Response to Referee #2

We thank the referee for their review. Below are the original comments in *italics* with our responses in normal text.

The manuscript presents the broadband radiative transfer (RT) algorism for the EarthCARE mission. The 1D and 3D RT schemes are implemented. Because the 3D RT scheme will be used operationally in the satellite mission for the first time, the authors presented in this manuscript how 3D RT is important in to achieve the mission's goal for the accuracy in radiative flux. The manuscript is generally well written. I recommend this paper is published after some revisions. Below are my specific comments and questions.

General comments

1. *In the manuscript, the authors used several technical terms specific to the EarthCARE project, such as "joint standard grid (JSG) column". Although they are shown with references, many of which are in the EarthCARE special issue, and they are unknown for the readers. It is helpful for the readers to be with some (even short) explanations (e.g., what to do for what purpose).*

   We have added text as and where appropriate in the manuscript to give a better sense of the EarthCARE specific technical terms.

2. *This is a similar issue as above. I miss the algorithm description of the "observed" radiative fluxes from BBR. Because the BBR actually measures the broadband radiances, the "observed" radiative fluxes would be some estimates. There is a citation to a manuscript that has not yet been published, but I could not find any further information about the paper. A brief explanation is required in the manuscript. Is the observed radiative flux accurate enough to compare with simulated radiative fluxes? As for radiative closure analysis, I support the usefulness of BBR multiangle radiance (instead of radiative fluxes).*

   The referee is correct that the "observed" radiative fluxes are estimates derived from the radiances. The citations for the paper describing the BMA-FLX processor, detail the method using angular distribution models. We do not believe that an explanation of the approach is necessarily required in this manuscript since the fluxes computed by the BMA-FLX processor are not used in this manuscript. The fluxes only described to indicate the reason for the choices made for the forward radiative transfer calculations, including the calculation of fluxes at particular reference heights and the size of the radiative closure assessment domains.

   However, the fluxes from the BMA-FLX processor are used in the radiative closure, so details of the radiance to flux conversion are described in the manuscript focused on the EarthCARE radiative closure processor. This includes questions related to the accuracy and uncertainty of the radiative fluxes both derived from the BBR and computed in ACM-RT.

3. *If local positive and negative 3D-1D flux differences are well cancelled in larger scales, 1D flux is enough to explain larger scale average. Averaging-scale dependence is interesting to see. Is there any plan to study that aspect in the future radiative closure studies?*

   Yes, there is a plan to look at this in future studies. It is an interesting way to analyse the 3D effects for both domains smaller and larger than that shown in this manuscript and relevant for analysis and interpretation. For example, to characterize the magnitude of the 3D effect in numerical weather prediction models, at the same scale or smaller, in contrast with climate models, which typically have larger scales.

4. *I have a question regarding the 3D radiative effect: Why the goal of the EarthCARE mission is set at local (of ~100 km^2 domain) radiative flux accuracy? I completely agree that 3D RT is required to simulate BBR radiances and to obtain the radiative closure, while the local radiative flux at TOA (~20 km height) is not directly measured. What is the benefit to obtain local 3D flux? Is CRE evaluated for 3D RT as well? If so, it would be interesting to see how CRE is different from 1D RT counterpart.*

   The local radiative flux accuracy was defined early in the EarthCARE mission. According to this document ESA 2001 cited in the manuscript, the size of the horizontal domain was the scale expected to the roughly the size of numerical weather prediction systems at the time of launch. The 10 W m^{-2} level of accuracy was noted to be the level needed to detect radiatively important variations in the retrieved profiles.

   The benefit of the local 3D flux is to provide a sample to characterize the magnitude of the 3D effect since we always do 1D radiative transfer calculations. The manuscript shows that 1D radiative transfer calculations are performed for all valid retrieved data and as shown in Figure 8 the 3D effect can be substantial under certain conditions. While it is not a perfect estimate of the radiative fluxes to compare against fluxes derived from BBR, using 3D calculation does seem to be important given the errors when using 1D calculations.

   Existing output from ACM-RT could be used to compute CRE from 1D and 3D radiative transfer calculations. To demonstrate this we repeated calculations using the Monte Carlo codes in ACM-RT configured to run in 3D and ICA mode and focus on solar CRE since it has larger 3D effects, as shown in the manuscript.

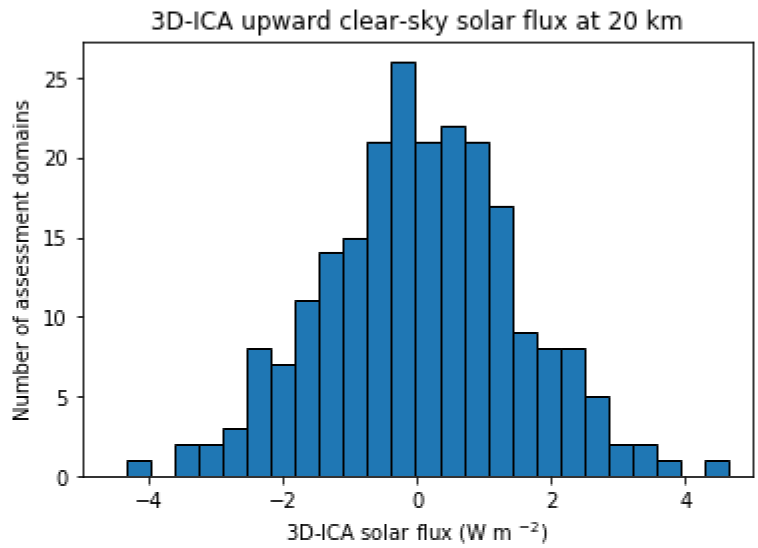

Figure R1. Assessment domain (5x21 km) mean differences for the Hawaii scene between 3D and ICA upward solar fluxes at 20 km for clear-sky conditions computed using Monte Carlo radiative transfer model.

Figure R1 shows the difference in clear-sky solar fluxes which are generally much smaller than differences for cloudy assessment domains (Figure 8 in manuscript). Differences in Figure R1 arise from the 3D calculations seeing surface albedos and atmosphere, i.e., aerosols, outside of the assessment domain that would not be seen by ICA calculations. When using 1D clear-sky fluxes there is will also be some differences due to using a 2-stream solution rather than a Monte Carlo but these should be small.

Figure R2 shows that differences in the clear-sky fluxes are frequently much smaller than the 3D effect on solar CRE, especially for cloudy scenes with larger cloud water paths. This suggests that it should be possible to use clear-sky radiative fluxes computed using the 1D radiative transfer code could be used in combination with the all-sky 3D fluxes to compute the 3D CRE.

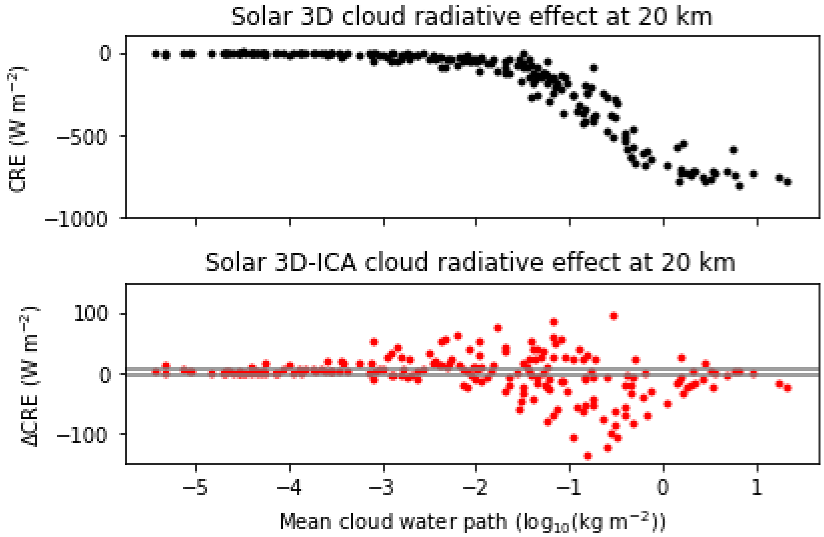

Figure R2. Assessment domain (5x21 km) mean differences for Hawaii scene, upper plot is the solar CRE computed using 3D radiative transfer as a function of domain mean cloud water path, while the bottom plot is the difference (3D-ICA) in CRE.

5. *Why the size of "assessment domain" was chosen as 5´21 km?*

The size of the domain for the radiative closure is ~100 km^2 which was driven in part by performance of the BBR which had its nominal performance requirements defined for this sized domain. Instead of using a 10 km by 10 km domain, we decided to use a domain that is larger orbit and smaller across orbit. This is a balance between a domain that is far from the track of the active sensors, for which the scene construction algorithm would have increasing impact on the results, and a narrow but long domain that would make interpretation of the closure difficult. The use of 21 km along orbit rather than 20 km is due to the 7 km period of the horizontal grid used for for retrievals (Eisenger et al, 2023).

We have added text and references to the manuscript to explain this choice at the beginning of the Results section

Eisinger, M., T. Wehr, T., Kubota, D., Bernaerts, and K. Wallace, 2023: The EarthCARE production model and auxiliary products. *Atmospheric Measurement Techniques*, to be submitted.

6. *The radiative flux distribution will be different by the reference height, which was set at 20 km in the manuscript. Many of readers should not be aware of the importance of the*

reference height. Can the authors add some explanation of the reason for their choice of the reference height?

In the operational processing of EarthCARE data, the reference height will be determined in the BMA-FLX processor and certainly be different for each 5x21 km domain. In this manuscript, which is highlighting the radiative transfer calculations we instead use for simplicity a constant height of 20 km rather than a varying reference height. A value of 20 km is used in this manuscript because it is shown in Loeb, Kato and Weilicki, 2002, to be an appropriate reference level for flux calculations in Earth radiation budget studies. Text indicating this is added has been at the beginning of the Results section.

Loeb, N. G., Kato, S., & Wielicki, B. A. (2002). Defining Top-of-the-Atmosphere Flux Reference Level for Earth Radiation Budget Studies, *Journal of Climate*, *15*(22), 3301-3309.

7. *Results are probably obtained from synthetic multi-sensor measurements made from GEM. This point should be clarified. In Fig. 3, retrievals are significantly different from the reference (GEM) profile. There are several possible reasons for the discrepancies in this type of experiment. The synthesis measurements are probably superimposed by measurement noise, inversion algorithm should be built on several assumptions and prior information, and the simulation may not be perfect. Please explain the reason of deviation from the reference.*

   We believe the referee is asking for an explanation of the differences between the cloud property retrievals and the original GEM data. This is best explained in the relevant manuscripts documenting the retrieval algorithms. They are not modified in ACM-COM, they are only prepared for use in the radiative transfer calculations, e.g., ACM-CAP processor output, or combined, e.g., the “composite” profiles created from the single instrument retrievals.

Specific or typographic comments/questions

Eq. (8): Is this the (modified) Gamma distribution? Is there a reference?

A reference for Equation 8 has been added to the manuscript,

Chylek, P., P. Damiano, and E. P. Shettle, 1992: Infrared emittance of water clouds, J. Atmos. Sci., 49, 1459–1472.

Fig. 5: SW and LW CREs are usually radiative flux anomaly due to the presence of cloud in the net downward flux at the TOA, and SW and LW CREs are negative and positive, respectively. The authors seem to use unusual definition of the SW and LW CREs. Please give the definition specifically.

We thank the referee for catching this error creating the plot in the figure. It indeed is reversed from the CREs computed using the standard definition. Figure 5 and associated text has been corrected and updated.

There are many uses of a word "get", which may be rewritten with more specific word (e.g., "become" and "obtain").

The text has been modified to reduce the use of the verb "get".

L419: "W/m2" could be "W m^{-2}"

Fixed.