Simulation of large-scale ice-sheet surges for the ISMIP HEINO set-up

Ralf GREVE (1), **Reinhard CALOV** (2), **Ryoji TAKAHAMA** (1)

(1) Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan

(2) Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

Introduction

Heinrich Events (HEs), which have been discovered in North Atlantic sediments as layers of ice-rafted debris, are associated with episodes of massive iceberg discharge from the Laurentide Ice Sheet into the Atlantic Ocean during the Weichselian glacial. The discharge events are likely caused by quasi-periodic collapses of the ice sheet over Hudson Bay and Hudson Strait, which occur when the basal temperature reaches the pressure melting point, so that very rapid basal sliding on a lubricating sediment layer develops. Besides representing catastrophic glaciological events, HEs are also closely related to abrupt climate changes via their impact on the Atlantic thermohaline circulation.

ISMIP HEINO

The ISMIP HEINO [Ice Sheet Model Intercomparison – Heinrich Event IntercOm-parison; see http://www.pik-potsdam.de/~calov/heino.html] experiments have been designed in order to investigate the dependence of these instabilities on atmospheric and basal conditions and compare the results of different ice-sheet models. The simplified geometry is shown in Fig. 1.

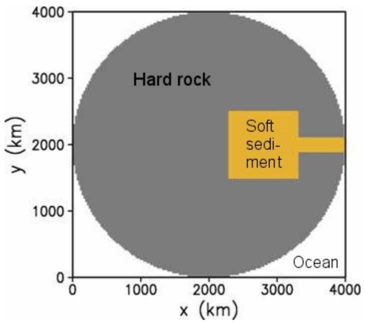

FIG. 1: Model domain of ISMIP HEINO. The sediment area mimics Hudson Bay (square) and Hudson Strait (channel towards the right).

Boundary conditions

Surface:

- Temporally constant glacial climate.
- Temperature: –40°C (center) ... –20°C (margin).
- Mass balance: 0.15 m/a (center) … 0.3 m/a (margin).

Bedrock:

- Rapid sediment sliding for $T = T_{pmp}$: $v_b = -C\tau/(\rho g)$, $C = 500\ a^{-1}$.
- Slow hard-rock sliding for $T = T_{pmp}$.
- No-slip condition for $T < T_{pmp}$.
- Geothermal heat flux 42 mW m^{-2}.

Model SICOPOLIS

For this study, we use the ice-sheet model SICOPOLIS, which simulates the large scale dynamics and thermodynamics (ice extent, thickness, velocity, temperature, water content and age) of ice sheets three-dimensionally and as a function of time. For all simulations, the resolution is 50 km, the model time is from t = 0 until t = 200 ka, starting from ice-free initial conditions, and the time-step is 0.25 a.

Results (standard run ST)

Set-up as defined above. Fig. 2 shows results for the period from 150 until 200 ka.

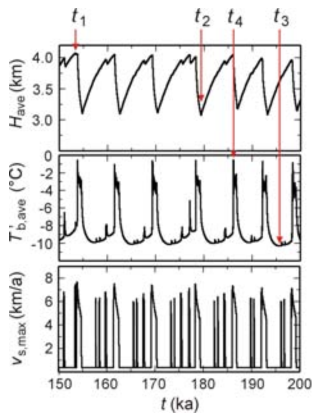

FIG. 2: Time series of run ST (for the last 50 ka only): average ice thickness, H_{ave}, average basal temperature relative to pressure melting, $T'_{b,ave}$, and maximum surface velocity, $v_{s,max}$.

The average ice thickness over the sediment area varies with a mean period of approx. 7500 years (see also Fig. 3) and an amplitude of about 1 km. One full cycle consists of a gradual growth phase, followed by a massive surge. During the growth phase, basal temperatures are below pressure melting for most of the sediment area, and the ice flows slowly by internal deformation only. During the surge, basal temperatures are at the pressure melting point, and flow velocities of up to 8 km/a are developed (see also Fig. 4).

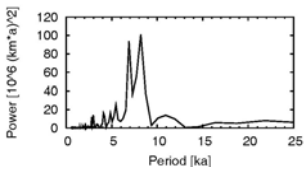

FIG. 3: Power spectrum of the average ice thick-ness H_{ave} of run ST (see Fig. 2, top panel).

The signal of the maximum surface velocity shows a number of additional, higher-frequency peaks. They are also visible in the power spectrum as peaks at periods between 1 and 5.5 ka.

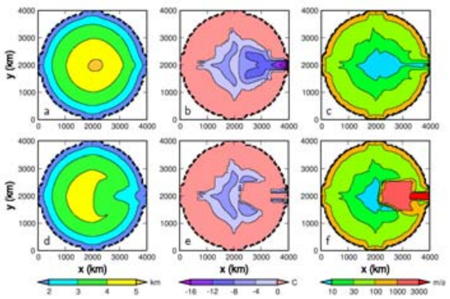

FIG. 4: Phases of a Heinrich Event (HE). (a) Ice thickness at time t_1, (b) basal temperature relative to pressure melting at time t_1, (c) surface velocity at time t_1 (before a HE). (d) Ice thickness at time t_2 (after a HE). (e) Basal temperature relative to pressure melting at time t_4, (f) surface velocity at time t_4 (during a HE).

Parameter variations

Additional runs with varied sediment-sliding parameter C have been carried out. Results are shown in Fig. 5. As expec-ted, the amplitude of the free oscillations increases strongly with increasing value of C.

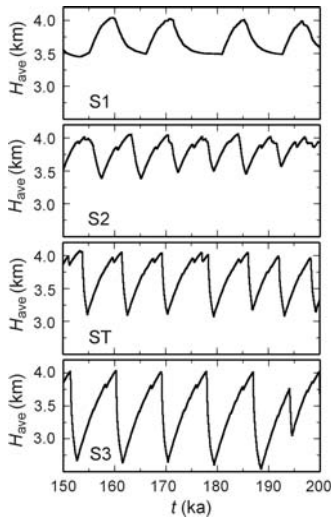

FIG. 5: Time series of average ice thickness, H_{ave}, for runs S1, S2, ST and S3 (sediment-sliding parameter C=100, 200, 500 and 1000 a^{-1}, respectively).

Conclusion

The ice-sheet model SICOPOLIS operated at the Institute of Low Temperature Science, Hokkaido University, has success-fully provided large-scale ice-sheet surges for the ISMIP HEINO set-up. This supports the idea that Heinrich Events are essentially the result of internal ice-sheet dynamics and thermodynamics and do not depend crucially on external climate variability. We hope and expect that results from other working groups doing the same exercise with different models will corroborate this statement.