Geophysical Research Abstracts, Vol. 7, 05053, 2005
SRef-ID: 1607-7962/gra/EGU05-A-05053

A Study of Climate-Cryosphere Hysteresis

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We study the hysteresis of the climate-cryosphere system with the Earth system model of intermediate complexity CLIMBER-2. The model encompasses atmosphere, ocean, terrestrial vegetation and inland ice. The statistical-dynamical atmospheric module interacts with the three-basins ocean through the surface fluxes of heat, fresh water and momentum. The vegetation module describes fractions of tree, grass and bare soil coverage. The inland-ice component is represented by the polythermal ice-sheet model SICOPOLIS, which simulates the thickness, velocity, temperature and water content of grounded ice sheets. The inland ice is coupled bi-directional to the climate component of CLIMBER-2 through surface mass balance and annual surface temperature in the one direction and through the change in orography, inland-ice cover and land-ocean distribution in the other direction.

In a previous study we demonstrated with a couple of steady-state simulations that the system climate-croysphere exhibits hysteresis and multiple equilibria. These simulations were performed with different initial conditions in inland-ice distribution on the Northern Hemisphere; these initial conditions were no inland ice and maximum inland ice. The Earths orbital eccentricity and precession parameters were varied in a way to obtain a variety of global insolation forcings which have boreal summer insolations between high and low values. This set of orbital parameter and the two different initial conditions in ice cover were used for a number of steady-state simulations with CLIMBER-2.

We found that there are two distinct sets of equilibria for a broad range of orbital parameters around present-day insolation. The first equilibrium branch with little ice cover (interglacial states) was yielded with the no-inland-ice initial condition and the second equilibrium branch with expanded ice cover (glacial states) was reached with maximum inland-ice cover as initial condition. For experiments with orbital param-

eters representing high boreal summer insolation solely existed only the interglacial equilibrium branch irrespective which initial conditions were used. Analogously, the simulations with orbital parameters corresponding to low boreal summer insolation resulted in a sole glacial equilibrium branch.

Here, we investigate how the hysteresis diagram depends on the atmospheric CO_2 content. In particular, the insolation values of the transitions between the equilibrium branches (from glacial to interglacial state or vice versa) depend on the CO_2 values used in the simulations. The runs were performed with different types of basal sliding over sediment; experiments with fast sliding and simulations with slow sliding. With fast sediment sliding the hysteresis diagram is considerably narrower than with slow sediment sliding indication the importance of fast sliding to model glacial terminations.

The steady-state runs were not the only method used to compute the hysteresis diagrams. In addition, we also performed transient simulation, where the eccentricity was changed very slowly. Comparison of the hysteresis diagrams from the transient runs show good agreement with the ones resulting from the steady-state method. Additionally, different methods in the variation of the orbital parameter led to broadly similar results.

In summary, the study of the hysteresis phenomenon in the climate-cryosphere system is of high importance for the understanding of glacial cycles, inceptions and terminations. Insightfully, it shows that the model with fast sediment sliding appears to be more realistic and adequate to describe the evolution of inland ice during the Quaternary. Further, the interglacial-glacial and glacial-interglacial transition thresholds depend on the atmospheric CO_2 content. Finally, we demonstrated that the climate-croysphere hysteresis is a robust characteristic of our model.