Sensitivity of Greenland ice sheet projections to spatial resolution in higher-order simulations: the AWI contribution to ISMIP6-Greenland using ISSM

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Ice Sheet Model Intercomparison Project
(Nowicki et al., 2016, 2020)

ISMIP6 is contribution to CMIP6.

Primary goals:

- Improve future projections.
- Quantify associated uncertainties.

  → Input for AR6
- no specific analysis to the grid resolution

http://www.climate-cryosphere.org/activities/targeted/ismip6

Focus of this study

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Preprints

Abstract | Discussion | Metrics

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Abstract. Projections of the contribution of the Greenland ice sheet to future sea-level rise include uncertainties primarily due to the imposed climate forcing and the initial state of the ice sheet model. Several state-of-the-art ice flow models are currently being employed on various grid resolutions to estimate future mass changes in the framework of the Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6). Here we investigate the sensitivity to grid resolution on centennial sea-level contributions from the Greenland ice sheet and study the mechanism at play. To this end, we employ the finite-element higher-order ice flow model ISSM and conduct experiments with four different horizontal resolutions, namely 4, 2, 1 and 0.75 km. We run the simulation based on the ISMIP6 core GCM MIROC5 under the high emission scenario RCP8.5 and consider both atmospheric and oceanic forcing in full and separate scenarios. Under the full scenarios, finer simulations unveil up to ~5 % more sea-level rise compared to the coarser resolution. The sensitivity depends on the magnitude of outlet glacier retreat, which is implemented as a series of retreat masks following the ISMIP6 protocol. Without imposed retreat under atmosphere-only forcing, the resolution dependency exhibits an opposite behaviour with about ~ 5 % more sea-level contribution in the coarser resolution. The sea-level contribution indicates a converging behaviour < = 1 km horizontal resolution. A driving mechanism for differences is the ability to resolve the bed topography, which highly controls ice discharge to the ocean. Additionally, thinning and acceleration emerge to propagate further inland in high resolution for many glaciers. A major response mechanism is sliding (despite no climate-induced hydrological feedback is invoked), with an enhanced feedback on the effective normal pressure N at higher resolution leading to a larger increase in sliding speeds under scenarios with outlet glacier retreat.

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https://www.the-cryosphere-discuss.net/tc-2019-329/

Approach:

- Following ISMIP6 protocol
- Only one GCM and ISM
- Different experiments to asses response from
  - Atmospheric forcing
  - Oceanic forcing
  - Full forcing

Projection experiments (2015-2100)

Experiment label	atmospheric forcing	oceanic forcing	combination	
RCP8.5-Rlow	SMB anomaly	low	full	‚full‘
RCP8.5-Rmed	SMB anomaly	med	full	
RCP8.5-Rhigh	SMB anomaly	high	full	
RCP8.5-Rnone	SMB anomaly	-	atmosphere only	‚AO‘
OO-Rmed	-	med	ocean only	‚OO‘
OO-Rhigh	-	high	ocean only	

- External forcing based on GCM MIROC5 (RCP8.5)
- SMB downscaled with MAR v3.9 (Fettweis et al., 2017, 2020)
- Oceanic forcing represented by retreat parametrization (Slater et al., 2019, 2020)

Model setup of ISM

Ice Sheet System Model
(Larour et al., 2012)

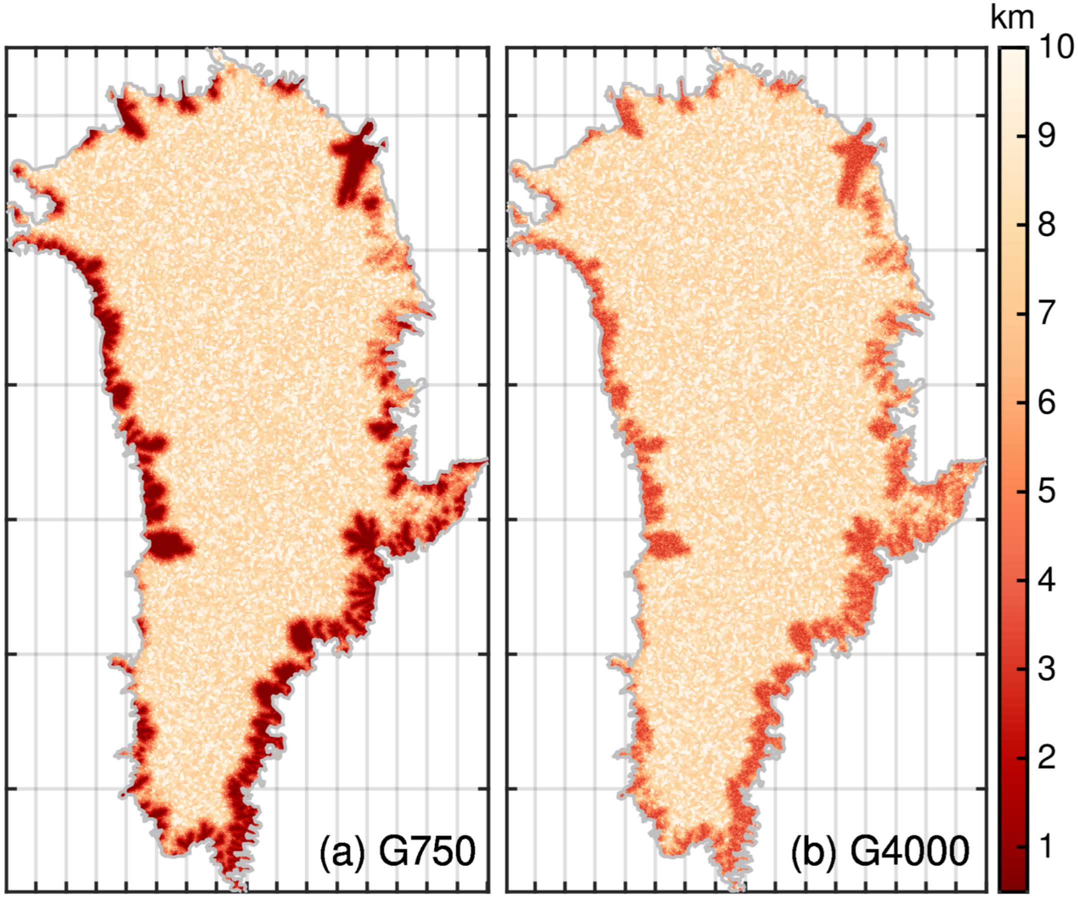
- Finite Element Method
- Higher-Order physics

Data assimilation:

- BedMachine
  (Morlighem et al. 2018)
- MEaSURE velocity
  (Joughin et al., 2016, 2018)

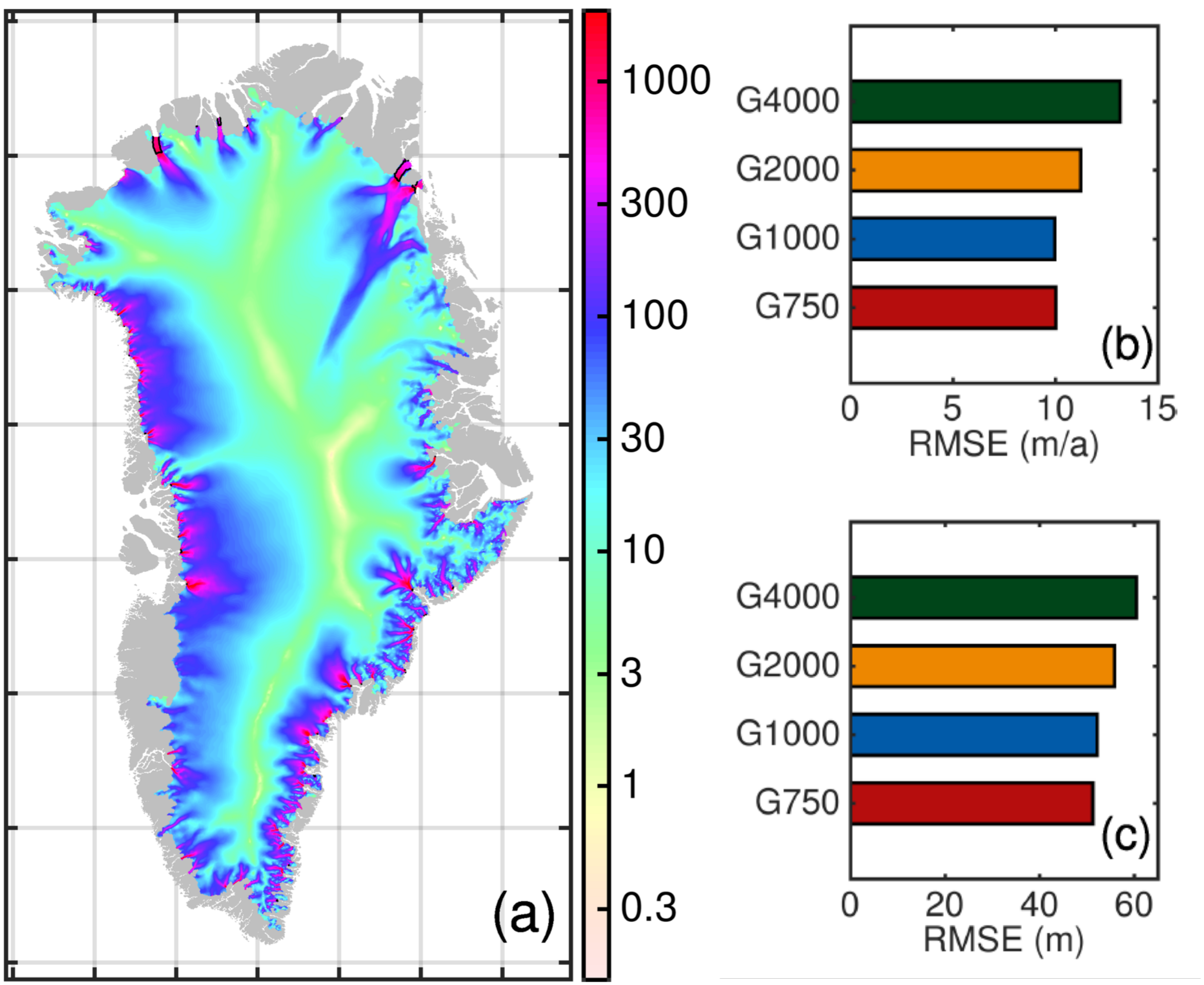
Constructed meshes:

- G4000: h_{min}=4 km
- G2000: h_{min}=2 km
- G1000: h_{min}=1 km
- G750: h_{min}=0.75 km



State at projection start date (2015)

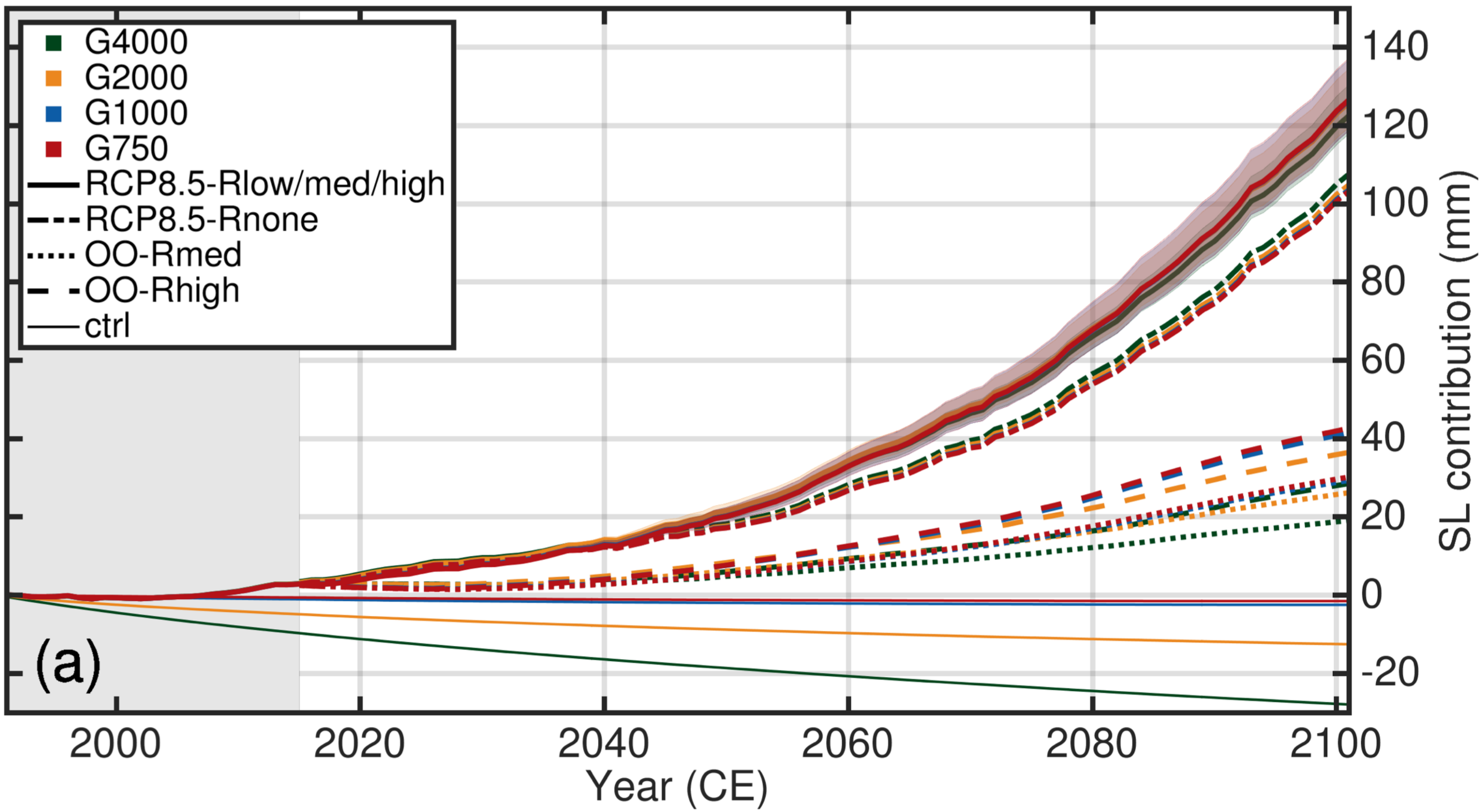
Horizontal velocity (m/a) of G750



RMSE of the horizontal velocity magnitude compared to MEaSURE

RMSE of the ice thickness compared to BedMachine

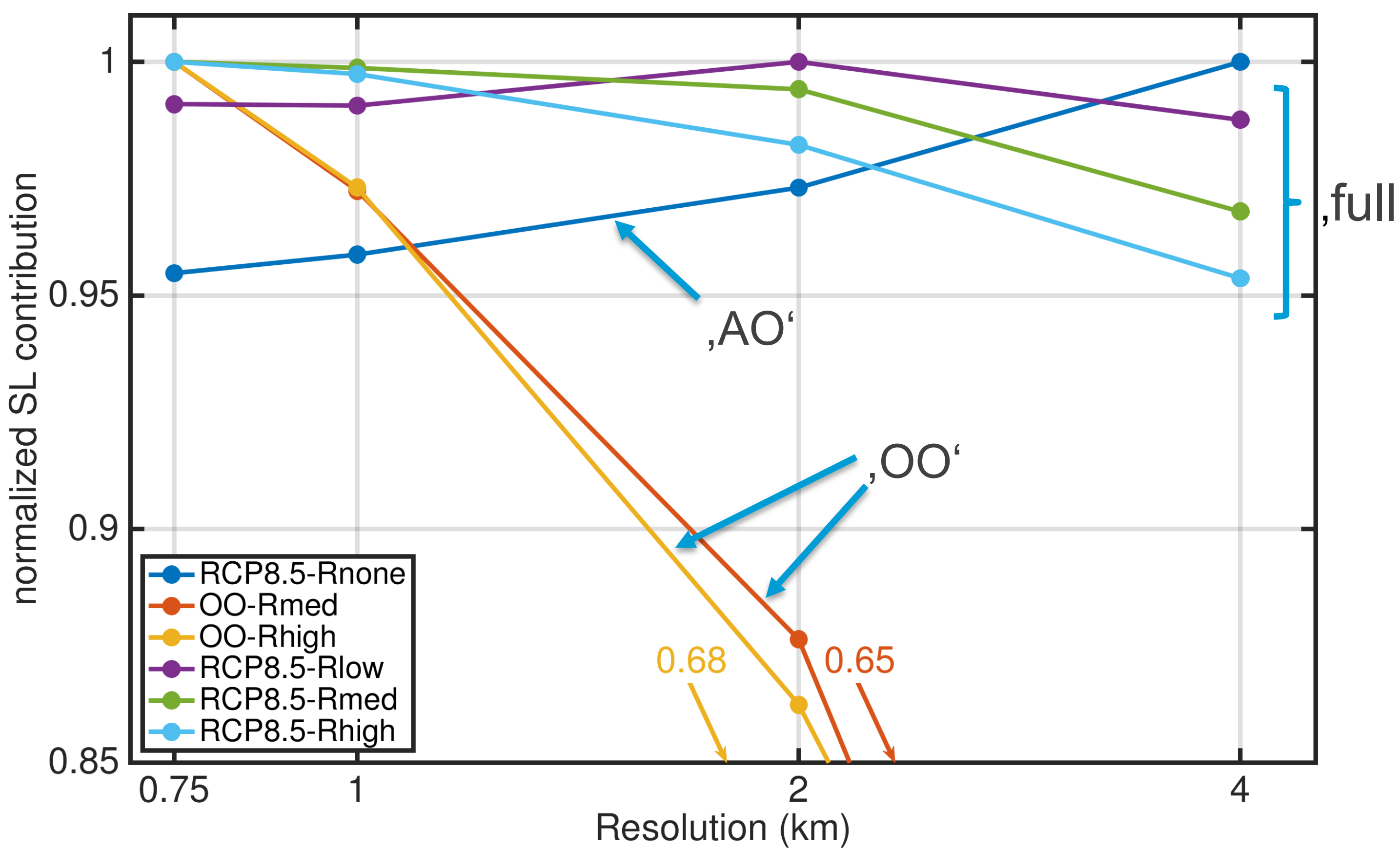
Sea-level contribution



Ranges between grids in 2100:

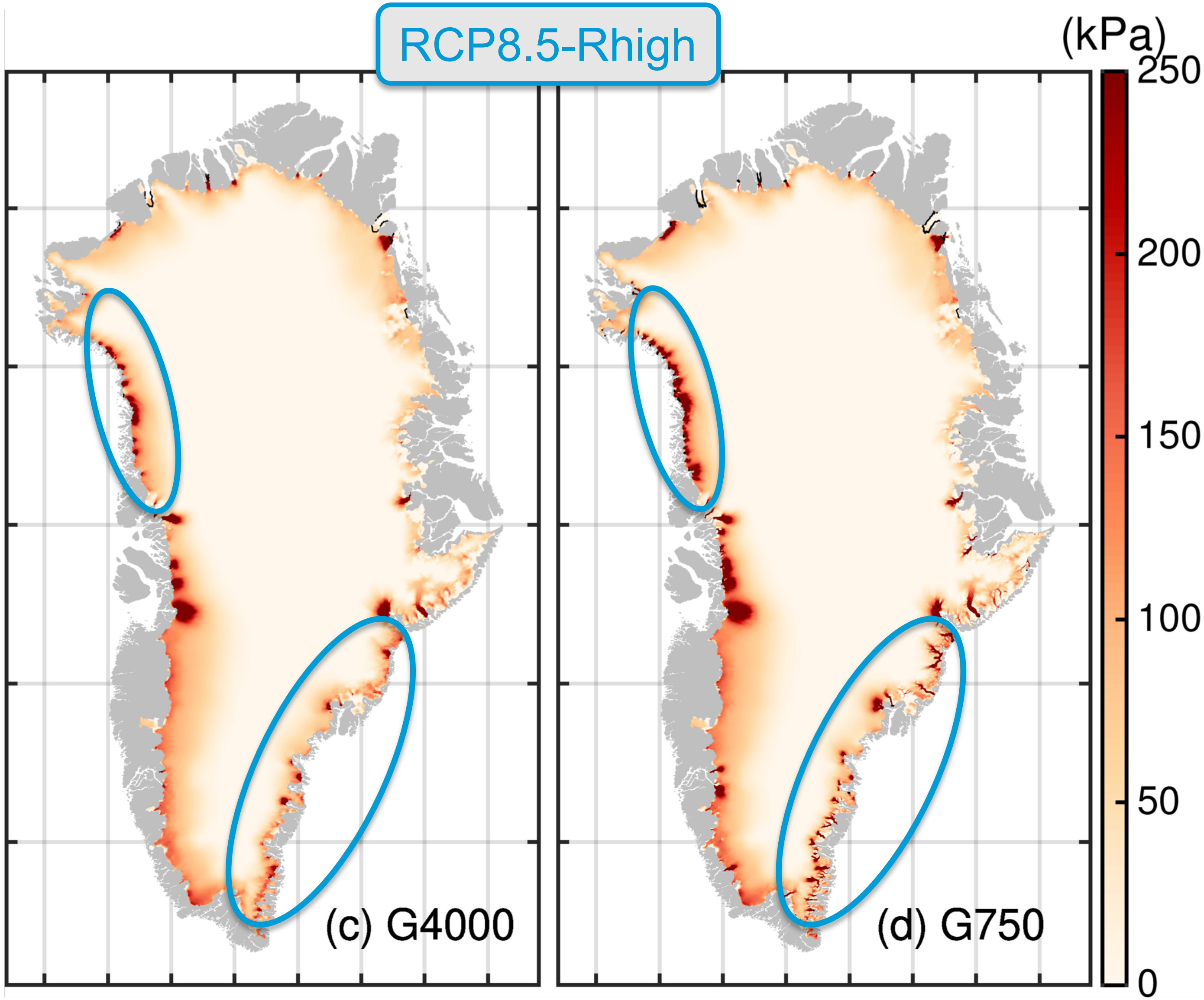
- RCP8.5-Rmed (‚full‘): 122.5 – 126.5 mm SLE
- RCP8.5-Rnone (‚AO‘): 103.1 – 108.0 mm SLE
- OO-Rmed (‚OO‘): 19.5 – 30.1 mm SLE

Grid-dependency of Sea-level contribution

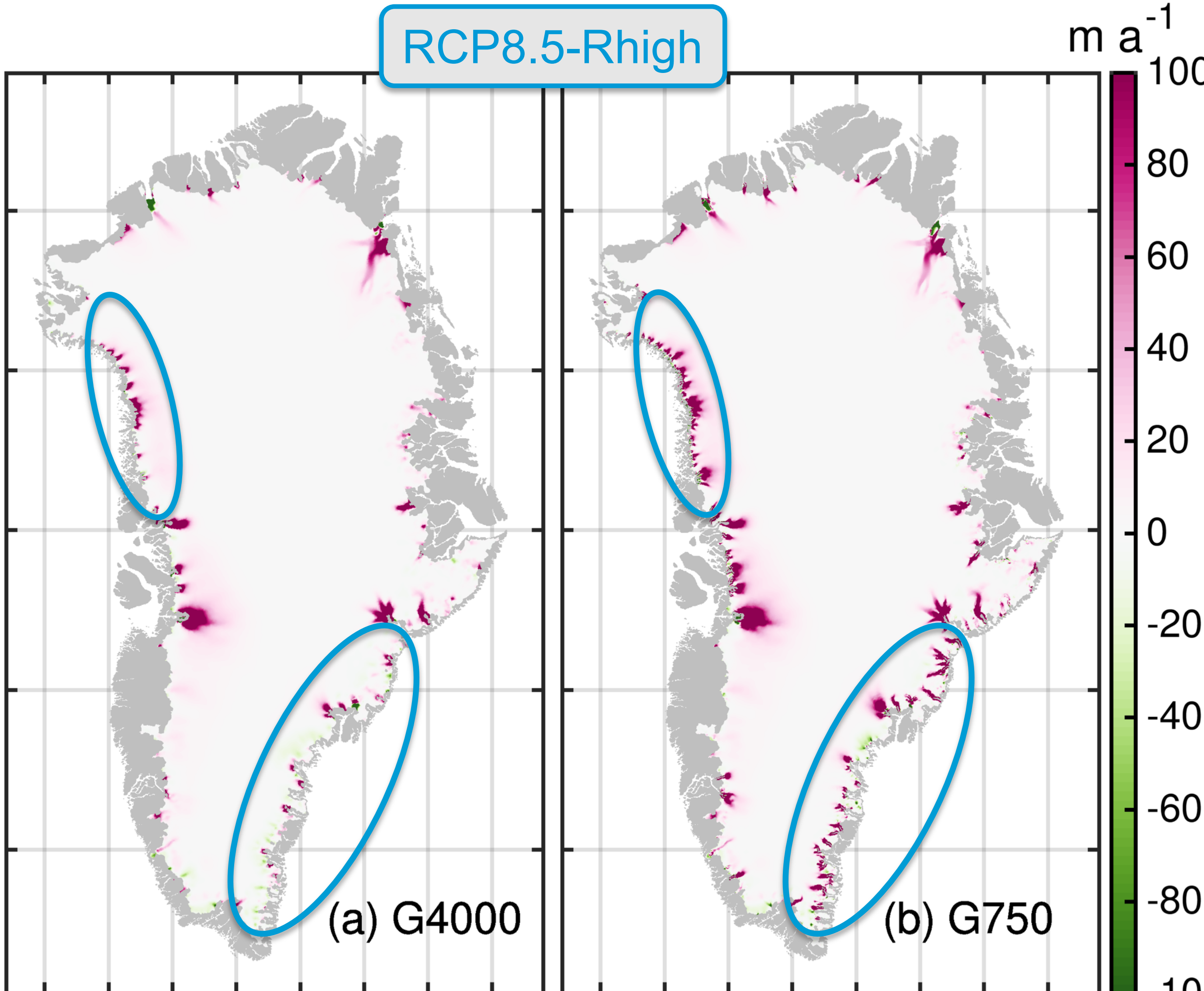


- Inverse grid-dependency between ‚OO‘ and ‚AO‘ scenarios
- Trend in ‚full‘ scenarios depend on strength of both forcings

Difference of effective Pressure (2100-2015)



Difference of basal velocity (2100-2015)



Conclusions

- The sensitivity of GrIS mass changes to the spatial resolution is tested by employing four different grids with varying horizontal resolution ranging from 4 to 0.75 km.
- The simulations reveal more mass loss for the fine resolution compared to the coarser resolution in the full scenarios (between 1.2 – 5.3%).
- In scenarios where a change in SMB is omitted the fine resolutions produce significantly more mass loss (up to 33%).
- When ocean forcing is omitted, the sensitivity of the grid-dependence exhibits an inverse behaviour, i.e. the coarser resolutions produce more mass loss.
- Differences between the different grids are attributed to the ability to resolve bedrock topography and the interaction with basal sliding.