Reply on RC1

Major Comments:

Q: Lines 99 – 100: The abstract does a wonderful job detailing why the low- and high-pressure systems associated with the Arctic ARs were considered to be unusual. However, the features that define them as unusual are not defined in the main body of the text. It may be useful to include a description of what makes these pressure systems unusual at or before this point. A more complete definition is provided between lines 190 – 195, but it would benefit the reader to include a broader definition earlier in the paper.

A: We thank the reviewer for this helpful suggestion. We agree that the term 'unusual' in reference to the driving cyclones and anticyclones requires a clearer explanation earlier in the manuscript. We have therefore expanded the description in the methods section 2.1. The revised text now reads: '*For MSLP, we examine the persistent intensity of low- and high-pressure systems associated with the Arctic ARs at their respective locations. For this, we determine the 7-day mean MSLP anomaly field for the target period and define bounding boxes enclosing each weather system. For each box, we construct a reference distribution of 7-day mean MSLP anomalies for April 1979–2023. The percentile of the target period anomaly is then computed within this distribution.*'

See lines 118-121 on page 4.

Q: Line 146: In the AR detection section, tARget v4 has Eulerian and Lagrangian tracking capabilities. In the Lagrangian parcel tracking section, it might be helpful to clarify why LAGRANTO v2.0 is being used and why the Lagrangian tracking features of tARget v4 aren't capable of achieving the goals that LAGRANTO v2.0 is being used for.

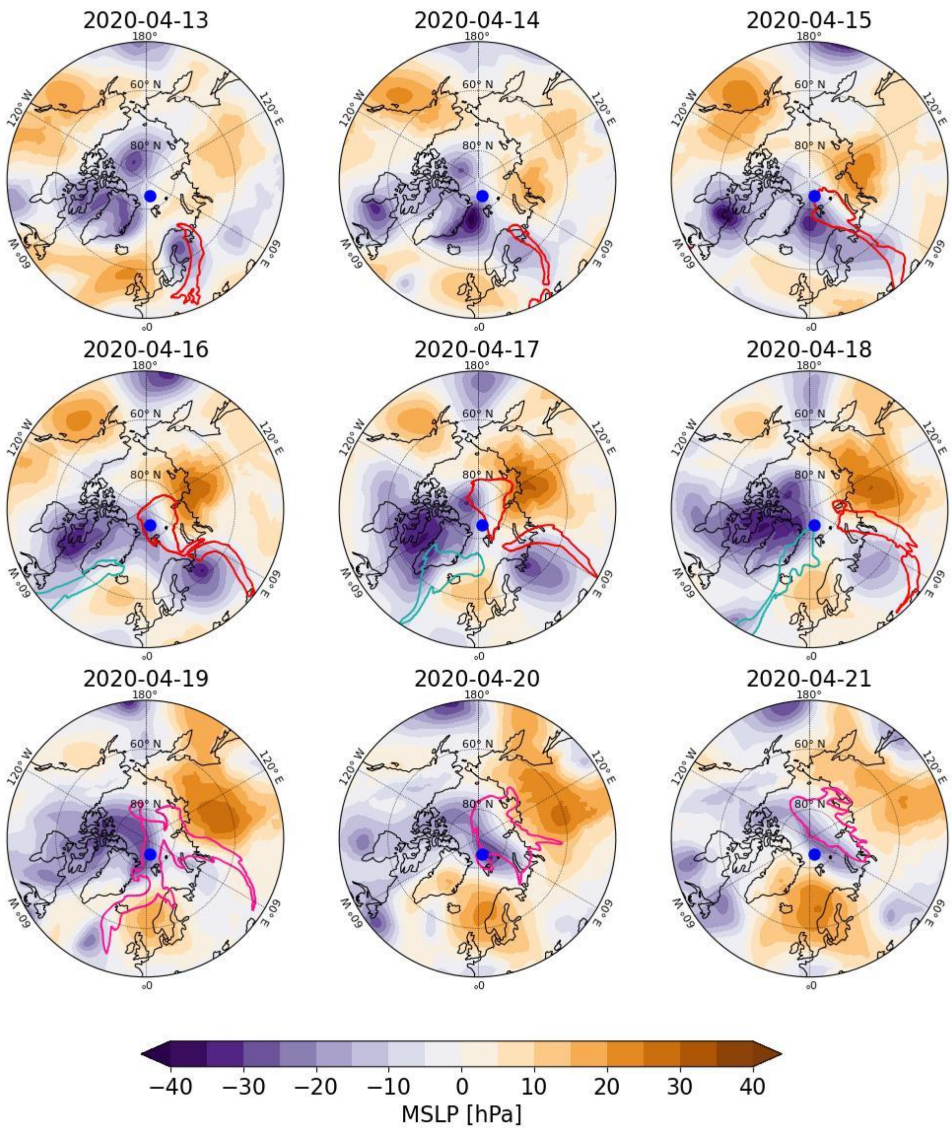
A: We thank the reviewer for raising this point. We now clarify the distinction between the two tools in the revised manuscript. While tARget v4 includes Lagrangian tracking capabilities, these are designed to track AR objects through space and time to record key life cycle characteristics such as lifetime and travel distance (Guan and Waliser, 2024). For the purposes of this study, we require full three-dimensional kinematic back-trajectory calculations to track individual air parcel pathways with flexible control over trajectory length, temporal resolution, and vertical motion constraints. LAGRANTO v2.0 is specifically designed for this type of detailed meteorological trajectory analysis (Sprenger and Wernli, 2015).

We have added a sentence in in Section 2.5 to clarify this rationale: '*While tARget v4 (see Sect. 2.4) includes Lagrangian feature tracking, it is limited to tracking the displacement of ARs over time, i.e. the propagation of a coherent pattern, which may move at a different speed and direction than the underlying airflow. LAGRANTO v2.0, by* *contrast, conducts air parcel tracking, computing full 3-D kinematic trajectories of individual air parcels that are essential for assessing sources and sinks of heat and moisture.'* This clarification now appears in lines 167-171 on page 6.

Minor Comments:

Q: Figure 1: It is slightly hard to tell which AR is of Atlantic or Siberian origin. Perhaps different contour colors can be used, with one color denoting the Atlantic AR and another color denoting the Siberian AR.

A: Different contour colours now indicate the Eurasian, Atlantic and merged AR outlines (see below). The figure caption now reads: '*Red (teal) contours outline the shapes of the Eurasian (Atlantic) AR at 12:00 UTC of the respective days diagnosed from the tARget database. After the ARs merge, the contours are shown in pink.*'



Q: Figure 3: The y-axis label on subplot (d) is a bit awkward to read. Is it possible to add more white space between the two columns of plots (e.g., between the subplots (a) and (c) column and the subplots (b) and (d) column)?
A: Fixed.

Q: Lines 29 – 31: It is mentioned that ARs enter the Arctic via the Pacific and North Atlantic sectors. Following that, it is mentioned that this is due to cyclones forming and deepening near Greenland. In this case, are Greenland cyclones responsible for both Pacific and North Atlantic AR intrusion? Further clarification might be needed for the mechanism that drives Pacific AR intrusion.
A: Thank you for pointing out this ambiguity. We have now clarified the text to distinguish more clearly between the mechanisms responsible for ARs entering the Arctic from the Pacific and Atlantic sectors. The revised passage now reads: '*Key regions include the Pacific sector and, in the Atlantic sector, the Nordic, Barents, and Kara Seas (Gong et al., 2025; Nash et al., 2018; Woods et al., 2013). Previous studies have emphasised the role of cyclone–anticyclone couplets in steering ARs into the Arctic (Gong et al., 2024). In the Atlantic sector, ARs are typically linked to cyclones that develop and deepen near Greenland, coupled with anticyclones over Scandinavia and Siberia (Papritz et al., 2022; Woods et al., 2013).*' See lines 29-32 on page 2.

Q: Line 93: It is mentioned that precipitation and rainfall data are retrieved from ERA5. Are these variables the same, or is the precipitation variable measuring both rainfall and snowfall?
A: We thank the reviewer for raising this point. Throughout the manuscript, the term precipitation refers to total precipitation, which includes both rainfall and snowfall. The term '*rainfall*' is only used in relation to Fig. 6, where we specifically show liquid precipitation to illustrate the surface impacts of the ARs over the SEG and BKS regions. We have added a sentence to the manuscript to clarify the term: *'In line with the ERA5 variable definition, here, precipitation refers to the combined total of rain and snow.'* See lines 111-112 on page 4.

Q: Lines 126 – 131: More of a clarification question, since it is not mentioned prior to this point, do both ARs of interest move directly over the 'Met City' observation site? If not, how close does each system get?
A: Both ARs pass directly above the RV Polarstern on their poleward propagation, which makes the in-situ measurements so valuable for this study. To clarify this, we have made a small modification to the relevant sentence at the end of the introduction to explicitly note that both ARs reached the ship. The revised sentence now reads '*These ARs coincided with the Multidisciplinary Drifting Observatory for the Study of Arctic*

Climate (MOSAiC) expedition (Nicolaus et al., 2022; Shupe et al., 2022) with both passing directly over the research vessel (RV) Polarstern, which thus provides unique in-situ measurements.' See lines 77-79 on page 3.

Q: Line 414: Please add a space in "align,indicating", such that there is a space between the comma and the word "indicating".
A: Thanks for noting this. The typo has been corrected.

Point to consider:

When studying ARs entering the central Arctic basin, the use of additional ARDTs can provide further insights into AR characteristics. Historically, the tARget suite of algorithms tends to do a better job at capturing ARs closer to the midlatitude storm track, with tARget V4 receiving significant modifications for improved polar AR detection. With that said, other algorithms have been developed (e.g., Wille vIVT [Wille et al. 2021: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020JD033788]) to capture meridionally propagating ARs that might reach the central Antarctic and Arctic regions and that deviate from the mid-latitude storm track. For this study, did you explore how the results change through the use of AR detection algorithms that differ in their general method of AR detection? Adding more than one ARDT to this study is not needed; this is just a curiosity I had.
A: Thank you for this thoughtful question. In this study we only used tARget V4, which consistently captures both ARs examined here. Both AR events are unambiguously strong and coherent features across multiple diagnostics (e.g., integrated vapour transport, moisture flux convergence, synoptic structure). Their presence and evolution are also directly confirmed by in-situ observations from RV Polarstern. This gives us high confidence that the AR identification does not depend sensitively on the choice of ARDT.
We acknowledge that ARDTs can differ substantially in their sensitivity to ARs propagating into high latitudes. Tools such as Wille vIVT were specifically developed to improve the detection of polar ARs, whereas tARget is relatively permissive in these environments (Shields et al., 2018; Rutz et al., 2019). In this study, however, the ARDT is primarily used to define an AR mask every six hours for initialising LAGRANTO trajectories, which are later subselected based on their thermodynamic properties. A more permissive detection is therefore advantageous, as it ensures that all potentially relevant air masses are included, reducing the risk of missing important contributions due to overly restrictive AR identification.
Comparing multiple ARDTs is beyond the scope of this work, but we agree it is an important direction for future studies, particularly for ARs reaching the high Arctic and for understanding uncertainties in their climatological and future impacts in polar regions.