Aerosol spectral optical depths over the Bay of Bengal: Role of transport

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[1] Recent experiments have shown the potential role of air masses in transporting aerosols to locations far away from source regions. Despite the importance of the Bay of Bengal to Indian climate and monsoon, no serious aerosol observations are available for this region. Extensive aerosol optical depth estimates, made for the first time from an island location, Port Blair (11.63°N; 92.71°E) in the Bay of Bengal, during the Indian winter of 2002, are used to examine the impact of air trajectories in modifying the optical depths and their spectral dependences. The results are examined for their distinctiveness with respect to the origin as well as transport. It is seen that the trajectories arriving from the regions east of the station (South China, Thailand, Laos, Cambodia, Vietnam, Burma) are richer in aerosol abundance, more in the sub micron size range, than those arriving from the west, across the Indian landmass. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0341 Atmospheric Composition and Structure: Middle atmosphere—constituent transport and chemistry (3334); 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 5405 Planetology: Solid Surface Planets: Atmospheres—composition and chemistry; 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry. **Citation:** Moorthy, K. K., S. S. Babu, and S. K. Satheesh, Aerosol spectral optical depths over the Bay of Bengal: Role of transport, *Geophys. Res. Lett.*, *30*(5), 1249, doi:10.1029/2002GL016520, 2003.

1. Introduction

[2] The role of regional and/or synoptic scale air mass types in influencing the aerosol properties and optical depth is quite recognized [e.g., *Moorthy et al.*, 1991; *Smirnov et al.*, 1994, 2002; *Pillai and Moorthy*, 2001]. Besides these, in the recent years there is an increase in the awareness of the potential of air trajectories in advecting aerosols from distinct source regions and causing changes in the optical depths/composition/physical characteristics at far off locations. [*Tyson et al.*, 1996; *Krishnamurti et al.*, 1998; *Moorthy et al.*, 2001]. Observations during the Indian Ocean Experiment (INDOEX) have shown that aerosol properties over the Arabian Sea are strongly influenced by aerosols advected from west-Asia, Africa and East/Southeast Asia besides those from Indian landmass [*Moorthy and Saha*, 2000; *Kamra et al.*, 2001; *Li and Ramanathan*, 2002]. INDOEX Meteorological reanalysis atlases [*Jha and Krishnamurti*, 1998, 1999] corroborated these. Recent cruise experiments over the BoB (closer to the Indian peninsula) have indicated higher abundance of sub micron aerosols compared to the Arabian Sea or Indian Ocean [*Satheesh et al.*, 2001]. Nevertheless, no rigorous efforts have been made in exploring the impact of air trajectories over the Bay of Bengal region, which has a significant role in the regional climate and monsoon over India. Being a rather small oceanic region, surrounded on more than three sides by densely populated continental landmass, with distinct anthropogenic activities, this region has a great potential for examining the impact of distinctive and discrete air trajectories. In this paper, we report the first results of an extensive observational campaign, over the BoB, and examine for their distinctiveness with respect to air back-trajectories.

2. Location, Experimental Details and Database

[3] Aerosol observations were carried out from Port Blair (PBR, 11.63°N; 92.71°E), the administrative capital of the Andaman and Nicobar group of islands (spread from 6° to 14°N and 92° to 94°E) in the BoB (shown schematically in Figure 1). It is located in the South Andaman Island, at a distance of ∼1300 km from the Indian mainland. The actual observation site was ∼6 km south of the town center and the port; in a building of ISTRAC (Indian Space Research Organization's Telemetry, Tracking and Command Network) on a hillock, ∼60 m MSL. To the further south are dense forests and mangroves. Port Blair has a population of ∼130,000; an airport; several thousands automobiles; and a port; and hence a fair amount of anthropogenic activity.

[4] Columnar aerosol spectral optical depths (AODs) were regularly estimated using an MWR at 10 narrow wavelength bands (full width half-maximum band width of 5 nm) centered at 380, 400, 450, 500, 600, 650, 750, 850, 935, and 1025 nm. The instrument had an overall field of view of ∼2°. More details are given in earlier papers [e.g., *Moorthy et al.*, 1997]. The MWR was operated from the rooftop (∼10 m above the ground) of the ISTRAC building, and AODs were retrieved following the Langley technique [*Shaw et al.*, 1973]. The details (of the application of this to analyze the MWR data) and the errors involved are published in several earlier papers [*Moorthy et al.*, 1997, 2001] and hence are not repeated. The errors in the deduced AODs lie in the range 0.015 to 0.02, to which the errors arising out of the regression analysis are also to be added (following the principle of error addition). The overall error thus, generally lie in the range 0.02 to 0.05, depending on the scatter of the points about the regression fitted line.

[5] The experimental campaign was conducted for 54 days from January 18 to March 14, 2002. The MWR data were collected on 26 clear days when the sky (or major part

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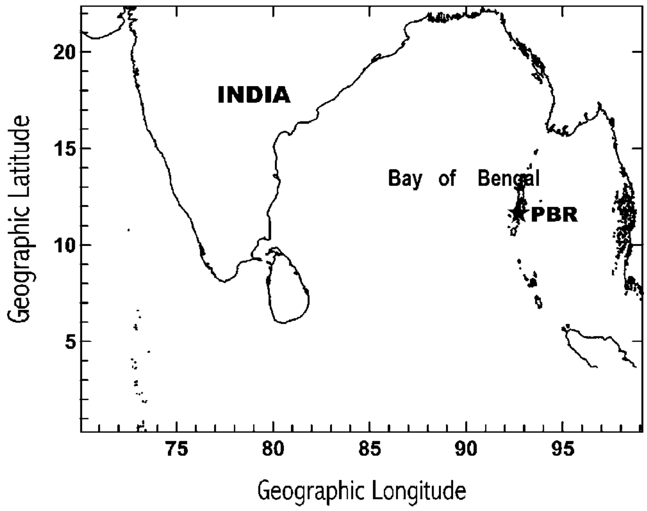

Figure 1. Location map of Port Blair (PBR).

of the sky around the sun) was cloud free. The entire observations made during a day (which spanned for at least three hours) were considered as a single set to estimate the daily mean AODs. On a few days when extended observations (> ~8 hrs) were made and the Langley plots showed two distinct slopes, the data were split in to forenoon and afternoon parts and separate AOD estimates were obtained. Thus, in all 29 sets of AODs were obtained from the 26 days of MWR data.

3. Synoptic Meteorology and Airmass Types

[6] The observation period falls during the northern hemispheric winter and the synoptic weather over Port Blair is in general conformity with that prevails over India during winter monsoon [*Asnani*, 1993]. The low level winds are generally weak, (<~5 m s^{-1}) easterlies/north-easterlies; generally, dry winter condition prevails with very little precipitation. The climatological total rainfall from January to March for Port Blair is ~78 mm (2.4% of the annual rainfall of 3181 mm). Nevertheless, no rains occurred at Port Blair during the entire campaign period. However, the mean winds were generally in conformity with the climatological pattern; being thus easterlies/north easterlies, favoring advection of aerosols and other species from East Asian region (lying to the east of the station,). This would further be accentuated by the absence of rainfall, so that typical lifetime of aerosols is longer than ~1 week [*Jaenicke*, 1984] in the lower troposphere.

4. Results and Discussions

4.1. Mean Aerosol Spectral Optical Depths

[7] In Figure 2 we show the daily mean AOD values at 4 representative wavelengths (380, 500, 750 and 1025 nm). The vertical bars through the points are the total error as described earlier.. The AOD spectra show high optical depths at the short wavelengths decreasing rapidly towards longer wavelengths resembling that of a continental environment [*Satheesh et al.*, 1999], rather than the flat spectra generally expected over marine environment [*Hoppel et al.*, 1990; *Moorthy and Satheesh*, 2000] or when a strong marine air mass prevails [*Moorthy et al.*, 2001; *Smirnov et al.*, 2002]. The steep increase in the AOD towards the shorter wavelengths is indicative of increased abundance of fine (sub-micron) aerosols, advected over to the marine environment by the airmass/trajectories from continental regions. This is because the basic marine aerosol generation mechanisms [e.g., *O'Dowd and Smith*, 1993] do not support large amount of sub-micron aerosols. Even though the anthropogenic activities prevailing over the island might contribute to the fine aerosol abundance, this alone would not be adequate to explain this type of an AOD spectrum. Figure 2 also shows that the visible AODs increase from January to February and then slightly decrease in March.

[8] An estimate of the relative dominance of sub micron aerosols was obtained by estimating the Angstrom wavelength exponent α in the relation [*Angstrom*, 1964]

$$\tau_{p\lambda} = \beta\lambda^{-\alpha} \quad (1)$$

where $\tau_{p\lambda}$ are the spectral AODs and β the turbidity coefficient. α and β have been estimated for each of the daily mean AOD spectra by evolving a linear least squares fit to equation (1) in a log-log scale and are averaged over the month. In general the fits were very good with a correlation exceeding 0.95. The monthly mean values of α and β are given in Table 1, along with the corresponding values of the AOD at 500 nm. Values of α range from 0.93 to 1.33, with the highest value in February. Based on INDOEX data, *Moorthy et al.* [2001] reported an average value of ~0.93 for α over the Arabian Sea, North Indian Ocean and coastal India while using data from Kaashidhoo island (in Indian Ocean), *Satheesh et al.* [1999] reported an average α value of 1.23 ± 0.21. Based on a recent cruise data *Satheesh et al.* [2001] obtained values for α as 1.23 over East-coast of India, 0.84 over the Arabian Sea, and 0.5 over Indian Ocean.

4.2. Back Trajectories

[9] With a view to examining the effect of trajectories, which act as potential conduits for aerosol transport, we computed the five-day back trajectories, for all the days on which the AOD data were available, using the Hybrid Single Particle Legrangian Integrated Trajectory (HYSPLIT) model of the National Oceanic and Atmospheric

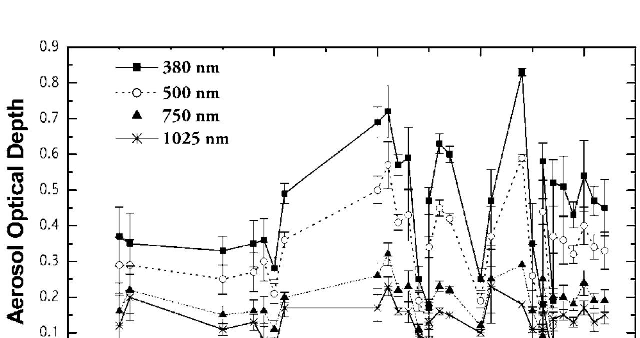

Figure 2. Variation of the daily mean AOD values at 4 representative wavelengths (380, 500, 750 and 1025 nm).

Table 1. Monthly-Mean and Trajectory-Mean AODs and Derived Parameters

Month/Trajectory group	Number of MWR data sets	Mean AOD at 500 (nm)	α	β	W (g cm^{-2})
		Monthly means			
January 2002	2	0.29 ± 0.004	0.93 ± 0.001	0.15	1.85 ± 0.16
February 2002	14	0.34 ± 0.034	1.33 ± 0.096	0.13	3.24 ± 0.17
March 2002	13	0.32 ± 0.036	1.21 ± 0.135	0.13	2.59 ± 0.32
		Trajectory Means			
ME	10	0.39 ± 0.04	1.38 ± 0.05	0.14 ± 0.01	3.53 ± 0.45
PEW	11	0.31 ± 0.04	1.20 ± 0.04	0.13 ± 0.01	2.87 ± 0.23
MW	8	0.29 ± 0.04	1.10 ± 0.14	0.14 ± 0.02	2.21 ± 0.29

Administration, NOAA [www.arl.noaa.gov/ready/hysplit.html]. The five day period was considered in view of the typical residence time of ~1 week for aerosols in the lower troposphere. These trajectories essentially back-trace the course of an aerosol parcel, which reaches the particular altitude over the observation site, in space (latitude, longitude and altitude) and time (days), backward up to five days (details are available on the HYSPLIT site). As the AOD values are due to the columnar aerosols, we considered three height levels over the observation site based on the marine boundary layer (MBL) characteristics of INDOEX [*Manghnani et al.*, 2000]; 500 m (within the MBL); 1800 m (above the MBL but below the trade wind inversion level and 3600 m (in the lower free troposphere). On all days, both the isobaric and isentropic trajectories were examined for consistency before accepting the trajectory.

[10] The retrieved back trajectories could be grouped into three distinct groups, namely, mostly east (ME), mostly west (MW), and partly east and partly west (PEW), mainly depending on the landmass traversed by most of the trajectories. A typical example of each is shown in Figure 3, with frames from left to right depicting respectively ME, MW and PEW. In the case of ME, all the trajectories are confined to the east of the station and at least two of them had traversed the eastern landmass. From the geographical location of PBR, this would mean the trajectories originating from and/or traveling over regions close to South China Sea/Cambodia/Thailand/Laos/Vietnam/Burma etc before reaching PBR. In contrast, the trajectories in the MW category lie entirely to the west of the station, with at least two of them traveling across the Indian landmass. In a few cases some of these trajectories originated from West Asia/Africa and traveled the entire continental landmass and entered the BoB across India to reach PBR. The third case contained such instances were one of the trajectories traversed across India, while the others came from the eastern landmass.

4.3. Role of Transport

[11] Subsequent to the above classification, the spectral AOD values of each observation day were put into one of these groups, as applicable. From each AOD spectra, α and β were also evaluated. These were averaged for each trajectory group and the results are given in Table 1 with the values appearing after ± symbols representing the standard deviations of the mean. The mean AOD values at 500 nm are also given. It is quite interesting and important to note that the AOD value, as well as α are distinctly higher when the trajectories are back-traced to the east than when they came from the west; with those for the mixed trajectories lying in-between. This suggests that the trajectories from the eastern side are richer in fine, sub-micron aerosols than those advected from the west. Moreover, even the abundance also appears to be higher (as indicated by the AOD values) if we assume that the aerosol compositions are broadly the same. (This assumption, of course, is debatable, as the two regions would have distinct anthropogenic activities.) Nevertheless, it may be noticed that the distinctive differences in AOD are discernible only at the short wavelength region ($\lambda \leq 750$ nm) as is evidenced by the mean AOD spectra of the three cases shown in Figure 4. At the longer wavelengths, where the contribution to AOD comes more from the coarse aerosols, the values appear to be almost trajectory independent. This can also be seen

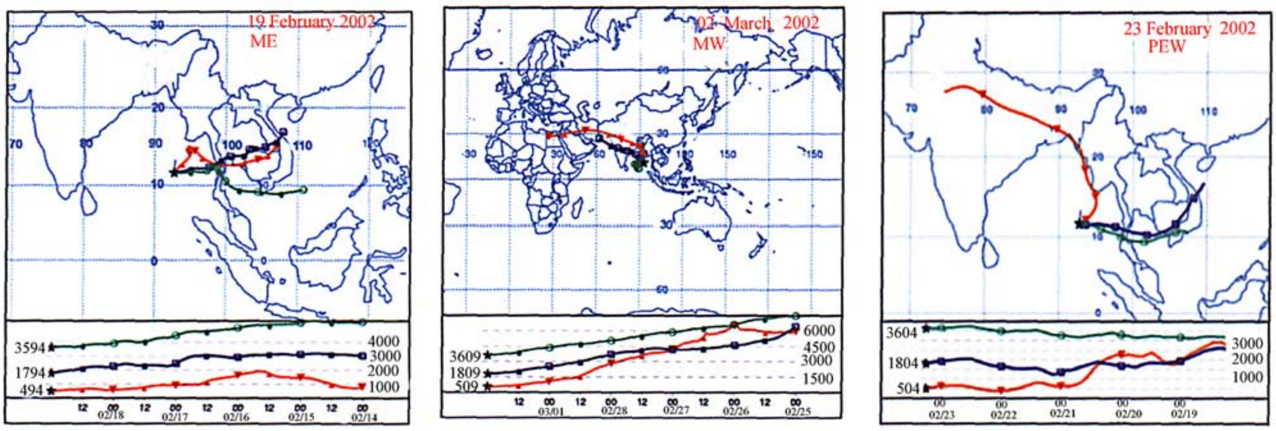

Figure 3. Examples of back trajectories showing (a) ME, (b) MW, and (c) PEW cases.

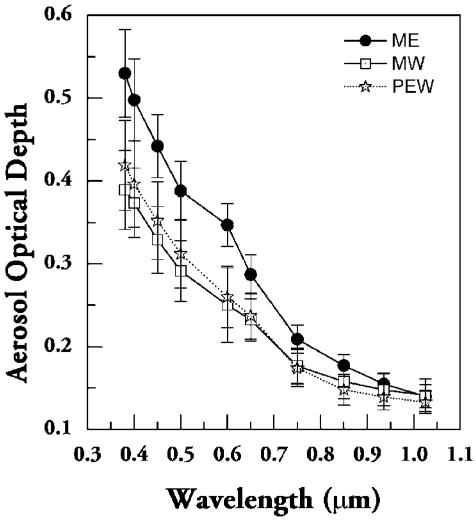

Figure 4. AOD spectra averaged for the three trajectory groups (MW, PEW, and ME). Note the high values for ME.

from the trajectory mean β values in Table 1, (which are very nearly the same as the mean τ_p at 1025 nm). This suggests that the coarse particle could be of rather local origin. It is also seen that most of the ME trajectories fell in the month of February, when the monthly mean AODs are the highest at the short wavelengths (Figure 2) and so too is α (Table 1).

4.4. Column Water Vapor Content

[12] From the MWR measurements at 935nm and 1025 nm, the columnar water vapor content (W, g cm^{-2}) has been estimated following *Nair and Moorthy* [1998]. The behavior of W (both monthly mean and trajectory mean) are shown in the last column of Table 1. It is seen that the trajectories across India tend to bring-in drier air compared to those from the east, even though the former has a longer sea-travel.

5. Conclusions

[13] 1. Aerosol optical depths measured at an island station Port Blair over Bay of Bengal for the first time show continental-type spectral characteristics during Indian winter season.

[14] 2. Aerosol optical depths at 500 nm are in the range 0.3 to 0.4.

[15] 3. The air trajectories from the regions east of the station lead to steeper AOD spectra, higher AODs at the shorter wavelengths and hence higher values of α ($\sim$1.38), than trajectories from the west (α = 1.1); indicating that trajectories coming from the landmass due east of the station are richer in fine aerosols than those coming across the Indian landmass.

[16] 4. The trajectories coming across India bring-in drier air compared to those from the east.

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