Responses to Reviewer 1

General Comments:

The radar simulator in RTTOV is a very important extension and makes the model even more usable for the community. Having a bright-band scheme included in the model is very good as well. Therefore, the manuscript gives a substantial contribution to the scientific progress. Technically, I would have appreciated an additional proofreading, maybe even by a native speaker, before submitting the manuscript to AMT for discussion. Some parts or sentences are not very easy to read. In addition, there are many inconsistencies:

- **the use of commas before and in enumerations**
- **whether bright-band is written "bright-band" or "bright band"**
- **same for Ku- and Ka-band**
- **using in units in situations like "15 dBZ and 10 dBZ" or "15 and 10 dBZ"**
- **acronyms they are sometimes introduced like "Global Precipitation Mission (GPM)" and sometimes "global precipitation mission (GPM)"**

In the specific comments, I'm not mentioning all typos and, in my opinion, falsely set commas.

General response:

The authors would like to thank the reviewer for its careful review of the manuscript and for providing valuable suggestions which significantly improve the quality of the work. In accordance with the suggestions, the authors have thoroughly checked the manuscript and shared the point by point responses to the comments by Reviewer 1 herewith. In the revised pdf file, the changes are highlighted in orange. For the English, the authors would like to note that the manuscript was originally reviewed by two native english co-authors. It has also been internally (ECMWF, Météo-France, UK Met-Office) reviewed by 5 native english speaking colleagues. Nonetheless, the authors agree that some sections were difficult to follow. Therefore, as an additional proofreading, the English has been reviewed by the one native speaking colleague from Météo-France. The English track changes can be seen in blue in the revised manuscript.

Specific comments:

Comment 1: p.1 l.4: TOVS is not explained here

Response 1: The authors expand the TOVS as TIROS Operational Vertical Sounder in line 4 in the revised manuscript.

Comment 2: p.1 l.9: GPM is not explained here

Response 2: In the revised manuscript, the full acronym of GPM as Global Precipitation Measurement is written line 9.

Comment 3: p.2 l.24: CloudSat should be written with capital S throughout the manuscript

Response 3: The authors thank the reviewer for this suggestion. The authors have rewritten the CloudSat with capital S everywhere in the revised manuscript.

Comment 4: p.2 l.45-47: The sentence should be rewritten to "In the melting layer, the maximum size snowflakes are first transformed into wet flakes and then to raindrops of smaller sizes of equivalent mass and less number density as compared to the original flakes (Galligani et al., 2013).". Thereby, I'm not sure about "less number density". Why should that change? You do not change the number of particles within the volume.

Response 4: The authors thank the reviewer for this comment and the sentence has been changed. According to Galligani et al., (2013) "the flakes collapse into raindrops of much smaller size than the original flakes of the same mass, but with an increased fall speed, yielding smaller particle concentration.". A similar statement can also be found in Rupayan Saha and Firat Y. Testik, (2023).

Galligani, V. S., C. Prigent, E. Defer, C. Jimenez, and P. Eriksson (2013), The impact of the melting layer on the passive microwave cloud scattering signal observed from satellites: A study using TRMM microwave passive and active measurements, J. Geophys. Res. Atmos., 118, 5667–5678, doi:10.1002/jgrd.50431.

Saha, R., & Testik, F. Y. (2023). Assessment of OTT Parsivel 2 Raindrop Fall Speed Measurements. Journal of Atmospheric and Oceanic Technology, 40(5), 557-573.

Comment 5: p.3 l.63: change "retains" to "retain". Geer and Bardo are two people.

Response 5: The authors thank the reviewer for the grammatical correction which has been changed.

Comment 6: p.3 l.79: Why are graupel and hail written capitals? Same later on in the manuscript.
Response 6: The authors change to small letters in the revised manuscript.

Comment 7: p.3 l.87: "whether if" remove "if" p.6 l.139: Remove "." in "mm6.m-3"
Response 7: The authors thank the reviewer for the corrections. We removed the 'if' and '.' in the revised manuscript.

Comment 8: p.6 l.149: "radar range gate"
Response 8: The authors change 'radar gate' to 'radar range gate' in the revised manuscript.

Comment 9: p.7 l.181: "The Marshall and Palmer (1948)(hereafter MP)" what?
Response 9: The authors forgot to mention the 'PSD' word here. It has been incorporated in the revised manuscript.

Comment 10: p.8 Table1: Remove "s" from hydrometeors
Response 10: The 's' is removed from Table 1 in the revised manuscript.

Comment 11: p.9 l.223: "density and mass ... are"
Response 11: The authors thank the reviewer for spotting out the grammatical mistake, which has been corrected in the revised version.

Comment 12: p.9 l.226: "...melted hydrometeor fraction f_m..."
Response 12: The authors made the correction in the revised manuscript.

Comment 13: p.9 l.231: "...has also been used..."
Response 13: The authors thank the reviewer for highlighting the grammatical mistake, which has been corrected in the revised paper.

Comment 14: p.10 l.243: "...melting layer model" or "scheme"
Response 14: To avoid the confusion, the authors have written 'melting layer scheme and two-phase model' in the revised manuscript.

Comment 15: p.12/13 figure 3/4: Why do the lines at different temperatures cross without following any rules.
Response 15: The authors would like to thank the reviewer for this interesting question. To answer this particular point, the authors investigated why the reflectivity is larger (resp. smaller) at 273K than at 277K for a content of 2*10^-5 kg/m3 (resp. 10-3 kg/m3). This non-linear behaviour is due to the evolution of the melting process, which is different at 273K than at 277K.

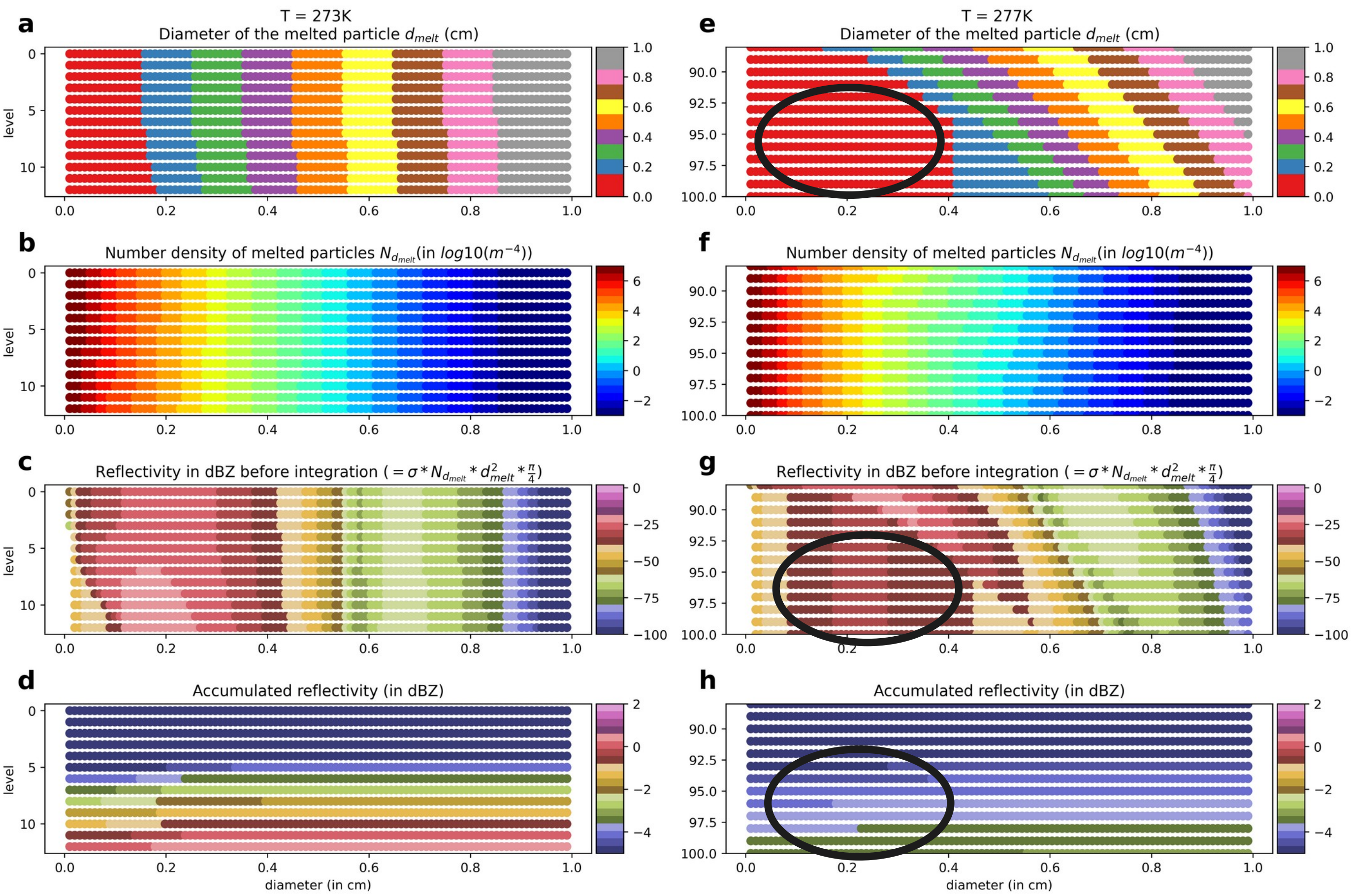
Indeed, in the next two figures, the authors show the variables which play a key role in the computation of the reflectivity inside the melting layer, for the two different temperature bins. The variables are shown as a function of the level inside each sub-melting layer on the y axis, and as a function of the diameter (x axis). The colorbar represents one variable of interest. The results are shown at Ka band only. They are shown on the left columns for the 273K bin, and on the right columns for the 277K bin. The authors have plotted:

- **The diameter of the melted particle (top panels a and e):** This diameter can be seen as the remaining frozen part of a given melted particle. It is equal to the frozen diameter at the top of the sub-melting layer, and it is equal to 0 (red colours) when the particle is fully melted. A given vertical column of the two-dimensional plot represents the melting process for a particular particle of diameter D across the sub-melting layer. For the T273K bin (top left panel, a), the melting process is slower than for the 277K bin (top right panel, e) because of the colder temperature. Therefore, the melted diameters are always almost equal to the frozen diameter for the 273K bin, except for the smallest diameters at the end of the 273K sub-melting layer. However, the melting process is quicker at 277K (see e panel) as more particles have their melted diameters which reach values close to 0 (red values).
- **The number density of the melted particles in panels b and f**.
- T**he reflectivity *before* integrating over the PSD and the height levels** (it is displayed in dBZ in panels c and g): This value corresponds to the backscattering cross-section, multiplied by the melted number density (for the melted diameter d_melt), and by the square value of the melted diameter (the equation is given in the subtitle). Therefore, when a particle is melted (i.e. its melted diameter equals 0), then its associated backscattering cross-section (for a given diameter and a given level) is close to 0 because the backscattering cross-section is multiplied by the diameter of the remaining frozen part of the particle. Therefore, wherever (in terms of levels and diameters) a particle is melted, its contribution to the overall reflectivity is very small (see for instance the area displayed by the black circle).
- **The reflectivity *after* integrating over the PSD and the height levels (panels d and h):** in the 2D plot, one can see the reflectivity that is being accumulated over the PSD and the height levels across the 273K bin (d) and the 277 K bin (h). The value on the bottom right corresponds to the value which is stored in the look-up table for this specific bin. For a content of 2*10-5 kg/m3, the final value (about 0~dBZ) is larger for the 273K bin, compared to the value of the 277K bin (about -3dB). This is because the areas in which the particles are completely melted at 277K, corresponds to levels in which they are not melted at all at 273K. Therefore, their contributions to the overall reflectivity is larger at 273K than at 277K, especially as there is a very large number of small particles for this content. This behaviour is not observed for larger content because of the PSD (see for instance the comparisons of the number density plots between a content of 10-3 kg/m3 and a content of 2*10-5 kg/m3). Indeed, the number of larger (resp. smaller) particles is larger (resp. smaller) for larger contents, and these large particles are not fully melted in most of the levels of the different

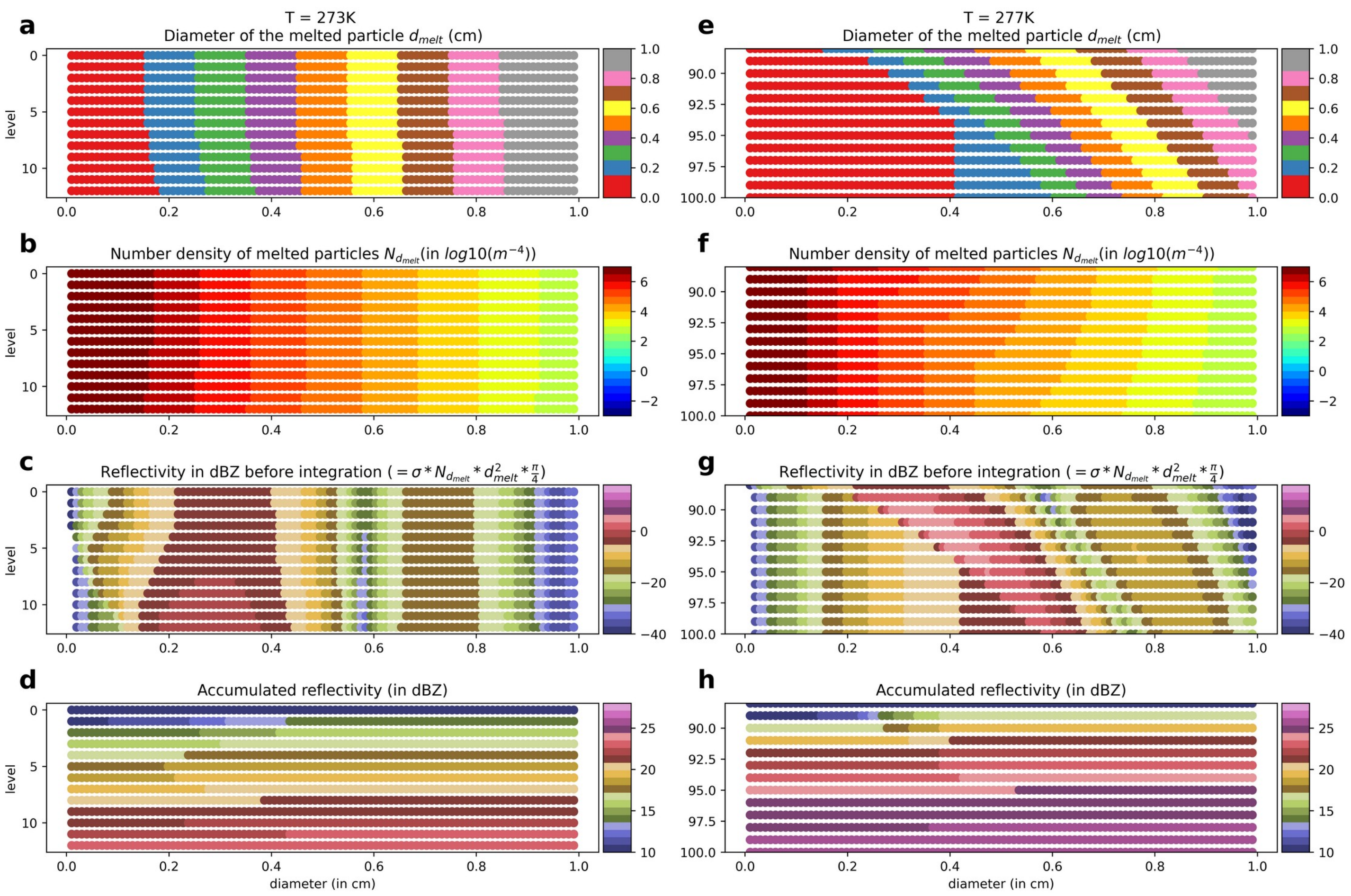
sub-melting layers. Therefore, we end up with a more logical behaviour, with larger reflectivity at 277K than at 273K.

The authors added a sentence to briefly describe this behaviour in section 4.1. The authors recognise that the assumptions made on the evolution of the melting process within each sub-melting layer has a strong impact on the subsequent simulated reflectivities. To avoid this issue, an alternative could be to add the melted fraction (calculated based on the liquid and frozen contents of the NWP model) as a predictor in the lookup tables (in addition to the temperature and hydrometeor content), as it is done in the T-matrix ground-based (Augros et al. 2016) and airborne cloud (Borderies et al. 2018) radar forward operator. This requires a lot of work and is therefore left for future work.

*<u>Variables of interest for a content of 2*10-5 kg/m3 at Ka band:</u>*



Variables of interest for a content of 10-3 kg/m3 (at Ka band):



Comment 16: p.20 l.345pp: "this can.." and "This can..."

Response 16: The authors revised the line.

Comment 17: p.21 l.361/362: I do not understand this sentence.

Response 17: The authors agree that the sentence was hard to understand and didn't provide any new relevant information. The sentence has been removed.

Comment 18: p.22 figure 9: "...less (larger)..." less and larger do not belong together. It is either "less and more" or "smaller and larger"

Response 18: The authors thank the reviewer for the correction. We corrected "smaller and larger" in the revised manuscript.

Comment 19: p.24 l.384: There is always a profile of DFR. Sometimes the values are just equal 0.

Response 19: Thank you for pointing out. To avoid the confusion, the sentence has been revised.

Comment 20: p.25: First define V1 and V2 before talking about them.
Response 20: The authors agree with the reviewer and have modified the text

Comment 21: p.25 l.405: "(given in the methodology diagram)" Please mention the threshold values here.
Response 21: As suggested, we added the threshold values.

Comment 22: p.26 l.418: Mention here what the markers I, II, and III denote.
Response 22: To avoid the confusion, the sentence has been revised with a clearer explanation of marker I, II and III.

Comment 23: p.26 l.426/427: This sentence needs to be revised by including some articles.
Response 23: As suggested, the sentence has been revised by adding a reference.

Comment 24: p.27 figure 12: labels on the colorbar need to be adjusted better.
Response 24: We revised the figure with clear visibility of the colorbar.

Comment 25: p.29 l.449: I do not see the bright-band peak in the observations.
Response 25: The authors agree that the bright-band peak is not visible in the CFADs in the mid-latitudes, but only in the Tropics. Indeed, as shown in Figure 14 (d) and 15 (d), the bright band peak is visible around 5 km in the observations in the tropics. The authors have revised the sentence in the manuscript.

Comment 26: p.29: In line 133 you mention the averaging of the profiles and promise to discuss it later. I would have expected this here.
Response 26: The authors thank the reviewer for pointing out this. As the results are similar (in CFADs as well as on the categorical scores), we didn't discuss it. According to your suggestion, the authors added one sentence in section 5.3 (from line 464). *"These discrepancies are similar in the three geographical domains, indicating that the differences of horizontal resolution across the globe with the ARPEGE stretch grid has a secondary effect with respect to other model biases."*

Comment 27: p.36 l.487: Please give a reference where the melting layer scheme is validated for the passive simulations.
Response 27: The authors thank the reviewer for this suggestion. As suggested, a reference (Bauer, 2001) has been added.

Comment 28: p.38 l.544: Why are there only five temperature bins but n_levels level?
Response28: This study is based on the original formulation of Bauer (2001), which was originally introduced in RTTOV. One important feature of this model is that the fraction of melted particles is not specified as input parameter. Therefore, the melting layer is subdivided into a given set of height profiles (nlevels). This subdivision is intended to allow a smooth vertical representation of the melting process, starting from the completely frozen particle, until fully melted. The resulting bulk scattering coefficients are then integrated over these n_levels heights. In the original formulation, only the 273 temperature bin was specified, even though the scattering coefficients were integrated between 273K and 275K, with a melting process which was discretized within n_levels. In this revised parametrization, it has been decided to slightly change the parametrization to get closer to the NWP models (in which we can have outputs at all temperatures), by adding 5 temperature bins in total, and by keeping the original subdivision of n_levels across the full melting layer. The authors added one sentence into the appendix to mention this point L573.