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A pollen-based reconstruction of summer temperature in central North America and implications for circulation patterns during medieval times

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ABSTRACT

We present a reconstruction of mean summer temperature for the northern Midwest of the USA based on lacustrine pollen records from three different lakes in Wisconsin. The results suggest a relatively warm period during the earlier part of the record (~1200–1500 CE) followed by a cooler Little Ice Age (~1500–1900) and a subsequent warming to modern conditions. The reconstructed modern summer mean temperature is in good agreement with observations, and the decades of the 1930s to 1950s appear to be the warmest such period in the proxy record (through 1974).

Analyses of circulation features associated with the warmest summers in the recent climate record suggest a prevalence of continental ridging accompanied by generally dry conditions during these warm summers in the Midwest. Drought reconstruction using the Palmer Drought Severity Index (PDSI) and tree-ring records as predictors also yield relatively dry conditions in medieval times for the central US. As reported in a number of recent studies, possible forcing mechanisms include La Niña-like conditions in the equatorial Pacific and warmer than average waters in the tropical Indo-western Pacific Ocean possibly coupled to a positive mode of the AMO/NAO North Atlantic circulation pattern.

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1. Introduction

Many aspects of the climate prevailing during the so-called Medieval Climate Anomaly (MCA) in the western United States have been well documented (e.g., La Marche, 1974; Hughes and Brown, 1992; Graumlich, 1993; Dean, 1994; Stine, 1994; Cook et al., 2004; Salzer and Kipfmueller, 2005; Graham and Hughes, 2007), while a number of modeling studies have endeavored to provide possible mechanistic explanations for the occurrence of reconstructed climate patterns during this time (Graham et al., 2007, 2010; Seager et al., 2007). Comparatively fewer paleoclimatic studies focused on the eastern United States have been published for the nominal period of the MCA (~900–1400 CE). Some representative studies covering this period include *inter alia* Booth et al. (2006), Stahle et al. (2007), and Shuman et al. (2009). Studies focused on the western prairies and Great Plains region to the west of our study area have inferred periods of aridity with sand dune mobilization and contraction of lakes for portions of the MCA (Laird et al., 2003; Mason et al., 2004).

Recently, a number of modeling studies that have incorporated the latest information on boundary conditions for parts of the last 500–1000 years (Graham et al., 2007, 2010; Seager et al., 2007) have demonstrated strong connectivity of multi-decadal hydrologic anomalies in North America to both the Indo-Pacific and Atlantic Oceans regions. Inferred circulation patterns from these studies suggest that the tropical Indo-Pacific was La Niña-like (i.e., with relatively cool waters in the eastern equatorial Pacific and warmer than normal waters in the western tropical Pacific and Indian Ocean) as well as a warm North Atlantic with strengthened subtropical high pressure.

Here we present a new approach to reconstructing summer (June–July–August, JJA) temperature in the northern Midwest of the USA for the last 1000 years using pollen records from three lakes in the state of Wisconsin. We also examine the possibility that circulation patterns associated with some recent extreme summers may be indicative of circulation patterns prevalent during the MCA and discuss their suitability as MCA circulation analogs.

2. Data and methods

Implementation of a new version of the pollen ratio method of temperature reconstruction (cf. Adam and West, 1983) is introduced. This new approach uses an optimized selection of pollen taxa in the binomial logistic form of the generalized linear model (GLM) to estimate a pollen-climate forward relationship based on modern pollen and associated climate data in temperate northeastern North America. [The methodology used is described in Wahl et al.(2010) and the included supplementary online material (SOM), and in Ohlwein and Wahl (accepted for publication); see also Whitmore et al.(2005) for the modern pollen data and associated bio-climatic information.] The

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GLM model was estimated using both classical and Bayesian inference methods in the R language (R Foundation for Statistical Computing). This forward relationship was then inverted to yield expected value (EV) reconstructions of summer temperature, based on fossil pollen assemblages. Explicit modeling of reconstruction uncertainty was done in the inverted form using a 2-way Monte Carlo framework, based on the

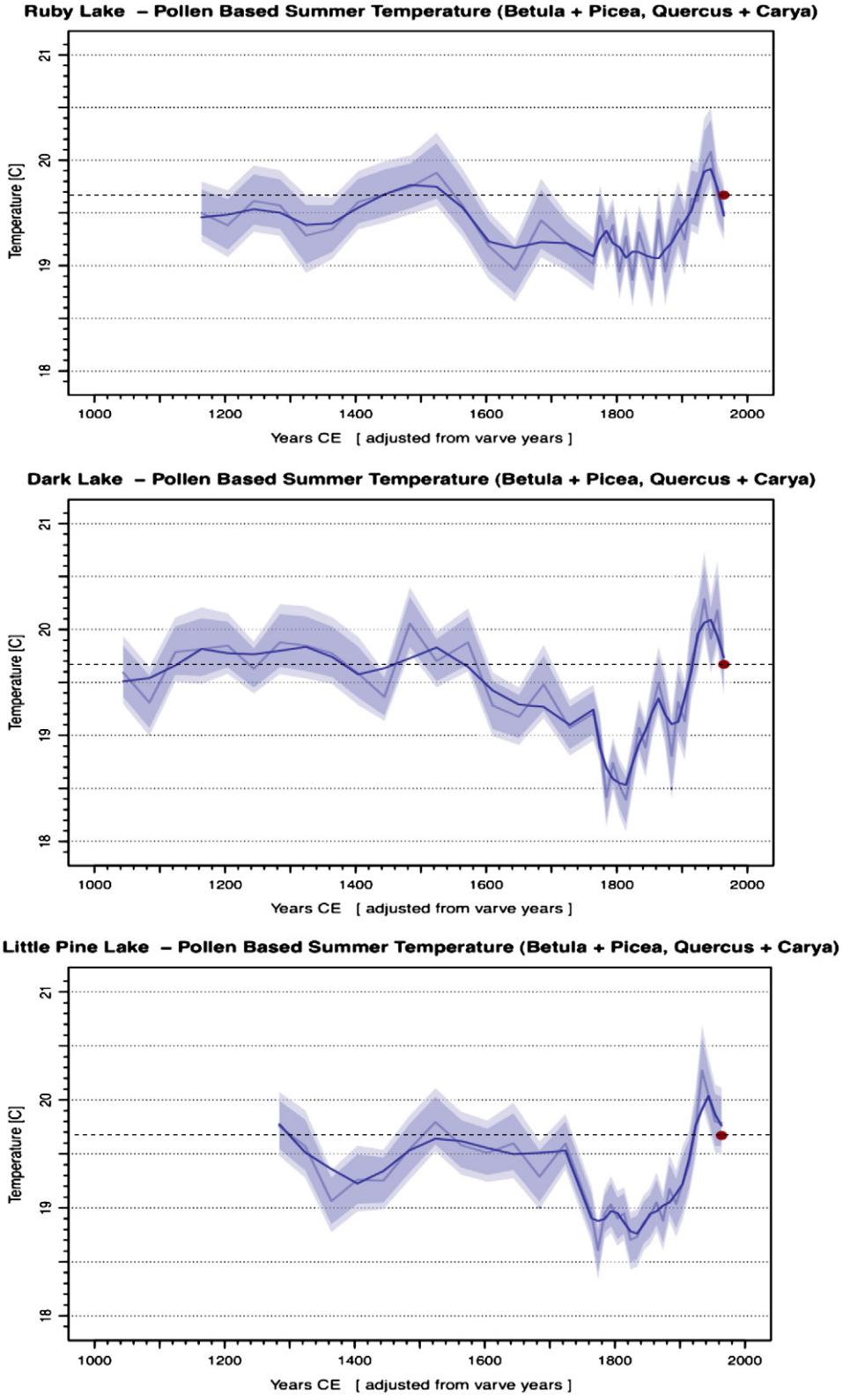

Fig. 1. Reconstruction of summer surface temperature in central North America over the past millennium (based on pollen preserved in varved sediments) at Ruby Lake, Dark Lake, and Pine Lake, WI, USA. Dark blue/light blue shading represent the 95/99% probability ranges of the reconstructions; the red dot and dashed line represent the modern long-term average (1961–1990) in the vicinity of the lakes; the smoothed line is a LOWESS fit of the ensemble median reconstruction. See appendix for details of reconstruction methods; results from the Bayesian version of the statistical model are shown.