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Potsdam Institute for Climate Impact Research

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DFG-SCHWERPUNKTPROGRAMM 1158 ANTARKTISFORSCHUNG mit vergleichenden Untersuchungen in arktischen Eisgebieten

PISM paleo simulations of the Antarctic Ice Sheet over the last two glacial cycles

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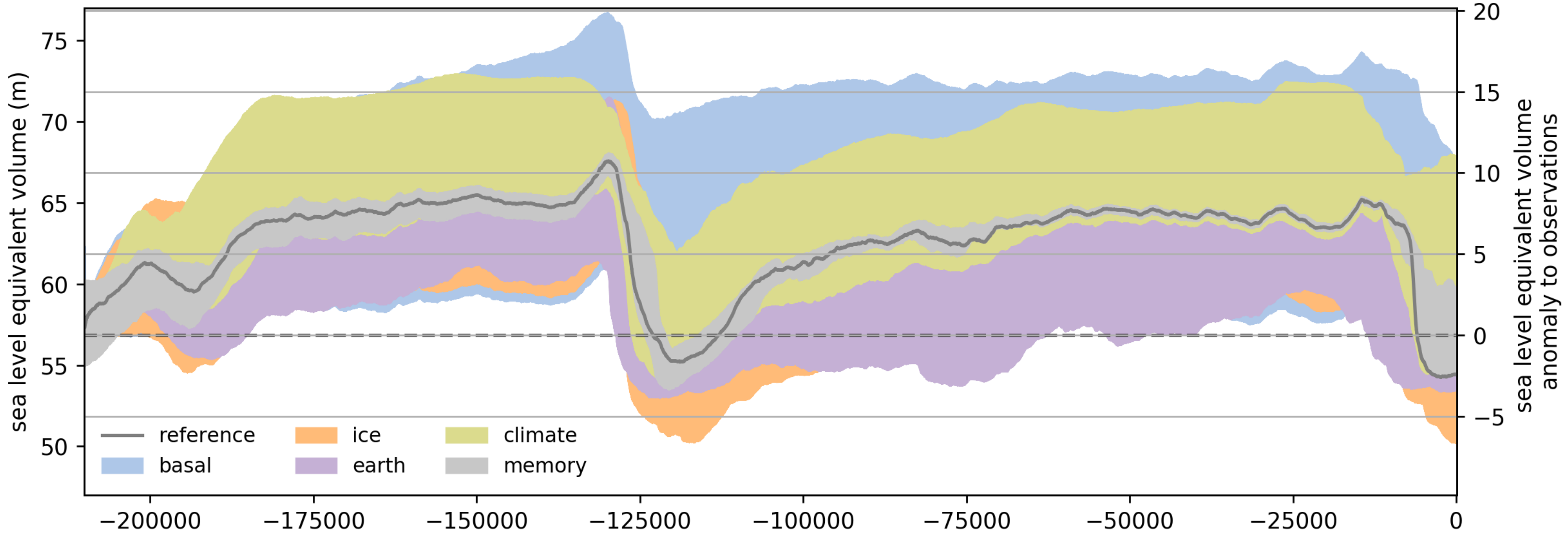

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1 Short summary

What?

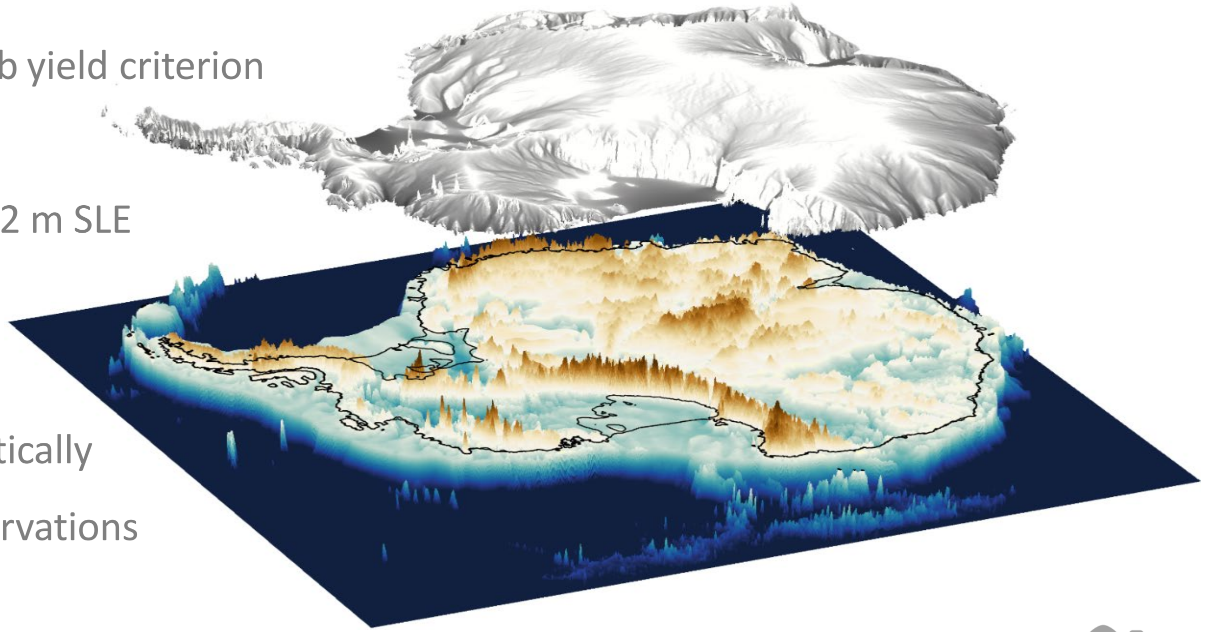
- PISM simulations over two glacial cycles reveal a strong sensitivity of Antarctic Ice Sheet volume history (sea-level equivalent: SLE) to model parameterizations and boundary conditions

And?

- in particular the basal sliding conditions arising from Mohr-Coulomb yield criterion and subglacial hydrology show a spread of more than 15 m SLE, but there is also some internal model uncertainty of the order of 1-2 m SLE

So what?

- choice of parameter and boundary conditions needs to be systematically constrained by scoring against multiple paleo and present-day observations



PISM ice veolocities (grey) over
Bedmap2 surface elevation and bed topography

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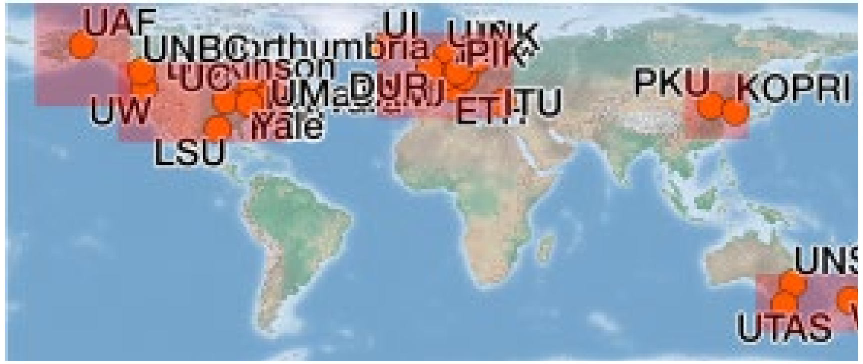
2 Parallel Ice Sheet Model (PISM)

- **ice dynamics**: hybrid of Shallow Ice Approximation (SIA) and Shallow Shelf Approximation (SSA) (Bueler & Brown, 2009)
- **grounding line** and calving front can freely evolve (on sub-grid scale) (Feldmann et al., 2014; Levermann et al., 2012)
- visco-elastic **bed deformation** by modified Lingle-Clark model (Lingle & Clark, 1985; Bueler et al., 2007)
- three-dimensional **polythermal enthalpy** conservation (Aschwanden et al., 2012)
- **sub-shelf melting** simulated using the Potsdam Ice-shelf Cavity mOdel (PICO, Reese et al., 2018)
- positive degree day (PDD) scheme that calculates **surface mass balance** (SMB) from parameterized air temperature and scaled RACMO precipitation (van Wessem et al., 2018)
- **temperature anomaly forcing** from EPICA Dome C and WAIS Divide ice core (Jouzel et al., 2007; Cuffey et al., 2016)
- **sea-level forcing** from ICE-6G_C (Stuhne & Peltier, 2015)
- **resolution**: horizontal 16 km for regular Cartesian grid (EPSG:3031), vertical quadratic spacing with 20m at base
- open source: http://pism-docs.org, **code version** based on v1.0: DOI 10.5281/zenodo.3574033

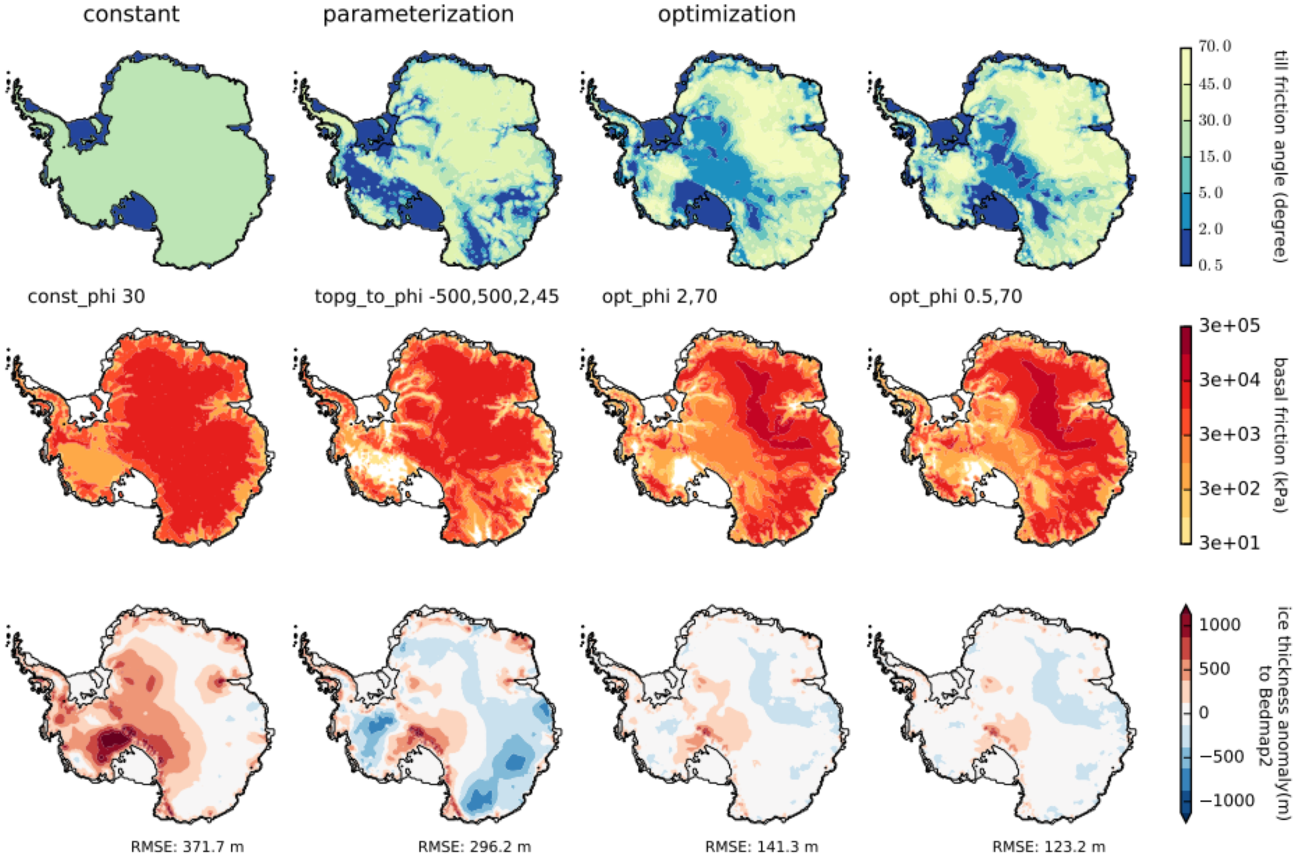


PISM users worldwide

3 Boundary conditions

Till friction angle

complexity of parameterization for till friction angle



decreasing anomaly to observed ice thickness

- describes a microscopic property of the till, which is difficult to measure underneath the ice sheet
- iterative optimization algorithm which targets observed ice thickness or surface elevation
- other parameterizations of boundary conditions:
  - summer and annual mean surface air temperature based on ERA-Interim data
  - ocean temperature at depth in response to surface temperature using response theory

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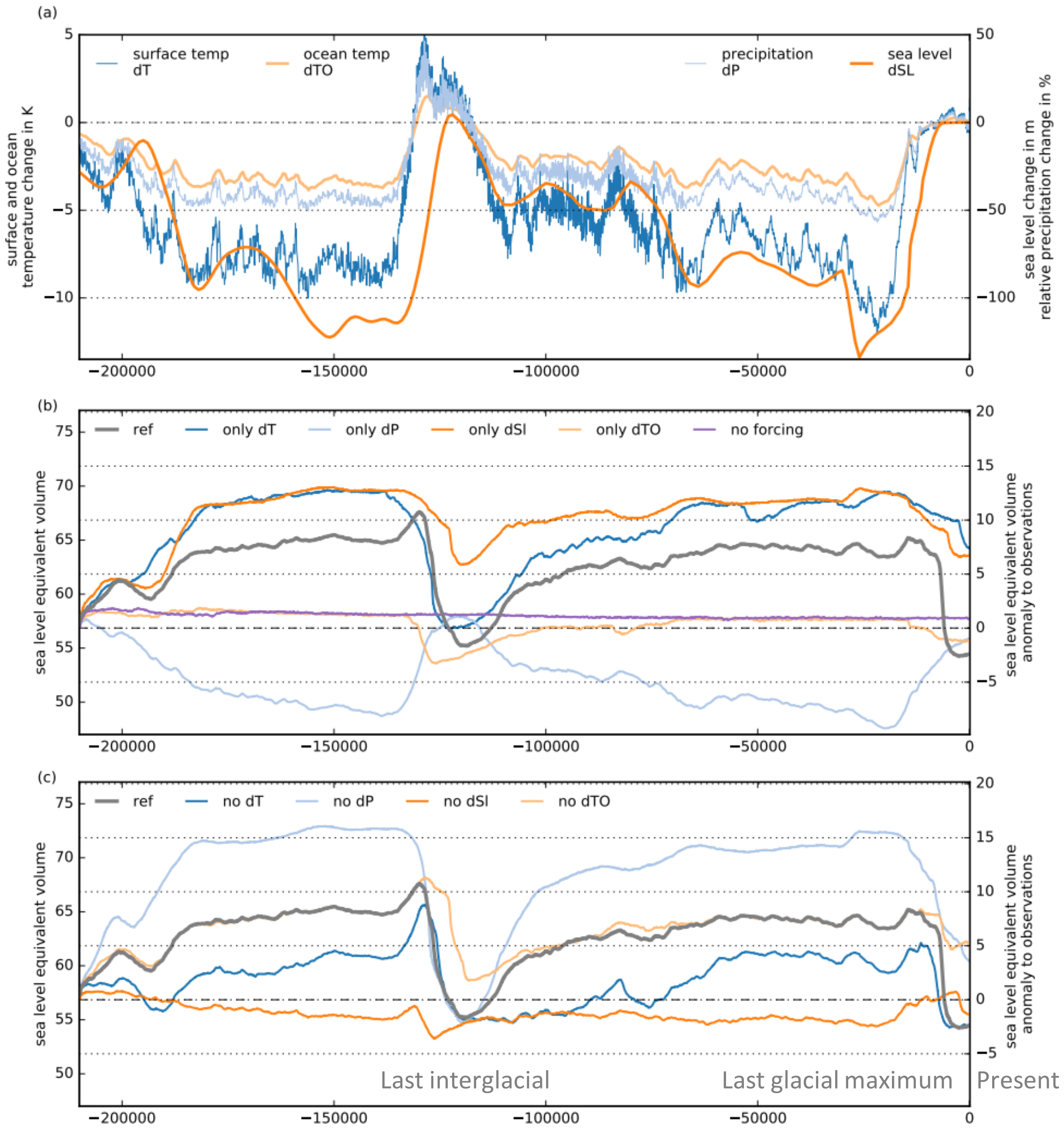
4 Sensitivity of ice volume — Climatic forcing



1. surface temperature anomaly dT(t)
2. ocean temperature anomaly dTo(dT)
3. precipitation scaling dP(dT)
4. sea-level anomaly dSl(t)

- one forcing alone cannot explain glacial cycle history of sea-level relevant ice volume (reference in grey, see movie)

- without sea-level forcing there is no significant ice sheet growth and decay

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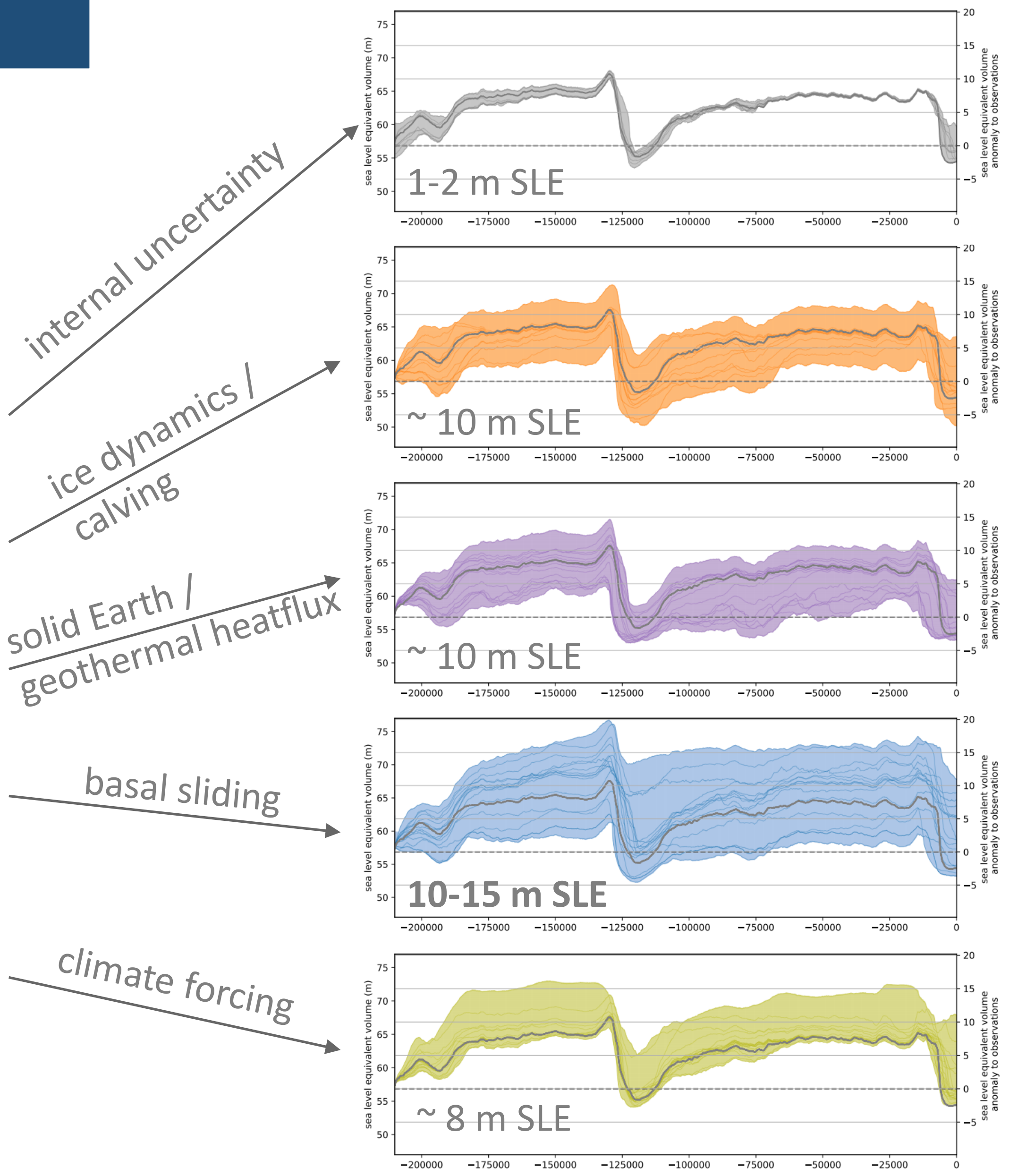
4 Sensitivity of ice volume

Table 2. Sensitivity (mean and standard deviation) of simulated ice volume at Last Interglacial (LIG), Last Glacial Maximum (LGM) and present day (PD) for varied input datasets and model parameters (some of which are already indicated in Table 1), and the used reference value. Selected ensemble parameters for each category are bold: VISC and PPQ are more relevant to deglacial and present WAIS dynamics, and ESIA and PREC are relevant rather to EAIS dynamics. Asterisk indicates a different PISM version used.

Name	Parameter meaning	Range	Unit	LIG (m SLE)	LGM (m SLE)	PD (m SLE)	Reference
	Reference simulation			−1.6	8.0	−2.4	
LGM range 0.0	enthalpy spin-up (Fig. 1)	Climate		−1.4 ± 0.4	8.1 ± 0.1	−1.2 ± 0.8	Const. PD
E_{SIA} **(ESIA)**	SIA flow enhancement (Fig. 3)	1–5		−1.9 ± 4.1	7.6 ± **4.3**	**−2.2 ± 4.4**	2
E_{SSA}	SSA flow enhancement (Fig. 3)	0.3–1.0		−1.2 ± 3.0	8.0 ± 0.3	−0.1 ± 4.7	0.6
n_{SIA}	SIA flow-law exponent (Fig. 4)	2–4		−2.0 ± 1.3	8.0 ± 0.2	−1.4 ± 1.1	3
n_{SSA}	SSA flow-law exponent (Fig. 4)	2–4		−1.0 ± 4.9	7.3 ± 0.7	0.1 ± 5.7	3
dz	Vertical resolution (Fig. 5)	1–40	m	2.2 ± 6.2	10.5 ± 4.9	2.9 ± 8.1	20
K	Eigencalving parameter (Fig. 6)	10^{16}–10^{18}	m s	−2.1 ± 0.6	8.0 ± 0.0	−1.6 ± 0.8	10^{17}
H_{cr}	Calving thickness (Fig. 6)	75–225	m	−2.3 ± 1.0	7.8 ± 0.4	−1.9 ± 0.5	75
η **(VISC)**	Upper-mantle viscosity (Fig. 7a)	0.1–10 × 10^{21}	N m	−2.0 ± 1.7	7.9 ± 0.3	**−1.5 ± 3.1**	0.5 × 10^{21}
D	Flexural rigidity (Fig. 7b)	0.5–10 × 10^{24}	Pa s	−3.3 ± 0.5*	4.0 ± 0.5*	−2.6 ± 0.0*	5 × 10^{24}
q **(PPQ)**	Pseudo-plastic exp. (Fig. 13)	0–1		1.3 ± 5.1	9.5 ± 2.4	**3.5 ± 4.6**	0.75
ϕ	Till friction angle (Fig. 15a)	Param.	°	0.7 ± 2.0	9.1 ± 1.6	2.1 ± 4.7	Opt. 2,70
ϕ_{min}	Min. till friction angle (Fig. 15b)	1–5	°	2.4 ± 7.7	9.8 ± 5.2	2.6 ± 6.9	2
C_d	Till water decay (Fig. 17)	1–10	mm yr^{-1}	2.5 ± 5.6	12.8 ± 4.6	2.6 ± 5.8	1
δ	Fr. eff. overburden pres. (Fig. 17b)	2–8	%	−0.6 ± 0.9	9.2 ± 5.2	−0.7 ± 1.9	4
G	Geothermal heat flux (Fig. 12)	Datasets	mW m^{-2}	−0.2 ± 1.3	9.3 ± 1.2	1.7 ± 3.2	Martos17
f_p **(PREC)**	Precipitation scaling (Fig. 23)	0–7	% K^{-1}	−1.8 ± 0.3	10.9 ± **3.5**	**0.1 ± 3.1**	7
σ_{PDD}	SD of daily temp. (Fig. 10)	0–5		−1.3 ± 0.3	8.0 ± 0.0	−1.2 ± 1.0	5
T_s	Temperature forcing (Fig. 10)	Datasets		−0.7 ± 0.7	8.4 ± 0.4	−1.6 ± 1.0	Param.
Δz_{sl}	Sea-level forcing (Fig. 18)	Datasets	m	−1.7 ± 0.7	8.0 ± 0.3	−1.1 ± 0.9	Peltier15
ΔT_s	Surface temp. forcing (Fig. 19)	Ice cores	K	−2.0 ± 0.5	8.2 ± 0.6	−0.5 ± 2.2	EDC + WDC
ΔT_o	Ocean temp. forcing (Fig. 22)	Param.	K	−1.4 ± 0.5	8.0 ± 0.0	−0.9 ± 1.9	EDC + WDC

range in modeled sea-level equivalent ice volume



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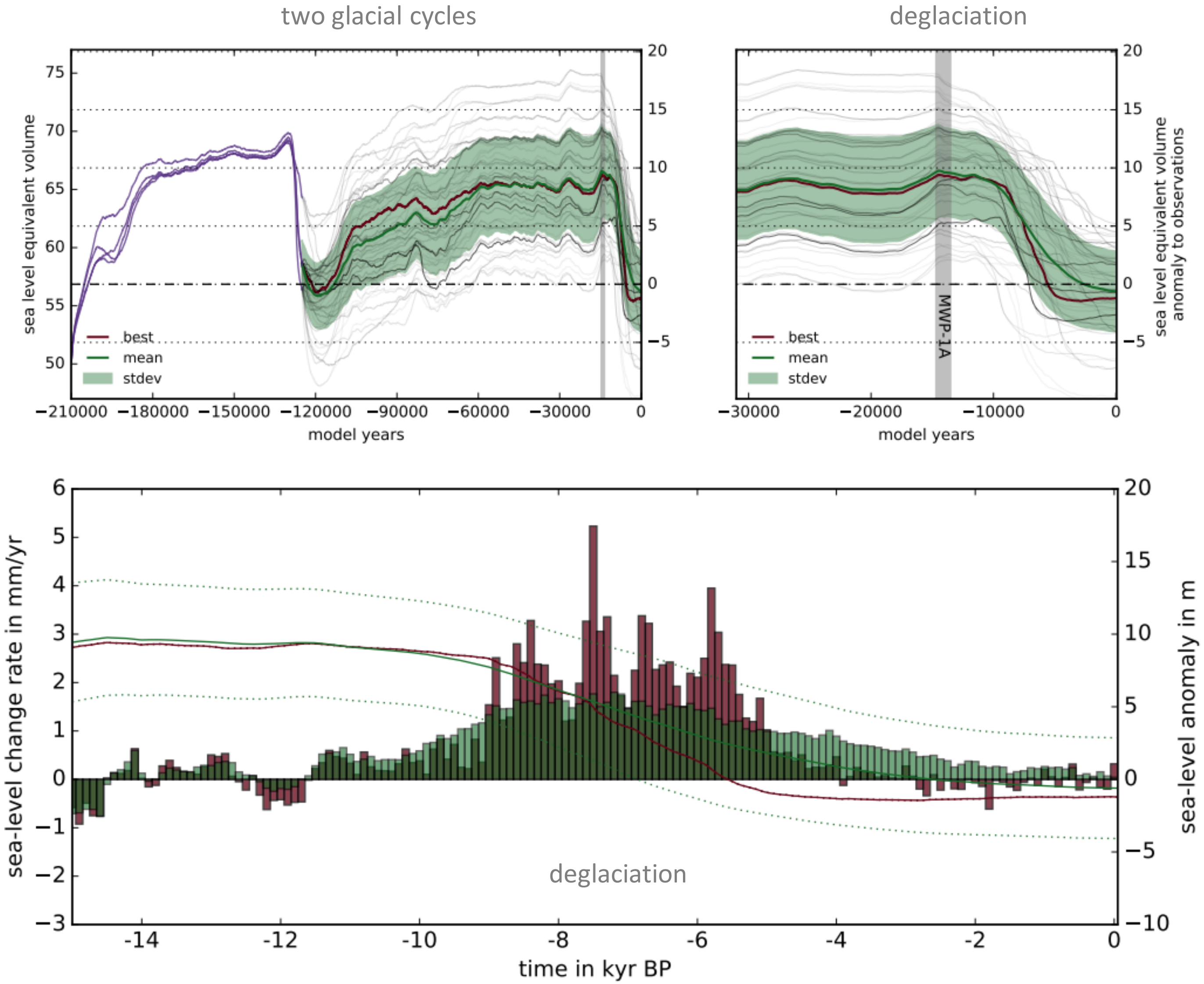
5 Parameter ensemble

- scoring an ensemble of 4 selected parameters for each of the uncertainty categories → 256 members
- at last glacial maximum (LGM) ensemble-mean ice volume yields 9.4 ±4.1 m SLE above present-day observation
- best score simulations (red) reached 5 mm SLE per year sea-level rise during deglaciation



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