

Comments on “Seasonal Predictability of Antarctic Sea Ice based on a Deep-learning Approach” by Baek et al.

This study develops a U-Net model for seasonal prediction of Antarctic sea-ice variability, using CESM2-LENS2 pre-training followed by observational/reanalysis-based fine-tuning. The authors further apply occlusion-based contribution and signed-contribution analyses to examine the seasonal and spatial dependence of predictor sensitivity, with particular emphasis on meridional wind and downward shortwave radiation.

The topic is relevant to *The Cryosphere*, and the attempt to combine seasonal prediction with physically oriented interpretation is interesting. However, I have substantial concerns about whether the current validation design provides an independent assessment of prediction skill. In particular, the manuscript does not provide sufficient evidence that temporal information leakage has been adequately excluded, which directly affects the credibility of the reported skill and subsequent attribution analysis. The definition of the prediction target, the comparison with dynamical forecast systems, and several aspects of the physical interpretation also require substantial revision. I therefore recommend major revision.

Major Comments:

- 1) Lines 128-131: The fine-tuning procedure does not clearly describe how the 11 folds are constructed in time or how validation and testing are kept independent. Please clarify the complete procedure and verify the main results using a temporally independent test period, with normalization derived from the training data only. The two pre-training experiments at Lines 70-73 should also be evaluated on the same independent test set.
- 2) The predicted variable is not consistently defined throughout the manuscript. It is described as regional sea-ice extent anomalies in the Methods, whereas sea-ice concentration (SIC) is used elsewhere in the text and figures. In addition, the negative values shown in Fig. 2k–o cannot represent SIC itself. Please clearly define the predicted variable, including its units and how anomalies or normalization are defined, and use consistent terminology and labeling throughout the manuscript.
- 3) The comparison with the numerical forecast systems is not described in sufficient detail. Please provide the relevant information for each system. In addition, the

statement that “the U-Net model shows superior performance in each season” does not appear to be fully supported by Fig. 2, where some numerical models show better skill in JJA and DJF. This statement should therefore be revised. Finally, the U-Net is evaluated only against numerical forecast systems. It would be useful to include simple reference forecasts, such as climatology and damped anomaly persistence, to quantify the added predictive skill of the U-Net model.

- 4) Section 3.3.2 requires substantial clarification. A strong SW contribution to spring prediction does not by itself demonstrate that preceding-winter SW exerts a critical physical control on the following spring sea ice. Likewise, the correlations in Fig. S6 provide supporting associations among SW, cloud cover, longwave radiation, and sea ice, but do not demonstrate that the model is using SW as a proxy for cloud-mediated longwave forcing. The opposite-signed SW contributions at lower and higher latitudes also require a clearer physical explanation. Please either provide additional process-based evidence for the proposed mechanism or moderate the corresponding interpretation.

Minor Comments:

- 1) The use of “predictability” should be reconsidered throughout the manuscript. The model may improve prediction skill, but it does not increase the intrinsic predictability of Antarctic sea ice.
- 2) Lines 31-32: The link between Antarctic sea ice and sea-level rise is overstated.
- 3) Lines 32-33: Lucas et al. (2025) examine the effects of iceberg meltwater rather than sea-ice loss and therefore do not directly support this statement. Please revise the text or citation accordingly.
- 4) Lines 36-37: This statement is misleading and should be revised. Reduced sea ice may facilitate ship access, whereas the loss of stable landfast ice can hamper over-ice resupply and coastal offloading operations at Antarctic stations.
- 5) Lines 67-68: LENS2 comprises 100 ensemble members (Rodgers et al., 2021), whereas this study uses only ten. Revise the wording to distinguish the subset used here from the full ensemble.
- 6) Line 175: The reference to the all-season RMSE appears to be incorrect; “Fig. 2b” should be changed to “Fig. 2f.”

- 7) Figure 2k-o: The individual numerical-model forecasts are difficult to distinguish. Please use more distinguishable colors and/or line styles and identify each model separately in the legend.
- 8) Figure 4 caption: The phrase “V fields overlaid with SIC differences” is unclear. Please revise the caption to clearly describe the variables shown in panels (c) and (d).
- 9) Figure S1: Please clarify how the time series were constructed (e.g., annual means or moving averages) and, if smoothing was applied, specify the averaging window.
- 10) Figure S3: The current layout makes comparison between the U-Net and individual numerical models difficult. Consider revising the figure to make the differences in prediction skill more apparent.
- 11) Line 328: “Intra-seasonal” appears inappropriate here because the model uses preceding-season conditions to predict the following season.

Reference

- [1] Lucas, N. S., Brearley, J. A., Hendry, K. R., Spira, T., Braakmann-Folgmann, A., Abrahamsen, E. P., et al. (2025). Giant iceberg meltwater increases upper-ocean stratification and vertical mixing. *Nature Geoscience*, 18(4), 305-312. <https://doi.org/10.1038/s41561-025-01659-7>
- [2] Rodgers, K. B., Lee, S.-S., Rosenbloom, N., et al. (2021). Ubiquity of human-induced changes in climate variability. *Earth System Dynamics*, 12, 1393-1411. <https://doi.org/10.5194/esd-12-1393-2021>