Answers to Comments from Reviewer 1

Paul Ockenfuss, Gregor Köcher, Isabel Petit, Stefan Kneifel

September 2, 2026

Preface

Dear Mariko Oue, thank you very much for taking the time to review our manuscript. We hope you found it interesting. Your comments are all valid, and below we will try to address each one in detail.

Structure

This document contains up to three items for each review comment. **Comment** contains the original comment by the reviewer. **Response** is our response to the comment, explaining our thoughts and decisions. **Changes to the Manuscript** lists the most important adaptations to the manuscript regarding this comment, if not already mentioned in the response. Line numbers refer to the submitted version of the manuscript, if not stated otherwise. For a full list of changes, please also have a look at the provided "latexdiff" document, which shows all differences between the submitted and revised versions of the manuscript.

Reviewer 1

Minor Comments

R1.1 **Comment:** This manuscript did not show or discuss reflectivity characteristics, except in some Doppler spectra plots. I think that reflectivity was also informative to mention of particle size and/or number concentration if it was shown together with the velocity plots (for example Fig. 7).

Response: You are right that we do not focus much on reflectivity, even though it is sensitive to particle size and concentration. This is for two reasons: First, from a physical perspective, the relationship between riming and reflectivity is ambiguous. Since, as you state, reflectivity is highly sensitive to particle size, large aggregates can have a higher reflectivity than dense but smaller rimed particles. This is why most riming retrievals that are based on reflectivity (e.g. Maherndl et al. [2024]) need additional information about the particle size distribution. On the other hand, it is known that Doppler velocity can provide a much more direct link to particle density and riming [Kneifel and Moisseev, 2020]. In our case, the regions with high velocity generally coincide with regions of high reflectivity. For example, in Figure 1, we see that the three fall streaks visible in Fig. 6a in the manuscript also manifest in the radar reflectivity. However, in the radar reflectivity, we also see, for example, an additional fall streak around 20:45 UTC, which is not present in the Doppler image in Fig. 6a in the manuscript.

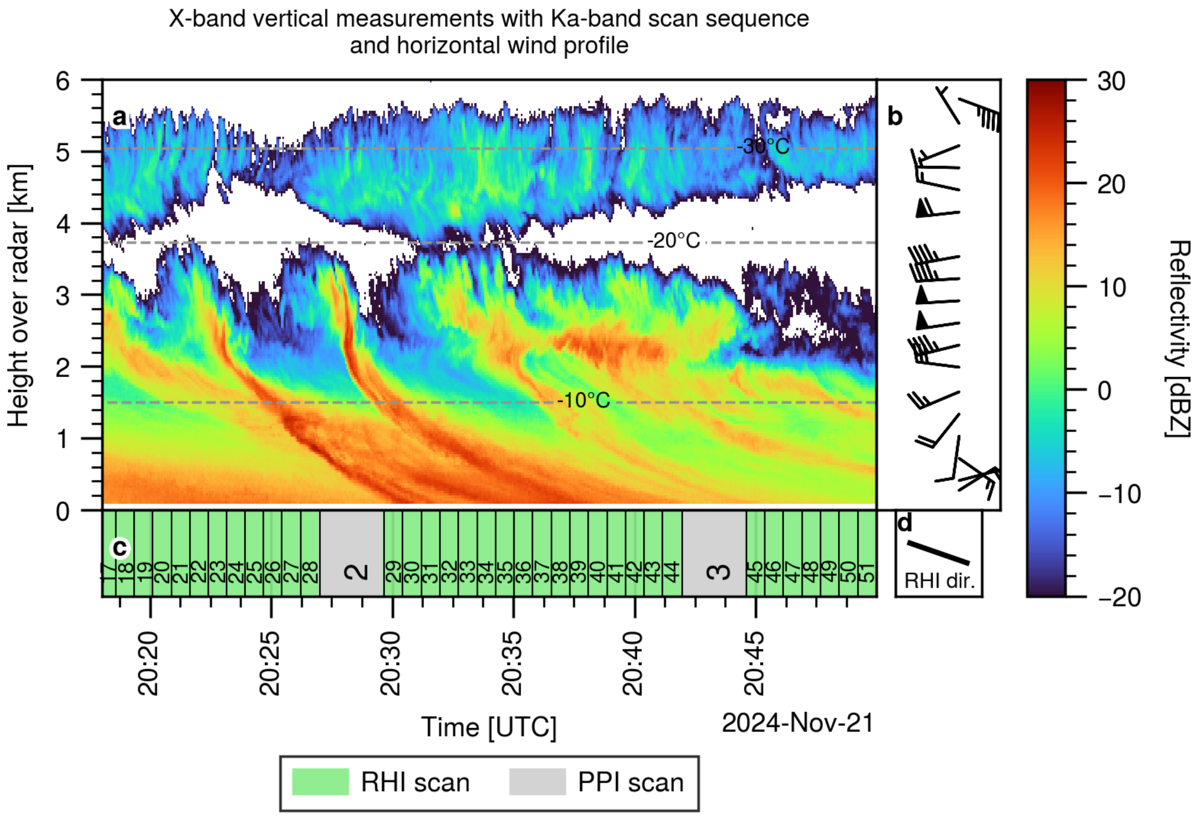

Figure 1: Same as Fig. 6 in the manuscript, but showing radar reflectivity instead of Doppler velocity.

Second, from a technical perspective, the novelty of this manuscript is the focus on Doppler velocity and on Doppler spectra in combination with scans and Lagrangian tracking. When it comes to the Lagrangian tracking of features in the reflectivity field, previous studies have already provided some excellent examples, e.g. Borque et al. [2014] (see their Fig. 4).

R1.2 **Comment:** The scan strategy to better track features of generating cells and riming signatures of falling particles is unique and interesting. Please comment on or discuss uncertainty if there is a strong directional wind shear in the cloud system. There is often directional wind shear that could be 90 degrees in a narrow layer in snow systems.

Response: This is a good point. We can actually see directional shear in the first case (Fig. 6b in the manuscript). In general, if there is substantial directional shear, Lagrangian tracking of particles passing through the shear layer based on RHI scans is not possible. Since the particles' trajectories cannot be reduced to a 2D plane in this case, volume scans would be necessary for Lagrangian tracking. However, at least with a classical, dish-based radar, volume scans take longer than RHI scans, which reduces the number of "snapshots" in time. This is why we have decided to base our analysis on RHI scans. In the first case, the presence of directional shear does not matter, since the situation is horizontally homogeneous. In the second case, there is no directional shear above the melting layer, which is why the Lagrangian tracking works.

Changes to the Manuscript: We added a new section "Prerequisites and recommendations for Lagrangian particle tracking" to the discussion section.

R1.3 **Comment:** Please give a comment or discussion of optimized spatial resolution in elevation, scan speed, sensitivity, and time of one cycle of scans.

Response: Generally, we found our scan parameters, as described in Sec. 3.1 in the manuscript, to be a good compromise between spatial and temporal resolution of the RHI scans. We also tried slower scan speeds in elevation. In this case, the spatial resolution of the RHI can be significantly improved, but the temporal resolution is reduced. We found that, considering the typical horizontal wind speeds in the observed weather systems and the range of the scans, slower RHI scans no longer provided enough "snapshots" of a feature for Lagrangian tracking. However, this choice may depend on the application. For example, Figure 2 shows a high-resolution scan through a cloud system with generating cells on top. If the focus is not on (Lagrangian) tracking over time but on the spatial structure of the cloud, slower scans can provide very interesting insights into the spatial organisation of cloud-top generating cells, as demonstrated in Figure 2b.

Changes to the Manuscript: We added a new section "Prerequisites and recommendations for Lagrangian particle tracking" to the discussion section.

R1.4 **Comment:** Lines 214-215: How about the components of vertical air motion and hydrometeor fall speeds? The sentence confused me. Please rephrase.

Response: The sentence is indeed confusing. What we meant is that, of the horizontal wind component, only the in-plane part matters for the RHI. We rephrased the sentence.

Changes to the Manuscript: For RHI scans, any velocity component perpendicular to the scanning plane does not contribute to the measured Doppler velocity ψ. Consequently, the RHI geometry contains information only about the vertical velocity component and the horizontal velocity component parallel to the scanning plane. We denote the latter by γ.

R1.5 **Comment:** The manuscript sometimes mentioned "turbulence" (e.g. line 308). However, it was unclear what features/characteristics was defined as "turbulence" in this study. How did you measure the turbulence? How did the turbulence impact the Doppler spectra?

Response: In general, by turbulence, we refer to air motion in the form of eddies. A circular eddy can affect the line-of-sight Doppler velocity regardless of the viewing angle, since it contains horizontal and vertical air velocity components.

Changes to the Manuscript: We changed the sentence: "Consequently, the regions of enhanced downward velocity around ± 2 km horizontal distance, highlighted by the red ellipses, are most likely caused by fluctuations in the horizontal wind, e.g., due to turbulent eddies being present during the formation phase of the layer."

R1.6 **Comment:** I was sometimes confused with the naming "vertical velocity" through the manuscript. Does this include air motion or fall speed (for example Figure 7)?

Response: It generally includes both. It is the remaining velocity component after we subtract the horizontal wind from the measured line-of-sight Doppler velocity. This value can be caused either by particle sedimentation or by air motion. Which one it is can only be determined by an analysis of further aspects such as spatio-temporal structure or Doppler spectra. For example, in the first case, the bimodal Doppler spectra clearly show that the downward motion

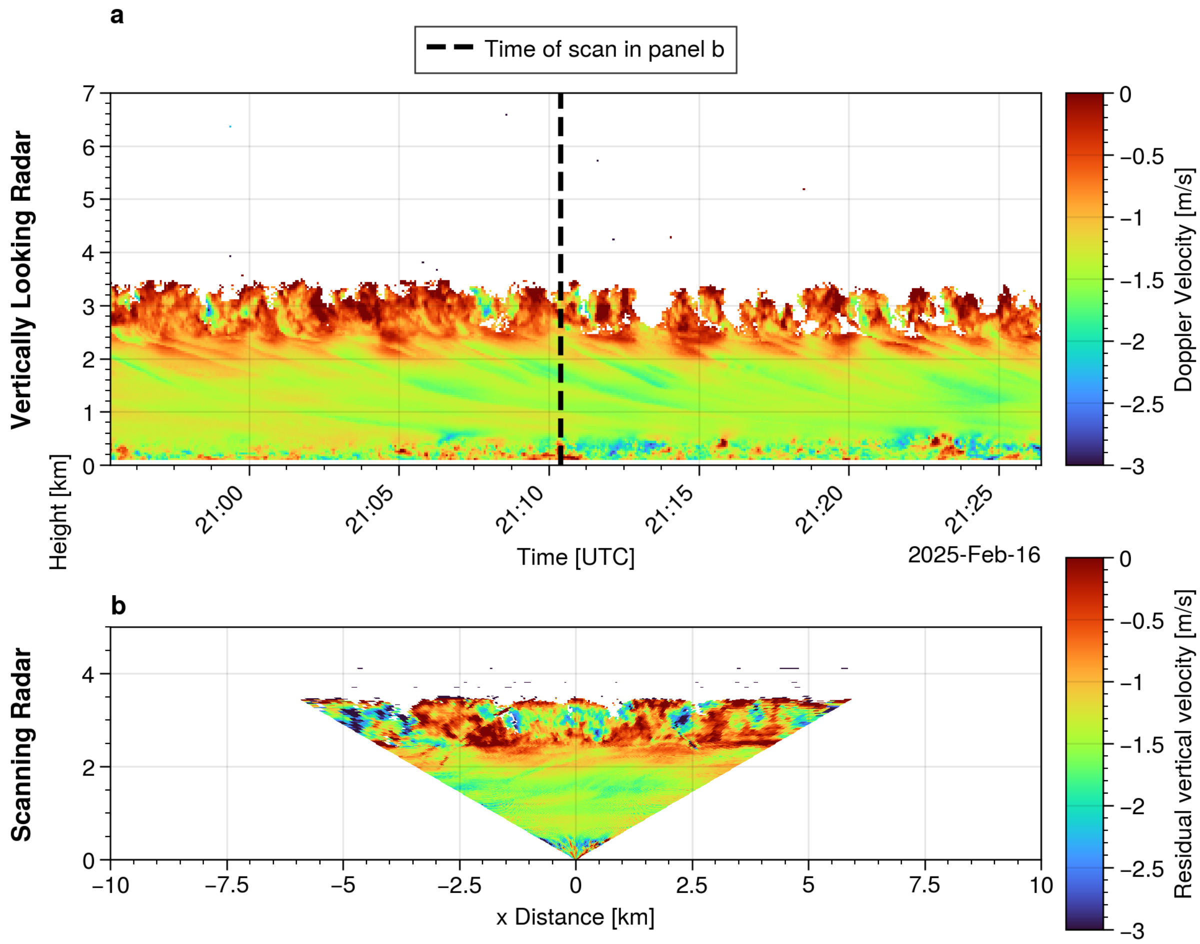

Figure 2: Example of a slower, and therefore higher-resolution, RHI scan through a weather system with cloud-top generating cells.

is due to different particle populations and sedimentation. In the second example case, the size sorting is a strong hint that the localized region with downward motion is of microphysical origin (riming) as well.

R1.7 **Comment:** Last paragraph in page 29: I just comment that some scanning radars do not have capability of horizon-to-horizon scans or vertically-pointing scans, which could limit the RHI observation regions.

Response: Good point! For our analysis, the ability to reach the horizon is not important. Our RHI scans are performed only down to 30 degree above the horizon. The ability to point vertically is more important. Near the vertical, the horizontal wind influence on the measured Doppler velocity is weaker and Doppler spectra reconstruction is more reliable.

References

P. Borque, P. Kollias, and S. Giangrande. First observations of tracking clouds using scanning arm cloud radars. *Journal of Applied Meteorology and Climatology*, 53(12):2732–2746, Dec. 2014. ISSN 1558-8432. doi: 10.1175/jamc-d-13-0182.1.

S. Kneifel and D. Moisseev. Long-term statistics of riming in nonconvective clouds derived from ground-based doppler cloud radar observations. *Journal of the Atmospheric Sciences*, 77(10): 3495–3508, 2020. doi: 10.1175/JAS-D-20-0007.1. URL `https://journals.ametsoc.org/view/journals/atsc/77/10/jasD200007.xml`.

N. Maherndl, M. Moser, J. Lucke, M. Mech, N. Risse, I. Schirmacher, and M. Maahn. Quantifying riming from airborne data during the halo-(ac)3 campaign. *Atmospheric Measurement Techniques*, 17(5):1475–1495, Mar. 2024. ISSN 1867-8548. doi: 10.5194/amt-17-1475-2024.