Juan A. Añel

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The RRTMG provide a license at the beginning of their instruction file (upload as the supplement file in response), I have uploaded the code of model I used and the instruction with license, at https://doi.org/10.5281/zenodo.14357597.
The modifications about code availability in manuscript are in Line 508 - Line 510: "And RRTMG models are available at https://doi.org/10.5281/zenodo.14357597 (official website http://rtweb.aer.com/rrtm_frame.html), the license can be found at the beginning of instruction file. The codes for running RRTMG and calculating radiative kernels are available at https://doi.org/10.5281/zenodo.14359763."

Hua Zhang

> This paper estimates the radiative fluxes and heating rates of absorbing aerosols, scattering aerosols, and cloud ice particles in tropical stratosphere using the newly developed radiative kernels. A notable merit of this study is the construction of aerosol kernels, and the application of them has the potential to better understand the radiative effects of aerosols in the upper troposphere and stratosphere.

Major comments:

> 1. Line 221. It seems that the kernels are calculated by perturbing aerosols at each level simultaneously. To my knowledge, previous studies all established kernels (e.g., water vapor, cloud) by perturbing the variable at each level at one time. It is necessary to clarify and justify the choice.

Thanks for your comments, I didn't give a clear explaination. I just use kernels perturbing at each level simutaneously when testing kernel method, while the aerosol kernel at each level seperately in application part. To clearify my method, the modifications are:
Line 221 "For convenience, aerosols are perturbed by increasing concentrations by 10% at each level simultaneously when testing the accuracy of various kernel methods."

Line 366 "We then use the results of these simulations to construct aerosol and cloud kernels at each level for UTS region."
Line 397-Line 400 "$R=\sum(\Delta\tau l\times kl)+Rref$ (6), where l is the atmospheric level. A vertical one-dimensional kernel is calculated for the disturbance of aerosol at each layer, and the total aerosol radiative effect is the sum of that at each layer."

> 2. Line 285. The authors select four reference state boundary conditions for the kernel calculations. It is not clear why these four points are selected and why these points can represent clear-sky, low cloud, middle cloud, and high cloud conditions.

Those four represent points are chosen because of their relatively high frequency in the distribution of 200 hPa shortwave and longwave radiative flux. Due to the significant difference in corresponding albedo (or emission temperature), it could be assume that they represent four different scenarios, and we name these four sceranios as clear sky, low cloud, middle cloud and high cloud.

We modify the pharagraph in Line 283 - Line 288: By analysing joint plots of shortwave and longwave radiative flux at 200 hPa within 30°S – 30°N (only Fig. S3 shown here as 30°S example), we identify four representative points with relatively high frequency between 30°S – 30°N (four red stars in Fig. S3). The albedo and emission temperature calculated from 200 hPa radiative flux are listed in Table 3, which can be regarded as four reference state boundary conditions. Four different albedos could broadly represent four different cloud cover in the underlying troposphere, name as clear-sky, low cloud, middle cloud, and high cloud. The upper troposphere lower stratosphere aerosol kernels are based on these four scenarios, with the frequency decreases sequentially.

> 3. Line 298. It seems that the changes of water vapor and ozone in the upper troposphere and stratosphere are ignored in the simulations. Any estimate of its impact?

We think the change of ozone and water vapor won't influence aerosol radiative effect. To test that, we run the rrtm model with different times of ozone and water vapor, even 1.5 times of them only cause about 0.001 W/m2 difference of aerosol radiative effect for both longwave and shortwave, which can be regarded as systematic error. We can emphasize this in the paper.

Modification in Line 298: Due to the changes of radiatively active components like water vapor and ozone do not significantly affect aerosol radiative effects, they are assumed have no large variations in UTS.

> 4. Line 299. The new kernels are constructed based on several linearity assumptions. However, it is not clear whether the cloud radiative effect varies linearly within a range of COD and whether the total radiative effects of aerosols and cloud ice can be represented as a linear sum of radiative effects associated with AOD and COD. It is necessary to validate these assumptions.

To improve our ability to represent the radiative effects of aerosol-cloud interactions through the kernels, we describe cirrus cloud ice using an aerosol-type input file, in other word, using the same module to calculate aerosol and cloud radiative effect in RRTMG, which is explained in Line 151-154 and shortly mentioned again in Line 301. So the variation of COD has the same pattern as AOD and can be linearly summed. Figure 5, 6 and 7 represent the all-sky radiative flux, which include both aerosol and cloud radiative effects.

To strength this, a sentence is added in Line 220: Since our formulation regards cirrus ice particles as aerosols, the radiative effects of cirrus clouds also conform to this conclusion.

> 5. Figures 2, 3, 5-7, S3. The authors select several months (i.e., January, May, July) to validate the assumptions of kernel calculations. Are these months representative? Are the test results in other months consistent with the results in these months?

We have plotted the aerosol and cloud distribution zonally averaged between 30°S – 30°N at each month, the variations across each month are not large, so it doesn't make much difference which month to choose.

I would show the distribution of AAOD, SAOD and COD in supplementary file as Figure S2 - S4, and give an explaination in Line 212: Because variations in relative ratio of AAOD, SAOD and COD are small within individual months (Fig. S2 - S4), results are similar for other months.

Other comments:

> 1. Line 200. Please correct the time range of reference state.

The modification is in Line 200: The atmospheric reference state is taken as the July 2019 average from MERRA-2 and the target state as July 2020.

> 2. Line 314. "Figure 5 and Fig. 6". Please use the uniform expression.

The template of this journal said: "The abbreviation 'Fig.' should be used when it appears in running text and should be followed by a number unless it comes at the beginning of a sentence, e.g.: 'The results are depicted in Fig. 5. Figure 9 reveals that.'". In Line 314, the sentence "Figure 5 and Fig. 6 show comparisons of ..." meets the formatting requirement.

> 3. Lines 413, 420, 478, 496. Please correct the superscript and subscript.

Modification has been done.

> 4. Table 2. Please add RMSE for the kernel calculation.

Modification has been done in Table 2, and some misuse of slope and correlation coefficient in Table 2 have been corrected in this revision.

Anonymous Referee

> During the Asian summer monsoon, strong deep convection helps lift aerosols from pollution into the tropical upper troposphere, lower stratosphere where it can impact radiation directly or by changing the thermodynamic and dynamic conditions of those layers. This paper introduces new radiative kernels designed specifically to quantify these components of radiation change in the tropical UTLS where this Asian Tropopause Aerosol Layer (ATAL) occurs. The paper shows these kernels are computationally efficient yet still able to properly represent the total aerosol radiative effects originally simulated directly by fully complex models. This manuscript is well written, and provides a nice approach to constructing aerosol kernels, which is a much needed tool. I provide some minor comments below.

Minor comments:

> 1. Line 48: Matus et al 2019 also developed aerosol kernels that the authors may consider citing and discussing in the into: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL083656

A brief discussion of this paper is in Line 48: Matus et al. (2019) used aerosol radiative kernels based on observations to estimate anthropogenic aerosol radiative forcing. Their aerosol kernels, which assumed a simple linear relationship between changes in aerosols and changes in radiative flux, produced results in reasonablely good agreement with CMIP5 simulations.

> 2. Line 98-100: I appreciate the need to use different data sources for different variables, but did the authors evalute these combinations for inconsistencies? For instance, are ERA5 temperatures sufficiently cold for instances where there is nonzero ice water content as reported by MLS? Or is the height reported by ERA5 a reasonable representation of where MERRA-2 thinks the aerosols are located? It would be useful to provide evidence of a sanity check to give the reader confidence that the dataset merging done here was appropriate.

The ERA5 temperatures in recent reanalyses near the tropopause are very similar to each other and in good agreement with radio occultation profiles (Tegtmeier et al., 2020).
Heights based on ERA5 and MERRA-2 are somewhat different, mainly because MERRA-2 suffers from a warm bias in the upper troposphere. As a result, geopotential heights in MERRA-2 are somewhat larger than those in ERA5. But since MERRA-2 is just the basic state for the kernel form of Taylor series expansion, so we wouldn’t expect this to matter much for the kernel computations. In the other word, we need an aerosol layer just for calculating kernel, but it doesn't need to be fully consistent with the actual situation.

The accuracy of ERA5 is supplemented in Line 100: Near-tropopause temperature profiles from ERA5 are in good agreement with radio occultation measurements (Tegtmeier et al., 2020).

> 3. Line 184-186: What is the shading effect of aerosols? And why is it not impacting the linearity of aerosol radiation at the tropopause? The authors should provide more discussion here about why linearity holds so well at the tropopause calculations.

The discussion of "shading effect" and no longer linear of aerosol radiative effect are in Line 185: Essentially, most radiation that can be scattered or absorbed has already been affected by existing aerosol particles, diminishing the intensity of SW radiation available for newly added aerosol particles to attenuate. As a result, aerosol effects on radiative fluxes no longer follow a linear relationship with AOD.

> 4. Line 213-216: More explanation about why AAOD is so impactful on tropopause radiation and SAOD is not would be helpful here. It may not be intuitive to most readers, who are likely more experienced with TOA or Surface conditions.

The discussion is in Line 219: The significant difference in the impact of absorbing and scattering aerosols on radiative heating rate results from the ability of absorbing aerosols to directly absorb radiation and convert that absorption into thermal energy, thereby heating the surrounding atmosphere. Whereas absorption increases the convergence of radiant energy, scattering only changes the direction of radiation propagation and thus contributsion little to local radiative heating.

> 5. Line 258: I can appreciate that aerosol effects have low sensitivity to the background thermodynamic or cloud state? But what about sensitivity to the background aerosol state? I would imagine a 10% aerosol perturbation in a high aerosol concentration condition vs a pristine

> condition would lead to a different radiative perturbation. And likewise, the heterogeneous spatial pattern of aerosol base state would matter. Is that the case? If so, does it mean the kernels are only relevant for simulations where the background aerosol fields are similar to those of MERRA2?

The state of the background aerosol is of great significance. However, when using the aerosol radiative kernel, it is not necessary to have the same background. Within the range of linear variation (not exceeding three times to radiative flux and no limitation for radiative heating rate), people can use kernels to calculate a new background radiation with different aerosol concentrations. And then calculate how the perturbation of aerosol could influence radiations with aerosol radiative kernels.

A supplement explanation is added in Line 399: A new reference state can also be defined with difference of aerosol concentrations.

> 6. Line 364: Mention of creating cloud kernels felt quite sudden as there was really no discussion of it in the intro. There are mentions of aerosol-cloud interaction but I thought that was in reference to setting the base state for the radiative transfer calculation. I recommend the authors spend a little more time in the intro or in this section explaining the motivation for making these cloud kernels and why its a natural fit to make these particular cloud ice kernels along with the aerosol kernels

The explaination about why cloud radiative kernel is included is in Line 151: In addition to aerosols, cloud ice also has important impacts on the radiative balance near the tropopause. Ice clouds that form in the upper troposphere due to convective detrainment or cooling during slow ascent impact the upward fluxes of shortwave and longwave radiation in the stratosphere. We therefore evaluate the potential for cirrus cloud radiative kernels to represent the radiative effects of cloud ice near the tropopause in comparison to aerosols. To do this, we describe cirrus cloud ice using an aerosol-type input file that specifies optical depth, single scattering albedo, and asymmetry factor.

> Conclusion: Especially since we are heading into CMIP7, I recommend a summary of the types of model various, levels and temporal resolutions one would need to apply these kernels to diagnose radiative effects. I suspect subdaily data is always needed given the preservation of diurnal information in the kernels, and often modeling centers do not provide more than monthly or daily mean data.

There is no limitation for model and temporal resolutions for these kernels, although they don't include hourly data, people can choose the time they want from kernel to calculate corresponding radiative effects. The recommendation of dataset has been added in Line 500: Dataset include 3-dimensional aerosol concentration or cloud optical depth data could use this radiative kernel, choose the corresponding month and local time to estimate stratospheric radiative effects.