Heinrich events modeled in a fully coupled ice sheet – climate model

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Introduction

We study is glacial climate variability with a coupled atmosphere-ocean general circulation model (AOGCM)–ice sheet model system, focusing on one of the most prominent features of glacial climate variability, the Heinrich events. Modeling past climates and periods of past climate change is an important test of the capability of climate models to correctly represent future climate changes. Only if we can correctly represent past climates and climate changes, we can be confident about our predictions of future climate changes.

Model setup

We coupled the AOGCM ECHAM5/MPIOM/LPJ interactively with the ice sheet model mPISM. mPISM is a modified version of the Parallel Ice Sheet Model from the University of Alaska, Fairbanks. We run ECHAM5 in T31 resolution (3.75°), MPIOM with a nominal resolution of 3°, and mPISM on a 20 km grid covering most of the northern hemisphere.

The models are coupled bidirectionally after every year of climate model integrations. We do not use flux correction or anomaly maps in our models. In the asynchronously coupled experiment, the models are coupled 1:10 and the experiment covers 3000 years in the climate model and 30 000 years in the ice sheet model. The synchronously coupled experiment focuses in on the third ice sheet collapse from the asynchronously coupled experiment and covers 3200 years in each model.

Results

The asynchronously coupled experiment is the first fully coupled long-term Last Glacial Maximum (LGM) ice sheet model – AOGCM experiment. In this experiment, we obtain reasonable LGM ice sheets (**Fig. 1**) and a reasonable LGM climate (**Fig. 2**). The ice streams show periodic surges (**Figs. 3, 5**) because of the internal instability mechanism proposed by MacAyeal (1993). The timescale of the repeat cycle is set by the time it takes the surface accumulation to rebuild the ice sheet. The freshwater pulses from the surges weaken the NADW cell and thus strengthen the AABW cell (**Fig. 4** for the NADW cell). In the synchronously coupled experiment, we first observe surges of the ice streams at the coasts of the Arctic Ocean. These ice released in these surges (**Fig. 6**) causes a regional sub-surface warming (**Fig. 7**), that could have synchronised the surges. This synchronization via the sub-surface ocean temperatures was ruled out by a sensitivity study with prescribed cold ocean temperatures. While the Labrador Sea sub-surface temperatures sink during the surges of the Arctic Ice Streams, they rise during the surge of the Hudson Strait Ice Stream (**Figs. 5, 7**). The surges cause large scale cooling on the northern Hemisphere (**Fig. 8**) and other climate changes consistent with proxy data.

Literature

Bueler and Brown, 2009, The shallow shelf approximation as a "sliding law" in a thermomechanically coupled ice sheet model

Calov et al., 2002, Large-scale instabilities of the Laurentide Ice Sheet simulated in a fully coupled climate-system model

MacAyeal, 1993, Binge/Purge oscillations of the Laurentide Ice Sheet as a cause of the North Atlantic's Heinrich events

Peltier, 2004, Global glacial isostasy and the surface of the ice-age earth: The ice-5G (VM2) model and grace.

Tarasov et al., 2012, A data-calibrated distribution of deglacial chronologies for the North American ice complex from glaciological modeling.

Asynchronously coupled experiment

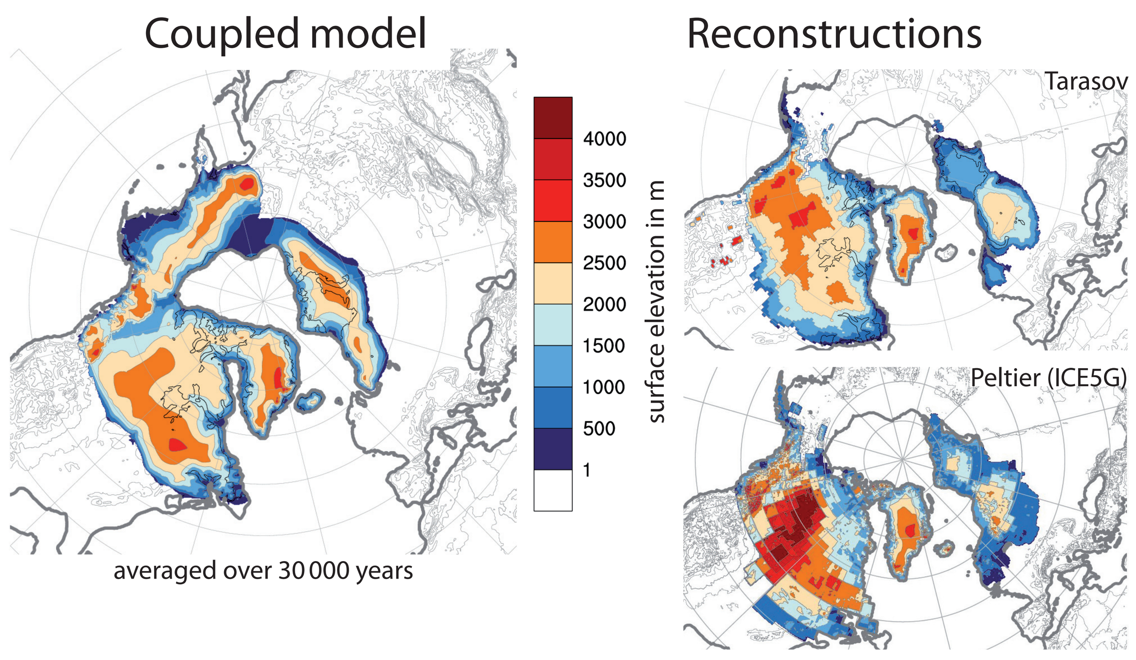

Fig. 1: Modeled and reconstructed LGM ice sheets
The modeled ice sheets reasonably agree with reconstructions for the Last Glacial Maximum by Peltier (2004) and by Tarasov (priv. comm., see Tarasov (2012) for a description of the methodology).

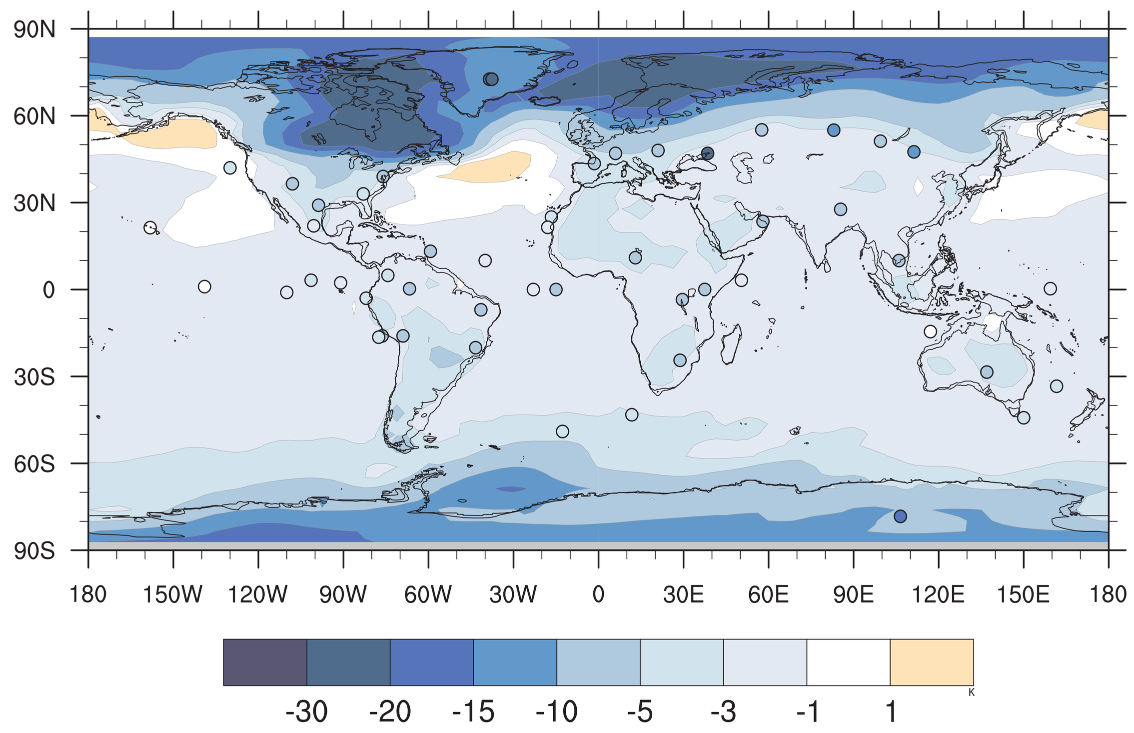

Fig 2: LGM air temperature anomaly
Surface air temperature difference between the asynchronously coupled LGM experiment and a pre-industrial control run. Dots indicate proxy reconstructions for LGM–present day by Kim et al. (2008).

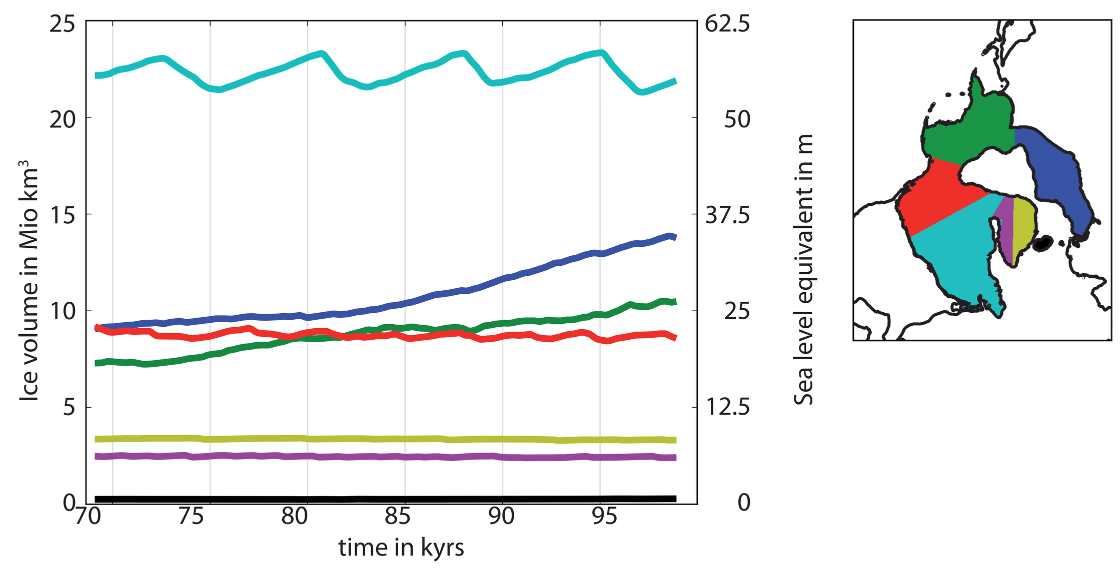

Fig 3: Ice sheet volumes in the steady-state experiments
The surges of the Hudson Strait Ice Stream dominate the variability. The period of 7000 years agrees with proxies for Heinrich events.

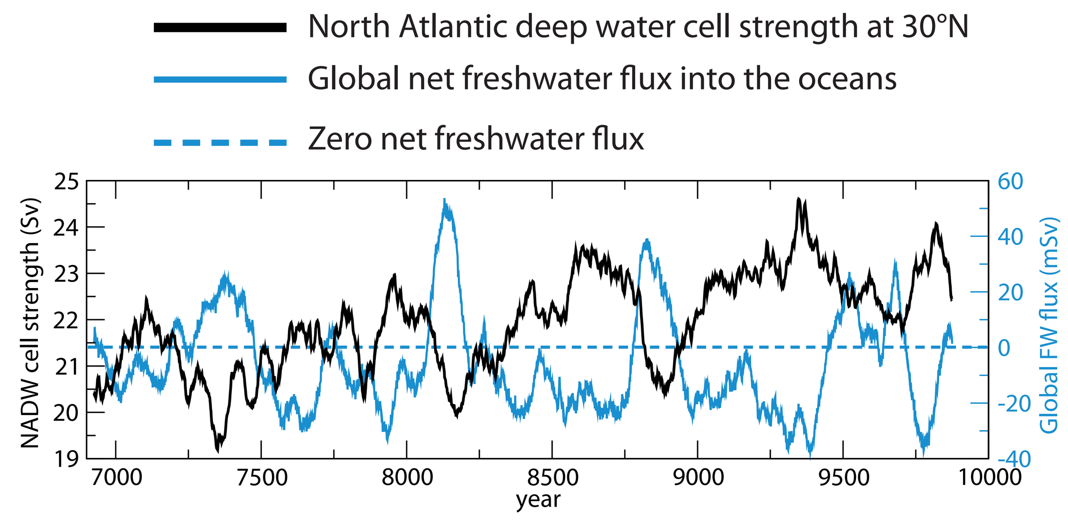

Fig. 4: Freshwater fluxes and NADW cell strength
The fresh water released in the surges stabilizes the ocean stratification, this weakens deep convection and thus the North Atlantic deep water cell.

Synchronously coupled experiment

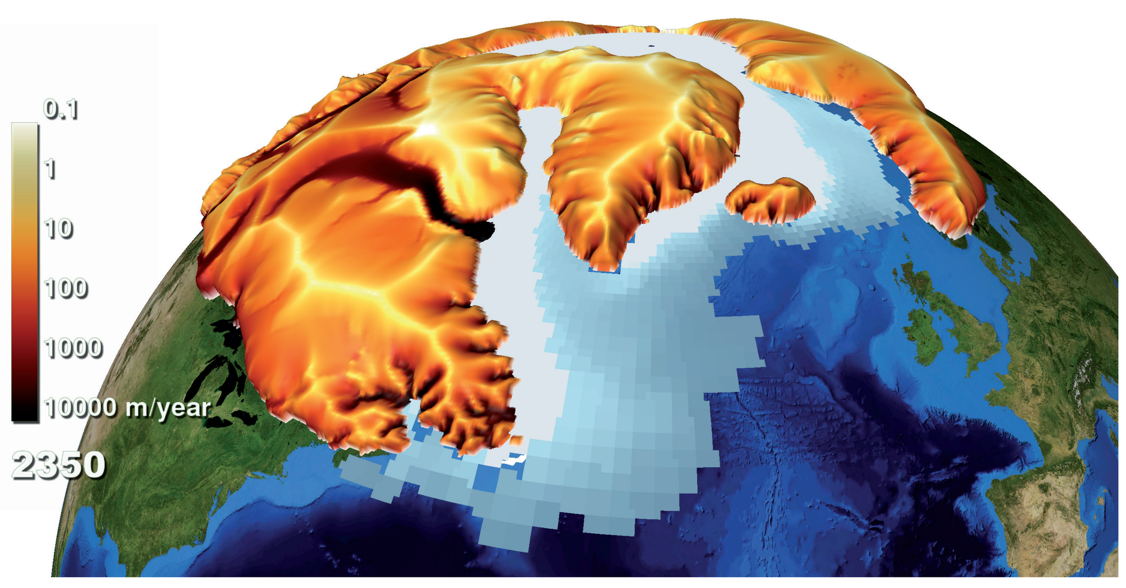

Fig 5: The surge of the Hudson Strait Ice Stream
The ice sheets are drawn for year 2350 (start of blue bar) Colors display the vertically averaged horizontal ice velocity. In the ocean, colors indicate annual mean sea ice cover fraction. Visualization by Niklas Röber/DKRZ

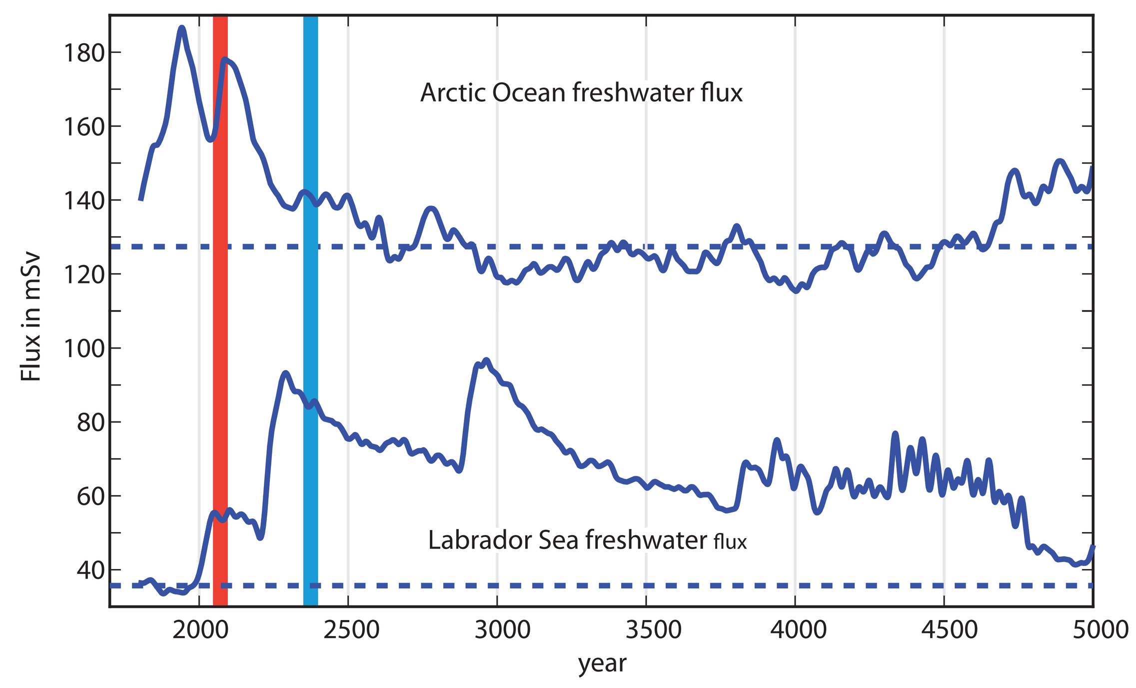

Fig 6: Net freshwater fluxes into the ocean
The ice stream surges cause freshwater pulses in the ocean. Dashed lines mark fluxes in the reference period. The colored bars mark the averaging intervals for the surges of the Arctic ice streams and the Hudson Strait Ice Stream.

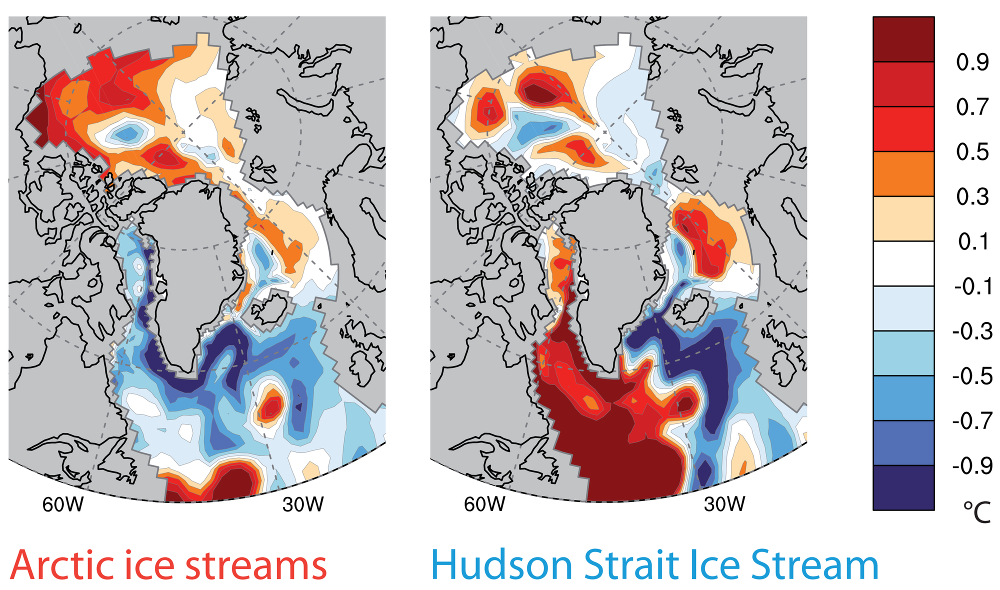

Fig 7: Sub-surface ocean temperature changes
Ice stream surges stabilize the ocean stratification and thus cause regional sub-surface warming. The sub-surface ocean temperature is decisive for ice shelf basal melt and a candidate for triggering ice stream surges.

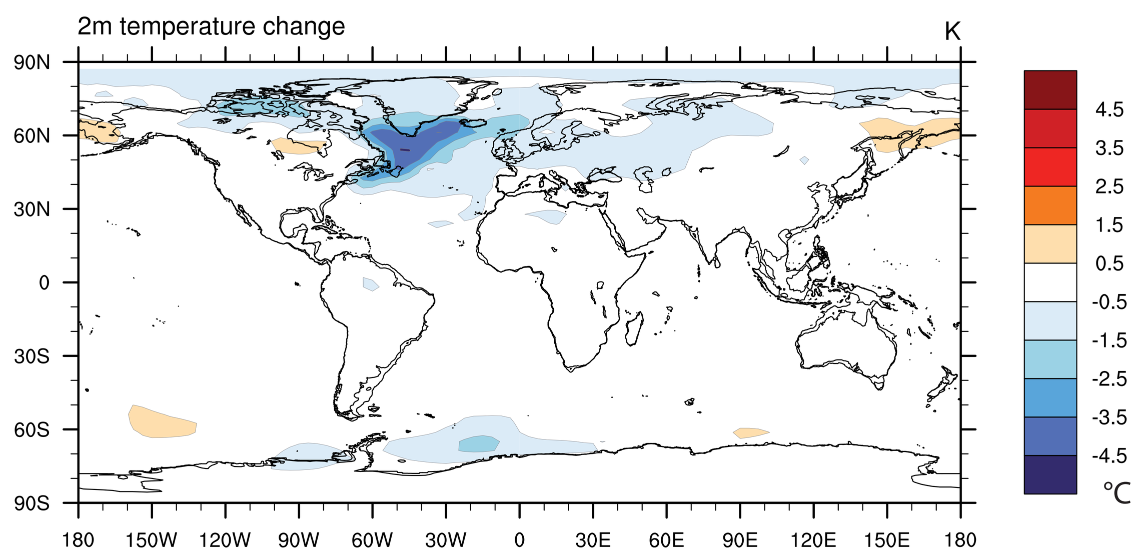

Fig 8: 2 m air temperature changes
The surge of the Hudson Strait Ice Stream causes cooling over the Labrador Sea and the Arctic, this spreads into Eurasia and the Arctic.

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The simulations were performed on the Blizzard supercomputer of the DKRZ. The resources were provided by BMBF project 675.

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