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Spatio-temporal variations in aerosol properties over the oceanic regions between coastal India and Antarctica

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ABSTRACT

Measurements of aerosol optical depth (AOD), mass concentrations of black carbon (M_B) and composite aerosols (M_T) in the marine atmospheric boundary layer (MABL) were made during onward [Dec 2007 to Jan 2008; Northern Hemispheric (NH) winter] and return (Mar–Apr 2008; NH spring) legs of the trans-continental cruise of 27th Indian Scientific Expedition to Antarctica (ISEA) during International Polar Year of 2007–2008. Large latitudinal gradients are seen; with AOD decreasing from coastal India (AOD ~ 0.45) to coastal Antarctica (AOD ~ 0.04) during NH winter. The measurements also evidenced a strong seasonality of AOD over all regions, with a decrease of the values and gradient in NH spring. BC concentration in the MABL decreases exponentially from 3800 ng m^{-3} (over 10°N) to 624 ng m^{-3} near equator and much lower values (< 100 ng m^{-3}) over southern oceanic region. Seasonality in the latitudinal gradients of AOD, M_B and M_T exists over regions north of 20°S. Multi campaign [Pilot Expedition to Southern Ocean (2004), Special Expedition to Larsemann Hills (2007) and Tropical Indian Ocean cruise (2010)] analysis over these oceanic regions showed that the pattern over the regions (south of 20°S) remained the same. Seasonality of AOD exists over Atlantic Ocean as well. Temporal variation of AOD at different latitudes derived from AERONET data also showed marked seasonality and latitudinal variation in northern hemisphere than in southern Hemisphere. Satellite retrieved AOD showed good correlation with the ship borne measurements; while GOCART retrieved AOD underestimates but gives a measure of the spatial variations.

1. Introduction

Spatio-temporal heterogeneity in aerosol characteristics, including their vertical distribution, remains one of the major factors leading to their inadequate representation in global and regional models aiming at improved estimation of aerosol radiative forcing (Satheesh and Moorthy, 2005; Bates et al., 2006; Remer et al., 2009; Smirnov et al., 2011). Aerosols properties at any given location being strongly governed by local productions, prevailing meteorology, long range transport, it is logical that as we move away from the populated continents, the aerosol characteristics change and there is a change in the ratio of anthropogenic to natural aerosol abundance. As ~70% of the Earth's surface area is covered by Oceans, which are also major sources of natural aerosols like sea salt (e.g., Woodcock, 1953; Monahan et al., 1986; Prospero, 1979; Moorthy et al., 1997; Satheesh and Moorthy, 2005; Smirnov et al., 2011), it is equally important to characterize aerosol properties over far Oceans. In addition to the local production of aerosols over oceans (sea spray, oxidation of DMS etc), aerosols from populated continents (mainly anthropogenic aerosols) are transported to long distances over the Oceans, thereby changing the optical and microphysical properties of oceanic aerosols (Satheesh and Moorthy, 2005). This further makes investigations of aerosols over the Oceans more important. Viewed in this perspective, the Indian Ocean region assumes special importance among major Oceans of the Earth, being under the influence of most populated continental land mass.

To understand the aerosol characteristics over the oceanic regions, there are many ship based campaigns (e.g., ACE I, TARFOX, ACE II, INDOEX, PRIDE, ACE-Asia, ARMEX, ICARB, W_ICARB etc), 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. These have revealed that there is a decrease in the concentration of near surface aerosols (Hoppel et al., 1990) and columnar spectral optical depth (Moorthy et al., 1997, 2005; Satheesh et al., 2008; Jayaraman et al., 1998; Smirnov et al., 2002, 2006) with increase in distance from the mainland. Despite of all these efforts, detailed measurements leading to characterization of inter-hemispheric gradients in aerosol properties over vast oceanic regions, in a short time span are sparse. The major Oceans providing the ideal location for

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studying the inter-hemispheric gradient are Pacific Ocean, Atlantic Ocean and Indian Ocean (region between the coastal India to coastal Antarctica). 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 (e.g., INDOEX, ARMEX, ICARB, W_ICARB) are mainly confined to Arabian Sea, Bay-of-Bengal and tropical Indian Ocean and had limited temporal coverage. Such information is important in determining the possible transport of aerosols from the Asian and African continent over the remote oceans of southern hemisphere and the consequent effects.

In the current paper, we examine the spatial gradients in the optical and physical properties of aerosols and their seasonality over distinct oceanic regions between coastal India and coastal Antarctica, based on measurements carried out onboard the ship cruise of 27th Indian Scientific Expedition (27-ISEA) in year 2007–2008, during the International Polar Year (IPY). For examining seasonality and latitudinal gradients, the data obtained during the following expeditions, (i) Pilot Expedition to Southern Ocean (PESO) in the year 2004, (ii) Special Expedition to Larsemann Hills (SELH) during 2006 and (iii) Tropical Indian Ocean (TIO) during year 2010 are also used. In addition, (i) satellite and model derived AOD over the oceanic region, (ii) data over the Atlantic and Pacific Ocean from the database of Maritime Aerosol Network (MAN; Smirnov et al., 2006), and (iii) long-term data from Aerosol Robotic Network (AERONET; Holben et al., 1998) operated at island locations between coastal India and coastal Antarctica (including the stations close to the coast of Africa and Australia) are also used.

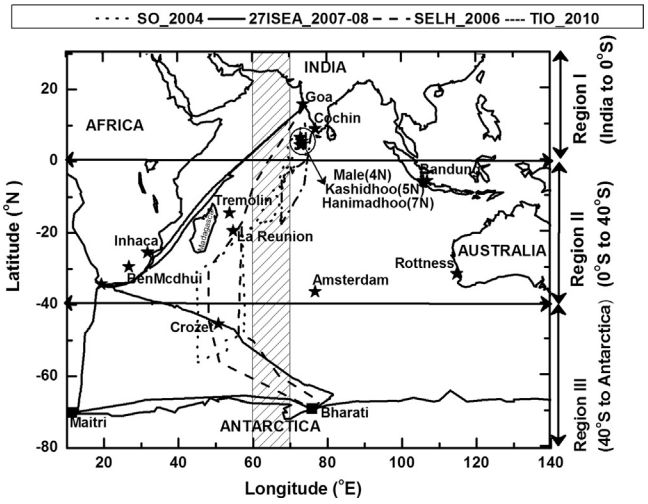

Fig. 1. Cruise track of the 27th Indian Scientific expedition to Antarctica (solid line), Pilot Expedition to Southern Ocean (dotted line), Special Expedition to Larsemann Hills (dashed line) and Tropical Indian Ocean cruise (dash and dotted line). Solid stars represents the AERONET stations between coastal India and coastal Antarctica while solid squares represents the Indian stations in Antarctica, Maitri (71°S, 11°E) and Bharati (69°S, 77°E). The shaded box shows the longitudinal grid used for satellite data.

2. Cruise track and campaign details

The cruise tracks, along which the primary aerosol data were measured are shown in Fig. 1, where the solid lines represents the track of the 27-ISEA (6 Dec 2007 to 11 April 2008), the dotted lines that of Pilot Expedition to Southern Ocean (PESO, 1 Jan 2004 to 30 March 2004), the dashed lines are for the Special Expedition to Larsemann Hills (SELH, 25 Jan 2006 to 1 April 2006) and dashed and dotted lines are for the Tropical Indian Ocean (TIO, 9 July 2010 to 6 August 2010) cruises. The solid stars locate the AERONET stations, and solid squares represent the Indian Stations in Antarctica; Maitri (71°S, 11°E) and Bharati (69°S, 77°E). The shaded rectangle shows the domain for which we have used satellite (MODIS, MISR) retrieved and model (GOCART) simulated AODs for the period (Dec 2007–Jan 2008 and March–April, 2008). The details of these expeditions, latitudes covered and duration of measurements are summarized in Table 1. During the main cruise, 27th ISEA, the ship M V Emerald Sea sailed off from Goa (15°24′N, 73°42′E) on 7 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 03 January 2008. Ship stayed there for 41 days and then sailed-off for Bharati (69°35′S, 76°12′E), the third Indian station in Antarctica. In the return leg, the ship left over coastal Antarctic Ocean (near Bharati) on 10 March 2008 and reached Goa on 11 April 2008 via Cape Town. While the PESO was limited up to 56°S, the other two campaigns have AOD measurements from as far as 69°S. Most interesting features of the data obtained during these expeditions are the time periods which are Northern Hemispheric (NH) winter (December–February) in the onward leg and the NH spring (March–April) in the return leg. Over the domain of the present study, while the aerosol measurements have been fairly wide spread over the northern hemisphere for Region I in Fig. 1, (Satheesh and Moorthy, 1997; Babu et al., 2007; Ramanathan et al., 2007), this remained quite limited over the region between equator and 40°S (Region II in Fig. 1), while scarce for the oceanic region between 40°S to coastal Antarctica (Region III in Fig. 1).

3. Instruments details and data base

In Table 2, we list the aerosol properties measured and instruments used. The spectral aerosol optical depth (AOD) measurements were made onboard using a hand held Microtops Sun photometer (Solar light Co.) at 30 min interval on all the days when the solar disk

Table 2
Aerosol properties measured, instrument details and latitude range of observations during 27th Indian Scientific Expedition to Antarctica.

Aerosol properties	Instrument used
Aerosol optical depth (AOD)	Sun photometer (Solar Light Co., USA)
Black carbon mass conc. (M_B)	Aethalometer (Magee Scientific Co., USA)
Total mass concentration (M_T)	Quartz crystal microbalance (California Ins. Co., USA)

Table 1
The time span and the latitudes covered during the onward and return leg of the expeditions.

Expedition name	Reference	Year	Onward leg		Return leg	
			Time period	Latitude range	Time period	Latitude range
27th ISEA	Present study	2007–2008	7 Dec 2007 to 3 Jan 2008	15°N to 69°S	10 Mar to 11 Apr	69°S to 15°N
SELH	Vinoj et al. (2007)	2006	25 Jan to 23 Feb	15°N to 69°S	5 Mar to 1 Apr	69°S to 15°N
PESO	Babu et al. (2010)	2004	1 Jan to 17 Feb	10°N to 56°S	17 Feb to 1 Apr	14°N to 56°S