Aerosol radiative forcing over East Asia determined from ground-based sunphotometry measurements

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Abstract: Mean radiative forcing efficiencies ($\Delta F/\Delta\tau_{0.5}$) over East Asia range from -65 to -95 W m^{-2} at the surface while -20 to -40 W m^{-2} at TOA under clear-sky conditions. These aerosol direct radiative forcings over East Asia are similar to other experimental results for different regions, i.e., the Indian Ocean Experiment (INDOEX) and the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), from which radiative forcing efficiencies of -75 W m^{-2} and -70 W m^{-2} for the Indian Ocean and the East Coast of the United States are reported. Nevertheless, the differences in aerosol parameters and relatively large STD values with regard to spatiotemporal variations suggest that the impact of aerosol on ARF over East Asia is more significant than previously recognized for other regions and should be continuously observed to determine the relation between increasing aerosols and associated radiative forcings in the region.
Keywords: Aerosol, Aerosol optical property, Aerosol radiative forcing

1. Introduction

It has been well known that aerosols can give profound impact on global and regional climates, both directly by interfering with solar radiation and indirectly by modifying cloud microphysics associated with CCN (cloud condensation nuclei) or IC (ice nuclei) changes. Global average of annual radiative forcing by anthropogenic aerosols ranges from about –0.3 to –2 W m^{-2} that is comparable to the forcing induced by greenhouse gas increases during the last century.[1],[2] The role of aerosols in climate has not been completely understood and thus it is very important to reduce uncertainties in determining aerosol characteristics for examining the role of aerosol in climate changes.

Because of importance of aerosols in the climate change studies, field experiments are much needed to reduce those uncertainties. In line with those field experiments, a ground-based aerosol/radiation observation network named as the SKYNET was established. In order to study the role of aerosol in climate over the Asian continent, sky radiance data as well as solar radiative fluxes are measured at the SKYNET observation sites. The primary objective of the SKYNET is to estimate direct and indirect radiative forcings of aerosols on climatological time and space scales. In determining the forcing over the Asian continent, we calculate downward radiative fluxes at the surface using a radiative transfer model in which optical properties derived from SKYNET observations are used as inputs. Radiation fluxes at the top of the atmosphere (TOA) are also calculated by matching the calculated surface radiation flux to measured values.

2. Surface measurements

Direct and diffuse solar radiations were measured using sky radiometer (POM-01L; Prede Co. Ltd.) in daytime at seven wavelengths of 315, 400, 500, 675, 870, 940, and 1020 nm. Aerosol optical properties are retrieved from measured data using the inversion software, SKYRAD.pack version 3, developed by Nakajima et al.[3] Detailed explanation about quality control, retrieval methods, and sensitivity analysis are found in Kim et al.[4] For the radiative forcing calculation, surface solar radiation measurements are used in conjunction with aerosol optical properties obtained from skyradiometer measurements. Direct solar fluxes are estimated by the pyrheliometer, and a pyranometer was used for measuring global downward solar fluxes and to measure diffuse solar radiation.

Measurements were taken at eight sites given in Fig. 1. Details of the geographical and climatological features of the observation sites which are closely related to local aerosol characteristics are found in Kim et al.[4]

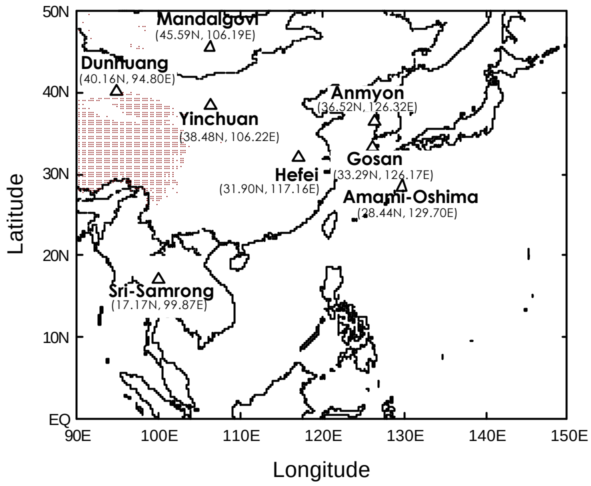

Fig. 1. Geographical locations of observation sites.

3. Results

1) Aerosol optical characteristics

Aerosol optical thicknesses (AOT) over East Asia were large compared with those found in North America or Europe, as there are various sources of aerosols such as urban pollution, biomass burning aerosols, and dust particles. Also found are the significant temporal variations even for a given location -- see the time series of optical properties at SKYNET sites provided in Kim et al.[4] Moreover, most Chinese sites are found to be influenced by dusts since those are transported from the arid source region in Northern China and Mongolia to surrounding areas.

The largest size difference between fine and coarse modes in Mandalgovi was in coincidence with the largest α range (0.0-2.0), suggesting that various sizes of aerosols exist at Mandalgovi in all seasons. In Dunhuang, the fine mode as shown in Mandalgovi almost disappears throughout the year, and thus only coarse mode exists because Dunhuang is located within one of the dust source regions as shown in Fig. 1. Yinchuan shows a fine mode around 0.2 μm and a coarse mode around 5 μm reflecting predominant urban aerosols in this area. The mode radius of fine mode at Sri-Samrong is around 0.2 μm, and the total volume of fine mode particles is largest among the sites due to the dominant biomass burning aerosols especially during the winter, and we could also find signs of dust particles transported from Indian arid region during April and May as seen in Sugimoto et al.[5] The single scattering albedos of dust particles over East Asia are around 0.9 at 0.5 μm, which are larger than the previously known values of 0.63-0.89,[6],[7] but similar to those found in the Aerosol Robotic Network (AERONET) analysis.[8],[9]

2) Optimum single scattering albedo

If we take the solar flux measurements as true values, the differences between the calculated and measured diffuse fluxes might be arising either from inherent uncertainties in input parameters or inaccurate parameterizations of radiative transfer modeling. However, as noted in the more uncertain characteristics in the simulated diffuse solar radiation, we assume the discrepancy between calculated and measured solar radiation fluxes are mainly due to the uncertainties in input parameters, in particular associated with aerosols.

Overall accuracy of AOT is less than 0.02 for all the range of measured AOT.[3] The uncertainty of the SSA, however, retrieved from skyradiometer increases for smaller solar zenith angle and smaller aerosol optical thickness (e.g., $\tau_{0.5} < 0.5$), providing more uncertainties when the retrieved SSA is used for the model calculation under such conditions.[4],[10] Nakajima et al.[3] has also shown that the absorption index (k) can be determined by considering the ratio of the diffuse radiative flux to the direct solar radiative flux. Fig. 2 shows comparison of the SSA values inverted from skyradiometer with optimum values from the ratio of diffuse/direct radiation at Amami-Oshima. The bias and root mean square error (rmse) between two values are 0.009 and 0.027, respectively. Although the fitted SSA values are slightly larger than those from skyradiometer, the ranges of fitted SSA are in accordance with those analyzed from skyradiometer. Therefore, we use these fitted complex refractive index from diffuse/ direct method along with AOT and volume size distribution from skyradiometer for evolution of aerosol radiative forcing.

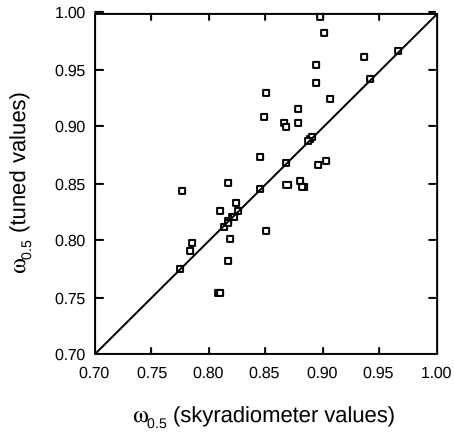

Fig. 2. Comparison of the single scattering albedo obtained from between skyradiometer and simulated with radiative transfer model from surface solar radiation at Amami-Oshima.

3) Aerosol radiative forcing

Aerosol radiative forcing was calculated using the measured aerosol optical properties derived from sky radiation measurements at SKYNET sites in conjunction with a radiative transfer model. In order to avoid the dependence on solar zenith angle in aerosol radiative forcing calculation, we use 24-hour averaged radiative forcing. In the calculations, constant aerosol optical thickness is assumed throughout the day.

Fig. 3 shows regional mean ARF under clear sky conditions. The top shows the ARF at TOA, the middle at the surface, and the bottom shows the differences between TOA and surface radiative forcing which are the atmospheric radiative forcing. ARF over East Asia range from –25 to –40 Wm^{-2} at the surface and –5 to –15 $W m^{-2}$ at TOA, while the radiative forcing efficiencies ($-\Delta F/\Delta\tau_{0.5}$) range from 65 to 95 $W m^{-2}$ at the surface while 20 to 40 $W m^{-2}$ at TOA under clear sky conditions. As the regional differences of ARF over East Asia are mainly due to changes in aerosol optical properties, these are much dependent on local sources of aerosols according to geographical location and on time, even at a fixed site. Thus, changes in aerosol properties by wind blown dust particles, considering local aerosol sources like biomass burning or transportation from continent under the westerlies over East Asia, could significantly affect flux changes over East Asia's surrounding regions.

The corresponding $-\Delta F/\Delta\tau_{0.5}$ values of 78.2 and 25.8 Wm^{-2} at the surface and TOA respectively over East Asia, are similar to those from other experimental results for different regions, i.e., INDOEX[11] and TARFOX[12] with a $-\Delta F/\Delta\tau_{0.5}$ value of 75 and 25 Wm^{-2} for the Indian Ocean and 70 and 30 Wm^{-2} for the East Coast of the United States respectively. In spite of a similarity in ARF values, there is much difference in aerosol parameters and in relatively large STD values with regard to spatiotemporal variations, e.g., relatively lower SSA and dominant coarse mode particles over East Asia compared to those found in other study areas. Therefore, the impact of aerosol on radiative forcing over East Asia is more significant than previously recognized for other regions, and should be continuously observed to determine the relation between increasing aerosols and associated radiative forcings in the region.

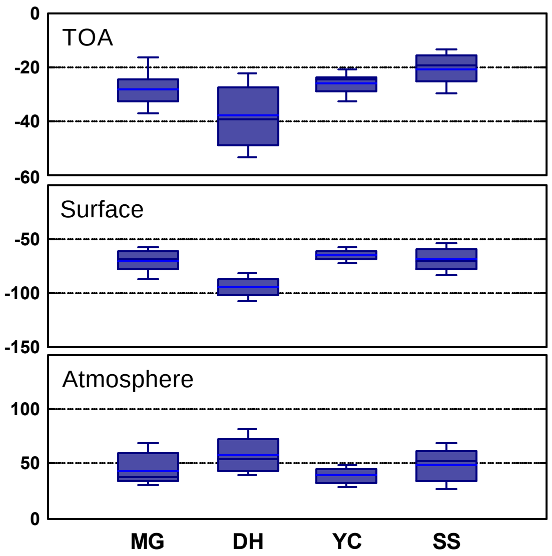

Fig. 3. Regional (a) 24-hour average aerosol radiative forcing ($W m^{-2}$) at MG (Mandalgovi), DH (Dunhuang), YC (Yinchuan), SS (Sri-Samrong). Each box presents the 10th, 25th, median, 75th, and 90th percentiles, and the thick solid line represents the total mean values.

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