Studies on aerosol properties during ICARB–2006 campaign period at Hyderabad, India using ground-based measurements and satellite data

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Continuous and campaign-based aerosol field measurements are essential in understanding fundamental atmospheric aerosol processes and for evaluating their effect on global climate, environment and human life. Synchronous measurements of Aerosol Optical Depth (AOD), Black Carbon (BC) aerosol mass concentration and aerosol particle size distribution were carried out during the campaign period at tropical urban regions of Hyderabad, India. Daily satellite datasets of DMSP-OLS were processed for night-time forest fires over the Indian region in order to understand the additional sources (forest fires) of aerosol. The higher values in black carbon aerosol mass concentration and aerosol optical depth correlated well with forest fires occurring over the region. Ozone Monitoring Instrument (OMI) aerosol index (AI) variations showed absorbing aerosols over the region and correlated with ground measurements.

1. Introduction

Atmospheric measurements on aerosols lagged behind as aerosols are an enigmatic yet indispensable component in global climate studies and modeling. Aerosol mass loading, optical properties, and their uncertainties in spatio-temporal distribution makes it difficult to quantify the aerosol impact on climate change with good accuracy (Kaufman *et al* 2002). Studying aerosol spatial distribution and dynamics is a great challenge, because of their shorter atmospheric lifetime (Zubko *et al* 2007) and their occurrence from a variety of sources. Atmospheric aerosols from natural and anthropogenic sources have important effects on the global and regional climate system because they scatter and absorb solar and thermal radiation (direct effect), modify the cloud optical properties acting as cloud condensation nuclei (CCN) (indirect effect), and change atmospheric radiative budgets (Haywood and Boucher 2000; Bellouin *et al* 2005). Atmospheric aerosols also affect the visibility impairment directly by both scattering and absorbing the solar radiation especially at the wavelength of visual range (Green *et al* 2000; Kim *et al* 2001).

The lack of globally distributed aerosol data limits the ability of chemical and radiative transport models. More studies and observations are needed to improve understanding of the complex nature of atmospheric aerosols and their effect on current and future climate changes (Hand *et al* 2004). Continuous and campaign-based field measurements are important to develop and support a network of systematic ground-based observations of aerosol properties in the atmosphere (Kaskaoutis and Kambezidis 2006; Kaskaoutis *et al* 2006). Intensive field experiments have been conducted throughout the world to examine the role of aerosols on climate change (Yu *et al* 2006). There are currently a limited number of measurements on aerosols available in the tropics to understand the radiative

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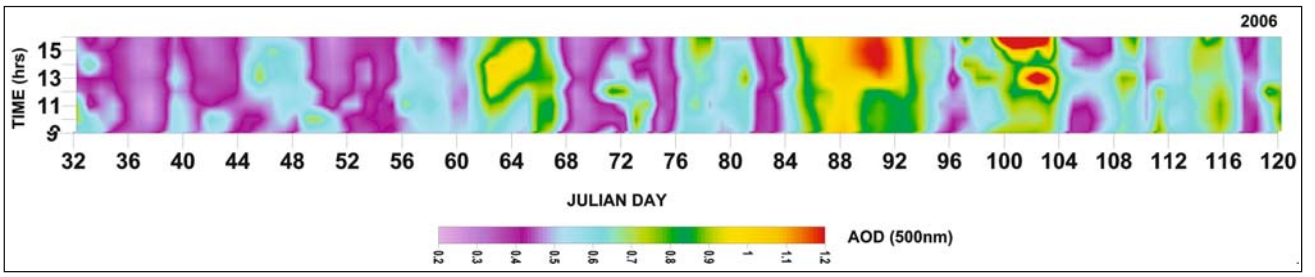


Figure 1. Julian day variation of aerosol optical depth (AOD) at 500 nm during February to April 2006 over Hyderabad.

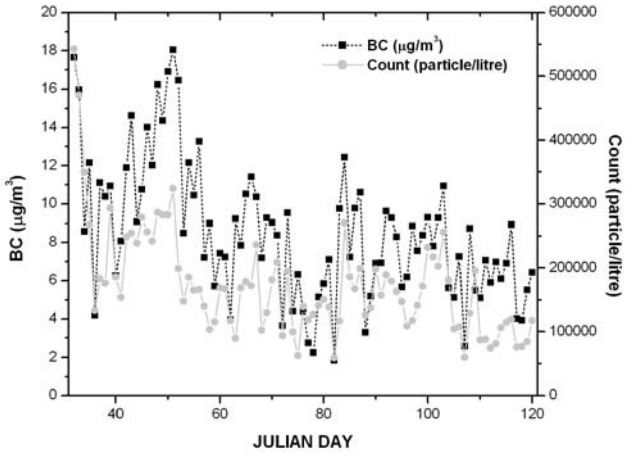


Figure 2. Julian day variation of black carbon aerosol mass concentration and aerosol number density during February to April 2006 over Hyderabad.

effects of aerosols (Krishna Moorthy *et al* 2005, 2007).

The present study describes the optical characteristics of atmospheric aerosols over urban regions of Hyderabad, India during ICARB–2006 campaign period. The study site is located on land midway between Bay of Bengal and Arabian Sea and provides a reference point for understanding observed variations in aerosol properties during the ICARB cruise period.

2. Study area

The study area of Hyderabad is located between 17°10′ and 17°50′N latitude and 78°10′ and 78°50′E longitude, in the southeastern part of the Indian region, approximately 300 km from the Bay of Bengal. Hyderabad is the fifth largest city in India; its population is 57,51,780 inhabitants according to the census of 2001. The description of the study area and climatology have been mentioned elsewhere (Badarinath *et al* 2007a, 2007c). India has a total geographical area of $32,87,590\,\mathrm{km}^2$ with a total forest cover of 67.5 million hectares under different climate zones (Kiran Chand *et al* 2006). All measurements for the study were carried out in the premises of the National Remote Sensing Agency (NRSA) campus at Balanagar (17°.28′N and 78°.26′E) located within the Hyderabad urban center.

3. Dataset and methodology

Synchronous and continuous observations of Aerosol Optical Depth (AOD) were carried out using a hand-held multichannel sun-photometer (Microtops-II, Solar Light Co., USA) at six wavelength bands centered around 380, 440, 500, 675, 870 and 1020 nm (Morys *et al* 2001) during ICARB–2006 (February–April) at Hyderabad, India. The sun-photometer works on the principle of measuring the surface-reaching solar radiation intensity at the specified wavelength bands and converts to optical depth based on the knowledge of the corresponding intensities at the top of the atmosphere (TOA). The TOA irradiances at each wavelength were calculated via the well-known Langley method, while the Kasten and Young's (1989) expression for the airmass was used. As per the details provided by the supplier, the calibration relies on a high-performance voltage reference with the temperature coefficient $>0.001\%$ per degree Celcius and long-term stability of $\sim 0.005\%$ per year. The full width at half maximum bandwidth at each of these wavelength channels is 2.4 ± 0.4 nm, and the accuracy of the sun-targeting angle is better than 0.1°. Great care has also been taken to avoid any error in sun targeting the MICROTOPS-II by mounting the instrument on a tripod stand. The details about the design, calibration, and performance of MICROTOPS-II have been described in Morys *et al* (2001). The detailed procedure for obtaining the AOD values from the Microtops-II sun photometer is described in Badarinath *et al* (2007a). Continuous and near-real-time measurements of the mass concentration of aerosol BC were carried out for February–April, 2006, using an Aethalometer; model AE021 of Magee Scientific, USA (Cooke *et al* 1997; Borak *et al* 2003)

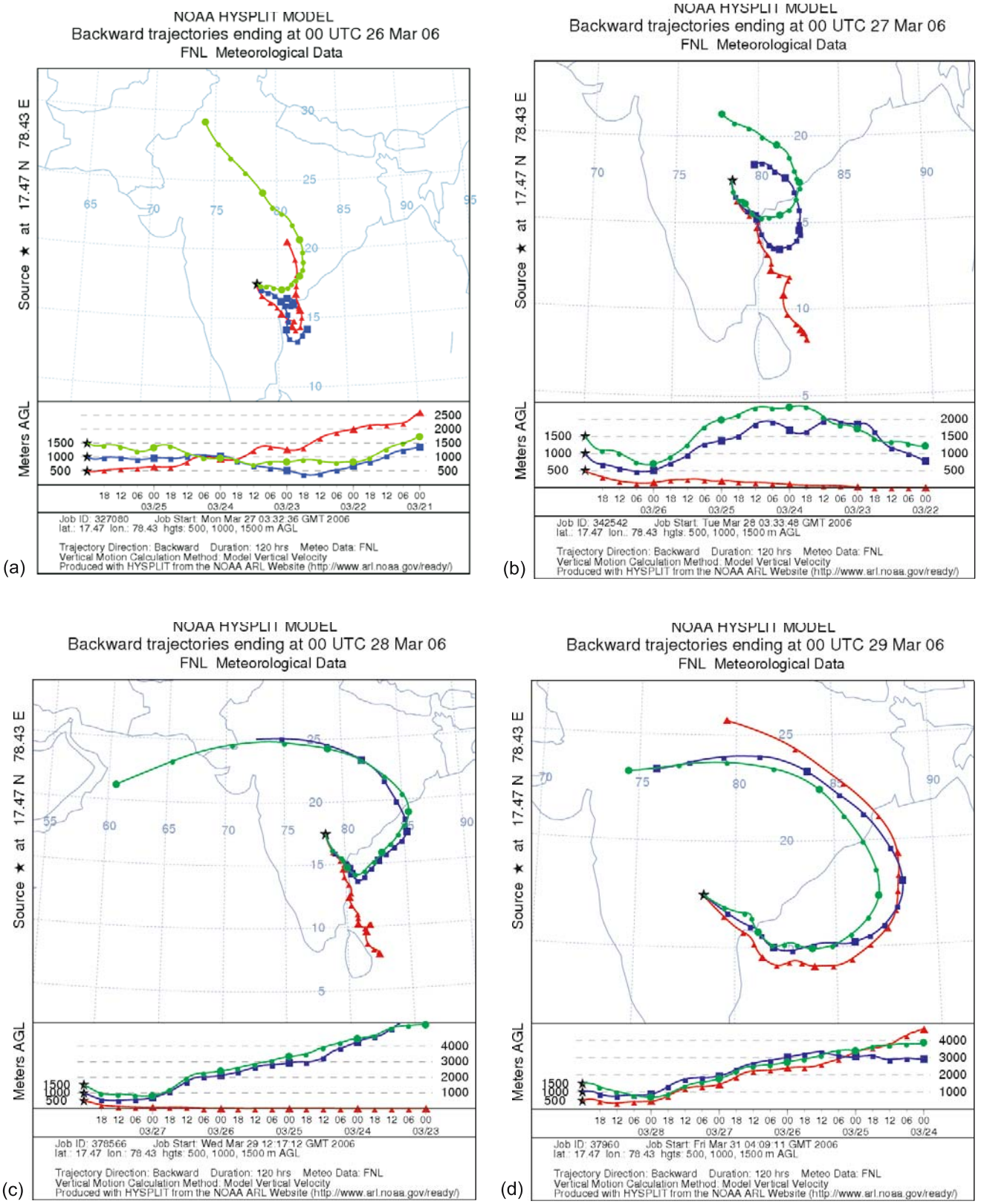


Figure 3. (*Continued*)

from a height of 3 m above the ground. The BC mass concentration is calculated by measuring the change in the transmittance of a quartz filter tape, on to which the particles impinge. The instrument was operated continually at a flow rate of 3 LPM using a 5-minute integration time. The

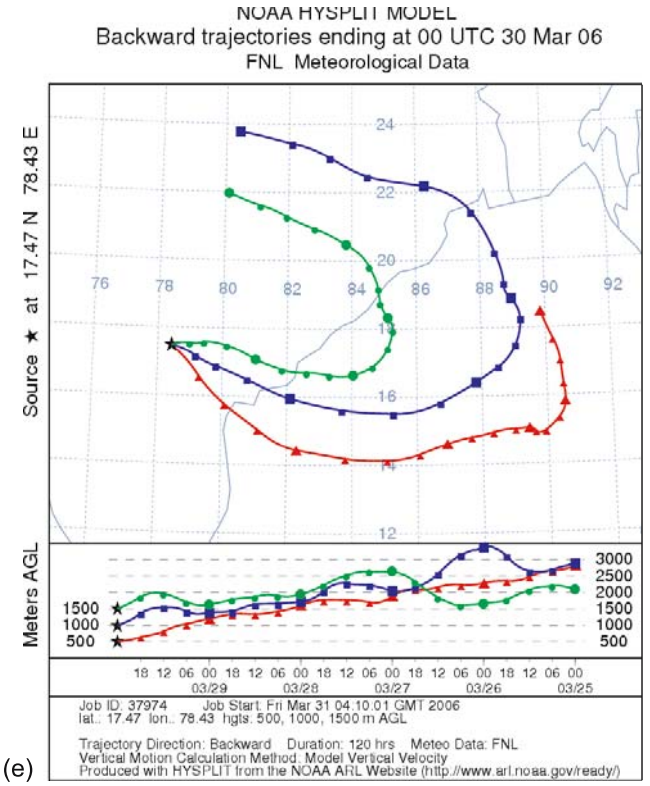


Figure 3(**a–e**). NOAA-HYSPLIT model run backward wind trajectory analysis at 500, 1000 and 1500 m altitude from 26–30 March, 2006 at Hyderabad, India.

instrument has been factory calibrated and errors in the measurements are approximately ±2%. Continuous measurements of particulate matter (PM) size distribution were carried out during February–April, 2006 using GRIMM aerosol spectrometer model 1-108 (Le Canut *et al* 1996). The GRIMM instrument works on the principle of counting the number of particles as it crosses a focused laser beam. Ambient air is drawn into the instrument by a mass flow controlled pump and passed through a light beam produced by a laser diode. Scattering induced by particles of various sizes is measured by a photo-diode detector, amplified and finally, binned to give the distribution of particulate matter in 15 different grain-size classes from 0.3 to 20 μm. The instrument is capable of counting particles from 1 particle l^{-1} of air to 2 million particles l^{-1} and the lower detectable mass is 0.1 μg m^{-3}.

Forest fires from biomass burning contribute to additional aerosols loading over the study region (Kharol and Badarinath 2006). We have analyzed night-time fire data from Defense Meteorological Satellite Program – Operational Line Scan System (DMSP-OLS) sensor (Elvidge *et al* 1997) to infer the forest fire characteristics over the Indian region. Daily datasets of DMSP-OLS for the period of February–April, 2006 provided via an automated subscription service from the NOAA National Geophysical Data Center (NGDC) in Boulder, Colorado, USA, were processed for active forest fire locations over the entire Indian region, including Hyderabad and its environs. DMSP operates F15 and F16 satellites in sun-synchronous orbits with night-time overpasses ranging from about 1900 to 2200 local time. The Indian region is observed in two or three OLS orbital passes from each of the satellites, as the swath width is 3000 km. The OLS is an oscillating scan radiometer with two spectral bands. The visible band pass straddles the visible and near-infrared portion of the spectrum (0.5 to 0.9 μm) and the thermal band pass covers the 10.5 to 12.5 μm region. At night, the visible band is intensified with a photo-multiplier tube (PMT) to permit detection of clouds illuminated by moonlight. Fire detection using DMSP-OLS night-time data is based on the identification of lights outside the set of known persistent light sources and a stable lights database over the Indian region is generated using a time series of OLS data. Basic procedures used to generate the stable lights image have been described by Elvidge *et al* (1997). The initial steps for generating OLS fire product, including the identification of lights and clouds, missing data, and bad scan lines, plus geolocation are fully automated and are described elsewhere (Elvidge *et al* 2001; Kiran Chand *et al* 2006).

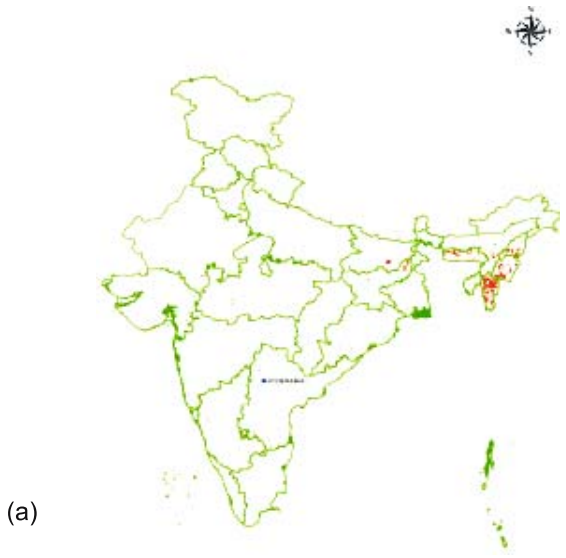
We have used aerosol index (AI) values from Ozone Monitoring Instrument (OMI) flown on the EOS Aura spacecraft, launched in July 2004. The absorbing AI from the current OMI sensor is defined as the difference between the measured (includes aerosol effects) spectral contrast at the 360 and 331 nm wavelength radiances and the contrast calculated from the radiative transfer theory for a pure molecular (Rayleigh particles) atmosphere (Levelt *et al* 2000; Ahmad *et al* 2003). The AI is calculated using the ratio of the upwelling radiance between observations at 331 and 360 nm as:

$$\mathrm{AI} = -100[\log_{10}(\mathrm{I}_{360}/\mathrm{I}_{331})_{\mathrm{meas}} - \log_{10}(\mathrm{I}_{360}/\mathrm{I}_{331})_{\mathrm{calc}}]. \quad (1)$$

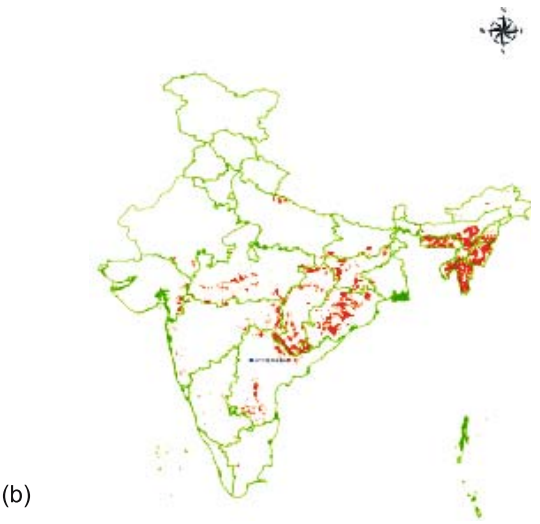
Since I_{360} calculation uses reflectivity derived from the I_{331} measurements, the AI definition essentially simplifies to:

$$\mathrm{AI} = 100 \log_{10} (\mathrm{I}_{360\_\mathrm{meas}}/\mathrm{I}_{360\_\mathrm{calc}}). \quad (2)$$

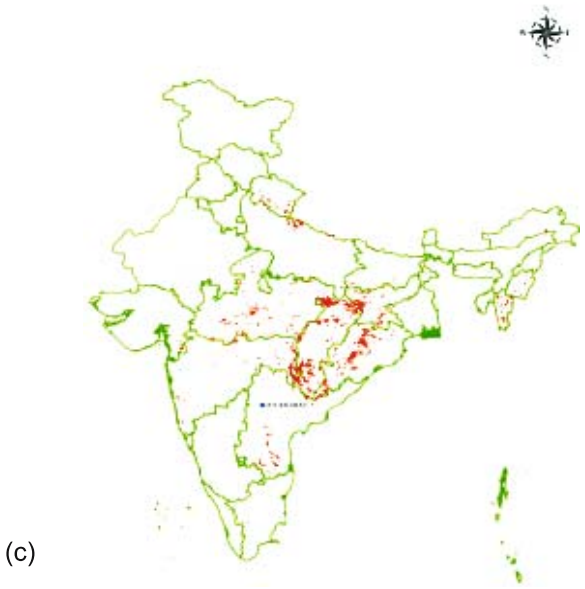
The AI detects dust, smoke and volcanic ash over all terrestrial surfaces including deserts and snow-ice covered surfaces (Torres *et al* 1998). Values of



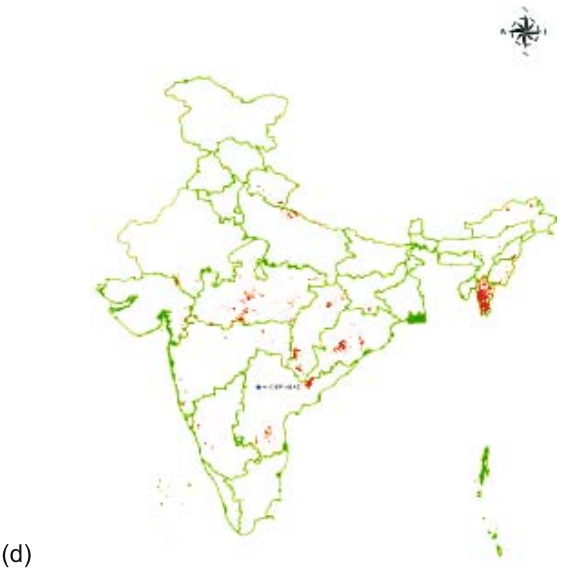
DMSP-OLS Nighttime forest fires during first fortnight of March, 2006



DMSP-OLS Nighttime forest fires during second fortnight of March, 2006



DMSP-OLS Nighttime forest fires during first fortnight of April, 2006



DMSP-OLS Nighttime forest fires during second fortnight of April, 2006

Figure 4**(a–d)**. DMSP-OLS night-time forest fires during March to April, 2006 over Indian regions.

AI near zero indicate cloud presence. In interpreting these results, care has to be taken as some surface effects, such as sea glint and ocean colour, can also enhance the AI.

4. Results and discussions

Julian day variations of aerosol optical depth at 500 nm showed large day-to-day variations (figure 1) with AOD_{500} values varying in the range of 0.2 to 1.2. It can be noticed from figure 1, that high AOD_{500} values occurred on certain days indicating an increase in the total column concentration of aerosols. The peak AOD_{500} values on certain days coincide with northerly flow component, associated with numerous forest fires during March–April, 2006 (shown in figure 4).

Julian day variations in Black Carbon (BC) aerosol mass concentration and aerosol number density (shown in figure 2) obtained during the period 09:00 to 16:00 h on each day, showed high values on certain periods during February to April, 2006. The higher values of BC concentration on

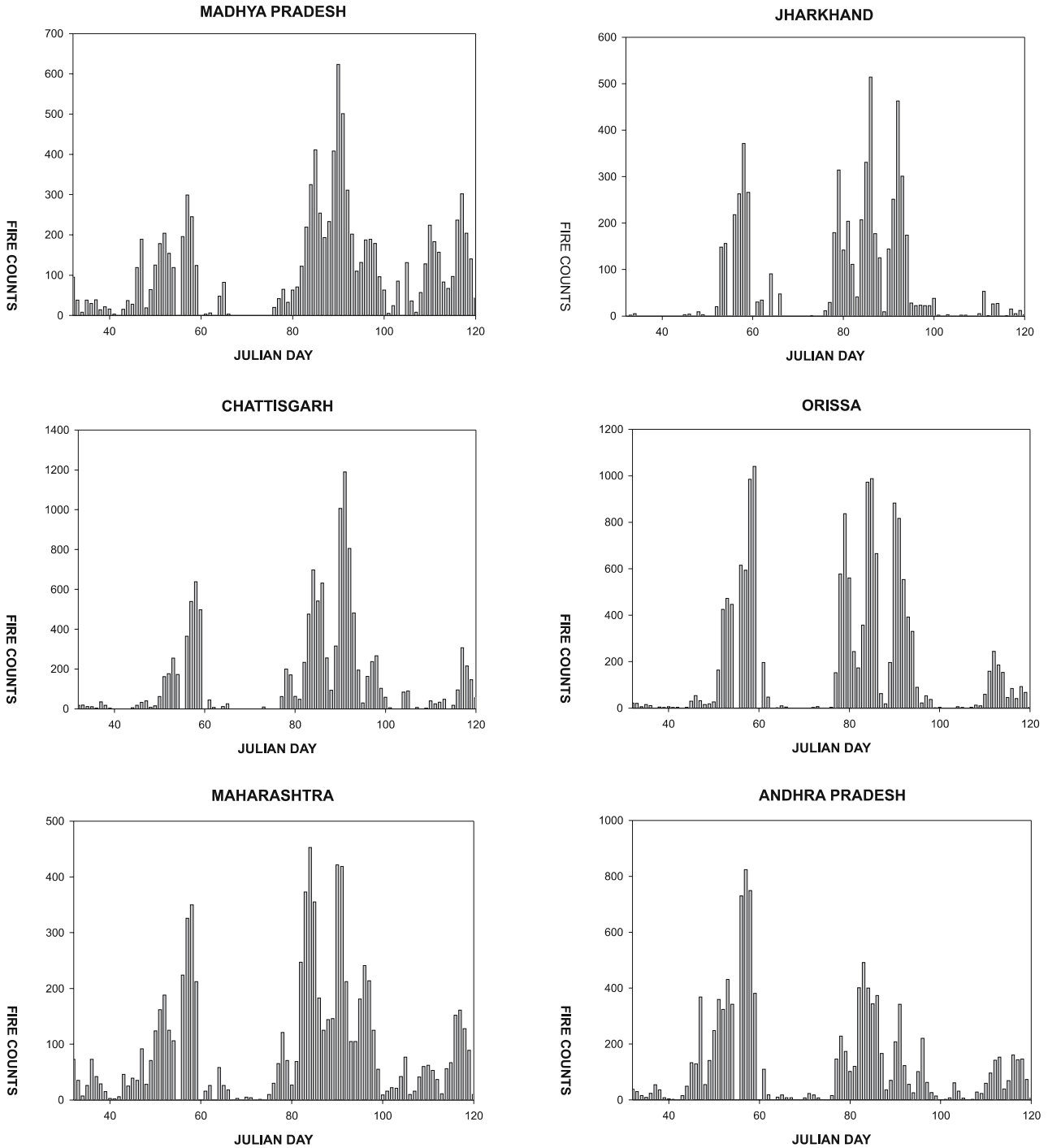


Figure 5. Julian day variation of DMSP-OLS night-time forest fire counts over Madhya Pradesh, Jharkhand, Chattisgarh, Orissa, Maharashtra and Andhra Pradesh during 2006.

certain days correlated with forest fires located in the north of the study area under favourable wind direction. BC values were observed to be four times higher than normal values during the last week of March 2006 and were attributed to emissions from forest fires towards north of the study area.

Back-trajectory analysis was also conducted using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) Model (version 4) developed at the Air Resources Laboratory, National Oceanic and Atmospheric Administration, USA (Draxler and Rolph 2003), at 500, 1000 and 1500 m altitude, ending at Hyderabad, India on 26–30 March, 2006 (shown in figure 3). It is clear from airmass back trajectories that the polluted airmass from forest fires

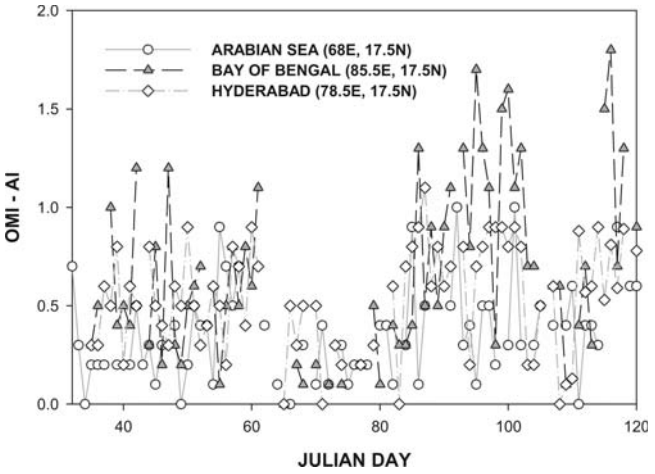


Figure 6. Julian day variation of OMI aerosol index (AI) over Arabian Sea, Hyderabad, and Bay of Bengal during the ICARB–2006 period.

originating from north of the study area influences the aerosol properties.

In India, forest fires which are anthropogenic in nature comprise a major source of atmospheric aerosols during February–April each year (Badarinath *et al* 2007b). In this context, DMSP-OLS satellite datasets were analyzed to detect night-time forest fires over the Indian region during February to April, 2006 to determine the sources of higher aerosol loading over urban regions of Hyderabad. Figure 4(a–d) shows fortnightly spatial variations of forest fires over the Indian region during March and April, 2006. It can be seen from the figures that occurrence of forest fires is more during second fortnight of March and first fortnight of April and during this period higher AOD values and BC concentrations occurred over Hyderabad. The additional loading of aerosols from forest fires is one of the contributing factors during favourable wind directions over the study area. Higher incidence of forest fires were observed over northeast regions of India, Chattisgarh, Orissa, Jharkhand, Andhra Pradesh, Maharashtra and Madhya Pradesh (figure 5) and these states are spatially located in favourable wind direction over the measurement site.

Figure 6 shows the Julian day variations of OMI aerosol index (AI) over the Arabian Sea (68°E, 17.5°N), Hyderabad (78.5°E, 17.5°N), and Bay of Bengal (85.5°E, 17.5°N) during the ICARB campaign period. It can be noticed from figure 6 that an increasing trend in AI values were observed over Bay of Bengal compared to Arabian Sea. AI values found to be high on certain days were attributed to additional absorbing aerosol loading due to forest fires and also due to dust storms during April 2006 (Badarinath *et al* 2007c).

5. Conclusions

Measurements of aerosol properties over urban regions of Hyderabad, India were analyzed using ground-based measurements and satellite datasets during the ICARB–2006 period. The results of the study suggested that:

- Aerosol optical depth (AOD) values were observed to be high on certain days suggesting additional aerosol loading due to anthropogenic disturbances. Occurrence of forest fires towards north of the study area correlated with high aerosol optical depth values with corresponding increase in accumulation mode particles and black carbon aerosol mass concentration.
- Black carbon (BC) mass concentration positively correlated with total particulate matter concentration ($r = 0.87$) over the study area.
- Aerosol index showed positive correlation with aerosol optical depth and correlation of the multi-datasets suggested that urban areas of Hyderabad are influenced by biomass burning in addition to anthropogenic vehicular pollution during fire season.

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