A study of climate-cryosphere hysteresis

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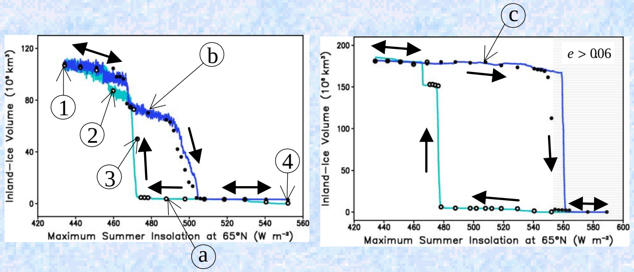
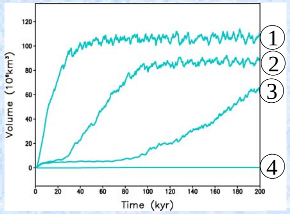
All simulations with the Earth system model CLIM*BER*-2 incl. SICOPOLIS

Hysteresis and ice mobility

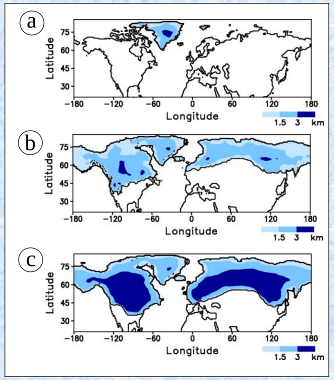
The hysteresis graphs are found with quasi-equilibrium simulations over 200 kyrs (200,000 years) and with transient simulation driven by slowly varying orbital parameters (obliquity of the Earth's axis ε=23°, angle between vernal equinox and perihelion ω=90°, 270° and eccentricity e=0, ..., 0.06) corresponding to rates of 1×10^{-4} W/m²/yr or 2×10^{-5} W/m²/yr near the bifurcations.



Hysteresis diagrams. Open small circles indicate quasi-equilibrium simulations with no ice as initial condition and full small circles show quasi-equilibrium simulations with maximum ice cover as initial condition. Solid curves are from slowly varying transient simulation. **Left:** Simulations with strong sediment sliding. **Right:** Simulations with low sliding velocities.



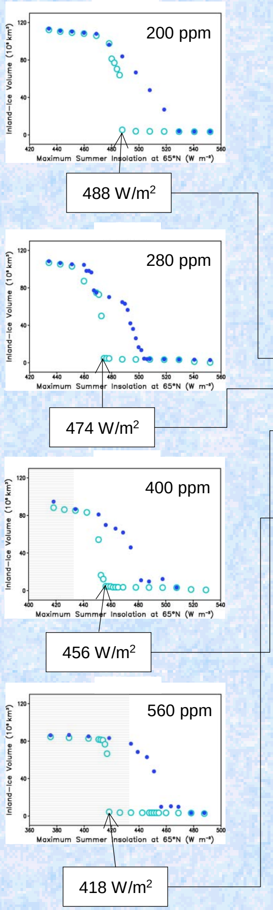
Top: Time series from equilibrium simulations with strong sediment sliding. Numbers 1, 2, 3 and 4 indicate positions in the hysteresis diagram at the top of this poster panel. **Right:** Equilibrium surface elevation. Letters a, b and c correspond to positions marked in the hysteresis diagrams

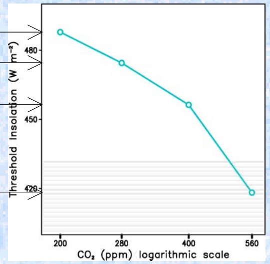


Results I: There are (at least) two distinct equilibria. The hysteresis graph from simulations with strong sliding is much narrower and the maximum ice volume is considerably smaller than those from simulations with weak sliding. The duration to equilibrate increases if the system comes closer to its bifurcations.

Atmospheric CO_2 content

Sets of equilibrium simulations over 200 kyrs with different values of the atmospheric CO_2 content lead to hysteresis graphs for each single CO_2 value. The transitions from interglacial to glacial state („glacial inceptions“) are plotted versus the CO_2 values.



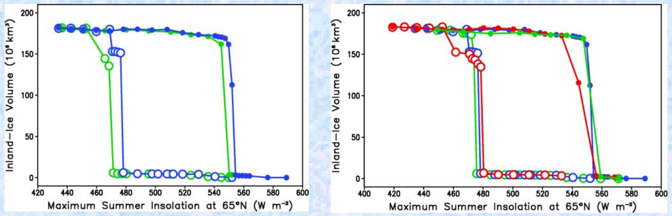


Left: Hysteresis graphs for several values of atmospheric CO_2 content from simulations with weak sliding. Regions with eccentricities which exceed 0.06 are grey shaded **Top:** Threshold for glacial inception of maximum summer insolation at 65°N versus atmospheric CO_2 content. The grey shading indicates insolation values which never appeared during the Quaternary.

Results II: The insolation causing the transitions between the states (interglacial to glacial state and vice versa) decrease noticeable with increasing atmospheric CO_2 content. The sensitivity of the glacial-inception threshold insolation to CO_2 increases for higher CO_2. The maximum equilibrium ice volume reduces with higher CO_2.

Orbital parameters

Here, the dependence of the hysteresis graph on the orbital parameters is inspected. This analyses have been performed in (equilibrium) simulations with weak sliding only. The same analysis with strong sliding is planned for the future.



Equilibrium simulations over 200 kyrs with different orbital parameters. Contrary, to the previous figures the marks of the equilibrium runs are connected with lines here. As before, open circles indicate simulations with no ice as initial condition and full circles display simulations with maximum ice cover as initial condition. In both panels, the blue curve originates from our standard procedure, where the angle between vernal equinox and perihelion ω is fixed, the obliquities of the Earth's axis ε=23° and the eccentricity is varied. **Left:** Alternatively, to the standard procedure the eccentricity is held fixed to e=0.06 and ω is varied from –90° to 90° with a step of 15°. **Right:** Simulations with different obliquities of the Earths axis (red curve: ε=22°, blue curve ε=23°, green curve: ε=24°) using the standard procedure.

Results III: The shape of the hysteresis graph depends only moderately on the method chosen to trace it if we plot our results against the maximum summer insolation at 65°N. The dependence of the shape of the hysteresis graph on different values of obliquity of the Earths axis is small if we plot our results against the maximum summer insolation at 65°N. The maximum summer insolation at 65°N a good proxy for the orbital forcing. The climate-cryosphere hysteresis is robust in our model.