Using the history of the Antarctic Ice Sheet to reduce uncertainties in projections of global sea level rise

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1. Introduction

- The dynamics of the Antarctic Ice Sheet (AIS) is the largest source of uncertainty in projections of future global sea level rise.
- The past evolution of the AIS provides an opportunity to constrain the description of physical processes within ice sheet models.
- We therefore use an ice sheet model to explore how past changes can be used to improve predictions of the future evolution of the AIS.

2. Constraining an ice sheet model

- We use the Parallel Ice Sheet Model (PISM; Winkelmann et al., 2011).
- A 100-member perturbed-physics ensemble is constructed, using a Latin hypercube approach to sample the range of uncertainty in the parameterisations of 10 key physical processes (Table 1).

	Parameter	Iteration 1		Iteration 2		Iteration 3	
		Min.	Max.	Min.	Max.	Min.	Max.
1	Shallow ice enhancement factor	1.00	5.50	1.00	4.25	1.00	4.25
2	Shallow shelf enhancement factor	0.50	2.00	0.50	2.00	0.75	2.00
3	Exponent of basal resistance model	0.10	1.00	0.10	0.73	0.10	0.73
4	Effective till pressure scaling factor	0.0050	0.0400	0.0050	0.0400	0.0111	0.0400
5	Calving rate scaling factor	1.00e15	1.00e20	1.00e15	1.00e20	8.94e15	1.00e20
6	Minimum thickness of floating ice shelves	50.0	400.0	191.9	400.0	191.9	335.8
7	Minimum till friction angle	5.0	20.0	5.0	20.0	5.0	20.0
8	Maximum till friction angle	20.0	40.0	20.0	40.0	20.0	40.0
9	Elevation of minimum till friction angle	-1500.0	0.0	-1500.0	0.0	-1500.0	0.0
10	Elevation of maximum till friction angle	0.0	1500.0	0.0	942.5	0.0	942.5

Table 1. The 10 physical parameters that are varied within the ensemble, including the convergence of the iterative process. Red text indicates a change in the value from the previous iteration.

- An iterative process is used to determine the parameter ranges:
  - Initial values are selected, based on prior published work.
  - The ensemble is integrated to equilibrium for modern conditions.
  - For each parameter, the range that gives a realistic simulation of the AIS is determined. Simulations are considered realistic if the ice distribution agrees well with Bedmap2 (Fretwell et al., 2013).
  - If the minimum or maximum parameter value differs from the previous iteration, according to a statistical test, then it is updated.
  - These steps are repeated until no further changes are required.
- This process is found to converge after three iterations (Table 1).

3. No single optimal configuration

- For the final iteration of the optimisation process, 36 of the 100 ensemble members give a realistic present-day simulation of the AIS.
- These 36 different sets of parameter values are used to determine the degree of covariance between the ten parameters, within the set of model configurations that can be considered realistic (Table 2).

	2	3	4	5	6	7	8	9	10
1	+0.14	-0.09	-0.10	-0.06	+0.07	+0.19	-0.24	-0.24	-0.03
2		+0.30	+0.01	+0.08	-0.12	+0.13	0.00	-0.04	-0.24
3			-0.59	+0.27	-0.05	-0.05	-0.18	-0.28	+0.14
4				-0.10	-0.19	-0.12	+0.34	+0.51	-0.27
5					-0.14	-0.17	-0.37	-0.37	+0.22
6						+0.28	+0.08	-0.15	-0.08
7							-0.12	+0.12	-0.19
8								+0.38	-0.32
9									-0.24

Table 2. The Pearson correlation coefficients for each pair of the ten physical parameters. Red text indicates that the correlation is statistically significant at the $p = 0.01$ probability level.

- Two of the relationships are statistically significant at the $p = 0.01$ probability level. These relationships are examined in Figure 1.
- Such relationships mean that there is no single configuration of the model that is optimal; rather, there is a family of optimal configurations. This requires the use of large ensemble modelling approaches.

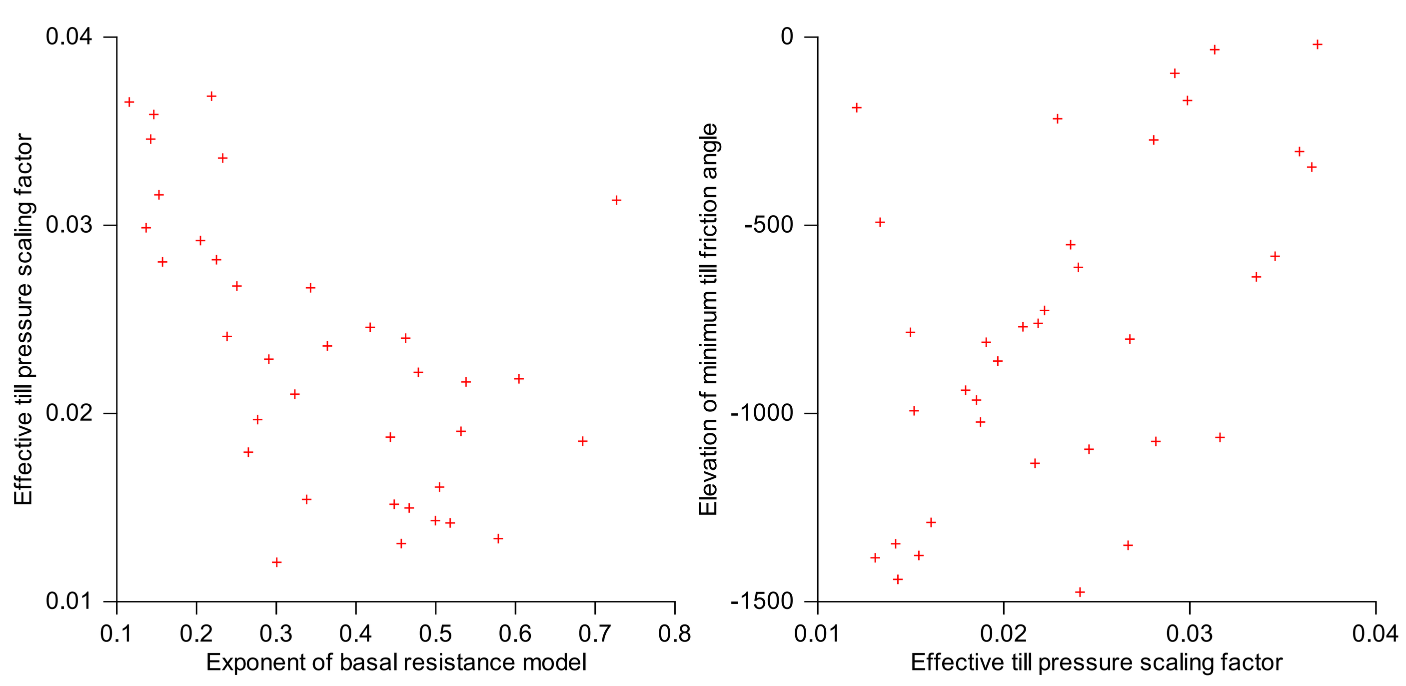

Figure 1. Scatter plots of the relationships between two key parameter pairs.

4. Future projections

- The full ensemble is integrated from the Last Glacial Maximum (LGM; 21,000 years ago) through to the future, under the RCP8.5 scenario.
- The atmospheric and oceanic boundary conditions for PISM are generated using the CSIRO Mk3L climate model (Phipps et al., 2011, 2012).
- The contribution of the AIS to global sea level is shown in Figure 2.

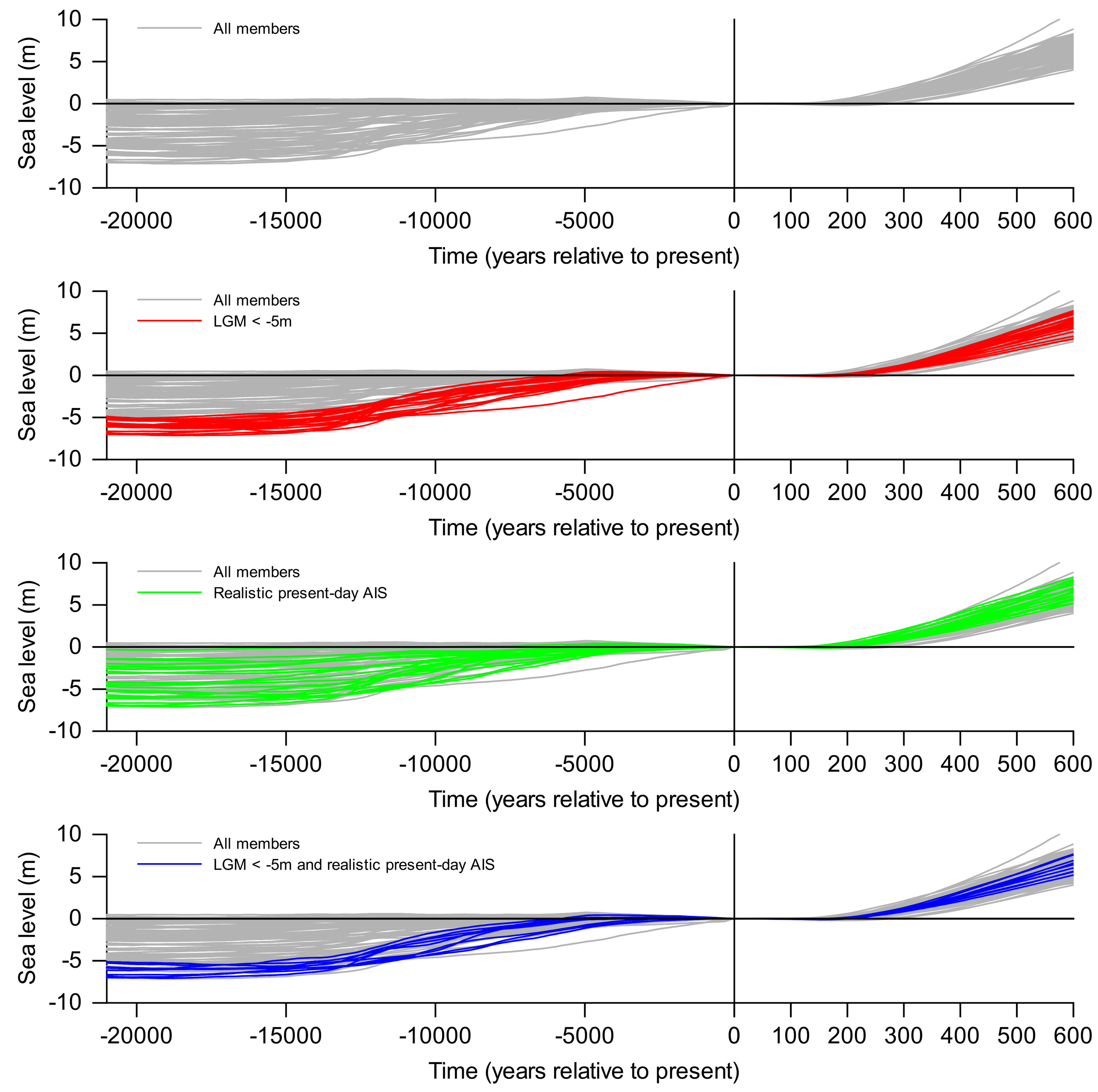

Figure 2. The simulated contribution of the AIS to global sea level, for each ensemble member.

- 20 members (red lines) satisfy the constraint that the LGM contribution should be at least 5m (Noble et al., in review).
- 21 members (green lines) have a realistic present-day AIS, as determined by comparison with Bedmap2 (Fretwell et al., 2013).
- 9 members (blue lines) satisfy both constraints.
- Information on past and present states of the AIS reduces uncertainty in future projections, but does not change the best estimates (Figure 3).

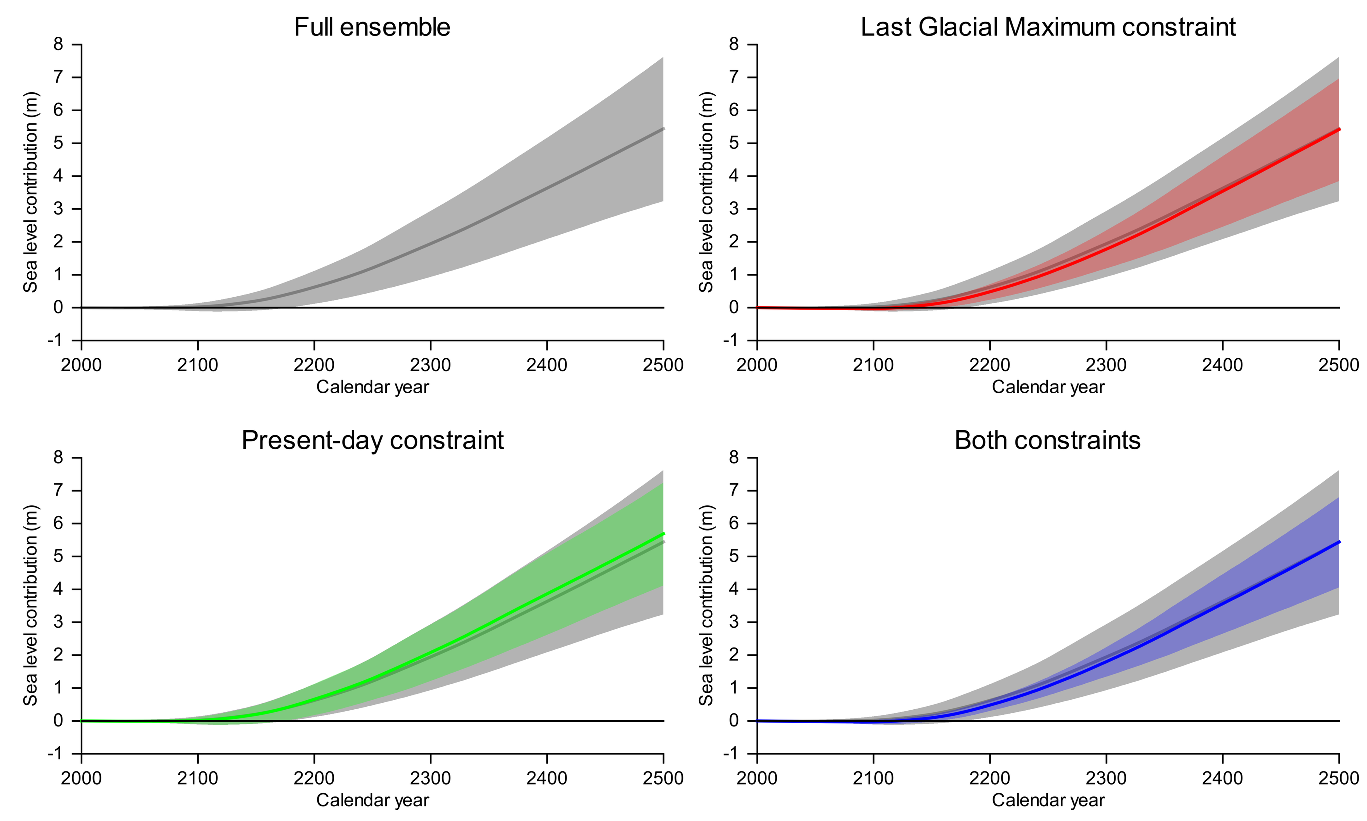

Figure 3. Mean and 95% range for the simulated future contribution of the AIS to global sea level.

- Under the RCP8.5 scenario, the projected AIS contribution to global sea level by 2500 CE is refined from 5.44±2.20m to 5.44±1.37m.
- Our estimates are significantly lower than DeConto and Pollard (2016), who project an AIS contribution by 2500 CE of 15.65±2.00m.

5. Conclusions

- Information on past and present states of the Antarctic Ice Sheet can be used to refine future projections of global sea level.
- The primary benefit is to reduce *uncertainty* in the projections, rather than to revise the best estimates.

References and acknowledgements

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