Response to Reviewer Comments

We thank the reviewer for thoughtful and helpful comments. Below are our responses (in regular font) to the comments (in ***bolded italic*** font).

Reviewer #2:

The paper presents a set of newly calculated radiation flux kernels using the ERA5 reanalysis dataset. The authors discuss how the new radiation flux kernels differ from previous ones and how they can be used to improve our understanding of Earth's climate system. Overall, this paper presents a valuable contribution to the field of climate science by providing a new set of radiation flux kernels that can help improve our understanding of Earth's climate sensitivity. I have several major concerns and recommend a major revision.

1. In recent years, one of the improvements of radiative kernels is the development of radiative kernels at the surface (SFC) and in the atmospheric column. The kernels at SFC have been calculated not only from reanalysis data but also from observational data (Karmer et al. 2019). Although the ERA5-derived kernels show high consistency with model-based kernels, feedback parameters obtained from model- and reanalysis-based kernels have large discrepancies with observation-based feedback parameters, especially for the cloud feedback (Karmer et al. 2019; Zhang et al. 2021). Would you like to conduct more analysis and add more discussion on the differences in cloud feedbacks derived from various data sources?

Agreed: we added in the kernel comparison the kernels based on CloudSat dataset (Kramer et al., 2019) (Figure 3-4) and also in the radiative feedback quantification (Figure 7-10)

2. Cloud feedbacks are diagnosed using the adjusted cloud radiative effect method by assuming that all-sky decomposition has the same non-closure residual. There are some flaws in the assumption. First, the residual (res^o ***) is introduced during the single variable perturbation or linear decomposition without involving cloud related process. Second, the all-sky decomposition is assumed that has the same non-closure residual with clear-sky (*** $res^o = res^c$ ***). It should be proved before being applied. Once the cloud related processes are introduced, it would be nearly impossible for the non-closure residual in all-sky to be same as the residual in clear-sky. Please reconsider Eqs. 5-6.***

This may be justified as the non-cloud nonlinear effects are comparable in the clear- and all-skies and the cloud-related terms normally dominate the nonlinear effects in the all-sky decomposition. We recognize there are inaccuracies in the adjusted cloud radiative forcing method, although it is the most widely used. This issue is beyond the scope of this paper but warrants future investigation.

3. The non-closure residual terms due to nonlinear effect are discussed in Figs. 11 and 12. As shown in Fig. 11, the residual term at the TOA mainly arises from shortwave radiation over regions with abundant sea ice cover. Huang et al. (2021) pointed out that the nonlinear effects are resulted from the coupling effect between the surface albedo and cloud, and between the air temperature and cloud. Given the significant interactive between cloud and other climate variables, it's inappropriate to assume the same residual between all-sky and clear-sky conditions. For the residual term at the SFC (Fig. 12), the magnitude of longwave radiation is comparable to the magnitude of shortwave. There is a lack of necessary discussion of the increase in LW residual at SFC relative to that at TOA.

See the response above, about the same issue of adjusted CRF method.

We see no strong evidence that surface residual is larger than TOA from figure 7 to 10, although there may be reasons for this to happen, e.g., because temperature and water vapor feedbacks and their biases tend to compensate for the TOA but not so for the surface. This is only a speculation though and would require further investigation to verify.

4. The most important issue is that what's the contribution of ERA5-based kernel to the radiative kernel method. It's highly consistent with model simulation-based kernel, while model simulation can be applied to more accurate analysis such as diagnostic analysis on the role of dynamic processes in climate response.

We added notes and discussions on the accuracy of ERA5 kernel in the abstract and conclusion. In short, the ERA5 TOA kernels are as good as other kernel datasets while for surface kernels, ERA5 kernels show better performance, in terms of both the radiative sensitivity and radiation closure test. Model based radiative kernels show good performance in TOA radiation budget while for surface, they may have some issues, e.g., larger inaccuracies and misattributed surface contribution (e.g., Figure 10, Figure A2). For observation-based kernel, for example, CloudSat kernel (Kramer et al., 2019), it also performs well for TOA but not that well for surface. Besides, satellite observations are subject to the detection of near surface layers and this may lead to some underestimated radiative sensitivity from the bottom layer for surface kernels. The newly generated ERA5 show good radiative closure for both TOA and surface and may best facilitate the analysis of surface energy budget change.

5. The order of the figures needs to be adjusted. It would be better to cite figures near the context instead of figures far away from the context.

We reorganize the figures.

6. In Fig. 6b, the fractional discrepancies of the sensitivity of the TOA SW flux to water vapor in the tropics show six large value centers from the east coast of Africa to the equatorial eastern Pacific. It's hard to understand these large value centers physically. Could you explain it?

This periodic pattern is caused by CAM3 kernel, likely due to a coarse temporal resolution that does not well resolve the diurnal cycle of solar insolation (Line 303-304)

References

Kramer, R. J., A. V. Matus, B. J. Soden, and T. S. L'Ecuyer, 2019: Observation-based radiative kernels from CloudSat/CALIPSO. J. Geophys. Res. Atmos., 124, 5431–5444, https://doi.org/10.1029/2018JD029021.

Zhang, Y., Z. Jin, and M. Sikand, 2021: The top-of-atmosphere, surface and atmospheric cloud radiative kernels based on ISCCP-H Datasets: Method and evaluation. J. Geophys. Res. Atmos., 126, 1–34, https://doi.org/10.1029/2021JD 035053.