

Aerosol optical properties over various locations in the North-Eastern parts of peninsular India.

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ABSTRACT

The characterization of the spatial heterogeneity of aerosol optical properties over the Indian sub-continent, an intensive field campaign was organized by the Indian Space Research Organization (ISRO) under the ISRO-Geosphere Biosphere Programme, named as the ISRO-GBP Land Campaign-I. Several research groups carried a host of instruments on mobile platforms and made representative measurements at several locations covering the entire peninsular India and a few meridional transects. The team from Andhra University, Visakhapatnam, India made extensive measurements of aerosol optical depths and near surface mass-size distributions along with the surface meteorological parameters at several locations in the states of Andhra Pradesh, Orissa and Chhattisgarh, in the northeastern part of peninsular India. The features of aerosol spectral optical depths and near surface aerosol mass size distributions over this region are presented in this paper.

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Introduction:

Ambient aerosols can directly modify the aerosol radiative forcing by back scattering and absorption. The accuracy with which the aerosol radiative properties can be predicted depends on the measurement of aerosol physical, microphysical and chemical properties [Wang et al., 2002]. Variety of sources both natural and anthropogenic and short life times of aerosols result in spatially and temporally heterogeneous aerosol field making aerosol characterization and modeling a real challenge [Smirnov et al., 2002].

The atmospheric aerosol is the end product of a complex array of chemical and physical processes [Prospero et al., 1983]. Because of these processes and the relatively short residence time of the aerosol product, the chemical and physical characterization of the aerosol will exhibit a great deal of variability in time and space. This variability is so great and the data base is so small that it is quite not possible to present any meaningful overall budget for atmospheric aerosols spatially and temporally. Spatio-temporal characterization of aerosols with high resolutions in space and time could solve this problem to an extent.

One of the recent advances in aerosol research is to make measurements over large areas, several thousands of kilometers, in order to assess the aerosol spatial variability over large geographical extents, which required ships, aircrafts, surface based observations and observations from mobile land platforms. Some such field experiments have contributed to enhance the understanding of aerosol physical properties and their role in regional and global radiative forcing; for example TARFOX [Russell et al., 1999], Aerosol characterization experiment – I [Bates et al., 1998], Aerosol characterization experiment – II [Raes et al., 2000] and more recently the INDOEX [Ramanathan et al., 2001].

It has been reported that the Asian continental outflow of air mass into the open ocean starts in November and continues up to April and therefore, the regional distribution of aerosols over the Indian ocean during this period is substantially modified by the characteristics of the continental aerosol composition [Nair et al., 2003].

Observations and Measurement Protocol:

Aerosol optical depth and the Angstrom exponent are the work horses of Sun photometry, by which the optical state of the atmosphere can be assessed [O'Neill

et al., 2003]. Measurement of aerosol size distribution is also important for the study of aerosol impact on the climate system, because the effects are quite size dependant. With this view, extensive measurements of aerosol spectral optical depths and near surface aerosol mass-size distributions were made in the study region. Figure: 1. shows the route followed by the team, and the triangles represent the locations (some locations were not shown to avoid overlapping of points) where aerosol measurements were made during 2–27 February 2004. The route covered 37 locations with a latitude extent from 16.5° N to 21.5° N, and the longitudinal coverage was from 78° E to 86.3° E, over a distance of about 1500 km.

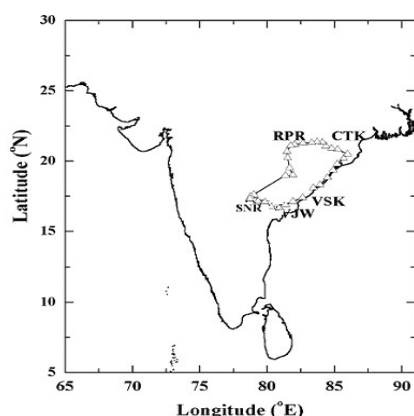


Figure: 1. Route taken by the Andhra University team in the ISRO-GBP Land Campaign.

The spatial resolution between two adjacent measurements is approximately 50 km. While making measurements, it was ensured that the measurement location was not close to any strong anthropogenic activity (avoiding cities and major industries), so that the measurements represent the ambient air mass conditions in the study region. It was also ensured that the measurements were taken at least 4–5 km away from the national/state highways, so that the automobile emissions and dust were not sampled. The parameters measured were the aerosol spectral optical depths at 380, 440, 500, 675 and 870 nm, using a Microtops II Sun photometer and near surface size segregated aerosol mass-size concentration in 10 channels, using California measurements Inc. Quartz Crystal Microbalance (QCM) with aerodynamic cutoff diameters in the range of 0.05 to 25 μ m. The pump aspirates the ambient air at a flow rate of 0.24 liters per minute and is sampled for a duration of 300 seconds. Each location is covered for half a day, and a set of at least four QCM samples at an interval of 30min were collected, and the average with a standard deviation for each location was evaluated. The aerosol optical depth measurements were made at every 15-min interval, with a minimum of eight observations for each location, and the mean AOD and the respective standard deviations were evaluated. Surface temperature, humidity, wind speed and wind direction

were measured at all observational sites, along with the QCM observations, to characterize the air mass. The surface temperature at all the locations during the time of observation was between 21.8 to 30° C (Figure 3.2 top panel), except at a couple of locations where it was around 35° C and the surface humidity was less than 60% at most of the locations. The surface vector winds, shown in Figure 3.3, were calm, with surface wind speeds less than 10 kmph, with different wind directions; the terrain was very uneven, and the surface wind speeds were showing different directions at different locations.

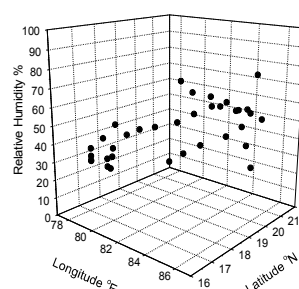
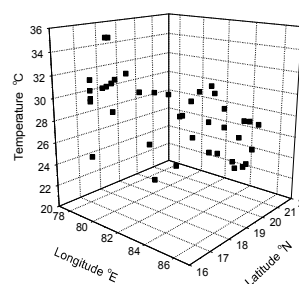


Figure: 2. Surface temperature (top panel) and humidity (bottom) at the observation sites.

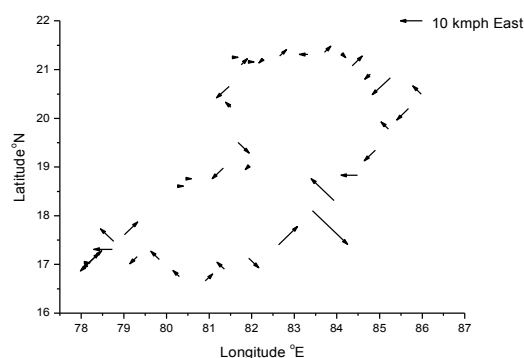


Figure: 3. Vector plot showing the wind speed and wind direction at the observing locations.

Aerosol Spectral Optical Depths:

Figure: 4. shows the aerosol spectral optical depths at 500 and 870 nm. The dot represents the coordinates of the location in latitude and longitude, and the length of the vertical bar represents the aerosol optical depth at the respective location. The vertical bar shown on the right top represents an aerosol optical depth of 0.3. In addition, subsequent figures, i.e. from Figure: 4. to Figure: 7, the length of the vertical bar represents the magnitude of the respective parameter, and the dots represent the co-ordinates of the observing location. It may be noticed from Figure: 4. that the aerosol optical depths are higher along the coastal locations on the East Coast. The aerosol optical depths decreased as we moved interior from the coast line and traveled towards Bhubaneswar (capital city of Orissa) and Cuttack, shown as CTK in Figure: 1. while traveling from east to west, from Cuttack to Raipur (shown as RPR in Figure: 1), the aerosol optical depths decreased as we moved away from Cuttack, which was having some industrial activity and again, the aerosol optical depths increased as we approached Raipur, the capital city of Chattisgarh, another urban location. In the north to south transect, from Raipur to Shadnagar (SNR), near Hyderabad, the capital city of Andhra Pradesh, there was a decrease in aerosol optical depth in the down wind direction.

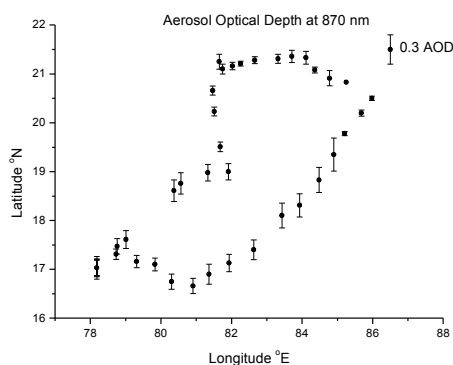
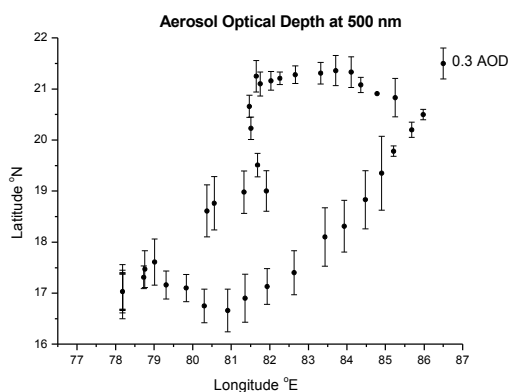


Figure: 4. Aerosol spectral optical depths at 500 nm (top panel) and 870 nm (bottom panel at different locations).

But high aerosol optical depths were observed near the forest regions between 18° N to 19° N latitude. Measurements could not be made for about 150 km in the forest area, as the region was sensitive from a safety point of view. Again, in the transect from west to east, around 17° N latitude, the aerosol optical depths increased as we moved towards the coastal regions. The spectral optical depths at 870 nm, shown in the bottom panel, also show similar features but were relatively smaller in magnitude.

In figure: 5a are shown the aerosol spectral optical depths at two typical locations where the aerosol optical depths are high (top panel: Location Gopalpur in Orissa) and at Murai in Andhra Pradesh (bottom panel) where the AODs are moderate. In contrast, figure: 5b shows AOD spectra at two typical locations in Chattisgarh and Orissa where the AODs are quite low. By and large the following gross features in aerosol optical depths were seen: a) the aerosol optical depths were higher on the eastern side compared to the central part of the peninsular India b) the optical depths were relatively higher in the southern latitudes compared to northern latitudes, and c) there were some locations where very low AODs, of the order of 0.1, were observed, which happened to be extremely rural locations devoid of any major anthropogenic activity.

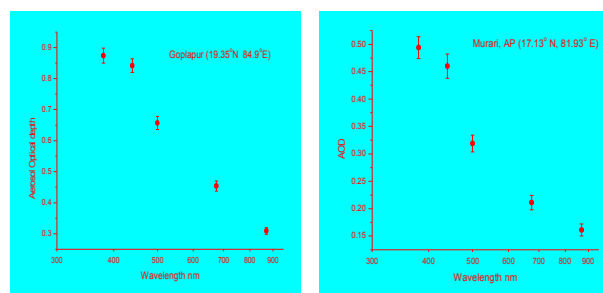


Figure: 5 a. Aerosol spectral optical depths at two typical locations where the AODs are high (top panel) and moderate (bottom panel)

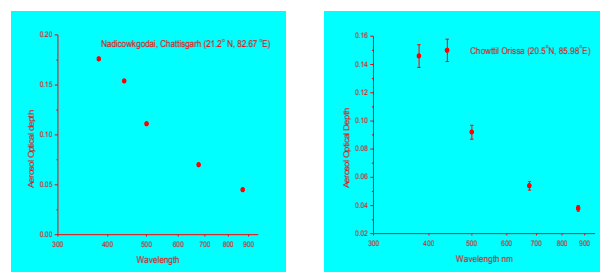


Figure: 5 b. Aerosol spectral optical depths at two typical locations where the AODs are low

The spectral slope, “ α ”, and the turbidity coefficient, “ β ”, are the two important parameters that characterize the shape of the aerosol size distribution. The Angstrom parameters (α and β) at the observed locations were evaluated from the spectral optical depths at 5 wavelengths, and Figure: 6 shows the spectral slope “ α ” which was found to be in the range of 1.3 to 1.8 at most of the locations, indicating the presence of anthropogenic aerosols at most of the locations.

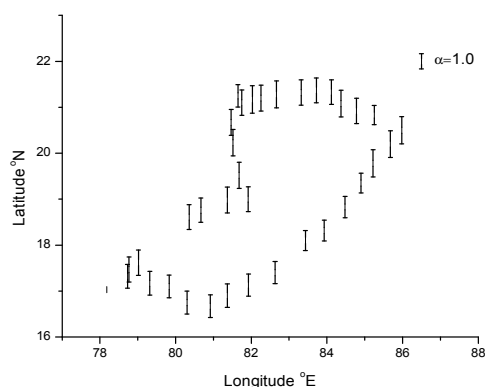


Figure: 6. Angstrom parameter “ α ” at various observational sites derived from aerosol spectral optical depths.

While a high value of spectral slope “ α ” indicates the dominance of fine mode aerosols, a high turbidity coefficient “ β ” indicates higher aerosol loading. It was observed that the mean value of “ α ” was 1.3 in the eastern and southern locations compared to a mean of 1.76 in the northern and western locations. High values of “ α ” are characteristic of an urban environment, which could be seen near Bhubaneswar/Cuttack and downwind of Visakhapatnam, a major coastal industrial city [Niranjan et al., 2004]. It was also observed that the values of “ β ” are higher on the southern and eastern locations, with relatively low values of “ α ” compared to the northern and western locations, as observed in the 500 nm aerosol optical depths.

Results and Discussion:

Aerosol physical properties at a given location are largely governed by the local processes that lead to aerosol formation, which are modified by the prevailing weather and interaction with air mass advection, besides transport of aerosol from sources of nonlocal origin. Marine aerosols produced in the surf zone at high concentrations are immediately available for heterogeneous chemical reactions and influence the composition of aerosols at coastal locations [Vignati et al., 2001]. Thus, the aerosol physical properties at coastal locations significantly differ from those observed at deep continental locations. In addition, large-scale transport of aerosols from dry continental regions significantly modify the aerosol radiative forcing over oceanic regions [Meywerk and

Ramanathan, 1999; Nair et al., 2003; Franke et al., 2003]. Thus, at coastal locations either on land or in the ocean, the aerosols exhibit complex physical properties due to the interaction of the continental and marine air masses [Niranjan et al., 2004]. In the present investigation, it is observed that the coastal locations indicate high aerosol optical depths and low values of the Angstrom exponent, as well as high near surface mass concentrations of accumulation mode aerosols. At coastal locations, the marine boundary layer penetrates inland, bringing in humid airmass, which contains some sea salt aerosol from the marine boundary layer. In addition, the humid airmass from the oceanic region interacts with the continental airmass, making conditions favorable for growth of hygroscopic aerosols, as well as for the formation of new particles by condensation and nucleation by gas-to-particle conversion from the precursors emitted from the continents due to anthropogenic activity. Thus, coastal regions show higher aerosol optical depths and mass concentrations.

One of the significant features observed in the present study is the high aerosol optical depth at southern locations in the latitudinal belt around 17° N compared to the northern locations around 21° N. It has been reported that there is a transport of aerosols from the northern and central Indian regions to peninsular India and oceanic regions. Figure: 9. shows the MODIS derived aerosol optical thickness for the month of February over the Indian region. A region of high pollution is seen in the northern and central India, which enters the Bay of Bengal region, increasing the aerosol concentrations over the Bay of Bengal. Figure: 10. shows the mean winds at 850 hPa obtained from the National Centre for Environmental Prediction/National Centre for Atmospheric Research reanalysis. It may be noticed that the winds carry the highly polluted airmass from the northern India into the Bay of Bengal and streamlines re-enter the peninsular Indian around 17–18° N latitude.

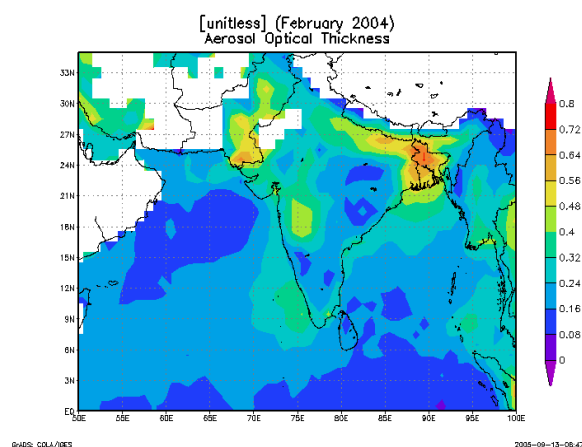


Figure: 9. MODIS derived map of aerosol optical thickness showing region of high pollution over

northern India that is entering the Bay of Bengal oceanic region through northeastern India.

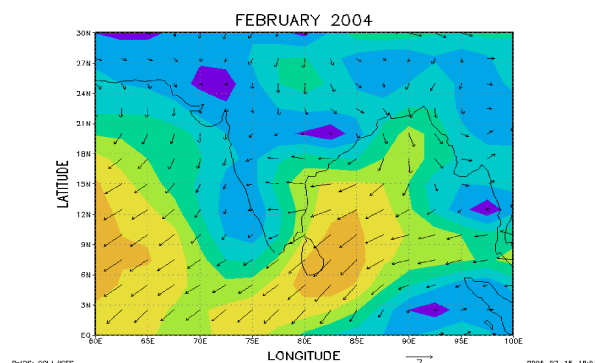


Figure: 10. Mean isotachs (ms^{-1}) at 850 hPa level over peninsular India for February 2004 obtained from NCEP/NCAR reanalysis

The airmass pathways reported by Nair et al. [2003] also show similar trajectories during February 1999, with streamlines at 850 hPa re-entering the peninsular India around 18°N .

Satheesh et al. [1999] reported that the major features affecting the aerosol characteristics over the tropical Indian Ocean during the northeast monsoon season are the transport of pollutants from the Asian sub-continent and to a lesser extent humidity, as direct production at the sea surface is not efficient due to low wind speeds. The non-sea salt AOD was more than 3 times the sea salt aerosol in the Indian Ocean [Rajeev et al., 2000]. The aerosol loading over the Bay of Bengal is significantly influenced by aerosol transport from the Indian sub-continent and the AODs increase by a factor of 1.7 from November to April [Nair et al., 2003]. Satheesh [2002] reported that the aerosol visible optical depths over the Bay of Bengal are as high as 0.6 and that the aerosol radiative forcing was high compared to other oceans, such as Pacific, Atlantic, Arabian Sea and Indian Ocean. Aerosol measurements made at an island station Port Blair in the Bay of Bengal show a continental type of aerosol with an AOD of 0.3 to 0.4 at 500 nm [Moorthy et al., 2003b]. The airmass passing through the highly polluted north Indian regions during winter traverses over the Bay of Bengal, interacts with the marine boundary layer and the modified airmass re-enters the sub-continent and travels across the peninsular India at latitudes south of 18°N . During this transit over the ocean, sub-micro meter particles grow in the marine boundary layer by homogeneous and heterogeneous mechanisms and the majority of the accumulation mode aerosols in such cases are certainly produced in the marine boundary layer [Covert et al., 1996].

Conclusion:

Aerosol spectral optical depths and near surface size segregated mass distributions measured in the northeastern part of peninsular India indicate that the

aerosol spectral optical depths and accumulation mode aerosol concentrations are high in the eastern coastal and southern regions (latitudes less than $17-18^\circ \text{N}$) compared to northern regions (latitudes more than 20°N) and deep continental locations. The coastal locations are thought to be affected by the proximity of the marine airmass and consequent hygroscopic growth of particles, besides new particle formation by condensation and nucleation, showing higher aerosol optical depths. The airmass trajectories and general wind patterns indicate that an abundance of accumulation mode aerosols is possible at the southern locations, as the airmass pathways through which transport of north Indian polluted airmass onto the locations of observation at southern latitudes takes place via the oceanic regions of the Bay of Bengal, making conditions favorable for the increase in the accumulation mode aerosols.

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