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Variability in radiative properties of major aerosol types: A year-long study over Delhi—An urban station in Indo-Gangetic Basin

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HIGHLIGHTS

- Four different aerosol types were identified using sun/sky radiometer measurements.
- Total aerosol was contributed from ~48% PD, 32% PC, 11% MBC and 9% MOC aerosols.
- AOD was similar for each aerosol type, with varying SSA as PD > MOC > PC > MBC aerosols.
- Highest atmospheric forcing was observed for PC and the lowest for MBC aerosols.

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ABSTRACT

Aerosol measurements over an urban site at Delhi in the western Ganga basin, northern India, were carried out during 2009 using a ground-based automatic sun/sky radiometer to identify their different types and to understand their possible radiative implications. Differentiation of aerosol types over the station was made using the appropriate thresholds for size-distribution of aerosols (i.e. fine-mode fraction, FMF at 500 nm) and radiation absorptivity (i.e. single scattering albedo, SSA at 440 nm). Four different aerosol types were identified, viz., polluted dust (PD), polluted continent (PC), mostly black carbon (MBC) and mostly organic carbon (MOC), which contributed ~48%, 32%, 11% and 9%, respectively to the total aerosols. Interestingly, the optical properties for these aerosol types differed considerably, which were further used, for the first time, to quantify their radiative implications over this station. The highest atmospheric forcing was observed for PC aerosol type (about $+40$ W m^{-2}, along with the corresponding atmospheric heating rate of 1.10 K day^{-1}); whereas the lowest was for MBC aerosol type (about $+25$ W m^{-2}, along with the corresponding atmospheric heating rate of 0.69 K day^{-1}).

1. Introduction

Radiative forcing due to aerosols is a key parameter in quantifying their crucial impacts on climate change. It largely depends on chemical, optical and microphysical characteristics of aerosols. These aerosol–climate effects are highly variable because of large variability in aerosol characteristics in both spatial and temporal scales, which attributed to the variety of their emission sources (natural and anthropogenic) and their dependence on the prevailing meteorological conditions. Variability in aerosol optical and microphysical characteristics over a wide range of spatial and temporal scales could increase the uncertainty in radiative forcing estimation (Intergovernmental Panel on Climate Change, IPCC, 2007). Thus, it is important to improve aerosol characterization on a regional basis; particularly over the region where high population is under the influence of these hazardous aerosols.

The Indo-Gangetic Basin (IGB) is one such region, which supports nearly 70% of the country's population and is one of the highly polluted and industrialized regions of the world. It is also one such region where large heterogeneity in aerosol optical and microphysical properties over a wide range of spatial and temporal scales continues to hinder in improving the estimates of aerosol-induced climate forcing (Jethva et al., 2005; Srivastava et al., 2011, 2012a; Tiwari et al., 2013). The IGB has been considered to be an important region of research interest due to its unique nature of topography, which demonstrates significant variability based on the complex combination of anthropogenic factors mixed with the contribution from the natural sources (mostly dust) during different periods of time (Srivastava et al., 2012b). Dust aerosols mix with various anthropogenic aerosols in the polluted environment, like IGB, which can change their optical properties and thus the associated

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radiative impacts (Dey et al., 2008; Singh et al., 2010; Srivastava and Ramachandran, 2013).

Several studies have been carried out over the region in the recent past to understand the characteristics of composite aerosols along with their radiative impacts (Pandithurai et al., 2008; Gautam et al., 2011; Srivastava et al., 2011; Singh and Beegum, 2013). However, detailed knowledge of the optical characteristics of the key aerosol types (desert dust, biomass burning, urban/industrial, black carbon etc.) is required to quantify their different radiative impacts over the region. Only a few studies have been done on the classification of aerosol types in different environments from the ground-based measurements (Dubovik et al., 2002; Bergstrom et al., 2007; Russell et al., 2010). However, these studies were conducted mainly on source specific locations and none of them have addressed the possible radiative impacts of different aerosol types.

In view of the immense importance of aerosol characterizations over IGB region, the present study aims to understand various aerosol characteristics based on their different types, inferred from ground-based automatic sun/sky radiometer derived aerosol products over Delhi during 2009. The radiative impacts of inferred aerosol types have also been quantified for the first time over the station.

2. Site description and instrumentation

The present study involves CIMEL sun/sky radiometer data measured at Delhi (28.6 °N, 77.2 °E, ~250 m amsl)—one of the Aerosol Robotic Network (AERONET) stations over the IGB. Delhi is one of the densely populated and industrialized urban mega cities in Asia, which typically represents the plains of Ganga basin, situated at the western IGB region in northern India. Being surrounded by various industrial facilities, Delhi is largely influenced by anthropogenic aerosols throughout the year. However, being in the proximity to the Thar Desert region in western India, it also experiences the influence of dust aerosols mostly during the pre-monsoon and monsoon periods (Pandithurai et al., 2008; Srivastava et al., 2011; Lodhi et al., 2013). The aerosols at this station are thus a complex mixture of natural and anthropogenic aerosols that cause variability in aerosol characterizations (Srivastava et al., 2012b).

The automatic sun/sky radiometer deployed at the Indian Institute of Tropical Meteorology, Delhi, is a part of the AERONET Program of NASA, USA. The instrument measures direct sun radiances at eight spectral channels (340, 380, 440, 500, 670, 870, 940 and 1020 nm) and provides column-integrated spectral aerosol optical depth (AOD) values at seven discrete wavelengths, and water vapor content at 940 nm (Holben et al., 1998). Furthermore, sky radiance measurements (in almucantar and principal plane) at four spectral channels (440, 670, 870 and 1020 nm) are used to retrieve columnar size distribution, single scattering albedo (SSA), asymmetry parameter (AP), refractive indices, fine- and coarse-mode fraction of the aerosols, which is restricted for large solar zenith angle (>50°) and high aerosol loading conditions (i.e. AOD > 0.4 at 440 nm) (Dubovik et al., 2000). The processed aerosol related data are available on-line at the AERONET site (http://aeronet.gsfc.nasa.gov/) in three categories (Smirnov et al., 2000): cloud contaminated (level 1.0), cloud screened (level 1.5) and quality assured (level 2.0). In the present study, level 2.0 aerosol products have been utilized during 2009 with the total available data of 103 clear-sky days. The uncertainty in the retrieved parameters by this instrument is discussed elsewhere (Holben et al., 2001; Dubovik et al., 2000).

3. Methodology

3.1. Discrimination of aerosol types

The approach used in the present paper is similar to that of Lee et al. (2010) in classifying aerosol types over Delhi. The method is based on sun/sky radiometer derived data products associated with the size of aerosols such as fine mode fraction (FMF) and radiation absorptivity such as SSA. To classify different aerosol types in the present study, appropriate thresholds for FMF and SSA are used as suggested by Srivastava et al. (2012a) after Lee et al. (2010). FMF at 500 nm is used to determine the dominant aerosol size mode, which provides quantitative information for each fine- and coarse-mode aerosol. However, SSA at 440 nm, which is the lowest sun/sky radiometer wavelength, is used to determine the characteristics of the absorptivity of aerosols and used to discriminate the aerosols from scattering to absorbing types. Out of the total available 103 clear-sky days, 66 days were identified for the concurrent measurements of FMF and SSA, and have been used for aerosol classifications over the station in the present study. Besides the present method, another method, based on the combination of AOD and Ångström exponent (AE) is also used to characterize different aerosol types at various locations (Kaskaoutis et al., 2009; Eck et al., 2010). However, both the methods are found to be well associated with each other (Srivastava et al., 2012a).

Although fine-mode pollution aerosols over the IGB region are continuously being produced by the combustion of biomass/fossil fuels and from the various other industries (Reddy and Venketaraman, 2002a,b; Rengarajan et al., 2007; Ramachandran and Cherian, 2008), dust aerosols have the dominant presence in the columnar AODs over the region during pre-monsoon period (Dey et al., 2004; Pandithurai et al., 2008; Srivastava et al., 2011; Lodhi et al., 2013; Tiwari et al., 2013). Since the present station is situated in proximity to the Thar Desert region of the western Rajasthan, therefore, mixing of transported natural dusts with various other anthropogenic aerosols may take place while approaching towards the station. Thus, the following major categories of aerosols can be expected at the station over IGB: (i) polluted dust (PD, dominance of dusts with anthropogenic particles), (ii) polluted continent (PC, dominance of anthropogenic particles with dusts), (iii) mostly black carbon (MBC, dominance of highly absorbing carbonaceous particles) and (iv) mostly organic carbon (MOC, dominance of low absorbing carbonaceous particles).

Fig. 1 shows the density plot of FMF (at 500 nm) versus SSA (at 440 nm) derived from the sun/sky radiometer measurements (n = 66) over the station for different aerosol types. During the entire measurement period, approximately 48%, 32%, 11% and 9% contributions were estimated to be from PD, PC, MBC and MOC type aerosols, respectively to the total aerosols. A wide range of SSA for each aerosol type except MOC is noticed from the figure. The mean values of SSA and the corresponding FMF (in bracket) are found to be 0.88 ± 0.04 (0.30 ± 0.06) for PD, 0.86 ± 0.03 (0.48 ± 0.07) for PC, 0.83 ± 0.07 (0.86 ± 0.03) for MBC and 0.92 ± 0.01 (0.87 ± 0.07) for MOC. Further, the detailed

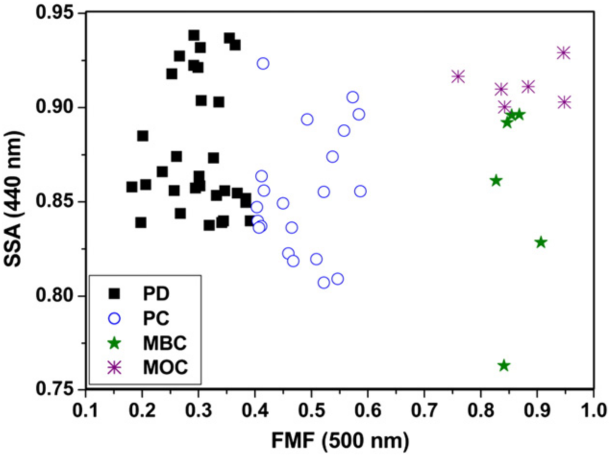

Fig. 1. Density plot of sun/sky radiometer derived SSA (at 440 nm) versus FMF (at 500 nm) for different aerosol types over Delhi during 2009 (n = 66).