A CASE STUDY ON THE IMPACT OF WET REMOVAL ON AEROSOL SPECTRAL OPTICAL DEPTH AND RETRIEVED SIZE DISTRIBUTIONS

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INTRODUCTION

Aerosols are removed from the atmosphere by dry deposition and wet removal. Of these, wet removal is more efficient, primarily because the falling speed of the precipitation greatly exceeds the dry deposition velocity of the particles. Wet removal includes (i) nucleation scavenging or rainout in which, aerosols either act as condensation nuclei in cloud formation or may get attached to cloud droplet by various processes (for e.g., Brownian diffusion, phoretic processes) and then are removed as the droplet falls as precipitation, and (ii) impaction scavenging or washout in which, the aerosols are captured by the falling precipitation (*Pruppacher and Klett*, 1978). Several observational studies have shown large depletion in aerosol concentration and extinction coefficient, in the well-mixed layer and free troposphere; decrease in columnar optical depths and change in aerosol size distribution associated with extensive and widespread rainfall such as Indian monsoon (e.g., *Moorthy et al.*, 1991; *Pillai and Moorthy*, 2001). However, these impacts are long lasting, compared to the shorter time scales involved in the mesoscale processes. Nevertheless, field studies are quite limited on the impact of strong, isolated, mesoscale thundershowers, which occur during dry periods. In this paper, we present the results from a case study on the impact of two isolated and strong thundershower events occurring in short succession during a long, dry season at a tropical station, Trivandrum (Saha and Moorthy, 2004).

EXPERIMENTAL DETAILS AND DATA

The experimental data used in this study consisted of columnar aerosol optical depths (AODs), estimated at ten wavelengths (380, 400, 450, 500, 600, 650, 750, 850, 935 & 1025 nm) using a 10-channel Multi-Wavelength solar Radiometer (MWR). Spectral AODs were estimated regularly using the MWR on clear/partly-clear days as part of ISRO's Geosphere Biosphere Programme and the data for the month of March 2002 is used for this study.

PREVAILING METEOROLOGY

Figure 1a shows the distribution of daily rainfall at Trivandrum for the months of February and March 2002. There were only 4 rainy days from 1 February to 31 March of 2002; the first occurred on 2 February, when there was a thundershower with ~14 mm rainfall. Subsequently, a long, dry spell prevailed for over 40 days followed by two thundershowers in quick succession; the first on 15 March and the second, stronger on 17 March. Both events were of ~1 to 2 hour duration. This was followed again by a dry spell till 27 March when there was a brief spell of weak rainfall. The spatial distribution of rainfall is examined in Fig.1b using the data from a network of rain gauges. Fig.1b clearly shows that the rainfall distribution was distinct for the two events and spatially heterogeneous. During the first event (15 March), the thundershower was rather localized, with maximum rainfall occurring around the observation site, decreasing rapidly upwind. But on 17 March, not only was the rainfall more intense at the observation site, severe thundershowers also occurred upwind.

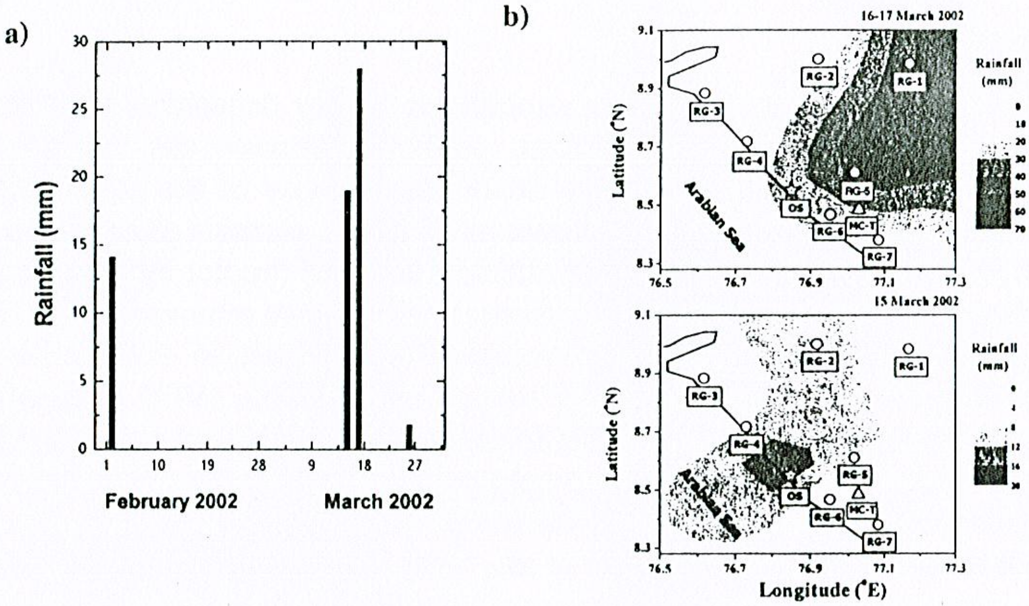

Figure 1: (a) Distribution of daily total rainfall. (b) Spatial distribution of daily total rainfall for 15 March (bottom panel) and 16-17 March (top panel). OS-Observation Site, RG's-Rain Gauge stations.

RESULTS AND DISCUSSION

Figure 2a shows the day-to-day variations in AODs at two representative wavelengths (500 and 750 nm) for the period 11 to 26 March 2002, with the distribution of daily total rainfall at the observation site superposed. It is clearly seen that prior to the rain event, the AODs remained moderately high during 11 and 12 March. This was then followed by a significant increase on 13 March and a further increase to a peak on 15 March, when the AODs were quite high. In the afternoon of 15 March, the station experienced the first thundershower lasting for ~1 hr, during which there was a precipitation of 19 mm. Subsequently, the MWR observations could be made only in the forenoon of 16 March, when a remarkable decrease in the AOD is seen. The next thundershower occurred in two spells during which the station received ~28 mm of rainfall. This event was more intense and widespread. However, as the sky continued to be cloudy on this day, the MWR data could be taken only on 18 March, when there was a substantial reduction in the AODs.

SPECTRAL DEPENDENCE AND COLUMNAR SIZE DISTRIBUTION

In order to investigate how the impact affects the aerosol size distribution, the AOD spectra on 15, 16 and 18 March are examined in Fig.2b. After the first event, there was a significant decrease in AOD at all the wavelengths, but relatively more at the longer ones, while after the subsequent event the decrease was more pronounced at the shorter wavelengths. This suggests that the wet removal process on the two days have affected different aerosol sizes differently. The simplest way to examine this is to compute the Angstrom parameters α and β, which connects AOD (represented by τ_p) to the wavelength (λ) through the relation (*Angstrom*, 1961)

$$\tau_p = \beta \lambda^{-\alpha} \quad \ldots(1)$$

where α is the wavelengh exponent and β is the Angstrom coefficient. α is a measure of the relative dominance of small particles, while β is a measure of the aerosol loading and is more associated with the large particles. α and β were computed for the individual AOD spectra shown in Fig.2b, by evolving a least squares fit to Equation (1) in each case. The mean variance of the regression slope is used to evaluate the standard deviation δα of α. The values of α, δα and β are given in Table 1 for the three different cases, along with the correlation coefficient (γ) between ln (τ_p) and ln (λ).

a) b)

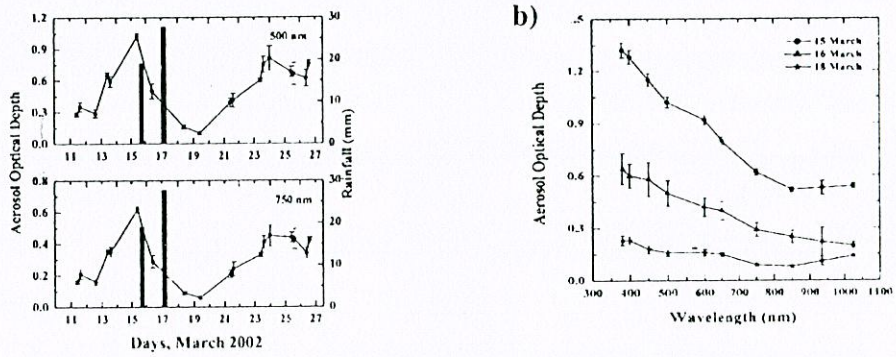

Figure 2: (a) Day-to-day variations of AOD at 500 nm (top) and 750 nm (bottom). The two long bars depict the thundershower events (b) Spectral variation of AODs for 15, 16 and 18 March.

Table 1: Angstrom parameters

Date, 2002	α ± δα	γ	β
15 March	1.03 ± 0.06	0.98	0.50
16 March	1.21 ± 0.06	0.99	0.21
18 March	0.81 ± 0.21	0.81	0.10

In all the cases γ is quite high, indicating a good fit to Eq. (1). Nevertheless, the higher value of δα (and lower value of γ) for 18 March, compared to the other days indicates that the AOD spectrum on that day deviated more from Eq. (1), because of the change in the size spectrum resulting from washout. Both α and β are high on 15 March, with β as high as ~0.5. After the first thundershower, the MWR data taken on the next day morning revealed that the AOD spectrum has changed significantly with a higher value of α and lower value of β, besides an overall decrease in the AOD at all wavelengths. This implies that there was an overall reduction in the aerosol burden, particularly larger reduction of coarse particles (which contributes to β). This relatively larger decrease in β has resulted in a steeper AOD spectrum and the higher value of α on 16 March. The next thundershower occurred in parts, on 16-17 March, producing 28 mm of rainfall. However, the clouds did not dissipate on 17 March and thus MWR could not be operated on that day. The next day (18 March) was clear and cloud free, and the AOD spectrum on this day is fairly flat (with α = 0.8), implying a substantial removal of fine, submicron aerosols. The decrease in β is comparatively much smaller. The large removal of aerosol burden at the fine particle sizes resulted in the flatter AOD spectrum, deviating more from Eq (1), with a higher value of δα.

This aspect is further examined in more detail by retrieving the columnar size distributions (SDs). The columnar SDs were retrieved from the AOD spectra following the constrained linear inversion technique (*King et al.*, 1978; *Moorthy et al.*, 1991). The retrieved SDs are shown in Fig.3a (bottom panel). The change in the SD after each event is seen clearly in the Fig.3a. After the first rain, there is a remarkable decrease in the coarse mode regime (r > 0.5 μm) and in the very fine particle regime (r < 0.1 μm), while in the optically active submicron regime (0.1 μm < r < 0.5 μm) the decrease is not much. The impact of the second event, however, is most discernible in this range, rather than in the fine/coarse ranges.

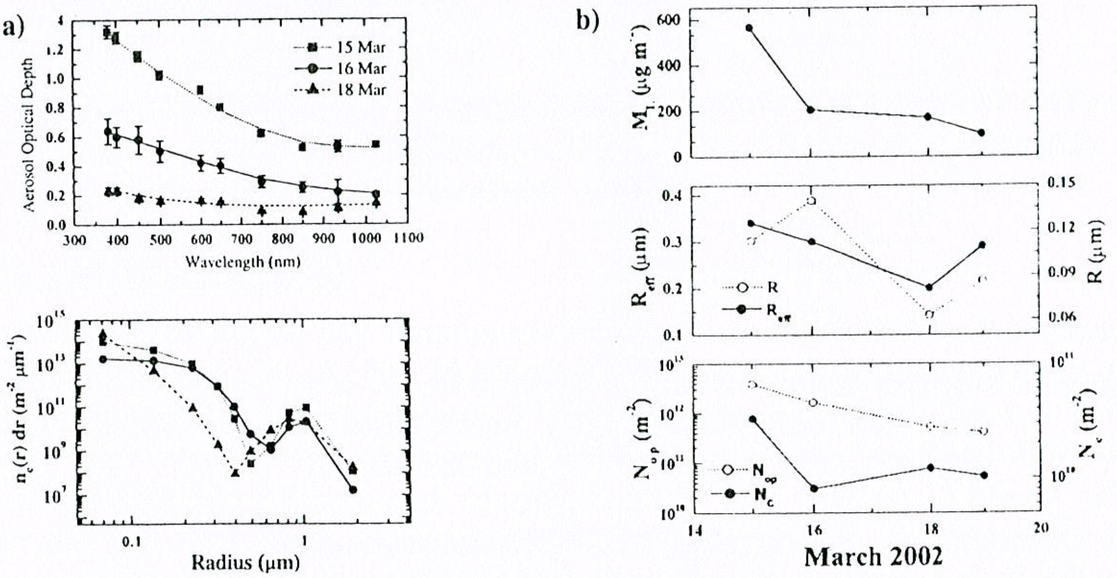

Figure 3: (a) Columnar SDs (bottom panel) for 15, 16 and 18 March, and the corresponding AOD spectra (top panel), in which the points with error bars correspond to the MWR estimated values and the lines, the AODs re-estimated from the inverted SDs. (b) Day-to-day variation in the aerosol parameters [M_L (top panel), R_{eff} and $\overline{R}$ (middle panel), N_{op} and N_c (bottom panel)) deduced from the retrieved SDs for the period 15 to 19 March 2002.

to quantify these changes, the physical parameters such as column concentration of coarse (N_c) and optically active submicron aerosols (N_{op}), effective (R_{eff}) and weighted mean radius ($\overline{R}$), and columnar mass loading (M_L) are deduced from the inverted size distribution. The variations of the retrieved parameters are shown in Fig.3b, which shows that the large removal of the aerosol mass (M_L) in the first rain (top panel) is mostly associated with the scavenging of coarse aerosols, as can be seen from the decrease in N_c. Consequently, R_{eff} decreases from ~0.36 to 0.30 µm, which shows that the aerosol size spectrum is now weighed more towards the smaller size. In the subsequent rain, the reduction in the mass loading is small mainly because the washout this time was confined primarily to the sub-micron (optically active) regime as can be seen from the continued decrease of N_{op} in the bottom panel of Fig.3b. Consequently, R_{eff} decreased further to 0.21 µm; but the decrease in M_L was quite small. This aspect is examined by obtaining an "apparent scavenging efficiency" S_c as

$$S_c = {P_s}/{P_o} \quad (2)$$

where P_s is the particular parameter of aerosol (mass or number) that has been scavenged (removed) and P_o is its value before the rain (scavenging process). Using Eq. (2), the scavenging efficiency for M_L, N_{op} and N_c are estimated and are given in Table 2. The apparent mass-scavenging efficiency was 0.64 for the first event, while for the second event it was only 0.17. This is closely associated with the very high value of S_c (0.75) for N_c during the first event, while it was negligible during the second. In contrast, in the sub-micron regime, the scavenging efficiency remained rather steady and high. In fact the efficiency was higher for the second event, which was stronger and extensive, due to the more efficient scavenging of accumulation aerosols by the intense precipitation, locally and upwind.

Table 2: Apparent scavenging efficiency for columnar mass loading and number concentrations

Parameter (P)	Event 1 (15-16 March 2002)			Event 2 (16-18 March 2002)		
	P_o	P_s	S_c	P_o	P_s	S_c
M_L	565	361	0.64	204	35	0.17
N_c (10^{10})	3.29	2.48	0.75	0.81	-	-
N_{op} (10^{12})	3.91	2.27	0.57	1.64	1.12	0.68

CONCLUSIONS

A case study is presented on the impact of two isolated and strong thundershowers on the spectral AODs and inferred columnar size characteristics. Results show a remarkable decrease in the AODs and change in the spectral slope after the rain. The scavenging was found to be dependent on the particle size distribution; the larger, super-micron particles were found to be removed faster during the first shower, even though it was of only moderate intensity, resulting in ~64% decrease in the columnar mass loading. In the second shower, which was stronger and more widespread than the former, more of sub-micron particles in optically active submicron size range were removed, but the reduction in mass loading was quite small. The inferred apparent scavenging efficiencies were ~57% and 68% for the columnar number density in the optically active submicron size range for the two events, whereas for the coarse aerosols, it was ~75% for the first event and insignificant for the subsequent event.

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ACKNOWLEDGEMENTS

This work was carried out under the Aerosol Climatology and Effects project of ISRO-GBP.