

We would like to thank the two anonymous referees for their evaluations with constructive comments that certainly will improve the manuscript. In the following, we will address the referees' comments point by point. We mark **red** the comments given by the referee, give our answers in black and indicate how we addressed the amendments in the manuscript in **green**.

Tiago Silva, on behalf of all co-authors.

Review of Downslope windstorms in southeast Greenland - Part II: Multi-scale dynamics and spatial evolution of piteraq events
by Silva and others

'Comment on egusphere-2026-3687', Anonymous Referee #1

General

This is part 2 of a study of the forcing (thermo-)dynamics of piteraq winds on southeast Greenland. The analysis is based on CARRA reanalysis, and a brief evaluation with AWS data is included. The CARRA performance in terms of correlation appears adequate for such a quantitative study. I enjoyed reading the paper, although with almost 30 pages, the paper is very long which makes it a demanding read. But the text is generally clear and the figures generally of good quality. The results are interesting and worthy of publication. As the paper clearly demonstrates, the considerable spatial footprint of associated pressure and temperature fields highlight that piteraq events are not localized, topographically isolated features, but rather the result of a synoptic-scale weather event impacting the entire southern half of Greenland. The study also clearly demonstrates the connection between piteraq and tip jets in the south. All in all, I recommend publication once the relatively minor comments below have been adequately addressed. I trust this can be checked by the editor and do not need to see the revised version again.

Meso comments

L. 10: Without further explanation, "Canadian cold vortex" comes across as jargon. Please provide some explanation here.

Thank you for the remark. To avoid misunderstandings, in the revised version we now write: **We demonstrate that piteraq events are dynamically triggered by persistent upstream westerlies followed by the crossing of a cold vortex from the Canadian Arctic over Greenland.**

Abstract and Introduction: too many acronyms are introduced, negatively impacting readability: DWE, LLJ, MCAO, AMOC, CARRA...only introduce and define those that are frequently used afterwards.

Thank you for the input. We substantially reduced the number of acronyms from the Abstract and Introduction not contributing to the later analysis.

Same for Section 2.2.

Thank you for the input, we substantially reduced the number of acronyms from the Section 2.2 not contributing to the later analysis.

L. 64: "...low spatial resolution fails to resolve sub-grid scale dynamic processes..."; sub grid scale processes are not resolved by definition (independent of resolution).

Thank you for pointing this semantic misunderstanding. We now write in the revised version: Furthermore, low spatial resolution fails to explicitly resolve highly localized dynamic processes, particularly the breaking of large-amplitude mountain waves (Oltmanns et al., 2015).

L. 107: "likely"? Please explain/expand, for CARRA evaluation this is of course important.

Thank you for the remark. We deleted the word "likely" and completed the sentence with a reference, confirming that 10 m wind speed in CARRA is not assimilated.

L. 117: Are the used wind components (at 10 m and at pressure levels) averaged or instantaneous? If they are averages, absolute wind speed cannot be calculated from the u, v components as in L. 156, this would lead to a negative bias. Same question is valid for the observations.

Thank you for the observation! We now clarify in one additional, final sentence in the revised version: It is important to note that the variables used in this study represent instantaneous values at every three hours, rather than temporal averages over the three-hour window.

Fig. 1: The positive bias in CARRA during piteraq events is fascinating. Could it be partly explained by the interpolation to the station location, i.e. what does the scatter plot look like if nearest-neighbor is used, without height correction (the use of which is questionable anyways for a variable such as wind speed that increases so quickly from the surface upwards)?

Thank you for the remark. The nearest nine grid points are used to interpolate each site, ranging between a few 100 meters to 3.5 km distance. Because the interpolated CARRA orography at Tasiilaq is 58 m a.s.l. (only 5 m higher than the AWS), no lapse rate or wind profile corrections were applied. We mentioned this in Section 3.1 LN151 and will now acknowledge in Section 3.2 that the interpolation method also contributes to the resulting bias: Furthermore, the elevation differences introduced by the horizontal interpolation, combined with the seasonally varying height of the anemometers at the ice-sheet stations (typically below 5 m a.g.l.), likely contribute to the observed wind speed biases during the extreme events.

L. 184: Please briefly explain how "CARRA precision" is defined.

Thank you for the remark. We now add the precision formula in this specific line: Defined as the number of true positives (AWS and CARRA agreement) divided by the total number of CARRA detections (true plus false positives), CARRA precision is 37.6%.

L. 192 - 194: This explanation is partly a repetition from previous L. 171 and further.

Thank you for the remark. We purposely mentioned the same arguments once more in this paragraph, as they support our methodological choices. In the revised version, we decided to condense it as: Despite successfully capturing unrecorded events, we rely on AWS observations for baseline event detection because CARRA generates a substantial number of false positives. As previously mentioned, the 2.5 km topographic smoothing removes critical

sub-grid frictional barriers. Consequently, this smoothing not only exaggerates wind speeds during actual piteraq events, but also allows moderate, synoptically forced flows to artificially propagate to Tasiilaq, triggering localized false alarms. This structural limitation directly motivates our multi-scale analysis: identifying robust upstream precursors is essential to reliably distinguish true piteraq events from topographically amplified model artifacts.

I. 261: What uncertainty is introduced by using a fixed lapse rate?

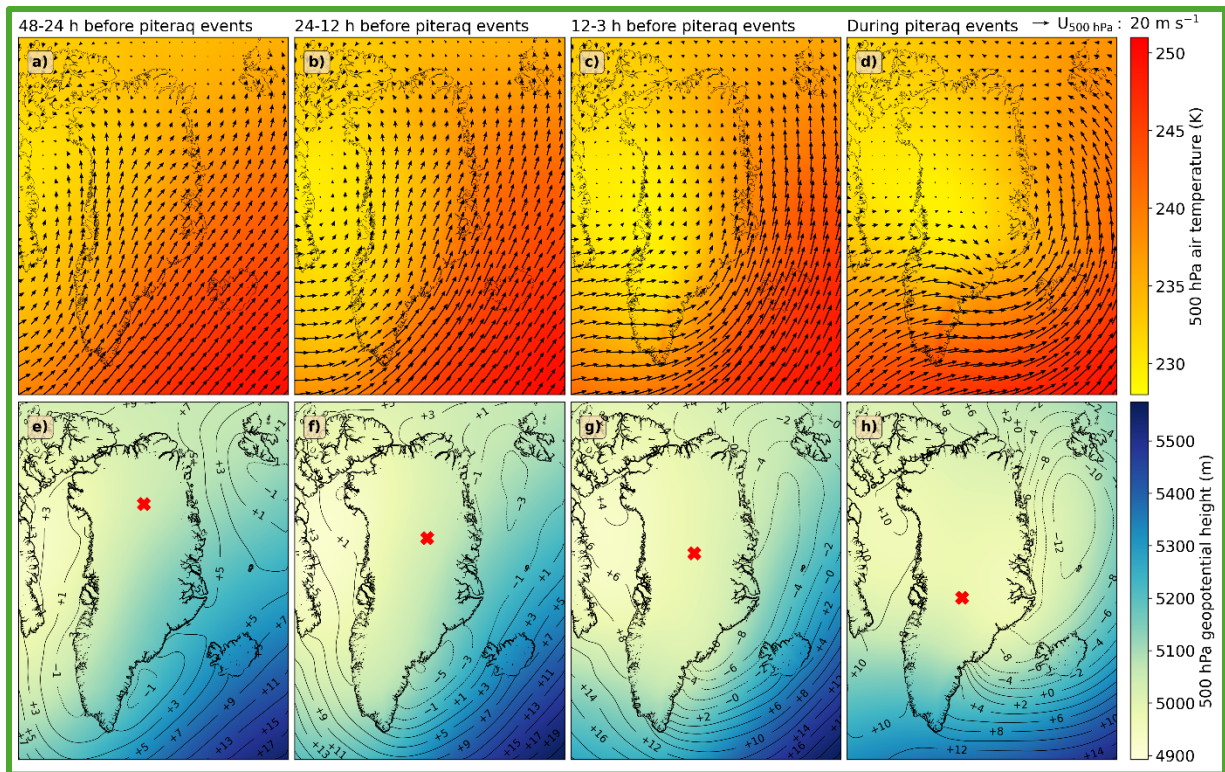
Thank you for making us reflect on potential uncertainty introduced by a fixed lapse rate decision in the hypsometric formula. This is also a point that Referee 2 questioned. Upon considering both referee comments in this matter, we now acknowledge that the hypsometric reduction using a fixed lapse rate provides a poor estimation of the mean sea-level pressure (mslp) at the Greenland crest (2632 m a.s.l.), particularly during periods of strong cross-barrier flow. We reached this conclusion by differentiating the hypsometric equation (LN259) with respect to temperature T . By plugging in the temperature variation associated with a fixed lapse-rate ($\Delta T = Z \times \Delta \Gamma$), we noticed that mslp estimation using a fixed lapse rate adds a quadratic error (Z^2), deteriorating the estimation with depth. Assuming all other variables remain constant, changing the mean column temperature from 230 K to 240 K introduces roughly 15 hPa of artificial variance into the mslp reduction. To avoid the artificial inflation and in line with approaches in other mountain regions (e.g., Colle and Mass, 1998; Zängl, 2003; Mayr et al., 2007), we calculated in the revised manuscript the horizontal pressure gradient between the crest (point B) and Tasiilaq at the crest level (2632 m a.s.l.). Although numerically smaller than the inflated mslp values, our alternative approach isolates the synoptic-scale forcing more clearly, reflecting the mid-to-lower tropospheric momentum and cross-barrier forcing required to potentially initiate wave breaking and severe downslope acceleration.

I. 267: At the surface the wind speed is zero, please use "Near the surface" or "at the lowest model level (XX m)".

Thank you for the remark! We now correct the sentence based on the suggestion as: ...higher than the wind speed recorded near the surface (at 10 m a.g.l.)...

Figure 3 is unclear and must be improved. Figures 3a-d are very similar, please try to make them more distinct by reducing the number of arrows and using another temperature colour scale. Same is true of colour scale in Figures 3 e-h. In the latter four graphs, consider removing MSLP from the elevated parts of the ice sheet where it becomes rather meaningless. Over sea, labels are missing.

Thank you for your observation. We have now reduced the number of arrows, increased their size, improved the colour scales, removed the mslp from land and added labels to mslp anomalies (in hPa) over the sea. We now also add the highest mslp over Greenland, noting its location further north prior to the onset of piteraq events.



Improved Figure 3: Synoptic evolution of winter (DJF) piteraq events averaged over the 1991–2024 period. (a–d) Top row: 500 hPa air temperature (shading) and wind fields (vectors). (e–h) Bottom row: 500 hPa geopotential height (shading), mean sea-level pressure anomaly (contours, with values below 1000 hPa dashed) and the highest mean sea-level pressure location over Greenland (red X). Columns represent time windows leading up to and during the event: 48–24 h prior (a, e), 24–12 h prior (b, f), 12–3 h prior (c, g), and during the event (d, h).

Fig. A4 is much clearer when it comes to explaining what causes the piteraq by the advection of a cold air mass. Consider moving to the main text or swapping with Fig. 3?

Thank you for the remark. We will swap Figure 3 by Figure A4 in the revised version.

I. 304: Please explain briefly what you mean by "thermodynamic erosion".

Thank you for the remark. The term is indeed misleading. We now improve the sentence to: Consequently, the typical background katabatic flow is dampened by two compounding factors: the opposing southwesterly winds and the weakening of the surface temperature inversion driven by the anomalous near-surface warming.

I. 307: I cannot see the "mesoscale surface low", only a larger system?

Thank you for the observation! The anomalously low surface pressure in southeast Greenland is now better seen in the improved Figure 3 above.

I. 317: Please expand on what you call "classical katabatic winds". Do you mean that they are forced by locally sourced cold air rather than advection of a cold air mass? The forcing mechanism of the downlope winds that ensue remains the same.

Thank you for the remark! We have now elaborated the specific sentence to avoid misunderstandings as: It is crucial to emphasize that the dynamically forced drainage flow should not be confused with classical katabatic winds, which result from persistent, localized

radiative cooling. In fact, the background radiatively driven flow is actively dampened during the earlier preconditioning phase.

l. 400: " It should be noted that while Alpine pressure gradients are traditionally evaluated across the entire mountain range, our piteraq gradient is calculated specifically over the leeward descent." Please elaborate on the reason(s) for this difference in analysis methods.

Thank you for your remark. We now elaborate in the revised version as: It should be noted that while Alpine pressure gradients are traditionally evaluated across the entire mountain range, our piteraq gradient is calculated specifically over the leeward descent. A trans-Greenland evaluation is unfeasible because the ice sheet width is not comparable to typical Alpine ranges, and the upstream frequency westerlies stretches over 700 km (Figure A6).

Minor and textual comments

l. 95: pressure gradients -> horizontal pressure gradients

Changed.

l. 107: are -> is

Changed.

l. 147: As CARRA is a model product, I prefer not to use "validated" but rather "evaluated". See also e.g. Section 3.2 heading and throughout.

Changed.

l. 387: Remove "to" (?)

Changed.

l. 479: "occasionally" does not conform to a frequency of 66%.

We modified the sentence to: Upstream of the crest, our results revealed that localized, shallow flow blocking frequently (66%) occurs on the windward side of the Greenland Ice Sheet.

l. 520: "descent air"; unclear, please reformulate.

We modified the sentence to: During winter piteraq events, our results showed negligible cloudiness over the Greenland Ice Sheet, consistent with the dry and dense downslope flow.

l. 521: "warmer temperatures"; please consider using the gramatically correct "lower"/higher temperatures" rather than "colder/warmer temperatures" throughout.

Changed.

RC2: 'Comment on egusphere-2026-3687', Anonymous Referee #2

General Comments:

This is a well-prepared and comprehensive climatological study of extreme wind storms that impact southeast Greenland and that are known as Piteraq. The analysis is based on the high-resolution regional reanalysis, CARRA, and emphasizes the dynamics. After reading the manuscript in detail, it should be accepted after some technical issues described below are addressed.

Specific Comments:

1. The manuscript should make clear that the CARRA 1 reanalysis that is nonhydrostatic is being used, not the more recent CARRA 2 reanalysis that is hydrostatic. Thank you for the remark, we now write in Section 2.1 as: *The Copernicus Arctic Reanalysis (CARRA) version 1 relies on a non-hydrostatic HARMONIE-AROME dynamical core (Bengtsson et al., 2017) adapted for high-latitude weather forecasting.*
2. Cross barrier forcing, section 3.4.3. Here the mean sea level pressure difference is used between the ice sheet crest and Tasiilaq to quantify the pressure gradient forcing. The reduction of surface pressure over cold ice sheets to sea level produces anomalously high MSLP values when the surface temperature is employed even with the lapse rate adjustment. This will exaggerate the pressure gradient forcing. Thank you for making us reflect on potential uncertainty introduced by a fixed lapse rate decision in the hypsometric formula. This is also a point that Referee 1 questioned. Upon considering both referee comments in this matter, we now acknowledge that the hypsometric reduction using a fixed lapse rate provides a poor estimation of the mean sea-level pressure (mslp) at the Greenland crest (2632 m a.s.l.), particularly during periods of strong cross-barrier flow. We reached this conclusion by differentiating the hypsometric equation (LN259) with respect to temperature T . By plugging in the temperature variation associated with a fixed lapse-rate ($\Delta T = Z \times \Delta \Gamma$), we noticed that mslp estimation using a fixed lapse rate adds a quadratic error (Z^2), deteriorating the estimation with depth. Assuming all other variables remain constant, changing the mean column temperature from 230 K to 240 K introduces roughly 15 hPa of artificial variance into the mslp reduction. To avoid the artificial inflation and in line with approaches in other mountain regions (e.g., Colle and Mass, 1998; Zängl, 2003; Mayr et al., 2007), we calculated in the revised manuscript the horizontal pressure gradient between the crest (point B) and Tasiilaq at the crest level (2632 m a.s.l.). Although numerically smaller than the inflated mslp values, our alternative approach isolates the synoptic-scale forcing more clearly, reflecting the mid-to-lower tropospheric momentum and cross-barrier forcing required to potentially initiate wave breaking and severe downslope acceleration.
3. Figure 3 and discussion. Also Fig. A4. The primary forcing of the piteraq is attributed to the advection of a cold vortex over Greenland rather “classical katabatic winds”. I wonder whether this is really true. Initially warm air advection with elevated

temperatures (and presumably cloudy conditions) is present then the cold vortex moves toward/over Greenland. This vortex appears to be cloud free that would promote rapid radiative cooling of the surface setting up downslope buoyancy forcing. The cold vortex would have little water vapor also promoting surface radiative cooling. Basically, I am saying it may not be possible to separate the two components. Thank you for the remark! We have now elaborated on LN217 what we mean by “classical katabatic winds” as: It is crucial to emphasize that the dynamically forced drainage flow should not be confused with katabatic winds, which result from persistent, localized radiative cooling. In fact, the background radiatively driven flow is actively dampened during the earlier preconditioning phase.

4. Line 304: “mechanical opposition of the southwesterly winds”. Please explain more fully what you are talking about.

Thank you for the comment. We now simplify the sentence in the revised version as: Consequently, the typical background katabatic flow is dampened by two compounding factors: the opposing southwesterly winds and the weakening of the surface temperature inversion driven by the anomalous near-surface warming.

5. Line 442. “..topographically forced subsidence enhances the negative buoyancy of the descending air mass”. This sentence needs more explanation to clarify exactly what you mean.

Thank you for the remark! We now rewrite and split the meaning of this sentence into two sentences to improve clarity: Vertically constrained by the local TI, the negatively buoyant downslope flow is forced through the flow-oriented, merged valley system leading to Tasiilaq. This topographic channelling directly drives a secondary downslope acceleration, causing the LLJs to re-intensify to their highest overall frequency (68%, Fig. 6) with median core wind speeds of 30 m/s.

6. Line 445: Please produce a figure that shows this spatial oscillation of the jet core.

Thank you for the comment. The figure showing the height of the low-level jet tip is added below. Along segment A, particularly after the Ammassalik Island (and Tasiilaq marked by the vertical gray line), it is possible to note the spatial oscillation briefly mentioned in the manuscript.

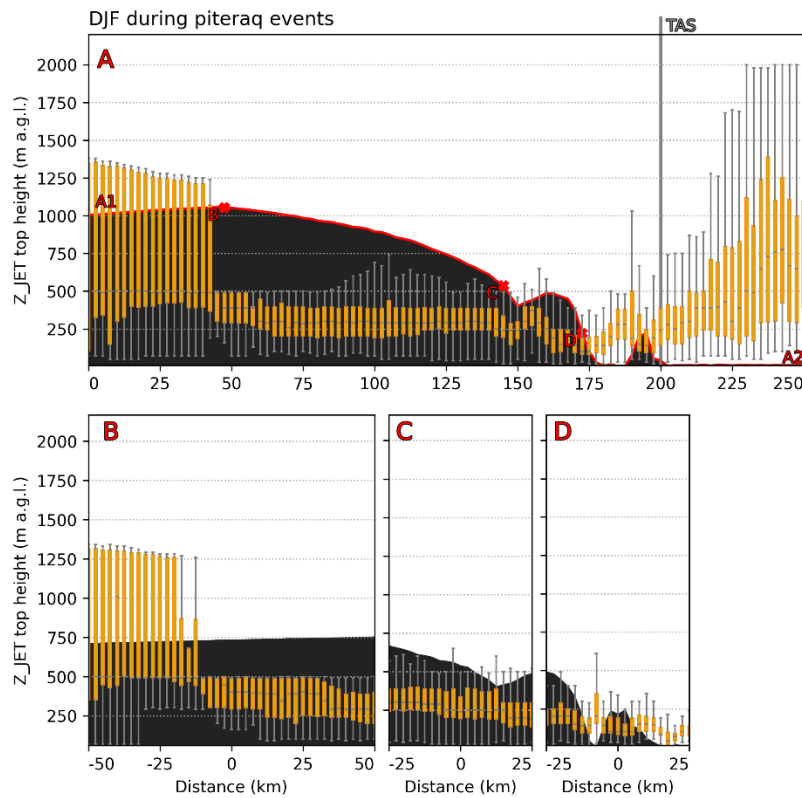


Figure 1: Height of the tip of the low-level jet (Z_{JET}) during the piteraq events for DJF between 1991 and 2024 along the segment A and across segments B, C, and D. The topography of the segments is normalized and displayed in the background. The position of Tas

We opt not to include this figure in the manuscript as the height of the tip of the low-level jet is not significantly contributing to the remaining findings and the fact that the current manuscript is already substantially long as noted by Referee 1.

7. Figure 7: I do not understand the wind vectors shown in B, C, and D. Please explain more clearly.

Thank you for your remark. We improved Figure 7 caption to: **Thermodynamic evolution during DJF piteraq events along the segment A and across three perpendicular cross-sections (segments B, C, and D).** Contours indicate isentropic lines. Vectors represent in-plane flow along each respective segment. Colors denote the orthogonal cross-segment wind speed, with purple indicating flow out of the page and green indicating flow into the page. Note that for the perpendicular segments (B, C, and D), these colored cross-winds represent the primary flow traveling along segment A. The position of Tasiilaq is marked with a gray vertical line along segment A.

References:

Colle, B. A., & Mass, C. F. (1998). Windstorms along the western side of the Washington Cascade Mountains. Part II: Characteristics of past events and three-dimensional idealized simulations. *Monthly weather review*, 126(1), 53-71.

Mayr, G. J., Armi, L., Gohm, A., Zängl, G., Durran, D. R., Flamant, C., Gaberšek, S., Mobbs, S., Ross, A. & Weissmann, M. (2007). Gap flows: results from the Mesoscale Alpine Programme. *Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography*, 133(625), 881-896.

Zängl, G. (2003). Deep and shallow south foehn in the region of Innsbruck: Typical features and semi-idelized numerical simulations. *Meteorology and Atmospheric Physics*, 83(3), 237-261.