The Cryosphere Discussions

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Comment on tc-2021-371

Anonymous Referee #1

Referee comment on "The Antarctic contribution to 21st-century sea-level rise predicted by the UK Earth System Model with an interactive ice sheet" by Antony Siahaan et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-371-RC1, 2022

General comments

This paper is a major step forward for coupled ice sheet–climate modeling. It presents results from the first simulations using a complex Earth system model with full two-way coupling of ice sheets to the atmosphere and ocean, for both the Greenland and Antarctic ice sheets (though Antarctica is the focus here). Many earlier studies have argued for the importance of coupling and speculated on what might happen when feedbacks are included. Here, these speculations are put to the test, in ensemble simulations to 2100 for both low-emission and high-emission scenarios. The authors explain why their study is novel, while giving due credit to previous work. The paper is well structured and clearly written, with figures and tables that effectively illustrate the main findings.

The results are both plausible and interesting. For me, the most important findings are (1) the intrusion of warm water into the Ross and Filchner Ice Shelf cavities by the end of this century under a high-emission scenario, with consistent timing across ensemble members; (2) the absence of a strong response in the Amundsen Sea region, where warm water is already present in cavities; (3) the fact that increased snowfall (a near-term response to warming) adds more mass above flotation than the ice sheet dynamic response can remove by 2100, but with the likelihood that the dynamic response would accelerate in the 22nd century. There are many uncertainties – related, for example, to the coarse ocean resolution and the challenges of ice-sheet spin-up. The authors acknowledge these uncertainties and are careful (except for a few minor cases noted below) not to draw conclusions that go beyond the data.

I have some suggestions to sharpen the text and to guide readers who may be unfamiliar with some of the details, but no major criticisms.

Specific comments

- p. 5, l. 127: Here or below, it would be useful to say more about how NEMO computes basal melt rates. It would be good to know, for instance, whether the melt rate is a strictly linear function of the thermal forcing, or if it also depends on the speed of the sub-shelf ocean current.
- p. 6, l. 162: "ice sheet model projections are typically initialized without any spinup". I would say "often" instead of "typically", because many ice sheet models (roughly half the models in the ISMIP6 projections) are spun up in some way.
- p. 7, l. 211: Were basal melt rates assumed to be zero in the Cornford (2016) initialization? If so, please state this, since the tuned ice-shelf viscosity could be compensating for missing basal melt.
- p. 8, l. 221: What is the magnitude of the steady value where the rms thickness rate settles? In what regions is the remaining drift largest? Did you do multi-century standalone ice sheet runs, continuing with the same forcing? Such runs would increase confidence that the drift is small enough to maintain stable grounding lines.
- p. 9, Fig. 1: In general, the figures in the paper are informative and easy to interpret. However, many figures (including this one) use a rainbow color scale that could be problematic for color-blind readers. Please consider a different scale.
- p. 11, Fig. 3: In Figs. 3a and 3b, there is good agreement with observations in the thinning of Pine Island and Thwaites Glaciers and thickening of the Kamb Ice Stream. My understanding is that this is largely the result of tuning basal coefficients to match observed ice speeds in the BISICLES spin-up. We would expect the tuned velocities to change the thickness in places where ice flow has recently accelerated (for PIG and Thwaites) or decelerated (for Kamb). This can be inferred from the text, but could be made more explicit for readers who are unfamiliar with tuning strategies.
- Another notable feature of Fig. 3 is the general slowing and thinning of ice shelves. The text (p. 12, l. 298) attributes the thinning to the SMB and basal melt forcing from the climate model. Is basal melt primarily responsible for shelf thinning, or does SMB also play an important role?
- p. 12, l. 297: Why would this slowing mostly occur during the first year of the standalone ice sheet initialization stage? I would expect it to occur more gradually as the shelf thins.
- p. 12, l. 302: You refer to "the SMB and basal melting implicit in the inverted reference velocities". I am not sure what this means. My understanding is that the SMB and basal melting in the BISICLES spin-up are part of the input forcing, with SMB based on reanalysis and basal melting (possibly?) set to zero. In that case, the shock could be attributed to the fact that the SMB and basal melt rates in the adjustment process (derived from the UKESM historical run and standalone ocean spin-up) are different from the SMB and basal melt rates in the spin-up. It would be helpful to describe or plot the differences.
- p. 15, Sect 3.2.1: The abrupt transition to warm water for the Filchner Ice Shelf is a very interesting result in an ESM, consistent with the recent regional studies.
- p. 16, Fig. 6: Since the transition occurs near 2100, I suggest extending the x-axis to 2115, if possible.
- p. 15, Sect 3.2.2: The transition to a warm Ross Ice Shelf cavity is another very interesting result, notwithstanding the fresh bias in the Ross Sea.
- p. 29, l. 629: "These results may indicate the bigger potential that Ross/Weddell sectors have in becoming major sea level contributors in future warming scenarios." Here, "bigger" seems to mean "bigger than PIG and Thwaites". It's true that the Ross and Weddell sectors have the potential to become major sea level contributors, but it's also true (based on present-day observations and published simulations) that PIG and especially Thwaites could be major contributors. The Amundsen Sea contribution might not be captured by the model, for the reasons discussed in Section 4.3. So I suggest rewording this claim.

- p. 29, ll. 642ff: This paragraph is a good summary of the novelty and importance of the study.
- p. 30, l. 666. The SROCC is cited several times, but I couldn't find a citation of AR6. Please add AR6 citations where appropriate. For context, I suggest including the projected GMSL from Antarctica under low and high forcing scenarios, according to AR6.
- p. 30, l. 667: It's plausible that the AIS would have a positive mass balance in this century, but it's misleading to call this a "rapid sea level fall". The snowfall contribution is better described as a modest offset (~2 cm) to a robust global trend of rising sea level (28 to 55 cm by 2100 under SSP1-19, and 63 to 102 cm by 2100 under SSP5-85, according to AR6).
- p. 31, l. 701: "… do not retreat." Doesn't Fig. 15 show some GL retreat for PIG and Thwaites?
- p. 31, l. 705: "Nevertheless, the impact of a future strong climate change in Amundsen Sea cavities is unlikely to be larger than our modelled changes in the Ross/Weddell cavities. This is because the Amundsen continental shelf and ice shelf cavities are already filled with the warm Circumpolar Deep Water and hence there is less potential for further warming and strong ice response." I think this is a bit too strong. It may be true that the ASE cavities have less potential for further warming, but this does not imply less potential for strong ice response. Because of its bed geometry, Thwaites might already be retreating unstably, or might be near a threshold such that it could be tipped into unstable retreat with a small amount of additional warming.
- p. 32, l. 715: "do not appear to simulate". I suggest "do not simulate".
- p. 33, Section 5: Many conclusions already appear in the Discussion section. Since some readers will look at only the Abstract and Conclusions, I suggest adding some content in Section 5. For example:

- You say here that these are the first AOGCM runs with full two-way ice-climate coupling; you could add a sentence or two (as in Section 4.1) about why this is important.
- You could point out that the Filchner warming is consistent with previous modeling studies, whereas the Ross warming is something new.
- You could mention the ASE non-response, with appropriate caveats about uncertainty.
- I would not end the paper with a sentence that refers to the Ross Ice Shelf alone.

Technical corrections

- p. 1, l. 21: "of **the** 21st century"
- p. 5, l. 137: The phrasing is awkward, with two uses of "along with"
- p. 7, l. 189: "integration" without the "s"
- p. 7, l. 210: "caving" -> "calving"
- p. 13, Fig. 4 caption: "The white boxes"
- p. 14, l. 330: "where the SSP1-EM melt rates become"?
- p. 14, l. 334: "large cold" -> "large, cold"
- p. 16, l. 358: "on the ice front" -> "at the ice front"
- p. 16, l. 360: "The shelf" -> "Water on the continental shelf" or something similar. In general, please be specific where the two meanings of "shelf" could be confused.
- p. 16, l. 361: "becomes" -> "is" (since the deep water is not becoming denser in an

absolute sense, but only relative to the shelf)

- p. 16, Fig. 6i: In this panel the x-axis is different from the other panels.
- p. 18, Fig. 8a: The dashed lines in this panel are hard to see in the ice shelf and continental shelf regions.
- p. 18, l. 415: Add comma after "simulation"
- p. 20, l. 441: Delete "is" before "already"
- p. 23, l. 501, Fig. 11 caption: Typo in "SSP5-EM"
- p. 24, l. 516: "on Queen Maud Land" -> "in Queen Maud Land"
- p. 25, l. 539, Fig. 13 caption: It's not accurate to describe the right-hand panels as "changes" like the left and middle panels. Please reword, e.g. using "differences".
- p. 26, l. 576: "end of **the** 2060s"
- p. 27, Fig. 14 caption: The descriptions of the middle and bottom rows are reversed. In the fourth line, delete "the" before "West Antarctica". In the last line, "column" -> "columns".
- p. 27, l. 588: "area-integrated" with a hyphen; delete "area" after "grounded ice sheet"
- p. 27, l. 591: "from **the** 2040s"
- p. 28, l. 598: Change "retreat up to 40 km takes place under southern Thwaites Glacier" to something like "the grounding line of Thwaites Glacier retreats southward by up to 40 km" (since the southern part of Thwaites Glacier lies far in the interior). Similarly for PIG.
- p. 28, Fig. 15: It took me a few moments to get my bearings for the left and middle panels, which are rotated with respect to the standard view in a polar stereographic projection (e.g., Figs. 11-13). Maybe rotate back to the standard view. On the left panel, perhaps add labels pointing to the Thwaites and PIG ice shelves.
- p. 29, l. 639: Instead of "a while", maybe "longer.
- p. 29, l. 647: "modern-day" with a hyphen, or just "modern". Similarly, "present-day" at l. 652.
- p. 31, l. 696: "end of **the** 21st century"
- p. 32, l. 726: I can't tell if there is a paragraph break after "century". If not, please add one.
- p. 33, l. 757: "brings" -> "bring"
- p. 33, l. 759: Add a period.
- References: Please check for consistent capitalization in paper titles.