Validation and Sensitivity analysis of the Polarimetric Radio Occultation technique

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1. Abstract

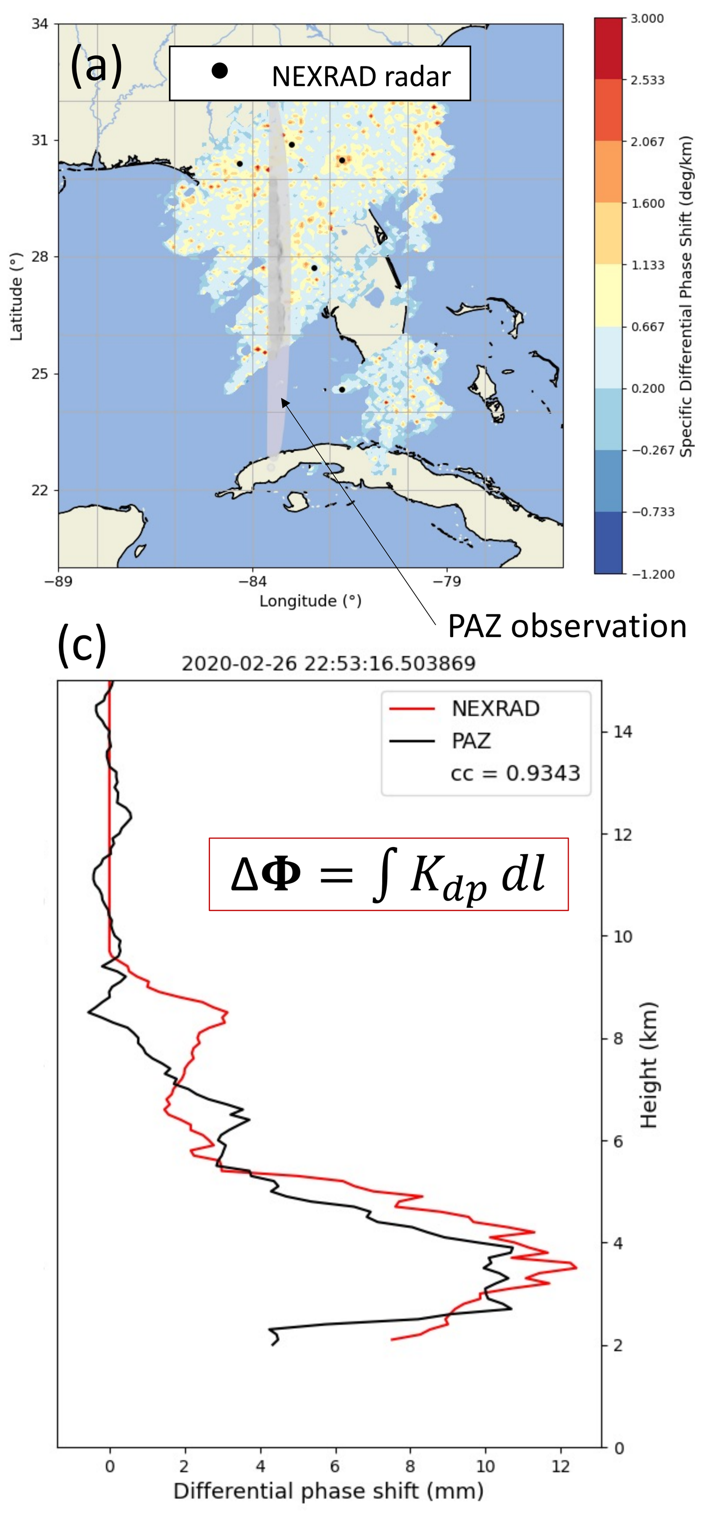
The Polarimetric Radio Occultation (PRO) technique enhances standard Radio Occultation (RO) by acquiring signals using two orthogonal linear polarizations (H and V). The novelty of the technique lies in measuring the difference in phase delay between these polarizations, known as the differential phase shift (**ΔΦ**), which provides information about the vertical structure of precipitation. The technique has been validated with 2D data, and this study extends validation to 3D using Next Generation Weather Radars' (NEXRAD) data to compare the specific differential phase shift (K_{dp}) with **ΔΦ**.

The study also examines PRO's sensitivity to hydrometeor vertical structures using the WRF-ARW model, focusing on Atmospheric Rivers. It compares the impact of different WRF microphysics schemes on simulated **ΔΦ** with PRO observations. Using the ARTS particle database, the study also analyses the impact on **ΔΦ** of different types of hydrometeor habits depending on their scattering properties. Preliminary results show that snow, specifically snow aggregates, seem to have the higher contribution on **ΔΦ** .

2. Objectives

Our objective is to validate the PRO technique using Next Generation Weather Radars' (NEXRAD) polarimetric weather data, focusing on comparing specific differential phase shift (K_{dp}) structures to the observable differential phase shift ($\Delta\Phi$) from PAZ. Please, see the details of the study in [1] (**DOI**: 10.3390/rs16071118). Additionally we aim to ellucidate the insights governing the microphysical processes of this kind of events, by using the Weather Research and Forecasting (WRF) model and the Atmospheric Radiative Transfer Simulator (ARTS) database.

3. Validation of PRO with NEXRAD weather radars



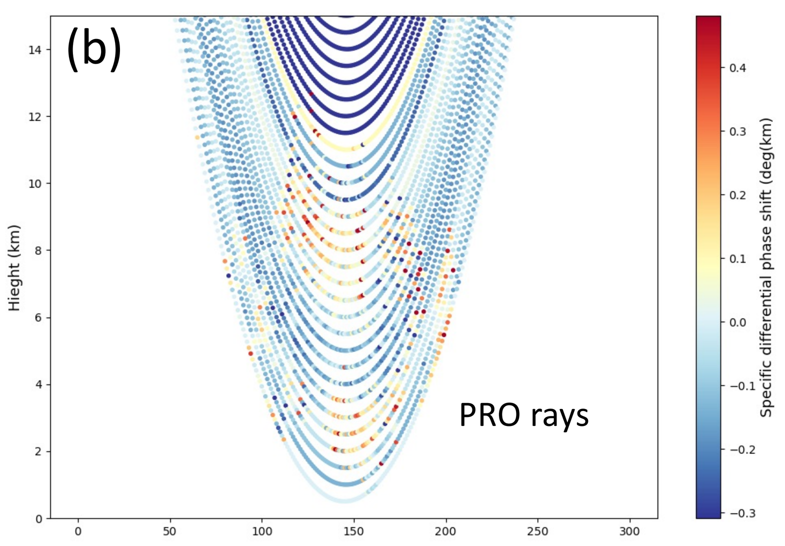


Figure 1. Panel (a) displays a co-location of an observation from PAZ and the surrounding NEXRAD radars. Panel (b) show the values of K_{dp} calculated from NEXRAD and interpolated to the PRO rays. Panel (c) panel illustrates the vertical profile of $\Delta\Phi_{PAZ}$ and $\Delta\Phi_{NEXRAD}$, along with the correlation coefficient between the two profiles (see legend).

- The agreement between $\Delta\Phi_{PAZ}$ and $\Delta\Phi_{NEXRAD}$ depends on the size of the smoothing window used in the calculation of K_{dp} (**Figure 2**).
- For higher intensity a smaller window size performs better, and vice-versa.
- This agrees with results in [2].

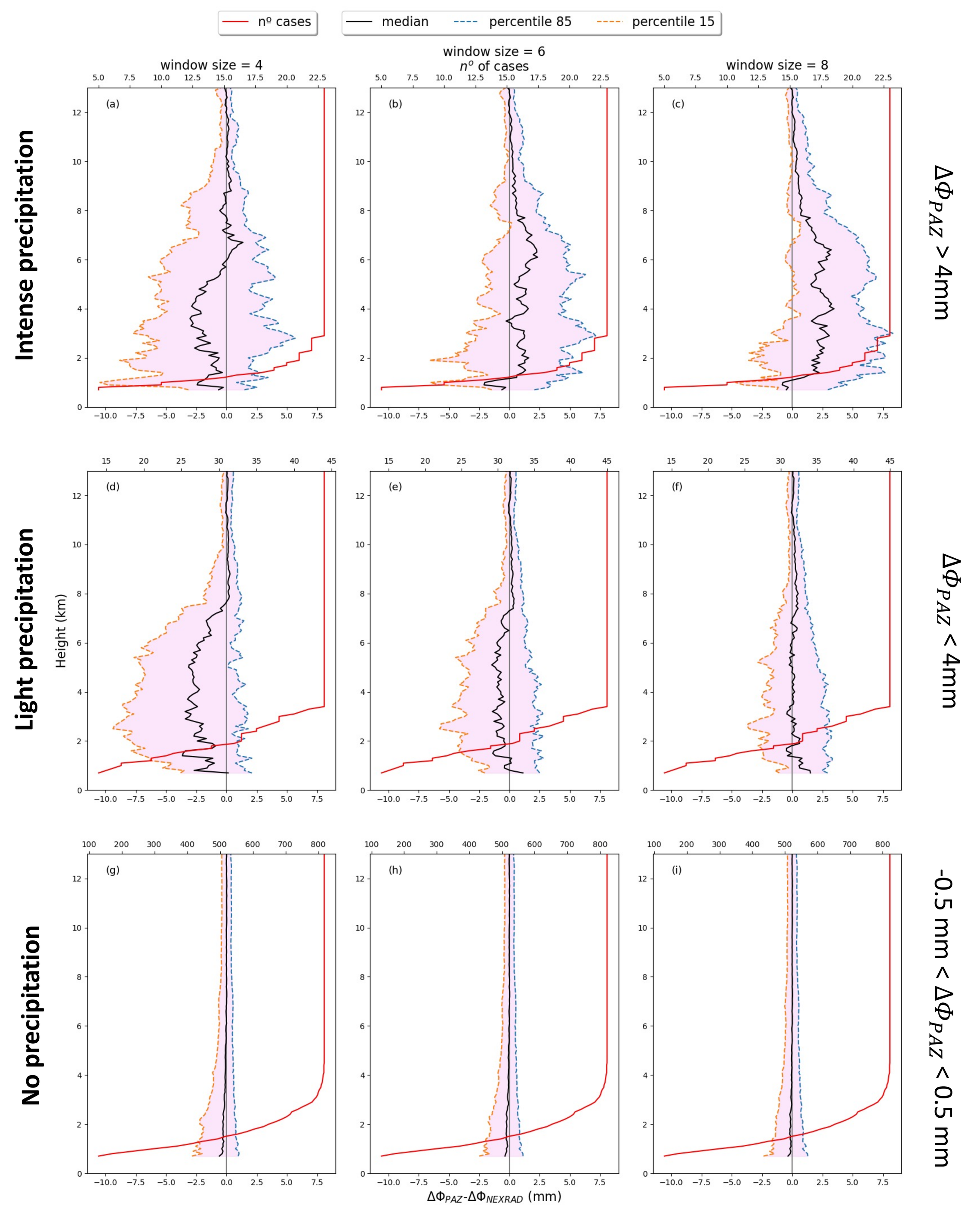


Figure 2. Difference between $\Delta\Phi_{PAZ}$ and $\Delta\Phi_{NEXRAD}$in terms of altitude. Each column represents a different window size, while each row represents a different condition for $\Delta\Phi_{PAZ}$, i.e. different precipitation regime.

4. Sensitivity analysis using WRF and ARTS

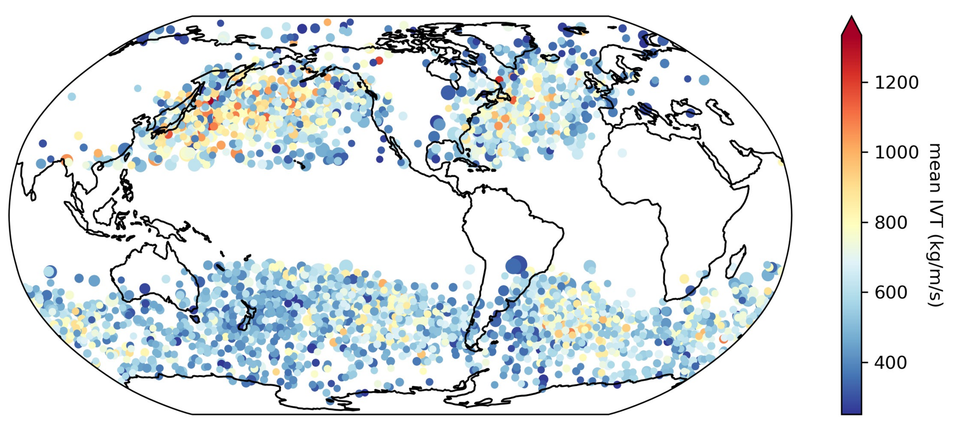


Figure 3. Co-locations of Atmospheric Rivers with PAZ and Spire-PRO.

Simulations with different microphysics schemes: **Morrison 2-moment, Thompson, Goddard** and **WSM6** for different **Atmospheric Rivers.**

Forward operator

$$K_{dp} = K_{dp,rain} + x_{snow} \cdot WC_{snow} + x_{ice} \cdot WC_{ice} + x_{graupel} \cdot WC_{graupel}$$

$$K_{dp,rain} = A \cdot WC_{rain}{}^{B}$$
$$A = 0.13$$
$$B = 1.314$$

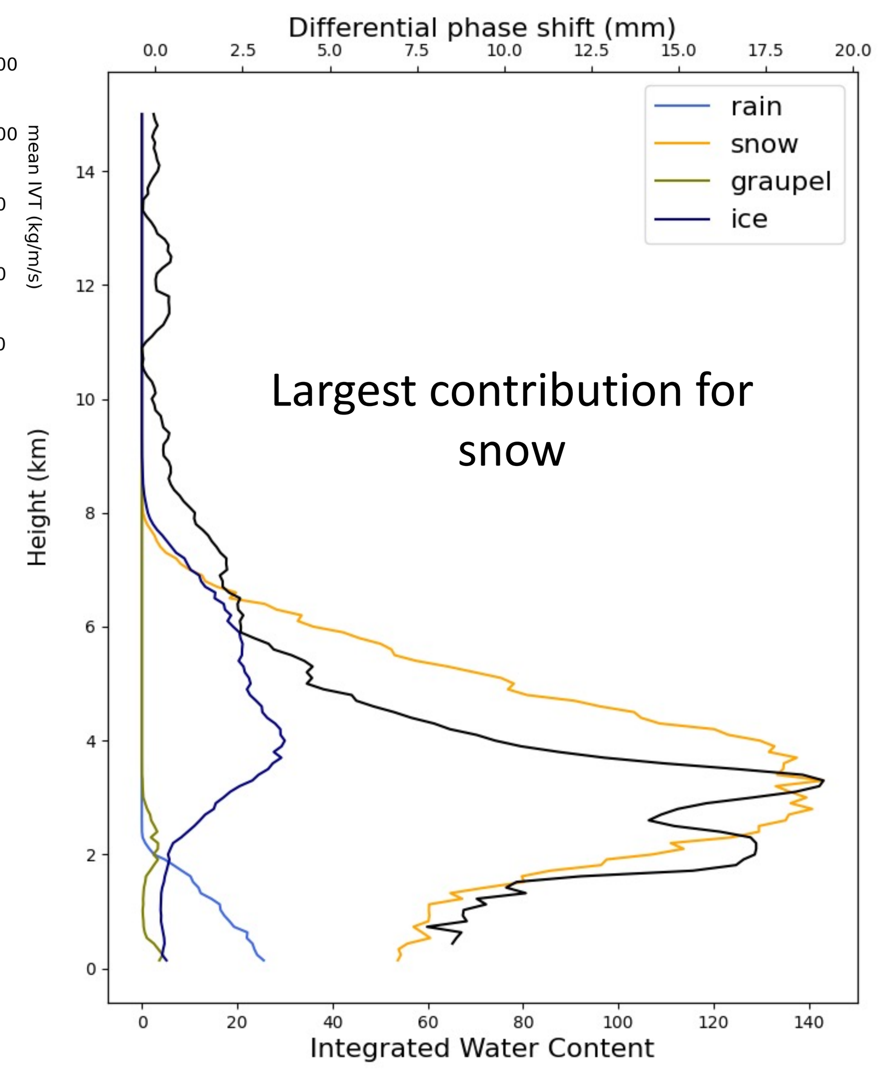


Figure 4. Profile of $\Delta\Phi_{PAZ}$ and the integrated water content of the different hydrometeors with Goddard microphysics for an Atmospheric River.

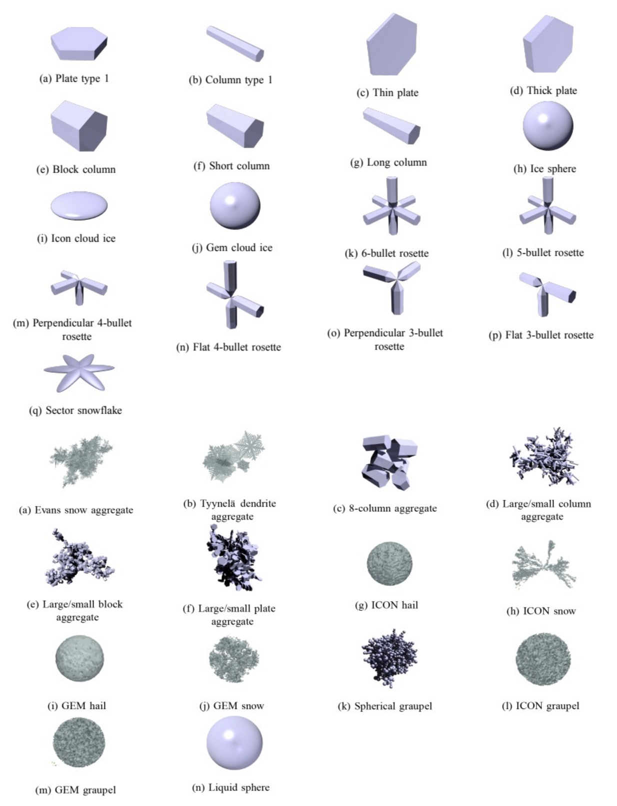


Figure 5. Crystal, aggregates and liquid habits included in the ARTS database, [3].

To see which **x-parameters** of the forward operator fit best our results we have perform the inverse least squared problem:

Cost function: $J(x) = (x - x_b)^T B^{-1}(x - x_b) + (y - H(x))^T R^{-1}(y - H(x))$

Minimize ⟶ $|\Delta\Phi_{PAZ} - x \int WC\, dl| = |\Delta\Phi_{PAZ} - \Delta\Phi_{WRF}|$

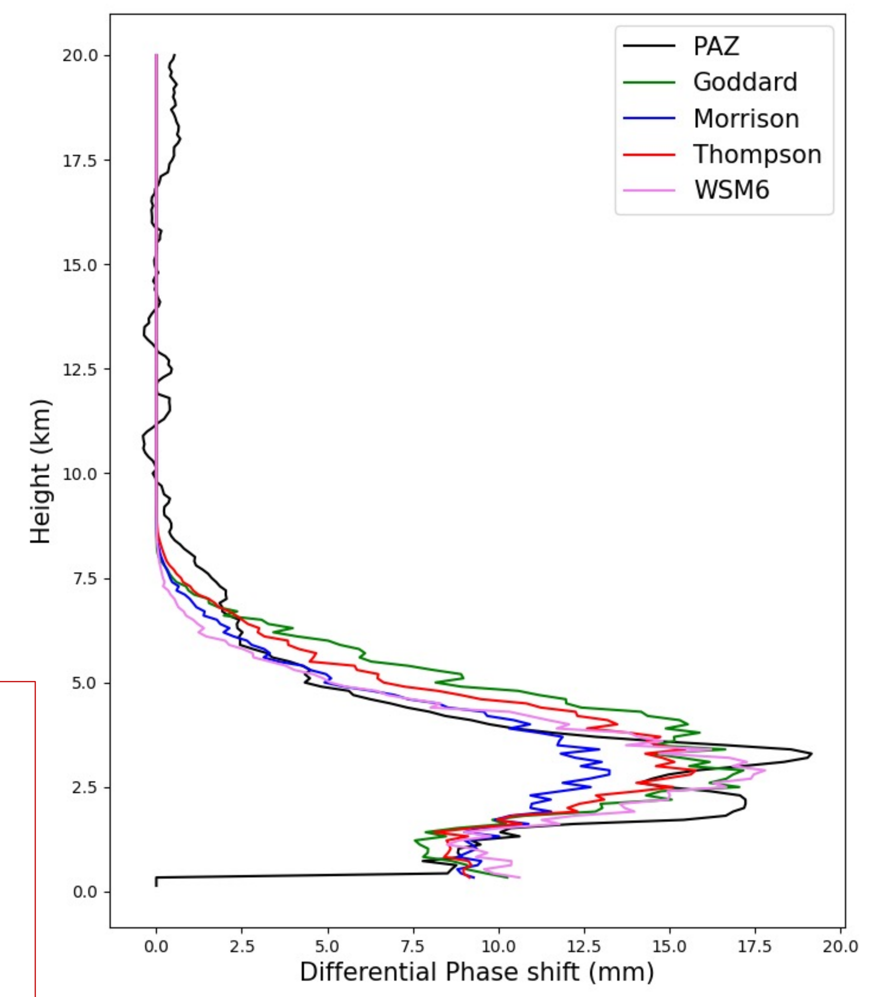


Figure 6. Verical profile of $\Delta\Phi_{PAZ}$ and $\Delta\Phi_{WRF}$ with the contributions of all hydrometeors and using the x-parameters that minimize the equation, for the different microphysics.

References

[1] Paz, A.; Padullés, R.; Cardellach, E. Evaluating the Polarimetric Radio Occultation Technique Using NEXRAD Weather Radars. *Remote Sens.* 2024, *16*, 1118. https://doi.org/10.3390/rs16071118.

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5. Conclusions

- The study demonstrates the effectiveness of the PRO technique in capturing the vertical structure of precipitation when compared with ground-based NEXRAD weather radars.
- Sensitivity analysis reveals variations in agreement between PRO observations and different microphysics schemes from WRF.
- PRO observations exhibit that snow contribution is the largest compared to other hydrometeor types such as rain, graupel, or ice.
- Preliminary results with ARTS show that snow aggregates seem to be the particles that fit best with PAZ.

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