The importance of geothermal heat flux in modelling of the Antarctic Ice Sheet

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1. Introduction

- Ice sheet models are typically "tuned" by finding the parameter values that give the most realistic present-day simulations.
- However, this approach implicitly assumes that there are no errors in the boundary conditions being used to drive the models.
- We test this assumption by using the Parallel Ice Sheet Model (PISM) to explore the sensitivity of the simulated Antarctic Ice Sheet to a range of different geothermal heat flux datasets.

2. Boundary conditions

- Ice sheet models typically aim to incorporate a complete description of the ice sheet itself, as well as some description of the underlying bedrock (Figure 1).
- However, the external boundary conditions are not known and must be provided e.g.
  - surface air temperature
  - surface mass balance
  - geothermal heat flux

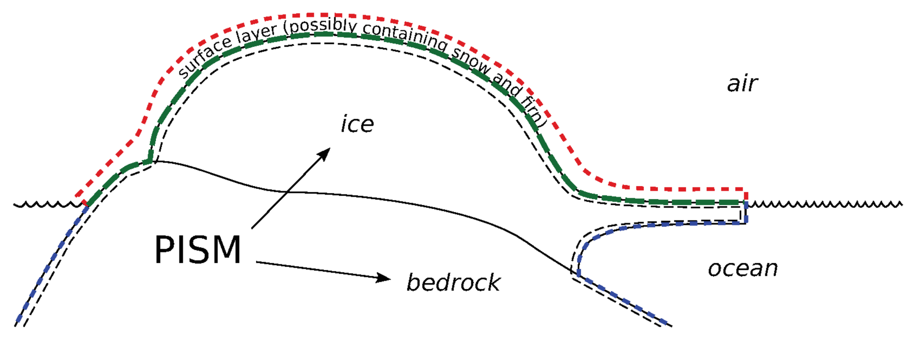

Figure 1. PISM's view of the interfaces between an ice sheet and the outside world (*PISM User's Manual*).

- We consider three alternative datasets for the geothermal heat flux (Figure 2). All three datasets resolve the first order difference in heat flux between the generally old, thick and stable East Antarctic lithosphere, and the more juvenile, thin and recently active West Antarctic lithosphere. However, there are significant differences between the models, especially in the rifted and volcanically active West Antarctic.

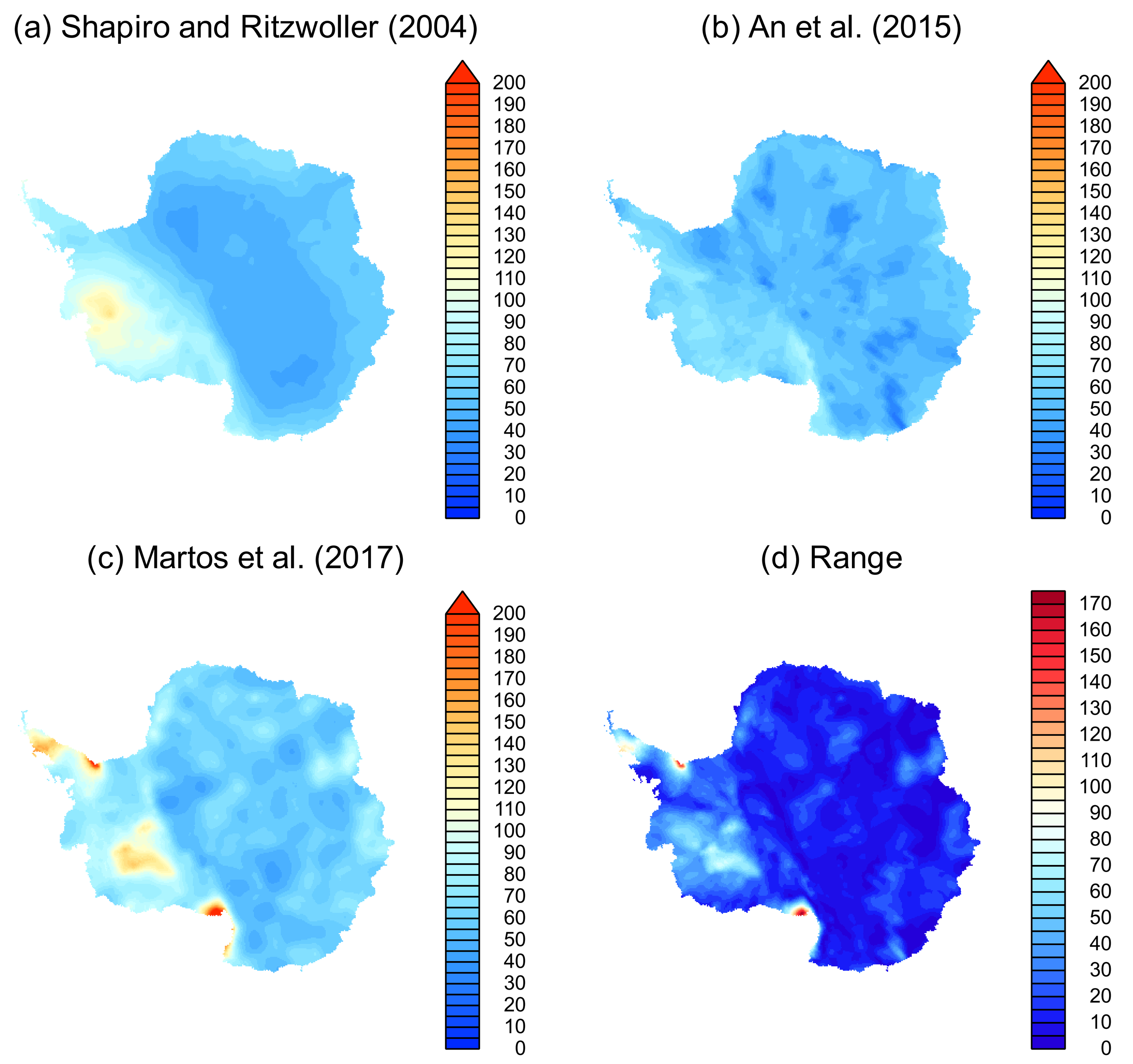

Figure 2. Geothermal heat flux (mW m^{-2}): (a) Shapiro and Ritzwoller (2004), (b) An et al. (2015), (c) Martos et al. (2017), and (d) the range spanned by the three datasets.

3. Optimising an ice sheet model

- Here, we attempt to determine the optimal configuration of the Parallel Ice Sheet Model (PISM; Winkelmann et al., 2011).
- We do this by constructing 50 different configurations of the model, using a Latin hypercube to sample the range of uncertainty in the parameterisations of six key physical processes (Table 1).
- Each model is then integrated for 100,000 years under present-day conditions, allowing it to reach dynamic and thermodynamic equilibrium. Surface air temperature and mass balance are taken from the RACMO2.3 regional climate model (van Wessem et al., 2014).
- This exercise is repeated three times, using each of the geothermal heat flux datasets in turn.

Parameter	Description	Minimum	Maximum
`-sia_e`	Shallow ice enhancement factor	1.0	4.5
`-ssa_e`	Shallow shelf enhancement factor	0.5	1.6
`-pseudo_plastic_q`	Exponent of basal resistance model	0.15	1.00
`-till_effective_fraction_overburden`	Effective till pressure scaling factor	0.01	0.04
`-eigen_calving_K`	Calving rate scaling factor	3.0e16	1.0e19
`-thickness_calving_threshold`	Minimum thickness of floating ice shelves	150.0	300.0

Table 1. The six physical parameters that are varied.

4. Results

- Each model is now evaluated by comparing the simulated ice thickness with the Bedmap2 dataset (Fretwell et al., 2013). The mean absolute error is used as a simple measure of model skill.
- There is considerable variation in skill within each ensemble (Figure 3). However, the skill also varies with the choice of geothermal heat flux dataset: model 39 gives the most realistic solution when using Martos et al. (2017), but model 36 is most realistic in the other two cases.

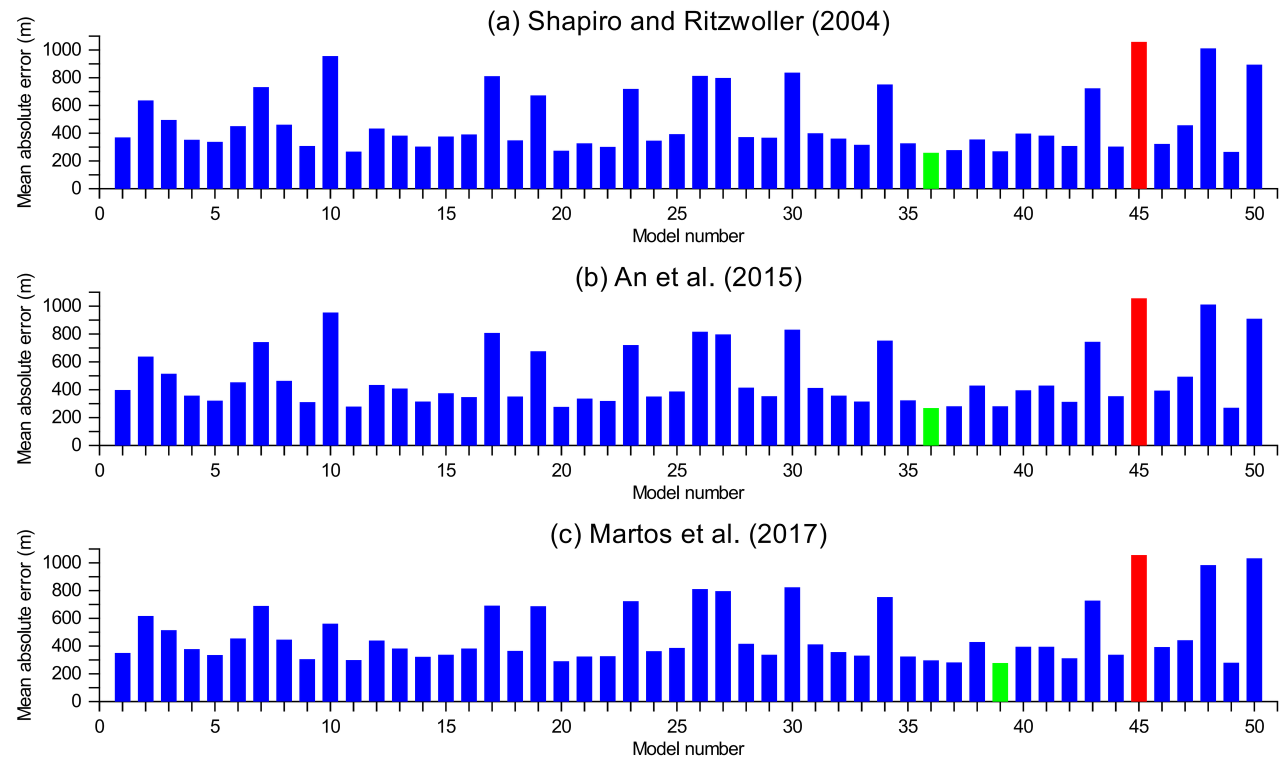

Figure 3. Mean absolute error in ice thickness (m) for: (a) Shapiro and Ritzwoller (2004), (b) An et al. (2015), and (c) Martos et al. (2017). Green indicates the best model in each case, and red the worst.

- Comparing the spread *within* the ensembles (Figure 4a) with the spread *between* the ensembles (Figure 4b), we see that the simulated ice thickness is much more sensitive to the choice of model physics than to the choice of geothermal heat flux dataset.

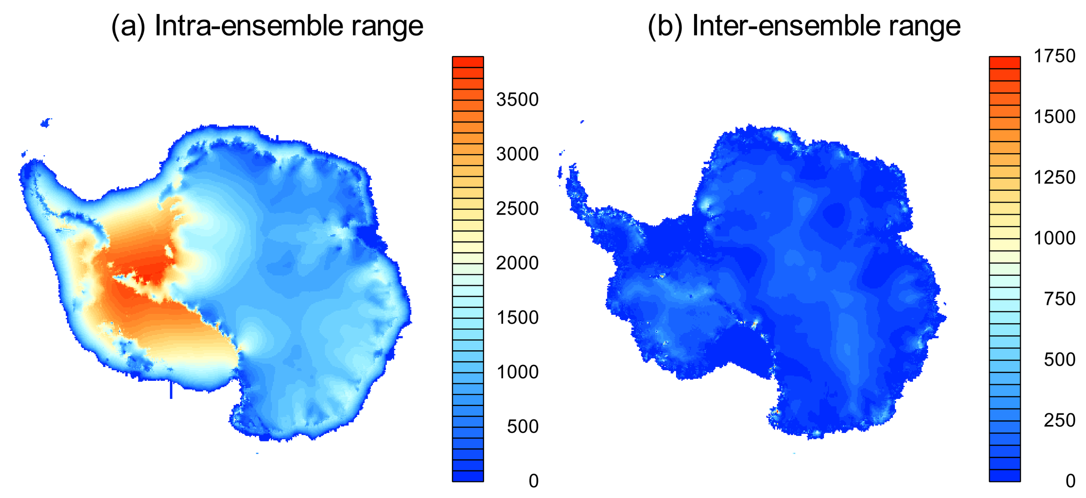

Figure 4. Intra- and inter-ensemble ranges in ice thickness (m): (a) the range spanned within the ensemble driven by An et al. (2015), and (b) the range spanned across ensembles by model 36.

- Figure 4 reveals that the model physics is the dominant source of uncertainty in West Antarctica, but that it is less important in East Antarctica. We therefore evaluate each model again, but this time for the East Antarctic Ice Sheet only (Figure 5).
- There is now less variation in skill within each ensemble. However, the choice of geothermal heat flux dataset continues to determine which model is identified as being optimal.

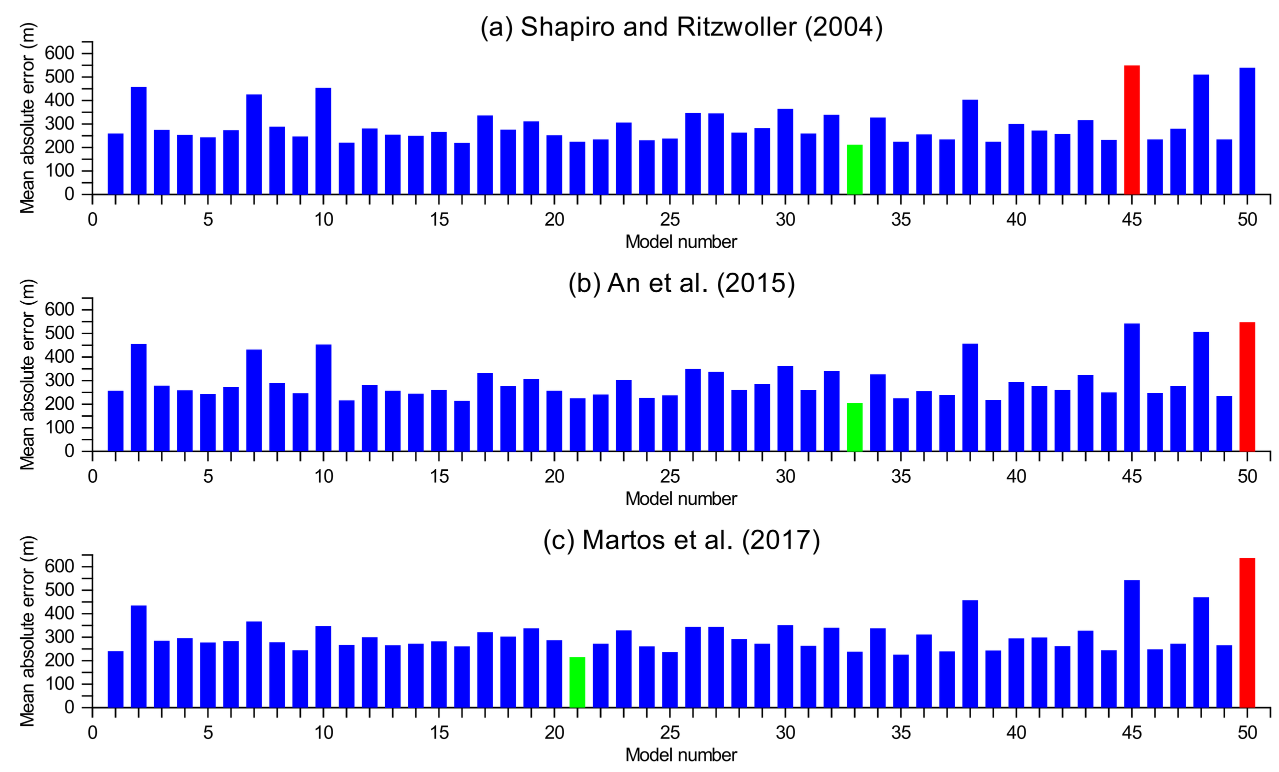

Figure 5. As Figure 3, but for the East Antarctic Ice Sheet only.

5. Conclusions

- Using PISM to simulate the Antarctic Ice Sheet, we find that uncertainty in model physics is a larger source of uncertainty in ice sheet modelling than uncertainty in the geothermal heat flux.
- Nonetheless, the choice of geothermal heat flux dataset does influence the process of "tuning" the model. This demonstrates the need for accurate estimates of the geothermal heat flux in Antarctica.

References

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