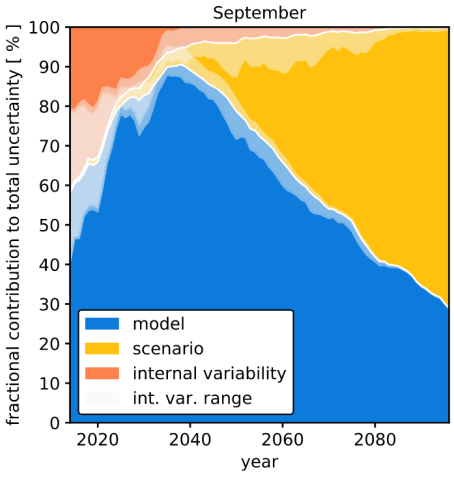
Richaud et al.: Anatomy of Arctic and Antarctic sea ice lows in an ocean–sea ice model

The authors in this study use the NEMO-SI3 model to investigate extreme lows in sea ice extent in both hemispheres over the historical period by using sea ice mass budget terms, both hemispherically and regionally. These modeled mass budget terms are particularly valuable as they are not available in observational products but they provide insight into the processes driving the low extent years. The authors find that basal processes (melt and growth) become increasingly dominant in the mass budget in both hemispheres. Additionally, they find that during case study low extent events the importance of thermodynamics and dynamics can vary, as can the importance of difference processes by season or hemisphere due to the local ice state and drivers. Overall, this study is well designed and provides insight into how sea ice evolution is changing. I have some major concerns, detailed below, about the analysis that I would recommend being addressed in a major revision before publication.

Mass budget analysis: The authors present their mass budget analysis in section 4 as absolute mass loss anomalies, which itself is dependent on mean state of the sea ice. As a result, I found that the conclusions and graphs were confusing and a bit misleading about the results and more care needs to be taken with how this is presented. In years with extreme low extent anomalies the anomalously high positive ice mass budgets were sometimes explained as "preconditioning" based on the mean state. I recommend showing the anomalous mass budget terms normalized by the total ice area each year to better understand how the budget terms compare to other years. Additionally, it would be beneficial to show how the dominant budget terms change over time to support your assertions about basal melt change (e.g. Line 480-485) since Table 1 just gives a single linear trend but doesn't show the budget terms over time. It would also be helpful to show a timeseries of the fractional contributions of each mass budget term, like this figure (right) from Bonan et al. 2021 (https://doi.org/10.1088/1748-9326/abe0ec), to show how basal terms become more dominant. Again, you'd want to normalize this so that it isn't just reflecting a mean state change of less melt due to less volume.



Ocean Heat Content: OHC is mentioned several times (Line 353, 358, 455, 454, 466) but is not clearly shown in figures and needs more analysis to support your assertions. For the Arctic cyclone in 2012, you should have a figure like Fig.6 that shows the OHC aspect of this story and the impact on basal melt. For the Antarctic, you should do a spatial correlation of OHC and ice anomalies to quantify the relationship described at Line 445. Since you're analyzing winter months, there may be important implication of OHC anomalies that are not just from surface heating or the albedo effect. Additionally,

for the panels in Figure 6, you say you are integrating OHC south of 50S. In many of the sectors this means you're including anomalies that are not actually in contact with the sea ice since they're well north of the seasonal sea ice zone. This makes your analysis at Lines 454-456 and 466-467 of the anomalously low OHC in the Ross-Amundsen sectors confusing since much of the anomalously low areas are not in contact with sea ice. I recommend you mask Figure 6 to show only that year's sea ice zone. Additionally, you may want to calculate a regional mean OHC anomaly only over points that are within the SIZ to better understand how the sea ice will be affected by OHC year to year.

Antarctic transport: The discussion from Lines 229-241 on Antarctic transport was confusing. You mention the "circumpolar current", which probably refers to the ACC that is on the northern edge of the sea ice zone. What about transport from other currents like coastal currents which are in the reverse direction? I think that the transport piece itself is complex and needs to be more carefully assessed and discussed.

Clarity: Much of the paper consists of VERY long paragraphs that are difficult to follow for a reader and often contain several points (e.g. Lines 132-162, 368-393, 402-435, section 5). Please break these paragraphs up so that they're clearer and more honed to the points you are making. A few places I found particularly challenging to follow were Section 4 and the discussion conclusions. Section 4 is framed as case studies of different hemispheres and years. I think it could be more powerful to frame these in terms of processes. For example, for section 4.1 a title like "the impact of ice volume on extremes" will help underscore the conclusion is that sea ice extent alone does not tell the full story and volume is necessary. Section 4.2 seems to be comparing hemispheres, but depends on how free drift and dynamics vs. thermodynamics impacts the extremes. Section 4.3 is better in that it clarifies seasonal differences are the focus. You may want to compare seasons for the Arctic too to confirm your results and see if the processes driving each hemisphere differ similarly by season. The discussion and conclusions sections are wordy with long paragraphs that make it difficult to separate the primary conclusions from the discussion. Perhaps make conclusions its own, small final section and better hone the paragraphs in this entire section.

Specific figure comments:

- Figure 1: Since a big part of this paper is showing that sea ice volume or mass is critical for understanding extreme ice extent loss events (e.g. line 166, 322, 326, etc.), you should include panels with the timeseries of volume anomalies in this figure. These are already Figures S1a and S4a, but they should be included as main figure panels as well. Additionally, it could be beneficial to compare to a hindcast that uses data assimilation (e.g. PIOMAS for the Arctic, SOSE for the Antarctic?) to see how well your model compares to some estimates of these variables.
- Figure 1: Panels a and c are averages over some years – you should list the years they are averaged over in the figure caption and show the standard deviation to indicate variability.

- Figure 3: This is a great figure! The map legend doesn't show white on white for the contour, so this should be fixed.
- Figures 3/4/5/6: These figures are nice, but the graphs overlain on the maps makes them hard to read, especially the center Antarctic one. Additionally, there are no y axis labels on the regional graphs. For figures 4/5/6, the bar charts axes limits aren't consistent, so it is hard to compare the panels with one another. Consider have a white, opaque background or reorganize the figures so that the graphs are separated from the maps and easier to compare, and please be sure to label axes.

Minor comments:

- Line 27: You should also cite the following two Holland papers about variability in a changing climate: https://doi.org/10.1007/s00382-010-0792-4 (Figure 8), https://doi.org/10.1029/180GM10 (Figure 3c, not plate 3).
- Line 52: You should mention the 2016 low was after years of a small positive trend.
- Line 120: Does the floe size (that impacts lateral melting) change or is it constant?
- Line 137: "millions" should be "million"
- Line 152: why are you considering just the last two decades? Is this justified?
- Line 167: it isn't true that thickness "cannot" be observed. Rephrase this to say: "However, it cannot be compared at similar spatial and temporal scales as areal extent since there are not long-term observations of thickness."
- Line 220: this sentence was not clear. Maybe you mean the signs of the transport are consistent with transpolar drift, but the sentence needs to be clarified.
- Line 248-251: This is consistent with Bitz et al. 2005 (https://doi.org/10.1175/JCLI3428.1) who show that the Antarctic ice edge is determined by ocean heat and in the Arctic the ocean mainly impacts the Atlantic sector.
- Line 257: "the Antarctic"
- Line 304: "more dynamical" than where? The areas you are referencing against isn't clear and this could be expanded.
- Line 327: I don't think "not obvious" is the right wording. Do you mean there aren't observations to show this? Could satellites ice thickness earlier in the year (e.g. March) help determine the ice state at the start of the melt season?
- Line 331: "ice low" I believe means extent only, but please clarify since a major conclusion is that ice volume lows matter too.
- Line 334: Clarify "ice loss" means negative extent negative anomaly only.
- Line 335: change "contrarily to" to "unlike in"
- Line 362-363: Please make clearer that ice volume vs. ice extent anomalies are not always linked as the key point of this section's analysis. This should be highlighted more as the topic sentence and then explain how 2012 is thermodynamic but 2007 is dynamic for high Arctic.
- Line 373: "sectors are specific"- what does this mean? Maybe better wording would be "sectors exhibit mixed anomalies"
- Line 407: remove "visible"
- Line 566: this final paragraph has a very awkward transition to justifying observational campaigns instead of reiterating this study's findings or explaining how those campaigns (which are limited in temporal and spatial scope) could contribute to understanding hemispheric mass/volume budgets and extrema.