Response to Referee Comments

We would like to thank Referee #2 for their consideration of our manuscript and for providing constructive comments and suggestions. With their feedback the presentation of the manuscript will greatly improve. In this document we will address the referee's feedback point by point. Below we show referee comments in orange text and provide our response in light blue text. In dark blue text, we list the changes in the manuscript that address these comments.

Referee #2 Comment on tc-2023-9

Referee comment on "Atmospheric highs drive asymmetric sea ice drift during lead opening from Point Barrow" by MacKenzie E. Jewell et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2023-9-RC2, 2023

This paper analyses the atmospheric conditions during observed sea-ice lead openings from Point Barrow from 2000 to 2020. The authors use the ERA5 reanalysis to generate an atmospheric composite describing the mean atmospheric state during a lead opening. This is augmented by the observed ice drift from the Polar Pathfinder sea-ice motion product. The authors analyse the mean atmospheric and sea-ice state during a lead opening, concluding that such events are primarily driven by strong winds associated with an anti-cyclone over the Beaufort Sea, driving the ice along the Canadian and Alaskan coast, causing a lead to open at Point Barrow, which acts as a focal point for the stresses in the ice. They also analyse the ice response to the different wind directions observed when the lead opens up.

The paper is interesting, well-written, and well deserving of publication in The Cryosphere. The approach is novel, interesting, and well-suited to analyse the lead formation, both of Point Barrow and in general. The paper is very informative, and there is much information there. It is also well-written and readable. I only have one general and a few specific comments on the paper and recommend publication once those are addressed.
We thank the referee for their assessment of the manuscript. Below we will address the general comments and specific comments on the manuscript, and our plan to address these comments in the revised manuscript.

General comment:
There's an anomaly in SLP associated with lead openings (e.g. figure 4). But this doesn't seem very dynamically relevant. So the anomaly in the SLP gradient (e.g. figure 7) should be highlighted instead.
We thank the reviewer for pointing out this distinction: the magnitude of SLP is not the primary mechanism that controls the dynamics associated with lead opening. Since the surface winds are the primary mechanism through which the atmosphere dynamically forces the ice, we highlight the differences in wind direction associated with these events compared to the climatological wind distribution in Figure 4b. Changes in wind direction appear most dynamically relevant to these events and are therefore discussed throughout the text. Associated anomalies in SLP gradient are included in Figure 7 and described in the text as a causal mechanism that produces onshore wind anomalies in the ensemble

sequence. This is highlighted in the discussion where we describe how differences in the shape of the weather system (deviations in SLP gradient direction from the average Beaufort High) produce the average ensemble event. We avoided referencing the SLP gradient specifically in Figure 4 since this is equivalent to describing the winds they produce. As ongoing research for the lead author's doctoral work, we believe the gradient SLP relationship to sea ice forcing contains a phase lag in relationship to energy buildup relative to the coast - which will complicate the paper and its interpretation beyond the current scope. We therefore feel it important to keep this point out for now and consider it a matter for future work.

We have chosen to include the SLP distribution in Figure 4 (and show SLP fields in other figures) to highlight that high pressure atmospheric systems transiting the Beaufort and Chukchi Seas are the source of the wind patterns (i.e. SLP gradients) relevant to lead opening. In the revised manuscript, we shorten and clarify the discussion and conclusion sections of the paper to improve flow and clarity. We expect this will help to highlight the roles of high-pressure systems as the source of the activity, and winds acting through SLP gradients as the way in which the highs directly force the ice during these events.

Specific comments:
L52: New paragraph at "Landfast ice ..."L52: No need for brackets explaining landfast ice
We will remove the bracketed description in the revised manuscript.

L63: Change "translating" to "traversing" (for example).
We will change “translating” → “traversing”

L92: MODIS lead detection is impressive under ideal conditions. But I would have liked to learn more about its ability to detect leads under less-than-ideal conditions. There is no mention of cloud cover problems, for example.
Issues detecting leads under cloud cover were addressed later in the manuscript, but we thank the referee for reminding us that the limitations of MODIS in detecting leads (due to clouds) should be stated in this section as well. We will add a statement clarifying the limitations after line 92: “Cloud cover can increase the minimum resolvable lead width or even mask surface conditions altogether, preventing lead detection.”

L235: Interesting that the winds strengthen after lead opening. It sounds like a selection bias, but how that would work is not immediately apparent. Should be addressed in the discussion.
In a previous publication (Jewell and Hutchings, 2023; https://doi.org/10.1029/2022GL101408) discussing the wind forcing associated with lead opening (from ERA5 reanalysis between 1993-2013), we have found that surface winds over the Beaufort Sea originating from the east are 40% faster than winds from the north, south, and west on average. Thus, the increase in wind speed following lead opening in the ensemble sequence here is likely associated with the tendency for winds to shift easterly (and consequently to strengthen) during and following opening as the high progresses

eastward following opening. Wind speed does not appear to be a key control on lead opening in these cases, as some events occur under very low wind speeds. This was similarly demonstrated by Lewis and Hutchings (2019, https://doi.org/10.1029/2018JC014898) who did not find a threshold for wind speed required to form lead opening patterns along the Alaska coast. We are hesitant to address the increase in wind speed in the discussion out of concern that it may imply there is a greater relative importance of wind speed during these events than there appears to be. We will address this in the results section where the ensemble is discussed by modifying line 235 as follows: "In the days following lead opening, winds ~~strengthen and~~ shift westward over the Beaufort ice pack as the high-pressure system continues traveling eastward. The winds also strengthen as they rotate westward, as is common in the Beaufort Sea where westward winds blow stronger than winds blowing toward other directions (Jewell and Hutchings, 2023)."

L276: Mention that \alpha is essentially the Nansen number (if you ignore ocean currents). As it stands, its appearance here can seem a bit random.
We originally omitted this description so as not to imply to the reader that this ratio was calculated in the way that wind factor or Nansen number would be calculated, but agree that the purpose of its use here could be unclear as a result. We thank the referee for this suggestion and have added a sentence to clarify this point. "This ratio is similar to the wind factor or Nansen number. However, rather than describing the instantaneous relationships between wind and ice drift, we calculate the ratio of the average wind and ice speeds at each location."

L330/Paragraph: Figure 8(b) needs a better explanation. Why do you take the projection of the ensemble drift onto the climatological one? What does this show us? You say it reveals "one of the most striking features of the ensemble event sequence", but this is lost on me. I feel like I do not understand something important here.
To make this point more clear, we adjust the figure and descriptions of Figure 8(b) in the revised manuscript (now Figure 9b) as follows: "Underlain is the ~~projection~~ component of the six-day average ice drift vector anomalies (u') ~~onto~~ aligned along the climatological drift vectors (U), calculated as $(u' \cdot U)|U|^{-1}$. This quantifies how much the ensemble ice drift ~~over this period~~ contributes to the climatological ice circulation over the six-day sequence. Positive ~~(negative)~~ values show where the anomalies are aligned along ~~(against)~~ the typical flow direction, corresponding to a strengthening ~~(weakening)~~ of the ~~typical flow~~ climatological drift pattern during the events. Negative values represent vector anomalies aligned against the climatological vectors and a weakening of the climatological drift."

We remove the phrase "one of the most striking features of the ensemble event sequence" and add more specific language in the following paragraphs to describe what Figure 9(b) is depicting: "As a result of these varying wind-driven ice-coast interactions, the ensemble lead opening sequence's contribution to the climatological Beaufort Gyre circulation varies regionally. Figure 9(b) demonstrates this, showing a pronounced zonal asymmetry in Gyre strength along the Alaskan coast during the ensemble sequences. The western flow of the Beaufort Gyre is strengthened by 1-2 cm/s on average throughout the ensemble, strengthening ice advection across the Chukchi, East Siberian, and Laptev Seas. Strengthening is greatest along the Chukchi coast of Alaska, where the climatological drift is enhanced by over 2 cm/s. The change in coastline orientation at Point Barrow marks the transition between where these events strengthen and weaken the climatological patterns of winter ice transport. Thus, in contrast to the strengthened Gyre circulation west of Point Barrow, in the Beaufort Sea the Gyre is weakened by up to 1 cm/s during the ensemble sequence."

L344: I found this to be the most interesting section! Seeing how the leads open along the wind streamline was particularly interesting. This indicates that the wind direction and topography combination is the controlling factor in lead formation off Point Barrow and that ice strength should have a relatively small impact. This also indicates that modelling such events should be pretty straightforward, but this is not the case. It also contradicts the results of Rheinlænder et al. (2022), who found that thinner ice broke up more easily. So there's food for thought here, which is highly appreciated.

Presentation-wise, I would have liked to see the mean wind field rather than the isolines you show. It's confusing that the in the easterly case, the lead opens perpendicular to the isobars, but this is actually along the wind streamline. I would also note that a more significant role of ice dynamics is indicated where the lead deviates from the wind streamline. Finally, I would remove the westerly case. You say you include it for completeness, but with such few members of your ensemble, I think it's safer to leave it out.

We thank the referee for this constructive feedback. We were also very interested to see the ways in which these observations align with and also contradict recent modeling studies. In Figure 9, we included pressure fields to show how offsets in high-pressure patterns can produce the wind fields that drive these events. We agree that showing the wind fields would be useful, so will include wind streamlines as an overlay on the bottom row of the figure, as opposed to the ice drift vector anomalies which are not key to the story. We also appreciate the suggestion to remove the westerly case, and will do so in the revised manuscript. We would be hesitant to state that ice dynamics play a more significant role when the lead orientation deviates from the local wind direction, since the leads may be forming under differing mechanisms when opening at different orientations relative to the winds (e.g. shear vs tension), each with a significant role of the internal ice dynamics. The differences in internal ice stress states in the vicinity of the lead openings are a very interesting point that were a motivating factor for developing this study. However, as we found the observational data employed were not sufficient to tease out specific stress states with certainty, we will leave specific statements regarding the momentum balance in the vicinity of the leads (and consequently the modes of failure that produce the patterns) to future work where stress states may be more accurately estimated.

L421: This paragraph belongs in the introduction rather than here.

This paragraph will be moved into the introduction in the revised manuscript.

L420: This is a nice and interesting discussion. But I would start by looking at the mean state (the ensemble means) and then discuss that there are variations from those. That order makes more sense. Simply moving sections around a bit would do.
We appreciate the suggestion to restructure this discussion section. We will begin with the ensemble mean then move to the cross-event variability in the revised manuscript.

L470: "… and in summer …" - I guess the "and" should not be there.
With this sentence, we were aiming to state how the linear relationship between winds and ice drift is more accurate in summer and in the Central Arctic (away from coastlines) since internal ice stresses are lower. However, we see that the wording of the sentence made this unclear. We will rearrange this paragraph to clarify this point and change the sentence to state: "Linear relationships between winds and ice drift successfully describe ice motion in summer when ice concentrations and internal stresses are low. As internal stresses increase during consolidation of the ice pack in winter, the ratio of ice drift to wind speeds decreases and correlation between winds and ice drift weakens, especially near coastal boundaries (Thorndike and Colony, 1982)."