P1.4 SIMULATION OF THE MONOCHROMATIC RADIATIVE SIGNATURE OF ASIAN DUST OVER THE INFRARED REGION

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ABSTRACT

Monochromatic radiative signature of Asian dust was simulated in the 650–2750cm^{-1} wavenumber band with a 0.25 cm^{-1} resolution. To solve the radiative transfer equation with the absorption and scattering by mineral dust, the Successive-Order-of-Interaction (SOI) radiative transfer model was used. Simulation was done for various aerosol optical depths (AODs) and dust altitudes using optical properties of mineral dust, which were obtained from mineral transported model of the Optical Properties of Aerosols and Clouds (OPAC) database. The OPAC data were updated with the size distribution retrieved from ten years of sky radiometer measurements at Dunhuang, China, which is located at the eastern edge of Taklamakan desert. Results indicate that the effect of mineral dust on IR brightness temperature appears significant in the window regions by considering that brightness temperature (BT) between clear and dusty conditions are up to 10 K with AOD of 2.0 and dust altitude of 2.4 km. The results will be used for developing the dust retrieval algorithm from hyperspectral images from sensors such as Infrared Atmospheric Sounding Interferometer (IASI).

1. INTRODUCTION

Asian dust is a typical event of mineral dust originating from China and Mongolia during the spring season and transferring to East Asia (Chun et al., 2001; Uno et al., 2003). Asian dust can affect the Earth's weather and climate system, atmospheric radiation budget, and human activity directly or indirectly. Although it plays the important roles in a variety of fields and has been focused as a subject of major research recently, still remains in unexplored field. Retrieval of Asian dust using satellite data has many advantages providing products with high temporal and spatial resolution. A next generation

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of sensor, the interferometer instrument such as IASI, has extremely narrow band width and capability to retrieve more accurate aerosol products(Chalon et al., 2001). In this study, monochromatic radiative signatures of Asian dust were simulated and discussed as a preliminary study in application of the infrared (IR) interferometer instrument to Asian dust.

2. DATA

2.1 OPAC

The software package Optical Properties of Aerosols and Clouds (OPAC) contains optical properties in the visible and IR range of cloud and aerosol particles (Hess et al., 1998). The optical properties such as the extinction, scattering, and absorption coefficients, the single scattering albedo, the asymmetry parameter, and the phase function are calculated using size distribution and refractive index under the assumption of sphere particle.

As well as the optical properties, OPAC provides complex refractive indices of 9 clouds and 10 aerosol components for 61 wavelengths in the range of 0.25—40 μm. The complex refractive indices of the aerosol components are dominantly based on the data of d'Almeida et al. (1991). In this study, Mie calculation was made under the assumption that dust particles are spherical. The refractive index of mineral aerosol in OPAC is taken to make Mie calculation.

2.2 Skyradiometer Measurements

Mie calculation needs the size distribution of Asian dust. Instead of the size distributions included in OPAC, in situ measurements were used in this study.

The size distribution of Asian dust was obtained from skyradiometer measurements at Dunhuang site of the Skyradiometer Network (SKYNET) (Kim et al., 2004). With Dunhuang being located at the eastern edge of Taklamakan desert in China, the measurements observed at this site fully reflect the properties of Asian dust. Chiba University in Japan has observed Asian dust with skyradiometer at Dunhuang since 1998 (See online at: http://atmos.cr.chiba-u.ac.jp/).

In this study, the size distribution retrieved from ten years (1998—2007) of skyradiometer measurements was used in Mie calculation. All size distributions observed during dust events were averaged and fitted to bi-lognormal function for simple calculation. Figure 1 shows the averaged size distribution and the fitted bi-lognormal function. The dust events were simply defined with AOD and Angstrom exponent (α). Measurements which have AOD greater than 0.5 and α smaller than 0.3 were regarded as dust events. Using the complex refractive index of OPAC and the fitted size distribution, the optical properties of Asian dust were obtained from Mie calculation.

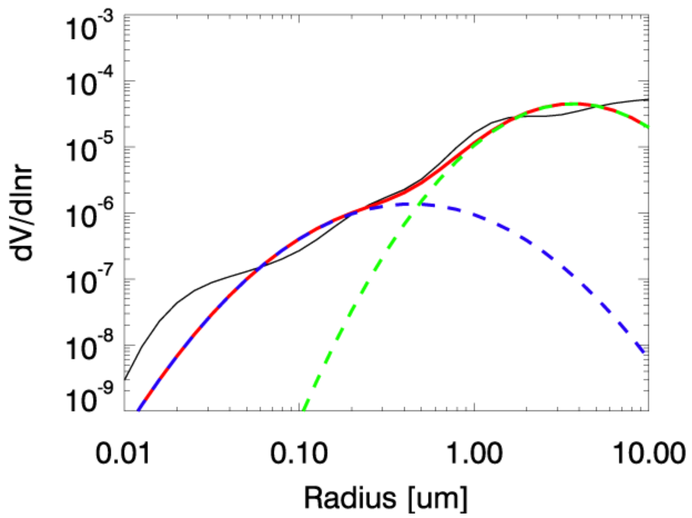

Figure 1. Averaged volumetric size distribution observed at Dunhuang site (black solid line). The fitted bi-lognormal function (red solid line) and two modes (dashed lines) are also plotted. The coarse and fine mode radii are 0.44 μm and 3.72 μm, respectively.

2.3 Global Infrared Land Surface Emissivity

A monthly averaged global infrared land surface emissivity database has been developed by UW(University of Wisconsin)/CIMSS(Cooperative Institute for Meteorological Satellite Studies) (See online at: http://cimss.ssec.wisc.edu/iremis/). Based on the baseline fit method, it is derived globally using the Moderate Resolution Imaging Spectroradiometer (MODIS) operational land surface emissivity product with 0.05° spatial resolution (Seemann et al., 2008). The emissivity database used in this study is available at 10 wavelengths of 3.6, 4.3, 5.0, 5.8, 7.6, 8.3, 9.3, 10.8, 12.1 and 14.3 μm.

3. METHODOROGY

The doubling technique (Peebles and Flesset, 1951; Van De Hulst, 1980) and the successive-order-of-scattering (SOS) technique (Greenwald et al., 2005; Liou, 2002) are two traditional methods of solution of radiative transfer. The doubling technique is a powerful tool for multiple scattering calculations and has been used in remote sensing applications (Liou, 2002). However it has the problem with expensive computation time for optically thick layers such as cloud or aerosol. In contrast, SOS technique which is computationally practical has a limitation on multiple scattering calculations (Greenwald et al., 2005).

The SOI method is an iterative approximation to the traditional adding and doubling method for radiative transfer (Heidinger et al., 2006). It combines advantages of the doubling technique and SOS technique. The truncated doubling method is applied to calculate radiative quantities, the reflectance, the transmittance, and the sources exiting the top and bottom of the layer. For efficiency of computation, an iterative method that used in SOS model (Greenwald et al., 2005) is applied to SOI. When integrating the radiative properties vertically, SOI uses this iterative method instead of traditional adding method which can be computationally expensive.

In this study, SOI model is used because of its capability to calculate radiances undergo the multiple scattering efficiently. The radiative signatures were simulated for various AOD and dust altitudes. As input variables, SOI model needs information about meteorological condition, surface, and Asian dust. The meteorological variables such as temperature and water vapor vertical profiles and surface temperature are obtainable from the standard atmospheric profile for mid-latitude summer (McClatchey et al., 1972) and the surface emissivity derived from UW/CIMSS are used in SOI model. Information on Asian dust including the extinction, scattering, and absorption coefficients, the single scattering albedo, the asymmetric parameter, and the phase functions can be calculated with the size distribution from the skyradiometer measurements at Dunhuang and OPAC refractive index. All simulations were made in the 650—2750 cm^{-1} wavenumber range with a 0.25 cm^{-1} resolution.

A principal component analysis (PCA) scheme is developed for observations from the IR interferometer (Aires et al., 2002; Huang and Antonelli, 2001). PCA has been used to reduce the noise in some spectral regions and compress the observations. Not only the performance of denoising and compression, a feature extracting approach is also possible through PCA scheme. In order to find spectral ranges that undergo the influences of Asian dust, we apply the simulated brightness temperatures for various AOD and dust altitudes to this scheme.

4. RESULTS

SOI simulations were made for various AODs and the dust altitudes. The differences of simulated BT of Asian dust and clear sky, hereinafter referred to as the radiative signatures of Asian dust, are shown in figure 2 and 4. As expected, it is clear in IR window spectral region and getting larger with AOD and the dust altitude.

The dust altitude was fixed at 707 hPa pressure level when BTs were simulated for various AODs. The radiative signature of Asian dust reaches around 6 K with AOD of 1.0, heavy dust condition in Korea, in figure 2. Its spectral variation is prominent in IR window regions about 800—1000 cm^{-1} and 1100—1200 cm^{-1}.

Sokolik found a negative slop of simulated BT in the about 820—920 cm^{-1} range in the case of mineral dust and suggested that it can be used to retrieve AOD of mineral dust (2002). However, the slop in this study is not obvious as that found by Sokolik. The difference of slops in BT could originate from different refractive indices. The radiative signature about 1100—1200 cm^{-1}, as well as the range of 800—1000 cm^{-1}, shows clear signature of Asian dust. Therefore this region has capability to detect and retrieve Asian dust.

In order to extract spectral regions which are sensitive to Asian dust, PCA scheme was applied to simulated BT series for various AODs. Since all parameters except AOD were under the control, the first component of PCA explain the radiative signature of Asian dust almost perfectly (the percentage of explained variance is 99.50%). Eigenvector of the first component shown in figure 3 has the same shape of figure 2 (b) but inverted. We can reconfirm that the IR window regions about 800—1000 cm^{-1} and 1100—1200 cm^{-1} are useful to detect and retrieve Asian dust.

Though the radiative signatures for various dust altitudes in figure 4 and 5 are also shown in IR window regions, likely those for various AODs in figure 2 and 3, the differences between those for various AODs and dust altitudes exist. For short wave range (3.5—5 μm), the radiative signatures are more dependent on the dust altitude than AOD. The inclination of the slop of the radiative signature in 800—900 cm^{-1} region is greater than for various AODs. These differences can be used to separate strong low level dust layers and week high level dust layers.

4. SUMMARY AND FURTHER STUDY

The Monochromatic radiative signature of Asian dust was simulated for various AODs and dust altitudes. The size distribution measured at Dunhuang and the refractive index in OPAC were used for Mie calculation. As a method of solution of radiative transfer, SOI model was adopted. Asian dust has clear spectral features especially on the IR window regions of 800—1000 cm^{-1} and 1100—1200 cm^{-1}. The results show a possibility of AOD and altitude retrieval of Asian dust using the IR interferometer instrument. This study will continue to develop an inverse method to retrieve AOD and altitude of Asian dust. As the invert method to be developed, Artificial Neural Network (ANN) is being considered. Training dataset for ANN has been constructed with the output of an operating Asian dust model of Korean Meteorological Administration, Asian Dust Aerosol Model (ADAM). Furthermore, the inverse method will be applied to real measurements of IR interferometer, IASI.

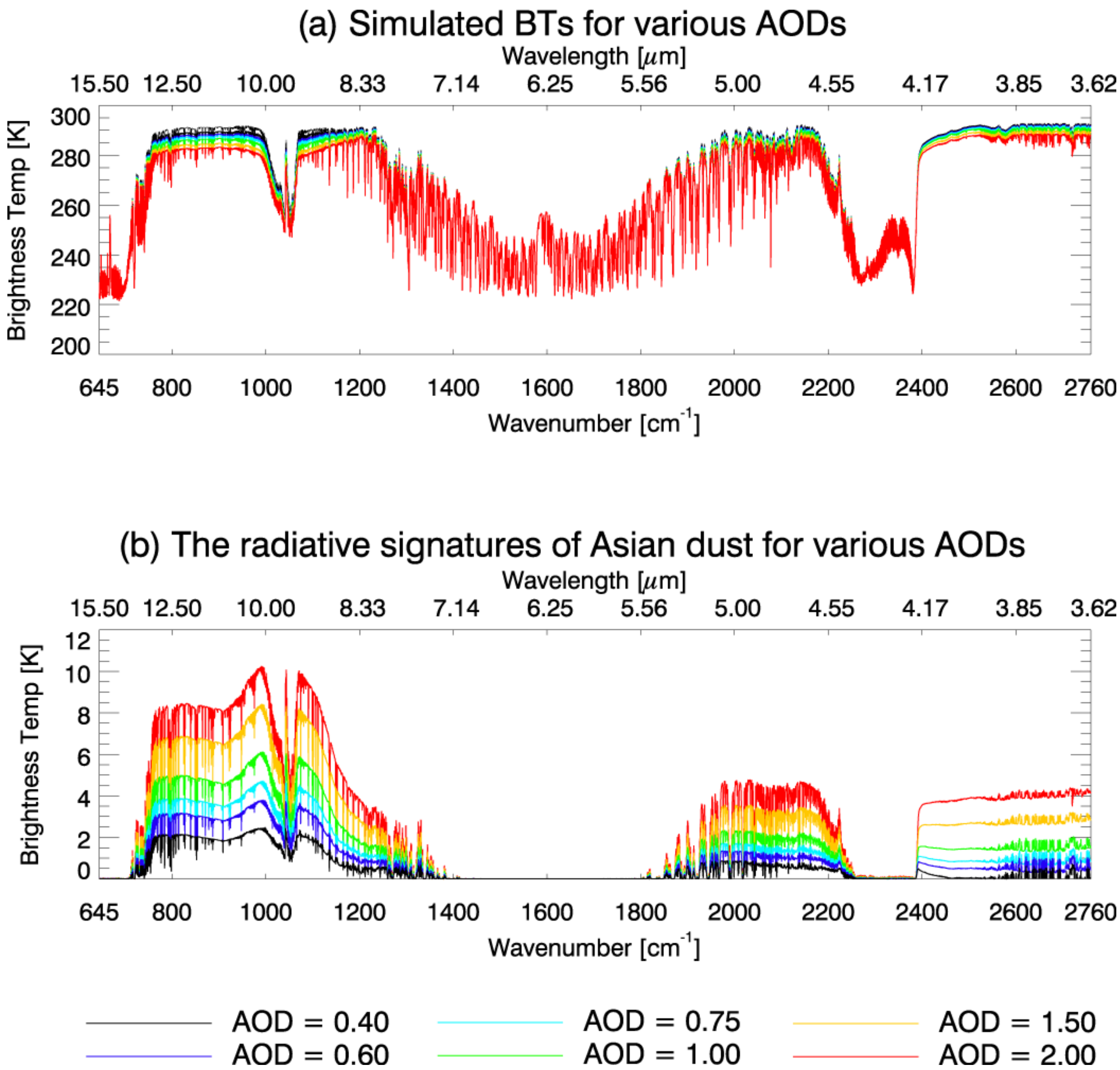

Figure 2. (a) Brightness temperatures simulated for clear sky (black line) and for various AODs. (b) The radiative signatures of Asian dust for various AODs. Numbers in the legend indicate AODs at 550 nm.

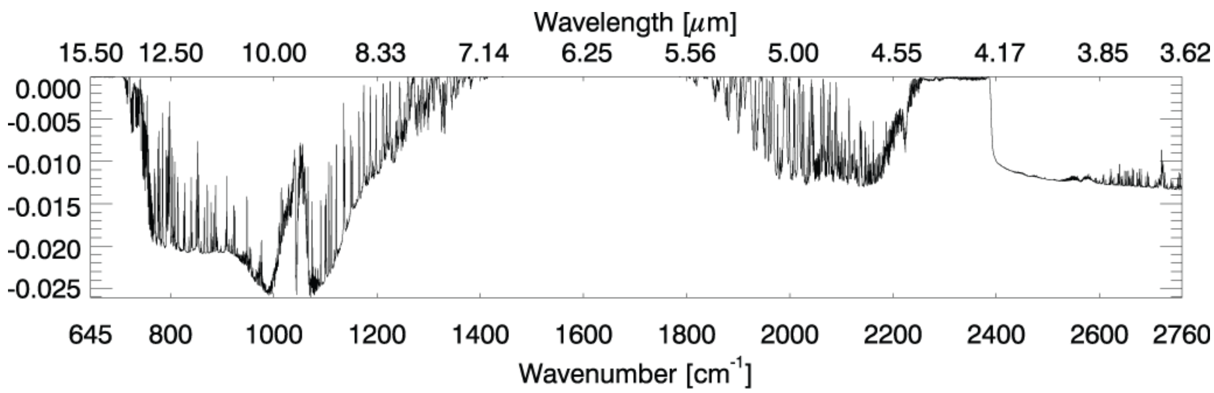

Figure 3. The first eigenvector of PCA components for various AODs. The explained variance percentage of the first component is 99.50%.

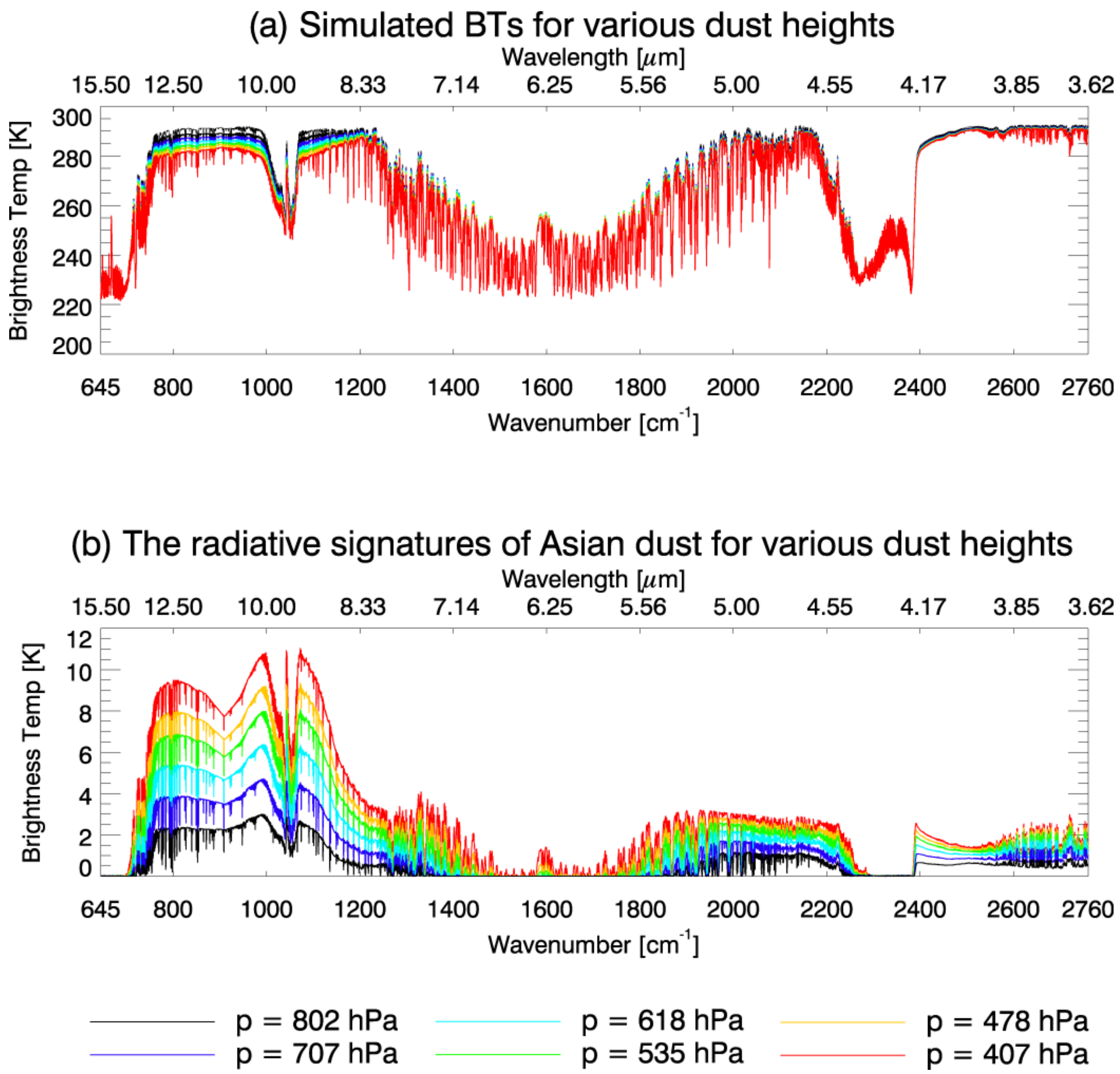

Figure 4. (a) Brightness temperatures simulated for clear sky (black line) and for various dust altitudes. (b) The radiative signatures of Asian dust for various altitudes. Numbers in the legend indicate the dust altitudes in unit of pressure, hPa.

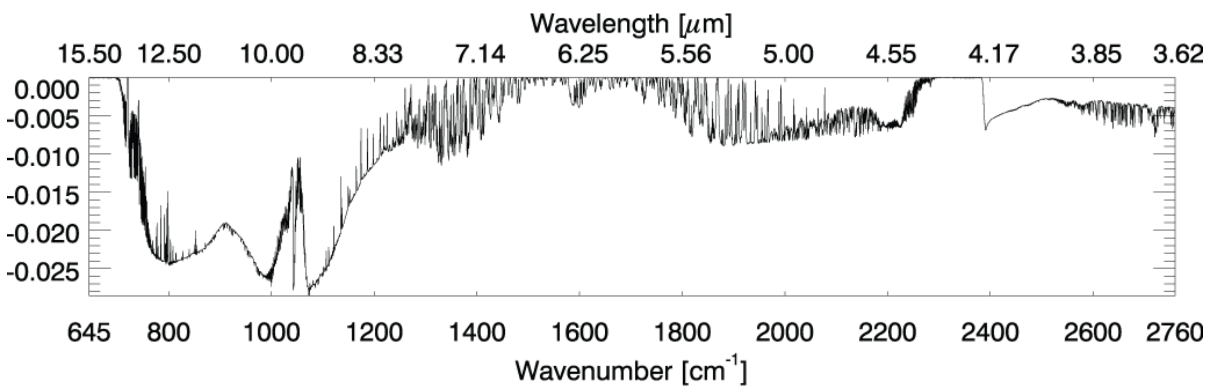

Figure 5. The first eigenvector of PCA components for various dust altitudes. The explained variance percentage of the first component is 98.85%.

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