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OPINION PIECE

The future of paleoclimate

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ABSTRACT: Our understanding of natural climate variability rapidly declines over the Common Era (CE) as the pre-instrumental temperature amplitude differs substantially among large-scale reconstructions. Highlighting such differences and emphasizing paleoclimatic findings is crucial for placing anthropogenic climate change in a long-term context. We argue that more proxy records are needed to accurately reconstruct first millennium CE temperature variability and value regional studies producing such data.

KEY WORDS: Temperature reconstruction · Tree rings · Multi-proxy · IPCC · Northern Hemisphere

Ever since the Intergovernmental Panel on Climate Change (IPCC) won the Nobel Peace Prize in 2007, the release of new reports every 6–8 yr generates an international media echo and informs policy makers around the world. Beyond their public impact, reports by Working Group 1 on 'The Physical Science Basis' are unique documents that summarize the state of climate science at a given point in time, and the chapter on paleoclimatic findings has become a pivotal benchmark within and beyond academia (Masson-Delmotte et al. 2013). This tradition will now be resigned, as the IPCC decided to not include a chapter on paleoclimatic findings in its next Working Group 1 report to be released in 2021, but to add information on past climate variability to several subsections. Even readers from outside the climate science community might wonder why this is the case. Are paleoclimatic findings less relevant to an understanding of the current climate dynamics, or have the fundamental paleoclimatic questions been answered sufficiently so that previous reports serve the purpose of informing the public? None of this is applicable. Information on past natural climate variability is still important to narrow uncertainties of future scenarios (Sherwood et al. 2020), yet our knowledge quickly fades over the most recent period of pre-instrumental climate variability, the Common Era (CE) spanning the past 2000 years.

Focusing on the first half of the Common Era (CE), several regional- and continental-scale studies revealed cooler conditions during the 6th–7th centuries, the so-called Late Antique Little Ice Age (LALIA; Büntgen et al. 2016), framed by warmer conditions during late Roman and high Medieval times (Moberg et al. 2005, Ljungqvist 2010, Christiansen & Ljungqvist 2012, Esper et al. 2012, Luterbacher et al. 2016, Büntgen et al. 2020). This broader picture was recently challenged by a global temperature reconstruction showing a steady mean fluctuating between −0.3 and −0.1°C (relative to the 1961–1990 mean), accompanied by large uncertainties ranging from −0.6 to +0.2°C (Fig. 1a). The reconstruction does not show substantial interannual to decadal scale variance, nor any sign of long-term trends supporting notions of a Roman Warm Period, LALIA, or Medieval Warm Period (PAGES 2k Consortium 2019).

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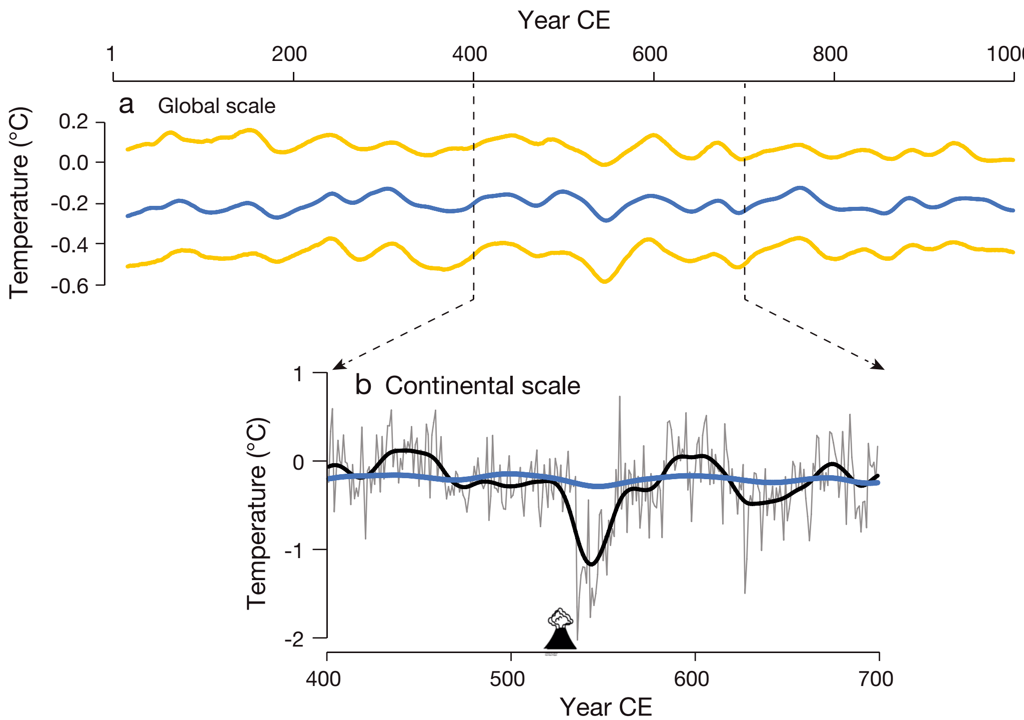

Fig. 1. Global- and continental-scale temperature reconstructions of the first half of the Common Era. (a) State-of-the-art smoothed global temperature reconstruction derived from high- and low-resolution proxies (blue curve) shown together with its 95% uncertainty range derived from sub-sampling and averaging the proxy records multiple times (yellow curves). The reconstruction integrates 257 proxies that were carefully selected from a pool of 692 temperature-sensitive records based on their fit with annual instrumental temperatures within 2000 km search radii (PAGES 2k Consortium 2017). Only ~10–20% of the paleo records extend back into the first millennium CE. (b) Annually resolved temperature reconstruction derived from 1 North American, 2 European, and 4 Asian tree-ring chronologies (gray curve). The bold black curve is a 30 yr filter, the blue curve is the global record from panel (a), and the symbol indicates the timing of major volcanic eruptions in 536 and the 540s CE. As with the global curve, only a fraction of tree-ring data from the 20th century calibration period extends back to the middle of the first millennium CE (~10%), thereby increasing the uncertainty estimates back in time (Büntgen et al. 2020)

The new temperature history is the result of an unprecedented group effort in which dozens of paleoclimatologists compiled data for each continent, which were then combined in a global mean for the CE. This final product combines information from 257 proxies using a range of methods and including annually-resolved tree-ring records, but also lower-resolution data from ice cores, lake and marine sediments, and other archives. The number of proxies as well as the quality of these series declines back in time (Esper et al. 2016), so that only a few records are available during the early centuries of the CE. All of these issues, i.e. the limited resolution, reduced replication, and increased dating uncertainty, affect our ability to accurately assess past temperatures and cause a blurring of the climate record back in time (Christiansen & Ljungqvist 2017).

The blurring effects become visible when the global temperature curve is compared with a continental-scale analysis (Büntgen et al. 2020), in which updated versions of the longest and best-replicated tree-ring chronologies from 7 locations in the Northern Hemisphere are combined (Fig. 1b). The latter shows more temperature variability as it represents much less space, i.e. parts of the Northern Hemisphere extratropics versus global land and ocean surfaces. Yet the regional data also demonstrate how large volcanic eruptions in 536 and the 540s CE caused a severe, multi-decadal temperature drop >1°C in large parts of the Northern Hemisphere, which can be simulated with climate models and corroborated by historical sources (Toohey et al. 2016). This climate anomaly marks the start of the LALIA and was accompanied by substantial socioeconomic transformations across Eurasia (Büntgen et al. 2016). The mid-6th century cooling is also depicted in the global estimate (the blue curve in Fig. 1b), but this deviation was not exceptional in the context of the smoothed variability throughout the first millennium CE.

At this point, it remains unclear to which degree these differences are caused by representing different spatial domains and/or including differently resolved and dated proxies. The widespread assumption that such fundamental questions on pre-industrial climate variability can be solved by employing climate model simulations is not supported, as such assessments rely on climate forcing estimates (solar variability, volcanic eruptions, land-use changes), again derived from proxy records. We therefore need to develop more high-resolution proxy records to provide a framework of natural climate variability at policy-relevant timescales and to support efforts of improving future climate predictions:

(1) There are only a few locations that provide reliable temperature estimates for the entire CE. Revisiting these, measuring new proxies from these 'old' sites, and updating existing records (towards present) is a research priority.

(2) Paleoclimatologists need to search for new locations from which additional, calibrated and verified, proxy records can be developed. These efforts should include both high- and low-resolution archives, proxies that are sensitive to hydroclimate variability, and records from lower latitudes and the Southern Hemisphere.

(3) International research initiatives extending beyond meeting support are needed to enable the development of proxy networks and improve paleoclimate data availability over the CE and beyond.

Whether the first millennium CE temperature history was invariable or characterized by large and persistent temperature changes is not a purely academic question. Yet the circumstance that the next IPCC report will no longer include a paleoclimate chapter should not mistakenly be interpreted as evidence that natural climate variability is understood. The opposite is actually the case. We are in the dark already before 1400 CE, have a rather limited idea of the magnitude (and forcing) of pre-industrial warm periods, and know much less about the Southern Hemisphere, not to mention precipitation and other climate elements.

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