Project 675

Simulating Heinrich Events in a Complex Climate Model

Period: 2011-01-01 – 2011-12-31
Uwe Mikolajewicz, Florian Ziemen, and Christian Rodehacke

Project summary

In order to predict future climate change, it is of utmost importance that we understand past rapid climate change events with large amplitudes. Only by reproducing these events that went beyond the linear range, we can test and expand our understanding of the nonlinearities in the climate system and improve our predictions of the large climate changes we expect for the future. The effects of changing ice sheet dynamics and especially their interaction with a changing climate are critical issues in predicting future climate change. We will contribute to the understanding of these issues by modeling Heinrich events[1] in a fully coupled climate model — ice sheet model (ISM) system and investigating the processes and feedbacks occuring in the coupled simulations.

[1] Heinrich (1988)

Heinrich events and Dansgaard-Oeschger events[2] were the dominant features of the Last Glacial climate variability.[3] In a Heinrich event, the main actors are the Laurentide Ice Sheet (LIS) and the Atlantic Ocean. The general assumption is that Heinrich events are caused by internal oscillations of the LIS that trigger a release of large amounts of ice into the northern Atlantic.[4] The sea level rises by up to 10 meters and the Atlantic meridional overturning circulation decreases strongly. This reduces the oceanic heat transport to the north, the sea surface temperatures decrease and sea ice forms over large areas that were ice-free before. These changes affect the atmospheric flow patterns and thereby cause feedbacks on the ice sheet and the ocean. The breakdown phase of a Heinrich event lasts for about 1 kyr and Heinrich events recurred quasi-periodically with intervals of about 7 kyrs during the Last Glacial.

[2] Dansgaard et al. (1993)

[3] See Rahmstorf (2002) for a review on the climate and Kageyama et al. (2010) for a review on modeling it.

[4] MacAyeal (1993); Marshall and Koutnik (2006)

There is evidence that the ice losses during Heinrich events occurred almost simultaneously in different areas of the northern hemisphere.[5] This indicates that there either was a common trigger for the discharges[6] or that atmosphere and ocean coupled the different ice sheets.[7] The recurrence interval of 7 kyrs strongly suggests internal oscillations of the ice sheets as driver since this is a very long timescale for the other components of the climate system.

[5] Revel et al. (1996)

[6] Bond et al. (1999)

[7] Calov et al. (2002)

Although we have a basic understanding of the processes that lead to Heinrich events, we are still lacking a complete picture of all the processes and feedbacks involved during the events. Previous studies either used earth system models of intermediate complexity (EMICs) in combination with ISMs,[8] or prescribed the fresh water input to the ocean and studied the reaction of the climate system in EMICs or Atmosphere-Ocean General Circulation Models (AOGCMs) (*fresh water hosing experiments*).[9] With our project, we

[8] Calov et al. (2002)

[9] Otto-Bliesner and Brady (2010)

will close this gap between coupled EMIC and standalone AOGCM simulations by modeling a Heinrich event in ECHAM5/MPIOM coupled with the ISM mPISM.[10] This will be the first time, a Heinrich event is modeled in a AOGCM coupled with an ISM, and thus provide the unique possibility to investigate the full interaction of the ice sheet and the climate system during a Heinrich event.

[10] mPISM is a modified branch of the *Parallel Ice Sheet Model* (PISM). PISM is being developed at the University of Alaska, Fairbanks (UAF). Another branch (PISM-PIK) is being developed at the Potsdam Institute for Climate Impact Research (PIK).

Previous Work

Our work builds on previous experiments. We use an existing version of ECHAM5 T31 / MPIOM GR30 / LPJ. This model has already successfully simulated the LGM and has been coupled to an ISM before.[11] To save spinup and tuning time, we continue with this model configuration. This also allows us to employ a previously developed asynchronous coupling between the atmosphere and ocean components to minimize computational time.

[11] Mikolajewicz et al. (2007); Vizcaíno et al. (2010)

During the last year, we performed stand-alone simulations with the ice sheet model mPISM, where periodic ice sheet instabilities were obtained with a steady state climate. They are comparable to those expected to have caused Heinrich events.

The next step is to combine the models and use the next year to perform coupled experiments under Last Glacial Maximum conditions. For this step we need the facilities of the DKRZ.

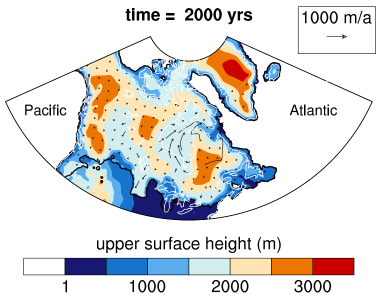

Figure 1: Snapshot of a Heinrich event in mPISM. Arrows indicate ice velocity.

References

Bond, G. C., Showers, W., Elliot, M., Evans, M., Lotti, R., Hajdas, I., Bonani, G. and Johnson, S., 1999. The north atlantic's 1-2 kyr climate rhythm: Relation to heinrich events, dansgaard/oeschger cycles and the little ice age. *Mechanisms of Global Climate Change At Millennial Time Scales*, 112:35–58.

Calov, R., Ganopolski, A., Petoukhov, V., Claussen, M. and Greve, R., December 2002. Large-scale instabilities of the laurentide ice sheet simulated in a fully coupled climate-system model. *Geophys. Res. Lett.*, 29. URL: `http://dx.doi.org/10.1029/2002GL016078`.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjornsdottir, A. E., Jouzel, J. and Bond, G., July 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature*, 364(6434):218–220. URL: `http://dx.doi.org/10.1038/364218a0`.

Heinrich, H., 1988. Origin and consequences of cyclic ice rafting in the northeast atlantic ocean during the past 130,000 years. *Quaternary Research*, 29(2):142 – 152. ISSN 0033-5894. URL: `http://dx.doi.org/10.1016/0033-5894(88)90057-9`.

Kageyama, M., Paul, A., Roche, D. M. and Meerbeeck, C. J. V., 2010. Modelling glacial climatic millennial-scale variability related to changes in the atlantic meridional overturning circulation: a review. *Quaternary Science Reviews*, 29(21-22):2931 – 2956. ISSN 0277-3791. URL: http://dx.doi.org/10.1016/j.quascirev.2010.05.029.

MacAyeal, D. R., 1993. Binge/purge oscillations of the laurentide ice sheet as a cause of the north atlantic's heinrich events. *Paleoceanography*, 8. URL: http://dx.doi.org/10.1029/93PA02200.

Marshall, S. J. and Koutnik, M. R., June 2006. Ice sheet action versus reaction: Distinguishing between heinrich events and dansgaard-oeschger cycles in the north atlantic. *Paleoceanography*, 21. URL: http://dx.doi.org/10.1029/2005PA001247.

Mikolajewicz, U., Vizcaíno, M., Jungclaus, J. and Schurgers, G., September 2007. Effect of ice sheet interactions in anthropogenic climate change simulations. *Geophys. Res. Lett.*, 34. URL: http://dx.doi.org/10.1029/2007GL031173.

Otto-Bliesner, B. L. and Brady, E. C., January 2010. The sensitivity of the climate response to the magnitude and location of freshwater forcing: last glacial maximum experiments. *Quaternary Science Reviews*, 29(1-2):56–73. URL: http://dx.doi.org/10.1016/j.quascirev.2009.07.004.

Rahmstorf, S., September 2002. Ocean circulation and climate during the past 120,000 years. *Nature*, 419(6903):207–214. ISSN 0028-0836. URL: http://dx.doi.org/10.1038/nature01090.

Revel, M., Sinko, J. A., Grousset, F. E. and Biscaye, P. E., 1996. Sr and nd isotopes as tracers of north atlantic lithic particles: Paleoclimatic implications. *Paleoceanography*, 11(1):95–113. URL: http://dx.doi.org/10.1029/95PA03199.

Vizcaíno, M., Mikolajewicz, U., Jungclaus, J. and Schurgers, G., 2010. Climate modification by future ice sheet changes and consequences for ice sheet mass balance. *Climate Dynamics*, 34: 301–324. ISSN 0930-7575. URL: http://dx.doi.org/10.1007/s00382-009-0591-y.