Reducing the uncertainty in projections of future ice shelf basal melting

Ralph Timmermann, Jürgen Determann, Hartmut Hellmer, Sebastian Goeller (all AWI), Willem Jan van de Berg (Utrecht University)

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Universiteit Utrecht

Introduction

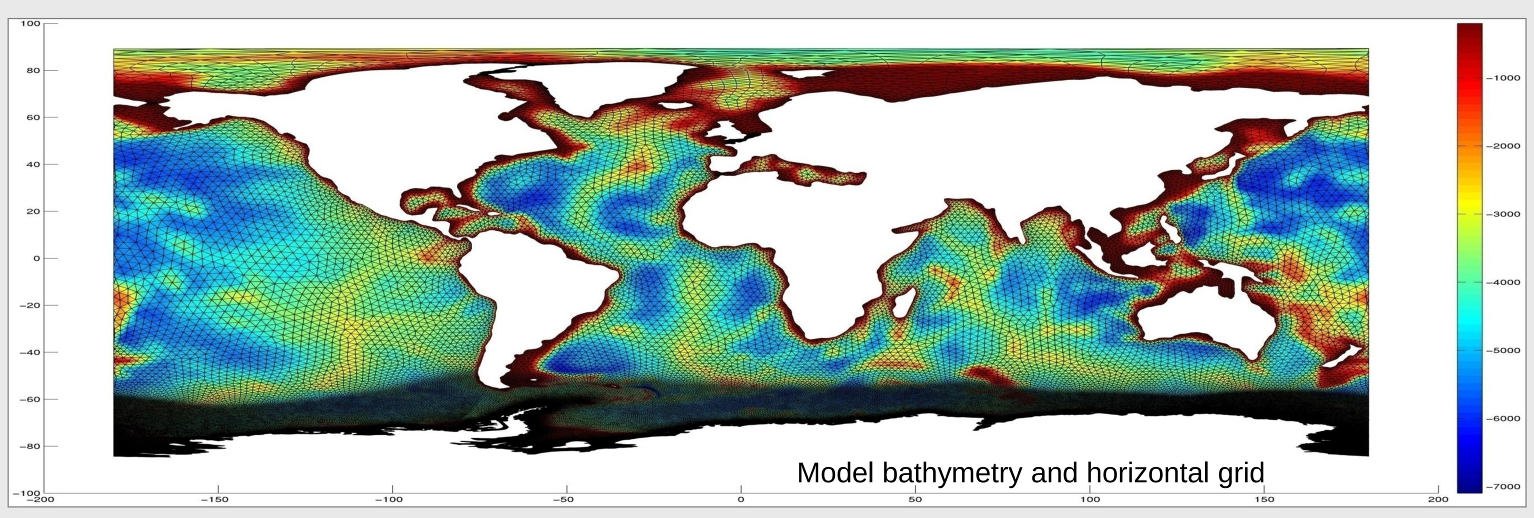
Simulations of ice shelf basal melting in the future climate scenarios proposed in the IPCC's Fourth Assessment Report (AR4) have revealed a large uncertainty and the potential of a rapidly increasing basal mass loss particularly for the large cold-water ice shelves in the Ross and Weddell Seas. The large spread in model results was traced back to uncertainties in the freshwater budget on the continental shelf, which is governed by sea ice formation. Differences in sea ice formation, in turn, follow the regional differences between the atmospheric heat fluxes imprinted by the climate models. A more recent suite of model experiments was performed with output from two members of the newer generation of climate models engaged in the IPCC's Fifth Assessment Report (AR5). Comparing simulations forced with output from the AR5/CMIP5 models HadGem2 and MPI-ESM, we find that uncertainties arising from inter-model differences in high latitudes have reduced considerably.

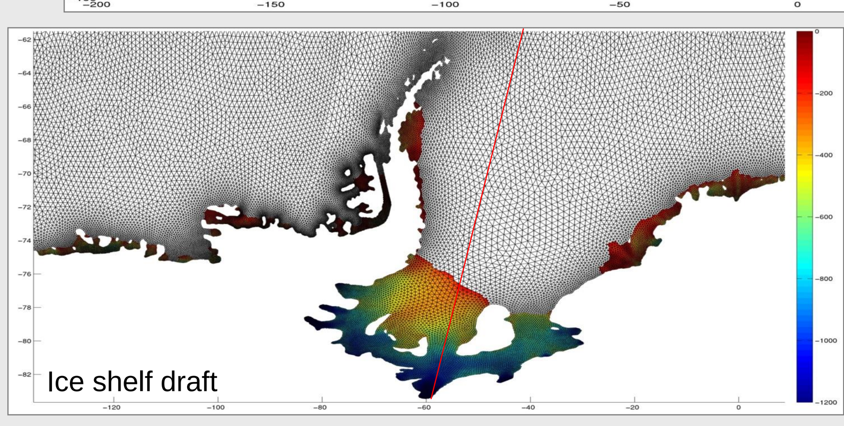
Modeling strategy

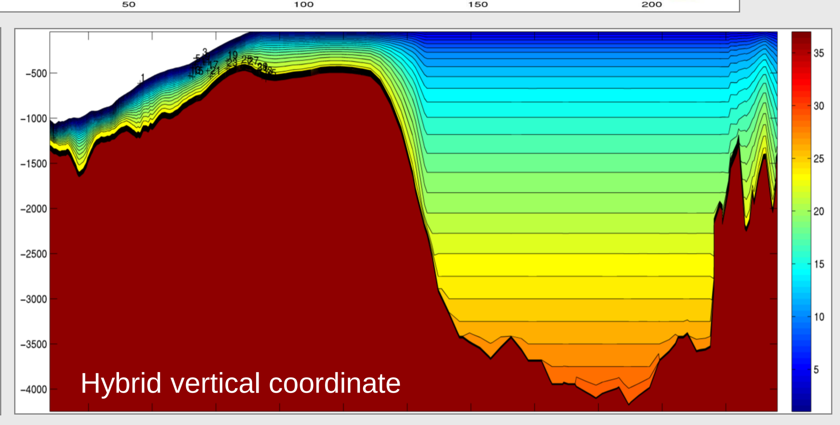
FESOM – Finite-Element Sea-ice Ocean Model

- Finite Element Sea ice-Ocean Model (FESOM; *Timmermann et al., 2012)*
- 3-equation model of ice shelf-ocean interaction
- global domain, resolution varying from 4' to 2.5°.
- hybrid vertical coordinate: 36 z-levels, 23 of which turn into sigma-levels on the Antarctic continental slope (above 2500 m) and enter the cavities
- ice shelf and ocean bottom topography: RTopo-1 (*Timmermann et al., 2010*)
- forcing from ECHAM5-MPIOM and HadCM3 for AR4 scenarios E1 and A1B
- forcing from MPI-ESM and HadGem2 for AR5 scenarios RCP4.5 and RCP 8.5

Model domain and discretization

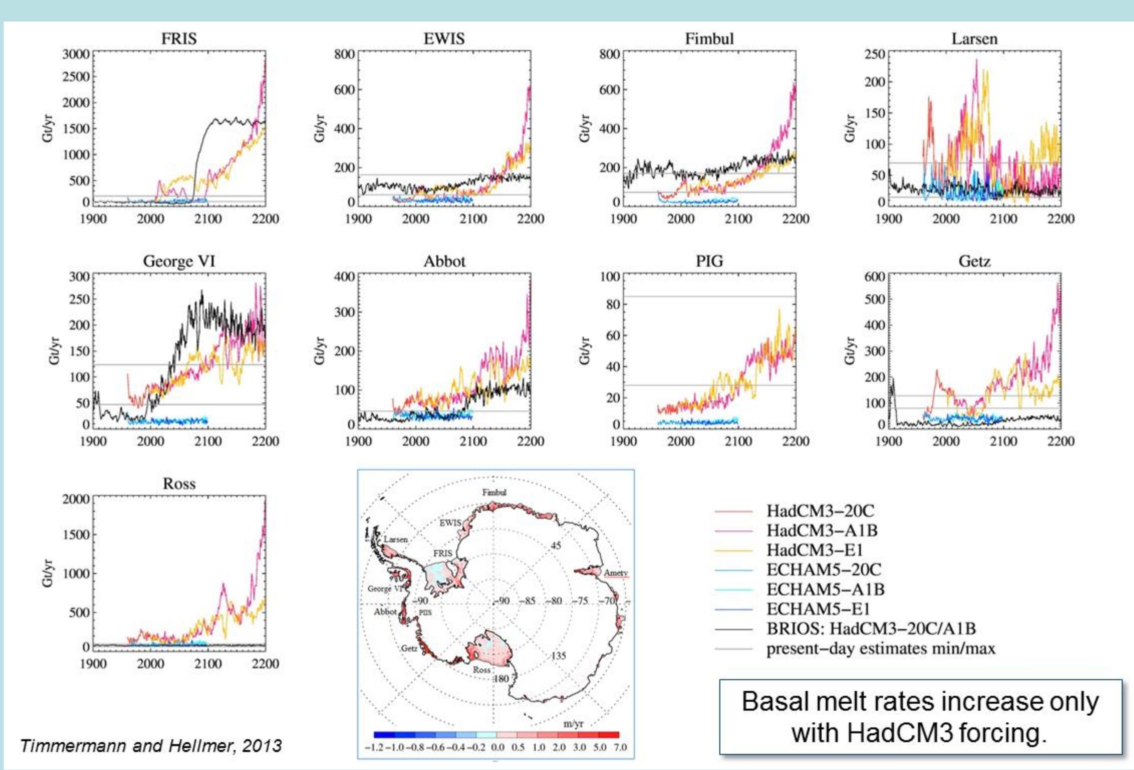

Model bathymetry and horizontal grid


Ice shelf draft


Hybrid vertical coordinate

Ice shelf basal melting for AR4 scenarios E1 and A1B

- difference between forcing models exceeds difference between scenarios.
- melt rates with ECHAM5 forcing too low, with no increase.
- simulations with HadCM3 output show increase for both scenarios.
- discrepancy goes back to surface freshwater flux (dominated by sea ice formation) on the continental shelf

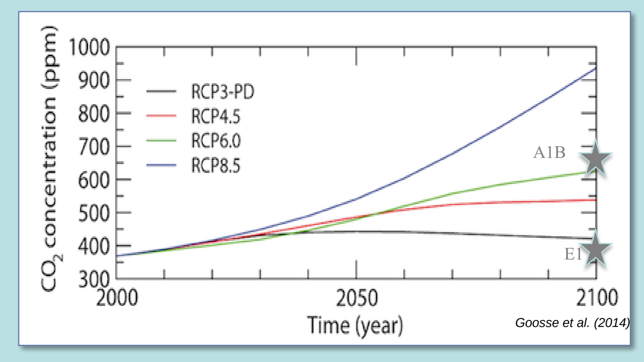


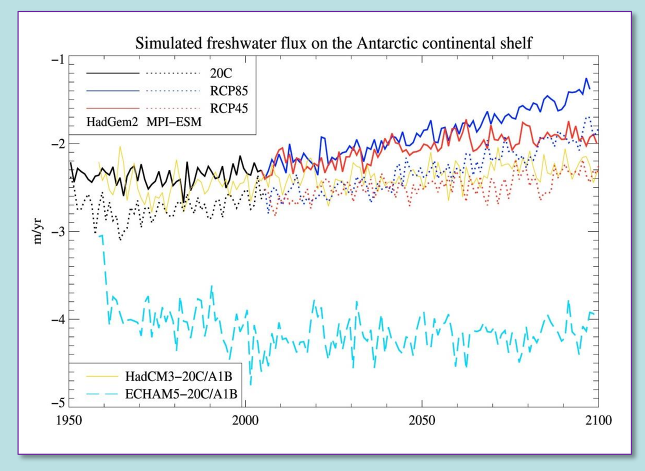
Basal melt rates increase only with HadCM3 forcing.

Timmermann and Hellmer, 2013

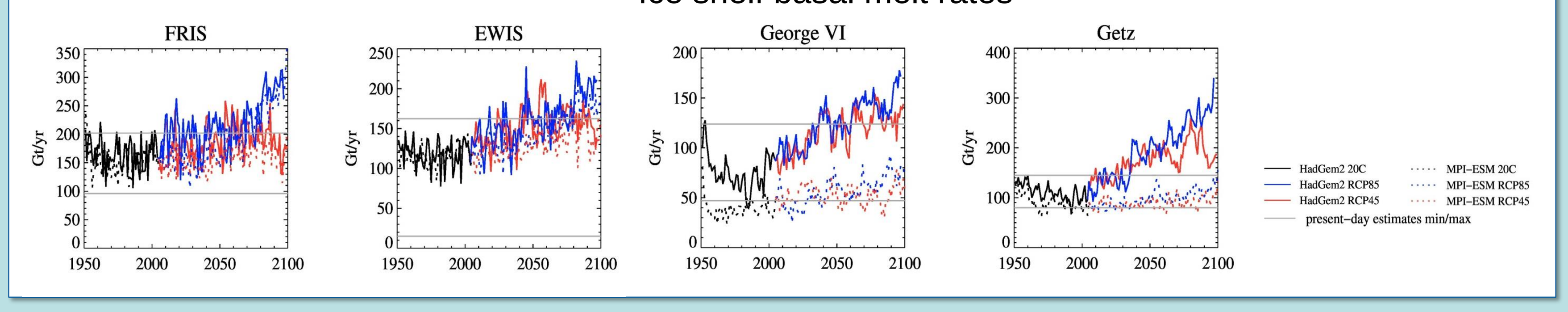
Reducing uncertainty: AR5 scenarios

- experiments with output from AR5/CMIP5 models
- scenarios RCP 8.5 („worst case", blue lines) and RCP 4.5 (moderate, red lines)
- difference in surface freshwater flux strongly reduced
- for the ice shelves in the Weddell Sea difference between scenarios is now bigger than between models
- for Amundsen and Bellingshausen Seas, the Hadley model still gives the larger increase (for both scenarios), but the difference between the models has reduced a lot.



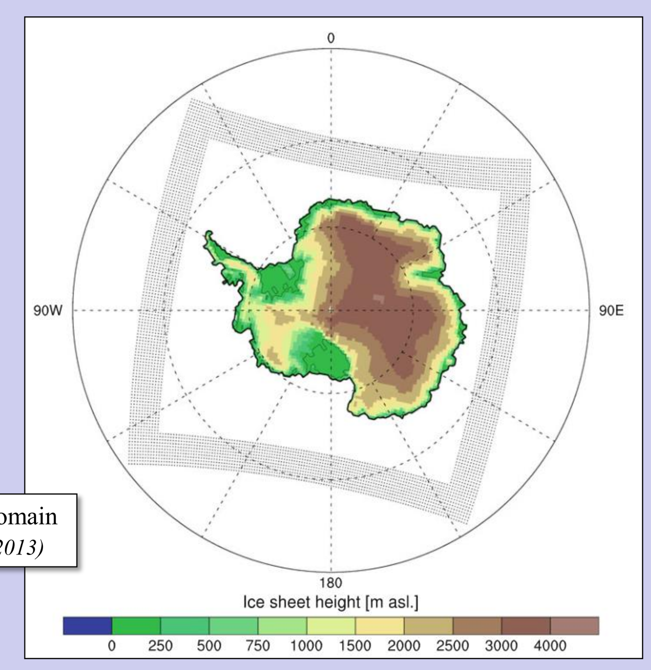


Ice shelf basal melt rates



Coupling FESOM to the Regional Atmospheric Climate Model (RACMO)

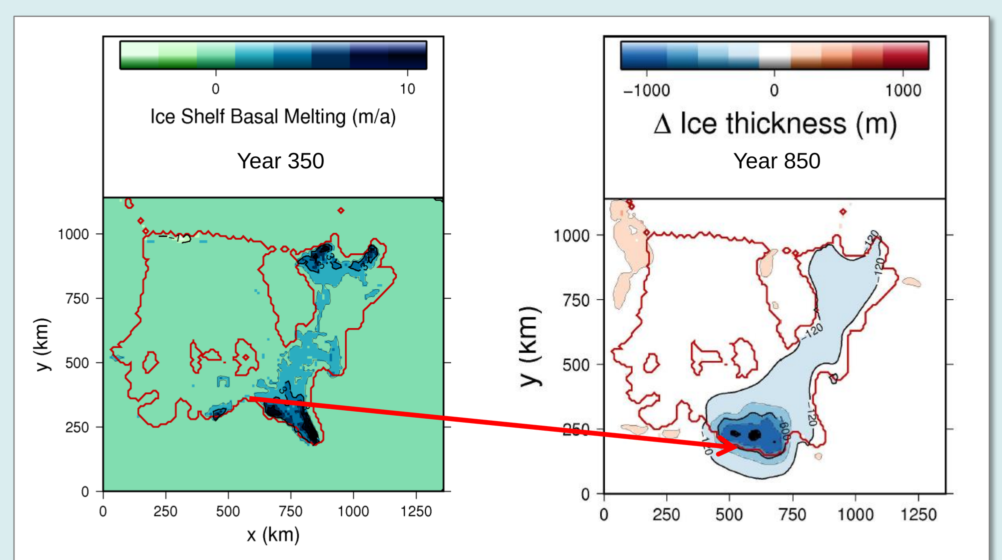
- joint project with University Utrecht (W.J. van de Berg and M. van den Broeke)
- 27 km resolution regional atmosphere model
- boundary conditions from
  1. ERA-interim reanalysis
  2. Climate model future scenarios
- PhD thesis Marta Anna Kasper (to be done)



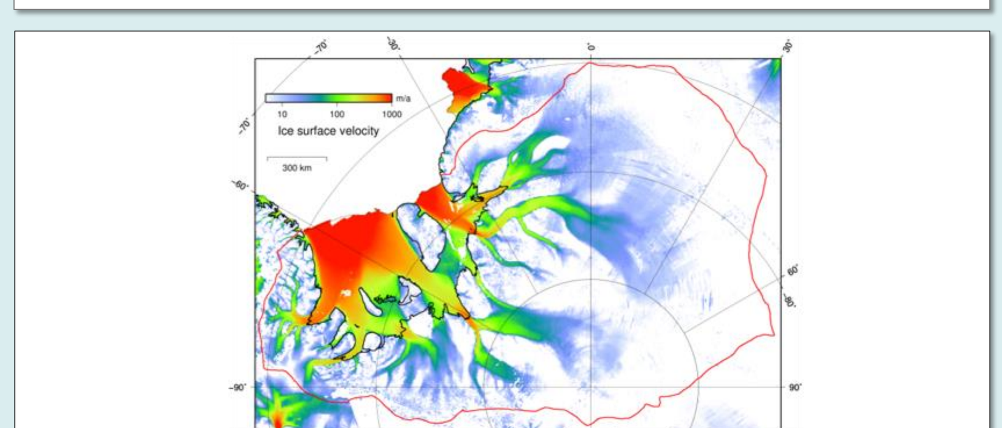
RACMO model domain (*Ligtenberg et al., 2013*)

Dynamic response of ice sheet

- RIMBAY regional ice shelf / ice sheet model forced with ocean data from HadCM3-A1B experiment
- 110 Gt/yr grounded ice mass loss -> 3 cm / century mean sea level rise over 500 years
- model domain to be extended towards the relevant ice divides to avoid open boundary conditions
- basal friction to be parameterized in a way that allows for the formation of ice streams with realistic velocities
- realistic representation of ice streams is expected to enhance effect of basal ice shelf melting on grounded ice discharge



Rimbay simulations forced with modeled shelf break T/S data


Ice surface velocities (Rignot et al., 2011) revealing the ice streams. The red line indicates the new ice sheet model domain.

Summary

- AR5 projections of heat fluxes / FESOM sea ice formation rates over the Southern Ocean continental shelves have converged to an ensemble with a much smaller spread than between the AR4 experiments.
- Gradual but accelerating increase of basal melt rates during the 21st century is robust for most ice shelves.
- Basal melt rates for Filchner-Ronne Ice Shelf in FESOM consistently double by the end of the 21st century in the RCP85 scenario.
- For the smaller, warm-water ice shelves, inter-model differences in ice shelf basal mass loss projections are still slightly larger than differences between the scenarios.
- Compared to AR4 projections, the model-dependent spread has been strongly reduced.
- Coupling to RACMO aims at further reducing uncertainties in ocean-to-atmosphere heat flux for present-day climate and future scenarios.
- Coupling to dynamic ice sheet / ice shelf model to capture effects of variable geometry and potentially increasing ice discharge.