Review of the paper, ***Atmospheric polarimetric effects on GNSS Radio Occultations: The ROHP-PAZ field campaign***, by Padullés et al., 2015.

Comment Summary:

This is a very interesting and important paper that demonstrated the polarimetric signatures introduced by the hydrometeors with in the GNSS radio occultation (RO) signals can be measured through a ground-based GNSS receiver equipped with two polarimetric antennas. This is a follow-up demonstration of the proof of concept proposed in a theoretical simulation study by Cardellach et al. (2015), which shows the differential phase between the horizontal and vertical polarimetric components is introduced by the hydrometeors along the radio link. The paper provided an important step-stone for the upcoming Spanish PAZ satellite mission that is targeting to provide the heavy precipitation detection capability with polaritric GNSS measurements.

The low elevation angle GNSS measurement (0-20 deg) covering various meteorological conditions (no rain, wet and rain days) during a 8-month field campaign on mountain peak at 1670 m above MSL. Near-coincident Meteorological C-band radar observation were interpolated into with the GNSS RO signal ray trajectory to identify and quantify the rain rate. Case studies were used to demonstrate the capture of the polaritimetric signatures induced by the hydrometeors along the radio-link based on the time series of the RO measurements, which is validated with the near coincident radar and ground station measurements. A forward scattering simulation was also carried out to explain the polarimetric GNSS observation. The data analysis shows that other than the rain droplet, the hydrometeors such as melting particles and ice crystals could have significant impact on the polarimetric phase difference measurements.

Overall the paper has important contribution to advance the understanding the hydrometeors impact on the RO polarimetric signals. It also provided the observational evidence for the upcoming PAZ satellite mission, which will use spaceborne GNSS RO for heavy precipitation measurements. However, the presentation of the work need some significant improvement. I would recommend the publication of the article after addressing the following issues:

<u>Major comments:</u>

1. The authors write the most part of the paper in the “first person”, which would be better to be in the “third person”. Some very short paragraphs (only one or two sentences) that should not be stand alone. The authors tend to use the “symbols” on discussion, which could cause big challenges for readers. Better to use the real observables (e.g., rain rate, instead of *R* especially when it does not shown up repeatedly)

2. Section 2.2, the process to derive the multipath is not clearly presented. More details are needed.

3. The Nowcasting and Very Short Range Forecasting (NWC-SAF) data description need some more details, such as horizontal resolution, what satellites in what band. Sounds like the data were not very critical in this research (only shown up in Fig. 4). If so, the dataset could be removed from the paper.

4. Many Figures require improvements before publication, such as Figure 1, 8, 9, 11 and 12. More specific comments are in the next section.
    a. Figure 1, better to mark/name the locations of the GPS antenna, weather radar and the near-by ground stations if included.
    b. Figure 9 is hard to read. Prefer with larger font.
    c. Figure 11 and 12 need to be improved. Hard to read. Suggest to remove the un-necessary x or y axis caption and enlarge the figures.

5. Section 5.3 is one of the most important section but the main text is a mess and require significant cleanup.

    P18764: The main text need to discuss/summarize the results on the Figure-10. You can't simply state "Fig. 10 is a illustrative case…"

    P18783-4: Figure 10 is confusing. The "orange shaded area" should be only ONE-color based on the simulation, right? Is the color variation inside the orange boxes due to the radar reflectivity? If so, the orange boxes shouldn't use shade, but simply a transparent box with color outline, without blocking the radar reflectivity contours. Same comments apply to Figure 11 and 12.

6. P18754-L1-3: Provide the "threshold" number of the radar reflectivity (Ze) for "rain-days" instead of using the vague "significant reflectivity". Does the same radar reflectivity threshold used to define no-rain days. Also, is there a requirement for how long the "rain" lasts to be counted as "rain-days"?

    "*We define as no-rain days those days when no rain is present in the area …"*
    → The radar reflectivity factors (Ze) are used to identify the "rain-days", with Ze exceed ### ….

    P18757: Similarly, in Section 4.2, the criteria for separating the three meteorological conditions is confusing and better to be more quantitatively. Also the three "σ" should be removed, which can be listed in L3. "The standard deviation of the differential phase delay as a function of elevation for different meteorological conditions, such as σ_dry, σ_wet and σ_rain are computed:"

    L9: "with rain in the surroundings", any "number" used to define the area, such as within 50 km or 100km radius of the GNSS station?

7. P18761-L15: The key results such as the correlation between the observed and simulated A_Φ (improvement from 0.6 to 0.75) shouldn't only be mentioned in the Figure-8 caption (P18781). The result need to be summarized in the main text too.

8. P18764-L9: Again, Figure 10 need to be explained in the main text. The context should not be only mentioned in the figure caption.

9. P18763-L3: The correlation between the observed and simulated A_Φ seemed to increase from 0.6 to 0.75 after including the ice & mixing phase particles. Should the adding criteria of "$A_\Phi < 20$ mm · deg" be "$A_\Phi > 20$ mm · deg" (in P18781) instead that lead to increasing correlation?

   All this results need to be included in the main text. Also it is probably more informative to highlight those "dots" that satisfy the extra criteria on Figure 8.

   However, Figure 8 still shows rather large scattering. Any other explanation?

10. P18762-L20: What is the typical time/distance difference between the METEOCAT's radiosondes to the major part of precipitation? Is the radiosonde temperature profile representative enough to guiding the phases of the particles?

    Any direct evidence of the "ice" particle presence from the near-coincident radar measurements that support the IWC amount (e.g., $1 gm^{-3}$) etc. in the simulation?

Other minor comments:

11. P18749-L21: "These GNSS satellites are identified by …"

12. P18752-L8: "denote**s**"

13. P18752-L9: What is "hardware effects" means? Is that "receiver measurement noise"?
    L10: Replace "K" in eq-3 with another character, as it could be confused with the "K_{dp}", the specific differential phase in eq-1

14. P18754-L11: Brief explain how the antenna pattern looks like and why it affects the multipath pattern. Reference is needed, i.e., Cardellach et al., 2015.

15. P18755-L5: "We have been provided by the data from …" → The weather radar, in-situ radiosonde and the METEOSAT satellite measurements near the GNSS observational site are used in this study.
    L17: has also → also has
    In a radius of 30km around the GNSS site, there are 5 ground weather stations, with one locating a few meters from the GNSS antennas.

L23: remove “the Support to”

L24: NWC-SAF: need more information regarding the model product, such as horizontal resolution, what satellite observations are assimilated? How accurate is the CTH especially during the rain? Reference need to be cited.

L25: “These data results…” → These data product is a combination of satellite observation and Numberical weather Prediction (NWP) model simulations.

Reference is needed for NWC-SAF.

16. P18756-L1: What satellite imagery? Visible band? Are the infrared and microwave observations included?

L3: Rewrite “*Using the CTY and CP ... of the top of the cloud. Combining this information ...*” → The cloud observation from NWC-SAF (CTY, CP and CTH) are then collocated with the GNSS ray trajectories.

L11: “Even though the temporal resolution is not very high” → “With the limited two-time daily soundings, the temperature and refractivity profiles can be interpolated into the GNSS observation time.

L15: “collocation of the observations” → “collocations of the GNSS polarimetric observations”

L24: “Standard deviation” → would be better to be more informative, such as “Polarimetric signature”

17. P18757-L1: “standard deviation” of ??
L2: in three sub-sets → into three meteorological condition. Suggest to replace “subset” with “met”

L11: “environmental situation” → “meteorological conditions”

L14: “the results of … and for the three day sub-sets” → “the mean σ across all elevation observations for each GNSS satellite during the three different meteorological conditions are summarized in Table 2.”

L21: The larger σ in rain-days comparing with the wet-days indicates other factor(s) should have contributed to the enhanced polarimetric signature other than the enhanced multipath due to the wet soil in the rain-days.

Better to state clearly, the wet-days and rain-days both could have wet soil condition, which could lead to enhanced multipath and so larger σ.

Would be good to also comments that such mulitipath will not be an important factor for spaceborne case.

L24: How to compute multipath_no-rain?

18. P18758-L22: This is one of the most important conclusion from the paper and could be better written. "This represents…signals." → "This is the first direct observational evidence of the polarimetric signatures induced by the precipitation in the GNSS signals."

19. P18759-L1: How about making the section title more informative such as, "Model study on the hydrometeors on the GNSS polarimetric signals"
L11: what is the "R" on the denominator?

20. P18760-L1: "Kw=(m_w^2-1)…" in the eq. 12?
L4: "The reason is that …" → This will allow to relate the reflectivity from the weather radar in C-band with the GNSS observations in L band.
L11: what the meaning of "through its moments"?

21. P18761-L6: "because the … suggested so" → as suggested by the meteorological ground stations
L7: "and we have limited …" → and an upper limit of LWC is set to be 3 gm^{-3} according to the observational evidence of severe storms described in Black and Hallett(2012).
L19: polarimetric signals observed (black dots in Fig. 8)

22. P18762-L23: How representative is the radiosonde sounding for such a large area of the radar observation. Would it be a problem of using the radiosonde many km away to represent the temperature of a storm?

23. P18763-L11: The discussion on the model uncertainty is not well presented. The tone of the writing made a bad impression to the readers that the model might be too simple and could be "wrong". Would be more persuasive by focusing on what the simple model is capable of doing, e.g., explain the major portion of the observations. In the mean time, discuss the potential impact of such "un-simulated" factors on the simulation results.

L23: Remove: "The goal of … signatures". No need to say the goals, but focus on the results.
L26: "other hydrometeors" → icy and mixing-phase particles significantly increases …
L27: "why favoured higher Kdp?

24. P18764-L11: Very messy section in writing, need some significant improvement.

L16: "It can be seen…" → Large positive ΔΦ is present when large radar reflectivity (Ze)

L27: "more than 90%", where is this number coming from? Better to state # of cases that is consistent with the model simulation. Also what is the criteria of "consistent cases"?

25. P18765-L2: "reflectivity" → radar reflectivity.
L3: Can the discrepancy in G15 due to the missing observational in radar? Or the false alarm in the hydrometeors in the model, which relies on the radiosonde temperature profiles that might not be representative inside the storm.

L7: "with the aim of…" → and the evidence of the polarimetric signature induced by the hydrometeors in the GNSS signals has been presented.

Some "passive words" were used in this session, which generated unnecessary negative impression on the research work and better to be changed. For example:

L19 "out of our control",
L20 "None of these effects are expected (or not as severely)"…
P18767-L2 "but we feel that this would be too speculative and impossible to validate…"

26. P18772: "Measurement difference between the ROHP-PAZ spacebore …"
Could simply add one more column for "parameters", for initial phase delay, local multipath and Thermodynamic profile" to reduce the redundancy.

27. P18773: The standard-deviation of the polarimetric phase differences under three meteorological conditions (e.g, dry, wet and rain days).
"for each day set i" → for each meteorological condition.

28. P18777: "Illustration …. Ray trajectory" → A vertical slice of radar reflectivity (shaded) at two epoch of a rising GNSS occultation event.

Remove "collocated with the CP…trajectory"

29. P18779: Figure 6, "Target shapes used" → Particle shape models used
"Oblabe ellipsoid, used to reproduce rain" → Oblate ellipsoid for rain drops, (middle) two concentric ellipsoids for melting ice particles, … (right) Dendritic shape for pristine ice particles.

30. P18780: typo: "hydrometeor"

31. P18781: Figure 8. Better to use two square panel. Remove "the gray dashed … modelling"
Should "it decreases to r=0.75" to be "increase to"?

20mm.deg → 20 mm • deg, where are those dots in the plot???

32. P18779: Figure 10, X-caption: Reflectivity "Z" → "Ze".

33. P18784: Figure 11: Why the time of the bottom two panels (left and right columns) are flipped. Remove the unnecessary X/Y axises caption to allow larger plot for each individual panels. Increase font size.

    G022 should be G22 at the 2nd panel on the left column

34. P18785: Figure 12: suggest use two column plot with 3 panel in each column. Also add time for the first panel ("no data").

    "with the used hydrometeors" → by the model simulation. The discrepancy might not necessary be only due to the problem of the hydrometeors used in the model, but attributed to the radar observation or other factors in the model simulation.