Responses to the Referee #1

This study developed a global dataset of direct radiative effect efficiency (DREE) of mineral dust for ten dust size bins with geometric diameter from 0.1 μm to 100 μm, three sets of refractive indices (weak, mean, and strong absorbing), and two shapes (spherical and spheroidal). The monthly DREE dataset is derived from the Rapid Radiative Transfer Model (RRTM) model using CALIOP-based dust aerosol optical depth (DAOD) and vertical distribution along with atmospheric profiles from MERRA-2 and surface variables. The global direct radiative effect (DRE) of dust aerosols is then examined using the DREE-integration method and DAOD climatology from CALIOP and MODIS, respectively. It is found that different spatial distributions of DAOD may contribute to about 10% differences in shortwave DRE of dust even with the same global mean DAOD. The calculated DRE is also sensitive to refractive index (RI) and particle size distribution (PSD) but much less affected by dust shape. Improving the estimation of the DRE of dust is essential to reduce the uncertainties of radiative forcing of aerosols to the climate system. This observation-based study and newly developed dust DREE dataset will provide a useful tool to constrain model simulations and study dust DRE. Overall, the paper is very well written, with thorough description and analysis of DREE calculation, validation, uncertainty, and comparisons with previous studies. I have some minor comments for the authors to consider.

Reply: We would like to thank the reviewer for the insightful comments. We have addressed these comments in the revision. An item-to-item reply to the reviewer's comments is provided below.

1. Section 3.1, it's not clear here which version of PSD is used in the calculation. Moving the information about PSD in lines 467-468 to here could be helpful.

Reply: Sorry for the confusion. In section 3.1, we calculate dust scattering properties (i.e., Qe, ω and g) for each of ten size bins. Therefore, we only need to consider dust particle within the corresponding size bin in the calculation of scattering properties of the size bin, we do not need the information of dust PSD of full-size range. The dust particle number of each size bin (i.e., sub-bin dust size distribution dN/dD) is assumed to be uniformly distributed within each size bin.

2. Line 295, is the $\mathrm{DRE}^{\mathrm{SW}}$ a vertical profile?

Reply: Thanks for the question. The $\mathrm{DRE}^{\mathrm{SW}}$ in Eq (1) represents dust $\mathrm{DRE}^{\mathrm{SW}}$ at TOA or surface. $\mathrm{DRE}^{\mathrm{SW}}$ is not a vertical profile.

We include vertical profile of water vapor, ozone, and carbon dioxide in Eq (1) to indicate that we account for gas absorption by water vapor, ozone, and CO_2 in SW radiative transfer calculations for each size bin.

This is clarified in the paper by adding 'We include 3-hourly monthly mean vertical profile of water vapor, ozone, carbon dioxide ($\overline{H_2O(t)}, \overline{O_3(t)}, \overline{CO_2(t)}$) to account for gaseous absorption.'

3. Line 306, please add more details about surface emissivity. Is it also from satellite retrievals?

Reply: Thanks for the question. The surface spectral emissivity from Huang et al. (2016) is based on MODIS emissivity retrievals and modeled different types of surface spectral emissivity.

This part in the paper is modified as ‘Surface spectral emissivity (‘*E*’) is obtained from Huang et al. (2016), which contains monthly mean spectral surface emissivity with 0.5-degree spatial resolution based on MODIS-retrieved mid-IR surface emissivity and modeled different types of surface spectral emissivity.’

4. Line 394, what about the uncertainties of ignoring the horizontal variations in dust particle size due to different dust lifetime?

Reply: Thanks for the great point. We added the limitation of ignoring the horizontal variation of dust size and modified the paper as ‘First, possible vertical and horizontal variations of dust particle size in each grid box ($5^{\circ} \times 2^{\circ}$) are not accounted for in our calculation. The entire dust-loading column is assumed to have the same dust size distribution.’

5. In the simulation where Fennec-Fresh PSD is used in the dust belt (covering dust sources in the Sahara, Middle East, and eastern Asia) and AER-D PSD over other regions, it’s interesting that shortwave DRE are much smaller over dust sources in the Indian subcontinent and Taklamakan Desert (Fig. 10), although DAOD is relatively high in these regions in both CALIOP and MODIS (Fig. 1). Can you comment on this?

Reply: Thanks for the comment.

That should be due to the difference in surface reflectance. Generally, dust induce a cooling effect in SW at TOA over dark surface (e.g., over ocean). However, when surface is bright, dust absorption is enhanced, dust SW cooling effect at TOA would be weakened or even turns to be a warming effect if surface is bright enough.

As we can see from the figure below, surface reflectance at visible band over Sahara Desert and Arabia is very high, thereby inducing warming effects in SW.

Over Indian subcontinent and Taklamakan Desert, surface reflectance is higher than surrounding ocean (e.g., Arabian Sea) but lower than Sahara and Arabia. The surface reflectance is not high enough to cause warming effect in SW but weakens the SW cooling effect.

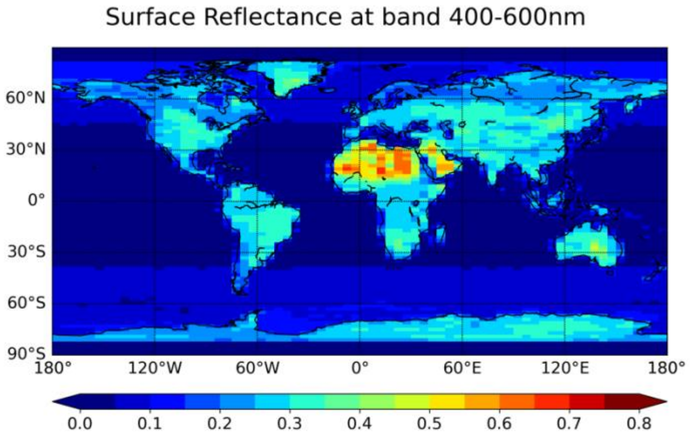

Figure 1. 4-year (2007-2010) annual mean surface reflectance at band 400nm to 600nm.

6. Line 676, consider providing more information about the dust RI used by Kok et al. (2017) for a brief comparison.

Reply: Thanks for the comment.

We add more information about dust RI used in Kok et al.2017. We modified this part of the paper as: ‘Second, the two studies use different dust RI. For example, the imaginary part of RI at 550nm in this study ranges from 0.00061 to 0.003, while that in Kok et al. (2017) ranges from 0.0014 as used in GEOS-Chem and GISS model based on Sinyuk et al., (2003) to 0.003 as used in WRF-Chem based on Zhao et al., (2010).’

References:

Sinyuk, A., Torres, O., and Dubovik, O.: Combined use of satellite and surface observations to infer the imaginary part of refractive index of Saharan dust, Geophys. Res. Lett., 30, https://doi.org/10.1029/2002GL016189, 2003.

Zhao, C., Liu, X., Leung, L. R., Johnson, B., McFarlane, S. A., Gustafson, W. I., Fast, J. D., and Easter, R.: The spatial distribution of mineral dust and its shortwave radiative forcing over North Africa: Modeling sensitivities to dust emissions and aerosol size treatments, Atmos. Chem. Phys., 10, 8821–8838, https://doi.org/10.5194/acp-10-8821-2010, 2010.