“Current policies and historical trends constrain future mass loss from the Greenland Ice Sheet” by Siew et al. 2026

Supplementary Figures

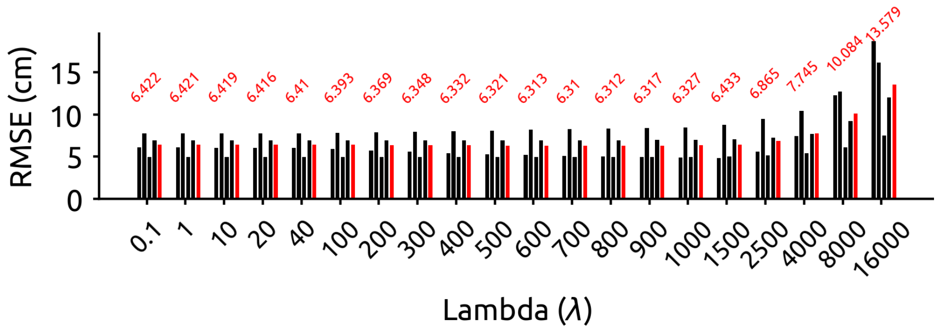

Figure S1: Root-mean-square error (RMSE) of the emulated and simulated Greenland sea-level contributions under the “leave-one-simulation-out” cross-validation approach with increasing values of λ, a hyperparameter in ridge regression. Black bars from left to right indicate the validation simulations: PISM forced by MIROC5 RCP85, RCP26, RCP2685, and RCP85-cooling. The red bars show the average RMSE across the four validation simulations. The numbers on top indicate the average RMSE values, which are minimized at λ=700.

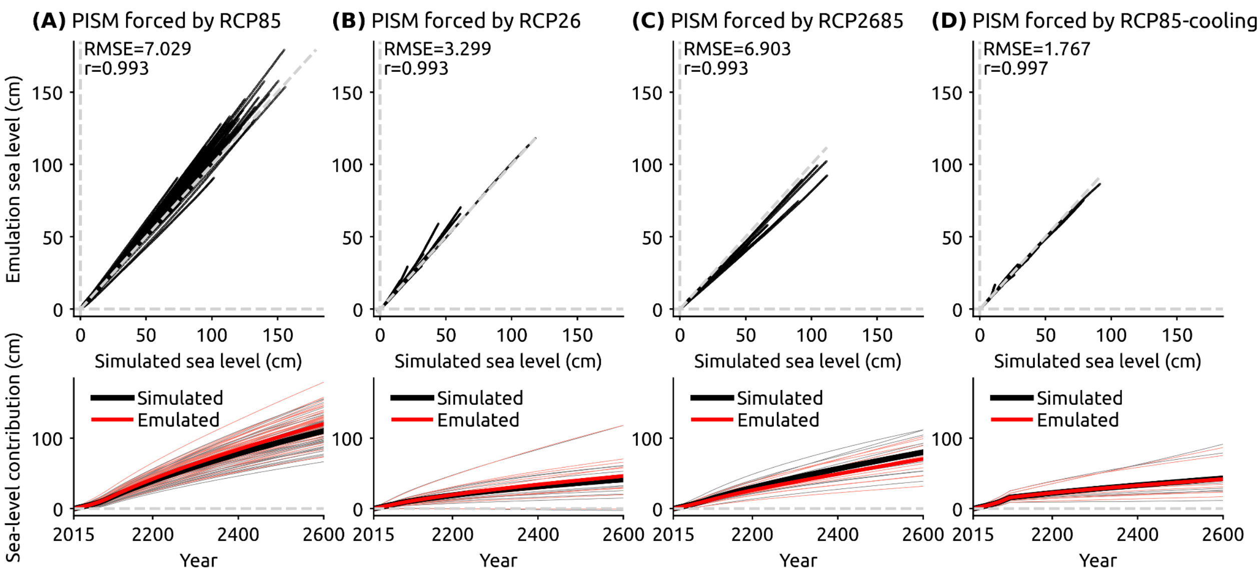

Figure S2: As in Figure 1 in the manuscript, but using an artificial neural network (ANN) rather than ridge regression for the emulator. The ANN consists of two fully connected hidden layers, each with 10 nodes. The ANN setup includes the ReLU activation function for the hidden nodes to introduce nonlinearities, the Adam optimizer, and mean squared error (MSE) as the loss function. Other hyperparameters include a batch size of 32, a learning rate of 0.01, and an L2 regularization strength of 0.0001. Additionally, 20% of the data was reserved for validation to implement early stopping during training. The ANN is randomly initialized five times, with the final results representing the average of these iterations. The ANN regression is performed using the scikit-learn Python package.

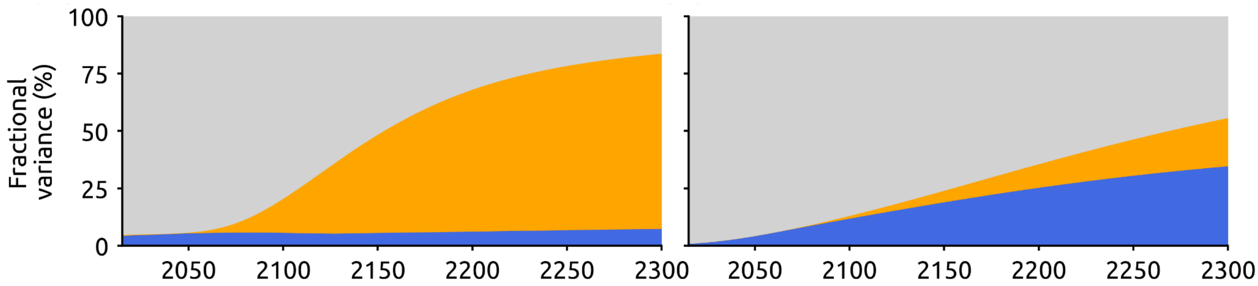

Figure S3: Left and right panels correspond to Figures 3C and 3F in the manuscript, but with grey shading showing the fractional variance (%) due to ice-sheet model parameters without history calibration.

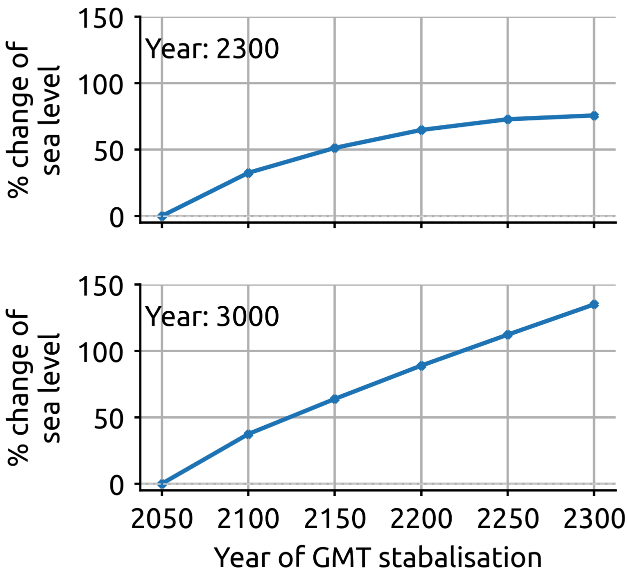

Figure S4: The percentage increase in Greenland sea-level contributions in years (A) 2300 and (B) 3000 if the GMT stabilization is delayed until 2100, 2150, 2200, 2250, or 2300, compared to stabilization occurring in 2050.

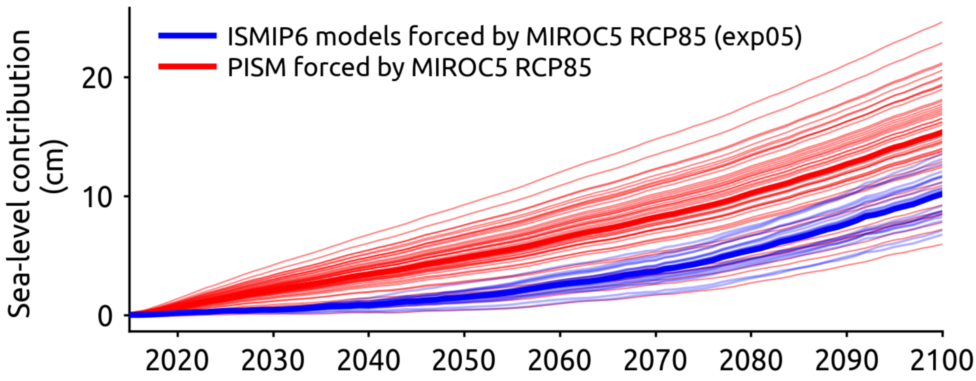

Figure S5: Simulated Greenland sea-level contribution (cm; relative to 2015) over the period 2015–2100 for the PISM simulations forced by MIROC5 RCP85 in this study (red; 48-member parameter ensemble) and ISMIP6 Exp05 (blue; 21 models). Thin lines show individual simulations, and the thick lines show their averages. The ISMIP6 Exp05 Greenland simulations include AWI-ISSM1, AWI-ISSM2, AWI-ISSM3, BGC-BISICLES, GSFC-ISSM, ILTS_PIK-SICOPOLIS1, ILTS_PIK-SICOPOLIS2, IMAU-IMAUICE1, IMAU-IMAUICE2, JPL-ISSM, JPL-ISSMPALEO, LSCE-GRISLI, MUN-GSM1, MUN-GSM2, NCAR-CISM, UAF-PISM1, UAF-PISM2, UCIJPL-ISSM1, UCIJPL-ISSM2, VUB-GISM, and VUW-PISM. The ISMIP6 simulations were downloaded from the archive documented in Goelzer et al. (2020): https://zenodo.org/records/3939037.

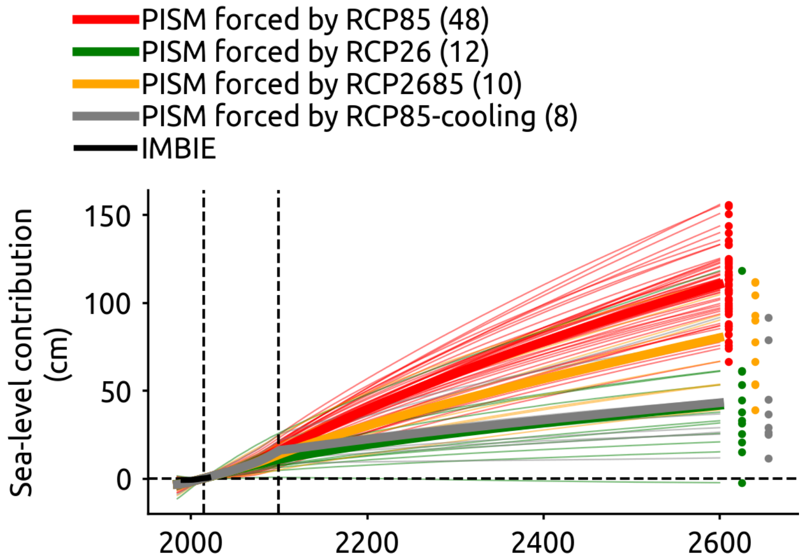

Figure S6: Simulated Greenland sea-level contribution (cm; relative to 2015) over the period 1990–2600 from PISM simulations forced by RCP85 (red), RCP26 (green), RCP2685 (yellow), and RCP85-cooling (grey). Numbers in parentheses in the legend indicate the number of parameter ensemble members for each simulation. The black line shows the IMBIE-observed Greenland sea-level contribution over the period 1992–2020. Two vertical dotted lines indicate the years 2015 and 2100.

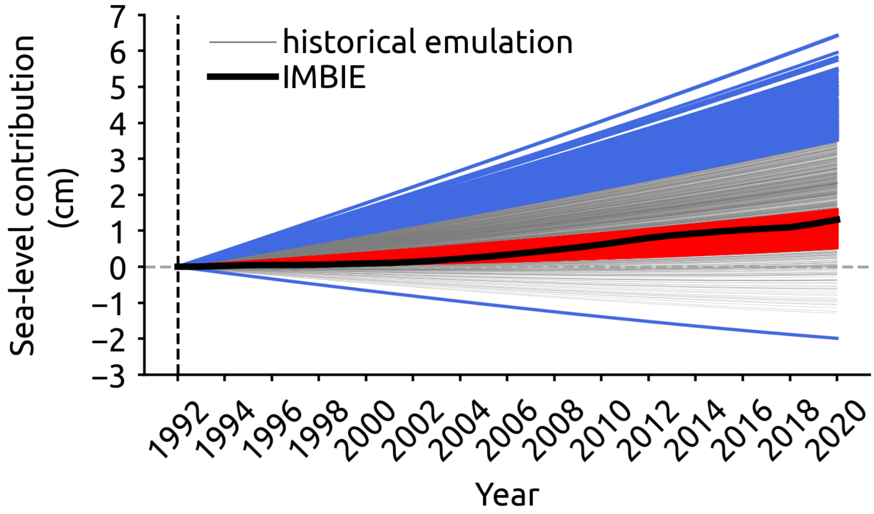

Figure S7: Emulated Greenland sea-level contribution (cm; relative to 1992) over the historical period 1992–2020 for the 1,000-member parameter ensemble using historical GMT (grey, blue, and red). The black line shows the annual-mean, IMBIE-observed Greenland sea-level contribution (cm; relative to 1992) over the same period. Each member is assigned a weight according to how close it is to the IMBIE observations: red (blue) lines show the 200 emulations that are the closest to (furthest from) the IMBIE observations.

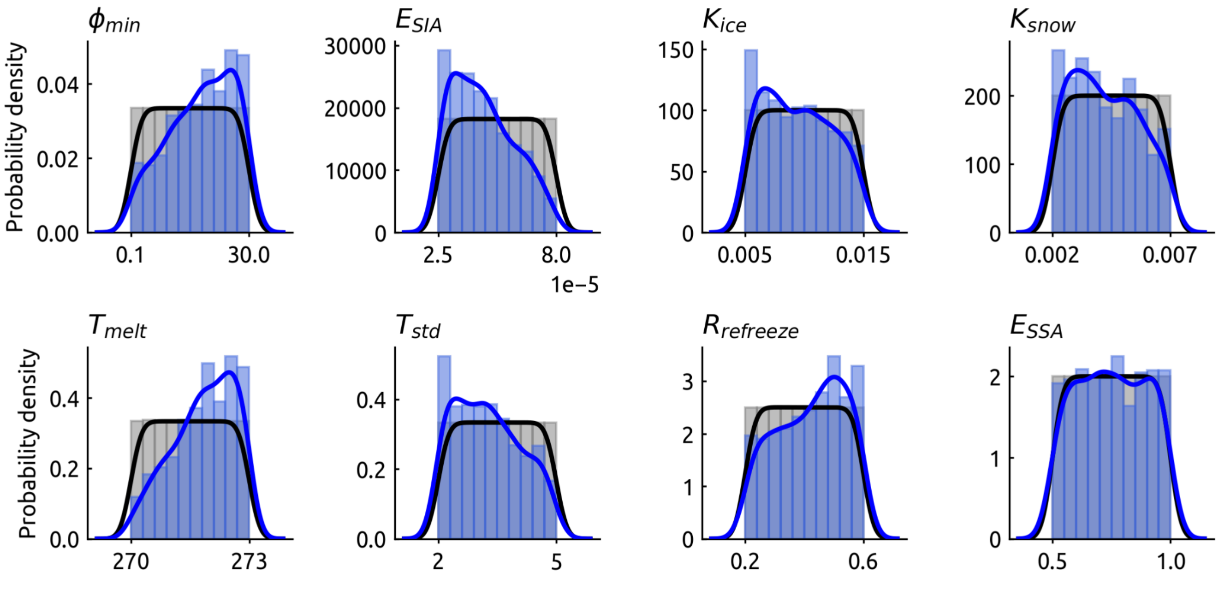

Figure S8: Grey histograms (normalized) show the original distributions of the eight PISM parameters among the 1,000 members (i.e., without history calibration). Blue histograms (normalized) show the updated distributions after accounting for the weights of each parameter ensemble member (i.e., with history calibration). The weights are based on the assumption that the emulated structural error is 20 times the observational error (the default choice in our analysis). Smooth solid lines show the probability density functions estimated by kernel density estimation (KDE) using Scott's Rule.

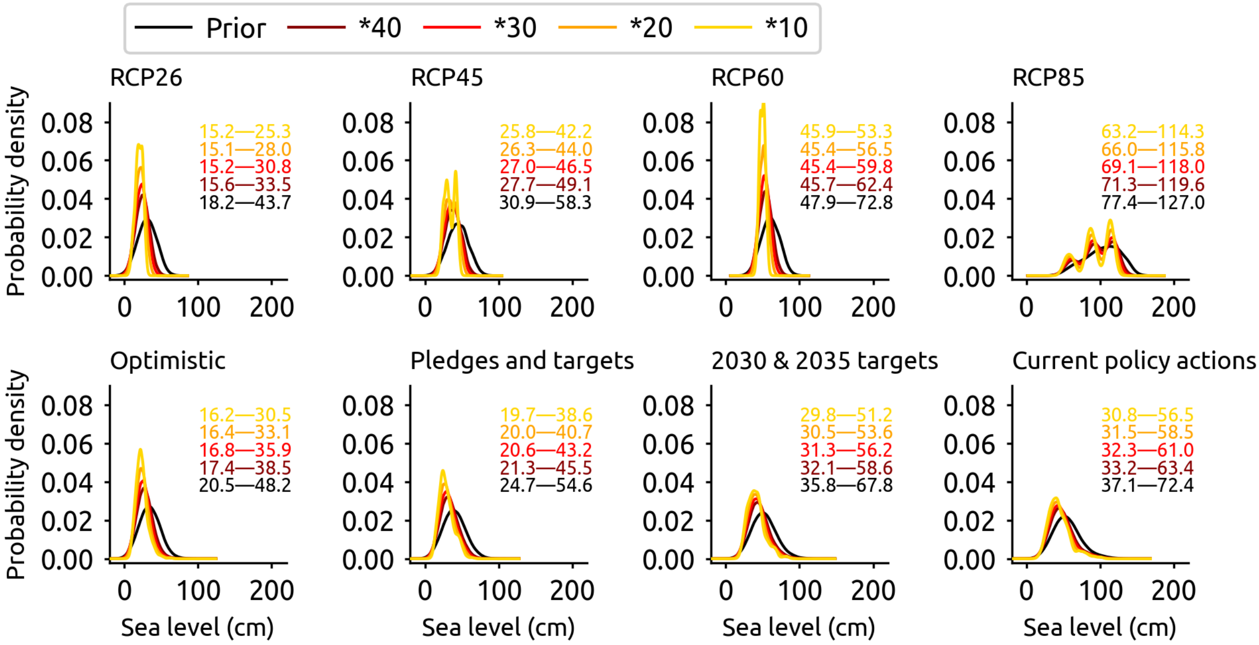

Figure S9: Probability density functions of the Greenland sea-level contributions by the year 2300 for the extended RCP scenarios (upper panels) and climate policy actions (lower panels). The black curves represent the original distributions (i.e., without history calibration; prior). Colored curves show the updated distributions (i.e., with history calibration; posterior), where the score of each parameter ensemble member is calculated by assuming that the emulated structural error is 40 (brown), 30 (red), 20 (orange), and 10 (yellow) times the observational error. Note that 20 is the default choice in the main analysis. The colored text indicates the likely ranges (17–83 percentiles) of the respective distributions. The probability density functions are estimated by kernel density estimation (KDE) using Scott's Rule.

Supplementary Tables

PISM forced by	Ensemble members	K_{ice}	K_{snow}	T_{melt}	T_{std}	$R_{refreeze}$	ϕ_{min}	E_{SIA}	E_{SSA}
MIROC5 RCP85	1	0.0114	0.0031	271.6	2.16	0.59	25.6	4.2e-05	0.61
	2	0.0096	0.0028	270.7	4.74	0.32	0.4	2.6e-05	0.74
	3	0.0139	0.0034	271.5	4.5	0.29	17.6	4e-05	0.65
	4	0.0128	0.0063	270.9	2.59	0.41	20.1	6.8e-05	0.87
	5	0.0086	0.0021	272.3	4.26	0.28	27.9	3.3e-05	0.69
	6	0.0145	0.0057	272.9	3.34	0.55	0.9	2.9e-05	0.56
	7	0.0147	0.0037	270.3	2.75	0.43	12.4	7.7e-05	0.77
	8	0.0059	0.005	272.8	4.68	0.26	21.0	7.4e-05	0.7
	9	0.0092	0.0052	270.5	4.48	0.32	28.6	6e-05	0.88
	10	0.0115	0.0051	270.0	2.38	0.27	23.4	4.4e-05	0.92
	11	0.0081	0.0044	270.4	2.48	0.42	22.2	7.2e-05	1.0
	12	0.0074	0.0024	272.1	3.91	0.51	24.0	3e-05	0.58
	13	0.0123	0.004	271.1	2.53	0.6	6.4	4.6e-05	0.96
	14	0.0065	0.0059	271.4	2.99	0.49	29.7	6.6e-05	0.75
	15	0.0132	0.0026	271.0	3.82	0.47	4.7	4.3e-05	0.6
	16	0.0119	0.0021	270.2	3.58	0.25	21.9	4.8e-05	0.86
	17	0.0051	0.0064	272.4	4.81	0.56	7.6	7e-05	0.81
	18	0.0076	0.0046	271.6	4.92	0.35	23.0	5.6e-05	0.84
	19	0.0091	0.0044	271.8	2.26	0.21	11.5	6.5e-05	0.58
	20	0.0095	0.003	273.0	2.84	0.24	15.0	3.8e-05	0.9
	21	0.0134	0.0058	270.8	3.22	0.3	5.7	5.2e-05	0.85
	22	0.0071	0.0067	271.2	4.32	0.53	27.2	2.5e-05	0.52
	23	0.0084	0.0062	271.3	3.09	0.4	5.2	6.5e-05	0.79
	24	0.0106	0.0041	272.6	2.7	0.52	11.2	7.2e-05	0.63
	25	0.0142	0.0046	272.1	3.39	0.21	16.9	4.5e-05	0.68
	26	0.0137	0.0048	271.8	4.03	0.58	19.6	7.6e-05	0.81
	27	0.0056	0.0038	272.2	2.0	0.46	26.5	6.3e-05	0.74
	28	0.0058	0.0043	270.1	2.9	0.36	1.5	6.1e-05	0.79
	29	0.0126	0.0054	272.5	3.01	0.48	26.1	5.3e-05	0.99
	30	0.0107	0.0056	272.2	4.95	0.51	2.6	5.6e-05	0.98
	31	0.0121	0.006	270.6	3.45	0.38	29.1	3.6e-05	0.62
	32	0.0111	0.0029	270.6	3.27	0.57	18.2	7.1e-05	0.91
	33	0.007	0.0055	271.0	2.67	0.23	24.8	3.1e-05	0.71
	34	0.0129	0.0053	272.9	4.15	0.25	13.1	5.9e-05	0.53
	35	0.0062	0.0036	272.7	4.87	0.34	8.5	4e-05	0.95
	36	0.0064	0.0023	272.0	4.23	0.44	15.3	6.3e-05	0.66
	37	0.011	0.0033	272.4	3.79	0.46	3.2	4.9e-05	0.94
	38	0.014	0.0066	270.4	3.19	0.35	4.0	3.5e-05	0.52
	39	0.0083	0.0024	271.9	4.58	0.29	10.2	2.7e-05	0.64
	40	0.0052	0.0027	270.1	3.71	0.5	2.2	5.4e-05	0.72
	41	0.0098	0.0065	270.5	3.63	0.39	7.2	7.9e-05	0.83
	42	0.0067	0.0032	271.7	2.34	0.55	13.8	7.5e-05	0.89
	43	0.0104	0.0068	272.7	2.07	0.37	17.1	7.9e-05	0.55
	44	0.0101	0.0036	271.3	4.4	0.22	15.9	5e-05	0.93
	45	0.0078	0.0061	270.9	3.56	0.54	19.1	5.8e-05	0.76
	46	0.015	0.004	271.6	2.19	0.41	9.2	5.1e-05	0.56
	47	0.0119	0.0069	271.2	3.99	0.44	9.5	3.4e-05	0.67
	48	0.0089	0.0048	272.6	4.12	0.33	13.5	3.6e-05	0.51
MIROC5 RCP26	1	0.0103	0.0061	272.3	4.89	0.57	6.5	6.9e-05	0.74
	2	0.0054	0.0049	272.6	3.62	0.33	4.7	6.2e-05	0.51
	3	0.0081	0.0022	270.8	2.24	0.28	28.5	2.6e-05	0.88
	4	0.0068	0.0029	272.2	4.55	0.26	9.6	4.8e-05	0.55
	5	0.0135	0.0068	272.8	2.79	0.38	23.6	4.8e-05	0.92
	6	0.0066	0.0039	270.3	3.84	0.34	22.4	3.9e-05	0.67
	7	0.0115	0.0065	270.2	2.4	0.49	13.8	3.3e-05	0.79
	8	0.0131	0.0056	271.9	4.46	0.56	11.5	7.7e-05	0.65
	9	0.0091	0.0025	271.1	3.43	0.43	19.9	3.7e-05	0.86
	10	0.0099	0.0034	271.7	3.0	0.5	25.3	5.4e-05	0.62
	11	0.0125	0.005	271.3	2.71	0.23	17.5	5.8e-05	0.98
	12	0.0146	0.0044	270.5	4.21	0.47	1.1	7.4e-05	0.8
MIROC5 RCP2685	1	0.0073	0.0056	270.8	2.13	0.44	1.1	7.8e-05	0.65
	2	0.0087	0.005	271.1	4.89	0.24	28.5	3.2e-05	0.76
	3	0.0144	0.0068	272.4	3.88	0.25	19.8	5.5e-05	0.85
	4	0.0109	0.0031	272.7	4.17	0.59	16.0	4.8e-05	0.98
	5	0.0095	0.0024	271.9	3.0	0.48	26.6	5.8e-05	0.91
	6	0.0138	0.0045	271.6	3.21	0.35	5.7	7.2e-05	0.6
	7	0.0069	0.0028	271.2	2.47	0.54	13.1	2.9e-05	0.86
	8	0.011	0.0052	272.9	4.46	0.32	10.3	4.5e-05	0.54
	9	0.0054	0.0062	270.4	2.83	0.51	7.4	3.9e-05	0.59
	10	0.0122	0.004	270.1	3.62	0.36	21.5	6.4e-05	0.75
MIROC5 RCP85-cooling	1	0.0125	0.0061	271.2	2.24	0.32	11.3	3.1e-05	0.7
	2	0.007	0.0047	272.7	2.42	0.45	24.4	6.1e-05	0.54
	3	0.0142	0.0053	270.4	3.53	0.36	4.8	4.5e-05	0.91
	4	0.011	0.0024	272.3	2.9	0.23	20.5	7.5e-05	0.66
	5	0.0096	0.0035	270.1	3.97	0.58	1.3	6.7e-05	0.86
	6	0.0054	0.0039	272.1	4.94	0.54	17.5	5.2e-05	0.8
	7	0.008	0.0069	271.0	3.41	0.48	28.4	3.2e-05	0.94
	8	0.0132	0.0028	271.8	4.5	0.26	12.4	5.4e-05	0.57

Table S1: The four PISM experiments and their associated parameter ensembles, comprising 78 simulations in total.

CMIP5 Extended RCP scenarios	Models (number of ensemble members)	Total numbers
RCP2.6	CCSM4 (1) CESM1-CAM5 (1) CanESM2 (1) GISS-E2-H (1) GISS-E2-R (1) IPSL-CM5A-LR (1) MPI-ESM-LR (1) bcc-csm1-1 (1)	8
RCP4.5	CESM1-CAM5 (1) CNRM-CM5 (1) CSIRO-Mk3-6-0 (3) CanESM2 (2) GISS-E2-H (5) GISS-E2-R (5) IPSL-CM5A-LR (1) IPSL-CM5A-MR (1) MIROC-ESM (1) MPI-ESM-LR (1) NorESM1-M (1) bcc-csm1-1 (1)	23
RCP6.0	CCSM4 (1) CESM1-CAM5 (1)	2
RCP8.5	CCSM4 (1) CNRM-CM5 (1) CSIRO-Mk3-6-0 (3) GISS-E2-H (1) GISS-E2-R (1) IPSL-CM5A-LR (1) MPI-ESM-LR (1) bcc-csm1-1 (1)	10

Table S2: CMIP5 extended RCP scenarios and the names of the climate models that ran these simulations. The numbers in parentheses represent the number of ensemble members for each model. There are 43 simulations in total.