Reprinted from *Current Science*

Ground-based lidar study of aerosol and boundary layer characteristics during INDOEX first field phase

P. C. S. Devara*, P. E. Raj, R. S. Maheskumar, K. K. Dani and G. Pandithurai†

Physical Meteorology and Aerology Division, Indian Institute of Tropical Meteorology, Dr Homi Bhabha Road, Pune 411 008, India
†Present address: University of Maryland, College Park, MD 20742, USA

This paper presents the extensive observations of atmospheric aerosol vertical distributions that have been carried out during the first field phase (FFP) of the Indian Ocean experiment (INDOEX–FFP 98) using the computer-controlled Argon-ion lidar system at the Indian Institute of Tropical Meteorology (IITM), Pune, a tropical urban station in India. These observations primarily will help explaining the teleconnections between the inland aerosol characteristics, and the marine aerosol properties observed from the ORV *Sagar Kanya* cruise during the same period. Vertical profiles of night-time aerosol concentration up to about 7 km above ground level were obtained on 25 days during the INDOEX–FFP 98 (17 February–31 March 1998). These profiles have also been utilized to investigate the nocturnal structure and stratification of the planetary boundary layer and associated air quality. The aerosol vertical distributions and the associated aerosol columnar content show significant day-to-day variations, particularly in the nocturnal boundary layer (NBL) and exhibit increasing trend during the study period. The derived ventilation coefficients are found to associate more closely with wind speed as compared to mixing depth.

THE central theme of the INDOEX programme is to assess the role of the Inter-Tropical Convergence Zone (ITCZ) in the transport of aerosols and their resultant forcing on land–atmosphere–ocean coupled system. It is evident from the studies in the past that marine aerosol characteristics undergo drastic changes as the continental air advects over ocean water depending mainly on the strength of marine air mass, particularly in the ITCZ region, and their space-time gradients play significant roles in the above assessment[1,2]. Therefore, observations of aerosol distributions over the land in conjunction with those over the oceanic regions are essential and greatly help in understanding the nature and extent of mixing of continental polluted air with the pristine marine air. With this objective, the Argon-ion lidar at IITM, Pune (18°32′N, 53°71′E, 559 m AMSL) has been operated during the INDOEX–FFP 98, and atmospheric aerosol vertical profiles were obtained on 25 days. Besides the altitude structures of aerosol concentration, the NBL parameters such as mixing depth, stable layer height and ventilation coefficients have also been derived from the aerosol profiles. In this paper, the experimental details, data analysis techniques and results are presented.

Lidar observations and analysis

The lidar system used in the present study consisted of a tunable Argon-ion laser as a transmitter and a 250 mm Newtonian telescope with condensing-collimating lenses, a narrow-band interference filter (1 nm FWHM) and a Peltier-cooled PMT as a receiver. The transmitter and receiver are coaxially separated by a distance of about 60 m in order to operate the system in the bistatic mode, the unique configuration which provides angular distribution of scattered intensity for obtaining aerosol size distribution. The on-line control and digital data system provides real-time acquisition, analysis and display of lidar data. The lidar experiment was conducted after sunset on 25 days during the INDOEX–FFP 98, i.e. between 17 February and 31 March 1998. The scattered intensity profile (covering the altitudes between 50 m and 6.8 km) obtained from each day's observations has been converted into aerosol number density profile using the inversion method detailed elsewhere[3,4]. The pibal wind observations on the days of the lidar experiments were collected from the IMD, Pune which is ~ 3 km (aerial distance) away from the lidar experimental site. From each profile of aerosol number density, columnar aerosol content and normalized concentration gradient profiles were computed for studying trends in the short-term changes in aerosol content and air quality during the period of observations.

Results and discussion

The possible aerosol type present over the station is a mixture of water-soluble, dust-like and soot-like aerosols. The major source of aerosols over Pune is soil–dust

---

*For correspondence. (e-mail: devara@tropmet.ernet.in)

carried by winds. Aerosols in the accumulation range are formed by gas-to-particle conversion processes from the land surface whereas coarse aerosols are attributed mainly to wind-blown dust. Since the conversion of trace gases by solar radiation is the main reason for the diurnal variation of aerosols in the Aitken nuclei range which behave more like pollutants, the particulate levels are low during night-time as compared to daytime. Although the average concentration of aerosols over the experimental station is high, they render the pH of rainwater alkaline as they are potentially basic in nature[5].

The observational period represents fairly the transition between the winter and pre-monsoon meteorological conditions. Generally, fair weather conditions with clear skies and very low relative humidity exist during the winter months over the experimental site. Low-level inversions and dust–haze in the morning hours occur during this period. Also, an incursion of dry polar continental air in the wake of low-pressure systems (western disturbances) moves across the far north-western parts of the country, and an onset of high dust content which leads to dust storms occurs during this period as well.

Space-time distribution of aerosol concentration

Figure 1 shows the aerosol number density profiles obtained, almost on every clear day, with lidar up to 6.8 km of the atmosphere during night-time for the period from 17 February to 31 March 1998. The two striking features that can be seen from these profiles are: (i) rapid decrease of aerosol number density up to about 150 m and thereafter exponential decay with increase in altitude; and (ii) stratified, fine-scale layer structures above the NBL. The first feature is a regular phenomenon seen in almost all the profiles of aerosol number density at this experimental site because of the effect of terrain, while the second is mainly due to stratified turbulence resulting from wind shear[6].

The mean aerosol number density profile obtained during the period of observations is shown in Figure 2. The deviations in aerosol concentration from the mean concentration at each altitude of measurements are depicted with horizontal lines in the figure. The daily distributions appear well-reproduced in the average profile, and the profile is quite stable and consistent.

Day-to-day variation in aerosol loading

Figure 3 displays the daily variation in lidar-derived aerosol columnar content estimated for the altitude region of 50–1200 m from the corresponding aerosol number density profiles. The variations in aerosol content are significant and show an increasing trend which may arise from meteorological conditions prevailing over the station. A polynomial regression analysis reveals an increase of about 20% in the aerosol loading at the station over this

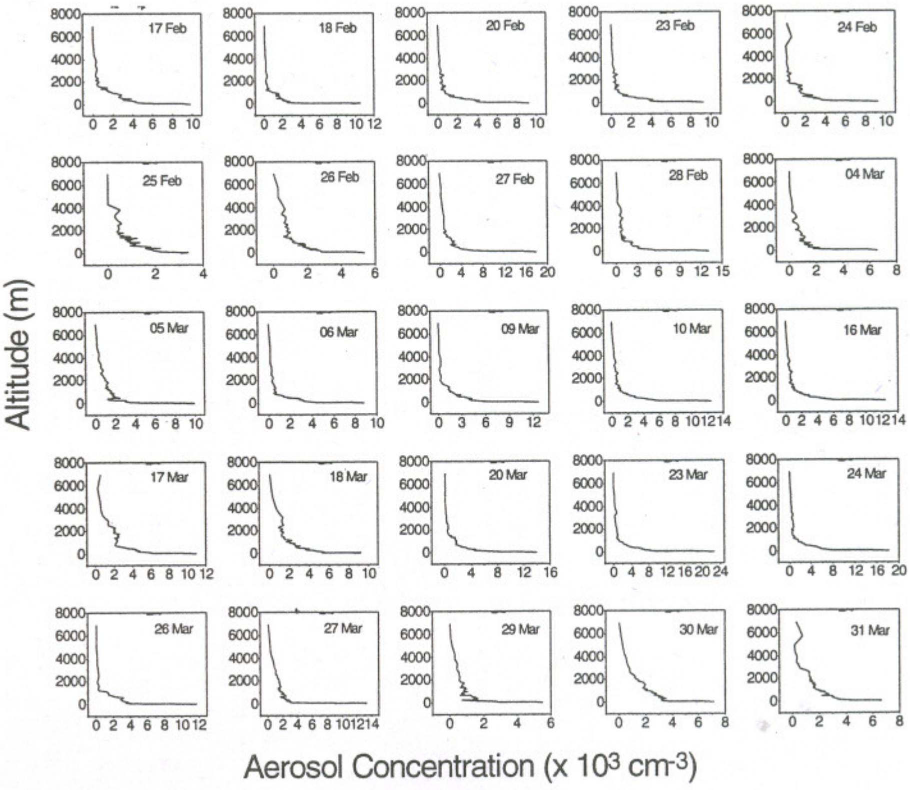

Figure 1. Day-to-day variation in vertical distribution of aerosol number density during the INDOEX–FFP 98.

short period. This increase in aerosol content is reasonable and also expected as the air mass undergoes considerable changes from winter to pre-monsoon months over the experimental station.

Aerosol structure, stratification and pollution potential

The inhomogeneities in aerosol content, which have a direct bearing on aerometric variations, can be used as tracers of the structures and stratification of the atmospheric boundary layer and associated environmental pollution potential. Aerosols which are lifted during daytime due to convective activity would be suspended for a considerable amount of time in the lowest layers of the atmosphere, and those emitted near the surface would be confined to lower levels during night-time. As the convective activity decreases, radiative cooling at the surface induces stable stratification near the ground, sometimes

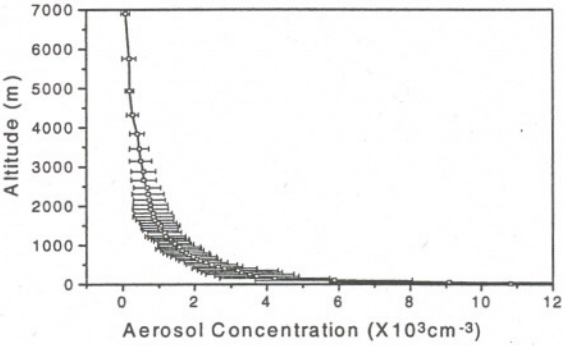

Figure 2. Mean profile of aerosol number density observed during 17 February–31 March 1998.

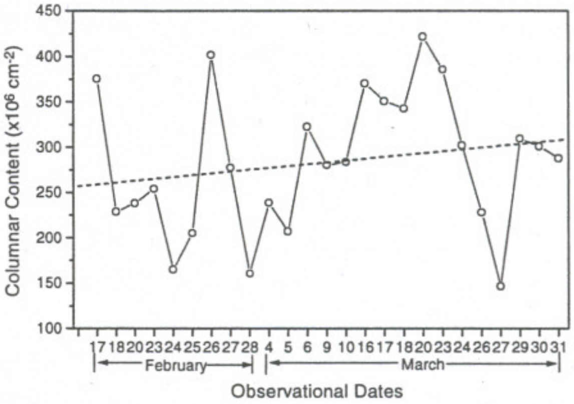

Figure 3. Day-to-day variation in aerosol column content. Dashed line indicates trend.

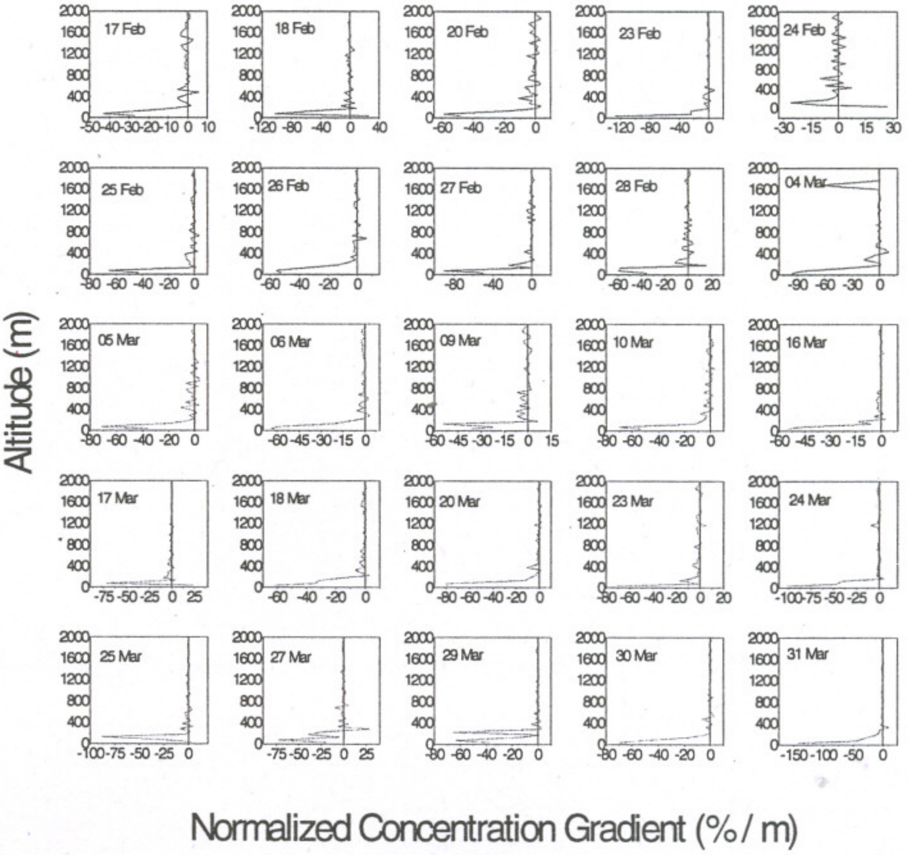

Figure 4. Vertical distribution of NCG corresponding to the profiles shown in Figure 1.

short period. This increase in aerosol content is reasonable and also expected as the air mass undergoes considerable changes from winter to pre-monsoon months over the experimental station.

Aerosol structure, stratification and pollution potential

The inhomogeneities in aerosol content, which have a direct bearing on aerometric variations, can be used as tracers of the structures and stratification of the atmospheric boundary layer and associated environmental pollution potential. Aerosols which are lifted during daytime due to convective activity would be suspended for a considerable amount of time in the lowest layers of the atmosphere, and those emitted near the surface would be confined to lower levels during night-time. As the convective activity decreases, radiative cooling at the surface induces stable stratification near the ground, sometimes

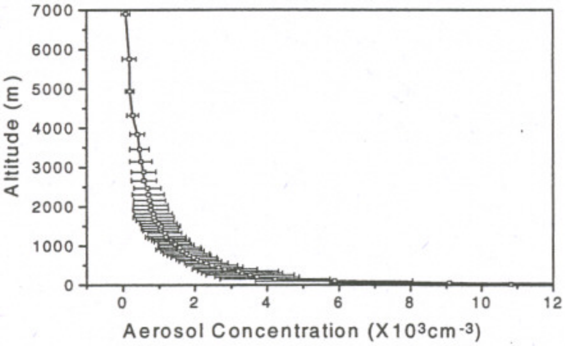

Figure 2. Mean profile of aerosol number density observed during 17 February–31 March 1998.

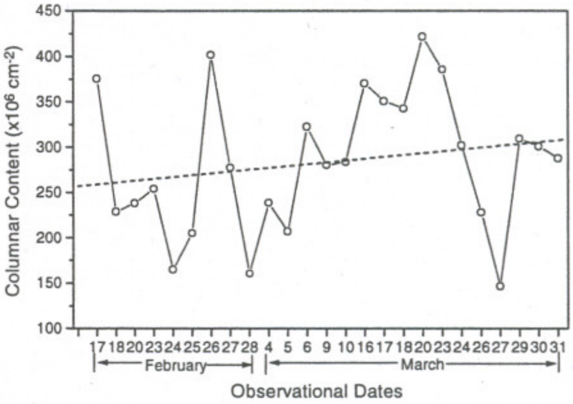

Figure 3. Day-to-day variation in aerosol column content. Dashed line indicates trend.

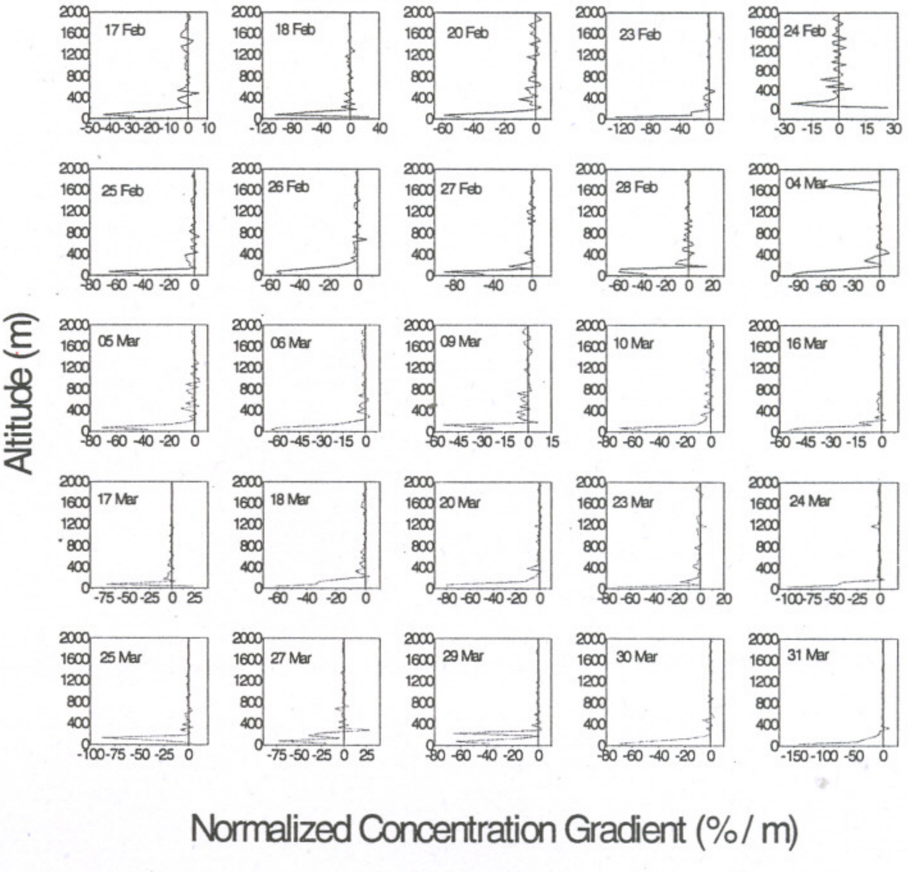

Figure 4. Vertical distribution of NCG corresponding to the profiles shown in Figure 1.

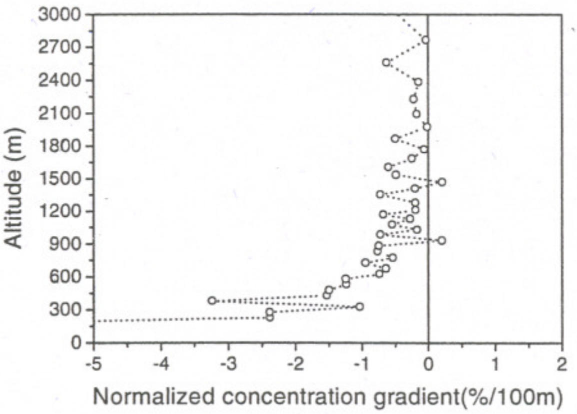

Figure 5. Mean profile of NCG observed during 17 February–31 March 1998.

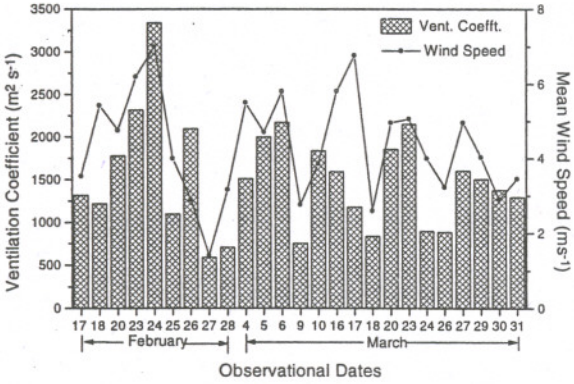

Figure 6. Co-variation between the ventilation coefficient and average wind speed during the INDOEX–FFP 98.

far above the NBL, and advection becomes increasingly important in determining aerosol concentration aloft.

Formation of aerosol layers in the atmosphere results in either heating or cooling of the combined earth-atmosphere system depending on the fraction of the incident solar radiation backscattered and absorbed by the aerosol layer. Thus aerosol layers affect the human life directly and the weather and climate indirectly on different time scales. With a view to studying such events, normalized concentration gradient (NCG) profiles have been derived from the vertical distributions of aerosol number density and are shown in Figure 4. The mean NCG profile obtained during the FFP 98 is shown in Figure 5. The largest negative gradient (decreasing concentration with increasing height) nearest the surface in lidar backscatter or aerosol number density is associated with the sharpest decline from high to low particulate concentrations and thus marks the mixing depth or mixed layer height; in addition, a significant positive NCG denotes the height of the stable layer. This method of deriving depths and stable layer heights is advantageous as it does not require absolute calibration of the lidar returns[7]. The profile clearly shows average mixed layer height around 375 m and stable layer height around 900 m.

Having derived the mixing depths, ventilation coefficients (product of mixing depth and mean wind velocity in the mixed layer), which represent the rate at which air within the mixed layer is transported and hence air pollution potential over a place have been computed. The higher the coefficients, the more the atmosphere is able to dispose off the pollutants. The ventilation coefficients thus computed using the lidar-derived mixing depth for each day's observation are plotted in Figure 6. The corresponding variations in average wind speed are also present in the figure to examine how and to what extent these variations as against the mixing depth are associated with those of the ventilation coefficient. As a result, the ventilation coefficient variations appear more closely associated with wind variations than that of mixing depth suggesting transport of pollutants is mainly due to wind field rather than temperature field.

Conclusions

The results of the study of vertical distributions of inland aerosol characteristics carried out with the ground-based Argon-ion lidar at Pune during the INDOEX–FFP 98 indicate: (i) variation in average aerosol concentration from 9000 to 74 cm^{-3} between the altitudes 50 m and 6.8 km; (ii) large negative height gradients in aerosol concentration up to about 200 m and thereafter exponential decay with an increase in altitude; (iii) increasing trend of about 20% in daily variation of aerosol columnar content, and (iv) average height of mixed layer around 375 m and that of stable layer around 900 m, with the average ventilation coefficient around 1613 m^2 s^{-1}. These ground-based continental aerosol observations are being synthesized to examine their relationship with the concurrent maritime aerosol data collected from the ORV *Sagar Kanya* cruise.

---

1. Hoppel, W. A., Fitzgerald, J. W., Frick, G. M. and Larson, R. E., *J. Geophys. Res.*, 1990, **95**, 3659–3686.
2. Prospero, J. M., *J. Geophys. Res.*, 1979, **84**, 725–731.
3. Devara, P. C. S. and Ernest Raj, P., *IETE Tech. Rev.*, 1987, **4**, 412–415.
4. Devara, P. C. S. and Ernest Raj, P., *J. Aerosol Sci.*, 1989, **20**, 37–44.
5. Khemani, L. T., Momin, G. A. and Singh, G., *PAGEOPH*, 1987, **125**, 167–181.
6. Devara, P. C. S. and Ernest Raj, P., *Atmos. Environ.*, 1991, **25**, 655–660.
7. Endlich, R. M., Ludwig, F. M. and Uthe, E. E., *Atmos. Environ.*, 1979, **13**, 1051–1056.

ACKNOWLEDGEMENTS. We thank the Director, IITM and Dr A. S. R. Murty for encouragement and support. We also thank Dr A. P. Mitra for his valuable suggestions. The pibal wind data support from the IMD, Pune, is gratefully acknowledged.