Review comments for *Constraining microphysics assumptions on the modeling of Atmospheric Rivers using GNSS Polarimetric Radio Occultations*

This paper investigates the potential of Polarimetric Radio Occultation (PRO) to provide insight into hydrometeor vertical structures, using WRF simulations and the ARTS scattering database to simulate differential phase ($\Delta\Phi$) for comparison with satellite observations. The use of PRO in this context is still emerging, and this study contributes to ongoing efforts to assess its sensitivity to different microphysical assumptions. Nonetheless, continued exploration of PRO for hydrometeor evaluation is valuable, and further development of physically consistent frameworks is encouraged.

That said, a fundamental concern arises from the physical inconsistency between the WRF microphysics (MP) schemes and the scattering properties derived from the ARTS habit database, which fundamentally undermines the interpretation and validity of the results.

1. Mismatch Between WRF MP Assumptions and ARTS Scattering Properties

The WRF MP schemes (e.g., Thompson, Morrison) are bulk microphysics parameterizations. They assume a fixed set of physical properties for each hydrometeor category: shape, density, and particle size distribution (PSD). For example, snow in the Thompson scheme may be represented by soft aggregates with a specific mass-size and PSD relationship, while graupel has a different assumed density and terminal velocity. These assumptions are not explicitly output but are embedded in the diagnostic formulas that compute water content and number concentration.

In contrast, the ARTS habit database provides scattering properties (x-parameters) computed for discrete particle habits, each associated with its own shape, refractive index, and PSD assumptions. These may include bullet rosettes, dendrites, plates, spheres, or irregular shapes, and often with a PSD that differs from the one assumed in WRF MPs.

By using x-parameters from ARTS in combination with WC fields from WRF, the method effectively combines microphysical representations that were never meant to work together. This is a physical inconsistency — mixing the absorption/extinction/scattering characteristics of one assumed hydrometeor population with the mass distributions of another. Even if the x-parameters are bounded within ARTS values, this does not correct the mismatch in underlying particle physics.

2. Optimization Does Not Evaluate Microphysics Skill

The second issue concerns the interpretation of the optimization procedure. The authors optimize the x-parameters (within ARTS bounds) to minimize the difference between observed and simulated differential phase shift (Kdp), holding the WRF-derived WC fixed. This means that any biases or errors in the WC fields are effectively absorbed by tuning the x-parameters.

Therefore, the optimization outcome does not evaluate whether the MP scheme is accurately predicting WC or phase shift — it only shows which x-parameters (within ARTS-defined bounds) can reconcile the WC fields with observations. This decouples the validation from the actual physical outputs of the MP scheme. Two different MP schemes could produce very different WC fields, but the optimization could find different x-parameters for each that yield similarly good fits to observations — misleadingly suggesting both are good, or that one is better based on fitted x alone.

3. Misuse of "Forward Operator" Terminology

The paper also uses the term "forward operator," which typically refers (in data assimilation) to a physically consistent transformation of model state variables (like WC) into observation space (like Kdp), based on known physics. In a proper forward operator, the mapping is fixed, and the state variables are adjusted (via a cost function) to minimize differences from observations.

However, in the present methodology, the forward operator is not fixed — it is being modified by optimizing x-parameters. This blurs the boundary between model physics and observation operator and makes it unclear what is actually being evaluated. Optimized x-parameters are not state variables and cannot be used to adjust the model state or improve forecasts, thus limiting the method's value even in a diagnostic context.

4. Suggested Alternative

A more physically meaningful approach would be to:

(i) Use x-parameters consistent with each MP scheme's assumed particle properties, either by matching ARTS habits or computing scattering from scratch;

(ii) Use those fixed x-parameters to compute simulated Kdp, and compare directly to observations, without optimization;

(iii) Evaluate the WC fields directly by assessing how well they reproduce observed Kdp under physically consistent scattering assumptions.

Summary

In short, while the idea of using observations of phase shift to evaluate model microphysics is important and timely, the current implementation is flawed due to the physically inconsistent blending of ARTS scattering properties with MP-derived WC, and an optimization procedure that does not test the microphysics predictions directly. The conclusions drawn about MP scheme performance are therefore not supported by the methodology, and a revision of the experimental design is recommended.

Besides, there are some other comments related as follows:

L43: Passive microwave radiometers have also been utilized to interpret precipitation vertical structures, (Turk…

Comma here should be removed

L47: These change depending…

These changes depend

L49: simulations will be conducted…

were conducted

L100: As the PRO rays traverse the derived from PRO.

This is a broken sentence

L101: provides valuable insightse from GPS to LEO

Typo "insightse"

L101: This, in turn, provides valuable insightse from GPS to LEO, refractivity gradients cause bending, resulting in rays becoming tangent to the surface at their lowest point, termed the tangent point, ht.

This whole sentence is not grammarly correct. Please fix.

L107: matching a regular grid between 0 and 20 km

What was the reason to pick top height at 20km? Is this limit of the WRF model top?

L127: For some of the simulations, instead of using the RRTMG schemes for shortwave and longwave radiation, the New Goddard Shortwave and Longwave Schemes were used due to certain errors that occurred in specific simulations

Could these mis-match lead to any difference among MP results used in the following comparison?

L139 whether hail or graupel is the third class of ice however,

A comma is needed before "however"

Section 2.2.1: The numbering of this section seems weird since there is no other subsection in section 2.2.

L215: where the x_b comes from? Is it from ARTS?

If so, please refer to my general comment

L266: figure captions (a) and (b) are opposite to with what are defined in Figure 6. Caption

L282: "Even though the minimization of J is performed jointly for both the microphysics scheme and x-parameter"

According to L210, x-parameters are obtained by optimizing the cost function as in (8) by fixing WC. Therefore, I don't understand what you meant as jointly.

L293: The results indicate that the Goddard scheme consistently outperforms the others, followed by WSM6.

Since the simulation has used optimized x-parameters, which is case dependent (I think if there are other 32 points, you would get a different set of x-parameters), it is hard to say which original WRF simulation, and its corresponding scheme are the best. We can only say the Godard scheme was compensated by the specific "optimized" x_parameter in this particular case and such a combination performs the best.

Line 333 The first relevant thing to note is that the optimized values for ice and graupel often lay over the lower limit (the allowed range of x-parameters values is shown with a gray shaded area and related discussions

This suggests the optimization problem is under-determined and constrained in a way that prevents a proper minimization of the cost function. As a result, I would question how robust the resulting conclusions are regarding the relative contributions of different hydrometeor species—especially if the optimization is not genuinely being achieved for some of them. The physical reason for not being able to minimize some of the MP results is that these MP schemes use different assumptions of the hydrometeor habits and therefore, you might not be able to get a convergence at all by using ARTS defined habits.

In its current form, the method raises a fundamental question about physical inconsistency between ARTS habits and MP assumptions. It might be helpful to examine whether the achieved x-parameters through Eq (8) match the assumption of the specific MP. If so, it might be meaningful to give some insights on habit distribution, matching the bulk parametrization but not described explicitly in MP. But it seems not the scope of current manuscript.