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Radiative Forcing Estimation of Aerosols at an Urban Site near the Thar Desert Using Ground-Based Remote Sensing Measurements

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ABSTRACT

The focus of present study is to quantify the radiation budget of aerosols over Jaipur (Northwestern, India) from 2011 to 2015. The Aerosol radiative forcing (ARF) has been determined for shortwave spectrum (0.3–3.0 µm) individually for the top of the atmosphere (TOA), bottom of the atmosphere (BOA) and within the atmosphere (ATM) over study region. Santa Barbara DISORT Atmospheric Radiative Transfer model (SBDART) is used to simulate the aerosols radiative effect.

The inter-annual monthly average of ARF at TOA during 2011–2015 is found between –11.40 to –5.60 W m^{-2}, while the ARF at BOA is found to be between –32.2 to –22.49 W m^{-2}. Likewise, the ARF within the atmosphere (ATM) comes between 14.04 to 22.47 W m^{-2} over Jaipur.

The SBDART model is run discretely for Dust period (DSP) and non-Dust Period (NDP) during the year 2012 to inspect the change in ARF during extreme events over the Jaipur site. During DSP, the net TOA and BOA forcing are found in the range –20.71 to –16.81 W m^{-2} and –45.15 to –39.6 W m^{-2}, respectively, and net ATM forcing varies in the range 22.7 to 24.4 W m^{-2}. For the NDP, the corresponding value varies in the range –10.1 to –6.6 W m^{-2} and –23.6 to –22.3 W m^{-2}. The net ATM forcing during NDP is between 12.2 to 17.05 W m^{-2}. The value of BOA increases more than ~67% during DSP than NDP. The more increase (–ve) in surface forcing represents the cooling of the surface during DSP. The results depict that dust over Jaipur in the vicinity of the Thar Desert is scattering in nature with high value (> 0.95) of SSA. The scattering is mostly high during summer and low in winter.

Keywords: Aerosols; Dust; Radiative forcing; AOT; SSA.

INTRODUCTION

Aerosols constitute prime uncertainty in the estimation of climate forcing (IPCC, 2007, 2013) due to scarce data representing aerosols and poor understanding of aerosol-cloud interactions. The radiative forcing depends on size distribution, chemical composition and abundance of aerosols. Thus the different aerosol types have different magnitude of the ARF (Verma *et al.*, 2006; Kaskaoustis *et al.*, 2007). Absorbing aerosols (mineral dust, black carbon) produce positive forcing (warming), while scattering aerosols (sea salt, sulfate) usually generate negative forcing (cooling) into the atmosphere.

The direct and indirect atmospheric radiative forcing by the dust has not been represented well in climate models (Tegen *et al.*, 1996). In India, dust is prevalent over most of north and western part of India and peaks during the pre-monsoon season (Ramachandran, 2015). The dust particles get transported to far off locations from their sources and over remote oceans with a combined action of convection and long-range transport of general circulation systems (Prospero *et al.*, 2002). It exhibits high variability in the imaginary part of their refractive index (Ginoux *et al.*, 2001; Zender *et al.*, 2003; Seinfeld *et al.*, 2004; Tegen *et al.*, 2004) that shows the absorbing potentiality.

There are three major dust source regions over India: Oman, southwest Asian basins, and the Thar Desert in Rajasthan (Chinnam *et al.*, 2006; Moorthy *et al.*, 2007; Prasad and Singh, 2007; Verma *et al.*, 2013) and the anthropogenic pollutants get mixed with the dust during transport. The aerosols studies over India show spatial and temporal variability of aerosols over the Indian subcontinents (Pandithurai *et al.*, 2008; Srivastava *et al.*, 2015, Bhaskar *et al.*, 2015). Previous studies of aerosol radiative forcing show strong variation over Delhi (Dey *et al.*, 2004; Singh *et al.*, 2005; Pandithurai *et al.*, 2008; Srivastava *et al.*, 2014, 2015), Lahore and Karachi (Alam *et al.*, 2012; Srivastava *et al.*, 2014), Kanpur (Kaskaoutis *et al.*, 2013), however mostly

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these studies focused on Indo-Gangetic Plains (IGP) region over India. Much more research is desired to improve the understanding of aerosols over other parts in India and their effects on climate.

A most recent study led by Jin *et al.* (2016) also suggest that the dust radiative values used in most current climate models are too low which led to underestimation of dust radiative impacts on the Indian Summer Monsoon system. The information about dust spatial, temporal distribution and radiative properties is essential to understand the climate impact of dust (Quijano *et al.*, 2000); however, the information so far is either restricted to one region or remains unavailable in most regions of India due to lack of measurements. Thus it is necessary to get the radiative forcing estimation over near dust source regions for climate studies.

To our knowledge, this is the first study on radiative forcing estimates over Jaipur, a region near to the Thar Desert. The earlier study of dust period over Northwestern India focuses on the aerosols optical thickness (AOT) behavior during severe dust episodes occurred in 2009 and 2010 (Verma *et al.*, 2013). In contrast, in the present paper, we provide the radiative forcing estimate of aerosols over Jaipur for years 2011–2015.

This paper first describes the experimental site and instruments used in the study. The aerosols radiative forcing and modeling tools are discussed in details in section 3. Then, the model values estimates are presented in section 4. To understand the variation of Atmospheric Radiative Forcing (ARF), we also explicitly explore the distinct episodes of the high-dust period and a low or no dust period (Section 4) over Jaipur during 2011–2015. Results are discussed in Section 4, and conclusions in section 5.

EXPERIMENTAL SITE AND INSTRUMENTS USED

The aerosols measuring instruments is located at the Birla Institute of Technology (BIT) Mesra Jaipur campus (26.9°N, 75.8°E, 450 m asl) over Jaipur, Northwestern India. The Jaipur city is situated in a natural basin surrounded by hills in north and the east. The study area experiences hot summers with low humidity during summer. The study area is about 500 km from the Thar Desert, and approximately 250 km from Delhi. The study location is close to the Thar Desert, it is often affected by dust intrusions (Prakash *et al.*, 2013; Verma *et al.*, 2013; Payra *et al.*, 2015).

MICROTOP-II

The MICROTOPS II (Solar Light Co., USA) is a multi-band hand held sunphotometer capable of measuring the AOT and direct solar irradiance at five different channels from low to higher wavelength (Shaw, 1983). The five spectral channels centered at 440, 500, 675, 870 and 936 nm and provide the subsequent AOT with a full field view of 2.5°. Typical errors in AOT measurements from MICROTOP-II are ~0.03 (Morys *et al.*, 2001). In the present study, AOT is observed in the wavelength range of 0.440–0.936 µm using MICROTOP-II sunphotometers during April 2011 to March 2015. Data were collected daily at 2 hours interval from 03:30–11:30 hr UTC (09:00–17:00 hr, IST). The AOT data collected only on clear sky conditions are included in present analysis.

METHODOLOGY

The shortwave (0.3–4.0 µm) ARF at the surface, top and within the atmosphere is estimated by combined use of aerosol optical model i.e., Optical Properties of Aerosols and Clouds (OPAC, Hess *et al.*, 1998) along with ground-based sun photometer data collected as part of the Department of Science and Technology (DST), Government of India integrated research program. The OPAC model provides the optical properties of aerosols like AOT, asymmetry parameter, single scattering albedo, extinction, scattering, absorption coefficients and the phase function following iterative procedures, which are then used to determine radiative forcing by SBDART model (Ricchiazzi *et al.*, 1998).

Optical Properties of Aerosols and Clouds (OPAC) Model

OPAC model, originally developed by Hess *et al.* (1998) provides the insight of optical and microphysical properties of 10 aerosol components. Surface albedo (SA), AOT, asymmetry parameter (*g*) and single scattering albedo (SSA) are most important aerosol parameters for estimation of ARF. The optical parameters are available for up to 61 wavelengths for aerosols in OPAC. The water clouds are available for wavelengths between 0.25 and 40 µm and up to 67 wavelengths for ice cloud between 0.28 and 40 µm to eight values of the RH (0%, 50%, 70%, 80%, 90%, 95%, 98%, and 99%). The aerosols are considered as mixture of different components. The five aerosol components i.e., soot, insoluble, water soluble, mineral accumulation and mineral coarse are used in combination to represent the total aerosol loading for best fit the mean AOT spectrum on each individual day. The components are tuned iteratively till the OPAC derived spectral AOTs become consistent with the MICROTOP retrieved AOTs (RMSE < 0.03) and the MICROTOP and OPAC-simulated values of SSA, g and α become similar (Das and Jayaraman, 2012; Sinha *et al.*, 2013). These spectral aerosol optical properties generated using the OPAC model (Hess *et al.*, 1998) are used as input in radiative transfer model for our study location.

In the present analysis, OPAC model is used to extract SSA from sunphotometer observations with assumptions as given in Singh *et al.*, 2010 following iterative method till a consistent value is reached.

The surface albedo values are obtained using the Clouds and the Earth's Radiant Energy System (CERES) derived broadband surface albedo product. The CERES-derived monthly mean surface albedo over Jaipur is in the range of 0.18–0.23 during the study period. So a fixed mean value is treated as input to the radiative transfer model.

Radiative Transfer Model: SBDART

Atmospheric radiative transfer model named Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) developed by Ricchiazzi *et al.* (1998) at the University of California, Santa Barbara. SBDART computes plane-parallel radiative transfer in clear and cloudy conditions within the earth's atmosphere and at the surface. SBDART estimates radiation flux in the shortwave (0.25–4.0 µm) as well as longwave (4.0–40.0 µm) range. In SBDART, the radiative transfer equations are integrated with Discreet Ordinate Radiative Transfer (DISORT) code, numerically. The DISORT provides a numerically stable algorithm solution for the equations of plane-parallel radiative transfer in vertically inhomogeneous atmosphere. The intensity of both thermally emitted and scattered radiation is computed at different heights and directions. Presently, SBDART allows up to 65 atmospheric layers and 40 radiation streams (40 zenith angles and 40 azimuthal modes).

In SBDART, five basic surface types— lake water (Kondratyev, 1969), vegetation (Reeves *et al.*, 1975), sand (Staetter and Schroeder, 1978), snow (Wiscombe and Warren, 1980) and ocean water (Tanre *et al.*, 1990) are given. The main inputs essential for DISORT module in SBDART include spectral values of columnar AOT, spectral values of solar radiation incident on the atmosphere, SSA and asymmetry parameter. These values are generated using the OPAC model (Hess *et al.*, 1998).

Eight radiation streams are used for the radiative forcing calculations in shortwave region (0.3–3.0 µm). The TOA and the surface downward and upward fluxes are calculated at the 1-hr interval for a 24-hr period with and without aerosol conditions separately. The diurnally averaged radiative forcing at the TOA and surface is obtained as difference between the net flux (down - up) with and without aerosols. Further, the resultant net atmospheric forcing (ΔF) is calculated using the difference between TOA and surface forcing. The aerosol produces a cooling effect if the sign of radiative forcing comes negative and warming effect for positive forcing.

RESULTS AND DISCUSSION

Measured vs. Modelled Parameter

Fig. 1 shows the comparison of AOT obtained from the OPAC model with MICROTOP derived AOT_{500} to validate model output. The OPAC model reproduces the observations with high significance (R^2 = 0.997). The OPAC model is then used to extract SSA from sunphotometer measurements with certain additional assumptions (e.g., Singh *et al.*, 2010) by the iterative method. The AOT and SSA values are designed in a recursive manner till the modelled and observed values match within ± 5% deviation.

Ångström exponent (α) values obtained from OPAC shows more existence of coarse size aerosols which is validated with AE derived from MICROTOP. There is some difference in observed α and OPAC derived α which may be attributed to possible incompleteness of chemical composition that is used as input in OPAC. Average relative humidity (RH) of 50% is used as the prevailing RH over Jaipur which ranged between 14 and 88% during the observational period.

Estimation of Atmospheric Radiative Forcing (ARF)

The spectral SSA, AOT and asymmetry parameter (ASP) as well as ozone, surface albedo and meteorological parameters are needed for estimation of ARF. The present study uses the integrated column ozone along with the average integrated water vapour values in the model for better representation of the atmosphere. The surface albedo along with column ozone values is obtained from the CERES-derived level 3 data during the study period and used as inputs for the radiative transfer model. The tropical atmospheric profile and the measured meteorological parameters are used in the present study for prevailing weather conditions.

Variation in Single Scattering Albedo

The monthly average of derived MICROTOP AOT at 440 nm and 870 nm varies in the range 0.43–0.83 and 0.24–0.62 respectively during the study period. The value of SSA gives the scattering fraction of a particle. The SSA varies in the range 0.75 to 1. The monthly mean of SSA at 450 and 850 nm varies between 0.87–0.93 and 0.90–0.96 respectively. For urban/industrial aerosols, the values of SSA drop off as a function of increasing wavelength and it increases for desert dust (Dubovik *et al.*, 1998) also. The

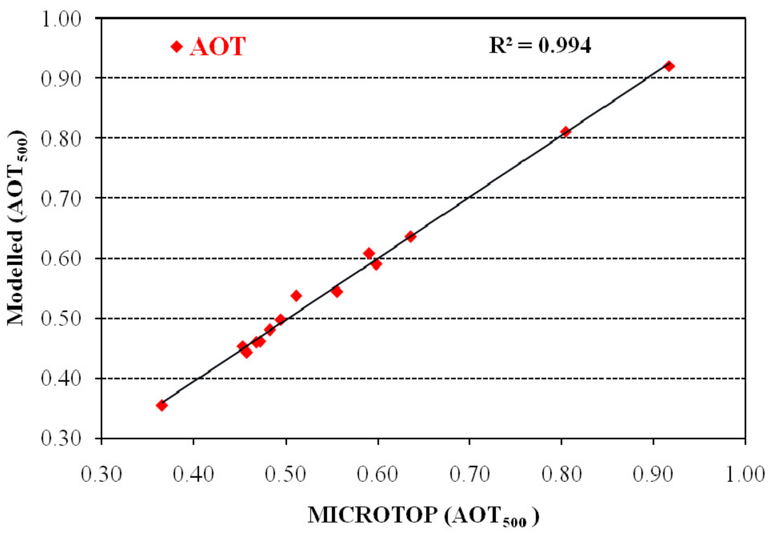

Fig. 1. Modelled AOT from OPAC vs. MICROTOP AOT_{500}.

value of SSA varies from ~0.2 for absorbing type aerosols, such as soot to ~1 for scattering type aerosols such as sea salt and sulfate.

The SSA is found higher over Jaipur at all wavelengths than Kanpur, Gual Pahari, Gandhi College during pre-monsoon months (Gautam *et al.*, 2011). The monthly mean of asymmetry parameter at 450 and 850 nm varies in the range 0.715–0.786 and 0.619–0.716 respectively during 2011–2015.

Annual Variations in ARF over Jaipur

To understand the changes in ARF at TOA, BOA and ATM during a complete year over Jaipur, the monthly averaged values of ARF at TOA, BOA and ATM, are estimated for the one year periods (January–December 2013). This year has more consistent data set than other years.

The monthly mean of ARF at TOA, BOA, and ATM during January to December 2013 has shown in Fig. 2. The BOA and TOA forcing is mostly negative (Fig. 2) during all months indicating cooling effect. The ATM forcing is positive during all months indicative of heating of the atmosphere. The ATM forcing becomes more pronounced during pre-monsoon (April–June). The ARF at TOA, BOA, and ATM varies in the range –11.25 to –3.22, –37.65 to –19.90 and 10.34 to 31.86 W m^{-2}, respectively over Jaipur during January to December 2013. The radiative forcing at BOA and ATM found higher during pre-monsoon months of the year. The Fig. 2 shows that the value of ATM forcing found higher during pre-monsoon months due to the presence of dust particles in the atmosphere.

Fig. 3(a) shows the average monthly ARF variations at the TOA, BOA and within the atmosphere during the entire study period (2011–2015). The ARF at TOA is found between –11.40 to –5.60 W m^{-2}, while at the surface the ARF is found –32.2 to –22.49 W m^{-2}. Likewise, the ARF within the atmosphere (ATM) is between 14.04 to 22.47 W m^{-2} over Jaipur during January to December.

As also seen from Fig. 3(a), the TOA, and BOA forcing is negative, and ATM forcing is positive during all months. Fig. 3(b) depicts that the TOA and BOA forcing has a negative sign in all seasons. The negative sign depicts the dominance of scattering aerosols. However, the negative forcing at TOA during winter is found to be somewhat less. This denotes the likely presence of absorbing particles due to combustion from local environs. The ATM forcing on the other hand is found positive in the seasons indicating the heating of the atmosphere, especially maximum during pre-monsoon. The ARF for TOA, BOA and ATM over Jaipur is –8.20 ± 4.58, –29.5 ± 7.41, 21.35 ± 7.14 W m^{-2} respectively, during pre-monsoon; –9.08 ± 4.90, –26.28 ± 6.64, 17.20 ± 7.87 W m^{-2} during monsoon; –9.76 ± 4.77, –27.14 ± 8.66, 17.38 ± 6.02 W m^2 during post-monsoon and –7.51 ± 4.76, –24.70 ± 9.43, 17.18 ± 7.05 W m^{-2} during winter. Comparing our present estimates on aerosol radiative forcing with earlier results obtained over the Indo-Gangetic Plain (Ramachandran and Kedia, 2012; Kaskautis *et al.*, 2013), we find comparable but lower radiative forcing values over the present study region. The ARF values over Jaipur for the present and previous studies over India are given in Table 1.

Radiative Forcing during Dust and Non Dust Period

To understand the variation of Atmospheric Radiative Forcing (ARF), we also explicitly explore the different episodes of the high DSP and a low NDP over Jaipur during 2011–2015. Five dust storms having high AOT along with low A.E values are first identified. These are termed as dust periods (DSP) and aerosol behaviour is compared with non dust periods (NDP). These two dust periods occurred on 21–23 May 2011 (DSP1) and 06–08 June 2012 (DSP2) with a high value of AOT and corresponding low value of A.E. These are then compared with aerosol behaviour on NDPs i.e., 15–18 May 2011 (NDP1) and 03–05 June 2012 (NDP2).

The variation of AOT at the five wavelengths of MICROTOPS-II during DSP and NDP has been shown in Figs. 4(a) and 4(b). Relatively small spectral dependence in AOT is observed during DSP as compared to NDP. The value of AOT found higher at all wavelengths during DSP in comparison with NDP. The average value of AOT at

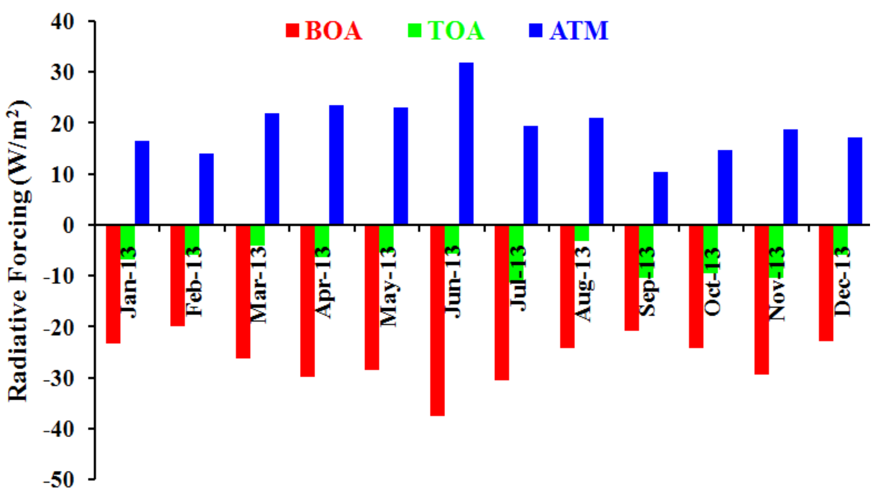

Fig. 2. Monthly variation of aerosol radiative forcing at TOA, BOA and ATM during January to December 2013.

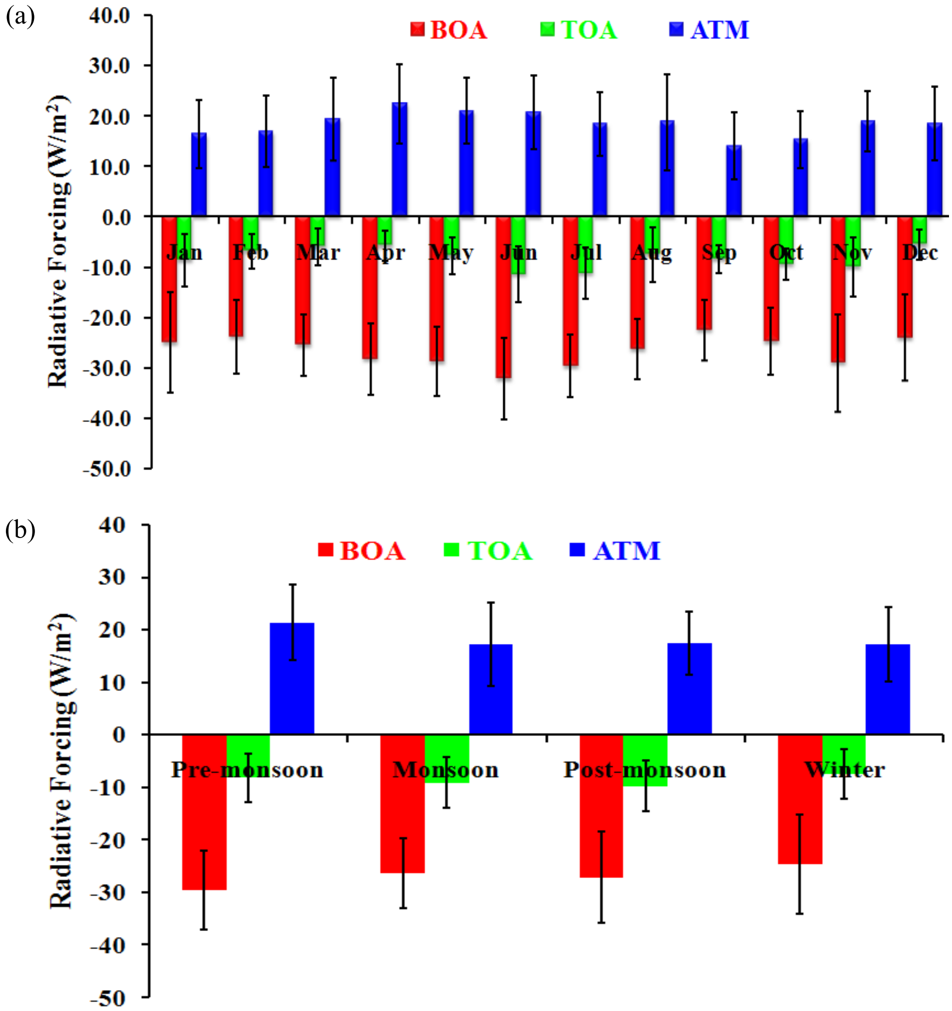

Fig. 3. The shortwave aerosol radiative forcing at BOA, TOA and ATM a) inter–annual b) inter-seasonal variations during 2011–2015.

Table 1. Comparison of aerosol radiative forcing estimated over Jaipur with those reported from other locations in India.

Period	Surface (W m^{-2})	TOA (W m^{-2})	Atmosphere (W m^{-2})	Reference
Pre-monsoon	–29.5	–8.2	21.35	Present study
Monsoon	–26.28	–9.08	17.2	Present study
Post-monsoon	–27.14	–9.76	17.38	Present study
Winter	–7.51	–24.7	17.18	Present study
Pre-monsoon	–57	–12.8	44.2	Kaskautis *et al.*, 2013
Monsoon	–42.5	–17.1	25.4	Kaskautis *et al.*, 2013
Post-monsoon	–47	–17.6	29.5	Kaskautis *et al.*, 2013
Winter	–49.1	–14.5	34.6	Kaskautis *et al.*, 2013
Winter (2006–08)	–33.6	–9.9	23.7	Ramachandran and Kedia, 2012
Pre-monsoon (2006–08)	–40.7	–4.6	36.2	Ramachandran and Kedia, 2012
Monsoon (2006–08)	–30.9	–6.3	24.6	Ramachandran and Kedia, 2012
Post-monsoon (2006–08)	–36.5	–12	24.5	Ramachandran and Kedia, 2012

500 nm and AE varies in the range between 0.40 to 0.45 and 0.22 to 0.56 during NDP that change to 0.85 to 1.01 and 0.09 to 0.14 during major DSP over Jaipur. The lower AE values (< 0.1) suggest predominance of coarse or dust particles over the study area. The aerosol characteristics during DSP thus imply a heavy dust loading in atmosphere in comparison to few days earlier aerosol data from the event.

Comparative Analysis

To understand the impact of dust episodes over Jaipur, we also analysed the aerosol properties over three other AERONET sites i.e., Kanpur (KP), Lahore (LR) and Karachi

(KR). The average value of AOT during NDP is found higher (Figs. 4(a) and 4(b)) at all wavelengths over Lahore, while during DSP the AOT found higher at all wavelength over Jaipur than other three AERONET sites.

The value of AOT at Karachi dominates during DSP2 and NDP2 than other AERONET sites. There is a significant increase in AOT values at Jaipur and Karachi while no impact of dust storm found at Lahore during DSP2 (Fig. 4(b)).

The spectral variation of SSA at four different locations (including Jaipur) during NDP and DSP has been shown in Fig. 5. Fig. 5(a) shows that the spectral value of SSA during NDP1 and DSP1 and 5(b) during NDP2 and DSP2 at Jaipur with other three AERONET locations. The figure reveals that the value of SSA found higher (> 0.95) at Jaipur than other three AERONET sites. The high value of SSA at Jaipur shows the existence of scattering aerosols due to loading of coarse particles (Moorthy *et al.*, 2007). The results depict that dust over Jaipur is of more scattering in nature as compared with other IGP stations in India. The scattering is high during summer and mostly low in winter.

The volume size distribution during NDP and DSP has shown in Fig. 6. The difference between dusty and non-dusty days is clearly evident from aerosols size distribution in Fig. 6. The particles in size range > 2 µm clearly shows dominance in Fig. 6 during the DSP. The coarse mode volume concentration is thus much higher over the study

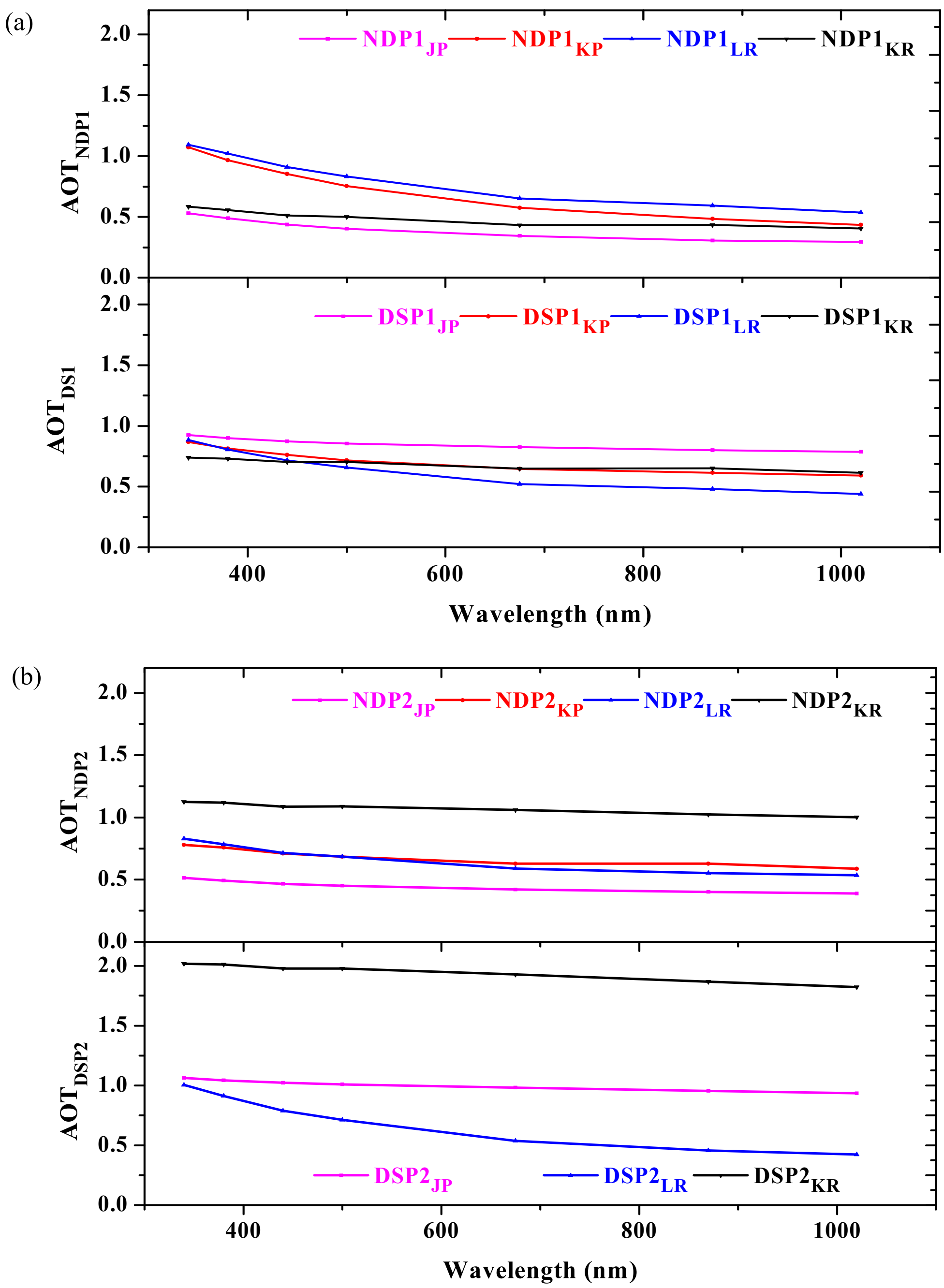

Fig. 4. Spectral variation of AOT during (a) NDP1 and DSP1 and (b) NDP2 and DSP2.

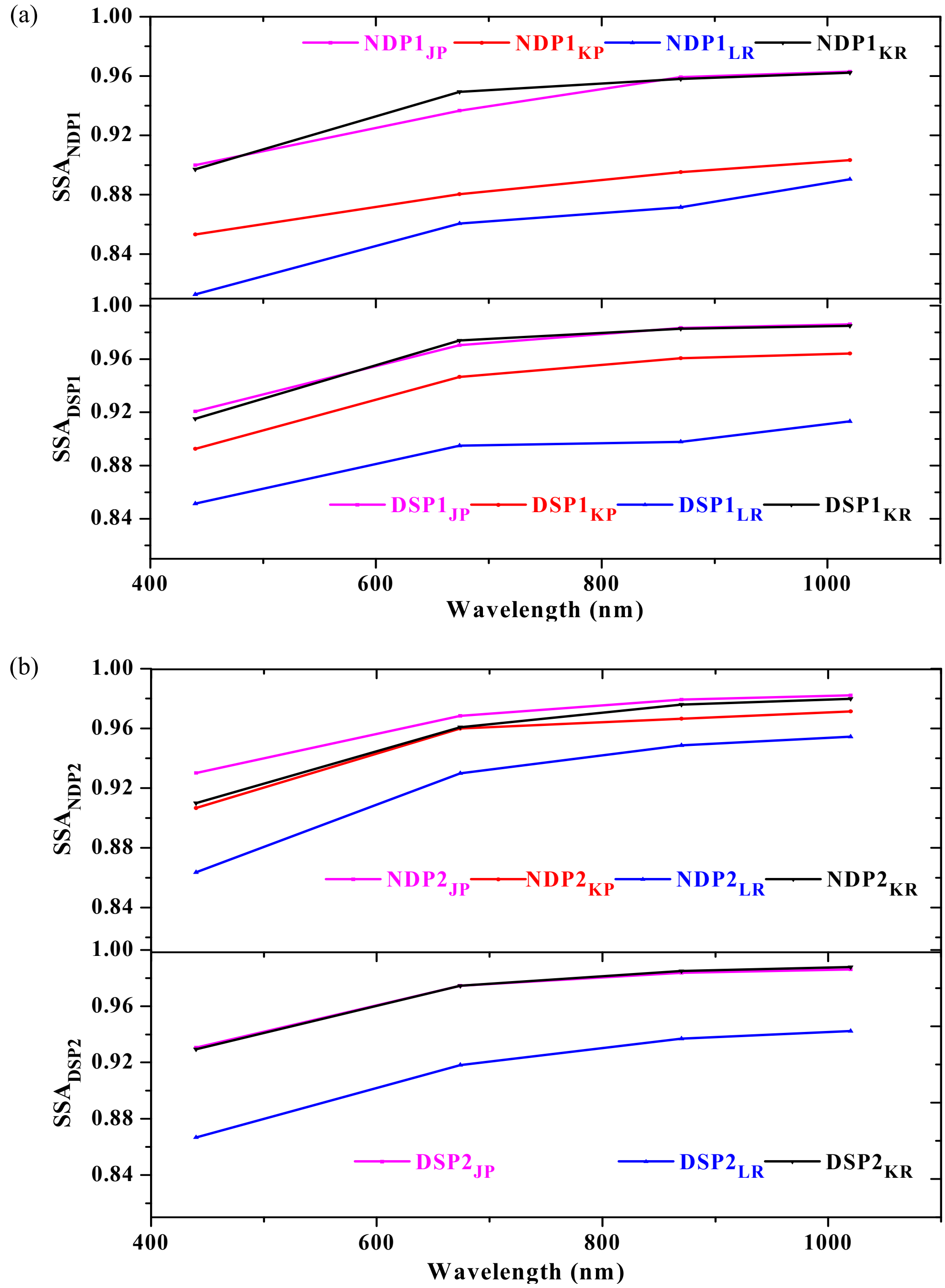

Fig. 5. Spectral variation of SSA during a) NDP1 and DSP1 b) NDP2 and DSP2.

area. The fine mode volume concentration on the other hand is very low in the range of 0.05 µm^3 µm^{-2} centered at the 0.1 µm radius. The aerosols concentration over Jaipur is thus mainly governed by the coarse-mode particles during DSP.

Estimation and Comparison of ARF for All Sites

The ARF during NDP and DSP has been calculated using SBDART as shown in Fig. 7. Figs. 7(a)–7(b) shows the estimated radiative forcing at TOA, BOA and in the atmosphere. Over Jaipur and Karachi, significant cooling is shown at the surface, which is more distinct during DSPs. A considerable heating in the atmosphere found at Jaipur during DSP1 and DSP2 (Table 2).

Table 2 shows the aerosol radiative forcing values at TOA, BOA and within the atmosphere for all four locations during NDP and DSP. The value of BOA increases more than ~67% during DSP than NDP. The negative increase in surface forcing represents the cooling at the surface during dust period. During dust storm, the sudden increase of aerosol load causes change in surface meteorological parameters by reduction of radiative flux at the surface level. Singh and Naseema (2013) also observed a reduction of ~25% in the relative humidity and temperature during dust day. A

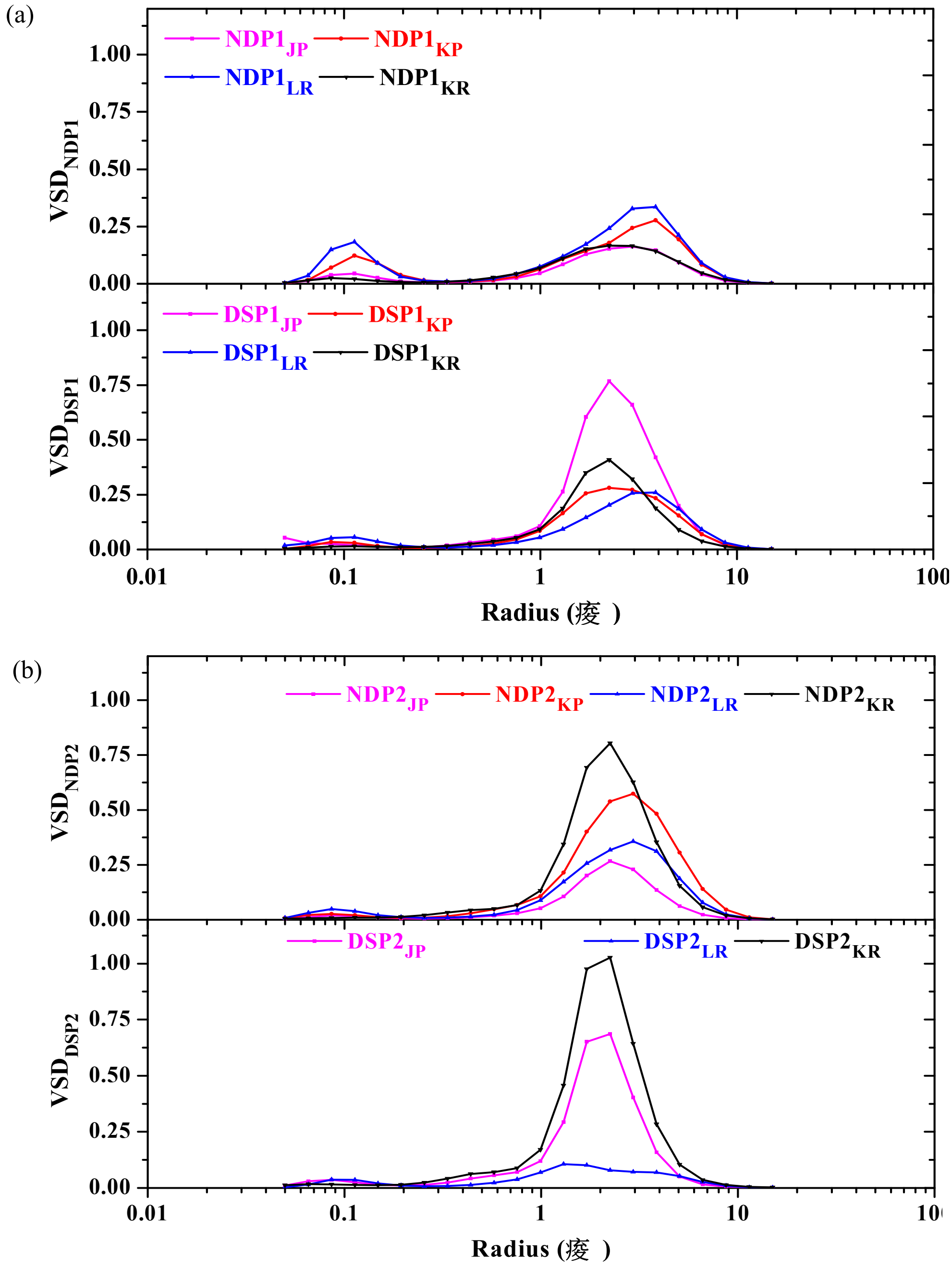

Fig. 6. Size distribution during a) NDP1 and DSP1 b) NDP2 and DSP2.

significant drop in surface temperature of ~6°C below its average value is also observed by Saeed *et al.* (2013) with reduction in surface forcing value.

CONCLUSIONS

We evaluated the aerosol radiative forcing (ARF) over Jaipur (Northwestern India) from 2011 to 2015 at temporal scales from seasonal to yearly average in the present study. In addition, the ARF during strong desert dust events is analyzed. The ARF has been estimated for short wave spectrum (0.3–3.0 µm) for top of the atmosphere, bottom of the atmosphere and atmosphere radiative forcing using the SBDART. The inter-annual monthly average of ARF at TOA, BOA was found between –11.40 to –5.60 W m^{-2} and –32.2 to –22.49 W m^{-2} respectively. Likewise the ARF within the atmosphere was between 14.04 to 22.47 W m^{-2} over Jaipur during 2011–15 The shortwave ARF at TOA, BOA and ATM over Jaipur is –8.20 ± 4.58, –29.5 ± 7.41, 21.35 ± 7.14 W m^{-2} respectively, during pre-monsoon; –9.08 ± 4.90, –26.28 ± 6.64, 17.20 ± 7.87 W m^{-2} during monsoon; –9.76 ± 4.77, –27.14 ± 8.66, 17.38 ± 6.02 W m^{-2} during post-monsoon and –7.51 ± 4.76, –24.70 ± 9.43, 17.18 ± 7.05 W m^{-2} during winter. The value of SSA found highest at Jaipur than other reported locations in India. The high value of SSA at Jaipur represents the occurrence of scattering

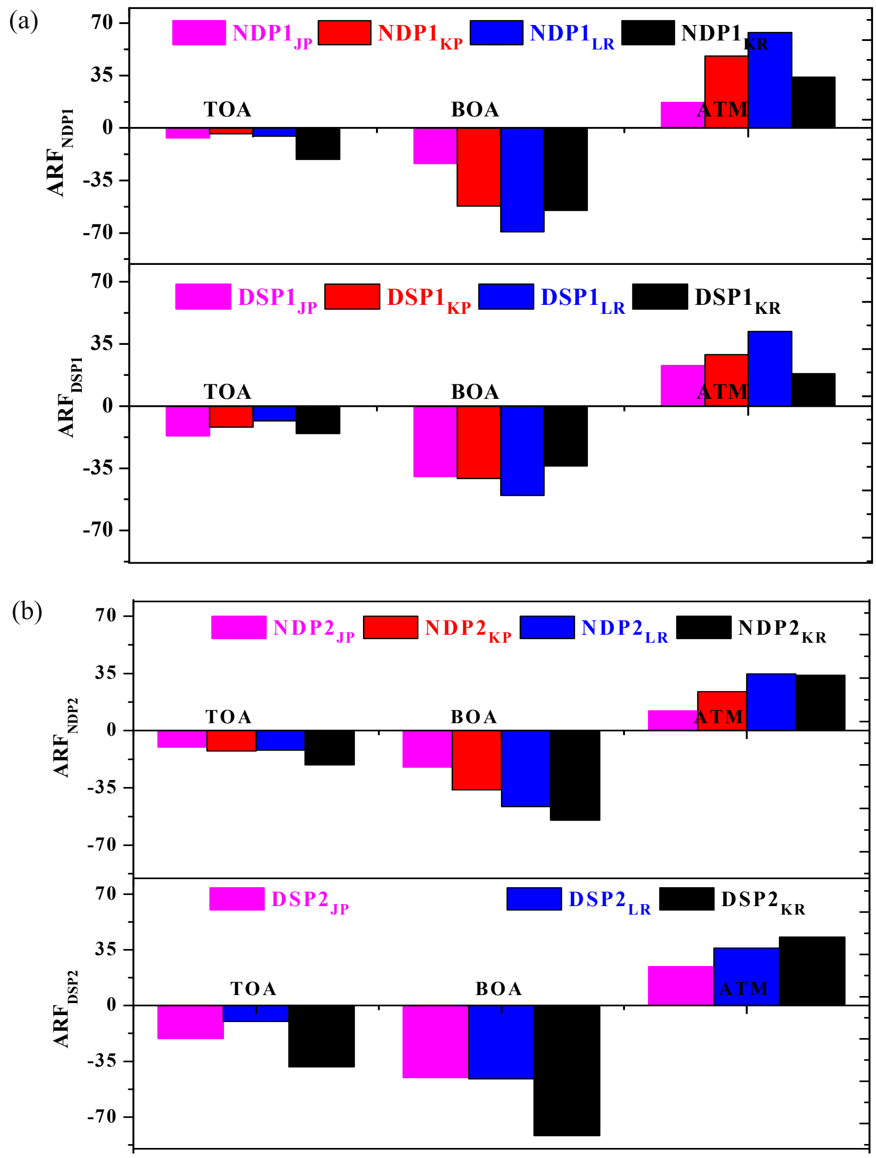

Fig. 7. Aerosol radiative forcing at TOA, BOA and ATM during (a) NDP1 and DSP1 (b) NDP2 and DSP2.

Table 2. Aerosol Radiative Forcing during dust and non dust period.

Event	Location	TOA	BOA	ATM
NDP1	Jaipur	**–6.64**	**–23.68**	**17.05**
	Kanpur	–3.95	–51.99	48.05
	Lahore	–5.43	–69.19	63.76
	Karachi	–20.89	–54.87	33.98
DSP1	Jaipur	**–16.81**	**–39.60**	**22.79**
	Kanpur	–11.79	–40.68	28.89
	Lahore	–8.38	–50.33	41.95
	Karachi	–15.48	–33.71	18.23
NDP2	Jaipur	**–10.09**	**–22.30**	**12.21**
	Kanpur	–12.49	–36.31	23.81
	Lahore	–11.89	–46.55	34.66
	Karachi	–20.89	–54.87	33.98
DSP1	Jaipur	**–20.71**	**–45.15**	**24.44**
	Kanpur	N/A	N/A	N/A
	Lahore	–9.87	–46.05	36.18
	Karachi	–38.50	–81.70	43.20

aerosols. The value of BOA increases more than ~67% during DSP than NDP. The negative increase in surface forcing represents the cooling of the surface during DSP. The ground-based measurements together with the radiative model in this study have provided means to understand the observed variability and impact on the aerosol radiative properties effectively over Jaipur.

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