Response to Referee

By Guokun Lyu on behalf of all coauthors

The paper introduces new tangent linear and adjoint model for the Viscous-Plastic parameterization of the sea ice model. The key to this work is the stabilization of the non-linear terms following the paper of Toyoda 2019. The novel contribution of this paper was evaluating of the stabilized adjoint in the framework of an Adjoint (ECCO-like) assimilation over the Arctic domain for the calendar year of 2012. I found the paper relevant to its target audience and is generally well written (see few technical comments in the annotated PDF). However, I found that the paper contains a single (but a key) conclusion that is not substantiated by the presented data (see major points below). I suggest that authors introduce new analysis in the revised paper that addresses my concerns (see specific suggestion in the major points section).

Major concerns:

- Ky finding of this paper is summarized in this citation from the manuscript:"Considering the amplitude of air temperature adjustments, the adjustments of the control variables in adjoint-VP are more reasonable than adjoint-FD, and adjoint-VP seems to project model-data misfits to the control variables more reasonably than adjoint-FD." Unfortunately, presented analysis does not provide evidence or error bars on what is reasonable and what is not. This is especially true, given that the authors are using a very old and outdated atmospheric analysis. I suggest that authors augment their paper by the analysis of the observation-minus-first guess errors for control variables that do have direct observations (e.g. wind speed, atmospheric temperature, ocean temperature from profiles). I understand that these measurements are very sparse over the Arctic. Nonetheless some are still available for analysis.

Response:

We thank the referee's comment and suggestion.

The adjoint method adjusts the control variables to make the model simulation consistent with available observations (within prior uncertainties). Therefore, it is more appropriate that the normalized adjustments are ~1.0. That is why we state "adjoint-VP are more reasonable than adjoint-FD" since adjoint-FD over-adjusted 2-m air temperature.

However, adjoint-VP doesn't ensure smaller errors in the adjusted atmosphere variables than the NCEP-RA1 and adjoint-FD at all times and geographic locations. A potential reason is that our coupled ocean-sea ice system doesn't have a dynamic and thermodynamic atmosphere model. We simplified their uncertainties to diagonal; in

this case, the adjoint method couldn't attribute local model-data misfits to remote atmosphere states through atmosphere dynamic processes and statistical correlations.

Since we don't have enough information about the size and spatiotemporal variability of prior uncertainties, we approximated them by the standard deviation of the non-seasonal signals of the NCEP/NCAR-RA1 (in this study) or differences among different atmosphere reanalyses (as in Nguyen et al., 2021). These approximations seem to overestimate their uncertainties as the normalized adjustments are usually smaller than one (~0.3-0.4), except for adjustments of 2-m air temperature.

In the revised manuscript, we use ERA5-NCEP differences as a reference to examine whether the size of the adjustments is reasonable and whether the adjustments may represent the old NCEP-RA1 and newly developed ERA5 reanalyses. As shown in Figures 8 and 11 in the revised manuscript, the adjustments after optimization are much smaller than the ERA5-NCEP differences (<40% of the differences), except the 2-m air temperature in adjoint-FD (>1.5 times the differences during May and July Figure 8c). It is evident that the adjustments in adjoint-VP are much smaller than inter-model (reanalyses) deviations, but adjustments of 2-m air temperature in adjoint-FD are unrealistic (Figure 8c and Figure 11a). These comparisons support our statement "Considering the amplitude of air temperature adjustments, the adjustments of the control variables in adjoint-VP are more reasonable than adjoint-FD, and adjoint-VP seems to project model-data misfits to the control variables more reasonably than adjoint-FD."

- Authors use an obsolete reanalysis product to drive their simulation. While (in itself) their choice does not invalidate their results. I suggest that authors quantify how their choice might impact their conclusions. For example, can the large errors that they report in air temperature corrections can be attributed to a very old reanalysis product?

Response:

We understand the reviewer's concern. If the adjustments represent the differences between new and old version reanalyses, the conclusion that adjoint-VP projects model-data misfits better to the control variables than adjoint-FD will be reversed.

To answer this question, we have compared the differences between the newly developed ERA5 reanalysis and the old NCEP-RA1 reanalysis with the adjustments in adjoint-FD and adjoint-VP (Figures 8, 11). The figures clearly show that the adjustments are much smaller than the ERA5-NCEP differences and don't represent the spatiotemporal patterns of ERA5-NCEP differences. Therefore, we believe that replacing the NCEP-RA1 reanalysis with an updated atmosphere reanalysis will not change the conclusion "adjoint-VP projects model-data misfits to the control variables more reasonably than adjoint-FD" because adjoint-VP represents sea ice process better than adjoint-FD in the adjoint model.

Minor concearns:

- I have attempted to hioghlight a few typos and rough sentences that authors might choose to improve in the revision (see annotated PDF).
- I find that some of the authors figures are very dense and could use more on-figure annotations (e.g. better panel labels). When appropriate, I provide such suggestions in the annotated pdf.

Response:

We thank the reviewer's comments and suggestions. We have revised the typos, and polished the rough sentences. Besides, we remade the busy figures (e.g., Figure 9, Figure 10) and made the explanations and statements more readable.

Nguyen, A. T., Pillar, H., Ocaña, V., Bigdeli, A., Smith, T. A., and Heimbach, P.: The Arctic Subpolar Gyre sTate Estimate: Description and Assessment of a Data-Constrained, Dynamically Consistent Ocean-Sea Ice Estimate for 2002–2017, Journal of Advances in Modeling Earth Systems, 13, e2020MS002398, https://doi.org/10.1029/2020MS002398, 2021.