





# Abrupt Holocene climate change and potential response to solar forcing in western Canada

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## Abstract

Several abrupt climate events during the Holocene, including the widely documented oscillation at 8.2 thousand years before present (ka), are attributed to changes in the North Atlantic thermohaline circulation. Additional mechanisms, such as interactions between atmospheric circulation, ice-sheet dynamics, and the influence of solar irradiance, also have been proposed to explain abrupt climatic events, but evidence remains elusive. This study presents evidence from multi-proxy analyses on the Holocene sediments of Eleanor Lake, interior British Columbia. Climatic inferences from our decadal-resolution record of biogenic silica (BSi) abundance are supported by changes in diatom and pollen assemblages from the same core and correlations with existing regional climate records. The BSi record reveals abrupt and persistent climatic shifts at 10.2, 9.3, and 8.5ka, the latter two of which are coeval with major collapses of the Laurentide Ice Sheet. The record also reveals a short-term cooling at 8.2ka that is distinct from the 8.5ka event and similar in magnitude to several other late-Holocene coolings. BSi is correlated with solar-irradiance indices ( $r=0.43-0.61$ ), but the correlation is opposite in sign to that expected from direct solar forcing and weakens after 8ka. Possible mechanisms causing the abrupt and persistent climate changes of the early Holocene include 1) sudden losses of ice and proglacial lake extent, causing a shift in the meridional structure of atmospheric circulation, 2) a possible link between solar minima and El Niño-like conditions that are correlated with warm spring temperature in interior British Columbia, and 3) the influence of solar irradiance variability on the position of the polar jet, possibly via effects on the strength of the glacial anticyclone.

## Highlights

► Multiproxy lake sediment record from Eleanor Lake, BC, reveals abrupt early Holocene climate change. ► Biogenic silica in lake sediment is correlated with temperature during spring or early summer. ► Abrupt climate change is coeval with deglaciation events. ► Early Holocene climate changes may be linked to solar activity effects on El Niño-like conditions.

## Introduction

Understanding the mechanisms of abrupt climate change requires identification of such events in high-resolution paleoclimate records and associating them with forcing factors that may have pushed the climate system past a threshold (Alley et al., 2003, Denton et al., 2010). Apart from the events attributable to thermohaline circulation

shutdown in the North Atlantic during deglaciation (e.g., Kleiven et al., 2008), evidence of abrupt and long-lasting (>several centuries) climate change events during the Holocene with plausible alternative mechanisms remains scarce in many regions. However, several mechanisms have been proposed, including abrupt shifts in the jet stream upstream of ice sheets associated with rapid deglaciation (Wunsch, 2006) and solar variability as a modulator of centennial-scale climatic fluctuations (Björck et al., 2001, Bond et al., 2001, Hu et al., 2003).

The scattered evidence of abrupt Holocene climate change no-doubt reflects the paucity of high-resolution records of sensitive climate proxies in regions that experienced abrupt events. Candidate regions for detecting abrupt Holocene climate events include transitions between climatic regimes and air-mass dominance (Kirby et al., 2002). One such region is eastern British Columbia in western Canada, where winter onshore flow collides with polar air masses, producing abundant snowfall, and where summer convective rainfall also is frequent. In this study, we analyzed sediments from Eleanor Lake (Fig. 1; 52°7'N, 119°18'W; 677m above sea level) in east-central British Columbia to infer patterns and drivers of Holocene climatic change. While the regional climate may be sensitive to large-scale forcing, paleolimnological approaches to climate reconstruction present challenges because the year-round wet climate may result in little climatic sensitivity of the biogeochemistry of lake water or of the assemblages and productivity of the diatom flora (Battarbee, 2000). It is possible, however, that the cool summer climate and variable ice-off dates affect springtime water temperature, nutrient dynamics, diatom species assemblages, and productivity (Smol and Douglas, 2007). Here we infer Holocene climatic change in the Eleanor Lake area from a variety of sediment measurements, with a focus on the biogenic silica (BSi) content, diatom assemblages, and pollen assemblages. These inferences are compared with nearby independent temperature-sensitive climate proxy records. Furthermore, we compared the Eleanor Lake climate record with commonly used proxies of solar activity, as several recent studies have shown that millennial-scale climate fluctuations throughout the Holocene are correlated with ice-core and tree-ring proxies of solar activity (e.g., Björck et al., 2001, Bond et al., 2001, Hu et al., 2003, Marshall et al., 2007, Marchitto et al., 2010).

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## Section snippets

### Geomorphic and hydrologic setting

Eleanor Lake is a 9.5-ha, 19-m deep, kettle lake in the valley floor of the North Thompson River in the town of Blue River, British Columbia. The climate of the region is cool and moist, with an average July temperature of 16.3°C and an average annual precipitation of 1002mm, 30% of which falls as snow (Fig. 1). The bedrock is classified in the Shuswap Assemblage, dominated by metamorphic rocks of quartzofeldspathic gneiss and biotite-quartz schist (Massey et al., 2005). The lake has no...

### Core collection and chronology

Two parallel cores were obtained from the deepest location of the lake using a modified square-rod Livingstone piston corer from an anchored platform. Cores were extruded and wrapped in the field and split lengthwise in the laboratory. The upper-most 57-cm of sediment was obtained using a clear polycarbonate tube fitted with a piston. The surface-sediment core was sectioned into plastic bags at 1-cm intervals in the field. The chronology of the sediments is based on nine <sup>14</sup>C ages on plant...

### Sediment chronology and characteristics

The 682-cm sediment core is characterized as brown gyttja with microlaminations and black banding, three volcanic tephras, and in the basal 35cm, alternating clay and organic sediment overlying coarse sand and gravel. The basal calibrated <sup>14</sup>C age of the core is 10.85ka, and the sequence of <sup>14</sup>C dates shows no age reversals. However, one date from a marginal quantity of unidentifiable plant material fell out of line with neighboring dates and had a large standard deviation (Table 1). This date is ...

### Multi-proxy evidence from Eleanor Lake

BSi and organic matter (estimated by loss-on-ignition) together comprise on average 75% of the sediment dry weight (Fig.2), and their fractions are negatively correlated. Specifically, BSi has a strong negative correlation with % organic nitrogen (% ON) and % organic carbon (% OC) ( $r=-0.86$  and  $-0.88$ , respectively; Fig 5). While fluctuations in one component (e.g., OC) affect the percent of the other component (e.g., BSi), we note that if computing % BSi and % OC relative to non-BSi mineral...

## Abrupt climate shifts

Several abrupt climate changes have been detected during the early Holocene throughout the northern hemisphere and have been related to the dynamics of the Laurentide Ice Sheet (Alley et al., 2003). The BSi record from Eleanor Lake also displays many early Holocene abrupt changes, which are supported by diatom and pollen data from the same core. For many of these events, however, the direction of the climate change, the timing of the events, and the persistence following the abrupt change...

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...Broad-leaf taxa remain at low levels while the relative abundance of *Alnus* decreased slightly. The major change to the Holocene forests near the lake was the abrupt increase of *Tsuga heterophylla*, which abruptly increased within a few hundred years from ~1% at (or prior to) 4700 to >8% after 4500, concomitant with regional expansion across southeastern British Columbia (Hebda, 1995; Rosenberg et al., 2003; Gavin et al., 2006, 2011; Hallett and Hills, 2006; Courtney Mustaphi and Pisaric, 2014a). *T. heterophylla* likely spread through the moist and cool valley base establishing the modern ICH forests by 4400 cal BP at Sasquatch Lake....

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