The manuscript has been revised in accordance with the reviewers' suggestions, for which we are grateful, as they have helped strengthen the study. In response to comments regarding clarity, paragraph length, language use to avoid implying causation, and the addition of significance testing to demonstrate robust signals, substantial changes have been made in the latest version. These revisions are reflected in the updated line numbering.

Reviewer 1

SUMMARY

The study presents the impact that different ENSO-induced atmospheric circulation changes have on Antarctic ice sheet mass changes and analyze teleconnections with the southern annular mode. The authors show that there is strong event-to-event spatial variability between ENSO events using GRACE observed mass changes, regional climate model output and ERA5. This work fits well within the scope of the journal and provides a contribution to the field. The manuscript is generally well written, but some paragraphs can be somewhat lengthy. The following comments should help with solving the remaining issues before publication, with e.g. L1 referring to line 1.

Author's response: We thank you for your thoughtful and constructive comments, which have contributed to improving the clarity, structure, and scientific integrity of the manuscript. All major and minor points have been carefully addressed.

General comments:

Reviewer comment

- Recently, a new version of the regional climate model RACMO2.4p1 was published for the Antarctic ice sheet (Van Dalum et al., 2025, https://doi.org/10.5194/egusphere-2024-3728), which includes new physics (in particular relevant here are changes in precipitation). Importantly, RACMO2.4p1 also has a higher horizontal resolution of 11 km compared to the 27 km resolution used in RACMO2.3p2. Using the SMB of RACMO2.4p1 would improve the comparisons done in this study and I suggest the authors to use this version instead of RACMO2.3p2. RACMO2.4p1 data can be found here: https://doi.org/10.5281/zenodo.14217231

Author's response: We were primarily interested in the broad patterns associated with ENSO. However, with the improved parameterisation in the new version of the regional model RACMO2.4p1, we updated the results using SMB from RACMO2.4p1. Even though there was not much difference compared to the RACMO2.3p2 results, we retained the updated version and described in the data section (page 8 L 237-245) but also feature in the rest of the manuscript such as in the abstract (page 1 L19).

Reviewer comment

- In the manuscript, basal melting is mentioned but SMB and mass changes are not studied on the ice shelves, hence relating the results to basal melting is difficult. Therefore, consider to include ice shelves in the comparison with RACMO SMB in e.g. Fig. 3b and elsewhere, and if possible also for GRACE, or explain why that cannot be done. Furthermore, it is also interesting to see how the SMB changes over the major ice shelves for each ENSO period.

Author's response: The mention of basal melting in this study is in the context of available literature and not considered in our analysis. To avoid confusion, we have removed any mention of basal melting in figure 3 to in the discussion (Page 26 L673-677). Again, description of El Nino conditions has been edited to "During El Niño conditions, a weakened ASL and reduced coastal easterlies allow westerly wind anomalies to bring marine air masses onshore, which, enhance snowfall and mass accumulation through orographic lifting (Paolo et al., 2018; Huguenin et al., 2024). In contrast, La Niña conditions strengthen the ASL and intensify coastal easterlies, limiting moisture transport and reducing precipitation (Huguenin et al., 2024; Hosking et al., 2013)." (page 28 L 707-716). Any other mention of basal melting is in the context of literature (page 36 L958-960 and page 37 L986).

Reviewer comment

- I think it is valuable for this study to mention whether an ENSO event is central or eastern and discuss if and how such events differ, as it may explain some of the patterns that are identified in this study and therefore increase understanding. The authors shortly discuss the potential importance in the manuscript, like on L486-495, but I think a more in-depth analysis will improve the manuscript. Other work, like Macha et al. (2024), may provide information about whether an ENSO event is central or eastern, or it can be determined by following methods described by Ren and Jin (2011).

Author's response: We used cumulatively summed ENSO indices to defined ENSO periods to capture the net influence of mass change during this period, which could include transitions between central and eastern Pacific events. How approach does not distinguish between El Nino event or seasonal changes. Therefore, associating a mass pattern to specific El Nino event type is not the primary focus, but the observed mass change is. Comparing the cumulatively summed Central, Eastern and Niño3.4 indices, we found that they are highly correlated and hence difficult to separate from one another in a cumulative sense, at least with the data span we have. This limitation has been included in the methodology showing a comparison of these indices (page 6 L216-220 , Figure shown in supplement page 38 L1027) and discussion "It is important to state that our defined ENSO periods do not distinguish between El Niño types or seasonal phases but instead capture the net mass change over the entire period, providing broader context for ice sheet mass balance." Page 29 L747-749.

Reviewer comment

- Not all locations that are discussed in the manuscript are shown on a map, like the Wedell Sea, Ross Sea, location of the ASL or the various ocean sectors. Including the locations mentioned in the manuscript will improve clarity, making it easier to follow.

Author's response: As suggested, we have revised the manuscript to include more regional delineation on the maps – specifically figure 2, improving clarity and ease of interpretation. Specifically, in Figure 2, we now define Antarctic Peninsula (AP), Bellingshausen Sea (BS), Amundsen Sea (AS), Amundsen Sea Low (ASL), Pacific Sector (PS), Ross Sea (RS), Indian Ocean (IO), Atlantic Sector (AS), Wilkes Land (WL), Enderby Land (EL), and Dronning Maud Land (DML), Coats Land (CL), and Weddell Sea (WS). We are unable to add all these regions to some of the later figures, as there is already a lot of content in the figures. The updated figure is on page 10 L292.

Reviewer comment

- Including maps where the SMB changes are shown in percentage of the total SMB for the considered periods will help to understand how big the impact of ENSO/SAM is on the various regions that are considered, as some changes may seem large in for example high precipitation

areas, while they are only relatively small. An alternative could be to report the integrated SMB values in Gt yr-1 for the ENSO events for the whole domain and smaller regions and compare them to the reference period.

Author's response: Our primary focus was on absolute mass change for each period since we have a focus on ice sheet mass change; however, we also included maps showing the relative impact of SMB changes expressed as a percentage of the climatological mean SMB for each ENSO-dominated period as supplementary material (page 39 L1043 and page 40 L1050). To do this, we computed the mean SMB for each period, compared it to the long-term climatological mean at each grid point, and then expressed it as a percentage. We have not changed the text which focuses on the absolute mass change but have include a line about the relative mass change on page 13 L364/ page 19 L507.

Specific comments:

Reviewer comment: L18: As you also use regional climate model output in your study, it should be mentioned in the abstract as well.

Author's response: We have included the model output in the text (L18-19).

Reviewer comment: L23-26: "… and its influence on the ASL and the Southern Ocean circulation can be equally (and in some cases more) important to AIS variability." Please specify with respect to what or rephrase this sentence.

Author's response: We have rephrased this sentence for better clarity. This part now read "In both East and West Antarctica, this study shows that the spatial impact of any given ENSO-dominant period can trigger distinct circulation patterns which can variably influence surface mass balance and ice mass changes" on page 1 L27-31.

Reviewer comment: Abstract: I think it is also important to shortly mention the uncertainties in the abstract that you also mention in the text, such as the relatively short time period that you use and the various teleconnections that may have not happened yet within this time period, or other processes like atmospheric rivers.

Author's response: We have now included a line about the uncertainties in the abstract "However, uncertainties remain, as the mass variability observed during ENSO-dominant periods may not be solely attributed to ENSO, due to teleconnections that may not have fully developed or may have been masked by other processes." page 1 (L31-33).

Reviewer comment: L29-30: "The drivers of inter-annual to decadal Antarctic Ice Sheet (AIS) mass variability are complex and not yet fully understood". Please add a reference to this.

Author's response: Reference now added to this statement "IMBIE Team, 2018" page 1(L37).

Reviewer comment: L35: Not only precipitation but also riming can add to the SMB.

Author's response: "Riming" has been included page 2 (L42).

Reviewer comment: L43: Can you specify here what typically the time scale is that the SAM changes from positive to negative, or vice versa and why the SAM happens?

Author's response: We have elaborated on the timescale of the SAM changes and provide further explanation of the underlying mechanisms driving these variations. The sentence now reads "The

SAM signal is driven by a combination of internal atmospheric dynamics and external forcings, including stratospheric ozone depletion, increases in greenhouse gases, and tropical teleconnections (Fogt and Marshall, 2020a). It varies on timescales from weeks to decades, and its influence on Antarctic precipitation is regionally dependent (Marshall et al., 2017). During the positive phase of SAM, the westerlies around 60° S strengthen, and the overall impact on the AIS is a net decrease in SMB (Marshall et al., 2017; Medley and Thomas, 2019). Conversely, the net influence of the negative phase of SAM on the AIS is an increase in SMB (Medley and Thomas, 2019; Marshall et al., 2017) on page 2 L50-58).

Reviewer comment: L50: Is the total reduction of precipitation in the East AIS typically comparable to the precipitation increase in West Antarctica and the western Antarctic Peninsula? In other words, looking at the AIS as a whole, does a positive SAM increase or decrease the SMB?

Author's response: We have revised this paragraph to more clearly reflect the net impact of SAM on AIS SMB The new sentence is now "During the positive phase of SAM, the westerlies around 60° S strengthen, and the overall impact on the AIS is a net decrease in SMB (Marshall et al., 2017; Medley and Thomas, 2019). Conversely, the net influence of the negative phase of SAM on the AIS is an increase in SMB" on page 2 L53-58. Believed now the polarity of SAM on AIS SMB as a whole is clearer.

Reviewer comment: L67-75: Please add the location of the ASL, sectors like the Pacific sector, Indian sector etc. and other names in a map (for example in Fig. 2), which would help visualize the processes described the paper.

Author's response: We have included more geographical locations with the mean locations of the ASL, as well as the Pacific, Atlantic, and Indian sectors, in Fig. 2 for clarity on page 10 (L292). We now define Antarctic Peninsula (AP), Bellingshausen Sea (BS), Amundsen Sea (AS), Amundsen Sea Low (ASL), Pacific Sector (PS), Ross Sea (RS), Indian Ocean (IO), Atlantic Sector (AS), Wilkes Land (WL), Enderby Land (EL), and Dronning Maud Land (DML), Coats Land (CL), and Weddell Sea (WS).

Reviewer comment: L76-83: Mention here why your study is different than the studies that you mention.

Author's response: To address this comment, we included a line explain how this study is unique to other sentence "In contrast, our study investigates the spatial impacts of multiple individual ENSO periods (as defined in our study), enabling an assessment of how AIS mass variability differs between events and capturing the diverse responses across the ice sheet, rather than a mean response" on page 3 (L100-102).

Reviewer comment: L87: As GRACE observes mass changes, the mass loss due to processes like runoff and sublimation are also included in the signal and should be mentioned here, even though they are relatively small compared to discharge.

Author's response: We have mentioned runoff and sublimation contributions to the GRACE observed mass changes "Although mass loss from runoff and sublimation is included in the GRACE signal, these components are relatively minor compared to discharge. Over the interannual timescales, atmospheric variability dominates the observed mass changes (King et al. 2023)." Page 3 (L106-109).

Reviewer comment: L139: Please mention that the index is normalized in Fig. 1a.

Author's response: We have now stated the index is normalised in Fig. 1a page 7 (L221).

Reviewer comment: L149: Also mention that the climate indices are detrended in Fig. 1c.

Author's response: We have revised the caption to mention the indices are detrended in Fig. 1c page 7 (L221).

Reviewer comment: L155-161: Consider moving this paragraph such that it is mentioned before the paragraph of L148-154.

Author's response: We have moved the paragraph to L177-183 on page 5 and deleted it on L191-197 on page 6.

Reviewer comment: L162-164: "...where the positive phase of ENSO dominates the negative ENSO phase until a positive peak in the cumulative index is reached…". I think that I know what the authors mean but consider reformulating this to improve clarity. Also, do you apply a minimum length that an ENSO period has to last?

Author's response: We have rewritten the sentence and included a minimum length as follows: "we defined El Niño-dominated periods as an interval during which the positive phase of ENSO persists and outweighs the negative phase, culminating in a positive peak. Similarly, La Niña-dominated periods are defined as intervals during which negative phase outweighs the positive phase, culminating in a negative peak. Only ENSO periods with a minimum duration of 12 months were considered in our analysis" on page 6 (L198-204).

Reviewer comment: Fig. 1: Please add a description to the Y-axis of the figures. In Figure 1.d, consider adding ENSO and in Figure 1.e SAM in the top of the figure, which would help reading the figure more quickly.

Author's response: We have labelled the Y-axis as Std. Dev" and added ENSO (Cumulative summed) Fig. 1d and SAM (Cumulative summed) Fig. 1e page 7 (L221).

Reviewer comment: Section 2.3: It has not been mentioned in the paper before why you want to use a regional climate model and why it is necessary, which should be explained in e.g. the introduction before explaining what regional climate model you are going to use.

Author's response: We have given a short rationale for using a regional climate model has now been included in the introduction. It reads as follows "Since GRACE observes total mass change without distinguishing between the individual components of the mass balance, we use SMB output from a regional climate model RACMO2.4p1 to assess the contribution of SMB to the spatial patterns detected by GRACE" on page 4 L123-126.

Reviewer comment: L189: ."..at its lateral and ocean boundaries…" → at its lateral boundaries and SST and sea ice extent at the sea surface boundary…

Author's response: We have revised accordingly "lateral boundaries and SST and sea ice extent at the sea surface boundary" page 8 (L240).

Reviewer comment: Section 2.4: The authors should mention here why it is necessary to use ERA5 over RACMO output for the 10 m wind speeds and sea level pressure.

Author's response: We have provided justification for using ERA5 pressure and winds variables instead of RACMO output. "We used ERA5 products instead of RACMO outputs because ERA5 provides broader spatial coverage and is more suitable for capturing large-scale atmospheric

circulation patterns, which are critical for analysing ENSO related teleconnections. Additionally, RACMO is forced by ERA5." Page 8 L253-256.

Reviewer comment: L225: Capital letter is missing in 'key'.

Author's response: We have revised accordingly page 10 L293. Now the whole caption reads "Figure 2. Linear rate and acceleration of AIS mass change (2002-2022) based on GRACE data from using univariate regression. Key Antarctic regions are labelled: Antarctic Peninsula (AP), Bellingshausen Sea (BS), Amundsen Sea (AS), Amundsen Sea Low (ASL), Pacific Sector (PS), Ross Sea (RS), Indian Ocean (IO), Atlantic Ocean (AO), Wilkes Land (WL), Enderby Land (EL), Dronning Maud Land (DML), Coats Land (CL), and Weddell Sea (WS). Stippling indicates areas not statistically significant ($\rho<0.05$). Significance tests do not reflect the effects of temporal correlations in these data (Williams et al., 2014)."

Reviewer comment: L227-229: Also mention here that you plot ERA5 and RACMO in Figure 3.

Author's response: We have included ERA and RACMO the main text and figure caption. In the text " Figure 3 presents the regression results of cumulatively summed anomalies in ERA5 reanalysis climate variables (sea level pressure and 10 m winds) and RACMO2.4p1 SMB" page 10 :301-302. Figure caption: **"**Figure 3. Maps show the regression of cumulatively summed sea level pressure (shaded region and contour) and 10 m wind anomalies (represented by reference vectors (m s^{-1}) from ERA5 reanalysis (a), cumulatively summed RACMO2.4p1 model SMB anomalies (b), and GRACE ice mass change anomalies (c)" Page 11 L312-314.

Reviewer comment: Fig. 3: I do not fully understand what is shown here. Is this the SLP and winds, SMB and GRACE mass loss averaged over the ENSO events? If this is the average over the ENSO events, including both El Nino and La Nina, would they not compensate each other?

Author's response: The figure shows the regression coefficient of sea level pressure (SLP) and winds anomalies (cumulatively summed), surface mass balance (SMB, cumulatively summed), and GRACE anomalies onto the cumulatively summed ENSO index. We have edited Figure 3 caption to improve clarity. "Figure 3. Maps show the regression of cumulatively summed sea level pressure (shaded region and contour) and 10 m wind anomalies (represented by reference vectors (m s^{-1}) from ERA5 reanalysis, cumulatively summed RACMO SMB anomalies, and GRACE ice mass change anomalies regressed against cumulatively summed Niño3.4. The u and v wind components were regressed separately. All panels reflect regressions of anomalies over the period 2002-2022. All variables were linearly detrended prior to regression using the full data periods. Stippling indicates regions where the regression results are not statistically significant ($\rho<0.05$)." on page 11 L312-318.

Reviewer comment: Fig. 4 and 5: Interpreting the results would be easier if you mention in this figure for each ENSO event whether the SAM index is positive, negative or neutral.

Author's response: We have indicated the phase of the cumulatively summed SAM for each ENSO-dominated period in Fig. 4 and Fig to help with the interpretation. New Fig 4 is now on page 15 L367 and Fig. 5 on page 21 L514

Reviewer comment: Fig. 4i-l: Do you know why the north-south striping is so much more pronounced in Fig. 4j and Fig. 4l compared to Fig. 4i and Fig. 4k?

Author's response: The north-south stripping is much more pronounced over shorter periods of time as there is less averaging. Furthermore, due to instrument degradation toward the end of the GRACE mission, the observational error increases, which likely contributes to the more noticeable north–south striping in Fig. 4j and Fig. 4l. Adding the significance hatching has helped with this interpretation Fig 4 is now on page 15 L367.

Reviewer comment: L310: Do you mean Fig. 4g instead of Fig. 4c?

Author's response: It is Fig. 4g instead – now changed page 17(L439). However, the paragraph has been edited and different to the earlier version. " Positive SMB (Fig. 4e, g) and ice mass anomalies (Fig. 4j, l) are observed during the 2002–2005 and 2014–2016 El Niño periods, particularly in GRACE (Fig. 4i, k), whereas negative mass anomalies are evident during the 2009-2010 and 2018-2020 periods (Fig. 4j, l).

Reviewer comment: L311-312: "Note that the 2002-2005 SMB anomaly is only marginally positive (Fig. 4a)." → Note that the 2002-2005 SMB anomaly is only marginally positive for the Antarctic Peninsula (Fig. 4e).

Author's response: We have revised as suggested the entire paragraph for clarity; hence, this sentence is no longer included. page 17 (L434-435).

Reviewer comment: L313, 314: Fig. 4f → Fig 4f, h and also Fig. 4j → Fig. 4j, l.

Author's response: We have revised as suggested page 17 L441.

Reviewer comment: L323: Please also show these sectors on a map, e.g. Fig. 2.

Author's response: We have included several sectors on the map (Fig. 2) page10 L292.

Reviewer comment: L330-353: Link the pressure anomalies and wind changes to moisture transport and their consequent impact on SMB and mass changes. These paragraphs can also be shortened.

Author's response: In line with the other reviewer comment to avoid use words that imply causation rather than correlation and since how analysis does not show moisture transport, we have decided to limit linking pressure anomalies and moisture transport in the results move that to discussion. However, we have also summarised the paragraph. Page 18 L453-463 and the line you referring to deleted on L471-4778

Reviewer comment: L380-381: Fig. 5f, g-h → Fig 5f-h and also Fig. 5j, k-l → Fig. 5j-l

Author's response: We have revised as suggested. "Fig. 5f-h and Fig. 5j-l is on page 22 L551.

Reviewer comment: L385-387: Can you explain more how the northerly winds from the Pacific and southerly winds from the continent can lead to convection? And how it may result in positive mass anomalies?

Author's response: After reversing our analysis and we observed the pressure anomalies during this La Nina period (2007-2009) is not robust at the 0.05% hence we can't directly link this pressure anomalies to the observed mass gain particular in GRACE. We have revised the text to reflect this and now reads "In contrast, during the 2007–2009 La Niña period, a mass gain is prominently observed in GRACE (Fig. 5i), a pattern more commonly associated with El Niño periods described earlier.

However, the SMB and pressure anomaly patterns during this period are not statistically significant at the 0.05 level." Page 23 L554-556.

Reviewer comment: L393-398: Similarly, as before, link the pressure and wind anomalies to moisture transport and then to SMB and mass changes.

Author's response: Again, as we mentioned earlier, based on a reviewer comment, have limited linking circulation and moisture transport and mass changes in the results and moved all to the discussion to avoid conclusions not captured in our results since we did not analyse moisture transport. We have revised the paragraph and now read "This contrasting mass change response between the two periods aligns with the position of the negative pressure anomaly in the Pacific sector. In the 2010–2014 La Niña period, the pressure anomaly is centred over the Bellingshausen Sea, accompanied by offshore wind anomalies over the Peninsula (Fig. 5b). In contrast, during the 2020–2022 La Niña period, the negative pressure anomaly is centred in the Amundsen Sea, with onshore wind anomalies directed into the Peninsula (Fig. 5d)." on page 23 L573-578.

Reviewer comment: L421-426: How much of the 2020-2022 La Nina SMB signal is caused by this atmospheric river event? Is it possible that it is (almost) completely dominated by it?

Author's response: We explored the analysis by finding the difference between inclusion and exclusion of the March 2022 event and we observed signal in Wilkes Land, which we have included in the text in our discussion and parts of it read "To determine the extent of the influence of this event, we examined the 2020-2022 period by comparing the inclusion and exclusion of the March 2022 event (Supplementary Fig. S5). While the March 2022 event increased the strength of the SMB positive anomaly in Wilkes Land, the region still observed a strong positive SMB anomaly during the 2020-2022 period when March 2022 was excluded (Supplementary Fig. S5). According to Wang et al. (2023), extreme events in March 2022 and October 2021 accounted for approximately 38% of the precipitation anomalies in Wilkes Land during the 2020–2022 La Niña period, driven by a pair of symmetrically distributed high–low pressure systems over the Southern Ocean near 120°W and 60°E." Page 32 L854-866. Supplementary figure on page 41 L1057

Reviewer comment: Fig. 6: How did you calculate the average of the anomalies shown here? Did you weigh them by the length of the El Nino or La Nina-dominated periods? Or did you simply take the average of the maps that you have shown in Fig. 4 and 5?

Author's response: We simply took the average of the maps shown in Fig. 4 and 5 and have clarified this in the text page 25 (L632) and figure caption page 26 L650. We are under the impression the Mean computed for the SLP/wind and the regression for SMB/Ice mass, has already accounted for the length of each EL Nino/La Nina period in Fig. 4 and 5.

Reviewer comment: 459-461: Can you elaborate about these unusual climate dynamics? Does this have any impact on ENSO/SAM related SMB changes that you have discussed in the paper?

Author's response: We have added a line elaborating the unusual climate dynamics and how it has shift large-scale circulation (Xin et al., 2023), particularly SAM and how it will potentially affect ENSO teleconnections and their impact in AIS mass variability and our mass change results page 28 L712-716 .This has now been moved to page 36 L941-943 "However, between 2000 to 2020, shifts in large-scale circulation, particularly in SAM , have been reported, potentially affecting ENSO teleconnections and their influence on AIS variability"

Reviewer comment: L474-476: I am not sure if I fully understand how your results support the findings that increased basal melt is compensated by higher SMB. If I am not mistaken, you do not include ice shelves in your analysis where basal melt can occur, so how do you know that the positive SMB anomalies and increased mass that you show compensate for increased basal melt?

Author's response: To have confusion we have revised the text and deleted this line. New paragraph "During El Niño conditions, a weakened ASL and reduced coastal easterlies allow westerly wind anomalies to bring marine air masses, onshore, which, enhance snowfall and mass accumulation through orographic lifting (Paolo et al., 2018; Huguenin et al., 2024). In contrast, La Niña conditions strengthen the ASL and intensify coastal easterlies, limiting moisture transport and reducing precipitation (Huguenin et al., 2024; Hosking et al., 2013)" page 28 L707-716.

Reviewer comment: L477: "… El Nino-dominated period in the Amundsen sector differ" → "… El Nino-dominated periods in the Amundsen sector differs"

Author's response: To summarise this section we have rewritten the paragraph and deleted the earlier version. Deleted version on page 29 :726-727 and new paragraph is on page 28 L718-720 "However, the 2009–2010 El Niño period deviates from this pattern, with negative SMB anomalies observed in the Amundsen Sea sector (Fig. 4f).

Reviewer comment: L483-485: As you include the complete events, doesn't it make your methods more vulnerable for irregular events, such as atmospheric rivers, that may overshadow the ENSO signals?

Author's response: We have included in the discussion, the limitation of our cumulative indexing method and how it is vulnerable to high frequency and short-term impacts. " However, across individual ENSO periods, the AIS response exhibits considerable variability, with each period associated with distinct atmospheric circulation patterns. It is possible that the teleconnection between tropical ENSO signals and Antarctic climate may not be fully established during a given ENSO phase or masked by other processes. Our analysis, which uses cumulative summed indices to match GRACE mass time series, is primarily sensitive to low-frequency variability and does not resolve shorter-term impacts, such as tropical convection pulses that initiate Rossby wave trains or high-frequency variability linked to storm systems like atmospheric rivers. Nonetheless, the integrated effect of these processes is captured by GRACE." Page 36 L970– 979).

Reviewer comment: L508-510: Considering moving this to the la nina part.

Author's response: We have deleted this section and combine the discussion of La Nina and El Nino, page 30 L767-782.

Reviewer comment: L524: "tie" → "tied"

Author's response: We have revised the text and combined the discussion of La Nina and EL Nino for West Antarctic and East Antarctic. Therefore, this has changed the text Page 28-30 L694-782.

Reviewer comment: L550-551: "ENSO impacts West Antarctica through modulation of the ASL via Rossby wave propagation, though the ASL's influence on East Antarctica remains unclear", please add a reference to this.

Author's response: We have revised the text and deleted this part page 34 L866-869. Most of this section has been revised to make it clear and not much lengthy.

Reviewer comment: L583-585: Consider reformulating this sentence.

Author's response: We have rewritten this section; hence, this part is deleted page 34 L897-902 .

Reviewer comment: L595: The reference to Fig. 1c seems to be larger than the surrounding text.

Author's response: We have reduced the font size, now on page 32 L853.

Reviewer comment: L631: "However, the timescale of the response of the upstream ice to the positive SAM forcing is unclear and would involve a substantial lag". Please also describe how substantial this lag is what it would mean to the GRACE signal that you have used in this study.

Author's response: We have briefly discussed the potential lag in the response of upstream ice to positive SAM forcing and how it reflects in the results on page 36 L958-960.

Reviewer comment: L649: "This dynamical signal is stronger in West than in East Antarctica.". Add a citation to this.

Author's response: Reference added (Rignot et al., 2019) page 37 L986.

Reviewer comment: L 658-659: The authors should add the time period that is considered in this study here. Also mention that you used ERA5 and RACMO.

Author's response: We have revised as suggested "To examine the AIS mass change during different ENSO-dominated periods, we analysed AIS mass change anomalies observed by GRACE/GRACE-FO spanning the period 2002-2022. These anomalies were interpreted alongside RACMO2.4p1 modelled SMB and mean sea level pressure and 10 m winds from ERA5 reanalysis products." Page 37 L995-1000.

Reviewer comment: L676-683: As it is the last concluding paragraph of the paper, remove references to figures and citations in this paragraph.

Author's response: We have revised as suggested with Fig. 3 removed (Page 38 L1015 and Macha e also removed page 38 L1024.

Reviewer comment: L676-683: Similar to my comment about the abstract, consider to shortly mention the uncertainties that have been discussed, such as the relatively short time period that you use and the various teleconnections that may have not happened yet within this time period, or other processes like atmospheric rivers.

Author's response: We have included the uncertainties in the conclusion "We acknowledge uncertainties in our analysis due to the relatively short ENSO-dominated periods considered. Some ENSO-related teleconnections may not have fully developed during these intervals, and other processes—such as atmospheric rivers—may have masked or modulated the ENSO signal, complicating the attribution of the observed spatial impacts." Page 36 L972-973.

Reviewer comment: L690: This citation does not lead to the correct RACMO2.3p2 SMB data, as it refers to a newer version of RACMO: RACMO2.4p1.

Author's response: We have included a new link to RACMO2.4p1 page 42 L1072.

RC 2.

SUMMARY

"The changing mass of the Antarctic Ice Sheet during ENSO-dominated periods in the GRACE era (2002-2022)" presents a comprehensive analysis of the circulation, surface mass balance, and ice mass variation patterns associated during four different periods of El Nino and La Nina phases of ENSO over two decades. The study ties together a number of prior studies on how ENSO impacts Antarctic surface mass balance by highlighting that the spatial impacts of this mode of variability vary strongly depending on the periods considered. It brings together observational, reanalysis, and model datasets to produce a compelling argument that the ENSO signal in Antarctica is dependent on event-specific atmospheric circulation patterns. I look forward to the publication of this manuscript; however, I have some major comments about the presentation of results without indications of statistical significance, the structure of the results, and the wording around association versus causation when establishing the occurrence of circulation and SMB/mass variability patterns during periods of El Nino and La Nina. Please see major and minor comments below.

Author's response: We appreciate your constructive feedback and believe that your suggestions will significantly enhance the clarity and scientific rigor of our study. We have carefully addressed each of the major and minor comments you raised.

MAJOR COMMENTS

Reviewer comment:

Statistical significance of trends and anomalies – many of the figures and corresponding analyses in this manuscript describe trends and anomalies in circulation, surface mass balance, and short-term mass change of the Antarctic Ice Sheet. However, the figures and discussion are missing critical information on the statistical significance of the results shown. For example, Fig. 2 shows the linear trend in ice mass change based on GRACE data, and here it would be very useful to add hatching or another indicator of where the trend is statistically significant. For Fig. 3, does the regression output p-values? If so, this would be another example of where it would be important to show where the statistically significant regions are. Same for Fig. 4 and 5 - for the composite maps, it would be key to add an indication for where the mean anomaly in sea level pressure is statistically significant (or exceeds the standard deviation among the different anomalies, for example). Without an indication on the maps for which regions exhibit statistically significant anomalies, readers cannot know which patterns are robust.

Author's response: We have implemented statistical significance tests for the trends and anomalies presented in this work. Significant regions are shown without stippling, whereas non-significant regions are stippled, to help readers identify where the observed patterns are robust. We have also included a section in the Methods describing the significance test approach (page 9 L 270-275). We further note here that the interpretation of this needs to be done in the context of our use of cumulative values of each of mass, winds and pressure and so the meaning of significance is different to using mass rates, or unmodified winds and pressure. The significance test is performed for the pressure, SMB and GRACE anomalies, no significance test was performed for the wind vectors.

Reviewer comment

For the analyses of figure 4 and 5, I recommend structuring the text either by region (then compare different periods) or by period (and go through each region). The current structure of the text alternates between period and region, and that makes it hard to follow.

Author's response: Our current structure of the presentation of the results in Figures 4 and 5 are now presented by period and go through region separately for El Nino and La Nina periods. We begin with West Antarctica, followed by the Antarctic Peninsula and East Antarctica, for both El Niño and La Niña periods separately, However, not sure how this differs from the recommendation of going by " period (and go through each region).

Reviewer comment

There are several instances of language that implies causation rather than correlation throughout the paper. For example, on L229, "the results show that ENSO influences circulation over Antarctica, driving short-term fluctuation in AIS mass…" – rather, the results show that ENSO periods are correlated with certain meridionally-oriented circulation patterns conducive to the flow of marine air masses onto the AIS. Furthermore, since there is not an analysis of the individual events that are contributing precipitation during the time periods in question, I would avoid using the word "driving" when it comes of the ENSO phase/circulation pattern and the associated SMB signals. As mentioned later in the text, precipitation can be driven by a few impactful events or many smaller snowfall events, or a mix of the two, and this study does not address the link between individual snowfall events and the large-scale circulation patterns. Furthermore, some of the language such as "that weakened the Antarctic high" or "a developing low-pressure system" or "leading to…" implies that this study examined the time-evolution of sea level pressure anomalies during the periods in question. My understanding of the methods is that this was not done – in which case, I would strongly recommend to the authors to remove any suggestions of the temporal evolution of anomalies throughout the text, unless there are figures to back up the claims.

Author's response: Regarding the language used, we have refined it to avoid implying causation or temporal evolution that is not supported by our methods. We have reviewed the manuscript to ensure that all wording clearly reflects correlation rather than causation and avoids terms that may suggest otherwise. Therefore, this is much revision to the in the latest edition compared to the earlier version.

Reviewer comment

L421-426 – I would be careful presenting the March 2022 event here as if it were the only extreme event/atmospheric river that occurred here over the time period studied. Certainly, this event was a standout and had a huge impact on the surface. At the same time, there are multiple atmospheric rivers impacting each location along the Antarctic coastline every year – meaning that there is the opportunity to assess the relationship between extremes, ENSO, and SAM. I would encourage the authors to discuss their results in the context of Shields et al. 2022 (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022GL099577) – which examined the associated between different modes of variability and atmospheric river occurrence and precipitation. Please see Fig. 3 of the Shields paper in reference to L565-566 of the Discussion as well – which shows the correlation between atmospheric river days and negative SAM.

Author's response: We explored the analysis by finding the difference between inclusion and exclusion of the March 2022 event and we observed signal in Wilkes Land, which we have included in

the text in our discussion and parts of it read “To determine the extent of the influence of this event, we examined the 2020-2022 period by comparing the inclusion and exclusion of the March 2022 event (Supplementary Fig. S5). While the March 2022 event increased the strength of the SMB positive anomaly in Wilkes Land, the region still observed a strong positive SMB anomaly during the 2020-2022 period when March 2022 was excluded (Supplementary Fig. S5). According to Wang et al. (2023), extreme events in March 2022 and October 2021 accounted for approximately 38% of the precipitation anomalies in Wilkes Land during the 2020–2022 La Niña period, driven by a pair of symmetrically distributed high–low pressure systems over the Southern Ocean near 120°W and 60°E.” Page 32 L854-866. Supplementary figure on page 41 L1057

MINOR COMMENTS

Reviewer comment: Abstract – would recommend removing/reducing the number of acronyms, including AIS, ASL, SAM, and SST.

Author’s response: We have reduced the number of acronyms used in the abstract to a limited number by removing ASL, SAM, and SST. However, we have maintained acronyms to words that appear twice (page 1 L13-34).

Reviewer comment: L17 – “… we investigate AIS mass variability” (add mass? Same for L26)

Author’s response: We have included “mass” to now become “we investigate AIS mass variability” page 1 L17).

Reviewer comment: L22 – “anticyclonic circulation anomalies” (add circulation)

Author’s response: We have added the term “circulation” as suggested page 1 L26).

Reviewer comment: L23-26 – sentence is a bit confusing, consider shortening or clarifying

Author’s response: T We have rephrased this sentence for better clarity. This part now read “In both East and West Antarctica, this study shows that the spatial impact of any given ENSO-dominant period can trigger distinct circulation patterns which can variably influence surface mass balance and ice mass changes” on page 1 L27-31.

Reviewer comment: L27 – what does “event-scale” mean? Synoptic-scale?

Author’s response: To avoid ambiguity, we have revised deleted the entire sentence from the text page 1 L33-34.

Reviewer comment: L43 – Add “The” to beginning of sentence, and “is regionally dependent and affects different regions” is redundant

Author’s response: We have rewritten this part and added “The” to being the sentence on page 2 L50 and removed the redundant part on page 2 L53.

Reviewer comment: L57 – it may be helpful to mention Pacific South American mode 1 (PSA1) in the Introduction, since this is another term used to describe the second most-dominant mode of variability around Antarctica, associated with ENSO.

Author’s response: We have included a brief introduction of the PSA1 in the ENSO introduction “This Rossby wave train leads to the formation of the Pacific South American mode 1(PSA-1), an atmospheric anomaly pattern that enables ENSO signals to reach Antarctica (Hoskins and Karoly, 1981). This creates a positive-pressure anomaly over the Amundsen-Bellingshausen sector (ABS)

during El Niño events—the positive phase of PSA-1— and negative-pressure anomaly during La Niña conditions—the negative phase of PSA-1 (Turner, 2004: Hoskins and Karoly, 1981)“ page 2 L69-73.

Reviewer comment: L65 – impact of ASL on East Antarctica – is there any evidence that the ASL influences East Antarctic circulation? This is also mentioned at the end of the manuscript, and I think it would be helpful to clarify (a) whether any links have been found between the ASL and East Antarctic circulation (to support the statement that “the impact” exists) and (b) what those links could be.

Author’s response: No direct linked has been found between ASL and East Antarctic circulation and it is an area of active research. In the introduction we have deleted this sentence on page 3 L80 Page 33 L877-880.

Reviewer comment: L73 – “reducing precipitation and SMB in West Antarctica” – please be specific about which regions of West Antarctica

Author’s response: Specific locations have been added to the sentence “over the Antarctic Peninsula and from the Bellingshausen Sea to the Ross Sea region in West Antarctica” page 3L88-89.

Reviewer comment: L84-105 – really nice summary here, framing the motivation for this study in the context of prior literature

Author’s response: We thank the reviewer.

Reviewer comment: L112 – clarify what COST-G RL-01 V0003 50km is, and please add a discussion either here or in the Discussion section about the spatiotemporal resolution of GRACE observations. How well do these observations capture spatial variability in accumulation? Is there a tendency to under/overestimate surface mass balance anomalies given the 300km resolution?

Author’s response: We have expanded on the description of the GRACE dataset which includes what COST-G RL-01 V0003 represent (“We used the COST-G release 1 version 3 (RL-01 V0003) gridded mass anomaly product, which combines GRACE/GRACE-FO solutions from multiple GRACE analysis centres” page 4 L136-138) and how the original resolution of GRACE (300km) limits GRACE ability to resolve small, localised surface mass balance anomalies (“This relatively coarse resolution limits GRACE’s ability to resolve small-small mass changes, particularly localised surface mass balance anomalies “ page 4 L140-141).

Reviewer comment: L128 – Is the linear trend sufficient for capturing ice mass variation over 2002-2022? Is the 7-month moving median specifically applied for the linear trend removal, or do all results shown include the 7-month-averaged signals? Are there regions where the trend is/isn’t statistically significant, by grid point? Is the trend removed everywhere or only where it is significant?

Author’s response: All results shown for GRACE and RACMO were smooth using a 7-month moving median window. The choice of a 7-month filter follows King et al. (2023) and is a subjective decision to dampen month-to-month noise in GRACE data after which the trend was computed from the smoothed data. To response to your question if the linear trend is sufficient, we have now included an acceleration. In response to RC, we have added indication of statistical significance on the figures. We have also added the acceleration of mass change and tested it for statistical significance page 10 L292. To study the variability, Figs 3, 4 5 and 6 have no trend.

Reviewer comment: L132 – do you know if there is a lag between the initiation of an El Nino or La Nina event and the teleconnection that impacts Antarctic surface mass balance? Do you know the timescale of the teleconnection?

Author's response: King et al 2023 looked at it and found a ~6-month lag - we can't resolve it with our method.

Reviewer comment: Fig. 1 – "shows the cumulatively summed normalised raw indices after which it is renormalized" – I'm having a hard time understanding what the method is.

Author's response: We have reworded the figure caption to improve clarity to "Figure 1. "Figure 1. Monthly climate indices of SAM (Marshall,2003) and Niño3.4 from 2002-2022: (a) normalised SAM and Niño3.4 indices; (b) normalised cumulatively summed SAM and Niño3.4 indices; (c) detrended, cumulatively summed SAM and Niño3.4 indices (normalised). Periods until positive peaks are reached in the cumulatively summed Niño3.4 are defined as El Niño-dominated and La Niña-dominated periods, respectively, represented as red and blue shaded areas in (d). Similarly, periods until positive and negative peaks are reached in the cumulatively summed SAM index (Marshall, 2003) are defined as SAM-positive and SAM-negative dominated periods, respectively, denoted as red and blue shaded areas in (e). Neutral dominated periods are represented by white shading. Page 7 L223-234.

Reviewer comment: Fig. 1 – please clarify what metrics where used to determine the ENSO phases shaded in (d) and (e). Also, I would recommend moving the legend from (c) to (a) and because there is no text labeling the figure axes, I'd recommend adding titles to each figure.

Author's response: Titles and metrics have been added to the figure, However, because there is no white space a) we have maintained the legend in c) (page 7 L221). To determine the ENSO phases shaded in (d) we used this threshold "Only ENSO periods with a minimum duration of 12 months were considered in our analysis" include in the method on page 6 L203.

Reviewer comment: L211/212 – "relative strengthening" and "relative weakening"

Author's response: Relative has been added as suggested page 8 L266-267.

Reviewer comment: Fig. 3 – how was the regression of 10m wind anomalies performed? For u and v separately, or did you use the wind vectors? For detrending the variables, did you use a linear trend? I think it would be helpful to have more information on the methods used here

Author's response: Additional information has been included in the caption to describe how the regression was done for u and v and the detrending method used; "Figure 3. Maps show the regression of cumulatively summed sea level pressure (shaded region and contour) and 10 m wind anomalies (represented by reference vectors (m s^{-1}) from ERA5 reanalysis, cumulatively summed RACMO SMB anomalies, and GRACE ice mass change anomalies regressed against cumulatively summed Niño3.4. The u and v wind components were regressed separately. All panels reflect regressions of anomalies over the period 2002-2022. All variables were linearly detrended prior to regression using the full data periods. Stippling indicates regions where the regression results are not statistically significant ($\rho<0.05$)." page 11 L313-319.

Reviewer comment: L240 – It could be helpful to readers if you present some Antarctic Ice Sheet-integrated SMB values when discussing the precipitation anomalies during El Nino and La Nina.

Author's response: We have included mean SMB anomaly for El Nino and La Nina over various regions based on composite of Annual accumulation anomaly and ENSO years in the text page 12 L332-338.

Reviewer comment: L242 – in Fig. 3, the W. Antarctic winds look more along-shore than onshore except over the Antarctic Peninsula – can you clarify? As a general comment, it is quite difficult to see the wind vectors along the Antarctic coast, meaning it's not always clear if/when a figure supports the conclusions in the text about wind directions at the coast.

Author's response: We have increased the size of the wind vectors in the figure to enhance visibility, particularly along the Antarctic coast. This adjustment will help clarify the wind patterns (wind vectors do not have a significance test applied) discussed in the text and more effectively, however, we have tried to remove enough of any discussion in the result and have deleted this part (page 12 L323-331.

Reviewer comment: L273 – for the different periods of El Nino events presented, it would perhaps be helpful as added context to know whether these events were central or eastern.

Author's response: This point was also raised by RC1. As we respond there, with a cumulative method, which may contain more than one event type, we cannot separate these. We used cumulatively summed ENSO indices to defined ENSO periods to capture the net influence of mass change during this period, which could include transitions between central and eastern Pacific events. How approach does not distinguish between El Nino event or seasonal changes.

Therefore, associating a mass pattern to specific El Nino event type is not the primary focus, but the observed mass change is. Comparing the cumulatively summed Central, Eastern and Niño3.4 indices, we found that they are highly correlated and hence difficult to separate from one another in a cumulative sense, at least with the data span we have This limitation has been included in the methodology showing a comparison of these indices (page 6 L216-220 , Figure shown in supplement page 38 L1029) and discussion "It is important to state that our defined ENSO periods do not distinguish between El Niño types or seasonal phases but instead capture the net mass change over the entire period, providing broader context for ice sheet mass balance." Page 29 L747-749.

Reviewer comment: L274 – "representing a weakened an/or shifted ASL" rather than an actual high-pressure system" – how do you know? Do you have a figure to show this?

Author's response: We made this reference to the climatology over the study period (2002-2022), figure not shown. However, to avoid confusion the section is rewrite to this "In West Antarctica, El Niño-dominated periods are characterised by a positive pressure anomaly in the Pacific sector off the West Antarctic coastline (Fig. 4a–b). The position and strength of these positive pressure anomalies vary for each El Niño-dominated period, which is also reflected in the variation of wind anomalies and spatial patterns of SMB (Fig. 4e–h) and ice mass change (Fig. 4i–l). However, during the 2018-2020 period, no significant pressure anomaly is observed, and in the 2009-2010 period, a significant pressure anomaly is located closer to the continent, with a non-significant pressure anomaly further north (Fig. 4a–b)." page 16 L384-389.

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Reviewer comment: L276 – "influencing meridional circulation, thus driving distinct spatial patterns in SMB" – could add a mention of "marine intrusions"/marine air masses here to link these two processes (the meridional circulation and the SMB)

Author's response: We have added to the discussion which is where it is more appropriate in regard to your previous comment on causation "allow westerly wind anomalies to bring marine air masses,

onshore, which, enhance snowfall and mass accumulation through orographic lifting" on page 28 L707-716.

Reviewer comment: L278 – "West Antarctica as two regions" – I'm very confused about what region is actually meant by the Amundsen Sea sector. Are you including all of Marie Byrd Land and the Ross coast in the Amundsen Sea? Where does the Bellingshausen fall? I would recommend adding region names to one of your early maps and being very specific in your description of regional patterns.

Author's response: To avoid confusion, we have deleted this sentence (page 16 L390-391). We have provided a detailed map (Figure 2) with additional regional labels to allow for clearer and more specific descriptions of the regional patterns discussed in the text on page 10 L293.

Reviewer comment: L280 – "different signs but broadly uniform" – I am slightly confused by the wording in this sentence

Author's response: This whole paragraph has been deleted (page 16 392).

Reviewer comment: L286 – "influences" – please use language of association and not causation

Author's response: We have changed the language to and the modified the most of this section to remove an implication causation but correlation. We have deleted this sentence page 16 L386.

Reviewer comment: L296 – "… over the continent that weakened the Antarctic high" – again, use "associated with a weakened Antarctic high" or similar

Author's response: The paragraph now reads different to avoid implying causation **"**For the 2014–2016 El Niño-dominated period, we observed weak and, in some regions, non-significant positive SMB and ice mass anomalies in the Amundsen Sea sector and western Ross Sea (Fig, 4g, k). During this period, our cumulative ENSO and SAM were out of phase (El Niño/+SAM) , as evidenced by significant negative pressure anomalies over the continent (Fig. 4c). The positive pressure anomaly in the Pacific was located away from the coastline and was associated more with wind anomalies along the shore, rather than onshore.", page 17 L409-419.

Reviewer comment: L298 – "observed positive anomalies" – from GRACE?

Author's response: Clarified to observed positive "SMB and ice mass" anomalies and rewritten as "For the 2014–2016 El Niño-dominated period, we observed weak and, in some regions, non-significant positive SMB and ice mass anomalies in the Amundsen Sea sector and western Ross Sea (Fig, 4g, k). "Page 17 L409-410.

Reviewer comment: L298 – "A low-pressure anomaly" – I see a low-pressure anomaly all along the coast, but not specifically between these two sites?

Author's response: Reworded to describe the negative pressure anomaly over the continent "During this period, our cumulative ENSO and SAM were out of phase (El Niño/+SAM) , as evidenced by significant negative pressure anomalies over the continent (Fig. 4c)." page 17 L413-414.

Reviewer comment: L301-307 – do you have a hypothesis for why this pattern occurred? Other modes of variability and/or teleconnections?

Author's response: Our potential hypothesis is the mass change observed for this period may be driven primarily more by the Central Pacific El Nino event. We now discuss this in discussion based on Macha et al., 2024. "However, the 2009–2010 El Niño period deviates from this pattern, with negative SMB anomalies observed in the Amundsen Sea sector (Fig. 4f). The pressure anomaly during this period is

distinct, with a positive pressure anomaly extending from the Amundsen Sea to beyond the Ross Sea. An important difference to the other El Niño periods, is the extension of this positive pressure anomaly further to the west, which decreases moisture transport into the region. This period encompasses a strong Central Pacific El Niño event (Kim et al., 2011), and associated pressure anomaly (Fig. 4b) resembles patterns linked to such events, which are associated with moisture depleted wind anomalies and suppressed precipitation in the Amundsen and Bellingshausen regions (Chen et al., 2023; Macha et al., 2024). on page 28 L718-725

"Our 2009-2010 El Niño mass pattern aligns with Macha et al. (2024), who reported reduced accumulation during Central Pacific El Niño events in the SON and JJA seasons. These similarities suggest that the observed mass change may reflect the impact of Central Pacific El Niño phases during the SON and JJA seasons in the Amundsen Sea sector.

It is important to state that our defined ENSO periods do not distinguish between El Niño types or seasonal phases but instead capture the net mass change over the entire period, providing broader context for ice sheet mass balance." On page 29 L743-746)

Reviewer comment: L308 – "two distinct mass variability responses" – I've seen this wording several times in the text and there are only two possible responses, right? Mass gain or loss? Please clarify.

Author's response: We have reworded to remove the confusion using "contrasting mass change" page 17 L431.

Reviewer comment: L327 – "western Dronning Maud Land" – please be specific about the region, and label on a map

Author's response: We provided a detailed map in Figure 2 and include the boundaries in other figures to give a detailed regional presentation. We have also reworded this to give a clear description page 18 L455-457.

Reviewer comment: L333 – "southerly wind flow" and "northerly winds" – these are wind anomalies, right? If so, please refer to them as anomalies throughout the text. Also, these wind vectors are very hard to see in the figure. Perhaps I am misunderstanding the text, but I find it a bit confusing regarding the generating of "northerly winds into western regions, supporting slight positive anomalies". I expect northerly winds to occur on the eastern flank of the low-pressure anomaly, and I also see a convergence of northerly and southerly winds at the coast.

Author's response: Yes, correct. We have modified the text to correct this. Emphasis has been highlighted on wind anomalies and the rest of the manuscript it edited to show wind anomalies.

Reviewer comment: L339 – "central-eastern Dronning Maud Land"

Author's response: We have resulted to sticking to robust signals. Hence, much of this section have been rewritten to capture significant and big signals mostly.

Reviewer comment: L340 – "mid-latitude blocking pattern" – I would not necessarily call a high-pressure anomaly a mid-latitude block, without first looking at the mid-upper level geopotential height patterns and sea level pressure (not the anomaly).

Author's response: We have deleted "mid-latitude blocking pattern" to avoid confusion and reworded then entire sentence to this "Conversely, during the 2009-2010 El Niño period, we observed a significant anomalous mass gain in Dronning Maud Land (Fig. 4f, j). This mass gain coincides with a significant positive pressure anomaly over the Atlantic, which supports onshore wind anomalies into Dronning Maud Land. "page 18 L475-478.

Reviewer comment: L344-347 – this sentence is long and a bit confusing, recommend breaking it into two

Author's response: The sentence has been rewritten for clarity "In the Indian Ocean sector/Wilkes Land, mass gain is broadly observed during the 2002–2005 and 2009–2010 El Niño periods (Fig. 4e, f, i, j), and a reduction in mass during the 2014–2016 and 2018–2020 El Niño periods (Fig. 4g, h, k, l). During the periods with mass gain, positive pressure anomalies were present over Wilkes Land (Fig. 4a, b), with the anomaly more intense and statistically significant during the 2009–2010 El Niño period and associated with a greater magnitude of mass gain in Wilkes Land (Fig. 4b, f, j). Conversely, during periods broadly associated with mass reduction (Fig. 4g, h, k, l), negative pressure anomalies were observed around the Wilkes Land region, aligned with offshore wind anomalies across much of the sector (Fig. 4c, d)." on page 19 L486-498.

Reviewer comment: L345 – 4c or 4b?

Author's response: 4b. We have fixed it page 19 L494.

Reviewer comment: L348 – I don't know that I see mid-latitude westerlies in 4c? (also these are wind anomalies, right?) – maybe more like the polar jet?

Author's response: The entire paragraph is deleted page 19 L499-504 .

Reviewer comment: L351 – "pressure anomalies" – specify low or high

Author's response: Same as above, the entire paragraph is deleted page 19 L499-504.

Reviewer comment: L351 – "developing" implies time-evolution

Author's response: Revised to avoid implying time-evolution "Conversely, during periods broadly associated with mass reduction (Fig. 4g, h, k, l), negative pressure anomalies were observed around the Wilkes Land region, aligned with offshore wind anomalies across much of the sector (Fig. 4c, d)" page 19 L496-498.

Reviewer comment: Fig. 5 - I am slightly concerned that the striping in Fig. 5k, for example, which extends all the way from the interior to the coast (especially because the patterns exhibit spatial continuity). I would recommend to the authors that they mask out the interior region most affected by the striping.

Author's response: We are wary of removing regions without a repeatable method. We now test for significance, and the striping has been heavily masked out with stipple. We also guide the reader in the caption that the more robust signals are along the coast, page 21-22 L514-527.

Reviewer comment: L373 – "strengthening" – implies time-evolution

Author's response: Language revised not to imply time-evolution " Overall, during our La Niña-dominated periods, the Pacific sector exhibits a persistent negative pressure anomaly (Fig. 5a-d), which appears more elongated than the positive pressure anomaly associated with El Niño periods." Page 22 L530-531.

Reviewer comment: L378 – these low-pressure anomalies all look pretty elongated to me?

Author's response: The statement has been deleted and edited to show this "Overall, during our La Niña-dominated periods, the Pacific sector exhibits a persistent negative pressure anomaly (Fig. 5a-

d), which appears more elongated than the positive pressure anomaly associated with El Niño periods." Page 22 L530-531.

Reviewer comment: L379 – "enhanced southerly wind anomalies" – in 5d, I see northeasterly onshore wind anomalies and positive SMB here in RACMO2?

Author's response: We can argue there is some signs of positive SMB in RACMO but broadly there is a reduction in mass, hence, that statemen. We have edited the who paragraph "Three out of the four La Niña periods (2010–2014, 2016–2018, and 2020–2022) are broadly associated with negative SMB (Fig. 5f–h) and ice mass anomalies (Fig. 5j–l) across the Amundsen Sea sector. The reduction in mass during the 2020–2022 and 2010–2014 La Niña periods aligns with a significant negative pressure anomaly in the Pacific sector, and offshore wind anomalies (Fig. 5b, d). Page 22 L550-553.

Reviewer comment: L386 – "potentially can support convection and positive mass anomalies" – reference for this?

Author's response: Based on the significance test, we observed the pressure anomalies were not robust. Hence, the sentence is rewritten "In contrast, during the 2007–2009 La Niña period, a mass gain is prominently observed in GRACE (Fig. 5i), a pattern more commonly associated with El Niño periods described earlier. However, the SMB and pressure anomaly patterns during this period are not statistically significant at the 0.05 level. Page 23 L554-557.

Reviewer comment: L400 – again, here it would be very helpful to show what the regions of statistically significant positive/negative SMB are on the RACMO2 SMB maps.

Author's response: We have included Statistical significance tests in Figures 2,3,4,5 and 6 and updated the text to reflect the additional information.

Reviewer comment: L409 – "resulting in uniform northerly winds and positive mass anomalies" – are you talking about the coast only? From the figure I see westerly and northwesterly winds, not purely northerly – though I would re-iterate that the wind vectors are so small in the maps that they are really hard to see. Finally, also mentioning once more that if these are wind anomalies they should always be referred to as such and not presented as if they were the actual wind field.

Author's response: Reworded and the new paragraph is "Along the Atlantic sector, a dipole-like mass anomaly pattern is present during the 2007–2009 and 2020–2022 La Niña periods (Fig. 5e, h), whereas a more uniform response is observed during the 2010–2014 and 2016–2018 La Niña periods (Fig. 5f, g). During the 2007–2009 La Niña period, positive SMB anomalies were observed over Coats Land and negative SMB anomalies toward Enderby Land (Fig. 5e), with this spatial pattern reversed during the 2020–2022 La Niña period (Fig. 5h).

Positive mass anomalies were also observed across the Atlantic region during the 2014–2016 La Niña period, with a reversed pattern during the 2016–2018 La Niña period. Regionally, Dronning Maud Land shows consistent positive SMB (Fig. 5f, h) and ice mass anomalies (Fig. 5j, l) during the 2010–2014 and 2020–2022 La Niña period" Page 23 L587-596.

Reviewer comment: L413 – "two distinct" – again, there are only two possible SMB responses, right?

Author's response: Reworded to reflect the observed SMB "In the Indian Ocean sector/Wilkes Land we found no consistent mass response to La Niña-dominated periods" on page 24 L606 .

Reviewer comment: L419 – "deepening" implies temporal evolution

Author's response: This part has now been deleted page 24 L622-629.

Reviewer comment: L419-421 – these two features (low-pressure anomaly in the Pacific and wind anomalies over Wilkes Land) seem far apart spatially – I'm missing the connection here with respect to the circulation?

Author's response: This part has now been deleted page 24 L622-629.

Reviewer comment: Fig. 6 – again, there needs to be information on the statistical significance of the patterns in this figure, which will presumably support the authors' claims that different ENSO events are associated with different circulation and surface mass balance patterns.

Author's response: Statistical significance test has been performed and added to the figure on page 26 L649(.

Reviewer comment: L430 – Amundsen Sea sector and Marie Byrd Land

Author's response: Edited as suggested on page 25 L636

Reviewer comment: L446-447 – language suggests causation

Author's response: Rewritten to avoid causation and as suggested to try and summarise most of the discussion is now rewritten page 27L659-665.

Reviewer comment: L453 – might help to remind readers what the bi-polar pattern is

Author's response: Edited to re-echo what the dipole pattern is on page 27 L662.

Reviewer comment: L454 – what is meant by "underlying"? Most common, strongest, dominant?

Author's response: This part is no longer part of the discussion and the dipole pattern is discussed as the longer timescale response page 27 L661-662.

Reviewer comment: L470 – "coastal easterlies" – could you clarify this? I see coastal westerly wind anomalies in 4a, c, and d.

Author's response: Edited to clarify that the westerly wind anomalies observed and now read "During El Niño conditions, a weakened ASL and reduced coastal easterlies allow westerly wind anomalies to bring marine air masses, onshore, which, enhance snowfall and mass accumulation through orographic lifting" page 28 L708-711.

Reviewer comment: L479 – western Ross Sea sector is not mentioned earlier in the text, nor is the Ross ice shelf shown in any figures. Could you clarify what is meant here?

Author's response: Detailed geographical regions has been included fig. 2 and text updated to reflect these regions (page 10 L292).

Reviewer comment: L490 – "the anomalous response can be attributed to altered Rossby wave propagation" – surely Rossby wave propagation influences almost all ENSO-associated circulation patterns around Antarctica?

Author's response: We have revised this to capture how results better "However, the 2009–2010 El Niño period deviates from this pattern, with negative SMB anomalies observed in the Amundsen Sea sector (Fig. 4f). The pressure anomaly during this period is distinct, with a positive pressure anomaly extending from the Amundsen Sea to beyond the Ross Sea. An important difference to the other El Niño periods, is the extension of this positive pressure anomaly further to the west, which decreases

moisture transport into the region. This period encompasses a strong Central Pacific El Niño event (Kim et al., 2011), and associated pressure anomaly (Fig. 4b) resembles patterns linked to such events, which are associated with moisture depleted wind anomalies and suppressed precipitation in the Amundsen and Bellingshausen regions (Chen et al., 2023; Macha et al., 2024)." Page 28 L719-726

Reviewer comment: L524 – "isolating ENSO signals" – I would be careful with stating that you are isolating ENSO signals here, because as was already mentioned, there are a number of different weather patterns and extremes that occurred during the periods over which the circulation and SMB patterns were composited.

Author's response: We have deleted it to prevent any potential confusion "Similarly, the 2007–2009 La Niña period shows a mass pattern that contrasts with other La Niña periods, featuring a positive mass anomaly in the Amundsen Sea sector (Fig. 5i). However, atmospheric circulation patterns during this period do not statistically support the observed mass gain, suggesting that it may be linked to unrelated weather events or other modes of climate variability." page 29 L750-753).

Reviewer comment: L525 – "convergence zone that enhances precipitation" – reference for this? And can you be specific about exactly where you see the convergence occurring? Do you see this in the actual wind fields too, not only the anomalies?

Author's response: We have deleted it prevent any potential confusion "Similarly, the 2007–2009 La Niña period shows a mass pattern that contrasts with other La Niña periods, featuring a positive mass anomaly in the Amundsen Sea sector (Fig. 5i). However, atmospheric circulation patterns during this period do not statistically support the observed mass gain, suggesting that it may be linked to unrelated weather events or other modes of climate variability." page 29 L750-753.

Reviewer comment: L4545-548 – reference?

Author's response: Reference added to support this statement "(Fogt et al., 2012; Fogt and Marshall, 2020b; Marshall et al. 2013)" (page 32 L829).

Reviewer comment: L550 – "ASL's influence on East Antarctica remains unclear" – as mentioned earlier, this implies that there is an influence, but we don't know what it is – is that the conclusion from Li et al. 2022, as cited?

Author's response: The is no direct link but suggestions has been made of a potential link, we have deleted

Reviewer comment: L559 – can use "significant" if you show statistical significance of mass changes in the figure

Author's response: Changed to anomalous (page 32 L832).

Reviewer comment: L574-579 – it's probably important to add there that it's equally likely that certain modes of variability and their associated circulation patterns may be conducive to atmospheric river landfall in certain regions.

Author's response: We have incorporated it and hinted on this (page L840) and also on the uncertainties to our analysis in manuscript (page 36 L970-981).

Reviewer comment: L598 – "structure of the westerlies was altered" implies causation and refers to the winds rather than the wind anomalies.

Author's response: Reworded to avoid implying causation and discuss in terms of other studies (page 32 L854-866).

Reviewer comment: Discussion – general comment: this is a very long section, and while it is interesting, I think it comes across as somewhat redundant following the results and before the conclusion. I would recommend shortening it where possible, to make the section more concise and less repetitive.

Author's response: Thank you for the helpful suggestion. To avoid repetition and have a more concise discussion, we have rewritten much of the discussion to capture this.