Reviewer #2

We sincerely thank you for your recognition of this study and for your careful and thorough review of the manuscript (EGUSPHERE-2026-5610). Your comments and suggestions, particularly those concerning the definition and physical meaning of HSI, figure presentation, and technical details, have been very helpful in improving the scientific analysis and overall quality of the manuscript.

We have carefully considered all your comments and have made corresponding revisions and additional analyses. The main changes are summarized in three aspects:

1) Hydrometeor Sedimentation Index (HSI): We reconsidered the mathematical definition and physical meaning of HSI. We added comparisons of HSI with radar reflectivity and the fast-sedimenting spectral energy fraction. We also conducted reflectivity-normalization sensitivity analyses and rolling correlation and covariance analyses to further clarify the information represented by HSI and its physical interpretation.

2) Figure presentation: Following your suggestions, we revised Figs. 3, 4, 7, 8, and 11. The revisions include adjustments to color scales, axis labels, and legend positions, as well as the removal of redundant information and improvements to the overall figure layout. These changes improve the clarity and readability of the figures.

3) Technical details: We carefully checked the figure captions, variable notation, color descriptions, and text throughout the manuscript. We corrected the identified errors and standardized the presentation of figure markers and related physical quantities.

Below, we respond to your comments point by point and describe the corresponding additional analyses and revisions to the manuscript. We sincerely appreciate your constructive suggestions.

Review of “Continuous Remote Sensing Observations of Hydrometeor Sedimentation Evolution during the Transition from Ice Cloud to Precipitating Mixed-Phase Cloud” Authors: Yun Yuan, Huige Di, Weitao He, Zewen Yang, Zhihao Song, and Dengxin Hua Egusphere-2026-5610

General comments

The manuscript proposes an index combining radar reflectivity and spectral contribution within the fast-sedimentation velocity range to capture the effects of their interaction on hydrometeor sedimentation evolution. The index is then applied to an in-depth analysis of a weakly precipitating stratiform mixed-phase event, covering the transition from high-level ice cloud to light precipitation. The analysis incorporates observations from a millimeter-wave cloud radar, multiwavelength polarization lidar, microwave radiometer, and radiosonde.

Overall, the study is well-structured and well-conceived, although some parts of the text could be more concise. My comments mainly suggest revisions to refine the Hydrometer Sedimentation Index, as well as improvements to how the figures are presented.

Specific comments

Hydrometeor Sedimentation Index (HSI) From lines 12-13 on page 7 and lines 13-15 on page 16, HSI is intended to be a good predictor when both variables increase concurrently, leading to a spike in its value. However, just multiplying them does not statistically characterize their covariance.

The way the index is defined, it is more sensitive to the radar reflectivity than to Ffast. Since Ffast varies from 0 to 1 and the radar reflectivity has no such rigid constraints, HSI basically weights reflectivity by Ffast. I would suggest assessing the index when both variables carry the same weight in the analysis. In fact, a true covariance would jointly measure how both vary relative to their means. Therefore, I wonder whether performing a rolling covariance calculation, for example, could achieve the distinction described in lines 15-17 on page 16 while providing a more robust characterization of the combined behavior of both variables throughout the system's evolution.

Although HSI provided a stronger signal than the fast-sedimenting spectral component alone, it would be appreciated if the value of such a metric was explicitly stated, along with the extent to which it could be applicable to other cases.

Response:

Thank you for your detailed comments on the mathematical definition, variable weighting, and applicability of the Hydrometeor Sedimentation Index (HSI). We have reconsidered the description of HSI in the original manuscript and further clarified its physical meaning and scope of application.

In response to your suggestion to use rolling covariance to distinguish the joint variations of the two variables, we conducted additional rolling correlation and covariance analyses (new Fig. S7). The calculations were performed over a fixed altitude range of 5.01–6.99 km using a 30 min moving window with a 5 min step. The results show that, for windows with valid-data coverage of at least 50%, the median rolling covariance of the globally standardized variables increased from 0.0087 before 06:00 CST to 0.310 afterward. Further decomposition showed that approximately 55% of this increase was associated with changes in the product of the within-window standard deviations, approximately 32% with changes in the Pearson correlation coefficient, and the remaining 13% with their interaction. Meanwhile, after removing the window-specific mean at each range gate, the median Pearson correlation coefficients before and after 06:00 CST were 0.224 and 0.228, respectively, remaining nearly unchanged. These results indicate that the late-stage increase in covariance was mainly associated with greater variability in the linear radar reflectivity factor within the moving windows.

Regarding the additional information provided by HSI relative to F_{fast}, we have further clarified the distinction between these two parameters. F_{fast} represents the fraction of the total power of the valid Doppler spectrum contributed by fast-sedimenting spectral components, whereas HSI combines this fraction with the linear radar reflectivity factor and therefore also represents the radar-scattering strength associated with these spectral components. In this case, fast-sedimenting spectral components were already present during the early stage, but the overall radar scattering was relatively weak and HSI remained low. After 06:00 CST, both radar reflectivity and HSI increased markedly, and regions of elevated HSI extended toward lower altitudes (Fig. S6 and original Fig. 11). Thus, compared with F_{fast} alone, HSI provides additional information on the radar-scattering strength associated with fast-

sedimenting spectral components, although it is not a statistical measure independent of radar reflectivity.

Regarding the applicability of HSI to other cloud processes, the index is constructed from the linear radar reflectivity factor and the fast-sedimenting spectral energy fraction, both of which can be derived from cloud radar observations with Doppler spectrum measurement capability. Therefore, the same definition can be applied to mixed-phase cloud cases in which fast-sedimenting spectral components can be identified and the required observations are available. In this study, HSI is used to examine the evolution of hydrometeor scattering and sedimentation characteristics during the observed mixed-phase cloud event, providing an additional perspective for the analysis of precipitation processes in mixed-phase clouds.

Based on these analyses, we retain the original definition of HSI in Eq. (2) of the manuscript. We will clarify its meaning in Sect. 2.4.2, revise the interpretation of the relevant results in Sect. 3.5, and further clarify the physical meaning of HSI, the observational conditions required for its application, and its specific role in analyzing the cloud-to-precipitation evolution in the Discussion and Conclusion sections.

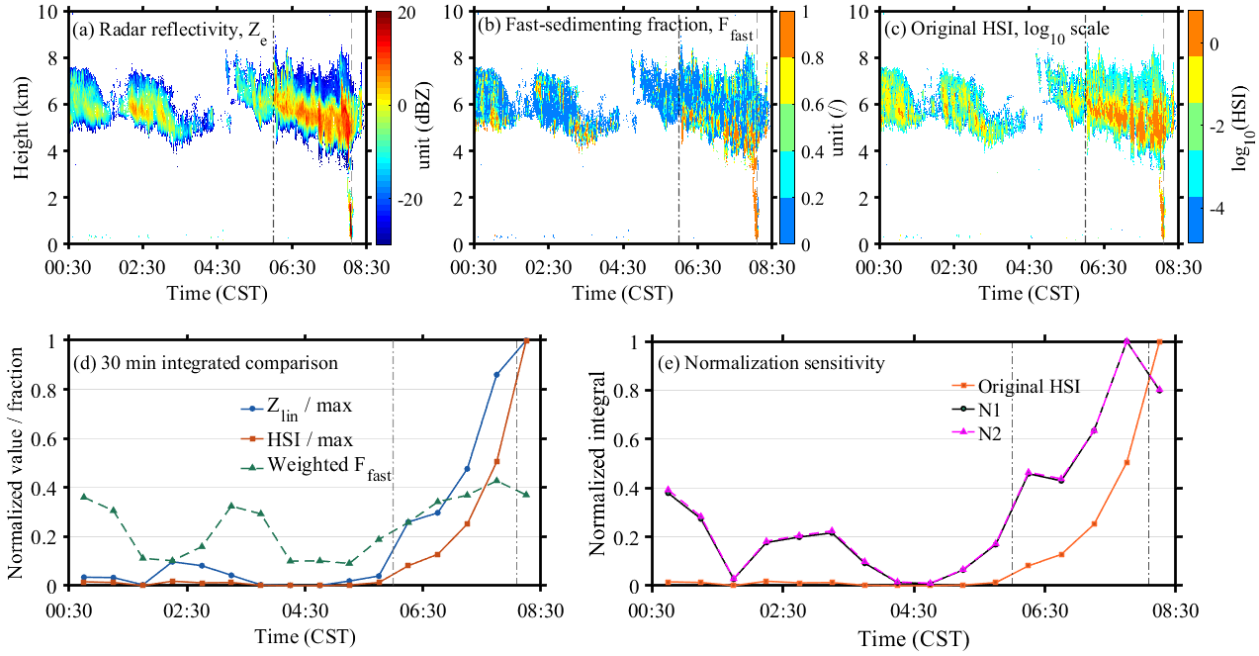


Figure S6. Comparison of radar reflectivity, fast-sedimenting spectral contributions, and HSI, together with reflectivity-normalization sensitivity analyses during the persistent mixed-phase cloud stage. (a–c) Height–time distributions of the Z_e, F_{fast}, and original HSI ($\log_{10}$ scale), respectively, from 00:30 to 08:30 CST on 7 June 2021. (d) Maximum-normalized 30 min vertical integrals of the Z_{lin} and HSI, together with the F_{fast}. (e) Comparison of the 30 min vertically integrated time series of the original HSI and two reflectivity-normalization approaches: N1, normalization with clipping based on a predefined dBZ range; and N2, normalization based on the percentile rank of dBZ values. Each series is normalized by its own maximum. The vertical dotted and dashed lines indicate 06:00 CST and approximately 08:05 CST, respectively.

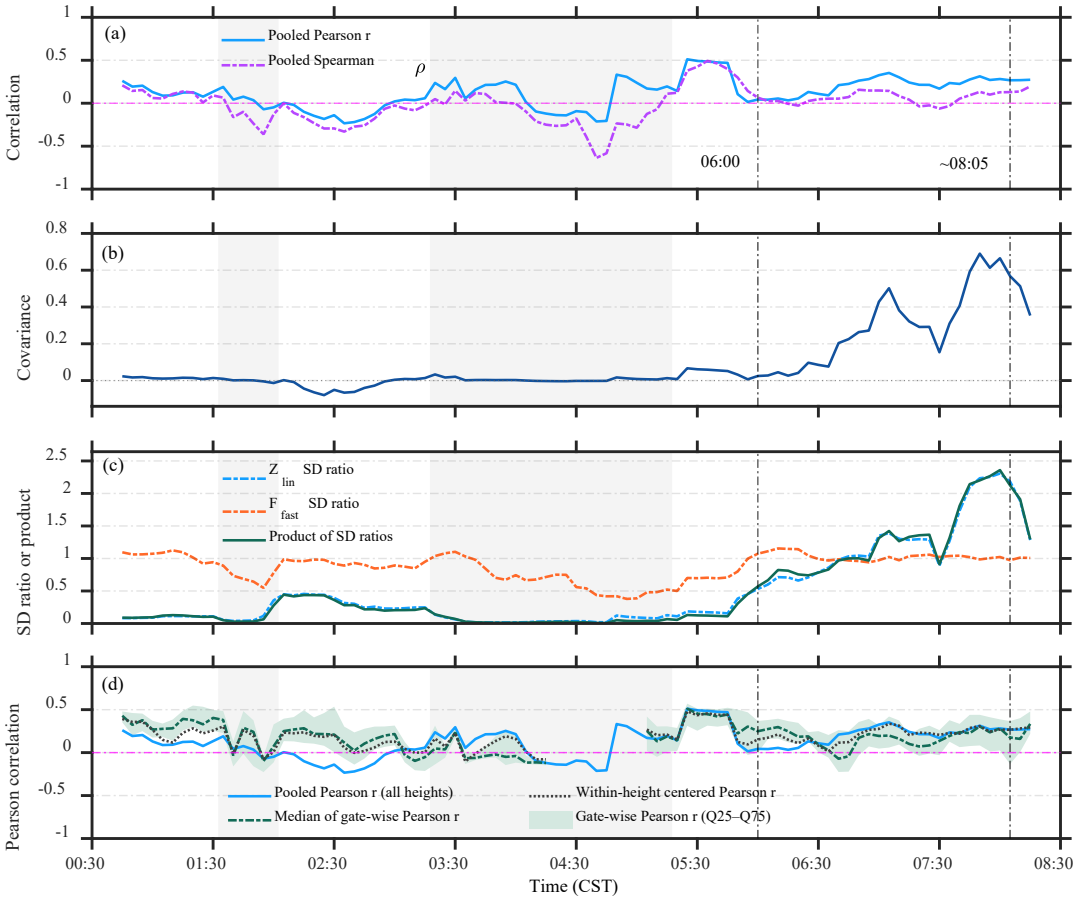


Figure S7. Rolling correlations and covariance between linear radar reflectivity (Z_{lin}) and the fast-sedimenting spectral fraction (F_{fast}) at 5.01–6.99 km above the radar on 7 June 2021. The 30 min windows advance in 5 min steps, and each estimate is plotted at the window center in China Standard Time (CST). (a) Pearson *r* and Spearman ρ calculated by pooling all valid time–height pairs within each window. (b) Dimensionless rolling covariance after standardizing both variables over the full 00:30–08:30 CST analysis period. (c) Ratios of the window sample standard deviations (SDs) to their respective full-period SDs for Z_{lin} and F_{fast}, together with the product of the two ratios. This product multiplied by the pooled Pearson *r* in (a) gives the covariance in (b). (d) Pooled Pearson *r*, the median of gate-wise Pearson *r*, and pooled Pearson *r* after subtracting each variable's window mean at each range gate. Green shading denotes the 25th–75th percentile range of gate-wise Pearson *r*. Each gate requires at least 180 valid pairs, and the gate-based estimates are shown for windows with at least 10 usable gates. Gray shading indicates coverage less than 50%. Vertical dashed lines mark 06:00 CST and approximately 08:05 CST, when weak precipitation began at the surface.

Figure presentation

Some figures contain a considerable amount of information, making them more difficult to interpret. I suggest revising them to improve readability and clarity. Specifically:

1) Figure 3: In panel (d), the LWP and Vint axis labels overlap with each other and with the color bar. Additionally, the temperature profile legends could be repositioned outside the plotting area to avoid overlapping with the data.

Response:

Thank you for your specific suggestions regarding Fig. 3. We have adjusted the color scale of the 532 nm volume depolarization ratio in Fig. 3(c) and revised the presentation of the water-vapor density color scale in Fig. 3(d). We have also rearranged the right-hand axis ticks and labels for Vint and LWP in Fig. 3(d) to avoid overlap between the two sets of labels.

Regarding the radiosonde temperature profiles, rather than retaining the full profiles and repositioning their legends, we have simplified their presentation to reduce visual clutter and avoid obscuring the lidar observations. The reference heights of the 0 °C and −38 °C isotherms, derived from the radiosonde temperature profile at 07:15 CST on 7 June 2021, are indicated by horizontal lines in the relevant panels. These reference levels provide the thermodynamic context without displaying the full temperature profiles.

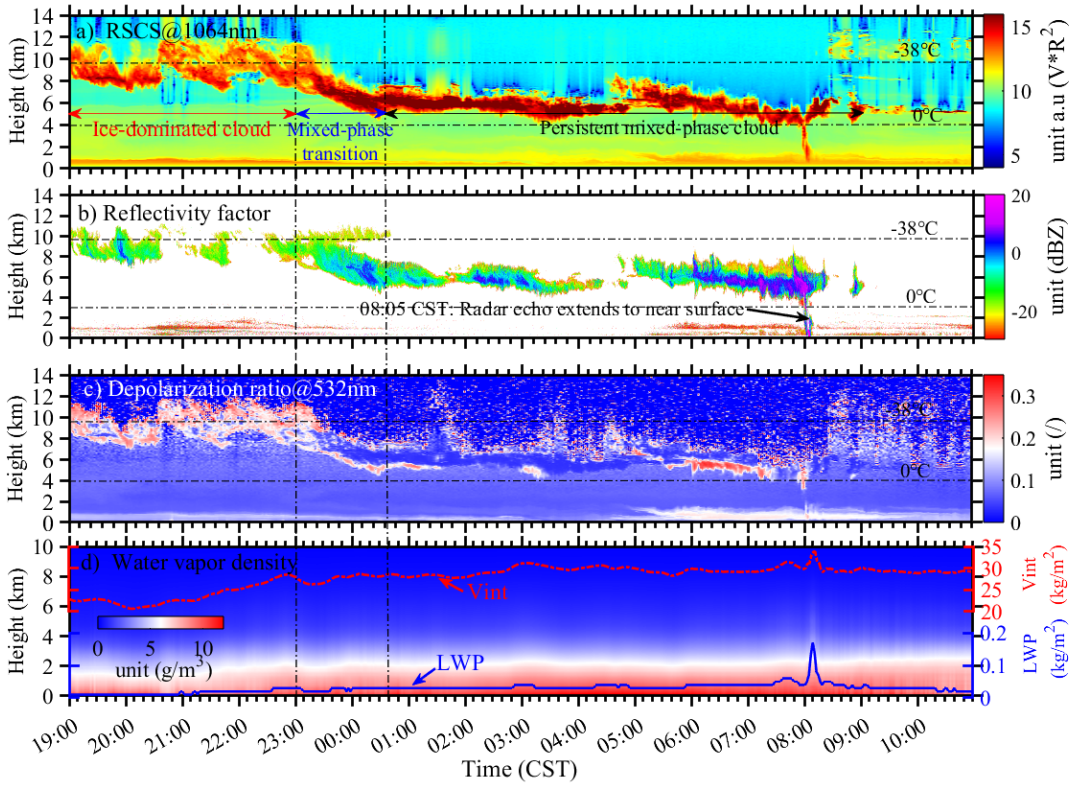


Figure 3. Multi-instrument ground-based remote-sensing observations of the cloud-system evolution on 6–7 June 2021. (a) 1064 nm RSCS from the multiwavelength lidar. (b) Ze from MMCR. (c) 532 nm lidar volume depolarization ratio, with radiosonde temperature profiles at 19:15 and 07:15 CST overlaid; the cyan and black curves indicate the corresponding moist- and dry-adiabatic temperature profiles, respectively. (d) Water-vapor density retrieved by the microwave radiometer, with Vint (red dashed line) and LWP (blue solid line). Vertical dashed lines separate the ice-dominated cloud stage, mixed-phase transition stage, and persistent mixed-phase cloud stage. At approximately 08:05 CST, the radar echo extended toward near-surface levels, coinciding with the occurrence of short-lived light precipitation at the surface. The horizontal dash-dotted lines in (a) indicate the reference heights of the 0 °C and −38 °C isotherms derived from the radiosonde temperature profile at 07:15 CST on 7 June 2021.

2） Figure 4: Regarding panel (a), please identify all the variables plotted in the figure caption, as they are not currently specified (relative humidity and temperature profiles). Also, the profiles are neither discussed in the text nor mentioned in the caption. If it is not relevant to the discussion at this point, please consider removing it. The temperature and relative humidity profile legends could be repositioned outside the plotting area.

Response:

Thank you for this suggestion. We agree that the relative-humidity and temperature profiles overlaid in the original Fig. 4(a) were not discussed in Sect. 3.2 and were not essential to the presentation of hydrometeor radar and dynamical characteristics during the ice-dominated cloud stage. We have therefore removed these profiles from the revised Fig. 4.

The revised figure now focuses on four radar-derived parameters: (a) radar reflectivity factor (Z_e), (b) Doppler spectral width (SW), (c) in-cloud vertical air velocity (w), and (d) hydrometeor terminal fall velocity (V_t). To retain the relevant thermodynamic reference, we have kept the horizontal lines indicating the −20 °C and −38 °C isotherm heights across the four panels. The full radiosonde temperature and relative-humidity profiles are retained in Figs. 3 and 8, where they are directly used in the analysis of cloud-phase evolution and the persistent mixed-phase cloud environment. The caption of Fig. 4 has also been revised accordingly.

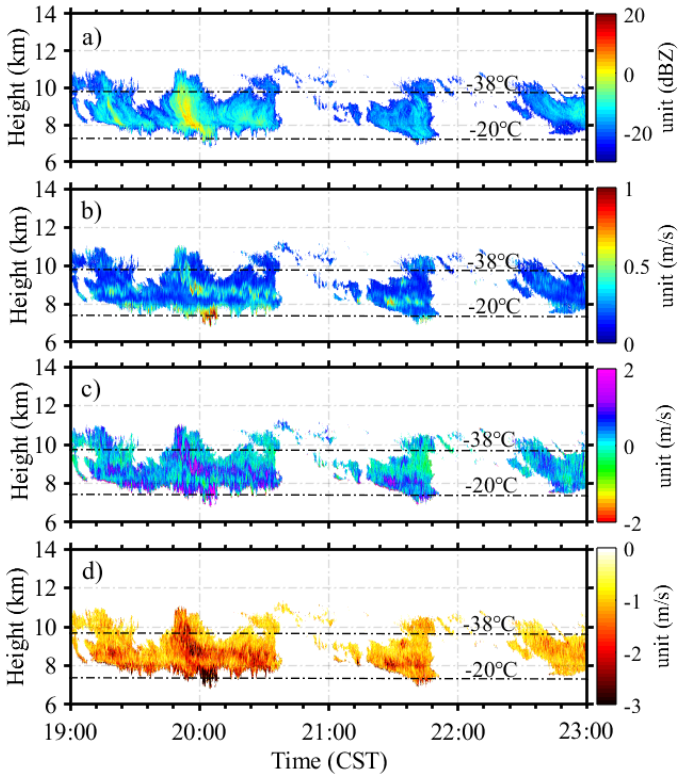


Figure 4. Radar and dynamical characteristics of hydrometeors during the ice-dominated cloud stage (19:00–23:00 CST). (a) Radar reflectivity factor (Z_e); (b) Doppler spectral width (SW); (c) in-cloud vertical air velocity (w); and (d) hydrometeor terminal fall velocity (V_t) after correction for vertical air motion. Positive and negative w indicate upward and downward air motions, respectively, while negative Vt indicates downward hydrometeor sedimentation. The horizontal dash-dotted lines indicate the reference heights of the −20 °C and −38 °C isotherms derived from the 19:15 CST radiosonde temperature profile on 6 June 2021.

3）Figure 7: There appears to be a residual plot element below the x-axis label. Please check and correct the figure layout.

Response:

Thank you for pointing out the graphical display and marker-description issues in Fig. 7(b1 – b3).

Upon inspection, the light-blue regions represent low-density areas of the normalized two-dimensional joint density distribution of Z_e and V_t, rather than additional data points or a distinct hydrometeor population. In the original figure, these regions are contained within the axes. However, in the preprint PDF, some light-blue regions extend below the lower y-axis limit of −2.5 m/s and overlap the axis tick labels and title. This may have resulted from an error during figure embedding or PDF conversion. We will re-export the figure and check its appearance in the final submission PDF.

Regarding the red and black crosses, we clarify that both sets of markers were manually selected by the authors to indicate two representative locations within the high-density regions of the Z_e -V_t t joint density distributions. They do not represent different statistical methods or quantities. To avoid ambiguity, the two markers have been changed to black crosses in the revised Fig. 7, and their meaning has been clarified in the figure caption. These markers are intended only to indicate representative locations within the high-density regions.

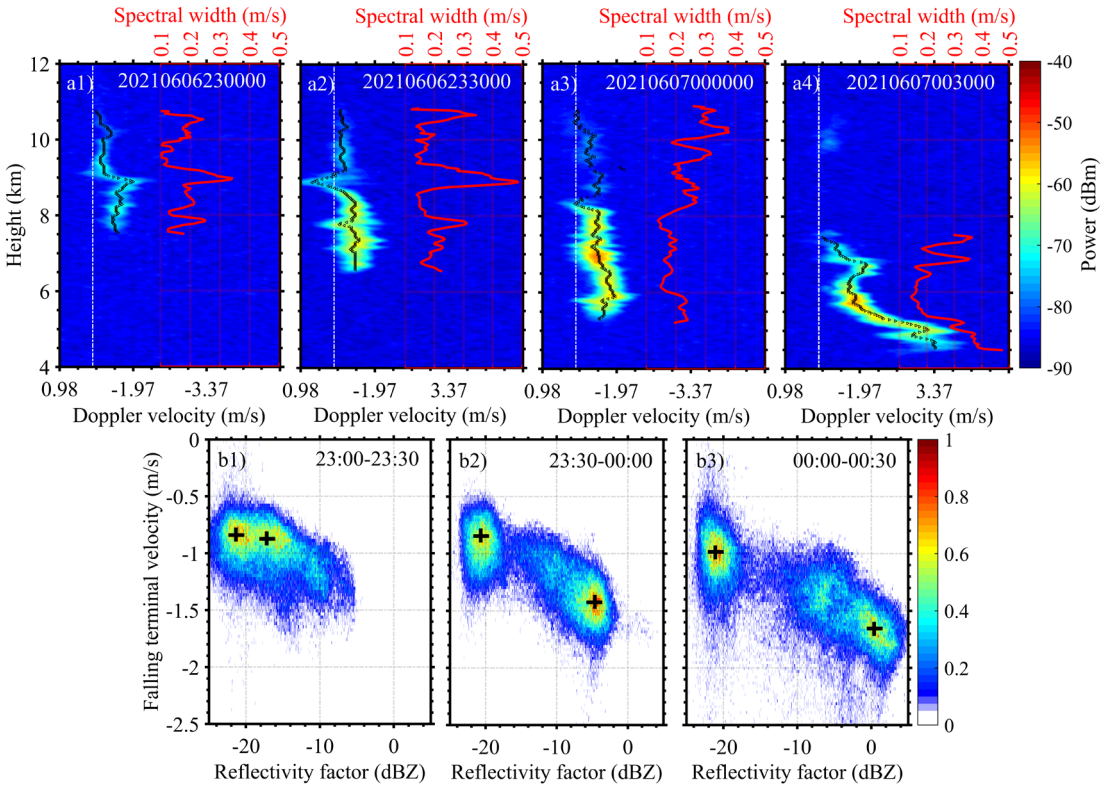


Figure 7. Evolution of Doppler spectra and the Ze–Vt relationship during the mixed-phase transition stage (23:00–00:30 CST). (a1–a4) Vertical profiles of Doppler power spectra at 23:00, 23:30, 00:00, and 00:30 CST, respectively. Colors indicate spectral power, black dotted curves denote the spectral peak velocity at each height, and red curves indicate Doppler spectral width (SW). (b1–b3) Normalized two-dimensional density distributions of Ze and Vt during 23:00–23:30, 23:30–00:00, and 00:00–00:30 CST, respectively. Colors indicate normalized density. The two black crosses in each of (b1–b3) indicate manually selected representative locations in the two high-density regions.

3) Figure 8: I would suggest repositioning the temperature and relative humidity profile legends outside the plotting area.

Response:

Thank you for this suggestion. We have repositioned the temperature and relative-humidity profile legends in Fig. 8(a) outside the plotting area so that they no longer overlap the radar reflectivity field. The profiles themselves have been retained because they provide the thermodynamic and humidity context used in Sect. 3.4 to characterize the persistent mixed-phase cloud environment.

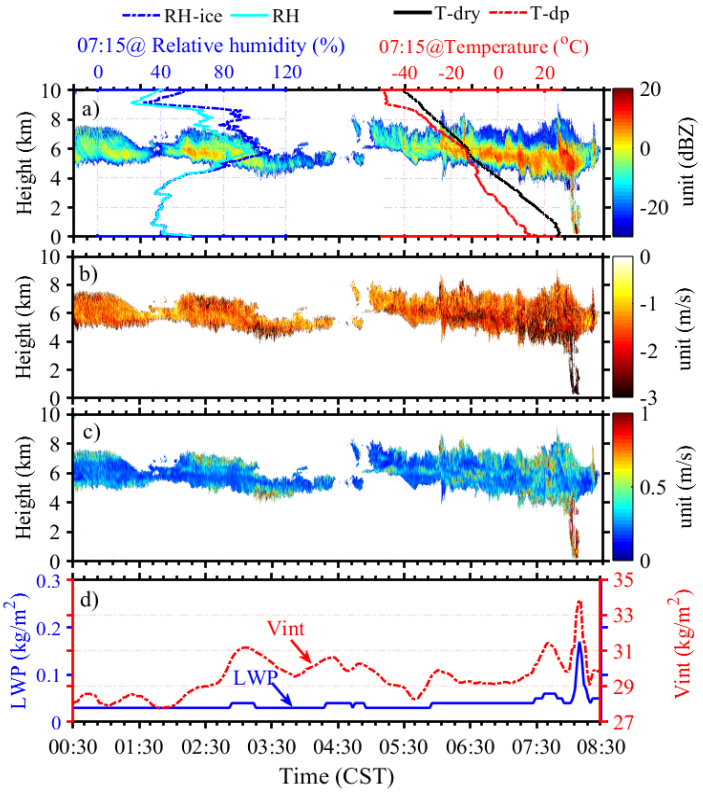
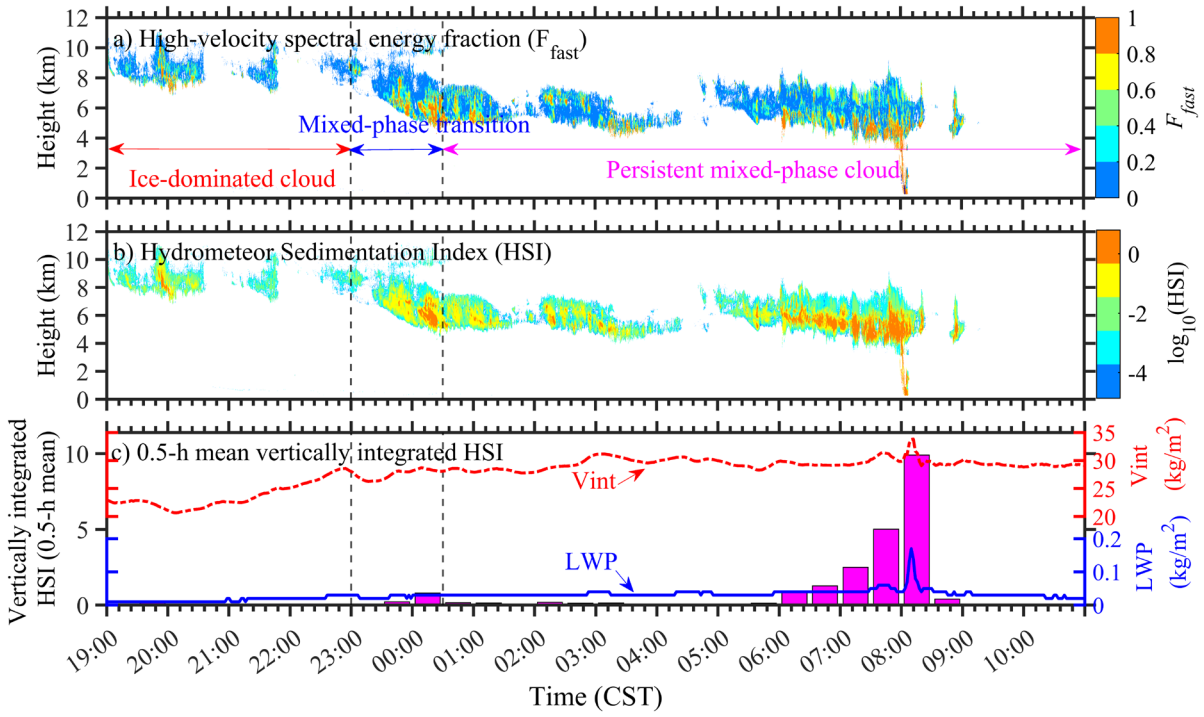


Figure 8. Evolution of hydrometeor properties and water-vapor–liquid-water conditions during the persistent mixed-phase cloud stage (00:30–08:30 CST). (a) Radar reflectivity factor (Z_e), with the 07:15 CST radiosonde relative-humidity and temperature profiles overlaid; (b) hydrometeor terminal fall velocity (V_t) after correction for vertical air motion; (c) Doppler spectral width (SW); and (d) liquid water path (LWP; blue line) and column-integrated water vapor (Vint; red dashed line) retrieved from the microwave radiometer.

5) Figure 11: In panel (c), the LWP and Vint axis labels are overlapping.

Response:

Thank you for pointing out the overlap in Fig. 11(c). We have repositioned the right-hand axis labels for LWP and Vint and adjusted the spacing at the right side of the panel to keep the two labels separate and clear of the figure frame.



Technical comments

1) In line 10-11 page 12, the line is black but the text reads "The White dash-dotted lines in (d) indicate ..."

Response:

Thank you for pointing out the incorrect color description in the caption of Fig. 6. Upon checking the figure, we confirmed that the −20 °C and −40 °C isotherms in Fig. 6(d) are represented by black dash-dotted lines. Therefore, the use of "white" in the original caption was incorrect. We will correct "white dash-dotted lines" to "black dash-dotted lines" in the revised manuscript to ensure consistency between the figure caption and the actual line colors.

Figure 6. Evolution of cloud structure and hydrometeor dynamical characteristics during the mixed-phase transition stage (23:00–00:30 CST). (a) Radar reflectivity factor (Z_e); (b) in-cloud vertical air velocity (w); (c) hydrometeor terminal fall velocity (V_t) after correction for vertical air motion; and (d) 532 nm volume depolarization ratio. Positive and negative w indicate upward and downward air motions, respectively, whereas negative V_t denotes downward hydrometeor sedimentation. The black dash-dotted lines in (d) indicate the −20°C and −40°C isotherms.

2) In line 24 page 12, please fix typo on "sedimentatio" to "sedimentation".

Response:

Thank you for pointing out this typographical error. We will correct "sedimentatio" to "sedimentation" in the corresponding sentence in Sect. 3.3 of the revised manuscript.

3) In line 7 pg 13, are both red and black crosses or just the black crosses representing high-density regions?

Response:

Thank you for pointing out the graphical display and marker-description issues in Fig. 7(b1 – b3).

Upon inspection, the light-blue regions represent low-density areas of the normalized two-dimensional joint density distribution of Z_e and V_t, rather than additional data points or a distinct hydrometeor population. In the original figure, these regions are contained within the axes. However, in the preprint PDF, some light-blue regions extend below the lower y-axis limit of −2.5 m/s and overlap the axis tick labels and title. This may have resulted from an error during figure embedding or PDF conversion. We will re-export the figure and check its appearance in the final submission PDF.

Regarding the red and black crosses, we clarify that both sets of markers were manually selected by the authors to indicate two representative locations within the high-density regions of the Z_e -V_t t joint density distributions. They do not represent different statistical methods or quantities. To avoid ambiguity, the two markers have been changed to black crosses in the revised Fig. 7, and their meaning has been clarified in the figure caption. These markers are intended only to indicate representative locations within the high-density regions.

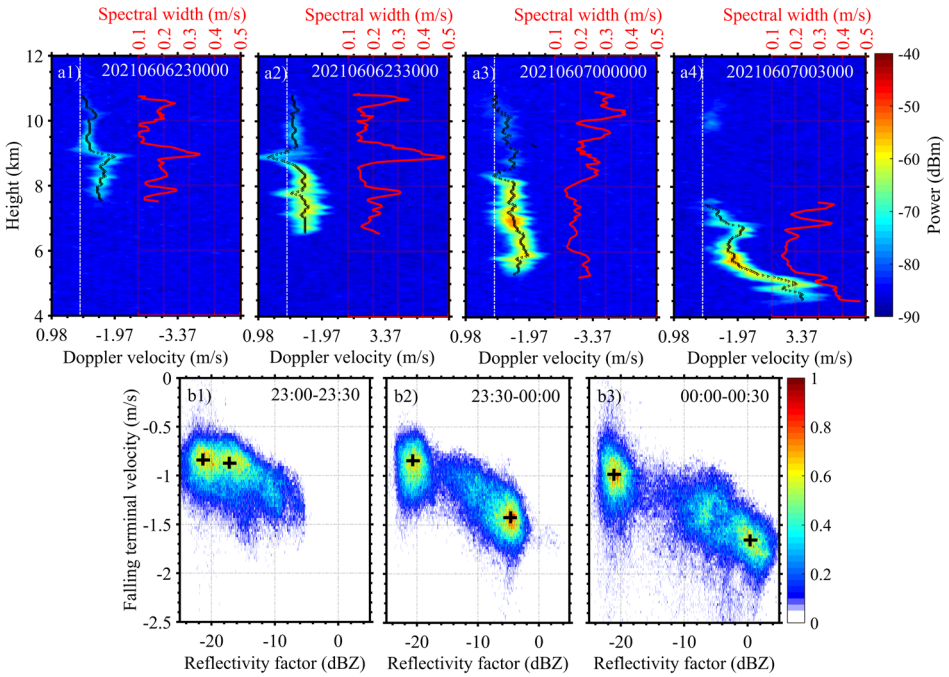


Figure 7. Evolution of Doppler spectra and the Ze–Vt relationship during the mixed-phase transition stage (23:00–00:30 CST). (a1–a4) Vertical profiles of Doppler power spectra at 23:00, 23:30, 00:00, and 00:30 CST, respectively. Colors indicate spectral power, black dotted curves denote the spectral peak velocity at each height, and red curves indicate Doppler spectral width (SW). (b1–b3) Normalized two-dimensional density distributions of Ze and Vt during 23:00–23:30, 23:30–00:00, and 00:00–00:30 CST, respectively. Colors indicate normalized density. The two black crosses in each of (b1–b3) indicate manually selected representative locations in the two high-density regions.

4） In line 5 page 19, would it be "|Vt|"?

Response:

We agree with your suggestion and will replace "V_t" with "$|V_t|$" in the revised manuscript to ensure that the notation accurately reflects the physical meaning.