Reply on co-editor's comments #2

1. Vertical Distribution and Moisture Sourcing

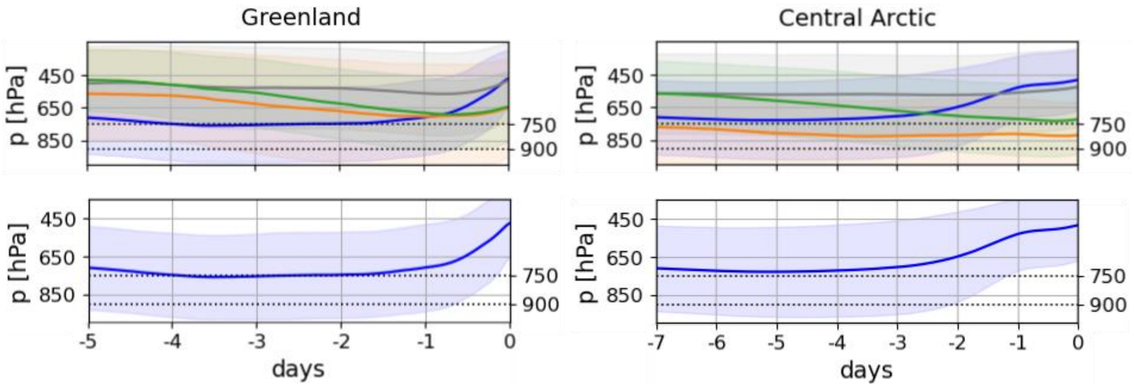
In your response, you state that nTpθ parcels descend to 900 hPa to interact with the surface. However, the figure in the response shows the mean height of this group at ~700 hPa, with the spread only reaching ~850 hPa.

If the bulk of the parcels remain at around 700 hPa, please clarify the physical mechanism for moisture acquisition, as they would effectively be decoupled from the surface.

A: We thank the co-editor for this follow-up question regarding the moisture sourcing along the AR pathways. We agree that the mean height of the nTpθ group during the first days is around 750hPa and the ±1 standard deviation envelope shown in Figs. 8 and 11 only extends down to approximately 850 hPa. However, this envelope represents only the central part of the nTpθ distribution and does not capture the full range of parcel altitudes.

To clarify, the figure below shows the broader distribution where the ±2 standard deviation envelope is plotted instead. It is evident that some of the parcels of the nTpθ and pTpθ groups extend below 900hPa. These lower-level parcels are therefore able to interact with the underlying surface and acquire moisture. In Figs. 8 and 11, we decided to show only the ±1 standard deviation envelope simply to avoid overcrowding the figures so that the temporal evolution of the main trajectories can be better revealed and the four groups of trajectories can be better differentiated from one another.

We have added the following sentence to the main manuscript to make this clearer: '*On average, nTpθ parcels are found at around 750 hPa (Fig. 8d), though the full distribution extends below 900 hPa (not shown). This allows parcels at the lower levels to acquire moisture from the surface and is consistent with previous studies showing that the core of an AR and the associated strongest horizontal moisture fluxes are typically concentrated in the lower levels of the atmosphere below 700 hPa (Guan and Waliser, 2015; Ralph et al., 2017).*' See lines 339-343 on page 16.



2. Wave Train Phase-Locking and Blocking

I found the analysis of the quasi-stationary wave train and the associated percentiles compelling. To complete the physical narrative regarding the event's persistence, I suggest expanding on the following:

Blocking Reinforcement: Please discuss whether the injection of low-PV air through latent heat release associated with the ARs contributed to the intensification of the downstream negative PV anomalies over Western Europe and Northern Siberia. Specifically, did these anomalies reinforce the regional blocking patterns (i.e., the Scandinavian High and the Siberian anticyclonic circulation)?

Phase-Locking: Given your mention of the "quasi-stationary" nature of the wave train, please elaborate on whether the coupled interaction between the upstream high-PV anomaly, the associated diabatic heating from the ARs, and intensified downstream low-PV anomalies effectively led to a phase-locked configuration.

A: We are very glad the co-editor found the PV-based analysis compelling and thank them sincerely for the suggestions. To address the suggestions above, we have now modified the Appendix to include the following text:

'Diabatic processes associated with the ARs may have contributed to the persistence and amplification of the downstream negative PV anomalies. Previous studies show that latent heating can enhance anticyclonic blocking through two mechanisms. The direct mechanism involves cross-isentropic ascent, often in moist ascending air streams, that transports low-PV air from lower levels and lower latitudes into the upper troposphere, thereby amplifying upper-level ridges (Pfahl et al., 2015; Steinfeld and Pfahl, 2019; Yamamoto et al., 2021). The indirect mechanism involves latent-heating-enhanced

divergent outflow on the western flank of the ridge, favouring its westward amplification (Steinfeld and Pfahl, 2019). Recent studies further highlight the role of North Atlantic and Gulf Stream moisture fluxes in supplying low-PV air and maintaining blocking through air-sea interaction and moist diabatic processes (Mathews et al., 2024; Mathews and Czaja, 2024). These processes likely helped maintain the low-PV anomalies over northern Siberia and western Europe, allowing them to extend further poleward into the Arctic and reinforce the Siberian anticyclonic circulation and Scandinavian High (see Fig. A2a).

Turning to the upstream side of the wave train, the extreme positive PV anomalies over North America are well placed to reinforce the driving cyclone located further south-east (see Fig. 1). Through PV inversion, such an upper-level anomaly supports cyclonic circulation, favours ascent downstream, and helps maintain low MSLP (Hoskins et al., 1985). The downstream block over the North Atlantic likely strengthens this coupling by slowing eastward Rossby wave propagation. The combination of the upstream positive PV anomaly and the downstream negative PV anomaly likely contributed to the persistence of the driving cyclone, although any deepening would still depend on low-level baroclinicity and diabatic processes (Davis and Emanuel, 1991).

Together, these diabatic mechanisms and the extreme upstream high-PV anomaly favour a self-maintaining configuration in which wave activity, surface cyclogenesis, and moisture transport remain coupled during this 7-day period. The quasi-stationary wave train shown in Figs. 2 and A2 is consistent with reduced Rossby wave phase speeds under enhanced blocking and weakened high-latitude zonal flow. Overall, Figs. 1, 2, A1, and A2 point to a dynamically coupled, potentially phase-locked configuration linking the upstream high-PV anomaly, downstream low-PV anomalies, wave breaking, and diabatically active AR corridors.' See lines 518–540 on pages 25-28.

3. Lastly, we have also added a sentence to the acknowledgement, thanking the reviewers and co-editor for their time and effort, which have helped us to significantly improve the manuscript.