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Late Holocene expansion of Istorvet ice cap, Liverpool Land, east Greenland

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ABSTRACT

The Greenland Ice Sheet is undergoing dynamic changes that will have global implications if they continue into the future. In this regard, an understanding of how the ice sheet responded to past climate changes affords a baseline for anticipating future behavior. Small, independent ice caps adjacent to the Greenland Ice Sheet (hereinafter called "local ice caps") are sensitive indicators of the response of Greenland ice-marginal zones to climate change. Therefore, we reconstructed late Holocene ice-marginal fluctuations of the local Istorvet ice cap in east Greenland, using radiocarbon dates of subfossil plants, ^{10}Be dates of surface boulders, and analyses of sediment cores from both threshold and control lakes. During the last termination, the Istorvet ice cap had retreated close to its maximum Holocene position by ~11,730 cal yr BP. Radiocarbon dates of subfossil plants exposed by recent recession of the ice margin indicate that the Istorvet cap was smaller than at present from AD 200 to AD 1025. Sediments from a threshold lake show no glacial input until the ice cap advanced to within 365 m of its Holocene maximum position by ~AD 1150. Thereafter the ice cap remained at or close to this position until at least AD 1660. The timing of this, the most extensive of the Holocene, expansion is similar to that recorded at some glaciers in the Alps and in southern Alaska. However, in contrast to these other regions, the expansion in east Greenland at AD 1150 appears to have been very close to, if not at, a maximum Holocene value. Comparison of the Istorvet ice-cap fluctuations with Holocene glacier extents in Southern Hemisphere middle-to-high latitude locations on the Antarctic Peninsula and in the Andes and the Southern Alps suggests an out-of-phase relationship. If correct, this pattern supports the hypothesis that a bipolar see-saw of oceanic and/or atmospheric circulation during the Holocene produced asynchronous glacier response at some localities in the two polar hemispheres.

1. Introduction

The Arctic today is displaying one of the largest and most pronounced reactions to global warming on the planet. In Greenland, this warming is expressed as rapid changes in ice-sheet behavior, including increases in ice-stream velocities, expansion of surface melting zones, and a drawdown of coastal and interior ice (e.g. Abdalati et al., 2001; Krabill et al., 2004; Luthcke et al., 2006; Velicogna and Wahr, 2006; Stearns and Hamilton, 2007; Joughin et al., 2010; Moon et al., 2012). Longer-term records of Greenland ice fluctuations place the present-day changes in context and aid in understanding the sensitivity of this ice to both natural and anthropogenic change. Moreover, records of past ice-sheet and nearby local-glacier fluctuations can, in turn, be used to examine proposed mechanisms for recent climate changes, such as the Little Ice Age (~AD 1250–1850) and the Medieval Warm Period (~AD 800–1100) (Lamb, 1965; Stine, 1994). We present a new multi-proxy record of recent changes in Istorvet ice cap, a local ice cap (~100 km^2) located some 200 km from the Greenland Ice Sheet (Fig. 1). We focus on this small ice cap because it responds sensitively to climate change and likely experienced climatic conditions similar to those that influenced the Greenland Ice Sheet.

2. Istorvet ice cap setting and background

Istorvet ice cap is located in Liverpool Land in the Scoresby Sund region of east Greenland (Fig. 1). This ice cap occurs adjacent to the

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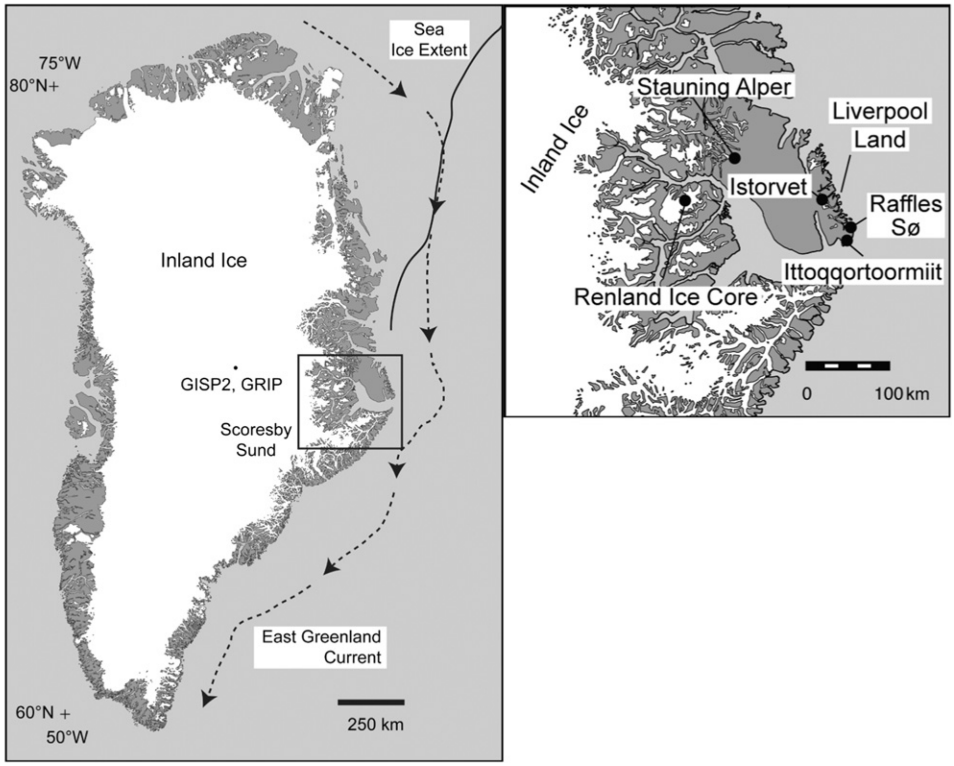

Fig. 1. Location of Istorvet ice cap, east Greenland, as well as the East Greenland Current (dashed line with arrow heads) and minimum sea-ice extent (solid line). The East Greenland Current is simplified from http://oceancurrents.rsmas.miami.edu/atlantic/east-greenland.html and Sutherland and Pickart (2008). The sea-ice extent is the average minimum September extent from 1979 to 2011 (http://nsidc.org/data/seaice_index/).

cold, southward-flowing East Greenland Current and is at a latitude similar to the present-day southern limit of sea ice in September (Fig. 1). A weather station at nearby Ittoqqortoormiit (70.48 °N, 21.96 °W, 65 m asl) registers monthly mean temperatures ranging from −14 to +5 °C and precipitation from 15 to 50 mm water equivalent (WMO station 04339, Carstensen and Jørgensen, 2009; SOM, Fig. S1). Liverpool Land is within the southern part of the high-arctic bio-climatic zone (Böcher, 1938). Modern vegetation is dominated by fell field and dwarf-shrub heaths. Woody plants, such as *Salix arctica*, *Dryas octopetala*, *Cassiope tetragona* and *Vaccinium uliginosum*, are common. Outlets on the eastern flank of Istorvet ice cap extend down to sea level. On the western side, outlets only reach ~400 m asl, likely due to drier air masses on the western slope of the ice cap. The ice cap divide is highest (~1035 m asl) in the south and descends to ~700 m asl in the north. Nunataks and subaerial bedrock ridges separate the Istorvet ice cap into at least five drainage basins.

Insights into the Holocene history of east Greenland come from several studies along the coast. Cremer et al. (2001b) developed a Holocene diatom record from lacustrine sediments on Raffles Sø just off the Liverpool Land coast. The onset of lacustrine sedimentation at ~9900 cal yr BP is interpreted to reflect the time of local deglaciation after the last ice age. Subsequent changes in lake-ice cover are thought to indicate relatively warm climatic conditions during the middle Holocene and the onset of colder conditions at ~AD 200 (Cremer et al., 2001b). At Basaltsø, an island ~250 km to the north, a pollen record indicates a slight warming between AD 1000 and 1200, followed by low dwarf-shrub pollen reflecting cooling (Wagner et al., 2000, Cremer et al., 2001a). In the same region, multi-proxy records from Ymer Ø also suggest general cooling during the late Holocene, but fluctuations of an adjacent ice cap are thought to result from changes in precipitation rather than temperature (Wagner and Melles, 2002). Overall, there is relatively little information about the Late Glacial or Holocene history of Liverpool Land.

3. Methods

To reconstruct past fluctuations of Istorvet ice cap, we used a multi-proxy approach that includes geomorphic mapping, radiocarbon dating of subfossil plants exposed by the retreating ice margin, coring of threshold and control-lake sediments, and surface-exposure (^{10}Be) dating of boulders from glacial landforms. We used a combination of remote imagery and field investigations to develop a geomorphological map of the western ice-cap margin (SOM, Fig. S2). Along this margin and on nunataks, we collected and dated *in situ* organic remains at two locations informally named North and South Istorvet. Since modern plants are just beginning to recolonize the recently deglaciated terrain, we sampled only those areas without modern growth. Radiocarbon dating was conducted at the National Ocean and Sciences Accelerator Mass Spectrometry Facility (NOSAMS). We used the CALIB 6.1.0 program and the INTCAL09 dataset (Reimer et al., 2009) to convert radiocarbon ages to calendar ages. Ages >2000 radiocarbon years BP are given as calendar years BP in the text, whereas younger ages are in calendar years AD (Table 1). We also collected samples of sediment adjacent to the *in situ* plants to obtain a complete a picture as possible of the local fossil flora. Sample size varied from about 1–4 kg, and a total of ~40 kg was analyzed. The samples were wet sieved to a mesh size of 0.1 mm and the residue analyzed using a dissecting microscope. The preservation was excellent and the results are tallied in Table 2.

We determined ^{10}Be ages of boulders on glacial landforms (Table 3). Samples were processed in the cosmogenic nuclide laboratories at Lamont-Doherty Earth Observatory and at Dartmouth