Response to Referee #4

Thank you very much for your time and effort taken to review our manuscript submitted to AMT. We really appreciate the reviewers' constructive comments that are very useful to greatly improve the manuscript. We have revised the manuscript based on your comments as explained below. Please see below for our point-by-point responses to your comments, where the original comments are shown in *italics* and our responses are shown in normal text just below your corresponding comments.

This manuscript describes the theoretical foundations of the Japanese radiative flux and heating rates product for EarthCARE. The algorithm derives vertical profiles of longwave (LW) and shortwave (SW) radiative fluxes and heating rates at 34 atmospheric levels by applying a radiative transfer model to aerosol and cloud profiles retrieved from the EarthCARE cloud profiling radar, lidar, and multi-spectral imager. The primary focus of this study is to document the anticipated accuracy of the product by applying the algorithm to existing observations collected by the A-Train. The subject is appropriate for Atmospheric Measurement Techniques €i0and the uncertainty analysis is quite thorough considering the algorithm has yet to be implemented for EarthCARE. My primary concerns center on the organization of the findings. In particular, the abrupt transition from the algorithm description to validation could be softened by including the preliminary results prior to discussing the comparisons. In addition, there are several opportunities to reference related literature that should be considered. Since I do not anticipate those modifications requiring substantial rewriting, I recommend the paper be published in AMT after the following minor revisions to address these concerns.

A. We sincerely thank the reviewer for the thoughtful comments and valuable suggestions. We appreciate the recognition of the manuscript's contributions to the field and have carefully considered the feedback provided. Our responses to each of the reviewer's comments are detailed below.

Specific Comments:

1. *The most significant issue with the paper in its current form is the organization of results. This transition from algorithm description immediately into comparisons with CERES is quite abrupt. It would be interesting to see some examples of the algorithm before discussing its evaluation. I think the example in Figure 1 could be used to simply illustrate the methods described in Section 2 (omitting the CERES comparisons in panel (e) which are hard to see anyway). That could be followed the spatial distributions of aerosol and*

cloud radiative effects in Figures 6 and 7 to provide context for what the algorithm does before assessing the accuracy of these results.

A. The entire text was reorganized following the reviewer's suggestion, with the demonstration of input and output referring to Figure 1 moved to Section 2 and the section on cloud and aerosol radiative forcing moved to Section 3. Figure 1(e) is drawn separately for SW and LW to make the plot easier to see. Some additional adjustments of texts have also been done for a smooth transition from description of methodology, through demonstration of aerosol and cloud radiative forcing, to evaluation against CERES and BSRN. We believe that the presentation became much smoother than the previous version. Thank you very much for your suggestion.

1. *Line 43: The acronym for CERES is missing some words "Clouds and the Earth's Radiant Energy System"*

A. We have added the phrase 'Clouds and the' as per your suggestion.

2. *Line 49: Since this is not the first paper to estimate fluxes using radiative transfer modeling with atmospheric inputs, I suggest referencing some of the pioneering papers on this topic (e.g. Rossow and Lacis, 1990; Rossow and Zhang, 1995; Zhang et al, 1995; Whitlock et al, 1995).*

A. The references have been added as suggested. Thank you very much for suggesting these literatures.

3. *Line 69: It may also be worth adding that these measurements will provide important continuity for the data record that began with the A-Train in 2006 (L'Ecuyer and Jiang, 2010).*

A. In response to your comment, we have added the following sentence to highlight the importance of these measurements in terms of the data record continuity that began with the A-Train in 2006, as discussed by L'Ecuyer and Jiang (2010).

'These measurements will also provide important continuity for the long-term data record that began with the A-Train in 2006 (L'Ecuyer and Jiang, 2010), ensuring that trends and patterns in atmospheric observations are consistently maintained.'

4. *Line 90: While it is likely beyond the scope of this particular study, there could be value in digging deeper into comparisons with FLXHR-lidar and CCCM to trace the source*

of discrepancies in all three algorithms. Since the algorithm has already been applied to CloudSat/CALIPSO/MODIS observations, it could immediately be compared to FLXHR-lidar and CCCM in a manner like that of Ham et al. (2014). The results would be very interesting for understanding all three algorithms.

A. We agree that a deeper comparison with FLXHR-lidar and CCCM would be valuable for tracing the source of discrepancies between the three algorithms. However, as this is beyond the scope of the current study, we have not included this analysis in the present paper. We do recognize the importance of this comparison and intend to pursue it as part of our future work. This will allow for a more comprehensive understanding of the differences and similarities among the algorithms, as highlighted by Ham et al. (2017). The following sentence has been added to the text.

'Ham et al. (2017) compared CCCM with 2B-FLXHR-Lidar, showing regional differences in radiative fluxes due to differences in cloud characteristics within the products, and we believe that more detailed comparisons between products, including our product, would be beneficial and needed to further improve the products as future work.'

5. *Line 113: I think 'were utilized' should be 'will be utilized' since EarthCARE data were not actually used in this paper.*

A. The text has been revised following the reviewer's comment. Thank you for correcting our English.

6. *Line 157: Do you mean 'daytime' instead of 'diurnal'?*

A. Corrected to 'daytime'. Thank you.

7. *Line 180 (and again on Line 311): The spatial resolution of CloudSat is 1.4 km (across track) by 1.8 km (along track).*

A. Spatial resolution was corrected to '1.8 km'.

8. *Line 229 - 231: There is precedence for separating results according to cloud phase in this way. Perhaps cite Matus et al. (2017) here.*

A. Matus and L'Ecuyer (2017) was added to cite here.

9. *Line 297: The preceding discussion does not provide adequate context for the value of these estimates. The ability of spaceborne active sensors to constrain surface fluxes and atmospheric flux divergence represents one of the most important contributions they*

have made to climate science. This is discussed in detail in papers like Haynes et al. (2010), L'Ecuyer et al. (2019), and Hang et al. (2019), for example. If this is better articulated in the introduction, the point here could be that without quantifying the uncertainties, it is hard to know how trustworthy this information is.

A. Thank you very much for this suggestion to better motivate our study. The following sentences were added to the introduction and Section 5, respectively, in the revised manuscript.

Introduction

'In addition, spaceborne active sensors have made significant contributions to climate science by providing more precise constraints on atmospheric and surface radiative fluxes compared to passive sensors. These active sensors play a crucial role in improving climate models by offering more accurate measurements of radiative fluxes and heating rates partitioned into atmosphere and surface (Haynes et al., 2013; L'Ecuyer et al., 2019; Hang et al., 2019). However, without quantifying the uncertainties, it is difficult to fully evaluate the reliability of these estimates of radiation based on active sensors. Therefore, one of the objectives of this study is to assess these uncertainties through comparisons with other products and ground-based observations, aiming to validate the accuracy and reliability of the radiative flux based on the active sensor.'

Section 5

'These findings highlight the importance of spaceborne active sensors in constraining surface and atmospheric fluxes, which are essential for accurate climate modeling. However, without quantifying the uncertainties associated with these estimates, it is challenging to fully trust the information they provide. Therefore, the quantification of uncertainties is crucial to assess the reliability of the derived fluxes and their implications for climate science.'

10. Line 328: It would also be good to compare against other recent studies that produce similar estimates (Matus et al, 2019 is one example but there are others, including some by Winker et al.)

A. We have added the following text that includes a comparison to Matus et al. (2019). Thank you for your suggestion.

'Our study's results align with those of Matus et al. (2019), who reported a global mean aerosol direct radiative effect (DRE) of −2.40 W/m², primarily driven by sulfate aerosols with significant uncertainty due to aerosol type classification and optical depth retrievals. Similarly, our findings emphasize the critical role of accurate aerosol classification in determining the radiative forcing. Matus et al. (2019) also highlighted that anthropogenic aerosols contribute significantly to the global radiative effect, estimating an anthropogenic direct radiative forcing (DRF) of −0.50 W/m². Our study corroborates these findings, further illustrating the substantial impact of anthropogenic aerosols on the Earth's energy budget. Both studies underscore the value of leveraging satellite-based observations to capture aerosol radiative effects, particularly in regions where ground-based measurements are sparse.'

11. *Line 337: Similarly, some qualitative comparisons against prior work are warranted here as well (there are lots of options but Matus et al, 2017; L'Ecuyer et al, 2019 and Hang et al, 2019 all utilize similar observations to extract the effects clouds at TOA, SFC, and in the ATM).*

A. The following sentence was added to Section 3.

'Our findings on cloud radiative forcing are consistent with those reported in previous studies, including Matus and L'Ecuyer (2017), L'Ecuyer et al. (2019), and Hang et al. (2019). These studies similarly identified significant impacts of clouds on radiative forcing at the top of the atmosphere, surface, and within the atmosphere, supporting the robustness of our results.'

12. *Line 363: This isn't an accurate statement. The analysis quantifies how the accuracy of radiative flux calculations varies with spatial and temporal averaging scale.*

A. The text has been corrected to be accurate as follows. Thank you very much.

'we quantified how the accuracy of radiative flux calculations varies with different spatial and temporal averaging scales.'

13. *Figure 1: The transition from yellow to light blue in the upper atmosphere in Figure (d) is likely an artifact of the color bar. It might be good to have a small band of white from -0.05 to 0.05 to represent areas of 0 heating.*

A. Thank you for the suggestion. Here, as we aim to distinguish between cooling and heating, we prefer not to introduce a white band around the 0 value, and would like to retain the current color bar that effectively separates the heating and cooling.

14. *Figure 3 caption: Technically this figure is only the same as Figure 2 panels (a) and (d).*

A. Added '(a) and (d)' to the caption.

15. *Figure 5 caption: Again, this figure is only the same as Figure 4 panels (a) and (d).*

A. Added '(a) and (d)' to the caption.

16. *There are also several minor grammatical errors throughout the paper. A few representative examples follow, but I suggest taking a careful read through the paper for other similar issues:a.Line 38: 'circulation' should be 'circulations'b.Line 44: 'radiometer' should be 'radiometers'c.Line 199: 'value' should be 'values'd.Line 200: 'of the aerosols' should be 'of aerosols'*

A. The grammatical errors have been corrected. Thank you.

References

1. Ham, S.-H., S. Kato, F. G. Rose, D. Winker, T. L'Ecuyer, G. G. Mace, D. Painemal, S. Sun-Mack, Y. Chen, and W. F. Miller, 2017: Cloud occurrences and cloud radiative effects (CREs) from CCCM and CloudSat radar-lidar products, J. Geophys. Res. 122, 8852-8884.

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3. Haynes, J. M., T. H. Vonder Haar, T. L'Ecuyer, and D. Henderson, 2013. Radiative heating characteristics of Earth's cloudy atmosphere from vertically resolved active sensors, Geophys. Res. Letters 40, doi:10.1002/grl.50145.

4. L'Ecuyer, T. S. and J. Jiang, 2010: Touring the Atmosphere Aboard the A-Train, Physics Today 63 (7), 36-41.

5. T. S. L'Ecuyer, Hang, Y., A. V. Matus, and Z. Wang, 2019: Reassessing the role of cloud type in Earth's radiation budget after a decade of active spaceborne observations. Part I: Top of atmosphere and surface, J. Climate 32, 6197-6217.

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7. Matus, A. V., T. S. L'Ecuyer, D. S. Henderson, and T. Takemura, 2019: New global estimates of aerosol direct radiative effects, kernels, and forcing, from active satellite observations, Geophys. Res. Letters 46, 8338-8346.

8. Rossow, W. B., and A. A. Lacis, 1990: Global, seasonal cloud variations from satellite radiance measurements. Part II: Cloud properties and radiative effects, J. Clim., 3, 1204–1253.

9. Rossow, W. B., and Y.-C. Zhang, 1995: Calculation of surface and top of the atmosphere radiative fluxes from physical quantities based on ISCCP data sets: 1. Validation and first results, J. Geophys. Res., 100, 1167–1197.

10. Whitlock, C. H., and Coauthors, 1995: First Global WCRP Shortwave Surface Radiation Budget Dataset. Bull. Amer. Meteor. Soc., 76, 905–922, https://doi.org/10.1175/1520-0477(1995)076<0905:FGWSSR>2.0.CO;2.

11. Zhang, Y.-C., W. B. Rossow, and A. A. Lacis, 1995: Calculation of surface and top of the atmosphere radiative fluxes from physical quantities based on ISCCP data sets: 1. Method and sensitivity to input data uncertainties, J. Geophys. Res., 100, 1149–1165.