# Past Climate Change and Perspectives for Archaeological Research: Examples from Norway, Svalbard, and Adjoining Seas

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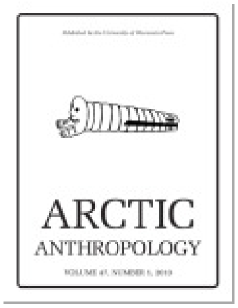
Arctic Anthropology, Volume 46, Numbers 1-2, 2009, pp. 8-16 (Article)

Published by University of Wisconsin Press
*DOI: 10.1353/arc.0.0020*



ARCTIC
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# Past Climate Change and Perspectives for Archaeological Research: Examples from Norway, Svalbard, and Adjoining Seas

**Morten Hald**

*Abstract.* Natural climate change has occurred throughout the history of Earth. Human impact on climate change has increased over the last two centuries. During the Quaternary period, climate change on $10^3$–$10^5$-year time scales is linked to the so-called Milankovitch cycles that have caused variations in the amount of energy from the sun reaching the Earth. This factor is thought to be a main cause for the shifts between glacial and interglacial periods during the Quaternary. However, superimposed on long-term natural climate change, are events of shorter duration (10–$10^2$-year time scales) climatic events. The present paper discusses examples of climate changes on land and in adjoining seas off Norway and Svalbard. The climatic changes from the last glacial maximum to the present, including the abrupt glacial-interglacial transition when the first human settlements occurred in northern Norway, are a particular focus of the paper. Finally, future climate perspectives at the high northern latitudes are discussed.

## Introduction

The climatic changes from the last glacial to the present have been severe and their causes and implications are not fully understood. The magnitude and speed of change, however, must have caused major restrictions, challenges, but also opportunities for human settlements. The purpose of the present paper is to review climate changes since the last glacial maximum to the present, and to discuss their causes and implications. Further, the paper will place ongoing and future climate changes into a perspective by examining past climate change in the Norwegian and Svalbard region, relevant for archaeological research. A special focus will be the Holocene, a period during which humans migrated into and settled Norway.

## Climate and Climate Forcing

The term climate is often used to describe the average weather conditions during a 30-year period. At present, weather conditions are usually compared against the average conditions during the period 1961–1990. Paleoclimate is defined as climate conditions dating prior to the period of instrumental observations of climate. Paleoclimatic reconstructions are based on records of climate indicators (hereafter termed proxies) studied in natural "climate archives" such as glacier ice, tree-rings, and ocean and land sediments.

Climate forcing refers to specific phenomena that directly influence changes in climatic dynamics on various time scales. Forces that influence climatic change can be broken down into those

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ARCTIC ANTHROPOLOGY, Vol. 46, Nos. 1–2, pp. 8–16, 2009 ISSN 0066-6939

beyond the Earth's environmental system (extraterrestrial) and those that relate to internal forces (terrestrial). The extraterrestrial factor that has attracted the greatest attention is the so-called Astronomical Theory (e.g., Ruddiman 2001). The theory is based on the assumption that surface temperatures of the earth vary in response to regular and predictable changes in the earth's orbit and axis. This results in variations in the input of solar energy to the earth on cycles of ca. 100,000, 41,000 and 23,000 years respectively. These cycles are termed Milankovitch cycles after the physicist Milutin Milankovitch, who put forward the theory of orbital climate forcing. There is an over-all agreement that these cycles explain the large scale pattern of glacial-interglacial cycles during the Quaternary period.

Long-term tectonic changes influence the earth climate both on local and global scales. Tectonic changes affect both the position and altitude of continents, as well as the size and position of oceans. Changes driven by plate tectonics are likely to occur very slowly, over several millions of years.

However, proxy records with a high time resolution provide evidence of rapid climatic variations, frequently of large amplitude, that are superimposed on the orbitally or tectonically driven changes. These may be related to, for example, release of gases or aerosols from volcanic activity, changes in solar activity, or changes in the energy transfer of the world's oceans, e.g., driven by salt density variations (thermohaline circulation). These short lasting periods, also termed "sub-Milankovitch" events, may occur over time scales varying from decades to millennia. Some of the forcing factors, such as the solar insolation cycles, are not large enough to explain the extreme variations between glacial and interglacial periods. However, combined with an earth-internal feedback, even a relatively small forcing factor may have a large climatic impact on the earth.

## Modern Climate in the Norwegian Svalbard Region

The present climate of high latitude northwestern Europe is to a large extent dominated by the influx of warm Atlantic water via the Gulf Stream, North Atlantic Current, and Norwegian Current systems (Fig. 1) (Hopkins 1991). Atlantic water contributes to the present mild climate of northwestern Europe. Large amounts of heat are released into the atmosphere during the winter time when this Atlantic water cools and sinks to contribute to the North Atlantic Deep Water (NADW). This deep-water formation is also a sink for atmospheric $CO_2$, and a large portion of the ventilated deep waters of the world oceans are formed in the northern North Atlantic. The inflow of Atlantic water to the northern North Atlantic is balanced by surface outflow of the cold East Greenland Current, together with the deep-water formation. This circulation pattern is part of the North Atlantic thermohaline circulation (THC) during which heat (about $1.4 \times 10^{15}$W) is transferred from the South Atlantic to the North Atlantic. An initial climate change in the northern North Atlantic region can be transmitted to the world oceans by the NADW, or to the global climate system through the carbon cycle, and via ice albedo feedbacks. The albedo of an object is defined as the extent to which it diffusely reflects light from the sun. In addition, climatic changes on sub-Milankovitch time scales-may be triggered in the northern North Atlantic by abrupt changes in, for example, Atlantic water heat flow, and sea ice distribution, or deep-water formation.

Climate on land in northwestern Europe is characterized by fairly mild conditions in the coastal region of Norway, with temperatures above freezing point throughout the year between 5–8° N. More distant from the coast there is less precipitation and in general colder winters and warmer summers. Svalbard, in particular the coast of West Spitsbergen, is also characterized by a relatively mild climate compared to its latitude (7–0° N), with seasonally ice free fjords during the summer months. Precipitation is in general low; February is normally the coldest month with average temperatures between −12° C and −17° C. Approximately 60% of the Svalbard islands are covered by glaciers.

## Past Climate from the Last Glacial to the Present

### The Late Glacial

The last glacial maximum (LGM) is defined as the period between 20,000 to 15,000 years B.P., when a large ice sheet covered most of the British Isles, northern Europe including the continental shelf, the Barents Sea, and Svalbard (Svendsen et al. 2004). Deglaciation started around 15,000 years B.P. (Fig. 2). The retreat of the ice sheet was particularly rapid at its marine based parts, i.e., the continental shelf and the Barents Sea (Landvik et al. 1998). A considerable climatic amelioration took place in most parts of Europe after ca. 15,000 cal. years B.P. The large ice sheet retreated rapidly and most of the outer coastal areas of Norway became ice free around 14,000 years cal. B.P. (Andersen et al. 1995) (Fig. 2).

The deglaciation period was interrupted, however, by colder periods during which the glacier fronts advanced, or at least their retreat

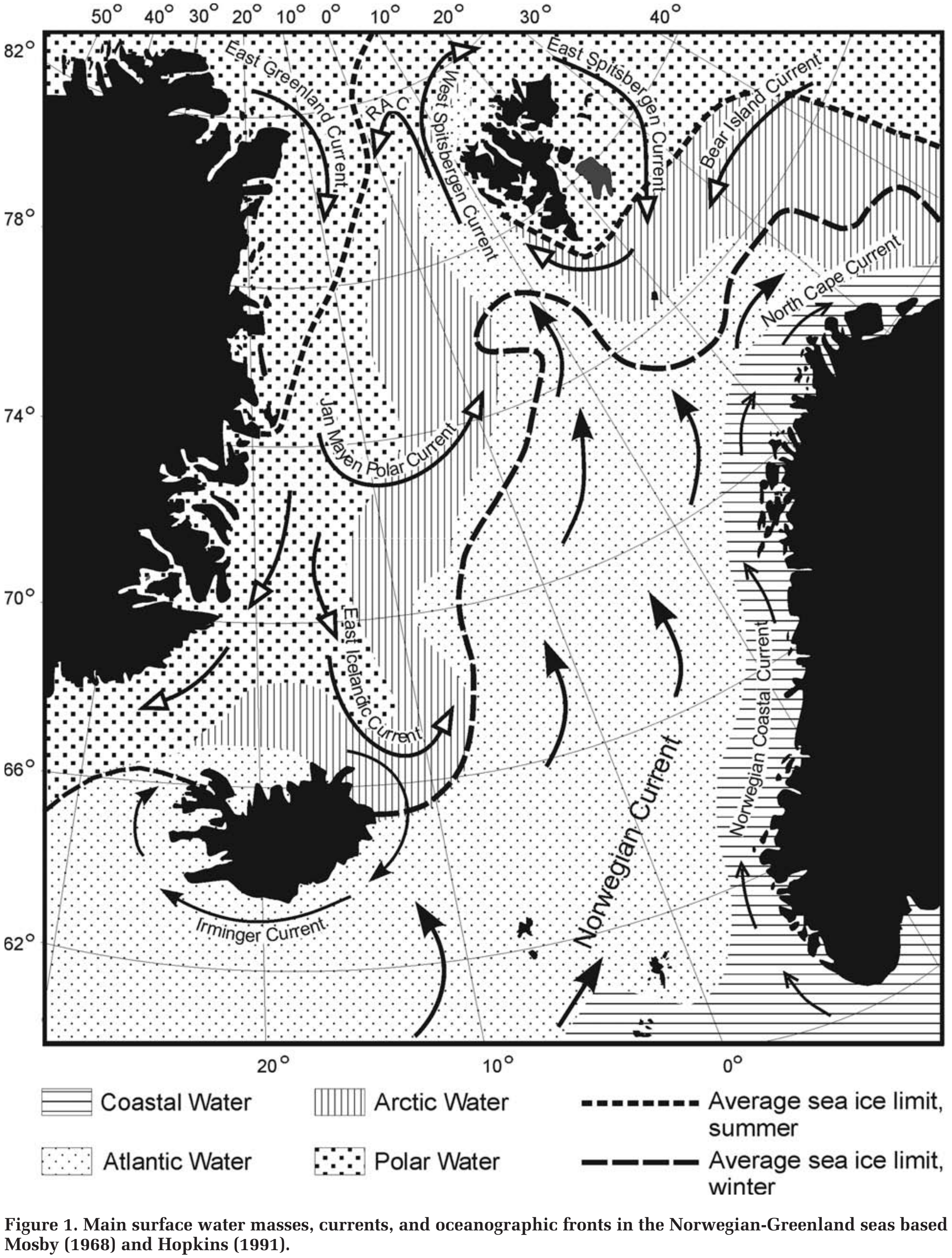

**Figure 1. Main surface water masses, currents, and oceanographic fronts in the Norwegian-Greenland seas based on Mosby (1968) and Hopkins (1991).**

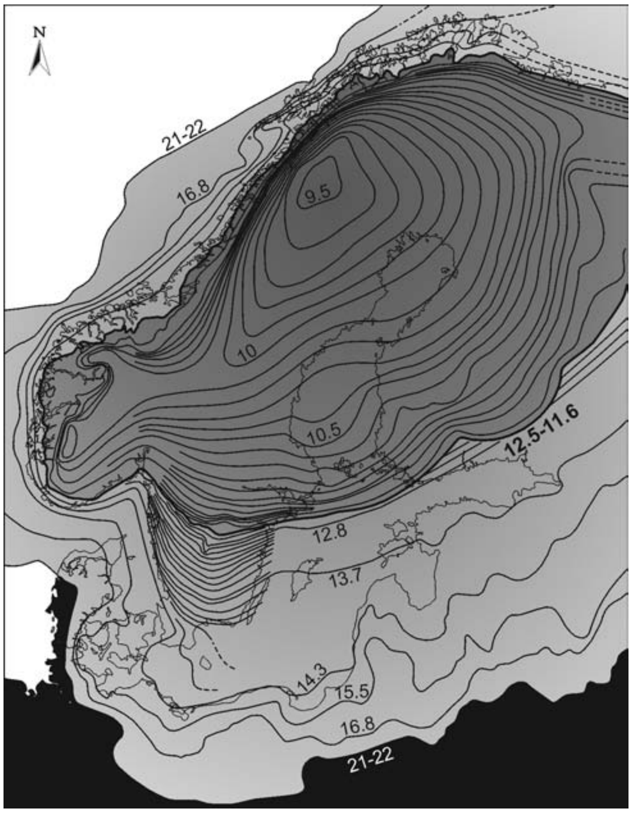

**Figure 2. Map showing the deglaciation of Scandinavia. The numbers indicate the calendar year B.P. age in $10^3$ years. Modified from Kleman and Strömberg (in press).**

halted. The most pronounced cooling period during the deglaciation, was the so-called Younger Dryas which lasted from 12,800 to 11,500 years cal. B.P. (e.g., Björck et al. 1998). During this period the Fennoscandian ice sheet advanced to the fjord districts along the entire coast of Norway and reached a maximum during the early Younger Dryas (see Andersen et al. 1995 for a review). The Younger Dryas was also characterized by a significant drop in atmospheric temperatures of about –0° C (Vorren et al. 1988) and influx of Atlantic water through the Gulfstream-Norwegian Current was considerably reduced (e.g., Ebbesen and Hald 2004; Koç, Jansen, and Haflidason 1993).

At the end of the last glacial period humans migrated from Eurasia to North America across the ice-free Bering Land Bridge and along the southern coast of Beringia (ca. 14,000–13,500 years cal. B.P.; Dixon 2001). According to Thommessen (1996) areas north of the Fennoscandian Ice Sheet in northernmost Finnmark (Norway) may have been settled by humans as early as about 12,200 years B.P. But a reassessment of the evidence (Blankholm 2004) indicates that this date may be too old. According to Blankholm (2008) early settlements along the coast of Norway occurred around 9,500 $^{14}$C years (corresponding to ca. 10,900 years cal. B.P.).

## The Glacial-Interglacial Transition

The transition from the cold and glacial conditions during the Younger Dryas into the present Holocene interglacial was very abrupt as exemplified by selected marine, terrestrial, and ice core records shown in Figures 3 and 4. Data from the GRIP and GISP ice cores reveal that the shift from glacial to interglacial conditions occurred within a few decades (Fig. 3) (Johnsen et al. 1992). Sediment records from lakes (Bjune, Birks, and Seppa 2004) (Fig. 3) and the continental margin (Hald et al. 2007) (Fig. 4) show that both atmospheric and ocean temperatures shifted from glacial to interglacial levels within less than 100 years.

The evolution of the temperature and extent of the "Gulfstream" along the coast of Norway and Svalbard during the Holocene were recently elucidated by a comparison of six high-resolution sediment cores along a N-S transect on the Norwegian-Svalbard continental margin from c. 60° N to 77.4° N, northern North Atlantic (Hald et al. 2007). Fossils of planktonic foraminifera in the cores were investigated to show the changes in upper surface and subsurface water mass distribution and properties, including summer sea-surface temperatures (SST) (Fig. 4). The abrupt temperature shifts during the earliest part of the Holocene, the so-called Preboreal (PB) Oscillations, are linked to the final stage of the deglaciation of Fennoscandian and Svalbard ice sheets. The subsequent Early Holocene warm oceanic climate seen in the western Barents Sea and Svalbard margin correlate well to other marine and terrestrial records from Norway, Svalbard, and

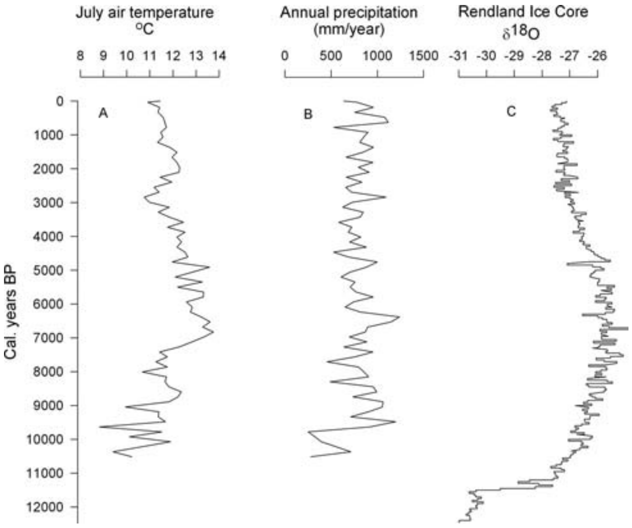

**Figure 3. A and B: Reconstructed air temperature and precipitation vs. age (cal. years B.P.) from Lake Dalmutladdo, northern Norway (from Bjune et al. 2004). C: Oxygen isotopes measured from the Renland Ice Core on the Greenland Ice Sheet (from Johnsen et al. 1992).**

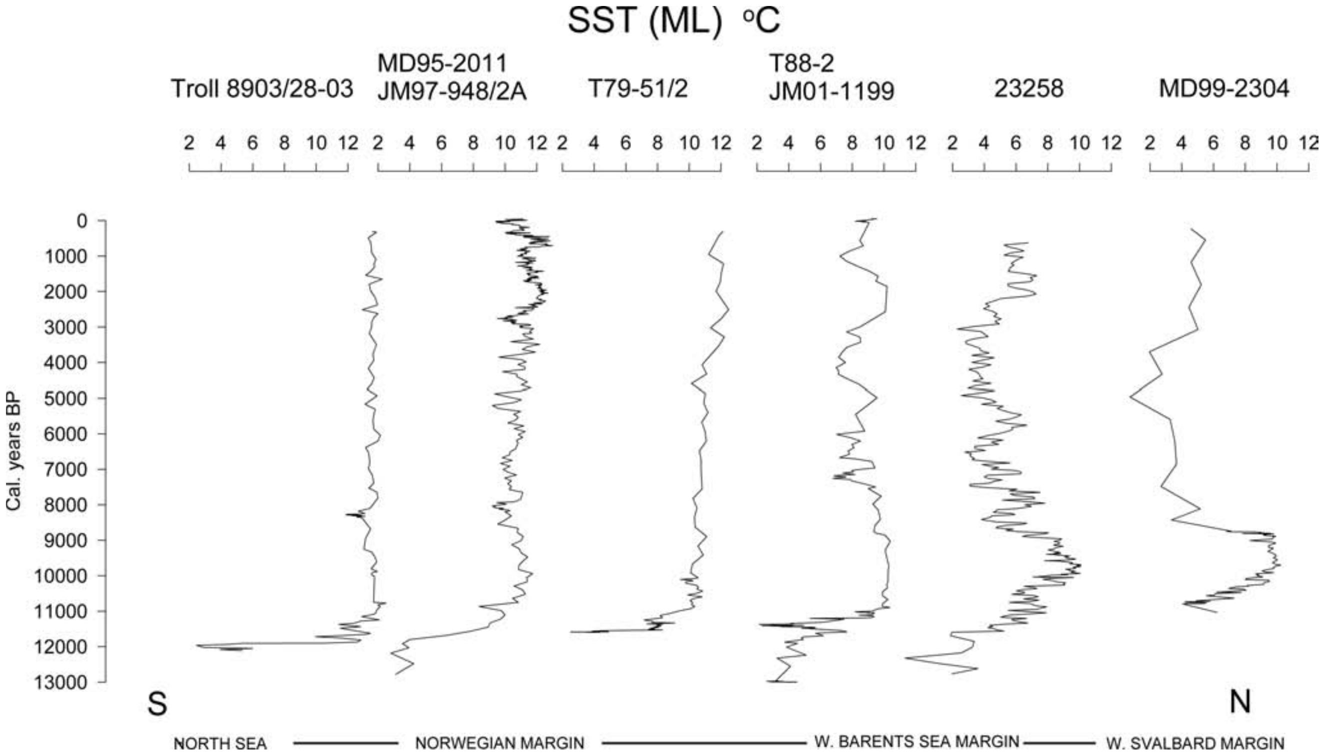

**Figure 4. Reconstructed sea surface summer temperatures (SST) vs. age (cal. years B.P.) in sediment cores on the Norwegian-Barents Sea-Svalbard margin, northern North Atlantic. The SST reconstruction is based on a planktonic foraminiferal transfer function using the Maximum Likelihood statistical approach. A second order polynomial fit is plotted through SST data for core 23258 for the last 12,000 cal. years (from Hald et al. 2007).**

adjoining seas. The Fennoscandian Ice Sheet, which covered the coast and fjords of Norway at this time, retreated rapidly on land during the mid-late PB (e.g., Eilertsen, Corner, and Aasheim 2005).

## Early and Late Holocene

Researchers believe that Norway was completely deglaciated for several multi-centennial periods during the early and middle Holocene (e.g., Bakke et al. 2005). On Svalbard, glaciers in the coastal region melted completely during the early Holocene (Svendsen and Mangerud 1997), although some tidewater glaciers were still present in central Svalbard (Hald et al. 2004). Studies of fossil benthic foraminifera and their oxygen and carbon stable isotopes from the fjords and on the continental shelf of Svalbard (Hald et al. 2004; Slubowska-Woldengen et al. 2006) and northern margin of the Barents Sea (Duplessy et al. 2005; Hald et al. 1999; Lubinski et al. 1996) indicate a stronger than present influence of Atlantic water during the early Holocene. Warmer than at present Atlantic water also influenced coastal areas of Svalbard as concluded by Salvigsen (Salvigsen 2002; Salvigsen, Forman, and Miller 1992;) based on their findings of fossils of the thermophilic mollusk *Mytilus edulis* ("blue shell") during early Holocene. This mollusk was much less frequent during the middle and late Holocene, but it has recently reappeared in the Isfjorden area, western Svalbard, linked to the ongoing global warming (Berge et al. 2005). The theory concerning Early Holocene warming is further supported by reconstructions of atmospheric temperatures of −°C warmer than today based on studies of pollen and plant macrofossils in lake sediments on western Svalbard (Birks 1991) and Bjørnøya, western Barents Sea (Wohlfarth et al. 1995).

In northern Norway atmospheric summer temperatures around 9000 cal. years B.P. similar to those at the present, were estimated from pollen and plant macrofossils in lake sediments from northern Fennoscandia (Bjune, Birks, and Seppa 2004) (Fig. 3). In the same area Bakke et al. (2005) found maxima in winter precipitation centered around 9500 and 9000 cal. years B.P. In southern Norway temperatures similar to those of the present were established at this time (Bjune et al. 2005). The subsequent cooling around 9000–8000 cal. years B.P., including the 8.2 k event, is also reflected in these and other terrestrial records. Based on studies of proglacial lake sediments of the Jostedalsbreen in southwestern Norway, Nesje, Lie, and Dahl (2000) reconstruct cold atmospheric winter temperatures between 8800–8200 and 7800–7300 cal. years B.P. The cold periods around, respectively, 7500 and 6500 cal. years B.P. are linked to increased tidewater glacier activity on western, central Svalbard, inferred from an ice rafted debris (IRD) record in the van Mijenfjorden (Hald et al. 2004). The IRD parameter is a measure for sediment grains larger than 1 mm in diameter that have melted or fallen out of an iceberg. An IRD record thus indicates proximity and activity of a glacier with a marine terminus. During this time there are indications of an increased regionalization in the human settlement pattern in Norway, as well as utilization or occupation of the inland areas of northern Norway (Blankholm in 2008).

The cold period 5000–3000 years cal. B.P. coincides with the onset of the Neoglacial cooling in the northern hemisphere as documented in the d$^{18}$O record of the Renland ice core from Greenland (Johnsen et al. 1992). At this time glaciers started to advance on Svalbard (Svendsen and Mangerud 1997), in northern Norway (Bakke et al. 2005), and in southwestern Norway (Nesje, Lie, and Dahl 2000). The Neoglacial cooling is also reflected by a marked reduction in the tree line altitude (Vorren and Alm 1999) and a drop in atmospheric summer temperature (Bjune, Birks, and Seppa 2004) in northern Norway.

## Causes for Climate Change

Both the build-up and subsequent deglaciation of the large ice sheet during the last glacial maximum are linked to large scale oceanic and atmospheric changes (Hald, Dokken, and Mikalsen 2001) in the North Atlantic region. Based on marine geological investigations they show that Atlantic water in the Norwegian Current and West Spitsbergen Current ("the Gulfstream system"), advected into the high northern latitudes of the North Atlantic Ocean at this time. This advection brought moisture to the area, supporting glacier growth. But advection of Atlantic water also brought heat into the area, and after 15,000 years B.P., this heat together with an increase in insolation probably contributed to deglaciation of the region (Hald, Dokken, and Mikalsen 2001).

The abrupt climate changes that took place during the deglaciation, for example the Younger Dryas cooling period and the Preboreal oscillations, have been attributed to changes in the North Atlantic thermohaline convection (Bond et al. 1997; Hagen and Hald 1998). As a result of the deglaciation of the large ice sheets in the northern hemisphere, large amounts of meltwater reached the ocean (Clark 2001). If this meltwater reached the deepwater convection cells in the North Atlantic, they may have hampered the THC and thus reduced the influx of warm Atlantic water to the high northern latitudes.

Late Holocene climate changes in the northern North Atlantic have been attributed to changes in temperature and influx of Atlantic water to the region. Long term changes for almost the entire Holocene period have been related to orbital forcing and its effects on insolation (Hald et al. 2007). On shorter time scales, influx of Atlantic water may be governed by the variations in the THC. In addition, there is a link between ocean circulation and atmospheric conditions in the North Atlantic region commonly explained by the North Atlantic Oscillation (NAO) winter index (Hurrel and Van Loon 1997). The NAO is a measure of the pressure difference between the Iceland low and the Azores high and normally varies on decadal time scale.

## Future Climate Scenarios and Implications for Archeological Research

Over the last few decades global temperatures have been rising at a rate unprecedented in modern history (IPCC 2007). This warming is reflected in the high northern latitudes, for example, by a reduction in the sea ice cover in the Arctic Ocean, rising atmospheric and oceanic temperatures, and reduction in permafrost (ACIA 2005). Modelling experiments suggest global warming of the surface air temperature (SAT) over the next century of between 2° C and 4.5° C (Meehl et al. 2007). Geographical patterns of projected SAT warming show the greatest temperature increases will occur over land and at high northern latitudes (Meehl et al. 2007). Climate change in the high northern latitudes is expected to affect other parts of the world. The melting of ice masses in the Arctic could contribute significantly to global sea level rise, and the addition of that fresh water to the salty oceans could alter global ocean circulation patterns. Arctic tundra also stores huge amounts of carbon, which could be released to the atmosphere during a thaw, further enhancing the greenhouse effect and global warming.

Future climate change may have direct implications for archaeological research. Two factors that might have the largest impact are sea level rise and thawing of permafrost. Sea level rise can result from thermal expansion of sea water, increasing the volume of the global ocean and melting of glaciers. Model experiments predict that during the next century a sea level rise along the Norwegian and Svalbard coasts of between 0.1 and 0.4 m (Meehl et al. 2007). Such a rise will increase coastal erosion and coastal lowlands may be flooded.

Permafrost is soil, rock, or sediment that has remained below 0° C for two or more consecutive years. Permafrost underlies most land surfaces in the Arctic, varying from a few meters to several meters thick. The "active layer" refers to the top layer above the permafrost layer that thaws each year during the warm season and freezes again in winter. The mountain and inland areas of northern Norway are occupied by a sporadic or discontinuous permafrost layer that is mostly a few meters thick (e.g., Heginbottom et al. 1993). Modelling experiments predict a SAT rise of > 4° C in northern Norway during the next century. If such a warming occurs, all permafrost in the northern Norway area will disappear (ACIA 2004). When the temperature in the permafrost increases, the active layer will deepen. This deepening is likely to cause collapse and destabilization of various structures. Such processes will put all archaeological sites at risk and possibly erase or dim traces of past human activities. Based on these predictions, it would be timely to enhance mapping and plan protection strategies for archaeological sites located in the coastal regions vulnerable to sea level rise and in the areas of permafrost.

*Acknowledgments.* Lindsay Wilson critically read the manuscript and corrected the English. Jan P. Holm helped with computer drawings and Ingvild Hald with references. Funding for this research was provided through the University of Tromsø and by the Research Council of Norway to the IPY project SciencePub.

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