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Short communication

A temperature reversal within the rapid Younger Dryas-Holocene warming in the North Atlantic?

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A B S T R A C T

The onset of the Holocene has been generally considered rapid and uninterrupted in the circum-Atlantic region. Loss-on-ignition (LOI – an index of organic carbon) profiles from 18 lateglacial-aged lakes in Nova Scotia, Canada, together with chironomid-inferred temperature reconstructions at 5 sites, demonstrate that the rapid warming from the Younger Dryas (GS-1) to the Holocene was interrupted by a cooling of 1.6–6.4 °C in summer surface lake water temperature. The resulting inflection or reversal on the rising temperature curve has also been identified at 35 sites outside Nova Scotia from terrestrial and marine settings, indicating that this cool step is a robust feature throughout the North Atlantic and is likely the result of major oceanic and atmospheric reorganization of the Holocene climate system.

1. Introduction

The Younger Dryas to Holocene (YD-Holocene) transition is the latest and largest of a number of warming steps that ended the last Ice Age ~11,650 years ago leading into our current interglacial (Dansgaard et al., 1993). This transition has been identified as an interval in need of greater study (Bakke et al., 2009). Warming in Greenland during the transition was rapid, 7 °C in less than 15 years (Taylor et al., 1997), and it has been used as an analogue to modern global warming. The YD-Holocene transition has been generally viewed as uninterrupted, (but see (Bakke et al., 2009)). However, we have produced new reconstructions of surface lake water temperatures using fossil midges and sediment organic content analyses from a dense network of sites located along the North Atlantic seaboard and found widespread evidence that the YD-Holocene transition was interrupted by a decadal-scale reversal in warming at ca. 11,550 years ago, which produced local cooling of 1.6–6.4 °C. This cooling is also apparent in records from throughout the North Atlantic, with some evidence for cooling in the eastern Pacific and Arabian Sea.

The YD-Holocene transition may also be an excellent starting point in a search for an analogue to the modern slowdown in surface warming in the North Atlantic. Recent cooling in North Atlantic sea surface temperatures (SST) has led to cool summers and severe winters in Eastern North America. Together with a 15-year plateau in global surface temperatures (NOAA, 2014; Trenberth et al., 2014), recent cool temperatures have cast doubt on global warming projections. But does this imply that the projections were wrong? Fyfe et al. (2016) suggest that the observations are sound, but a more complete understanding of the observation biases (Karl et al., 2015; Morice et al., 2012) and internal variability (Fyfe et al., 2016) of the climate system are necessary to improve model projections. For example, a recent analysis of ocean temperatures from the Argo Program (Roemmich et al., 2009) indicates that excess heat is currently being stored within deeper ocean waters, indicating that global temperatures are in fact rising as predicted (Chen and Tung, 2014) even while the surface temperatures remain cool.

At the surface, the slowdown is marked by increased melt water and subsequent surface freshening in the vicinity of the Greenland Ice Sheet, which has been identified as a possible trigger to slow the Atlantic Meridional Overturning Circulation (AMOC), which transports heat from the equator to the North Atlantic (Rahmstorf et al., 2015). Meanwhile, sea ice loss has weakened the stratospheric polar vortex bringing cold winter temperatures to the Northern Hemisphere (Kim et al., 2014). Changes in North Atlantic ocean

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circulation have been linked to previous climate events in earth history (Chen and Tung, 2014; Clark and Shakun, 2012; Kim et al., 2014; Liu and Milliman, 2004; Monnin et al., 2001). The reversal reconstructed in this study occurs under similar conditions and may prove to be analogous to the modern global warming slowdown.

2. Materials and methods

2.1. Field methods

We collected complete lateglacial records from cores extracted from the deepest part of 24 small (<10 ha) lakes without inflowing streams throughout Nova Scotia (Fig. 1) using a modified Livingstone piston corer (Wright, 1967). Lateglacial sediments in Nova Scotia possess distinct lithologies that permit detailed sampling of visually evident events such as the Killarney Oscillation (GI-1b), the YD and the transition from the YD to the Holocene (Mayle et al., 1993; Walker et al., 1997).

2.2. Laboratory methods

Loss-on-ignition (LOI) is an index of the organic content of sediments that can be influenced by many factors, such as temperature, lake productivity, vegetation on the local landscape, succession, soil formation, lake morphometry, bedrock composition and watershed characteristics. In lateglacial Nova Scotia, however, LOI appears to respond primarily to temperature changes and has been a reliable indicator of the Younger Dryas (Levesque et al., 1993; Mayle and Cwynar, 1995a; Mayle et al., 1993; Mott et al., 2009; Whitney et al., 2006).

Each core was analyzed for LOI (Heiri et al., 2001) at 0.5 or 1.0 cm contiguous increments from the base of the core into the early Holocene so that the entire YD was apparent in the plotted LOI curve. Based on the LOI curves, samples were selected for chironomid analysis and for macrofossils for radiocarbon dating (Table 1). Chironomid samples were prepared as outlined in Brooks et al. (2007) and Walker (1988) with a minimum count of 50 whole head capsules (Quinlan and Smol, 2001). Chironomid head capsules were identified using a variety of keys and a reference collection at the University of New Brunswick (Brooks, 2006; Walker, 1988; Wiederholm, 1983). Maximum surface water temperature estimates were calculated for each sample using the temperature transfer function of Walker et al. (1997).

The YD-Holocene transition was identified using the LOI and sediment lithology changes at all 24 sites. The YD is characterized by a shift from dark, silty, organic sediments to pale, clay-rich sediments, with sharp contacts between the two. The change in lithology is reflected in a dramatic decrease in LOI values at the onset of the YD and a concomitant increase at the end. The portion of the LOI curve that spans the YD-Holocene transition was inspected for evidence of a step or reversal. Sites that contained a reduction in LOI values spanning at least 3 data points (1.5 cm), within the YD-Holocene transition, were included in the study.

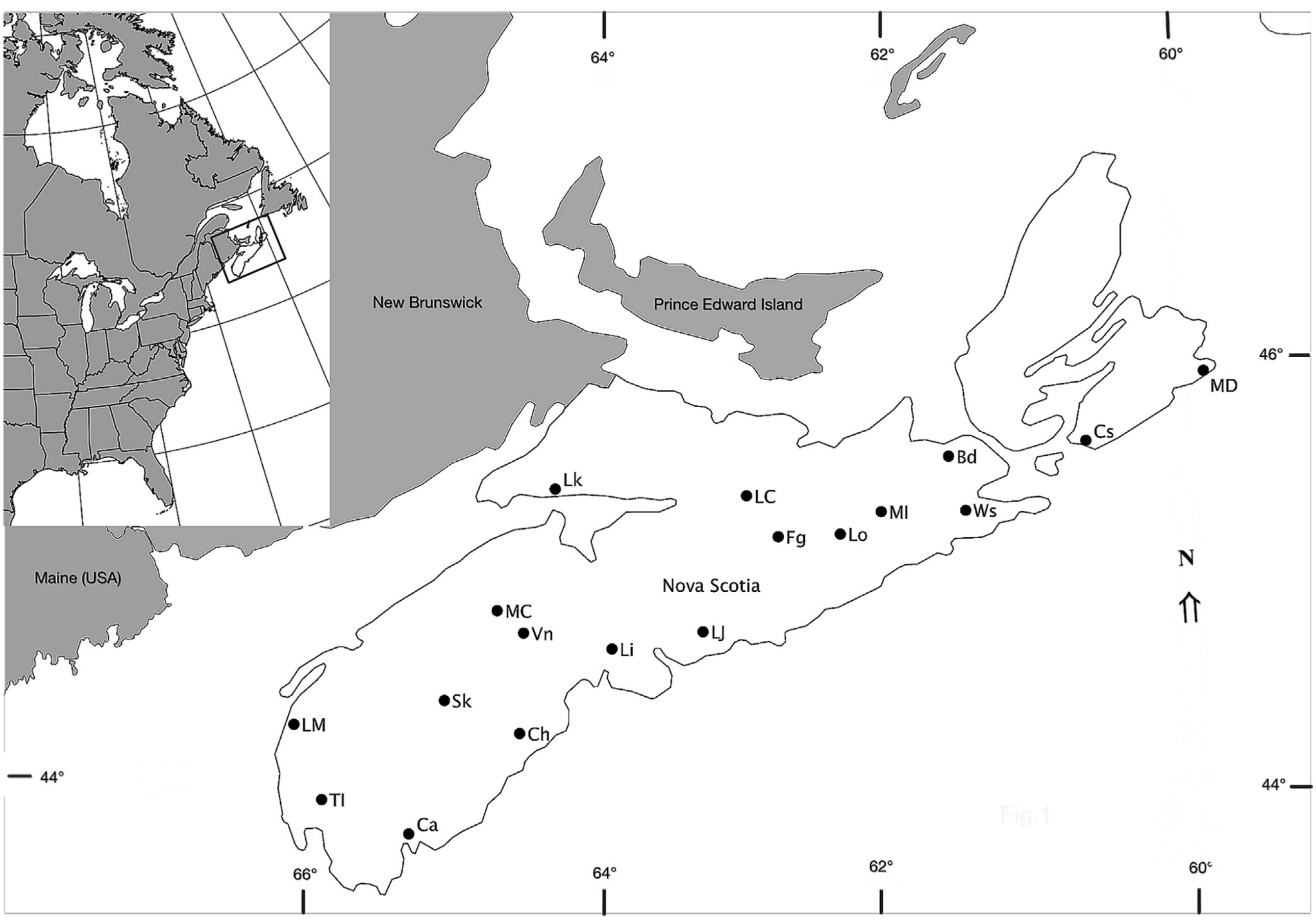

Fig. 1. Site map showing position of lakes included in this study. Site names: Lac à Magie (LM), Thin Ice Pond (TI), Campbell's Pond (Ca), Skating Bench Pond (Sk), China Lake (Ch), Midconnor Lake (MC), Veinot Lake (Vn), Little Lake (Li), Li'l Jess Pond (LJ), Leak Lake (Lk), Little Lake (Colchester County) (LC), Foghorn Pond (Fg), Long Lake (Lo), McInnis Lake (MI), Western Pond (Ws), Borden's Lake (Bd), Chase Pond (Cs), Main à Dieu Pond (MD).