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Variability and extremes of northern Scandinavian summer temperatures over the past two millennia

Jan Esper [a], Ulf Büntgen [b], Mauri Timonen [c], David C. Frank [b d]

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Abstract

Palaeoclimatic evidence revealed synchronous temperature variations among Northern Hemisphere regions over the past millennium. The range of these variations (in degrees Celsius) is, however, largely unknown. We here present a 2000-year summer temperature reconstruction from northern Scandinavia and compare this timeseries with existing proxy records to assess the range of reconstructed temperatures at a regional scale. The new reconstruction is based on 578 maximum latewood density profiles from living and sub-fossil *Pinus sylvestris* samples from northern Sweden and Finland. The record provides evidence for substantial warmth during Roman and Medieval times, larger in extent and longer in duration than 20th century warmth. The first century AD was the warmest 100-year period (+0.60 °C on average relative to the 1951–1980 mean) of the Common Era, more than 1 °C warmer than the coldest 14th century AD (−0.51 °C). The warmest and coldest reconstructed 30-year periods (AD 21–50=+1.05 °C, and AD 1451–80=−1.19 °C) differ by more than 2 °C, and the range between the five warmest and coldest reconstructed summers in the context of the past 2000years is estimated to exceed 5 °C. Comparison of the new timeseries with five existing tree-ring based reconstructions from northern Scandinavia revealed synchronized climate fluctuations but substantially different absolute temperatures. Level offset among the various reconstructions in extremely cold and warm years (up to 3 °C) and cold and warm 30-year periods (up to 1.5 °C) are in the order of the total temperature variance of each individual reconstruction over the past 1500 to 2000years. These findings demonstrate our poor understanding of the absolute temperature variance in a region where high-resolution proxy coverage is denser than in any other area of the world.

Highlights

► A 2000-year JJA temperature reconstruction from tree-ring density data is presented for Northern Scandinavia. ► The reconstruction provides evidence for substantial warmth during Roman and Medieval times. ► Comparison with existing records reveals synchronized climate fluctuations but substantially different absolute temperatures. ► Among-reconstruction temperature differences are in the order of the total variance of each individual reconstruction over the past 2000years.

Introduction

Millennial-length temperature reconstructions became an important source of information to benchmark climate models (IPCC, 2007), detect and attribute the role of natural and anthropogenic forcing agents (Hegerl et al., 2006), and quantify the feedback strength of the global carbon cycle (Frank et al., 2010b). Newer approaches are using palaeoclimatic reconstructions to assess the likelihood of simulation ensemble members, and thus help to constrain future climate scenarios (Yamazaki et al., 2009). These efforts are, however, limited by the number of high quality reconstructions and their ability to properly quantify the absolute range of past temperature variations (Esper et al., 2002), adding considerable uncertainty to hemispheric scale reconstructions that combine multiple regional proxy records (Frank et al., 2010a). At this point, we seem to have a fairly good understanding of the course of temperature change over the past millennium, i.e. the Medieval Warm Period (MWP), cooling into the Little Ice Age (LIA), and subsequent warming into the 20th century. However, the absolute variance (or amplitude) of temperature change (in degrees Celsius) is more poorly constrained, and might range from less than 0.5 °C to more than 1 °C over the past 1000 years at hemispheric scales (Frank et al., 2010b and references therein). The situation is even less clear prior to medieval times, as only few high-resolution reconstructions are available for the Common Era (Jones et al., 2009) complicating assessments of the absolute temperature amplitude during the Roman and subsequent Migration periods (Büntgen et al., 2011).

While discrepancies in hemispheric scale reconstructions have received considerable attention over the past decades (Frank et al., 2010a), less debate has been centred on the uncertainties of regional reconstructions and their abilities to properly estimate the evolution and amplitude of temperatures over the past centuries to millennia. This is surprising for a variety of reasons including the fact that large-scale reconstructions are often a simple aggregation of these regional reconstructions. It should thus be clarified how large errors at the regional level may be, and how these regional errors contribute to large-scale uncertainties.

Northern Scandinavia is one of the core regions from where multiple tree-ring based summer temperature reconstructions spanning the past 1–2 millennia are available (overview in Gouirand et al., 2008). The most widely cited (and integrated in hemispheric scale reconstructions) of these records is the timeseries derived from tree-ring maximum latewood densities (MXD) from the Tornetraesk region in northern Sweden (Schweingruber, 1988, updated in Grudd, 2008). Reasons for this extensive consideration include the length of the reconstruction (back to AD 500), as well as the robust climate signal of MXD data (correlation against summer temperatures typically > 0.7) that is generally stronger than for traditional tree-ring width (TRW) data (typically < 0.5). The Tornetraesk MXD data have also been combined with TRW data from the same trees to form an alternative reconstruction reaching back to AD 500 (Briffa et al., 1992). Since then, three additional reconstructions from Fennoscandia have been developed – all based on TRW, spanning the past two millennia, but partly relying on the same raw measurement series (Grudd et al., 2002, Briffa et al., 2008, Helama et al., 2010) – so that multiple, independently developed records can be used to assess the variability of summer temperatures over the past 1500 to 2000 years at a regional scale.

We here address this issue by *(1)* introducing a new summer temperature reconstruction that is longer and much better replicated than any other published MXD-based record, *(ii)* using this timeseries to derive estimates of the absolute range of regional summer temperature variation considering extremely cold and warm reconstructed years and periods over the past two millennia, *(iii)* comparing these estimates with existing tree-ring based reconstructions, and finally *(iv)* using the differences among these various records to assess the uncertainty of reconstructed temperatures within a confined region.

Section snippets

Material and Methods

We developed 587 high-resolution density profiles (Frank and Esper, 2005) from living and sub-fossil *Pinus sylvestris* in northern Sweden and Finland to form a long-term MXD record (N-Scan) spanning the 138 BC to AD 2006 period (Table 1). The living-tree samples were obtained from pines growing at the shores of three lakes to ensure data homogeneity with the sub-fossil samples obtained from 14 lakes in the region (Fig. 1). Spatial data homogeneity was assessed using a total of nine *Pinus*…

Summer temperatures derived from N-Scan

The N-Scan chronology contains multi-decadal to centennial scale fluctuations superimposed on a long-term negative trend over the past two millennia (Fig.2). The number of single MXD measurement series integrated in this record changes considerably through time, from only 5 series before 46 BC to 11 series in AD 1 and 197 series in AD 2001. Mean chronology age calculated for each year over the 138 BC – AD 2006 period is, however, fairly balanced throughout time, largely due to the integration…

Discussion and Conclusions

The MXD-based summer temperature reconstruction presented here sets a new standard in high-resolution palaeoclimatology. The record explains about 60% of the variance of regional temperature data, and is based on more high-precision density series than any other previous reconstruction. Importantly, MXD sample replication prior to the Little Ice Age, during Medieval times and throughout the first millennium AD, is much better than in any other record, and we demonstrated – based on calibration…

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2024, Dendrochronologia

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Partly decoupled tree-ring width and leaf phenology response to 20th century temperature change in Sweden
2022, Dendrochronologia

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Investigation of age trends in tree-ring stable carbon and oxygen isotopes from northern Fennoscandia over the past millennium
2022, Quaternary International

> *Citation Excerpt :*
> …The extent of age-related trend or its absence becomes critically important in cases where tree-ring isotope chronologies are extended back in time through subfossil materials, for which only the innermost segments of trunks are available due to decay and weathering (Duffy et al., 2017). Northern Fennoscandia houses some of the most important dendrochronological records globally, combining living and subfossil wood samples for the last millennia (e.g., Esper et al., 2012a; Linderholm et al., 2010). The resulting annually resolved temperature reconstructions have had significant implications for our understanding of long-term climate variability (e.g., Esper et al., 2012b).…

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