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Aerosol Characteristics over parts of East Antarctica

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ABSTRACT

The properties of marine and Antarctic aerosols, their dependence on meteorological, geographical and human influences are examined using measured spectral aerosol optical depth (AOD), total mass concentration (M_T) and mass concentrations of black carbon aerosol (M_B), in the marine atmospheric boundary layer (MABL) from coastal India and Antarctica and over two distinct coastal locations of Antarctica; Maitri (70.77°S, 11.73°E, 123 m m.s.l.) and Bharati (69.40°S, 76.20°E, 48 m m.s.l.), during southern hemispheric(SH) summer (December to March) of 2007-2008, as a part of the 27th Indian Antarctic Expedition, during International Polar Year (IPY). Over the oceans, large latitudinal gradients are seen; with AOD decreasing from coastal India (AOD~0.45) to coastal Antarctica (AOD~0.04) during the Northern Hemisphere (NH) winter leg (Dec 2007 to Jan 2008), with a strong seasonality of AOD over all regions, with a decrease of the values and gradient in NH spring (Mar-Apr 2008). MB also decreases exponentially from 3800 ng m^{-3} (over10 °N) to 624 ng m^{-3} near equator and much lower values (~100 ng m^{-3}) over southern oceanic region. Satellite retrieved AOD showed good correlation with the ship borne measurements; while GOCART retrieved AOD underestimates but gives a measure of the spatial variations. In contrast, our investigations showed comparable values for the mean columnar AOD at 500 nm over Maitri (0.034 ± 0.005) and Bharati (0.032 ± 0.006) indicating good spatial homogeneity in the columnar aerosol properties over the coastal Antarctica. Estimation of Angstrom exponent (α) showed accumulation mode dominance at Maitri (~1.2 ± 0.3) and coarse mode dominance at Bharati (0.7±0.2). On the other hand, mass concentration (M_T) of ambient aerosols showed relatively high values (~8.25 ± 2.87 μgm^{-3}) at Maitri in comparison to Bharati (6.03 ± 1.33 μgm^{-3}).

Keywords: Marine Aerosol, Antarctic Aerosol, Indian Antarctic Expedition.

1.0 INTRODUCTION

Over the past few decades, the global scale of the impact of atmospheric aerosols on climate and clouds is at the focus of investigation of the climate science community [IPCC, 2007]. Despite these efforts, climate forcing of aerosols remains largely uncertain primarily due to their large spatio-temporal heterogeneity and inadequate representation in

climate models (Satheesh and Moorthy, 2005; Bates et al., 2006; Remer et al., 2008; Smirnov et al., 2011). One of the important reasons for this uncertainty is the lack of information on the regional distribution of aerosols from distinct environments, including pristine marine environments and Polar Regions and there still is a need for extensive observational data. As ~70% of the Earth's surface area is covered by Oceans, which are also major sources of natural aerosols (e.g., Woodcock, 1953; Monahan, 1968; Prospero, 1979; Moorthy et al., 1997; Satheesh and Moorthy, 2005; Smirnov et al., 2011), it is more important to characterize aerosol properties over Oceans. In addition to the local production of aerosols over oceans (sea spray, oxidation of DMS etc), aerosols from populated continents (mainly anthropogenic aerosols) get transported to long distances over the oceans, thereby changing the optical and radiative properties of oceanic aerosols. This further makes investigations of aerosols over the oceans more important for better characterization of anthropogenic and continental impact. To understand the aerosol characteristics over the oceanic regions there are many campaign based ship cruises and continuous Island based measurements (Holben et al., 1998; Smirnov et al., 2002, Moorthy and Satheesh, 2000; Moorthy et al., 2003) apart from the satellite measurements. The data strength acquired from different campaigns over Atlantic Ocean and Pacific Ocean is comparatively larger than that over Indian Oceanic regions. Most of the campaigns in the Oceanic regions in the Indian longitude sector are mainly constrained to Arabia n Sea, Bay of Bengal and tropical Indian Ocean and had limited temporal coverage. Such information is important in determining the possible transport of the aerosols from the Asian and African continent over the remote oceans of southern hemisphere and the consequent effects.

On the other hand, Antarctica is a unique continent at the extreme south, separated from the other populated continental masses by oceanic regions, making it one of the most pristine places on the Earth (Wall, 2005). Due to the pristine characteristics, it provides an excellent environment to examine the natural and background aerosols in the atmosphere over snow and ice. Not only that, the large ice sheet of the Antarctic continent affects atmospheric circulation patterns over this region, which affects the transport and removal of the aerosols particles (Shaw, 1979). In the recent years, with the increase in human interventions (exploratory, scientific and tourism), there is an increase in the emissions of anthropogenic species arising from fossil fuel combustion, both at the research stations as well as those associated with transport. These include atmospheric particles as

well (Shaw, 1979; Tomasi et al., 2007; Weller et al., 2008). Even a small quantity of absorbing aerosols (anthropogenic or natural) over the highly reflecting snow of Antarctica might enhance the warming of the atmosphere (Chylek and Coakley, 1974; Randles et al., 2004) and the deposition of these particles over the surface of the snow or ice reduces the albedo (Russell et al.,2002; Hansen and Nazarenko, 2004). As such, there is an increased interest and need to investigate the properties of Antarctic aerosols, and their spatial temporal and microphysical properties to understand their climate forcing potential (Valero et al., 1983; Herber et al., 1993; Schwartz and Andreae, 1996; Hatzianastassiou et al., 2004; IPCC, 2007). Despite the initiation of investigations of aerosols over Antarctica in the early sixties, characterization of various aerosol properties, examination of their inter-relationship and delineating the local effects still remains a hot scientific pursuit (Tomasi et al., 2007) especially due to the scarcity and difficulty of measurements. In addition, in the Southern Hemisphere, areas south of ~35 °S have no spatial and temporal coverage of ground based measurements. All these make the characterization of Antarctic aerosols and regular and continuous measurements from Antarctic stations all the more important. The earlier studies over Antarctica have also pointed out the importance of assimilating analogous data from in situ measurements on physical and optical parameters of aerosols for complete characterization of the polar aerosols on the spatial and temporal scales.

In the light of above, we examined the spatial gradients in the optical and physical properties of aerosols and their seasonality over distinct oceanic regions between coastal India to Antarctica and over the Indian stations, Maitri and Bharati in the coastal East Antarctica, based on measurements carried onboard the ship cruise of 27th Indian Antarctic Expedition, during the International Polar Year (IPY) 2007-2008.

2.0 CRUISE TRACK AND EXPEDITION DETAILS

The cruise track of 27th expedition, along which the aerosol data were collected over the oceanic regions, is shown in **Figure 1a,** where the arrows show the directions of the cruise. The important locations, including the Indian stations in Antarctica are marked as red sphere. During the expedition, the ship MV Emerald Sea sailed off Goa (15º24'N, 73°42'E) on 7th December 2007, passing via Cape Town (South Africa; 34°54'S, 19°36'E) to reach coastal Antarctica (near Maitri; 69°12'S, 12°42'E) on 03rd January 2008. Experiments were conducted for about 39 days at Maitri (70.77 °S, 11.73 °E) from 5 January 2008 to 13 February 2008.

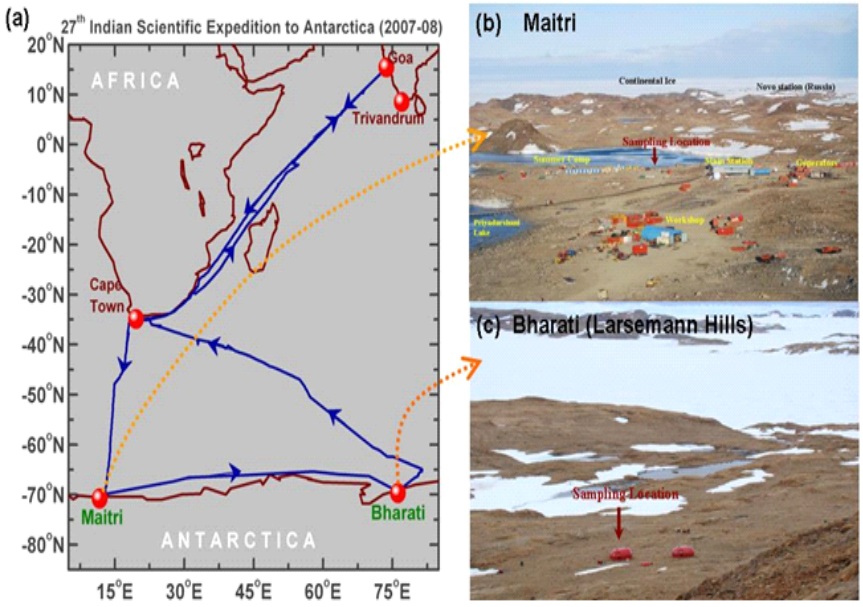

Fig. 1: (a) Cruise track of the 27th Expedition. Solid spheres represents important locations, including Indian stations in Antarctica, Maitri (70.77 °S, 11.73 °E) and Bharati (69.40 °S, 76.89 °E). (b) Aerial view of Maitri with important locations marked on it, (c) Aerial view of Bharati with sampling location marked on it.

Subsequently the ship sailed off to reach Bharati (69.40 °S, 76.20°E), third Indian station in Antarctica on 24 February 2008, where the experiments were conducted from 24 February 2008 to 10 March 2008. In the return leg, the ship left coastal Antarctic Ocean (near Bharati) on 10th March 2008 and reached Goa on 11th April 2008 via Cape Town. As it is seen in Figure 1a, the expedition had covered distinct oceanic region from coastal India to southern Oceanic regions, almost in the same longitude belt. Most interesting feature of the data obtained during the expedition is the time periods of onward and return leg, which is northern hemisphere (NH) winter (December-January) and the NH spring (March-April).

The two Indian stations in Antarctica, Maitri (Figure 1b) and Bharati (Figure 1c) have distinctively different features. Maitri is situated in Schirmacher Oasis, which is near continental ice, 80 km away from the open ocean and is not a coastal location like Bharati in Larsemann Hills. Maitri is a rocky area of ~35 km^2 and is operational throughout the year since 1989. The thick continental ice is only 500 m due south of the station. The day to day activities and life are supported by electrical generators working on fossil fuel. In contrast to Maitri, Bharati in the

Larsemann Hills Island is located close to the open Ocean, 3000 km east of Maitri. The station was not constructed and fully operational during the study period. Here observations were carried out by 4 to 5 observers, who visited the site daily from the ship during day time by helicopter. The instruments operated mainly on solar power. As such, Maitri is a continental coastal station under moderate anthropogenic influence, while Bharati (at study-time) was a pristine location, more under the influence of marine environment.

3.0 INSTRUMENT DETAILS AND DATA SET

In **Table 1**, we list the instruments used and the aerosol properties measured. The spectral aerosol optical depth (AOD) measurements were made onboard cruise, as well as at Maitri and Bharati, using a hand-held Microtops Sun photometer (Solar light Co.) at 30 min interval on all the days, when the solar disk was free of clouds, following the standard protocols (Ichoku et al., 2002). A GPS connected to the sun-photometer, provided the time of measurements and geographical position of the ship. The instrument was calibrated prior to the campaign. The estimated uncertainty of the optical depth in each channel did not exceed ± 0.01. Details of the sun photometer operation and measurements onboard ship are available in Morys et al., (2001); Ichoku et al., (2002) and Nair et al., (2009).

Table1 – Instruments used at different locations and aerosol properties measured during the 27th expedition

Instruments	Parameters measured/used	Cruise	Maitri	Bharati
Aethalometer	Black Carbon mass concentrations	√	Instrument Malfunction	Instrument Malfunction
Sun Photometer	Spectral Aerosol Optical Depth	√	√	√
Quartz Crystal Microbalance	Total mass concentrations	√	√	√

Near-real-time measurements of the total mass concentration (MT) of composite aerosols near the surface were made at hourly intervals using a Quartz Crystal Microbalnce (QCM, model PC-2, California Measurements Inc.) cascade impactor. The ambient air was aspirated from a height of 10 m above Ocean surface during the cruise period and ~ 2 m above surface over Maitri and Bharati. Size resolved measurements of

aerosol mass concentrations were determined in 10 size bins; with 50% lower cut-off diameters at 25, 12.5, 6.4, 3.2, 1.6, 0.8, 0.4, 0.2, 0.1, and 0.05 µm for the bins 1 to 10, respectively. Measurements were made manually at a flow rate of 0.24 L min-1 and data collected in every 1-hour interval, with a sampling time of 5 min. Measurements were restricted to periods when the ambient RH was less than 75% (with a view of the affinity of Quartz crystal to changes in RH at higher RH levels). Following the error budget given by Pillai and Moorthy (2001), the estimated error in the measured mass concentration was in the range of 10 to 15% for each measurement.

Black Carbon (BC) mass concentration (MB) was measured continuously using the Aethalometer (model AE-41 of Magee Scientific, USA) by sampling air from a height of ~10 m above sea surface. The BC mass concentration is estimated from the change in attenuation at 880 nm and laboratory calibrated value of the specific mass absorption cross section. Details of the aethalometer principle, data analysis and error budget can be found extensively in the literature (Moorthy et al., 2005; Weingartener et al., 2005; Schwarz et al., 2008 and Babu et al., 2011).

4.0 GENERAL METEOROLOGY AND AIRMASS TYPES

4.1 Prevailing Meteorology over Oceans during Cruise Period

The synoptic meteorological conditions during the cruise period inferred from National Center for Environmental Prediction (NCEP) data, are shown in **Figure 2**, separately for each part of the cruise track (a and b are for NH winter, while c and d are for NH spring). Mean wind pattern

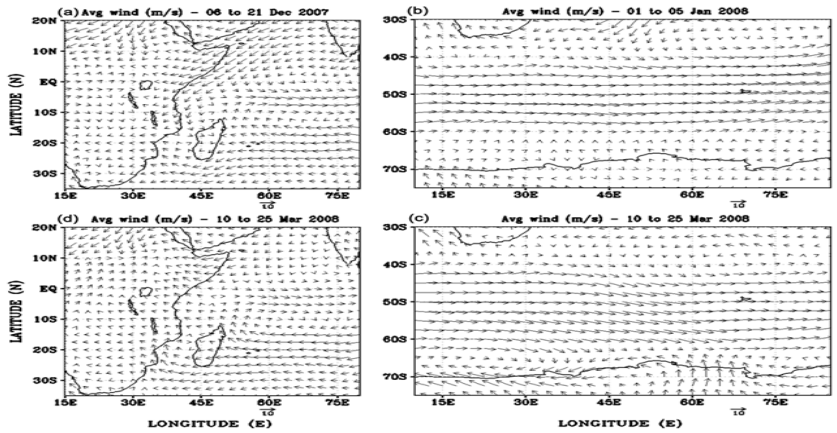

Fig. 2: Synoptic meteorological conditions during the cruise period for NH winter leg in (a) from 15 °N to 35 °S and (b) 30 °S to 75 °S, and for NH spring legs in panel (c) and (d)

during the NH winter (cruise period from Goa to Capetown) comprised of strong northeasterlies directed from the west coast of India. The winds gradually weakened and shifted to easterly in the Mozambique Channel. Near the coastal African region, winds were easterly and weak. However, winds became strong westerlies in the region between 40 ºS - 60 ºS, both during onward and return phases **(Figures 2b and 2c)**. Near the coastal Antarctica winds were weak southeasterly in December-January, while it became strong easterly/ southerly during March-April. Most importantly, winds were weaker in the Indian Ocean and Arabian Sea region during NH summer, with diverging wind field observed around ~10 ºN.

With a view to examining the possible pathways for aerosol transport during the different days of the expedition cruise, we computed seven-day back trajectories using Hybrid Single-Particle Legrangian Integrated Trajectory (HYSPLIT) model ending at height of 1000 m above the location, for different locations of ship at 0530 GMT on each day. This is shown in different panels of **Figure 3**, where the panels (a) and (b) are for the NH winter leg and panel (c) and (d) for NH spring leg.

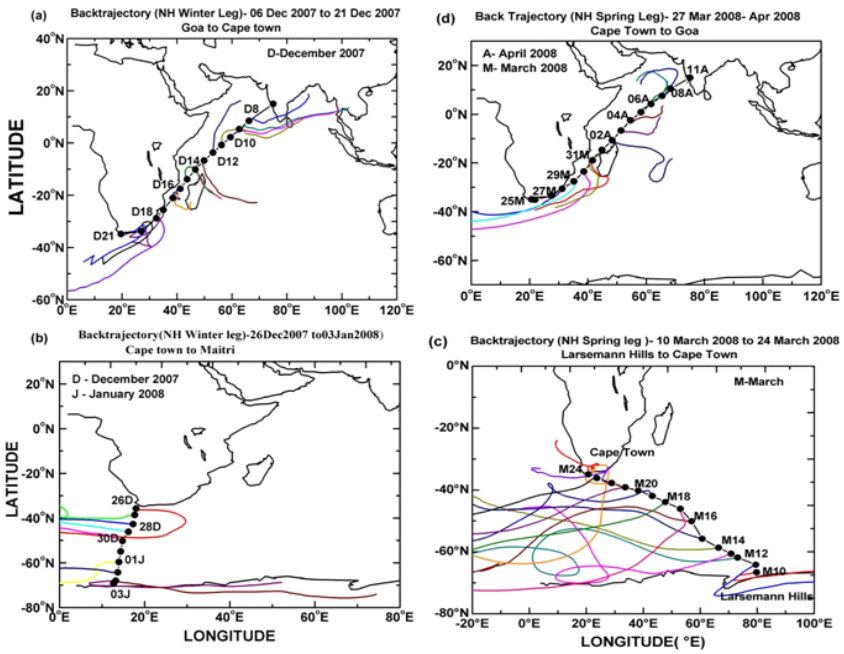

Fig. 3: 7-day back HYSPLIT trajectories, ending at a height of 1000 m, at different locations of ship during the cruise at 0530 GMT of each day. Panel (a) and (b) are for onward leg and panel (c) and (d) are for return leg. Respective dates are also marked on the map

The back trajectories showed significant variations in the sector from Goa to 20 ºS, as the season changes from NH winter to NH spring. During NH winter, for the regions north of equator, trajectories originated from Bay of Bengal, traveled across peninsular India and Sri Lanka to arrive at the ship location, while they were mainly oceanic (confined to far oceanic regions with no continental traverse) during the NH spring. To the south of the equator, trajectories were confined in the region bound between Madagascar and African coast (Mozambique Channel). After crossing the channel, when ship was near the coastal Africa, trajectories arrived from southern oceanic regions. Similar to NH winter, trajectories over the southern oceanic regions arrived from the oceanic regions during NH spring.

4.2 Prevailing Meteorology over Maitri and Bharati

Meteorology over the Antarctic region is highly important in understanding the properties, sources and the characteristics of the aerosols because it determines the role and region of transport .Information on the local meteorology was obtained from the automatic weather stations (AWS), operated regularly by the Indian Meteorological Department (IMD) at Maitri, which yielded air temperature (T, °C), relative humidity (RH) and ambient pressure (P) at every minute, while wind speed (U m s^{-1}) and wind direction (θ°) are available at every three hour interval. As Bharati was a recently chosen base for India's third permanent station, there were no permanent setup such as AWS during the study period and as such we used the AWS data onboard the ship, which was anchored ~15 km due north to the station, as the representative values for Bharati. The daily mean meteorological features of Maitri and Bharati during the observation period are shown in **Figure 4**, where the solid circles show the daily average values and the error bars passing through them are the standard deviations.

During the study period at Maitri, the average temperature was ~-1.5 °C (min of -8.6 °C and max of 1.8 °C), the higher values being observed on the clear sky days. The mean pressure at Maitri was 983 hPa; being ~992 hPa during the normal days and decreased to ~963 hPa during the blizzard episode. The pressure drop on 5 February was also due to the stormy condition that prevailed over the station for a short period. Surface winds were calm to moderate (~ 10 m s^{-1}) during the normal clear sky days, and increased, going up to ~ 28 m s^{-1} during the blizzards. The prevailing winds over the Maitri were generally south-easterly. The surface relative humidity averaged for the full study period was 53%, showing the dryness of the continent. It varied from a low value of ~ 38% in normal clear sky days to a comparatively high value of ~ 70% during the blizzard days. In comparison, at Bharati the variation in the temperature were

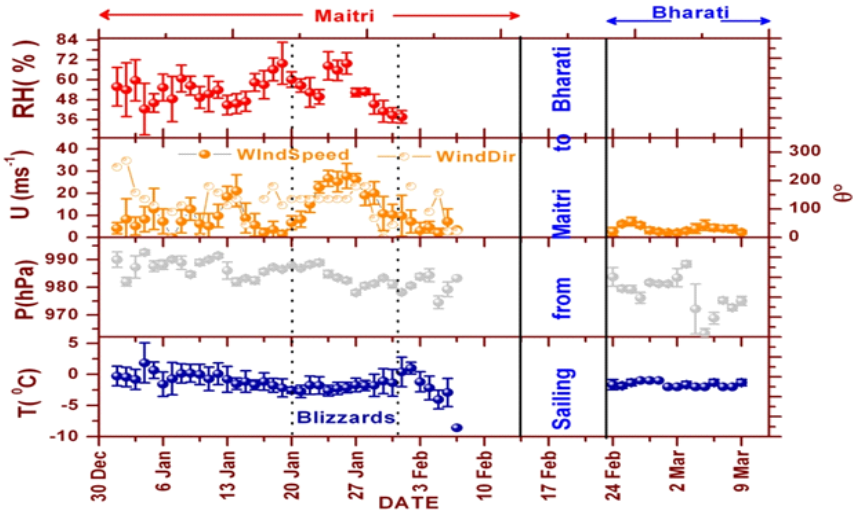

Fig. 4: Graph showing daily mean meteorological variations at Maitri and Bharati. The panels (a), (b), (c), (d) shows the day to day variation of relative humidity, wind speed and direction, pressure and temperature. The line passing through it represents the standard deviation from the mean values of the day. The open circles in the wind parameter panel represent the wind direction. The period between the dotted vertical lines represents the duration of a long blizzard that occurred at Maitri during the observation period.

smaller; the daily average temperature being always below zero during the study period, while the winds were generally calm to low (< 5 m s^{-1}).

With a view of examining the potential advection pathways of aerosols at Maitri and Bharati, we performed 7-day airmass back trajectory analyses HYSPLIT model of NOAA for the Antarctic summer season (December-April) of 2007-2008. All these back trajectories were grouped into three mean clusters and these mean clusters are shown in **Figure 5**, separately for Maitri (panel a) and Bharati (panel b).

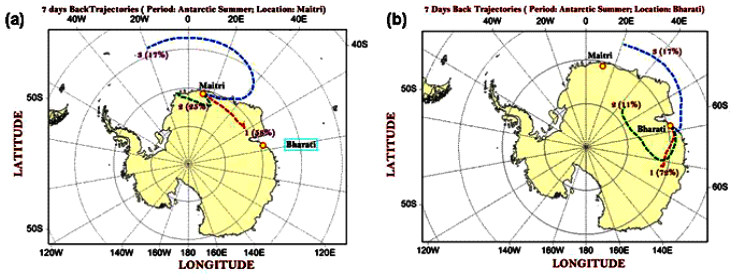

Fig. 5: Mean HYSPLIT back trajectories ending at height of 100 m agl at Maitri (panel a) and Bharati (panel b). The number is the cluster number while the number in the parentheses is the percentage of times the air parcel arrived from that direction during the full summer period of 2007-2008.

The figure clearly shows that, the three clusters of trajectories are: (i) coming from due east (~58 % at Maitri and 72% at Bharati; red dashed line in the figure) of the location, (ii) from the west (~25% at Maitri and 11% at Bharati; green dashed line in the figure) and (iii) from the oceanic regions (~ 17% at Maitri and Bharati; blue dashed line in the figure). This indicates that at both the locations for the entire summer season, trajectories arrived mostly (~ 83% of the total) from the polar continental regions, and only a very few (~17% of the total) from the nearby oceanic regions, that too during blizzards. As such, both locations are influenced by the activities taking place locally and also from upwind nearby stations.

5.0 AEROSOL PROPERTIES OVER OCEANIC REGIONS

5.1 Columnar Aerosol Optical Depth (AOD)

Latitudinal variations of columnar AOD at 500 nm for the onward leg (NH Winter, 7 Dec 2007 to 3 Jan 2008, solid circles) and return leg (NH Spring, 10 Mar to 11 Apr 2008, hollow circles) are shown in **Figure 6.** The striking features that emerge are (i) a steady decrease in AOD from north (coastal India) to south reaching fairly low values (~ 0.1) by 20 °S, and (ii) a near steady AOD further to south. In the NH Spring leg, the AODs increased from 0.05 (near 30°S) to 0.20 (near coastal India).

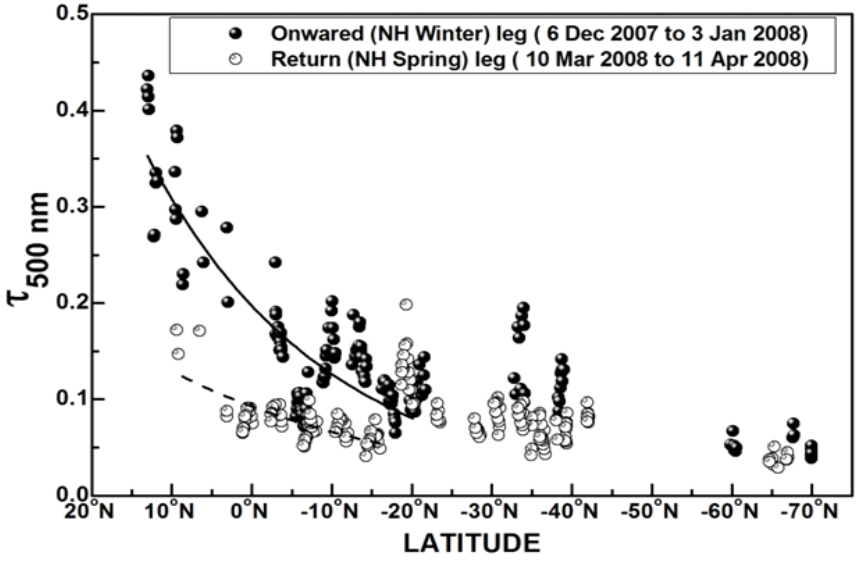

Fig. 6: Per degree latitudinal average aerosol optical depth (AOD) at 500 nm for the onward (NH winter; solid circles) and return leg (NH summer; open circles) of the cruise of the 27th expedition. The solid and dashed lines are the best fit line for the onward and return leg respectively from costal India/ Arabian Sea to 20 ºS

Examining this, in the light of the cruise track (which shows that the track covered a large oceanic area in the Southern Ocean and Antarctica, while almost retraced its path over north of 20 °S), it emerges that in addition to substantially reduced aerosol burden, the Southern Ocean and Antarctic regions exhibit large spatial and temporal homogeneity. In sharp contrast, the northern region (north of 20 °S), shows large changes both in the temporal and spatial scales, with the columnar aerosol concentrations decreasing from North to South consistently, though the loading itself was higher during NH winter compared to NH spring. While the spatial variations could arise mainly due to the changes in the continental source impacts, the temporal changes could be attributed to the seasonal changes in the prevailing circulations (Figure 2 and Figure 3), which favour continental advection during the former period and a long marine history for the airmass during the latter case. With a view to quantifying the enhancement in AOD as we approached the northern landmass from the south, we have parameterized the spatial variation of AOD using an exponential growth function of the form

$$\tau(\Lambda) = A \exp(\Lambda / \Lambda_D) \qquad \ldots.(1)$$

where $\tau(\Lambda)$ is aerosol optical depth at the latitude Λ, A is the amplitude and Λ_D is AOD scaling length expressed in degrees of latitude for an exponential growth. The data was least squares fitted for the latitude region from 20 °S to 13 °N in the onward leg and 16 °S to 9.4 °N in the return leg, where the gradients were conspicuous. These are shown as continuous (NH winter leg) and dashed (NH spring leg) lines in Figure 6. A good fit was observed with respective correlation coefficients of 0.75 and 0.54 for the NH winter and NH spring respectively. The value of A for the onward leg (return leg) has been 0.20 (0.09) while Λ_D was 22.4° (29.8°). Thus the amplitude and the gradient remained higher in the NH winter than NH spring.

With a view to examining the regional features over the distinct oceans, we have grouped the data regionally as listed in Table 2, and averaged separately for the onward and return legs. The number of data points used for the particular regions are given in the parentheses. The AOD values are generally higher in the NH winter over all the regions. Most importantly, seasonality in AOD was more prominent in the NIO, AS and CI region (northern hemispheric oceanic region) and less pronounced over southern Ocean regions (Southern Hemispheric region).

Table 2– Different regions, their respective latitude bins, mean AOD values for the regions with standard deviations during the onward (NH winter) and return (NH spring) legs of the cruise

(The numbers inside the parentheses represent the total number of data points used for the study in that region.)

REGIONS	LATITUDE BIN	AOD ± std. dev (No. of data points used)	
		Onward Leg	Return Leg
Coastal India (CI)	15 °N to 11°N	0.36±0.06 (10)	NA
Arabian Sea (AS)	11 °N to 2 °N	0.29 ±0.06 (11)	0.09 ± 0.03 (18)
North Indian Ocean (NIO)	2 °N to 10 °S	0.13± 0.04 (48)	0.08 ± 0.01 (30)
South Indian Ocean (SIO)	10 °S to 21°S	0.12± 0.03 (57)	0.09 ± 0.04 (40)
Coastal Africa (CAF)	21 °S to 34 °S	0.14 ±0.03 (12)	0.08 ± 0.01 (36)
Southern Ocean (SO)	34 °S to 60 °S	0.11± 0.03 (12)	0.07 ± 0.01 (44)
Coastal Antarctic Ocean (CAN)	60 °S to 69 °S	0.52 ±0.01 (15)	0.04 ± 0.01 (10)

Prior to 27th expedition, measurements of aerosol properties over such a long latitude stretch were made during the Pilot Expedition to Southern Ocean (PESO, Moorthy et al., 2005b; Babu et al., 2011) in 2004 and Special Expedition to Larsemann Hills (SELH, Vinoj et al., 2007) during 2006. As these cruises covered oceanic regions between coastal India to coastal Antarctica almost similar to the 27th Antarctic Expedition, this enables a comparison of our results with those earlier measurements (note-worthy is that, we have not considered the longitudinal gradients, which might be very less effective over these regions, due to absence of significant anthropogenic sources over the regions under consideration). The spatial gradients from North to South in the tropical Oceans, its seasonal pattern and the rather low loading and large spatial homogeneity over the southern Ocean and Antarctic Oceans are consistent over the years. AOD over the CI showed a significant variability during these campaigns (~ 0.5 in 2007, 0.65 in 2006 and ~0.4 in 2004), while the variability was

not significant as we moved further downwards in line with the pattern expected due to the decreasing source impacts. Unlike 27th expedition, e-growth scale distances for NH winter and NH spring were 21° and 19° respectively during PESO (2004) and they were 24.8° and 12.3° respectively during SELH (2006), showing that the gradient is steeper in March than in January. However, due south of 20 ºS, AOD remained almost around the same level (< 0.1) in all the campaigns, despite these being made over a span of nearly 5 years. This indicates the climatological pattern prevailing over these regions.

5.2 Spectral Variation of AOD and Angstrom Parameters

Using the spectral measurements of AOD and the available dataset for the regions as classified in Table 2, mean spectral variation for the NH winter and NH spring legs were determined for different regions and are shown in the **Figure 7.** The bars through the points show the spread (standard deviation) in AOD over that region. It can be seen that the spectral variations are quite similar in both the legs for all the regions except for the difference in the absolute magnitude of AOD, indicating that the general nature of the aerosol environment prevailing over these regions remained similar; only the location changed.

By parameterizing the spectral AODs using the Angstrom equation (Angstrom, 1964)

$$\tau(\lambda) \approx \beta\lambda^{-\alpha} \qquad \text{....(2)}$$

(where α is the wavelength exponent, indicating the size characteristics of the particles, β is the turbidity parameter indicating the aerosols columnar loading and γ is the wavelength in μm) the values of α and β are estimated. It is well recognized that values of $\alpha > 1$ indicate, in general, the relative dominance of accumulation mode aerosols in the size spectrum, while $\alpha < 1$ is considered to have a coarse mode derived particles (Schuster et al., 2006; Moorthy et al., 2010). High value of β indicates high aerosol loading. The regional mean values of α and β, alongwith corresponding standard deviations are listed in each panel of **Figure 7**, separately for the onward $(\alpha_o\ \beta_o)$ and return $(\alpha_r\ \beta_r)$ legs. Except for the AS (during NH spring) and SIO (in NH winter), in general, the values of α were < 1 over all the regions, showing the relative dominance of coarse mode aerosols in the columnar size spectrum. Despite this, general feature of α increased from south to north, while in the NH winter leg, α showed a random variations as we moved towards south;

with maximum value over SIO (~1 ± 0.1) and minimum value over SO

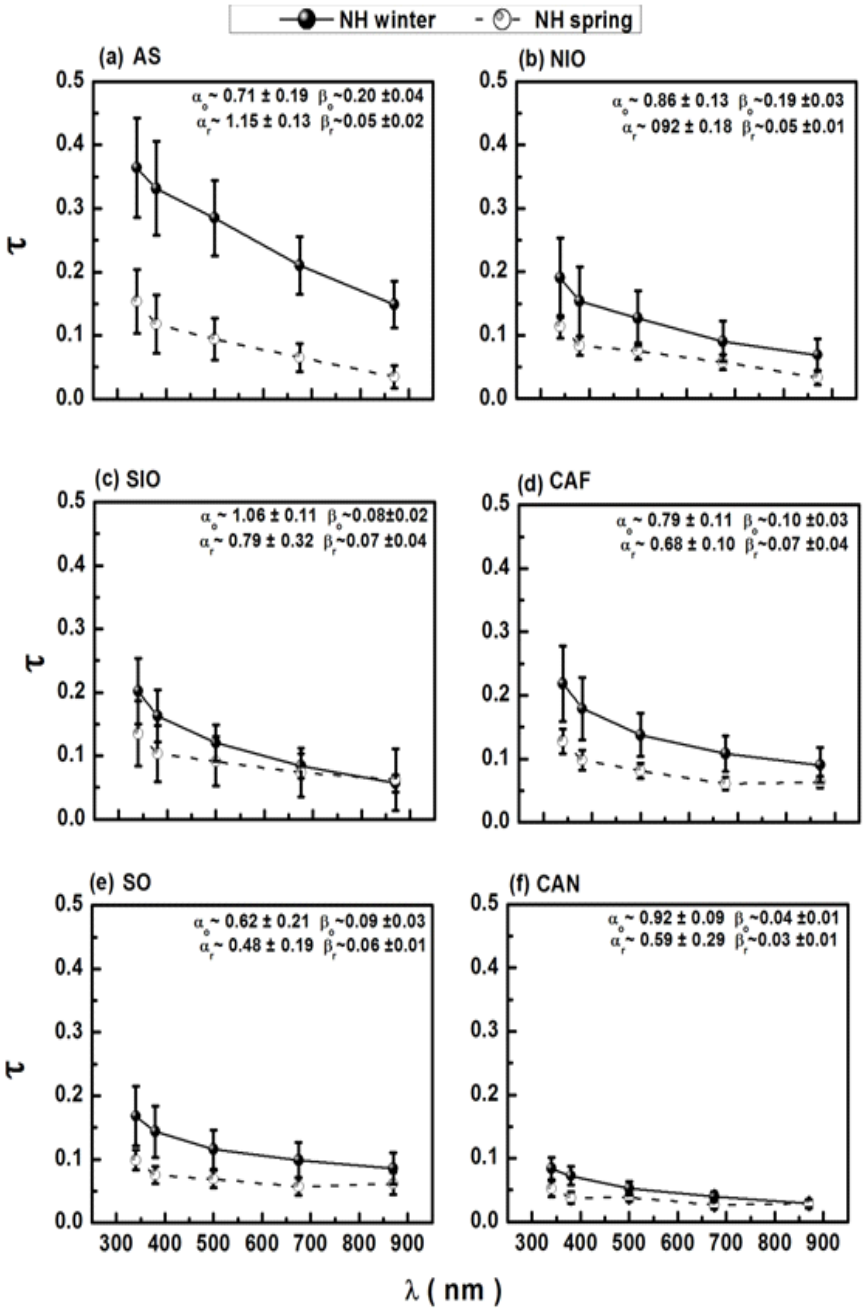

Fig. 7: Spectral variation of the AOD in different oceanic regions AS, NIO, SIO, CAF, SO CAN respectively in panels a to f. The Angstrom parameters values along with standard deviation, for onward leg (NH summer, α_o β_o) and return leg (NH spring, α_r β_r) are also

listed in the panel
(0.6 ± 0.2), in the NH spring it showed a gradual increase from SO (0.5 ± 0.2) to AS (1.2 ± 0.1).

It is to be especially noted that, over SO region α remained very low and almost similar in both the seasons. This feature is in line with the reported wavelength dependence of AOD over open Oceans by many authors (Hoppel et al., 1990; Villevalde et al., 1994; Moorthy et al., 1997; Smirnov et al., 1995, 2002; Volgin et al., 1988) and is primarily attributed to the decrease in accumulation mode abundance due to reduced impacts of continental-sources. The sources of coarse mode aerosols over open Oceans could be wind generated sea-salt (Moorthy et al., 1997; Moorthy and Satheesh, 2000; Vinoj and Satheesh, 2003) or transported dust (Prospero et al., 2002; Li and Ramanathan, 2002; Satheesh et al., 2006). As the trajectories that arrived at SO regions are from Atlantic Ocean (Figure 3), the most probable reason for the flat spectra is the sea salt aerosols. Columnar loading (β) showed a weak decrease from the CI (~0.24) to AS (~0.2), then decreased more rapidly in NIO (~0.1) and remained almost constant thereafter in SIO, CAF and SO. Variation of the Angstrom exponent (α) supports the decreasing influence of anthropogenic activities to the far off oceanic regions. Over CI and AS, α varied from a low value of < 0.5 to high values of ~ 2, with values > 1 being more frequent, indicating influence of accumulation mode aerosols advected from the populated South-East Asian region. As we moved southwards, spectral variations tended to become more flat indicating considerable reduction of accumulation mod aerosols and increase in the dominance of coarse mode aerosols (mainly wind generated sea salt). The almost flat AOD spectra observed over SO region are typical of clean remote oceanic regions (Hoppel et al., 1990; Moorthy et al., 1997; Volgin et al., 1988; Smirnov et al., 2006; Vinoj et al., 2007). Relatively higher values of α over the Antarctic Oceanic region (consistent in SELH and 27 ISEA) could be resulting from the large decrease in the abundance of coarse mode particles. In addition to this, high α over CAN might be also due to the already existing dominance of fine mode aerosols as reported by many authors for coastal Antarctic stations (Hara et al., 2004; Tomasi et al., 2007). On the other hand, during the NH spring leg, there was a small reduction in β values from NH winter leg but it remained < 0.1 for all the regions. Most importantly, the least values of β were found over coastal Antarctica (~ 0.04) indicating the low aerosol loading in the column near the Antarctic coast, over a vast region of SO, showing no seasonality, indicating the rather of pristine nature of southern hemispheric oceans as compared to northern hemispheric oceans.

5.3 Concentrations of Composite Aerosols (M_T) and Black Carbon (M_B)

Similar to AOD, the mass concentrations (M_T) of total (composite) aerosols also showed significant latitudinal changes (top panel of **Fig. 8**) which are rather random in nature. The concentrations are quite high near coastal India (~ 60 µg m^{-3}) during NH winter, but it reduced to the range of 5 to 30 µg m^{-3} due south of 5°N (North Indian Ocean region). Most importantly the absolute magnitude was comparatively lower (< 10 µg m^{-3}, south of equator), and day-to-day variations are subdued during return leg (the NH spring) of the expedition, and reached ~ 25 µg m^{-3} in CI; which has been much lower than the values encountered during NH winter season. This feature, analogous to that of the columnar AOD, indicates that the significant decrease in the aerosol concentration occurs in the MABL as well as in the column as the season changes from NH winter to spring which is associated with the changes in the prevailing air mass types.

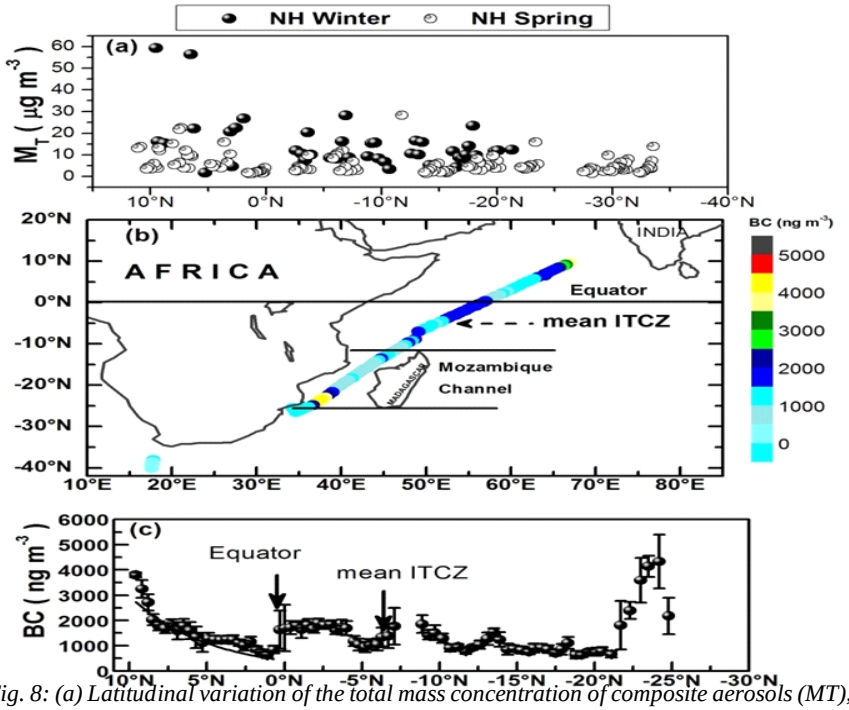

Fig. 8: (a) Latitudinal variation of the total mass concentration of composite aerosols (MT), where solid and open circles are for NH winter (onward leg) and NH summer (return leg) respectively. (b) Variation in the black carbon mass concentration (M_B) along the cruise track in NH winter, colour indicates the M_B values, while position of equator, mean ITCZ positions and area of Mozambique channels are also marked, (c) latitudinal variation of MB, north of 20 °S, vertical bars are the standard deviations and the solid continuous line is the growth fit from equator to coastal India

The spatial variation of BC mass concentrations (M_B) along the cruise track is shown in the middle panel of Figure 8, where the colors represent the concentration. The position of equator, the mean position of Inter Tropical Convergence Zone (ITCZ) for the study period (Waliser and Gautier, 1993; Moorthy et al., 2007) and the area of Mozambique Channel are also marked. The figure shows a steady decrease from ~3800 ng m^{-3} at 10 ºN, to ~624 ng m^{-3} at 1 ºN (near equator), probably due to reduced continental source impacts. Notwithstanding this, BC showed an increase from around the equator to ~5 ºS, with maximum value of ~ 1900 ng m^{-3} at 2 ºS. This might be due to the presence of the ITCZ, which acts a virtual boundary for the horizontal transport of aerosols across it. Interestingly, M_B remained low in the Mozambique Channel, even though the ship was in the vicinity of two continental land masses (Africa and Madagascar). This may be probably due to the weak continental aerosol transport to the ship location (Figure 3a) as well as the bad weather conditions (including little rainfall) encountered at ship location in this region. BC mass concentration showed an increase as the ship crossed Mozambique Channel, and it reached ~ 4330 ng m^{-3} near coastal Africa (~ 23 ºS), almost similar to that measured over coastal Indian oceanic regions, showing enhanced continental influence. As we moved to the southern Ocean, BC concentration decreased again rapidly and remained very low (< 100 ng m^{-3}). However a technical snag with the instrument led to no further data. Parameterizing the increase in BC concentration due north of the equator using eqn (1) by replacing AOD with M_B (dashed line in the bottom panel of Figure 8), we find that the scaling distance for an e-fold increase is as small as ~5 º near the surface unlike the column. Lower scaling distance for M_B, compared to that of AOD, shows the stronger source control on the MABL aerosol concentrations. The BC concentration during 27th expedition, are generally in-line with the values during the PESO, where it varied over wide range of ~2000 ng m^{-3} in the AS to as low as 20 to 50 ng m^{-3} in the SO (Moorthy et al., 2005; Babu et al., 2011). The values observed in the present study for the southern oceanic regions are marginally higher than the seasonal ones recorded in PESO and this might be due to the spatial difference in the proximity to the continents. Moorthy et al., (2005) also reported the significant temporal changes in MB (scaling distance of 7.49° in January and 9.25° in March), over the oceanic regions north of 20 °S, possibly associated with the change in synoptic conditions.

5.4 AODs retrieved from Satellite and Estimated from GOCART Model

An examination of Figure 1 reveals that the oceanic region in the

longitude range from 60° E to 70° E remains rather free from the proximity to any major continental anthropogenic source impacts over the entire latitude range covered in the study (~ 10° N to 70° S; from coastal India to coastal Antarctica). As such, we made a comparison of the AOD measured from the ship during the 27th expedition with the collocated values (within 1° x 1° grid) of AOD estimated from satellite such as MODIS (Aqua and Terra) and MISR as well as those given by global chemical transport model (such as GOCART) simulation for the study period. The regional mean AOD values at 550 nm, obtained from these various measurements/ simulation / retrievals are shown in **Figure 9**, with the top panel depicting the features for December- January (NH winter) and the bottom panel for March- April (NH spring). While the points represent the regional means, the vertical lines through them depict the respective standard deviations.

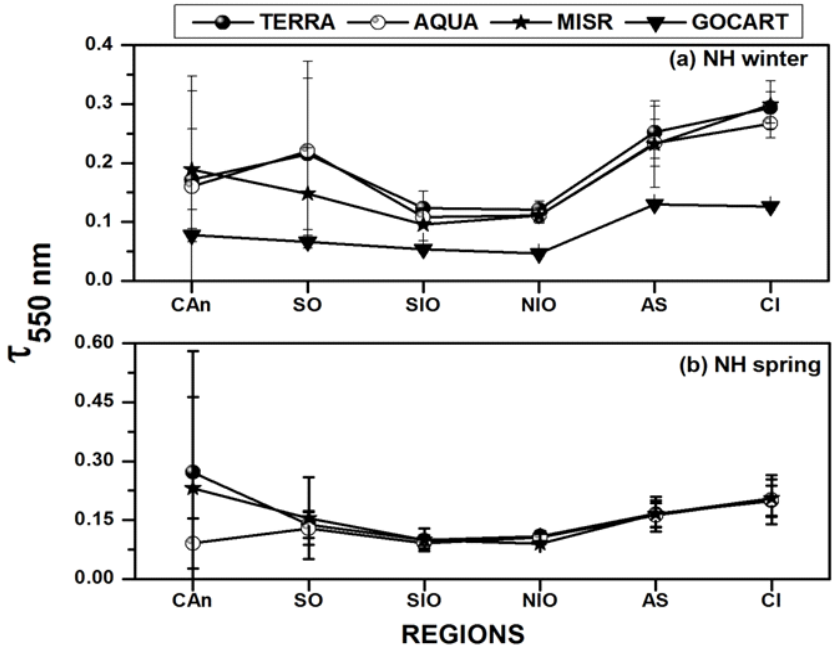

Fig. 9: Regional variation of satellite (MODIS and MISR) and model (GOCART) derived AODs. The vertical bars are the respective standard deviations

Though, there is fairly good agreement between the regional mean AOD, from the different measurements, the GOCART model seems to significantly underestimate AOD over all regions, even though the spatial variations are reproduced. The agreement is closer during NH spring, as

compared to NH winter period. Based on the measurements carried out over Atlantic Ocean during October to December 2004, Smirnov et al., (2006) have showed good agreement between shipboard measurements and satellite (MISR and MODIS) retrieved AODs and GOCART simulations.

6.0 AEROSOL PROPERTIES OVER MAITRI AND BHARATI

6.1 Aerosol Optical Depth

Temporal variations of the daily mean AOD at 500 nm, estimated by averaging the individual microtops measurements of each day, are shown in top panel of **Figure 10**, where the brown circles represent Maitri observation and blue circles those measured over Bharati. The vertical lines passing through the circles represent the respective standard deviations. It can be seen (panel a) that over Maitri AOD showed significant day to day variations, that was random in nature. The AOD at 500 nm showed the peak value of 0.046 (on 13 January 2008) and least value of 0.026 (on 08 February 2008) with an average of 0.034 ± 0.005 for the full study period at Maitri.

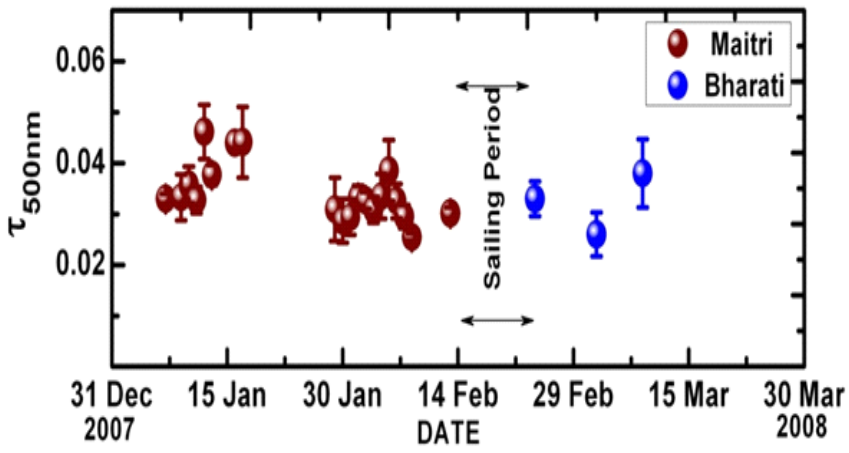

Fig. 10: Daily mean aerosol optical depth ( ) at 500 nm for the Maitri and Bharati, where the brown and blue circles represent Maitri and Bharati respectively. The vertical line passing through them are standard deviation from the mean value

The two mechanisms which might be contributing to this are:

(i) marine particles (sea salt) and dust particles from the oasis; both produced and transported by the winds, and

(ii) those produced by the local activities at Maitri and nearby stations

As Maitri is situated in an oasis and experiences a fair amount of local station activities during the summer period, both the mechanisms would be significant. Moreover, advection from the neighbouring stations lying upwind, movement of men and transport of goods (more frequent during Antarctic summer at all stations) also contribute to the local (regional) aerosol abundance and to the day to day variations in the AOD. Nevertheless, the average AOD values measured over Maitri were comparable to those measured over Bharati (within the standard deviation), except that, over Bharati, the AOD depicted smaller day to day variations, remaining between 0.026 and 0.038 with an average of 0.032 ± 0.006. It may also be noted that AOD measurements were available only for 4 days (a total of 84 measurements) at Bharati due to the frequent cloudy sky condition during the measurement period. Nevertheless, these formed the first ever measurements of AOD from this region of Antarctica. It is also interesting to note that the monthly mean value of AOD at 550 nm for March (8 days of data are available from 2nd to 21st March, 2008) obtained from MODIS satellite sensor, (http://gdata1.sci.gsfc.nasa.gov/daac-in/G3/ gui.cgif instance_id =MODIS_DAILY_L3) over the open ocean close to Bharati during the study period is found to be 0.33 ± 0.005 is comparable to the mean value observed in the present study. AOD values over Maitri were measured in January-February whereas at Bharati the measurements were made at the end of February and beginning of March. The slight decrease in AOD (from Maitri to Bharati), although not much significant, can be attributed to the decrease in the aerosol loading over Antarctica as season changes (Shaw, 1988; Wolff and Catchier, 1998; Hara et al., 2005). Notwithstanding this, agreement between AODs at the two locations indicates the prevalence of spatially homogeneity in columnar aerosol abundance at coastal Antarctic atmosphere spatially. This is in contrast to that reported over the populated continental regions of northern hemisphere where significant heterogeneity (vertically and spatially) due to elevated aerosol layers are reported frequently (Muller et al., 2001; Satheesh et al., 2008).

The storm belts that surrounds Antarctica act as efficient barriers for the migration of aerosols and trace gases from low latitudes (Shaw, 1982) and vice versa. As shown in Figure 5, during the study period, the airmass arrived at Maitri and Bharati from the Antarctic continental regions. As such, a major part of aerosols over here might be attributed to local activities. Shirsat and Graf, (2009) have shown that in Antarctica 0.004 Tg of SO_2 is produced per year from power generation and transportation alone.

Table 3– Antarctic stations, there features, location and measured optical depth (C-Coastal, I-Inland, HA-High Altiude, LA-Low Altitude)

Station Name	Type	Country	Location	AOD	Wavelength (nm)	Year	References
Maitri	C,LA	India	71S, 12E	0.034±0.005	500	2007-2008	Present study
Bharati	C, LA	India	69S, 76E	0.032±0.006	500	2007-2008	Present study
Terra nova Bay	C	Italy	76S, 164E	0.01-0.0	500	2005	Tomasi et al., 2007
Aboa	I, LA	Finland	72S,13W	0.035-0.063	500	2000	Wehrli, 2005, Tomasi, 2007
Neumayer	C, LA	Germany	71S, 8W	0.044	500	1999-2002	Wellereta l., 2008
Mirny	C,LA	Russia	67S, 93E	0.01-0.02 0.03	1000	1980-88	Radionov, 1994
					500	2006	Tomasi et al., 2007
Kohnen	I, HA	Germany	75S, 0E	0.013	500	1999-2002	Tomasi e tal., 2007
Dome C	I, HA	Italy/France	75S, 123E	0.02 0.007	500 870	2003-2004	Tomasi et al., 2007
South Pole	I, LA	USA	90S	0.01 - 0.02	1000	1958, 1962	Vielhbrock and Flowers, 1968
McMurdo	C,LA	USA	78S, 167E	0.02	1000	1978	Shaw, 1982
Maudheim	C, LA	Norway	71S, 11W	0.025	1000	1950-51	Liljequist, 1957
George Forster	C,LA	Germany	71S, 12E	0.022	1000	1988-91	Herber, 1993
Plateau	I, HA	USA	79S, 41E	0.02	1000	1969	Tomasi et al., 2007

Notwithstanding this, the daily mean values seen in our study are significantly lower than the values reported for the different remote and coastal oceanic regions (Smirnov et al., 2002 and references cited therein; Vinoj et al., 2007) outside Antarctica vortex. The AOD values reported from different locations of Antarctica starting since 1950s are listed in Table 3. It shows that while our values are quite comparable to those at other coastal locations, but slightly higher than the values reported from the inland stations.

6.2 Spectral Variation of AOD

The mean spectral AODs were estimated for the respective measurement periods, separately for Maitri, Bharati are shown in the top panel of **Fig. 11.** It clearly shows that spectral variation is flat for Bharati compared to Maitri and CAO, indicating aerosol size distribution at Maitri and Bharati are different. As the spectral dependence of AOD contains information about aerosol size distribution, which can be inferred in a simplest way by using the Angstrom power law as shown in eqn (2).

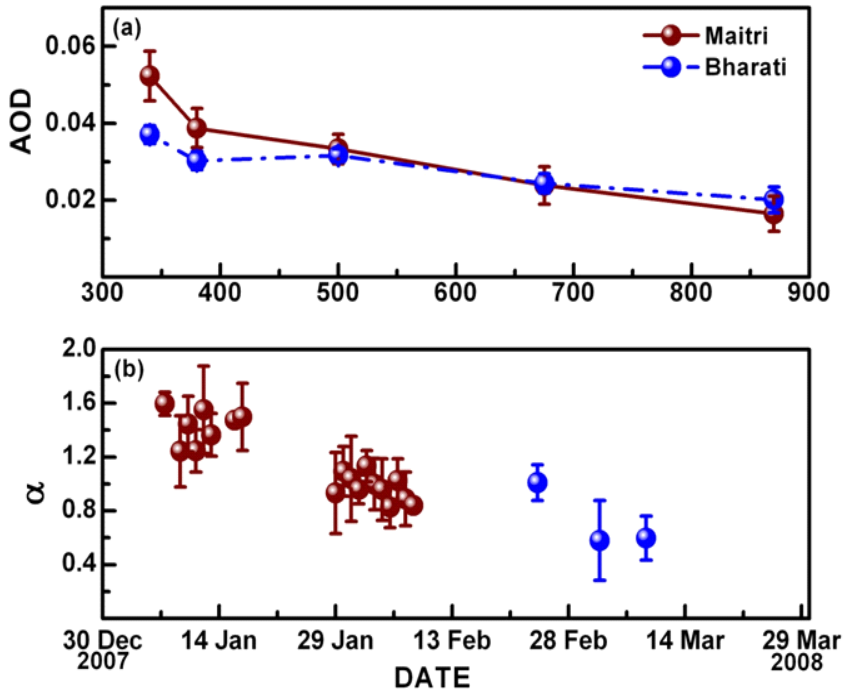

Fig. 11: (a) Mean AOD spectrum for the entire period at Maitri (brown circles) and Bharati (blue circles). The vertical line passing through the symbol represents the standard deviation from the mean value. (b) Daily mean variation of at Maitri and Bharati

The day-to-day variations of at Maitri and Bharati are shown in the bottom panel of Figure 11, where the solid and open circles represent the values at Maitri and Bharati respectively. For the study period at Maitri, the daily average α varied from 0.8 to 1.6 with an average of 1.2 ± 0.3, whereas for Bharati it varied from 0.6 to 1 with an average α of 0.7 ± 0.2 which is significantly lower than that at Maitri and CAO. Angstrom coefficient β, varied from 0.009 to 0.02 at Maitri (with an average of 0.015 ± 0.005) and from 0.015 to 0.024 at Bharati (with an average of 0.02 ± 0.004). These values are comparable to the range of values (0.002 - 0.1) reported by Tomasi et al., 2007 for the different coastal and inland Antarctic station.

The decrease in the steepness of AOD spectra (correspondingly lower α) may be due to the occurrence of high sea surface winds over open Ocean and the consequent production of sea salt particles which are generally larger in size (Fitzgerald, 1991; O' Dowd et al., 1997; Moorthy et al., 1997; Moorthy and Satheesh, 2000; Vinoj and Satheesh, 2003). An examination of the surface wind over the oceanic regions adjacent to the island stations (Amsterdam and Crozet) by using QuickSCAT wind data showed variable winds varying from a minimum of 3 m s^{-1} to maximum of 16 m s^{-1} with an average of 10 m s^{-1}. Similar results depicting the surface wind speed dependence on spectral AOD has been reported over same latitude region by Smirnov et al., 2006 and Vinoj et al., 2007.

The dominance of fine and accumulation particles at Maitri might be due to—

(i) the enhanced station activities there,

(ii) pre-existing accumulation mode dominant background aerosols in the coastal Antarctic atmosphere as suggested by Herber et al. (1993) and Hara et al. (2005); and

(iii) those of biogenic species (like methane sulphonate) and non sea salt sulphate (products of dimethyl sulphide) which have been reported during Antarctic summer (Weller et al., 2008).

On the other hand, Bharati being very near to and surrounded by the open Ocean and having a low elevation of just 48m msl, it is conducive of being influenced by the local (wind generated) sea salt particles much more than Maitri (almost 80 km away from the open Ocean). Moreover as the coarse mode sea salt particles get settled faster in comparisons to the

fractionated sea salt aerosols and as such the marine airmass reaching Maitri would be strongly deprived of the coarse mode component. This would explain the difference in α between the two stations. From extensive measurements at multiple Antarctic stations, Tomasi et al., 2007 have reported values in the range 0.02 to 2.54 for α at different stations in Antarctica in which the values over the coastal locations varied from 0.5 to 1.2 similar to the values reported in the present study.

6.3 Mass Concentrations of Ambient Aerosol

From the size segregated mass concentrations, accumulation mode mass concentration (M_A) was determined as the sum of the mass in channels 7 to 10 of the QCM (size range 0.8 µm). The individual estimates of total mass concentration (M_T) and M_A for each day were averaged to get the daily mean values. In **Figure 12**, we have shown the day-to-day variations of M_T in top panel and M_A in the bottom panel where the brown circles correspond to the values at Maitri and blue circles correspond to Bharati. The vertical bars through the points represent the corresponding standard deviations. MT depicted fairly large day-to-day variation at Maitri, from a minimum value of 4.4 µg m^{-3} to a maximum of 14.7 µg m^{-3}, with a mean value of 8.25 ± 2.87 µg m^{-3}. Comparatively lower values are found at Bharati where it varied from 4.58 µg m^{-3} to 8.53 µg m^{-3} with a mean value of 6.03± 1.33 µg m^{-3} for the study period.

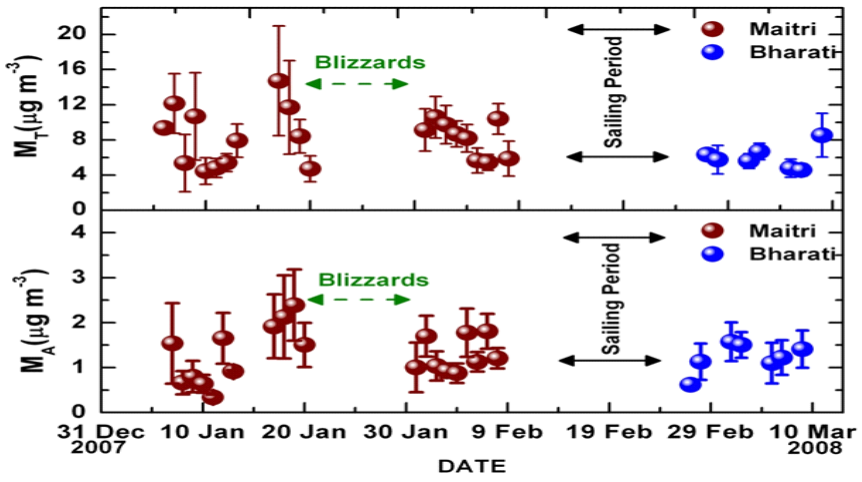

Fig. 12: Daily mean total mass concentration (MT) and accumulation mode mass concentration (MA). The brown and blue circles are daily averages of MT and MA for Maitri and Bharati in top and bottom panel respectively. The vertical lines passing through the symbol are the standard deviations from the mean values

While the minimum values at both locations are comparable, showing the homogeneity in the background values over coastal Antarctica. The maximum values are rather higher over Maitri before the blizzard event. The standard deviation in both M_T and M_A at Maitri were quite larger than the deviations at Bharati, similar to the columnar AOD. The measured value of M_T with day to day variations over Maitri were higher than the values reported by Mazzira et al., 2001 for PM10 particles at Mc Murdo station, Antarctica. The low variabilities in M_T and M_A at Bharati are consistent with the subdued station activities and the absence of any neighbouring stations upwind.

Other processes such as troposphere-stratosphere exchange of aerosols is very less effective over Antarctica due to the low pressure in the upper stratosphere that makes wind flow always towards the oceans. Only when the polar vortex breaks down, the exchange of the stratosphere and troposphere air takes place and the aerosols are brought down to the lower troposphere and that too mainly at high latitudes region (Hogan et al., 1979). These aerosols are then transported towards the coastal Antarctica by the katabatic winds and strength of this cycle may contribute significantly in the day-to-day variation in the ambient mass concentration. Not withstanding the day-to-day variations, the mean values of MT reported in our study were significantly lower than the values reported for distinct regions between coastal India and coastal Antarctica (Moorthy et al., 2005, Nair et al., 2008, Jayaraman et al., 1998,) which reveals a large gradient with higher values in the northern oceanic regions, decreases towards south, showing the highly subdued impacts of anthropogenic activities over Antarctica.

6.4 Number Size Distributions

From the individual mass size distribution obtained from the QCM measurements, the daily mean number size distribution (NSD) were determined (Pillai and Moorthy, 2001) and averaging them over the study period, mean representative NSD for Maitri and Bharati were estimated. These are shown in a log-log scale, in **Figure 13**. The low resolution (in size) of the QCM does not bring out any fine features in the size spectrum, and at both locations the NSD showed a rather monotonic decrease in number concentrations (with increase in particle size) which could be parameterized using an inverse power-law distribution of the form

$$n(r) = Cr^{-v} \qquad \text{....(3)}$$

where C is a constant which depends on the total number of particles. The

size index *v* was estimated by a regression fit of equation (3) to the mean NSD. The size indices estimated from the individual QCM measurements varied from 3.4 to 3.8 with an average value of 3.6 ± 0.1 at Maitri where as it ranged from 3.1 to 3.7 with mean of 3.5 ± 0.3 at Bharati. This indicates that on an average the size distributions of ambient aerosols were quite similar at the two locations; which is in contrast to the feature seen with columnar AOD earlier. Considering the columnar size distributions of the aerosols to follow a form given in equation (3), Angstrom exponent α (estimated from equation (2)) and the size index ν (estimated from equation (3)) could be related by the expression

$$\nu = \alpha + 3 \qquad \text{....(3)}$$

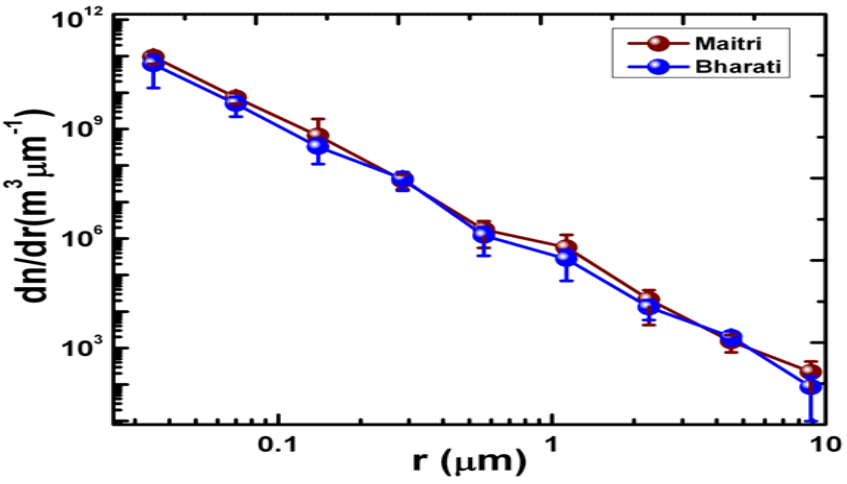

Fig. 13: Aerosol number size distributions for Maitri (brown circles) and Bharati (blue circles) estimated from QCM measurement, where the vertical lines are the respective standard deviation

In such case, a comparison of ν values estimated from AOD spectral index α and from the QCM measurements could be used to qualitatively infer on the vertical homogeneity of the aerosol size distribution. Our result shows that over Maitri, the size index ν estimated from α is significantly higher than that seen near the surface, which in turn suggests the presence of significant abundance of fine and accumulation mode aerosols aloft (above the Antarctic boundary layer) at Maitri. In other words, the mean size distribution of aerosols in vertical column differed significantly from that seen near the surface at Maitri for the most of the period, except towards the end of study period, after a long and intense blizzard event. This is examined in detail subsequently. Such a feature was not seen at Bharati, during the study period.

6.5 Effect of Blizzards and Snow Scavenging on Aerosol Properties

Scavenging of the aerosol particles in the Antarctic atmosphere occurs mainly by the blizzards, accompanied by snowfall, and snow or ice drift, which are more frequent in winter than in summer. Snowfall is the only type of precipitation over Antarctica, and wind generated snow or ice particles in the atmosphere are also good scavengers of the aerosol particles. While the snowfall is a good scavenger at higher altitudes of the atmosphere, the snow or ice drift mainly contributes in the removal of near surface aerosols. At Maitri, a long blizzard event (20th January to 28th January 2008) occurred during the study period and we examined the impact of this on the measured and derived aerosol properties in **Figure 14.** In this figure we show AOD, α, β and M_T in four panels respectively from the top to bottom. In each panel, the points are the daily mean values, the vertical bars through them are the standard deviation and the horizontal lines represent the mean value of the parameter before and after the blizzard and the thick error bar is the respective standard error. The duration of the blizzard is shown by double headed arrow in each panel.

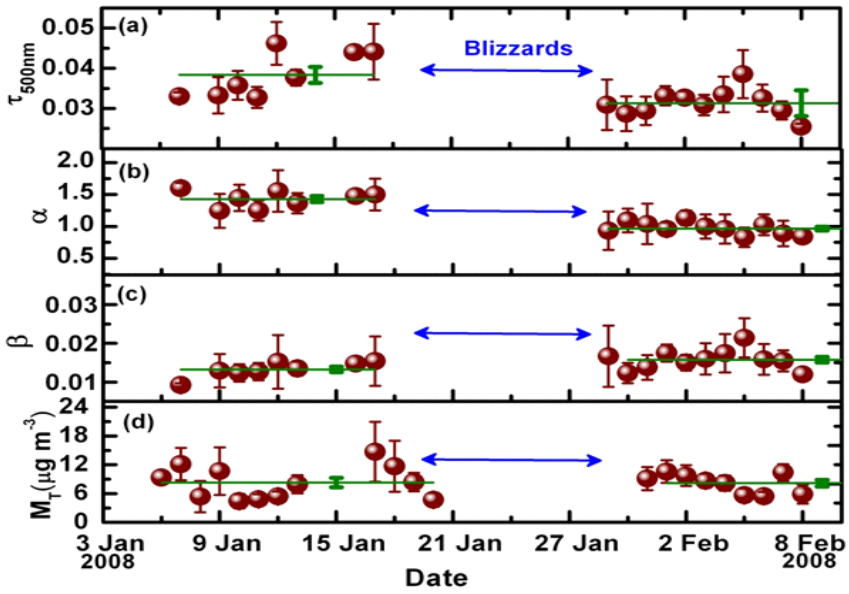

Fig. 14: Aerosols optical depth (τ), Angstrom exponent α, columnar loading 'β' and total mass concentration (M_T) before and after the blizzard at Maitri. The vertical line passing through the circles are the standard deviation from the mean value whereas the horizontal line represents the mean value before and after the blizzard event whereas the thick vertical line is the standard error

The figure clearly shows that the effect of blizzard is clearly discernible in the columnar AODs, which dropped significantly after the event. Prior to the blizzard AOD varied in range 0.032 to 0.046 giving an average of 0.038 ± 0.006, which reduced to be in the range of 0.026 and 0.039 giving an average of 0.031 ± 0.03 after the blizzard. In fact the drop is much more if we consider the AODs for the days just before the blizzard onset (AOD ~ 0.042) and the day immediately after the blizzard (0.030). The mean AOD value remained low even after a week and became comparable to the values at Bharati showing that the snow scavenging has cleaned the environment over Maitri significantly, particularly at higher levels. Examining the other parameters, it is interesting to note that, α showed a significant reduction after the event indicating a substantial washout of the fine and accumulation mode aerosols from the column. The presence of large ice crystals in the Antarctic atmosphere following a blizzard (Tomasi et al., 2007) also would have contributed to flatter AOD spectra after the blizzard. The low mean temperatures prevailing after the blizzard period (below 0ºC; Figure 3), would favor the formation of such ice crystals in the atmosphere. However, β, which corresponds to AOD at 1 μm, did not show remarkable changes.

In the case of M_T, the variations within a day were higher before the blizzard. After the blizzard even though there was no significant drop in the mean value, the intra-day variation became smaller. This could be due to the prevalence of the local station activities, which maintains a steady flux of aerosols input to the atmosphere, replenishing the particles that were removed from the atmosphere. After the blizzard the movement and transport were restricted in and around Maitri due to snow or ice cover and this would have resulted in reduction of the wind produced dust from ground, which may result in the reduction of the variability during the day. However, these aspects need more investigations after the blizzards to characterize appropriately. Our studies show that there was a significant change in the aerosol size characteristics, and columnar abundance after the blizzard, resulted into the reduction of AOD and Angstrom exponent α.

7.0 SUMMARY AND CONCLUSIONS

Measurements of aerosol optical depth (AOD), total mass of composite aerosols (M_T) and black carbon (BC) mass concentration (M_B) were made over the oceanic regions between coastal India to Antarctica and at the Indian stations in Antarctica, Maitri and Bharati, during the 27th Indian Antarctic Expedition in the International Polar Year (2007-2008). Our investigations over these locations have revealed that:

1. Large latitudinal variation in AOD from coastal India (~0.45) to coastal Antarctica (~0.04) is observed during NH winter. AOD showed strong seasonality with lower values over all regions during the NH spring. Gradient in AOD, north of 20 °S, was steeper in NH winter leg (scaling distance of 22.4 degrees) than NH spring (scaling distance of 29.8 degrees). Spectral variations of AOD showed wavelength dependence features typical of predominant extinction by coarse particles over southern oceanic regions.

2. Fairly good agreement between the ship-borne measurements and satellites retrieved AODs were observed for the NH spring season, when the columnar aerosol content and particle concentrations near the surface are low. GOCART model underestimates at all latitudes but captures the spatial variations.

3. Near-surface total mass concentrations (M_T) showed random variations (~60 µg m^{-3} near coastal India to ~ 5-30 µg m^{-3} south of equator during NH winter, with no specific latitudinal dependence but showed subdued variabilities and lower concentrations during NH Spring over region north of equator.

4. Strong gradients in black carbon mass concentrations (M_B) varying from 3800 ng m^{-3} near coastal India to ~ 624 ng m^{-3} near equator, with a scaling distance of 5 degrees of latitudes. Lower gradients for the near surface aerosol properties than the columnar AOD, indicative of the reduced continental advection in the lower troposphere

5. Mean AOD over Maitri (0.034 ± 0.005) is comparable to that at Bharati (0.032 ± 0.006), showing the spatial homogeneity in aerosol properties over the Antarctic atmosphere.

6. Spectral variations are similar for Bharati, Amsterdam Island and Crozet Island but differ significantly from Maitri. Estimated α showed a fine mode dominance at Maitri (α~1.2) and coarse mode dominance at Bharati (α~ 0.7), Amsterdam and Crozet Islands.

7. Blizzard resulted into the reduction of AOD and Angstrom exponent α over Maitri where as total mass concentration M_T remained more or less same. This needs to be investigated in detail for delineating the local effects in the ambient aerosol concentrations.

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