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Interactive comment on "The HadGEM3-GA7.1 radiative kernel: the importance of a well-resolved stratosphere" *by* Christopher J. Smith et al.

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This paper has two objectives: 1) to present a new set of radiation kernels with high top, and 2) to intercompare this and a few other sets of radiation kernels, specifically with respect to the estimate of the radiative impact of stratospheric temperature adjustment in response to CO2. These are both potentially important contributions to make and warrant the efforts here. While I find the first objective well done and generally welcome a new kernel set to enrich the feedback analysis toolbox, I find the second objective relatively poorly executed. I'd suggest the authors take into consideration of the following comments and questions in revising this paper.

»» Yi, thank you for the considered review of our paper. The first point about the addi-

tion of a new kernel is well taken and we are pleased that this is a useful addition to the existing set of model kernels. We note the deficiencies highlighted in your second point and trust we have addressed these satisfactorily in the response to your comments and in the forthcoming revised paper.

There lacks a solid basis for the "recommendation" of the three kernel datasets concluded by the paper. For making such an important and strong statement as to which kernels are better, a principle (criterion) needs to be explicitly stated and justified for comparing them – this is currently missing in the paper. Note that a high-top kernel does not guarantee a higher accuracy in its assessment of radiative impact because the atmosphere which the kernel is based on can be biased – one should be especially cautious if the atmosphere is from a GCM – or because the radiation code used for the kernel computation is biased against the radiation code used in the target GCM simulation. On the other hand, a lower-top kernel also does not necessary lead to a poorer assessment, as shown by the GFDL kernel included here, due to fortuitous compensation of errors or due to some technical details of radiative transfer. Fore instance, some kernels may have used high-top atmospheric profiles in their computation but then truncated to lower top when applied to computing feedback. Moreover, computing and applying kernels at lower vertical resolution may be less subject to the nonlinear coupling between different vertical layers – one can test the non-radiation closure due to this issue, for example, by comparing the sum of vertical kernels to the true radiation change computed using the same radiation model from a vertically uniform 1-K temperature change. To make a more objective and informative assessment, I suggest adding: 1) the comparisons of a) the global mean radiation change (Ax) due to layers above 1hPa, 10 hPa, tropopause and surface (whole column), respectively, assuming a uniform 1 K change of atmospheric temperature - this would disclose how the different kernels differ with respect to the radiative sensitivity to different portions of the atmosphere and whether there may be compensation of errors from different vertical portions; and b), like a), but using the atmospheric temperature adjustment to CO2 forcing as simulated by one representative GCM or the multiple model mean.

»» As described further on in the response the "recommendation" is weakened to a suggestion. We have included the comparisons that you suggest as additional figures.

2) additional kernels, especially those observation-based kernels, such as the kernels of Huang et al. (2017) based on ERA-interim and of Yue et al. (2016) based on satellite. The former one (available from https://huanggroup.wordpress.com/research/) was computed with a high-top atmospheric profile using RRTMG and provides kernel values up to 1hPa, which would provide a good comparison to ECMWF kernel here based on another radiation model (Oslo) – e.g., for assessing radiation code dependency noted above.

»» Thank you for the suggestion here. The Huang et al. (2017) kernels will be added to the analysis which were missed in the original submission. This kernel has a very strong negative temperature response at the 1 hPa level, in negative excess of -2 W m-2 (100hPa)-1 K-1 (shown in the update to figure 3) which provide large estimates of the stratospheric adjustment (update to figure 5).

»» The Yue et al. (2016) observational kernels focus on clouds and are more appropriately compared with the ISSCP simulator kernel (Zelinka et al., 2012) rather than our kernels derived from atmospheric state variables. While we use the ISCCP kernel to derive cloud radiative adjustments in the IPSL model from ISSCP simulator diagnostics, a comparison of cloud kernels produced by other groups is beyond the scope of this paper. But we thank you for making us aware of this paper and include references to it as further evidence of the utility of kernel approaches.

Additional comments: Line 17. It is recommended to include Zhang & Huang (2014) here, as this is one of the earliest that quantified CO2 forcing, including both instantaneous forcing and the adjustment components, using kernels. The quantification of adjustment in multiple models reported by this work would make good comparisons to the results reported here, e.g., Table 2, 3.

»» The reference to Zhang and Huang (2014) near line 17 for using kernels to diagnose

adjustments has been included, so thank you for reminding us of this study.

»» It is an excellent suggestion to compare our results to Zhang & Huang (2014). It in fact gives more weight to the claim that stratospheric changes are important. A new table 4 will be included comparing the results and showing that the IPSL-CM6A-LR model with our kernel is outside the 2-sigma range of the 11 models' stratospheric temperature adjustment in Zhang & Huang (2014). IPSL-CM6A-LR is fairly typical of CMIP6 models in terms of ERF and stratospheric adjustment as shown in Smith et al. (2020), and this paper also discusses the fact that ERF is increased in CMIP6 compared to CMIP5 for 4xCO2. Therefore we speculate that an increase in stratospheric temperature adjustment could be partially responsible for an increase in CMIP6 ERF, although we can't prove it without IRF calculations from more models and the fact that most CMIP5 model output does not include the 5 hPa and 1 hPa levels, again preventing a formal comparison.

Line 108. It is not obvious to me that cloud masking has a lesser impact on the surface flux. Please clarify and be more quantitative here.

»» In figures 1 and 2 the subfigures were actually mislabelled. This statement was meant to refer to (what is erroneously labelled) the difference between 2(c)-2(g) and 1(c)-1(g), which are the surface temperature kernels for all-sky and clear-sky for the surface and TOA. In the attachment to this review the differences are shown. The differences in the TOA kernels are large but for the surface kernels are small. The figure captions and surrounding text will be updated. Thank you for spotting this.

[Figure A: differences between surface temperature kernels for TOA and surface fluxes]

Line 148-150. Can you illustrate the biases of these low-top kernels mentioned here?

»» To keep the structure of the paper as it is we refer to the following section where we show the decomposition in the IPSL-CM6A-LR model using our kernel but explain the bias here. Using either equation 7 or 8 we get a small positive residual (table 3).

Figure 5 implies that the low-top kernels (excluding GFDL) are around 0.5 W m-2 or more lower in their stratospheric adjustment than HadGEM3-GA7.1, so that the residuals would be more positive assuming the tropospheric adjustments are similar across kernels. Although we don't compare non-stratospheric adjustments in this paper, I showed previously that kernels agree well for tropospheric adjustments (Smith et al., 2018), as they do for climate feedbacks (e.g. Soden et al., 2008).

»» The following addition to the manuscript is made around line 148:

»» "We show in section 5 that adjustments calculated using the HadGEM3-GA7.1 kernel in the IPSL-CM6A-LR model for a quadrupled CO_2 experiment provide small residuals (i.e. the adjustments are appropriately captured), suggesting that assuming there are no compensating errors, low-top kernels would underestimate the stratospheric temperature response and produce larger residuals."

Line 201. Again, the first that applied this residual method was Zhang&Huang [2014].

»» Thank you for this suggestion. This reference has been added here.

Line 10, 206. Can't approve such a "recommendation" for the reasons above. And such a recommendation could lead to wrongly denial of the use of the other kernels - both the lower top ones like the GFDL one that can achieve similar quantitative results and those the authors failed to include for comparison here.

»» We are inclined to agree that for a data description paper recommendation may be a bit strong and have changed the sentence near the end:

»» "We suggest that radiative kernels with a higher stratospheric resolution and model top are better able to fully capture stratospheric adjustments to CO_2 forcing in general, and generate smaller residuals. This effect has become more prominent with the additional 5 hPa and 1 hPa model levels archived as standard in processed CMIP6 model output compared to CMIP5."

»» and in the abstract:

»» "We show in the IPSL-CM6A-LR model where a full set of climate diagnostics are available that the HadGEM3-GA7.1 kernel exhibits linear behaviour and the residual error term is small, and from a survey of kernels available in the literature that in general low-top radiative kernels underestimate the stratospheric temperature response."

References

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Kernel data: https://huanggroup.wordpress.com/research/

Yue, Q., Kahn, B. H., Fetzer, E. J., Schreier, M., Wong, S., Chen, X., & Huang, X. (2016). ObservationâAËŸ Rbased longwave cloud radiative ker- ËĞ nels derived from the AâAËŸ RTrain. Journal of Climate, 29(6), 2023–2040. ËĞ https://doi.org/10.1175/JCLIâAËŸ RDâ ËĞ AËŸ R15â ËĞ AËŸ R0257.1 ËĞ

Zhang, M. and Y. Huang (2014), Radiative forcing of quadrupling CO2, J. of Climate, 27, 2496–2508. doi: http://dx.doi.org/10.1175/JCLI-D-13-00535.1

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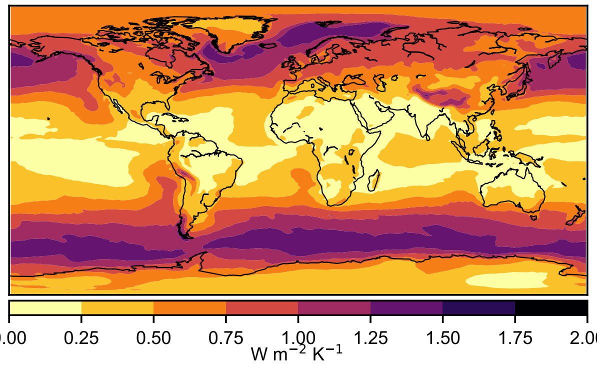
(1e - 1f) All-sky minus clear-sky TOA surface temperature kernel



(2e - 2f) All-sky minus clear-sky surface surface temperature kernel