Report #1

We sincerely thank the reviewer for the positive assessment and for highlighting the need to further strengthen the physical interpretation of our results.

Following the recommendations, we have redrafted the discussion section to shift the focus from attenuation-based arguments towards a DSD-driven microphysical interpretation.

Below we address each point raised.

1. **Why the externally derived Z–R relationship behaves the way it does?**
2. **and why surface gauge comparisons differ strongly with altitude?**

The Z–R relationship applied in this study was originally derived from drop size spectra obtained during four research flights into three hurricanes (Jorgenses and Wills, 1981). Given that tropical cyclones feature both stratiform and convective rainfall (Houze, 1977), Jorgensen and Willis (1981) aimed to develop a single, unified Z–R relationship suitable for Tropical Cyclones. Their best-fit result is:

$$Z = 300\, R^{1.35}$$

We adopted this Z–R relation for our analysis, because our dataset includes both stratiform and convective precipitation, conditions for which this relationship was originally calibrated.

However, Jorgensen and Willis (1981) themselves noted that this relationship exhibits less scatter near the surface compared to higher altitudes (~1500 m). At higher altitudes, measurements are above the cloud base, where updrafts transport a greater number of small drops upward. This process introduces larger variability in the Z–R relationship.

Their findings aligned with our results: at low-altitude stations (Group 1), the Z–R relationship performs better, as the drop size distribution more closely represents the climatological conditions assumed by the $Z = 300\, R^{1.35}$relationship.

At higher-altitude stations (Group 2 — Bellecombe and Commerson), performance degrades significantly. According to literature, two compounding mechanisms could explain this:

- First, these stations are located on mountain peaks and are therefore subject to orographic precipitation processes. Singh et al. (2024) have demonstrated that in both orographic and convective rainfall, microphysical processes such as collisional drop breakup are frequent due to enhanced turbulence, strong vertical motions, and frequent drop–drop interactions. These processes reshape the DSD by increasing the concentration of small drops while reducing the proportion of large drops.

  It leads to significant deviations from standard Z–R relationships. Notably, Singh et al. (2024) also show that the occurrence of equilibrium DSDs decreases with increasing rain rate, meaning that at high rain rates, the DSD is least likely to match the assumptions embedded in climatological Z–R relationships.

- Second, at high altitudes stations (above 2000m), the radar's sampling volume may lie within or just above the cloud base, where updrafts actively sort droplets by size, preferentially transporting the smallest ones upward.

In summary, the degraded performance of the Z–R relationship at high-altitude stations is the combined result of: (1) the intrinsic limitation of Z–R relationships above cloud base, as acknowledged by their original authors; (2) orographic microphysical processes influence the DSD; and (3) the absence of large drops needed to trigger the D^6 sensitivity of reflectivity. These conditions systematically cause the Z–R estimator to underpredict rain rates at high-altitude gauge locations.

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(3) why the authors' new R–KDP relationship performs differently?

In addition, unlike reflectivity, which is proportional to the sixth moment of the drop size distribution ($\propto D^6$) and is therefore highly sensitive to large drops, kdp scales approximately with the fourth moment ($\propto D^4$). As a result, kdp is less dominated by a few large drops and is more closely related to drop concentration and liquid water content.

Under tropical-cyclone conditions, particularly at the outer rain bands where very high concentrations of small-to-medium drops are often observed, so kdp can become large even when Z remains only moderate. This provides a physical explanation for why the derived $R(\text{kdp})$ relationship performs better for heavy rain (Bellecombe and Commerson) than the borrowed Z–R relation in this event. Furthermore, warm-rain processes below the freezing level, including coalescence and breakup, play an important role in shaping these DSD characteristics (Thurai et al., 2020; Yang et al., 2025). The present $R(\text{kdp})$ relation should therefore be viewed as event-specific, reflecting the microphysical conditions sampled during this tropical cyclone rather than a universally transferable X-band relation.

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Report #2

We sincerely thank the reviewer for their time, careful reading, and constructive comments. We greatly appreciate the insightful feedback, which has helped us improve the clarity scientific quality of the manuscript.

We have carefully addressed all comments and revised the manuscript accordingly.

(1) In section 2.2, please state why a multi-parameter combined polarimetric estimator (e.g., Matrosov et al., 2002) was not also tested.

Many studies have demonstrated the effectiveness of multi-parameter polarimetric rainfall estimators, such as $R(K_{DP}, Z_{DR})$or $R(Z_H, Z_{DR}, K_{DP})$(e.g., Figueras I Ventura et al., 2012; Illingworth, 2005; Koffi et al., 2014; Li et al., 2023)). These estimators, whose empirical coefficients are derived from observations, generally outperform the classical $R(Z)$relationship, particularly for rainfall rates exceeding 10 mm h^{-1}.

However, estimators involving Z_{DR} require accurate calibration of the radar system. In particular, two main sources of bias can significantly affect Z_{DR}:

(i) the transmission and reception chains, especially uncertainties in the relative attenuation or gain between the two polarimetric channels, and

(ii) near-radome effects and the radome itself (Sugier and Tabary, 2006; Thiruvengadam et al., 2025).

Even a small bias of 0.2 dB in Z_{DR}can lead to an overestimation/underestimation of rainfall by about 15% (Figueras I Ventura et al., 2012; Zeyong et al., 2019), making the reliability of such estimators highly dependent on calibration quality.

Calibration methods exist in the literature, including approache based on the intrinsic properties of meteorological targets observed at high elevation angles (near 90° in PPI mode), where Z_{DR}values close to 0 dB are expected (Gorgucci et al., 1999). However, such high-elevation PPI scans were not available during the first campaign in La Réunion, as the system was still in a testbed phase.

(During a subsequent deployment in the Seychelles and Madagascar, a 90° elevation scan was included in the scanning strategy.)

Given these constraints and to avoid potential errors associated with poorly calibrated Z_{DR}. This study relied exclusively on $R(Z)$ and $R(K_{DP})$ estimators. Nevertheless, this choice is further supported by previous studies showing that $R(Z)$ performs better in light to moderate rainfall, while $R(K_{DP})$is more robust in heavy rainfall conditions (Koffi et al., 2014b).

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(2) In Table 3, please use consistent precision for each variable (2 decimal places recommended). Even if the second digit is 0, this is not clear from the table.

Thank you for the recommendation, we will take it into account in the revised article.

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