Quaternary Science Reviews 189 (2018) 31–42

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Punctuated Holocene climate of Vestfirðir, Iceland, linked to internal/external variables and oceanographic conditions

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ARTICLE INFO

Article history:
Received 10 November 2017
Received in revised form
21 March 2018
Accepted 6 April 2018

Keywords:
North Atlantic
Iceland
Holocene
Glaciers
Lake sediment
Dead vegetation
Paleoclimate
8.2 ka event
Neoglaciation
Little Ice Age

ABSTRACT

Emerging Holocene paleoclimate datasets point to a non-linear response of Icelandic climate against a background of steady orbital cooling. The Vestfirðir peninsula (NW Iceland) is an ideal target for continued climate reconstructions due to the presence of a small ice cap (Drangajökull) and numerous lakes, which provide two independent means to evaluate existing Icelandic climate records and to constrain the forcing mechanisms behind centennial-scale cold anomalies. Here, we present new evidence for Holocene expansions of Drangajökull based on ^{14}C dates from entombed dead vegetation as well as two continuous Holocene lake sediment records. Lake sediments were analyzed for both bulk physical (MS) and biological (%TOC, $\delta^{13}C$, C/N, and BSi) parameters. Composite BSi and C/N records from the two lakes yield a sub-centennial qualitative perspective on algal (diatom) productivity and terrestrial landscape stability, respectively. The Vestfirðir lake proxies suggest initiation of the Holocene Thermal Maximum by ~8.8 ka with subsequent and pronounced cooling not apparent until ~3 ka. Synchronous periods of reduced algal productivity and accelerated landscape instability point to cold anomalies centered at ~8.2, 6.6, 4.2, 3.3, 2.3, 1.8, 1, and 0.25 ka. Triggers for cold anomalies are linked to variable combinations of freshwater pulses, low total solar irradiance, explosive and effusive volcanism, and internal modes of climate variability, with cooling likely sustained by ocean/sea-ice feedbacks. The climate evolution reflected by our glacial and organic proxy records corresponds closely to marine records from the North Iceland Shelf.

1. Introduction

Spatially distributed and temporally accurate paleoclimate records are required to both disentangle natural variations in Earth's climate from anthropogenic change (Masson-Delmotte et al., 2013), and to evaluate the performance of climate models (Braconnot et al., 2012). Due to the amplification and sensitivity of climate change inherent to the cryosphere (Serreze and Barry, 2011), targeting the higher latitudes for such reconstructions is essential. Iceland's geographic location within the North Atlantic is ideally situated for high-latitude Holocene climate reconstructions due to its position at the confluence of major oceanic and atmospheric circulation patterns integral to global heat distribution (Fig. 1). As these circulation patterns change, the resultant climate evolution influences the status of Icelandic ice caps and leaves continuous archives of past terrestrial and marine environments in sedimentary records (Geirsdóttir et al., 2009a). Marine records are complicated by the integration of climate signals over various portions of the water column (e.g. Kristjánsdóttir et al., 2016), salinity and relative sea level changes (e.g. Quillmann et al., 2010) and dating problems due to variable ^{14}C reservoir corrections (e.g. Eiríksson et al., 2004). Thus, Iceland's terrestrial realm can provide valuable insight into the nature and causes of northern North Atlantic Holocene climate variability.

During the Holocene, the orbitally driven reduction of Northern Hemisphere (NH) summer insolation has been the predominate control over Iceland's climate over millennial timescales (Larsen et al., 2012; Geirsdóttir et al., 2013; Jiang et al., 2015). Along Iceland's insular shelves, the insolation forcing is recorded by general cooling of surface currents through the Holocene (Andersen et al., 2004; Castañeda et al., 2004; Giraudeau et al., 2004; Smith et al., 2005; Solignac et al., 2006; Bendle and Rosell-Melé, 2007; Justwan et al., 2008; Ólafsdóttir et al., 2010; Jiang et al., 2015;

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https://doi.org/10.1016/j.quascirev.2018.04.009
0277-3791/

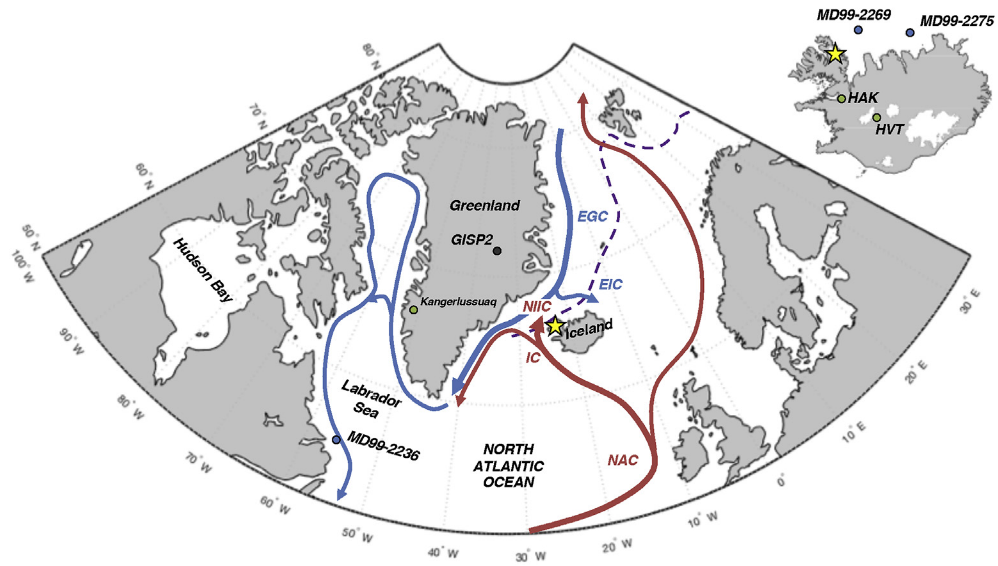

Fig. 1. Northern North Atlantic region, including simplified ocean surface currents and 1870–1920 CE sea ice edge position (dashed purple line, Divine and Dick, 2007). Key sites mentioned in text are labeled (blue marine sediment cores and green lake sediment cores), as well as the location of Vestfirðir (yellow star). HAK = Haukadalsvatn, HVT = Hvítárvatn. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Moossen et al., 2015; Kristjánsdóttir et al., 2016) and by increases in sea ice during the late Holocene (Moros et al., 2006; Cabedo-Sanz et al., 2016). However, emerging datasets point to a non-linear response of Icelandic climate to a first-order cooling trend (Larsen et al., 2012; Geirsdóttir et al., 2013). Notable cold perturbations include the '8.2 ka event' (Castañeda et al., 2004; Larsen et al., 2012; Quillmann et al., 2012; Geirsdóttir et al., 2013; Jiang et al., 2015), likely induced by meltwater floods from the waning Laurentide Ice Sheet (Alley and Ágústdóttir, 2005; Rohling and Pälike, 2005), and the Little Ice Age (LIA, 1250–1850 CE), linked to sustained volcanism and subsequent sea ice expansion (Miller et al., 2012; Sicre et al., 2013). The mechanisms behind other Holocene perturbations however remain ambiguous (Larsen et al., 2012; Geirsdóttir et al., 2013).

In this study, we focus on the Vestfirðir peninsula, where recent studies have constrained the Holocene evolution of the region's local ice cap, Drangajökull (Brynjólfsson et al., 2015a; Harning et al., 2016a; b). We expand upon these studies by presenting new evidence for the timing of Drangajökull expansions based on ^{14}C-dated *in situ* dead vegetation revealed from beneath the receding ice margins and in the physical characteristics of nearby lake sediment. Second, we develop a series of continuous and qualitative lacustrine-based Holocene climate records to make inferences about past spring/summer temperature and validate the glacier record. Ultimately, our new Vestfirðir climate records are employed to evaluate the nature of and further constrain the causes of Icelandic climate variability. Considering the vulnerability of Iceland's terrestrial climate to dynamic ocean currents, Vestfirðir is an ideal target for assessing the marine influence on Icelandic climate during the Holocene.

2. Regional setting

2.1. Vestfirðir peninsula

Vestfirðir comprises Iceland's northwesternmost extension into Denmark Strait and, as such, is the closest sector to the instrumental (post 1870 CE) sea ice edge (Fig. 1, Divine and Dick, 2007). The warm and saline Irminger Current (IC) branches off the North Atlantic Current (NAC) and flows north along the west coast of Iceland until it reaches Vestfirðir where it turns east along the North Iceland Shelf as the cooler, lower-salinity North Iceland Irminger Current (NIIC). The East Icelandic Current (EIC) branches off the East Greenland Current (EGC) and flows eastward along the north coast of Iceland (Fig. 1). Sea ice rarely forms along the insular shelves, but sea ice exported from the Arctic Ocean via the EGC is commonly transported along north Iceland's coastline via the EIC.

Regional bedrock on Vestfirðir is primarily composed of Neogene tholeiitic lava successions separated by thin sedimentary units of fluvial and aeolian origin (Harðarson et al., 2008). On eastern Vestfirðir, the northeastern highland plateau hosts the polythermal ice cap, Drangajökull (~142 km^2 area in 2011 CE; Jóhannesson et al., 2013). Three surging outlet glaciers drain most of the east, north and west catchments through deeply incised valleys (Fig. 2B). Each surging outlet glacier occupies a cirque-like bowl whereas the non-surging southern half of the ice cap mantles a relatively low-relief high plateau (Magnússon et al., 2016). Drangajökull's modern glacier-wide equilibrium line altitude (ELA) is considerably lower than other Icelandic ice caps with a 2000–2015 ELA at ~660 m asl. This low ELA likely reflects the ice cap's proximity to the relatively low SST of the adjacent ocean resulting in short, cool summers (www.vedur.is) and high snow accumulation (Belart et al., 2017).

2.2. Selected lakes

Non-glacial lake Skorarvatn (Fig. 2C, SKR; 66.25627°N, 22.32213°W) is situated in a low mountain pass (183 m asl) ~3 km north of Drangajökull and ~4 km from the sea. The threshold for receiving glacier meltwater terminates ~1 km closer to Drangajökull at ~420 m asl. Skorarvatn reaches a maximum depth of 25 m with a lake surface area of ~0.2 km^2 and catchment area of ~1.2 km^2. Modern catchment vegetation is sparse and dominated by a variety of moss species, which tend to clump on small tussocks. The only apparent aquatic vegetation is algae and moss.

Pro-glacial lake Tröllkonuvatn (Fig. 2D, TRK; 66.14252°N, 22.05607°W) is a higher-elevation (366 m asl) lake on Drangajökull's eastern periphery. Total lake surface area is ~1.3 km^2 and