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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Shortwave radiative forcing and efficiency of key aerosol types using AERONET data" *by* O. E. García et al.

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Dear Referee #2,

We would like to thank your suggestions in order to improve the manuscript, which are fully addressed below. Your comments are numbered.

1. The omission of most data from sites in China in this paper is puzzling since this is an extremely important region for aerosol forcing effects, and you even state this on page 32659 lines 17-18. There are several long-term sites such as Beijing, Taihu, and Xinaghe available. Page 32659 lines10-12: Your choice of 2 stations (GSFC and Baltimore) that are only _40 km apart, does not "cover the East Coast" as you suggested here Page 32657 lines 16-19: It is misleading to claim that 2 sites define the regional

AOD climatology especially when these sites differ so much in seasonality.

Following the referee's recommendation, some stations have been included in the study: Beijing station (39°N, 116°E) in the region 10 in order to complete the description of the Asian urban-industrial aerosols; CCNY station in New York (40°N, 73°W) to add more stations representative of the East Coast of USA; Yulin station (38°N, 109°E) to characterize more appropriately the regional AOD climatology of the region 4. It is important to mention that in the latter region (R4) there are a few AERONET stations with data available and most of them only have data during intensive campaign (a few months). Therefore, the results of this region should be treated with care.

2. Additionally, the AERONET AOD shown in Figure 2 are very puzzling. For the Mauna Loa Observatory (MLO) site the AERONET climatology of AOD at 500 nm (see AERONET website for AOD climatology Tables) shows many years of data for every month, yet Fig. 2l shows no data for some months. The AOD values at MLO in Fig 2l are nearly twice as high as from the AERONET website for all months. This may be due to the authors only using AOD associated with Level 2 almucantar retrievals rather than all direct sun AOD measurements. The AOD for the Banizoumbou site (Fig. 2b) shows a variable saw-tooth pattern from March through July however the climatology table from AERONET shows a smooth seasonal progression. These 'noisy' AOD annual patterns exist for other sites in Fig. 2 and are not truly representative of the complete AERONET database, as the data you utilized are a small and sometimes biased subset of all observations of AOD.

The annual cycle of the aerosol optical depth (figure 2 of manuscript), was calculated considering only the AOD L2 almucantar retrievals at the sza interval of 60±5° in order to be consistent with the radiative forcing analysis. As referee commented, for some stations the AOD behaviour is not the expected one and this fact may be a bit confusing. We agree with the referee that using all direct sun measurements would be more appropriate for a comprehensive analysis of the AOD annual cycle. Nonetheless, our AOD climatology aims to show the seasons more representative of each aerosol type

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for each station. For that, the whole range of almucantar retrievals (50°-80°) could be considered representative of AOD behaviours to choose the aerosol seasons. Therefore, the annual cycle of AOD for all stations have been re-evaluated considering L2 almucantar retrievals for the whole sza range (50°-80°). Then, the figure 2 of manuscript has been changed, including the figure 1 shown below. In addition, as example, the figure 2 shows the AOD annual cycle at Banizoumbou considering the AOD climatology from direct sun measurements, from L2 almucantar retrievals for sza between 50° and 80°, and for sza between 55° and 65°.

3. Page 32656 lines 1-4: Would be very useful to plot fine fraction for all sites in Fig 3.

The figure 3 of manuscript has been changed by a new figure (see below as figure 3) showing the aerosol fine fraction for all AERONET sites used.

4. Page 32652 lines 28-29: How do you model the surface reflectance from satellite data?Your use of vocabulary may be confusing here.

The surface albedo is a crucial parameter in evaluating the aerosol radiative forcing, especially at the Top of Atmosphere. Therefore, following the editor's comment and the referee's comment, an explanation in detail of how it is calculated has been included in the manuscript in the page 32652. This is:

"The appropriate characterization of the surface albedo is a critical issue to estimate aerosol radiative effect [Myhre et al., 2003] as well as an important error source in the retrieval of aerosol properties [Dubovik et al., 2000; Sinyuk et al., 2007]. For that reason, the surface reflectance is approximated by a bidirectional reflectance distribution function (BRDF): Cox-Munk model for over water [Cox and Munk, 1954] and by Ross-Li model over land [Ross 1981; Li and Strahler 1992; Wanner et al. 1995]. The BRDF parameters for land sites are adopted from MODIS Ecotype generic BRDF models (courtesy of Feng Gao, NASA/GSFC). The BRDF models are mixed according to Ecotype map of Moody et al. [2005, 2008] and NISE SSM/I snow and ice extent and MODIS snow cover map. For Cox-Munk calculations we adopted the wind speed from

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NCEP/NCAR Reanalysis data."

5. Page 32667 lines 22-23: You should also mention that the uncertainty in SSA for the free tropospheric aerosols is VERY large since at such low AOD there is very low sensitivity to absorption in the AERONET retrievals. You should not use SSA from AERONET that are not Level 2 (AOD (440 nm) > 0.40). The uncertainty in SSA contributes to uncertainty in estimates of free tropospheric forcing.

The AERONET estimates of solar fluxes, radiative forcing and forcing efficiency are calculated for the whole range of AOD values, being the uncertainty in retrieved single scattering albedo (SSA) quite high, typically »0.05 at the low AOD levels [Dubovik et al., 2000]. Nevertheless the increase of errors for SSA with decrease of AOD is not critical for estimations of fluxes. This is due to the diffuse fluxes and the influence of aerosol on radiation fluxes decrease when AOD diminishes. Indeed, if we have a very small amount of aerosol it does not care so much about the fact that we know SSA with accuracy 0.07 instead of 0.03. In addition, while the accuracy of SSA decreases with decrease of aerosol loading, the error in absorption optical thickness stays constant at the level of 0.01 and, therefore, the error in flux stays also rather constant. In fact, the comparison results for broadband solar fluxes and radiative forcing at surface shows that these uncertainties for low AOD do not seem decisive in the solar fluxes simulations due to modest impact of atmospheric aerosols. Moreover, we did not observed significant differences between modelled and measured fluxes for small AOD. The mean differences between observed and modelled magnitudes show a smooth increase for high AOD (Figure 4b of García et al., 2008).

At the same time, it should be mentioned that even not significant uncertainties in the absolute values of radiative forcing at the low AOD can present more significant impact on relative to AOD values of forcing efficiency.

6. Page 32664 lines19-20: "However, it should be mentioned that despite instantaneous forcing for high sun elevation can present positive values, for low sun it can

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remained negative therefore the daily average forcing can still be negative. Anyway, in these situations, aerosols cooling effect is significantly reduced and they do not strongly counteract the warming effect of the greenhouse gases." Your statement here supports my claim that the instantaneous forcing values are of limited value. Page 32670 lines 10-12: "However, it is quite difficult to compare directly the obtained results on literature due to the different methodologies and data used." This statement in your Conclusions section is the reason why I say that your use of instantaneous values of aerosol forcing in this study are of limited value, since you cannot compare them to other studies.

The main purpose of this work is to compare radiative forcing effects for different aerosol types in similar observational conditions (that mainly means similar solar zenith angles, sza). To do so, we have used the operational AERONET products and, thus, the analysis was limited to sza between 50° and 80°. Note that the AERONET radiative forcing estimates are operationally calculated with the inversion aerosols products (i.e. aerosol size distribution, single scattering albedo, refractive index, etc.), which are obtained with a complete set of restrictions to assure the quality of the products [Dubovik et al., 2000]. One of these restrictions sets a limit to the scattering angle, which limits the solar zenith angles (sza) between roughly 50°-80°. Due to the aerosol radiative forcing strongly depends on solar geometry, the study was focus on a limited sza range: 60±5°. This interval concentrates the maximum number of AERONET almucantar retrievals and, thus, it may be representative of the AERONET sza range (50°-80°).

The daily averages of aerosol radiative forcing are more climatologically significant, as Editor commented, especially for evaluating climate aerosol effects and comparing to other studies. However, the daily averaged fluxes may strongly depend on several factors other than aerosol properties, e.g. location of sites, seasons, etc. In addition, derivation of daily fluxes required making extra assumptions and extra efforts that were outside of the framework of this paper. Note that the AERONET operational products of radiative forcing and forcing efficiency are only provided for sza between 50° and

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80°.

7. The rest of minor comments have been modified following the referee's recommendations.

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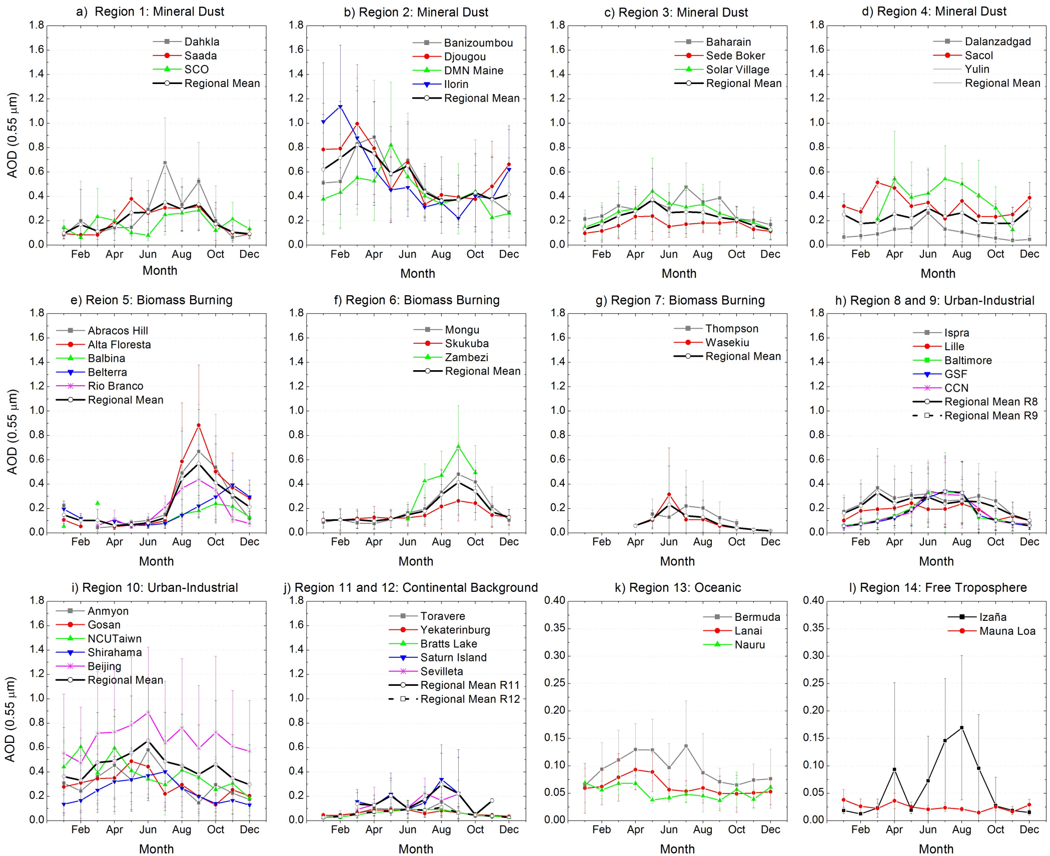

Fig. 1. Monthly evolution of the inter-annual average of the aerosol optical depth, AOD, at 0.55 μm for all regions (R1-R14).

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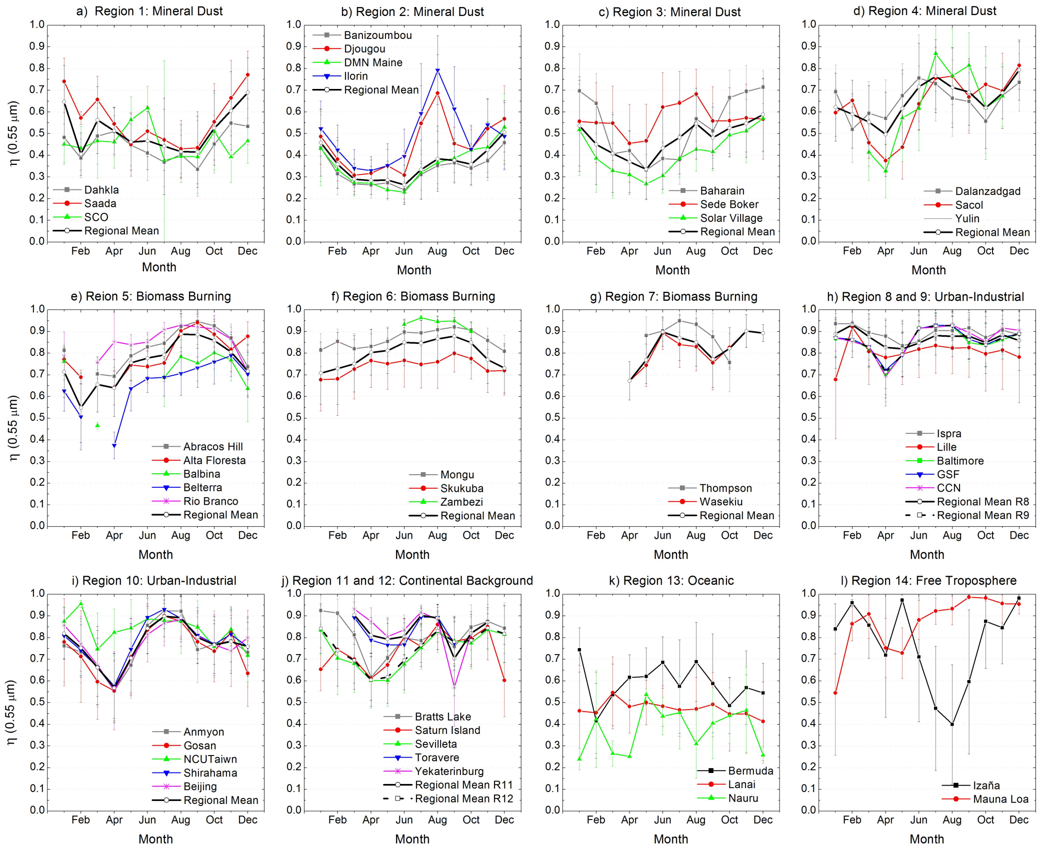

Fig. 2. Monthly evolution of the inter-annual average of the aerosol fine fraction at 0.55 μm for all regions (R1-R14).

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