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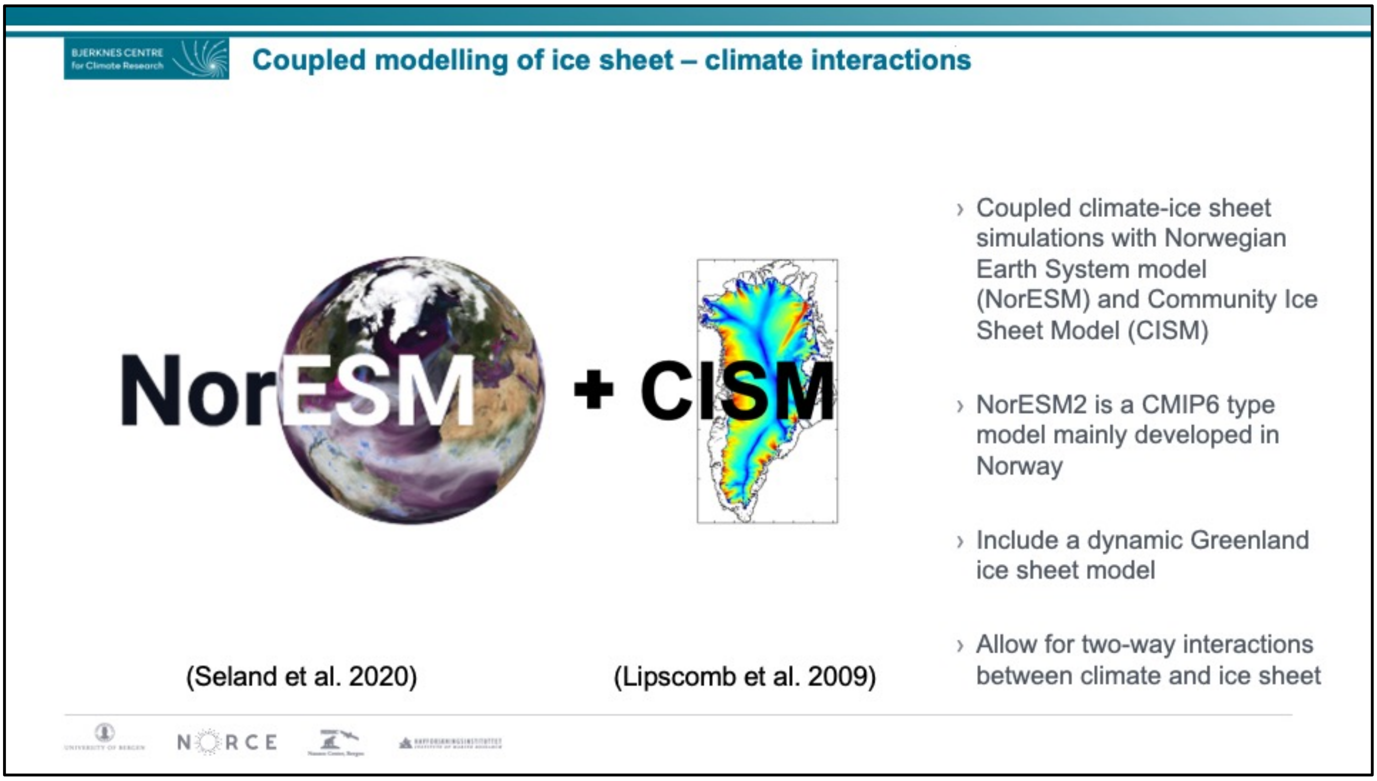
Coupled Greenland ice sheet-climate simulations with the Norwegian Earth System Model (NorESM2)

Hi, thanks for visiting my display material. If you have any questions or suggestions, please get in touch (heig@norceresearch.no).

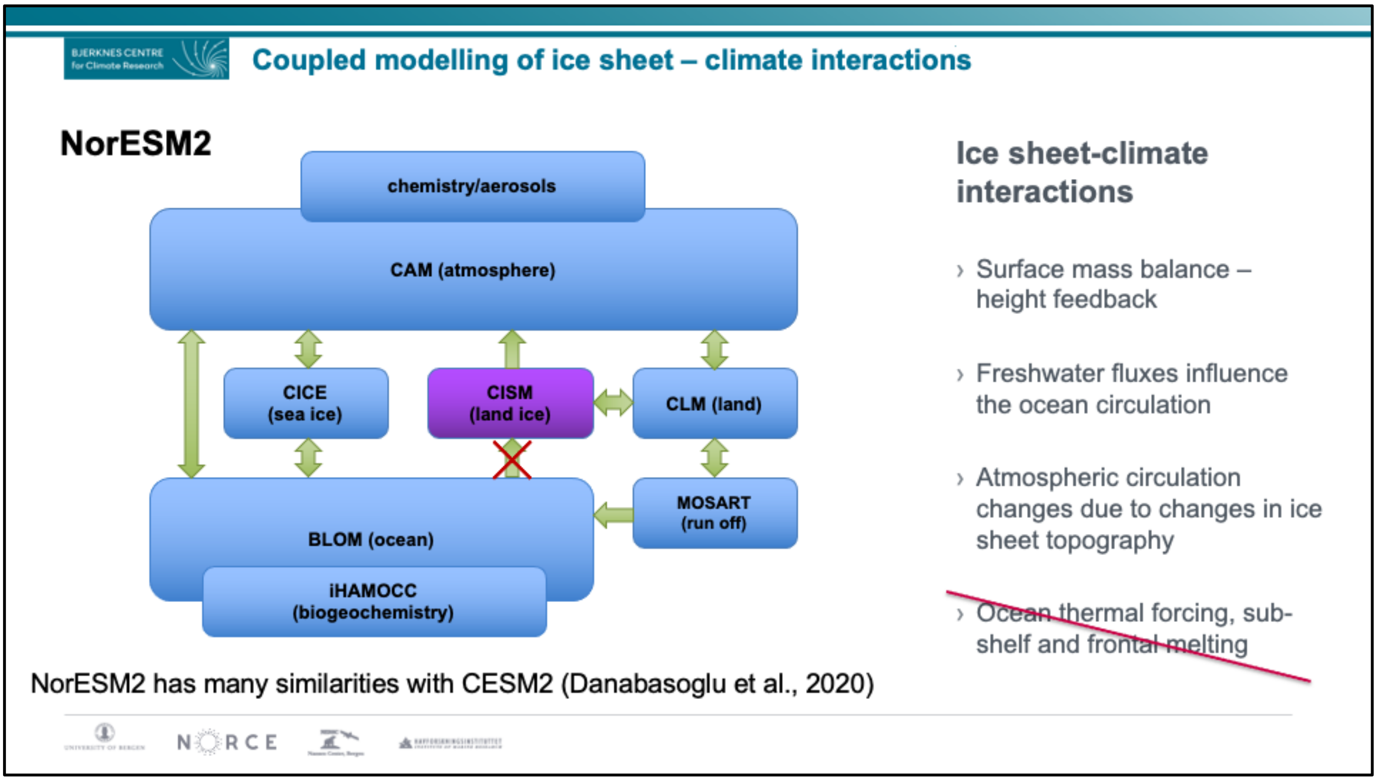
Best greetings
Heiko



The aim of this project is to run coupled climate-ice sheet simulations with the Norwegian Earth System model (NorESM) and the Community Ice Sheet Model (CISM).

NorESM2 is a CMIP6 type model mainly developed in Norway. CISM is being developed at NCAR in the US.

In the present setup we include a dynamic Greenland ice sheet model to allow for two-way interactions between climate and ice sheet.



NorESM2 shares many components with CESM2, another well-known CMIP model. Notable difference are a different ocean model (BLOM) and a model for the biogeochemistry (iHAMOCC). There are also NorESM specific additions in atmospheric chemistry and aerosols.

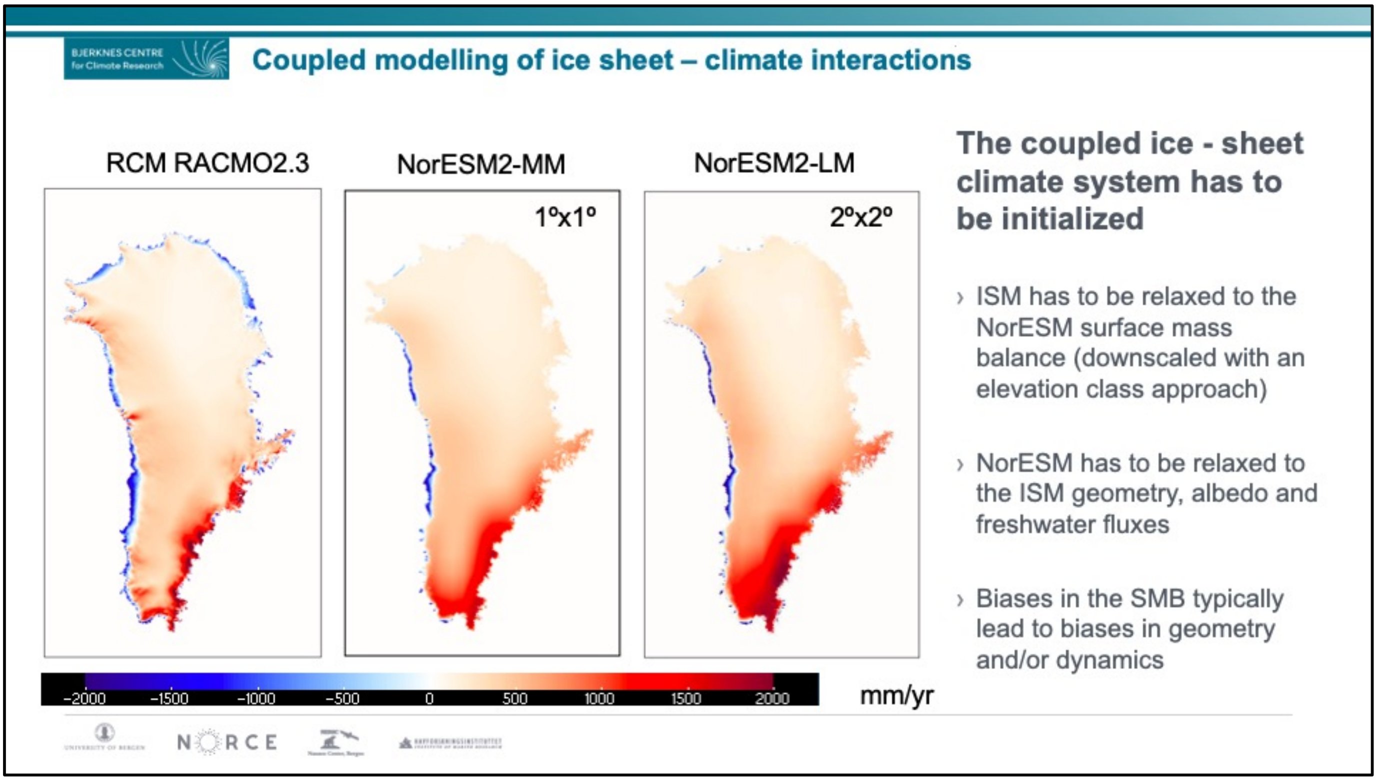
In terms of the interactive Greenland ice sheet model (CISM), the coupling infrastructure and ice sheet model are very similar to that in CESM2.

We acknowledge important development work and help from various CESM-CISM modellers at NCAR and elsewhere (Bill Lipscomb, Gunter Leguy, Kate Thayer-Calder, Marcus Lofverstrom, Miren Vizcaino, Laura Muntjewerf, Michele Petrini, Leo van Kampenhout, Raymond Sellevold, …)

The interactions that we want to capture with this setup are:

- Surface mass balance – height feedback
- Freshwater fluxes influence the ocean circulation
- Atmospheric circulation changes due to changes in ice sheet topography

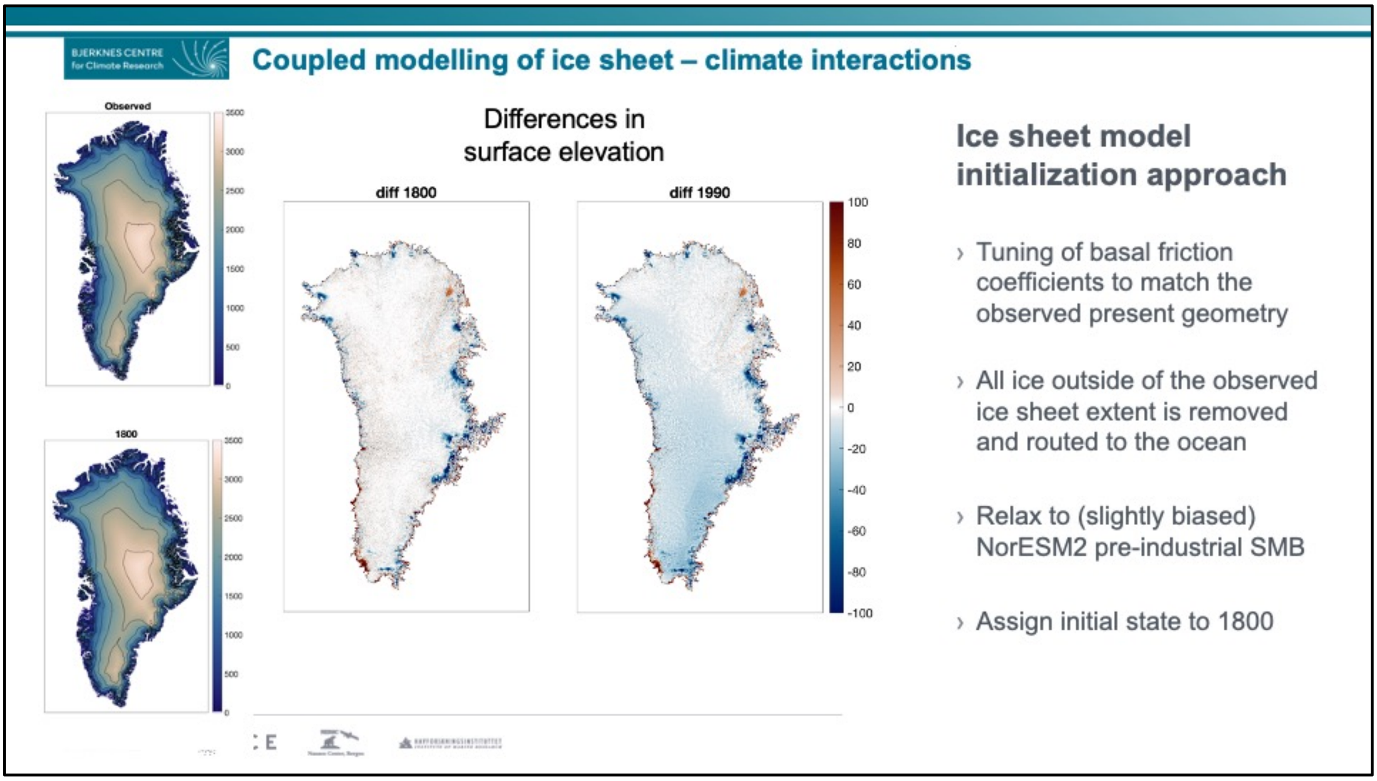
We are working on including a parameterisation to take into account the effect of ocean thermal forcing and runoff on marine-terminating outlet glaciers.



Initializing the coupled ice sheet-climate system is a huge challenge due to the large resolution contrast between the ice sheet and the relevant climate components (atmosphere, land, (ocean)).
Even with improved representation of the climatic boundary conditions (downscaled here with an elevation class approach), the surface mass balance over Greenland is sub-optimal.

This is illustrated by comparing the 1960-1989 surface mass balance coming from NorESM2 at two different horizontal resolutions of the atmosphere model CAM (1ºx1º, 2ºx2º) to output of a high-resolution regional climate model (RACMO2.3). We can see e.g. that precipitation is smoothed inland in NorESM2, which fails to generate sufficient orographic precipitation due to the coarse topography. The output also lacks important negative SMB around the ice sheet, due to a model cold bias and problems to resolve the ablation zones.

These biases in the climate model would typically carry into biases in ice sheet geometry and/or dynamics.

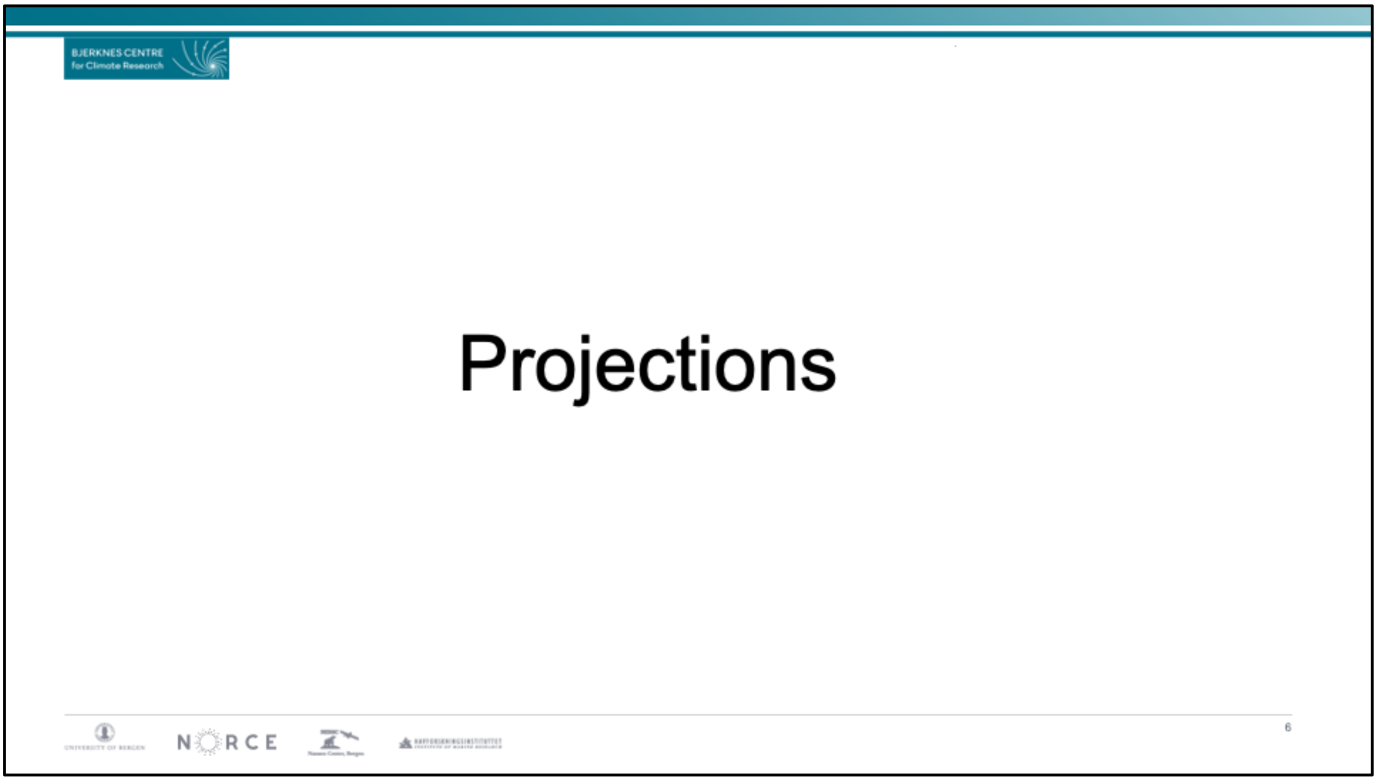


The approach that we chose for initialising the ice sheet model in this set of experiments is motivated by experience from standalone sea-level projections and trying to circumvent some of the climate biases.

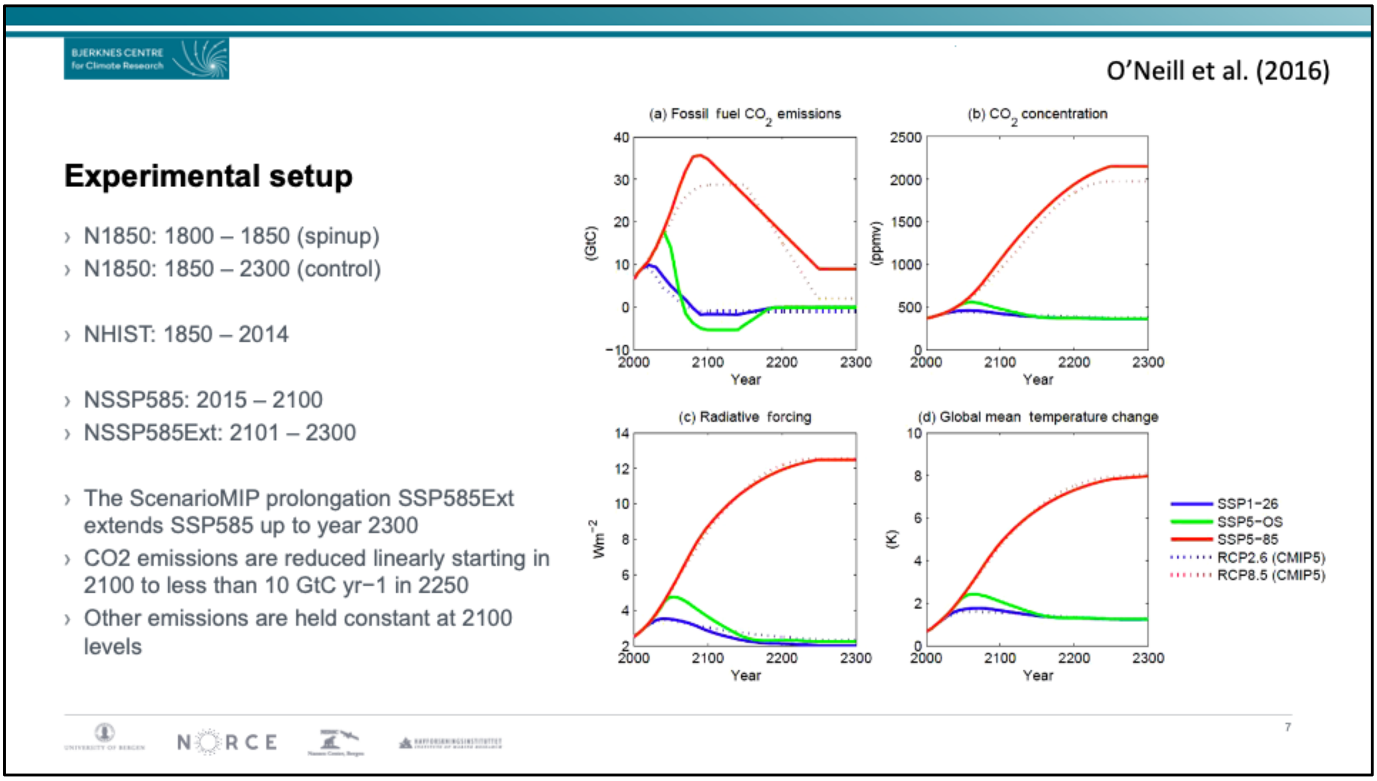
We bring the ice sheet model close to the present day ice sheet geometry by tuning the basal friction coefficients when relaxing the model to the preindustrial SMB coming out of NorESM2, and by controlling its maximum extent. All ice outside of the observed ice sheet extent is removed and routed to the ocean as freshwater. This is only justified for the strong forcing scenario applied in the following, where we expect a retreat of the ice sheet in the future.

We assign that initial state to the year 1800 and then run coupled with the climate model until 1850 as initial condition for historical experiments.

In preliminary runs we observed a small mass gain of the Greenland ice sheet over the 50 year coupled experiment due to an increase in precipitation. Therefore, we chose a pre-industrial NorESM2 SMB which was slightly biased high for initialisation, so that by design a net mass loss over the historical period is achieved, which is the expected behaviour.



We have used the described setup to run a CMIP6 projection under scenario SSP585 prolonged until 2300 following the ScenarioMIP extension.

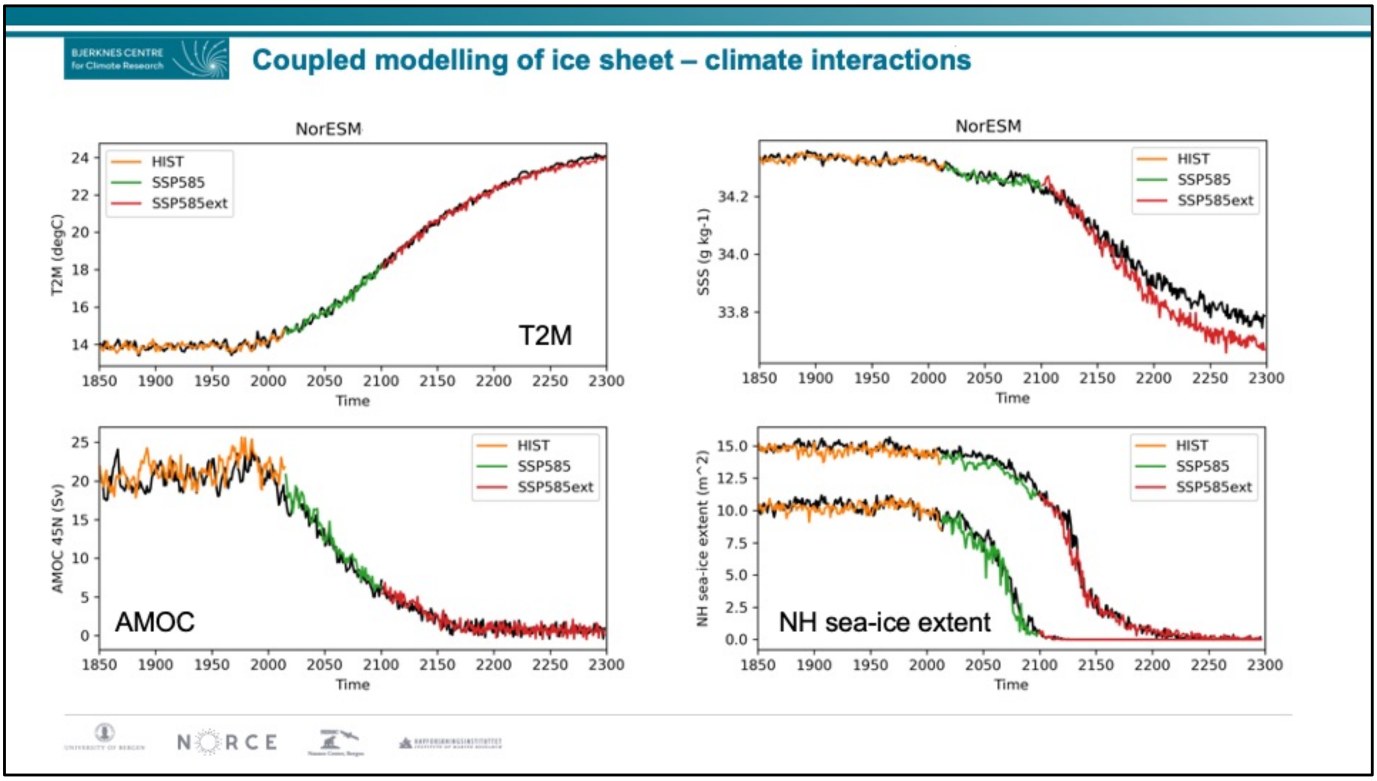


The individual spun-up climate model and ice sheet component are brought together at 1800 for a first coupled run with 50 years of relaxation to 1850. Model drift is very limited due to the highly constrained Greenland ice sheet which is close to the prescribed ice sheet in uncoupled NorESM2 and CISM is relaxed to the pre-industrial NorESM2 SMB.

The result of this experiment serves as initial state for a historical simulation (1850-2014) and is also prolonged until 2300 as a pre-industrial control experiment.

The projection (2015-2100) and extension (2101-2300) follow the CMIP6 scenario SSP585 and its extension SSP585Ext (ScenarioMIP).

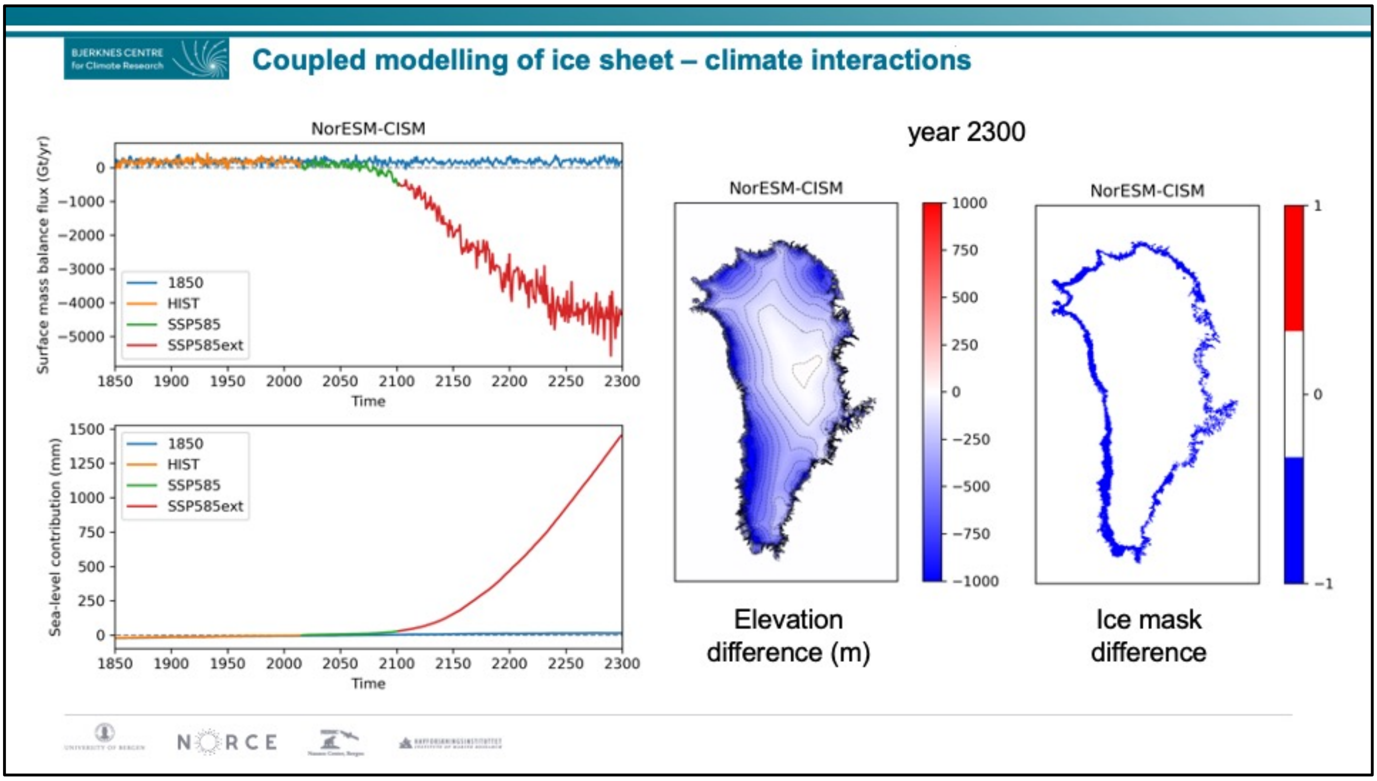
For the extension of SSP585, CO2 emissions are reduced linearly starting in 2100 to less than 10GtCyr−1 in 2250, while all other emissions are held constant at 2100 levels.



We compare results from the coupled climate-ice sheet run with an uncoupled climate-only experiment (black). Colours (orange, green, red) indicate the different segments in the experiment.

We find that most global indices show little influence of the coupling, with exception of global sea surface salinity, representing the freshwater input from the melting Greenland ice sheet. Interestingly, the freshwater input has a negligible impact on the strength of the Atlantic meridional overturning circulation, which already responds very strongly in the uncoupled climate-only experiment.

A focussed regional analysis of changes around Greenland and in the Arctic is forthcoming.



The ice sheet response in this very high forcing scenario is muted over the 21 century (green) e.g. in comparison to standalone ice sheet model projections. We can explain this to a large extent by a NorESM2 cold bias, the strong AMOC response which leads to regional cooling and a generally low transient climate response of NorESM2.

A much stronger response out to 2300 is in line with the relatively large equilibrium climate sensitivity of NorESM2, which kicks in in the second and third century.

Coupled modelling of ice sheet – climate interactions

Summary

› First coupled climate - Greenland ice sheet simulations with NorESM2

› Initialization approach to work around some of the climate biases

› Minor effect of ice sheet coupling on global climate variables

› Strong Greenland ice sheet response until 2300, in line with large equilibrium climate sensitivity

› Muted response of the Greenland ice sheet over the twenty-first century explained by NorESM2 cold bias, strong AMOC response and low transient climate response

Thank you

BJERKNES CENTRE for Climate Research

This work was performed under NFR projects

INES

Infrastructure for Norwegian Earth System Modelling

https://www.ines.noresm.org/

KeyCLIM

https://keyclim.met.no/

Key Earth System Processes to understand Arctic Climate Warming and Northern Latitude Hydrological Cycle Changes

… and will continue in NFR project

GREASE

Greenland Ice sheet evolution and stability

https://grease.heikogoelzer.info/

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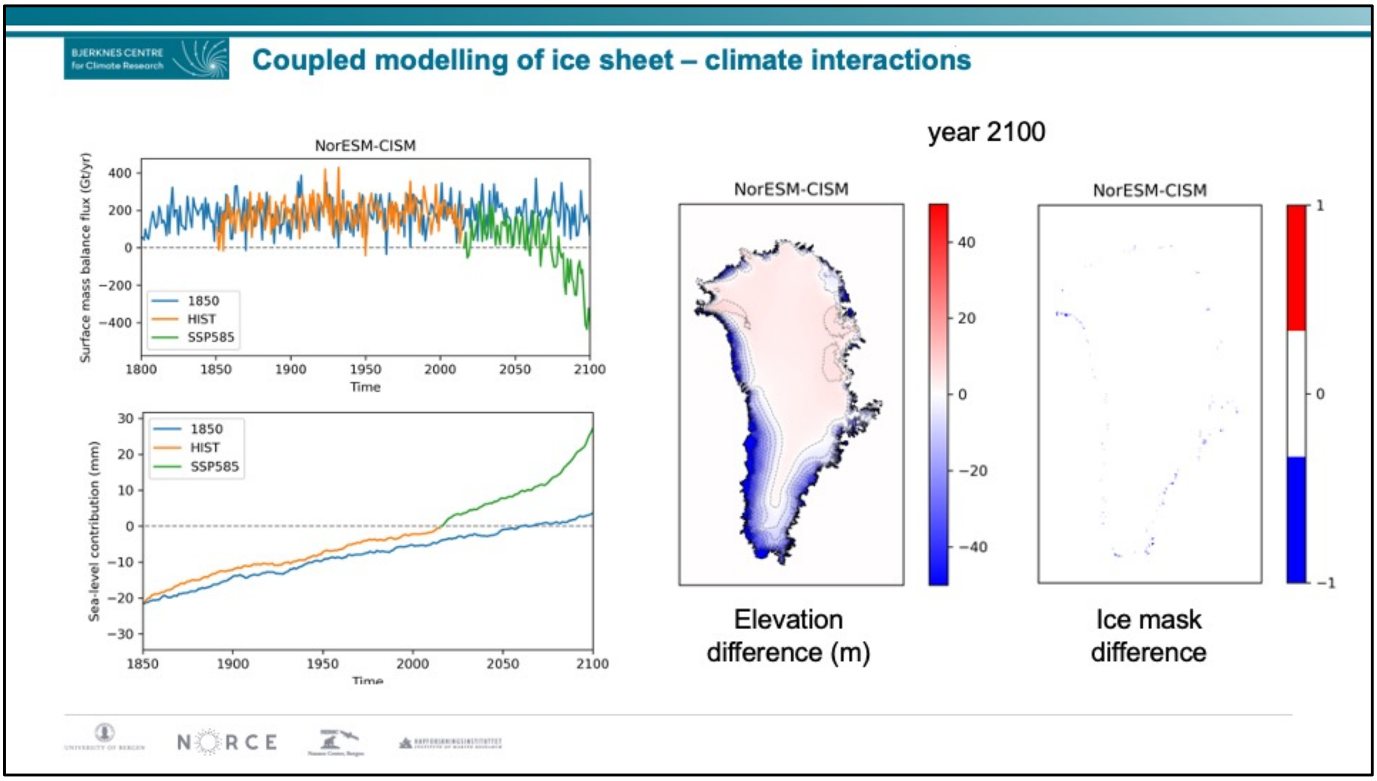
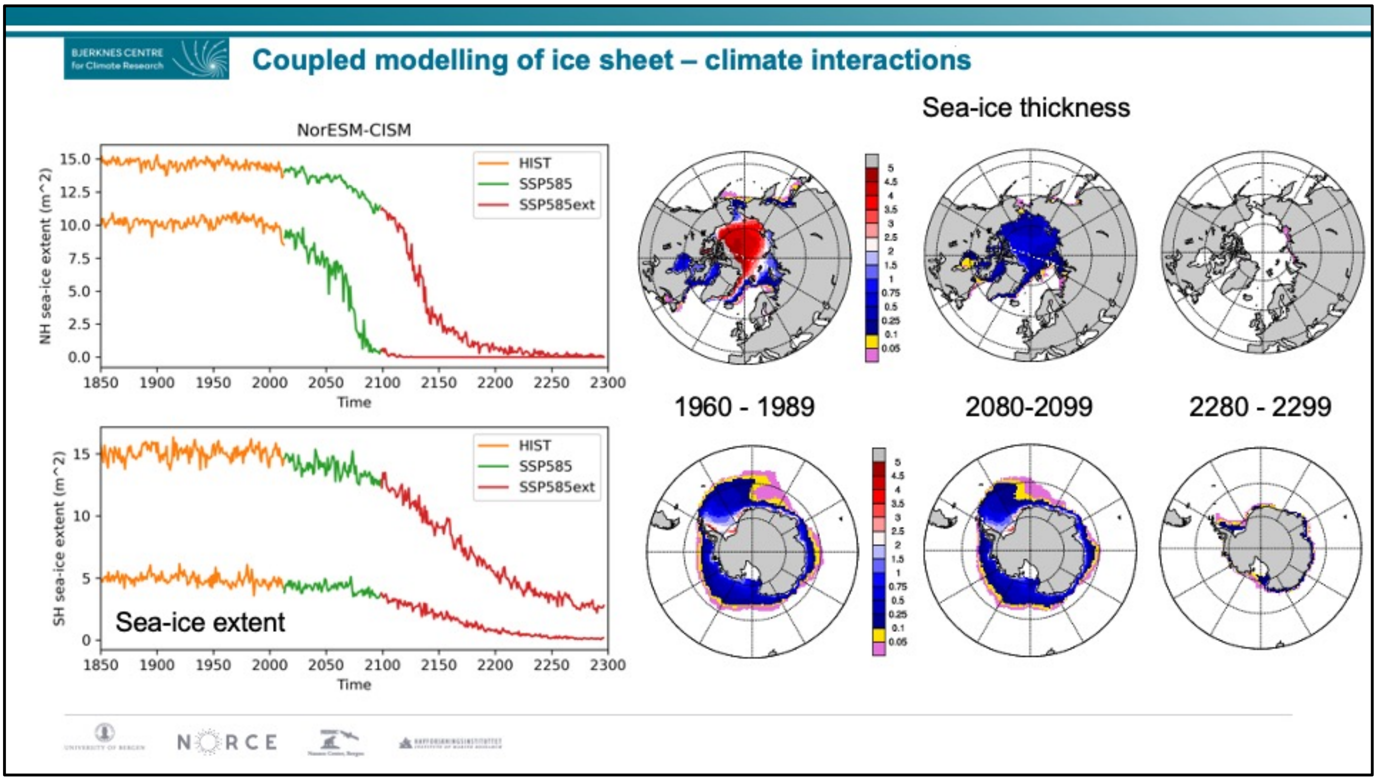
Extras


BJERKNES CENTRE for Climate Research
Coupled modelling of ice sheet – climate interactions
NorESM-CISM
Surface mass balance flux (Gt/yr)
Time
1850
HIST
SSP585
Sea-level contribution (mm)
year 2100
Elevation difference (m)
Ice mask difference
NORCE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Coupled modelling of ice sheet – climate interactions
NorESM-CISM
NH sea-ice extent (m^2)
HIST
SSP585
SSP585ext
Time
SH sea-ice extent (m^2)
Sea-ice extent
Sea-ice thickness
1960 - 1989
2080-2099
2280 - 2299
NORCE

Coupled modelling of ice sheet – climate interactions