Reviewer 2 Comments

In this study, the authors analyze the local- and large-scale controls on the presence of polynyas in the Ross Sea sector of Antarctica. They use EOF analysis to identify recurring spatial patterns of sea ice variability, then perform two sets of maximum covariance analysis to link spatial patterns of (a) extreme winds and sea ice variability, and (b) 500-hPa heights and extreme winds. They find that SIC in the region's three major polynyas most often varies in sync with one another, but less frequently, SIC anomalies in the three polynyas are of different sign. These dominant modes of SIC variability are driven by variable patterns of large-scale circulation and local-scale extreme winds, and a notable finding is that the three polynyas can respond differently to the same 500-hPa height anomaly pattern.

In my assessment, the methods and scientific merit of the paper are sound. It provides some novel insight into the atmospheric contribution to polynya variability in the Ross Sea region. However, I feel there is still work to be done in connecting the study objectives to the results and in cleaning up various other aspects of the paper, as detailed in my comments below.

Major comments

- In general, I feel that something is missing in providing the detailed process understanding promised in the introduction – i.e. mechanistic, process-aware interpretation of the interactions between large-scale flow, local-scale extreme winds, and detailed sea ice processes within the polynyas – compared with what is actually found in the results. Reading lines 63–70, I'm satisfied that gap (i) in the existing literature has been addressed by this study, but what about (ii) and (iii)? Are the "process zones" (frazil/accumulation/young floe) described in (ii) actually resolved in this study's results? Can the authors clearly point them out in the figures if so? Likewise, can melting vs inhibited freeze-up (iii) processes actually be seen in the figures?

  I realize this is a somewhat vague comment, but I would like to see a more conclusive and explicit connection between what can be seen in the figures and the study objectives described in the introduction.

  Response:

  We thank the reviewer for raising an important point regarding the level of process-based interpretation in relation to the study objectives. We acknowledge that this study does not use field observations to explicitly resolve or validate polynya process zones (e.g., frazil, accumulation, young floe). In the revised manuscript, we have clarified that our analysis is based solely on satellite derived SIC and atmospheric fields, and that the identified spatial patterns are interpreted as being consistent with known process regimes described in previous observational studies, rather than directly resolving them.

  We have revised the Introduction to remove the implication of direct linkage to field observations and have ensured that the Results section more explicitly connects the observed SIC patterns to physically plausible process interpretations, while avoiding overstatement. We also clarify that processes such as melting versus inhibited freeze-up cannot be unambiguously distinguished from SIC alone. [This is a good response Girija. I think that toning down the promised results in the Abstract etc is crucial, and pointing out the data and what we see vs what we infer is also a good move.]

- A set of overview maps at the beginning of the Results section would be helpful to orient the reader. I realize the location of the study domain in Antarctica can be seen in Fig. 4, but as it stands, the results jump straight into a zoomed view of the Ross Sea sector of Antarctica without any spatial context. A map of the region's topography would also make the results more interpretable, given that topographic modification of the air flow is emphasized in reporting the study results (e.g. L281–289). I suggest a large-scale map showing the location of the Ross Sea sector within Antarctica, and a more zoomed-in map that shows the topography of the study region.
  Response: We thank the reviewer for this helpful suggestion. In the revised manuscript, we have incorporated the requested spatial context into the first figure of the Results section. Specifically, this figure (Figure 1) now includes (i) a large-scale map showing the location of the Ross Sea sector within Antarctica, and (ii) a zoomed-in view of the study region with underlying topography. This addition is intended to better orient the reader and provide clearer context for the role of topographic influences discussed in the Results section.

- ~L632: Why is this conceptual diagram included in the manuscript PDF? It is not assigned a figure number and does not appear to be discussed anywhere in the text.
  Response: The conceptual diagram was included solely to provide a simplified visual overview of the overall idea and physical framework of the study. It is not intended to be part of the main set of figures or the core results of the manuscript. We acknowledge that its placement in the current version may cause confusion; in the revised manuscript, we will either move it to supplementary material or remove it to maintain clarity and consistency.

Minor comments

- The abstract would be more impactful if it included more details and specific results in the second paragraph. For example, there are details of the study findings in L370–382 that could be summarized with more specifics in the abstract.
  Response:
  Thank you for this suggestion. We agree that the original abstract was a bit too general i. In response, we have revised the second paragraph of the abstract to include more specific details from the main findings presented in Lines 370–382. The revised abstract now more clearly summarizes the dominant spatial and temporal characteristics of the polynya variability, the associated atmospheric circulation patterns, and the identified links with large-scale climate drivers. We believe these additions improve the clarity and overall impact of the abstract by better reflecting the major outcomes and significance of the study.

- L35: I think "satellite imagery" would be more accurate to use rather than "satellite soundings" here. Although passive microwave satellite instruments are capable of both "imagery" and "sounding" products, I think "imagery" is typically the term used when referring to a 2D retrieved field such as sea ice concentration, while "soundings" is reserved for retrievals of vertical profile variables (such as temperature and moisture profiles). See e.g. Rouzegari et al. (2025).
  Response: Modified as suggested in revised document (L36)

- L87–99: This paragraph provides a convincing justification for why late austral winter through early spring (ASO) was chosen as the time period of analysis for this study. However, the primary

motivation for the study as whole given in the Introduction is the role of Ross Sea polynyas in air-sea heat exchange and shelf water / deep water formation. Is ASO a critical part of the year for these globally relevant processes? Some effort should be made to connect the time period chosen in the study to its background and motivation.

Response: In the revised manuscript, we have expanded this paragraph to explicitly highlight that ASO coincides with the period of peak sea-ice production in coastal polynyas, when enhanced brine rejection contributes to the formation of High-Salinity Shelf Water, a precursor to Antarctic Bottom Water. We now clarify that variability in polynya activity during ASO directly influences air–sea heat exchange and dense water formation, thereby linking the selected season to the primary motivation of the study.

- L105–106: What are the properties of the grid on which the SIC data are provided (the "SIC grid")? Is this an equal-area polar stereographic grid (such as the NSIDC EASE grid?)

  Response:

  For the AMSR-E/AMSR2 6.25 km SIC product, the grid is not an equal-area grid like the NSIDC EASE grid. Instead, the SIC data are provided on a polar stereographic projection grid, centered on the pole (separate grids for Arctic and Antarctic). The grid spacing of SIC data used in this work is 6.25 km, defined at a standard latitude (typically 70°), is regular in projected x–y space (i.e., evenly spaced in the projection plane), not in true surface area. As a result, grid cell areas are not constant and vary slightly with latitude (distortion increases away from the standard latitude). Therefore, this grid is not strictly equal-area, unlike the NSIDC EASE/EASE2 grids, which are specifically designed to preserve area. [Do we need to say any of this in the manuscript? Seems like a minor point to me.]

- L112–113: I am confused as to why the area-weighting by the square of latitude is necessary for the SIC fields. Per my comment above, I assume that the SIC data are provided on an equal-area grid?

  Response: Although the SIC fields are provided on a near-equal-area grid, $\sqrt{\cos\phi}$ weighting was applied for consistency with the atmospheric fields used in the coupled analysis.

- L160–162: This sentence appears to state that 3.125 km sea ice products were used in this study for validation and for illustrating process detail. However, I don't see anywhere in the text, figures, or Supplement where the higher-resolution product is compared to the 6.25 km product used in this study. I do think that some comparison of the 6.25 km data to the 3.125 km product would be convincing to prove that it is sufficient for process-aware interpretation and has sufficient spatial resolution to resolve the active frazil/young=flow bands, as stated in L80–84. This appears to be the intention of Figure S1 in the Supplement, although this figure is difficult to interpret.

  Response: Thank you for this insightful comment. We have now added an additional comparison figure (Figure S4) to provide a clearer evaluation of the 6.25 km and 3.125 km SIC products during a polynya event. The intention of including the 3.125 km product was to demonstrate that the 6.25 km AMSR-E/2 SIC dataset used in the primary analysis adequately resolves the major spatial characteristics of the thin-ice regions and associated polynya structures.

  The 6.25 km SIC product was selected because it provides sufficient spatial detail to capture the major Ross Sea polynya regions while maintaining computational efficiency and reducing small-

scale noise within the EOF/MCA framework. As the focus of this study is on large-scale SIC variability and its coupling with atmospheric circulation, rather than fine-scale lead morphology or instantaneous polynya edge detection, the 6.25 km resolution is appropriate for identifying the dominant spatial and temporal variability patterns. Similar-resolution passive microwave SIC products have also been widely used in Antarctic polynya and climate-scale studies.

We agree that the purpose of this comparison was not sufficiently clear in the original manuscript, and that the earlier Supplementary Figure S1 was difficult to interpret. In response, we have revised the manuscript and Supplement to clarify the role of the 3.125 km product and improve the associated discussion. The revised Figure S4 now presents a direct qualitative comparison between the two SIC products. The updated discussion shows that, although the 3.125 km product captures finer-scale edge variability and sharper gradients, the 6.25 km product consistently reproduces the overall spatial organization, orientation, and evolution of the active thin-ice and polynya regions. This demonstrates that the 6.25 km product is sufficient for the process-aware interpretation and large-scale circulation analysis conducted in this study. The figure caption and accompanying text have also been revised to improve clarity and readability.

- L171–172: How and why was a value of 12% SIC SD chosen to represent the spatial extent of polynya domains for subsequent analyses? Also, it doesn't appear that these domain definitions are actually used in any subsequent analyses, other than to outline these areas in the map panels on the left side of Figure 2?

  Response:

  The 12% SIC standard deviation threshold was chosen empirically to delineate regions of persistently enhanced sea-ice variability associated with recurrent polynya activity. We tested a range of threshold values and found that 12% provides the most physically consistent representation of the active polynya zones, while avoiding excessive spatial expansion into the surrounding compact pack ice. Lower thresholds tended to include broad areas of seasonally mobile ice with weaker variability signals, whereas higher thresholds fragmented the coastal polynya regions and excluded known recurrent activity areas.

  We agree that the original manuscript did not clearly justify this choice or its role in the analysis. The threshold-defined domains are intended primarily as a visual and interpretative aid to consistently highlight the principal regions of recurrent coastal polynya activity in Figures 1 and 2, rather than as strict masks used in subsequent quantitative calculations. To avoid ambiguity, we have revised the manuscript to explicitly clarify this interpretative purpose and to remove any implication that these domains were directly used in later statistical analyses.

Technical corrections

- L24–26: I suggest breaking this into two separate sentences rather than joining two sentences with a semicolon. Please check for run-on sentences elsewhere (e.g. L35–38, L80–84).

  Response: We agree that the sentence was overly long and revised it for clarity by splitting it into two separate sentences. We have also reviewed the manuscript for similar run-on sentences and made additional edits where necessary to improve readability

- L28: "polynya" --> "polynyas"?

  Response: Modified

- L28: "is strongly modulated" - what is strongly modulated? The polynyas in the Ross Sea sector?
  Response: Thank you for pointing out this ambiguity. We agree that the phrase "is strongly modulated" was unclear in its reference. We have revised the sentence to explicitly specify that the modulation refers to sea-ice variability, improving clarity and readability.

- L51–52: I suggest moving this sentence to be the topic sentence of the next paragraph
  Response: Moved the sentence to the beginning of next paragraph as suggested.

- L73: Insert the word "and" before "(b)"
  Response: Modified as suggested in L73

- L87: "operate" --> "occur"?
  Response: Thank you for this suggestion, modified in L87

- L188–189: "Within the SD boundary, east-west split in RS region" – what does this mean?
  Response: Thank you for pointing this out. We agree that the phrase "east–west split" was unclear. We have revised the sentence to explicitly describe this feature as an east–west contrast (dipole) in sea-ice concentration across the Ross Sea region, improving clarity and interpretability

- L191: "PCs associated 3" – what does this mean?
  Response: This is a typo, modified to PCs associated with Mode 3.

- L248: "analysis of MCA analysis" – the word "analysis" is used twice redundantly here
  *Response: Thank you for identifying this. Redundant word 'analysis' is deleted. The sentence now reads as "*It is also worth noting, that in our localised analysis of MCA with wind vectors and MaxWinds (not shown)."