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Temporal variability of primary and secondary aerosols over northern India: Impact of biomass burning emissions

N. Rastogi [a,*], A. Singh [b], M.M. Sarin [a], D. Singh [b]

[a] Physical Research Laboratory, Ahmedabad, 380009, India
[b] Punjabi University, Patiala, 147002, India

HIGHLIGHTS

- Year-round $PM_{2.5}$ composition has been studied over the IGP.
- Significant seasonality in primary and secondary aerosol abundances.
- Emissions from biomass burning dominate the abundances of carbonaceous aerosols.
- Contribution of secondary inorganics to $PM_{2.5}$ is maximum during winter.
- Water-soluble fraction of $PM_{2.5}$ vary from ~30 to 60% over annual cycle.

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ABSTRACT

The ambient particulate matter injected from biomass burning emissions (BBEs) over northern India has been a subject of major debate in the context of regional air quality and atmospheric chemistry of several organic and inorganic constituents. This necessitates an observational approach over a large spatial and temporal scale. We present an extensive data set on $PM_{2.5}$ samples (n = 147) collected for one full year from a sampling site (Patiala: 30.2°N, 76.3°E) in the source region of BBEs in northern India. During the sampling period from October 2011 to September 2012, $PM_{2.5}$ mass concentration varied from ~20 to 400 $\mu g\ m^{-3}$. Among the major constituents, contribution of total carbonaceous aerosols (OC + EC) ranged from 8 to 60%. The average OC/EC and K^+/EC ratio, varying from 3.2 to 12 and 0.26 to 0.80, respectively, emphasizes the dominance of BBEs over the annual seasonal cycle. The average secondary organic matter (SOM) accounts for ~10–40% of $PM_{2.5}$ mass in different seasons; whereas contribution of secondary inorganics was maximum (~40%) during the winter. The pronounced temporal variability in SOM suggests its contribution from varying sources, their emission strength and process of secondary organic formation. Diurnal differences in the chemical constituents are attributable to regional meteorological factors and boundary layer dynamics. The emerging data set from this study is important to understand feedback mechanism from anthropogenic activities to the regional climate change scenario.

1. Introduction

The Indo-Gangetic Plain (IGP) spread over northern India has large amount of gaseous and particulate air pollutants due to emissions from vehicles, industries, thermal power plants, large-scale post-harvest biomass burning, and bio-fuel burning. Further, the IGP represent a huge agricultural area for much of South Asia. Rice and wheat (major crops) are grown in rotation on almost 12 Million hectare of land (Aggarwal et al., 2004), and large amount (hundreds of million tons) of crop residue is burnt during October–November and May when crop changes from one to another (Badarinath et al., 2006). Pollutants from various sources cause poor air quality, impact atmospheric chemistry, increase vulnerability of people to cardiopulmonary diseases, influence rainwater composition, reduce crop yield, degrade visibility, affect biogeochemistry of northern Indian Ocean, and change the regional Earth's radiation balance (Crutzen and Andreae, 1990; Ramanathan et al., 2001; Jethva et al., 2005; Rastogi and Sarin, 2007; Sarin et al., 2010; Auffhammer et al., 2012). As the IGP has the maximum population density in the world, relatively more people would be affected due to any pollution in this region. Towards designing

* Corresponding author. Geosciences Division, Physical Research Laboratory, Navrangpura, Ahmedabad, 380009, India.
E-mail address: nrastogi@prl.res.in, neeraj6676@gmail.com (N. Rastogi).

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mitigation strategies, global and regional models often take input data from emission flux studies of pollutants.

Emission flux studies provide information on the emissions of primary particles and gaseous species from variety of sources over a given region, however, the contribution through secondary aerosol formation is highly uncertain. Primary particulate pollutants are compounded by the large emissions of secondary aerosol precursors, resulting in the production of large amounts of secondary inorganic and organic aerosols through various chemical processes in the atmosphere. Secondary aerosol formation especially secondary organic aerosol formation is poorly understood, and a considerable mismatch has been documented between its observed and modeled values (Heald et al., 2011). Secondary aerosol formation over a given region may depend upon several factors such as availability of precursors, presence of catalysts, total aerosol loading, meteorological condition, and rate of removal of the species from the atmosphere through different removal mechanisms.

The IGP comes under tropical/sub-tropical region that is unambiguously important to understand secondary aerosol formation through atmospheric processing because the tropics have larger amount of water vapor, higher UV radiation flux, and higher temperature than that over temperate regions. Further, deep convection over tropics efficiently lifts substances emitted at the surface into the upper troposphere and increases their lifetime and thus, regional emissions over tropics can have global effects (Lawrence and Lelieveld, 2010 and references therein). Poor understanding on the formation and abundances of secondary aerosols on temporal and spatial scale remains among the major cause of uncertainty in assessing effects of aerosols on regional climate and air quality. Present study focuses on the temporal behaviour of abundances and characteristics of ambient aerosols and their primary and secondary fractions over the IGP.

2. Experiment

This study was systematically carried out for one whole year (from October 2011 to September 2012). The study site, Patiala (30.2 °N, 76.3 °E; 250 m amsl), is located in the northwest of Indo-Gangetic Plain (IGP) in the Punjab state of India (Fig. 1). The IGP is surrounded by the unique topography with the Himalayan range of mountains in the north and northeast and hills in the south and southwest. This topography and westerly/northwesterly winds during most of the year (Fig. 2) transport air pollutants along the IGP to the Bay of Bengal. The dominant emission sources and meteorological conditions vary with time during a year. A 440 MW thermal power plant is located in Bhatinda (40 km west of Patiala) and several small and big thermal power plants with total capacity of ~2100 MW are located at different places in Punjab province of Pakistan (within ~200 km west of Patiala). Winds are westerly/northwesterly during majority of the seasons that can bring significant contribution from fossil fuel burning emissions to the study region. The period of middle of October to mid November is dominated by large scale post-harvest paddy residue burning by local farmers to change the crop from paddy to wheat, fertilize the soil and control pests. Wheat residue is burnt during end of April or early May. Cow-dung cakes and wood are often used for cooking in rural areas in all the seasons over the IGP. The additional emission source during winter is the burning of dry woods by local people to keep themselves and livestock warm. Detailed site description has been reported elsewhere (Rajput et al., 2011; Rastogi et al., 2014).

Average daytime and nighttime temperature and relative humidity during different seasons are presented in Table 1. Atmospheric mixing height (MH) also exhibits large seasonal and diurnal variability (Table 1). The mixing height data were retrieved from the stability time series data center which is available on NOAA, ARL for the provision of the HYSPLIT transport and dispersion model from the READY website (http://www.arl.noaa.gov/ready.html) on the basis of three hourly intervals. The mixing height data was averaged for daytime (08:30, 11:30, 14:30 and 17:30) and nighttime (20:30, 23:30, 02:30 and 05:30) periods for different seasons. Depending upon different meteorological conditions and prevailing emission sources, the data was classified into five seasons: autumn (October–November), winter (December–February), spring (March–April), summer (May–June) and wet (July–September) (Table 1). Here, July–September months are defined as wet season because of frequent southwest monsoon rain in this season. Majority of annual rainfall over the IGP occurs in wet season (July–September) under southwest monsoon. Winds are westerly/northwesterly and calm during the autumn and winter, become stronger during the spring and summer, and come from southeast during the wet season (Fig. 2). The length of the day varies with season with shorter days (~10 h) during winter and longer days (~14 h) during summer. Further, the days are mostly sunny, except during wet season.

The sampling site was located at the terrace of the Department of Physics, Punjabi University, Patiala, ~20 m above ground

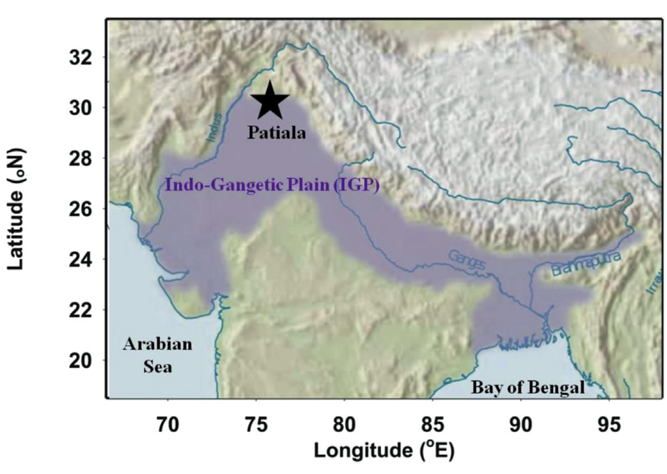

Fig. 1. Sampling site Patiala is located at the source region in the Indo-Gangetic Plain (shaded area) and characterized by large emissions from crop residue burning twice a year, and perennial emissions from bio-fuel, wood burning, industries and thermal power plants.

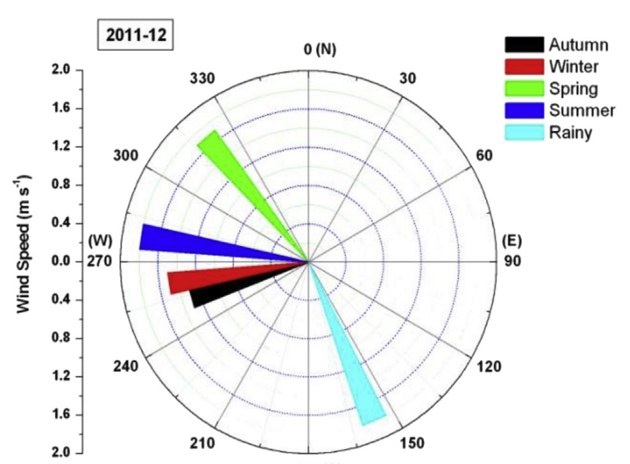

Fig. 2. Wind rose plot depicting average wind speed and directions during different seasons over the study site.