Atmospheric Environment 43 (2009) 1071–1078

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Spatial distribution of aerosol black carbon over India during pre-monsoon season

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ARTICLE INFO

Article history:
Received 5 July 2008
Received in revised form
8 November 2008
Accepted 12 November 2008

Keywords:
ICARB
Black carbon
HYSPLIT
Forest fire

ABSTRACT

Aerosol black carbon (BC) mass concentrations ([BC]), measured continuously during a mutli-platform field experiment, Integrated Campaign for Aerosols gases and Radiation Budget (ICARB, March–May 2006), from a network of eight observatories spread over geographically distinct environments of India, (which included five mainland stations, one highland station, and two island stations (one each in Arabian Sea and Bay of Bengal)) are examined for their spatio-temporal characteristics. During the period of study, [BC] showed large variations across the country, with values ranging from 27 $\mu g\, m^{-3}$ over industrial/urban locations to as low as 0.065 $\mu g\, m^{-3}$ over the Arabian Sea. For all mainland stations, [BC] remained high compared to highland as well as island stations. Among the island stations, Port Blair (PBR) had higher concentration of BC, compared to Minicoy (MCY), implying more absorbing nature of Bay of Bengal aerosols than Arabian Sea. The highland station Nainital (NTL), in the central Himalayas, showed low values of [BC], comparable or even lower than that of the island station PBR, indicating the prevalence of cleaner environment over there. An examination of the changes in the mean temporal features, as the season advances from winter (December–February) to pre-monsoon (March–May), revealed that: (a) Diurnal variations were pronounced over all the mainland stations, with an afternoon low and a nighttime high; (b) At the islands, the diurnal variations, though resembled those over the mainlands, were less pronounced; and (c) In contrast to this, highland station showed an opposite pattern with an afternoon high and a late night or early morning low. The diurnal variations at all stations are mainly caused by the dynamics of local Atmospheric Boundary Layer (ABL). At the entire mainland as well as island stations (except HYD and DEL), [BC] showed a decreasing trend from January to May. This is attributed to the increased convective mixing and to the resulting enhanced vertical dispersal of species in the ABL. In addition, large short-period modulations were observed at DEL and HYD, which appeared to be episodic. An examination of this in the light of the MODIS-derived fire count data over India along with the back-trajectory analysis revealed that advection of BC from extensive forest fires and biomass-burning regions upwind were largely responsible for this episodic enhancement in BC at HYD and DEL.

1. Introduction

The aerosol Black Carbon (BC) is a byproduct of all incomplete combustion processes (fossil fuel and biomass) and as such most of the atmospheric BC is of anthropogenic origin. Current estimates of total global emission is approximately 8 Tg C yr^{-1} (IPCC, 2007). Being chemically inert, and in fine size range, the only removal

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doi:10.1016/j.atmosenv.2008.11.042

mechanism of BC from the atmosphere is wet deposition, and as such, BC particles have long lifetime in the atmosphere (> ~1week in the lower troposphere (Babu and Moorthy, 2001)), making them amenable for long-range transport. This long life time, coupled with the strong absorption of light over a wide spectral range, makes BC an important contributor to radiative forcing of the atmosphere and green-house warming (Jacobson, 2001; Chung and Seinfeld, 2005). This absorption can greatly offset the 'white house cooling' due to sulphate aerosols (Schuster et al., 2005), and can even surpass the green-house warming effects of some of the atmospheric trace gas species (Jacobson, 2001). Coated with hydrophilic materials, BC can act as cloud condensation nuclei, thereby contributing to indirect forcing of climate (Lohmann et al., 2000; Ackerman et al., 2000). BC causes serious health problems too; as it can get easily deposited into the respiratory system through inhalation because of its fine sub-micron size. In the recent years, there have been several investigations on BC aerosols globally including South Asia (Novakov et al., 2003; Huebert et al., 2004; Mayol-Bracero et al., 2002; Babu et al., 2002, 2004; Moorthy et al., 2004; Corrigan et al., 2007; Husain et al., 2007; Nair et al., 2007). However, several of these studies, except perhaps Nair et al. (2007), focused only to a specific location and the efforts to synthesize the data and to examine the spatio-temporal heterogeneity are scarce. The spatial synthesis is important particularly over India with large density of population, diverse living habits, distinct topographical features, and above all, the large-scale synoptic changes in the prevailing meteorology.

In this paper, we present a regional synthesis of BC mass concentrations using a database generated from a network of eight observatories as a part of the field experiment, Integrated Campaign for Aerosols, gases and Radiation Budget (ICARB) conducted under Indian Space Research Organization's Geosphere Biosphere Program during January–May 2006 (Moorthy et al., 2008). A concerted effort was taken to examine the spatio-temporal heterogeneity in BC mass concentrations over Indian region using the network measurements following a common protocol.

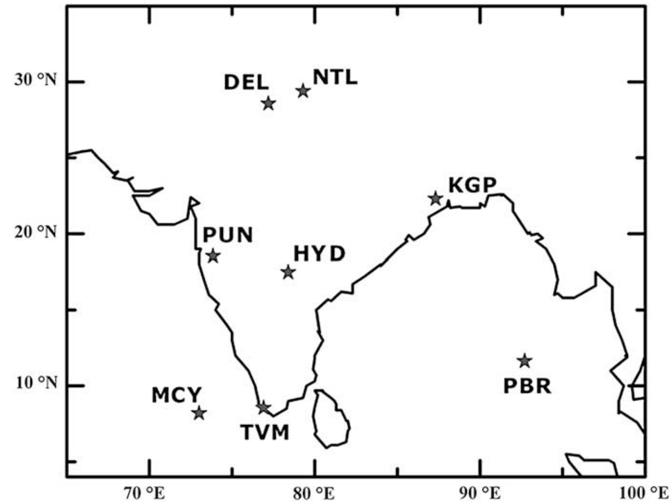

Fig. 1. The spatial distribution of the network stations having measurements of BC mass concentrations during ICARB, which includes five mainland locations, one highland location and two island locations. Among the five mainland stations, three are located in the Peninsular India, and two in the Indo-Gangetic Plain (IGP). It also includes a high land station in central Himalayas and the two island locations one on each of Bay of Bengal and Arabian Sea.

2. Instrument and data description

Continuous and near-real-time measurements of BC mass concentrations were carried out using Aethalometers from eight aerosol observatories; Minicoy (8.3° N, 73.0° E, 1 m msl, MCY), Trivandrum (8.55° N, 76.9° E, 3 m msl, TVM), Port Blair (11.63° N, 92.7° E, 60 m msl, PBR), Hyderabad (17.48° N, 78.4° E, 545 m msl, HYD), Pune (18.52°, 73.85°, 559 m msl, PUN), Kharagpur (22.52° N, 87.52° E, 28 m msl, KGP), Delhi (28.58° N, 77.2° E, 260 m msl, DEL) and Nainital (29.2° N, 79.3° E, 1950 m msl, NTL), (where msl stands for altitude above mean sea level), spread across India and adjoining oceans (Fig. 1). Out of these eight stations, DEL and KGP are urban/semi-urban locations in the Indo-Gangetic Plain (IGP); HYD, an urban location in the central Peninsula; PUN, an urban location over the western plateau, TVM a coastal station in the south west Peninsula; NTL, a high altitude remote location in the central Himalayas, and MCY and PBR are two island locations representing the Arabian Sea (AS) and Bay of Bengal (BoB). Continuous measurements are made at these stations during the period of ICARB using intercompared aethalometers following a common protocol. The measurement locations were far removed from the proximity of significant traffic or industrial and house-hold activities, except at Delhi and Hyderabad.

The aethalometers use continuous filtration and optical transmission technique to measure the mass concentration of BC in near- real- time (Hansen et al., 1984). The instrument aspirates ambient air through an inlet at a preset flow rate. The particles in the air impinge on its quartz fiber filter tape. BC mass concentrations are estimated by measuring the change in transmittance of this quartz fiber tape consequent to the deposition of the particles on it. The attenuation (ATN) of the beam is a measure of the absorber mass. The mass concentration of BC ([BC]) is obtained from an incremental ATN between two measurements using the effective specific mass absorption cross-section of the black carbon deposited on the filter (16.6 $m^2 g^{-1}$, for 0.88 μm channel), area of the sample spot, and the flow rate. More details of the instrument and error budget are given elsewhere (Hansen et al., 1984; Babu and Moorthy, 2002). In this study, the Aethalometer was configured for a flow rate of 3 l min^{-1} and the timebase was set as 5 min for all the above stations. For the configuration used in this study, the uncertainty in [BC] was in the range 0.040–0.060 μg m^{-3}.

The limitations and uncertainties of aethalometer in BC measurements and corrections needed are well documented in the recent literature (Weingartner et al., 2003; Arnott et al., 2005; Schmid et al., 2006). The effective specific absorption cross-section accounts for the amplification of the absorption due to multiple scattering in the filter fiber matrix (the so called '*C*' factor, Weingartner et al., 2003) and also the 'shadowing' effect ('*R*' factor) to certain extent.

3. General meteorology

The general meteorological conditions that prevailed over the Indian landmass during winter (December–February) and pre-monsoon seasons (March–May) of 2006, comprised of dry conditions with scanty rainfall. The monthly mean winds (at 850 hPa) show a shift from weak easterlies/northeasterlies to westerlies/northwesterlies over the subcontinent, as the season progresses from winter (January–February) to pre-monsoon (April–May). During January, the anticyclone prevailing over central India results in strong northeasterlies over the peninsula and northwesterlies over IGP. Towards February, the high-pressure system weakened and stronger northwesterlies were established over IGP and central India; and easterlies/northeasterlies, over the Peninsula, Arabian Sea and BoB. By March the winds weakened over the subcontinent with a weak anticyclonic circulation near the eastern coastal India. The wind speed increased gradually towards April and another stronger anticyclonic circulation appeared over the northwest

Arabian Sea, which drove strong northwesterlies over the Arabian Sea and western coastal India. These anticyclonic circulations disappeared by May and the winds became westerlies/northwesterlies over the mainland. At PBR (BoB), the northeasterly winds of March changed to southwesterlies by May. These shifting synoptic conditions are found to influence the aerosol characteristics over India and adjoining oceans.

4. Results and discussions

4.1. Diurnal variations of BC mass concentrations

In order to examine the spatio-temporal characteristics of [BC], we categorized the network of eight stations into mainland stations (DEL, KGP, PUN, HYD and TVM), island stations (PBR and MCY) and highland station (NTL), based on the predominant environmental conditions. All the mainland stations are prone to significant human impacts and are located in the plains/midlands (<600 m). Two of these stations (HYD and DEL) are large urban centres also. The monthly mean diurnal variations of [BC] for 6 stations, representative of each of the different terrains are shown in Fig. 2 for the pre-monsoon season. The vertical lines on the abscissa on each panel mark the local sunrise and sunset times, which show a progressive increase in the duration of daytime as we move from March to May as the sun is more and more to the north. For all the mainland stations and the island stations, BC mass concentration ([BC]) exhibited similar diurnal variations with an afternoon minimum, and a nocturnal maximum, which occurs 2–4 h after the local sunset. Subsequently [BC] decreases towards morning, and a short-lived peak occurs shortly after the local sunrise. Despite this similarity, the diurnal variations over the island locations were far less pronounced than those over the mainland. For example, the diurnal amplitude of [BC] (ratio of the nocturnal peak to the day time minimum value) for PBR is only ~50% of that seen over the mainland stations. For the highland station NTL, diurnal variations showed an opposite pattern, with a late afternoon high and a late night/early morning low. In place of the short enhancement after sunrise at all other stations, NTL showed a short dip. At all the mainland stations, the diurnal amplitude decreased consistently as the season approached summer conditions, except at HYD and DEL. The reasons for the deviation for HYD and DEL are examined in a later section.

The observed diurnal variation of [BC] is mainly attributed to the dynamics of the local Atmospheric Boundary Layer (ABL) at all the stations, though the urban and local human activities might be contributing to the nocturnal peak. Over the mainlands, as the ABL evolves after sunrise, the strengthened thermals lift and eventually break the nighttime inversion causing the aerosols in the residual layer to mix with those near the surface leading to a sharp increase in the near-surface concentrations; an effect known as fumigation (Stull, 1998; Fochesatto et al., 2001; Babu et al., 2002). The deepening of the ABL during daytime, and the associated convective turbulence thoroughly mix and redistribute aerosols, which were confined in the shallow Nocturnal Boundary Layer (NBL) of the previous night, to greater vertical extent. This results in a dilution of their concentrations near the surface, despite the contributions due to increased vehicular traffic and house-hold activities contributing to BC. This dilution increases with the deepening of the ABL and [BC] reaches the diurnal low around the time when the ABL is deepest (~14:00 local time, Nair et al., 2007), when the ABL deepens to nearly 1 km from its nighttime value of <100 m. Towards the evening, the solar heating decreases and after the sunset, the land cools rapidly leading to inhibition of the thermals. The mixed layer deforms to a shallow Stable Boundary Layer (SBL) near the surface and a residual layer aloft separated by an inversion (e.g. Nair et al., 2007), which inhibits the vertical transport of aerosols. The resulting confinement leads to an increase in the concentration of the species near the surface. Similar diurnal variations in [BC] associated with the changes in local ABL or mixed layer height were also reported from other locations (Husain et al., 2007; Nair et al., 2007). Over islands, as the land area is very small compared to vast expanse of the water body, the weaker thermal contrast does not leads to high convective activity as over the mainland. Consequently the ABL variations are not as strong and deep as those over the continents (Garrett, 1992) and so are the diurnal variations in [BC].

However, the scenario is different for highland stations. During nighttime, the shallow nocturnal boundary layer acts as a capping inversion, confining the emissions from the adjoining valley regions well below the mountain peak and as a result, the BC concentrations at the station is mainly due to particles in the residual layer and a very small amount of local emission. The convective motions set off after the sunrise gradually raise the inversion to higher altitudes over the plains, and this increased vertical mixing brings up the pollutants. This continues and eventually the capping inversion over the valley breaks and the pollutants are flushed to higher levels of the atmosphere. This, while reducing the BC concentration in the plains, enhances it over the mountain peak at NTL. Similar diurnal variations have also been reported elsewhere by Bhugwant et al. (2001) based on BC measurements from an elevated location (~2.5 km m s l) at La Reunion Island.

Apart from the dynamics of the local ABL, the local traffic, burning of fossil fuels from industrial and urban activities also play a crucial role in modifying the diurnal pattern of [BC]. The sharp increase in [BC] after sunset cannot be attributed totally to the collapse of the ABL and the formation of NBL. This is particularly for the urban centres of HYD and DEL (Delhi is a mega city and Hyderabad is the 5th largest city in India), where nocturnal peak is taller than even the fumigation peak. The effect of local traffic in modifying the diurnal variations over large urban centres have been reported by earlier investigators (Latha et al., 2004; Husain et al., 2007).

4.2. Monthly variations of BC mass concentrations

With a view to examining the nature of the mean temporal changes on longer time scales, as the season changed from winter to pre-monsoon, we have examined the monthly mean values at each station. The spatial distribution of the monthly mean [BC] from January 2006 to May 2006 is shown in Fig. 3, where the diameter of each circle is proportional to the values of [BC] at the particular location (the mean value in $\mu g\, m^{-3}$ is also written beside the circle). Extremely high values of [BC] are observed at DEL and HYD throughout the period with the highest value of ~ 27 $\mu g\, m^{-3}$ occurring in January at DEL and followed closely by HYD. Excluding these two urban centres, all the mainland as well as island stations, showed a remarkable decreasing trend from January to May; whereas the highland station NTL registered a weak increase initially and remained almost at the same level for the rest of the period. The coastal station TVM showed lower [BC] than those seen at similar semi-urban inland locations of PUN and KGP. These features are attributed to the increase in the ventilation coefficient (V_c) as the season advances. Ventilation coefficient, the product of ABL height and the transport wind, is a measure of the efficiency of the ABL in pollutant dispersion and air quality maintenance. Based on extensive studies in the IGP, Nair et al. (2007) have shown that changes in BC concentrations are strongly correlated with the ventilation coefficient. The influence of the increase in the mixing height in producing the diurnal variations in [BC] has also been demonstrated by Husain et al. (2007) using measurements from Lahore, west of our network. As the (daytime) ABL, in general,

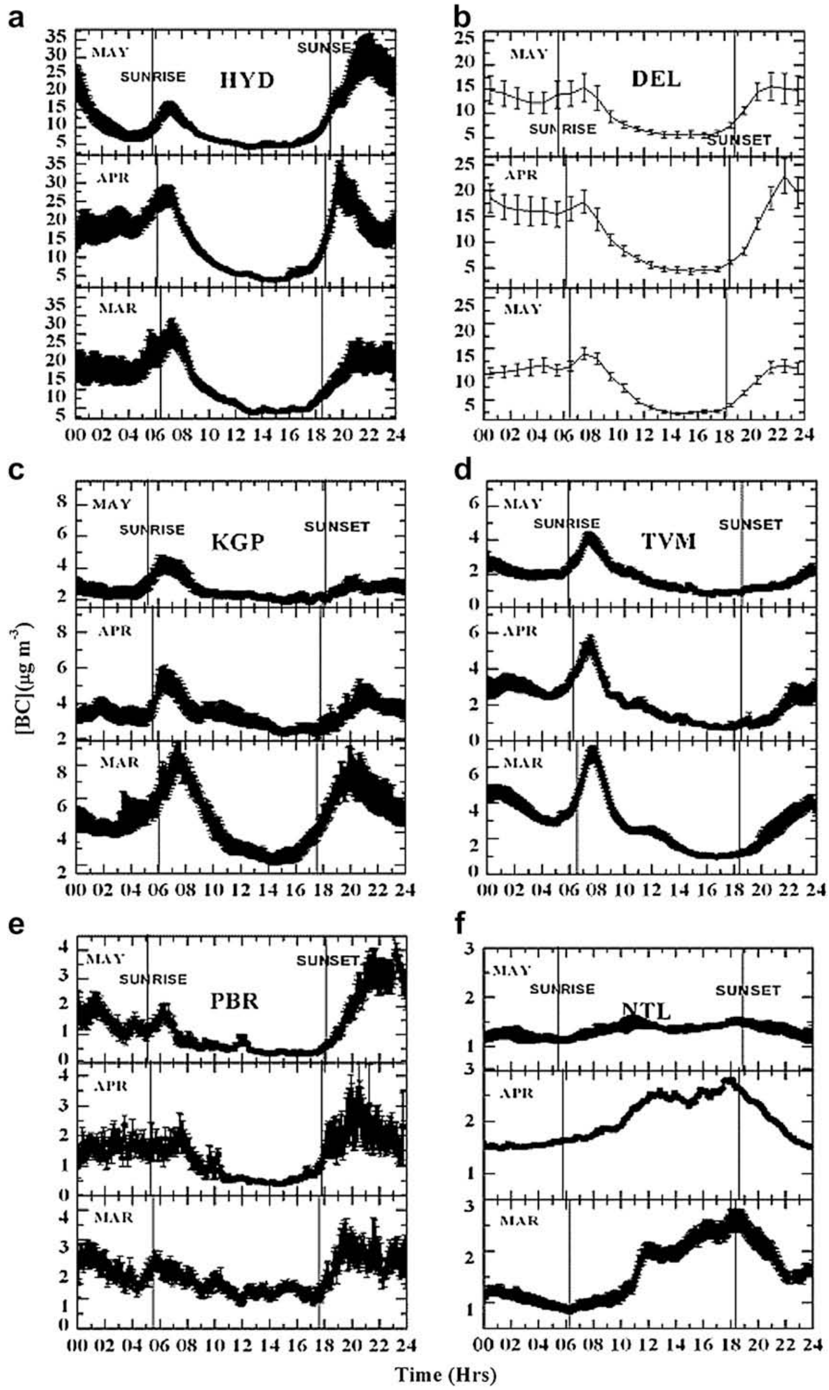

Fig. 2. The monthly mean diurnal variations of BC mass concentrations for six representative stations. This includes four mainland stations (TVM, HYD, KGP and DEL), one high land station and one island station. The vertical lines in each panel represent the local sunrise and sunset times.

deepens from winter to pre-monsoon period over entire India and winds also strengthen, there is a constant increase in V_c from January to May at all the stations. This leads to reduction in [BC], except at the urban centres where the local emissions continue to dominate.

Seasonal variations in [BC] are associated with the prevailing airmass type too. At all the mainland stations over the Peninsula, continental airmass prevail during January/February. Towards March/April, the winds shift to northwesterlies, which brings airmass from the AS (to the peninsula), west Asia/western coastal India; and towards May, strong northwesterly marine airmass gets established. At KGP, the mainland station at the eastern end of IGP, the prevailing northwesterly/westerly winds change to strong southerly winds by May bringing in marine airmass from BoB (Nair et al., 2007). At the island locations of PBR and MCY, the continental airmass that prevailed during winter gives way to pure marine airmass by May. Thus the synoptic meteorology and local ABL dynamics play significant role in causing temporal changes in the surface BC.

Among the island locations of PBR and MCY, PBR shows much higher values of [BC] than MCY. This is primarily due to two reasons. (i) PBR is located over a much longer island chain than MCY and is much more inhabited, and urbanized than MCY. It has a major airport, a harbour and a large number of automobiles. (ii)

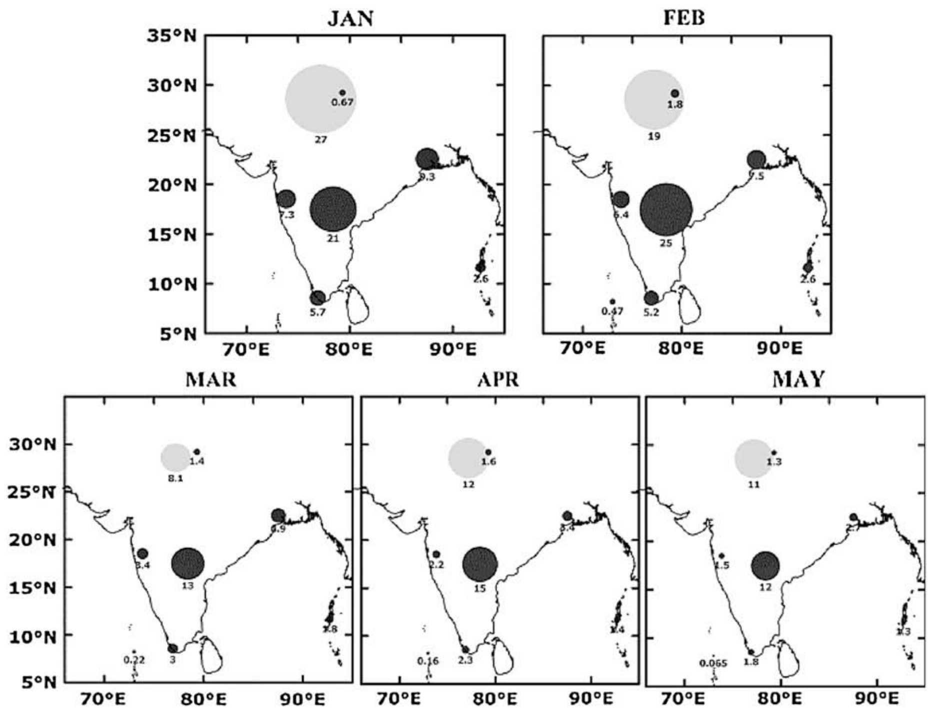

Fig .3. Temporal variation of the spatial pattern of monthly mean [BC] at all the eight stations shown in Fig. 1. The diameter of each circle is proportional to [BC] at the station. Station DEL is given gray colour to differentiate it from the adjacent station Nainital.

Besides the local impact, PBR is also significantly impacted by advection from East Asia, South China and East/Central India. Increase in fine mode aerosols, AOD, and BC associated with long-range transport from these continents have been reported by Moorthy et al. (2003) and Moorthy and Babu (2006). The extensive shipboard measurements of BC during ICARB have also shown a longitudinal gradient in [BC] with higher values of BC in the eastern BoB than close to the eastern coast of India (Nair et al., 2008). On the other hand, MCY is a tiny island with a land area of $\sim$10 km ^{2} with no major human activities other than household and fishing. Thus the geographical differences and long- range transport produce the distinctiveness in the BC over the over island locations in BoB and AS.

The low values of [BC] at NTL are primarily due to its elevated and remote nature. Nevertheless, the influence of the effluents from IGP maintains fairly high values of [BC]. Even though it is lower than that seen at PBR, [BC] is higher than that expected for pristine environment at that altitude. It could also be influenced by long-range transport from west during pre-monsoon and summer monsoon seasons. Thus we infer that the spatial distribution of BC over India is the net result of local production, modulated by the ABL dynamics plus advected from far away source regions. The longer atmospheric lifetime of BC in these seasons favour such long- range transport. The metropolitan cities like DEL and HYD, depict very high values of BC mainly due to urban activities, as has been reported for other neighbouring urban locations such as Lahore, with a mean value of $\sim$21.7 $\mu g\, m^{-3}$ during the winter season (e.g. Husain et al., 2007). In all these discussions that have forgone, it should be borne in mind that the decrease in BC concentration as season advances occurs only at the surface and this is mainly due to the enhanced vertical and horizontal dispersion, at least in the inland stations, where the changes in airmass types have not yet set in. This decrease should not be mistaken as a reduction in the emissions. The BC particles that have been dispersed from the surface by the deep convection, would essentially reach higher levels of the atmosphere and maintain a higher concentration there; as can be seen from the NTL results (Fig. 2f). Observations of enhanced [BC] above the ABL seen in the airborne measurements off Bhubaneswar (BBR) over northwest BoB during ICARB (Babu et al., 2008), also support this.

4.3. Day-to-day variations

Besides the two types of temporal variations in BC aerosols examined above, day-to-day variations with episodic fluctuations lasting over a few days were also observed, particularly at some of the locations. The top panel of Fig. 4 shows the day-to-day variation in [BC] at DEL and HYD, where these effects are substantial, while the bottom panel shows the variations at the other stations. The figure depicts the episodic nature of variation in [BC] at HYD and DEL, which is not as conspicuous at other stations. Highest values of

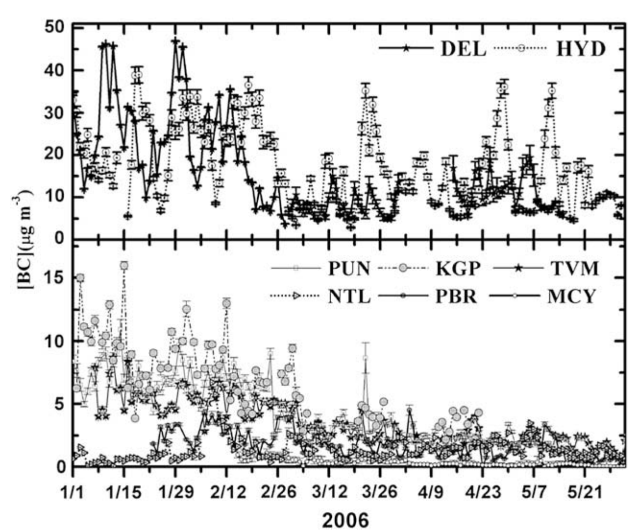

Fig. 4. Day-to-day variations of [BC] for the stations shown in Fig. 1. The top panel shows the temporal variations at the urban locations of DEL and HYD, and the bottom panel shows the temporal variations at all other stations.

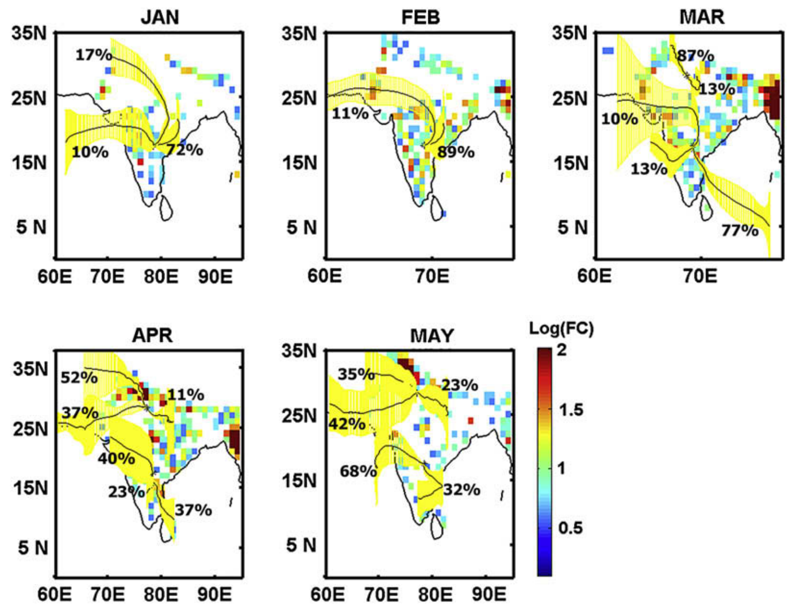

Fig. 5. The monthly total fire counts from MODIS (Terra) over the Indian subcontinent for the period January–May 2006. The 5-day isentropic airmass back-trajectory clusters arriving at DEL and HYD are also superposed.

[BC] are observed at DEL during January followed closely by HYD during February, where the values are much above than reported earlier (Latha and Badarinath, 2005). At these stations, [BC] range from extremely high values ($\sim$45 μg m^{-3} at DEL and $\sim$35 μg m^{-3} at HYD) to as low as $\sim$5 μg m^{-3}, which are comparable to that at other mainland locations, within the span of about a week, implying the impact of episodic events such as biomass-burning/forest fires.

4.4. Role of forest fires

Substantial increase in the occurrence of forest fire activities has been reported over India during winter months (Leon et al., 2001). With a view to investigating their role in the episodic increase in [BC], we have examined the MODIS-derived (Moderate Resolution Imaging Spectrometer) fire products at $1^\circ \times 1^\circ$ spatial resolution over India during the period of study. The monthly total fire counts are shown in Fig. 5 (pixel diagram in logarithmic scale). Over the Peninsula, during January and February, fire counts remain high with many hot spots rendering values as high as 100. The counts reduce considerably ($\sim$10) towards March and remain almost same upto May. However, during this period, the fire counts increase over northwestern India. Here the counts reach as high as 200 during April/May. In order to examine the role of advected BC from the effluents of the forest fire/biomass-burning regions in contributing to the enhanced concentrations of BC at HYD and DEL, five day HYSPLIT derived isentropic airmass back-trajectory clusters reaching the two stations at 500 m above ground level, are also superposed in Fig. 5. It is seen that during January and February, more than 70% of the trajectories arriving at HYD traverse over the regions of high fire counts due north and west of the station during the two days, prior to the arrival at HYD. It appears that these might be contributing to the extremely high values of [BC] during the months of January and February at HYD. Impacts forest fires during winter (from November 2005 to January 2006) have also been reported by Husain et al. (2007) based on measurements from Lahore, northwest of HYD. As the fire counts reduce considerably over the Peninsula from March onwards, and the station is under the significant influence of advection from BoB or Arabian Sea (Fig. 5) the values of [BC] decrease to almost half the values observed during February, and the amplitude of the modulations comes down. Kharol and Badarinath (2006) have reported the fine mode dominance in surface measurements as well as in the column abundance evident from the increased optical depth at shorter wavelengths due to the forest fire during the same study period. Coming to DEL, more than 70% of the trajectories reaching the station are through the regions of biomass-burning/forest fire during April, which raises the surface [BC] to reach as high as $\sim$15 μg m^{-3} despite the strong convective mixing during this season. Towards May, eventhough the fire counts remain more or less the same over the northwest India, only 40% of the trajectories traverse through these regions; the remaining arrive from more western arid regions or the IGP. As such there is decrease in [BC] towards May at DEL. In Fig. 6, we examine the monthly mean diurnal variations of [BC] for HYD for the 5 months; January–May. An interesting feature observed is that during the months when the impact of higher fire counts are noticed (January and February), the fumigation peak goes as high as 80 μg m^{-3}, (for the other months

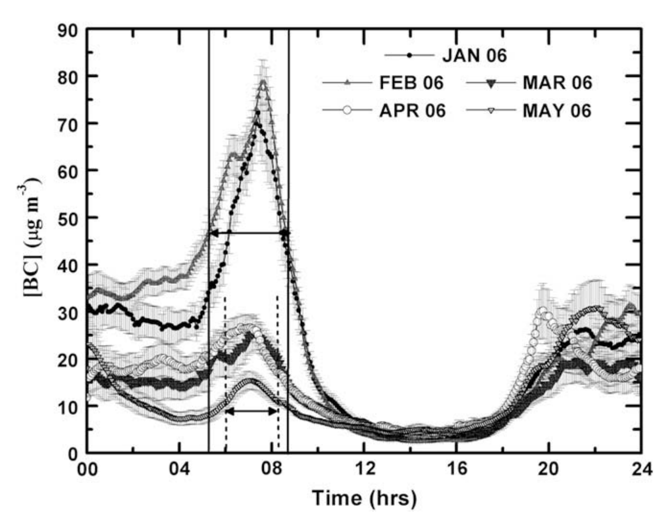

Fig. 6. The monthly mean diurnal variations of BC mass concentrations at HYD from January to May. The solid vertical lines mark the (larger) width of the fumigation peaks for January and February (when the impact of forest fires was significant), while the dotted lines the other months.

the values are <25 μg m^{-3}), eventhough the nocturnal peaks of all the months are around the same level. In addition, fumigation peaks for January and February are 1.5 times broader than that for the other months when the forest fire counts are low. This is important and adds further to the arguments. The nocturnal peaks are mainly due to the reduced ventilation (due to the formation of NBL) and local emissions. These did not change significantly in all the months. On the other hand, the fumigation peak arises mainly due to the particles in the residual layer, above the NBL, being brought in by the convective eddies. The particles brought in by the airmass from the regions of forest fires during night would be left in the residual layer or the entrainment zone above. Being shielded by the shallow nocturnal inversion below, the concentration in the residual layer builds up during the night, but would not contribute to the surface concentrations. This enhanced concentration in the residual layer leads to the large build up of concentrations near the surface during fumigation, and it takes longer time for the particles to be dispersed by the deepening daytime convective boundary layer and enhanced V_c. Similar effects have also been reported by Beegum et al. (2008) while analyzing the impact of mountain grassland fire on the BC mass concentrations at a coastal station ~20 km downwind. The forest fire impacts are thus most discernible in the fumigation peak, rather than in the nocturnal high or daytime low values.

5. Conclusions

A space-time synthesis of the surface mass concentrations of aerosol black carbon (BC) was carried out using continuous measurements from a network of six observatories spread over Indian mainland and two islands in Bay of Bengal (BoB) and Arabian Sea (AS). The major findings are:

1. The observed values of BC mass concentrations ([BC]) showed large variations spatially with values ranging from 27 μg m^{-3} over industrial/urban locations to as low as 0.065 μg m^{-3} over AS.
2. Diurnal variations were well pronounced over all the mainland stations, with an afternoon low and a nighttime high. Eventhough the same pattern of variability over the islands, it remained less conspicuous. For highland stations, [BC] showed an opposite diurnal pattern with an afternoon high and an early morning low. The diurnal variations over all stations were mainly attributed to the dynamics of local Atmospheric Boundary Layer (ABL).
3. [BC] remained high over all mainland stations compared to highland as well as island stations. However, spatially the Indo-Gangetic plain had much higher BC concentration than the peninsular stations. Similarly the urban centres also exhibited large abundance of BC.
4. Among the islands, Port Blair (PBR) showed higher values of [BC] than Minicoy (MCY) and this is attributed to more wide spread human activities over Andaman Islands, as well as advection from East Asian countries.
5. At all the mainlands as well as at the island stations, except at HYD/DEL, [BC] showed a continuous decrease from January to May; being attributed to enhanced ventilation as well as due to change in airmass types from continental to marine.
6. Large modulations over the mean pattern were observed at Hyderabad (HYD) and DEL, which were episodic in nature. These are associated with wide spread forest fire/biomass-burning activities. An examination aided by MODIS-derived fire count data over India along with the back-trajectory analysis revealed that the advection of BC from extensive forest fires and biomass-burning lead to the abnormal enhancement of BC at HYD and DEL. This also resulted in much taller and broader fumigation peaks.

Acknowledgements

The work was carried out under the Geosphere Biosphere Program of Indian Space Research Organisation. The authors acknowledge Dr. A. Jeyaram, Dr. M. Behera, and other colleagues of the Regional Remote Sensing Service Center, Kharagpur; and Mr. S. K. Pandey of ISTRAC ground station, Port Blair for supporting the campaign and in data collection. We thank Mr. Pradeepkumar of SPL for the technical support of the network. We also thank the NOAA Air resources Laboratory for the provision of the HYSPLIT transport and dispersion model and READY website (http://www.arl.noaa.gov/ready.html).

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