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# Introduction to the special issue "Climate of the past 2000 years: regional and trans-regional syntheses"

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**Abstract.** This PAGES (Past Global Changes) 2k (climate of the past 2000 years working group) special issue of *Climate of the Past* brings together the latest understanding of regional change and impacts from PAGES 2k groups across a range of proxies and regions. The special issue has emerged from a need to determine the magnitude and rate of change of regional and global climate beyond the timescales accessible within the observational record. This knowledge also plays an important role in attribution studies and is fundamental to understanding the mechanisms and environmental and societal impacts of recent climate change. The scientific studies in the special issue reflect the urgent need to better understand regional differences from a truly global view around the PAGES themes of "Climate Variability, Modes and Mechanisms", "Methods and Uncertainties", and "Proxy and Model Understanding".

## 1 Introduction

Since the late twentieth century, scientific understanding of our global environment and climate has undergone a remarkable transformation (Lamb, 1965, 1977). Reconstructions of historic globally averaged temperatures indicate the second-half of the twentieth century experienced a rise of 1 °C (Hawkins et al., 2017), during which the planet has experienced unprecedented rates of environmental change (Steffen et al., 2018). Future climate extremes are projected to increase in amplitude and frequency compared to the historic period (IPCC, 2013), enhanced by climate–human–carbon feedbacks (Friedlingstein et al., 2013; Randerson et al., 2015; Bronselaer et al., 2018; Comyn-Platt et al., 2018), with potentially irreversible consequences (centennial to millennial in duration) for the environment. However, a major source of uncertainty in projections of future climate change and its impacts lies in the validation of models using observational climate data that are limited in both space and time (Rayner et al., 2003). There is increasing recognition that instrumental and satellite observations do not fully capture the ampli-

tude of changes and range of extremes we are projected to experience in the next century and beyond (Masson-Delmotte et al., 2013).

This PAGES (Past Global Changes) 2k (climate of the past 2000 years working group) special issue of *Climate of the Past* brings together the latest understanding of regional change and impacts from PAGES 2k groups across a range of proxies and regions. The special issue has emerged from a need to determine the magnitude and rate of change of regional and global climate beyond the timescales accessible within the observational record. This knowledge also plays an important role in attribution studies and is fundamental to understanding the mechanisms and environmental and societal impacts of recent climate change (Turney et al., 2006; Caseldine and Turney, 2010; Huber and Knutti, 2012; Nelson et al., 2016). With these considerations, an increasing number of reconstructions have been developed from proxies that preserve sub-annual (e.g. ice cores, tree rings, and corals) to multi-decadal (e.g. sediments, pollen, boreholes) changes; so-called "natural archives" (Masson-Delmotte et al., 2013). The rapid expansion of sites has come with unintended consequences, most notably the need for shared protocols and databases to fully exploit these archives (PAGES2k Consortium, 2017).

The community-driven PAGES 2k Network was established in 2008 to provide global leadership in this endeavour. The first phase of the network (2008–2013) focussed on generating and analysing a global array of regional climate reconstructions (representing Australasia, the Arctic, the Antarctic, South America and Central America, North America, Europe, Asia, and the oceans) for the last two millennia. Notably, in 2013, the regional PAGES 2k reconstructions demonstrated clear regional expressions of temperature variability at the multi-decadal to century scales, with a long-term global cooling trend prior to the twentieth century (PAGES 2k Consortium, 2013). During the second phase (2014–2016), and with the support of the CMIP5/PMIP3 project (Taylor et al, 2012), the focus shifted towards the identification of processes and the behaviour of phenomena, integrating projects addressing climate changes across regional boundaries (Abram et al., 2014; Neukom et al., 2014; McGregor et al., 2015; Abram et al., 2016; Tierney et al., 2017; Zhong et al., 2018). A major community effort consisted of creating a global database of temperature data for the Common Era using well-defined selection criteria and applying a clear open-data policy (PAGES 2k Consortium, 2017; Kaufman and PAGES 2k special-issue editorial team, 2018). Since 2017, a network of projects identified and led by 2k community members has been addressing questions articulated around the PAGES themes of "Climate Variability, Modes and Mechanisms", "Methods and Uncertainties" and "Proxy and Model Understanding".

The scientific studies in the special issue reflect the urgent need to better understand regional differences from a truly global view. They report annually resolved reconstructions of precipitation and temperature derived from ice, marine, and terrestrial archives for Antarctica (Stenni et al., 2017; Thomas et al., 2017), Australia (Freund et al., 2017), China (Shi et al., 2017), and India (Xu et al., 2018), placing hydroclimate extremes in the context of historic trends, and providing new insights into variability and their regional forcing(s). The work of Guevara-Murua et al. (2018) exploits historic archives to report 300 years of hydroclimate change in Central America and finds major societal impacts associated with extremes; this is an area of research that we anticipate will become increasingly important with future attempts to both recover historic climate archives and adapt to the impacts of climate change.

Alongside these efforts, lower-resolution (interannual to multi-decadal resolution) archives offer the opportunity to develop longer records of past climate and environmental change. In this special issue, several new reconstructions are presented that highlight the complementary value of lower-resolution records for deriving millennial-length reconstructions from Australia (Dixon et al., 2017), the North Atlantic (Franke et al., 2017), North America (Shuman et al., 2018), the sub-Arctic (Nicolle et al., 2018), and the Arctic (Linderholm et al., 2018). These studies provide insights into multi-decadal to centennial forcing mechanisms, and provide a long-term context for late twentieth century regional change. At the same time, they also highlight where future work should be focussed, including the importance of comprehensive dating strategies for reducing chronological uncertainties, and identifying geographic areas where there remains a paucity of paleoclimate data. The latest compilation of borehole temperature profiles from North America reported by Jaume-Santero et al. (2016) is a demonstration of the value of an extensive network of sites. Here, the reconstructions show that North America has experienced relatively greater warming than the global historic mean, with evidence for amplified temperature changes at high latitude.

This PAGES 2k special issue also illustrates the importance of integrating climate model-proxy studies to better understand the mechanisms and future impacts of high-latitude change. Seftigen et al. (2017), for instance, explore the drivers of hydroclimate change in Scandinavia over the past two millennia and identify important differences between model simulations and proxy data, demonstrating the critical importance of having a dense network of records for such studies. Pendleton et al. (2017) model the radiocarbon-dated extent of an ice cap on Arctic Baffin Island and find that only twentieth century warming can explain its retreat. Worryingly, this study projects that this particular ice cap will soon disappear if current trends continue through this century.

To complete this special issue, Kaufman and PAGES 2k special-issue editorial team (2018) report the challenges and benefits of data stewardship to facilitate further use of published data. Although there is strong support for making data more findable, accessible, interoperable, and reusable (FAIR;

Wilkinson et al., 2016), the vigorous discussion that accompanies this note illustrates some of the questions that may arise. Further work to identify, attribute, and make accessible the climate of the past 2000 years will support efforts to place the climate of the past two centuries in context, and provide a basis for assessment of the emergent effects of continued anthropogenic forcing of the climate over the forthcoming century and beyond.

**Data availability.** All papers in this special issue were reviewed by a data stewardship team to ensure they followed data availability practices consistent with the recommendations of Climate of the Past and of PAGES. For further details please see Kaufman et al. (2018).

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