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A brief history of climate – the northern seas from the Last Glacial Maximum to global warming

Tor Eldevik [a,*], Bjørg Risebrobakken [b], Anne E. Bjune [b], Carin Andersson [b], H. John B. Birks [c,g,h], Trond M. Dokken [b], Helge Drange [a], Mirjam S. Glessmer [a], Camille Li [a], Jan Even Ø. Nilsen [d], Odd Helge Otterå [b], Kristin Richter [e], Øystein Skagseth [f]

[a] Geophysical Institute, University of Bergen, and Bjerknes Centre for Climate Research, Bergen, Norway
[b] Uni Research Climate, and Bjerknes Centre for Climate Research, Bergen, Norway
[c] Department of Biology, University of Bergen, and Bjerknes Centre for Climate Research, Bergen, Norway
[d] Nansen Environmental and Remote Sensing Center, and Bjerknes Centre for Climate Research, Bergen, Norway
[e] Institute for Meteorology and Geophysics, University of Innsbruck, Innsbruck, Austria
[f] Institute of Marine Research, and Bjerknes Centre for Climate Research, Bergen, Norway
[g] Environmental Change Research Centre, University College London, London, UK
[h] School of Geography and the Environment, University of Oxford, Oxford, UK

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ABSTRACT

The understanding of climate and climate change is fundamentally concerned with two things: a well-defined and sufficiently complete climate record to be explained, for example of observed temperature, and a relevant mechanistic framework for making closed and consistent inferences concerning cause-and-effect. This is the case for understanding observed climate, as it is the case for historical climate as reconstructed from proxy data and future climate as projected by models. The present study offers a holistic description of northern maritime climate – from the Last Glacial Maximum through to the projected global warming of the 21st century – in this context. It includes the compilation of the most complete temperature record for Norway and the Norwegian Sea to date based on the synthesis of available terrestrial and marine paleoclimate reconstructions into continuous times series, and their continuation into modern and future climate with the instrumental record and a model projection. The scientific literature on a variable northern climate is reviewed against this background, and with a particular emphasis on the role of the Norwegian Atlantic Current – the Gulf Stream's extension towards the Arctic. This includes the introduction of an explicit and relatively simple diagnostic relation to quantify the change in ocean circulation consistent with reconstructed ocean temperatures. It is found that maritime climate and the strength of the Norwegian Atlantic Current are closely related throughout the record. The nature of the relation is however qualitatively different as one progresses from the past, through the present, and into the future.

1. Introduction

The poleward transport of heat and salt by the North Atlantic Ocean's thermohaline circulation (THC) is a principal component of the global climate system. Its northern surface limb – the Norwegian Atlantic Current – progressively gives up its excess heat en route toward the Arctic (Fig. 1), and thus moderates the regional climate. This interaction between a variable ocean circulation and climate is therefore central to current understanding of past, present, and projected future climate change in the northern seas region. Warm and cold phases of past regional climate back to the Last Glacial Maximum (and beyond), as well as present and future change, are understood to relate tightly with the extent and vigour of North Atlantic THC and the Norwegian Atlantic Current (e.g., Rahmstorf, 2002; Gregory et al., 2005; Rhines et al., 2008; Bakke et al., 2009; Spielhagen et al., 2011).

The term the northern seas refers collectively to the northern North Atlantic, the Nordic Seas (comprising the Norwegian, Greenland, and Iceland seas), and the Arctic Ocean, including the

* Corresponding author. Geophysical Institute, University of Bergen, PO box 7803, N-5007 Bergen, Norway. Tel.: +47 55582602.
E-mail address: tor.eldevik@gfi.uib.no (T. Eldevik).

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Norwegian Atlantic Current (NwAC) that connects the three regions (Fig. 1). The warm and saline Atlantic inflow is totally transformed as it travels the northern seas: a water-mass transformation that is the integrated signature of the NwAC's interaction with climate. Heat loss, predominantly in the Norwegian and Barents seas, and freshwater input, predominantly in the Arctic Ocean, result in two distinct outflows across the Greenland–Scotland Ridge: fresh and cold Polar Water with the East Greenland Current, and dense and cold overflow water at depth (Hansen and Østerhus, 2000; Eldevik and Nilsen, 2013).

The Atlantic Water subducts where it meets Arctic sea ice and its heat becomes essentially unavailable to the atmosphere. A shift in the marginal ice zone that separates the Atlantic and Polar domains is thus a sensitive indicator of climate change (Serreze et al., 2007; Årthun et al., 2012). The inflow has upon subduction been cooled to the extent that it is of overflow density (Mauritzen, 1996a). The overflows are however less saline and slightly colder. The subducted water, either recirculating in the vicinity of the Fram Strait or travelling the Arctic Ocean, mixes with fresher and colder water masses to finalize the transformation into overflow water (e.g., Saloranta and Haugan, 2004). The subducted branch into the Arctic proper and the regional freshwater input are the sources of the estuarine circulation that largely maintains the East Greenland Current (Stigebrandt, 1985; Eldevik and Nilsen, 2013).

An assessment of the northern THC's role in regional climate is accordingly very much about quantifying and explaining the variable temperature and strength of the Norwegian Atlantic Current. The recent Arctic-ward retreat of sea ice in the Fram Strait and Barents Sea – and the corresponding progression of the Atlantic domain (Årthun et al., 2012) – have, for example, resulted in record-warm wintertime temperatures on neighbouring Svalbard (Førland et al., 2011).

Here we review and synthesize present knowledge about climate and climate change at the THC's northern terminus. The framework of our study is presented in Section 2, and the reference records for reconstructed, observed, and projected climate are compiled and presented in Section 3. The relation between climate and predominantly northern THC – but also, for example, solar insolation – is reviewed for eight distinct climate periods or transitions in Section 4. The findings are discussed and synthesized in Section 5, which also includes a relatively simple framework that diagnoses the strength of the Norwegian Atlantic Current consistent with reconstructed Norwegian Sea temperatures. The resulting "brief history of climate" is summarized in Section 6.

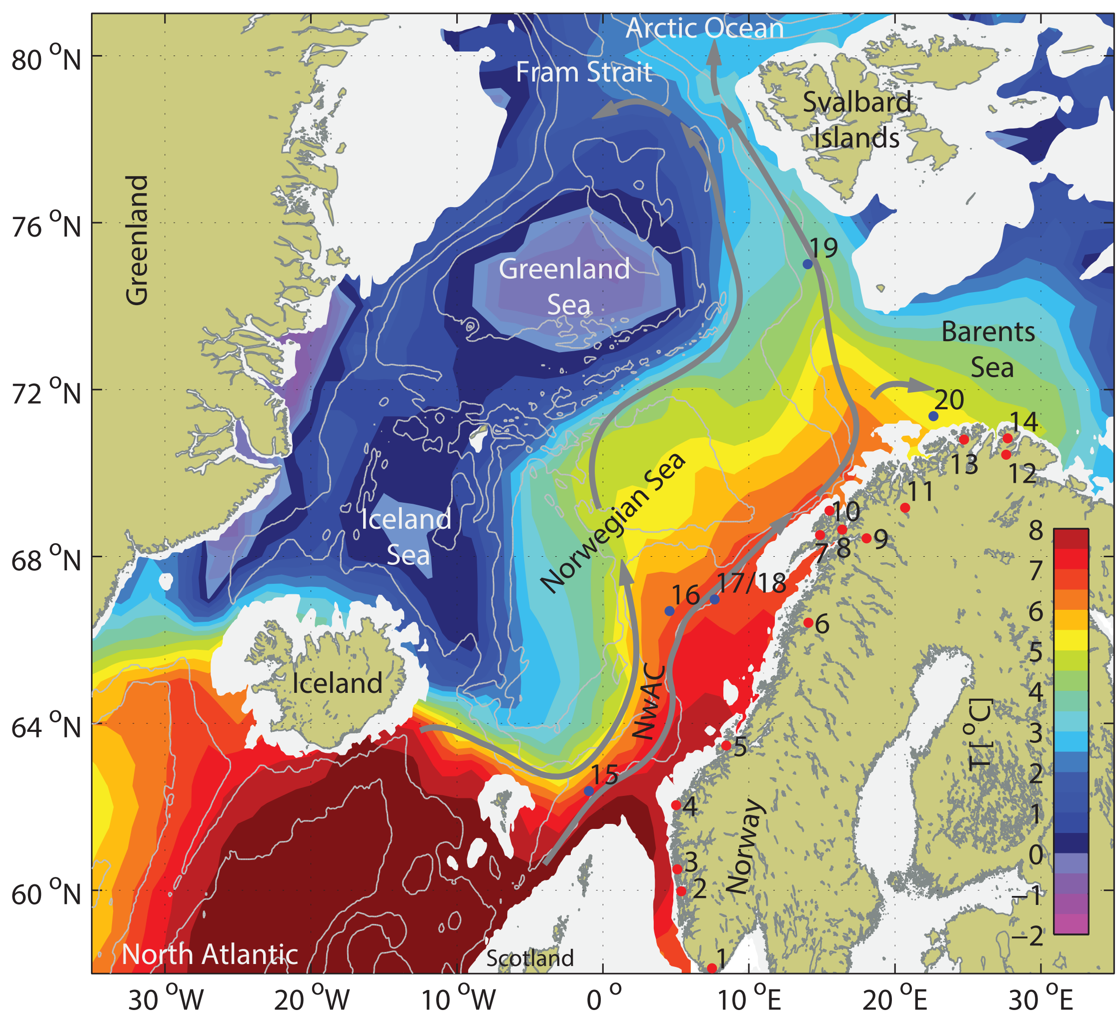

Fig. 1. Northern seas temperature climatology at 200 m depth. The arrows indicate the two branches of the Norwegian Atlantic Current (NwAC). The branches span out the region of temperate Atlantic Water that connects the North Atlantic Ocean with the Barents Sea and Arctic Ocean. Isobaths are given for every 1000 m; the figure is adapted from Eldevik et al. (2009). The numbered locations are the sites of the paleo reconstructions listed in Table 1.