----- For clarity: Reviewer comments are shown in black italics, Author responses are shown in RED. -----

-------------------- *REFEREE 1* --------------------

Summary: *This manuscript outlines simulations of spectral polarimetric radar observations for rain. The single-scattering properties are calculated using the T-matrix method for spheroids with aspect ratios determined from previous empirical relations. The spectra are then simulated using two methods for randomly generating radar signals, and the spectral ZDR and backscatter differential phase are computed from these signals and compared to observations. The simulated power spectra are fit using gamma PSD parameters and a parameter for the wind speed variability due to turbulence. The general shapes of the simulated polarimetric spectra are similar to the measurements; the magnitudes show substantial differences.*

General comments: *This manuscript provides some interesting insight into using the spectral polarimetric radar measurements to better understand rain microphysics. However, there are some issues with this study that need to be addressed before it is acceptable for publication.*

The first issue I have with this study is that the fitting of the PSD parameters and the air motion variability parameter (σ_t) are only done with respect to the spectral power. Therefore, the PSD parameters controlling the width of the particle spectrum may be compensated by the σ_t to best fit the spectrum. As such, the assumed σ_t may deviate substantially from the σ_t associated with the measurements, introducing errors into the comparisons with the spectral polarimetric variables. To address this issue, the authors may want to show the sensitivity of the spectral polarimetric variables to σ_t and the PSD parameters. Additionally, showing the range of PSD parameters and values of σ_t that have similar RMSE during the fitting process would clarify how well constrained these parameters are.

Excluding the effects of noise and spectral averaging, the primary physical factors influencing the spectral polarimetric variables are the axis ratio–diameter relationship, the canting angle distribution, and variability in air motion, characterized by σ_t. The particle size distribution (PSD) has a comparatively minor impact on these variables. When $\sigma_t = 0$, the spectral polarimetric variables become independent of the PSD. In fitting the Doppler power spectrum, the PSD parameters that influence spectral width can be offset by variations in σ_t to optimize the spectral fit. Consequently, rather than fitting the entire Doppler spectrum, we focus on its upper portion (above a threshold of-8 dBZ/ms^{-1}), which emphasizes the resonance notches—whether sharp or smoothed—providing a more robust indication of the magnitude of σ_t. This is illustrated in the following figures (1-3).

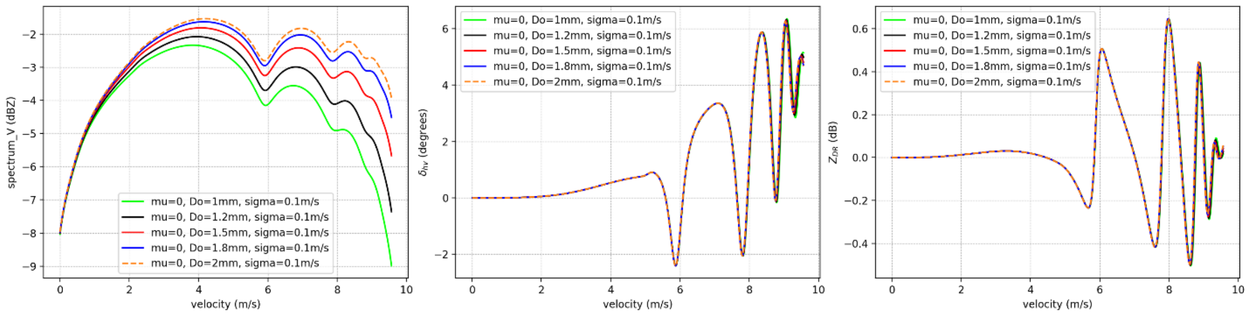

Figure 1 Simulated Doppler spectra and spectral polarimetric variables for rain at different mass-weighted mean diameter (Do).

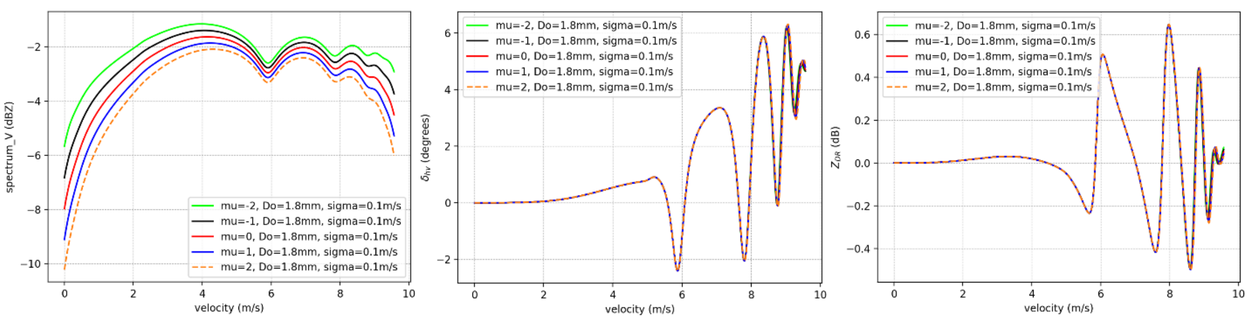

Figure 2 Simulated Doppler spectra and spectral polarimetric variables for rain at different mu (μ).

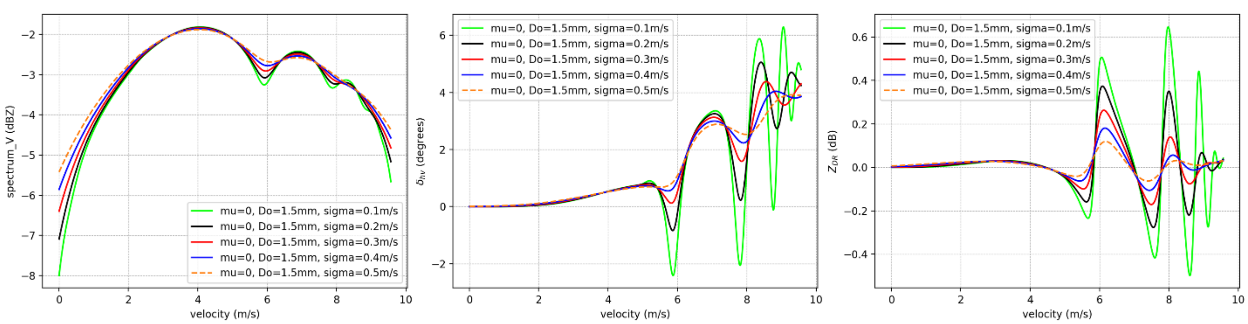

Figure 3 Simulated Doppler spectra and spectral polarimetric variables for rain at turbulence conditions (σ_t).

Similarly, the authors mention that the spheroid shape may not adequately represent the scattering of natural raindrops due to processes such as drop oscillations. However, a variety of spheroids with the same fall speed but different aspect ratios could better represent this process and provide evidence as to whether the assumption of fixed aspect ratios for a given particle size is responsible for the poor comparisons between the simulated and measured spectral ZDR. Randomly sampling aspect ratios for particles of the same fall speed would help demonstrate whether the broadening of the spectral polarimetric variables due to aspect ratio variability produces simulated spectra that are more consistent with the measurements.

We thank the reviewer for this valuable suggestion. By comparing simulated and observed spectral polarimetric variables at W-band, this study has demonstrated overall agreement, while also highlighting specific discrepancies. As such, it represents an initial step toward improving the simulation of spectral polarimetric variables at W-band. Future work will focus on investigating the potential causes of these discrepancies (this comment, next comment,....). One possible factor to explore is the assumption of a fixed aspect ratio for a given particle size.

Finally, there should be more discussion of simulating spectral polarimetric variables for radars with different transmission and reception strategies. For instance, fully polarimetric radars that transmit horizontal, receive horizontal and vertical, transmit vertical, and receive horizontal and vertical are processed differently than simultaneous transmit/receive radars. These differences could also explain some of the discrepancy between the observed and simulated spectral polarimetric variables. It is unclear what the transmission and reception strategy is for the radar observations presented in the manuscript. This information needs to be included to better understand how faithfully the method for simulating the spectral radar variables emulates the processing algorithm of the radar.

The polarimetric data acquisition is now mentioned at the beginning of section 3 (Lines 259-260): "The cloud radar measurements were obtained using a RPG Frequency Modulated Continuous Wave (FMCW) Dual Polarization W-band Cloud Doppler Radar, operating at 94 GHz in a simultaneous transmission- simultaneous reception (STSR) mode."

Specific Comments

- *Lines 24-25: Vertically pointing radar are also able to do this. Please add that radars in slant polarization mode can take advantage of polarimetric measurements.*

The text is modified accordingly (Lines 24-27): "This configuration has the critical advantage that particles with different sizes are separated in the spectral domain (because they have different sedimentation velocities), which allows to disentangle the contributions of different particle types. While vertically pointing radars can also achieve this separation, radars in slant polarization mode additionally exploit polarimetric measurements."

- *Line 39: Do you mean vertically profiling here? Please clarify.*

No, we don't mean "vertical profiling". We wrote "slant or horizontal profiling" because meaningful polarimetric variables are obtained at low/intermediate elevation angles. However, there is an exception for the linear depolarization ratio, which can be used for applications involving vertical profiling.

- *Lines 50-52: "Describing the methodology to compute spectral polarimetric variables" doesn't really address a science question. Based on the previous line and my impression of* *the study, a stronger goal might be to explore how different assumptions impact the simulated spectral polarimetric variables.*

The text is modified to (Lines 66-68) "Goal of this study is to explore how different assumptions that are related to atmospheric conditions (turbulence) and white and stochastic noise of a real radar spectrum, impact the simulated spectral polarimetric variables. The second objective is to present a novel comparison between simulated and observed data." This text is placed at the end of the introduction before the description of the paper structure.

- *Lines 57-58: The T-matrix method can simulate the scattering properties of arbitrary shaped particles (as long as the numerical integration converges; Wriedt 2002). However, these codes are not widely available and are much less efficient. Please change this sentence accordingly.*

The text is modified to (Lines 56-59) "However, raindrops generally change due to oscillations, which cause departure from rotationally symmetric shape. The T-matrix method can, in principle, simulate scattering from non-rotationally symmetric particles (given numerical convergence; Wriedt 2002), but such implementations are computationally demanding and not widely available. As a result, most T-matrix applications rely on the assumption of rotationally symmetric particles."

- *Lines 74-75: Does equation (1) come from one of these studies specifically? Please clarify.*

This is now specified at Lines 78-79. "In the following, Eq. (1) is employed to describe the raindrop axis ratio. For small raindrops, the axis ratio follows the parameterization by Keenan et al. (2001), while for larger drops, the formulation of Beard and Chuang (1987) is applied."

- *Line 144: Please add some reference(s) for these equations.*

We have cited Altas et al., (1973) where the relationship between drop diameters and corresponding terminal velocities is described, and the relevant curves are shown in Figure 5.

- *Line 157: Where does this equation come from? Please address.*

A reference is added in Line 166.

- *Line 158: Shouldn't this denominator be in terms of v_{los} instead of v_t? What if the horizontal wind is large compared to the fall velocities or the radar has an elevation angle near 0? If this equation is an approximation, please indicate under what conditions it is valid.*

For clarification, we added the following sentence in Line 171: "Eq. (8) is formulated for elevation angles θ_{el} significantly greater than zero, without accounting for the contribution of turbulence."

- *Line 178: It is a bit unclear why these two methods for calculating the spectra are being discussed. Are they the only two such methods? Please add some brief discussion on this point at the end of the previous section.*

A section 2.2.5, Rationale for simulation based on IQ, is added (Line 247).

- *Lines 240-241: What is the transmission and reception strategy of this radar? Can it measure retrieved co-polar signals independently?*

We are now mentioning in the text that the radar operates in a simultaneous transmission-simultaneous reception (STSR) mode (Lines 261-262).

- *Line 257: I think the "e" is missing from the subscript on the elevation angle symbol.*

We changed to θ_{el}.

- *Line 264: Please be more specific about the degree of turbulence during this case and the following case. Are these cases on the extreme ends of the turbulence that might be observed during these such events?*

No, these cases are not on the extreme ends of the observed turbulence. Therefore, the titles of the subsections are changed:
3.1 Case Study 1: Moderate turbulence conditions
3.2 Case Study 2: Light turbulence conditions

- *Lines 278-279: How were they adjusted? According to the measured values of the smallest particles? Please clarify.*

Yes, the corrections were determined by measuring the offset observed for the smallest particles, which are assumed to be spherical. The sZ_{DR} and $s\delta_{HV}$ values were adjusted such that the smallest particle measurements align with 0 dB and 0°, respectively.

- *7: What does the gray shading on the plot represent? Please add this information to the figure caption.*

We added the following sentence in the text relating to Fig. 8: "The spectral polarimetric variables are analyzed outside the gray-shaded regions, where the Doppler spectral power exceeds-8 dBZ/ms^{-1}, to ensure a sufficiently high signal-to-noise ratio."

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------------------- *REFEREE 2* -------------------

Summary: *The manuscript under revision presents a comparison of simulated and measured spectral polarimetric variables at W-band. The analysis is done for rain assuming well known sizeshape-velocity relations for raindrops. The manuscript clearly shows that more investigation is required for cloud radars to accurately simulate the spectra. The study is of a great importance for the cloud radar community. I have one major comment and several minor comments. I believe addressing these comments can considerably improve the manuscript.*

Major comment:

1. *Even though the Sec.2.2 is in general clear, there is a lack of explanation why it is necessary to generate noisy spectra using I/Q components. In general, average spectra can be used. These can be derived simply by adding spectral noise power to S_{vv} and Shh (as it is done in Eq. 14 of the manuscript). Assuming no correlation between noise in the two orthogonal channels, on average there is no effect on S_{hv}. The variance of spectral S_{vv}, S_{hh}, and S_{hv} taking into account the number of averaged spectra can be found as demonstrated in Myagkov and Ori 2022 (https://amt.copernicus.org/articles/15/1333/2022/). My question is, what are the benefits of generation of random individual spectra instead of the average ones? Please clarify this in the manuscript*.

The reason we chose to generate noisy spectra using I/Q components, instead of working with average spectra with added noise power, is to explicitly investigate whether the use of random individual noisy spectra can help explain or reproduce the variability and degradation often observed in measured spectral polarimetric variables, particularly in variables that rely on cross-channel correlations like S_{hv}, at low SNR and low correlations where approximated formulas as proposed in Myagkov and Ori 2022 (https://amt.copernicus.org/articles/15/1333/2022/) tend to fail. We included such considerations in the revised version.

By simulating the noisy spectra from I/Q components, we aimed to test whether noise characteristics contribute to the spectral variability seen in observations and whether this could help explain the persistent discrepancies between simulated and observed spectral polarimetric variables. In this sense, our work seeks to fill a gap in the literature and offer an alternative angle to understanding the role of noise in radar polarimetry.

Minor Comments:

1. L. 2 Change "spectral differential correlation coefficient" to "spectral correlation coefficient"
Changed (Line 2).

2. *L. 6 "W band millimeter-wavelength radar" keep either W-band or millimeter-wavelength, these two terms are kind of redundant*
Changed (Line 6).

3. I have a feeling that some sentences in the introduction are not well connected to each other. I recommend reformulating the text to improve the reading flow:
a. L12-18 are about cloud radars. L.18-20 start with "Additionally" and emphasize advantages of polarimetry in precipitation radars, and then afterwards there is a jump back to cloud radars.
Rephrasing is performed for improving the reading flow.
b. *L24-29 I understand what is meant here, but for a general reader this might be confusing. I would recommend the following sequence: Integrated variables at centimeter-wavelength are very informative. At millimeter-wavelengths signatures in integrated polarimetric variables become less pronounced. Spectral polarimetry in cloud radars is better because different particle sizes are observed independently.*
This part is rewritten (Lines 24-31). "This configuration has the critical advantage that particles with different sizes are separated in the spectral domain (because they have different sedimentation velocities), which allows to disentangle the contributions of different particle types. While vertically pointing radars can also achieve this separation, radars in slant polarization mode additionally exploit polarimetric measurements. At higher frequencies, where multiple resonances occur across the particle size distribution (PSD), the polarimetric variables—resulting from integration over the entire PSD—tend to average out the characteristic features of single-particle scattering, often balancing positive and negative contributions. Consequently, these variables exhibit low sensitivity to PSD variations. Further, they reflect both scattering and propagation effects. A way to mitigate these challenges at millimeter wavelengths is to analyze polarimetric variables in the spectral domain."
c. *L29-38 I recommend making a separate paragraph and to indicate that these are some of advanced applications of polarimetric measurements at W-band.*
A separate paragraph is made (Lines 32-40)

4. The introduction section does not explain the novelty of the study, although the manuscript definitely shows novel results of comparison between state-of-the art simulations and real measurements. In the sentence (L50), there is one sentence stating that the goal is to describe the simulation. But I think the goal is much more than that, the study shows a comparison between *an advanced spectral modelling based on empirical knowledge about rain drops (including size-shape relations, size-velocity dependence, turbulence, orientation etc) and real observations. And I would put the goal of the study in the end of paragraph, i.e. after existing simulation studies have been discussed.*

The rephrased goals of the study are now placed at the end of the paragraph as recommended by the reviewer (Lines 66-68). “Therefore, the first goal of this study is to explore how different assumptions that are related to atmospheric conditions (turbulence) and white and stochastic noise of a real radar spectrum, impact the simulated spectral polarimetric variables. The second objective is to present a novel comparison between simulated and observed data.”

5. I am just curious, what is the reasoning to use a Eq.1 apparently based on studies before 2001 as a reference? And why using Thurai et al. 2008 as the second relation? Would not one be enough? Or is there a reason why two are needed, especially taking into account that the scattering simulations are often hard to distinguish in the figures?

We used two axis ratio parameterizations to demonstrate that the choice of parameterization does not have a significant impact on the polarimetric variables.

The first relation (Eq.1) was included as it has been traditionally used in scattering simulations, while the Thurai et al. (2008) relation was included because it is based on more recent measurements and is widely adopted in polarimetric studies.

To further illustrate the limited influence of the axis ratio parameterization, we plotted the polarimetric variables in Figures 3 and 4, showing that the differences between the two parameterizations are minimal.

6. Sigma on the y-axis in Fig. 2 should have VV as the subscript not just V.

This is now corrected.

7. L118-121 for me it is hard to follow these sentences. I would recommend to simply write that the broader the width of the canting angle distribution is, the lower the magnitude of the polarimetric variables.

This is rephrased (Lines 121-126). “In Fig. 3 (right), δ_{HV} remains near zero for small drop diameters, consistent with Rayleigh scattering. As the diameter increases, δ_{HV} departs from zero and exhibits oscillatory behavior, attributed to resonance effects and the transition from spherical to oblate shapes. These fluctuations become more pronounced at larger diameters. Variability in drop orientation within the radar sampling volume, described by canting angle distributions, further contributes to the observed variations in δ_{HV}. The broader the width of the canting angle distribution is, the lower the magnitude of the polarimetric variables.”

8. Instead of Fig3 right/left I would recommend marking the panels (a) and (b) and refer to panels using these marks.

We thank the reviewer for this recommendation, it is really appreciated. However, in order to maintain consistency with the style used throughout the manuscript (and in similar figures), we have chosen to continue referring to the panels as “left” and “right.”

9. L124-125, elements Zij are not elements of the backscattering matrix but the Muller matrix, or as it is called in the manuscript, the phase matrix

Corrected (Line 130).

10. L129-134 and Fig 4. Please mention that neither antenna pattern effects, nor antenna coupling for the quasi-bistatic radar configuration, nor multiple scattering, nor noise are included in the calculations of rhohv at this stage. One or a combination of these effects may drive rhohv below the stated minimum value.

Thank you for this clarification, which is now mentioned in the article (Lines 140-141).

11. Sec.2.1.2 again here, why using 2 parameterizations?

As explained previously, we used two parameterizations to demonstrate that the choice of raindrop fall velocity model does not significantly impact the simulated polarimetric variables. This was important to show the robustness of the results against different commonly used relations.

12. L281 Why would one expect the opposite? If I understood correctly, the same Svv,Shh, and Shv were used for both methods. The difference is only in the randomness introduced by stochastic sampling. The averaged values are expected to be the same.

Yes, indeed agreement is expected. We rephrased the statement (Line 308). The use of both methods was to ensure that the stochastic perturbations respect the physical relationships between the scattering elements. The fact that both methods demonstrated consistency when producing the polarimetric variables provided confidence in the turbulence generation on the simulations and that the discrepancies in the observations were not due to a simulation artefact.

13. L283 I recommend to avoid using the term correlation, when “agreement” is meant. Please check this throughout the manuscript

We avoided the term correlation when discussing the results.

14. L287 L318 I see a significant difference between simulations and measurements in Fig. 8 at 5 m/s. Please check your conclusion about close alignment up to 7 m/s. Also, I do not see any noticeable differences at 3.5 m/s as written in the following sentence.

“For drops with terminal velocities up to 7 m/s, the simulations and the observations of sZ_{DR} and $s\delta_{HV}$ show reasonable agreement. Although, around velocities of 5 m/s, smaller values of sZ_{DR} and bigger values of $s\delta_{HV}$ are simulated relatively to the observations.” In section 4- conclusions and ways forward, we modified: “The results reveal that the simulations closely align and show reasonable agreement with observations only within a limited area of the Doppler spectrum, approximately to terminal velocities up to 5 and 7 ms^{-1} (i.e. equi-volume diameters smaller than 1.33 and 2.25 mm), respectively.”