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Wintertime characteristics of aerosols at middle Indo-Gangetic Plain: Impacts of regional meteorology and long range transport

M. Kumar [a], S. Tiwari [b], V. Murari [a], A.K. Singh [b], T. Banerjee [a, *]

[a] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[b] Atmospheric Research Laboratory, Department of Physics, Banaras Hindu University, Varanasi, India

HIGHLIGHTS

- Exceptionally high aerosol mass loading for both PM_{10} and $PM_{2.5}$ at middle IGP.
- Space borne & ground based AOD reveal variability and moderate association with PM.
- CALIPSO cross-section profiles depicts altitudinal distributions of aerosols.
- At lower altitude continental wind accumulate fine PM from north-western dry part.
- At higher altitude coarser PM accumulate due to strong intercontinental westerly.

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ABSTRACT

To develop a coherent picture of possible origin of Asian aerosol, transport and meteorological interaction; wintertime aerosol (January, 1 to March, 31, 2014 (n = 90)) were measured in middle IGP in terms of aerosol mass loading, optical properties, altitudinal distributions and both high and low altitude transportation. Both space-borne passive (Aqua and Terra MODIS) and active sensor (CALIPSO-CALIOP) based measurements were concurrently used over the selected transect (25°10′–25°19′N and 82°54′–83°4′E). Exceptionally high aerosol mass loading was recorded for PM_{10} (233 ± 58.37 μg m^{-3}) and $PM_{2.5}$ (138 ± 47.12 μg m^{-3}). Daily variations of $PM_{2.5}/PM_{10}$ persist in a range of 0.25–0.97 (mean = 0.60 ± 0.14; n = 90) and were in accordance to computed Angstrom exponent (0.078–1.407; mean: 1.002 ± 0.254) explaining concurrent contribution of both $PM_{2.5}$ and PM_{10} for the region. Space borne (Aqua MODIS-AOD: 0.259–2.194) and ground based (MTP-AOD: 0.066–1.239) AODs revealed significant temporal variability and moderate association in terms of PM_{10} (MODIS-AOD: 0.46; MTP-AOD: 0.56) and $PM_{2.5}$ (MODIS-AOD: 0.54; MTP-AOD: 0.39). Varying association of AOD and aerosol mass loading was also explained in terms of meteorological variables. CALIPSO altitude-orbit-cross-section profiles revealed presence of non-spherical coarse particulates (altitude: 1.2–5.4 km) and dominance of spherical fine particulates (altitude: 0.1–4.2 km). Contribution of trans-boundary aerosols transportation to mass loadings at middle IGP were recognized through lagrangian particle dispersion model, synoptic vector wind profiles at different geopotential heights and satellite images.

1. Introduction

Aerosols are multi-component mixtures originate from a range of regional and global sources and have potential to alter Earth's climatic balance by affecting physical, chemical or optical properties. Aerosol-climate chemistry includes heterogeneity at spatial levels and hence their effects vary with topography, climate and meteorological conditions (Murari et al., 2014). Among several identified regional hotspots around the globe, Indo-Gangetic Plains (IGP) is considered to be most vulnerable to aerosol induced climate impacts. Thus creates the essentiality of conducting a comprehensive research to identify local and transboundary sources of aerosol, its association with regional meteorology, transport mechanism and altitudinal distribution. The nature of aerosols at middle IGP is mostly characterized by presence of mineral dust, organic aerosols and elemental carbon produced through burning

* Corresponding author. Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, India.
E-mail addresses: tb.iesd@bhu.ac.in, tirthankaronline@gmail.com (T. Banerjee).

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of biomass and fossil fuels, which further get complicated by trans-boundary movement of aerosols originating from the Middle-east countries and Thar Desert. Additionally, burning of agricultural residues during winter has been a common practice in eastern Uttar Pradesh and Bihar which predominately adds large quantity of aerosols of different nature and sizes (Ram et al., 2010; Murari et al., 2014). A substantial number of studies on varying spatial and temporal scale at different locations of IGP, i.e. Lahore (Ghauri et al., 2012), Patiala (Mittal et al., 2009), Hisar (Raman et al., 2011), Delhi (Sharma et al., 2014), Varanasi (Murari et al., 2014; Tiwari and Singh, 2013) and Kolkata (Karar and Gupta, 2007) highlights the presence of quantum of both primary and secondary aerosols. However, for the present analysis, efforts were made to understand the entire spectrum of aerosol from origin to its transport, meteorological interaction and vertical distribution so that a coherent picture may be established.

For the current analysis, ground based aerosol observations were made at Varanasi, India. Situated at middle IGP, Varanasi is not an exception of having worst statistics in terms of aerosols which exceeds the national standards on a frequent basis. The submitted manuscript initially presents an approach to associate the behavior of ambient aerosols (PM_{10} and $PM_{2.5}$) with regional meteorological parameters. Such association is extremely critical in terms of forecasting aerosol chemistry in context of projected climate change. Additionally, efforts were made to identify interrelations of ground based aerosol mass loading with its optical properties collected both through ground and satellite based platforms. Altitudinal distribution of aerosol for the selected transect was made through active lidar instrument. Conclusively, based on aerosol vertical profile, synoptic meteorological data was plotted for entire region to understand trans-boundary origin and transport of aerosol for middle IGP. The implications of such findings may well be useful to understand uncertain association of aerosol mass concentrations with regional meteorology and its optical properties, aerosol origin and transport for a region long been projected as most vulnerable through aerosol induced climate change.

2. Experimental methods

2.1. Site description

Varanasi, located at the bank of the river Ganges in the middle Indo-Gangetic Plains is considered as one of the ancient and holiest cities of the world. The entire study was carried out at the premises of IESD-BHU campus, Varanasi (25°16′29″N, 82°59′46″E) (Fig. 1). The sampling site is represented by an institutional set up surrounded by an urban environment typically characterized by traffic congested roads with mixed residential and commercial sprawl in the northern side and densely populated residential areas in the eastern, western and southern part. The region is climatologically affected by wide range of synoptic weather patterns but is devoid of any localized effects of oceans and mountains. Relatively flat topography is believed to simplify the atmospheric boundary layer structure of the region and improve the applicability of assimilated meteorological parameters used in the analysis.

2.2. Ground-based in-situ measurements

All ground-based in-situ aerosol measurements for the current analysis were made at Varanasi (25°16′N, 82°59′E, 77 m msl). Aerosol samples having aerodynamic diameter $\leq$10 μm (PM_{10}) and $\leq$2.5 μm ($PM_{2.5}$) were collected continuously seven days a week for entire winter months i.e. January, 1 to March, 31, 2014 (n = 90). Aerosol samplers were placed at an elevation of 7.5 m at the roof of IESD-BHU and monitoring was continued for 22 h (1200–1000 h) on each consecutive day. Coarser particulates were collected through particulate sampler with size selective inlet (IPM-FDS, Instrumex). Ambient air was passed through the sampler using glass fiber filter (GF/A, Whatman, 47-mm diameter) with an airflow of 16.67 LPM (flow meter resolution of ±2% under actual operating condition). Additionally, fine particulates ($PM_{2.5}$) were sampled through polytetrafluoroethylene filters (PTFE, Whatman, 47-mm diameter) with an airflow of 1 m^3 h^{-1} (accuracy ±2%) by fine particle sampler (APM 550, Envirotech). Filter papers were pre-conditioned in a desiccator for 24 h before sampling and pre-weighed using a microbalance (AY220, Shimadzu). Pre-conditioned filter papers were placed in filter holders (for $PM_{2.5}$) and cloth-lined envelope (for PM_{10}) before being taken to the field for sampling to avoid any possible contamination. Exposed filters were placed into cassettes and wrapped in aluminum foils to prevent exposure to sunlight and photo-oxidation. Aerosol mass concentration was gravimetrically calculated and exposed filters were stored under cool and dry condition (−20 °C) for further particulate speciation. All instruments deployed for the sampling have been frequently calibrated both before and after sampling.

Fig. 1. Geographical location of aerosol ground monitoring station.