ALGORITHM FOR AEROSOL RETRIEVAL BASED ON RADIANCE AND POLARIMETRY FOR SGLI

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ABSTRACT:

Atmospheric aerosols play an important role not only in the climate research but also in the remote sensing of the Earth surface. This work focuses on the retrieval procedure for such aerosol properties as optical thickness, Angstrom exponent and single scattering albedo with the Second Global Imager (SGLI) on Japanese Global Change Observation Mission - Climate satellite (GCOM-C). The SGLI is designed to observe atmosphere, land, and ocean in total by using 18 channels from near ultra violet to thermal infrared spectra. One of the interesting features of SGLI is to measure the polarization of reflectance from Earth with long track tilting angles covering +/- 45 degrees. Our algorithm is based on the efficient usage of this polarization information as well as radiance measurements. Namely aerosol optical thickness (AOT) and its wavelength tendency are derived by combination use of polarization and radiance with two-channel algorithm. In addition it is known that the carbonaceous aerosol is an unknown item for climate modelling. Here the retrieval algorithm for carbonaceous particles is especially focused by using the near UV measurements. Our algorithms are validated with the data given by POLDER and GLI sensors equipped on the satellite ADEOS-II.

1. INTRODUCTION

Atmospheric aerosols influence upon the Earth's radiation budget. The magnitude of influence depends on the aerosol characteristics which also contribute to the process of cloud formation and its properties. Japanese future satellite mission, called global change observation mission (GCOM) is planned to monitor the Earth's climate system. GCOM-Climate carries an imager sensor (second global imager; SGLI) which observes Earth's geophysical parameters. Aerosol information is one of key parameters for GCOM-C/SGLI. The SGLI, is a successor of global imager (GLI) on advanced Earth observing satellite-II (ADEOS-II) which was operated in 2003, measures the polarization information at visible and near IR wavelengths for aerosol retrieval. It has also capability to measure the total radiance from near UV to short infrared wavelength. The purpose of this work is to develop an algorithm for estimating aerosol information from SGLI measurements.

2. AEROSOL MODEL

Aerosols can be roughly classified into two categories in according to the natural or the anthropogenic with respect to the emission form in origin. Each category has each specific character. For example the natural origin particles as sea salt and soil dust are generally large. On the contrary, most of anthropogenic particles produced by the burning of fossil fuel, coal, and biomass are small. Sulphuric and carbonaceous particles are representative of anthropogenic one. Naturally more complex processes, such as internal or external mixing of both types of aerosols are expected, and have been demonstrated with the facts observed in the ACE-Asia field campaign (Huebert *et al.*, 2003).

In order to retrieve the aerosol information from the satellite data, various parameters of aerosol model are needed for theoretical calculation of TOA radiance. The Aerosol Robotic Network (AERONET) has begun to deploy the ground sun/sky photometers since early 1990s over the world (Holben *et al.*, 1998). The network adapts standardized instrument, calibration method, inversion scheme, and database. Note that the inversion of optical properties of aerosols is developed by Duvobik and King, (2000a) and Duvobik *et al.* (2000b). All of retrieved results are distributed from a web site (AERONET web).

2.1 Size distribution

Definition of size distribution is an important issue for satellite aerosol retrieval. Shettle and Fenn (1976), and d'Almeida *et al.* (1991) compiled the characterization of aerosols in global scale. The AERONET project provides us with the size information based on the newly obtained measurements and inversion scheme. This work adopts the AERONET results as size information which is compiled by Duvobik *et al.* (2002) and Omar *et al.* (2005).

In this work, bi-modal size distribution is adopted, where two values of the mode radii (rg) and those of the standard deviations (σ) are fixed. However, mixing ratio of coarse mode to fine one varies according to the atmospheric conditions. The value of mixing ratio relates to the value of Ångström exponent from ~0 to 2.5 (see Table 1).

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Table 1 Size distribution.

models / parameters	Description
Size distribution	Bi-modal volume size distribution dV(r) / d ln r
Fine mode (rg_{fine}, σ_{fine})	Urban, Industrial and Biomass burning aerosols observed at GSFC, Paris, Mexico, and Maldives (rg_{fine}=0.135, σ_{fine} =0.430 μm) Ref. Dubovik et al., 2002
Coarse model (rg_{coarse}, σ_{coarse})	Dust and Oceanic aerosols observed at Bahrain, Solar-Village, Cape Verde, and Lanai Island (rg_{coarse}=2.365, σ_{coarse} =0.630 μm) Ref. Dubovik et al., 2002
Ratio of each mode (γ)	Volume ratio of coarse mode to total

2.2 Optical constants

Chemical composition of aerosol can be represented by complex refractive index in radiation field. Shettle and Fenn (1976), and d'Almeida *et al.* (1991) compiled of the complex refractive index for various aerosol types and conditions. The world wide sun/sky radiometer deployed network, AERONET, provides us with the updated complex refractive index with recent sun/sky radiometer inversion technique (Dubovik *et al.* 2000; Dubovik and King, 2000b; Dubobik *et al.*, 2002).

In order to cover the various types of aerosols, the wide range of complex refractive indices from 1.33-0.00i for pure water particles to 1.70-0.04i for absorbing particles are taken into account here. For estimation of biomass burning particles in detail as the stage of burning over the plume region, mixing of several kinds of aerosols are examined. The internal mixture of several components, i.e., black carbon (BC) and organic one (OC), is express by expressed by Maxwell-Garnett rule, (Bohren and Wickramasinghe, 1977; Chýlek and Srivastava, 1983; Burkhard, 1984), which calculates the complex refractive index for heterogeneous particle consisting of small spherical particles (called inclusions) suspended in a homogeneous medium (called matrix). The matrix is assumed as weak absorbing particles ($m \approx 1.450 - 0.0001i$), i.e. OC aerosols. The inclusions are absorbing one, such as carbonaceous aerosols ($m \approx 1.60 - 0.02i$) (Hungershoefer, 2008). Note that, more absorbing case, $m=1.70 - 0.04i$ is also considered for extreme case.

Table 2 shows the complex refractive indices for various volume fractions of the inclusions from 0 % to 40 %, and 100%, and a strong absorbing case. Figure 1 shows single scattering albedo (SSA) at a wavelength of 0.55 μm calculated for various volume fractions and a fixed bi-modal size distribution function as: (rg_{fine}= 0.135 μm, σ_{fine} = 0.43 μm) and (rg_{coarse}=2.365 μm, and σ_{coarse}= 0.63 μm) (see Table 1), and 1.5 of Ångström exponent value for small particle, is presented in Fig. 1.

Table 2 Complex refractive indices of absorbing aerosols based on Maxwell-Garnet mixing rule.

Volume fraction of inclusions [%]	Real part of refractive index	Imaginary part of refractive index
0	1.450	0.0001
10	1.465	0.0020
20	1.480	0.0040
30	1.494	0.0059
40	1.509	0.0079
100	1.600	0.02
Extreme case	1.700	0.04

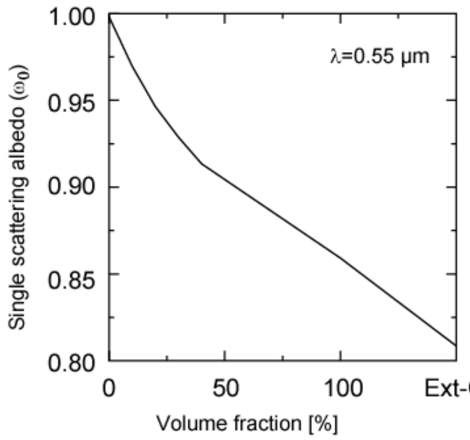

Figure 1 Single scattering albedo for various volume fractions.

3. AEROSOL RETRIEVAL

Satellite sensor measures Earth's reflectance values which are composed of scattering light from atmospheric particles and reflected light from the ground/ocean. One of difficulty in satellite aerosol retrieval is how to treat the ground/ocean reflectance including the space-based measurements. In order to avoid this problem, polarization information is available. And hence the combined data of polarization and total intensity information are used for aerosol retrieval in this work.

Herman *et al.*, 1997 have pointed out that the polarization information taken by satellite is mainly occupied by the polarization by the atmospheric particles, such as molecules and aerosols. This means that the ground polarization effect is small in the measurements. Another advantage is that the wavelength tendency of polarization is also small compared to total radiance, because the ground polarization is caused by the reflection of the surface which is described by the geometrical relation of incident and emergent angles. However, the ground polarization effect should be considered to estimate accurate aerosol properties. Nadal and Bréon (1999) proposed the empirical polarization model, which is called bi-directional polarization distribution function (BPDF) based on polarization and directionality of the Earth's reflectances (POLDER) sensor on Advanced Earth Observing Satellite (ADEOS) (Deschamps *et al.*, 1994). The BPDF model is categorized for four types, i.e., forest, shurubland, low vegetation, and desert, which is used to select the IGBP land classification (Loveland *et al.*, 2000) and normalized differential vegetation index (NDVI) based on POLDER data. A modified version of BPDF data is made by using POLDER-2 on ADEOS-2 and POLDER on PARASOL data Maignan *et al.*, (2009).

The total intensity measurement is observed by many sensors. Ground surface reflectance is composed of the measurements as well as atmospheric lights (aerosol information). The ratio of ground light to total one is relatively large compared to polarization method. The bi-directional reflectance distribution function (BRDF) is required to retrieve the aerosol information from the intensity data in general. This work adopts a combination method in order to reduce the ground albedo effect. The method is composed of estimating minimum reflectance from the satellite and calculating the ratio of two observing wavelength for evaluating aerosol properties. The minimum reflectance method is shown below.

Radiation field at TOA (R_{TOA}) can be expressed by the reflectance of ground(R_{ground}), single scattered light(R_{single}), and multiple scattered light($R_{multiple}$) by atmospheric particles, such as molecules and aerosols,

$$R_{TOA} = R_{ground} + R_{single} + R_{multiple}. \quad (1)$$

Thus, the reflectance by ground surface can be estimated by

$$R_{ground} \sim R_{TOA} - (R_{single} + R_{multiple}). \quad (2)$$

The term of R_{single} / $R_{multiple}$ represents the singly / multiply scattered light by atmospheric particles, which also might be influenced by ground reflection. The scattered light by molecules can be estimated by radiative transfer equation. On the contrary, the aerosols are unknown, and hence in order to compensate the aerosol effect, the minimum value of reflectance during satellite observation period is available. Then, atmospheric light can be estimated from the subtraction of R_{ground} from the TOA measurement (R_{TOA}).

The second procedure is to calculate the ratio from the obtained values of atmospheric lights at two different observing wavelengths. This procedure can eliminate the effect of remaining ground albedo in the measurements after first procedure (obtaining minimum reflectance). However, both wavelengths must be close. Modern satellite sensor has many observing wavelengths from near UV to thermal infrared region. It should be considered for aerosol retrieval from the following point of view:

a) each observing wavelength is enough to close in order to cancel the ground albedo effect,

b) the value of ratio ($I_{\lambda 1}/I_{\lambda 2}$) can distinguish the absorbing and non-absorbing particles.

It has been shown by previous wok (Hsu *et al.*, 1996; Herman *et al.*, 1997; Toress *et al.*, 1998) that the near UV information is useful to detect such absorbing aerosols as mineral dusts and biomass burning plumes from TOMS UV data. In this work, investigation is made with both near UV measurements and visible measurements. Figure 2 presents the numerical results of TOA-reflectance ratio of 0.38 to longer wavelengths for various types of aerosols (Table 2). We found from Fig. 2 that the TOA-reflectance ratio linearly decreases with wavelength for non-absorbing aerosol but it has a peak around the violet wavelength for absorbing aerosol case. Moreover the peak becomes sharp with the increasing volume fraction of inclusions, namely magnitude of aerosol absorption. That is why a ratio of TOA-reflectance at the violet to that at 0.38 µm looks promising to be a good indicator to estimate the absorption character of aerosols. All figures in Fig. 2 suggest that 0.41 µm is the best wavelength for our desired indicator. Note that the retrieval of volume fraction is equivalent to obtaining single scattering albedo and complex refractive indices of absorbing aerosols. Thus a ratio of TOA-reflectance at 0.41 µm to that to 0.38 µm is selected for an index to estimate the refractive index of biomass burning aerosols.

The aerosol characteristics are retrieved based on the comparison of the observed radiance and polarization data by POLDER with the simulated results for multiple light scattering in the Earth atmosphere land and ocean model. The ocean model is described by Cox and Munk (1954) model which also provides us with the slope of wave with wind speed, thus BPDF of ocean is also available. AFGL model (Kneizys *et al.*, 1988) is adopted as molecular information. Finally, the radiative transfer equation is solved with Adding – Doubling method (Hansen and Travis, 1974; Mukai *et al.*, 1991; Sano and Mukai, 1998). The computational results are stored in the look up table (LUT).

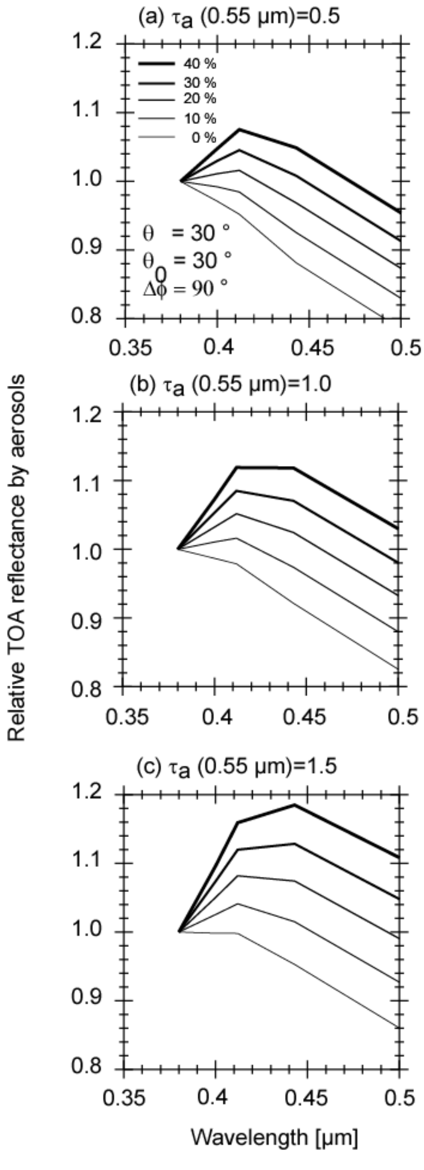

Figure 2 Simulated TOA-reflectance ratio with various aerosol conditions for detecting absorbing aerosols.

Deuzé *et al.* (2001), and Sano (2004) have retrieved aerosol optical thickness and index of size distribution (Ångström exponent) based on two channel polarimetric information observed by POLDER-1 period.

Figure 3 shows the TOA polarized reflectance at 0.67 and that of 0.87 µm which are calculated by radiative transfer model with various aerosol conditions. The figure implies that the polarization information are useful to retrieve the aerosol optical thickness (τ_a) and its wavelength tendency (Ångströom exponent; α). It should be noted that the figure 3 is the result of model calculations with the fixed refractive index.

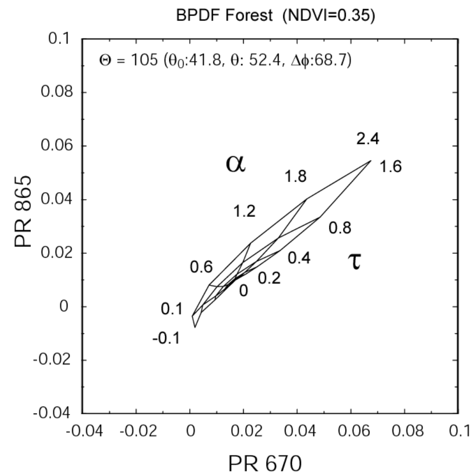

Figure 3 Simulated TOA-polarized reflectance at 0.67 and 0.87 µm with various aerosol conditions.

In order to extract the absorbing information, we use the color index of near UV and violet which has already been shown in Fig. 2. Thus the combined use of radiance at and polarization information gives us with optical properties of aerosols, aerosol optical thickness τ_a, Angstrom exponent α, and Single scattering albedo (ω_0).

The algorithm is tested with Siberian biomass burning scene which was observed by the POLDER and GLI on May 20th 2003. Figure 4a shows the ratio of reflectance at 0.41 to that of 0.38 µm. The higher value indicates the strong absorption region. Figure 4b and 4c represent the retrieved results of AOT and Ångström exponent over the region. Gray region in Fig. 4b and 4c represents the no results due to large error in the retrieval, cloudy, or over ocean (the algorithm is only applied over continent). Figure 5 shows the measurements by ground sun photometry at Shirahama, Japan from May to June in 2003. Each dot surrounded ellipse is each measurement on May 21st. We can see that high values of AOT and Ångström coincides with the results of Fig. 4b and 4c.

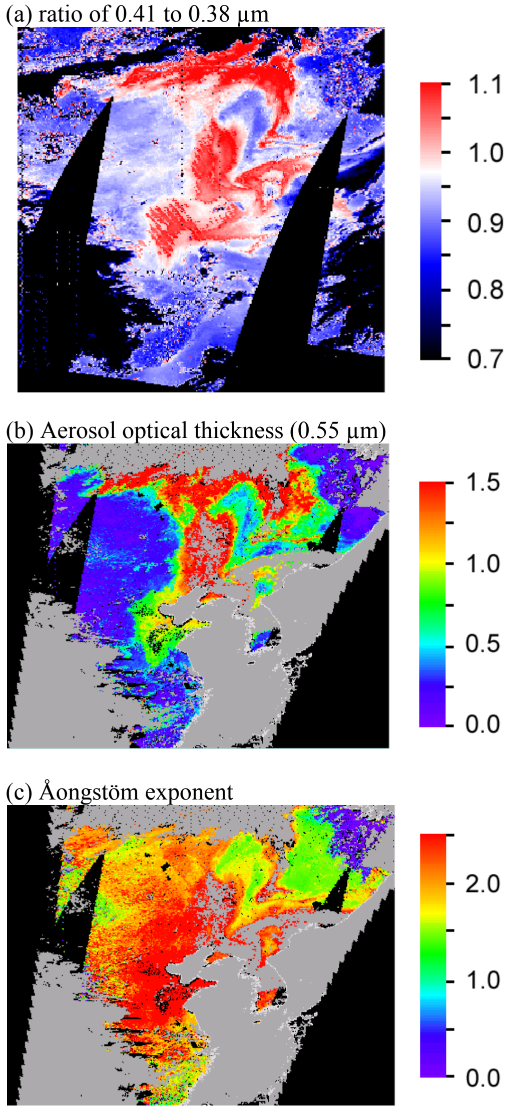

Figure 4 (a) Absorbing index (ratio of the reflectance at 0.41 to that of 0.38 µm) , (b) aerosol optical thickness at 0.55 µm, and (c) Ångström exponent.

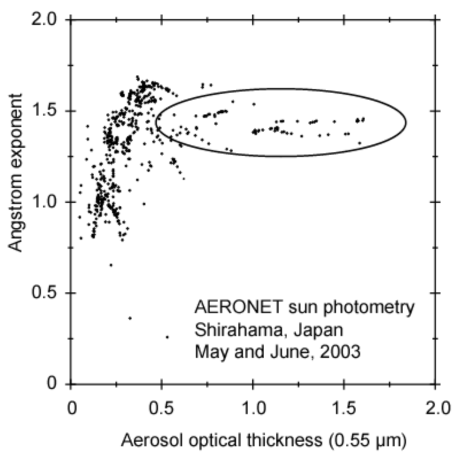

Figure 5 Aerosol optical thickness at 0.55 µm and Ångström exponent at Shirahama from May to June in 2003.

4. SUMMARY

This work proposes a retrieval algorithm for such an absorbing aerosol as the carbonaceous particle. It has been shown that combination use of polarization and radiance provides us with the amount of aerosol loading (τ_a), size information of particles (α) and single scattering albedo (ω_0).

Acknowledgements

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