Reply to Anonymous Referee #2

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We thank the referee for the helpful and constructive comments. Our responses are detailed below.

This paper advances the field in performing a novel parameterization and quantification of the effect of subgrid-scale wind variability on fluxes of sea salt and dust aerosols. The result that this subgrid-scale wind variability is important to dust emission, but not particularly important to sea salt emission, is interesting albeit not surprising. The paper is well written and interesting.

Comment: The main deficiency of the paper is the lack of a test of whether including the SGV parameterization actually improves the model fidelity. Without that, the value of this work to the community is limited. I suggest the authors for instance use hourly AERONET AOD measurements for this, or the SEVIRI satellite product.

Reply: Evaluation is indeed a major challenge of this study due to the lack of direct observation of sea salt and dust emissions on the global scale. The AERONET AOD data are limited in their spatial and temporal coverage when dust is the species of interest. We have selected AERONET sites near dust source regions and compared high-frequency AOD measurements with model simulations in the format of scatter plots, time series, and frequency distributions. It turns out the measurements that fall in our simulation period are located in regions where the CTRL simulation and the modified model (EXP4) give very similar annual mean dust AOD (Figure R1.1). The frequency distributions (Figure R1.2) and seasonal cycles (Figure R1.3 and R1.4) are also very similar. These figures are not included in the paper because they do not indicate systematic improvement or degradation of model fidelity. In dust source regions where CTRL and EXP4 do give considerably different AOD (Taklamakan Desert, Southeast Iran, and Pakistan), there are unfortunately no AERONET data in the year 2006, and only a few days of measurements in the other years. In the future it would be useful to find other sources of observational data to evaluate the simulations in those regions.

We have added the following discussions to the revised paper.

Section 5.4, "Comparison with AOD observations", on AERONET measurements:

"*In addition to MISR, we have compared the simulated AOD with high-frequency measurements from the Aerosol Robotic Network (AERONET) sites close to the dust source regions. It turns out that the AERONET measurements falling in our simulation period are located in regions where CTRL and EXP4 give very similar dust AOD. The comparison thus did not indicate systematic improvement or degradation in terms of the agreement between model results and measurements. In the Taklamakan Desert,* *Southeast Iran, and Pakistan where AOD in EXP4 is considerably higher than that in CTRL (Fig. 18), it is not yet known how the two simulations compare with observations due to the unfortunate lack of data."*

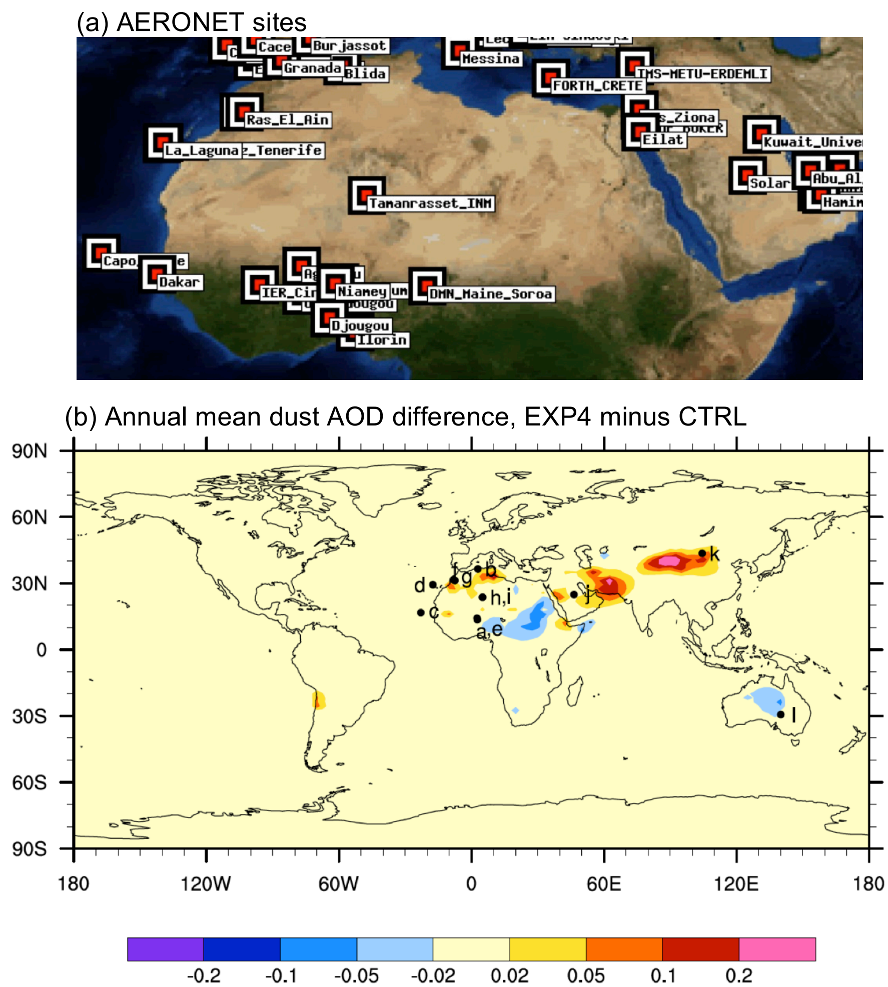

Figure R1.1 (a) AERONET sites in or near North Africa that have measurements available for the year 2006. (b) Simulated annual mean AOD differences between EXP4 and CTRL of the year 2006. The black marks and the labels indicate locations of the AERONET sites where observed and modeled AOD are compared in Figures R1.2, R1.3, and R1.4 below.

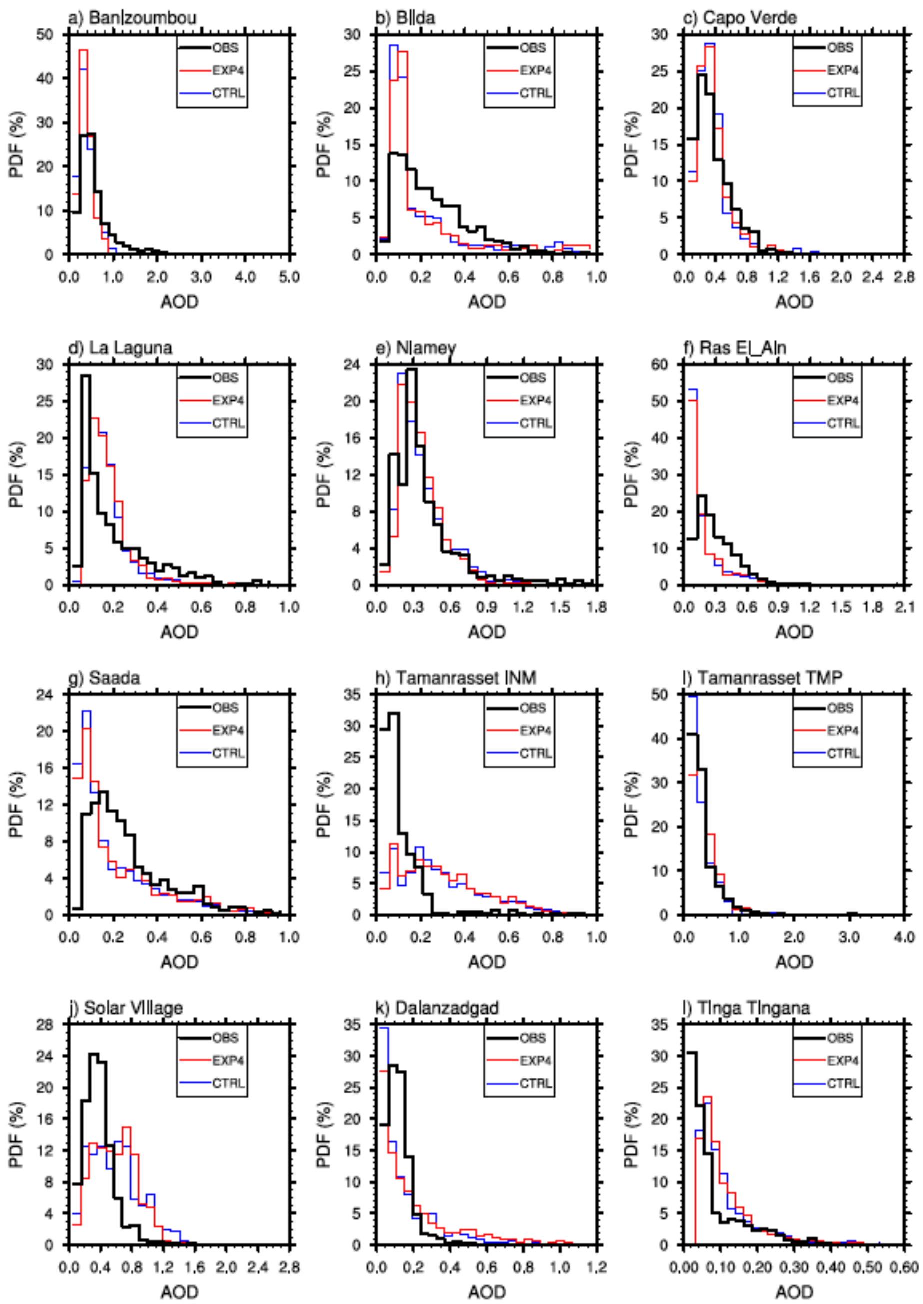

Figure R1.2. Frequency distributions of measured and simulated hourly AOD at the 12 AERONET sites indicated in Figure R1.1. Both measurements and simulations are from the year 2006. Model results are masked out when the AERONET measurements are missing.

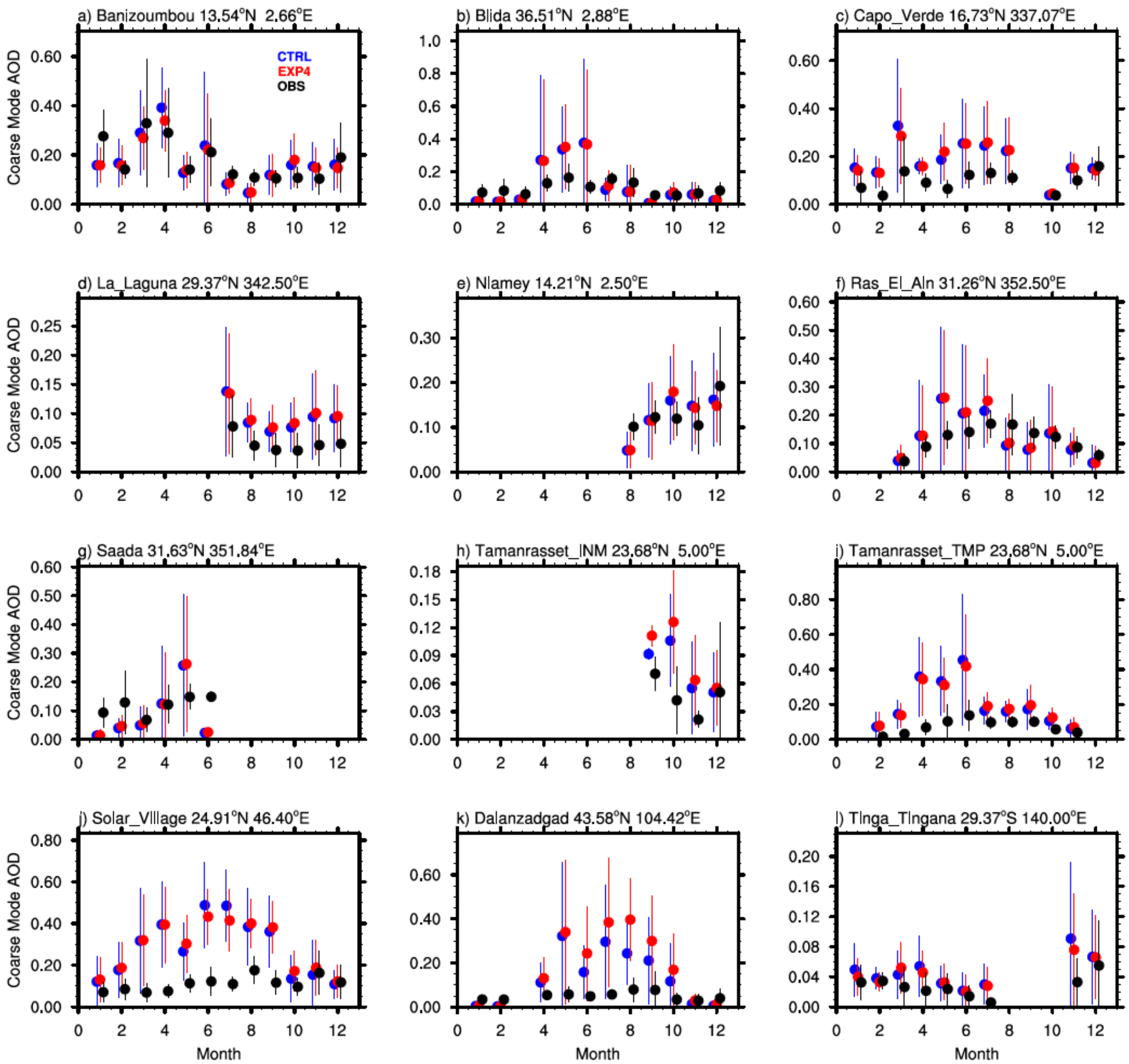

Figure R1.3: Observed and simulated monthly mean *total* AOD at 12 AERONET sites indicated in Figure R1.1. The error bars indicate ± 1 standard deviations of hourly AOD. Model results are masked out when the AERONET measurements are missing.

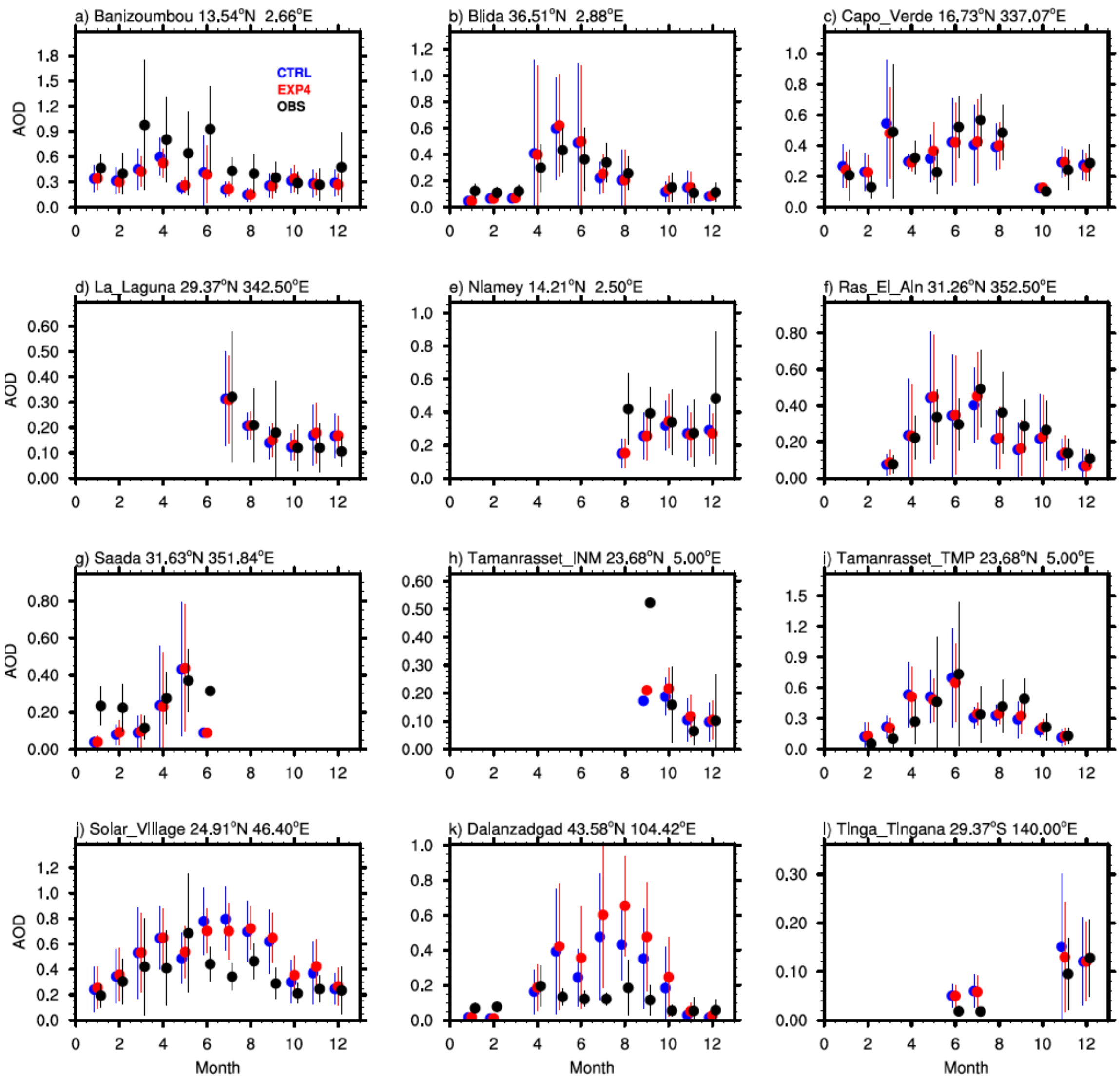

Figure R1.4: As Figure R1.3 but for *coarse mode* AOD.

Section 5.5, "Dust emission frequency", on the SEVIRI satellite product:

"Ideally it would be nice to use observational data sets to evaluate whether such a shift also makes the simulated emissions more realistic. For example, Schepanski et al. (2007) presented seasonal dust source area maps for the Sahara and Sahel region derived from IR-channel images of Meteosat Second Generation. A quantitative comparison between our simulations and their results is however difficult, because the absolute value of the emission frequency depends strongly on the dust mass flux threshold that is used when identifying an emission event. In the work of Schepanski et al. (2007), dust emission was identified by visually detecting dust plumes, then visually tracing the plume patterns back to their origin by inspecting consecutive images during dust mobilization and transport events. In order to directly compare their maps

with our simulations, one would need to implement a satellite simulator in our model, produce the IR-channel images, then apply the same human-involved method of visual dust activation identification. Such an evaluation is impractical in our study; below we limit ourselves to a qualitative comparison with the results of Schepanski et al. (2007).

Maps of seasonal dust emission frequencies in Africa and Asia are presented for CTRL and EXP4 in Fig. 20. Since it is unclear what dust emission flux thresholds the maps of Schepanski et al. (2007) correspond to, we chose a somewhat arbitrary (but low) threshold of 10^{-9} kg^{-2} s^{-1}. Fig. 20 indicates that the inclusion of wind SGV generally increases the frequency of dust emission; this is consistent with the PDFs shown in Fig. 19. In addition, EXP4 features enhanced seasonal differences compared to CTRL: wind variability associated with dry convective eddies leads to considerably more frequent dust emission in boreal spring/summer than in autumn/winter.

In terms of geographical distribution, Schepanski et al. (2007). showed seasonal shifts of dust emission patterns in North Africa. In our simulated, however, dust emissions largely occur at the same locations all year round, except in Northwest China where the source regions are larger in spring and summer. The frequency patterns in CTRL and EXP4 are similar, and both differ in the details from the maps of Schepanski et al. (2007). The same turned out to be true when we increased the emission flux threshold to higher values. Our analysis showed that the wind SGV changes the magnitudes of the emission frequency, but does not significantly change the spatial pattern. This is not surprising since apart from wind speed, the simulated dust emission also depends on other assumptions in the parameterization scheme as well as the surface properties in the model."

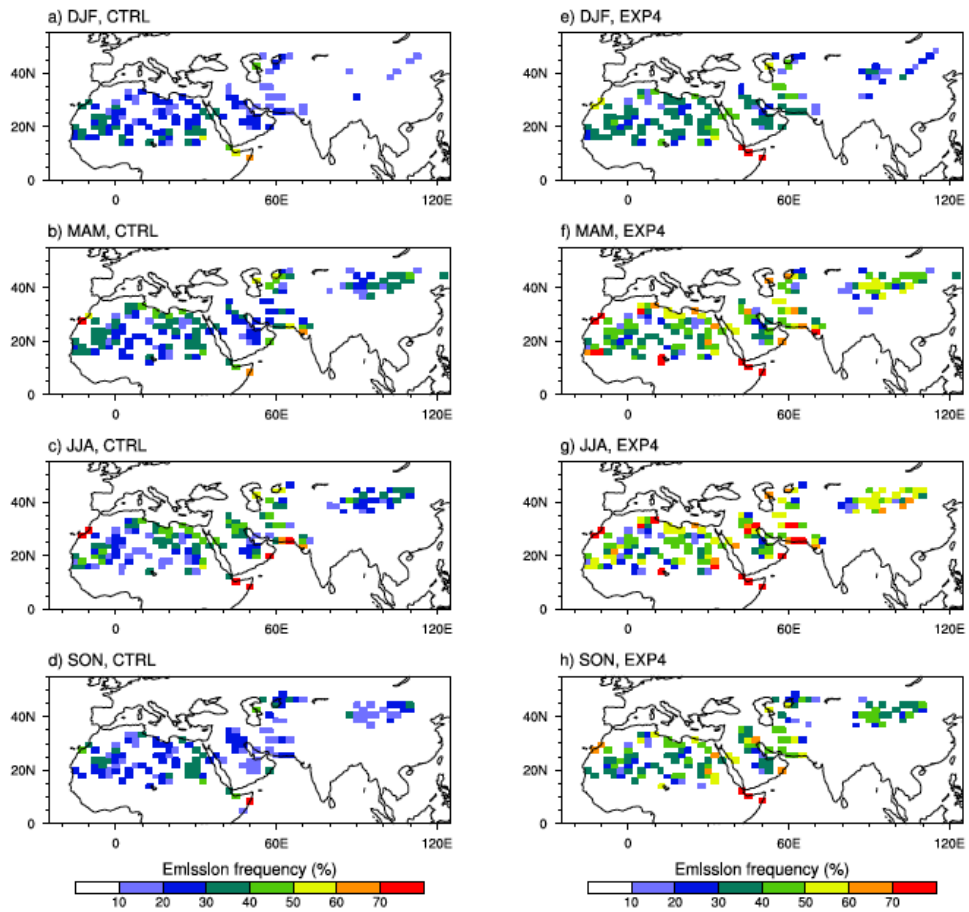

Figure 20. Frequency of occurrence (unit: %) of dust emission fluxes stronger than 10^{-9} kg^{-2} s^{-1} in Africa and Asia in the CTRL simulation (left column) and in EXP4 (right column). Different rows correspond to different seasons: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON).

Other comments:

Comment: - Equation (5) for the saltation flux repeats an error in the original White (1979) paper. See Namikas and Sherman (1997) for the correction. Please correct.

Reply: Thanks for pointing out this. A clarification has been added to the revised paper:

"Note that there were typographical errors in the original Eqn. (22) of White (1979), and in Eqn. (10) of Zender et al. (2003). Our model uses the formula corrected by Namikas and Sherman (1997, Eqn. (3) therein)."

Comment: - P. 7257: How exactly is the effect of moisture on u*t accounted for?

Reply: The parameterization (Zender et al. 2003) is based on Fe´can et al (1999). When the soil gravimetric water content (w) exceeds a threshold w_t, the threshold friction velocity for saltation is increased by multiply a scaling factor f_w:

$$f_w = \begin{cases} 1 & : \quad w \le w_t \\ \sqrt{1 + 1.21[100(w - w_t)]^{0.68}} & : \quad w > w_t \end{cases}$$

w_t is given by

$$w_t = a\left(0.17 M_{\text{clay}} + 0.14 M_{\text{clay}}^2\right)$$

where M_{clay} is the mass fraction of clay particles in the parent soil, and *a* is an adjustable factor chosen to improve model simulations.

Comment: - P. 7261: The simplification here eliminates the threshold dependence of dust fluxes. This threshold dependence makes dust emissions very sensitive to SGV, so eliminating it will cause a substantial underestimate of the effect of SGV on dust emissions. This should be discussed here.

Reply: We agree that the simplified comparison has limitations. The following discussion has been added to the revised paper, immediately below the simplified equations (12) and (13):

"It should be pointed out that unlike the actual parameterization in the model, this simplified comparison does not take into account the dependence of emission flux on the threshold friction velocity. As can be derived from Eqn. (5), the omission will lead to an underestimation of the emission flux and emission error when $u_{*s} > 1.6u_{*t}$, and an overestimation when u_{*s} is close to or smaller than u_{*t}. The purpose of using the simplified formulae here is to give a first, rough estimate of the impact of wind SGV. More accurate comparisons using the CAM5 model with the Zender (2003) parameterization are presented in Sect. 5."

Comment: - P. 7270: I find it non-intuitive that a larger C means a smaller influence of SGV. I would suggest inverting C in its definition in Eq. (25), such that the importance of SGV scales with C.

Reply: We have revised the figure so that it shows 1/C, and updated Eqns. (25)–(27) so that they use a new parameter D=1/C.

Comment: - P. 7277 and 7278: I think the negative values of TOA flux difference over the ocean has more to do with the low albedo of the ocean surface, and much less with changes in the dust optical properties during mixing. Please correct / discuss this.

Reply: Thanks for the comment. We agree with the reviewer that the low albedo of the ocean surface probably plays a much larger role, given that a very sharp gradient is seen in the figure at the west coast of African continent. The impact of albedo might also apply to land areas downwind of the dust source regions, since with vegetation cover the surface albedo is also lower.

On a different note, following review #1's suggestion, we have removed this section from the paper so as to make the manuscript more focused.

Comment: - Why does the relative error reverse sign at k ~ 1.5 in Fig. 7a? That seems odd - please explain.

Reply: We believe the different magnitudes of relative error result from using one formula (Eqns. 15-16) to approximate the entire set of Weibull distributions despite the different shape parameters. The properties of the Weibull PDF change substantially with the shape parameter k (see Figure blow). The PDF is a monotonically decreasing function when k <=1, and non-monotonic with a peak at the mode when k > 1. The PDF's coefficient of skewness approaches zero when k approaches 3.7, and becomes negative when k > 3.7. Fig. 7a in our discussion paper indicates that "method 3" of Justus et al. (1978) (Eqns. 15-16 in our paper) for estimating the shape parameter gives excellent accuracy for the negatively skewed Weibull PDFs, but produces larger errors for the positively skewed PDFs, and is particularly not suitable for shape parameters considerably smaller than 1.

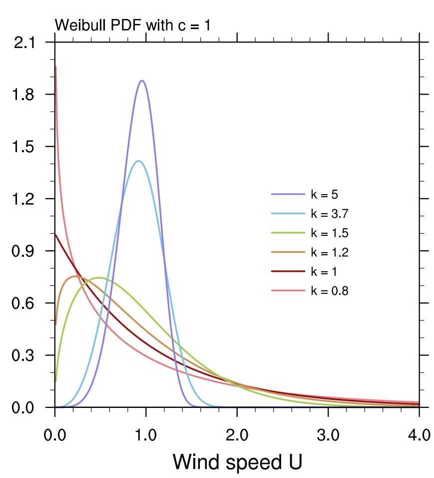

Figure R2.1. Weibull PDFs with different shape parameters.