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Invited review

Last millennium northern hemisphere summer temperatures from tree rings: Part I: The long term context

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ABSTRACT

Large-scale millennial length Northern Hemisphere (NH) temperature reconstructions have been progressively improved over the last 20 years as new datasets have been developed. This paper, and its companion (Part II, Anchukaitis et al. *in prep*), details the latest tree-ring (TR) based NH land air temperature reconstruction from a temporal and spatial perspective. This work is the first product of a consortium called N-TREND (**N**orthern Hemisphere **Tre**e-Ring **N**etwork **D**evelopment) which brings together dendroclimatologists to identify a collective strategy for improving large-scale summer temperature reconstructions. The new reconstruction, N-TREND2015, utilises 54 records, a significant expansion compared with previous TR studies, and yields an improved reconstruction with stronger statistical calibration metrics. N-TREND2015 is relatively insensitive to the compositing method and spatial weighting used and validation metrics indicate that the new record portrays reasonable coherence with large scale summer temperatures and is robust at all time-scales from 918 to 2004 where at least 3 TR records exist from each major continental mass. N-TREND2015 indicates a longer and warmer medieval period (~900–1170) than portrayed by previous TR NH reconstructions and by the CMIP5 model ensemble, but with better overall agreement between records for the last 600 years. Future dendroclimatic projects should focus on developing new long records from data-sparse regions such as North America and eastern Eurasia as well as ensuring the measurement of parameters related to latewood density to complement ring-width records which can improve local based calibration substantially.

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1. Introduction

Over the past two decades, substantial effort has been directed towards reconstructing late Holocene Northern Hemisphere temperature trends and variability from high resolution palaeoclimate proxy data (Frank et al., 2010; Masson-Delmotte et al., 2013). While some studies have focused entirely on the use of tree rings (Esper et al., 2002; D'Arrigo et al., 2006; Frank et al., 2007a; Wilson et al., 2007; Schneider et al., 2015; Stoffel et al., 2015), most have also included different types of proxy archives and are thus considered multi-proxy reconstructions (Jones et al., 1998; Mann et al., 1999, 2009; Moberg et al., 2005; Hegerl et al., 2007; Wahl and Ammann, 2007; Ljungqvist, 2010). The majority of these reconstructions have generated a single hemispheric wide mean temperature composite, although a few noteworthy spatial field reconstructions have been produced (Briffa et al., 2002b; Mann et al., 1998, 2009; Ljungqvist et al., 2012; Tingley and Huybers, 2013). Such analyses are crucial not only to place recent warming in a longer term spatiotemporal context, but also allow, through comparative analysis with global climate models, improved understanding of the high-to-low frequency forcing mechanisms of long-term and recent climate changes using formal detection and attribution (Hegerl et al., 2006; Schurer et al., 2014).

Fig. 5.7 in the most recent IPCC Working Group 1 report (Section 5.3.5; Masson-Delmotte et al., 2013) synthesises the majority of the published Common Era reconstructions for the Northern Hemisphere (NH). Focussing on the last millennium, the NH ensemble indicates warm conditions around the end of the 10th century, a cooling trend over the subsequent 500 years, a prolonged cool period from ~1450 to 1850 (often referred to as the Little Ice Age) and steep warming from the middle of the 19th century to present. Although the basic centennial "shape" of these NH reconstructions is in general agreement, there are notable differences in the timing and amplitude of some cold and warm periods (e.g. Esper et al., 2004). This uncertainty hampers detection and attribution studies and makes it difficult to constrain modelled scenarios of future temperature change (Edwards et al., 2007).

We hypothesise that these differences partly reflect the use of multi-proxy data in the current ensemble of NH reconstructions and the quality of many constituent proxy series. Although the multi-proxy approach may appear ideal - incorporating and subsuming the independent advantages and disadvantages of the various proxy types - in practice the biases inherent to each proxy archive potentially compound the uncertainty in the final large-scale composites, which are further exacerbated by the influence of the varying statistical methods used to combine the proxy records (Smerdon et al., 2011). For example, many of the proxies utilized in Common Era reconstructions actually reflect varying seasonal signals (e.g. summer vs. annual) and some do not even represent local temperature well (Mann et al., 1998, 2009). Combining such heterogeneous data may produce a network possessing a reasonable correlation with an annual instrumental target, but that also contains spatio-temporal proxy biases that add to the uncertainty in the final reconstruction. Furthermore, non-annual proxies, lacking precise annual resolution and dating, must be smoothed to decade or longer time-scales reducing (1) the ability of these data to accurately record short-term climatic response to large volcanic events, and (2) the degrees of freedom — which places limitations on the ability to perform robust calibration and validation analyses to assess reconstruction fidelity, stability and skill.

In this paper (and its part II companion, Anchukaitis et al. *in prep*), we focus entirely on temperature-sensitive tree-ring (TR) records to both reduce and better characterize many of the uncertainties detailed above. Tree-ring archives are annually resolved (facilitating robust validation), precisely dated (Stokes and Smiley, 1968) and the interpretation of their measurements is supported by a wealth of ecological and biological process-based knowledge of how climate variability influences ring formation (Fritts, 1976; Korner, 2003; Vaganov et al., 2006; Deslauriers et al., 2007; Vaganov et al., 2011; Rossi et al., 2012, 2013, 2014; Palacio et al., 2014). Temperature-sensitive TR archives are derived from many high elevation/latitude environments where growth is predominantly limited by summer temperatures, permitting the development of a well replicated, annually resolved network of summer temperature proxies for the mid/high latitudes of the Northern Hemisphere (Briffa et al., 2001). Furthermore, as the summer season is most sensitive to short term volcanically forced cooling, a tree-ring only reconstruction increases the potential for more robust assessment of volcanic forcing in attribution studies in comparison to large-scale mixed season multi-proxy composites (Schneider et al., 2015; Stoffel et al., 2015).

Herein, we introduce a new and substantially updated network of temperature-sensitive tree-ring records for the mid-to-high latitudes of the Northern Hemisphere. These data are used to reconstruct both a single mean hemispheric series (Part I) as well as explicit spatial temperature fields (Part II, Anchukaitis et al. *in prep*) for the last millennium. Careful comparison is made between the new reconstruction and two previous TR based NH index reconstructions; D'Arrigo et al. (2006 — hereafter DWJ06 — a predominantly ring-width (RW) based composite) and Schneider et al. (2015 — hereafter SCH2015 — a maximum latewood density (MXD) based composite) to explore the strengths and limitations of RW and MXD. This work is the product of a tree-ring community consortium called N-TREND (**N**orthern Hemisphere **Tre**e-Ring **N**etwork **D**evelopment). The aim of N-TREND is to bring together dendroclimatologists to identify a collective strategy for improving large-scale summer temperature reconstructions from new and existing tree-ring archives. These two papers, the first product of the N-TREND consortium, aim to not only improve our knowledge of Northern Hemisphere temperature changes, but to also emphasise the strengths and limitations of TR archives and guide future dendroclimatic research.

2. Tree-ring data

Many thousands of tree-ring site chronologies are archived within the International Tree-Ring Data Bank but the majority are either relatively short (<200-years in length), have not been updated to the recent post-2000 period and/or do not reflect summer temperatures (St. George, 2014; St George and Ault, 2014). For N-TREND, rather than statistically screening all extant TR chronologies for a significant local temperature signal, we utilise mostly published TR temperature reconstructions (or chronologies used in published reconstructions) that start prior to 1750. This strategy explicitly incorporates the expert judgement the original authors used to derive the most robust reconstruction possible from the available data at that particular location. The data-set used herein is defined as version number N-TREND2015, recognizing the fact that as new local/regional tree-ring temperature reconstructions are developed, the N-TREND database will expand and be further refined. N-TREND2015 includes 54 TR records located between 40 °N and 75 °N (Table 1 and Fig. 1). TR data south of 40 °N are not included as trees tend to exhibit an increasingly complex sensitivity to multiple climate influences including precipitation (Fritts, 1976; St. George, 2014; St George and Ault, 2014)