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Characterization of Atmospheric aerosols over Indian Antarctic station during the Southern Hemispheric summer of 2008-2009

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ABSTRACT

Aerosol optical depth (AOD), Aerosol black carbon (BC) mass concentrations (M_B) and total mass concentration (M_T) were measured over two Antarctic locations Maitri (70°45'52" S & 11°44'03" E, 123 m MSL) and Bharati (69° 24.41' S, 76° 11.72' E approximately at 35 m above sea level.) as a part of the 28th Indian Scientific Expedition to Antarctica during the southern hemispheric summer of 2008-2009. Our study showed relatively high values of M_B and mass mixing ratio (F_{BC}) over Maitri (~ 75 ng m^{-3} and 2 %) compared to that over Bharati (~ 13 ng m^{-3} and 0.2 %). At both locations, M_B fall abruptly after the blizzard where the values reduces to as low as half of the pre-blizzard values. This BC scavenging by snow can leads to change in snow albedo and will have strong climate implications. The Angstrom exponent (α_{abs}) estimated from the spectral values of absorption coefficients (σ_{abs}) are found to vary from 0.5 to 1 indicating that the BC over Antarctic region is mainly originating from fossil fuel burning.

Keywords: Black Carbon, Antarctic aerosol, Indian Scientific Expedition

1. 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., 2009; 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.

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 char-

acteristics, 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). 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.

Amongst all the aerosols, black carbon (BC) aerosols influence the snow cover by warming the atmosphere (by light absorption), reducing surface incident solar energy (dimming) and reducing the snow reflectance or darkening due to deposition [Flanner et al., 2009]. Radiative effects of carbonaceous particles are the largest sources of uncertainty in the assessment of the climate forcing due to atmospheric aerosols because of their potential to absorb solar radiation over a wide band [Bond and Bergstrom, 2006], burn off of the clouds if present within them [Ackerman 2000] and change the albedo of the snow [Hansen and Nazarenko, 2004]. As such most of the BC resides in the lower troposphere and it significantly augments the climate warming as recently highlighted by Ramanathan and Carmichael [2008] who estimated that BC emissions are currently the second strongest contributor to the global warming after CO_2. The major problem in assessing the climate impact of BC is the large uncertainty associated with the atmospheric residence time of these particles, and scarcity of measurements with adequate regional representation. The warming effect of BC in snow can affect the snow effective radius, besides darkening the snow itself [Flanner and Zender, 2006]. Although BC is known to show a seasonal variation in Antarctica with a minimum in the southern hemisphere winter [Bodhaine et al., 1995; Hansen et al., 1988], the above effects become pronounced during the summer season due to the availability of the short wave radiation and the high albedo. The long-range transportion of BC from the north is more during the Antarctic spring and the removal mechanisms being weaker in comparison to winter result in a higher concentration of BC in summer. Viewed in the light of the above, the Antarctic region with its vast snow cover assumes significance. In addition to the effects of BC in air over Antarctic continent, the small quantity of BC deposited on snow and ice reduces the snow reflectance because of multiple scattering in the snow pack, resulting in huge disparity between mass absorption coefficients of snow and ice [Warren and Wiscombe, 1980]. The larger population in Antarctica during summer (~5000) and the increasing trend of tourists from < 9000 in the year 1992/1993 to 46000 in year 2007/2008 (British Antarctic Survey) has its share too in contributing

to BC abundance over this icy continent, making the necessity of regular monitoring all the more important.

In the light of above, and in continuation to our summer-time measurements of 27 Indian Scientific Expedition to Antarctica (ISEA), we further examined the spatial gradients in the optical and physical properties of aerosols over the Indian stations, Maitri and Bharati during the 28th Indian Scientific Expedition (28-ISEA) in year 2008-2009, with special emphasis on BC aerosols.

2. Cruise track, Expedition Details and Antarctic Stations

The measurements were made during the 28th Indian Scientific Expedition to Antarctica (28 ISEA) during Antarctic summer, from two coastal locations in the Eastern Antarctica, Bharati (69° 24.41' S, 76° 11.72' E approximately at 35 m above sea level) and Maitri (70°45'52" S &11°44'03" E, 123 m MSL). The expedition of 28 ISEA started sailing by M V Emerald Sea on 6th January 2009 from Cape Town and reached Prydz Bay near to Bharati on 17th January 2009. After making measurements for 22 days at Bharati, ship sailed from Prydz Bay on 11th February 2009 and reached India Bay (near to Maitri) on 18th February 2009, where the measurements were made from Maitri until 8 March 2009. The ship started its return voyage from India Bay on 15th March 2009 and reached Cape Town on 23rd March 2009. The cruise track and the location of the sampling stations are shown in Figure 1.

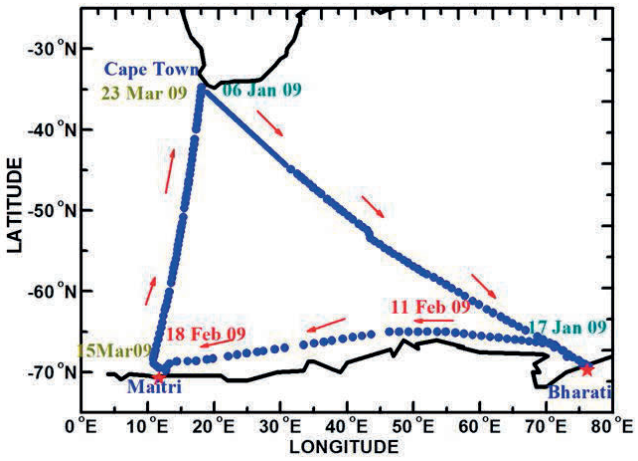

Figure 1: The cruise track of 28 ISEA and the location of the Indian Antarctic stations Maitri and Bharati in East Antarctica.

The two sampling locations have distinctly different features. Bharati is the site for third Indian station in Antarctica, and is one of the islands of

Larseman Hill , very near to open Ocean and as of now it is free from any human interference. Islands of Larsemann Hills are separated by Ocean water, either in form of sea ice or in the form of open Ocean during summer. The extent of the Ocean water in between different islands varies from few meters to few kilometers. On the other hand Maitri is situated on Schirmacher Oasis (a rocky area of 35 km^2) which is near to continental ice, ~75 km away from the open ocean. The Maitri station, in general has a population of approximately 75 during summer, and the day-to-day activities are more in comparison to Bharati.

3. Instruments details and data set

The spectral aerosol optical depth (AOD) measurements were made 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). 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).

Near-real time measurements of the mass concentration of BC (MB) were made continuously at Bharati from 20 January 2009 to 10 February 2009 (22 days) and from 20 February 2009 to 08 March 2009 (17days) at Maitri by using an Aethalometer (model AE-41 of Magee Scientific, USA). The ambient air was aspirated from a height of 2 m above ground level at both the locations following the protocols described in Babu et al, [2004]. The flow rate was kept at 5 lpm (liters per minute) and the time base was kept 5 minutes at both the locations. The Aethalometer gives the change in optical attenuation at seven different wavelengths of 370, 470, 520, 590, 660, 880 and 970 nm by measuring the intensity of the light beam passing through a fare and loaded (with particle) filter tape. The BC mass concentration is estimated from the change in attenuation at 880 nm and laboratory calibrated value of the mass specific absorption cross section. Several recent papers deal with the inherent uncertainties in the Aethalometer technique, arising because of the multiple scattering effects in the filter tape (the so called "C" factor) and the shadowing effects ("R" factor) [e.g.,Weingartner et al., 2003; Arnott et al., 2005; Corrigan et al., 2006; Hitzenberger et al., [2006]] and the corrections for these. These corrections have been taken care of while analyzing the Aethalometer data. The long averaging times helped to reduce the instrumental uncertainties, which are of random in nature. Following the error budget described in several earlier papers the maximum uncertainly in the measured BC was up to

20%, with the higher percentage of error being applicable to lower concentrations.

The mass concentration obtained from Aethalometer was used to estimate the absorption coefficient (σ_{abs}) at all wavelength using the relation.

$$\sigma_{abs} = \frac{1}{C}\frac{1}{R}\frac{\Delta ATN}{\Delta t}\frac{A}{Q}\left[\text{Weingartener et al., 2003}\right] \quad (1)$$

Where A is the filter spot area, Q the volumetric flow rate and ΔATN is the change in attenuation during the time interval Δt. The factors, C and R pertain to correction for multiple scattering of the light beam and the shadowing effect respectively. Following Weingartner et al., [2003] the shadowing effect is negligible for the mixed and the aged aerosols where BC constitutes only a very small fraction in the ambience (as in Antarctica) i.e. R=1 and the C factor used is 2.1, suggested for aged aerosols. The spectral variation of σ_{abs} were regressive fitted (on log-log scale) using the equation.

$$\sigma_{abs}(\lambda) = \beta_{abs}\lambda^{-\alpha_{abs}} \quad (2)$$

where α_{abs} is the wavelength exponent and β_{abs} indicates the aerosol loading. Values of α_{abs} and β_{abs} were estimated for each measurement. A α_{abs} value of <1 indicates the dominance of the BC from the diesel soot or fossil fuel and >1 show the dominance of the biomass produced BC [Corrigan et al., 2006]

Mass concentrations of the composite aerosols were estimated using a single stage high volume sampler (HVS, model GHV 2000P1 of Thermo-Anderson, USA). The sampler was operated at a flow rate of 0.6 m^3 min-1 for different durations ranging from few hours to few days to get detectable loading on pre-desiccated, tare-weighed, numbered, and sealed quartz fiber filter papers. After sampling, the filters were sealed in their respective envelopes and taken to the laboratory where they were desiccated and weighed using the same microbalance. Total mass concentration (M_T) was estimated from the difference in the initial and final weights, flow rate and the sampling time. It was regularly monitored and made sure that a uniform flow rate was maintained during the sampling period.

4. Results and Discussions

4.1 Columnar Aerosol Optical Depth (AOD)

Temporal variations of the daily mean AOD at 440nm for Bharati and Maitri, estimated by averaging the individual microtops measurements of

each day are shown in Figure 2, where the solid spheres represent the daily means and the vertical lines passing through them are the respective standard deviations. It can be seen that both over Bharati and Maitri, AOD showed day to day variations that was random in nature. The AOD at 440 nm varied from 0.03 to 0.05 for majority of the days. These types of the random variations observed at Maitri were reported in Chaubey et al., [2011] for the same location. The mechanisms which might contribute to the variations in the AOD can be marine particles (sea salt) and dust particles from the oasis; both produced and transported by the winds, and those produced by the local stations activities. Nevertheless, the average AOD values measured by us over Maitri are comparable to those measured within the standard deviation; over Bharati. This agreement between AODs at the two locations indicates the prevalence of spatial 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 (Satheesh et al., 2008, Muller et al., 2001).

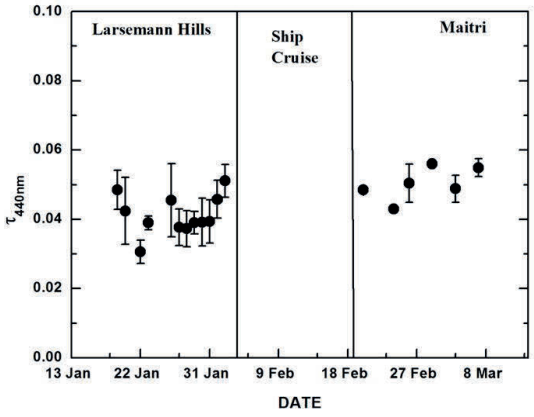

Figure 2: Daily average AOD at 440nm for Bharati and Maitri, where the solid spheres represent the daily mean and the vertical lines passing through them are the respective standard deviations

4.2 Black Carbon Mass Concentration (M_B) and Snow Scavenging

Temporal variations of the daily mean M_B during the period of the expedition is shown in Figure 3a, where the points are the daily means and the vertical bars through them are the ensemble standard deviation, quantifying the spread of the values. The values pertaining to each of the stations (Bharati and Maitri) are identified by the bars in the figure where the unshaded parts with the letter B identifies the blizzard events which took

place during the measurements, with the length of the unshaded bar corresponding to the duration of the blizzard.

The blue filled circle corresponds to the measurements made at Bharati and the red circles correspond to the measurements at Maitri. The two regions are considered separately in view of the approximately 1-month time difference between the measurements, the large differences in the geographical and meteorological features, the difference in the human activities and the large differences in the BC concentrations at the two locations. The daily mean values at Bharati varied between 4 ng m^{-3} to 19 ng m-3 with an average value of 13±5 ng m^{-3}. Compared to Bharati, the concentrations were much higher at Maitri. The daily average values varied from 20 ng m^{-3} to 157 ng m^{-3} with an average value of 75 ± 33 ng m^{-3}. The large standard deviation shows the extent of the day-to-day variability experienced at Maitri. It is also interesting to note that even the lowest daily mean values of M_B at Maitri was comparable or little higher than the mean value at Bharati, while the mean values at Maitri was marginally lower than the minimum values measured over Arabian sea (~125 ng m^{-3}) and Bay of Bengal (~250 ng m^{-3}) during the period of marine air mass in northern hemisphere summer [Nair et al., 2008.]. In sharp contrast to the high temporal variation over Maitri the temporal variations over the Bharati are remarkably low (as shown in Figure 3a) with daily average M_B always < 20 ng m^{-3}. One source of BC at any location in Antarctica is the emission from other nearby research stations. The closest operating station at Maitri is almost 7 kilometres away from the sampling site in the east direction; Novo (Russian;70.82°S, 11.64°E, 120 m MSL). There is an Airbase (70.99°S, 11.59°E) almost 12 kilometres southwest to Maitri purely on continental ice, operational in summer period. As the prevailing winds at Maitri are south easterlies there could be some influence from these especially during the strong winds. The sampling location at Bharati is separated by small islands and sea ice (varying from few meters to few kilometres) from the two permanent bases in this area, Zhong Shan (Chinese; 69.38°S, 76.38°E) and Progress (Russian; 69.36°S, 76.38°E), which are almost 9 to 10 km from the Indian site in the northeast direction and a summer camp Law Base (Australia) in east direction with two persons staying there during summer. There is no traffic activity of any type except for brief helicopter sorties for the transport of men and materials. As such the effects of BC emissions from other places influencing Bharati is quite low as winds are from southeast.

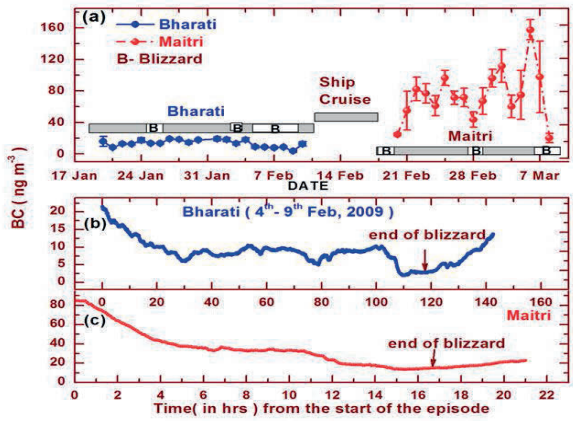

Figure 3: Temporal variation of the daily mean M_B during the period of the expedition is shown in the top panel where the points are the daily mean values and the vertical bars through them represent the ensemble standard deviation, quantifying the spread of the values. The values pertaining to each of the stations (Bharati and Maitri) are identified by the bars in the figure where the unshaded parts with the letter B identifies the blizzard events with the length of the unshaded bar corresponding to the duration of the blizzard. The time series of the BC scavenging during the long blizzard event at Bharati (marked as long white bar in top panel) and an intense snow fall event at Maitri are shown in the middle and bottom panels respectively.

Another source of BC at Antarctica is through long range transport from low to high latitudes mainly through the upper troposphere in the summer months when the circumpolar vortex breaks down and surface inversions are weaker [Konig-Langlo et al., 1998]. The surface inversion layer, along the slope of the Antarctic continent induces a strong katabatic wind from the continental high latitudes to the coastal regions. So the air mass reaching at the coastal regions are affected by the long range transport from the inland station activities (which are maximum in summer) along with the local station activities at the sampling location. These are also the reasons for the large day to day variability observed over Maitri. The day to day variability in BC mass concentration due to local interferences was reported from other coastal and inland Antarctic stations also. Hansen et al., [2001] had measured a BC value ranging from 20 to 200 ng m^{-3} at McMurdo (78° S, 167° E) station. Hara et al., [2008] had measured a BC value at Swoya (69° S, 39° E) station ranging from below detection level to 176 ng m-3. Hansen et al., [1988] and Bodhaine, [1995] had measured BC value of 0.02 to 50 ng m^{-3} at the South Pole (90S). Similar large variability are found at Halley [72° S, 26° W; Wolff and Cachier, 1998], and Ferraz [62° S, 58° W; Perirra et al., 2006]. The spatial variation of BC in Antarctica can be a parameter to study the transport processes and human influence in this continent.

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. During the campaign period there were six episodes of blizzards, 3 each at Maitri and Bharati. The events are marked by 'B' in Figure 2a, and their duration by the length of the white bars, which inscribes 'B'. While 5 of them were rather short events, lasting about few hours to a day; one was quite intense with higher amount of snowfall, lasting for 5 days which occurred at Bharati during 4th February 2009 to 9th February 2009 (Figure 2a). Though we did not have a quantitative measurement of the snowfall rate during the events, this provided an opportunity to get a zero order assessment of the snow scavenging of BC. Despite having no measurements of the amount of snowfall, the duration of the event was daily logged. Though snowfall was not continuous during the blizzard, the blizzard conditions persisted over the duration marked for each case in Figure 3a. The consistent and noteworthy feature was the abrupt fall in M_B levels associated with the blizzard. The time series of the BC scavenging during the long blizzard event at Bharati (marked as long white bar in Figure 2a) and an intense snow fall event(last blizzard event at Maitri) at Maitri are shown in Figure 3b and 3c respectively. It can be seen from the figure that decrease was almost exponential after the start of the blizzard; they continue to decrease or remain at the low levels during the event and start recovering to the normal day levels after the cessation of blizzard, there by indicating the fast replenishment. While during the first two events at Bharati the fall was not significant from 18 ng m^{-3} prior to the events, dropping down to 13 ng m^{-3} on the next day. The subsequent decrease was rather weak, and after the event, the M_B level reaches close to the normal level. However during the strong and long event of the 4th February 2009 (as shown in Figure 3b), the M_B value started depleting from 22 ng m^{-3} to 8 ng m^{-3} after 24 hours of the start of the blizzard, continue to decrease with time, though much weaker and after 109 hours of the blizzard, M_B levels came as low as 2 ng m^{-3}. It is also interesting to note that the M_B levels started increasing slowlyafter the end of blizzard.

At Maitri also the blizzards presented a spectacular depletion in the concentration, nevertheless even after blizzard events the M_B values remained higher than the normal day values at Bharati; probably due to the higher levels of the BC prevailed over Maitri, the certain degree of anthropogenic activities and due to the short duration of the events. As the obser-

vation at Maitri started after a short blizzard event (as shown in Figure 2a), M_B on the first day was as low as 24 ng m^{-3}. Thereafter the M_B levels showed an increase with small variations until the second blizzard which started on 28th February 2009. During the second blizzard , mean M_B value came down from 72 ng m^{-3} to 43 ng m^{-3} showing a drastic reduction of 29 ng m^{-3} of BC from the atmosphere. Thereafter the M_B levels started increasing until the intense snow fall observed during the third blizzard event where the M_B decreased from 87 ng m^{-3} (before the start of the blizzard as shown in Figure 2c) to as low as 15 ng m^{-3} after 15 hours of the blizzard event showing a significant decrease of BC values in the atmosphere. As the snow flakes offer a large area to capture the air borne particles and scavenge them along the snow fall, snow scavenging is known to be a more efficient removal mechanism than impaction scavenging by precipitation (Cragin and Hewitt, 1993; Lie and Wania, 2004; Sauter and Wang, 1989). All the observation showed that, after each blizzard a significant amount of BC was deposited on the snow. A quantitative measurement of the temporal distribution of the snow fall would have been helpful to quantify the amount of BC that might have gone into snow.

The amounts of BC getting deposited on snow and ice by scavenging and BC produced by activities of the inland stations in Antarctica have great climate implication. The deposited BC would decrease the single scattering albedo (SSA) of snow and ice (which covers almost 98% of the Antarctica) by absorbing the incident radiation or by effecting snow grain size [Jacobson 2001]. Based on the analysis of snow for the presence of light absorbing particles Warren and Clarke [1990] and Grenfall et al., [1994] reported that Antarctic ice contains 0.1 to 0.3 parts per billion by weight (ppbw) of BC in snow, two orders of magnitude less than the values reported for the Arctic. They also reported 3 ppbw at 1 km downwind of the South Pole station where the station's power plant and aircraft operations (human interference) were a suspected source. Chylek et al., [1987] had reported a BC of 3 ppbw in snow at Siple Dome above the Ross Ice Shelf. Clarke and Noone, [1985] found a consistent 'scavenging ratio', relating BC amount in snow to BC concentration in air, in Polar regions of both hemispheres. Flanner et al., [2007] have reported a global mean equilibrium warming of 0.15 and 0.10 °C due to the inclusion of BC in snow for the year of 1998 and 2001 respectively. All these indicate the importance of the climate forcing by the deposition of BC in snow. Nevertheless, there is a scarcity of the ground-based measurements of snow impurity over Antarctica and amount of snow scavenging of BC aerosols. The reduction in MB after the snowfall, which has been reported here, has more consequences in these regards. On the other hand the BC produced due to the

activities over Antarctica will lead to increase in concentration over this region (mainly coastal Antarctica) because of a strong circumpolar current which will not allow the aerosols to penetrate and cross the continent. As the frequency of blizzards are less in summer in which aerosols transfer from Ocean and continent may take place and with Sun for 24 hrs even at low elevation, these increase in the aerosols concentration might cause a change in radiation balance.

4.3 Total Mass Concentration and BC Mass Fraction

The collocated measurements of BC mass concentration (M_B) and the composite aerosol mass concentration (M_T) enabled us to compute the mass mixing ratio of BC (F_{BC}), parameter quite important in assessing the radiative impact. For this we estimated the average value of M_B corresponding to each sampling done using the HVS, by averaging the aethalometer data over the duration of HVS measurements. Thus the ratio M_B/M_T is estimated as the mass mixing ratio F_{BC} of BC. It is interesting to note that the M_T over Maitri is ~ half of that at Bharati, where as the F_{BC} over Maitri is ~ 10 times than at Bharati. The mean M_T over Maitri is ~ 2.25 g m^{-3}, comparable to the value reported by Hess et al., [1998] for Antarctic aerosols. However, the M_T over Bharati is quite high may be due to the proximity of the observation site to the coast where the marine aerosol production is quite significant. The aerosol measurements made during the 27th ISEA also revealed similar results where the M_T over Bharati and Maitri were 6.4 ± 1μg m^{-3} and 2. 01 ± 0.4μg m^{-3}.

4.4 Spectral variation of Absorption Coefficients (σ_{abs})

Absorption coefficients (σ_{abs}) were determined from the aethalometer measurements at different wavelengths using equation (1) , by keeping the value of R=1 and C=2.1 [Weingartener et al., 2003]. The data has been averaged for the each wavelength separately for the study period at Bharati and Maitri to obtain the spectral variation of σ_{abs}. The mean spectral variation of σ_{abs} for Bharati and Maitri are shown in the top panel of Figure 4.The average values varied from 0.2 ± 0.13 Mm^{-1} at 370 nm to 0.1 ± 0.04 Mm^{-1} at 950 nm at Bharati, whereas the average values for entire measurement period at Maitri varied from 1.14 ± 0.5 Mm^{-1} at 370 nm to 0.56 ± 0.26 Mm^{-1} at 950 nm. It is noticed that σ_{abs} decreases monotonically from the shorter to the longer wavelengths but vary over a wide range at Maitri in comparison to Bharati. Bodhaine et al., 1995 showed maximum value σ_{abs} (550nm) of 0.5 Mm^{-1} and minimum value of 0.0002 Mm^{-1} at South Pole with a seasonal variation peaking in southern

hemisphere summer and minimum in the winter. It can be seen that σabs values at Bharati are lower than South Pole values in summer but Maitri values are on the higher side. A higher σabs at lower wavelengths over Maitri in contrast to Bharati, might be due to the fine dust, which are efficient absorber at shorter wavelengths, raised to ambience by wind and local activities.

To explore the source characteristics of BC at Bharati and Maitri, the wavelength exponent α_{abs} is estimated from the spectral values of the absorption coefficients. The temporal variation α_{abs} is shown in the middle panel of Figure 4 where the gap in the data set corresponds to the time taken by the ship to travel from Bharati to Maitri. The average α_{abs}| obtained for the Bharati region was 0.5±0.6, whereas the average α_{abs} obtained for the Maitri was 0.7±0.2. The frequency distribution of α_{abs} over Bharati and Maitri are shown in the bottom panel of Figure 4, which shows that most of the σabs values lies between 0.5 and 1 showing the dominance of the anthropogenically produced BC from fossil fuel or diesel exhaust at the sampling locations.

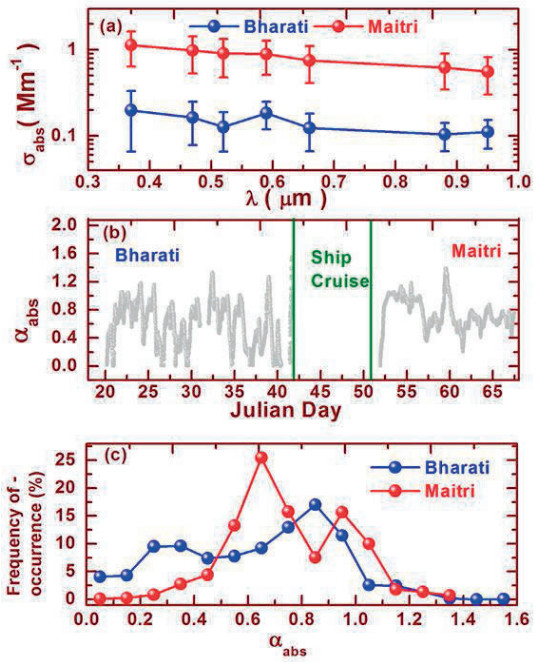

Figure 4:Mean Spectral variation of absorption coefficient over Bharati and Maitri is shown in the top panel where the vertical bars are the standard deviation from the mean values. The time series of Angstrom exponent (α_{abs}) is shown in the middle panel and the frequency distribution of α_{abs} is shown in the bottom panel.

5. Summary and Conclusions

Temporal variations of physical and optical properties of aerosol were investigated from Indian stations Bharati and Maitri in the eastern coastal Antarctica during the 28th Indian Scientific Expedition to Antarctica (28 ISEA). Our results indicated that the temporal variations of aerosols are large at Maitri, and differed significantly from those of Bharati where the human interference is very less.

1) Daily mean AOD over Maitri and Bharati showed random day-to-day variations but it varied in the same range showing the spatial homogeneity in aerosol properties over the Antarctic atmosphere.

2) Mean BC mass concentration at Bharati and Maitri during the study period are 13 ± 4 ng m^{-3} (which is comparable to the values reported for other few coastal Antarctic locations) and 75 ± 33 ng m^{-3} (which is to the higher side of the background concentration and values reported at other coastal Antarctic locations) respectively. Day to day variations in M_B at Maitri are mainly attributed to local factors including station activities and transport from the inland station by strong winds in katabatic flow.

3) BC mass fraction was 10 fold higher at Maitri (0.02) relative to Bharati (0.002) whereas average total mass concentration for the study period at Bharati was higher than that at Maitri.

4) Snow scavenging leads to substantial removal of BC from the atmosphere. These reduced the M_B levels to half of the normal day values. BC scavenged or dry deposited on snow and ice, can produce large climatic and radiative implications.

5) Absorption coefficient (σ_{abs}) decreased monotonically at higher wavelengths both at Maitri and Bharati. It varied at Maitri from 1.14 ± 0.5 Mm^{-1} at 370 nm to 0.56 ± 0.26 Mm^{-1} at 950 nm, whereas at Bharati it is almost flat with a very small difference i.e. 0.2 ± 0.13 Mm^{-1} at 370 nm to 0.1 ± 0.04 Mm^{-1} at 950 nm. The Angstrom wavelength exponent for α_{abs} was 0.5 ± 0.6 at Bharati and 0.7 ± 0.2 at Maitri during the study period, which indicates significant influence of combustion sources.

6. Acknowledgements

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the experiments. Majority of this work is published in Journal of Geophysical Research-Atmospheres (115,D10210,doi:10.1029/2009JD013381.)

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