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Dust aerosol height estimation: A synergetic approach using passive remote sensing and modelling

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HIGHLIGHTS

- Proxy index inferring on dust layer altitude has been deduced.
- GOCART dust AOT and OMI AI values are used for the study.
- Study made over Arabian Sea on temporal variation of the dust layer height.
- Linear regression between AI and dust AOT revealed information on dust aerosol height.

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ABSTRACT

In this paper, a simple methodology for deducing a proxy index inferring on the dust aerosol layer height (in the atmosphere) has been presented by exploiting the dependence of the relationship between Aerosol Index (AI) and aerosol optical thickness (AOT) on the aerosol altitude. For the purpose, OMI-AI and GOCART model simulated dust AOT values over northern Arabian Sea are used. Northern Arabian Sea has been chosen as the study grid due its frequent vulnerability to the Arabian dust storms. Temporal variations in the dust AOT and AI values over the study region are discussed. Linear regression to the scatter plots between the dust AOT and AI values revealed the qualitative information on the dust layer altitudes. Results indicated that dust aerosols over the study region attain their highest altitude during July, August months. CALIOP aerosol sub-type measurements are examined in order to support the results obtained. Expansion of the present technique on inferring the spatio-temporal variability in the aerosol altitude over dust storms prone regions can be highly advantageous in fine tuning the regional dust aerosol radiative forcing calculations.

1. Introduction

The role of aerosol particles in atmospheric processes is extremely important in climate research, rain formation, weather forecasting, bio-geochemical cycling as well as remote sensing of the reflectance and texture of ground and other surfaces. Among various types of aerosols, dust is considered to be one of the major sources of tropospheric aerosol loading, and constitutes an important key parameter in climate aerosol-forcing studies (Slingo et al., 2006). The optical and physical properties of the dust aerosols differ due to variability of sources, or/and distance from the source (Sokolik et al., 1998). Dusts in the atmosphere have terrestrial sources, major sources creating a more or less continuous region from the west coast of North Africa, through the Middle East into the direction of Central and South Asia. This is the so called “Global Dust Belt” (Prospero et al., 2002). Desert dust from the western part of Africa and the Arabian Peninsula (Saudi Arabia and Cape Verde) are strongly dominated by large particles and seem to have optical properties more representative of so-called pure desert dust (Dubovik et al., 2002). From the viewpoint of mineralogical composition, desert dust causes the strongest absorption in the ultraviolet through the visible wavelength due to the presence of haematite (Iron oxide) and silica (Derimian et al., 2008). As dust aerosols have significant absorbing characteristics, its altitude (with respect to the presence of cloud) can play an important role in aerosol induced warming. Clouds influence the direct radiative impact of dust, increasing or decreasing it several orders of magnitude depending on their altitude and optical depth (Quijano et al., 2000). Using one-dimensional columnar radiation model Liao and Seinfeld (1998) have demonstrated that, in the absence of clouds, shortwave forcing is not sensitive to the altitude of the dust

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layer; both TOA (top of the atmosphere) and surface shortwave forcing are about the same as those with the dust layer at 0–3 km. In the presence of a cloud layer, TOA warming is strongest when the dust layer lies above the cloud layer, since the dust absorbs both incoming solar radiation and that reflected by the cloud layer (Haywood and Shine, 1997).

Dust aerosols mainly originating from continental regions, are transported out over marine regions, often being carried considerable distances before being deposited to the surface waters. It is well known that significant transport of dust occurs from the arid areas in Saudi Arabia, Iraq, Iran, and Thar Desert to the Arabian Sea during pre-monsoon and summer monsoon seasons (Moorthy et al., 2005; Aloysius et al., 2009). The flux of dust to the Arabian Sea depends on deflation and vertical uplift at the source areas (related to surface characteristics and cover, soil moisture, wind strength and direction), the atmospheric transport pathways (wind strength and direction, cloud and rain processes), and deposition (wet and dry). Transported Arabian-dust signatures even been observed over the central peninsular India (Badarinath et al., 2010) and East coast of India (Niranjan et al., 2007). In present study, an attempt has been made on investigating the qualitative temporal variation of the dust layer height over the northern Arabian Sea by deriving a proxy index for the dust height in the atmosphere. The study grid has been chosen as 18–22°N and 62–67°E, located in the dust outflow region from the Saudi Arabia, Iran, and Thar Desert, over which numerous studies have reported the presence of strong transported dust plumes/storms (Middleton et al., 1986; Tindale and Pease, 1999; Badarinath et al., 2010). Data from the passive satellite sensors Moderate Resolution Imaging Spectroradiometer (MODIS) and Ozone Monitoring Instrument (OMI) along with the modelled dust AOT from the global aerosol model 'Georgia Institute of Technology–Goddard Global Ozone Chemistry Aerosol Radiation and Transport (GOCART)' have been analysed. The study period has been chosen between October 2004 and December 2007 based on the simultaneous data availability from OMI, MODIS and GOCART.

2. Sensor details and model description

Simultaneous datasets form MODIS (Aqua) and OMI (Aura) sensors and GOCART model have been utilized in the present study. MODIS Aqua data has been chosen due to the near matching in the equator crossing time of both the satellites Aqua and Aura. Level 3, collection 5 1° × 1° daily gridded MODIS Small Mode Fraction (SMF, a quantitative indicator of fine mode aerosols), cloud fraction; OMI UV Aerosol Index (AI) for the study period are acquired from the Giovanni online data system, developed and maintained by the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC). UV AI has been used in a variety of atmospheric applications, viz., (i) mapping the global distribution of UV-absorbing aerosols (Herman et al., 1997), (ii) correcting for aerosol induced errors in the retrieval of column ozone amounts (Torres and Bhartia, 1999), (iii) aerosol characterization from space during Smoke, Clouds, and Radiation-Brazil (SCAR-B; Gleason et al., 1998), (iv) identifying dust aerosol induced biases in retrieved sea surface temperature from brightness temperature measurements (Diaz et al., 2001), (v) estimating UV reduction at the earth's surface (Krotkov et al., 1998), (vi) estimating the radiative forcing effects of mineral aerosols used in conjunction with Earth Radiation Budget Experiment (ERBE) data (Hsu et al., 2000), (vii) in the environmental characterization of soil dust sources (Prospero et al., 2002), (viii) in the study of the inter-annual variability of soil dust aerosols in conjunction with Advanced Very High Resolution Radiometer (AVHRR) data (Cakmur et al., 2001) and (ix) aerosol classification schemes (Sreekanth, 2014).

MODIS sensors are uniquely designed (wide spectral range, high spatial resolution, and daily global coverage) to observe and monitor the changes in the Earth's atmosphere. MODIS with its 2330 km viewing swath provides daily global coverage. Since February 2000, MODIS has been continuously acquiring measurements at 36 spectral bands between 0.415 and 14.235 μm with spatial resolution of 250 m, 500 m and 1000 m. The retrieval of aerosol data by MODIS is performed with special algorithms (see e.g., Tanré et al., 1997; Kaufman et al., 1997; Levy et al., 2003, 2007; Remer et al., 2005), which are different over land and ocean because of differences in their surface characteristics. MODIS Collection 5 data set is an improvement over earlier collections, generated with upgraded algorithm (Remer et al., 2005, 2008). These improvements include incorporation of polarization information in the radiative transfer calculations as well as more realistic aerosol models for different parts of the globe. The accuracy of satellite estimates of AOD was first suggested based on theoretical analyses (Kaufman et al., 1997). The Ozone Monitoring Instrument (OMI) is a high resolution spectrograph that measures the upwelling radiance at the top of the atmosphere in the ultraviolet and visible (270–500 nm) regions of the solar spectrum (Levelt et al., 2006). It is one of four sensors on the Eos-Aura platform. It has a 2600 km wide swath and provides daily global coverage at a spatial resolution varying from 13 × 24 km at nadir to 28 × 150 km at the extremes of the swath (Torres et al., 2007). Although the instrument was designed primarily for retrieval of trace gases like O_3, NO_2, SO_2, etc., it contains valuable information on aerosols. OMI's advantage for aerosol characterization from space is the availability of measurements in the near-UV region for which retrieval technique of aerosol sensing works equally well over all land and water surfaces because of the low UV surface albedo of all ice-snow-free terrestrial surfaces. More details of MODIS and OMI sensors are available in Remer et al. (2005) and Levelt et al. (2006) respectively.

The GOCART model simulates major tropospheric aerosol types, including sulphate, dust, Organic Carbon (OC), Black Carbon (BC), and sea salt aerosols. The model has a horizontal resolution of 2° latitude by 2.5° longitude and 20–30 vertical sigma layers, and uses the assimilated meteorological fields generated from the Goddard Earth Observing System Data Assimilation System (GEOS DAS). The GEOS DAS fields are model-assimilated global analyses constrained by meteorological observations, with extensive prognostic and diagnostic fields archived for chemistry transport model applications (Schubert et al., 1993). Emissions from anthropogenic, biomass burning, biogenic, and volcanic sources and wind-blown dust and sea salt are included. Other aerosol processes are chemistry, convection, advection, boundary layer mixing, dry and wet deposition, gravitational settling, and hygroscopic growth. Details of GOCART model and evaluation of its results against observations and models are documented in previous publications (e.g., Chin et al., 2000, 2002, 2009; Ginoux et al., 2001). Dust source parameterization has been constructed in the GOCART model, where locations of the dust sources are determined at the topographic depression areas with bare soil surfaces, while the dust uplifting probability is defined according to the degree of depression. The model simulation of dust aerosol has been found to be consistent with surface, lidar, and satellite observations (Ginoux et al., 2001). Uncertainties in the GOCART simulations are associated with uncertainties in emissions of individual aerosol types and their precursors, parameterizations of a variety of sub-grid aerosol processes (e.g., wet removal, dry deposition, cloud convection, aqueous-phase oxidation), injection heights of biomass burning smoke and dust, and assumptions on size, absorption, mixture, and humidification of particles.

To support the results obtained in the present study, CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) aerosol sub-