Response to Referee 1

On behalf of the co-authors, I would like to thank the referee for their supportive and thoughtful review. Clarifying the processing methodology and providing further detail on cyclone seasonality and the choice of subdomains have improved the manuscript in terms of both interpretability and reproducibility.

The response is formatted with reviewer comments in grey, author responses in black, additions underlined in purple, and removed text struck through.

Summary and General Comments

This study uses a sea ice-wave model to assess cyclone impacts on the Antarctic marginal ice zone (MIZ). The authors find that enhanced wave activity modulates the inner boundary of the MIZ whereas ice drift and thermodynamic effects impact the extent of the ice edge. They also found that expansion events are more likely earlier in the season, with compaction events dominating later. The two-part study covering both cyclone case studies and statistical analysis of nearly 400 cyclones clearly demonstrates these results.

The title and abstract describe the contents of the paper well. The introduction provides full, clear context for the contribution of this work and is well-cited. The choices made in the methods seem appropriate, however additional clarification on the methods is needed in spots, as listed below.

Overall, the paper is well written, and the figures are clear and easy to understand. The results are novel and an interesting way to assess storm impacts, with the integration of a wave model leading to unique results on the evolution of MIZ width and extent. These results are important to consider in future cyclone-sea ice studies. I have a few, hopefully minor, suggestions listed below.

Specific Comments

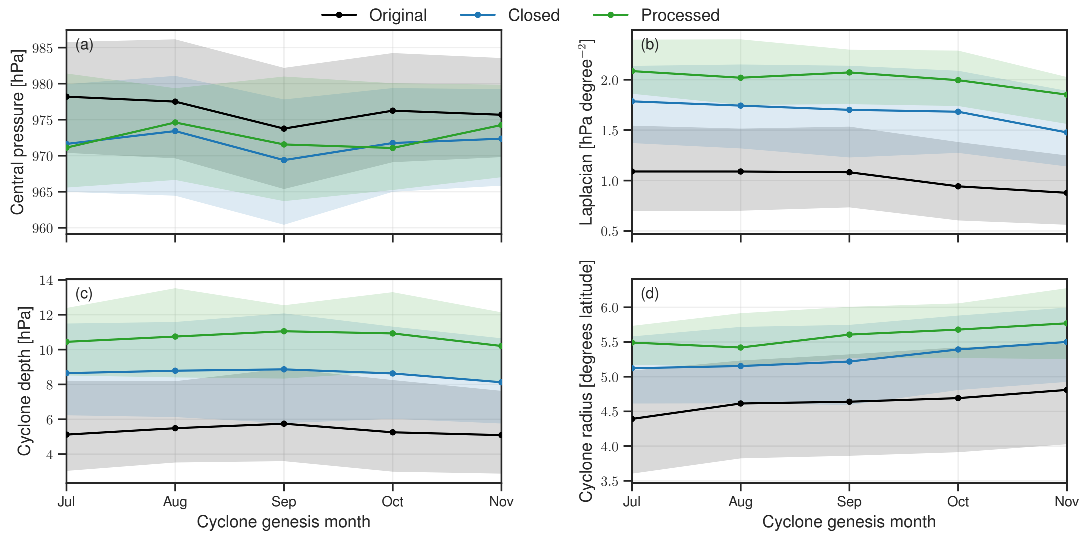
119-129/Fig. 1: It might be helpful to include a short description of the cyclone dataset here, just to ensure that the month-to-month differences described later in the paper cannot be attributed to differences in cyclone characteristics like pressure or size.

A new figure has been added to the Appendix of the manuscript (see below), showing cyclone central pressure, Laplacian of central pressure, depth, and radius for the months considered in this analysis. From July–November, we observe minimal changes in central pressure and depth, a slight decrease in the Laplacian of central pressure, and a slight increase in cyclone radius. However, the monthly medians remain within the interquartile ranges across the months considered, indicating substantial overlap in the cyclone characteristics. We therefore find no clear evidence that the seasonal differences identified in our analysis are attributable to systematic changes in cyclone characteristics.

The new line in the main manuscript is: "The cyclone track selection technique was evaluated against cyclone statistics to ensure that it did not introduce biases in spatial distribution, central pressure, or cyclone radius ~~(not shown)~~over the months considered (see Appendix A Figs A.4 and A.5)."

132: How was this arc length selected and does the analysis change significantly if using a different subdomain? Please provide some justification to this choice. An extra figure demonstrating the size of the sector relative to a cyclone case might be useful here (or add to Figs. 2-4, since the cyclone case studies are different sizes). I also assume the values described in each of the following cases are averaged over the MIZ across this width, however, I don't believe this is explicitly stated in the methodology.

We have now indicated the corresponding analysis region in the case-study figures to illustrate the spatial extent of the ice cover considered. We have also clarified in the methodology that the reported quantities are averaged over the MIZ within this sector. Since we have added the analysis sub-domain to the case-study figures, we have replaced the term 'arc length' (which could now be interpreted as



Median cyclone statistics across the months considered in the analysis. Median central pressure, Laplacian of central pressure, cyclone depth, and cyclone radius averaged over all tracks per month are shown in panels (a–d), respectively. Each coloured line signifies the processing stage in the cyclone track selection criterion, with the original (full) cyclone track dataset in black, after selecting for only "closed" cyclones (blue), and the final processed dataset (green).

referring to the perimeter of the sub-domain) with 'radius' to more accurately describe the analysis region. Although we did also test smaller radii of ∼300 km and ∼150 km, we settled on a diameter of ∼580 km since it is approximately consistent with the 600 km cyclone proximity criterion used in the initial track selection.

We have now clarified this in §2.4: "Following the selection of cyclone tracks that come within 600 km of the CICE6-WIM modelled ice edge, we analyse their influence on the ice edge and MIZ over sectors with diameter of approximately 580 km (41 grid cells). For each cyclone, the sector is centred on the location where the cyclone intersects the modelled ice edge (referred to as the "cyclone crossing location") and is fixed in space."

170-171: Perhaps reference Figs. C1e,i here since ice age and concentration are not shown in the figure in the main text.

The cross-references to the appendix are now added.

182: Please be clear about what regions are being averaged over, whether it's just the MIZ or the domain shown in Figure 3.

The meridional wind component time series was averaged along the ice edge. We have now corrected the caption so it is consistent with the results presented.

Figure 3 caption: Only the meridional speeds appear to be shown in panel h.

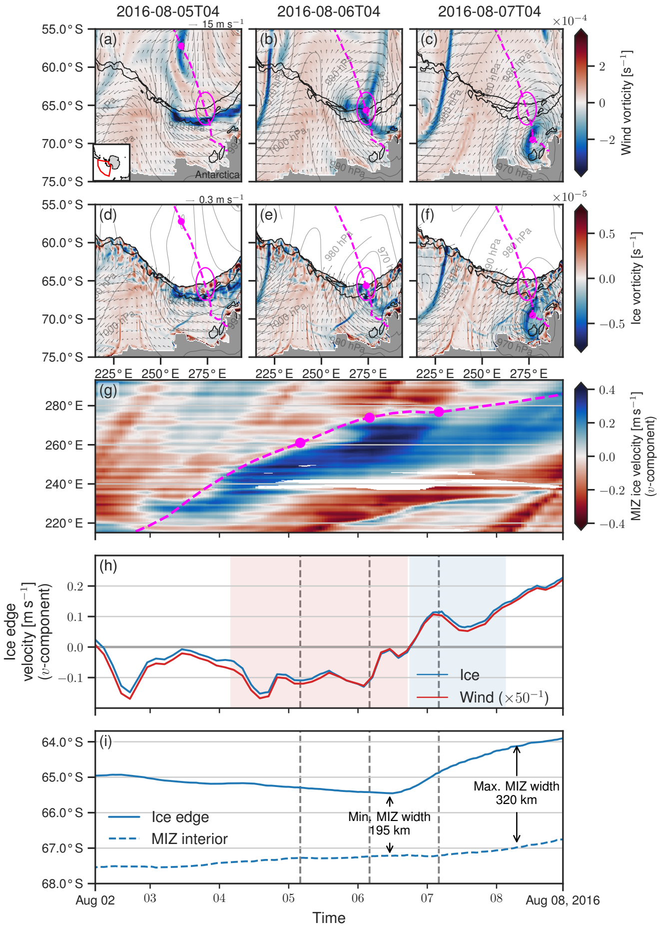
The caption is now consistent with the figure.

224: I think a little more detail is needed here, whether this is specifically at the cyclone crossing location or averaged across a region.

These results are averaged along the ice edge around where the cyclone crosses. Additional detail in text has been added.

Figs 5+6: I found these time series to be very effective!

Thank you!



Similar to Figure 2 but for impacts of sea ice drift and ice edge location at ∼270° E from 2 to 9 August 2016. (a–c) Wind vorticity maps with wind velocity quivers over the crossing (similar to Fig. 2). Overlaid are isobars in 10 hPa intervals, plus the cyclone's location (magenta dot), its track (dashed magenta line), and the area considered for the analysis (magenta circle). Black contours indicate the boundaries of the MIZ. Panels (d–f) correspond to (a–c) but show ice vorticity with quivers representing ice drift. (g) Hovmöller diagram of the north–south sea ice velocity component averaged across the MIZ, along with the cyclone track and position at the snapshot times. (h) Time series of the ~~east–west (red) and north–south (blue)~~meridional (north–south) ice and wind velocity components (~~solid and dashed lines~~red and blue lines, respectively), averaged ~~over the MIZ~~along the ice edge centred around the cyclone crossing location. (i) Latitude of the ice edge and inner MIZ boundary over the same sector as in (h).

247-251: It should be made clear here whether the values if v_{wind} and T_{ice} are averages across the MIZ or just at the point of cycle crossing.

The corrected text is presented below:

"To identify wind-driven conditions we analyse meridional wind direction averaged along ∼580 km of the ice edge and centred around the cyclone crossing location. ~~, w~~We define *on-ice wind events* as periods when $v_{\text{wind}} < 0$ for at least six consecutive hours and *off-ice wind events* as periods when $v_{\text{wind}} > 0$ for the same duration. The net impact of these wind events is assessed by comparing conditions 24 hours before and after cyclone crossings.

Using the same ice edge averaging method, ~~W~~we categorise thermodynamic events based on the ice surface temperature to isolate the effects of temperature changes on sea ice evolution. *Melting events* occurs when ice surface temperature (T_{ice}) exceeds −1.8°C for at least six consecutive hours, while *freezing events* occur when T_{ice} falls below this threshold for a similar duration. This classification is used to highlight the role of cyclone-driven atmospheric forcing in modulating ice melting and formation."

259: Is N_i the sector width of 21 grid cells? If so, it should state that this value is the same for all cyclone events.

Yes, that's correct. We have now added this in text.

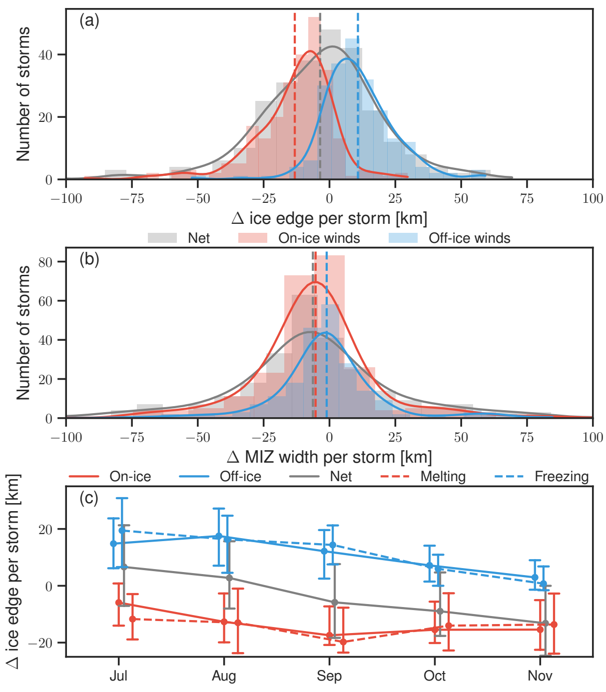
"where the summation is performed over latitudes (j) and averaged over longitudes (i) across N_i grid cells within the analysis sub-domain ($N_i = 41$ or approximately 580 km)."

273: Please clarify the duration the MIZ changes are calculated over. Does it depend on the cyclone lifecycle or is it +/-96 hours as in Figs. 5+6?

All figures use a +/-24 hour window and are averaged over a 41-cell-wide domain. However, as the events must occur within this window their impacts will always be measured over < 48 hours. "The change in ice edge location and MIZ width per storm for on-ice winds, off-ice winds, and the net impact are shown in Figure 8(a–b). The impacts during on- and off-ice winds are calculated during the specific event so the time period will be less than 48 hour window considered around the cyclone crossing. The median changes in the ice edge location are approximately -10 km and 10 km for on- and off-ice wind events, respectively."

Fig. 8c: What does the spread for melting/freezing events look like?

We have now added the error bars for the melting and freezing events to the figure.



Effect of wind events on ice edge location and MIZ width. Line plots with interquartile ranges for July to November, averaged over 2015–2018, grouped by event type. (a) Change in ice edge location per storm, and (b) change in MIZ width per storm, grouped by on-ice winds (red), off-ice winds (blue), and net change over the cyclone crossing (grey), with their respective means indicated by vertical dashed lines. (c) Seasonal variation in ice edge location change, grouped by on-ice winds (solid red), off-ice winds (solid blue), net change, melting (dashed red), and freezing (dashed blue). Error bars denote interquartile ranges.

Fig. 8: I'm curious to know if July and August have a greater fraction of (or perhaps longer) off-ice events than later in the season. I also recognize that this is new analysis, but I wonder if it is possible to add this information to this figure or within the discussion.

This is an interesting idea. We have computed the percentage of wind events for each month and have reported them here in Table 1. We find no significant difference in the frequency of these events with seasonality, so as a result have not included this data on the figure. We have added the following text: "Seasonality strongly influences the magnitude of the change in ice edge location (Fig. 8c). This is despite on- and off-ice events occurring at approximately equal frequencies across the months considered; for example, the number of events in July was comparable to that in November."

Monthly distribution of on-ice and off-ice wind events. Percentages are calculated within each event type.

Event	July	August	September	October	November
On-ice	20.6%	21.8%	14.7%	20.6%	22.2%
Off-ice	19.1%	21.9%	16.3%	21.4%	21.4%

305: Could this figure be moved to an appendix within the main text?

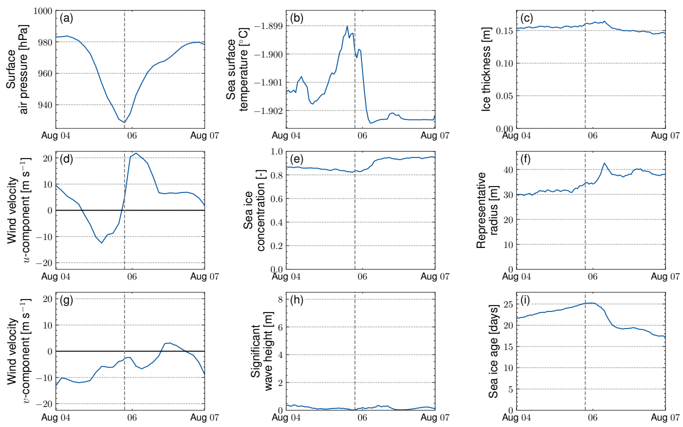
The reference to the figure was incorrect, it is now referring to a figure already in the appendix. "Major breakup events consistently produce substantial MIZ widening, with the largest impacts in November, coinciding with circumpolar MIZ expansion following earlier narrowing (see ~~Supplemental Material Fig. S1~~Appendix B Fig. B.1)."

308: Should the beginning of this sentence refer to "early" winter for clarity?

"Early" has been added to this sentence.

Fig. C1 caption: The labels here appear to be a bit out of order and the label for ice thickness is missing.

The caption has been correct so that it is consistent with the panels.



Time series from the ice edge taken during the case study in §3.1 (a) Surface air pressure; (b) sea surface temperature; (c) ~~u-component of wind velocity~~ice thickness; (d) ~~sea ice concentration~~zonal wind velocity; (e) ~~v-component of wind velocity~~sea ice concentration; (f) ~~sea ice age~~representative floe radius; (g) ~~significant wave height~~meridional wind velocity; (h) ~~representative floe size~~significant wave height; (i) sea ice age. The time at which the cyclone crosses the ice edge is shown as grey-dashed vertical lines.

Technical Corrections:

176: missing verb ("edge from")

Added “retreats” to this sentence. “During the cyclone passage, the ice edge retreats from 60.4° S to 61.1° S, while the inner MIZ boundary moves southward by only 0.4° (panel h).”

230: extra parenthesis around figure reference

Removed.

Kind regards,
Noah Day