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The climate of North America during the past 2000 years reconstructed from pollen data

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ABSTRACT

The temperature of the warmest month was reconstructed for the past 2000 years using 748 pollen sites from the North American Pollen Database. The Modern Analog Technique was used to quantify paleoclimate conditions using a modern pollen database with calibration sites from across North America. Across North America, both the Medieval Warm Period (MWP) and Little Ice Age (LIA) were cooler than the present (AD 1961–1990). The MWP was warmer than the LIA over at least the boreal and eastern portions of the continent and perhaps across the continent. These reconstructed anomalies during the MWP and LIA are significant anomalies from the long-term neoglacial cooling. The atmospheric circulation was likely dominated by a poleward shift of the summer Subtropical High Pressure system in the North Atlantic during the MWP.
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1. Introduction

The last 2000 years of our climate history has been the focus of much research effort (e.g. Lamb, 1965; Stine, 1994; Mann et al., 1998; Crowley, 2000; Crowley and Lowery, 2000; Bradley et al., 2003; Mann et al., 2008, 2009a). Much of the recent discussion is centered on the period between ~800 and 1200 AD that has been called the Medieval Warm Period (MWP) or Medieval Climate Anomaly (MCA) (Lamb, 1965; IPCC, 2007; Mann et al., 2009b; McIntyre and McKitrick, 2009). Although the subsequent period, the Little Ice Age (LIA, 1450–1850 AD), is generally considered a global phenomenon, the geographical extent of warmer conditions prevailing during Medieval times has not been clearly established (Hughes and Diaz, 1994; Bradley et al., 2003; IPCC, 2007).

Several studies have attempted to provide large-scale syntheses of Earth's climate history by computing time series or showing maps of average summer temperatures on global or hemispheric scales for the past 2000 years (e.g. Mann et al., 1998; Esper et al., 2002; Moberg et al., 2005; Mann et al., 2008, 2009a). These reconstructions have been based primarily on tree-rings, as there are many series available from around the northern hemisphere and world, and these have been shown to be reliable paleoenvironmental indicators (Fritts, 1991). Tree-rings provide precisely-dated records with annual or seasonal resolution that have provided climate records on interannual to multi-decadal scales for the past 600 years, but there is less confidence in the reconstructions during Medieval times, as there are fewer available series extending back to this time period (IPCC, 2007; Jones et al., 2009). This limitation has created a need to look toward other sources of data for information about the climate during this time.

Annually-resolved reconstructions based on ice cores, corals, and speleothems, as well as lower-resolution borehole records have been included in these large-scale temperature syntheses but have added limited geographical coverage to an already partial picture of changes in climate during the first millennium AD (IPCC, 2007). Although there have been significant advances in improving the methodology of combining tree-ring records with other high-resolution records, it remains a problem when attempting to reconstruct back further in time where the network of sites becomes extremely sparse and inadequate for firm conclusions about the climate during the MWP. Some attempts have been made to include lower-frequency climate variability by incorporating records such as pollen-based reconstructions from lakes with varved sediments, and these have proven quite useful in reconstructing longer-term variations on the order of century to multi-century scales (e.g. Moberg et al., 2005). Ljungqvist (2009) used a more elaborate averaging technique with several multi-proxy high-resolution temperature reconstructions, but this attempt included reconstructions of different seasons, potentially masking the amplitude of change. What is needed to better understand the climate of the past 2000 years, especially during Medieval times, is to increase the spatial coverage of past observations in order to understand the patterns of

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change at regional scales (IPCC, 2007). These regional reconstructions can provide physically-based climate models with a benchmark dataset to test mechanisms responsible for the variability in the climate of the past 2000 years, as well as to confirm global scale reconstructions.

In this paper, we reconstruct summer temperatures of the past 2000 years using a dataset consisting of moderate-resolution pollen records from lake sediments from across North America. This reconstruction provides a quantitative evaluation of the regional extent of the MWP and LIA across the continent. We use the North American Pollen Database (NAPD) (Grimm et al., 2007; Gajewski, 2008; Grimm, 2011), which is the most spatially extensive terrestrial data archive that spans the entire last 2000 years and beyond. These data have been extensively used to reconstruct past environmental conditions of the past 21,000 years (Wright et al., 1993; Bartlein et al., 2010, and references therein). Many of the climate reconstructions using pollen records have focussed on target periods such as 6000 and 21,000 years BP, and have proven useful in validating climate model simulations at hemispheric to global scales (e.g. COHMAP, 1988; Wright et al., 1993; Sawada et al., 2004; Williams et al., 2007; Bartlein et al., 2010).

The use of these pollen records in high-resolution paleoclimate reconstructions has been underexploited but we argue that pollen records can provide high-resolution climate series of the past 2 ka (Gajewski, 1983, 1987, 1993, 2006; Viau et al., 2006; Gajewski et al., 2007; Gajewski and Viau, 2011). Analysis of several years of pollen monitoring in Europe has shown that, whereas the overall pollen composition is a function of the vegetation type on the surrounding landscape, changes in pollen production (the influx of pollen to the deposition site) are affected by weather at a daily to seasonal scale (e.g., Hicks, 2001; Autio and Hicks, 2004; Barnekow et al., 2007; Huusko and Hicks, 2009). Results going back to the 1980s have clearly shown that pollen records can be used to reconstruct climatic variations during the LIA and MWP (Gajewski, 1987, 1988, 1993; Gajewski et al., 2007). Numerous studies have shown a rapid response of terrestrial ecosystems to climate variations, with little or no time lag, during the late- and postglacial period (Webb, 1986; Gajewski, 1987; Grimm and Jacobson, 1991; Grimm et al., 1993; Viau et al., 2002; Williams, 2002; Viau et al., 2006; Peros et al., 2008) when the sediment cores were samples at high enough resolution (Gajewski, 1993). Viau et al. (2008) and Viau and Gajewski (2009) have presented regional time series of temperature and precipitation from the boreal zone of Canada and Alaska that quantified the temperature and precipitation anomalies of the LIA and MWP.

Pollen records have been collected from around the world, and these are accessible in public databases (Grimm et al., 2007; Gajewski, 2008). Thus, although pollen-based paleoclimate reconstructions do not presently have the resolution of tree-rings, for example, they nevertheless can provide important insight into the magnitude and spatial distribution of multi-decadal to century-scale climate variations such as the MWP.

2. Methods

2.1. Data

We use the North American Pollen Database (NAPD) (Grimm, 2011) which is an archive of 748 pollen records distributed unevenly across North America (Fig. 1B). At each site a pollen diagram was prepared, where the pollen was extracted from a series of levels in the core. The sediments were dated using radiocarbon; a smaller number of samples are dated per sequence due to cost and sediment needed (Grimm et al., 2007; Gajewski, 2008). For calibration, we had available 4833 modern pollen samples broadly distributed across North America (Fig. 1A). Modern calibration data are available from all of the major vegetation zones and from ~75% of the "climate space" of North America (Whitmore et al., 2005).

The spatial distribution of the fossil sites is uneven across North America although the Boreal, Conifer/Harwood, and Deciduous biomes are particularly well represented (Fig. 1B). The temporal resolution varies from record to record but in total includes ~8200 pollen samples and ~320 ^{14}C dates for the period in question. These data are sufficient to evaluate persistent century to multi-century scale changes in climate (Viau et al., 2006). All radiocarbon dates were calibrated to calendar years BP using INTCAL04 (Reimer et al., 2004).

The uppermost sediments of lakes are less compacted, and if we assume a linear interpolation from the uppermost radiocarbon date

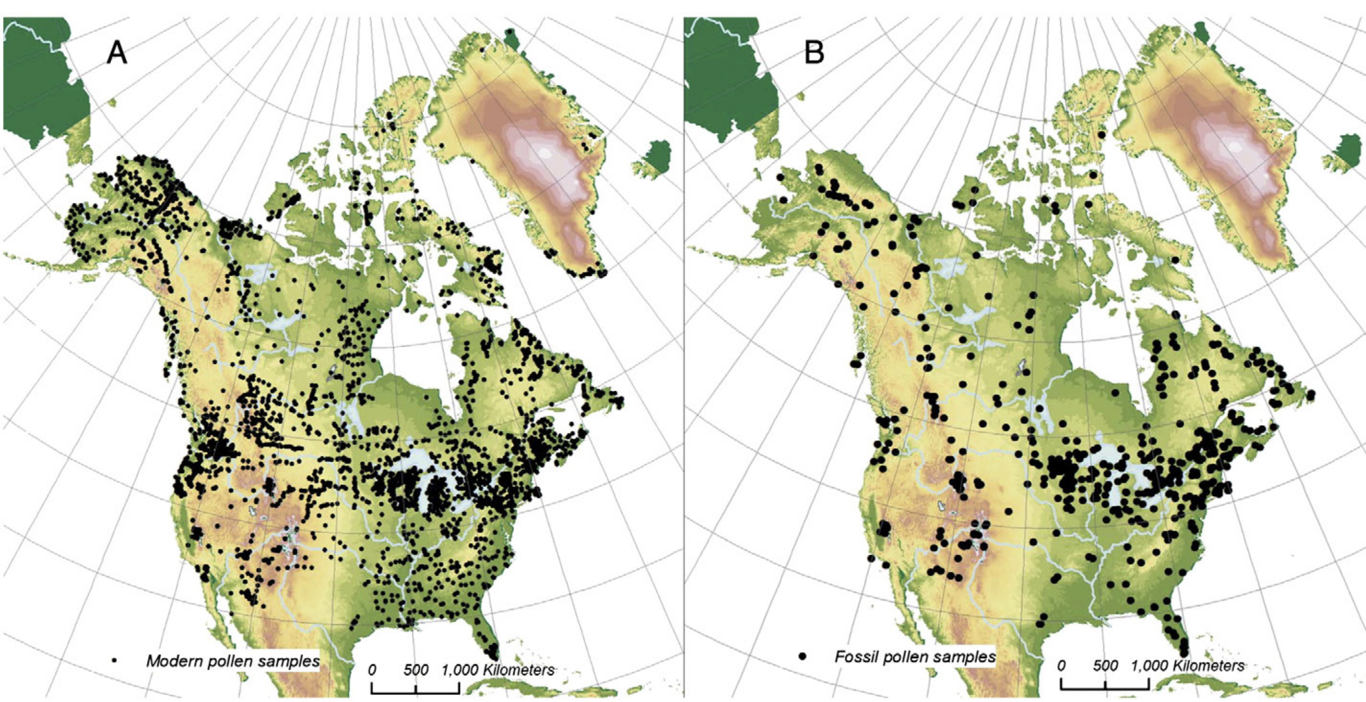

Fig. 1. Location of samples used in this study. (A) Modern pollen sites (Whitmore et al., 2005). (B) Fossil pollen sites (Grimm, 2011).

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