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Long term characterization of aerosol optical properties: Implications for radiative forcing over the desert region of Jodhpur, India

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HIGHLIGHTS

- Long term continuous data on aerosol optical properties at a desert location in India.
- Dominance of coarse absorbing dust particles in AOT, especially during pre-monsoon.
- Pronounced diurnal variation in AOT and α during all seasons.
- ARF indicated cooling at SUF and TOA and warming of ATM.
- ARF at ATM twice more in pre monsoon than rest of the year.

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ABSTRACT

AOT data for eight years period (2004–2012) using the MICROTOPS II Sun photometer has been used to study the wavelength dependent optical characteristics of aerosols over Jodhpur, situated in the desert region in NW India. The daily mean AOT at 500 nm for the present study period was 0.66 ± 0.14 with an average Angstrom exponent as 0.71 ± 0.20. Linear regression analysis of monthly AOT and Angstrom Exponent indicated an increasing trend of both. Seasonal variations of daily AOT and α as well as spectral dependence of seasonal mean AOT are presented. Diurnal variation of AOT and α in different season is studied. Impact of dust storm events on the aerosol characteristics over Jodhpur during the study period is studied. AOT values derived from MICROTOPS II were cross checked with Sun Sky Radiometer (Model POM-01, Prede Inc.) data for the period from May 2011 to April 2012 and were found to be in good agreement. Short wave aerosol radiative forcing (ARF) was computed for one year period of May 2011 to April 2012. Spectral variation of AOT, SSA and ASP showed more AOT and ASP during pre monsoon period when SSA was comparatively low; indicating towards more prevalence of coarse size absorbing dust in this period. The ARF at SUF and TOA was negative during all the seasons indicating dominance of scattering type aerosols mainly dust particles whereas that at ATM was positive in all the seasons indicating heating of the atmosphere, especially more during pre monsoon (+40.5 W/m^2) than during rest of the year (+19.5 W/m^2). A high degree of correlation between ARF at the SUF with AOT ($R^2 = 0.94$) indicated that ARF is a strong function of AOT. The radiative forcing efficiency inferred to scattering nature of aerosols at SUF (−4.2 W/m^2/AOD) and TOA (−63.2 W/m^2/AOD) indicating cooling at surface and top of the atmosphere whereas, there was warming of the atmosphere in between (+59 W/m^2/AOD). The atmospheric heating rates varied from 0.49 K/day in post monsoon to 1.13 K/day in pre monsoon. This study has enabled us to understand the long term nature and physical characteristics of atmospheric aerosols over Jodhpur.

1. Introduction

The effect of aerosols on climate is one of the largest uncertainties in current global climate models and lack of extensive and reliable measurements in most regions, makes it difficult to quantify the global impact of aerosols on Earth's climate (Hansen

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et al., 1997). Aerosols interact with solar and earth radiation directly and indirectly leading to the respective aerosol radiative forcing (ARF). The magnitude and sign of ARF is determined by nature, size distribution and chemical characteristics of aerosol species. Mineral dust aerosols significantly alter the magnitude and sign of the ARF by altering the aerosol single scattering albedo. Several studies and field experiments have documented the characteristics and impact of mineral dust aerosols (Duce, 1995; Miller and Tegen, 1998; Prospero et al., 2002; Tegen et al., 2004; Zhu et al., 2007). Such studies over Indian subcontinent are rather few and limited to short term observations only (Dey et al., 2004; Deepshikha et al., 2006; Moorthy et al., 2007; Pandithurai et al., 2008; Singh et al., 2010; Sharma et al., 2012; Harikishan et al., 2015) whereas studies with large data sets conducted for longer periods are almost non existent.

Dust storms are common in the northwestern part of the Indian subcontinent which is one of the primary sources of mineral dust aerosols in south Asia (Washington et al., 2003; Badarinath et al., 2007; Gautam et al., 2009). Dust aerosols from these source regions are driven by winds to Indo Gangetic Plains and further as a land atmosphere interaction (Tegen et al., 1996; Ginoux et al., 2001). During their traverse, dust aerosols encounter with anthropogenic aerosols of different size and nature over different regions and mix with them and as a result the aerosol optical characteristics, earth's atmosphere radiation energy balance and ambient air quality of the respective regions get modified (Nastos et al., 2011). Therefore the study of aerosol optical characteristics over desert area in the north/western India will give important information on the anthropogenic, natural as well as mixed aerosol characteristics.

The present investigation, for the first time, reports the temporal variation of aerosol optical thickness (AOT) along with other optical characteristics during different seasons over Jodhpur, located to the east of Thar Desert in western Indian region for the period during October 2004 to April 2012 using hand held MICROTOPS-II sun photometer. The station joined the SKYNET-WORK from 2011. The optical properties of aerosols such as AOT, single scattering albedo (SSA) and asymmetry parameter (ASP) obtained from Sun Sky Radiometer during May 2011 to April 2012 are used in SBDART model for the estimation of aerosol radiative forcing and atmospheric heating rates.

2. Details on location and methodology

Jodhpur (26°18′N, 73°01′E, 217m) is located in Rajasthan in the Great Indian Desert also known as Thar Desert in the north western India and experiences dry and hot weather and scanty rainfall. Summer temperature peak goes beyond 41 °C during daytime and the lowest temperature in winter season reaches 5 °C in the night. The rainy season for Jodhpur is during July and August when higher humidity levels exist with annual precipitation of about 30 cm and annual relative humidity about 46%. During the April–June period, frequent dust/sand storms from western and north-western desert regions cause large scale loading of dust aerosols over Jodhpur. This causes considerable reduction in visibility and in the radiation flux reaching the surface (Singh et al., 2005). In the summer monsoon season, western parts of Rajasthan are convergent region of pollution from peninsular India and marine influx from the Arabian Sea and with the onset of monsoon rains, heavy dust loading significantly diminishes due to aerosol washout from the atmosphere. The sources of aerosols over Jodhpur are therefore dust from deserts in the west and north of Jodhpur, sea salt from Arabian Sea as well as anthropogenic particles from local as well as distant sources. Thus this region provides an excellent setting for studying the optical and radiative characteristics of anthropogenic as well as natural aerosols over the region.

AOT data for the period of 87 months for the eight year period during October 2004–April 2012 at Jodhpur is used in the present study. Instantaneous cloud free observations inferred from hand held MICROTOPS II Sun photometer (Solar Light Co., USA) at around 03, 05, 06, 07, 09, 11 & 12 UTC are used to study the wavelength dependent optical characteristics of aerosols. The cloud free day implies that the sun was completely visible in the whole or intervals of the day and conducive for taking MICROTOPS II observations. MICROTOPS II sun photometer instrument measures the total columnar AOT from the direct sun radiation centered at 368, 500, 675, 778 and 1028 nm and subtracts the Rayleigh scattering component. Angstrom exponent (α) in the UV–vIS range is calculated from optical thickness values at wavelengths 368 and 675 nm (Angstrom, 1929). As the MICROTOPS-II instrument measured AOT values are susceptible to occasional spurious values due to erratic behavior of filter and various other components, extreme outliers are rejected through a simple statistical technique. Daily data points outside three times of standard deviation, on either side of long term mean for AOT at 500 nm and α were excluded barring dust storm event days data. The accuracy of measurements for precision and consistency of the MICROTOPS-II instruments are discussed in detail by Srivastava et al. (2006). The present dataset is unique not only, because the AOT measurements in the desert regions are very sparse (Holben et al., 2001), but also because of its relatively long-term continuous observations.

AOT and α values obtained from Sun Sky Radiometer (Model POM-01, Prede Inc.) for the period from May 2011 to April 2012 have been compared with values derived from MICROTOPS II for validation of the data. The sun/sky radiometer (Model: POM-01 of Prede, Japan), installed at Jodhpur is capable for measuring direct solar and diffuse sky radiance at seven spectral channels from visible to near-infrared spectral regions (340, 380, 400, 500, 675, 870 and 1020 nm), with a half band width of 3 nm for 340 nm wavelength and 10 nm for other wavelengths. The aerosol optical parameters such as AOT, SSA and ASP are derived using Skyrad.Pack (version 4.2) radiative transfer code (Nakajima et al., 1996). Sky radiometer measures diffuse radiation at various scattering angles from the Sun at different wavelengths in narrow band. The measured sky spectral radiances can be used to obtain different optical and size related properties of aerosols in the total atmospheric column. The operational details and errors associated with the instrument are already described elsewhere (Pandithurai et al., 2008; Ningombam et al., 2014).

3. Results and discussion

3.1. Monthly variation of AOT and Angstrom Exponent

The daily mean AOT at 500 nm for the present study period (Oct 2004 to Apr 2012) was 0.66 ± 0.14 with an average value of α as 0.71 ± 0.20 (Since AOT varies with season/month, only the years that contain all months data were considered). Excluding the dust storm events, the above figures were 0.62 ± 0.19 and 0.72 ± 0.25, respectively. Daily maximum AOT and minimum α for the study period were 3.17 and 0.21 whereas; the instantaneous maximum AOT and minimum α values were 7.51 and −0.15, respectively indicating significant contribution of coarse mode aerosols. Instantaneous AOT at 500 nm showed fluctuation from 7.51 to 0.37, whereas daily and monthly average values were between 3.17 to 0.33 and 1.11 to 0.27, respectively. Broad range of instantaneous α value (1.49 to −0.15) over Jodhpur suggests that accumulation mode aerosols either from local sources or from distant sources through transportation are combined with coarse mode dust particles from surrounding desert area. The monthly mean AOT averaged for the period of Oct 2004–Apr 2012 (Fig. 1) showed an