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The Island of Amsterdamøya: A key site for studying past climate in the Arctic Archipelago of Svalbard

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ABSTRACT

This paper introduces a series of articles assembled in a special issue that explore Holocene climate evolution, as recorded in lakes on the Island of Amsterdamøya on the westernmost fringe of the Arctic Svalbard archipelago. Due to its location near the interface of oceanic and atmospheric systems sourced from Arctic and Atlantic regions, Amsterdamøya is a key site for recording the terrestrial response to marine and atmospheric changes. We employed multi-proxy approaches on lake sediments, integrating physical, biogeochemical, and isotopic analyses to infer past changes in temperature, precipitation, and glacier activity. The results comprise a series of quantitative Holocene-length paleoclimate reconstructions that reveal different aspects of past climate change. Each of the four papers addresses various facets of the Holocene climate history of north-western Svalbard, including a reconstruction of the Annabreen glacier based on the sedimentology of the distal glacier-fed lake Gjøavatnet, a reconstruction of changing hydrologic conditions based on sedimentology and stratigraphy in Lake Hakluytvatnet, reconstruction of summer temperature based on alkenone paleothermometry from lakes Hakluytvatnet and Hajeren, and a hydrogen isotope-based hydrological reconstruction from lake Hakluytvatnet. We also present high-resolution paleomagnetic secular variation data from the same lake, which document important regional magnetic field variations and demonstrate the potential for use in synchronizing Holocene sedimentary records in the Arctic. The paleoclimate picture that emerges is one of early Holocene warmth from ca. 10.5 ka BP interrupted by transient cooling ca. 10-8ka BP, and followed by cooling that mostly manifested as two stepwise events ca. 7 and 4 ka BP. The past 4ka were characterized by dynamic glaciers and summer temperature fluctuations decoupled from the declining summer insolation.

1. Introduction

There is no region on Earth where climate is changing as fast as in the Arctic, as the effects of global greenhouse forcing are strengthened by regional feedbacks (e.g. sea-ice) (Miller et al., 2010). The rapid climate transition underway in the Arctic is observed as temperatures rising twice as fast as the global average (Screen and Simmonds, 2010), as well as by increases in precipitation (Boisvert and Stroeve, 2015; Masson-Delmotte et al., 2013). By increasing the surface area of open water, on-going sea-ice retreat enhances evaporation and heat fluxes from the surface ocean, intensifying the regional hydrological cycle and amplifying warming (Bintanja and Selten, 2014; Boisvert and Stroeve, 2015; Screen and Simmonds, 2010). Indeed, climate model projections suggest that Arctic precipitation may increase by more than 50% during the 21st century (Bintanja and Selten, 2014), while temperatures could rise by 11 °C above the 1986–2005 mean (Van Oldenborgh et al., 2013). The anticipated climatic changes will pose significant challenges to societies in the Arctic and beyond.

Despite the observed rates of change and its anticipated impacts, our knowledge of the *natural* variability of the Arctic climate system remains limited due to the scarcity of data and the relatively

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short period (≤100 yrs) of instrumental observations. These natural variations will be superimposed on anthropogenic change, and should therefore be part of any assessment of future climate. Furthermore, an evaluation of the spatiotemporal patterns of past natural variability is necessary to determine the sensitivities and connections within the climate system. Hence, an informed understanding of the history, causes, and impacts of natural arctic climate variations is imperative assessment of future change. This notion has given rise to a number of critical questions in the scientific community: what is the range of natural Arctic climate variability on societally relevant (i.e. multi-decadal to centennial) timescales? What external and internal forcing mechanisms and boundary conditions influence the timing and patterns of natural climate variability in the Arctic? How can the past provide useful analogues to the future state of Arctic climate?

Compared to the glacial periods, the Holocene has been characterized by large-scale climatic boundary conditions (e.g. albedo, sea-level, ice-sheet configuration, oceanography) similar to the present and thus represents a critical reference period when trying to understand teleconnections and feedbacks that may drive future change in the Arctic. For example, the North Atlantic Oscillation (NAO), the Atlantic sector manifestation of the Arctic Oscillation (AO), is the leading mode of climate variability (ignoring the global warming signature) recognized in instrumental observations from the North Atlantic Arctic. This atmospheric phenomenon represents changes in the distribution of atmospheric mass between high- and mid-latitudes and has a major impact on the distribution of heat and moisture throughout the Arctic (Thompson and Wallace, 1998). Paleoenvironmental reconstructions have revealed the importance of these systems with respect to past variability in the Arctic system, extending our understanding beyond just the recent instrumental period (Darby et al., 2012; Funder et al., 2011; Olsen et al., 2012; Renssen et al., 2009). The spatial climate patterns associated with the AO/NAO provide just one example of the importance of internal climate dynamics in determining Arctic climate. The development of a greater number of spatially distributed climate reconstructions is critical to document the connections and sensitivities within the Arctic climate system. Our aim is to fill part of the knowledge gap through our cross-disciplinary paleoclimate investigations of Amsterdamøya. In this special issue, we have collated lacustrine sedimentary records that record changes in Holocene temperature, precipitation and glacier activity – key parameters of atmospheric climate, on Svalbard – strategically located at the dynamic interface of competing Arctic and Atlantic influences. To extract this sensitive climate signal from the investigated sediments, we used a range of analytical techniques, including novel sedimentological, organic geochemical, and isotope approaches.

2. Study area

The Island of Amsterdamøya (N79°46′, E10°45′) (Fig. 1) is one of the northernmost islands in the Arctic Archipelago of Svalbard. It was discovered by Dutch explorer Willem Barents in 1596 CE and was later occupied by Dutch whalers, who built a seasonal whaling station on the Island during the peak of their operations in the 17th century. The main Dutch settlement called Smeerenburg (Fig. 1) (Dutch for "blubber town") occupied a flat area on the eastern side of the island. The island measures 18.8 km^2 and is characterized by glacially eroded cirques, steep cliffs, and flat valley floors. The mountain plateau Hollendarberget (Fig. 1) is the highest point on the Island (472 m a.s.l.) and is covered by an allochthonous block field.

Exposure ages on glacial erratics found in the block field at Hollendarberget indicate that the summits of Amsterdamøya have remained ice-free since >80 ka BP, although the valleys were glaciated until 18–15 ka BP (Landvik et al., 2003). Annabreen (0.4 km^2), the largest glacier on the Island, is located in a north-facing valley. There are also two smaller glaciers, Hiertabreen (0.1 km^2) and Retziusbreen (0.2 km^2). The island contains a number of lakes, the largest of which are Gjøavatnet (2 m a.s.l.) and Hakluytvatnet (12 m a.s.l.). Gjøavatnet is supplied by meltwater from Annabreen glacier, while Hakluytvatnet is fed by two perennial snow patches located south of the lake. There are no morphological features indicating the marine limit (ML) on the island, and it is believed to be close to present day sea level (Boulton and Rhodes, 1974; Landvik et al., 1998; Salvigsen, 1979). There has been little postglacial emergence in north-western Svalbard, and neither Amsterdamøya nor Danskøya (to the south) (Fig. 1) display patterns of post-glacial uplift relative to sea level (Boulton and Rhodes, 1974; Landvik et al., 1998; Salvigsen, 1977). Therefore, Gjøavatnet and Hakluytvatnet contain sedimentary accumulation spanning most of the Holocene, despite their proximity to sea level.

The climate of Amsterdamøya is moderated by the West Spitsbergen Current (WSC), the northernmost limb of the Norwegian Atlantic Current (NwAC), which transports warm Atlantic water along the NW coast of Svalbard along its route to the Arctic Ocean (Fig. 1). The warm WSC, and its warming influence on air masses, results in warmer temperatures, greater precipitation, and less sea ice on the western coast of the Svalbard Archipelago than on the eastern coast, which is influenced by the cold East Spitsbergen Current (ESC) (Fig. 1). In addition, the alternating westerlies and the polar-front jet stream, both affected by the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), modulate the present climate of Amsterdamøya.

3. Terrestrial paleoclimate evidence

Our research presented in this special issue builds upon decades of terrestrial studies on Svalbard. The archipelago's glaciation history and its deglaciation have been intensely examined by a combination of stratigraphic studies, (cosmogenic) dating, analysis of offshore marine sediment cores, and bathymetric mapping of submerged glacial landforms (e.g. Gjermundsen et al., 2015; Ingólfsson and Landvik, 2013; Jessen et al., 2010; Landvik et al., 1998). Interestingly, there is no equivocal terrestrial evidence for any significant glacial advance during the Younger Dryas (12.9–11.7 ka BP). Mangerud and Landvik (2007) hypothesize that the most recent episode of glacier advance (i.e., the so-called Little Ice Age (LIA) may have overridden the Younger Dryas front position based on the stratigraphic relationship between dated shorelines and moraines. However, retarded glacio-isostatic uplift rates (Forman et al., 1987; Landvik and Salvigsen, 1987) and changes in fjord sedimentation (Forwick and Vorren, 2009) suggest that glaciers re-advanced in Younger Dryas time, similar to those in Scandinavia (Bakke et al., 2009).

Holocene climatic variations on Svalbard have been examined by many researchers over the past decades. Most Holocene terrestrial paleoclimate studies on Svalbard have focussed on glaciers because they are ubiquitous and act as sensitive climate recorders with the potential to resolve seasonal climate variations (e.g. Humlum et al., 2005; Reusche et al., 2014; Røthe et al., 2015; Svendsen and Mangerud, 1997; van der Bilt et al., 2015; Werner, 1993). A great deal of attention has been focused on studies of the Linné catchment on western Spitsbergen (Fig. 1), a valley occupied by a glacier and downstream lake of the same name. Pioneering work by Svendsen et al. (1987) revealed that the lacustrine sediment record from Lake Linné captured changes in glacier size. A robust chronology published by Snyder et al. (1994) afforded new possibilities for studying the lake record, enabling