Optical Properties of Mineral Dust over the Global Deserts

Sumit Kumar Mishra and S. N. Tripathi*
Department of Civil Engineering, Indian Institute of Technology Kanpur, India
Corresponding author Email: snt@iitk.ac.in
http://home.iitk.ac.in/~snt

1. Introduction

The deserts are known to be a source of sharp edged, non-spherical mineral dust. The sharp edged non-spherical particles show significantly different scattering signature compared to their equivalent spheres. In general the present satellite retrieval algorithms assume the dust particles to be spherical. Thus there exists an eminent need for the improvement in dust model used in retrieval algorithm to account for their sharp edges together with their index of refraction based on the latest chemical composition at the sensing wavelengths. The Saharan, Middle-East and East-Asian deserts are such major deserts. The calculated refractive indices of regional dust lead to the region specific dust optics. In the present study, the region specific optical properties have been modeled for Central Sahara (CS), Western Sahara (WS), Middle East (ME) and East-Asia (EA) using most recent mineral composition of dust particles. We consider basic components of the desert dust as clay, hematite, calcite, quartz and gypsum. Further clay is assumed to be a mixture of illite, kaolinite and montmorillonite. The dust optical properties over Middle-East have been modeled for the first time in the present study. As the mineral dust interact from short to long wavelength radiation so the calculations were done at wavelengths ranging from visible to infrared (0.55-10.5 μm) for all the deserts except Middle East where the computations were constrained (0.55-1.02 μm) due to lack of information on optical constants of one of the mineral components at longer wavelengths. Based on modeling study by *Miller et al.* [2006] and Scanning Electron Microscope (SEM) images in Fig 2, particle effective radius from 0.1-5.0 μm is considered. Some standard basic non-spherical model dust shapes have been chosen for modeling optical properties for all the deserts which encompass most of the shapes shown in SEM images. Representative dust particle shapes considered are sphere, cylinder, spheroids, rectangle, hexagonal column and Chebyshev particles. The optical properties have been modeled using Discrete Dipole Approximation (DDA) method upto particle size 1 μm while T-matrix was used for particle size range 2-5 μm. The optical properties such as Single Scattering Albedo (SSA), phase functions and asymmetry parameter have been calculated.

2. Study Region

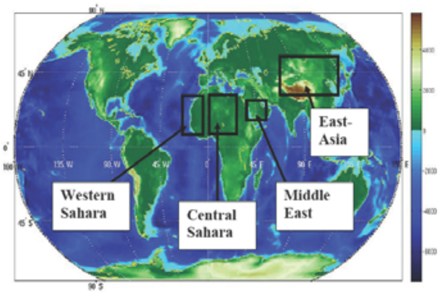


Fig. 1 Schematic of the study region (The column in the right is showing the altitude in meter).

3. Dust Morphology and Mineralogy

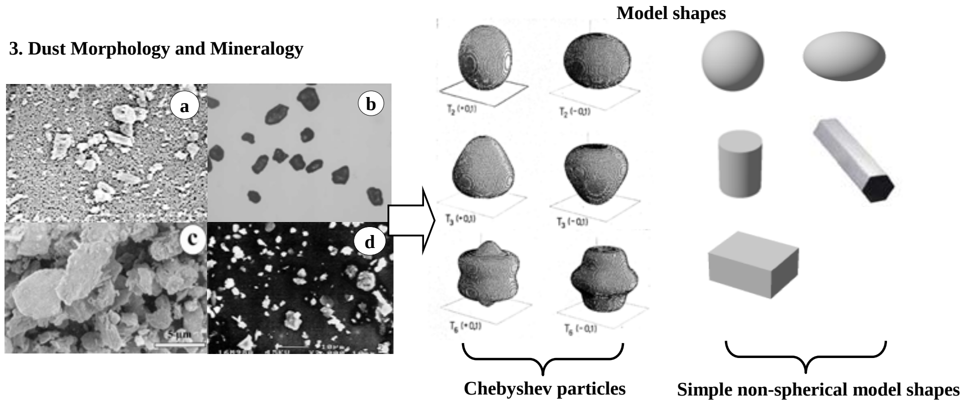


Fig. 2 SEM images of dust particles collected at (a) Sahara [Volten et al., 2001], (b) Central Sahara (Libya) [Munoz et al., 2007], (c) East-Asia [Whittaker et al., 2003] and (d) Middle–East (Israel) [Falkovich et al., 2001]. The model shapes for computations are also shown.

4. Optical Constants (n and k) of Composite Dust

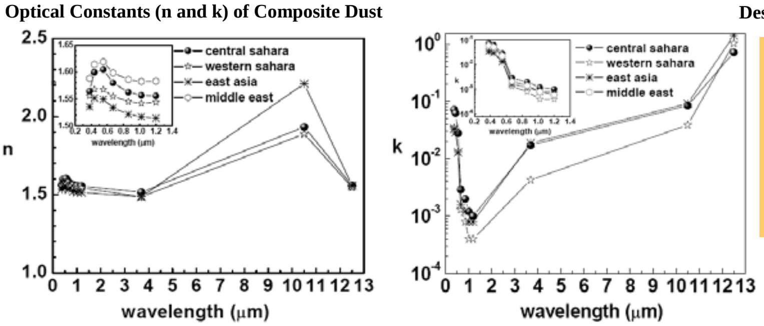


Fig. 3 Spectral variation of optical constants of mineral desert dust over various deserts

Desert Dust Composition

- West Sahara (Mali) [Khiri et al., 2004; Sokolik and Toon, 1999]
- Central Sahara (Chad) [Falkovich, 2001; Sokolik and Toon, 1999]
- Middle East (Arab) [Modaihsh, 1997]
- East Asia (China) [Goudie and Middleton, 162pp, 2006]

❑ Effective refractive index of clay (A) and non-clay (B) components of mineral dust are calculated using simple volume/mass fraction weighted mixing rule independently and the effective refractive index of the composite mineral dust with A and B as constituents is also calculated by the same rule.

5. Model Description

Optical properties of the mineral desert dust with particle radius <1 μm have been computed using DDA [Draine and Flatau, 2004]. DDA method computes light scattering for randomly oriented, spherical and non-spherical particles such as spheres, ellipsoids, rectangular solids, cylinders and hexagonal prisms etc. The DDA code has been tested and verified with the results earlier published by *Kalashnikova and Sokolik* [2004] for exactly similar conditions.

Optical properties of the mineral desert dust with particle radius 2-5 μm have been computed using T-matrix code [*Mishchenko and Travis*; 1998]. T-matrix method computes light scattering for polydisperse, randomly oriented, rotationally symmetric particles such as sphere, spheroid, cylinder and Chebyshev particles etc. The volume equivalent radius of the non-spherical particle (reff), refractive index , wavelength (μ m), particle shape and the aspect ratio are the input to the above codes. The outputs of the codes are extinction and scattering cross-sections, asymmetry parameter (g), SSA and scattering matrix elements.

6. Results and Discussion

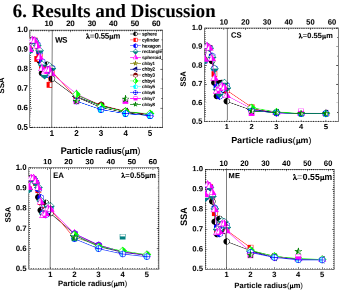


Fig. 4 SSA variation of desert dust with particle size at λ =0.55μm. The top x-axis in each plot represents size parameter, α .

- Dust from Central Sahara was found to be most absorbing at visible wavelength (0.55 μm).
- Dust from West Sahara and East Asia shows nearly same absorptive nature.
- Dust from Middle East is less absorbing compared to that of Central Sahara while more absorbing compared to West Saharan and East Asian dust.

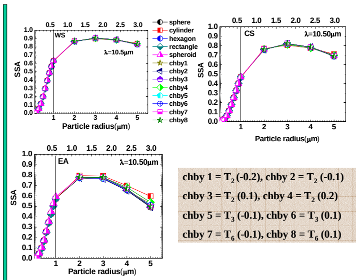


Fig. 5 SSA variation of desert dust with particle size at λ =10.5μm. The top x-axis in each plot represents size parameter, α .

- Dust with particle size < 1 μm from Central Sahara was found to be most absorbing at infrared wavelength while dust from East Asia with size > 1 μm shows a marked reduction in SSA with increasing size.
- The SSA of the dust with particle size < 1 μm shows nearly same pattern for all the deserts considered.
- The non-spherical particles follow the pattern of their volume equivalent spheres except for East Asia with increasing size (> 3 μm).

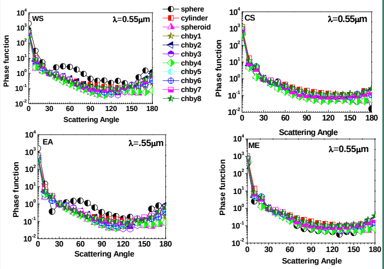
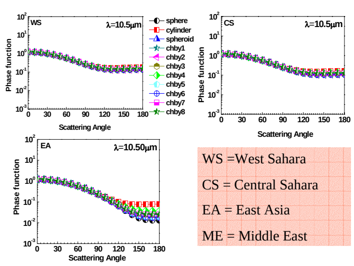


Fig. 6 Normalized phase function with respect to the value at scattering angle 30^0 of the desert mineral dust of radius 2 μm at λ = 0.55μm.

- The phase function is overestimated by considering dust to be of spherical shape for the scattering angle range (30 < theta < 120) for the West Saharan and East Asian dust.
- The phase function of the Central Saharan dust is flattened with increasing scattering angle > 90^0. Thus, the redistributed energy is independent beyond above scattering angle for all shapes.
- The dust with spherical shape particles underestimate the phase function for scattering angle range (60 < theta < 150) for Middle East which is source of more absorbing dust compared to West Sahara and East Asia at 0.55μm wavelength .



WS =West Sahara
CS = Central Sahara
EA = East Asia
ME = Middle East

Fig. 7 Normalized phase function with respect to the value at scattering angle 30^0 of the desert mineral dust of radius 2 μm at λ = 10.5μm.

- The effect of particle non-sphericity on phase function is insignificant for the scattering angle range 0-120 for the considered deserts.
- For scattering angle >120, the cylindrical shape particles showed deviation to their volume equivalent spheres.
- For above scattering angle range, spherical particles underestimate the phase function for East Asian dust.

7. Conclusions

- The change in SSA is sharp for particle radius < 1 μm while the same does not hold good for particles > 1 μm.
- The variation for the phase-function for a given desert, for a given size and interacting wavelength, solely depend on the optical constants or in other words on the mineralogical information of the desert.
- The modeled regional dust optical properties will reduce the uncertainty in dust forcing calculations at the considered deserts.

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