

Response to the Reviewer #3

We really appreciate your time and effort taken to review our manuscript submitted to Atmospheric Chemistry and Physics. We have revised our manuscript according to your comments as explained below. Please see the following for our point-by-point responses shown in red just below the corresponding comments shown in black.

This study analyses EarthCARE CPR observations to investigate the statistical relation between Doppler velocity and existing indices of convective intensity such as cloud-top height and echo-top height (0 dBZ or 10 dBZ). It is concluded that  $\Delta H = \text{cloud-top height} - \text{0-dBZ height}$  is a robust proxy of updraft strength. Region-to-region comparison consistently supports this conclusion. The findings appear to be focused on a confirmation of the widely-known climatology of convective systems (ocean-land contrast in convective intensity etc.) rather than an exploration of previously unknown aspects. This paper nonetheless convincingly underscores the utility of EarthCARE for better understanding the convective dynamics and microphysics. I have several suggestions that would hopefully help the authors improve the paper, but otherwise the paper is well worth publishing in ACP.

Thank you very much for the thoughtful assessment and constructive suggestions that are very useful to greatly improve our manuscript. Before addressing the specific comments, we note that the folding-related results have been reorganized in the revised manuscript. Doppler-velocity folded columns are now treated as candidate extreme-updraft (EU) columns throughout the manuscript. The former standalone folding-ratio figure, originally Fig. 10, has been incorporated into revised Fig. 6, where the MaxVd-based SU ratio and the Doppler-velocity folded-column (EU) ratio are shown side by side as functions of CTH and ETH(0 dBZ). The folded-column CFAD requested by the reviewer has been added as panel (c) of revised Fig. 3 and is now described as the EU-column CFAD.

Major comment ---

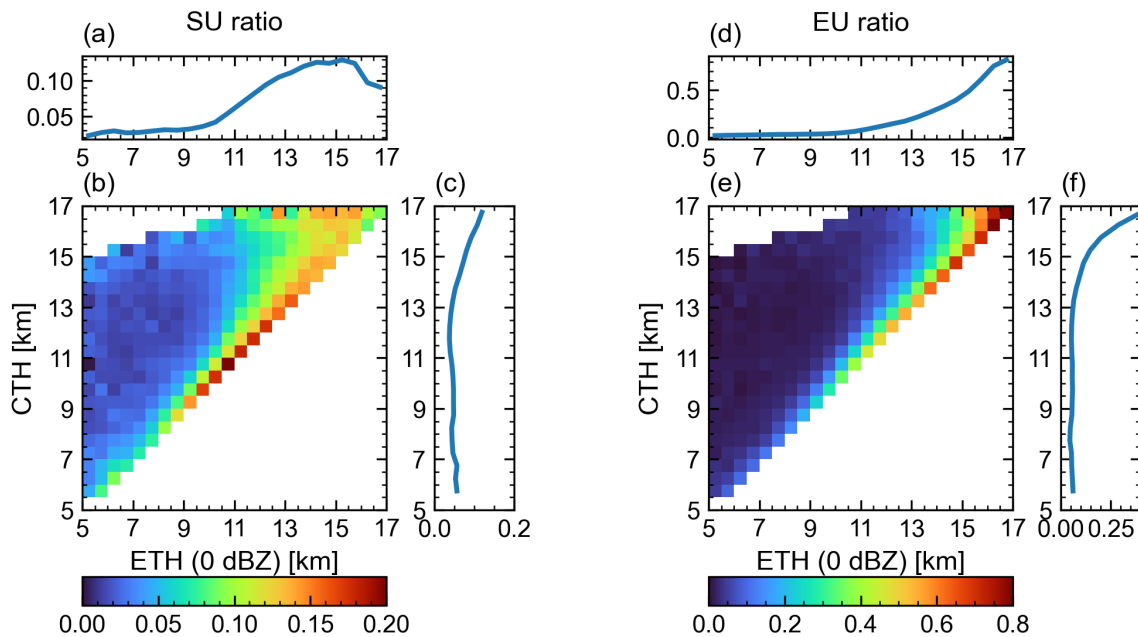
As the authors are aware, a major technical limitation of EarthCARE CPR is the velocity folding, hindering measuring very intense convection with a Vd exceeding the Nyquist velocity ( $\sim 5$  m/s). I think that Section 3.3 would benefit from an additional plot or two demonstrating the extent to which vigorous convection is made inaccessible by the Vd folding.

1) In Figure 10, color scale is saturated in reddish pixels especially near the top-right corner: the values can be 0.2 or possibly as high as, say, 0.5 but I can't tell. If the number is close to 0.5, that would mean that aliasing occurs almost as often as it doesn't. The color scale can be adjusted to avoid saturation, or

alternatively a similar PDF plot could be added with the folding occurrence normalized by the unfolding occurrence (instead of the total) to better emphasize the domains with a high occurrence of folding.

We agree that the original Fig. 10 color scale did not adequately show the high-folding-frequency regime. In the revised manuscript, the former Fig. 10 has been incorporated into revised Fig. 6. Revised Fig. 6 now shows both the MaxVd-based SU ratio and the Doppler-velocity folded-column ratio, with an expanded color scale for the folded-column ratio to avoid saturation.

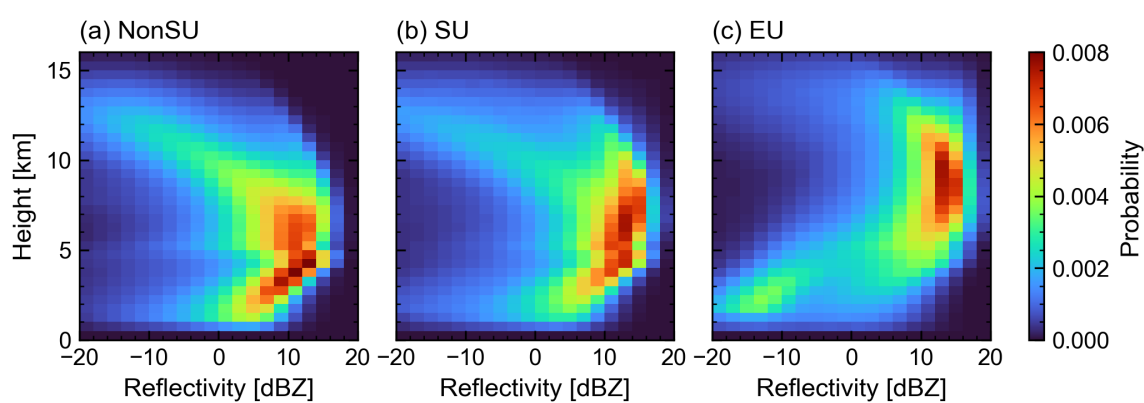
After revising the folding criterion, the overall folding fraction increased, and the high-frequency regions became clearer. We have revised the color scale in revised Fig. 6 to avoid saturation and added quantitative statements in the text. Specifically, in the extreme cases with  $CTH \geq 11$  km and  $CTH - ETH(0 \text{ dBZ}) \leq 0.5$  km, more than half of the selected convective columns are now flagged as folded. This emphasizes that velocity folding marks a regime in which quantitative MaxVd is unavailable and the folded columns must be interpreted separately.



**Figure 6 in the revised manuscript. Occurrence ratios of SU columns and EU columns as functions of ETH(0) and CTH. (a–c) SU ratio and (d–f) EU ratio. The SU ratio is defined as the number of non-folded columns with  $MaxVd > 2.0 \text{ m s}^{-1}$  divided by the total number of selected convective columns in each bin. The EU ratio is defined as the number of folded columns divided by the same denominator. Note that the SU and EU panels use different color scales. Panels (b) and (e) show two-dimensional ratios in the CTH–ETH(0) phase space; marginal ratios are shown as functions of ETH(0) and CTH.**

2) I would like to see a CFAD for Vd-folded columns only. How would it compare with Figure 3, in particular the SU CFAD?

Thank you very much for such a nice suggestion. We now have added the requested folded-column CFAD as a new figure. Because the measured Vd values in folded columns are aliased, the CFAD focuses on reflectivity rather than the aliased Doppler velocity. The folding-based EU CFAD shows that folded columns occupy an extreme structural regime relative to the MaxVd-based SU population, with high reflectivities extending to high altitudes. We now added some discussion referring to this result in the revised manuscript.



**Figure 3 in revised manuscript. Normalized contoured frequency-by-altitude diagrams (CFADs) of EarthCARE/CPR radar reflectivity (Ref; dBZ) for (a) non-strong-updraft (NonSU) columns, (b) strong-updraft (SU) columns, and (c) extreme-updraft (EU) candidate columns. Reflectivity is binned in 2 dBZ intervals, and the vertical coordinate is binned in 500 m intervals. Each panel is normalized by its total number of height-reflectivity samples such that the color indicates probability (i.e., the sum over all bins in each panel equals 1).**

Specific points ---

l.25: "determines" might be a little too strong a word here. Something like "accounts partly for" may sound better. The maximum height of convection depends on many factors including environmental stability (LNB) and entrainment rate. Updraft certainly correlates with the maximum height but is not the sole reason for it.

We agree and have softened the wording as follows.

“The strength of these updrafts also contributes to the maximum height reached by convective clouds and the horizontal extent of their anvils.”

l.30: For the same reason as above, "...are controlled by" could be toned down to "...related to the strength of" or something like that.

We agree. We replaced "are controlled by" with softer wording as follows.

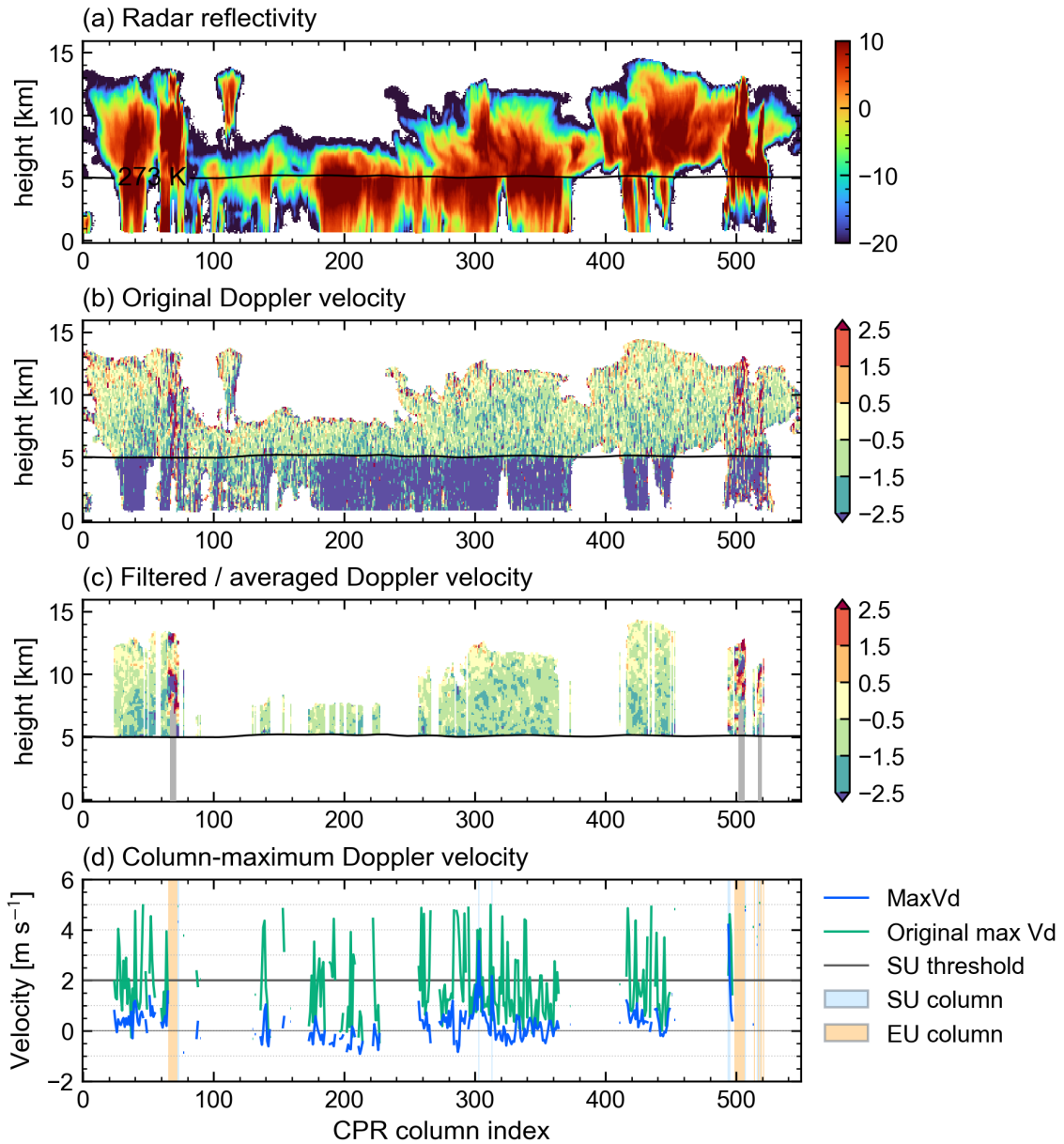
In addition, the heights and lifetimes of deep clouds, which are affected by updrafts, exert a strong influence on the planetary energy budget by reflecting incoming shortwave radiation and trapping outgoing longwave radiation (Ramanathan et al., 1989; Hartmann et al., 2001).

l.156: Where does the threshold of -19 dBZ come from? Would you be able to add a reference?

Thank you for noting this omission. We have added a reference to Hagihara et al. (2023), who evaluated Doppler-velocity uncertainty as a function of radar reflectivity and showed that random errors increase at low SNR. We also clarified that -19 dBZ is used as a quality-control threshold to remove unreliable Doppler estimates, not as a physical threshold separating cloud regimes.

l.204: Multi-layered clouds in Figure 1 look confined to  $x=100-120$  rather than "column indices 80-180" as indicated. I am wondering why a large portion of the cloud layer between  $x=80$  and 260, which seems to clear all the filtering criteria, is missing in Figure 1c except for sparsely survived columns.

We are sorry that the original description of the multilayer cloud region was inaccurate. We corrected the column-index range from "80-180" to approximately "100-120." We also clarified why many radar-echo columns between approximately  $x = 80$  and 260 do not appear in Fig. 1c. Panel 1c shows only columns that pass both the convective-selection criteria and the Doppler-quality filters, not all radar echoes. Columns are removed, for example, when cloud layers are vertically separated, when the cloud-top temperature is warmer than 258.15 K, when the cloud-base temperature is colder than 273.15 K, or when insufficient valid Doppler pixels remain after quality control. We revised the manuscript to make this point explicit.



**Figure 1 in the revised manuscript. Example illustrating Doppler-velocity quality control, folding detection, and the definition of the updraft metric MaxVd for an EarthCARE/CPR scene. (a) Radar reflectivity factor (Ref; dBZ). (b) Input CPR\_CLP Doppler velocity (Vd; m s<sup>-1</sup>) after applying only the cloud-mask threshold (cloud mask  $\geq 20$ ); positive values indicate upward motion. The black line marks the 273.15 K isotherm. (c) Doppler velocity after applying the column-selection criteria and quality control. Gaps indicate columns or gates for which no valid Doppler velocity remains after column selection and quality control. Grey shading near column indices approximately 70, 500, and 510 denotes gates flagged as being affected by multiple scattering. (d) Column-maximum Doppler velocity as a function of column index, computed from the input field in (b) for visual comparison (“Original”; green) and from the filtered and averaged field in (c) for the quantitative metric (“MaxVd”; blue). Light-orange shading denotes columns flagged as folded and classified**

**as extreme-updraft (EU) candidate columns. Light-blue shading denotes columns with  $\text{MaxVd} > 2.0 \text{ m s}^{-1}$ , classified as strong-updraft (SU) columns.**

l.212: To my eyes, a convective tower around  $x=60-80$  is obviously affected by velocity folding but is not marked as grey. The filtered  $\text{MaxVd}$  there exhibits a sudden jump, which I am afraid might be an aliased artifact that failed to be filtered out for some reason. Do you have any comment on this?

**We thank the reviewer for identifying this case. We re-examined the tower near column indices 60-80 and found that the original folding detection missed this example. In the revised analysis, we apply the updated folding criterion, and this region is now flagged as folded. We therefore updated Fig. 1 and repeated the statistical analysis throughout the manuscript using the revised folding flag.**

l.235-239: I agree that the targeted life stages and de-aliasing/averaging operations are among the reasons why  $V_d$  is much smaller than the typical updraft velocities as known in the literature. That said, it seems to me that a more essential reason may be that  $V_d$  is not updraft velocity itself.  $V_d$  can be far lower in magnitude than updraft, or even negative (falling) within an ascending cloud air, in the presence of large precipitating ice. The Z-weighted terminal velocity depends heavily on large particles and even a limited amount of large particles could have an overwhelming effect. You can see how  $V_d$  differs from updraft velocity even above the freezing level in Figures 2-4 of Heymsfield et al. (2010).

**We fully agree. This is an important clarification. We added text explaining that CPR Doppler velocity is a reflectivity-weighted hydrometeor Doppler velocity, not the air vertical velocity itself. In the presence of large precipitating ice particles, the reflectivity-weighted terminal fall velocity can substantially offset upward air motion, as the reviewer pointed out. As a result,  $V_d$  can be much smaller than the true air updraft velocity, or even downward, within ascending cloudy air. We also have added Heymsfield et al. (2010) as a reference to this additional argument, as the reviewer suggested.**

l.270: "strong updraft loft large hydrometeors" may be only a part of the story. A strong updraft may also promote the production (deposition) of ice particles and a subsequent growth by aggregation or riming at a higher altitude than a weaker updraft.

**We agree that dynamical lofting is only a part of the interpretation. We revised the sentence to include both lofting and microphysical growth processes, including ice production and growth by deposition, aggregation, and riming at higher altitudes.**

l.296: "Relation" may be a better word for "interplay" in this context?

**Corrected. We replaced "interplay" with "relation" in this context.**

l.370-373: I would suggest that you consider to mention Jeyaratnam et al. (2021, <https://doi.org/10.1029/2020GL090675>) as well. Their Figure 4 looks consistent with the present result.

We thank the reviewer for this useful suggestion. We added Jeyaratnam et al. (2021) to the discussion and now mention that their satellite-based vertical-velocity estimates show behavior consistent with our regional contrast. This connection helps place the EarthCARE Doppler-based results in the context of earlier satellite-based estimates of convective vertical velocity.

Reference: The reference list can be improved for readability by applying a hanging indent. The publisher will take care of it anyway but it will be easy for authors to do that.

Thank you for this suggestion. We checked the current Copernicus Word template and retained the template formatting for the reference list. The template examples do not appear to use an explicit hanging indent. We therefore did not manually apply additional indentation. The final layout will be handled during production if further formatting is required.