# Retrieval of Asian Dust Amount over Land using ADEOS-II/GLI near UV Data

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## Abstract

We propose a retrieval method of Asian dust (Yellow sand or Kosa aerosol) columnar amount around source regions using a near ultraviolet radiometry observation from space. The method simultaneously retrieves an optical thickness and mode radius of Kosa aerosol, and then derives its columnar amount. The method was applied to ADEOS-II/GLI data in the spring of 2003 around Taklimakan desert source region, inland China. The retrieved optical thickness and mode radius were about 0.34 and 1.75 μm, respectively, at a validation site. They are comparable to the *in situ* observations conducted within the framework of ADEC project. The estimated columnar amount around a validation site is about 2.77 g $m^{-2}$, which seems reasonable under a relatively calm situation. The method should be further validated with a regional model simulation study, and then it is useful to monitor Asian dust around source regions from space in the future.

## 1. Introduction

Tropospheric aerosol has a crucial role in our environment. It has influence not only on a radiation field but also on a mass transportation of long distance. Over Japan in spring, we have mineral dust storm events, so-called Yellow wind (Yellow sand or Kosa aerosol), transported from inland arid regions of China.

Satellite remote sensing is potentially one of the optimum tools in monitoring Yellow sand transportation on a continental scale. Targeting absorbing aerosol such as Asian and Saharan dusts, Fukushima and Toratani (1997) retrieved single scattering albedos at 443, 520, and 550 nm spectral bands of the Costal Zone Color Scanner (CZCS) within the framework of atmospheric correction for an ocean color study.

Herman et al. (1997) showed residual maps of total ozone analyses using Total Ozone Mapping Spectrometer (TOMS) data, well corresponded to Saharan dust and biomass burning regions where UV-absorbing aerosol dominates. Their residual value is widely used as TOMS Aerosol Index (AI), which qualitatively reflects UV-absorbing aerosol existence.

Based upon the above residual method, Torres et al. (1998) developed the Direct Method, so-called "the method retrieves optical thickness and single scattering albedo of UV-absorbing aerosols such as dust and soot". The method was applied to the TOMS long-term dataset (around 20 years) for semi-global analyses of aerosol optical thickness (Torres et al. 2002). In spite of the fact that aerosol layer height is one of the greatest error sources, the heights in their simulation model of the TOMS signals are prescribed as a fixed or a monthly mean ones.

As for Asian dust retrieval again, Gu et al. (2003) presented the estimation of columnar dust amount with Moderate Resolution Imaging Spectroradiometer (MODIS) infrared (IR; split-window) data, and compared their result to the TOMS AI. Their IR method was originally developed with Advanced Very High Resolution Radiometer (AVHRR) data for targeting volcanic plume (Wen and Rose 1994) and is useful irrespective of daytime and nighttime. In the infrared spectral region, however, dust optical properties are not tabulated well for Asian region, and water vapor amount also influences the brightness temperature difference, which was not clearly taken into consideration in their retrieval.

Under the circumstances, it is anticipated that more dedicated retrieval method of the Asian dust from space based upon *in situ* observations near source regions. We propose a retrieval method of an Asian dust with near UV spectral observation from space in this article.

## 2. Satellite and *in situ* observations

Global Imager onboard Advanced Earth Observing Satellite-II (GLI/ADEOS-II) is a nadir-scanning optical imager for global observation of cloud, aerosol, water vapor as well as surface properties of vegetations, ocean color, sea surface temperature, and snow/ice (Nakajima et al. 1998). ADEOS-II is a sun-synchronous polar orbiter, and GLI observes a whole globe in four days. The satellite had operated from March to October 2003. The spectral range of GLI covers from near UV (380 nm) to thermal IR (12 μm). The spatial resolution is around 1 km at nadir, and its field of view (FOV) is about 1600 km. GLI has near UV or blue window bands in 380, 400, and 412 nm. In particular, the 380 nm band is a unique one, which is not configured on the other similar kinds of sensors such as MODIS.

Aeolian Dust Experiment on Climate impact (ADEC) is a bilateral project between Japan and China. The project has a final goal so as to estimate an Aeolian dust amount supplied to the atmosphere around source region in China and its climate impact. The main component of the project consists of the following three features: 1) *in situ* observation of dust around source regions, 2) ground-based remote sensing observation network for the detection of dust transportation, and 3) numerical model development in terms of a life cycle of an Aeolian dust and its radiation effect.

Within the framework of the ADEC project, four in-

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tensive observation campaigns were conducted in spring and summer seasons: in April and July 2002, March 2003, and March to April 2004. During the third Intensive Observation Period (IOP-3), at the Shapotou observation site (37.27°N, 104.57°E, and 1250 m asl.), several *in situ* observations were carried out, using a LIDAR and a skyradiometer for an aerosol layer height and aerosol optical thickness, respectively.

Fortunately, in March 22, 2003, ADEOS-II flew over the Shapotou site, and we had a simultaneous observation with GLI, LIDAR, and skyradiometer. Using the synchronized dataset, we retrieved an optical thickness and mode radius of Kosa aerosol with GLI data, and compared the optical thickness to LIDAR and skyradiometer observations. And finally, we estimated the Kosa aerosol columnar amount as a by-product even though several assumptions were introduced in this preliminary study.

## 3. Methodology

Our retrieval method is based upon the Direct Method developed with TOMS data by Torres et al. (1998). The Direct Method originally retrieves optical thickness and single scattering albedo of UV-absorbing aerosols over land and ocean using 340 and 380 nm spectral radiances.

The single scattering albedo retrieved with the Direct Method, is an indicator of the degree of aerosol absorption, which mainly depends upon a refractive index and a size distribution of the particles. Instead of single scattering albedo, we try to retrieve mode radius assuming the size distribution shape and refractive index as the typical ones observed near source regions of the Asian dust.

The assumptions in our retrieval are the following: a plane-parallel atmosphere, a mono-modal log-normal distribution as a particle size distribution, and sphere particles with Mie scattering calculations. A polarization effect with Rayleigh scattering is not taken into account in this study. The particle size distribution is the following:

$$n(r) \equiv \frac{dN}{dr} = \frac{c}{r}\exp\left[-\frac{(\ln r - \ln r_0)^2}{2\sigma^2}\right], \quad (1)$$

where $N$ is a number of particles, $r$ is a particle radius, $c$ is an arbitrary constant which is normalized as a total particle number, $r_0$ is a mode radius, and $\sigma$ is a standard deviation, which is expressed as $\ln s$ The value $s$ is assumed as 2.0 (Uchiyama et al. 2005).

Simulations are carried out with GLI Signal Simulator (GSS; Nakajima et al. 2003) so as to calculate radiances to be observed with GLI. At that time, we made a weighting approach with some monochromatic radiative transfer calculations with GSS, since GLI has some bandwidths in each channel. The simulated radiances $I$ is calculated as follows:

$$I_i = \sum_j L_{i,j}\eta_{i,j} / \sum_j \eta_{i,j}, \quad (i = 1, 2) \quad (2)$$

where $I_i$ is a radiance for GLI $i$-th channel, $L_{i,j}$ and $\eta_{i,j}$ are a radiance and a response function for $j$-th sub-spectral bin within the $i$-th channel, respectively. The total sub-spectral bin number in terms of $j$ for Ch. 1 and Ch. 2 is 22 and 34, respectively.

The refractive index of Yellow sand (Kosa aerosol) used in this study is that compiled in GSS. A surface spectral reflectance measurement was carried out with a broadband radiometer at Tengger desert near the Shapotou site in autumn 2003. We adopt this value since a surface reflectance of a desert region has little seasonal variation. Table 1 summarizes the refractive index and surface reflectance used in this study.

Table 1. Optical parameters used in this study.

| GLI Ch. # | Central wavelength (nm) | Bandwidth (nm) | Refractive index* | Surface reflectance (%) |
|---|---|---|---|---|
| 1 | 380 | 10 | 1.55–0.0074i | 5.4 |
| 2 | 400 | 10 | 1.55–0.0066i | 6.4 |

*Refractive index is shown only for each central wavelength. Appropriate refractive indices, corresponding to the sub-spectral bins within the channel, were used for the simulations with GSS.

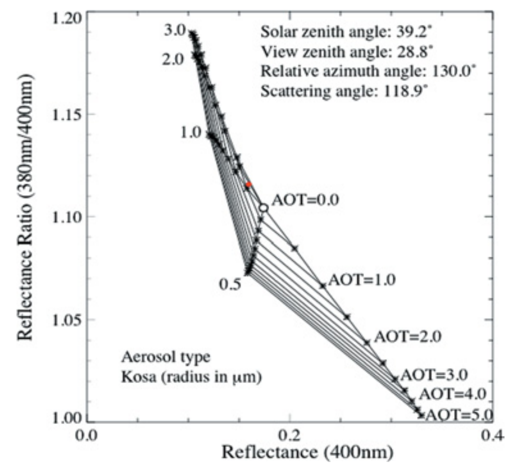


Fig. 1. An example of schematic diagram of our retrieval method for Yellow sand (Kosa aerosol) for the pixel at Shapotou. The abscissa is reflectance of GLI Ch. 2, and the ordinate is the reflectance ratio between Ch. 1 and Ch. 2. The simulation was carried out corresponding to the scan geometry at Shapotou. The AOT means aerosol optical thickness ($\tau_a$) at 500nm, and has the cases from 0.0 to 5.0 with an interval 0.5. The mode radius ($r_0$) has the cases with 0.1, 0.5, 1.0, 2.0, and 3.0. Each node point is connected with solid lines to the next points. The red point corresponds to the Shapotou's pixel. The optical thickness and mode radius are retrieved as 0.34 and 1.75 μm, respectively in this case.

Figure 1 illustrates an example of simulated diagram. The abscissa is a reflection function (a spectral reflectance) at GLI Ch. 2 (400 nm) and the ordinate is a reflectance ratio between Ch. 1 (380 nm) and Ch. 2 (400 nm).

The reflectance $R$ is expressed as follows:

$$R_i = \frac{\pi I_i}{\mu_0 F_i}, \quad (i = 1, 2) \quad (3)$$

where $I_i$ and $F_i$ are a radiance and a solar irradiance for GLI $i$-th channel, respectively. $F_i$ is calculated with an weighting approach just like $I_i$ in Eq. (2). $\mu_0$ is a directional cosine of solar zenith angle.

Using the diagram, we can determine aerosol optical thickness ($\tau_a$) and mode radius ($r_0$) simultaneously for the GLI observation data. For general cases, a look-up table approach is adopted: At first, a look-up table in terms of the reflectances and their ratio is made with relevant parameters such as solar zenith angle, sensor zenith angle, and their relative azimuth as well as aerosol optical thickness and mode radius. And then, an optimum parameter set is searched in the look-up table, which most explains the GLI-observed reflectances and ratio. A detailed discussion on the sensitivity study will be published separately.

## 4. Preliminary results and analysis

One of the greatest factors that cause retrieval error is the aerosol layer height as well as the surface reflectance. In previous aerosol retrieval studies with UV spectral region such as the Direct Method, the aerosol layer height used to be assumed as some constant values. However, a difference in aerosol layer height assignment by 1 km, possibly causes up to 70 % retrieval error in optical thickness (Torres et al. 1998). Fortunately, we had a simultaneous LIDAR observation at the Shapotou site. The observation indicates the aerosol layer ranged from surface to four kilometers in altitude. The aerosol profile was used for the retrieval with the GLI data. In connection to the aerosol height, surface pressure is one of the key factors, since the UV retrieval method is based upon the interaction with multiple scattering among air molecules, aerosols, and surface. The surface pressure observation was also carried out at Shapotou simultaneously with the GLI overpass, and the value was 880 hPa. As a result, we obtained the optical thickness 0.34 and the mode radius 1.75 μm at the Shapotou pixel in Fig. 1.

The retrieved mode radius is equivalent to 7.40 μm as a volume size distribution. The result is a little bit larger than the retrieved mode radius for the coarse mode (1 to 6 μm) with the skyradiometer observation (Uchiyama et al. 2005), but it is reasonable for Kosa particles in the same order of magnitude. The GLI retrieved optical thickness 0.34 at 500nm is larger than the value of 0.30 with a LIDAR measurement at 532 nm (Yasui et al. 2005), and, on the other hand, smaller than the value of 0.59 at 500nm with a skyradiometer measurement. Here, we use the LIDAR data only at lower than 4 km height, since the signals above 4 km height suffered from severe noises. Consequently, LIDAR observation might underestimate the optical thickness. Further, the GLI retrieval does not consider the aerosol layer above 4 km height, which is one of the reasons the GLI retrieval underestimated the aerosol optical thickness compared to the skyradiometer observation. As a result, we consider the retrieved optical thickness is valid within the range between the two *in situ* observations at this stage.

Based upon the retrieved results for a pixel of Shapotou, we extended the retrieval for the GLI scene as illustrated in Fig. 2. At that time, we adopted the look-up table approach in terms of reflectance ratios between Ch. 1 and Ch. 2, reflectances in Ch. 2, solar and sensor zenith angles, solar-sensor relative azimuth angles in relation to optical thickness and particle mode radius of Kosa aerosol. The other parameters, such as the aerosol layer profile, surface pressure, standard deviation of size distribution and so on, were the same as the case of the pixel of Shapotou.

As seen in Fig. 2, Kosa aerosol appeared in a wide area in spite of an analysis under a relatively calm condition. Comparing both results, it is found that areas with larger optical thickness have larger mode radius. A scene statistics of optical thickness and mode radius in Fig. 2 is summarized in Table 2 as well as the retrieved results at Shapotou.

Using the retrieved optical thickness and mode radius, we further try to estimate columnar amount of Kosa aerosol. As an analogy of the cloud liquid water estimation study (Stephens 1978), we estimate columnar aerosol amount as follows:

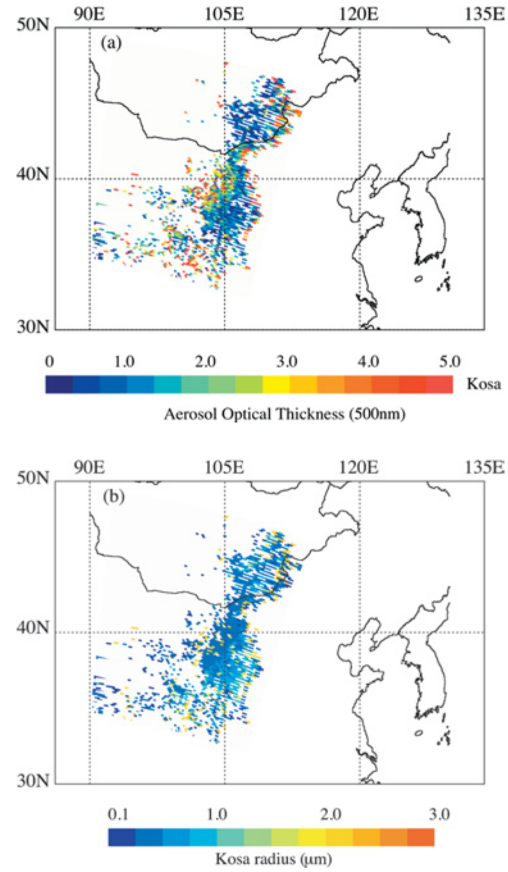


Fig. 2. Maps of Kosa aerosol properties: (a) optical thickness and (b) mode radius, retrieved using GLI near UV data (380 and 400 nm) with 1 km spatial resolution (March 22, 2003 around Shapotou: 37.27°N and 104.57° E). The color codes are linear scales and their ranges correspond to the diagram in Fig. 1.

$$\Gamma \approx \frac{4}{3}\cdot\frac{\rho_\gamma}{\overline{Q_{ext}}}\cdot\tau_a\cdot r_e, \tag{4}$$

where $\Gamma$ is a column amount of Asian dust (Kosa aerosol), $\rho_\gamma$ is a density of Kosa, $\overline{Q_{ext}}$ is a representative extinction efficiency corresponding to a size parameter estimated with relevant wavelengths, mode radius, and refractive index. $\tau_a$ is a retrieved optical thickness and $r_e$ is a effective particle radius defined as follows (Hansen and Travis 1972):

$$r_e \equiv \frac{\int r\cdot \pi r^2 n(r) dr}{\int \pi r^2 n(r) dr}, \tag{5}$$

and, is estimated with the retrieved mode radius as follows:

$$r_e = r_0 \exp(2.5\sigma^2), \tag{6}$$

where $\sigma$ is the standard deviation in Eq. (1).

In the cloud retrieval study, former two factors of right hand in Eq. (4) are approximately (2/3), since a liquid water density is about 1.0 g cm$^{-3}$ and the extinction efficiency asymptotically becomes a constant 2.0. In case of Kosa aerosol, $\rho_\gamma$ is 2.6 g cm$^{-3}$ (Han et al. 2004) since its main component is considered as quartz. The extinction efficiency still has a fluctuation around size parameter 30, but we assume $\overline{Q_{ext}}$ as a representative value 2.5 for simplicity in this study.

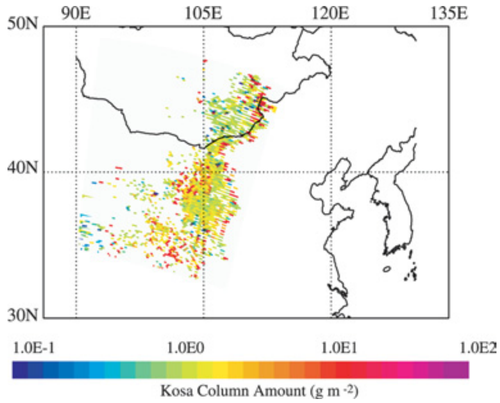


Fig. 3. A map of Kosa aerosol columnar amount. This is derived from optical thickness and mode radius in Fig. 2 (March 22, 2003 around Shapotou: 37.27°N and 104.57°E).

Table 2. A summary of Kosa properties retrieved with the GLI near UV data around Shapotou.

| | $\tau_{a,500}$ | $r_0$ (μm)[b] | Γ (g $m^{-2}$)[c] |
|---|---|---|---|
| Shapotou[d] | 0.34 | 1.75 | 2.77 |
| Scene average (standard dev.)[e] | 1.89 (1.46) | 0.64 (0.54) | 7.40 (13.27) |

[a] Aerosol optical thickness at 500 nm.
[b] Mode radius of log-normal size distribution for number density.
[c] Columnar amount of Kosa aerosol.
[d] Retrieved values with a pixel at Shapotou site.
[e] Retrieved values with the only pixels classified as Kosa aerosol.

Under these assumptions, a column amount at Shapotou and within the GLI scene is estimated as 2.77 and 7.40 g $m^{-2}$, respectively, under a relatively calm condition as summarized in Table 2. Figure 3 illustrates the estimated column amount map, derived from Fig. 2 with Eq. (4). The estimated result seems reasonable but slightly overestimated, since dust columnar amount 6.26 g $m^{-2}$ was retrieved with MODIS IR method under a dust storm condition (Gu et al. 2003). This would be possibly ascribed to the assumed parameters in Eqs. (4) and (6), such as the dust density, the extinction efficiency and the standard deviation at this stage.

## 5. Concluding remarks

We proposed a retrieval method for Asian dust column amount over land using ADEOS-II/GLI near UV data near source region. At first, we devised the Direct Method (Torres et al. 1998) so as to retrieve optical thickness and mode radius of Kosa aerosol. Our method was applied to the GLI dataset with several kinds of *in situ* observations, which were used as an ancillary dataset for the retrieval and as a validation.

The validation study indicates the satellite-retrieved optical thickness and mode radius are smaller and larger than those retrieved with the skyradiometer measurement, respectively. One of the reasons for the differences is ascribed to the treatment of the aerosol layer height. The satellite retrieval assumed the aerosol layer profile with the LIDAR measurement only at below the 4 km height due to severe noises at higher levels. Actually, the consistency of the optical thickness is good between the GLI retrieval and the LIDAR measurement.

Next, using the retrieval of the optical thickness and particle size, we estimated the columnar amount of Kosa aerosol. The estimated amount is comparable to that retrieved with MODIS IR method for the same season in the other year. The retrieved results as a whole should be validated in detail, compared to a regional model simulation and any other estimations.

## Acknowledgments

The authors are grateful to Drs. R. Hoeller, T. Y. Nakajima and T. Nakajima for their constructive comments. This study is funded by Japan Aerospace Exploration Agency (A2-RA-G-0030).

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(*Manuscript received 13 December 2004, accepted 1 February 2005*)