

Reviewer 1:

Aerosol radiative effect is a hot topic in the science community, which is dependent on the aerosol optical properties, size distribution, aerosol types, and their vertical distribution. While many studies have examined the seasonal and diurnal variations of aerosols, few studies have examined the vertical distributions of aerosol amount and types, which can strongly affect the aerosol radiative effect and corresponding thermal impacts on the profiles of temperature. Using multi-satellite observations along with the surface observations of aerosols, this study examines the seasonal and diurnal variations of aerosol column loading, vertical distribution, and particle types over three populous regions: the Eastern United States (EUS), Western Europe (WEU), and Eastern and Central China (ECC). Interesting statistical characteristics about the dominant aerosol types and vertical distributions have been obtained. The paper is also organized and written well.

Response: We thank the reviewer for the valuable comments. We have followed these comments in revising the manuscript. Point-to-point responses are given below.

Detailed Comments:

Line 45-48: I am not sure if the climate effects of CO₂ also depends on its intra-annual variability, particularly considering the higher outgoing longwave radiation from surface in summer than in winter.

Response: We no longer mention the climate effects of CO₂ in the revised manuscript. The revised sentence is as follows:

Therefore, the climatic and health effects of aerosols are not only induced by inter-annual concentration changes, but also strongly depend on their intra-annual variability. (Line 41-43)

Line 49-54: Not only the scattering and absorption properties, but also the size distribution and vertical distribution of aerosols can also cause problems. Zheng et al. (2017, ACP) have shown that the vertical distribution of AOD could have strong impacts on the aerosol concentration (mass concentration) within PBL, which directly affect cloud properties and then change cloud radiative forcing. Garrett et al. (2004, GRL) showed that nucleation mode aerosols and accumulation mode aerosols have very different scattering radiative effects.

Response: Following this comment, we have described the impact of size distribution and vertical distribution and cited these two references. The revised text is as follows:

However, the wide ranges of particle optical properties and size distribution mean that even for the same AOD, different aerosol components have different effects on not only the magnitude, but also the sign, of aerosol radiative forcing (IPCC, 2013; Gu et al., 2006; Garrett et al., 2004). (Line 46-49)

Besides aerosol type, the aerosol vertical distribution influences its mass concentration within the planetary boundary layer (PBL) (Zheng et al., 2017) and the vertical profile of heating rate (Johnson et al., 2008; Guan et al., 2010; Zhang et al., 2013), which subsequently modifies the atmospheric stability and convective strength (Ramanathan et al., 2007), with potential changes in cloud properties (Johnson et al., 2004). (Line 54-58)

Line 54-58: Besides to the TOA radiative balance, convective clouds development, absorptive and non-absorptive aerosols have different impacts on the surface radiative cooling effects, as shown by Yang et al. (2016, JGR) which demonstrated that more absorptive aerosol can cause more surface cooling effects.

Response: We have mentioned the different impacts of absorptive and non-absorptive aerosols on surface radiative cooling effects in the revised manuscript:

Furthermore, absorbing and non-absorbing aerosols have been found to have very different impacts on the surface radiative cooling effects (Yang et al., 2016) and the development of convective clouds (Massie et al., 2016; Ramanathan et al., 2005; Rosenfeld et al., 2008). (Line 51-54)

Line 59-63: The vertical distributions are also important for aerosol-cloud interaction since only the aerosols near cloud bases have strong interaction with cloud properties. Zhao et al. (2018, Earth and Space Science) showed Twomey effect using in-situ aircraft observations in East China instead of anti-Twomey effect found using column aerosols based on satellite observations.

Response: Following the reviewer's comments, we have added this point in the revised manuscript:

Understanding aerosol variability as a function of height is also important because the indirect effect of aerosols is mainly dependent on those mixed with the clouds (Zhao et al., 2018b). (Line 59-60)

Line 101-103: You may indicate the data observation time, such as day time and night time.

Response: We have added the following description in the revised manuscript:

The aerosol retrievals from MISR and MODIS are only available for clear-sky conditions in the daytime. CALIPSO provides retrievals during both day and night, but only clear-sky daytime profiles are used in order to be consistent with the products from MISR and MODIS. (Line 99-102)

Line 158: I would suggest "variations of AODs with heights below 200 m"

Response: Done. Thank you! (Line 155)

Line 162-167: The different time representation errors could be noticeable for monthly average. For example, Wang and Zhao (2017, JGR) showed that the MODIS cloud time representation errors could be up to 3-4% for monthly average (10 years data) while much smaller for yearly average and much larger for daily average. However, this might not affect the findings/conclusions of this study. You may simply indicate/inform the noticeable time representation error of 3-4% (Wang and Zhao, 2017) while what they studied are cloud coverage instead of aerosols.

Response: In the revised manuscript, we have investigated the impact of spatiotemporal sampling on seasonal variations of AOD using two sensitivity scenarios, and cited this reference. The added text is shown as follows:

As described in Section 2.1, MODIS provides near-daily global coverage but MISR and CALIPSO do not. As a result, the monthly mean AOD from different sensors is calculated based on different sets of days, which might lead to uncertainties in the estimation of monthly mean AOD (Colarco et al., 2014; Wang and Zhao, 2017). To rule out the impact of spatio-temporal sampling on seasonal variation patterns, we design two sensitivity cases: a “MODIS/Terra_match MISR” case in which the monthly mean AOD of MODIS/Terra is calculated using only the days when MISR overpasses, and a “MODIS/Aqua_match CALIPSO” case in which the monthly mean AOD of MODIS/Aqua is calculated using only the overpassing days of CALIPSO. The results are illustrated in Fig. 2. In all three regions, the monthly mean AODs are slightly different for “MODIS/Terra” and “MODIS/Terra_match MISR”, but the seasonal variation patterns are largely the same. The same results are found for “MODIS/Aqua” and “MODIS/Aqua_match CALIPSO”. As such, we conclude that sampling has little effect on the AOD seasonal variation patterns reported in this study. In fact, this conclusion is compatible with the findings of Colarco et al. (2014). Colarco et al. (2014) revealed that the spatial sampling artifacts were significant for fine aggregation grid (e.g., 0.5°), but they are reduced at coarse grid scales (e.g., 10°). In this study, we use only the mean AOD over three large regions (about 20°×20°) across 10 years, therefore the sampling artifacts are expected to be even smaller. (Line 208-224)

Line 267-269: I highly agree with this analysis. By doing this, the effects of PBL and relative humidity could be minimized.

Response: Thank you!

Line 303-304: Yang et al. (2018, AR) also showed the winter vs summer patterns (high in winter, low in summer) of inter-regional transport (between pearl river delta and Hongkong) of aerosols; Garrett et al. (2010, Tellus B) also showed the strong transport in winter and weak transport in fall for aerosols from mid-latitudes to Arctic. Actually, the vertical distribution of aerosols is very interesting in the Arctic, with high values at heights around 2-7 km, mainly caused by long-range transport from other regions such as mid-latitudes.

Response: Thank you for providing these useful references. We have included them to support the point that the seasonal variations of AOD at different vertical levels are influenced by the seasonal patterns of inter-regional transport of aerosols. (Line 328-331)

Line 374, acts -> act, strengthens -> strengthen

Response: Done. Thank you! (Line 401-403)

Line 400-405, Since AOD includes the impacts of relative humidity, is it possible that relative humidity also contributes to the diurnal variation of AOD? Another possible contribution might be

the growth of fine aerosols, as indicated by Zhao et al. (2018, AAS), the growth rates of fine mode aerosols generally starts from the morning time with a growth rate of around 2-7 nm/hour (1.7-6.5 nm/hour near Beijing region in summer). They could become accumulation mode from fine mode aerosols at night time or on next day (then day time) making AOD larger.

Response: Thank you for your suggestions. We have removed the section about diurnal variations in the revised manuscript following the 2nd reviewer's comments. We hope this is acceptable for you.

Line 462-465: I agree that absorbing aerosols could play different roles to convection and clouds from non-absorbing aerosols. However, I think both absorbing aerosols and non-absorbing aerosols will reduce the direct solar radiation reaching the surface, causing surface cooler and further affect convection and clouds in similar way (of course, no absorption of solar radiation in the air), while the effects could be weaker than absorbing aerosols.

Response: Following the reviewer's comment, we have revised these sentences as follows:

Both absorbing and non-absorbing aerosols could invigorate deep convection by serving as cloud condensation nuclei and affect convection by reducing downward solar radiation and causing surface cooling (Rosenfeld et al., 2008). However, absorbing aerosols play unique roles in convection and cloud development by heating the atmosphere. This inhibits convection in most situations (Ramanathan et al., 2005; Massie et al., 2016; Zhao et al., 2018a) but may enhance convection and cloud formation above the PBL (Wang et al., 2013; Bond et al., 2013), depending on the vertical distribution of absorbing aerosols. (Line 445-452)

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