Responses to reviewer 2:

General Comments: I appreciate the significant contribution this work makes to radar remote sensing and its potential to enhance the assimilation of radar observations in NWP models. While the radar equations appear to be sound, I have some concerns regarding the use of NWP profiles for evaluation in this context. There are noticeable discrepancies between the simulations and observations, yet the authors seem to overlook these differences, suggesting that there is good agreement, despite the figures indicating otherwise. Additionally, the text would benefit from revisions for clarity and consistency, as some sections can be challenging to follow.

Response:
The authors are grateful to Reviewer 2 for his/her in-depth review of the manuscript and his/her constructive comments which significantly improved the manuscript. We appreciate the concern regarding the input profiles taken from the global NWP model ARPEGE, which has been operational at Meteo-France since 1992. The authors recognize that this concern is particularly true in the context of a global NWP model in which the convection is parametrized and for which the effective resolution of the model is larger than the observations. Therefore, the differences between the model and the observations can indeed arise from several sources such as the modeling of the radiative transfer within the forward operator (e.g. Particle Size Distribution, precipitation fraction, shapes, etc...), as well as modelling of the clouds and precipitation within the forecast used as input. One alternative to reduce the latter source of error in the comparison would be to use cloud and precipitation retrievals as inputs of the radiative transfer (Johnson et al. 2016). This is kept in mind for future work and the authors added some sentences in the manuscript to highlight this particular point. Nonetheless, the authors think that the present work and analysis between observations and simulations is important as it is a preliminary step before the assimilation of these observations in a global NWP model, which has proven to be useful by several NWP centers (Ikuta et al. 2021; Fielding et al. 2020).

Please, you can find in the next pages our point-to-point responses, along with the revised version of the article (changes have been made in red in the text). Besides, the sections which were difficult to follow have been modified (changes have been made in blue in the text).

Comment 1:

Page 2 L38: Some recent CRTM references would be more suitable here, including: https://doi.org/10.1175/BAMS-D-22-0015.1

https://doi.org/10.1109/TGRS.2023.3330067

Response 1: The authors thank the reviewer for sharing the references. The authors included the above references in the revised manuscript in the introduction.

Comment 2:

Page 3 L70: you can still see bright band in CloudSat CPR frequencies, e.g., see https://doi.org/10.1109/TGRS.2023.3330067

Response 2: The authors thank the reviewer for this comment. The paragraph has been slightly modified.

Comment 3:

P5 L130: 30 minutes seems too high for cloud and precipitation related collocations. Any comment on how this would impact the results?

Response 3: In this study, the authors wanted to remain close to the temporal window of the 4DVar data assimilation system of ARPEGE, in which observations are assimilated within a 6-h assimilation window divided in 11 time slots of 30 minutes (+-15 minutes), and 2 time slots of 15 minutes. For each time slot, all the observations are assimilated as if they were valid at the time of the centre of the time slot. To increase the number of samples, in our study we decided to slightly increase this temporal collocation window from +-15minutes to +-30 minutes. The authors think that this temporal window is a good compromise to gather a sufficiently large number of cloudy and precipitating observations which are still valid at the forecast time. The authors added this sentence in the dedicated section of the manuscript.

Please note that to take into account the spatial and temporal mismatches between observations and simulations, the statistics have only been calculated when a cloud or precipitation system is observed and simulated.

Comment 4:

P6 L138: do you also interpolate when there is gap in reflectivities? That can be quite problematic.

Response 4: The authors thank the reviewer for this question. During the interpolation step, when a gap in the reflectivities is found, it is indeed preserved in the interpolated data. The FG departure is computed only when both observed and simulated reflectivities have value above radar sensitivity at the same height bin, otherwise not considered for statistical analysis. To make it clearer for the reader, one sentence was added in the reviewed manuscript after the sentence highlighted by the reviewer.

Comment 5:

P6 L146: "set of specific number of hydrometeors": do you mean ensemble of hydrometeors?

Response 5: Exactly, the authors meant "an ensemble of hydrometeors". RTTOV 13.1 can allow any arbitrary set of hydrometeors and this study considers an ensemble containing the 6 hydrometeors predicted by ARPEGE (rain, convective rain, snow, graupel, cloud water and cloud ice). The total radar reflectivity is then the summation of the reflectivity computed from each of the six hydrometeors (as mentioned in equation 1). The authors have changed "set of specific number of hydrometeors" to "an ensemble of hydrometeors" in the text.

Comment 6:

P6 Equation: I am confused by fraction "f" – isn't that already being represented in the water content values? Is this the maximum overlap probability? We are looking at individual layers when calculating the reflectivity so why would we need to worry about maximum overlap?

Response 6: In RTTOV-SCATT, the hydrometeor contents are normalized by a hydrofraction based on Geer et al. (2009) for passive microwave instruments. When radar capability was added to RTTOV-SCATT, a specific normalization was added. In RTTOV-SCATT V13, a hydrometeor fraction profile needs to be specified as input for each hydrometeor type.

Then, the hydrofraction (f(R)) variable serves two purposes in the radar equation. (1) to normalise the hydrometeor content (W(R) =Wav,i(R) /fi(R),see equations 2 and 4) by the fraction occupied by each hydrometeor over the grid cell. This is particularly important for global NWP models (such as ARPEGE) for which the resolution ranges from 5km to 25km. The normalised content is then used to derive reflectivity and extinction coefficients from the look-up table. (2) The hydrometeor fraction f(R) is then used to denormalize the scattering/extinction coefficients. Please note that this coefficient is only used for "hydrometeor-related" bulk scattering coefficients. The attenuation implied by the presence of gas are not affected by the fraction (see eq.3)

Comment 7: On Page 9, Line 225, and in the last paragraph on Page 11, the text is difficult to understand. Overall, the manuscript would benefit from editing for clarity and language.

Response 7: The text has been revised. For the English, the authors would like to point out that the manuscript was originally reviewed by two native English speaking co-authors. It has also been internally reviewed by 5 native English speaking colleagues from ECMWF, Météo-France and UK Met-Office. Nonetheless, the authors agree that some sections were difficult to follow. As an additional proofreading, the English has been reviewed by an internal native speaking colleague from Météo-France. The English track changes can be seen in blue in the revised manuscript.

Comment 8:

P14 L279: Please rewrite this paragraph for clarity.

Response 8: As the reviewer suggested, the authors revised the paragraph.

Comment 9:

P14 L280-300: it states around L280 that "overall the spatial structure of simulated cloud is well …". I don't really think so. It clearly shows that the structure of clouds in simulations and observations are quite different. Again, around L288, it states the same for vertical structure of clouds but again I disagree with the statement as there is clearly a large discrepancy between vertical structure of simulations and observations. This is likely due to error in input profiles.

Response 9: The authors agree with the reviewer's comment that there are discrepancies between the observed cloud and the forecasted cloud structures. This is expected as we are considering a global model with parameterized convection. We have carefully checked and there is no error in the input profiles. To address the reviewer's comment, we have erased the sentences which were stating that the simulation was well representing the observed cloud structure.

Comment 10:

P14 L292: "(e.g., spherical …)" I think the role of input profiles is extremely important here and should be emphasized.

Response 10: The authors agree that it should be clearer in the text that a source of errors is also the forecast model. The sentence highlighted by the reviewer was modified to emphasize this.

Comment 11: P14 L297: this should be better discussed and how it impacts the results. The NWP profiles may not be even suitable for this kind of evaluation studies.

Response 11: The authors agree with the reviewer's comment and we have added a dedicated paragraph at the end of the conclusion regarding this limitation of the study. However, the authors believe that the NWP profiles are important for this kind of evaluation study because the analysis of differences between observations and simulations are the first step prior to assimilation.

Fielding MD, Janisková M. Direct 4D-Var assimilation of space-borne cloud radar reflectivity and lidar backscatter. Part I: Observation operator and implementation. Q J R Meteorol Soc. 2020; 146: 3877–3899. https://doi.org/10.1002/qj.3878

Geer, A. J., P. Bauer, and C. W. O'Dell, 2009: A Revised Cloud Overlap Scheme for Fast Microwave Radiative Transfer in Rain and Cloud. J. Appl. Meteor. Climatol., ***48****, 2257–2270,* https://doi.org/10.1175/2009JAMC2170.1.

Ikuta Y, Okamoto K, Kubota T. One-dimensional maximum-likelihood estimation for spaceborne precipitation radar data assimilation. Q J R Meteorol Soc. 2021; 147: 858–875.
https://doi.org/10.1002/qj.3950