Aerosol measurements at Trombay relating to the 1995 solar eclipse

B. K. Sapra, Y. S. Mayya, V. D. Sawant and K. S. V. Nambi

Environmental Assessment Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

This study examines the effect of the solar eclipse on the characteristics of atmospheric environment, particularly on the aerosol concentrations at Trombay, Mumbai. Results of the measurements indicated 2–4 fold increases in the aerosol number and mass concentrations which occurred mainly in the sub-micron size range and were not noticeable above 1.0 µm. The increases occurred after a time lag of about 80 min from the beginning of the eclipse. These may be explained in terms of the combined effect of condensational growth due to increased relative humidity and a build-up of particle concentrations arising out of a suppressed level of atmospheric turbulence.

A total solar eclipse occurred on 24 October 1995. A study was undertaken to examine its effect, if any, on the characteristics of the atmospheric aerosols. The eclipse was total in Rajasthan, Uttar Pradesh and West Bengal and partial in Mumbai (72% obscurity) lasting from 0725 h (IST) to 0945 h with a peak at 0831 h. A total eclipse was last seen in India across the southern Indian peninsula on 16 February 1980. A large body of information exists on several atmospheric effects of the eclipse such as the solar radiation measurements[1–4], ozone levels[5], radon levels[6], atmospheric conductivities[7], etc. However, there exists no report of measurements on the eclipse-related behaviour of aerosols, although it is expected that cooling of the atmosphere due to reduced solar radiation intensity would result in increased aerosol levels. The need for these measurements arises from the fact that they are useful in interpreting the changes in the ground level radiation fluxes and atmospheric conductivities occurring during the eclipse. This also gives an idea of the response time of the atmospheric particles to the solar radiation changes. Besides, ambient aerosols can affect public health; from this point of view also, it is important to ascertain the change in aerosol levels, if any, during the solar eclipse.

Methodology

Several supporting measurements, viz. solar radiation variations, meteorological parameters and major pollutant levels were made, the details of which are published elsewhere[8]. However, here we emphasize the aerosol measurements as they have shown interesting changes. These were made at a height of about 10 m above the ground at the terrace of Modular Laboratory building inside Bhabha Atomic Research Centre on the day of the eclipse (24 Oct.) as well as on the preceding (23 Oct.) and succeeding days (25 Oct.) between 0700 and 1300 h. A brief description of the different monitoring instruments used and the observations made is as follows.

Mass-size distribution

The mass-size distribution measurements of the aerosols were carried out using the Quartz Crystal Microbalance Cascade Impactor (QCMCI), which is a near real-time measuring instrument operating at a flow rate of 0.24 lpm. It measures the suspended particulate matter (SPM) concentration (µg/m^3) and the mass distribution in ten size intervals with lower cut-off sizes at 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.5 and 25 µm. Size classification is achieved by impaction on quartz crystal substrates and estimating the deposited masses on each stage by relating them to the changes in the oscillation frequencies of the crystals. The measurements were made every ten minutes.

Number-size distribution

The number size distribution measurements of the aerosols were carried out using three different instruments at every ten-minute interval. Two of them were optical particle counters (OPCs of Met-One and Malvern), while the third was the automatic condensation nucleus counter (ACNC) developed indigenously[9].

The Met-One OPC is a single particle counter based on the principle of scattering of a laser beam by particles and operating at a sampling flow rate of 2.8 lpm. It monitors the number concentration (no./cc) in six size ranges with the lower cut-off sizes at 0.1, 0.2, 0.3, 1.0, 3.0 and 5.0 µm. The size classification is achieved by relating the scattered intensity from each particle to its size. The other OPC (Malvern) is a portable instrument which monitors the number concentration in 4 size intervals with lower size cut-offs at above 0.3, 1.0, 3.0 and 5.0 µm. It essentially works on the same principle and flow rate as the Met-One OPC, but uses a laser diode as the light source.

The total particle number concentrations in the entire size range (> 0.003 μm) were monitored using the ACNC. It works on the principle of condensing water vapour on otherwise undetectably small particles and allowing them to grow in sizes at which they are detected through scattering of light.

Results

Figure 1 *a* shows the variation of the SPM concentration with time beginning at 0700 h up to 1330 h (330 min) for the three days as per the protocol. On the days preceding and succeeding the eclipse day, the variations are similar and indicate a level ranging from 10 to 80 μg/m³. A general trend of decrease interspersed with minor peaks and troughs is seen as the day progresses. However, on the eclipse day, the behaviour is distinctly different and several phases of change are noticed. The mass levels were significantly high in the early morning (0700 h) which can be attributed to the haze that was observed that morning and then decreased rapidly to a low value at the time of the onset of the eclipse. The most noticeable aspect is the sharp increase to a value of 140 μg/m³ beginning at 0850 h and lasting up to 1020 h. The duration of this peak (≈ 90 min) is comparable to that of the eclipse (80 min), although it manifests after a time lag of about 85 min with respect to the beginning of the eclipse. This lag is to be qualitatively expected since the aerosol behaviour is coupled to several complex atmospheric processes related to the reduction in the solar intensity and consequent cooling. After this period, the levels remained higher than those found on the other two days. A size-resolved analysis of the data (Figure 1 *b*,*f*) indicates that a significant part of the increases observed during the eclipse period is attributable to the particles in the 0.1–0.4 μm MMAD range. For larger sizes, this increase progressively diminishes.

Similar results are obtained for the number size distribution of aerosols. The measurements by Met-One OPC in the size group above 0.3 μm, presented in Figure

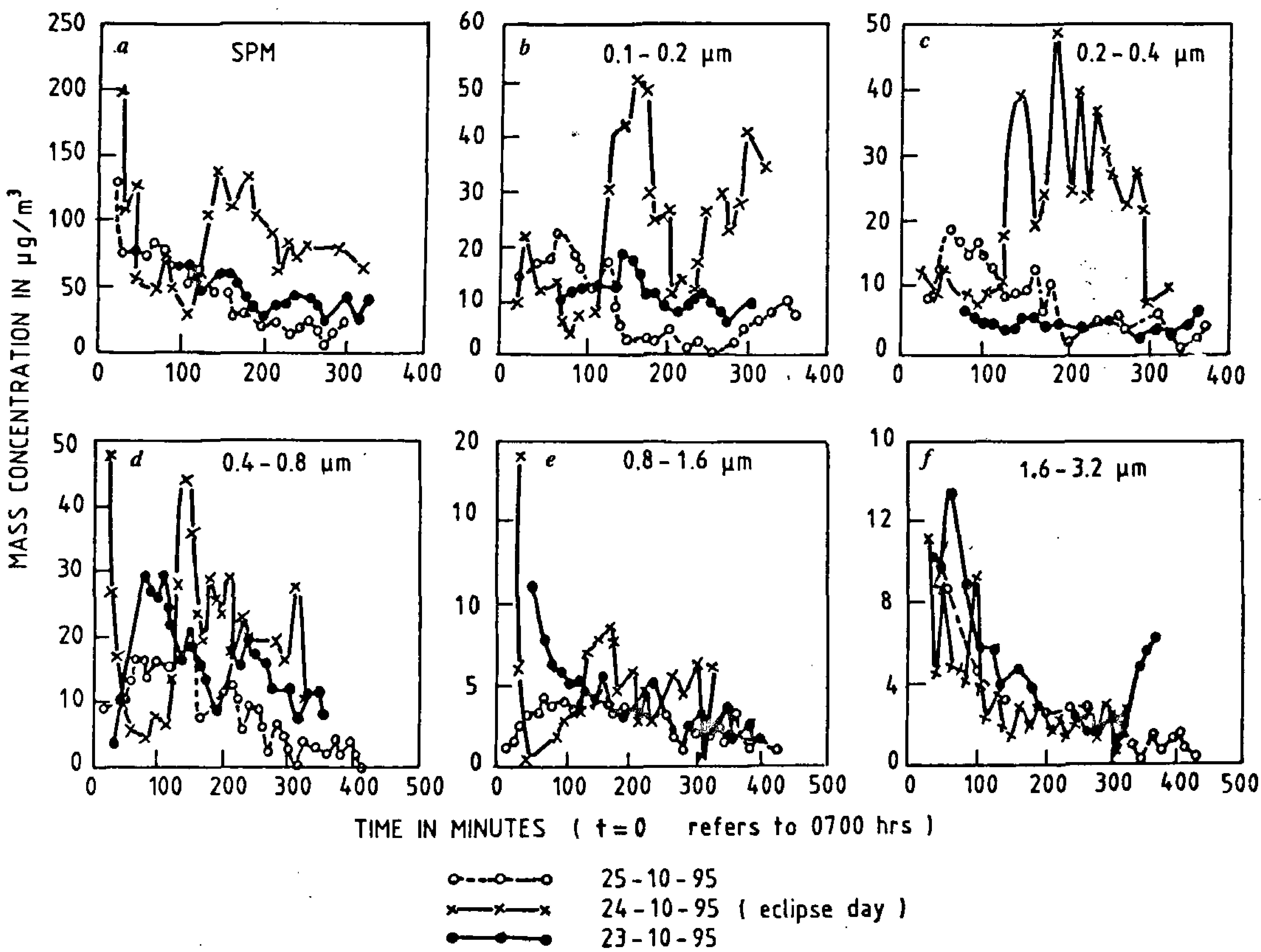

Figure 1. Temporal variation of mass concentration in different size groups as monitored by quartz crystal microbalance cascade impactor.

2 *a*, indicate that the concentration levels are low on the days preceding and succeeding the eclipse and there is a sharp peak corresponding to the eclipse period. The crest-to-trough ratio is about 3.5, similar to that observed for mass concentrations. The elevated concentrations during the haze period as well as in the post-ecliptic period are also reproduced here. Like in the case of QCM measurements, the size-resolved analysis (Figures 2 *b*, *e*) indicates a significant contribution to this increase from the size range of 0.3–0.5 μm. The results with the Malvern OPC in the size range > 0.3 μm, especially the peak number concentration observed during the eclipse period are also in conformity with those of the Met-One OPC.

The variation of the total number concentration of particles (> 0.003 μm) as measured by ACNC is shown in Figure 3. The overall trend including the concentration increase is similar to that observed with the other instruments, the main contribution in this case being from the ultrafine nuclei (< 0.1 μm) which are not recorded with the OPCs. The main difference is the appearance of a wider peak (≈ 160 min) with a greater lag time than that shown by the other instruments.

Discussion

The results indicate that an increase in the aerosol concentration (mass as well as number) did indeed occur between 0830 and 1030 h on the eclipse day which can be directly attributable to this phenomenon. The explanation, in all likelihood is contained in the time variation of the relative humidity (RH) and atmospheric turbulence profiles for that day. The temperature and humidity profiles for the eclipse day and the next day are shown in Figures 4 *a* and 4 *b* respectively. On the eclipse day, there is a definite cooling by about 2°C in the period between 0800 and 0900 h. Coincidentally, the RH was high (~90%) in the early morning hours of the eclipse day and is linked to the prevalence of the hazy conditions (which was not the case the next day). It decreased rapidly to 69% by 0800 h. Between 0800 and 0900 h, it showed an increase to a level of about 80%, consistent with the decrease in temperature. This can lead to condensation effects, especially on salt particles expected to be present in Trombay (situated on the sea coast), which manifest as increases in the number concentrations as well as in the mass concentrations. The former increase is due to the shift of very fine undetectable particles into the detection range of the OPCs and the latter includes the actual change in the mass of the particles due to water vapour condensation. It may be noted that the observed increases in concentrations (Figures 1–3) occurred after about 0840 h, but lasted much longer than the duration of humidity changes.

The observed changes will also be related to wind and turbulence conditions in the atmosphere. The wind

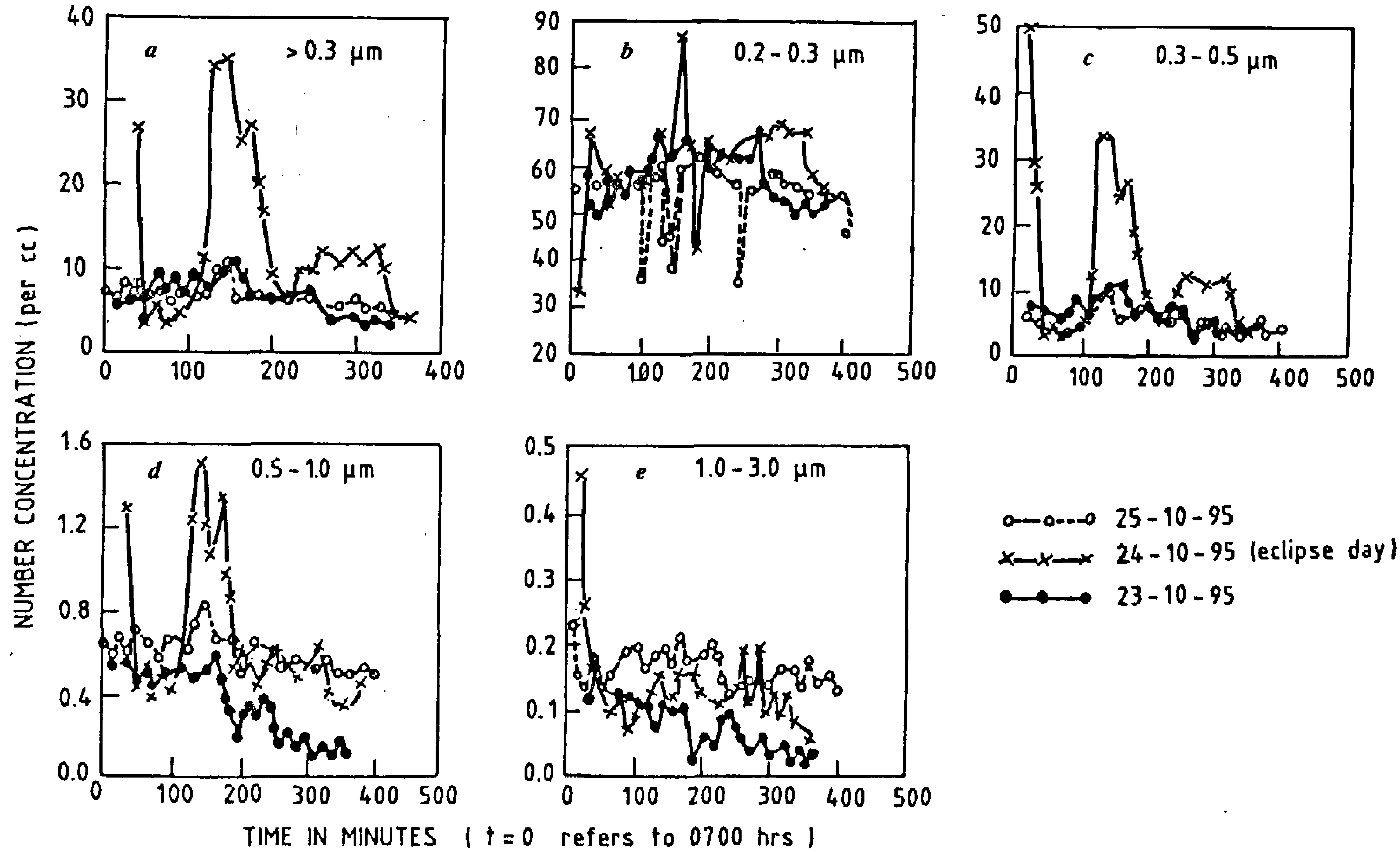

Figure 2. Temporal variation of particle number concentration in different size groups as monitored by optical particle counter.

speed, direction and standard deviation in the direction (σ_θ) are presented in Table 1 for the three days. As may be seen, both the wind speed and σ_θ were lowered during the eclipse period and calm conditions prevailed. Aerosol build-up under such conditions is a likely cause of the observed increases.

Another supportive argument for the prevalence of calm conditions and lower turbulence levels during eclipse is provided by the atmospheric back-scatter profiles up to a height of about 1000 m recorded by the SODAR (Sound Detection and Ranging) system installed at BARC. These are directly related to the thermal turbulence present in the atmosphere. The SODAR echograms for the time–height profiles showed lower back-scattered intensities (lower turbulence levels) at the ground level (below 200 m) during the eclipse period, in contrast to that on the next day during the same period. This would lead to an overall build-up of particle concentrations. The increase monitored by the ACNC (a significant part of which falls in the Aitken size range) which cannot be directly explained in terms of the humidity effects, is largely attributed to this build-up effect. A possible increase in the ground level rad concentrations as was observed during the earlier so eclipse[6] can lead to the production of small ions. Th can result in the enhancement of the concentration radon-generated-ion-induced nuclei in the presence water vapour that might be an additional reason for t increases observed with the ACNC.

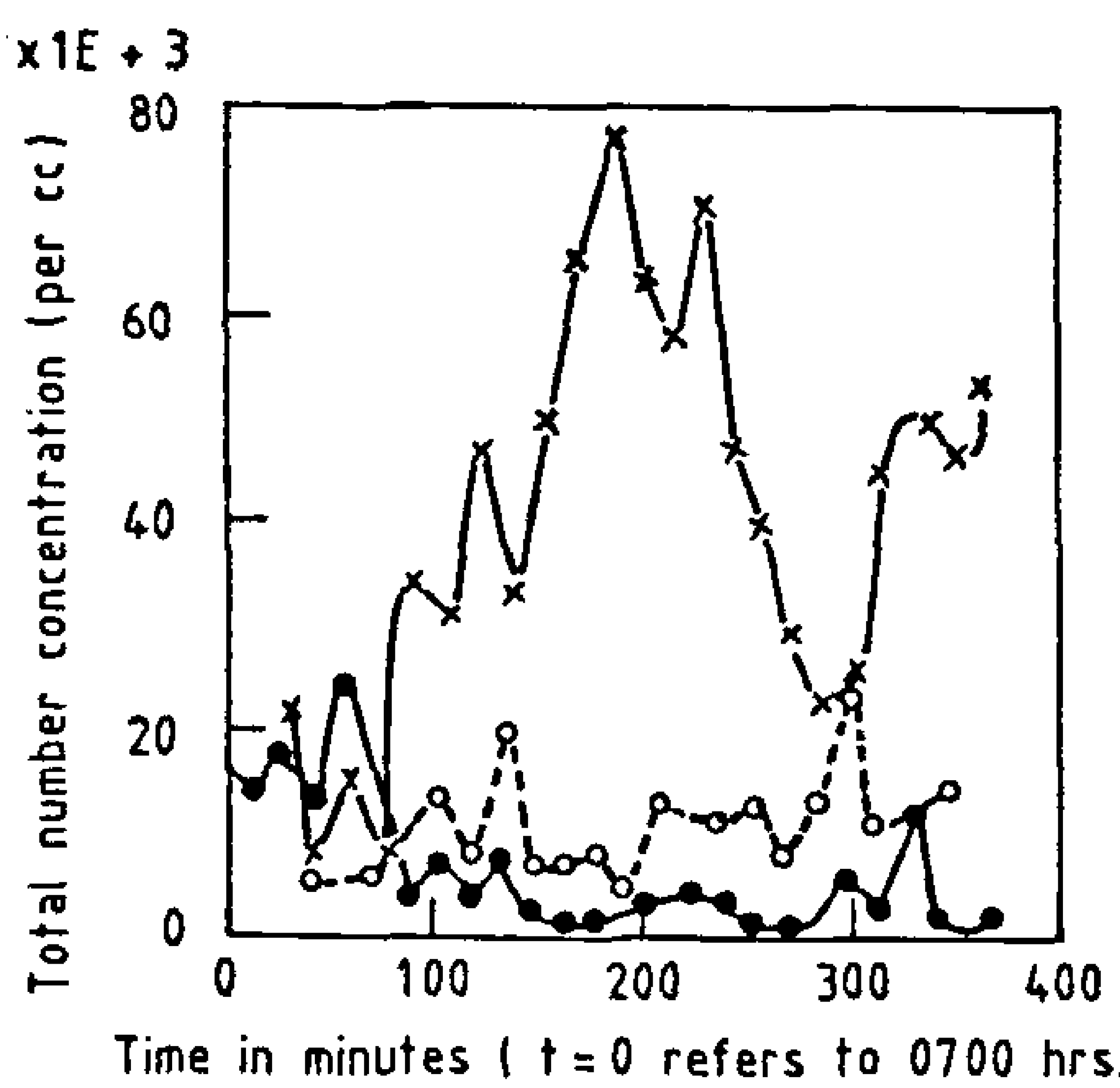

Figure 3. Temporal variation of total particle number concentration as monitored by automatic condensation nucleus counter. o– –o 25.10.95, x—x 24.10.95 (eclipse day), •– –• 23.10.95.

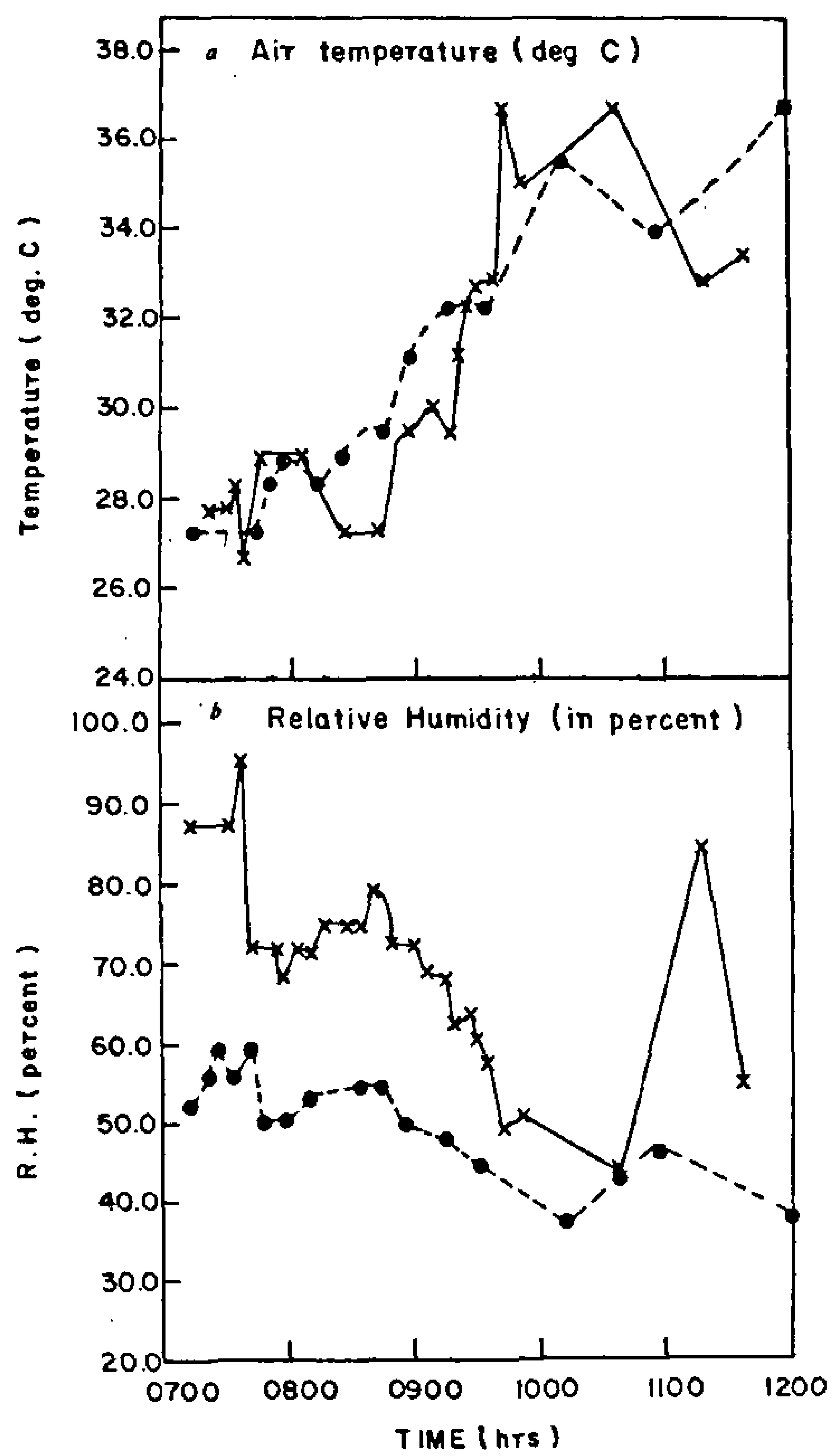

Figure 4. Temporal variation of (*a*) air temperature and (*b*) relat humidity. x—x 24.10.95 (eclipse day), •– –• 25.10.95.

Table 1. Results of wind measurements made during this study

	23 Oct. 1995			24 Oct. 1995			25 Oct. 1995		
Time (h)	Wind speed (km/h)	Wind dir.	σ_θ	Wind speed (km/h)	Wind dir.	σ_θ	Wind speed (km/h)	Wind dir.	σ_θ
0600	3	ENE	9	5	SSE	10.5	7	NNE	9
0700	4	ENE	9	2 (C)	E	4.5	7	NE	7.5
0800	5	ENE	10.5	3 (C)	E	7	5	ENE	9
0900	7	ENE	12	3 (C)	V	V	4	V	V
1000	7	NE	–	7	ESE	10.5	5	ENE	10.5
1100	7	ENE	–	6	ESE	8.3	8	ESE	10.5
1200	8	NE	–	5	SE	9	6	ESE	13.5

V: Variable; C: Calm; σ_θ: Standard deviation in the wind direction (in degrees).

As may be seen, there was a second increase in the mass and number concentrations at about 300 min (1100 h) on the eclipse day. At the same time, we note that the temperature showed a decrease (from 36°C to about 33°C) with a corresponding rise in humidity from 50% to 80%. This suggests a possibility of repeated condensational growth due to natural changes in meteorological conditions.

An important point to be noted while comparing the size-wise results of the OPCs with those of the QCM is the differences in the interpretation of the sizes. The OPCs refer to the light-scattering diameter which for spherical particles would be the geometrical diameter. The QCM, on the other hand, groups particles according to their aerodynamic diameters, which depend on the aerosol density. As the density is not clearly known in the present case (although a value of 1.5–1.8 g/cc might be appropriate for aerosol particles), size comparisons are made only to indicate the trends. Another point is that the changes in the number concentration implies generation or build-up of particles but does not give information on their growth due to condensation. On the other hand, changes in the mass concentrations include this aspect as well.

Conclusions

There does not exist previous data on aerosol build-up from direct measurements during solar eclipse. Nevertheless, this had been earlier inferred from the lowered atmospheric conductivity measurements[7]. The present studies provide a direct confirmation of the expected increases in the aerosol concentrations due to the build-up effect. Although the changes in the temperature and relative humidity are small during the eclipse, they seem to have an important bearing on the observed increases in the aerosol concentrations. Apart from this, suppression of ground level turbulence and also possible enhanced nucleation processes induced by radon-generated ions, could be other explanations for the observed increases.

1. Kapoor, R. K., Adiga, B. B., Singal, S. P., Agrawal, S. K. and Gera, B. S., *Proc. Indian Nat. Sci. Acad.*, 1992, **A48**, Part A, Suppl. 3, 224–233.
2. Srivastava, B. N., Sharma, M. C. and Talwar, R. S., *Ibid*, 131–134.
3. Chandrasekharan, C. K., Sarkar, A. B. and Kalipada Chatterjee, *ibid*, 143–149.
4. Desikan, V., Chandrasekharan, C. K., Rahalkar, C. G. and Srivastava, G. P., *ibid*, 150–158.
5. Chatterjee, K. and Ahuja, H. S., *ibid*, 125–130.
6. Kotrappa, P., Mayya, Y. S., Dua, S. K. and Gupta, P. C., *Health Phys.*, 1981, **40**, 559–560.
7. Manohar, G. K., Kandalgaonkar, S. S. and Ramanamurty, B. V., *Indian J. Radio Space Phys.*, 1985, **14**, 80–81.
8. Nambi, K. S. V. *et al.*, BARC Report: BARC/1996/E/006.
9. Sawant, V. D., Joshi, P. V., Nadgir, S. B. and Nair, P. V. N., *Indian J. Environ. Hlth.*, 1991, **39**, 171–181.

ACKNOWLEDGEMENTS. We thank Dr P. V. N. Nair and Dr T. M. Krishnamoorthy for useful discussions.

Received 5 November 1996; revised accepted 6 February 1997