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Aerosol Optical Depth and Size Distribution Changes During the Total Solar Eclipse of 24 October 1995

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ABSTRACT

This paper reports the results obtained from a study of the changes in aerosol spectral optical depths and size distribution during the total solar eclipse of 24 October 1997. These results were obtained from the measurements of ground reaching multispectral direct solar flux in the visible and near IR wavelengths using a Multi-Wavelength Solar Radiometer (MWR). During the maximum phase of the solar eclipse an increase in the aerosol optical depths has been observed at different wavelengths. The aerosol size distribution became modified into a monomodal distribution during the eclipse phase as compared to a regular bi-modal distribution. The observed changes are attributed to the changes in the surface meteorology due to the reduction in temperature and increase in humidity during the eclipse period.

(Key Words: Aerosols, Solar radiometer, Optical depth, Size Distribution, Solar eclipse)

1. INTRODUCTION

A network of 5 Multiwavelength Radiometers (MWR) is being operated in India for the evaluation of aerosol climatology over the region (Moorthy *et al.*, 1993). Visakhapatnam, on the east coast of India, is one of the network stations characterising a typical coastal industrial location (Niranjan *et al.*, 1997b). The aerosol system in a coastal industrial environment is complex due to the multiplicity of the sources and the effect of the surface meteorology on aerosol genesis. Short period changes in the form of forenoon - afternoon variation in aerosol spectral optical depth and size distribution have been observed at this location due to the mesoscale changes in the surface weather (Niranjan *et al.*, 1995). Though the reduction in the solar flux due to a solar eclipse does not affect the aerosol system directly, it is expected that the changes in the local weather viz., changes in the temperature, wind, humidity etc. may modulate the aerosol system in a coastal industrial environment. A study of such changes may provide a handle on the characterisation of the time evolution of the aerosol system. With these aspects in view, we have attempted to study the changes in the aerosol spectral optical depths and size distribution over Visakhapatnam (17.7° N, 83.3° E) during the total solar

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eclipse of 24 October 1995.

2. EXPERIMENT AND METHODOLOGY

The Multiwavelength Solar Radiometer used to measure the direct solar flux is based on the principle of filter wheel Radiometers (Shaw *et al.*, 1973). The system measures the intensity of incoming direct solar radiation at nine discrete wavelengths in the visible and near IR region namely 400, 450, 500, 600, 650, 750, 850, 940 and 1025 nm. The half power bandwidth of the filters is 5 nm. The system comprises of automatic data acquisition and sun tracking electronics and the details of the system and data analysis are available in Niranjan *et al.* (1997b). The solar flux measured at these different wavelengths is used to evaluate the total optical depths following the Langley technique, and aerosol optical depths are subsequently derived by subtracting the optical depths due to Rayleigh scattering and molecular absorption due to ozone and water vapour.

The direct solar flux is normally collected at coarse intervals of 15-20 minutes using the MWR system with the intention of evaluating the daily mean optical depths. However, it is observed that the aerosol system at this location shows certain short period changes following mesoscale changes in the local weather (Niranjan *et al.*, 1995). Evaluation of aerosol optical depths at short time intervals of 20 minutes and multiples is possible provided the time period selected shows a reasonable variability in solar zenith angle for the fitting of the regression line while evaluating the total optical depths. However, the data quality has to be checked for the consistency of the zero airmass solar flux (or the Y-intercept of the regression line of the Langley plot) which must be constant at all the sampling intervals and must tally with the normal mean value. In fact, it is an indication of the system calibration and hence is used daily to check system stability. For evaluation of aerosol optical depths at every 20 minutes, we record the solar flux data every two minutes and the data taken every 20 minutes is subjected to regression against the Secant of the solar zenith angle in order to evaluate the optical depths. Care is taken to select the data points at 99.5% confidence level and an iterative computer algorithm is used to evaluate the slopes through linear regression by incorporating the error estimates and corrections wherever necessary (Bendat and Piersol, 1971).

3. RESULTS AND DISCUSSION

The eclipse started at 07:32 hrs at Visakhapatnam, with maximum obscuration at 08:44 hrs. The eclipse event came to an end at 10:08 hrs and the degree of maximum obscuration was 81% at 08:44 hrs. As the occurrence of the eclipse was during the morning hours, the change in the solar zenith angle was rather fast, facilitating the study of the short period changes in the aerosol optical depths. However, one major problem in handling this data was the rapid change in the solar flux during the progressive occultation of the solar disc. To handle this, we categorised the data points of approximate 15-20 minute intervals that represent approximately the same level of solar disc obscuration and evaluated the total optical depths and the zero airmass solar flux values. Figure 1 shows the zero airmass solar flux values thus evaluated from the Langley intercepts at a typical wavelength of 400 nm, as a function of time which

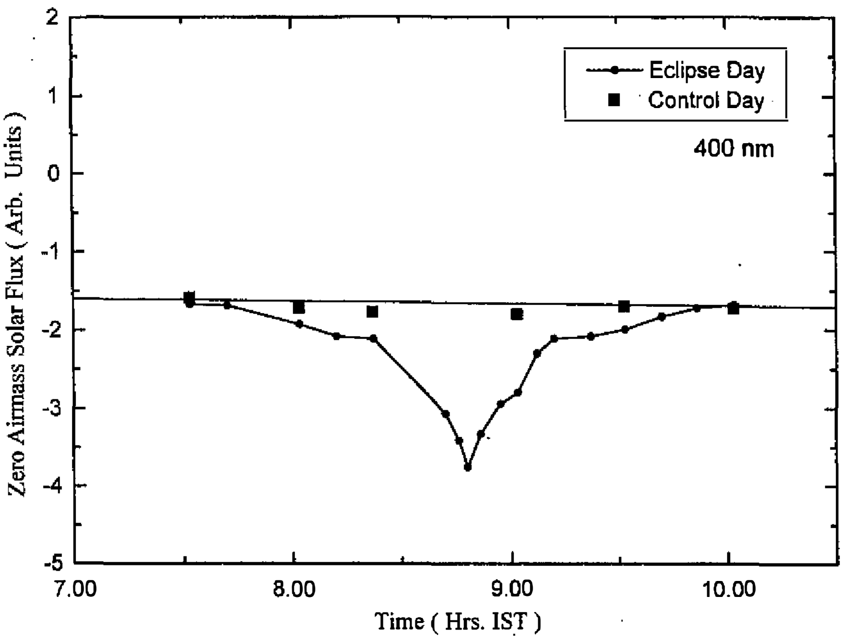

Fig. 1. Time variation of zero airmass solar flux on a normal day and eclipse day.

very nearly coincided with the percentage obscuration of the sunís disc at the respective times. This is an indication of the correctness in the evaluation of aerosol spectral optical depths during the eclipse period. The same figure shows the time variability of the zero airmass solar flux for the same time period on a control day which remained constant throughout the period.

The spectral variation of aerosol optical depth at 08:00 hrs, 08:44 hrs , in the afternoon (after the eclipse event is over) and also for the control day on 25 October 1995 are shown in Figure 2. Also shown in this figure is the spectral variation of the monthly mean aerosol optical depth during October 1995 along with the standard error for that month. During the eclipse period on 24 October 1995, there is a significant change in the spectral variation of the aerosol optical depths which showed a peak around 650 nm in contrast to the normal feature of a maximum at the shorter wavelength of 450 nm. The optical depths at all the wavelengths increased as the eclipse progressed and during the afternoon hours the aerosol spectral optical depths returned to the normal spectral trend. This can be more obviously seen from Figure 3b which shows the surface plot of the time variability of the aerosol spectral optical depths against the wavelength during the eclipse event. The same data for a control day on 25 October 1995 is shown in Figure 3a. It may be observed from these figures that the aerosol optical depth decreased from 07:30 hours onwards followed by a gradual increase from 08:10 hours to 09:30 hours and from 09:30 hours onwards it decreased till the end of the eclipse. The post eclipse total optical depths for the remaining period of the day did not show any significant variation in their value (Niranjan *et al.*, 1997a). The aerosol optical depths evaluated for the control day also show no significant variation with time. Any changes in the aerosol optical

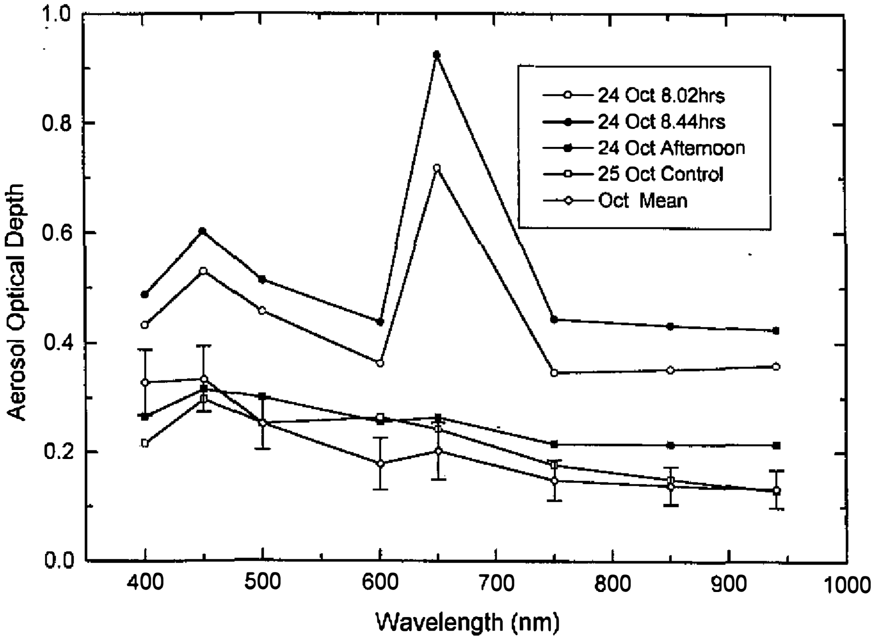

Fig. 2. Spectral Variation of aerosol optical depths at different times on a eclipse day (24 Oct. 1995), a control day of 25 October 1995 and the monthly mean of October 1995 alongwith the error bars.

depths have to be investigated in conjunction with the changes in the surface meteorology and its effect on the aerosol size and optical parameters.

Surface meteorological parameters such as temperature, humidity, windspeed during the eclipse day are shown in Figure 4. The meteorological data were obtained from the Cyclone Warning Centre of the Indian Meteorological Department, which is situated at a distance of 500m from the MWR observations site. It can be seen that with the progress of the eclipse, the relative humidity showed a sharp increase in its value with the increase in percentage obscuration, and the temperature decreased. Until the maximum phase, windspeed was more or less constant and after the maximum, it increased. The meteorological data during the control day does not show any significant variations in these parameters. This clearly indicates the role of meteorological parameters for the increase in optical depth values during the eclipse maximum. Niranjan and Ramesh Babu (1993) studied the effect of integrated water vapour and relative humidity at the observation site and found that the aerosol optical depths increased with increase in atmospheric water vapour content and relative humidity. The growth of aerosol particles results in a change in the size distribution of the aerosol particles and changes the overall refractive index thereby affecting the optical depth by altering their scattering characteristics (Hanel.,1976; Shettle and Fenn., 1979 and Moorthy *et al.*, 1993) Furthermore, at coastal locations, the onshore and offshore winds play an important role in modifying the aerosol characteristics (Suzuki and Tsunogai, 1988; Peterson *et al.*, 1981). Moorthy *et al.*

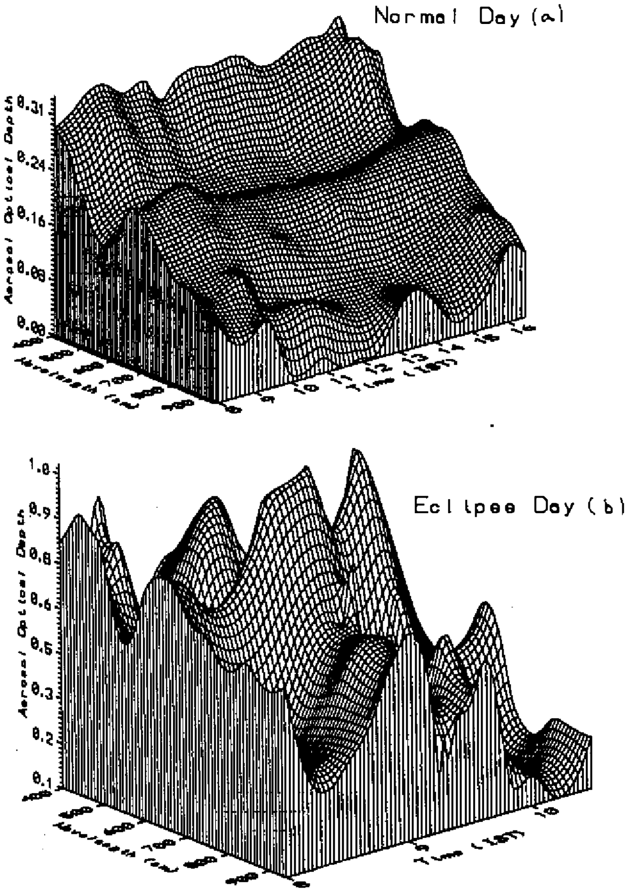

Fig. 3. Surface plot showing the variation of aerosol optical depths as a function of time and wavelengths for (a) Normal day of 25 October 1995 and (b) during the eclipse event.

(1991) and Nair and Moorthy (1995) studied the association of the aerosol optical depth with windspeed and rainfall at a coastal station, Trivandrum and observed a positive correlation with windspeed. The prevailing air mass greatly influences the aerosol optical depths (Mani *et al.*, 1969; Peterson *et al.*, 1981) and at coastal stations, marine air masses increase the aerosol optical depths significantly compared to continental air masses (Hoppel *et al.*, 1990).

During cool winter nights the industrial exhaust in an urban environment gets trapped under low level capped inversions (Niranjan *et al.*, 1995) thereby increasing the particulate loading during winter morning hours. However, as the land heats up after the sunrise, the inversion breaks due to increased convective activity leading to effective mixing of aerosols and a consequent reduction in the spectral optical depths. The initial decrease in the aerosol optical depths both after sunrise and before the onset of the eclipse can be attributed to this process. However, because of the eclipse phenomenon, the land could not become suffi-

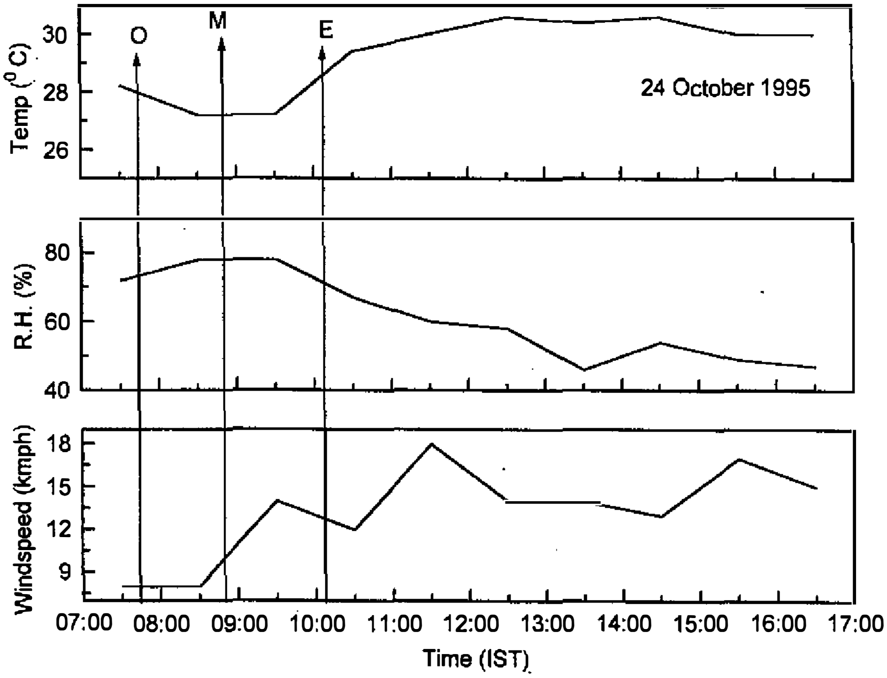

Fig. 4. Diurnal variation of surface meteorological parameters on the eclipse day.

ciently hot. Due to the progressive occultation of the solar disc, the solar heating was obstructed and consequently the temperature again decreased increasing the surface humidity. This has led to the increase in aerosol optical depths between 08:30 and 09:30 hours. After the eclipse event was over, the land temperature again increased and due to the increased convective activity and subsequent pollution dispersion, the aerosol optical depths decreased to the normal value and remained constant till the evening.

The aerosol size distributions (Figure 5) during the eclipse times i.e. during the maximum phase of eclipse, in the afternoon hours and for a control day have been evaluated by inverting the spectral optical depths using the constrained linear inversion technique. The inversion procedure is dealt with in detail elsewhere. (King *et al.*, 1978; Moorthy *et al.*, 1993; Niranjan *et al.*, 1997b). It can be seen that the control day size distribution (line with open circles) and the afternoon size distributions on the eclipse day show a clear bimodal form aerosol columnar size distribution, with the primary mode around 0.1 microns characterising the particulate population as being of industrial origin and the secondary mode at 0.82 which is typical of a sea salt component. The size distribution during the eclipse maximum (line with black circles) shows a broad monomodal form between 0.2 to 0.5 microns. It is known that aerosols grow in size with increasing humidity and such an increase is reflected in size distribution. The industrial component of aerosol is highly sensitive to change in humidity and owing to the increase in relative humidity the small particles, showing a peak near 0.1 microns, grew in size and

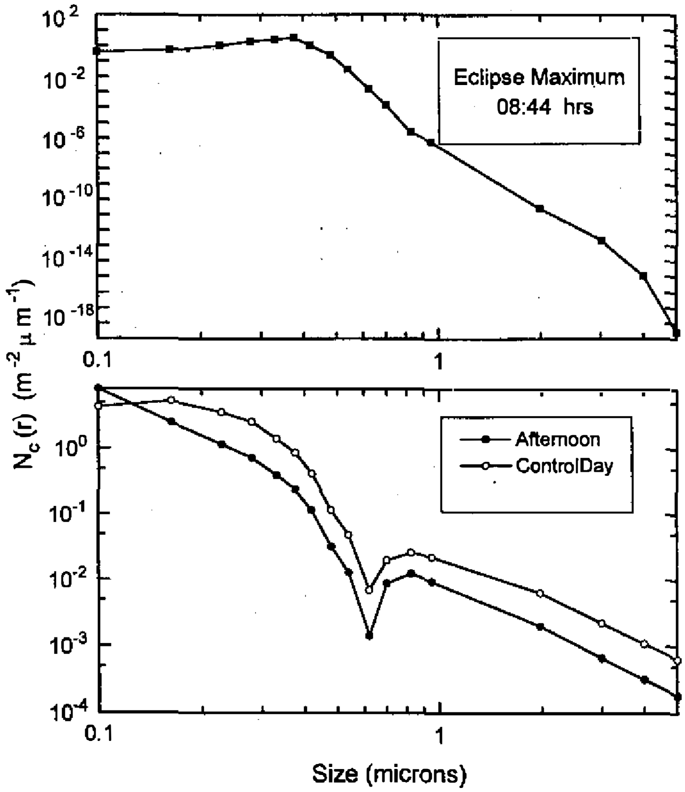

Fig. 5. Variation of aerosol columnar size distributions during the eclipse maximum, after noon hours and for a control day.

consequently the size distribution shows a broad peak between 0.2 and 0.5 microns. Because of the low wind speeds, the secondary mode typifying the marine component might have decreased in prominence and become obscured by the broad primary mode.

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