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Impact of emissions from anthropogenic sources on satellite-derived reflectance

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Abstract

The present study deals with the impact of extensive anthropogenic activities associated with festivities and agricultural crop residues burning in the Indo-Gangetic Plains (IGP) on satellite-derived reflectance during November 2007. Intense smoke plumes were observed in the IRS-P4 OCM satellite data over IGP associated with agricultural crop residue burning during the study period. Terra-MODIS AOD and CALIPSO LIDAR backscatter datasets were analysed over the region to understand the spatial and temporal variation of the aerosol properties. Ground-based measurements on aerosol optical properties and black carbon (BC) mass concentration were carried out during 7–14 November 2007 over urban region of Hyderabad, India. Top of the Atmosphere (TOA) reflectance estimated from IRS-P4 Ocean Color Monitor (OCM) data showed large variations due to anthropogenic activities associated with crop residue burning and fireworks. Atmospheric corrections to OCM satellite data using 6S radiative transfer code with inputs from ground and satellite measurements could account for the variations due to differential aerosol loading. Results are discussed in this paper.

Keywords: Agriculture residue burning; Diwali fireworks; 6S; Aerosol; Smoke; LIDAR

1. Introduction

Atmospheric aerosols play a potentially important role in the Earth's climate system because of their direct interaction with solar and terrestrial radiation through scattering and absorption thereby modifying the Earth's radiation budget. The knowledge of spatial and temporal distribution of aerosols on a global scale is important to understand the dynamics of aerosols and the associated influence on global climatic conditions (Tripathi et al., 2005).

Globally, biomass burning is recognized as an important source of atmospheric pollution giving rise to the release of large quantities of gaseous emissions and particulate matter (Crutzen and Andreae, 1990). Each year more then 100 million tons of smoke aerosols are released into the atmosphere from biomass burning out of which 80% is in the tropical regions (Kharol and Badarinath, 2006). In India, forest fire biomass constitutes only 8% of total biomass consumption and contributes to 16% of BC and 33% organic carbon (OC) emissions (Reddy and Venkataraman, 2002). Earlier studies over Amazonian region have demonstrated that during the dry season, vast forest fires release the huge amounts of smoke, and consequently pyrogenic aerosol particles dominate the atmospheric aerosols over most of the Amazon Basin (Potter et al., 1998; Freitas et al., 2005) which causes pronounced seasonal changes over the region (Artaxo et al., 2002). In the Mediterranean basin, fire activity regularly affects several hundred thousand hectares with consequences on ecosystems and local air pollution (Lelieveld et al., 2002). Globally these fires release large amounts of greenhouse gases (Liu et al., 2005) and contribute to the reduction of world biodiversity through the extinction of species populations. Furthermore, anthropogenic emissions from forest fires

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have a negative impact on human health, as they contribute to respiratory and cardio-pulmonary diseases and mortality (Kharol and Badarinath, 2006).

In India, each year agricultural crop residues are burnt in IGP during October/November (Badarinath et al., 2006). The Indo-Gangetic Plains are one of the world's largest and highly agriculturally productive areas encompassing a vast area from 21.75°N, 74.25°E to 31.0°N, 91.50°E. The IGP is composed of the Indus (areas in Pakistan, and parts of Punjab and Haryana in India) and the Gangetic Plains (Uttar Pradesh (UP), Bihar, and West Bengal in India, Nepal and Bangladesh). It accounts for ~21% of the land area of Indian subcontinent and holds nearly 40% of the total population. In the IGP region nearly 12 million hectares account for rice–wheat crop rotation. Harvesting of these crops with combine harvesters is very popular among the farmers of Punjab, Haryana and Western Uttar Pradesh. Crop residues after harvesting get burnt in these areas because of the high labour wages and anxiety of the farmers to get the crops produce collected and marketed as early as possible. Residues burning in the rice–wheat-rotation procedure has resulted in pollutant emission, loss of nutrients, diminished soil biota, and reduced total N and C in the topsoil layer (Kushwaha and Singh, 2005).

Diwali is a major Indian festival, known as the "Festival of Lights," it symbolizes the victory of good over evil, and lamps are lit as a sign of celebration and hope for humankind. It usually occurs in October/November, and is one of the most popular and eagerly awaited festivals in India. On the occasion of this festival, people burn crackers and sparkles to express their happiness which is the most unusual source of aerosol and trace guesses. High concentrations of anthropogenic aerosols and metals are injected into the atmosphere due to burning of crackers and fireworks especially in urban regions. Fireworks mainly contain chemicals such as arsenic, sulfur, manganese, sodium oxalate, aluminium and iron dust powder, potassium perchlorate, strontium nitrate, barium nitrate and charcoal (Kulshrestha et al., 2004; Wang et al., 2007). Burning of fireworks releases pollutants, like sulfur dioxide (SO_2), carbon dioxide (CO_2), carbon monoxide (CO), suspended particles (including particles below 10 μm in diameter, i.e. PM_{10}) and several metals like aluminium, manganese and cadmium, etc., which are associated with serious health hazards. Due to the combined effect of Diwali fireworks and agricultural crop residue burning the entire belt of the Indo-Gangetic Plain was under influence of high aerosol loading during the study period.

The atmospheric effects due to anthropogenic perturbations contribute significantly to the signal received by a multi-spectral satellite sensor (Hadjimitsis et al., 2004). The atmospheric constituents affect the visible and near-infrared satellite signals modifying the spectral and spatial distribution of the radiation incident on the surface. The Second Simulation of Satellite Signal in Solar Spectrum (6S) radiative transfer model is widely used for atmospheric corrections to satellite data (Tachiri, 2005; Vermote and Saleous, 2006). It simulates the reflection of solar radiation by a coupled atmosphere–surface system for a wide range of atmospheric, spectral, and geometrical conditions. The parameters required to run the 6S radiative transfer model include AOD, water vapour and trace gases, etc. In the present study, the impact of anthropogenic aerosols on the satellite-derived reflectance over the Hyderabad region and its surroundings are studied using long-term satellite data from IRS-P4 Ocean Color Monitor (OCM) sensor, ground-based measurements and satellite-derived aerosol parameters. The main objective of the study is to estimate and correct for the effect of anthropogenic emissions on satellite-derived reflectance. Atmospheric corrections to satellite data were implemented using radiative transfer model with inputs on MODIS-derived AOD/water vapour/OMI-Ozone which were validated with ground observations.

2. Data sets and methodology

2.1. Ground-based measurements

AOD, water vapour and ozone measurement were carried out using a handheld multi-channel microprocessor-controlled total ozone portable sun photometer (MICROTOPS-II) instrument in the premises of the National Remote Sensing Agency (NRSA) campus located at Balanagar (17°.28′N and 78°.26′E), Hyderabad. The sun photometer performs measurements at six spectral bands centered on 380, 440, 500, 675, 870 and 1020 nm (Morys et al., 2001). The sun photometer works on the principle of measuring the surface solar radiation intensity in the specified bands and calculates the corresponding optical depths by knowing the respective intensities at TOA. The details about the design, calibration, and performance of MICROTOPS-II have been described elsewhere (Morys et al., 2001; Badarinath et al., 2007a).

Nighttime measurements of aerosol vertical profile were carried out using the portable micro pulsed LIDAR operating at 532 nm. The LIDAR laser output pulse energy was set at 10 μJ with 2500 Hz pulse-repetition rate (Klett, 1981). The laser system bin width was set at 200 ns, corresponding to a height resolution of 30 m. The raw data profile was integrated every 2-min interval. The design specifications of the portable LIDAR system are described elsewhere (Kumar, 2006).

Continuous measurements of black carbon mass concentration (BC) were also carried out using an aethalometer; model AE-21 of Magee Scientific. The instrument aspirates ambient air at the height of ~3 m above the ground with the aid of a pump. The BC mass concentration is estimated by measuring the change in the transmittance of a quartz-filter tape, on to which the particles impinge. The instrument had been operating at a time base of 5 min, continuously on the experiment days with a flow rate of 3 l min^{-1}. The instrument has been factory-cali-