P1.3

SEASAONAL VARIATION OF AEROSOL DIRECT RADIATIVE FORCING AND OPTICAL PROPERTIES ESTIMATED FROM GROUND-BASED SOLAR RADIATION MEASUREMENTS

Tomoaki Nishizawa and Shoji Asano
Tohoku University, Sendai, Miyagiken, Japan

1. INTRODUCTION

Atmospheric aerosols substantially affect the radiation budget of the earth-atmosphere system by directly scattering and absorbing solar radiation. The radiative forcing is an important parameter to assess the aerosol direct effect on the radiation budget. However, only a few estimations have been made from the field radiation measurements, especially, for aerosols in the Asian region.

In this study, we have developed a retrieval scheme for simultaneously estimating the optimal size distribution and imaginary index of refraction of aerosols in a vertical air column from the ground-based solar radiation measurements. We also estimated the aerosol direct radiative forcing on various components of the surface solar irradiances. Then, we discuss the correlation among seasonal variations found in the estimated aerosol forcing and optical parameters. This study has three advantages. Firstly, we estimate the aerosol radiative forcing not only in the total (*TTL*) solar spectral region, and but also in the visible (*VIS*) and near infrared (*NIR*) regions. The second advantage is to use the long-term observational data over two years. Thirdly, by combining the measurements with four pyranometers as well as a sunphotometer, we can estimate not only the aerosol radiative forcing but also such optical properties as size distributions and imaginary indices of refraction.

* *Corresponding author address:* Tomoaki Nishizawa, Center for Atmospheric and Oceanic Studies, Tohoku University, Sendai, Miyagi-ken 980-8578, Japan;
e-mail: nisizawa@caos-a.geophys.tohoku.ac.jp

2. OBSERVATION

The Meteorological Research Institute (MRI), located at 36.05° N and 140.13° E in Tsukuba, Japan, has conducted accurate solar radiation measurement with the ground-based pyranometers and a sunphotometer. The area is about 50 km apart from the Tokyo metropolitan in the north-east direction. Here we use the observational data obtained only under completely cloudless conditions in the period from April 1997 to March 1999.

Four broadband pyranometers (Kipp & Zonen; CM21) were used to measure the surface global (*GL*) and diffuse (*DF*) solar irradiances in the *TTL*-band (305-2900 nm) and the *NIR*-band (715-2900 nm), respectively. For measuring the *DF* irradiances, two (*TTL*-band and *NIR*-band) pyranometers were shaded with the sun-synchronized shadowing disks. The direct (*DR*) solar irradiances were obtained as differences between the *GL* and *DF* irradiances. The *GL*, *DR* and *DF* irradiances in the *VIS*-band (305-715 nm) were obtained from the difference between the corresponding irradiances measured in the *TTL*-band and the *NIR*-band. The relative uncertainty in solar irradiance measurements by the CM21 pyranometers were estimated within 2%.

The sunphotometer (EKO; MS-115) was used to measure aerosol optical thicknesses (*AOT*s) at six wavelengths, λ = 369, 500, 675, 778, 862, 1050 nm. The sunphotometer calibration constants could involve a relative error of as much as 2% at each channel, and the error might bring an uncertainty of, at most, ±0.02 in optical thickness.

3. METHOD OF ANALYSIS

We estimated the aerosol radiative forcing (*AF*) at the surface from the following equations:

$$AF_l = F^{\downarrow}_{obs,l} - F^{\downarrow}_{mol,l}, \quad (1)$$

$$AF_{NET} = (1-\alpha)AF_{GL}. \quad (2)$$

Here, $F^{\downarrow}_{obs,l}$ is the measured surface downward irradiance, and $F^{\downarrow}_{mol,l}$ denotes the surface downward irradiance computed for the corresponding molecular atmospheres without aerosols, where the suffix '*l*' means the components of downward irradiance, *i.e., GL, DR or DF*, and α denotes surface albedo. Since we did not measure the upward solar irradiances which could properly represent the surface albedos of the area, we adopted the values of 0.09 for the *VIS*-band and 0.19 for the *NIR*-band from *Asano and Shiobara* [1989].

We estimated the aerosol forcing efficiency (β) from a linear fitting as,

$$\frac{AF_{l\ or\ NET}}{\mu} = \beta_{l\ or\ NET}\left(\frac{\tau_{500}}{\mu}\right), \quad (3)$$

where $\mu = \cos\theta_o$, and θ_o is the solar zenith angle. Thus, the aerosol forcing efficiency β represents a change in radiative forcing per unit change in aerosol visible optical thickness at wavelength of 500 nm (τ_{500}). Note that we estimated only for the limited cases with $\tau_{500}/\mu < 0.8$ to minimize the effect of non-linear dependence of the solar irradiances on *AOT*s.

Further, we have developed a retrieval scheme for simultaneous estimation of an optimal aerosol size distribution and imaginary index of refraction (m_i) in the *VIS*-band from the combination of sunphotometer and pyranometer measurements. The estimated optimal aerosol parameters could simulate the measured spectral *AOT*s and *VIS*-band *DF* irradiances. Figure 1 shows the schematic of the retrieval algorithm. The aerosol size distributions can be retrieved from the measured spectral *AOT*s by means of the so-called inversion method [e.g., *King et al.,* 1978]. Values of "Estimated-$F^{\downarrow}_{DF}$" are computed by using aerosol optical properties calculated with Mie-theory from the sunphotometer-retrieved size-distribution and an assumed complex refractive index (m), which is used in the size-distribution retrieval. In the estimation, we fixed the real part m_r-value of the refractive index to be 1.52. Until the convergence of $|\text{Estimated-}F^{\downarrow}_{DF} - \text{Observed-}F^{\downarrow}_{DF}| < \delta$ is achieved, we repeat calculations of the size distribution and "Estimated-$F^{\downarrow}_{DF}$" by changing m_i-values. Here, δ is a convergence criterion, and we set δ = 1 W m^{-2} in the retrieval of an optimal VIS-band m_i-value. The estimation uncertainty of m_i depends on such various factors as measurement errors of $F^{\downarrow}_{DF}$, *AOT*s, and the magnitude of m_i itself. We estimated the mean uncertainty of ±0.008 for the retrieved m_i values in the whole period.

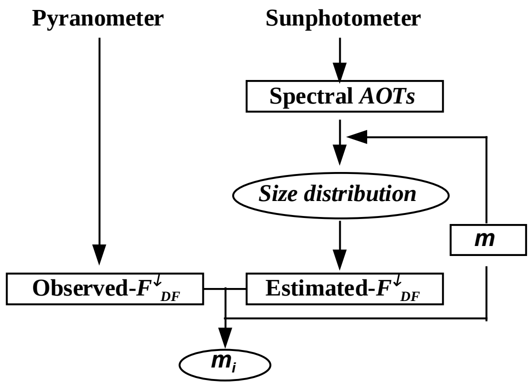

Fig. 1 Schematic algorithm for simultaneous retrieval of the optimal aerosol size distribution and imaginary index m_i. Here, m denotes the complex refractive index ($m = m_r - i\, m_i$)

4. RESULTS

Figure 2 shows the normalized radiative forcing (AF_{NET}/μ) on the *VIS*-band and *NIR*-band *net* irradiances, as a function of τ_{500}/μ, in the whole period. The figure shows three evident features of AF_{NET}/μ, and the similar features are also seen in the corresponding forcing on other irradiance components as AF_l/μ (*l* = *GL*, *DR* or *DF*). Firstly, the magnitudes of AF_{NET} in the *VIS*-band are larger than those in the *NIR*-band: the AF_{NET}/μ in the *VIS*-band is almost 4 times larger than that in the NIR-band. This larger *VIS*-band AF_{NET} is primarily due to larger *AOT*s in the *VIS*-region than in the *NIR*-region (see Figure 3). The mean value of τ_{500} was almost 2.5 times larger than

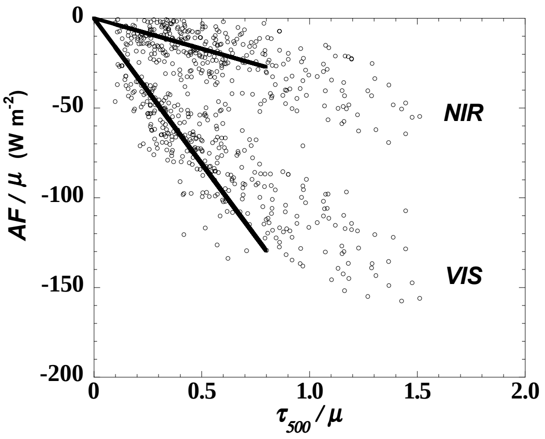

Figure 2 AF_{NET}/μ in the *VIS*-band and the *NIR*-band as a function of τ_{500}/μ for the whole period

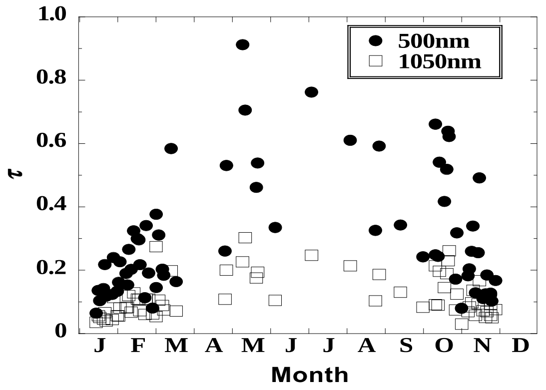

Figure 3 Temporal variation of *AOT* at λ = 500 and 1050 nm

that of τ_{1050} averaged over the period.

Secondly, the AF_{NET}/μ reveals almost linear dependence on τ_{500}/μ for the cases of $\tau_{500}/\mu < 0.8$. The straight lines in the figure are linear regression lines fitted by Eq. (3). Values of the aerosol forcing efficiency β, estimated for AF_{NET}/μ and AF/μ over the whole period, are summarized in Table 1. Here, the β-values stand for an increase in AF/μ in unit of W m^{-2} with an increase of 1.0 in τ_{500}/μ.

Table 1 β-values for the whole period

	DR	*DF*	*GL*	*NET*
VIS	-343	165	-178	-162
NIR	-138	96	-42	-34

* The unit of β-*values* is [W m^{-2}]

The third feature evident in Fig. 2 is a rather wide dispersion of the radiative forcing data points around the fitted lines. The dispersion might be caused by time variations of aerosol size distributions and complex refractive indices. We estimated the seasonal-mean values of β from the net radiative forcing AF_{NET} / μ in each season. The estimated β-values are summarized in Table 2. The table shows a seasonal variation of the *VIS*-band forcing efficiency with the maximum magnitude (β = –180 W m^{-2}) in winter and the minimum magnitude (β = –134 W m^{-2}) in summer. The seasonal variation of the *NIR*-band forcing efficiency is less evident, and different from that of the *VIS*-band, with the maximum magnitude during winter to spring and the minimum during summer to autumn.

Table 2 Same as Table1 but for β_{NET} for different each season

	Spring	*Summer*	*Autumn*	*Winter*
VIS	-144	-134	-158	-180
NIR	-50	-16	-25	-39

* The unit of β-*values* is [W m^{-2}]

Figure 4 shows the seasonal-mean volume size distributions, which were obtained by averaging many size distributions retrieved in each season. Figure 5 shows the seasonal variation of daily-mean imaginary index of refraction m_i in the *VIS*-band. Figures 4 and 5 indicate that aerosols in summer season were dominated by rather smaller particles with less absorbency in the *VIS*-band compared to aerosols dominant in winter season. The summer aerosols may bring smaller magnitude of the aerosol forcing efficiency with larger *AOT*s (see Figure 3) in the *VIS*-band due to their effective scattering ability for the visible radiation.

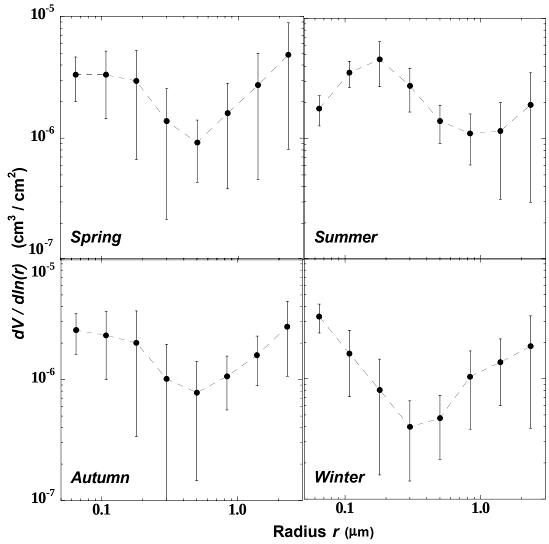

Fig. 4 Seasonal variation of volume size distributions. The vertical bars indicate the standard deviations for each season average.

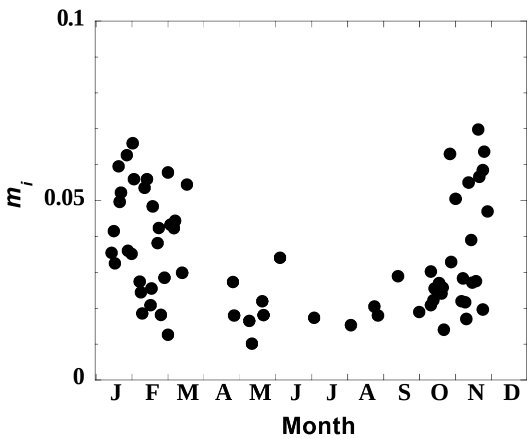

Fig. 5 Seasonal variation of m_i in the *VIS*-band.

5. SUMMARY

From the ground-based solar radiation measurements, we have analyzed the direct aerosol radiative forcing on the surface irradiances, and we retrieved optimal size distributions and *VIS*-band imaginary indices of refraction for columnar aerosols. The radiation measurements were conducted under clear-sky conditions at the MRI in Tsukuba, Japan, for two years from April 1997 to March 1999. The seasonal variations of aerosol radiative forcing and optical properties are discussed in this study. The highlighted results are as follows:

- The aerosol radiative forcing on the surface irradiances, averaged over the whole period, in the *VIS*-band was almost 4 times larger than that in the *NIR*-band.
- The *VIS*-band forcing efficiency has an evident seasonal variation with a largest magnitude of –180 W m^{-2} in winter, and a smallest magnitude of –134 W m^{-2} in summer. For the *NIR*-band, the seasonal variation of the forcing efficiency is less evident, and different from that in the *VIS*-band, with the maximum magnitude during winter to spring and the minimum during summer to autumn.
- The estimated volume size distributions and imaginary indices of refraction m_i indicated that aerosols in summer season over the Tsukuba area were dominated by rather smaller particles with less absorbency in the *VIS*-band compared to aerosols dominant in winter season.
- We found close correlations, with corresponding seasonal variations, among the surface radiative forcing and the optical properties of the columnar aerosols. The results suggest that the correlated seasonal variations could be caused by seasonal changes in dominant aerosol components over the Tsukuba area.

Acknowledgements

We thank Drs. A. Uchiyama and A. Yamazaki of Meteorological Research Institute for their advises about this study, and their exertion to keep the accuracy in long-term solar radiation measurements with pyranometers and a sunphotometer.

References

Asano, S., and M. Shiobara, 1989: Aircraft measurements of the radiative effects of tropospheric aerosols: I. Observational results of the radiation budget. *J. Meteor. Soc. Jpn.*, **67**, 847-861.

King, M. D., D. M. Byrne, B. M. Herman, and J. A. Reagan, 1978: Aerosol size distributions obtained by inversion of spectral optical depth measurements. *J. Atmos. Sci.*, **35**, 2153-2167.