The manuscript addresses an important problem in dual-frequency radar retrieval of raindrop size distributions, namely the ambiguity in the DFR-Dm relationship. The proposed use of an additional Ka/W-band constraint is an interesting idea and may have value for improving retrievals in weak-echo or small-drop regimes. However, in its current form, the manuscript requires substantial revision before the method and conclusions can be fully evaluated.

My primary concern is that the retrieval framework is not described clearly enough to determine how independent the information used in the retrieval actually is. In particular, the Ka/W-band constraint appears to be based on W-band reflectivities simulated from measured DSDs rather than independent W-band radar observations. This creates a potential circularity problem, especially because the same or closely related DSD information appears to be used to construct retrieval relationships and evaluate the retrieved parameters. The manuscript should more clearly distinguish observed quantities from simulated or fitted quantities and explain how the method would be applied to independent radar observations.

More broadly, the study is based on a small dataset from a single location and relies heavily on fitted relationships derived from that dataset. The authors should therefore be more cautious in presenting the method as generally applicable. Additional discussion is needed regarding calibration uncertainty, attenuation correction, FMCW radar-specific issues, beam mismatch, representativeness of the 2DVD validation, and the practical limitations of using W-band observations in rain. The discussion and conclusion should also be expanded to address these limitations and to identify the additional validation required before the method can be considered robust across different precipitation regimes, locations, and radar systems.

1) The abstract is too general and should quantify the claimed improvement. The authors state that the proposed method substantially reduces the DFR-Dm ambiguity and performs better than conventional approaches, especially for weak echoes, but the abstract does not report any specific performance metrics.

Response: We thank the reviewer for this valuable suggestion. The revised abstract has been completely rewritten to include specific quantitative metrics that substantiate the claimed improvements:

a. Ambiguity reduction: We now explicitly state that the proportion of data permitting a unique Dm solution increased from 35.38% (using DFR(X, Ka) alone) to 87.5% after incorporating the DFR(Ka, W) constraint.
b. Weak-echo performance: We specify that the proposed framework maintains robust accuracy for weak echoes (< 20 dBZ), where conventional methods fail.
c. Proof-of-concept scope: We have re-framed the study as a "proof-of-concept"

investigation to appropriately constrain the claims.

2) The authors should clarify that the method retrieves DSD parameters under an assumed normalized gamma distribution with fixed μ, rather than independently retrieving the full DSD shape. Since μ is fixed and LWC is obtained from a fitted ZKa-LWC relationship, the resulting DSD is strongly constrained by the assumed distribution form and fitted relationships. The manuscript should avoid implying that the full DSD is independently retrieved without these assumptions.

Response: This is an important clarification. We have made the following revisions to explicitly state the assumptions and constraints:

a. Figure 1 caption (Section 2.1): The caption now explicitly reads: "Flowchart of X/Ka dual-frequency radar retrieval for normalized gamma raindrop size distribution." This makes the assumed DSD model immediately visible to the reader.
b. Section 2.2, Step 8: The final step of the retrieval procedure now explicitly states that Dm-est and Nw-est are substituted into the normalized gamma distribution function with $\mu = 3$.
c. New Section 5.1 ("Practical Applicability of Ka-W Constraints"): We added a paragraph discussing the limitations of the fixed-μ assumption and the trade-off between Dm and Nw retrieval accuracy for different μ values. We acknowledge that the full DSD is not independently retrieved, but rather reconstructed under the normalized gamma assumption.
d. Title change: The title has been revised to "The Proof-of-Concept for Raindrop Size Distribution Retrieval..." to better reflect the constrained nature of the retrieval framework.

3) The use of an FMCW radar system should be discussed in more detail. The proposed retrieval depends on accurate X- and Ka-band reflectivity measurements, so the authors should explain how the two radar channels were calibrated and matched in range, timing, sensitivity, and beam volume.

This is especially important because the method relies on DFR, which can be strongly affected by small calibration offsets or system artifacts. Since the authors claim improved performance in weak-echo conditions, they should also discuss FMCW-specific issues such as signal-to-noise limits, leakage/clutter suppression, range sidelobes, and range-Doppler effects. These factors could affect the computed DFR and therefore the retrieved Dm and Nw.

Response: We have significantly expanded the discussion of the FMCW system and its implications for retrieval accuracy:

a. Section 3.1 ("Instruments"): We added explicit text stating that the X/Ka dual-frequency radar, developed by the 38th Research Institute of China Electronics Technology Group Corporation (CETC-38), employs a fully solid-state frequency-modulated continuous wave (FMCW) system with **coaxial scanning and has undergone absolute calibration prior to field deployment**.

b. New Section 5.2 ("Radar Calibration and DFR Uncertainty"): We added a dedicated subsection that explicitly discusses four critical uncertainty sources:

   - Calibration error propagation: How calibration errors at either frequency directly propagate into DFR estimates.
   - Beam mismatch: The sampling volume differences between the X-band (1°) and Ka-band (0.4°) antennas, and how temporal smoothing mitigates this.
   - Attenuation correction uncertainties: Particularly at Ka-band where both attenuation and Mie scattering are significant.
   - DFR error amplification: How small errors in individual reflectivity measurements can be amplified in DFR calculation, especially in weak echo regions with low SNR.

We emphasize that this study serves as a proof-of-concept investigation, and that for operational implementation, these uncertainties require quantitative assessment and the development of corresponding mitigation strategies.

4) The manuscript states that the Ka-band beamwidth is 0.4° and the X-band beamwidth is 1°, and that a 3-point moving average along the time dimension adjusts the Ka-band beamwidth to 1.2°. This statement needs clarification. Temporal smoothing does not directly change antenna beamwidth.

The authors should revise this section to describe the procedure more accurately. If the intent is to reduce scale mismatch between the two frequencies by temporal averaging, then the authors should say so and quantify the effective sampling distance associated with the averaging window. If the authors are claiming an effective beamwidth adjustment, they need to justify how this was calculated.

Response: The reviewer is absolutely correct. We have revised the statement in Section 3.1 and removed the misleading claim regarding "effective beamwidth adjustment." The revised text now accurately describes the procedure:

“To mitigate the scale mismatch between the two frequencies, Ka-band reflectivities are temporally smoothed using a 3-point running mean. This increases the effective averaging scale along the time dimension, rendering the smoothed Ka-band sampling volume approximately equivalent to that of the X-band.”

This revision clarifies that the intent is to reduce scale mismatch by increasing the effective sampling volume through temporal averaging, not to alter the physical antenna beamwidth.

5) A major concern is that the Ka/W-band constraint does not appear to come from independent W-band radar observations. Instead, the W-band reflectivity appears to be simulated from the same measured DSD dataset used to build the retrieval relationships. This creates a risk of circular reasoning: the method appears to use DSD observations to create a simulated W-band constraint, then evaluates the retrieval against DSD-derived quantities.

The authors should clearly separate observed radar quantities from simulated quantities. They should also show that the method works on independent data that were not used to build the simulated Ka/W relationships, preferably through event-independent or site-independent validation.

Response: This is indeed the most critical concern, and we have addressed it directly and comprehensively throughout the revised manuscript:

a. Abstract: We now explicitly state: "W-band reflectivities obtained through scattering simulations based on measured raindrop size distributions, combined with the DFR(Ka, W) constraint..."
b. Section 2.1 (Retrieval Framework, Figure 1): We added a clear visual and textual distinction: blue boxes represent scattering simulation results, and green boxes represent radar observation data. The caption reads: "Blue arrows indicate the scattering simulation workflow, while green arrows represent the retrieval workflow for real radar observation data."
c. Section 2.2 and Section 5.1: We explicitly acknowledge that this study does not include W-band radar observations, and that the DFR(Ka, W) constraint is currently a theoretical assessment of its potential to mitigate ambiguity.
d. New Section 4.4 ("Independent Validation"): To address the circularity concern, we explicitly separated the dataset:
    - Development data: Three precipitation events in 2022 (May 1, May 11, June 11) used to construct the retrieval relationships.
    - Independent validation data: A separate precipitation event on June 14, 2025, which was not included in the relationship development.
    - The independent validation results (Dm-validation and Nw-validation) demonstrate comparable accuracy to the training-period evaluation (Table 7), supporting generalizability to unseen data.
e. Section 6 (Conclusions): We explicitly state that the practical applicability of the Ka-W constraint for operational three-frequency radar systems requires further validation with real W-band observations.

We agree that the independent-event validation does not completely eliminate the conceptual dependence introduced by the simulated W-band constraint, because the DFR(Ka,W) relationship is still derived from DSD-based scattering simulations. Therefore, the present study should be regarded as a proof-of-concept investigation demonstrating the potential value of an additional high-frequency constraint, rather than a fully independent validation of an operational triple-frequency retrieval framework.

6) Although a retrieval flow chart is provided, the manuscript does not include a clear narrative description of the algorithm. As a result, the operational retrieval procedure remains difficult to follow. The authors should walk the reader through the method step by step, identifying the required inputs, which quantities are directly observed, which are simulated or fitted, and the order in which Dm, LWC, and Nw are retrieved.

The manuscript should also clarify the mathematical form of the retrieval. Is the method simply direct evaluation of fitted relationships, lookup-table interpolation, numerical inversion, optimization, or another approach? This clarification is important for reproducibility and for understanding how the algorithm would be applied to independent radar observations.

Response: We have substantially revised Section 2.2 ("Retrieval Procedure") to provide a comprehensive, step-by-step algorithmic description. The retrieval now consists of eight clearly numbered steps:

Step 1: 2DVD observations → ground-truth DSDs, Dm, LWC, Nw.

Step 2: T-matrix scattering simulations → theoretical Z_X, Z_{Ka}, Z_W, A_X, A_{Ka}, k(X, Ka).

Step 3: Fitting of retrieval relationships (DFR-Dm, DFR-Z, k(X,Ka)-A, LWC-Z_{Ka}).

Step 4: Attenuation correction of observed reflectivities using differential specific attenuation, constrained by theoretical DFR(X, Ka)-Z_X.

Step 5: Calculation of DFR*(X, Ka) and DFR*(Ka, W) from corrected reflectivities.

Step 6: Dm retrieval using combined DFR*(X, Ka) and DFR*(Ka, W).

Step 7: LWC retrieval from $Z_{Ka\text{-}cor}$, then Nw computation from Dm and LWC.

Step 8: DSD reconstruction via normalized gamma function (μ = 3).

We also clarify that the method uses direct evaluation of fitted polynomial relationships (Eq. 12, 17) rather than numerical inversion or optimization, which improves reproducibility and operational clarity.

7) The comparison between radar retrievals at approximately 120 m and surface 2DVD measurements requires more discussion. The authors should address the representativeness error caused by fall time, wind drift, vertical air motion, radar sampling volume, and the much smaller sampling area of the disdrometer. These effects may contribute to differences between retrieved and observed DSD parameters and should be considered in the validation.

Response: We have added a new subsection, Section 5.3 ("Representativeness of 2DVD Validation"), that comprehensively discusses these issues. We explicitly address:

a. Wind drift: Horizontal displacement between the radar sampling volume and the disdrometer location during raindrop fall, particularly under strong wind conditions.
b. Temporal lag: The time required for raindrops to fall from the radar sampling height (120 m) to the ground, which may result in sampling different parcels in rapidly evolving precipitation systems.
c. Sampling volume mismatch: The fundamental difference in sampling volumes (radar: ~30 m resolution; 2DVD: ~10 cm), which can lead to statistical representativeness errors in inhomogeneous precipitation fields.

We acknowledge that these factors limit the absolute accuracy of quantitative comparisons and clarify that the 2DVD measured DSDs are used to ensure that the radar retrieved results are reasonable and relatively accurate, rather than to claim perfect agreement.

8) A large fraction of the dataset falls in the DFR(X,Ka) ≤ 0 ambiguous regime. This may be physically reasonable for light rain or small-drop populations, but the authors should show the distribution of DFR, Dm, rain rate, and reflectivity and explain why this regime dominates the dataset. They should also demonstrate that the large negative-DFR fraction is not caused by relative calibration bias, attenuation-correction error, beam mismatch, or limited sampling of precipitation regimes.

Response: We have analyzed the DFR distribution and its physical basis in Sections 3.5 and 4.1, with supporting evidence from Figure 4 and Table 6:

Physical explanation: The high proportion (64.62%) of DFR(X, Ka) ≤ 0 is physically attributable to the predominance of small-to-moderate raindrops in the subtropical precipitation regime of Yangjiang, Guangdong. As shown in Figure 4 and Table 6, the dataset includes extensive stratiform and light-rain periods (e.g., May 1, 2022; the weakening stratiform phase of June 11, 2022), characterized by narrow DSDs with small mass-weighted mean diameters.

Exclusion of instrumental artifacts: Since the DFR values used to define the ambiguous zone are theoretically derived from T-matrix scattering simulations based on measured DSDs, negative DFR values cannot be caused by relative calibration bias, attenuation correction errors, beam mismatch, or limited sampling of precipitation types. The ambiguity is an intrinsic physical property of the DFR(X, Ka)-Dm relationship for small drops.

Impact assessment: In Section 4.1 and Figure 14, we show that rain rates do not exceed 0.6 mm h^{-1} when Dm < 0.5 mm, confirming that the residual ambiguity in the DFR(Ka, W) regime corresponds to negligible precipitation intensities.

9) The choice of fixed μ = 3 needs stronger justification. The sensitivity test shows that μ affects both Dm and Nw retrievals. However, the results appear *to show that μ = 0 gives the smallest Dm retrieval error, while larger μ values improve Nw error. The authors choose μ = 3, citing consistency with prior work. This may be reasonable, but the justification should be expanded.*

The authors should clarify the objective function used to select μ. Is the priority minimizing Dm error, Nw error, DSD shape error, or some combined metric? Since the proposed method is intended to retrieve DSDs, not only Dm, the authors should consider evaluating full DSD reconstruction error as a function of μ. The authors should also discuss whether μ is expected to vary by precipitation regime and whether fixing μ = 3 limits performance in convective or light-rain cases.

Response: Thanks for your suggestion, which has made our work more rigorous. We have added an cost function. Although a full DSD reconstruction error metric would be desirable, the primary purpose of the retrieval framework is to estimate Dm and Nw, which are the governing parameters of the normalized gamma distribution. Therefore, Dm and Nw retrieval errors were selected as the optimization criteria in this study.

To determine the optimal μ that minimizes the retrieval errors of both Dm and Nw against the ground-truth values, the Euclidean distance from each candidate μ to ideal point —serving as the cost function:

$$J = \sqrt{[RMSE(Dm) - min(RMSE\_Dm)]^2 + [RMSE(Nw) - min(RMSE\_Nw)]^2}$$

Here, min(RMSE_Dm)= 0.0006 and min(RMSE_Nw) = 0.0412 (Table 5), defining the coordinates of the ideal point in the objective space. The Euclidean distance from each candidate μ is presented in Fig. 11. The results indicate that μ=3 corresponds to the shortest distance (0.061), closely followed by μ=6 (0.063), while μ=−3 exhibits the largest deviation. Therefore, μ=3 represents the optimal value that minimizes the retrieval errors of Dm and Nw, consistent with the value adopted by Meneghini et al. (2022).

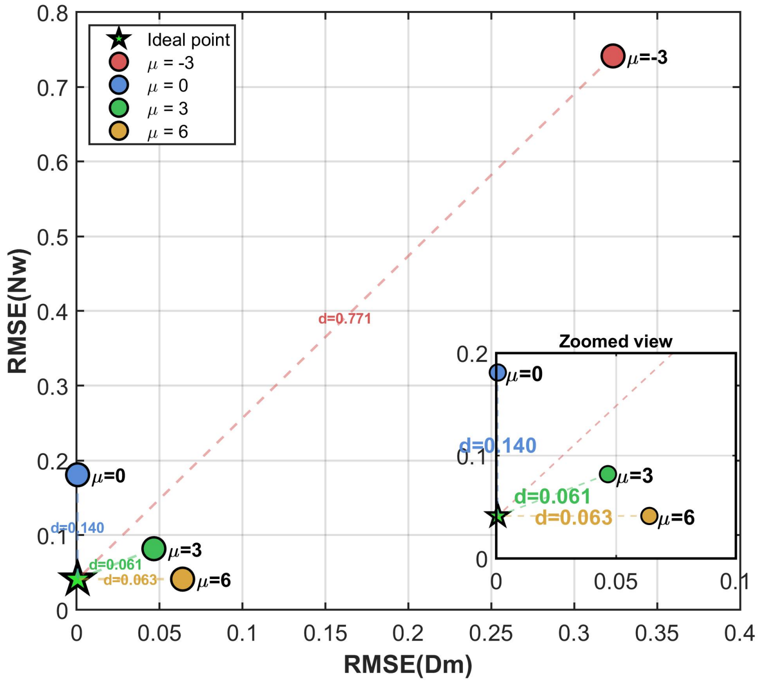

Figure 11. The Euclidean distance between each candidate μ and ideal point.

10) The manuscript introduces a raindrop axis-ratio relationship after discussing polarization-dependent scattering from oblate raindrops. However, the radar observations used here are vertically pointing, for which the authors state that polarization-dependent differences are effectively eliminated and ZH≈ZV. The authors should clarify the role of the assumed axis-ratio model in the vertically pointing T-matrix simulations. If the axis ratio is used only to compute absolute backscatter cross sections and frequency-dependent DFR behavior under vertical incidence, this should be stated explicitly. The authors should also quantify the sensitivity of the simulated DFR–Dm relationships to the assumed axis-ratio relation, especially at Ka and W band where non-Rayleigh scattering effects may be important.

Response: The reviewer is correct. The axis-ratio model is still required in the T-matrix calculations because the scattering and extinction properties depend on particle shape. However, under vertically pointing observations, polarization-dependent differences are negligible and do not directly affect the retrieval framework.

11) The manuscript should discuss the practical difficulty of using W-band radar measurements in rain. While the simulated Ka/W-band DFR relationship may help reduce the DFR(X,Ka)-Dm ambiguity, real W-band observations can *be strongly attenuated by rain, cloud liquid water, atmospheric absorption, and wet radome effects. In moderate or heavy precipitation, the W-band signal may become too weak or unreliable to provide a useful constraint.*

This point is especially important because the manuscript claims that the proposed method is useful for weak-echo situations. Weak echoes are also where W-band detectability, calibration uncertainty, and signal-to-noise limitations may become especially important, while moderate to heavy rain introduces severe attenuation concerns. Since the manuscript uses simulated W-band reflectivity rather than actual W-band radar observations, the authors should clarify whether the method is intended for real triple-frequency radar measurements or only as a simulation-based constraint. If it is intended for real W-band use, they should show under what rain-rate, range, reflectivity, and attenuation conditions W-band observations would remain useful.

Response: We have significantly expanded this discussion in the new Section 5.1 ("Practical Applicability of Ka-W Constraints"). We explicitly state:

"It is important to explicitly acknowledge that this study does not include W-band radar observations. The W-band reflectivities used herein were obtained entirely through T-matrix scattering simulations based on measured DSDs. Therefore, the DFR(Ka, W) constraint should currently be regarded as a theoretical assessment of its potential to mitigate DFR-Dm ambiguity, rather than a fully operational retrieval constraint that has been validated with real three-frequency radar data. The practical implementation of this approach would require a three-frequency radar system with X/Ka/W bands, and the actual performance may be affected by W-band radar calibration accuracy, atmospheric attenuation at W-band, and signal-to-noise ratio limitations. This study provides a proof-of-concept demonstration that motivates the development of future three-frequency radar systems for operational DSD retrieval."

This statement makes clear the current theoretical nature of the constraint and the operational requirements for future implementation.

12) Figure captions should be much more descriptive and should pay careful attention to which values are simulated vs. measured.

Response: We have revised all figure captions to explicitly distinguish between simulated and measured quantities. For example:

Figure 1: Blue arrows indicate scattering simulation workflow; green arrows represent retrieval workflow for real radar observation data.

Figure 6: Scatterplots of simulated X-band reflectivity and DFR(X, Ka) from T-matrix calculations.

Figure 8: Comparison between observed/corrected radar reflectivities and reflectivity derived from measured DSDs.

Figure 11: Scattering simulation scatterplots showing theoretical DFR-Dm relationships.

Figure 15. Scatterplots of the Ka-band reflectivity (Z_{Ka}) and liquid water content (LWC)

through scattering simulation.

13) The discussion and conclusion are too limited given the scope of the claims. The study is based on only three development cases and one validation case from a single observation site. This is a small and geographically limited dataset, and the manuscript does not adequately discuss whether the retrieval relationships would generalize to other locations, precipitation regimes, seasons, climates, or radar systems.

This limitation is especially important because the proposed method relies heavily on curve fitting and regression relationships derived from the available DSD dataset, including the DFR-Dm relationships, the simulated Ka/W constraint, and the ZKa-LWC relationship. With such a small and localized dataset, these fitted relationships may reflect site-specific DSD characteristics rather than a generally applicable retrieval method.

The authors should add a more complete limitations section. In particular, they should discuss the limited sample size, the use of one site, the dependence on local DSD characteristics, the lack of independent W-band observations, and the uncertainty of applying near-surface DSD-derived relationships to elevated radar volumes. The future-work discussion should also be expanded. The introduction states that limitations and future research directions will be discussed, but the conclusion only briefly mentions height-dependent DSD models and does not provide a broader path for validating or extending the method.

Response: We fully acknowledge that the original discussion of limitations was insufficient. We have completely restructured the discussion and conclusion to address these concerns:

a. New Section 5.4 ("Generalization and Sample Limitations"): We explicitly state:
    - The framework was developed using data from a single observational site (Yangjiang, Guangdong) and a limited number of precipitation events (four cases total: three for development, one for independent validation).
    - The fitted relationships (DFR-Dm, DFR(Ka,W)-Dm, LWC-Z~Ka~) may reflect site-specific DSD characteristics (e.g., maritime-influenced warm-rain processes in South China) rather than universally applicable physical laws.
    - The generalization capability to other climatic regions, seasons, and precipitation regimes remains to be demonstrated.

b. Vertical representativeness (Section 5.3): We acknowledge that applying near-surface 2DVD-derived relationships to elevated radar volumes assumes vertical homogeneity that may not hold in practice.

c. Expanded Conclusions (Section 6): We have significantly expanded the future-work roadmap to include:
    - Real W-band validation with actual three-frequency radar observations.
    - Leave-one-event-out cross-validation with a larger sample size.

- Multi-site and multi-season validation across diverse geographical locations.
- Height-dependent DSD models for upper-level retrievals.
- Polarimetric constraints using the full polarimetric capability of the radar system.
- Operational uncertainty quantification including calibration error propagation and attenuation correction sensitivity.