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Optical exploration of biomass burning aerosols over a high-altitude station by combining ground-based and satellite data

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ABSTRACT

Biomass burning activity captured the attention of the scientific community because of its significant impact on global climate change. In this paper, we present the results of a study of variations in aerosol optical, microphysical and radiative properties during biomass burning at an high-altitude rural station, Sinhagad (18°21'N, 73°45'E, 1450 m AMSL), employing ground-based observations of MICROTOPS-II and short-wave (SW) Pyranometer, as well as satellite (MODIS) measurements of AOD during 28 April 2011–06 May 2011. Vertically resolved feature mask images from CALIPSO during night-time on available days are utilized as an additional tool to monitor the smoke/dust vertical distributions. A prominent smoke/dust layer is observed between 2 and 4 km altitude, whereas the CALIPSO observations of the vertical profile of aerosols are in qualitative agreement with the values of MODIS-$AOD_{550\ nm}$. During the smoke/dust event, a drastic increase (~0.9) in Terra/Aqua MODIS $AOD_{550\ nm}$ is observed. Satellite data indicate a long-range transport of aerosol particles from Indo-Gangetic Plains (IGP) over large regions. The observed short-wave solar flux at the bottom of the atmosphere (BOA) is found to decrease due to aerosol extinction and was found to be −25 and −16 Wm^{-2} for the aerosol-laden days and normal days, respectively. In addition, the transport of a wide-spread forest fire plume is observed across the country as evidenced by the MODIS imagery and HYSPLIT back trajectories. The observed features are also explained on the basis of the results from the NCEP/NCAR and ECMWF re-analysis data.

1. Introduction

Knowledge of particle emission characteristics from biomass burning is crucial for the quantitative assessment of the possible impacts of aerosols on climate. Characterization of the optical properties of biomass burning aerosols aids the study of radiative processes and remote sensing of both surface and atmospheric properties. Biomass burning has attracted the attention of people around the world due to its contribution of large amounts of particles and gases to the atmosphere (Dennis et al., 2002; Uherek, 2004), thus resulting in, most cases, exposure to high levels of air pollution (Schwela et al., 1999), and the impact of these emissions on human health, which have been linked to morbidity and mortality (Dockery

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et al., 1993; Levy et al., 2000; Peters et al., 2000; Samet et al., 2000a, b). These emissions also play a significant role in affecting atmospheric processes (Bodhaine, 1983; Shaw, 1987), such as radiation balance (Wurzler & Simmel, 2005), acidification of clouds, rain and fog (Nichol, 1997). The impact on the radiation balance of the Earth occurs both directly by absorbing and scattering incoming solar radiation and indirectly by acting as cloud condensation nuclei (CCN), and also by altering the cloud microphysical processes on a mesoscale (Kaufman et al., 1998; Wurzler & Simmel, 2005).

Pollution due to biomass burning is not only a local problem but also a regional and global problem. Each year, more than 100 million tons of smoke aerosols are released into the atmosphere as a result of biomass burning (Hao & Liu, 1994). More than 80% of this burning occurs in the tropical regions and these sub-micron smoke aerosols play a major role in the radiation balance of the Earth–atmospheric system (Balis et al., 2004; Kaufman et al., 1998). The smoke particles can travel even around the world (Damoah et al., 2004). Jaffe et al. (2004) demonstrated that long-range transport of Siberian biomass burning emissions can impact ozone in North America. Forster et al. (2001) reported the transport of emissions of Canadian fires to Europe. Badarinath et al. (2009) studied the effect of biomass burning episodes on aerosol optical properties over the Hyderabad region and pointed out that the enhancement in aerosol concentration is due to the transport of biomass burning in the downwind direction. Raghavendra Kumar (2010) reported the concentration of black carbon (BC) aerosols on burning days is almost twice than that on normal days; moreover, the share of BC to total mass concentration is ~5% during normal days and up to 12% during burning days over the Ananthapur region.

The majority of the biomass burning occurs mainly in the tropical continents such as Southeast Asia, southern Africa, South America and northern Australia. In tropics, biomass burning activity due to forest fires and agriculture crop residue burning inputs significant aerosol particles and trace gases into the atmosphere, which affects the atmospheric chemistry and radiative budget of the troposphere (Aghedo et al., 2007; Koren et al., 2007; Labonne et al., 2007). Gustafsson et al. (2009) highlighted that biomass burning is one of the main causes for dense "brown clouds (BC)" in South Asia and 50–90% of the South Asian BC originates from fossil fuel combustion (Stone et al., 2007; Menon et al., 2002). The major sources of biomass burning in India are from shifting cultivation, accidental fires, controlled burning, fire wood burning, burning from agricultural residues, burning due to fire lines, etc. Scientific interest in the impact of biomass burning on atmospheric chemistry grew when it became evident that it is an important source of atmospheric pollution (Crutzen & Andreae, 1990) and its products could affect large areas of the world as a consequence of long-range transport (Andreae, 1983). Long-range transport is one of the most important factors that control the spatial and temporal variability of the aerosol concentration. Although a large fraction of aerosols remains in the planetary boundary layer, particularly desert dust plumes and biomass burning plumes may be lifted into the free troposphere and transported over long distances, even between continents. During long-range transport from the source region to the far field, the microphysical, optical and radiative properties of aerosols are modified.

The size as well as the absorption and scattering properties of particles in the smoke are related to fuel type (grasses, shrubs, and tress), fire intensity, efficiency of combustion, and particle composition (Reid & Hobbs, 1998; Beegum et al., 2008; Badarinath et al., 2009). The emitted aerosol particles from biomass burning are a major source of cloud condensation nuclei, which affect the microphysics of boundary layer clouds and thus the radiation budget of the Earth by increasing the albedo (Penner & Novakov, 1996). Almost thousands of hectares of forests of the Indo-Gangetic Plain (IGP) regions are burned every year by forest fires. The fire season starts in March/April and continues up to June. The IGP is a very important agro-eco region in South Asia, which occupies nearly one-fifth of the total geographic area in four countries (Pakistan, India, Nepal, and Bangladesh). The IGP in India covers 20% geographical area and contributes ~42% to the total food grains production and holds nearly ~40% of the total population (Tripathi et al., 2005).

Measurements over high-altitude stations yield background levels of aerosol concentration (Dani et al., 2003; Sagar et al., 2004; Jain et al., 2007; Gautam et al., 2011; Chatterjee et al., 2012; Devara et al., in press). Hence, it would be possible to examine and assess the extent to which the 'clean' remote areas have been affected by growing urbanization/industrialization (Jaenicke, 1979). Biomass burning aerosol optical depth, in conjunction with long-range transport of air mass over remote areas, plays a pivotal role not only in understanding the regional climate change but also in serving as reference values for the quantitative estimation of pollutant concentration over surrounding environments. Moreover, modulation of background aerosols over high-altitude sites by local and wind-driven long-range transport of aerosols will act as an important input to air quality models. In the present study, we analyze, for the first time, the optical, microphysical and radiative properties of aerosols during biomass burning period over Sinhagad, India, using the ground-based measurements by Microtops-II, Pyranometer complimented with MODIS and CALIPSO satellite observations during 28 April 2011–06 May 2011. Moreover, wind back-trajectory analysis using HYSPLIT, fire image given by MODIS satellite and meteorological conditions from NCEP/NCAR and ECMWF re-analysis data have been carried out to explain the variations in AOD.

2. Experimental site

Figure 1 displays the map of the experimental site. The study area of Sinhagad (18°21'N, 73°45'E, 1450 m AMSL) is a historical fort situated on the hill at a mountain-top in the Western Ghats region. It is located about 40 km by road, to the south-west of Pune. Its top is a flat terrain with an area of about 0.5 km^2. Other mountain peaks of comparable height also located in its neighborhood. This part of the Western Ghats is covered with vegetation, grass and trees. The only major local source of pollution is wood burning, mainly for domestic cooking. A few people live at the summit and some tourists visit the area (by foot). A few vehicles, mainly cars, jeeps and two-wheelers, enter the mountain but they have to stop at the