Atmospheric cloud-radiative heating in CMIP6 and observations, and its response to surface warming - Response to Reviewers 2

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We thank the reviewers for their second round of thoughtful evaluations. We are particulary grateful to reviewer 2 for their valuable comment on "cloud masking." In fact, this was a misunderstanding from our side and we have revised the manuscript to properly address this point, as detailed below.

Reviewer comments are in bold, our response is normal font. Quotes from the revised manuscript are in blue (line numbers refer to the tracked-changes version).

We also found an error in figure reference that we have corrected (L194).

Reviewer 1

I commend the authors on a nice paper and recommend that it be accepted at this time.

Thank you!

Reviewer 2

The authors addressed most of my comments and I appreciated that. I think the paper has significantly improved as a result.

Thank you.

I do still have some questions/comments about the "masking effect". I'd like to note again that CRH, as defined as all-sky and clear-sky heating rate difference, is unable to accurately represent CRH change caused by cloud change, because it potentially aliases the masking effect of cloud "existence" as the effect of cloud "change". Do the cited/added results (Eq. 5 and Fig 4) really rule out this potential aliasing issue? I don't think so. These results showed the variance of all-sky heating isn't explained by clear-sky (which I agree), but can't tell if the dominant cloud term (sigma_cloud) is really due to cloud change or cloud existence (the "masking effect"). One must decompose the CRH term to know if, or to what extent, the masking effect is an issue. Although it is probably beyond the scope to do this decomposition within this paper, this issue should be properly acknowledged by referencing the relevant literature and (e.g., heating rate kernels). This paper can also motivate future work to elucidate and mitigate the issue - with regard to this, I am unclear why the authors, in their reply, seem to suggest it is not feasible to use the heating rate kernels for this purpose. Please clarify.

Agreed! We have revised the manuscript to discuss the issue of cloud masking and added references to Soden et al. (2004), Huang and Huang (2023) and Huang and Huang (2024). The latter manuscript is currently in review and particularly relevant to our work.

L97-104 (Introduction): Because cloud-radiative heating is defined as the difference between all-sky and clear-sky radiative heating, it depends not only on the cloud field itself but also the clear-sky background state of the atmosphere, an effect known as "cloud-masking" (Soden et al., 2004; Huang and Huang, 2024). Differences in cloud-radiative heating between models, between models and observations, or between different climate states may thus be influenced by non-cloud fields such as temperature and water vapor. These

clear-sky effects could be quantified by explicit radiative transfer calculations or radiative kernel methods, but given the paucity of studies on atmospheric cloud-radiative heating we leave such refinements to future work.

L188-189 (Sect. 2.4): ... and may be affected by cloud masking (cf. Sect. 1).

L223-225 (Sect. 3): Future work that takes into account cloud-masking effects would be helpful to quantify the sources of model differences in all-sky and cloud-radiative heating, for example by means of radiative kernels (Huang and Huang, 2023, 2024).

References

Huang, H. and Y. Huang, 2023: Radiative sensitivity quantified by a new set of radiation flux kernels based on the ECMWF Reanalysis v5 (ERA5). Earth Syst. Sci. Data, 15 (7), 3001–3021, doi:10.5194/essd-15-3001-2023.

Huang, H. and Y. Huang, 2024: Diagnosing atmospheric heating rate changes using radiative kernels. doi:10.22541/essoar.171828386.61901229/v1.

Soden, B. J., A. J. Broccoli, and R. S. Hemler, 2004: On the Use of Cloud Forcing to Estimate Cloud Feedback. J. Climate, 17 (19), 3661 – 3665, doi:10.1175/1520-0442(2004)017¡3661:OTUOCF¿2.0.CO;2.