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Modelling iceberg trajectories, sedimentation rates and meltwater input to the ocean from the Eurasian Ice Sheet at the Last Glacial Maximum

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Abstract

We model iceberg flow paths from the Eurasian Ice Sheet, and the associated meltwater production and sedimentation rates within the Norwegian–Greenland Sea during the last glaciation. Results from a numerical ice sheet model, an atmospheric general circulation model and an ocean general circulation model are collated and used to provide iceberg production rate, wind field and surface current forcings to an iceberg trajectory model. The iceberg model then determines how icebergs issuing from the Eurasian Ice Sheet travel across the ocean and eventually melt. In addition the release of iceberg sediments is also predicted. The results show that iceberg trajectories are complex and that common features of iceberg movement are clustering in zones of convergence and exit into the North Atlantic through the Iceland–Faeroes Channel. Eurasian icebergs do not penetrate into the interior of the Arctic Ocean. The gathering of icebergs produces a complex meltwater pattern that does not follow the conceptual idea of decreasing meltwater production with distance from the ice sheet margin. Sedimentation results are compared with the meltwater configuration and are found to be a poor indicator of past zones of iceberg melt, with zones of sedimentation extending significantly less far.

Keywords: Icebergs; Ice sheet; Ice Rafted Debris; Meltwater; Greenlad–Iceland–Norwegian Seas; Late Quaternary

1. Introduction

Modelling iceberg discharge from ice sheets is critical to evaluating their role in perturbing the state of the oceans during glacial periods. Meltwater pulses within the North Atlantic, as identified by excursions in $\delta^{18}O$ within marine sediment records (Bard et al., 2000), are associated with the presence of Ice Rafted Debris (IRD), thereby implicating the role of icebergs in salinity changes (Heinrich, 1988; Bond et al., 1993; Grousset et al., 1993; Dowdeswell et al., 1995; Grousset et al., 2001).While attention has been paid to modelling the decay of the Laurentide ice sheet (MacAyeal, 1993; Alley, 1998), little focus has yet been placed on quantifying the glacial products of the Eurasian Ice Sheet in the Late Quaternary. Such information is critical to reconstructing the supply of freshwater to the Greenland–Iceland–Norwegian (GIN) Seas, the North Atlantic and the Arctic Ocean.

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At the Last Glacial Maximum (LGM) an ice sheet occupied Scandinavia, extending northwards into the Barents Sea, and parts of the Kara Sea, and stretching south to cover the northern region of the British Isles. The boundaries of the ice sheet are well defined through both numerical modelling and geological data sets (Svendsen et al., 1999). In particular two projects, Polar North Atlantic Margins (PONAM), from 1990–1995, and the subsequent program Quaternary Environments of the Eurasian North (QUEEN), from 1996–2002, specifically aimed to increase the level of glacial-geologic data in this region. The resulting ice sheet limits at the LGM are fully described by Svendsen et al. (1999) and illustrated in Fig. 1. The western margin and parts of the northern margin are well defined by sequences of marine sediments on the adjacent continental shelf edge, indicating that the ice sheet reached the shelf break. Furthermore, the marine sequences also locate where major ice streams were active through glacial cycles, through the presence of large trough mouth fans. Of particular interest to this study is that both the western and northern margins of the ice sheet are marine based and therefore, loss of ice would have most likely occurred through iceberg calving (Siegert et al., 2002).

The discharge of ice into the GIN Seas is of great interest, as in the present day these seas are one of the sources of deep water production and, therefore, changes in this region can be transmitted globally. Additionally, these seas are oceanographically sensitive to changes in salinity and temperature, and thereby meltwater from the Eurasian and Greenland ice sheets. Evidence that the LGM circulation was indeed different is provided through a number of palaeoclimate and palaeoceanographic indicators (Koç et al., 1993; Hebbeln et al., 1998; Bauch et al., 2001). The most documented difference is North Atlantic Deep Water (NADW) production being further south than the Norwegian Seas and weakened, so it formed

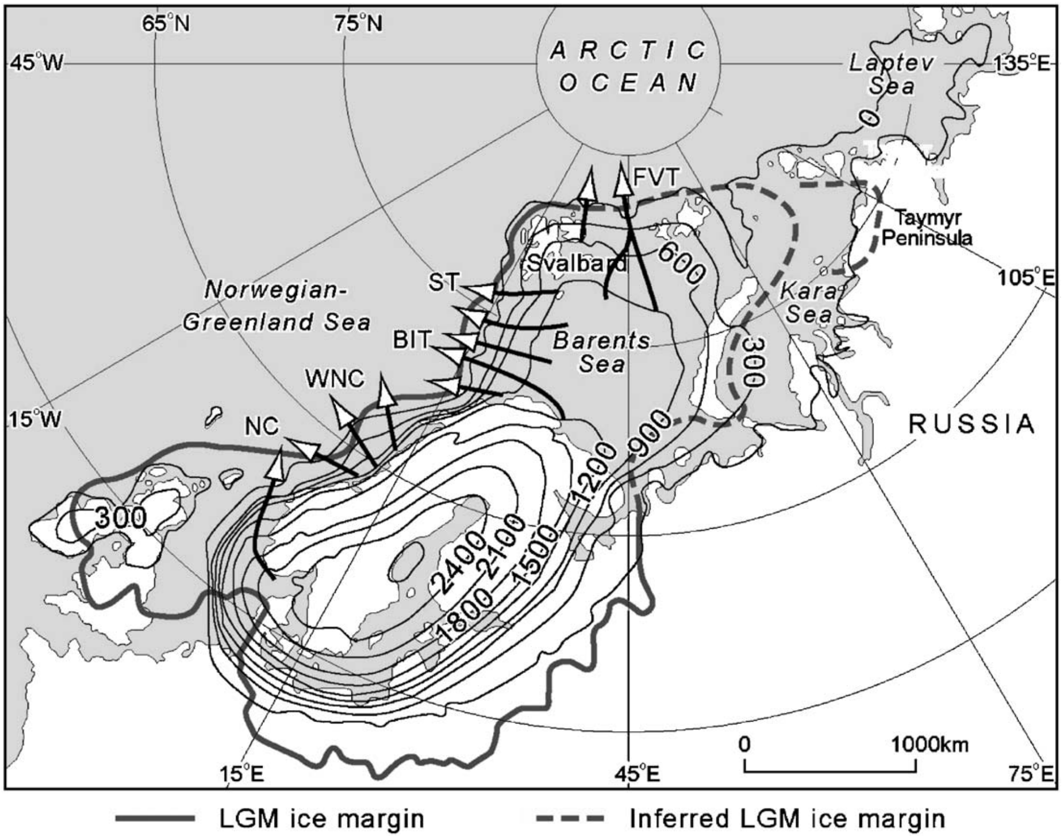

Fig. 1. The Eurasian Ice Sheet thickness at the LGM as modelled by Siegert et al. (1999). Contours are provided every 300 m. The flow directions and locations of major ice streams within the Norwegian Channel (NC), a series of western Norwegian Channels (WNC), the Bear Island Trough (BIT), Storfjorden (ST) and the Franz Victoria Trough (FVT) are denoted by arrows. Also shown is the ice sheet margin derived from geological evidence as a thick grey line (after Svendsen et al., 1999).