

**Comments of Anonymous Referee #1**

**Comment of Reviewer 1**

The manuscript presents a link between the stratospheric polar vortex and recent record low Antarctic sea ice anomalies courtesy of a strong coupling between the tropospheric westerlies and the polar-front jet stream. Coincident wind and sea ice anomalies are shown, and some interesting insights emerge from the close inspection of variables considered (though sadly, many of these are in the Supplementary Material rather than the manuscript proper). As the changes to recent Antarctic sea ice behaviour continue to be a topic of high interest, the main concept of this manuscript is a thought-provoking and valuable angle of exploration. The analysis starts strong, but appears to lose confidence when attempting to correlate the shape of the vortex to sea ice anomalies, with the conclusions managing to be both tentative and brash at times. The findings are interesting, but not yet robust enough. Furthermore, the manuscript is sparsely sourced in many places, putting the onus on the reader to research much of the context and background. It is unclear why so much material is in the Supplementary Material compared to the 4 Figures in the manuscript proper, but the text of the manuscript could easily be reduced substantially to make more room for some of this additional material. Several parts of the results and discussion sections felt a bit disjointed and awkward and could be shortened. The general structure is adequate, but much of the manuscript would benefit from consideration as to whether the flow and phrasing is optimal, a check for missing words and duplication, as well as a sweep for clarity and conciseness. There is considerable potential for this work, and I therefore recommend it for reconsideration after major revisions, with the hope that the authors will find my following comments useful.

We thank the reviewer for her/his helpful comments and constructive remarks. We agree with the reviewer that interesting insights have emerged from the investigation that we carried out on the quasi-simultaneous evolution of sea ice cover, the tropospheric westerlies, and the polar-front jet stream. As pointed out by the reviewer, the main concept of our manuscript is a thought-provoking and valuable angle of exploration.

The reviewer argues that our conclusions are “both tentative and brash at times”. It is an interesting point, and we thank the reviewer for raising it. Certainly, there are some aspects of the study that are more conclusive since they are built upon previously published results. For example, there is prior convincing evidence regarding the stratosphere-troposphere coupling. However, there are other aspects of our study that we have to be cautious about, since we are challenging a commonly accepted hypothesis. For example, the dynamics of the polar vortex is often assumed to not be consequential for Antarctic sea ice extent. In our manuscript we challenge this hypothesis with evidence that strongly suggests that the stratospheric polar vortex dynamics do play a role in the year-to-year changes of the Antarctic sea ice cover. Although our manuscript will hardly close the case, we do expect that it will trigger the cross-disciplinary work required for further exploration on the effects of the polar vortex dynamics on Antarctic sea ice extent. In the revised version of our paper, we will do our best to appropriately scale the emphasis of our conclusions.

We also agree with the reviewer on the significance of some of the information currently shown as “Supplementary Material”. We are happy to incorporate his/her suggestions in this regard. As further discussed below, we believe that the clarity and conciseness of our manuscript will be greatly improved by the reviewers’ remarks and suggestions.

**General Suggestions of Reviewer 1**

Check that the tenses of consecutive sentences is consistent (e.g. line 80-85). Section 2 (Data and Methods) is too long and wordy. It could easily be condensed down by stating at the top that ‘daily estimates’ of all data are used, and the reference period from which mean and anomalies are calculated

(except in the case of ozone), and then just stating where each dataset is from, with careful consideration of the most efficient presentation of any remaining information.

Figure captions tended to be too long and with too much detail. They could easily be shortened and tightened up. The submission policies for TC state that, as long as any abbreviations (e.g. datasets used) are already defined in the text, they do not need to be explicitly re-defined in the caption. After a concise description of the actual plot, any extra information would be better placed in the introduction and data/method sections – and I don't think necessary to include the programming package used to create each Figure at the end of each Figure. Perhaps an acknowledgement is a better option.

According to the suggestions of the reviewer, in the revised version of our manuscript, we propose to

- Check the consistency of the tenses of consecutive sentences (e.g., line 80-85).
- Shorten Section 2 (Data and Methods) stating at the top that 'daily estimates' of all data are used, and the reference period from which the mean and anomalies are calculated (except in the case of ozone). As suggested by the reviewer, in the new Section 2 we will just state where each dataset is from, carefully considering the most efficient presentation of the information.
- Shorten and tighten up Figure captions using abbreviations when possible (e.g., datasets used) and reducing the degree of details. After a concise description of the actual plot, any extra information will be placed in the introduction and data/method sections. As suggested by the reviewer, the programming package used to create the Figures will be included in the Acknowledgements.

#### **Line-by-Line Suggestions of Reviewer 1**

**Line 87:** It is common practice for sea ice extent to be defined in the data/method section, and thereafter referred to by the abbreviation of SIE in the following sections for efficiency.

**Line 101:** Can any of these variables be abbreviated or denoted using a symbol to be more efficient, since they're used multiple times in this (and other) paragraphs?

**Line 109:** There are almost no references in this section, other than for the data itself. Are these domains from the literature, or defined by the authors? The text states that average east-west wind speed between 45°S-75° is near the peak of the polar jet maximum, but the peak itself could be defined here too (and referenced for readers wanting to know more). The text states 'this is a good measure of the overall temperature of the polar vortex' – how do we know? How much variation occurs in zonal mean zonal temperature across the 60-90° domain? Is there a specific reference here for non-specialists?

**Line 128-131:** There is some redundancy here in highlighting the record minimum – a single (or two shorter) sentence/s could be crafted to incorporate this information more efficiently.

**Line 131:** Attributed by whom? Is there a study to which you are referring here? And why do low annual averages suggest the influence of persistent circulation anomalies of climate modes? Aren't the influences of some of these modes seasonal too?

**Line 136:** The text discusses sector-based domains, but the map only names four locations. If common sectors (ABS, RAS etc) are discussed, it would be helpful to clearly define these sectors both in the text and with lines on the map, clearly stating the place names for all sectors and sub-sectors of note.

**Line 145:** The SAM and La Nina discussion comes out of nowhere here. They are briefly discussed in the introduction, but no references are given explicitly here. In fact, between lines 145-157 could be reorganised and reworded entirely for clarity and flow. I really like Figure S4, and wonder if more could be made of it - perhaps incorporated into the body of the manuscript rather than supplementary material. I note the ASL is discussed more at lines 174-179 and again at 250-252; perhaps this would be a good place to incorporate an additional Figure to robustly illustrate your point.

**Line 159:** This states that the enhanced temporal variability occurs 'around Antarctica' – but is this also reflected in spatial variability?

**Line 156** states that the 2017 record event was due to a circumpolar pattern of ice loss, whereas the 2022 record was due to regionally opposing anomalies. Is spatial variability also enhancing over this period, or staying roughly the same?

**Line 164:** Firstly, this line is a direct repeat of lines 43-45. Also, the reference is Doddridge & Marshall, 2017 not Doddridge et al. 2017. Furthermore, the aforementioned reference states that the effect of wind anomalies on sea ice in 2017 was due to the negative SAM in 2016/17 summer, but so far in the manuscript the only discussion has been of persistently positive SAM anomalies. Figure S6 only shows September SAM index, where this negative polarity does not appear. Also, both these references discuss the effect of wind anomalies on the ocean and the combined effect on sea ice, whereas I do not see discussion of these important coupled processes in this manuscript.

**Line 166:** Are the strengthened westerly winds really the cause of the positive SAM?

**Line 168:** Does this hold true only for September? Is there a similar ranking of SAM anomalies for August, or October?

**Line 189-190:** Reconsider routine use of the word ‘favor’ throughout the manuscript. Reworking this paragraph to include a brief, simple description of why the same driver has opposing seasonal effects would be more impactful.

**Line 222-224:** I’m not enamoured by the argument that, of 42 years, 6 of the highest 15 occurred in the past 10 years. Why choose the top 15 highest? A qualitative look at Figure S10b tells me that 3 of those years were in the 80s, 5 were in the 90s, a single year was in the 2000s, and 6 occurred post-2015. If you only chose the top 10, the 2000s and beyond would barely feature compared to the 90s. I think there is probably a better way to present your argument, as this feels less than robust.

**Line 224-231:** I’m having trouble following the flow here. The strength of the jet since the mid-2010s is remarkable because of the healing ozone hole, but it is unlikely that ozone depletion provided a considerable contribution to it? In fact, the entire paragraph 230-240 is difficult for me to follow. Consider rewording for clarity and flow.

**Line 256:** In general, yes, compatible. But there are notable differences, which are not discussed. For the 2022 case, the Bellingshausen and Amundsen seas region are a stark contrast, and even the Ross Sea region to a lesser extent is not closely matched. In the 2017 case, the anomalies match more closely. Is it possible to condense these plots down? Does (b) really need shading? Perhaps the mean vortex line could be overlaid in a different colour to the mean extent line on the ice concentration plots, and stippling instead of shading for the vortex pattern? It would make it much easier to compare them rather than shifting constantly between panels.

**Line 279-281:** This feels overly pithy, and would benefit from rewording for clarification and flow. It gives a sort of ‘shrug’ impression to the end of the results section, which is oddly deprecating.

**Line 291:** I’ve seen this ‘all-time records’ a couple of times in the manuscript, and I think it would be better to frame this as according to the satellite data record, which only spans 43 years.

**Line 301-302:** Why are these underlined? It’s distracting. If worried that the reader will not pick up on the difference between the two words, perhaps word it differently so it is clearer.

**Line 303:** I’m not sure about this. Technically they aren’t remarkably nor consistently strong compared to previous decades, at least according to Figure S10 – the value for 2021 is the highest but 1982 was almost as high, and 2016, 2018 and 2020 rank well under the 5 ranking years from the 90s. 2017 doesn’t even make the table. Compared to the 2000s, yes, the values are remarkably stronger, but is that what is meant here?

**Lines 321-331:** Requires editing and reworking – several adjoining words are missing and others are superfluous. The flow is difficult, and the conclusion seems hesitant. By contrast, the conclusion of lines 335-7 seems overly confident based on the evidence presented, particularly with no discussion of the effects of SST nor much of a mention of spatially heterogeneous or competing drivers.

According to the suggestions of the reviewer, in the revised version of our manuscript, we propose to

- Line 87: Define the sea ice extent in the data/method section and use thereafter the abbreviation of SIE.
- Line 101: Use abbreviations for improving efficiency.

- Line 109: Clarify that using these domains is a common practice and provide references supporting our statements regarding the peak of the polar jet maximum and the overall temperature of the polar vortex.
- Line 128-131: Reword these lines avoiding redundancies.
- Line 131: Cite prior studies that have studied first the effect of deep storms on annual SIE minima, and second the influence of climate modes (operating on seasonal or annual timescales) on the annual SIE mean.
- Line 136: Identify in the Figures common sectors (ABS, RAS etc) discussed in the text.
- Line 145: Reorganize and reword lines 145-157 for clarity and flow and provide references supporting our discussion involving SAM and La Nina.
- Incorporate Figure S4 into the body of the manuscript. As noted by the reviewer, this Figure can support the point we make in lines 174-179 and 250-252.
- Line 159: Clarify that the text in this line refers to the temporal variability only.
- Line 156: Clarify that, although the 2017 and 2022 SIE anomalies concurred with persistently positive SAM values, they exhibited considerably different regional patterns.
- Line 164: Avoid needless repetitions and correct reference (from Doddridge et al. 2017 to Doddridge & Marshall, 2017).
- Clarify that while Doddridge & Marshall (2017) studied the effects of SAM anomalies in the austral summer, we focused on the effects of SAM anomalies in the austral spring. We agree with the reviewer that both references in line 164 (Eayrs et al., 2021; Doddridge & Marshall, 2017) address points beyond the scope of our paper. However, both references underline the influence of the SAM and the westerly winds on the SIE, which is one of the main points made in our manuscript.
- Line 166: Rephrase the text avoiding any suggestion of causality.
- Line 168: Confirm that similar records have been seen in spring months (Fig. S1c) but not in winter months (Fig. S1e).
- Line 189-190: Avoid the use of the word ‘favor’ and rework this paragraph to include a brief description of why the same driver has opposing seasonal effects would be more impactful.
- Line 222-224: Eliminate the unnecessary argument regarding the strength of the jet. We agree with the reviewer that it is not particularly compelling.
- Line 224-231: Rephrase the paragraph 230-240 for clarity. According to the comment of the reviewer, we will clarify that although the ozone depletion provided a considerable contribution to strengthening the jet stream in the past, the ozone healing observed since the mid-2010s has likely erased that contribution.
- Line 256: Discuss the notable differences shown in Fig. 4 between the regional patterns associated with the springtime sea ice anomalies and large-amplitude anomalies in the stratospheric zonal flow.
- Explore different variants for Fig. 4 following the helpful suggestions of the reviewer. We will try to make it easier to compare plots a) and b).
- Line 279-281: Reword these lines for clarification. We appreciate the comment of the reviewer. It is of course not our intention to be self-deprecating, but we believe that it is important to be transparent regarding the limitations of the available evidence.
- Line 291: Avoid the repetitive use of the expression ‘all-time records’. According to the suggestions of the reviewer, we will frame this as according to the satellite data record, which only spans 43 years.
- Line 301-302: Eliminate underlined text and make the text clearer.
- Line 303: Link the text in line 303 with Fig. 2a that shows that the significant losses in the sea ice extent that started to occur around Antarctica in 2016 coincided with remarkably strong tropospheric westerly winds in September.
- Lines 321-331: Edit these lines paying special attention to the adjoining words.
- Better calibrate the emphasis of our conclusions and explicitly state some of the limitations of this work, such as the effects of spatially heterogeneity or competing drivers, like the SST).

### **Suggestion of Reviewer 1 (Figures)**

**Figure 1a:** I found it difficult to make sense of the arrows here. Why is the minimum arrow pointing near to the sea ice maximum, while the maximum arrow pointing towards the summer? I think the caption is a better place for this detail, as the presence and positioning of the arrows detracts from its readability. In addition, I wonder if higher density is warranted on the X axis, and perhaps gridlines to show the start of each month rather than just a rough indication of each 3-month period. The text discusses late February and early September, but only shows a little marker for 1-Jan and 1-Oct. I'm not a big fan of the stretched Y axis either; I guess it shows the minimum more clearly but loses a lot of detail in the early September period which is also discussed in the text.

**Figure 3b:** Again, why not remove the arrow and simply state the 30-day running mean beneath the reference period in the legend for this part of the Figure? It is already stated in the caption that the bold line is the 30-day centered moving mean.

**Figure S4:** This seems an important and clear difference between the two years, though wind vectors overlaid on both plots to show anomalous wind directions resulting from the pressure anomalies would be a welcome addition.

According to the suggestions of the reviewer, in the revised version of our manuscript, we propose to

- Eliminate arrows in Fig. 1a and use the caption for details.
- Include gridlines to show the start of each month in Fig 1a.
- Explore different variants for the Y axis of Fig. 1a.
- Eliminate arrows in Fig. 3b and use the caption for details.
- Include wind vectors in Fig. S4.

We thank the reviewer once again for their helpful suggestions and constructive remarks. We believe these revisions will greatly improve the clarity and conciseness of our manuscript. As explained above, the revised version of our manuscript will be modified accordingly.

Best regards,

The authors.