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Deglacial hydroclimate of midcontinental North America

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ABSTRACT

During the last deglaciation temperatures over midcontinental North America warmed dramatically through the Bølling-Allerød, underwent a cool period associated with the Younger-Dryas and then reverted to warmer, near modern temperatures during the early Holocene. However, paleo proxy records of the hydroclimate of this period have presented divergent evidence. We reconstruct summer relative humidity (RH) across the last deglacial period using a mechanistic model of cellulose and leaf water $\delta^{18}O$ and δD combined with a pollen-based temperature proxy to interpret stable isotopes of sub-fossil wood. Midcontinental RH was similar to modern conditions during the Last Glacial Maximum, progressively increased during the Bølling-Allerød, peaked during the Younger-Dryas, and declined sharply during the early Holocene. This RH record suggests deglacial summers were cooler and characterized by greater advection of moisture-laden air-masses from the Gulf of Mexico and subsequent entrainment over the mid-continent by a high-pressure system over the Laurentide ice sheet. These patterns help explain the formation of dark-colored cumulic horizons in many Great Plains paleosol sequences and the development of no-analog vegetation types common to the Midwest during the last deglacial period. Likewise, reduced early Holocene RH and precipitation correspond with a diminished glacial high-pressure system during the latter stages of ice-sheet collapse.

Introduction

During the transition from the Last Glacial Maximum to the early Holocene, the Laurentide ice sheet retreated northward by up to 1200 km in midcontinental and eastern North America, causing drastic changes to ocean circulation in the North Atlantic through meltwater additions. These deglacial events had both direct and indirect effects across North America as climates and associated vegetation types underwent a dynamic period of reorganization (Gill et al., 2009; Grimm and Jacobson, 2004; Shane and Anderson, 1993; Shuman et al., 2002a; Williams et al., 2004; Yu and Wright, 2001). Many lines of evidence from the midcontinent indicate the last deglacial period was characterized by temperatures increasing from 3 to 10°C or more depending on the location and seasonal resolution and paleo proxy employed (Gonzales et al., 2009; Grimley et al., 2009; Nordt et al., 2008; Shane and Anderson, 1993; Shuman et al., 2009; Viau et al., 2006; Voelker et al., 2012; Webb and Bryson, 1972; Yu and Eicher, 1998). In contrast, the deglacial hydroclimate is poorly understood. For example, geomorphic evidence and records from buried soils during the Younger-Dryas (YD) have been interpreted to suggest the midcontinent was drier for at least portions of the deglacial period (Campbell et al., 2011; Cordova et al., 2011; Dorale et al., 2010; Haynes, 1991; Holliday, 2000; Wang et al., 2012), while other evidence, based largely on inferences from pollen, has been interpreted to suggest this period was characterized by relatively greater moisture availability (Buhay et al., 2012; Curry and Filippelli, 2010; Curry et al., 2013; Gonzales and Grimm, 2009; Gonzales et al., 2009; Grimm and Jacobson, 2004; Haynes, 2008; Mullins, 1998; Shuman et al., 2009; Webb and Bryson, 1972).

Over much of the midcontinent and the eastern United States, many late Quaternary records indicate the deglacial period was characterized by communities of plants and animals with no modern analogs. In the Midwest and eastern United States modern forest associates often include *Picea*/*Alnus*/*Betula* or *Fagus*/*Tsuga* and *Pinus* is abundant. During the deglacial *Pinus* was not as abundant while *Ostrya*/*Carpinus*

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communities were widespread and *Picea*/*Fraxinus* communities were common although these species are generally allopatric under modern climatic conditions (Williams et al., 2004). There are many possible reasons for these unique combinations of plants, including individualistic species responses to relatively low atmospheric [CO_2], increased temperature seasonality, changes in ecosystem water balance and ecological effects following the demise of the Pleistocene mega-fauna (Gill et al., 2009, 2012; Shane and Anderson, 1993; Williams and Jackson, 2007). Although quantitative reconstructions of variables relevant for the deglacial hydroclimate may be poorly constrained due to no analog conditions, there are many qualitative signs pointing to increases in effective moisture. These include the prevalence of plant taxa that thrive in poorly drained or seasonally flooded environments, increases in fire-intolerant tree species and increases in species dependent on large, intense disturbances such as fires (Amundson and Wright, 1979; Curry et al., 2007; Gill et al., 2012; Gonzales and Grimm, 2009; Grimm and Jacobson, 2004; Williams et al., 2004). Due to prevalent no-analog conditions across the midcontinent during the deglacial period, other independent sources of data need to be developed to better characterize the hydroclimate.

In this paper, we use available data to provide new insight on the hydroclimate of midcontinental North America by employing a regional, multi-proxy approach. For our purposes we define the midcontinent of North America as the region encompassing the transition between the modern distributions of short grass prairies of the Great Plains and the Eastern Deciduous forest. Not all of the data we use or review here fall directly within this zone because long and well-dated sediment records that are sensitive to hydroclimate are relatively rare and sub-fossil wood has seen few systematic collections. Therefore, we also include some data that are located downwind of the dominant meridional and/or zonal flows of moisture from this region. We reconstruct relative humidity (RH) using mechanistic models to interpret patterns of ^{18}O and ^{2}H in wood cellulose from log cross-sections ^{14}C-dated to the last glacial and deglacial period in conjunction with a high-resolution pollen record of temperatures from this region. Although this approach cannot be used to discern higher-resolution, centennial-scale variation, uncertainties in other paleo records in regard to dating as well as ecological and physiological filters that influence many paleo records should be minimized. As a result we provide new insights on first-order variation in RH and hydroclimate for the Last Glacial Maximum, late deglacial and early Holocene.

Methods and materials

Data from wood samples considered here were collected at sites across midcontinental North America, with most collected in northern Missouri, USA (Fig. 1, Table S1). For Missouri samples, a chainsaw was used to cut cross-sections from sub-fossil oak logs recovered from stream channels and banks (Guyette et al., 2008; Stambaugh et al., 2011; Voelker et al., 2012). Stream channels and banks in northern Missouri are composed of alluvial sediments and conducive to the frequent burial and excavation of wood (Guyette et al., 2008). Sub-fossil oaks were distinguished from other taxa by their ring-porous vessel arrangement, the extensive radial cracks that form along their thick ray parenchyma, and the gray to black color of the heartwood, which occurs after hundreds of years of burial. Based on the current distribution of habitats along these streams most of these oaks are probably bur oak (*Quercus macrocarpa* Michx.), but swamp white oak (*Quercus bicolor* Willd.)

Figure 1. Locations of data collection sites for data used in RH and paleotemperature reconstructions. For sub-fossil wood collections, each symbol type gives the collector and/or curator of the wood and the symbol sizes were scaled to the number of sample trees collected at a site (see Table S1 for details). Crosses mark the locations of sediment/pollen collection sites used for the paleoclimate reconstructions at Crystal Lake (Gonzales et al., 2009), and Brewster Creek (Curry et al., 2007) sites in northeast Illinois as well as Blood Pond (Marsicek et al., 2013) in Massachusetts and Sutherland Pond (J. Marsicek, unpublished data) in New York.