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WINTERTIME AEROSOL OPTICAL PROPERTIES AND RADIATIVE FORCING OVER ROHTAK

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ABSTRACT

The present work was focused on analyzing the aerosol optical properties over Rohtak during winter season from December 2015 to February 2016 using sky-radiometer data. The results reveal that AOD shows strong spectral dependence. Higher value of AOD was observed during January at all wavelengths. The monthly mean AOD at 500 nm were found to be 0.44±0.23, 0.80±0.37 and 0.57±0.34 for December, January and February, respectively with seasonal average of 0.63±0.36. Higher values of Alpha predominantly ranged from 0.8-1.4 indicates the relative dominance of fine mode particles to the aerosol loading over the station. Volume size distribution exhibits bimodal distribution with dominant fine mode around 0.17 µm and coarse mode around 11 µm. The derived aerosol optical properties are used in SBDART model for aerosol radiative forcing estimation. Monthly mean atmospheric radiative forcing values are +7, +14 and +12 Wm^2 for December, January and February respectively.

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INTRODUCTION

Along with the green house gases, atmospheric aerosols also affect the radiative balance of the earth-atmosphere system at local, regional and global scale, therefore acts as the main source of uncertainty in assessing the anthropogenic climate perturbation (IPCC 2007, 2013). The crucial factors in this uncertainty are the highly heterogeneous properties of aerosols over spatial and temporal scale due to type of aerosol sources, their chemical composition, prevailing meteorological conditions and transport of aerosols (Ram *et al.,* 2010; 2012; 2015). Therefore a global network of campaign is required for estimating the aerosol optical and microphysical properties and their effects on weather and climate (Meloni *et al.,* 2005; Moorthy *et al.,* 2009). Indo-Gangetic plain (IGP) is one of the densely populated and heavily polluted region in India (Prasad *et al.,* 2005) with more than 50% population of the country (Gautam *et al.,* 2011, Tiwari *et al.,* 2015a). Several studies have been carried out for analyzing aerosols properties and estimation of aerosol radiative forcing at different sites of IGP (Tiwari *et al.,* 2016; Patel and Kumar, 2015; Srivastava *et al.,* 2012; Ram *et al.,* 2016).

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This region exhibits strong seasonal variation in aerosol particles size and their concentration (Tiwari *et al.,* 2016a; Tiwari *et al.,* 2016, Sharma *et al.,* 2014; Lodhi *et al.,* 2013). This region suffers from severe haze, fog and smog problems due to the large population growth and increasing urbanization (Gautam *et al.,* 2007). During winter season prevailing meteorological conditions with shallow boundary layer and minimum rainfall also helps in the fog formation over this region (Kaufman *et al.,* 2002). Over IGP large scale biomass burning takes place during winter months, which emits large concentration of black carbon (BC) and other aerosols (Kanawade *et al.,* 2014). During winters high aerosol load from biomass burning also favors the formation of early morning fog, which turns into production of smog and causes severe reduction in visibility that leads to many problems like road accidents, health problems, delay in air traffic, etc. In the present study, we have analysed the aerosols optical properties like aerosol optical depth (AOD), angstrom exponent (α), single scattering albedo (SSA), asymmetry parameter etc. and their radiative effects during the winter months. This study was focused on the estimation of aerosol radiative forcing, forcing efficiency and heating rate over Rohtak, an urban site in western part of IGP by using the sun/skyradiometer observational data from a period of December-2015 to February-2016.

Measurement site, Instrument and Methodology

The experimental site Rohtak is located in the North-Western part of India (Lat 28.89°N, Long 76.58°E, 214m AMSL) 70 km northwest of Delhi. Like most Indian cities, Rohtak has also a mixed pattern of land use with a population of 0.37 million. The instrument used for aerosol measurements during this study is a Prede POM-02 Sun/sky radiometer located on the roof top of three story building of Maharishi Dayanand University. The instrument can make measurements of both direct and diffuse sky radiances at predefined scattering angles at regular intervals within the spectral range of 340-2200nm. The precision of the in situmethod has been estimated to be in between 1-2.5% depending on the wavelength (Campanelli *et al.,* 2004). In this study, the 7 wavelengths data 340, 380, 400, 500, 675, 870, 1020 nm has been used to retrieve aerosol optical properties. The SKYRAD.pack software (Nakajima *et al.,* 1996) version 4.2 is used to process the radiance measurements to retrieve the aerosol optical depth, angstrom exponent, single scattering albedo, refractive index and asymmetry parameters. In the present study data from December 2015 to February 2016 is used to retrieveaerosol optical properties over Rohtak. In situ calibration constant can be estimeted using the improved Langley plot technique (Campanelli *et al.,* 2004).

Aerosol radiative forcing was estimated using Santa Barbara DISORT Atomspheric Radiative Transfer (SBDART) model, which has been developed by the atmospheric community (Ricchiazzi *et al.,* 1998). The main input data for the model consists of the solar zenith angle or a particular date, time, latitude and longitude to calculate the solar zenith angle; the spectrum range of fluxes; atmospheric profile; the concentration of trace gases (CO_2, CH_4 and N_2O); surface albedo; aerosols parameters (AOD, SSA and ASY). Based on the weather conditions tropical model profile of atmospheric parameters (e.g. temperature, pressure, ozone etc.) was used in SBDART to derive the net flux in the spectral range of 0.3-4μm at the surface, at top of the atmosphere and in the atmosphere. Diurnal average aerosol DRF was estimated by computing the difference between the net radiative fluxes (downward-upward) with aerosols and without aerosols. Uncertainity in the estimation of radiative forcing due to deviation in simulation was found to be in the range of 10-15% (Ricchiazzi *et al.,* 1998). The difference between the surface and TOA forcing gives the net atmospheric forcing. Aerosol optical and physical properties have a significant effect on aerosol radiative forcing which can influence the radiative balance over the region.

RESULTS AND DISCUSSION

AOD and Angstrom exponent

AOD is one of the crucial parameters to understand the aerosol loading in the atmosphere. Spectral variation of monthly average AOD shown in Figure 1 for winter season (December, January and February). Monthly variation in spectral pattern of AOD was observed during all months, with highest value of AOD in January and lowest value during December at all wavelengths as expected from the Mie theory. The similar trend of decreasing AOD with increasing wavelength was also observed by Mishra *et al*. (2013) and Balarabe *et al*. (2016). This indicates that dominant aerosol during this season are more influential scattered at shorter wavelength range as compared to longer wavelength range (Nwafor *et al.,* 2007). From this it is also evident that AOD shows relatively strong spectral dependence at shorter wavelength with steeper slope as compared to the longer wavelength with gentle slope. Srivastava *et al*. (2012) also observed the similar pattern over Delhi.

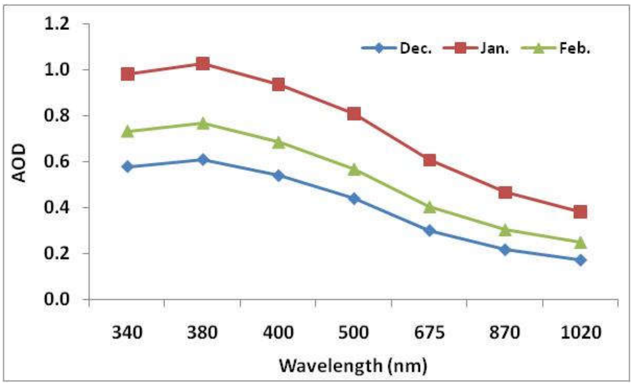


Fig. 1. Monthly spectral variation of AOD

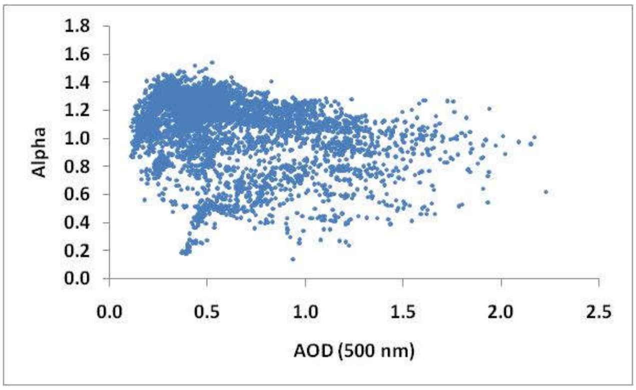
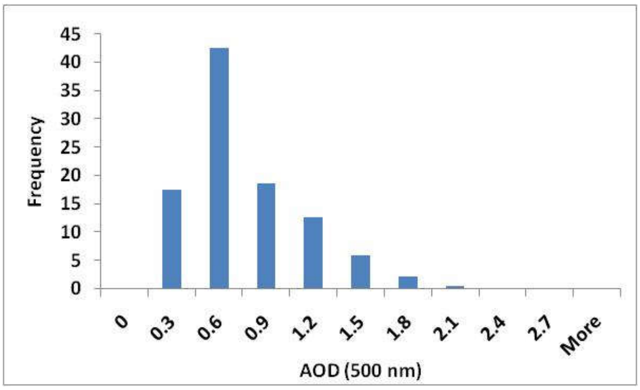
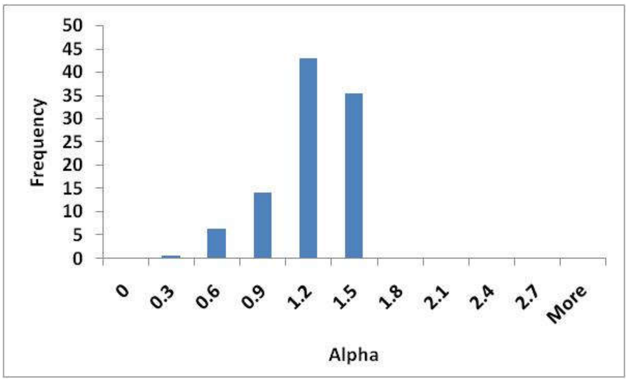


Fig. 2. Scatter plot of Alpha as a function of AOD_{500}

The monthly mean AOD at 500 nm were found to be 0.44±0.23, 0.80±0.37 and 0.57±0.34 for December, January and February, respectively with seasonal average of 0.63±0.36. The seasonal mean AOD at 500 nm is comparable to that observed by Singh *et al*. (2004) and Kaskautis *et al*. (2012) over Kanpur while it is much lower than that observed over Delhi (Lodhi *et al.,* 2013). The AOD during this season was mainly associated with fine mode aerosol particles produced from fossil fuel and biomass burning activities (Dey and Tripathi, 2008). Alpha represents the particle size distribution of aerosols while the AOD represents the aerosol loading in the atmosphere therefore AOD-Alpha scatter plot gives qualitative indication about the aerosol load due to different size particles. Figure 2 shows AOD-Alpha scatter plot for study period. From this it is clearly evident that predominantly alpha ranged from 0.8-1.4 which indicates the relatively more contribution of fine mode particles to the aerosol loading over the station during winter time. Lower boundary layer also contributes to higher AOD over station during winter (Kaskoutis *et al.,* 2009). Figure 3a and 3b shows the frequency distribution of AOD (500 nm) and Alpha for entire study period. For both AOD (500 nm) and Alpha frequency distribution is mono-modal with modal value of 0.6 and 1.2, respectively. Frequency distribution of AOD (500 nm) shows that ~60% of AOD varied between 0.0-0.6 and only ~20% AOD was found higher than 1.0. Approximately 80% of the Alpha values varied in the range of 1.0-1.5 which clearly indicates the dominance of fine mode aerosol associated with anthropogenic activities (Venkataraman *et al*., 2005; Pandithurai *et al*., 2007).



(a)



(b)

Fig. 3. Frequency distribution of AOD_{500} (a) and Alpha (b)

Single scattering albedo (SSA)

SSA is the common and fundamental parameter for measuring the relative contribution of absorption to extinction and it plays crucial role in assessing the climatic effects of aerosols (Dubovik *et al*., 2002). It varies from 0 to 1 depending on the ratio of absorbing to scattering type aerosols. When the extinction is caused only by absorption than it is 0 whereas if the extinction is caused only by scattering than it is 1. Monthly spectral variability of SSA depicted in Figure 4. It clearly shows increasing trend with increasing wavelength except a slight decrease at 1020 nm with higher value during December. Lower SSA at shorter wavelength indicates the dominance of absorbing type fine mode aerosols. SSA does not show significant monthly variation during different entire study period. The average SSA at 500 nm for this season was 0.94 which is much higher than the SSA observed over Delhi for winter 2004 by Ganguly *et al*. (2006). Lower SSA values over Rohtak as compared to Delhi indicates the less pollution.

Variation in volume size distribution

Aerosol volume size distribution is a crucial parameter for understanding the climatic effects of aerosol.

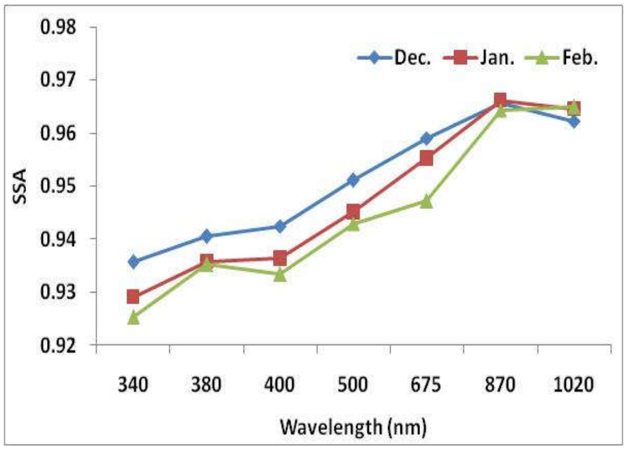


Fig. 4. Monthly variation in spectral distribution of SSA

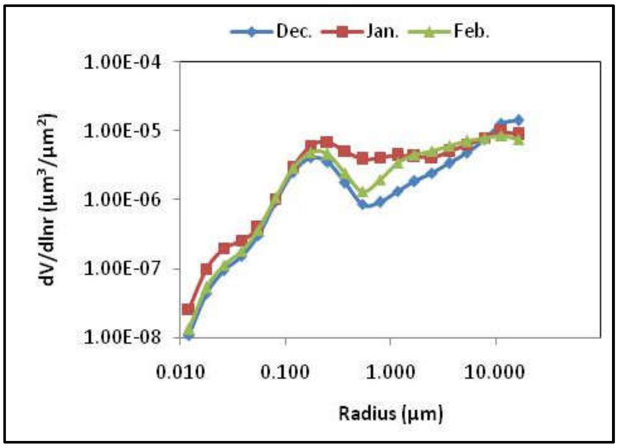


Fig. 5. Monthly variability in volume size distribution

Generally the aerosol exhibits bimodal size distribution worldwide, with fine mode <0.6 µm and coarse mode with >0.6 µm particles size (Dubovik *et al*., 2002). The aerosol volume size distribution was retrieved from the skyradiometer using 20 radius size bins in the range of 0.01 to 16.54 µm. Monthly variation in aerosol size distribution was illustrated in the Figure 5. From figure it is evident that size distribution exhibits bimodal distribution with dominant accumulation/fine mode around 0.17 µm and coarse mode is dominant around 11 µm. Generally the low volume of fine mode aerosol was found as compared to coarse mode aerosol during all seasons but during winter there is not much difference between fine mode and coarse mode volume. The high volume of accumulation mode aerosols is attributed with the hygroscopic growth of particles (Alam *et al*., 2010; Tripathi *et al*., 2005; Singh *et al*., 2004). Similar results of higher fine mode aerosol during winter was observed by Alam *et al*. (2012) over Karachi. Higher volume of fine mode aerosol was found during January than February and March. January is the coldest month of winter over northern India, therefore higher biomass and fuel burning for heating purposes contributes to the higher volume of fine mode aerosol.

Radiative forcing and heating rates

Average aerosol radiative forcing (ARF) at top of the atmosphere and at the surface is estimated by computing the difference between net solar flux (down-up) with and without aerosols (Singh *et al*., 2005). The difference between the radiative forcing at TOA and at the surface gives the atmospheric radiative forcing. SBDART compute plane parallel radiative transfer in clear and cloudy conditions which is widely used for the radiative transfer calculations. For December, January and February average TOA, at the surface and the atmospheric forcing was illustrated in Figure 6. The estimated monthly average ARF at the surface is -20, -34 and -27 Wm^{2} for December, January and February, respectively. TOA forcing for December, January and February is -13, -20 -16 Wm^{2}, respectively. Both TOA and surface forcing have negative sign for all three months. The atmospheric forcing values are +7, +14 and +12 Wm^{2} for December, January and February respectively. Relatively higher value of ARF is observed for January.

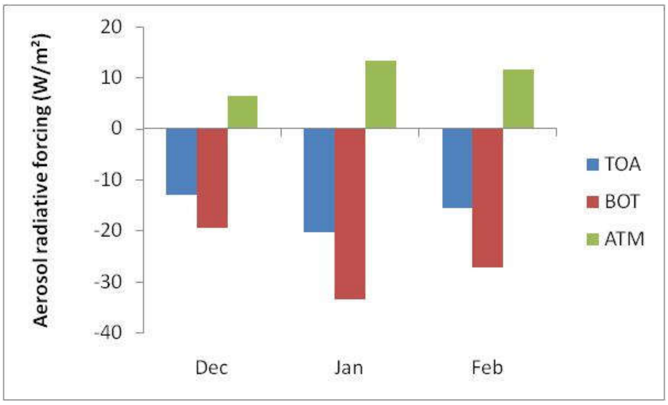


Fig. 6. Monthly variation in aerosol radiative forcing

Another important aspect is atmospheric heating rate due to aerosol radiative forcing, which can be calculated by following Liou (2002) as

$$\frac{\partial T}{\partial t} = \frac{g}{C_p}\frac{\Delta F}{\Delta P}$$

where $\partial T/\partial t$ is the heating rate (K day ^{1}), g is the acceleration due to gravity, *Cp* the specific heat capacity of the air, ΔF is the atmospheric ARF and ΔP is the atmospheric pressure difference between the surface and 3 km (300 hPa). The monthly mean atmospheric heating rate for December, January and February is 0.18, 0.37 and 0.33 K day ^{1}, respectively which exhibits a similar pattern as atmospheric radiative forcing. This indicates the dependence of atmospheric heating rate on the chemical characteristics and concentration of aerosols during different months. Higher heating rate during January attributed to the higher black carbon concentration due to biomass burning and anthropogenic activities.

Conclusions

The present study analyzed aerosol optical and radiative properties over Rohtak during winter season. Aerosols optical and physical properties shows significant monthly variability. AOD exhibits strong spectral dependence with decreasing trends from 340 nm to 1020 nm during all three months. Higher value of AOD was observed during January at all wavelengths indicates the higher aerosol loading associated with anthropogenic activities. The monthly mean AODs at 500 nm were 0.44±0.23, 0.80±0.37 and 0.57±0.34 for December, January and February, respectively. Higher values of Alpha around 80% ranged between 1.0-1.5 which clearly indicates the dominance of fine mode aerosol. Volume size distribution exhibits bimodal distribution with fine mode around 0.17 µm and coarse mode around 11 µm. The monthly mean atmospheric forcing values are +7, +14 and +12 Wm^{2} for December, January and February, respectively. Similar pattern of mean atmospheric heating rate was observed with values of 0.18, 0.37 and 0.33 K day ^{1} during December, January and February, respectively.

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