Light scattering and absorption properties of dust particles retrieved from satellite measurements

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Abstract

We use the radiative transfer model and chemistry transport model to improve our retrievals of dust optical properties from satellite measurements. The optical depth and absorbing optical depth of mineral dust can be obtained from our improved retrieval algorithm. The solar radiative forcing of dust aerosols has also been calculated using refined optical model and radiative transfer model.

1 Introduction

Mineral dust particles are the most widespread natural and anthropogenic aerosols and play an important role in climate forcing by altering the earth's energy budget through scattering and absorption of radiation (Tegen et al., 1996; Sokolik and Toon, 1996), and changing the cloud formation (Kaufman et al., 2005). In spite of decadal efforts, the detailed information on physical, chemical and optical properties of mineral dust is still limited. Satellite remote sensors have provided rich information on aerosol optical properties in recent years (King et al., 1999; Mishchenko et al., 1999; Kaufman et al., 2002, Kahn et al., 2005). However, the uncertainties stem from simplified assumptions of dust composition, dust profile, dust mixing state and morphology used in retrieval algorithms. In this study, we use the additional information from global chemistry transport model (GEOS-Chem) to improve the results of satellite retrievals of dust aerosol optical depth (AOD) and absorbing aerosol optical depth (AAOD).

2 Methodology

The backscattered radiance measured by satellite sensors can be converted to aerosol optical properties such as AOD and aerosol effective radius. In order to estimate the dust AOD, we use the AOD data from the Moderate Resolution Imaging Spectrometer (MODIS) measurements (Chu et al, 2002, Remer et al., 2002). As the data over bright surface such as Saharan desert are rejected, we use the Multiangle Imaging Spectro-Radiometer (MISR) (Kahn et al., 2005) AOD data over these regions. The calculation of dust AOD δ_{dust} is as follows:

$$\delta_{dust}(\lambda) = \delta_a(\lambda) \cdot f_{dust} \tag{1}$$

Where δ_a is AOD at wavelength λ and f_{dust} is the fraction of dust aerosols. We use the aerosol fraction values generated from GEOS-Chem model (Bey et al., 2001, Park et al., 2005). The model is driven by assimilated meteorological data from the Goddard Earth Observing System (GEOS-3) at the NASA Global Modeling and Assimilation Office (GMAO). The mineral dust simulation is based on the Dust Entrainment and Deposition (DEAD) scheme Zender et al. (2003) as implemented by Fairlie et al. [2006]. The size distribution of dust aerosols is assumed to be lognormals with four size bins (Martin et al., 2003).

For dust aerosol absorption, we first retrieve the column effective aerosol single scattering albedo (ω_0) that reproduces the Total Ozone Mapping Spectrometer (TOMS) aerosol index (Torres et al., 2005), when constrained by MODIS and MISR aerosol optical depth and by relative vertical profiles from GEOS-Chem model (Hu et al., 2007). We use a Mie scattering algorithm (Mie, 1908) for small spherical dust particles and the T-Matrix algorithm (Mishchenko et al., 1995) for large non-spherical dust particles to calculate the optical quantities. The total backscattered radiance is calculated by the vector discrete ordinate radiative transfer model VLIDORT (with polarization) (Spurr, 2007; Natraj etal., 2006). A look-up table of backscattered radiances was developed for a variety of atmospheric and surface conditions as function of all sun-satellite viewing geometries. The most likely solution is selected by a chi-squared minimization method for ambiguous solutions (Hu et al., 2002). As we assume the external mixing state of aerosol components such as sulfate, soot, mineral dust, sea salt and organics, the dust ω_0 can be calculated from the column effective ω_0 with the aerosol fractions inputted from GEOS-Chem simulations. Then we can calculate the dust absorbing aerosol optical depth (AAOD) from the dust AOD and ω_0. Finally, the solar radiative forcing of dust particles at the top of atmosphere can be calculated using radiative transfer model VLIDORT.

3 Results and discussions

The vertical profiles of dust particles are determined from the GEOS-Chem simulations. We performed dust simulation for year 2003. Figure 1 presents the vertical profiles of dust particles for different size bin at Dahkla, Western Sahara. We find the dust particles can be lifted to high level under the suitable meteorological condition. Interestingly, the peak altitudes of dust profiles for particle radius between 0.1 and 3 μm are almost same.

Figure 2 shows the dust AOD at 360 nm retrieved from MODIS and MISR during spring of 2003. The high values of AOD are seen over Sahara, Gobi and Australia deserts with strong dust emission sources. The enhancement of AOD over the part of Atlantic Ocean, East Asia, Pacific Ocean and North America is clear evidence that the dust particles are long range transported far away from source regions. The dust particles originated from seasonal dust storms are harmful to human health and create poor visibility in surrounding regions.

Figure 3 presents the dust AAOD derived from dust AOD and ω_0. High values of AAOD are found over areas driven by dust storms. As the AAOD is less sensitive to cloud contamination and aerosol humidification (Kaufman et al., 2006), it is very suitable to detect aerosol type such as dust particles. The high values of dust AAOD have been found over the Atlantic Ocean in downwind of Saharan region. Strong negative solar radiative forcing occurred over the most part of deserts and near areas (Figure 4).

The physical and chemical processes of dust formation, evolution and transport are very complicated. It is highly challenge for model simulation and satellite retrieval. Uncertainties exist in size distribution, refractive indices, morphology and mixing state of dust particles. Indeed, there is no consensus on the radiative forcing of anthropogenic dust particles in current stage. Subsequent measurements from ground-based, airborne and space-based instruments can provide more information on the optical, microphysical, chemical properties, and the temporal and spatial variation of dust particles. The combination of modeling and observation to improve our understanding of dust properties is highly recommended.

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References

[1] Bey I., D. J. Jacob, J. A. Logan, R. M. Yantosca, Asian chemical outflow to the Pacific: origins, pathways and budgets, *J. Geophys. Res*., 106, 23,097-23,114, 2001.

[2] Chu, D.A., Y.J. Kaufman, C. Ichoku, L.A. Remer, D. Tanre, and B.N. Holben, Validation of MODIS aerosol optical depth retrieval over land, *Geophys. Res. Lett*., 29, 10.1029/2001GL013205, 2002.

[3] Fairlie, T. D., D. J. Jacob and R. J. Park, The impact of transpacific transport of mineral dust in the United States, *Atmos. Environ.*, in press, 2007.

[4] Hu, R.-M., R.V., Martin, and T. D. Fairlie, Global retrieval of columnar aerosol single scattering albedo from space-based observations, *J. Geophys. Res.*, 112, D02204, doi:10.1029/2005JD006832, 2007.

[5] Hu, R.-M., K.S. Carslaw, C. Hostetler, L.R. Poole, B. Luo, T. Peter, S. Fueglistaler, T.J. McGee, and J.F. Burris, Microphysical properties of wave polar stratospheric clouds retrieved from lidar measurements during SOLVE/THESEO 2000, *J. Geophys. Res.*, 107, 8294, doi:10.1029/2001JD001125, 2002.

[6] Kahn, R., et al., Multiangle Imaging Spectroradiometer (MISR) global aerosol optical depth validation based on 2 years of coincident Aerosol Robotic Network (AERONET) observations. *J. Geophys. Res*., 110, D10S04, doi:10.1029/2004JD004706, 2005.

[7] Kaufman, Y.J., D.Tanre, and Boucher, A satellite view of aerosols in the climate system, *Nature,* 419, 215-223, 2002.

[8] Kaufman, Y.J., I. Koren, L. A. Remer, D. Rosenfeld, and Y. Rudich, The effect of smoke, dust and pollution aerosol on shallow cloud development over the Atlantic Ocean, *Proc. Natl. Acad. Sci. U.S.A.*, 102, 11207-11212, 2005.

[8] Kaufman, Y.J., I. Koren, Smoke and pollution aerosol effect on cloud cover, *Science*, 313, 655-658, 2006.

[9] King, M.D., Y.J. Kaufman, D. Tanre and T. Nakajima, Remote sensing of tropospheric aerosols from space: Past, present and future, *Bull. Am. Meteo. Soc*., 2229-2259, 1999.

[10] Martin, R.V., D.J. Jacob, R.M. Yantosca, M. Chin, and P. Ginoux, Global and regional decreases in tropospheric oxide emissions constrined by space-based observations of NO2 columns, *J. Geophys. Res*., 108, 4097, doi:10.1029/2002JD002622, 2003.

[11] Mie, G., Beitrage zur Optik truber Medien, speziell Kolloidaler Metallosungen. *Ann. Physik, 25*, 377-445, 1908.

[12] Mishchenko, M. I., and A. A. Lacis, B. E. Charlson, and L. D. Tavis, Nonsphericity of dust-like tropospheric aerosols: Implications for aerosl remote sensing and climate modeling, *Geophys. Res. Lett*., 22, 1077-1080, 1995.

[13] Natraj, V., R. Spurr, H. Boesch, Y. Jiang, and Y. Yung, Evaluation of errors in neglecting polarization in the forward modeling of O2 A band measurements from space, with relevance to CO2 column retrieval from polarization sensitive instruments, *JQSRT*, in press, 2006.

[13] Park, R.J., D.J. Jacob, M. Chin, and R.V. Martin, Sources of carbonaceous aerosols over the United States and implications for natural visibility conditions, *J. Geophys. Res*., 108, 4355, doi:10.1029/2002JD003190, 2003.

[14] Remer, L.A., et al., Validation of MODIS aerosol retrieval over ocean, *Geophys. Res. Lett*., 29, doi:10.1029/2001GL013204, 2002

[15] Sokolik, I. N., and O. B. Toon, Direct radiative forcing by anthropogenic airborne mineral aerosols, *Nature*, 381, 681-683, 1996.

[16] Spurr, R. J. D., VLIDORT: A linearized pseudo-spherical vector discrete ordinate radiative transfer model for forward model and retrieval studies in multilayer, multiple scattering media, *JQSRT*, in print, 2007.

[17] Tegen, I., A. A. Lacis, and I. Fung, The influence on climate forcing of mineral aerosols from disturbed soils, *Nature*, 380, 419-422, 1996.

[18] Torres, O., P.K. Bhartia, J.R. Herman, Z. Ahmad, and J. Gleason, Derivation of aerosol properties from satellite measurements of backscattered ultraviolet radiation - theoretical basis, *J. Geophys. Res., 103*, 17099-17110, 1998.

[19] Zender C. S., H. Bian, D. Newman, Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology, *J. Geophys. Res*., 108 (D14)}, 4416, doi:10.1029/2002JD002775, 2003.

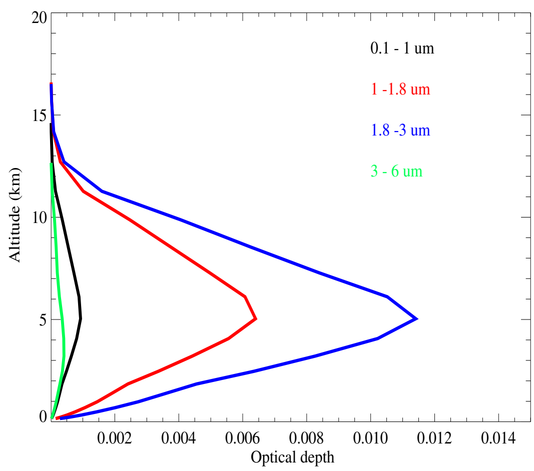

Figure1. The vertical profiles of dust particles simulated by GEOS-Chem at Dahkla.

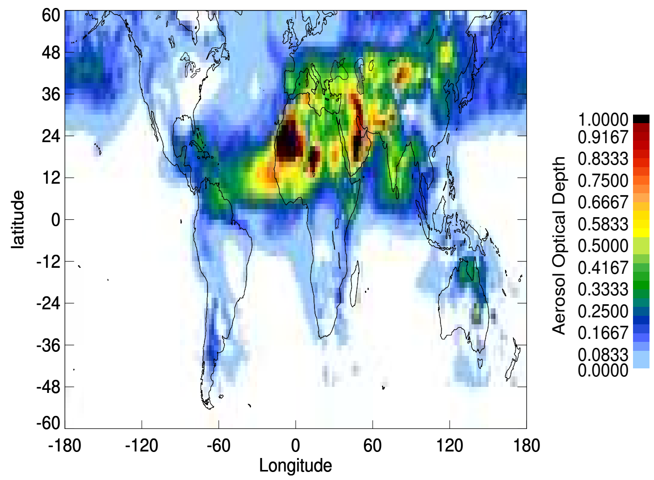

Figure 2. The dust aerosol optical depth retrieved from satellite measurements during spring of 2003.

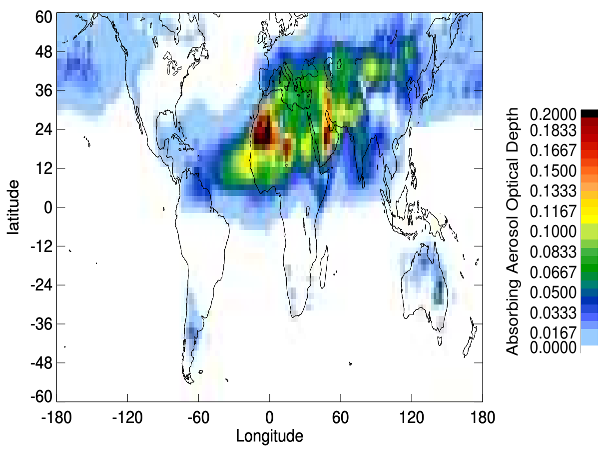

Figure 3. The dust AAOD retrieved from satellite measurements during spring of 2003.

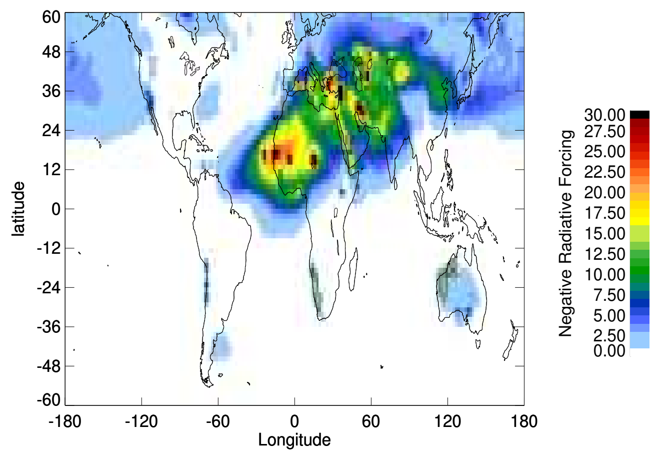

Figure 4. The solar radiative forcing (W/m^2) of dust aerosols at TOA calculated from VLIDORT during spring of 2003.