Coupled ice sheet-climate modeling

For a better understanding of the climate system, past climates (paleoclimates) are studied with model simulations. During the last ice age, massive ice sheets covered not only Greenland and Antarctica, but also large parts of North America, Scandinavia, and parts of northern Siberia. Florian Ziemen and his colleagues from the Max Planck Institute for Meteorology (MPI-M) coupled an ice sheet model (mPISM) interactively with MPI-M´s global climate model (ECHAM5/MPIOM). With this new model system, they studied coupled ice sheet–climate simulations for pre-industrial times and the last ice age for the first time.

In the comprehensive coupled climate models, the ice sheets previously were prescribed when studying the ice age. Ice sheets vary on timescales of centuries to millennia, and their changes were therefore considered as negligible for shorter simulations. Nevertheless, these ice sheets do change and interact with the other climate-system components atmosphere and ocean. Therefore, simulations are required that can represent the climate as well as the ice sheets and their interactions.

The results of the ice-age and pre-industrial simulations agree reasonably well with reconstructions and observations. This shows that the new model system adequately represents large, non-linear climate perturbations (fig. 1).

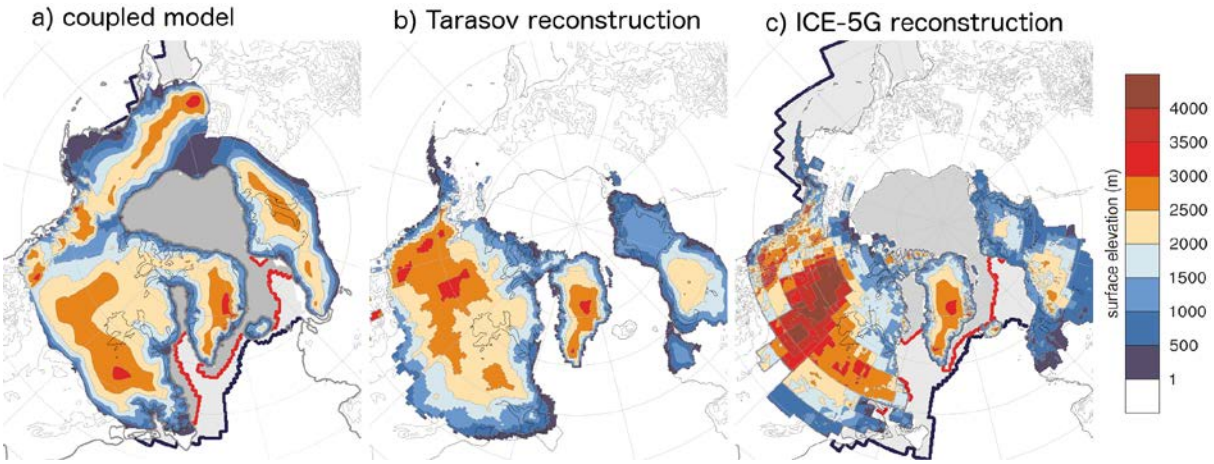

Fig. 1: Comparison of the modeled ice sheets with geological reconstructions. Ice-covered regions are colored. Isolines are drawn every 500 m. Over the ocean, dark gray with a red outline indicates areas with perennial ice cover (>15 %) in more than 50 % of the model years. Light gray with a black outline indicates temporary ice in more than 50 % of the model years. **(a)** Surface topography and sea ice from the ice age experiment (averaged over the full ice age simulation). **(b)** Geological reconstruction by Lev Tarasov (Tarasov and Peltier, 2003; Tarasov et al., 2012). **(c)** Reconstruction ICE-5G by Peltier (2004) and sea ice from an experiment with a climate model where ice sheets are prescribed.

A large part of the drainage of the modeled ice sheets occurs in ice streams. Many of the modeled ice streams show recurring surges. Gradual ice build-up is followed by quick discharge into the ocean. The Hudson Strait Ice Stream surges with an ice-volume equivalent of about 5 m in global sea level and a recurrence interval of about 7000 years (fig. 2). This is in agreement with basic expectations towards occurrences and reconstructions for Heinrich events[1] in Atlantic sediment cores.

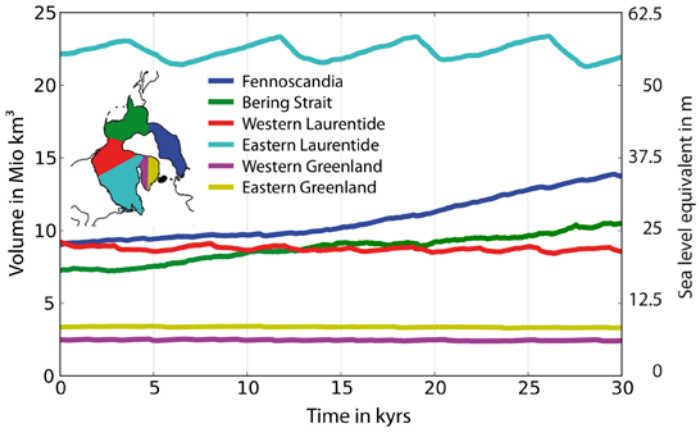

Fig. 2: Temporal development of ice-sheet volumes during the experiment. The inset displays the split of the ice sheets into different regions. The eastern part of the Laurentide Ice Sheet shows gradual ice build-up followed by a quick decrease in ice volume. The oscillations stem from the pulsation of the Hudson Strait Ice Stream in the model.

The model shows two different stable states of circulation and deep water formation in the North Atlantic, both depending on the ice-sheet geometry. Multiple stable deep-water formation states in the North Atlantic can lead to rapid switches between these states. Such a shift would cause a significant climate change within a short time and could be a possible mechanism for the significant glacial climate change events.

To gain further insight into ice sheet–climate interactions, Uwe Mikolajewicz and Florian Ziemen run simulations on timescales of thousands of years, studying the ice-sheet melting at the end of the ice age. The models are being refined by comparisons with reconstructions. Hence, future sea-level and ocean circulation projections will also benefit from their studies.

[1] **Heinrich events** are climate fluctuations that occurred during ice ages, when many icebergs transported sediments from Canada over the North Atlantic. This coincides with a considerable decrease of the North Atlantic Current that supplied Europe with warmth. Imprints of these events can be found as far away as China. The events were postulated by Hartmut Heinrich on the basis of sediment studies of the Atlantic seabed.

Paper:

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