Multiple sea-ice states and abrupt MOC transitions in a general circulation ocean model

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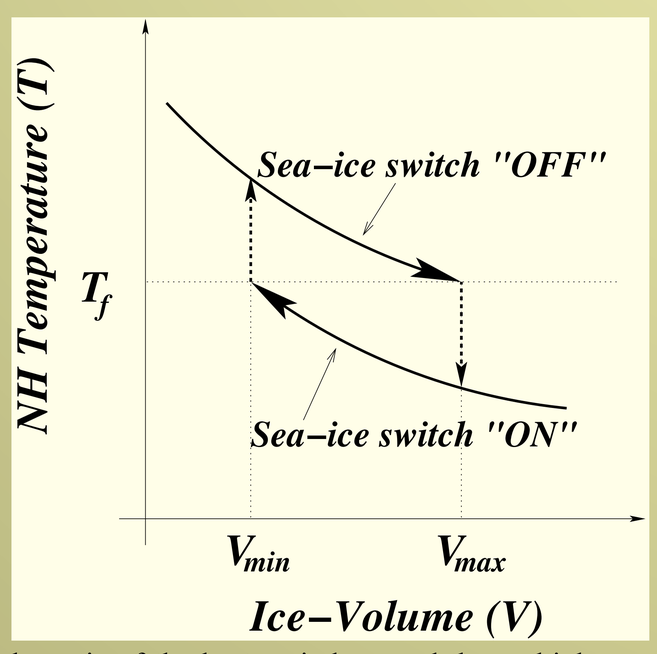
Abstract

Sea ice has been suggested, based on simple models, to play an important role in past glacial-interglacial oscillations via the so-called "sea-ice switch" mechanism. An important part of this mechanism is that multiple sea-ice extents exist under the same land ice configuration. This hypothesis of multiple sea-ice extents is tested with a state-of-the-art ocean general circulation model coupled to an atmospheric energy-moisture-balance model. The model includes a dynamic-thermodynamic sea-ice module, has a realistic ocean configuration and bathymetry, and is forced by annual mean forcing. Several runs with two different land ice distributions represent present-day and cold-climate conditions. In each case the ocean model is initiated with both ice-free and fully ice-covered states. The present-day runs converge approximately to the same sea-ice state for the northern hemisphere while for the southern hemisphere a difference of ~3◦ latitude between the sea-ice extents of the different runs is observed. The cold climate runs lead to meridional sea-ice extents that are different by up to four degrees in latitude in both hemispheres. While approaching the final states, the model exhibits abrupt transitions from extended sea-ice states and weak meridional overturning circulation, to less extended sea ice and stronger meridional overturning circulation and vice versa. These transitions are linked to cooling and warming of the North Atlantic high-latitude deep water. Such abrupt changes may be associated with the Dansgaard-Oeschger events, as proposed by previous studies.

Background

The sea-ice was previously suggested to underlie the glacial-interglacial via the sea-ice-switch (SIS) mechanism. Is this mechanism valid in an oceanic general circulation model?



Schematic of the hysteresis loop and the multiple sea ice and temperature states under the same continental ice volume. The arrows indicate the direction of the hysteresis loop.

The model

MITgcm coupled to an atmospheric energy moisture balance model (EMBM); dynamic/thermodynamic ice model is used.

Numerical experiments

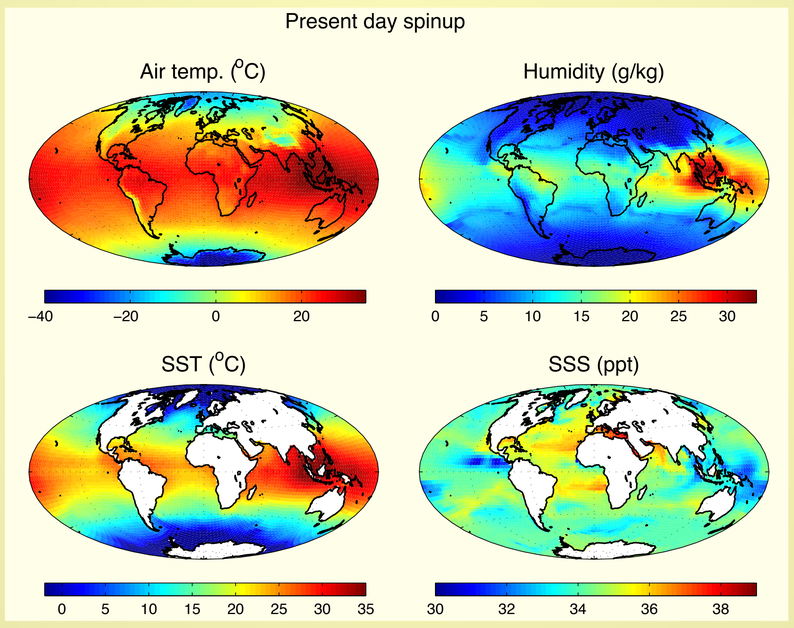
(i) *Present day* initial conditions and land-ice.

(ii) *Cold climate 1*: land ice albedo for latitudes 40–90°N, sea-ice albedo set to 1, atmospheric CO_2 level of 180 ppm, and increased atmospheric albedo profile.

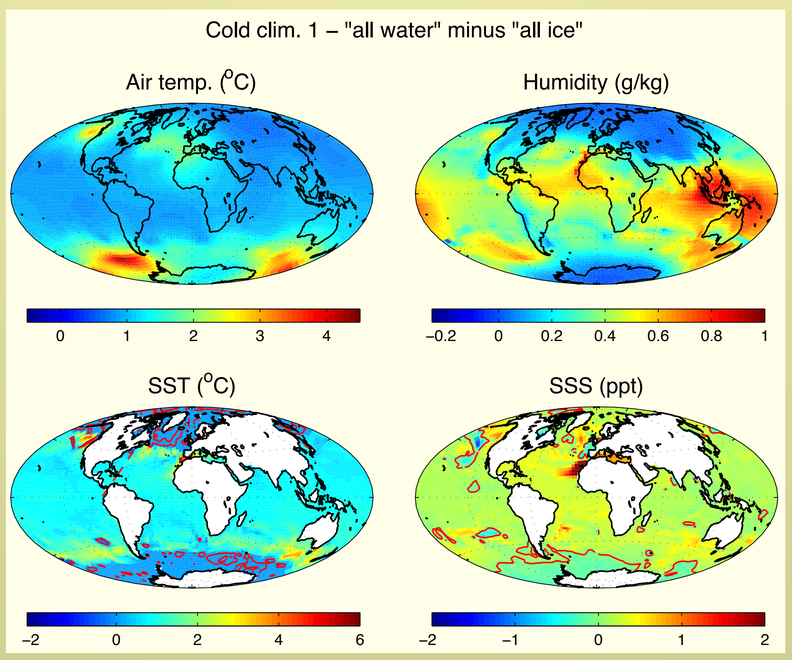
(iii) *Cold climate 2*: As cold climate 1 experiment but with a higher-yet atmospheric albedo.

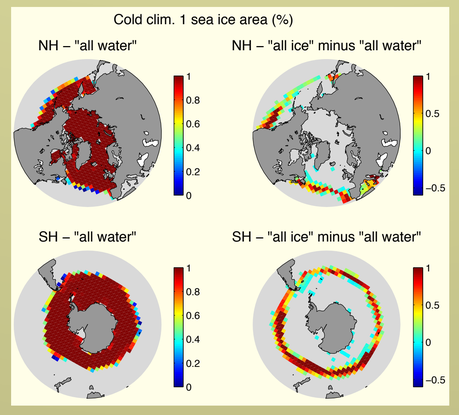
We first perform a spinup run 4000 years. Then, to capture a possible multiple states we start from either "all water" initial conditions—water is ice-free, or "all-ice" initial conditions—ocean is globally covered with sea ice.

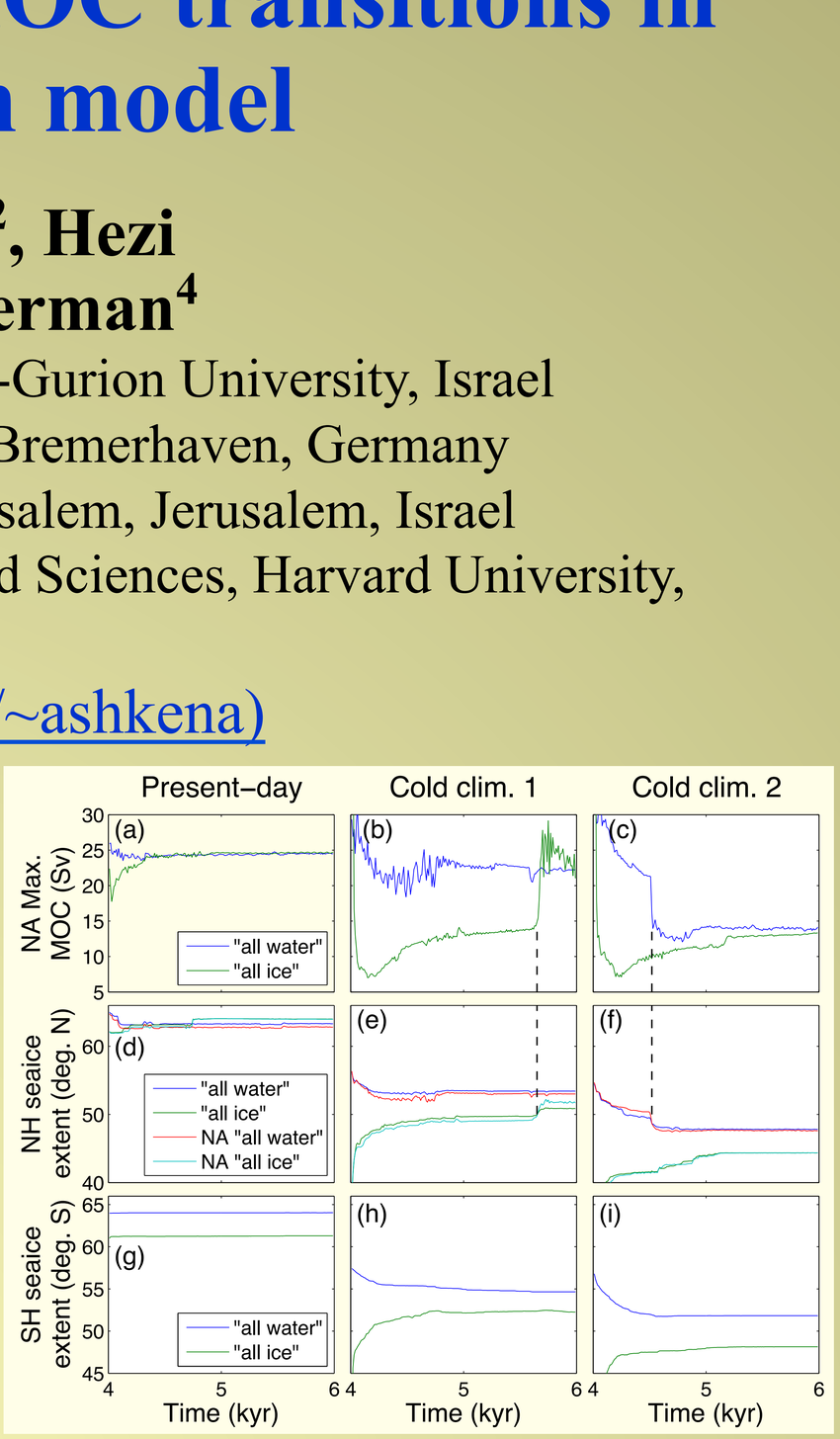
Results

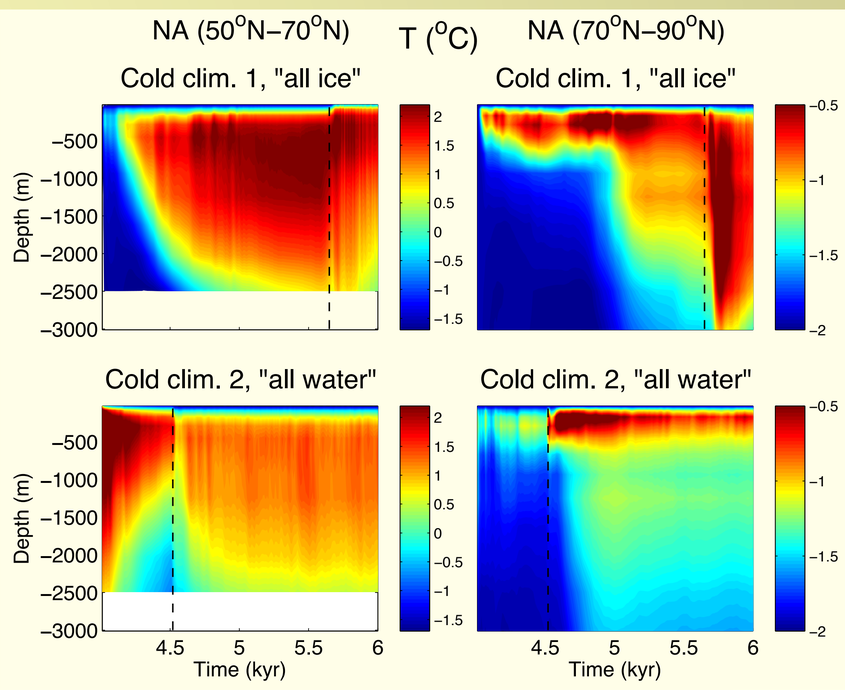


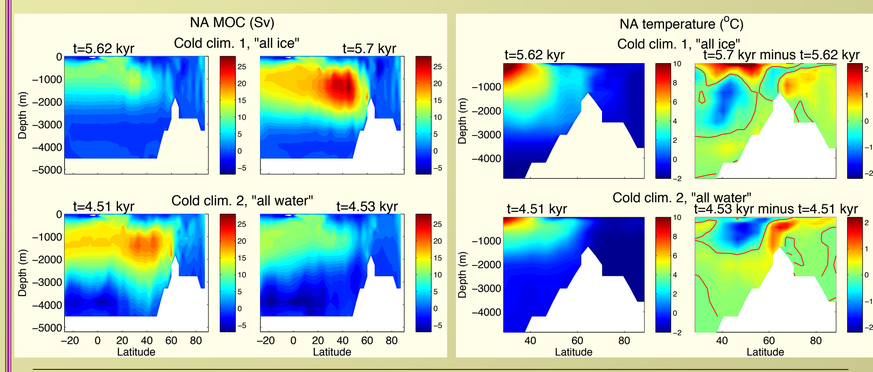
Present day: Results almost identical when starting from the different initial conditions. Some difference in sea-ice cover of the SH.











Conclusions:

- Indications for multiple seaice states under cold climate conditions.
- In the NH, changes in seaice cover may be associated with changes in the MOC.
- Transition cold-warm and warm-cold transtions are possible. Possible implications for the DO events.
- The multiple states of the SH are more pronounced and exist in all experiments.
- Seasonality may enhance or suppress the multiple seaice states.

The results presented here provide some support to the SIS mechanism of Gildor and Tziperman (2001).