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Climate response of the Florida Peninsula to Heinrich events in the North Atlantic

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ABSTRACT

Hydrogen and carbon isotope values (δD & $\delta^{13}C$) were measured on lipid biomarkers from a sediment core collected in Lake Tulane, Florida, USA, to infer shifts in climate and hydrologic variables during the Last Glacial. Isotopic trends from 24 samples correlate with plant community shifts evaluated in a previous pollen study by Grimm et al. (2006). We observe maxima in Δ_{leaf} values and minima in δD values concurrent with peaks in *Pinus* pollen abundances and Heinrich Events 4-2. Increased Δ_{leaf} values during North Atlantic cold spells indicate lower water-use-efficiency among angiosperms around Lake Tulane. Combined δD values from terrestrial and aquatic lipids, confirm that aridity decreased during cold, stadial periods (Heinrich Events), and increased during warm, interstadials. Furthermore, lower δD values in aquatic lipids during stadials are attributed to warming, as well as changing moisture sources. The anti-phase relationship between temperatures and aridity derived from our subtropical lacustrine record and those at high latitude in the North Atlantic is likely the result of complex ocean-atmosphere teleconnections that resulted from the collapse of Atlantic Meridional Overturning Circulation during Heinrich Events in the North Atlantic.

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1. Introduction

Lake Tulane is a relatively small (~36 ha), deep (z_{max} ~25 m) solution lake located in south-central Florida, USA (Fig. 1). Its depth and location on a structural high, the Lake Wales Ridge, enabled continuous sediment accumulation since before the last glacial maximum. Palynological analysis of a sediment core from Lake Tulane indicated major shifts in plant communities over the past 60,000 years (Grimm et al., 1993). Of particular note are six peaks in *Pinus* (pine) pollen relative abundance, which coincide with the most intense cold phases of high-latitude Dansgaard–Oeschger (D-O) cycles and the Heinrich Events (HE) that terminated them. Alternating with *Pinus* peaks are zones with high relative percentages of *Quercus* (oak), *Ambrosia* (ragweed), *Lyonia* (staggerbush) and *Ceratiola* (rosemary) pollen, genera that today occupy the most xeric sites on the Florida landscape (Grimm et al., 2006). Additionally, the *Quercus* zones are replete with seeds from emergent aquatic plants, whereas all but one of the *Pinus* zones is devoid of macrofossils. Lack of emergent macrofossils in *Pinus* phases suggests that the lake was too deep to support emergent aquatic vegetation close to the core site. Based on the quantitative similarity of the Pleistocene *Pinus* zones with modern/Holocene Florida vegetation, the *Pinus* peaks, and therefore the HE, were interpreted as warm and wet periods in Florida, whereas the *Quercus* zones were inferred to have been drier, and likely colder than the *Pinus* zones.

The assertion that the *Pinus* phases, and HE, represent warm and wet periods in the subtropics is contentious. HE are recorded in the sediment record of the North Atlantic as layers of ice-rafted debris, lithic fragments from rocks of continental origin, which were derived from the calving and melting of large continental ice sheets (Bond et al., 1993). During Earth's last glacial interval, these episodic iceberg discharges perturbed global heat transport via reduction in the Atlantic meridional overturning circulation (AMOC) (Lynch-Stieglitz et al., 2014). Although the mechanism responsible for

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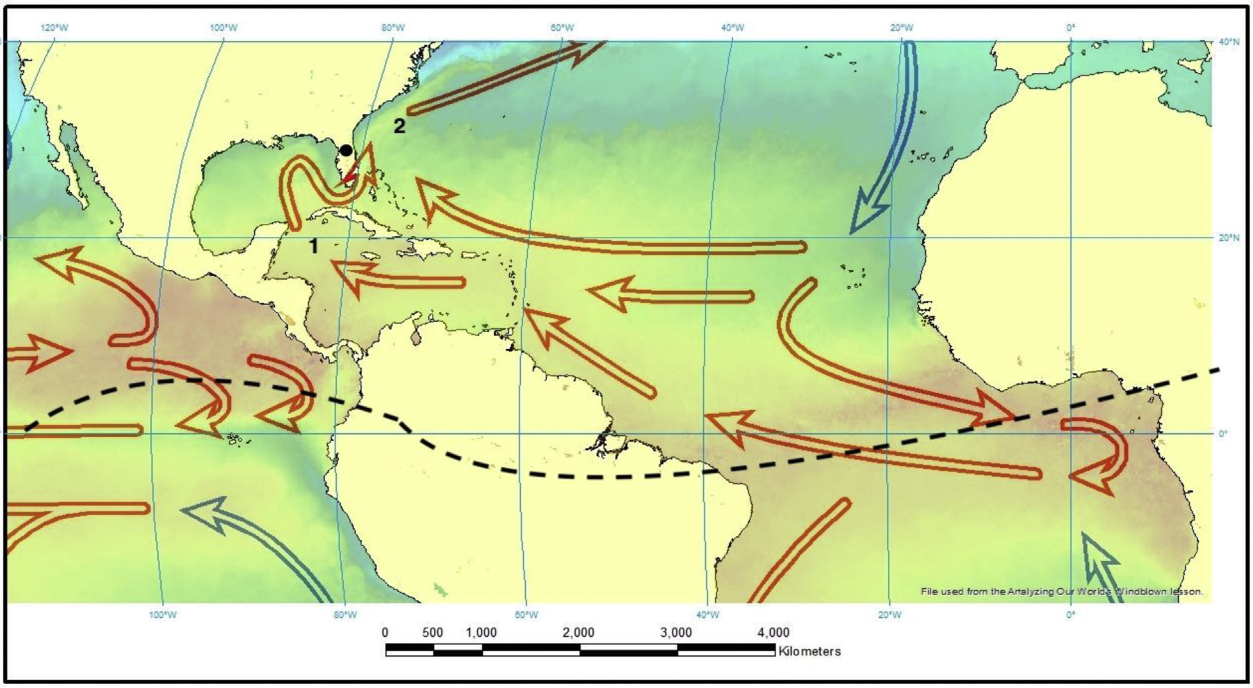

Fig. 1. Sea-surface temperatures and major surface ocean currents (warmer surface water in red, cooler surface water in blue). Location of Lake Tulane (black dot), the Loop Current (1), Gulf Stream (2), and the approximate location of the Inter-Tropical Convergence Zone (dashed line) during the boreal winter. The Atlantic Warm pool is the area of high temperatures (red colors) in and around the Gulf of Mexico and the Caribbean. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

these events is still debated (Hemming, 2004; Marcott et al., 2011), teleconnections between HE and rapid climate oscillations have been recorded globally (Broecker, 2006). Their occurrence at the end of progressively cooler Greenland D-O interstadial cycles has led to the conclusion that HE were synchronous with lower temperatures and increased aridity over large regions of the Northern Hemisphere (Broecker et al., 1992; Zhao et al., 2003; Zhou et al., 2008). This hypothesis is supported by numerous lines of evidence, including Iberian Margin sea-surface-temperature (SST) reconstructions derived from Mg/Ca ratios (Patton et al., 2011) and alkenone $U_{37}^{K'}$ records (Pailler and Bard, 2002), the relative abundance of the polar planktonic foraminiferan *Neogloboquadrina pachyderma* (sinistral) in the western Mediterranean (Cacho et al., 1999), and $\delta^{18}O$ records from marine sediment cores in the Icelandic and Irminger Seas (Kreveld et al., 2000).

Although these studies indicated an in-phase relationship between SST and climate conditions in Greenland, there appears to be an anti-phase tendency in numerous other climate reconstructions, in particular, those from low to middle latitudes in the Atlantic (Hemming, 2004). Alkenone-based temperature reconstructions from the southernmost portions of the ice-rafted debris belt (40–55°) indicate that surface waters were 2–4 °C warmer during all six Heinrich Events (Naafs et al., 2013). Farther south in the western Atlantic, temperatures approached modern values during HE1 (Weldeab et al., 2006; Carlson et al., 2008) and HE5a (Schmidt et al., 2006), implying warm surface waters prior to transitions into interstadials. These results are in line with late-glacial circulation models, which produce warmer and more saline waters in middle latitudes of the western Atlantic when AMOC strength is at its minimum, prior to the onset of HE farther north (Renold et al., 2010).

Reduced northward transport of heat just before and during HE could be the source of the subtropical warming, hypothesized by Grimm et al. (2006) to be a prerequisite for *Pinus* proliferation. This idea was corroborated by coupled climate model simulations (Weaver et al., 2003) and pollen-climate inference models specific to Florida (Donders et al., 2011). Results from these modeling experiments demonstrate that a decrease in SST in the North Atlantic would increase the meridional temperature gradient, strengthen the trade winds and expand the Atlantic Warm Pool, resulting in more precipitation across the Florida Peninsula during HE (Donders et al., 2011).

Despite the results of modeling experiments, there are few empirical terrestrial records that document changes in temperature and precipitation across stadial/interstadial boundaries. In fact, the palynological studies from subtropical Lake Tulane represent the primary archive for terrestrial changes associated with HE in North America (Grimm et al., 1993, 2006). Shortcomings of pollen reconstructions, however, which include inter-species differences in pollen production, dispersal, and preservation, make sedimentary pollen records potentially equivocal with respect to their ability to provide an accurate characterization of regional plant communities (Bennet and Willis, 2002). Furthermore, pollen of different species within the genera *Pinus* and *Quercus* cannot be distinguished. Today, taxa within each genus occupy different habitats across Florida's effective moisture gradient, and this complicates assignment of plant genera to wet or dry environments. Given the lack of terrestrial records associated with HE, and potential problems associated with palynological reconstructions, additional lines of evidence are needed to test hypotheses regarding climate changes at low latitudes during HE.

1.1. Carbon isotopes and precipitation

Carbon isotope ratios ($\delta^{13}C$) of plant leaf waxes (*n*-alkanes) in lake sediment cores have been used to infer shifts in precipitation and aridity over geologic timescales (e.g., Magill et al., 2013). Variations in the carbon isotopic composition of leaf waxes, are caused