Reply to reviews for 'The stability of present-day Antarctic grounding lines — Part B: Possible commitment of regional collapse under current climate.'

Reese, R., Garbe, J., Hill, E. A., Urruty, B., Naughten, K., Gagliardini, O., Durand, G., Gillet-Chaulet, F., Chandler, D., Langebroek, P. M., Winkelmann, R.

October 31, 2022

Reply to Michele Petrini Referee 1, https://doi.org/10.5194/tc-2022-105-RC1

General comments:
In this paper, Reese et al. use the 'Parallel Ice Sheet Model' (PISM) and the sub-shelf melt module 'Potsdam Ice-shelf Cavity mOdel' (PICO) to analyse the multi-millennial evolution of the Antarctic grounding-lines under a constant, present-day climate forcing, and the reversibility of associated large-scale changes. The authors first calibrate the sub-shelf melt module PICO against observed (Dotson ice-shelf) and modelled (Filchner-Ronne ice-shelf) melt sensitivity to ocean temperature changes. Optimised PICO parameters are then used in an ensemble of continuous spin-up (pre-industrial forcing) - historical (1850-2015 forcing) PISM simulations, which are evaluated against present-day observations. Simulations showing best agreement are then extended for 10,000 years beyond the historical period under constant present-day climate forcing and bathymetry. The evolution of the Antarctic grounding-lines is then analysed, and reversibility is tested for simulations showing large-scale retreat by reverting climate forcing to pre-industrial conditions.
In my opinion, this is a great paper, addressing an extremely relevant scientific topic (future states and reversibility of Antarctic grounding-lines) with the use of advanced modelling tools (e.g., PICO instead of simpler sub-shelf melt parameterizations) and innovative techniques to calibrate numerical modelling results against observations (e.g., PICO parameters optimisation, PISM ensemble scoring methods). The study presents some limitations (e.g., no isostasy, no full equilibrium reached at the end of the simulations), but these are clearly discussed throughout the manuscript, and are in my opinion acceptable considering the technical challenges (and, likely, computational costs) associated with this type of study.
In view of this, I consider this work definitely worthy of publication, and I commend the authors for the great deal of technical work they have undertaken.

I have only two major comments, mainly related to the quality and number of figures included in the manuscript. In fact, I think some important figures are missing, and some of the included figures do not allow the reader to easily verify what is stated in the main text.

Many thanks for reviewing our manuscript and for your constructive comments on how to further improve our manuscript. We are happy about your evaluation of the work! We hope to have answered all questions and addressed all improvements appropriately.

During the review process we found that the temperature corrections applied during the PICO paremeter selection were too weak, i.e., the present-day melt rates were underestimated. We redid the parameter selection. The parameters are only marginally affected, but the temperature corrections changed. Based on this we then updated our ensemble. Doing so, we also changed the ensemble parameters and now focus on the most sensitive parameters from the previous ensemble (C_d and δ). This allows us to sample more values of the parameter δ and also include the 'min' and 'max' parameters for PICO. Doing so, we found 21 possible present-day configurations for the Antarctic Ice Sheet (called AIS1-AIS21). For all configurations, we redid the present-day continued and reversibility runs. We find that our main conclusions are not affected by this. The main difference we find is that our states are more sensitive now, which is consistent with higher present-day melt rates, and reflected in all ensemble members showing long-term irreversible retreat of Thwaites and some now also showing retreat of Pine Island.

We are currently waiting for some simulations to finish before we can finalise the update of the manuscript that we will submit at a later stage. We reply to all comments below and provide the updated versions of the figures. Note that figures and tables reference to the numbers used here.

1. As stated in the main text (L140–141), I fully agree that the PICO calibration proposed in this study approach has a great potential to be used in further Antarctic studies, including future sea-level projections. However, I was a bit disappointed not finding any 2D-map of sub-shelf melt rates, and I think some of these figures should definitely be included (either in the main text or as Supplementary material) to see the outcome of the calibration procedure, and also to get a sense of the magnitude and spatial variability of the sub-shelf melt forcing. For instance, 2D maps of sub-shelf melt rates could be included for ANT2/ANT2+0.1K/ANT2+0.3K simulations at pre-industrial and present-day snapshots. Moreover, since the calibration goal is to obtain correct melt rates and sensitivity (P.7, L179-180), I think it is necessary to include one additional figure showing the comparison between present-day PICO and observed sub-shelf melt rates, and briefly discuss this comparison in the text. Another interesting thing (but I leave this as a suggestion, rather than a request) would be to show, for one or two snapshots, a comparison of PICO sub-shelf melt rates and same melt rates calculated off-line using the simple two-equation quadratic parameterization. In fact, in this study PICO is calibrated to

'behave' like the two-equation quadratic parameterization in terms of sensitivity to ocean warming, but it would be interesting to see the difference in terms of spatial variability within the ice-shelf cavities.

Thank you very much for the suggestions. We created new a supplementary figure, see Fig. 1 below, showing the melt rates for the 'historic' ocean conditions and 'present-day conditions' for the best scoring initial configuration for the 'mean' PICO parameters (AIS5), the 'min' PICO parameters (AIS12), and the 'max' PICO parameters (AIS1). Scores and results for the model simulations of the new ensemble are given in Fig. 2 and Table 6. Since we include the range of PICO parameters now, we did not explicitly test for the sensitivity to ocean temperatures as this is indirectly included when testing the different sensitivities to ocean temperatures through the different PICO parameters. We compare the aggregated melt rates per ice shelf for all parameter combinations in supplementary Tables with the new versions given below (Table 1, 2, 3, 4, 5) and will add a discussion in the text: "In general, we can find temperature corrections that yield aggregated melt rates close to present-day estimates. Exceptions are basins 15 (Bellingshausen Sea) and sometimes 16 (George VI Ice Shelf), where temperature corrections of -2 K are not sufficient. Figure 1 shows the spatial pattern of melt rates for the 'min', 'mean' and 'max' PICO parameters. Generally, PICO shows a pattern of higher melt close to the grounding lines and refreezing in the large, cold cavities. Due to the box approach, melt rates are 'smoothed out' and do not show as much spatial variability as observations.". Note that figures and tables reference to the numbers used here.

We decided not to include a comparison with a quadratic parameterisation. One central difference between PICO and the quadratic parameterisations as implemented for example in Jourdain et al. (2020) is that PICO uses only one temperature input per ice shelf while the quadratic parameterisation requires a two dimensional field or at least a vertical profile of ocean input at the ice shelf base. In fact, spatial variability in the ice shelf for the quadratic parameterisation will depend on this temperature input, which makes it not straightforward to compare both parameterisations. Work in this direction has been done by Favier et al. (2019) and Burgard et al. (2022). The latter paper was already discussed, we will add also the first paper to the discussion, e.g. "For an idealised cavity, Favier et al. (2019) compared PICO together with other melt parameterisations to a coupled model and found that modelled ice mass loss was comparable."

2. I found it very difficult to track the evolution of the Antarctic integrated ice volume in the spin-up, historical, 10,000-extension and control simulations, since these are included in three different figures (Fig. 4, Fig. 5, Fig. B2) with different scales. I fully understand why the evolution under historical forcing is highlighted in Fig. 4, but then I would also like to have time series similar to Fig. B2 for the present-day forcing and recovery simulations (maybe in the Supplementary). I was very confused when looking at Fig. B2, as it seems that at the end of the control runs the ice-sheet is not in full equilibrium - which is also stated in the text (P16, L365-

367). However, by looking at Fig. 4, it seems that before introducing the historical forcing there is full equilibrium - maybe I am missing something, but I think some work should be done to show these results more clearly. I also think that a panel with integrated sub-shelf melting (perhaps averaged over ice shelf area?) like in Fig. 4 should be included also in Fig. 5. More in general, I think that the quality of some figures should be improved:

Thank you very much for pointing this out. Some of the confusion might have come from us sometimes showing results relative to the control simulations and sometimes the not-corrected variables. We made Figure 3 and Figure 4 (which are the Figures 3 and 4 below) now consistent by showing all simulations relative to the drift in the control runs and discuss this as well as the drift in the control runs in the text (we will add "We refer to the initial states as 'quasi-equilibrium' states, since the initial simulations have not yet reached a full equilibrium, even after 25,000 years in their 1850 initial configurations, see Fig. 5. We continue the control runs parallel to the historic simulations and for a further 10,000 years. During the historical simulations (years 1850 to 2015) the drift is 3-8 mm SLE, and during the 10,000 year extended simulations the drift is less than 26 cm SLE (see Tab. 6). All runs remain close to their 1850 configuration. Figure 5 shows that grounding lines move only a little for the ensemble and that rates of volume change monotonically decrease towards zero. In the following, results are presented relative to the respective control runs unless stated otherwise.").
Furthermore, as requested, we added the evolution of the ice volume under constant present-day climate and under the reversed forcing to Figure B2 (see Fig. 5 below). We prefer to not include the BMB in Figure 4 (Figure 4 below) as the figure already contains a lot of information and the ocean temperatures are constant over the simulations so that any changes arise from changes in the geometry. We added a new figure to the Supplement (see Fig. 6 below) showing the evolution of basal melt rates, surface mass balance, grounding line fluxes and fluxes at the calving front.
We hope these changes make it easier for the reader to follow.

3. (a) Fig. 4: it would be nice to include the figure with the observed ice thickness change from Smith et al. 2020, so that the reader can directly compare modelled and observed pattern/magnitude. The ensemble-average and BedMachine grounding-lines are a bit difficult to distinguish, I suggest using different colours/line thickness. I also think that the time series should also include total ice volume, not only dV. Finally, I think that in the caption it should be specified whether BMB refers to sub-shelf melting + grounded ice melting at the base (frictional heating, GHF), or sub-shelf melting alone (I'd rather include sub-shelf melting alone, but I leave this choice to the authors);

   Many thanks for the suggestions. We increased linewidth to make the grounding lines easier to distinguish and changed the BMB value to only include the melting below ice shelves. While it would be nice to have a direct comparison, we prefer to not include the figure of Smith et al. (2020) as this is no original work of ours. To make *it easier for the reader to pull up both figures, we will add a direct reference to the Figure in that paper ("... see for example Fig. 3 in Smith et al. (2020)"). Since ice volume differences between ensemble members are larger than the changes over the historic period, we do not include the ice volume in Fig. 4 (Fig. 4 below) as only straight lines would be visible in such a panel. However, to have the option to compare these values, we use the total ice volume in the Fig. B2 (Fig. 5 below).*

(b) Fig. 5: it would be nice to also have the time series for the evolution of sub-shelf melting and grounding-line flux;

We think that adding them here would overload the figure, so we created a new supplementary figure (see Fig. 6 below).

(c) Fig. 6: I suggest either showing this figure for the whole domain, or including a pan-Antarctic map to show the area considered in the zoomed figures;

We added a map to show the zoom region. Since more ensemble members show large-scale retreat now, we only show a selection of runs in this figure (see Fig. 7 below). We will create an additional figure with reversibility plots for all members and will add it to the supplement and discuss the results in the manuscript.

(d) Fig. 7: this figure is a bit too small, and there is a dark blue line labelled 'revere' which I assume is a typo. It would also be very nice to have this type of figures also for the 10,000–extension runs + recovery runs.

Thanks for the recommendations. We are currently waiting for some simulations and will adjust the figure accordingly.

Specific comments:

P1, L8: I would add to the abstract the fact that isostatic rebound is not accounted for in the simulations, e.g., "...under constant present-day climate forcing and bathymetry".

Done.

P2, L54-56: I suggest rephrasing, and including a citation for CMIP5.

We re-arranged this whole section to first discuss the section on PICO and then introduce the PISM experiments. We reformulated the sentence and added a citation for CMIP5 "Using the new PICO parameters, we create a set of plausible model representations of the present-day Antarctic Ice Sheet with the Parallel Ice Sheet Model (PISM). The ice sheet states are forced from 1850 to 2015 by historic changes in the ocean and atmosphere from a simulation of the Coupled Model Intercomparison Project Phase 5 (CMIP5: Taylor et al., 2012) and their mass loss compared to observed trends. We then let the ice sheet states evolve *under constant present-day climate conditions. To test for (ir)reversibility of grounding line retreat, the simulations showing large-scale retreat are extended for another* $20,000$ *years under (reverted) pre-industrial forcing.".*

P3, L62: '... let the ice sheet states evolve'.

We understand this comment as to stop the sentence here and not repeat the experimental design in too much detail. Based on this we will shortened the paragraph removing some more general information.

P3, L65: '... to occur eventually under…'.

Will be included.

P3, L65-67: I suggest rephrasing, e.g., 'To test … retreat, the simulations showing large-scale retreat are extended for 20,000 years under reverted pre-industrial forcing'.

Done.

P5, L125-126: I suggest rephrasing.

Done.

P6, L134: 'The present paper can be understood to investigates…'.

We reformulate this to "The present paper investigates..." to make the sentence less complicated.

P6, L149: '...which differ in between across…'.

Done.

P6, L.160-165: I found these sentences not very clear, I suggest rephrasing.

We suggest "Note that often ocean temperatures are also given in terms of thermal driving, that is the temperature above the freezing point, and we use both hereafter. If we use thermal driving, the freezing point is determined by local salinity and a reference pressure value. For simplicity, we use the surface freezing point, as the ice shelf draft (and therefore the in-situ freezing point) varies both in space and time.".

P7, L165: '...we hope *aim* to represent'.

Done.

P11, Section 4.1: I suggest including how the SMB is calculated in PISM, either in this section or in Section 4.2.

We directly use the data from RACMO. We will add in the methods section 'Note that we apply the surface mass balance from the regional climate model directly and do not calculate melting in PISM with a positive-degree-day or equivalent model.' to make this clearer.

P12, L291: I suggest specifying how many thousand years, rather than stating 'several'. Also, I'd use 'at 8 km horizontal resolution'.

Done.

P12, L301: I suggest including the notation Hmax as in Table 2.

Done.

P13, L315: I would remove 'the best run is used ... in Urruty et al.', as this is not relevant for this paper.

Done.

P15, L326: I would expand here on what quasi-equilibrium means, and what are the implications. I think it would be enough to move the text at P16, L365-369 at the beginning of the section.

Good idea, thanks. Done.

P15, L335: I would add some text linking the discrepancy from observation to simulated and observed sub-shelf melt rates pattern (either here, or in the discussion section). Also, the same could be done with simulated and observed SMB.

We will add and rearrange the discussion on this in the new manuscript.

P15, L343-345: I would split this sentence in two.

Done.

P15, L348-350: I suggest rephrasing.

Based on the new results, this will be reformulated.

P16, L374-376: I suggest rephrasing.

Done. We say now "Figure 4 shows that the grounding lines of the present-day configurations retreat substantially in the marine regions of West Antarctica over the 10,000 years with constant climate conditions. Overall, mass loss ranges between 2.5 m and 3.5 m SLE, which is lost over 10,000 years (see Table 6). For comparison, the drift in the historic initial states over this period is less than 30 cm." Note that figures and tables reference to the numbers used here.

P21, L468: I would use 'Moreover' instead of 'in particular'.

Done.

P21, L468-470: I would also add something like '...as well as glacial isostatic rebound, which can induce changes in the local bathymetry and ice shelf cavity geometry'. Also, I think the paper by Whitehouse et al. 2019, ('Solid Earth change and the evolution of the Antarctic Ice Sheet', Nature Comms.) should be cited here.

Added. Thanks for pointing us to the paper.

P24, L541: Rather than '...change in sub-shelf melt rates is thought to be a major trigger…' I would use something stronger, e.g., '... recent observations and modelling suggest that…'.

Done.

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Table 1: Temperature corrections and melt rates for Antarctic basins with PICO parameters C =2.0 Svm^3kg^{-1} and $\gamma_T^\star$ =5.0 $\times 10^{-5} ms^{-1}$.

basin	m_{obs} (Gt/yr)	δTD (K)	m_{PICO} (Gt/yr)	m_{B_1} (m/yr)	m_{B_2} (m/yr)
1	75.2	0.17	74.18	1.27	-0.14
2	38.2	-0.03	38.72	2.68	0.44
3	17.1	-0.24	16.22	1.92	0.14
4	57.9	-0.15	55.32	2.63	0.55
5	6.8	-0.51	6.32	1.41	-0.13
6	29.3	-0.15	30.53	1.76	-1.46
7	79.2	0.07	76.71	6.75	2.57
8	89.3	-1.13	88.52	8.89	1.39
9	24.4	-0.39	25.74	3.78	0.66
10	7.6	-0.75	7.51	2.05	-1.45
11	7.4	-0.15	7.62	3.45	0.15
12	135.1	0.35	137.83	1.50	0.02
13	167.0	-1.10	164.69	6.88	2.63
14	236.4	-1.35	236.45	19.61	11.09
15	68.5	-2.00	222.18	13.15	6.63
16	143.1	-2.00	171.91	11.97	5.91
17	6.5	-1.23	6.46	18.36	17.62
18	67.8	-0.38	65.97	2.69	0.64
19	4.7	-0.15	4.39	1.19	-0.63

We use m_{obs} which are observational melt rates from Adusumilli et al. (2020). The temperature corrections δTD are applied to the input temperature, and m_{PICO}, m_{B_1} and m_{B_2} denote melt rates calculated by PICO for the respective basin and boxes.

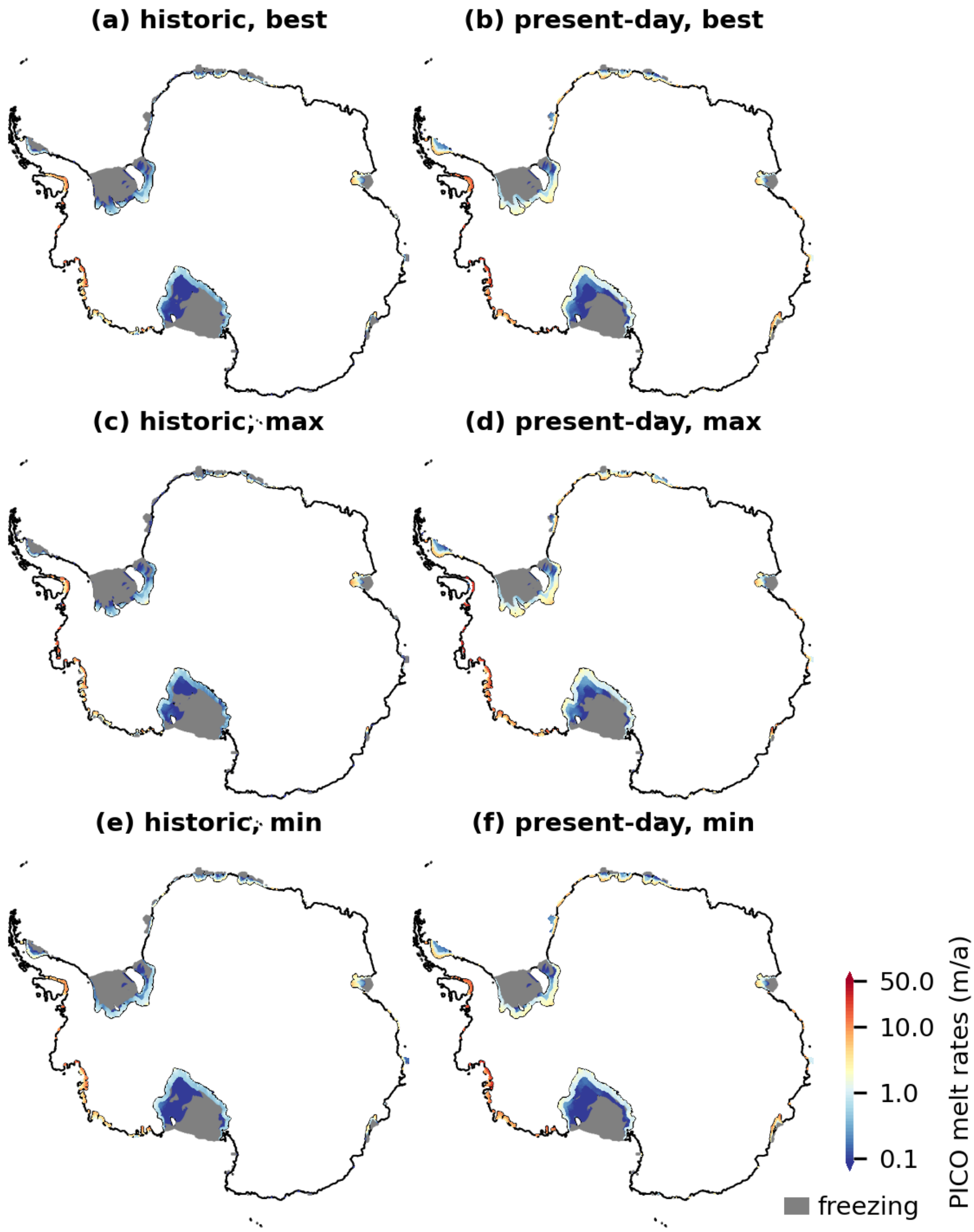

Figure 1: PICO basal melt rates for the 'best' PICO parameters for the AIS5 configuration in (a) the historic control run, and (b) the present-day extended run, the 'max' PICO parameters in the AIS1 configuration in (c) the historic control run, and (d) the present-day extended run, and the 'min' PICO parameters in the AIS12 configuration in (e) the historic control run, and (f) the present-day extended run.

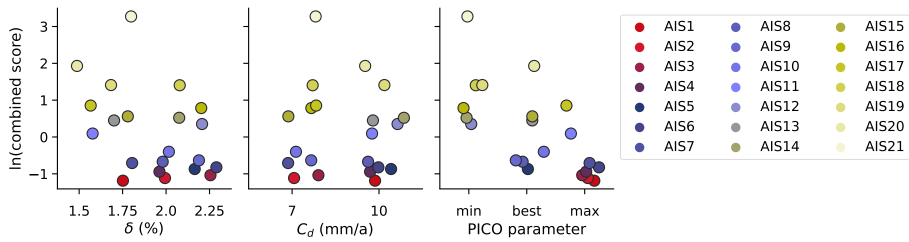

Figure 2: Scoring of ensemble of initial configurations in 2015. Scores are based on observed ice thickness, velocities, mass loss, grounding line positions, and a special focus is given to the Amundsen, Ross and Weddell seas. Initial ensemble members were obtained from equilibrium simulations of a full parameter ensemble with all runs that showed grounding lines broadly in agreement with present-day continued after 5000 to full 25,000 years (total of 21 runs). For each a historic simulation was run from 1850 to 2015. The 2015 state is then scored with present-day observations. Shown is the natural logarithm of the scores. The lower the values the better the agreement with present-day.

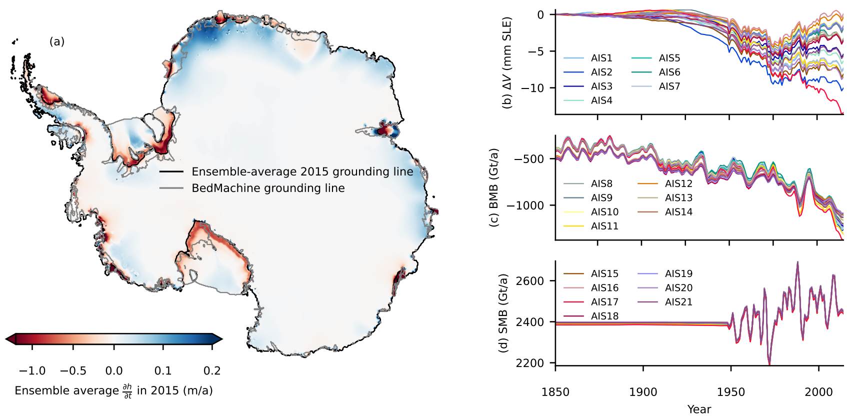

Figure 3: **Historic simulations from 1850 to 2015 and present-day ice sheet configurations.** Shown are (a) ensemble-average rates of ice thickness changes in 2015 (relative to control) with average grounding line position, and evolution of (b) the sea-level relevant ice volume (in millimetres sea-level equivalent, mm SLE), (c) basal mass balance of ice shelves (excluding melting in grounded regions), and (d) surface mass balance (both in gigatons per year).

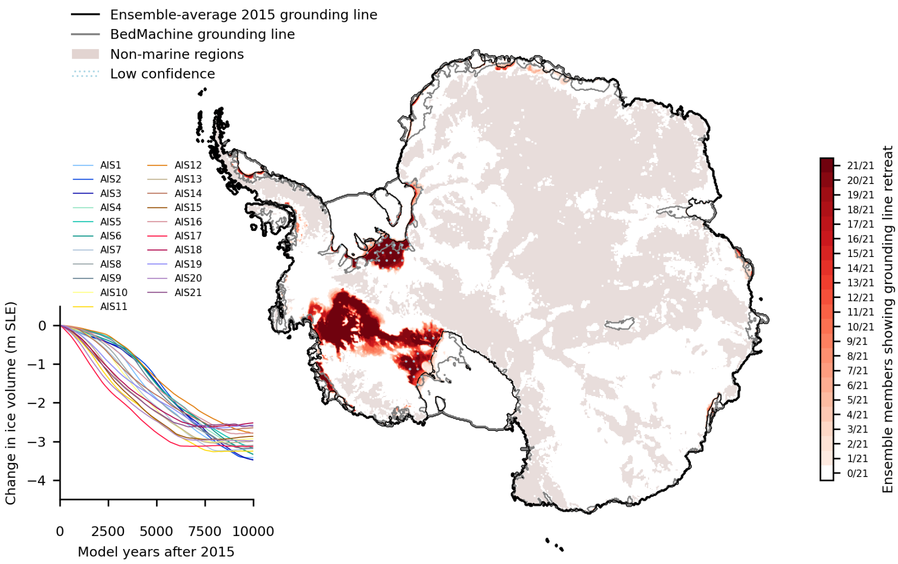

Figure 4: **Long-term evolution of present-day Antarctic grounding lines under constant present-day climate conditions.** Starting in present-day after the historic forcing from 1850 to 2015, simulations are continued with constant present-day climate for 10,000 years. Red colors show regions over which the grounding line retreats. The darker the red, the more simulations show grounding line retreat over the respective region in the different simulations corresponding to variations in basal sliding and ice flow parameters (retreat is plotted in comparison to a control simulation). Black contour shows ensemble-average initial grounding line position in 2015. Inset shows the evolution of sea-level relevant ice volume for all ensemble members (m SLE, metres sea-level equivalent, relative to the drift in the initial state over that period). Dots on retreat areas indicate regions in which present-day modelled thinning deviates from observations (namely for Filchner-Ronne and Ross ice shelves). Light brown indicates bedrock above sea level, white areas indicate bedrock below sea level. Note that retreat occurs only in marine regions which have bedrock below sea level.

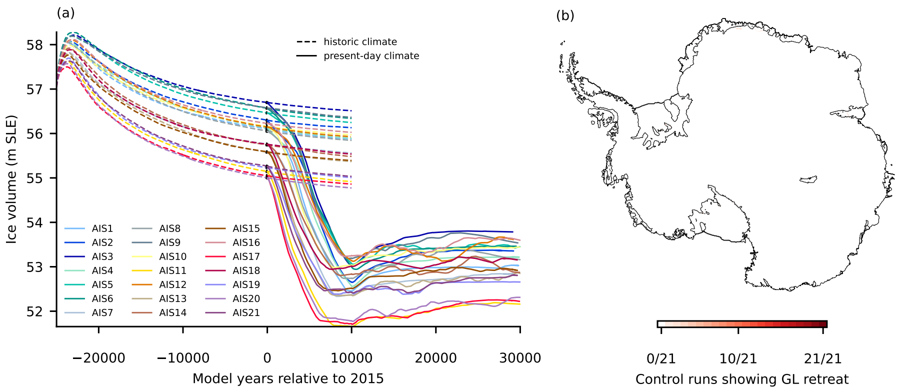

Figure 5: **Sea level evolution and control runs.** Panel (a) shows the evolution of Antarctic Ice Sheet volume (in meters sea-level equivalent, m SLE) during the control runs and the simulations with constant present-day climate conditions and the reverse to historic conditions for all ensemble members used in the manuscript. Black dots show historic control from 1850 to 2015. Dashed lines show control runs, solid lines show the simulations with constant present-day forcing. Panel (b) shows the regions that unground in the control runs between 1850 and year 12,015 (hardly any). The grey line is the BedMachine grounding line.

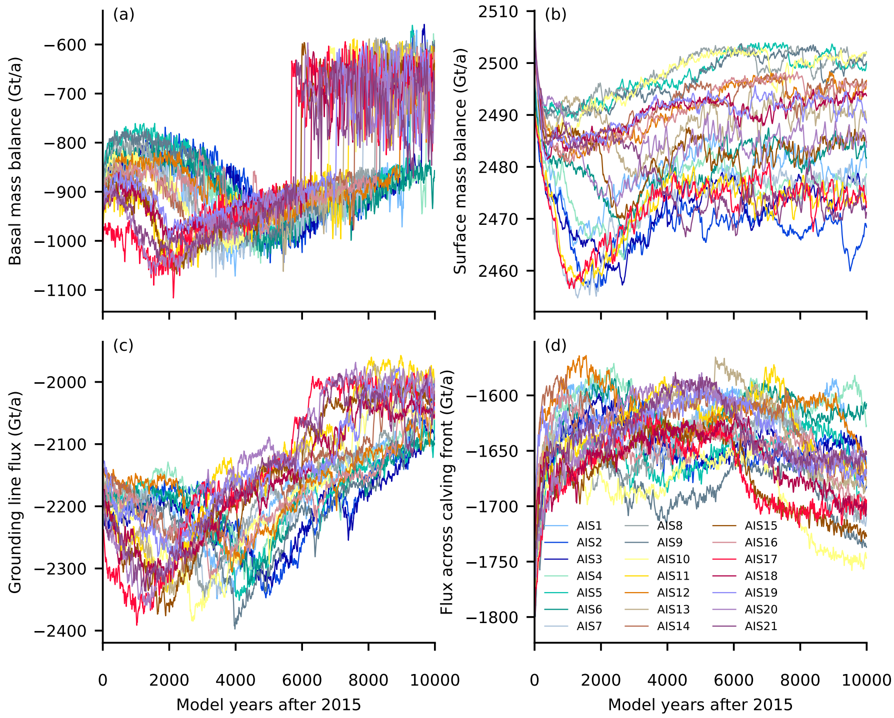

Figure 6: Evolution of the basal mass balance (only over floating regions), the surface mass balance, the grounding line flux and the flux across the calving front which is kept at its present-day location for all ensemble members over the 10,000 years of constant present-day climate conditions. Values are 25-year running means.

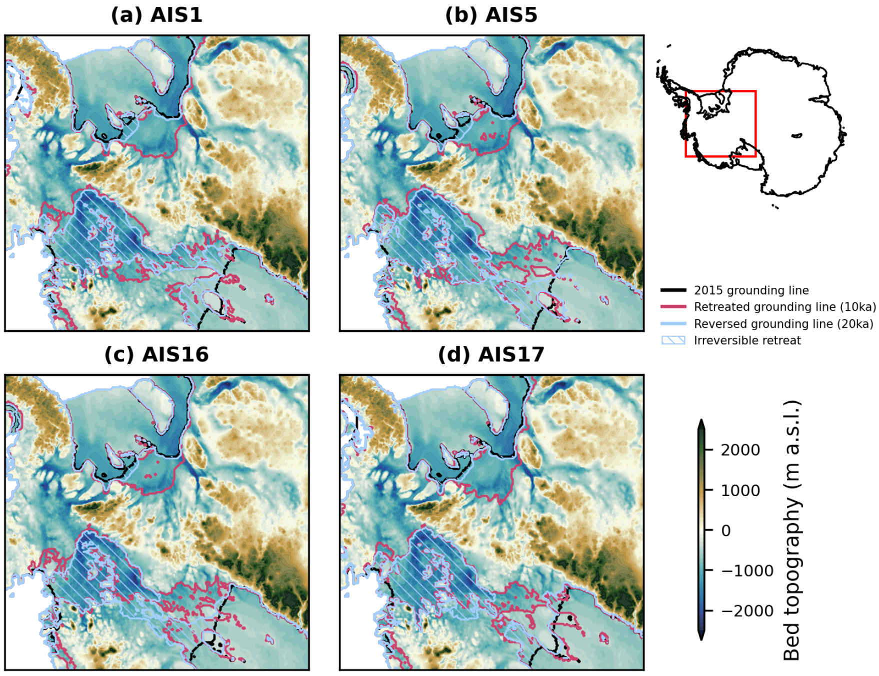

Figure 7: **Reversibility experiments of large-scale retreat in West Antarctica.** Four present-day configurations of West Antarctica, with their 2015 grounding lines shown in black, show large-scale retreat under constant present-day climate (red lines show grounding line positions after 10,000 years), see also Fig. 4. When reversing the climate to historic conditions for 20,000 years, the grounding lines evolve to the positions shown in blue. The blue hatches show areas over which grounding lines are not reversible. The spatial map shows the bed topography from Bedmachine (Morlighem et al., 2020). We here show the best ensemble member (AIS1), the best ensemble member for 'mean' PICO parameters (AIS5), the least sensitive member, i.e., with most mass gains between 1992 and 2015 (AIS15), and the most sensitive member, i.e, with most mass loss between 1992 and 2015 (AIS16). Inset shows the map location in Antarctica.

Table 2: Temperature corrections and melt rates for Antarctic basins with PICO parameters C =1.0 Svm^3kg^{-1} and $\gamma_T^\star$ =4.0 $\times 10^{-5} ms^{-1}$.

basin	m_{obs} (Gt/yr)	δTD (K)	m_{PICO} (Gt/yr)	m_{B_1} (m/yr)	m_{B_2} (m/yr)
1	75.2	0.52	76.35	1.09	-0.09
2	38.2	0.15	39.31	2.59	0.49
3	17.1	-0.09	16.48	1.83	0.17
4	57.9	0.02	57.98	2.63	0.58
5	6.8	-0.48	6.33	1.35	-0.03
6	29.3	0.02	28.02	1.42	-1.03
7	79.2	0.27	79.33	6.84	2.69
8	89.3	-0.93	88.41	8.47	1.96
9	24.4	-0.32	24.81	3.55	0.73
10	7.6	-0.72	7.30	1.80	-0.99
11	7.4	-0.11	6.92	2.97	0.26
12	135.1	0.75	132.34	1.38	0.04
13	167.0	-0.85	164.64	6.90	2.55
14	236.4	-0.93	234.56	19.59	10.96
15	68.5	-2.00	141.53	9.05	3.96
16	143.1	-1.70	144.18	10.63	4.79
17	6.5	-0.98	6.51	18.50	17.56
18	67.8	-0.16	66.52	2.66	0.69
19	4.7	-0.10	5.00	1.12	-0.44

We use m_{obs} which are observational melt rates from Adusumilli et al. (2020). The temperature corrections δTD are applied to the input temperature, and m_{PICO}, m_{B_1} and m_{B_2} denote melt rates calculated by PICO for the respective basin and boxes.

Table 3: Temperature corrections and melt rates for Antarctic basins with PICO parameters C =3.0 Svm^3kg^{-1} and $\gamma_T^\star$ =4.0 $\times10^{-5}ms^{-1}$.

basin	m_{obs} (Gt/yr)	δTD (K)	m_{PICO} (Gt/yr)	m_{B_1} (m/yr)	m_{B_2} (m/yr)
1	75.2	0.00	78.07	1.38	-0.10
2	38.2	-0.08	38.91	2.55	0.55
3	17.1	-0.29	16.27	1.84	0.24
4	57.9	-0.18	60.62	2.65	0.71
5	6.8	-0.51	5.68	1.26	-0.11
6	29.3	-0.25	30.08	1.74	-1.31
7	79.2	0.05	77.65	5.98	2.75
8	89.3	-1.10	91.12	8.56	2.27
9	24.4	-0.39	24.37	3.36	0.84
10	7.6	-0.75	7.58	1.92	-1.13
11	7.4	-0.15	7.21	3.05	0.28
12	135.1	0.12	131.34	1.43	0.05
13	167.0	-1.13	170.38	6.45	3.05
14	236.4	-1.30	236.22	18.19	11.79
15	68.5	-2.00	232.13	12.34	7.28
16	143.1	-2.00	201.46	11.86	7.07
17	6.5	-1.00	6.57	18.65	18.21
18	67.8	-0.43	70.12	2.73	0.81
19	4.7	-0.15	4.99	1.24	-0.58

We use m_{obs} which are observational melt rates from Adusumilli et al. (2020). The temperature corrections δTD are applied to the input temperature, and m_{PICO}, m_{B_1} and m_{B_2} denote melt rates calculated by PICO for the respective basin and boxes.

Table 4: Temperature corrections and melt rates for Antarctic basins with PICO parameters C =3.0 Svm^3kg^{-1} and $\gamma_T^\star$ =7.0 $\times 10^{-5} ms^{-1}$.

basin	m_{obs} (Gt/yr)	δTD (K)	m_{PICO} (Gt/yr)	m_{B_1} (m/yr)	m_{B_2} (m/yr)
1	75.2	0.07	78.24	1.55	-0.23
2	38.2	-0.13	36.77	2.78	0.28
3	17.1	-0.31	15.90	2.06	0.04
4	57.9	-0.23	57.59	2.93	0.52
5	6.8	-0.53	6.27	1.47	-0.25
6	29.3	-0.23	31.20	2.12	-2.09
7	79.2	-0.03	80.04	7.62	2.54
8	89.3	-1.27	86.17	9.56	0.05
9	24.4	-0.46	24.31	3.96	0.22
10	7.6	-0.78	6.64	2.24	-2.25
11	7.4	-0.19	7.95	4.09	-0.18
12	135.1	0.17	132.64	1.54	-0.04
13	167.0	-1.25	163.64	7.21	2.46
14	236.4	-1.68	232.45	20.25	10.35
15	68.5	-2.00	320.98	18.77	9.65
16	143.1	-2.00	251.75	17.21	8.70
17	6.5	-1.48	6.56	18.64	17.87
18	67.8	-0.48	69.46	2.93	0.58
19	4.7	-0.16	4.99	1.50	-0.89

We use m_{obs} which are observational melt rates from Adusumilli et al. (2020). The temperature corrections δTD are applied to the input temperature, and m_{PICO}, m_{B_1} and m_{B_2} denote melt rates calculated by PICO for the respective basin and boxes.

Table 5: Temperature corrections and melt rates for Antarctic basins with PICO parameters C =1.0 Svm^3kg^{-1} and $\gamma_T^\star$ =9.0 $\times 10^{-5} ms^{-1}$.

basin	m_{obs} (Gt/yr)	δTD (K)	m_{PICO} (Gt/yr)	m_{B_1} (m/yr)	m_{B_2} (m/yr)
1	75.2	0.92	76.70	1.27	-0.17
2	38.2	0.10	39.51	2.90	0.24
3	17.1	-0.09	16.72	2.09	-0.03
4	57.9	-0.03	58.83	3.05	0.40
5	6.8	-0.52	6.64	1.54	-0.25
6	29.3	0.15	28.58	1.73	-1.78
7	79.2	0.12	77.25	8.58	1.82
8	89.3	-1.13	88.14	10.23	-0.58
9	24.4	-0.41	25.36	4.42	-0.05
10	7.6	-0.75	6.94	2.30	-2.25
11	7.4	-0.17	7.26	4.09	-0.51
12	135.1	1.07	135.57	1.49	-0.02
13	167.0	-1.00	169.15	8.31	1.83
14	236.4	-1.40	237.50	23.80	8.70
15	68.5	-2.00	202.88	14.58	4.76
16	143.1	-1.85	144.60	13.27	3.86
17	6.5	-1.58	6.63	18.90	16.82
18	67.8	-0.21	69.12	2.88	0.55
19	4.7	-0.13	4.73	1.23	-0.66

We use m_{obs} which are observational melt rates from Adusumilli et al. (2020). The temperature corrections δTD are applied to the input temperature, and m_{PICO}, m_{B_1} and m_{B_2} denote melt rates calculated by PICO for the respective basin and boxes.

Table 6: PISM parameters of the 21 ensemble members and modelled mass changes. Runs are sorted starting with the best scores shown in Fig. 2. Given are modelled mass changes between 1992 and 2015, between 1850 and 2015 (both relative to the control run), and drift in the control run between 1850 and 2015 in mm SLE for all ensemble members. This can be compared to observed mass loss of 7.6 ± 3.9 mm SLE between 1992 and 2017 (Shepherd et al., 2018). Furthermore, we summarise committed mass loss after 10,000 years, relative to the control run, and the drift in the corresponding control run (in m SLE). Positive numbers indicate mass gain, negative mass loss.

	δ (%)	C_d (mm/a)	PICO	$\Delta V_{2015-1850}$ (mm SLE)	$\Delta V_{2015-1992}$ (mm SLE)	$\Delta V_{CTRL,2015-1850}$ (mm SLE)	$\Delta V_{12,015-2015}$ (m SLE)	$\Delta V_{CTRL,12,015-2015}$ (m SLE)
AIS1	1.75	10	max	-7.35	-0.49	-7.03	-3.41	-0.22
AIS2	2.00	7	max	-10.06	-0.99	-5.02	-3.47	-0.17
AIS3	2.25	7	max	-5.44	-0.50	-4.28	-3.48	-0.19
AIS4	2.00	10	max	-6.39	-0.67	-5.45	-3.32	-0.23
AIS5	2.25	10	best	-1.88	1.39	-5.71	-3.17	-0.22
AIS6	2.25	10	max	-3.32	0.07	-7.00	-3.34	-0.23
AIS7	1.75	7	max	-7.54	-0.85	-5.96	-3.19	-0.20
AIS8	2.00	10	best	-3.56	0.67	-5.45	-3.10	-0.21
AIS9	2.25	7	best	-1.94	1.29	-5.30	-3.17	-0.21
AIS10	2.00	7	best	-1.61	1.32	-4.81	-2.93	-0.19
AIS11	1.50	10	max	-8.28	-1.54	-4.27	-3.25	-0.23
AIS12	2.25	10	min	-0.38	2.13	-5.47	-2.79	-0.22
AIS13	1.75	10	best	-3.35	0.66	-5.88	-3.00	-0.21
AIS14	2.00	10	min	-3.48	0.81	-4.58	-2.65	-0.26
AIS15	1.75	7	best	-8.17	-0.32	-5.54	-2.87	-0.19
AIS16	2.25	7	min	0.04	2.26	-2.90	-2.78	-0.20
AIS17	1.50	7	max	-13.39	-3.99	-4.30	-3.13	-0.19
AIS18	2.00	7	min	-3.57	0.92	-5.02	-2.52	-0.22
AIS19	1.75	10	min	-1.56	1.81	-4.67	-2.58	-0.22
AIS20	1.50	10	best	-8.53	-1.16	-3.90	-2.98	-0.23
AIS21	1.75	7	min	-5.65	0.07	-7.81	-2.60	-0.23