Response to Referee #3

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.

The manuscript describes the algorithm to compute top-of-atmosphere and surface radiative fluxes and radiative flux profiles in the atmosphere using measurements from EarthCERE instruments, CPR, ATLID, MSI, and BBR. The algorithm was developed by the EarthCARE Japanese group. TOA flux is used to evaluate retrieved properties by comparing fluxes with fluxes derived from BBR. The EarthCERE's goal is to achieve the difference less than 10 Wm-2. The authors test the algorithm using A-train data. When instantaneous fluxes are averaged in 5-degree grids and over a month, the bias and RMS difference compared with CERES derived fluxes are, respectively, 24 Wm-2 and 36 Wm-2 for shortwave and -11 Wm-2 and 14 Wm-2 for longwave. The purpose of the manuscript is to describe the algorithm and evaluation of the algorithm. While the manuscript meet this goal, it does not provide new information other than these purposes. Using 1D radiative transfer and comparing with observed TOA fluxes with A-train data are not new. New science results are missing. In addition, given similar products are available from the European team, the manuscript needs to highlight unique aspects of the Japanese flux products, distinguishing from European products.

A. Thank you very much for your comments. The 1D radiation calculation is used to develop the present algorithm to meet the requirements for data delivery latency in JAXA's standard product generation. For the research product, which is another data category in JAXA without such latency requirements differently from the standard product, we plan to provide the outcomes of 3D radiation calculations although it is beyond the scope of this paper. Our detailed responses to your comments are provided below including these points.

Major comments.

The authors describe radiation budget, especially downward longwave radiation at the surface in the introduction section. However, given what the authors describe in this manuscript, I do *not see how the algorithm and data products described in this manuscript will contribute to improving global surface radiation budget and downward longwave, in particular, from the level where we are with A-train data. If Japanese flux products are to improve surface radiation, please describe how to improve in the manuscript.*

A. This paper primarily demonstrates the preparatory stage for the EarthCARE product, and once EarthCARE data becomes available, the cloud data will be replaced with those from EarthCARE. With the enhanced capabilities of CPR and ATLID, which will better capture low-level clouds, we expect to see improved contributions to downward longwave radiation as well. The following sentence has been added to the introduction.

‘With the enhanced performance of EarthCARE's CPR and ATLID, which will better capture low-level clouds, we expect to see improved contributions to downward longwave radiation as well.’

Similarly, the authors mention that aerosol and cloud vertical profiles affect vertical profile of radiative fluxes. The number of aerosol type is increased from three to four in the algorithm. This is still less that the number of aerosol types used in CALIPSO algorithms (see for example Omar et al. 2009; Burton et al. 2012, 2013) and flux computations. Please provide thoughts of how to improve our knowledge of vertical flux profiles with the flux products described in this manuscript.

A. As aerosol species, fine-mode particle (WS), fine-mode and light-absorbing particle (LA), coarse-mode particle (SS), and coarse-mode and light-absorbing particle (DS) are assumed in the JAXA EarthCARE lidar retrievals. These four aerosol components are similar to aerosol species of the chemical transport model. The definitions of aerosol type are different between JAXA and NASA products. For example, smoke and polluted continental of NASA product (Omar et al. 2009) are consist of WS and LA. In addition, polluted dust of NASA product is the mixture of smoke and dust, which are consist of WS, LA, and DS. In this study, the light-absorption of aerosols emitted from biomass burning and air pollution may be underestimated, because of the lack of LA. The estimation of aerosol radiative effect will be improved in the JAXA EarthCARE product by including LA. The following sentence has been added to the section 1.

‘By adding LA in the EarthCARE product, the estimation of light-absorption for biomass burning and air pollution, which include LA, will be improved and aerosol radiative effect is expected to be more accurately evaluated during the EarthCARE mission.’

The introduction provides some background of surface radiation budget. EarthCARE data are, however, likely to contribute improving our knowledge of vertical flux profiles than improving global radiation budget.

A. Although we believe that improving the vertical cloud coverage will enhance global radiation calculations, improvements in cloud physical quantities such as cloud water content and ice water content, as well as better aerosol characterization enabled by ATLID, will also lead to better estimates of vertical profiles of radiative fluxes, as the reviewer pointed out. We have added these points in the revised manuscript as follows: “Such enhanced information of Earth’s energy budget will also be facilitated by improved knowledge of vertical profiles of radiative fluxes expected from the detailed cloud profiling capability combined with cloud dynamics information.”

The approach described in the manuscript has been used with A-train data for at least 10 years. Could you describe the uniqueness of the data products? What do they offer scientifically that is not available from European products and A-train products (e.g. FlxHR or CCCM)? Unless the authors describe clearly here, users are not motivated to use the Japanese products unless they are involved in the project.

A. Thank you very much for raising these important points. For the past A-Train data, FLXHR and CCCM data can be utilized, but for EarthCARE, to our knowledge, there has been no announcement regarding the provision of radiative flux data beyond the Japanese and European data. Also, given our another development of 3D radiative transfer (RT) code, called MCstar, and its application to some cases of cloudy scene as described in Okata et al. (2017), it would be possible in the future to seamlessly compare 1D and 3D radiative calculations based on the common assumptions and settings of particulate and gaseous optical properties that are used in our 1D RT code (MstrnX used in this study) and 3D RT code (MCstar). This would allow for error quantifications of 1D RT against 3D RT and possible introduction of several methods for approximating 3D RT effects in the framework of 1D RT computation, as also described in Okata et al. (2017). We plan to incorporate these improvements into the standard algorithm with

1D RT described in the present paper, as well as development of the research product with 3D RT, so as to add values to our Japanese radiation products. Additionally, we also believe that comparing these Japanese data products based on the 1D and 3D RT computations with those from European side will lead to improvements in both datasets. These points are added in the revised manuscript at the beginning of Section 2.

Okata, M., T. Nakajima, K. Suzuki, T. Inoue, T. Y. Nakajima, and H. Okamoto, 2017: A study on radiative transfer effects in 3-D cloudy atmosphere using satellite data. J. Geophys. Res. Atmos., 122, 443─468, doi:10.1002/2016JD025441.

It is not critical but given the bias at TOA, how the Japanese team is going to achieve the goal of EarthCARE of 10 Wm-2? In addition, this manuscript is revealing that the Japanese flux algorithm is more primitive compared to European flux algorithms. I think that it is useful for the international community having independent flux results from the Japanese and European teams. From this point, it is useful if the authors provide their thoughts on how the international community will benefit having the Japanese flux products in addition to Europeans.

A. As mentioned in the previous response, we believe that comparing the Japanese and European products will contribute to the improvement of both, benefiting from having independent radiative flux algorithms from the Japanese and European teams, as the reviewer pointed out. By providing the algorithm development team for cloud physical properties with findings from this paper, such as the flux error characteristics of ice clouds, we expect to contribute to improvements in the cloud properties retrievals toward an achievement of the 10 W/m² accuracy. Furthermore, the European team has focused on analyzing specific cases, without conducting long-term analyses, which suggests that operationalizing 3D radiative transfer calculations may not be feasible for them. In this regard, we also plan to develop a flux algorithm based on 3D radiative transfer calculations (Okata et al., 2017) as part of our research products. The improvement of the 1D standard product is also planned through comparison with 3D radiation calculations in future studies, as mentioned in our previous response. The following sentence has been added to the text to reflect the argument above.

“it is worth noting that our previous study developed a three-dimensional (3D) radiative transfer code and applied it to some cases of cloudy scenes as described in Okata et al. (2017). It would then be possible in future studies to seamlessly compare the 1D and 3D radiative calculations based on the common assumptions and settings of particulate and gaseous optical properties that are used in our 1D and 3D radiative transfer codes. This would allow for error quantifications of 1D against 3D radiative transfers and possible introduction of several methods for approximating 3D effects in the framework of 1D radiative transfer computation, as also described in Okata et al. (2017). In future studies, we plan to incorporate these improvements into the standard algorithm with 1D radiative transfer described in the present paper, as well as to develop a radiative flux algorithm based on 3D radiative transfer calculations (Okata et al. 2017) as part of the research product, so as to add values to our Japanese radiation products."

Minor comments

Line 134: Could you explain what the Voronoi particles are?

A. The Voronoi particles are particles that do not have regular spherical shapes, but rather particles with irregular polyhedral shapes. Voronoi particles are commonly used to model the scattering properties of ice crystals in clouds. For more details, please refer to the work of Ishimoto et al., (2010) which is cited in the manuscript. The following sentence has been added to the text in the revised manuscript to describe the Voronoi particles.

'The Voronoi particles are particles that do not have regular spherical shapes, but rather particles with irregular polyhedral shapes.'

Line 247: Could you justify reducing the optical thickness by 30%?

A. This is based on the bias estimate of the COT retrieval for ice clouds. Nakajima et al. (2019) show a COT bias of 2.4 for ice clouds relative to MODIS products, so a 30% reduction for ice clouds with small COT is considered reasonable. The following sentence has been added to the text.

'Nakajima et al. (2019), who described the cloud property retrievals from shortwave reflectance, showed a COT bias of about 2.4 for ice clouds relative to MODIS products, so that a 30% reduction of COT for ice clouds with small COT can be considered reasonable.'

Line 253: If the authors claim EarthCARE instruments detect more clouds, then computed OLR is even lower, which increases the bias. Please explain why EarthCARE is expected to reduce the LW bias.

A. EarthCARE's ATLID and CPR will provide more accurate vertical profiles of cloud properties, such as cloud phase and cloud-top height, which are crucial factors in determining LW radiation. These enhancement in accuracy of cloud microphysical properties, when used as input data for radiative transfer computation, is anticipated to lead to better estimates of longwave radiation.

Line 330: Could you elaborate why aerosol radiative forcing is important in the upper atmosphere? Also, does the Japanese team retrieve aerosol properties everywhere all the time? What do you use when retrieved aerosol properties are not available (e.g. below clouds)?

A. We intended to mean simply “atmosphere” contrasted against “surface”, not specifically meaning the “upper atmosphere”. Therefore, we have deleted the “upper” from the sentence in the revised manuscript. However, aerosols above clouds are important because they can induce multiple scattering between clouds and aerosols, thereby altering radiative effects. When aerosols are present above clouds, this interaction can significantly impact the overall radiative forcing of aerosols. Including such an “above-cloud aerosol” case, the vertical stratification of aerosols and clouds is a key factor in determining aerosol radiative forcing as Oikawa et al. (2013, 2018) have shown. The Japanese team's approach primarily uses aerosol data from ATLID, which allows for more detailed calculations of these interactions. However, when thick clouds are present, aerosol data cannot be retrieved, as the reviewer pointed out. For future research products, we are considering incorporating aerosol reanalysis products as input data, which would allow us to include aerosols below the cloud layer as well.

Oikawa, E., Nakajima, T., Inoue, T., and Winker, D.: A study of the shortwave direct aerosol forcing using ESSP/CALIPSO observation and GCM simulation, J. Geophys. Res. Atmos., 118, 3687–3708. https://doi.org/10.1002/jgrd.50227, 2013.

Oikawa, E., Nakajima, T., Inoue, T., and Winker, D.: “An evaluation of the shortwave direct aerosol radiative forcing using CALIOP and MODIS observations”, J. Geophys. Res. Atmos., 123, 1211–1233, https://doi.org/10.1002/2017JD027247, 2018.

References

Burton, S. P., and coauthors, (2012). Aerosol classification using airborne high spectral resolution lidar measurements – methodology and examples, Atms. Meas. Tech., 5, 73-98.

Burton, S. P., Ferrare, R. A., Vaughan, M. A., Omar, A. H., Rogers, R. R., Hostetler, C. A., and Hair, J. W., (2013). Aerosol classification from airborne HSRL and comparison with the CALIPSO vertical feature mask, Atmos. Meas. Tech., 6, 1397-1421.

Omar, A., Winker, D., Kittaka, C., Vaughan, M., Liu, Z., Hu, Y., Trepte, C., Rogers, R., Ferrare, R., Kuehn, R., Hostetler, C., (2009). The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm, J. Atmos. Oceanic Technol., 26, 1994–2014.