Reviewer’s comments on “EarthCARE Observations of Vertical Motion and Cloud Microphysical Structure in Tropical Cyclones” by Huang et al.

General Comments

This paper examines EarthCARE observations of tropical cyclones (TCs), focusing on the vertical structure of radar reflectivity, Doppler velocity, vertical air motion, and cloud particle types. Based on 14 months of observations, the authors compiled a few hundred to a few thousand snapshots of TC-related clouds and precipitation, depending on the distance from the TC center. Radial composites of the above variables were then constructed. In addition, the authors performed a NICAM simulation of Hurricane Humberto, which was sampled by an EarthCARE overpass through the storm center, and compared the simulation with the corresponding EarthCARE observations.

Overall, this is a useful study that will make a valuable contribution to the literature, as it represents the first spaceborne statistical characterization of TCs from the perspective of a cloud profiling radar (CPR) with Doppler capability. The observations provide a unique opportunity to jointly examine the cloud microphysics and dynamics of tropical cyclones.

The paper consists of two main components: (1) an EarthCARE-based characterization of tropical cyclones and (2) a comparison between EarthCARE observations and NICAM simulations. I find the first component to be strong, comprehensive, and well developed. In contrast, the NICAM–EarthCARE comparison is much more tentative. My primary concern is that the model evaluation is based on only a single case study (Hurricane Humberto), and the overall simulation of storm intensity for this case is rather poor (e.g., minimum sea-level pressure and maximum near-surface wind; see Fig. 8), with differences in storm intensity approaching 80%. It is entirely reasonable that a global storm-resolving model (GSRM) cannot faithfully reproduce every individual tropical cyclone. Such models are generally expected to perform better in a statistical sense than for individual storms. However, evaluating the model using only one case substantially limits the significance of the comparison. After all, it could simply be an unfortunate case in which NICAM failed to reproduce Hurricane Humberto particularly well. At the same time, asking the authors to perform NICAM simulations for a large sample of TCs comparable to the EarthCARE observational dataset would likely be impractical. Consequently, the second half of the paper is considerably less compelling than the first.

We thank the reviewer for this thoughtful assessment. We agree that the comparison between NICAM and EarthCARE is more limited than the observational analysis because it is based on a single TC case and the simulated intensity of Hurricane Humberto is not fully reproduced.

To improve the representation of the storm, we repeated the simulations using the ECMWF IFS operational analysis at approximately 9-km resolution as the atmospheric initial condition instead of the coarser ERA5 reanalysis used previously. In addition, we changed the initialization time to 26 September so that the simulation begins from an earlier and weaker stage of the hurricane, which helps reduce the intensity bias. These changes improve the simulated storm intensity and bring it closer to the IBTrACS data (see Fig. 8 below), although the maximum near-surface wind remains underestimated

We have also reduced the emphasis placed on the model comparison throughout the revised manuscript. The NICAM analysis is now explicitly described as a preliminary single-case comparison rather than as a general evaluation of NICAM performance. The purpose of the comparison has been reframed to examine how two commonly used NSW6 microphysical configurations affect EarthCARE observable cloud structures under comparable simulated storm states, rather than to assess the overall ability of NICAM to reproduce tropical cyclones.

This limitation is now emphasized in the Abstract, Introduction, Section 4, and Summary. We also state that the differences between K21 and T24 demonstrate sensitivity to the microphysical configurations in this particular case and should not be generalized to NICAM performance for TCs as a whole.

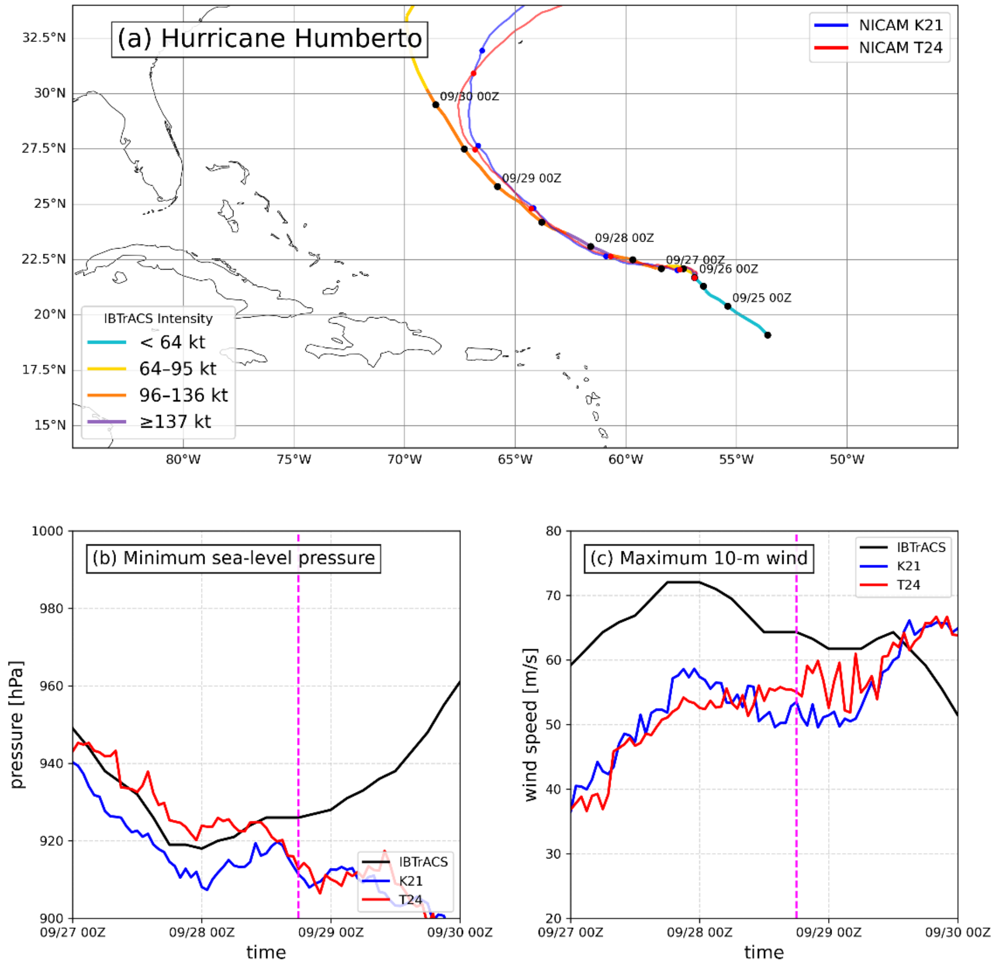


Figure 8. (a) Tracks of IBTrACS, K21, and T24. The colored segments along the IBTrACS track indicate the observed storm-intensity categories. Time evolutions of (b) minimum sea-level pressure and (c) maximum near-surface wind. The vertical dashed pink lines indicate the timing that EarthCARE intercept with hurricane Humberto.

Another major point concerns the interpretation of EarthCARE's Doppler velocity measurements and vertical air motion. The paper should clearly state, early in the introduction or data section, that the EarthCARE CPR has a Doppler Nyquist velocity of approximately ±5 m s ^{1}. Vertical velocities exceeding this range are therefore aliased $^{-}$ (folded). Without this explanation, readers, particularly those familiar with ground-based or airborne radar observations of tropical cyclones, may be surprised that the vertical motions within the hurricane eyewall rarely exceed 5 m s ^{1}. To be fair, this is not a flaw, $^{-}$ but rather a consequence of the instrument’s design. EarthCARE's Doppler capability was developed primarily to observe the relatively weak vertical motions associated with clouds such as cirrus and stratocumulus, rather than the intense convective updrafts found in tropical cyclones.

We thank the reviewer for pointing out this important issue. We have added a clear description of the CPR Doppler Nyquist velocity in Section 2.1.1. We also clarify that all vertical velocities in this study are defined as positive upward, so particle fall velocities are negative. The added part can be found ‘The CPR Doppler Nyquist velocity is approximately ±4.8 m s^{-1}, so velocities exceeding this range are aliased in the raw measurements and subsequently corrected through Doppler unfolding in the Level-2 processing. In this study, all vertical velocities are defined as positive upward, so particle fall velocities are negative.’ in Line 103-106. These additions are intended to help readers interpret the relatively limited range of Doppler velocities observed in the TC inner-core region.

On balance, I recommend major revision. One option would be to remove the model comparison section and focus exclusively on the EarthCARE observational results. Alternatively, the authors could substantially reduce the emphasis placed on the NICAM comparison. Presenting a single-case comparison in which the simulated storm intensity differs so substantially from observations ultimately weakens confidence in the model evaluation, especially since NICAM is not intended to function as a numerical weather prediction (NWP) model optimized for reproducing individual storms.

Specific Comments

● L29: Roh et al. (2026) is missing from the reference list.

We thank the reviewer for pointing this out. The publication year has been corrected to Roh et al. (2025).

● L43–44: The synergy between CPR and ATLID is not, by itself, what makes

EarthCARE unique. CloudSat/CALIPSO already provided radar-lidar synergy. EarthCARE's distinguishing feature is that its CPR has Doppler capability, whereas the CloudSat CPR does not.

We agree with the reviewer. We have revised the Introduction to clarify that the distinguishing capability of EarthCARE for this study is the Doppler measurement provided by CPR, rather than radar–lidar synergy itself. We now explicitly note that CloudSat provided radar reflectivity without Doppler velocity and emphasize that EarthCARE CPR adds new information on cloud particle motion and vertical air motion.

● L95–96: This sentence unnecessarily repeats the information already presented in L88–90.

We thank the reviewer for the suggestion. We have reorganized this part of Section 2.1.1 and removed the repetitive description.

● Fig. 1d: It should be explicitly stated that positive velocity denotes upward motion in this figure. By convention in radar meteorology, positive Doppler velocity usually indicates motion away from the radar, which would correspond to downward motion for a spaceborne radar.

We thank the reviewer for pointing out this convention. We have clarified that 'The CPR Doppler Nyquist velocity is approximately ±4.8 m s^{-1}, so velocities exceeding this range are aliased in the raw measurements and subsequently corrected through Doppler unfolding in the Level-2 processing. In this study, all vertical velocities are defined as positive upward, so particle fall velocities are negative.' in Line 103-106.

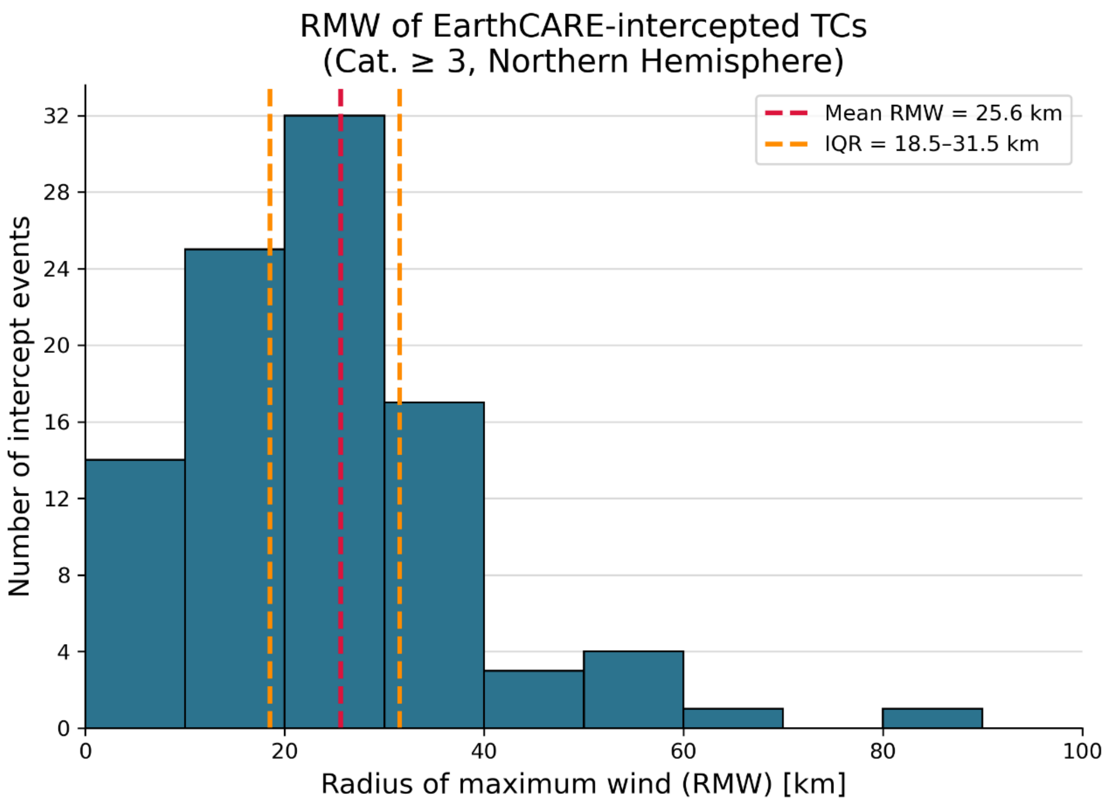
● Fig. 1d: Readers familiar with ground-based or airborne radar observations of TCs may be surprised that Doppler velocities within the eyewall only reach about 6 m s ^{1}. It should therefore be explained that the EarthCARE CPR has a Doppler Nyquist velocity of approximately ±5 m s ^{1}, so vertical velocities exceeding this range are $^{-\ -}$ aliased (folded). A similar discussion should also be included for Figs. 2c and 2d to facilitate proper interpretation.

We thank the reviewer for this important suggestion. We have added a description

‘The CPR Doppler Nyquist velocity is approximately ±4.8 m s^{-1}, so velocities exceeding this range are aliased in the raw measurements and subsequently corrected through Doppler unfolding in the Level-2 processing. In this study, all vertical velocities are defined as positive upward, so particle fall velocities are negative.’ in Line 103-106.

● Fig. 2 (and L127): Some statistics of the radius of maximum wind (RMW) should be provided for the general reader. For example, if a typical RMW is on the order of 50 100 km, this normalization implies that one unit of normalized distance corresponds to roughly 50–100 km from the storm center.

We thank the reviewer for this suggestion. We have added statistics of the RMW for the sampled TCs to provide a physical scale for the normalized radial distance



and desccription: ‘The sampled TCs have a mean RMW of 25.6 km and an interquartile range of 18.5–31.5 km (Fig. S1).’ in Line 149-151.

Figure S1. Distribution of the radius of maximum wind (RMW) for EarthCARE intercept events of Category 3 or stronger TCs. The dashed line indicates the mean RMW (25.6 km) and interquartile range (18.5-31.5 km).

● Fig. 2a: I suggest plotting the actual counts rather than their logarithms. Since the counts span roughly 50–3000, the color scale can still be displayed on a logarithmic scale to preserve dynamic range. However, requiring readers to mentally convert values of 2.0–3.4 into powers of ten interrupts the flow of reading and interpretation. The same comment applies to Fig. 3a.

We thank the reviewer for this suggestion. We have revised Figs. 2a and 3a to display the actual sample counts rather than their logarithms. This allows the sampling density to be read directly.

● L186: Is there a previous reference supporting the use of RMW = 5 as the boundary between the primary rainband and the outer rainband? If so, it should be cited.

We thank the reviewer for raising this point. We do not intend to interpret 5 RMW as a strict physical boundary between the rainband and outer regions. We have revised the manuscript to clarify that 5 RMW is used as a practical threshold for the regional analysis. We also performed sensitivity tests using 4 and 6 RMW as alternative boundaries. The resulting Doppler velocity distributions are qualitatively similar, indicating that the main conclusions are not sensitive to the exact choice of this boundary. These sensitivity results are provided in the Supplement.

● L195–205: The differing air-motion characteristics among the eyewall, rainbands, and outer region are arguably among the most important findings of this study. This section deserves substantially more discussion. In particular, how do these EarthCARE CPR results compare with previous studies based on ground-based or airborne radar observations? Relevant references should be included.

We thank the reviewer for this important suggestion. We added two paragraph to discuss that: 'Airborne and ground-based Doppler radar observations provide a useful context for the vertical air motions observed by EarthCARE. Black et al. (1996) found that more than 70% of vertical velocities in eyewall, rainband, and stratiform regions of seven hurricanes were within -2 to 2 m s-1, while the eyewall exhibited the broadest distribution and approximately 5% of the vertical velocities exceeded 5 m s-1. In our EarthCARE observations, vertical air velocities in the sampled inner-core region are mostly around 1-2 m s-1 above the freezing level, with stronger upward motions exceeding 2 m s-1 occurring on the more positive side of the Doppler velocity distribution. Thus, although the strongest updrafts reported by airborne radar are not well represented in the present EarthCARE composite, the broader distribution and stronger upward air motion in the inner-core region are qualitatively consistent with previous observations. Ground-based dual-Doppler observations of Hurricane Ike also identified localized eyewall updrafts with a mean peak upward velocity of approximately 8.3 m s-1 associated with mesovortices (Wingo and Knupp, 2016), further illustrating that localized eyewall updrafts can be substantially stronger than the composite values observed here.

For the rainband region, the EarthCARE composite is dominated by weaker upward motion of approximately 0.5 m s-1 and a pronounced bright band, indicating mainly stratiform-like characteristics in the sampled profiles. Airborne Doppler radar studies, however, have shown that localized convective updrafts can be embedded within TC rainbands (Hence and Houze, 2008; Barron et al., 2022). Barron et al. (2022) reported that the modal maximum velocity of identified rainband convective updrafts was approximately 1-2 m s-1, with 2-3 m s-1 updrafts also frequently observed at larger normalized radii. The weaker motions in our composite therefore should not be interpreted as evidence that convective elements are absent from rainbands. Instead, these elements are intermittent and occupy only part of the rainband area, while the limited number of independent EarthCARE intercepts and the narrow nadir sampling make them difficult to isolate in the present analysis. The EarthCARE composite therefore mainly represents the more frequently sampled stratiform component of the rainband, and additional observations will be needed to better characterize the embedded convective elements. Overall, the EarthCARE results are qualitatively consistent with previous Doppler radar observations, while differences in sampling should be considered when comparing the magnitude of vertical motion.' in Line 357-380.

● Fig. 4: The rationale for compositing reflectivity and vertical air velocity on a Doppler velocity–height diagram should be explained.

We thank the reviewer for this comment. We have clarified the motivation for Fig. 4 in the revised manuscript. Doppler velocity reflects the combined effects of vertical air motion and hydrometeor fall speed. Therefore, compositing radar reflectivity and retrieved vertical air velocity in Doppler velocity–height space allows us to examine which cloud and dynamical structures are associated with different parts of the Doppler velocity distribution. This analysis helps determine whether the regional differences identified in the Doppler velocity PDFs are more closely associated with differences in air motion or particle sedimentation.

● L281–283: It is not clear how terminal velocity is retrieved from particle size, shape, orientation, and temperature. Some explanation or an appropriate reference is needed. Figure 9 also suggests that the retrieved terminal velocity differs substantially from (V_{tz}), which warrants clarification.

We thank the reviewer for pointing out the need for clarification. We have substantially revised the description of terminal velocity in Section 2.1.1 and the discussion associated with Fig. 5. Following Sato et al. (2009, 2025), vertical air velocity is retrieved by estimating the hydrometeor terminal velocity from inferred particle properties and removing its effect from the observed Doppler velocity. The estimated particle terminal velocity depends on particle properties such as size, shape, orientation, and atmospheric conditions.

We now also distinguish explicitly between the retrieved particle terminal velocity and the radar reflectivity-weighted terminal velocity. The former represents the estimated falling speed of particles based on the retrieved particle properties, whereas the latter represents the sedimentation component of the measured Doppler velocity after radar-reflectivity weighting. Because the radar product does not directly provide the latter quantity, we estimate it as the difference between Doppler velocity and retrieved air velocity. This distinction explains why the two quantities can differ substantially.

● Fig. 8a: The four storm-intensity curves should be explicitly identified as IBTrACS observations.

We thank the reviewer for this suggestion. We have revised Fig. 8 and its caption to clearly distinguish the IBTrACS observations

● L354–355: I am concerned about the substantial discrepancy between the simulated and observed intensity of Hurricane Humberto. The maximum near-surface wind speeds differ by nearly 80%. Given such a large difference in the overall storm intensity, it is not surprising that the structural differences shown in Figs. 10 and 11 are also significant.

We agree that the large intensity discrepancy in the original simulation, which leads to difficulties in interpreting the structural differences. In the revised manuscript, the simulation setup has been improved by using ECMWF IFS operational analysis and by initializing the model earlier on 26 September. The simulated intensity is consequently closer to the IBTrACS observations, although the near-surface wind remains underestimated. Therefore, these differences are interpreted cautiously, and the comparison is used mainly to examine the relative response of the simulated cloud structure to the K21 and T24 microphysical configurations rather than to attribute all discrepancies between model and EarthCARE to microphysics alone.