Aerosol characteristics at Patiala during ICARB–2006

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The spectral AOD measurements have been made for the first time over Patiala during multi-platform field campaign ICARB–2006 using a Multi-Wavelength Radiometer (MWR) along with the suspended particulate matter measurements with a high volume sampler. Spectral AOD has higher values in May in comparison to March and April. The monthly mean AOD values at 500 nm are 0.26 ± 0.08, 0.36 ± 0.19 and 0.58 ± 0.20 for the months of March, April and May respectively. The mean AOD is more during afternoon in comparison to forenoon at all wavelengths. The atmospheric turbidity is higher in May and is attributed to dust transported by southerly winds prevailing during this month. The Ångström parameter α varies between zero and 0.68 while β ranges from 0.1 to 0.9. The columnar water vapour content ranges from 0.12 to 2.92 cm, having a mean value of 1.06 ± 0.648 cm. The mean total suspended particulate matter is $334.41 \pm 97.56\,\mu$gm/m^3, an indication of high aerosol loading over Patiala during the campaign period.

1. Introduction

Aerosols produced by a variety of natural and anthropogenic sources exert both direct and indirect forcing on climate (Charlson *et al* 1992). The direct effect is due to absorption or scattering of the solar irradiance by aerosols and indirect influence modifies the cloud microphysical properties (Toon 2000). The magnitude of direct radiative forcing at any location and time depends on the amount of aerosols present, their physical and optical properties and underlying surface albedo (Hansen *et al* 1997; Satheesh and Ramanathan 2000; Houghton *et al* 2001). In Punjab, urbanization, industrialisation and changed agricultural practices have contributed significantly to an increase in the concentration of different types of aerosols. Systematic studies for aerosol characterisation and their impact on radiation budget are practically non-existent in this part of India. Realising the need for such studies, a Multi-Wavelength Radiometer (MWR) was set up at the Punjabi University Campus, Patiala (30°–21.5′N, 76°–27′) in March 2006 under the ISRO-Geosphere Biosphere Programme (IGBP).

Patiala (249 m asl), being at the centre of the agrarian region of northwest India, is close to Shivalik Hills in the east and Thar Desert in the southwest. It is surrounded by industrial cities Ludhiana and Gobindgarh in the northwest and Ambala in the east. This region suffers with severe fog, haze and smog which are due to increasing anthropogenic activities (Singh *et al* 2004). It is thus important to monitor the aerosol parameters and its variability over this site and compare the data with other locations to infer the relative contribution of anthropogenic activities and natural sources to aerosol loading.

Regular measurements for spectral aerosol optical depths (AODs) and columnar water vapour content (W) were carried out on all clear, hazy and partially cloudy days during the integrated campaign for aerosols, gases and radiation budget over India (ICARB) from March–May 2006. The present paper details the results of AOD

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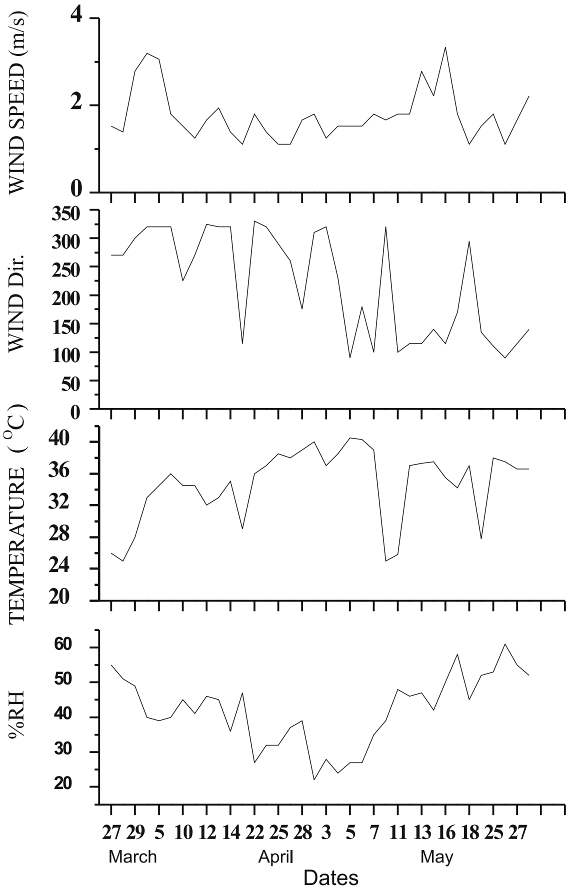

Figure 1. Temporal variation of daily mean relative humidity (RH), temperature, wind speed and wind direction.

measurements obtained during this period. The data are supplemented by suspended particulate matter measurements carried out with a High Volume Sampler (HVS; Envirotech make).

2. Observations and analysis

2.1 *Prevailing meteorology*

The weather conditions over Patiala during the campaign period remained dry with moderately low values of relative humidity in the range of 22 to 62% (figure 1). The daytime temperature varied from 24°C to 40°C. The temperature was maximum during April and the slightly lower temperature during May is attributed to the obscuring of sunlight due to high haze that persisted continuously for many days. The prevailing wind was north-westerly during April but changed to south-easterly during May and wind speed ranged between $1\,ms^{-1}$ and $3\,ms^{-1}$. Out of the total 69 days of observing period, the sky was almost clear for 7 days, clear but hazy for 13 days, partially cloudy for 19 days and overcast for 31 days.

2.2 *Spectral AOD measurements*

An MWR along with necessary electronics and software for data acquisition at regular intervals and for automatically tracking the Sun, has been designed and developed by the Space Physics Laboratory, Thiruvananthapuram. It takes measurements of the ground reaching solar flux as a function of the solar zenith angle at ten wavelengths, centred at 380, 400, 450, 500, 600, 650, 750, 850, 935 and 1025 nm and having FWHM ranging from 6 to 10 nm. Field limiting optics restrict the FOW to 2 degrees before falling on to the solid-state photo detector. Krishna Moorthy *et al* (1999), describe more details of the instrument and the principle of data reduction and error budget. Spectral AOD values were estimated following the Langley Plot technique applied on spectral measurements (Shaw 1973). The software to calculate the AOD and columnar water vapour content (W) has been provided by SPL Thiruvananthapuram.

2.3 *Mass loading measurements*

The mass loading of total suspended particulate matter (TSPM) near the surface was measured using a high volume air sampler, which first separates the coarser particles (> 10 microns) from the air stream before filtering it on a filter paper at a flow rate of $1\,m^3\,min^{-1}$. The coarser particles were collected in a separate sampling bottle under the cyclone. To avoid clogging of the filter paper, sampling of TSPM was limited to a maximum of twelve hours.

3. Results and discussion

3.1 *Aerosol optical depth*

The temporal variations of the spectral aerosol optical depth estimated are shown in figure 2. The AOD values are more at shorter wavelengths than at longer wavelengths. It also reveals considerably higher values of AOD during May as compared to March and April. During May, most of the time, southerly winds carry dust particles from the Rajasthan side (Sikka 1997) leading to hazy conditions.

The monthly mean variations of spectral AOD for the months of March, April and May are shown in figure 3. Mean AOD values at 500 nm were estimated to be 0.26 ± 0.08, 0.36 ± 0.19 and 0.58 ± 0.20 respectively during these months.

The full day spectral AOD measurements were separated into forenoon (FN) and afternoon (AN) data sets. The AOD values when calculated for forenoon (FN) and afternoon (AN) parts of the

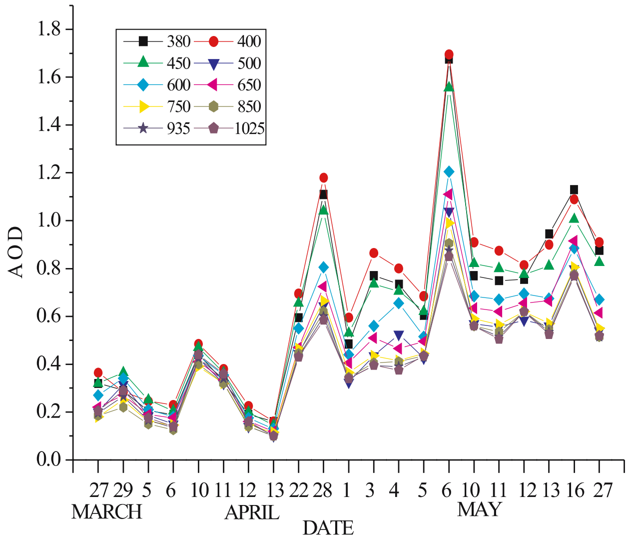

Figure 2. Temporal variation of daily mean spectral AODs over Patiala during ICARB.

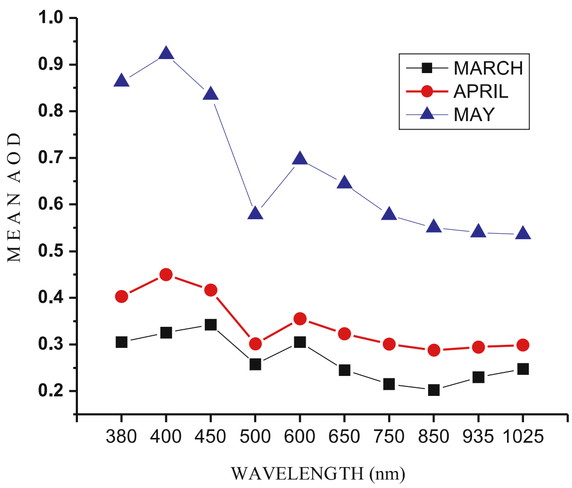

Figure 3. Monthly mean variation of spectral AOD over Patiala during ICARB.

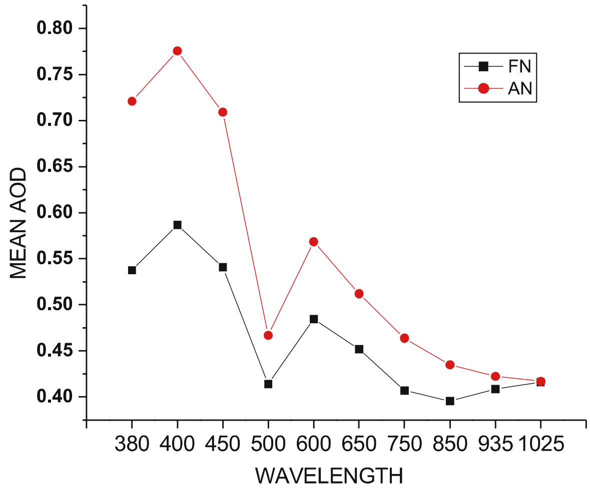

Figure 4. FN and AN variations of mean AOD.

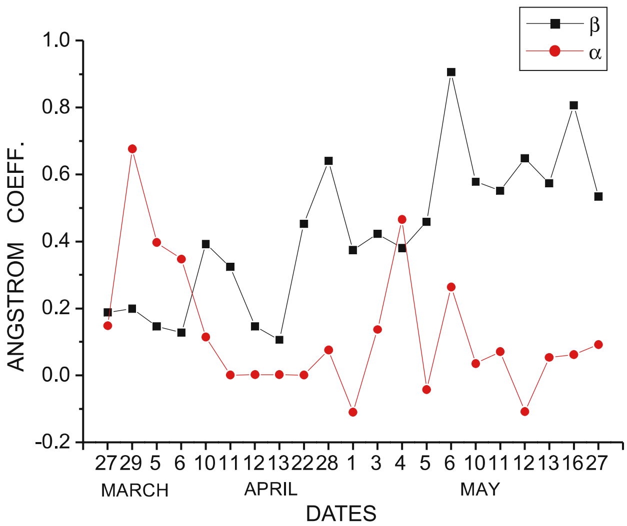

Figure 5. Temporal variations of Ångström parameters.

same day give distinctly different AODs. Analysis of AOD measurements for such days shows higher values of mean AOD during afternoon as compared to forenoon at all wavelengths during the study period (figure 4) and ranges between 0.4 and 0.58 during forenoon and 0.43 and 0.78 in the afternoon. Higher values of AOD in the afternoon are due to the fact that the atmosphere remains convective for a longer duration as compared to the forenoon.

3.2 *Ångström parameters*

Aerosol optical depths contain information pertaining to their size distribution (Satheesh *et al* 2001). A simple way of expressing the wavelength dependence of AOD is through the Ångström relation (Ångström 1964), expressed as:

$$\tau_{p\lambda} = \beta\lambda^{-\alpha}$$

where $\tau_{p\lambda}$ is AOD at wavelength λ, and α, β are Ångström turbidity parameters. The wavelength exponent α is an index for the aerosol size distribution and depends on the ratio of the concentration of small to large aerosols while β denotes the aerosol concentration present in the vertical column. The values of α and β evaluated by linear least square fitting of $\tau_{p\lambda} - \lambda$ estimates on a log–log scale are shown in figure 5. There is an overall increase of turbidity parameter β during the month of May as compared to March and April and the reverse is true for α with few exceptions.

Higher turbidity during May is attributed to the dust transportation from the Rajasthan side by

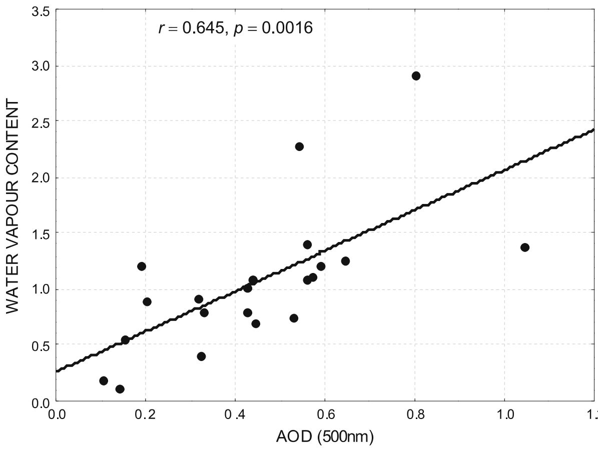

Figure 6. Correlation of water vapour content with AOD at 500 nm.

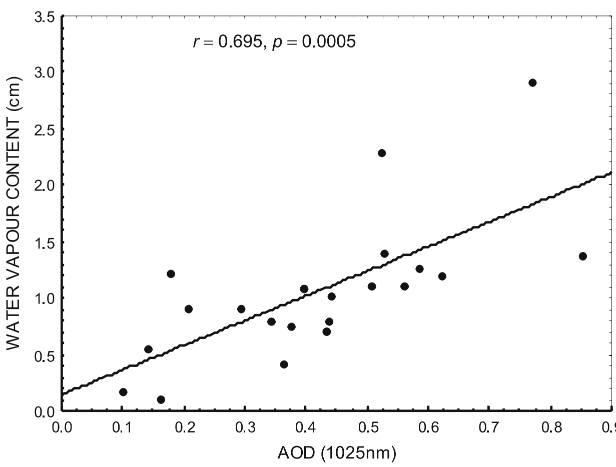

Figure 7. Correlation of water vapour content with AOD at 1025 nm.

southerly winds and occasional dust storms that raise the dust/sand particles into the atmosphere. The estimated α in the present study ranges from nearly zero to 0.68 while β ranges from 0.1 to 0.9. Values of α close to zero or sometime negative in the second half of April and in the month of May indicate the dominance of coarse particles during this period.

3.3 *Columnar water vapour content*

Temporal variations of columnar water vapour content (W) evaluated during the study period show an overall increase from March to May and varies from 0.12 to 2.92 cm, having a mean value of 1.06 ± 0.648 cm. Scatter plots of AOD at 500 nm (figure 6) and 1025 nm (figure 7) *versus* W show positive correlation coefficients 0.645 and 0.695 (p-levels = 0.0016 and 0.0005) respectively at 95%

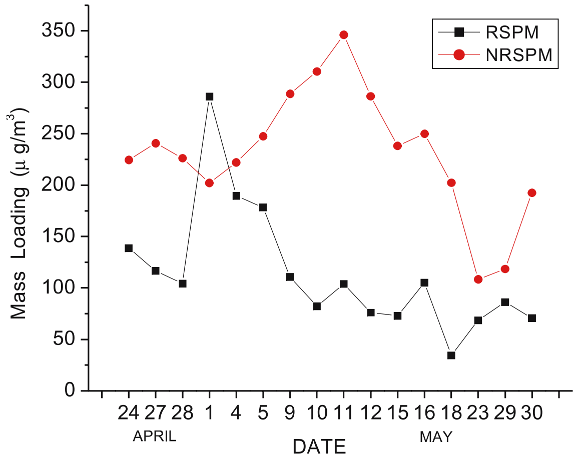

Figure 8. Temporal variations of RSPM and NRSPM.

confidence limits. Moderately higher correlation at 1025 nm is due to the fact that the higher water vapour content helps in the formation of larger particles through coagulation.

3.4 *Suspended particulate matter (SPM)*

The temporal variations of the RSPM ($< 10\,\mu$m) and NRSPM are shown in figure 8. Mass concentration of RSPM varies from 34.4 μgm/m^3 to 189 μgm/m^3 with a mean value of $112.27 \pm 61.54\,\mu$gm/m^3 while NRSPM mass varies between 108.42 μgm/m^3 and 346.2 μgm/m^3 with a mean value of $222.14 \pm 69.97\,\mu$gm/m^3. Because of the continued presence of haze and dust, there is an overall low concentration of RSPM as compared to NRSPM during the month of May.

4. Conclusion

The monthly mean AOD values at 500 nm are 0.26 ± 0.08, 0.36 ± 0.19 and 0.58 ± 0.20 for the months of March, April and May respectively. Temporal variations of spectral AOD show higher values in May in comparison to March and April at all wavelengths. The estimated AOD values at shorter wavelengths are higher than those measured at longer wavelengths. There is an asymmetry in FN and AN spectral AOD values. The mean AOD is more during AN as compared to FN at all wavelengths. The Ångström parameter α varies between zero and 0.68 while β ranges from 0.1 to 0.9. Higher turbidity during May is attributed to dust transported from the Rajasthan side. The mean value of water vapour content is 1.06 ± 0.648 cm. The mean values of RSPM and NRSPM are 112.27 ± 61.54 and $222.14 \pm 69.97\,\mu$gm/m^3 respectively.

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References

Ångström A 1964 The parameters of atmospheric turbidity; *Tellus* **16** 64–75.

Charlson R J, Schwartz S E, Hales J M, Cess R D, Coakley J A, Hansen J E and Hoffman D J 1992 Climate forcing by anthropogenic aerosols; *Science* **255** 423–430.

Hansen J, Sato M and Ruedy R 1997 Radiative forcing and climate response; *J. Geophys. Res.* **102** 6831–6864.

Houghton J T, Ding Y and Griggs D J 2001 IPCC: Climate change 2001 – the scientific basis, Intergovernmental Panel on Climate Change, Cambridge University Press.

Krishna Moorthy K *et al* 1999 Aerosol Climatology over India, 1-ISRO GBP MWR Network and Database, ISRO GBP SR-03-99.

Satheesh S K and Ramanathan V 2000 Large difference in the tropical aerosol forcing at the top of atmosphere and Earth's surface; *Nature* **405** 60–63.

Satheesh S K, Krishna Moorthy K and Das I 2001 Aerosol spectral optical depths over the Bay of Bengal, Arabian Sea and Indian Ocean; *Curr. Sci.* **81** 1617–1625.

Shaw G E, Reagan J A and Herman B M 1973 Investigations of atmospheric extinction using direct solar radiation measurements made with multi-wavelength radiometer; *J. Appl. Meteorol.* **12** 374–380.

Sikka D R 1997 Desert climate and its dynamics; *Curr. Sci.* **72(1)** 35–46.

Singh R P, Dey S, Tripathi S N, Tare V and Holben B 2004 Variability of aerosol parameters over Kanpur, northern India; *J. Geophys. Res.* **109** D23206, doi:10.1029/2004 JD004966.

Toon B D 2000 How pollution suppress rain; *Science* **287** 1763–1764.

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