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OPTICAL PROPERTIES OF ATMOSPHERIC AEROSOL AT RAJKOT DURING DUST STORM EVENT

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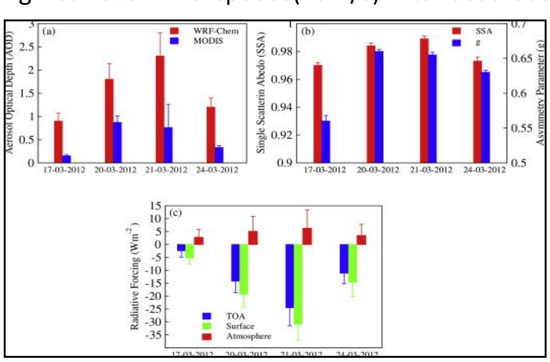
ABSTRACT

Columnar Aerosol Optical Depth (AOD) at six different wavelengths covering from UV to NIR (380–1020 nm) have been retrieved and studied during dust day periods (both were transported from Thar desert over to Rajkot (22o18´ N, 70o44´ E and 142m above sea level), India, located downwind the arid regions of Western India and Eastern Pakistan). Two hand held microprocessor based sun photometers, MICROTOPS II (version 2.43 and 5.5) were used to monitor the AOD and Precipitable Water Vapour Content (PWC) (using NIR band 936 nm). Significant increase (by 0.40 and more) was observed in AODs at all wavelengths when compared with the average for normal clear sky days (the AOD increase was highest by 0.42 at 675nm wavelength). The angstrom parameters α and β were studied during these periods and the results are included. The day-to-day variation of the aerosol size distribution, estimated using inversion technique, shows an increase in coarse mode particles as compared to clear sky days. It is also found that surface temperature is lower at higher values of AOD during both the events.

KEY WORDS: *political correspondence , system structures, functionalities, calculations.*

1. INTRODUCTION

A dust storm is a meteorological phenomenon common in dry, arid and semi-arid regions. In aerosol science, dust refers to airborne mineral particles, or soil dust. The source regions are mainly deserts, dry lakebeds, and semi-arid desert environs. Dust particles are generally large (> 1 µm), they can be transported to long distances from their sources. Dust particles are composed mostly of silicon, calcium, aluminum and iron. Crystalline halite (NaCl) also contributes to dust. The atmospheric lifetime of dust depends on particle size; large particles are quickly removed from the atmosphere by gravitational settling, while sub-micron size particles can have atmospheric lifetimes of several weeks. Dust clouds are formed when the friction from high surface wind speeds(>5m/s) lifts loose dust particles into or above the atmospheric boundary layer (Gillette, 1978). The transport of desert dust from Asia to the North Pacific atmosphere is well documented [*Shaw*, 1980] and results in a maximum in aerosol loading each spring. Windblown dust originating from the arid deserts of Mongolia and china is a well-known spring time meteorological phenomenon throughout East Asia. Reports of successive outbreaks of extremely dusty air from the Saharan desert with high turbidity and strong attenuation of solar irradiance are observed each year in Cairo and Alexandria, Egypt (Sabbah et al. 2001). Results



obtained in the study reported by Sabbah et. al 2001 in Alexandria show that alpha was around zero during the Kamaseen storms characterized by heavy dust with optical thickness above 1.0. In another related study, Vaughan et. al 2001 analyzed the April 1998 Asian dust over the Columbia plateau. The results showed that aerosol optical thickness reached an event high of 0.43 on April 27 while the angstrom exponent alpha reached a minimum of ~0.2. a severe Asian dust storm called yellow sand was observed in korea for the period of 14-22 april 1998. Park and Chang 2000 simulated long range transport of this event in Korea using the tracer continuity equation with starting and ending days of the yellow sand the Asian dust storms have also been studied for decades to understand their sources, mechanisms of transport, and aerosol characteristics, including the effects on radiation (Vaughan et al 2001). Ogunjobi et. al (2003) reported a brief survey of research literatures of Asian dust storms in their paper. During investigation Ogunjobi et. al. found that for the period of major dust event days in 1999 and 2001 the AOD increased from the spring average value of 0.43 at 501nm to values >0.70 and computed Angstrom exponent showed dramatic changes from high values to low values on dust day periods with a sharp increase in the single scattering albedo.

The large dust storms, major forest fires and volcanic eruption are often associated with catastrophic consequences to humans and their environment. Hence the study of such events generally has to depend on the integration of routine monitoring data and unexpected observations. In this present work we have focused on two major dust outbreaks during the Asian dust events (April 2005 and April 2006). It became possible to detect the signature of major Asian dust outbreak in Rajkot, India due to the continuous monitoring of AOD using hand held sun photometer (MICROTOPS II). The day-to-day variations in AOD, Angstrom parameters and size distributions of dust storms generated aerosols (April 2005 and April 2006) are presented in the paper. The characteristics of aerosol during normal days and disturbed days will be compared. This paper also includes the observed significant variation in surface temperature during both dust storm events.

This paper is organized in the following manner; a brief description of observation Site, instrument used (MICROTOPS II sun photometer) and methodology are given in section 2 , results and discussions are presented in section 3 and a summary and conclusions drawn from the work are given in section 4.

2. SITE, INSTRUMENT AND METHODOLOGY

2.1 site description

Rajkot (22^{o}18$'$ N, 70^{o}44$'$ E and 142m above MSL), a tropical semi-arid region near Arabian Sea, is a part of Saurashtra region of Gujarat (INDIA). It has unique weather patterns. The Physics Department of Saurashtra University is situated outskirt of the main city of the town. In normal days the Department has pristine environment. A hot summer and dryness in non-rainy seasons characterize the climate of Rajkot. The year may be divided into four seasons. The winter season extends from December to February followed by summer from March to June, monsoon from July to September and post-monsoon in October and November, the temperature at Rajkot is found to rise consistently from March to May. May is the hottest month with the mean daily maximum temperature of about 41 ^{0}C (Ganguly et al. 2006). About 95% of the annual rainfall is received during the south-west monsoon season, July-August being the months with the highest rainfall. During the south-west monsoon the sky is heavily clouded to overcast on most of the days. In the rest of the year the air is comparatively dry and sky is clear of lightly clouded skies prevail (IMD Report, 1995). Winds are generally moderate, but in summer and southwest monsoon season they become stronger, the prominent wind directions during summer are NW and W during monsoon winds blow from the SW direction. During post monsoon WSW, ESE, ENE and NE, and during winter NE, NW and N flow directions are predominant.

2.2 Instrument description

The aerosol optical properties are measured routinely since June 2004 using two sun photometers. MICROTOPS–II (version 2.43 and 5.5) is a five-channel, hand held, multi-band sun photometer with a full field of view of 2.5^0. Estimated values of AOD at different wavelengths are directly obtained from this instrument. It is capable of quick and inexpensive measurements of the columnar AOD at remote places, where infrastructure and logistics are not readily available. For AOD measurement six wavelengths (380, 440, 500, 675, 870 and 1020 nm) are used.

2.3 Methodology

Estimation of Aerosol Optical Depth

For the case of single scattering, intensity of solar radiation reaching the earth's surface is given by Beer-Bouger-Lambert law,

$$I(\lambda) = I_0(\lambda)\exp(-\tau m) \qquad \text{....(1)}$$

where $I(\lambda)$ and $I_0(\lambda)$ represent the solar intensity of the wavelength λ at the earth's surface and at the top of the atmosphere respectively , τ is the total optical depth of the atmosphere at given wavelength and *m* is the secant of the solar zenith angle (for solar zenith angle, $Z<70^0$). The value of I_0 is estimated using Langley plot [ln$I(\lambda)$ versus secant of solar zenith angle] at the wavelength λ. The Langley plot is a straight line graph having negative slope giving numerical value of τ. The AOD (τ_a) is determined from τ by subtracting contributions due to Rayleigh scattering and gaseous absorption (Aher,1993).

Estimation of Angstrom parameters

Many studies of AOD and its spectral (wavelength) dependence rely on the Angstrom wavelength exponent α to quantify this spectral dependence. Recent studies[19-21] have shown useful application of α measurements for characterization of aerosol physical and radiative properties (α varies from 4 to 0; when the aerosol particles are very small, of the order to air molecules, α should approach 4 and it should approach 0 for very large particles). Angstrom suggested the following empirical expression

$$\tau_a = \beta\, \lambda^{-\alpha} \qquad \text{...(2)}$$

where λ is the wavelength in microns of the corresponding AOD values (τ_a), β the Angstrom turbidity coefficient and α the Angstrom wavelength exponent. For the purpose of determining α and β values by linear regression, the above equation can be further expressed in the form:

$$\ln \tau_a(\lambda) = \ln\beta - \alpha\ln\lambda \qquad \text{........(3)}$$

Substituting the derived $\tau_a(\lambda)$ values in the above equation (2), the slope of ln $\tau_a(\lambda)$ vs lnλ graph provides wavelength exponent α and its intercept lnβ. For spectral analysis this method of linear fitting is the best way of obtaining the Angstrom parameters (Cachorro et al, 1987 and Maheshkumar et al, 2001).

Retrieval of columnar aerosol size distribution by inversion of spectral optical depth measurements

Having obtained AOD at different wavelengths, aerosol size distribution (ASD) can be determined by following the inversion scheme suggested by king et al (1978) which connects the AOD and ASD as

$$\tau_a(\lambda) = \int_0^\infty \pi r^2 Q_{ext}(r,\lambda,m)\, n_c(r)\, dr \qquad \text{.......(a)}$$

where r is the particle radius, m is the complex refractive index of aerosol particles; $Q_{ext}(r,\lambda,m)$ is the Mie extinction efficiency parameter, $n_c(r)$ is the columnar aerosol size distribution (the number of particles per unit area per radius interval in a vertical column through the atmosphere).

3. RESULTS AND DISCUSSIONS

Two major dust storms (7-8 April, 2005 and 10-11 April 2006) were selected for the study of the aerosol characteristics during dust storm event over Rajkot. The day-to-day variability of spectral aerosol optical depth at Rajkot during the dust storm periods are shown in Figure 1 a & b for April, 2005 and April, 2006 respectively. AOD at 500 nm, increases from the average value of 0.34 on control day to the values ~ 0.74 and 0.79 during the major dust event days of April 8, 2005 and April 10, 2006 respectively. Wavelength exponent, α and turbidity coefficient β were estimated using Angstrom relation ($\tau = \beta\lambda^{-\alpha}$; where τ is the measured AOD at wavelength λ= 0.38, 0.44, 0.50, 0.68, 0.87 and 1.02 μm, α is the wavelength exponent and β is the turbidity coefficient) for the both the events.

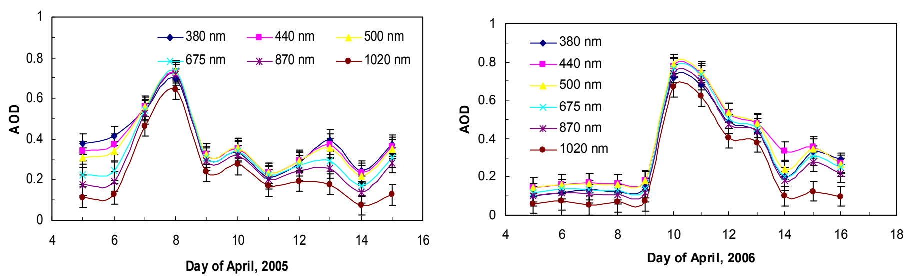


Figure 1: (a) Variation of AOD at 380, 440, 500, 675, 870 and 1020 nm during event days (7-8 April, 2005), (b) Variation of AOD at 380, 440, 500, 675, 870 and 1020 nm during event days (10-11 April, 2006).

The aerosol size distribution at Rajkot for event days (7^{th} April, 2005 and 10th April, 2006) and for mean of the control days (rest of the days in April) estimated using iterative inversion technique (King et al, 1978) are shown in Figure 2a & b. The observed size distribution during the dust outbreak days is distinctly bimodal with large amounts of coarse and fine particles transported to the site consistent with smaller wavelength exponent α. The columnar concentration of number density of aerosol particles (r~ 0.12 μm) during control days is of the order of 10^{13} and during event it is of the order of 10^{10}. The number densities of the aerosol particles (r ~ 0.47 and 0.64 μm) were increased by a factor of 10 in both the events. The possible path way of transported dust during both events has been studied and reported with help of backward trajectory analysis and Total Ozone Mapping Spectrometer (TOMS) Aerosol Index (AI). Figures 3a, b show 5-day backward trajectories from 7 April 2005 and 10 April 2006 respectively, to locate the path of the dust-carrying air mass to the region at three altitudes, viz 600 m, the mixed layer; 1500 m, above the boundary layer where the dusts are lifted by convection and transported over long distance; and 2500 m, the relatively free troposphere. The wind in the mixed layer is responsible for raising the loose soil dust particles in the atmosphere. In both the trajectories, air mass has been close to the surface while passing over the western Thar Desert before reaching at Rajkot. Also, it is evident that the air mass at 2500 m altitude is coming from the Middle East regions in both cases.

Figure 4 a, b shows variation of Total Ozone Mapping Spectrometer (TOMS) Aerosol Index (AI) during both the dust events over Rajkot, which shows regional distribution of aerosols. The AI ranging from 1.7 to 3.2 (Dey et al., 2004) in the images marks the spreading of the dusts in the atmosphere. The dusts were seen over the Thar region on 5 April 2005 and then spread over north-west India on 7 and 8 April 2005. Similar observations have also been made on 10, 11 and 12 April 2006. Higher AI values have been observed over Rajkot in the most intense dust storm event of 10 April 2006 showing a pronounced effect on the optical properties of the aerosols. Both from the trajectory and AI images, it is clear that the dust originated from the Thar Desert. The optical properties have been found to change in response to the changing nature of the aerosol loading over the measurement site. Because of the unavailability of chemical data it is difficult to comment on the source of the dusts in terms of mineralogy; but the back trajectories and AI images clearly indicate the transport of dusts from the western Thar Desert over this region during the dust storms.

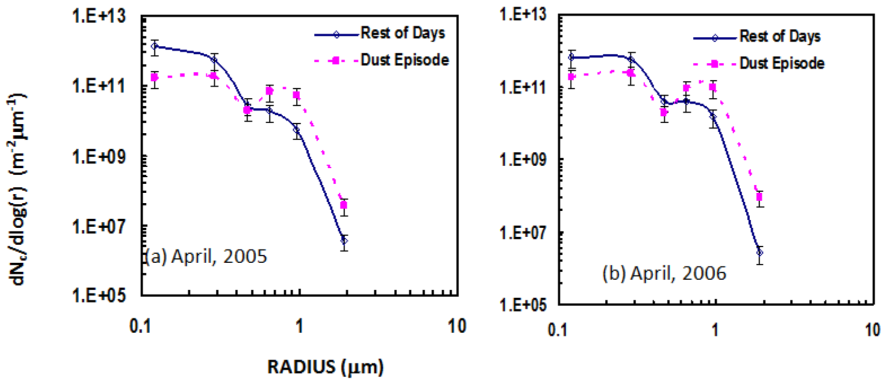


Figure 2: (a) Variation of columnar size distribution of Aerosol for the dust event (7-8 April, 2005), (b) Variation of columnar size distribution of Aerosol for the dust event (10-11 April, 2006). During the events secondary peak is higher than primary peak.

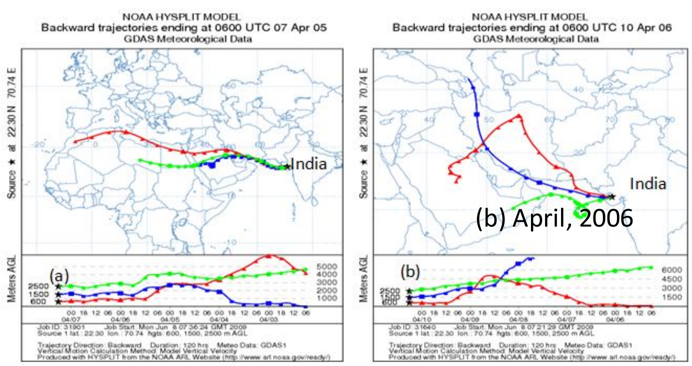


Figure 3: These plots show NOAA-HYSPLIT model run backward wind trajectory analysis at 600, 1500 and 2500 m altitude at Rajkot, India (a) for 3-7 April, 2005 and (b) for 6-10 April, 2006.

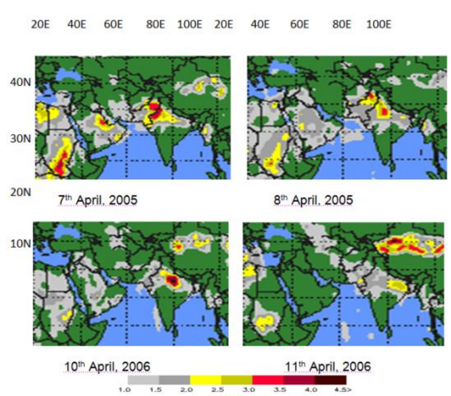


Figure 4: Total Ozone Mapping Spectrometer (TOMS) aerosol index images showing the dust cloud over Rajkot during the dust storm events (a) 7– 8 April, 2005 and (b) 10– 11 April, 2006 respectively.

4. SUMMARY AND CONCLUSIONS

Signatures of two dust storm events over Rajkot (April, 2005 and April, 2006) were short-lived (a few days). Higher the value of β and lower the value of α in present study indicates higher aerosols loading and the dominance of coarse mode particles over the measurement site. Following are the major findings:

1. During dust storm events AOD is high at higher wavelengths.
2. The very low value of wavelength exponent α during dust event and high value on control day indicate that the coarse mode particles are dominated during these events.
3. The inverse relation between wavelength exponent and turbidity coefficient with good anti-correlation sustains during such events.
4. The decreasing magnitude of ambient temperature at noon time observed during both events indicates enhancement in back scattering of incoming solar radiation at certain size range and concentration of aerosols.
5. Columnar mass concentration was increased two to three times with normal.
6. Estimated size distributions were bi-modal during dust period while pre and post event period the estimated size distributions were almost power-law type distributions.
7. The effective radius was estimated ~ 0.6 μm during dust storm events and ~0.3 μm during pre and post dust storm events.

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