Response to RC2

We thank the reviewer for carefully reading our manuscript and providing constructive comments that helped improve it. We have carefully considered all the comments and provided detailed, point-by-point responses. The reviewer's comments are copied below in regular font and our responses are shown in bold.

In this study, the authors investigated the impact of assimilating SIC data on improving sea ice initial conditions (ICs) and prediction skill. Their results demonstrated that SIC assimilation generally improves both the IC and subsequent predictions, although the improvement exhibits strong regional and seasonal dependence. A slight decrease in skill occurs in the Weddell Sea and the Ross Sea for prediction initialized from December and January. The possible reasons accounting for this were also discussed. In addition, the authors compared the influence of SIC assimilation between two polar regions and concluded that SIC assimilation has a larger impact in the Antarctic than in the Arctic, which is of broad scientific interest to many researchers.

Overall, I found this paper is well organized, clearly expressed and addresses a cutting-edge research topic. I only have some minor comments and suggestions listed as below. I recommend minor revision for this manuscript.

Specific Comments:

1) Line 45, a recent study also demonstrated that SIT is a strong source of predictability for summer sea ice in the Weddell Sea, and it can be well constrained through atmospheric initialization.

Thanks for providing the additional reference. We've added the reference into our introduction in Line 46. The text is also copied below.

"Bushuk et al. (2021) and Xiu et al. (2025) found that SIT is a strong source for summer sea ice predictions in the Weddell Sea, which can be well constrained by realistic atmospheric forcings."

Reference: Xiu et al. Impact of Ocean, Sea Ice or Atmosphere Initialization on Seasonal Prediction of Regional Antarctic Sea Ice. Journal of Advances in Modeling Earth Systems 17, e2024MS004382 (2025)

2) Line 60, please correct "C2S" to "C3S".

We thank the reviewer for pointing out the typo. We've corrected it in the manuscript.

3) Section 2.2, please consider to add some descriptions on how other variables (e.g., SIT) adjust in response to SIC DA since SIT is later used for analysis.

Thanks for the suggestion. We added some descriptions in Section 2.2. The text is copied below.

“The SIC of each category (5 thickness categories in total) is the only state variable that's directly updated by DA. The ice and snow thickness of each category remain unchanged, while their aggregate thicknesses are adjusted by the update in the concentration of all categories.”

4) Line 103, (Bushuk et al., 2021).

We’ve corrected the format. Thanks for the edit.

5) Section 2.3, what is the frequency of the hindcast?

We added a table to list the configuration of the two hindcasts (table 1) and modified Section 2.3 accordingly. Please see the modified text below.

“Each reforecast experiment consists of 15 ensemble members, covering the period 1992--2017. The reforecasts are initialized on the first day of each month and integrated for one year. Only the first 45 days are analyzed in this study as we focus on the subseasonal time scale of their prediction skills. “

6) Line 123, it could be misleading to claim that GIOMAS can reasonably represent the Antarctic sea ice thickness climatology, as it shows large discrepancy with the satellite-based observation (e.g., Figure 3 in Liao et al. (2022)).

We agree that GIMAS suffers from biases. We’ve rephrased the sentence in Line 129. The modified text is copied below.

“Previous studies (e.g., Liao et al., 2021; Shi et al., 2020) evaluated it against satellite retrievals, shipping and airborne observations and concluded that the GIOMAS SIT field can reasonably represent the interannual variability, and trends of Antarctic sea ice, although it suffers from biases. It was found to underestimate SIT, especially in the deformed ice zone, for example, the northwestern Weddell Sea.”

7) Lines 140-141, just for clarification: do you first compute the ensemble-mean SIC and then calculate SIE from the ensemble mean?

Yes we compute the ensemble-mean SIC and then calculate SIE.

8) Lines 165-166 and lines 180-185, do you have any hypotheses on the seasonally dependent improvements from DA?

We have some speculations on the seasonal differences in the DA performance. The sea ice DA tends to be more effective when there are larger errors to be corrected

from the first place. Figure 2 shows that the SIE of SPEAR_IC has relatively small negative bias in summer compared to the observation and much larger positive errors in winter. Hence there's more room for correction in the winter and spring. The similar contrast is seen in the spatial map of SIC bias in Figure 3 as well. The ice variability zone is much larger in the winter and spring seasons, where the model tends to have more uncertainty and larger bias.

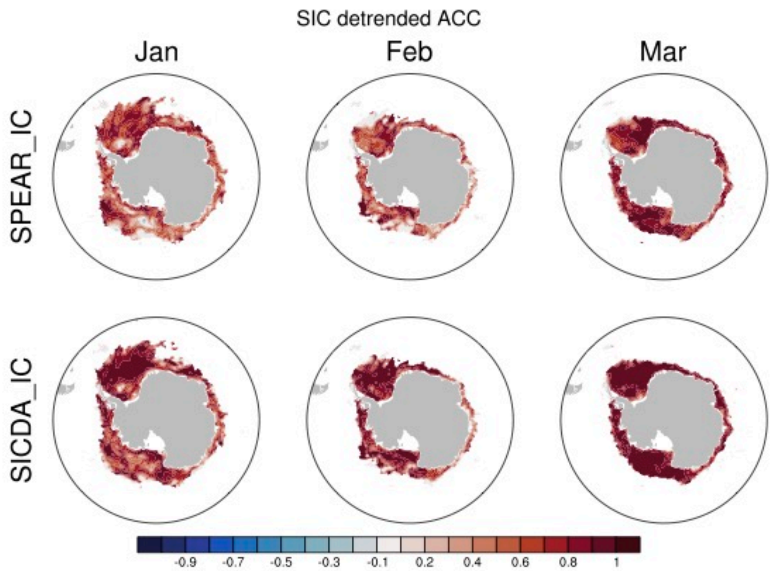
9) Lines 221, I think the 'negative SIC biases' only hold for the spring, while in other seasons, the positive biases dominate (Figure 2).

Yes we agree that the negative SIC biases only appear in limited regions and times. We've rephrased the sentence in Line 225 to be more rigorous. Please find the text copied below.

"It also has thicker ice in the Ross Sea in all seasons. These are also regions where SICDA_IC reduces the negative SIC biases, e.g., the Weddell sector in winter and spring and the Ross sector in spring (Figures 3g and h)"

10) Lines 238-239, Figure 1 suggests that some regions are ice free in summer. Considering this, where does the SIC anomaly in the summer originate, especially for the western Antarctic? Can you add a spatial pattern of detrended ACC to support this claim?

We agree that Figure 1 (Figure 2 in the updated manuscript) suggests some regions are ice free in summer, but there's still ice lingering, even in the western Antarctic. The following plot shows the detrended ACC for the winter months. It is true that the variability zone is mostly located in the West Antarctic: Weddell, A&B, and Ross. In the East Antarctic, there's still a narrow band of variability zone along the coast. The ice variability zones are also highlighted in Figure 3 (black lines).



11) Lines 241-242, It is somehow unexpected that the Damped Persistence is weaker in the Arctic than in the Antarctic because the Arctic SIT is thicker than Antarctic counterpart overall, as also mentioned in Lines 38-42. Is this conclusion strongly dependent on the assessment metric used?

The skill we chose is the detrended ACC of grid-cell SIC averaged over the ice variability zone. We believe it is a more informative matric than the total SIE which may cancel out errors spatially. Previous studies have focused on analyzing the total or regional SIE, but very few studies have looked at the persistence of grid cell SIC. Another metric nSPS (Figure 9) also suggests that the probabilistic prediction skill of ice edge position also decays slightly slower in the Antarctic than in the Arctic. This is also seen in Figure 1 of Zampieri et al (2019).

12) Lines 247-248, Please specify the season and lead times more precisely. I think it should write as 'Figure 8 also shows that SPEAR is generally less skillful in the Antarctic than the Arctic in autumn and winter, suggesting a larger room for correction in the Antarctic. In contrast, SICDA shows slightly better skill in the Antarctic than in the Arctic in the first two weeks in winter and summer.'

Thanks for the suggestion. We have edited the text as the reviewer suggested.

13) Lines 297-299, The statement "The co-location of an initial negative SIC bias and the faster decay in skill for SICDA suggests that the SIC-based sea ice albedo plays a role in exacerbating the low SIC bias" maybe need to be further clairfied. Specifically, what is the role of model error v.s. initial error in degrading prediction skill. For example, I notice that the SPEAR has no negative bias along the Weddell Sea coast (Figure 12g), but its prediction bias turns out negative. This obviously can't be solely explained by the ice albedo

feedback. So I’m wondering how model error versus initial error contributes to skill degradation?

We thank the reviewer for the comment. As the reviewer pointed out, there’s a development of negative SIC bias in the West Weddell Sea coast in both SPEAR and SICDA (seen in Days 20 and 40). SPEAR starts with neutral SIC condition and slowly develops the negative bias in this region, which indicates an intrinsic model bias. The mass budget analysis of the SPEAR system in the Weddell Sea (Figure 14c in Bushuk et al 2021) shows that the decrease of sea ice in summer is dominated by sea ice melt. Hence the negative bias in this region suggests that SPEAR tends to melt too fast in this particular region in summer. And we know that SICDA starts with a thinner SIT (Figure 6) in West Weddell coast, which explains why SICDA melts even faster and develops a more negative bias. We certainly didn’t mean the IC error is the only reason for degraded skill, we agree with the reviewer it’s a combination of IC and model errors. We didn’t elaborate on this West Weddell coast bias because we didn’t see skill degradation in this region in detrended ACC or RMSE. The SIC bias does seem larger in the SICDA Dec-initialized run, which suggests that the slight improvement in ACC cancels out the slight increase in bias and leads to negligible difference in their RMSE difference.

We actually discussed the role of model intrinsic bias in the next paragraph in the manuscript, although in a different scenario, e.g., SPEAR melts too slowly compared to the observations in the Ross sector, which compensates for its initial negative bias and results in less biased SIC condition in the forecasts (Line 309–317).

It is out of our scope to quantify the contributions of IC and model intrinsic errors, but we added the West Weddell coast case in the manuscript to emphasize that model intrinsic bias also plays a role in the skill differences between the two reforecasts (Line 318–321).

“The interplay between model intrinsic bias and the exacerbation from ice albedo feedback also manifests in the West Weddell coast. SPEAR starts with close-to-observation SIC in this region (Figure 12g) and develops negative SIC bias with time (Figures 12h and i), which indicates that sea ice melts too fast in SPEAR in December. With close-to-observation SIC to start with also, SICDA has thinner SIT IC in the West Weddell coast than SPEAR, hence the sea ice in SICDA melts even faster and shows worse negative SIC bias by Day 40 (Figure 12i).”

Comments on Figures:

Figure 5, please add the units to y-axis label

Label added, thanks!

Figure 8, SICDA

We thank the reviewer for catching the typo. It's been corrected.