Response to Referee Comments

We would like to thank Dr. Willmes for evaluating our manuscript and for providing constructive feedback. With their suggestions the clarity of the manuscript will greatly improve. In this document we will address the comments 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 #1 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-RC1, 2023

Summary

The presented paper aims to evaluate typical dynamic conditions throughout the process of lead formation at Point Barrow. The authors construct an ensemble average lead sequence from MODIS thermal-infrared satellite imagery and derive the associated daily atmospheric conditions and sea ice motion. From this combined data set they find a typical synoptic condition over the Beaufort Sea region during lead opening that is mainly characterized by SLP above average. This pattern appears to cause a strong zonal asymmetry in sea ice drift north of the Alaskan coast, which in combination with coastal interactions, drives the break-up of sea ice with the typical pattern found at Point Barrow. The authors conclude that wind direction and coastal geometry are key controls of lead formation in the Beaufort Sea during wintertime.

General comments and decision

The paper represents an interesting study on sea-ice dynamics in the Beaufort Sea during winter and its drivers in the atmosphere. The analysis and the presentation of results are scientifically sound and certainly provide new insight into the causes of sea-ice variability in the Arctic and sea ice - atmosphere as well as sea ice – coastal interactions in general. The study nicely adds up to some other recent publications about what drives the formation of leads in the Arctic and thereby contributes to an improved understanding of the Arctic climate system.

I suggest the paper to be published after mostly minor corrections that I am listing below.

We thank Dr. Willmes for their assessment of the manuscript. Below we will address the minor corrections to the manuscript, and our plan to address these corrections in the revised manuscript.

Specific comments

My only major annotation is that the process of the ensemble lead sequence calculation lacks some information to the reader. Although the obtained leads and their patterns are well described in Appendix A1 and B2, it would surely improve the paper if for one exemplary lead sequence the associated satellite images were shown additionally to demonstrate how the observations make up the ensemble. In this context, I am a bit surprised about how exactly the long time series (Fig. A1) was extracted. The authors mention that "each acquired thermal MODIS image was visually analyzed to document the sea ice activity in the region". But that would mean that more than 7000 MODIS composites (3x daily, 120 days, 20 years) were individually screened for the presence of leads? I think that adding the above-mentioned example for some scenes would help clearing this issue. In this context, I also recommend adding a simple graphical demonstration of how the mentioned active contour model (2.4) does extract a lead from the thermal infrared image (raw image and derived lead).

We thank Dr. Willmes for this feedback. We did individually screen more than 7000 MODIS composites for the presence of leads for this analysis. We chose to evaluate this many images (three daily, as opposed to once daily or weekly for example) in an effort to determine the timing of lead openings since the leads can deform or be advected shortly after their formation. We agree that showing an example lead sequence, including the satellite imagery, would make this process more clear. We originally omitted this for considerations of the manuscript length, but as pointed out this would provide clarity for the reader. We therefore incorporate a figure depicting an example sequence in the revised manuscript. This figure (now Figure 3) will show a series of three daily MODIS images during an example lead event, and plots of the associated daily winds and ice drift. We overlay the lead coordinates that were extracted from the image in which the lead was first identified. We think this figure will make our process more clear by showing an example to identify a cohesive lead pattern from the imagery and resulting extracted coordinates.

Minor comments:

L 22: "within O (550 km)" What is meant? I guess a technical correction is necessary here.

We will adjust this to state "within approximately 500 km"

Figure 1: A small inset or subfigure with an overview map (whole Arctic) might be useful.

In the revised manuscript, we add an overview map in Figure 1 to show what portion of the Arctic is displayed in the map.

Section 2.4 can be shortened I think. Especially the first two paragraphs seem a bit misplaced.

We thank Dr. Willmes for this comment on the manuscript structure, and will make this section more concise, in part by shifting some of the content of the first two paragraphs into the introduction.

LL 128-130: “However, … Point Barrow”. Unclear what is meant here.
This sentence was intended to describe how a set of geometric constraints were used to eliminate leads from the analysis that are understood to form with a strong influence from pre-existing leads. Some leads open in connection to other leads that were already opening at Point Barrow. To eliminate these patterns, whose geometries may be more strongly influenced by the local ice properties than by winds, we included only leads that opened along a distinct path offshore from any existing opening leads at Point Barrow. We will edit the sentence as above to clarify this point, and also restructure the paragraph in which it was written to make this point more clear.

L 156: “200 m”. Is that a fixed value determining the minimum width of a lead to become apparent in a MODIS image? Wouldn’t that depend on the contrast between lead temperature and surrounding temperature rather than on width only?
We included the phrase “at least 200 m” here to remind readers of the minimum resolvable lead width from 1 km thermal infrared imagery under ideal conditions as described in section 2.1. It is correct that the resolvable lead width would vary depending on the temperature contrast and atmospheric conditions and may sometimes be much larger than this minimum possible value. From this comment we see that including the value here may be more confusing than helpful, so we will remove the phrase “(at least 200 m)” from this section and keep discussions of resolvable leads to section 2.1.

Figure 5: I find it a bit confusing that the lead in the DLO subplot disappears in DLO+1. It might make the reader think that the leads last for one day only.
We thank Dr. Willmes for pointing this out, as it may confuse other readers as well. We initially attempted to address this point by adjusting the figure showing the ensemble sequence by overlaying points where the Reiser et al. (2020) MODIS-derived daily lead data showed a lead present across at least 10% of events in the ensemble on each day of the sequence. However, the figure became very messy and therefore did not show clearly enough the persistence of lead patterns following the DLO. We plan instead to address this point with the figure we will include showing examples of sea ice imagery from an example event, as suggested above, which will show that the leads persist after opening. We will also state this specifically in the ensemble sequence figure caption to clarify this point: “Mean lead (yellow line on h, width not shown to scale) displayed only on DLO although individual openings can persist for longer.”

L319: “average speeds” … please add “of sea ice drift”
We will change “calculated from the average speeds of the six-day sequence” to “calculated from the average wind and sea ice drift speeds across the six-day sequence.”

L323, L329: These numbers (0.2%, 0.3%) are really small. How does that relate to the effect size? The shown spatial patterns underline that the effect is definitely important, but some discussion about this might help here.

We appreciate this suggestion, and have decided to alter the figures where anomalies in the ice to wind speed ratio are shown in order to more clearly demonstrate the effect size. Where we originally calculated the anomaly in the ice to wind speed ratio $\alpha' = \alpha_{event} - \alpha_{clim}$, we will instead calculate the relative difference from climatology as $(\alpha_{event} - \alpha_{clim})/\alpha_{clim}$. This will make the effect size much more clear in the discussion.

L364: What is exactly meant with "streamline"?
Streamlines are curves that are everywhere tangent to the local velocity in a fluid flow. The wind streamline intersecting Point Barrow traces out the path from which the winds intersecting Point Barrow originate. We will add a sentence in the revised manuscript to clarify this: "Wind streamlines (curves tangent to the local wind velocity) are displayed in Fig. 9a to trace the direction and extent of wind forcing across the region. North of Alaska, the wind streamline intersecting Point Barrow marks the transition…" We point this out in the text and figures because this streamline delineates the portions of the wind circulation that force the ice against the Alaskan coast to the east of Point Barrow and along the coast west of Point Barrow.

L435: To me it was not really clear what is meant with "a synoptic center aligns with a known center of action".
We will restructure the paragraph preceding this sentence in an effort to provide more clarity, and also provide examples of what is meant within the sentence: "Even as the center of a synoptic forcing system (e.g. a passing high) aligns with a known center of action (e.g. the mean Beaufort high position), regional wind differences between the two aligned forcing systems can yield pronounced differences in the large-scale ice circulation."

L 439: "O (500 km)" also in L 481.
L 439: We will replace "O(500 km)" with "on the order of 500 km"
L 481: We will replace "O(500 km) offshore" with "approximately 500 km from shore"

The Discussion (4) is very extensive and can be shortened, I think. Some arguments seem to repeat.
We thank Dr. Willmes for this feedback, and will shorten the discussion sections to improve the flow and clarity of the manuscript.

LL 522-528. The description in this paragraph was not clear to me.
We have modified this paragraph to clarify that we were emphasizing the frequency of these events in winter (occurring about 20% of the time) as a motivation for why these seemingly transient events need to be represented accurately in dynamic ice models. The paragraph will read: "We identified 82 distinct event sequences, nearly one six-day sequence per month in the analysis period. Cumulatively, these events span approximately one-fifth of winter periods (January-April) between 2000 and 2020. This is a conservative estimate, as nearly 40% of the total 135 identified lead opening events overlapped with the distinct

sequences included in the ensemble. Given the frequency of these episodic events throughout the consolidated season, their associated ice drift patterns must be represented accurately in models in order to support predictions of ice transport on seasonal timescales."

Section 5: Is also very extensive, could maybe be shortened.
We appreciate this suggestion and will shorten the summary and conclusion section in the revised manuscript.

Technical corrections
None.