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# Absorbing and scattering aerosols over the source region of biomass burning emissions: Implications in the assessment of optical and radiative properties

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## HIGHLIGHTS

- Chemical composition of aerosols coupled with optical model simulations.
- Chemical composition of $PM_{2.5}$ was dominated by water soluble aerosols.
- AOD, Ångström exponent and $a_2$ coefficient has been studied.
- Fine mode particles were dominated.
- Ratio of scattering to absorbing aerosols was significantly high.

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## ABSTRACT

The current study focuses on the assessment of model simulated optical and radiative properties of aerosols incorporating the measured chemical composition of aerosol samples collected at Patiala during October, 2011–February, 2012. Monthly average mass concentration of $PM_{2.5}$, elemental carbon (EC), primary organic carbon (POC), water-soluble (WS) and insoluble (INS) aerosols ranged from 120 to 192, 6.2 to 7.2, 20 to 39, 59 to 111 and 35 to 90 μg $m^{-3}$, respectively. Mass concentration of different components of aerosols was further used for the assessment of optical properties derived from Optical Properties of Aerosols and Clouds (OPAC) model simulations. Microtops based measured aerosol optical depth ($AOD_{500}$) ranged from 0.47 to 0.62 showing maximum value during November and December, and minimum during February. Ångström exponent ($\alpha_{380\text{-}870}$) remained high (>0.90) throughout the study period except in February (0.74), suggesting predominance of fine mode particles over the study region. The observed ratio of scattering to absorbing aerosols was incorporated in OPAC model simulations and single scattering albedo (SSA at 500 nm) so obtained ranged between 0.80 and 0.92 with relatively low values during the period of extensive biomass burning. In the present study, SBDART based estimated values of aerosol radiative forcing (ARF) at the surface (SRF) and top of the atmosphere (TOA) ranged from −31 to −66 $Wm^{-2}$ and -2 to −18 W $m^{-2}$ respectively. The atmospheric ARF, ranged between + 18 and + 58 $Wm^{-2}$ resulting in the atmospheric heating rate between 0.5 and 1.6 K $day^{-1}$. These results signify the role of scattering and absorbing aerosols in affecting the magnitude of aerosol forcing.



## 1. Introduction

The quantification of aerosol radiative forcing is one of the major uncertainties in estimating the anthropogenic climate perturbations (IPCC, 2013). The spatial distribution of aerosols over regional and global scale is highly heterogeneous. Thus, the uncertainty in estimation of radiative forcing due to aerosols is more in

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comparison to forcing of well mixed green house gases. These uncertainties are due to inadequate knowledge of spatial and temporal variations in the physical characteristics and chemical composition of aerosols. The data sets on chemical composition are sparse in comparison to the extensive study of physical and optical properties (such as size distribution and aerosol optical depth) as the study of chemical characteristics requires dedicated field experiments and expensive instrumentation. Thus, it is imperative to infer the chemical composition of aerosols and incorporate these observations in the model simulations which will facilitate in reducing the uncertainty during assessment of optical and radiative properties. In the context of the Indo-Gangetic plain (IGP), the hot spot for aerosol research due to diversity in emission sources and unique topography, it is necessary to know the chemical composition of aerosols and incorporate these observations in the model for forcing calculations. Patiala is a source region of extensive biomass burning emissions during October–November in the western part of the IGP. In view of this, $PM_{2.5}$ (particulate matter with aerodynamic diameter less than or equal to 2.5 μm) samples were collected and chemically analyzed for carbonaceous aerosols and water soluble major ions ($Cl^-$, $NO_3^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$ and $NH_4^+$) with collocated measurements of spectral aerosol optical depth (AOD) over Patiala. Further, we have incorporated these chemical characteristics in model simulations of aerosols optical and radiative properties. The chemical analyses of samples provide surface based characteristics of aerosols and their column properties may differ to some extent. Thus, the assumption of same aerosols vertical profile over different days can result in error in the estimation of aerosol forcing (Satheesh, 2002). In the present study, attempt has been made to normalize the measured chemical composition with vertical profile by comparing the observed columnar AOD and OPAC (Optical Properties of Aerosol and Clouds) derived columnar AOD. The present research paper examines the impact on the model simulated optical and radiative properties of aerosols by employing measured chemical composition of aerosols in the OPAC model using aerosol samples collected during the period October 2011 to February 2012 at Patiala, which is situated in the western part of the IGP.

## 2. Observations and methodology

### 2.1. Sampling site

Patiala (30.33°N; 76.4°E; 250 m a.s.l), a source region of biomass burning emissions, is semi-urban location, situated in the western part of the IGP (Fig. 1). Sampling site is surrounded by vast agricultural fields and also affected by various types of industrial emission sources mostly located in its north-west side. The study region is significantly influenced by emissions from extensive paddy residue burning in the autumn season (October–November) every year. The emissions from bio- and fossil fuel combustion are dominant in winter season (December–February) (Rastogi et al., 2014). During the study period, variation in various meteorological parameters such as temperature (temp), relative humidity (RH) and rain fall (RF) are summarized in Table 1. These meteorological parameters were measured with automatic weather station of Indian Meteorological Department (IMD) observatory situated in Punjabi University Patiala campus. The air mass back trajectories have been computed using Hybrid Single-Particle Langrangian Integrated Trajectory (HYSPLIT) model over Patiala from October, 2011 to February, 2012 (Draxler and Rolph, 2003). The back trajectories were computed for past 72 h (3 days) at height of 1000 m to infer the direction of transported aerosols to the sampling site (Fig. 1). The back trajectory analysis shows that from October to January, generally the air mass comes from northwest direction of Patiala and occasionally shifts towards the southwest direction (Thar Desert) during the month of February.

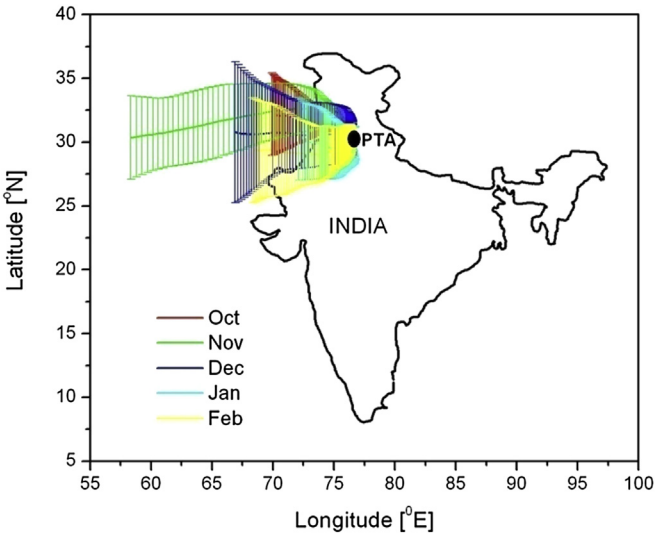


**Fig. 1.** Three days air mass back trajectories computed with HYSPLIT model, ending at sampling site (Patiala) at 1000 m height during October, 2011 to February, 2012.

**Table 1**
Variation in temperature, relative humidity (RH) and rainfall from October, 2011 to February, 2012.

| Months | Temperature (°C) (Avg ± 1σ) | RH (%) (Avg ± 1σ) | Rainfall (mm) (Total) |
|---|---|---|---|
| October, 2011 | 29 ± 2 | 54 ± 09 | 0.0 |
| November, 2011 | 25 ± 3 | 53 ± 14 | 0.0 |
| December, 2011 | 19 ± 4 | 61 ± 14 | 9.6 |
| January, 2012 | 15 ± 3 | 65 ± 17 | 7.6 |
| February, 2012 | 19 ± 3 | 56 ± 13 | 0.5 |

### 2.2. Aerosol collections and chemical analysis

The $PM_{2.5}$ samples (n = 37) were collected on tissuquartz filters (PALLFLEX, 2500QAT-UP) using high volume air sampler (Thermo Scientific, USA, flow rate: 1.13 $m^3$ $min^{-1}$). $PM_{2.5}$ mass concentration was determined gravimetrically on a high precision analytical balance (Sartorius, model LA130S–F). The filters were equilibrating at relative humidity of ~45% and temperature of 22–24 °C while weighing. Generally, $PM_{2.5}$ concentration contributes significantly (~70%) to the total aerosol loading over the study region as the anthropogenic sources predominate during autumn and winter (Singh et al., 2015). The concentrations of elemental carbon (EC) and organic carbon (OC) were measured on EC-OC analyzer (Model 2000, Sunset Laboratory, USA) using National Institute of Occupational Health and Security 5040 (NIOSH-5040) protocol (Birch and Cary, 1996). In EC-OC analyzer, OC and EC oxidized to $CO_2$ separately, by heating the aerosol sample in inert (helium) and oxidizing condition (helium + oxygen), respectively. Subsequent conversion of $CO_2$ to methane by methanator facilitates the quantification of OC and EC using flame ionization detector (FID). Simultaneous monitoring of optical attenuation (ATN) from a laser source (at 678 nm) determines the split point between OC and EC and facilitates the correction for pyrolyzed carbon. The concentration of water-soluble organic carbon (WSOC) and water soluble ionic species (WSIS) was measured using a total organic carbon (TOC) analyzer (Shimadzu, model TOC-5000A) and ion chromatograph (Dionex-500), respectively. For analysis of WSOC and WSIS, water