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Original article

Analysis of optical and physical properties of aerosols during crop residue burning event of October 2010 over Lahore, Pakistan

Salman Tariq*, Zia ul-Haq, Muhammad Ali

Remote Sensing and GIS Group, Department of Space Science, University of the Punjab, New-Campus, Lahore, 54590, Pakistan

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ABSTRACT

Aerosols released from biomass burning affect the tropospheric chemistry, radiation budget and cloud processes and hence can cause significant climate modifications. Due to certain economical reasons, the open burning of crop residue has become popular in Pakistan. In the present work we have analyzed the optical and physical properties of aerosols during crop residue burning over Lahore, a central location of Pakistan. The data from ground based Aerosol Robotic Network (AERONET), satellite based MODIS and CALIPSO remote sensing instruments have been used for the characterization of aerosols during crop residue burning event of October 2010. The maximum value (2.75) of daily mean AOD was observed on 20 October 2010 and the next highest value of 2.64 was observed on 19 October 2010, indicating heavy aerosol loading over Lahore on both days due to intense crop residue burning. The fine mode AOD values ranged from 0.14 to 2.68 (on 20 October 2010) with average value of 0.87 during October 2010 over Lahore. It was found that fine mode aerosols have greater contribution than coarse mode aerosols towards total aerosol burden indicating the presence of fine mode (crop residue burning) aerosols over Lahore. Cluster analysis showed that the mixed aerosols (biomass burning and urban-industrial) were present during the heavy aerosol loading period over Lahore. The highest volume concentration of fine mode occurred on 19 and 20 October 2010 representing the dominance of fine mode aerosols. Due to scattering of incoming solar radiation by intense smoke observed on 19 and 20 October 2010 high values of SSA (~0.95) were found. HYSPLIT model backward trajectories showed that the winds transported aerosols from southeast and northwest directions.

1. Introduction

Rapid industrialization and urbanization have caused harmful effects on the regional air quality and human health. Anthropogenic biomass burning activities have increased dramatically in the last 20–30 years and becoming seasonal phenomenon especially in the developing regions of Asian continent (Field et al., 2009). Anthropogenic emissions (aerosols and trace gases) from biomass burning affect the climate by changing radiation budget and atmospheric chemistry (Andreae and Merlet, 2001; Beringer et al., 2003; IPCC, 2007).

Biomass burning is also one of the most important causes for the formation of atmospheric brown clouds (ABC) over the South Asia that considerably affect the absorption/scattering of solar radiation (Jacobson, 2001; Ramanathan et al., 2005, 2007; Pinker et al., 2005; Dey and Tripathi, 2007). Aerosols released from intense biomass burning can cause solar dimming and surface cooling. Effect of biomass burning on aerosol optical and physical characteristics over different European regions have been described by Arola et al. (2007) and Kaskaoutis et al. (2011). Singh et al. (2010) showed that crop residue burning and vehicular emissions have substantial contribution towards total aerosol burden over northwestern India. Biomass burning is very important source of air pollution as the fine particles due to crop residue burning are lifted by high-speed winds and are driven to large distances (Fearnside et al., 2005; Badarinath et al., 2009a, 2009b; Ali et al., 2014). Due to long range transport of these fine mode aerosol particles biomass burning is not only a local problem but also a global problem. Badarinath et al. (2009b, 2009c) have studied the long range transport of biomass burning aerosols and analyzed the aerosol optical properties using satellite and ground based remote sensing instruments data 1600 km away

* Corresponding author. Tel.: +92 3008844797.
E-mail address: salmantariq_pu@yahoo.com (S. Tariq).

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from the biomass burning site at Hyderabad, India. They observed aerosol layers up to 3 km due to mixing of biomass and anthropogenic aerosols on specific days of October and November. Although very high aerosol loading events (aerosol optical depth (AOD) > 1.5) due to biomass burning are not common in most regions but they are of increased concern because of adverse effects on respiratory health and visibility reduction (Eck et al., 2003). ABC, a layer of air pollutants, covers northern Pakistan (including megacity of Lahore) and India. ABC are formed from biomass burning and urban-industrial aerosols and are of increased concern regarding health, changes in monsoon rainfall patterns and retreat of Hindkush and Himalayan glaciars and snow packs.

Rapidly increasing population has caused substantial increase in aerosol loading over Pakistan. Due to large anthropogenic emissions, the densely populated areas of Pakistan experience pollution with high amounts of particulate matter. There are few studies conducted over Pakistan to assess air pollution using remote sensing techniques (e.g. Alam et al., 2010, 2011, 2014; Ali et al., 2014; Tariq and Ali, 2015; ul-Haq et al., 2014, 2015). Recently, Ali et al. (2014) studied the seasonal average properties of aerosols using relatively long term AERONET data over Lahore. Nevertheless, influence of crop residue burning events on optical and physical properties of atmospheric aerosols and characterization of difference in aerosol compositions (biomass burning, urban-industrial and mineral dust) requires more detailed observations. In the present work we have analyzed the optical properties of crop residue burning aerosols over Lahore, a central location of Pakistan. The crop residue burning event of October 2010 was selected for this study because of the occurrence of the highest value (3.73) of AOD ever recorded by AERONET (Aerosol Robotic Network) instrument installed in Lahore. In this study we have used all the available AERONET data (level 2.0) during October 2010 to analyze the aerosol optical depth (AOD), fine mode fraction (FMF), absorption Angstrom exponent (AAE), extinction Angstrom exponent (EAE), volume size distribution and single scattering albedo (SSA). We have also used Aqua-MODIS AOD and CALIPSO data to understand spatio-temporal distribution of aerosols and aerosol subtypes during biomass burning. In order to understand the transport of aerosol particles over the study region HYSPLIT model (HYSPLIT, 2015) backward trajectories were also computed. For the purpose of analysis, available data for the month of October 2010 have been divided into three episodes i.e. 7–14, 15–22, and 23–31 October. The outcomes of this study could provide valuable information about aerosol optical and physical properties during intense biomass burning period over Lahore.

2. Methodology and study area

2.1. AERONET

In Lahore, the AERONET site was established in December 2006, with the association of NASA and Institute of Space Technology. The AERONET data from the direct sun and diffused radiances have been used for this study. Direct sun and diffused sky radiances are taken within the ranges 340–1020 nm and 440–1020 nm respectively (Holben et al., 1998). The AERONET data are available at three levels; level 1.0 (unscreened), level 1.5 (cloud free), level 2.0 (quality assured). The computed AOD in cloud free conditions has uncertainty less than ±0.01 for wavelengths higher than 440 nm while for wavelengths less than 440 nm the uncertainty is less than ±0.02 (Dubovik et al., 2000). The inversion aerosol products in total atmospheric column such as SSA and volume size distribution are retrieved by using improved inversion algorithm at four different four wavelengths (440, 675, 870 and 1020 nm) (Dubovik et al., 2002). Depending on aerosol type and loading the retrieval uncertainty in SSA is estimated to be 0.03–0.05 (Dubovik et al., 2000). The aerosol particles have been considered to be divided into two categories: spherical and non-spherical. The spherical aerosol particles are modeled by ensemble of polydisperse and homogeneous spheres while non-spherical aerosol particles are mixture of polydisperse randomly oriented homogeneous spheroids (Mishchenko et al., 1997). The distribution of spheroid aspect ratio is predetermined as reported by Dubovik et al. (2006). The detailed information about inversion aerosol retrievals is reported by Dubovik and King (2000) and Dubovik et al. (2000, 2002, 2006). In the present work, we have used Level 2.0 data to retrieve AOD and fine mode fraction (FMF) at 500 nm from direct sun and SSA, volume size distribution, AAE and EAE of aerosols from inversion algorithm over Lahore during October 2010.

2.1.1. Volume size distribution

The AERONET derived aerosol volume size distribution is calculated by using inversion algorithm from sun/sky radiance data. The volume concentration is retrieved in the particle radii varying from 0.05 to 15 μm. Depending on the types of aerosols the retrieval error in dV(r)/dlnr generally does not go beyond 15–35% for every aerosol size bin between 0.1 and 7 μm. For very small aerosol particles having size 0.05–0.1 μm and very large aerosol particles having size 7–15 μm the retrieval error may increase to 35–100% for a certain particle radius bin (Dubovik et al., 2000). The volume size distribution is characterized by the sum of two lognormal distributions. For each mode, it can be given as follows:

$$dV/d\ln r = \left(C_v\big/\sigma\sqrt{2\pi}\right) exp\left[-\frac{1}{2}\left(\frac{\ln(r/rv)}{\sigma}\right)^2\right]$$

Where C_v is the columnar concentration of aerosol particles, σ is the standard deviation, r is particle radius and r_v is the volume mean radius. The algorithm formulated by Dubovik and King (2000) have been used to derive volume size distributions.

2.2. MODIS and CALIPSO

The MODIS (MODerate resolution Imaging Spectro-radiometer) sensor is launched by NASA onboard Terra satellite in 1999 and Aqua satellite in 2002. The MODIS sensor is primarily designed to monitor aerosol fields, cloud cover and radiation budget (King et al., 1992). The Terra satellite crosses the equator from north to south in the morning while Aqua satellite crosses the equator from south to north in the afternoon (Levy et al., 2007). The MODIS instrument acquires data in thirty six spectral bands. It provides a high radiometric resolution (12 bits) data in all the thirty six bands. In order to analyze spatial and temporal distribution of AOD we have used MODIS C005 Level 3 AOD_{500} product having spatial resolution of $1° \times 1°$. The MODIS data can be obtained from the website: http://giovanni.gsfc.nasa.gov (GES DISC, 2015).

Understanding of vertical profile and subtypes of aerosols is now possible with CALIPSO satellite. This information is very helpful for weather forecasting and climate modeling. CALIPSO satellite has been launched on April 28, 2006 with the collaboration of NASA and CNES (Winker et al., 2007). The active and passive remote sensing sensors on board CALIPSO have the capability to acquire data during both day and night times. It measures backscattered radiations at 532 nm and 1064 nm. CALIPSO data can be obtained via the website: http://www-calipso.larc.nasa.gov (CALIPSO, 2015).