Two-way coupled ice sheet–earth system model simulations: Spin-up, Validation, Skyrocketing forcing responce

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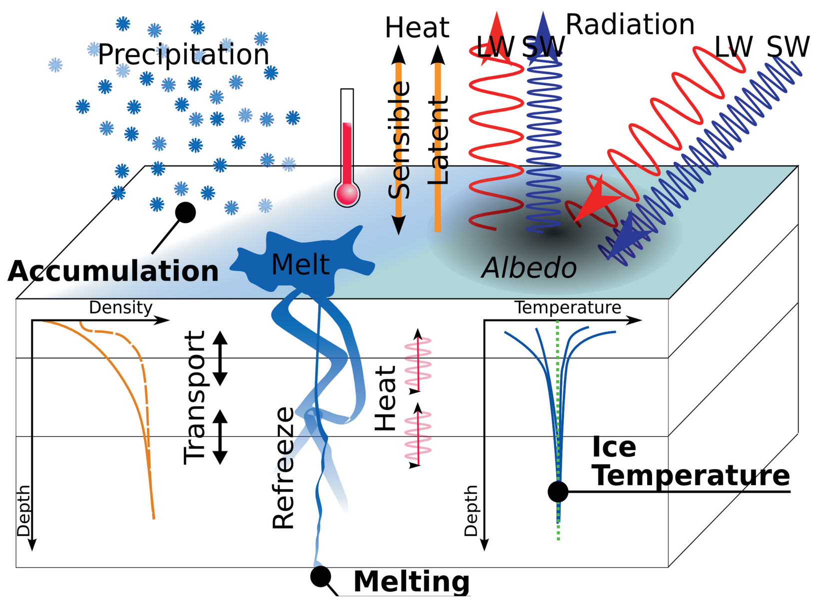
Introduction

Since ice sheets are slow climate components, they are usually not interactively coupled in climate models. The inclusion of ice sheets in climate models is necessary to tackle fundamental questions, such as how ice sheets have shaped and have contribute to abrupt climate changes in the past and how they contribute to sea level rise.

Method

The Earth system model (ESM) is coupled via an energy/mass balance model to the ice sheet model (Mikolajewicz et al., 2007, Vizcaino et al., 2009). After one ESM year, atmospheric fields are used to compute the ice sheet's surface temperature and surface mass and energy balance.

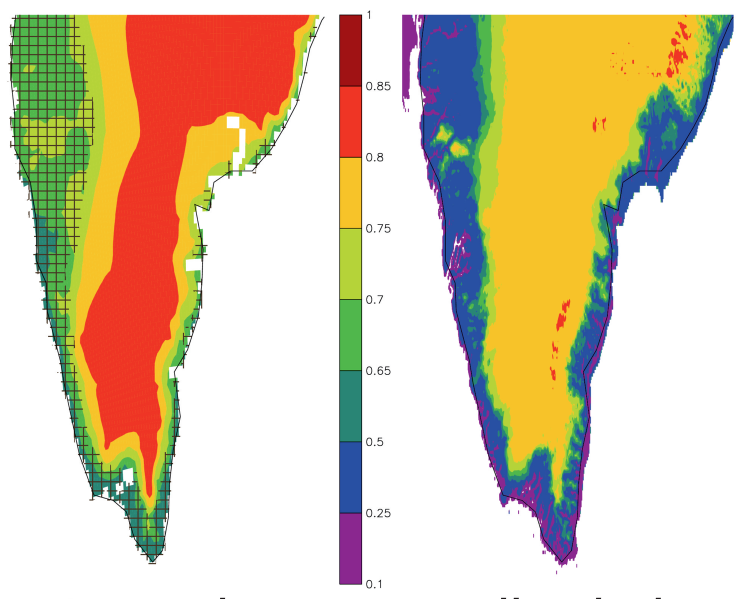


We correct height differences between the ice sheet model PISM (10 km grid) and the MPI-ESM (T63L47/GR15L40). The energy balance considers rain induced heat transfer and cloud cover dependency of the broad band albedo. Aging and related darkening of ice/snow, melting and refreezing, and the snow depth above the background determines the albedo.

The land's melt water is routed by the hydrological model. Ocean-ice sheet interaction releases melted ice into the ocean. Height changes of the ice sheet modify the orography and adjust the gravity wave drag parameterization in the atmosphere model. Retreating or advancing ice alters the surface in the vegetation model.

Validation

The surface mass balance (SMB) calculation is sensitive to the albedo parametrization. The computed annual albedo agrees generally with MODIS data: High values inland and lower values along the ice sheet margin, whereby the latter ones are essential. The winter values tends to be slightly larger, however the observation density is reduced during winter. The fractional proportioning of the surface melt vs ice berg loss exceeds observational estimates probabley to account for a too large ice extend and precipitation in the North.



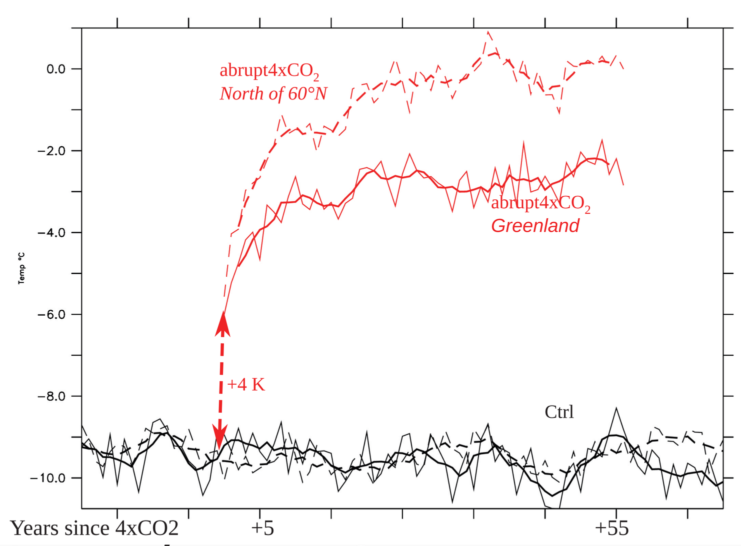
Annual average albedo in southern Greenland: right MODIS (2000-2013); left SMB model where hatched areas are ice free.

Coupled Runs

- The control run **Ctrl** has an atmos. CO_2 concentration of 285 ppm.
- The atmospheric CO2 jumps immediately to 4xCO_2 (1140 ppm) in 1850 in the run **abrupt4xCO_2** .

Earth System Response

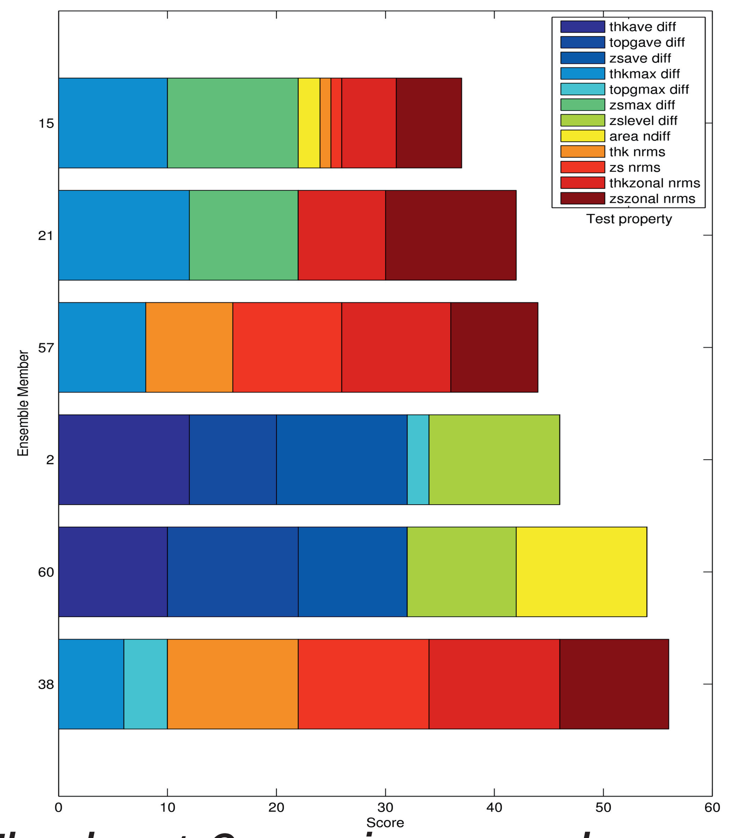
In abrupt4xCO_2 the skyrocketing CO_2 strengthens the radiative forcing that raises the annual mean temperature north of 60°N by 4 K in the first year and reaches 9 K after 55 years. The temperature raise over Greenland is reduced by 3 K compared to the circumpolar mean probably due to the albedo feedback.



Annual mean 2m-temperature for Ctrl and abrupt4xCO_2, north of 60°N and over Greenland

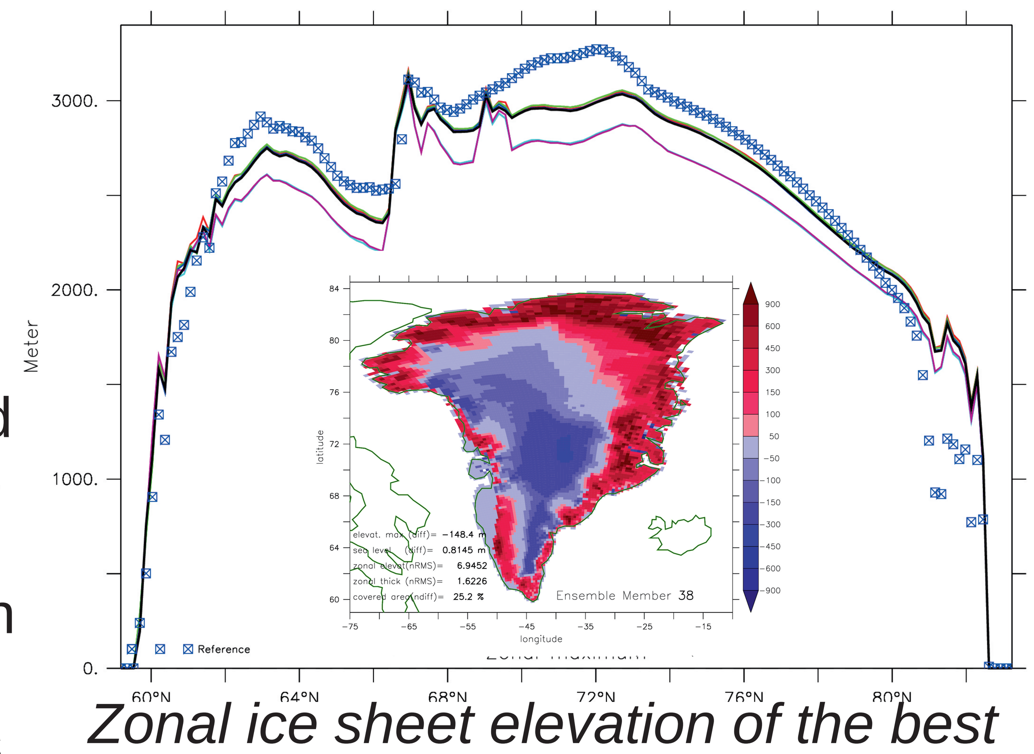
Ice Sheet (pre)Spin Up

Before coupling Greenland starts from the current geometry and is spun up for 150 kyr using ice core temperature anomalies to scale the precipitation and compute the temperature on top of pre-industrial temperatures fields from our ESM control run. Only for the (pre)spin-up the ablation is computed by the positive degree day method (PDD). The accumulation equals the precipitation for an air temperature of -10°C and decreases linearly to zero until the freezing point is reached. Our ice sheet should show an adequate ice softness.



The best 6 scoring members out of 64 based on 12 quantities: eg. differences in the maximal and mean ice thickness (thk) or height (zs), ice volume and RMS of zonal thk or zs.

Since parameters controlling the ice sheet are uncertain, we've performed Latin Hyper Cube (LHC) simulations by varying the lapse-rate (4.5K/km to 7K/km), the enhancement factor for the ice softness (1.0 to 3.5) and the PDD factors. The member best reproducing the current state is coupled with our ESM. The overstimated ice thickness in the North is a common problem and related to slightly to strong precipitation.

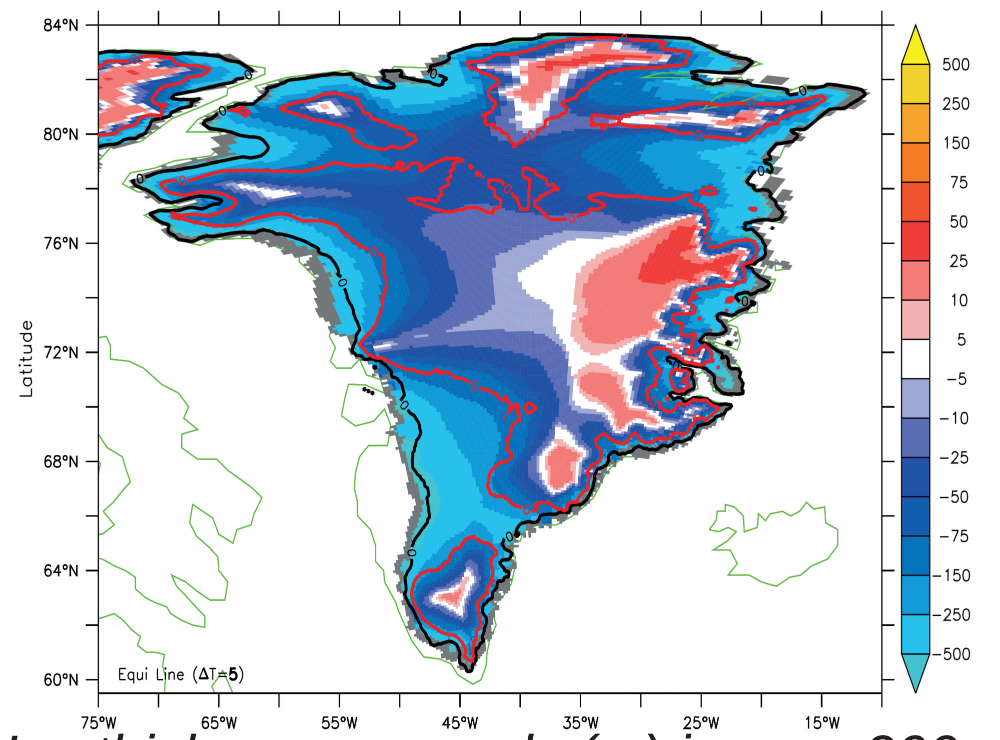


Zonal ice sheet elevation of the best performing members (lines) and observations (dots; Sea Rise data). The Inlead shows the surface elevation anomaly.

Ice sheet response

The strong strong radiative forcing increases beside the atmospheric temperature also the melting over Greenland. After 250 years the margin losses ice completely (grey) and the equilibrium lines migrates inside Greenland.

The ice sheet losses ice and only few confined areas showing a growing ice thickness. There the enhanced hydrological cycle in a warmer climate increases accumulations and overwhelms any increased lateral ice transport or melting.



Ice thickness anomaly (m) in year 200. Equilibrium lines (5 yr mean) are black (Ctrl) and red (abrupt4xCO_2). Grey patches show complete ice loss.

Summary

- Our coupling scheme between ESM and ice sheets conserves mass, and does not use anomaly coupling nor flux correction.
- The essential albedo agrees reasonably with observations.
- Strong CO2 forcing causes enhanced surface melting rates of the Greenlandic ice sheet, which exceed the increased precipitation.
- Few higher elevated areas show a positive surface mass balance.

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References:

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Vizcaino, M., U. Mikolajewicz, J. Jungclaus, and G. Schurges (2009). Climate modification by future ice sheet changes and consequences for ice sheet mass balance, Climate Dynamics, 34, doi: 10.1007/s00382-009-0591-y

THOR combine

The research leading to these results has received funding from the European Community's 7th framework pro-gramme under grant agreement no. GA212643, THOR ("Thermohaline Overturning – at Risk", 2008-2012) and under grant agreement no. 226520, COMBINE (Comprehensive Modelling of the Earth System for Better Climate Prediction and Projection).

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