# Projection the Antarctic Contribution to Sea Level Rise

## Improved projections of the Antarctic Ice Sheet contribution to sea level rise until 2100 using coupled ice sheet–ice shelf–ocean modelling

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### In Short

- Coupled ice sheet–ocean modelling
- Sub–ice shelf cavities with varying geometry!
- Finite element method in all components
- Projections of Antarctic contribution to sea level rise until 2100

In the context of the Horizon 2020 project PROTECT (PROjecTing sEa-level rise: from iCe sheets to local implicaTions), the aim of this project is to provide well-constrained projections of the Antarctic ice sheet contribution to sea level rise until 2100, under scenarios of high interest to stakeholders. Within PROTECT, results will inform coastal impact topics and quantify uncertainties related to longer-term projections. To achieve this, we couple two state-of-the-art numerical models, a global ocean circulation model (FESOM) that resolves the complex geometry of ice-shelf cavities and the ice-flow model Úa simulating dynamics of the Antarctic Ice Sheet.

Protecting future generations from the potentially devastating effects of climate change is one of the greatest challenges of our time. Sea level rise is at the forefront of these effects and accurate projections are critical for implementing efficient measures for protection. Predictions until 2100 under low-probability, high impact emission scenarios are of greatest relevance for long-term coastal infrastructure planning. However, the uncertainties associated with these high-end scenarios are also exceptionally large and originate mostly from the unknown response of the ice sheets to warming oceans, especially in Antarctica.

Coupled simulations of ice sheet-ocean interaction will improve the reliability of projections dramatically. Ocean-driven melting at the base of Antarctic ice shelves (the floating extensions of the ice sheet) is known to play a critical role for grounded ice decay in a warmer climate. About 40 % of the Antarctic ice sheet is grounded below sea level and susceptible to an unstable and irrevocable retreat, known as the Marine Ice Sheet Instability (MISI), which is triggered and sustained by ocean-driven melting. Current mass loss projections are typically derived from stand-alone ice sheet models with ocean-melt parameterisations and results strongly depend on debatable choices regarding ocean-ice interaction. It is now recognised that numerous aspects of the interaction between the geometry of ice shelves and ocean dynamics require a full coupled ocean/ice-sheet model.

Coupled models are now becoming available and are successfully used for projections at a regional scale. However, obtaining good results with a global ocean model and the entire Antarctic ice sheet remains challenging. A key aspect is flexible horizontal resolution in the ice and ocean component to resolve critical aspects in all Antarctic regions, while keeping computational demands feasible. Accurately resolving ocean-ice interaction near grounding lines (the junction of ice sheet and ice shelf) is particularly important to predict the timing of MISI.

| FESOM | Úa |
|---|---|
| Finite Element Sea ice — ice shelf — Ocean Model | Large-scale ice-flow model |
| (Timmermann et al., 2012) | (Gudmundsson et al., 2012) |
| • Domain: global<br>• Horizontal resolution: 1.9 - 250 km<br>• Vertical resolution: 100 z-level layers with spacing between 5 and 100 m<br>• Dynamic-thermodynamic sea ice model<br>• 3-equation model of ice shelf-ocean interaction<br>• Forcing: ERA-Interim for hindcasting and AWI-CM IPCC scenario RCP8.5 for projections | • Domain: Antarctic Ice Sheet<br>• Horizontal resolution: 2-200 km<br>• Ice dynamics: SSA<br>• Initiation: Inversion for A and C using surface velocities and Bedmachine geometry<br>• Surface mass balance: Annual mean surface accumulation from RACMO (hindcast) or improved atmospheric simulation (PROTECT deliverable) |
| • Coupling: ice shelf thickness and grounding line position from Úa (once a month) | • Coupling: ice shelf basal melt rates from FESOM (monthly mean, once a month) |

***Figure 1:** Characteristics of the FESOM-Úa coupled model*

The coupled FESOM-Úa model (Fig. 1) has been developed in co-operation with our project partners H. Gudmundssson and J. De Rydt (Northumbria University, Newcastle; UNN) using the infrastructure from the FESOM-RIMBAY [1] and FESOM-PISM regional applications (expired HLRN project hbk00034 and concurrent projet bbk00016). For the first time, we will run Antarctic-wide coupled ice-ocean simulations using unstructured grids in both components, which allows for a particularly high resolution near the grounding lines. For the ice flow model Úa, a pan-Antarctic mesh with a resolution derived from observed ice flow velocites has been created (Fig.2). We will explore the potential benefit of further mesh refinement in FESOM and Úa by the end of the year 2022, i.e. before the start of the HLRN project proposed here. Apart from topics related to model tuning, the model is fully functional and ready to be used for production experiments.

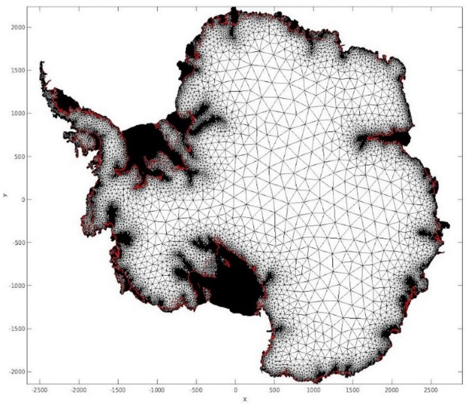

***Figure 2:*** *Computational mesh of the ice flow model Úa in our pan-Antarctic configuration. Resolution has been derived from observed ice flow speed.*

We plan to conduct simulations to 2100 to provide well-constrained projections of the Antarctic ice sheet contribution to sea level rise until the end of the 21st century, under scenarios of high interest to stakeholders. Next to an optimistic-but-still-realistic mitigation scenario, this requires the use of a high-end (lower probability) scenario that defines the upper bound of the sea-level rise that coastal commmunities need to prepare for. Within PROTECT, our results will directly inform coastal impact topics and quantify uncertainties related to longer-term projections.

The Finite Element Sea ice-Ocean Model FESOM [2] is a global primitive-equation, hydrostatic ocean model developed at the Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI) that is specifically targeted at a massively parallel computing system like the HLRN. FESOM comprises a dynamic-thermodynamic sea-ice component and the thermodynamic interaction at ice shelf bases. The governing equations are solved on a horizontally unstructured mesh using the finite-element method.

Úa [3] is a large-scale ice-flow model that has been used successfully to study ice shelf–ice stream systems in idealised experiments as well as in realistic, more complex setups. Úa is initialised using an inverse approach, allowing to derive estimates for, e.g., the basal slipperiness using measurements of horizontal surface velocities. The computational domain can grow and shrink with glacier size by activating and deactivating individual elements, while iceberg calving is implemented using the Level-Set method. Úa's design choice excludes thermodynamics and subglacial hydrology.

The coupled configuration consists of a global implementation of FESOM and a pan-Antarctic setup of Úa. The coupler is based on the Regional Antarctic and Global Ocean (RAnGO) model [1] and follows a sequential approach in that it runs the ice and ocean components subsequently and at different time steps, but eventually covering identical timespans. The coupling time step in FESOM-Úa is once per month. At each interval, FESOM provides Úa with mean ice shelf basal melt rates as boundary conditions to compute the ice flow and the evolution of ice thickness. After a month of integration, Úa returns ice shelf thickness and grounding location to the coupler and a new cavity geometry is derived. Prognostic ocean variables are remapped from the last month and extrapolated where the ice has retreated. Subsequently, FESOM is run forward for another coupling interval, and so on and so forth.

The locally high resolution of the ocean model in a global domain together with the century-scale simulation times required for this project exceed the capacity of the smaller clusters available at AWI. In the ocean, this resolution is critical to correctly represent ocean circulations on the continental shelf and in the sub-ice cavities, particularly near the ice shelf grounding line. The project therefore depends on the computational power of the HPC infrastructure at HLRN.

## WWW

https://protect-slr.eu/

## More Information


[1] Timmermann, R., and S. Goeller. *Ocean Science* **13 (5)**, 765-776 (2017). doi:10.5194/os-13-765-2017

[2] Timmermann, R., Q. Wang, and H.H. Hellmer. *Annals of Glaciology* **53 (60)**, 2012. doi: doi:10.3189/2012AoG60A156

[3] Gudmundsson, G.H., J. Krug, G. Durand, L. Favier, and O. Gagliardini. *The Cryosphere* **6 (6)**, 1497-1505 (2012).


## Project Partners

Northumbria University, Newcastle

## Funding

EU Project PROjecTing sEa-level rise: from iCe sheets to local implicaTions (PROTECT)

## DFG Subject Area

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