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Inception of the Northern European ice sheet due to contrasting ocean and insolation forcing

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Abstract

About 115,000 yr ago the last interglacial reached its terminus and nucleation of new ice-sheet growth was initiated. Evidence from the northernmost Nordic Seas indicate that the inception of the last glacial was related to an intensification of the Atlantic Meridional Overturning Circulation (AMOC) in its northern limb. The enhanced AMOC, combined with minimum Northern hemisphere insolation, introduced a strong sea–land thermal gradient that, together with a strong wintertime latitudinal insolation gradient, increased the storminess and moisture transport to the high Northern European latitudes at a time when the Northern hemisphere summer insolation approached its minimum.
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Keywords: Glacial inception; Nordic Seas; Northern European ice sheets; Paleo-reconstruction: OGCM; AMOC; Insolation; Insolation gradient

Introduction

Due to the general acceptance of the orbital (or Milankovitch) theory, there is a basic understanding of the fundamental drivers of the glacial cycles. The specific feedbacks that are involved in the triggering or inception process of a glacial cycle remain, however, to a large degree elusive. A common conceptual view is that the inception was initiated by lowered summer insolation at high northern latitudes, which cooled the Nordic Seas and other high latitude oceans, and which in turn provided snow and sea-ice feedbacks that accelerated cooling by a freshening of the surface ocean and concomitant reduction of the Atlantic Meridional Overturning Circulation (AMOC) (Cortijo et al., 1994; Imbrie et al., 1992). Contradicting this scenario, we here show by a combination of paleo-reconstructions and General Circulation Model (GCM) results from the Bergen Climate Model (BCM) that the strength of the AMOC apparently increased in its northern limb at the end of the last interglacial (marine isotope sub-stage (MIS) 5.5: ~126,000–115,000 yr), at the time when major ice sheets nucleated. Our results indicate that nucleation of the Northern European ice sheets was a result of the specific orbital forcing at that time, coexisting with an enhanced AMOC, increased winter precipitation, lowered snow melting due to reduced summer insolation, and related feedbacks.

Materials and methods

Paleo-reconstructions

Three sediment cores have been studied at high temporal resolution through the MIS 5.5 and the MIS 5.5/5.4 transition. All cores were obtained at IMAGES cruises with R/V Marion Dufresne. MD95-2010 is from the Vøring Plateau, whereas MD99-2303 and MD99-2304 are from the Fram Strait (Fig. 1). They are located to reflect changes in extent and variability of Atlantic Water transport towards the Arctic. Risebrobakken et al. (2005) determined the marine isotope stage 5 age models of the cores through stable isotope correlation towards the chronology established on the NEAP18K core (Chapman and Shackleton, 1999). The same age

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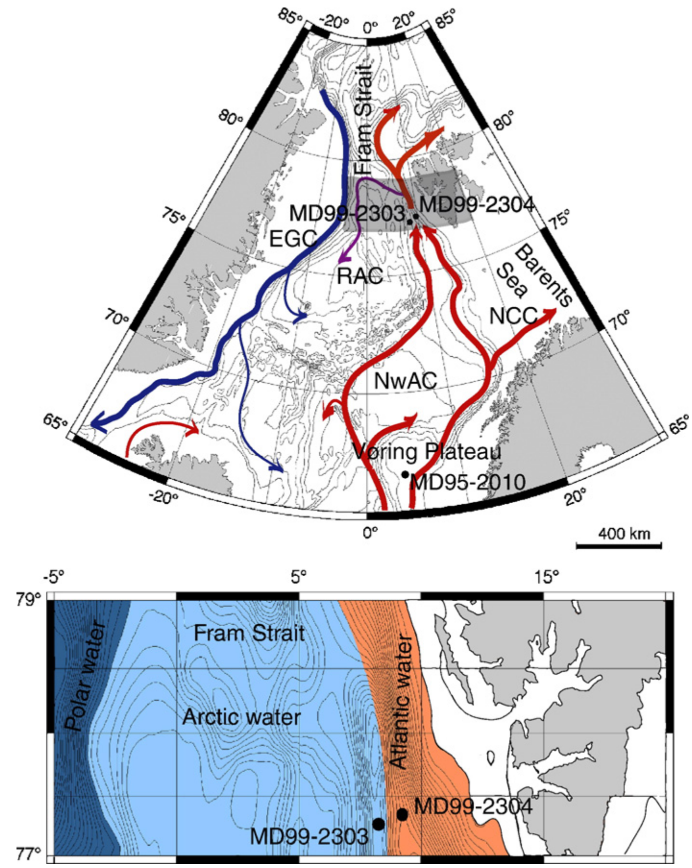

Figure 1. The main surface currents in the Nordic Seas and locations of the studied cores (MD95-2010 (66°41.05′N, 04°33.97′E: 1226 m water depth), MD99-2304 (77°37.26′N, 09°56.90′E: 1315 m water depth) and MD99-2303 (MD99-2303; 77°31.18′N, 08°23.98′E: 2277 m water depth)) are shown in the upper panel. NwAC = Norwegian Atlantic Current, NCC = North Cape Current, RAC = Return Atlantic Current and EGC = East Greenland Current. The bathymetry is indicated by isolines every 500 m. The distribution of the surface water masses in the Fram Strait is indicated in the lower panel, representing the area indicated by the grey square in the upper panel.

models have been used in this study, and detailed information on the procedure can be found in Risebrobakken et al. (2005). The studied time interval, 126,000 – 110,000 yr, is represented by 32 cm in MD95-2010 (1227.5 – 1259.5 cm core depth), 171 cm in MD99-2304 (2086.5 – 2257.5 cm core depth) and 31 cm in MD99-2303 (904.5 – 935.5 cm core depth). All three cores were sampled every cm throughout the studied time interval, giving approximate time resolutions of 500 yr (MD95-2010 and MD99-2303) and 100 yr (MD99-2304).

Stable isotope measurements were performed every cm on the left coiling form of *Neogloboquadrina pachyderma* (150–500 μm fraction), using Finnigan MAT 251 and MAT 252 mass spectrometers at the GMS lab at the University of Bergen, both equipped with automatic preparation lines ("Kiel device"). The samples were crushed and cleaned with methanol in an ultrasonic bath before being measured. All results are reported in ‰ vs. VPDB.

The present number of minerogenic grains >0.5 mm has been counted every cm in all cores through the studied time interval. These grains are assumed to be ice rafted, and they are presented as number of grains/gram sediment.

The number of planktonic foraminifers was counted at irregular intervals at the 150–500 μm fraction (26, 56 and 20 samples in MD99-2303, MD99-2304 and MD95-2010, respectively). A minimum of 300 foraminifers was counted from each sample, if possible (in MD99-2303, MD99-2304 and MD95-2010 this is valid for 14, 44 and 8 samples, respectively). The assemblages were separated into *N. pachyderma* sinistral and dextral, *Globigerina quinqueloba* and other planktonic species. The relative abundance of *N. pachyderma* (s), *N. pachyderma* (d) and *G. quinqueloba* were calculated for all samples with a total of more than 100 planktonic foraminifers (in MD99-2303, MD99-2304 and MD95-2010 this is valid for 20, 51 and 20 of the counted samples, respectively).

Model experiments

The applied model system consists of a global version of MICOM (Bleck et al., 1992), fully coupled to a dynamic (Harder, 1996) and thermodynamic (Drange and Simonsen, 1996) sea ice module. The model is configured with a local horizontal orthogonal grid system with one pole over North America and the other pole over central Europe (Bentsen et al., 1999). The horizontal grid resolution in the North Atlantic/Nordic Seas region is about 40 km in experiment E1, and 80 km in experiments E2 and E3. For all model experiments there are 26 vertical layers, of which the uppermost mixed layer (ML) has a temporally and spatially varying density. The

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