, and resilience (Adamson et al., 2018a; Pfister et al., 2018; Sörlin & Lane, 2018).

Since the 2010s, the field has seen new and expanded initiatives. Projects such as Atmospheric Circulation Reconstructions over the Earth (ACRE) have continued the recovery and analysis of early instrumental weather data from around the world (Allan et al., 2016), and the Past Global Changes Climate Reconstruction and Impacts from the

Archives Societies working group (CRIAS) has organized workshops and publications focused on international collaboration and methodological advances in the field (Camenisch et al., 2020). While work has continued through established schools of historical climatology, climate history has received numerous and diverse contributions from new teams and new disciplines.

3 | RECENT DIRECTIONS IN RESEARCH

Reconstructing historical climates from archives of societies remains a core mission of historical climatology. Recent years have brought numerous new studies of early weather measurements (Brugnara et al., 2020; Camuffo et al., 2019, 2020, 2021), further digitization and publication of early instrumental records (Ashcroft et al., 2021; Burt & Burt, 2019; Gergis et al., 2021; Pappert et al., 2021; Rodrigo, 2019a), as well as applications of early instrumental data to analyze climate and weather events, such as the cooling impact of volcanic eruptions (Brönnimann et al., 2019; Picas & Grab, 2020; Rodrigo, 2019b). Research has continued into descriptive records as well, including weather chronicles (e.g., Filipiak et al., 2019), ships' logbooks (e.g., García-Herrera et al., 2018), and official records (e.g., Haolong et al., 2020). In some cases, researchers have drawn creatively on new types of source material, including phenological indicators in classical Chinese poetry (Liu et al., 2021).

Recent scholarship has emphasized reconstruction and impacts of extreme precipitation events as well as temperature. A special issue of *Climate of the Past* (Brázdil et al., 2018) and special collection of *Regional Environmental Change* have highlighted gaps and progress in research on historical droughts (Maughan et al., 2022). This work features new methods for identifying exceptional drought seasons (Glaser & Kahle, 2020), new perspectives on vulnerability and adaptation (Gorostiza et al., 2021; Pribyl et al., 2019), and work on peculiar drought records such as rogation ceremonies (Tejedor et al., 2019) and “hunger stones” (Elleder et al., 2020). Initiatives such as the PAGES Floods working group have initiated multidisciplinary analysis of historical flooding and impacts using multiple proxies from archives of nature and societies (Barriendos et al., 2019; Schulte et al., 2019). Recent years have also brought new work in past storm reconstruction (e.g., Athimon & Maanan, 2018; Diodato et al., 2021), as well as analysis of regional storms, impacts, and adaptations, such as Rohland's (2018) long-term study of hurricanes in New Orleans.

Well-established regions such as the Czech lands have remained at the forefront of much reconstruction and impact research (e.g., Brázdil et al., 2019). Nevertheless, other regions and countries have seen rapid growth, such as southeastern Europe (Botić, 2020; Cheval et al., 2020; Kužić, 2020; Mrgić & Dražeta, 2020; Pašić et al., 2020; Perşoiu & Perşoiu, 2018) and Ireland (Kelly, 2020; Kelly & O'Carragáin, 2021; Sweeney, 2020). Significant new work on climate and history has also continued for Latin America (e.g., Mora Pacheco, 2019) and Africa (e.g., Klein et al., 2018), as well as parts of Asia that had received little coverage until the past five years (Adamson & Nash, 2018b): Korea (Jun & Sethi, 2021), Singapore and Malaysia (Williamson, 2021), and the Middle East (Fleitmann et al., 2022; Meklach et al., 2021; Pehlivan, 2020). Since 2021, for example, studies combining historical research with speleothem and tree-ring data have demonstrated the impact of a previously unknown drought on crises in Safavid Iran and Ottoman Iraq at the end of the 17th century—regions almost completely lacking in climate history research just a decade before (Gustafson & Speer, 2022; Husain, 2021). Furthermore, a growing number of studies have looked into climate, weather, and culture during the Middle Ages and earlier centuries, both in Europe and China (e.g., Chen et al., 2020; Ebert, 2021; Labbé, 2020; Wozniak, 2020).

Recent research has also emphasized short-term global extremes associated with large volcanic eruptions. This shift reflects advances in dating techniques and high-resolution paleoclimatology that highlight the role of volcanic forcing in the cooling of the Little Ice Age (LIA) and other episodes of historical climate variability (Sigl et al., 2015; Toohey & Sigl, 2017). Moreover, volcanic eruptions and climate impacts represent discrete and sudden global events, which draw attention to their societal consequences and provides synchronic and diachronic comparisons of societal vulnerability and resilience (e.g., D'Arrigo et al., 2020; Guillet et al., 2020; Huhtamaa et al., 2022; Stoffel et al., 2022). Furthermore, attempts to reconstruct volcanic eruptions and better understand their influence on climate—as in the PAGES Volcanic Impacts on Climate and Society (VICS) working group—have encouraged new forms of integration between historical research and earth and atmospheric sciences. Examples include the use of paleoclimate modeling to test volcanic forcing of climate change and impacts described in historical records (Xoplaki et al., 2018) as well as the use of historical observations to examine mechanisms of volcanic forcing identified in paleoclimate simulations (White et al., 2022).

4 | INTERSECTIONS

As climatic change, impacts, and adaptations have become a pressing global concern, historical climatology involves a larger and more complex intersection of disciplines. Some of these intersections have been well established. For instance, the integration of historical climatology, paleoclimatology, economic, and agricultural history continues to refine understandings of historical interactions among weather, crops, prices, and mortality (e.g., Chambru, 2020; Ljungqvist, Thejll, et al., 2021; Martínez-González et al., 2020). Moreover, the last few years have brought major new studies of climate and famines in medieval and early modern Europe, with in-depth analysis of political, social, and cultural as well as meteorological factors (Camenisch, 2019; Collet, 2018; Damodaran et al., 2019; Kiss & Pribyl, 2020; Pribyl, 2017; Slavin, 2019).

Further intersections have arisen in the field of environmental history. Although only a small portion of environmental histories concern weather or climate, journals of the field publish articles with a focus on meteorological events (e.g., Wolfe, 2020) and studies incorporating historical climatology (e.g., Grau-Satorras et al., 2021). Environmental history monographs have contextualized and integrated historical climatology and paleoclimate evidence, examined climate impacts, and advanced theories of societal impacts and adaptations for individual regions and periods. In the past 5 years, for example, books from environmental historians Degroot (2018a) and Sundberg (2022) have explored Dutch resilience and political and technological responses in the face of meteorological disasters throughout the early modern period. A monograph by environmental historian Skopyk (2020) has made a painstaking examination of centuries of climate variability and environmental change for a single valley in colonial Mexico to demonstrate how LIA impacts depended on specific shifts in local crops, economic incentives, and indigenous demography.

New intersections have also emerged in areas of archaeology with long traditions of multidisciplinary work combining archives of nature and societies. In particular, the Climate Change and History Research Initiative (CCHRI) based at Princeton University has organized interdisciplinary research combining archaeology, history, paleoclimatology, and modeling, particularly for the late antique Mediterranean. The initiative has resulted in numerous publications and collections exploring methods and debating the written and physical evidence of climatic variability and change, societal impacts, adaptation, and resilience (e.g., Erdkamp et al., 2021; Izdebski et al., 2018; Izdebski & Mulryan, 2019).

5 | SYNTHESES AND REFLECTIONS

Another recent feature of historical climatology has been the proliferation of syntheses, reviews, and methodological studies. These include a first concise undergraduate textbook for climate and global history (Lieberman & Gordon, 2018) and a new synthesis of European historical climatology of the past millennium by Pfister and Wanner (2021). The CRIAS working group has produced special issues on the global state of the field in historical climatology and international methods in reconstruction and impacts from archives of societies (Camenisch et al., 2020). Recent edited volumes have aimed for a global perspective on historical episodes. For example, a collection of regional studies on the "Dantean anomaly" of the early 14th century reveals different sources and degrees of vulnerability to the twin disasters of climatic change and the Black Death (Bauch & Schenk, 2019). Meanwhile, scholars have also aimed to synthesize national histories of climate, culture, science, and politics in countries such as Australia (Gergis, 2018), Russia (Bruno, 2018), and the United States (White, 2018).

Further reviews consider the possible insights that historical climatology and high-resolution paleoclimatology bring to human history. These reviews summarize current understandings of societal effects such as famines (Slavin, 2016), periods in climate history such as the LIA (Degroot, 2018a, 2018b, 2018c), or historical climate–society interactions within geographical regions (Ljungqvist, Seim, & Huhtamaa, 2021). A common theme among this research is the significance of societal vulnerabilities and responses in magnifying or mitigating impacts of climatic variability and extreme events.

The growth of interdisciplinary studies on climate and human history has also invited reflections on the promises and challenges of consilience across the sciences and humanities (Wilson, 1998). These include enthusiastic claims that historical climatology is "in the process of achieving the long-imagined re-unification of the sciences and the humanities" (McCormick, 2019), as well as more tempered, if hopeful reviews (Haldon, Mordechai, et al., 2018; Newfield & Labuhn, 2017). Interdisciplinary historian Adam Izdebski et al. (2016) and collaborators analyze disciplinary differences in research focus, bases of interpretation, and publication styles; their recommendations for future collaboration emphasize the search for common ground on research and writing procedures, common spatial and temporal scales of analysis, and a shared narrative of results.

Finally, a 2021 *Nature* review examines research in what it terms the "history of climate and society (HCS)." The authors call for a new approach to correct "the overwhelming focus in HCS on crisis and collapse" that "misrepresents the character of historical interactions between humanity and climate change." They identify common issues in past studies, including a misunderstanding of historical sources, misuse of climate reconstructions, mismatches in scales of analysis, simplification of historical processes, and confusion between correlation and causation. They call for a new framework of research questions to "address four key challenges in HCS: interpreting evidence, bridging dynamics across scales, establishing causal mechanics and estimating uncertainty" (Degroot et al., 2021).

6 | EMERGING CHALLENGES (1): INTEGRATING EVIDENCE

We find that this trend of synthesis and re-examination reflects the challenges of holding together the growing and diverse field of historical climatology and of applying its insights to urgent research and policy problems. A first set of challenges concern the collection and integration of an increasing, heterogenous mass of evidence on past weather, climates, and societies. Researchers in climate history often face disparate data sources, including scanned and digitized records—and those awaiting discovery in historical archives—early instrumental measurements, diaries, logbooks, and evaluations by historical climatologists. The challenge of assembling historical climate databases have even been the focus of a first "ethnographic" study of historical climatology research teams (Decker, 2018). At the time of writing, the first projects were underway to compile and analyze a global inventory of historical documentary evidence (Burgdorf, 2022) and to formalize standards for prioritizing "data rescue" and digitization projects of old weather records as well as assessing trust in the resulting databases (Sieber et al., 2022).

Even where heterogeneous sources are already converted to single index values for climate and weather variables, researchers may encounter diverse methods and scales. Nash et al. (2021) have undertaken the first global review of these disparate indices—often a legacy of different national or regional traditions—and recommended practices to improve their compatibility, reliability, and transparency. Additionally, Adamson et al. (2022) have undertaken the first study in quantifying and reducing researcher subjectivity in the generation of climate indices from documentary sources, finding that teams of as few as two trained researchers may produce consistent and reliable results.

Further issues arise in the integration of historical climatology and paleoclimatology: that is, reconstructions based on archives of societies and those based on archives of nature. High-resolution paleoclimate proxies such as tree-ring width and density promise valuable insights into climate variability and impacts on human historical scales, independently or alongside information from written records and artifacts (e.g., Kolář et al., 2022; Ljungqvist et al., 2019). Recent studies have engaged in systematic comparisons of historical records with tree ring-based reconstructions to identify strengths, weaknesses, and patterns in results. These have found, for example, that historical observers might record only 1 year of multiyear droughts identifiable in tree ring-based reconstructions (Kiss, 2017; White, 2019); and where paleoclimate proxies have a lower resolution, as in southeast and west-central Africa, even sparse written evidence may help pinpoint years of extremes (Hannaford & Beck, 2021).

Nevertheless, most studies lack a formal method to combine information from both written and natural sources to produce a single best estimate of past temperatures, precipitation, or frequency of extreme weather. Where historical climatology and paleoclimatology reconstructions agree, this convergence may be taken as mutual support for their conclusions. Yet where they disagree or provide mixed information, there is no widely accepted way to reconcile or integrate the results. Moreover, prior knowledge of the other's reconstructions can influence how paleoclimatologists and historical climatologists each interpret their own data, posing a risk of circular reasoning. These problems have been one reason most historical climatology indices cover only those regions and periods with consistent and high-quality documentary evidence. For earlier periods or other regions with thinner evidence, the studies lose precision. Weak or vague descriptions cannot justify high or low index values (e.g., +3 or −3); the series must leave out seasons without descriptions; and paleoclimatology cannot sharpen the results or fill in the gaps. For this reason, there is currently little prospect of extending historical climatology reconstructions beyond the national or regional scale (e.g., central Europe).

Finally, the mix of qualitative and quantitative evidence complicates the task of utilizing climate and weather reconstructions in the study of human history. The index method has helped to address the basic challenge of converting qualitative into quantitative information. However, the field continues to produce disparate narrative histories of climate and society alongside statistical analyses of climate and weather variables and economic and demographic indicators such as prices and populations. Where their findings converge, these two types of studies can be mutually reinforcing. However, where they differ, there is no established method to reconcile their results or decide between them. Such problems occur particularly when reconciling statistical patterns of impacts on large temporal or spatial scales with small-scale qualitative historical and archeological studies that emphasize local continuity and resilience (e.g., Kouki, 2013).

7 | EMERGING CHALLENGES (2): FRAMEWORKS OF HISTORICAL KNOWLEDGE AND CAUSATION

As these considerations indicate, the growth and diversity of scholarship in climate history can pose conceptual as well as methodological challenges. These have given rise to divides within the field, two of which are especially revealing.

A first divide concerns so-called "maximalist" and "minimalist" positions on climatic change and its role in history, particularly during the "Late Antique Little Ice Age" (LALIA, early 6th century CE). On the one hand, scholars such as Harper (2017) have drawn on a combination of sources to build a narrative of massive climate change impacts with enduring historical consequences, particularly in the Byzantine Empire. These include tree-ring and other proxy evidence for exceptional cold or drought, contemporary accounts of dust veils and famines, and dramatic descriptions of mortality during the ensuing Plague of Justinian in the eastern Mediterranean (ca. 540 s CE). On the other hand, critics have pointed to numerous exceptions and alternative interpretations of the evidence. Not all parts of the world touched by the LALIA reveal the same impacts; even in the eastern Mediterranean, the climate record can be ambiguous; many physical records, from pollen assemblages to pottery remains, do not indicate drastic changes in land use or population; and the historical written evidence may have had political and religious motivations (Haldon, Elton, et al., 2018b, 2018c).

A second division concerns the use of long-term, large-n statistical studies to assess historical links among climate variability and change and societal impacts including conflict, famine, and migration. This type of research has been especially common among Chinese scholars, who have drawn on imperial China's abundant and distinctive records of weather events, natural disasters, and population and economic indicators, many of them already compiled into databases (Pei, 2021; Pei & Forêt, 2018; Wang et al., 2018). Researchers have traditionally adopted long durations and large spatial scales to perform quantitative (statistical) studies of historical climate–society interactions, using mainly linear regression analysis (e.g., Zhang et al., 2011). More recently, studies have appeared using a regional rather than national scale, including studies of the ancient Silk Road route (Feng et al., 2019; Hao et al., 2019) and marginal regions with high vulnerability to climate change, such as Mu Us Desert (Cui et al., 2017) and northeastern China (Cui et al., 2019). Statistical methods have branched out from linear regression (e.g., Lee, 2018) to non-linear approaches (Damette et al., 2020) and wavelet and phase analysis (Lee, 2019). More complex quantitative methods have enabled more systematic analyses incorporating a greater variety of socio-economic factors (Pei et al., 2018; Su et al., 2018). Studies have also examined short-term climate–society interactions and individual historical events, such as volcanic eruptions in southwestern China (Hao et al., 2020), as well as weather and disasters during the collapse of Liao Dynasty (Li et al., 2019) and Northern Song Dynasty (Storozum et al., 2018). Nevertheless, studies demonstrating large-scale linear correlations between variables such as temperature and conflicts remain the most highly cited, and reviews from qualitative researchers and scholars outside China have faulted much Chinese climate history for uncritical use of data and for climate determinism (Degroot, 2018c; Degroot et al., 2021; van Bavel et al., 2019). Few studies have tried to bridge the divide between quantitative climate history research in China and work in other parts of the world (Pei, 2021).

As some scholars have noted, these divisions in historical climatology concern not only the sources and use of historical evidence but also approaches to historical knowledge and causation (Mordechai & Eisenberg, 2019; Sessa, 2019). Scholars from different nations and disciplines, as well as different publication styles, bring different concepts, vocabulary, and assumptions to these research topics. The result, we argue, has been less a productive debate or diversity of opinion than a breakdown in communication, limiting opportunities for new scholarship that would draw from both macro and micro, quantitative and qualitative approaches (White & Pei, 2020).

8 | BAYESIAN APPROACHES TO INTEGRATING EVIDENCE

The following sections consider two emerging areas of scholarship that may help address these challenges. First are Bayesian new approaches to integrating heterogeneous evidence and multiple reconstructions. Examples include techniques to extend weather reanalyses back into the 19th century (Devers et al., 2020) as well as reconstruction of daily to weekly weather patterns: for example, "Lamb-type" weather series for western Europe since the 18th century (Delaygue et al., 2019) and daily "synthetic weather diaries" for Switzerland since the 19th century (Brönnimann, 2020). In addition, researchers have developed Bayesian approaches for combining diverse sources of information at different scales into single reconstructions of climate variables. In paleoclimatology, these include methods such as Bayesian hierarchical modeling to combine information from multiple natural proxies (Gennaretti et al., 2017; Gergis et al., 2016; Hernández et al., 2020) and to produce climate field reconstructions for temperature and precipitation (Reichen et al., 2022; Weitzel et al., 2019).

Bayesian approaches may prove especially significant for utilizing archives of societies, since they promise to overcome challenges of integrating information from disparate and uncertain sources. For example, Salinas et al. (2016) have used a fuzzy Bayesian approach to incorporate imprecise or unreliable written records into historical flood reconstructions. Luterbacher et al. (2016) have also used Bayesian hierarchical modeling to integrate historical climatology indices into a multiproxy reconstruction of European summer temperatures. Most recently, Camenisch et al. (2022) have developed a Bayesian method to reconstruct climate in the late medieval Burgundian Low Countries.

The significance of such Bayesian methods extends beyond their immediate practical applications in climate reconstruction. These approaches instantiate a key epistemological insight: that most historical knowledge consists of explanatory inference (Box 1). They can express the relationship between written and physical evidence and past climate and weather as a probabilistic causal relationship rather than a merely statistical relationship or analogy. Proxies and written descriptions provide information about past climates and weather insofar as hypothesized past climate states or weather events (C) were causally necessary and/or sufficient to leave that evidence (E). Therefore, Bayesian methods may start with prior probability estimates about hypothesized past climate states or weather events [$p(C)$] and use likelihoods for the evidence given those hypothesized states or not [$p(E|C)/p(E)$] to update our knowledge, generating improved posterior probability estimates [$p(C|E)$].

In this way, Bayesian methods may overcome the challenges of integrating heterogeneous evidence and multiple historical climatology and paleoclimatology reconstructions. In theory, Bayesian approaches can always incorporate new information from new sources to update our knowledge. Furthermore, they may effectively combine expertise from multiple fields: for example, paleoclimate modeling may produce prior probability estimates, while historians may judge the causal necessity and sufficiency of climate states and weather events to produce certain written descriptions and phenological records. The advantages of Bayesian methods may prove particularly strong in improving seasonal temperature and precipitation indices in regions and periods with weak or inconsistent historical records. In such cases,

BOX 1 Explanatory inference and Bayesian methods

Explanatory inference here refers to probabilistic reasoning from effects to causes, including what philosophers term "abduction" and "inference to the best explanation." Explanatory inference is distinct from deduction (reasoning from premises to conclusions) and induction (reasoning from particulars to patterns), and it represents a vital form of reasoning in both everyday situations and the practice of science (Douven, 2022; Godfrey-Smith, 2003). In historical research, explanatory inference often involves reasoning from traces of the past—that is, written or physical evidence—to conditions in the past that offer the best causal explanation for those traces. Thus, dendroclimatologists who reconstruct a dry summer from a set of tree rings have inferred a certain degree of dryness because it provides the best causal explanation (but not the only possible cause) for the narrowness of those rings, while historical climatologists who reconstruct a cold winter from historical descriptions have inferred a certain degree of cold because it provides the best causal explanation (but not the only possible cause) for those descriptions.

Bayesian is here used to qualify methods that explicitly or implicitly employ Bayes' theorem: that is, that the probability of a hypothesis given some evidence ("posterior probability") is equal to the prior probability of said hypothesis times the conditional probability of the evidence given the hypothesis ("likelihood") divided by the probability of the evidence regardless of the hypothesis, or: $p(h|e) = p(h) \times p(e|h)/p(e)$.

Although philosophers disagree whether explanatory inference is always or necessarily Bayesian, it has been shown that this is typically the case in historical research (Tucker, 2004). That is, the posterior probability of some past condition (or cause) given some evidence (or effect) is assessed, explicitly or implicitly, in terms of the prior probability of the condition and the ratio of the likelihood to the probability of the evidence: $p(c|e) = p(c) \times p(e|c)/p(e)$.

Bayesian methods can combine written and physical evidence, extract more information from the written sources, and distinguish cases of weak evidence for strong anomalies from strong evidence of weak anomalies, which might look the same in a conventional index series. They can also express a range of probabilities and uncertainties rather than just a single best estimate for each target variable (Camenisch et al., 2022).

Bayesian reasoning can extend to the quantitative analysis of past climate and society as well. Most quantitative studies of historical impacts and adaptations have employed frequentist approaches, particularly regression analysis, to establish statistical relationships among climate variables and movements in prices, populations, or conflicts. However, such frequentist approaches rarely specify prior probabilities for causal hypotheses or likelihoods for finding statistical patterns in the data whether or not such hypotheses are true (Clayton, 2021). These studies may produce statistical inductions relevant to causal analysis, yet drawing causal inferences will require background knowledge and theory to supply the prior probabilities for causal hypotheses and to distinguish among relationships of causal necessity, causal sufficiency, and mere correlation in the data. Studies adopting Bayesian methods may thus help distinguish meaningful causal relationships between climate variability and societal impacts from statistical relationships arising from chance, artifacts, or autocorrelation in time series. Such studies have, for example, cast doubt on some historical connections between short-term variability in climate and warfare (Carleton et al., 2021), and given mixed results regarding the global impacts of the 4.2 ka drought event (Ön et al., 2021).

9 | ANALYZING HISTORICAL KNOWLEDGE AND CAUSATION

A second significant area of scholarship to help address challenges in the field concerns changing motivations and perspectives in climate history research. That is, through closer examination of the background and context of scholarship, studies can shed light on different use of language, concepts, and causal frameworks employed in current studies. Drawing on these insights, the field may overcome challenges of miscommunication and find new grounds for collaboration and consensus—or more productive ways to disagree and debate.

In a previous critical review, Carey (2012) observed how analyses of climate impacts and stories of crisis and collapse had predominated in historical climatology. He argued that researchers should no longer aim to prove what science and common sense had already demonstrated: that the earth is warming and that climate change has societal consequences. Instead, scholars throughout the broader field of climate history should emphasize more subtle lessons: the role of culture and power in shaping perceptions of climate and risk, the economic and political roots of vulnerabilities, and the sources of societal resilience and adaptive capacity. In the decade since, there has been a further shift away from stories of collapse and other cautionary tales intended to demonstrate the relevance of climate in history and the urgency of climate change mitigation. As substantial global warming has become inevitable, raising the likelihood of imminent catastrophic impacts, there has been more interest in histories of adaptation, resilience, and hope (Haldon et al., 2020; Mauch, 2019).

Furthermore, perspectives and goals of historical climatology research have also changed in response to evolving paradigms of climate–society interactions in the social and natural sciences. In this regard, Adamson et al. (2018a) have identified three distinctive roles for historical research in current discussions of climate change: "particularizing adaptation" based on local long-term climate–society interactions; illustrating path dependency and sources of institutional memory; and "second-order observation," or historical reflection on sources of relevant knowledge and concepts. For example, research has begun to examine the influence of gender and power on historical weather and climate observations, their preservation, and dissemination (Lehmann, 2018; Mercer, 2021).

In short, many scholars have shifted their categories of enquiry over the past decade, and this shift has generated grounds for miscommunication, particularly regarding historical knowledge and causation. First, researchers in historical climatology now work with two conflicting meanings of the term "data." In many studies, "data" refers to basic measurements and facts (i.e., low-level inferences) which serve as the basis for induction. For example, the frequency of droughts and famines in Ming China, inferred from historical records, may serve as data for analyzing statistical relationships and patterns. However, for many studies, especially those of humanist historical perspective and those focused on the reliability of underlying climate information, "data" can only mean the raw historical sources—the traces of the past from which we might draw explanatory inferences. Measurements and low-level inferences cannot be taken as "data"—literally, as "given"—because these are themselves the objects of analysis. Therefore, these historical studies could not start with the frequency of droughts and famines in Ming China as their data because inferring that frequency from the underlying Ming records is itself a target of historical investigation. This is true *a* *fortiori* of studies exploring cultural and historical circumstances behind the historical production of climate and weather knowledge.

Moreover, in terms of causation, researchers pursue conflicting *questions* about climate and human history as well as offering competing *answers*. Starting in the late 20th century, historical climatology research usually examined whether historical climate variability and change had significant historical impacts *anywhere*. That is, researchers aimed to demonstrate—for historians skeptical of climatic factors and climatologists skeptical of historical evidence—that past climate had demonstrable effects on human history, whether across large spatial and temporal scales or during particular periods of crisis. This perspective has continued to guide certain topics and methods of research. Yet a growing body of scholarship in the past decade has begun to question whether historical climatic variability and change had the same or significant historical impacts *everywhere*. That is, amid dire forecasts of global warming disasters, researchers aim to demonstrate that climate change impacts have not been inevitable, and that culture, economics, and politics could make a difference in outcomes. These two lines of enquiry overlap but lead in different directions.

Therefore, apparent divides between maximalist and minimalist interpretations and between macro-quantitative and micro-qualitative research often come down to confusion over terminology, including different meanings of data and different frameworks of causation. As examined by White and Pei (2020), three issues seem to generate the most confusion. First, scholars in different research traditions use different contrast sets in causal analysis, which they fail to specify. For example, a macro-quantitative study or maximalist interpretation may claim that "climate caused conflict" but only mean that the *timing* of climate change caused the *timing* of conflict; while a micro-qualitative study may claim "climate did not cause conflict" but only demonstrate that climate change caused conflict in some regions and periods but not others. Second, some studies use effect-of-cause analysis—that is, they examine large-scale patterns to demonstrate general causal sufficiency; yet other studies use cause-of-effect analysis—that this, they examine case studies to determine specific causal necessity. For example, a macro-quantitative study may find that past decades of colder climate predicted decades of more frequent conflicts on a continental scale, while a micro-qualitative study may examine a single region and find that climate variability was not a necessary condition of a historic conflict there. These results may appear contradictory, yet they are logically compatible. Third, where historical societal impacts such as conflicts had multiple necessary conditions, including climatic variability or change, researchers may disagree over whether to label climate "a cause" or "the cause" of the outcome in preference to social, economic, or other factors. The grounds for such disagreement may be normative as well as positive. A recent study of violent encounters among Arctic whalers by Degroot (2022) exemplifies some of these complexities in causal attribution.

Research in the history of climate and migration (reviews in McLeman, 2014 and Mauelshagen, 2018) further illustrates the need for close analysis of climate and causation. This topic has drawn both large-scale analyses of time series demonstrating statistical associations between climate and emigration (e.g., Glaser et al. 2017) as well as focused qualitative case studies that complicate links among past climate, disasters, and population movements (e.g., Di Cosmo et al., 2018). Yet neither type of study necessarily justifies an inference that climate caused migration or that populations were resilient. A meaningful, testable causal claim would start with contrast sets in the explanans and explanandum: what *distinctions* in past climate (e.g., duration or intensity of variability or change) caused what *differences* in migration (e.g., timing, volume, destination, or composition of migrants). It would distinguish between causal sufficiency and necessity: was some feature of climate a sufficient cause of migration in general [i.e., high $p(M|C)$], or was some feature of climate a necessary condition of migrations that took place [i.e., high $p(C|M)$]? Returning to the Bayesian insight outlined above, the study would justify prior probabilities for climate-migration links and reasons for updating those probabilities based on the evidence. This step may require further grounding in theory and models of migration. In fact, current research on climate and population demonstrates that change and extremes have heterogeneous and at times counterintuitive effects on short- and long-distance movements for different groups. For example, among more vulnerable populations, sudden extreme events such as floods may cause more involuntary *immobility* or domestic displacement, while less vulnerable populations may *choose* to emigrate in response to rising climate threats such as worsening drought (Kaczan & Orgill-Meyer, 2020). Therefore, historical correlations between interannual climate variability and emigrant numbers are not necessarily evidence of vulnerability, nor are stable or declining emigrant numbers evidence of resilience.

Of course, not all projects in historical climatology can address all such factual and theoretical questions—nor should they have to. For instance, many studies provide useful empirical evidence or statistical inductions concerning past climate, weather, and society, yet they lack the context and resources to draw detailed causal inferences or are published in a format that emphasizes quantitative analysis rather qualitative discussion. In such cases, formulating and demonstrating historical knowledge and causation could involve further studies drawing on new collaborations and additional areas of expertise.

10 | RECOMMENDATIONS AND CONCLUSION

In summary, the continued growth and diversity of historical climatology brings challenges of bridging diverse data, methods, results, and perspectives across topics, regions, disciplines, and different policy and intellectual priorities. To avoid misunderstandings and to continue to profit from intersections with other fields, scholarship in historical climatology should be open to new methods, improvements in communication, and closer analysis of historical knowledge and causation. Individual projects may not have the expertise or personnel to answer all relevant questions across domains of climate, environment, and society (Degroot et al., 2021). Yet individual studies in each of these areas may take steps to ensure their reasoning and results are transparent and contribute to improving reconstructions of past climate and weather and applying those to the study of human history. To this end, we propose the following four recommendations:

- *Act locally, think globally*. Most projects in historical climatology will continue to be local or national in focus and limited to at most a few disciplines. Nevertheless, studies should consider international comparisons, best practices, and the needs and scholars in other disciplines. They should keep in mind how their work may contribute to a global picture of past climate and human history and the refinement of methods and concepts in the field. Researchers could also look for further synergies across areas of research—for example, use of newly digitized and analyzed early instrumental series for calibration and verification of historical climatology indices.
- *Distinguish inductions about data from inferences about the past*. Research in climate history, as in other historical sciences, often involves both induction and explanatory inference. Researchers engage in empirical research and identification of patterns in data using quantitative and qualitative analysis. This empirical research and induction may then aid in inferring historical conditions and causal relationships. Nevertheless, as this review has shown, drawing appropriate and justified inferences may require specialized background knowledge, theory, and methods requiring new collaborations. Moreover, the best inferences may change with new information, causal understandings, and frameworks of research. Bayesian approaches that distinguish priors, likelihood ratios, and posterior probabilities offer one solution to this problem. Yet even conventional studies can take more care to separate prior assumptions from new information and to provide transparent reasoning behind inferences about past conditions and causation.
- *Recognize two meanings of "data."* Historical climatologists currently use "data" to mean both (1) traces of the past gathered as evidence and (2) the measurements and low-level inferences drawn from these traces and employed in climate reconstruction and impact studies. These different categories of data should provide opportunities to improve scholarship rather than creating confusion or division in the field. In particular, scholars who use data in the sense of measurements or facts should consider the relevance of scholarship using data in the sense of historical sources, including the way that biases in measurement, reporting, transmission, and preservation of historical source material on weather, climate, and society may introduce artifacts into statistical associations.
- *Clarify causal frameworks*. Scholarship in the field appears divided on basic issues of causation regarding historical climate impacts and adaptations. Yet on closer examination, these divisions often come down to clashing use of terminology, concepts, or communication styles in different disciplines. The problem, we argue, is not that scholars disagree about climate and causation in history but that they have trouble specifying the grounds for disagreement, rendering some debates divisive and unproductive. We propose that causal claims should include the following: (1) Contrast sets in the explanans and explanandum—that is, what distinction in conditions caused what difference in outcome. In particular, studies should distinguish between cases where the *timing* of some climate or weather phenomenon influenced the *timing* of some impact from cases where the presence or absence of that phenomenon influenced whether or not the impact occurred at all. (2) Distinctions between causal necessity, causal sufficiency, and mere correlation. If possible, large-n quantitative studies should try to move from correlation or regression analysis to statements of conditional probabilities [i.e., $p(\text{effect}|\text{cause})$ and $p(\text{cause}|\text{effect})$]. (3) In cases of complex multicausality, grounds for (not) regarding climate as "a cause" or "the cause" of an outcome. (4) More use of Bayesian reasoning in causal inference. Where possible, studies should justify prior probability estimates for causal hypotheses and consider how their evidence and inductions can or cannot update those probabilities.

Many scholars have called for greater consideration of historical perspectives in climate change policy, including Intergovernmental Panel on Climate Change reports that privilege the physical sciences and economics (Holm & Winiwarter, 2017). This review finds that historical climatology remains a thriving field, and one that promises valuable contributions to scholarship and public discussion on climate. Nevertheless, historical climatology faces challenges of integrating heterogeneous evidence and reconstructions, as well as communicating across different disciplines and approaches. We hope that the new methods and perspectives highlighted in this review and the evaluations and recommendations presented here may help historical climatologists meet these challenges and provide sharper insights into the past and lessons for the present.

AUTHOR CONTRIBUTIONS

Sam White: Writing – original draft (lead); writing – review and editing (equal). **Qing Pei:** Writing – original draft (supporting); writing – review and editing (equal). **Katrin Kleemann:** Writing – original draft (supporting); writing – review and editing (equal). **Lukáš Dolák:** Writing – original draft (supporting); writing – review and editing (equal). **Heli Huhtamaa:** Writing – original draft (supporting); writing – review and editing (equal). **Chantal Camenisch:** Writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST

The authors report no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Sam White https://orcid.org/0000-0002-1046-3944
Qing Pei https://orcid.org/0000-0002-9699-2950
Katrin Kleemann https://orcid.org/0000-0002-9719-3413
Lukáš Dolák https://orcid.org/0000-0003-1325-298X
Heli Huhtamaa https://orcid.org/0000-0001-5829-5575
Chantal Camenisch https://orcid.org/0000-0002-2107-9681

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FURTHER READING

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