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Hydroclimate variability of High Arctic Svalbard during the Holocene inferred from hydrogen isotopes of leaf waxes

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ABSTRACT

The response of the Arctic hydrologic cycle to global warming includes changes in precipitation patterns and moisture availability associated with variable sea ice extent and modes of atmospheric circulation. Reconstructions of past hydroclimate changes help constrain the natural range of these systems, identify the manners in which they respond to different forcing mechanisms, and reveal their connections to other components of the climate system, all of which lead to a better understanding of present and future changes. Here we examine hydroclimate changes during the Holocene in the High Arctic archipelago of Svalbard by reconstructing the isotopic composition of precipitation. We measured the hydrogen isotopic composition (δD values) of leaf wax compounds (*n*-alkanes; C_{25}-C_{31}) in a sediment core from Lake Hakluytvatnet on the island of Amsterdamøya, northwest Spitsbergen. We interpret δD values of mid-chain (C_{25}) and long-chain (C_{29}, C_{31}) length *n*-alkanes to represent changes in the isotopic composition of lake water and precipitation over the last 12.9 ka. After deglaciation of the catchment, water supply became restricted and the lake experienced significant evaporative isotopic enrichment indicating warmer conditions from 12.8 to 7.5 ka. The isotope values suggest an increase in the delivery of moisture from warmer sub-polar air masses between 12.8 and 9.5 ka, followed by generally warm, but unstable conditions between 9.5 and 7.5 ka, possibly indicating a response to meltwater forcing. Sedimentary evidence indicates a hiatus in deposition c. 7.5–5.0 ka, likely as a result of desiccation of the lake. At c. 5.0 ka lacustrine sedimentation resumed and over the last 5 ka there was a progressive increase in the influence of polar air masses and colder conditions, which culminated in an abrupt shift to colder conditions at c. 1.8 ka. This late Holocene cooling ended c. 0.18 ka, when isotopic data indicate warmer conditions and greater influence of moisture derived from lower latitudes.

1. Introduction

Future climate change in the Arctic is expected to involve increased surface temperatures as well as changes in the amount and seasonality of precipitation (Kattsov et al., 2007; Rawlins et al., 2010; Bintanja and Selten, 2014). However, it is uncertain how these changes compare to the natural variability of the Arctic climate system over different timescales. By reconstructing past climate changes, we can better contextualize the impact of anthropogenic warming on the Arctic and define the natural range of precipitation and temperature fluctuations in response to long- and short-term forcing mechanisms. Many terrestrial proxy records from the Arctic have been used to infer past temperature, but few have been used to reconstruct hydroclimate (Sundqvist et al., 2014). This is despite the fact that hydroclimate change is an extremely important aspect of Arctic climate variability and is coupled to other aspects of the Arctic system. For example, current warming of the Arctic has resulted in intensification of the hydrologic cycle, attributed to enhanced moisture transport from lower latitudes and greater evaporation from the decline in winter sea ice extent (Bengtsson et al., 2011; Bintanja and Selten, 2014). In this study, we examine isotopic evidence for hydroclimate change during the Holocene on Svalbard (Fig. 1).

The High Arctic Svalbard Archipelago is positioned at the boundary between the northern North Atlantic and the Arctic Ocean (Fig. 1). Svalbard's climate is strongly influenced by the

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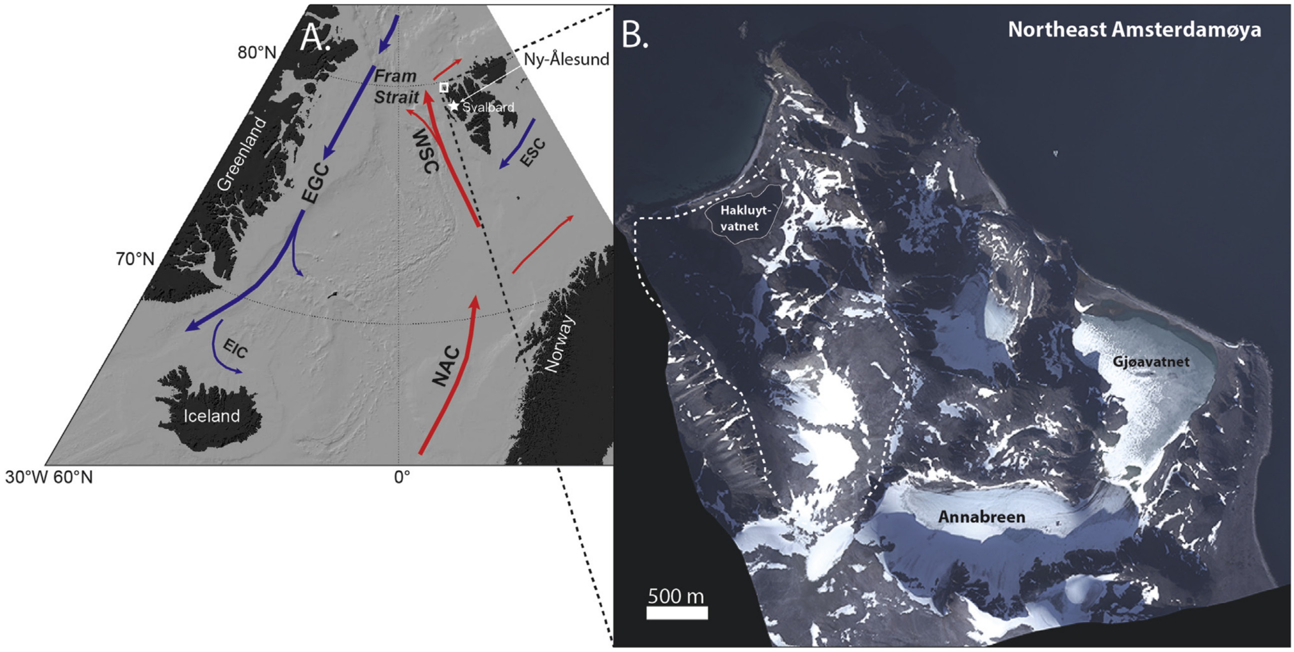

Fig. 1. (A) Map of Svalbard at the northern end of the Norwegian-Greenland Sea with the major surface ocean currents. Warm and saline Atlantic Ocean sourced currents are shown in red (NAC - North Atlantic Current, WSC - West Spitsbergen Current), and cold and fresh Artic Ocean sourced currents are shown in blue (ESC – East Spitsbergen Current, EGC – East Greenland Current, EIC – East Iceland Current). The northwestern island of Amsterdamøya is bounded by a white box and the location of Ny-Ålesund is indicated. (B) Air photograph of northeastern Amsterdamøya showing Hakluytvatnet. The extent of Hakluytvatnet's catchment is shown by the white dotted line, and the Annabreen glacier and Lake Gjøavatnet are labeled. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

delivery of relatively warm water via the Norwegian Atlantic Current, which results in mild temperatures relative to the average for this latitude. Millennial-scale Holocene climate changes for Svalbard have been documented using nearby marine records (Jessen et al., 2010; Müller et al., 2012; Werner et al., 2016), glacier reconstructions (Werner, 1993; Svendsen and Mangerud, 1997; Reusche et al., 2014; Røthe et al., 2015; van der Bilt et al., 2015), and macrofossil records (Birks, 1991; Salvigsen, 2002). Generally, these studies suggest the early to mid-Holocene was 1–2 °C warmer than present, likely in response to higher summer insolation, and that the late Holocene was marked by declining temperatures and the expansion of glaciers. Over the last 1000 years, ice core records from western Svalbard record a progressive decrease in winter temperatures until the 20th century, when rapid warming reversed this long-term cooling trend (Divine et al., 2011).

Hydroclimate change can be reconstructed by analyzing geologic archives that record the isotopic composition of meteoric water. Water isotopes reflect aspects of the hydrologic cycle and can be related to moisture source, temperatures, and air mass trajectories (Dansgaard, 1964). Here we reconstruct precipitation and lake water isotope variability from the analysis of leaf wax hydrogen isotopes (δD values) preserved in lake sediments, which have been shown to record the isotopic composition of environmental source water used by plants during photosynthesis (Sachse et al., 2012). We isolated leaf wax compounds (*n*-alkanes) from a sediment core from Lake Hakluytvatnet on Amsterdamøya, Svalbard that spans the last c. 13.1 ka (thousands of years before present) (Fig. 1) (Gjerde et al., this issue). We show that millennial-scale patterns of Holocene climate are recorded as changes in local precipitation isotopes and the hydrologic balance of the lake (amount of evaporation relative to precipitation), and that higher resolution data during the late Holocene capture hydroclimate changes on multi-decadal timescales associated with intervals of cooling as well as recent warming trends.

2. Regional setting & background

2.1. Regional climate

Weather station data from Ny-Ålesund, located 100 km south of our study site (Fig. 1), provide a general understanding of regional climate. Average annual temperatures at Ny-Ålesund (78°55′25″N, 11°54′36″E) range from −12 °C to 5.6 °C, and average annual precipitation is 427 mm (Førland et al., 2011) (Fig. 2). Winter air temperatures are high relative to the latitudinal average, and are also quite variable on an intra-annual basis due to the competing influence of cold polar and mild sub-polar air masses. Pressure differences associated with the Arctic Oscillation largely control

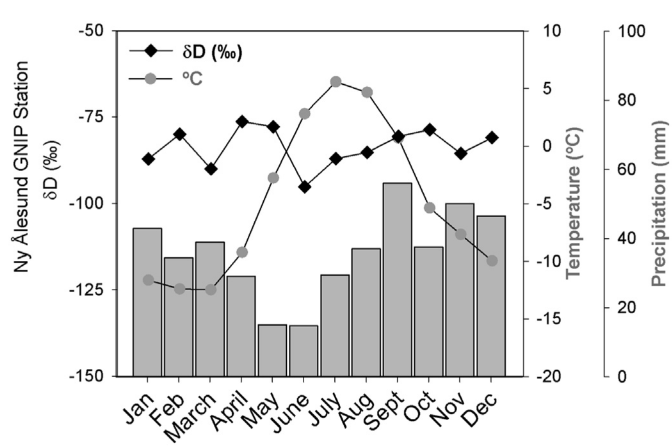

Fig. 2. Climate data from the Ny Ålesund weather station, part of the Global Network of Isotopes in Precipitation (78°55′25″N, 11°54′36″E) (IAEA/WMO, 2006). Monthly average temperature, precipitation, and hydrogen isotopes (δD) are based on data from 1990 to 2009.