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Aerosol and Black Carbon Properties During Different Seasons in Eastern Part of India

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Abstract: Continuous and near-real-time measurements of the mass concentration of Aerosol Black Carbon (BC) were carried out July-2010 March-2011 using an Aethalometer (model AE-31 of Magee Scientific, USA). The principle of the Aethalometer is to measure the attenuation of a beam of light transmitted through a filter, while the filter is continuously collecting an aerosol sample. This measurement is made at successive regular intervals of a time base period. The BC mass concentration is estimated by measuring the change in the transmittance of a quartz filter tape, on to which the particles impinge. The instrument was operated at a time base of 5 min, round the clock with a flow rate of 4-liter min^{-1}, to study the impact of rainy season on black carbon concentrations over a typical urban environment namely Ranchi, India.BC concentrations were high during morning (0600 to 0900 h) and evening hours (1900 to 2300 h) compared to afternoon hours. During early morning hours, high values of BC are attributed to the turbulence set-in by the solar heating which breaks the night-time stable layer and aerosols in the nocturnal residual layer are mixed up with those near the surface. In a very clean air location it may be as low as 500 ng/m^3 and in a much polluted location it may be as high as 20000 ng/m^3. During the period from July-2010 to March 2011 the average monthly BC concentration varied between 1100 to 8100 ng/m^3 and daily average value were found in the range of 1000 to 18000 ng/m^3.

Key words: Black Carbon (BC) · Aethalometer · Aerosol

INTRODUCTION

For several decades optical properties of aerosols have been an important subject in atmospheric research. Angstrom (1929) found an empirical relationship between the size of the aerosol particles and the wavelength dependence of the extinction coefficient [1] introduced the first handheld analogue instrument, the technology of ground based atmospheric aerosol measurements using sun photometry has changed substantially. The observations, so far have been limited to point measurements through balloons, flux towers etc. Modern Aethalometer today can automatically collect data continuously with greater accuracies. The measured sky spectral radiances can be used to obtain the different optical and size properties of the aerosols in the total atmospheric column [2, 3]. The principle is based on the dependence of the light scattering phase function on aerosol particle size and wavelength.The radiative effects of BC cannot be neglected as BC is dominant light-absorbing component of atmospheric aerosols. Accurate information on BC is essential for the predictions of the radiative forcing caused by Black Carbon Aerosols. Relatively small changes in the BC input data can change the radiative forcing from positive to negative [4]. Several studies have shown that BC has typical lifetimes ranging from 1 week to 10 days in the absence of precipitation (Reddy and Venkataraman, 2000; Babu and Moorthy. 2001). [5, 6].

Black carbon aerosols are one of the important factors in the global climate change phenomenon. This is mainly due to their absorptive nature, which directly accounts for the reduction in incoming short wave solar radiation. It is the graphitic form of carbonaceous aerosols emitted into the atmosphere as by-product of all combustion processes such as industrial pollution, traffic, outdoors fires and household burning of coal and biomass fuels. The ability of carbonaceous aerosols to

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modify local meteorology and climatology in regions where emissions are high, like china and India, has been postulated (Ramanathan *et al*., 2001; Menon *et al*., 2002). Most of the BC are fine accumulation size particles (radius <0.2micrometer) which are hydrophobic or weakly hydrophilic *(Jacobson, 2001)* and have global residence times of about 1 week. It ultimately changes the dynamics of the atmospheric boundary layer. Aerosols have been identified as the major source of uncertainty in the present day climate studies[Intergovernmental panel on Climate Change (IPCC), 2007]. Lack of adequate observational data, coupled with poor understanding of the spatiotemporal and vertical distribution of aerosol properties has been identified as the major cause for the uncertainty. In addition to their effect on radiation, they also serve as cloud condensation nuclei and thereby influence the number and size distribution of cloud droplets. This process can change cloud radiative properties, cloud lifetime and precipitation properties, thus indirectly affecting the climate [7-9].

The monsoon is a large-scale atmospheric phenomenon active over the Indian subcontinent. In the present paper, extensive measurements of aerosol black carbon at this semi-arid location for winter season (December 2010) using collected instruments have been discussed in details.

Location and General Meteorology of the Sampling Site: The study area is BIT Mesra, Ranchi, comes under the non-polluted area, the campus is cover with large no. of trees, here source of pollution is mainly the vehicular and domestic wood burning by the villagers where as Climate of the Jharkhand in general is tropical with hot summers and cold winters. Located between the Latitude 23°25°N, Longitude 85°24'°E and attitude on an elevation of 300 to 610 meter above sea level, the climate ranges from dry semi humid to humid semi-arid types. There are regional variations and some parts of the state like Ranchi, Netarhat and Parasnath have pleasant climate even during the summers. Maximum rainfall takes place during the months from July to September that accounts for more than 90% of total rainfall in the state with annual rainfall of 1400mm. Precipitation is rather variable. *Winter season precipitation is meager and highly variable*. There are on an average 130 rainy days in a year and 75 days, rainfall is below 2.5 mm. On 55 rainy days evaporation level is more than 2.5 mm per day. The monitoring has been carried out from December 1st to 31st 2010 in the premises of Centre of Excellence, B.I.T. Mesra Ranchi,Jharkhand.

Prevailing Meteorological Conditions: In general, sky was hazy on most of the days during the campaign period. Sky was overcast on Julian days (JD) 340, 341,342 and 343. The temporal variation of surface temperature during the campaign period is shown in Figure 2. Towards the end of December month, the entire northern India experienced severe cold wave condition, which significantly lowered the temperature. The minimum temperature recorded during the campaign was 3°C on JD 357. Figure 2 shows the variation of relative humidity (RH) and Temperature at the surface.

MATERIAL AND METHODS

During the experimental year of 2009-10, experiment has been conducted to study the effect of dust and rain events on aerosol optical properties and radiation for this region using radiometer data as well as micrometeorological tower observational system data. But work on documentation and collecting data from Aethalometer is continued after July'10. Daily data was performed for Black carbon Aerosols using instruments. It is also tried to estimate Radiative Forcing over Indo-Gangetic Plains using Satellite Data and Back Trajectories which may be used to validate the groung observed data set.

Based on the objectives, the paper has been sub-divided into three sections:

Section 1: Aerosol Properties over Ranchi during rainy season

Section 2: Aerosol and Black carbon over Indo-Gangetic basin during the period of Lighting festival (Diwali) in the Indo-Gangetic Plains using Aethalometer and back trajectory datasets.

Section 3: Study of Aerosol black carbon and Aerosol optical Depth from Ranchi during winter

Experimental Set-up: Continuous and near-real-time measurements of the mass concentration of aerosol BC were carried out from July 2010 using an Aethalometer; model AE-31 of Magee Scientific, USA. The BC mass concentration is estimated by measuring the change in the transmittance of a quartz filter tape, on to which the particles impinge. The instrument has been operated at a time base of 5 min, round the clock with a flow rate of 4LPM. The instrument has been factory calibrated and errors in the measurements are~± 2.

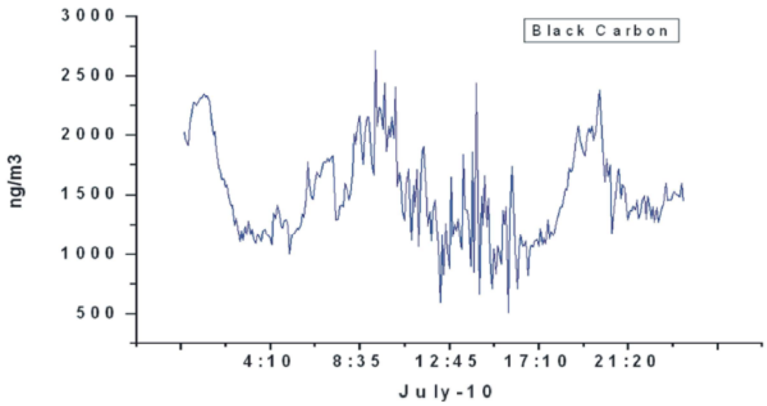


Fig. 1.1: Diurnal variation of Aerosol concentration on rainy season of July on 880nm black carbon concentration on hourly basis for july-10.

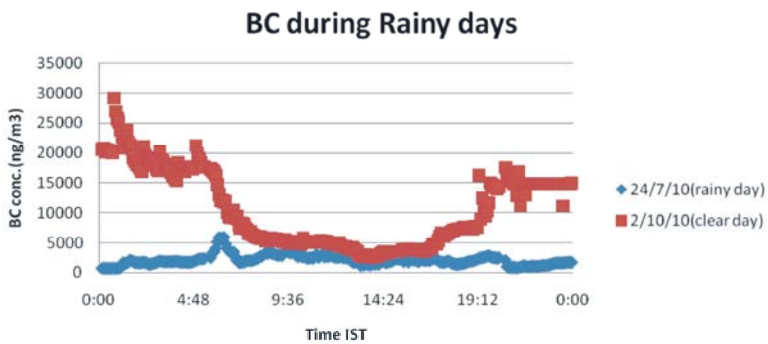


Fig. 1.2: Diurnal variation of BC during rainy days

The AE-31 series 'Spectrum' models of Aethalometer use an optical source assembly that incorporates seven different solid-state light sources. These sources are activated sequentially to illuminate the aerosol sample at seven discrete wavelengths each time base cycle. In this way, we determine the optical attenuation at seven points across the spectrum from ultraviolet to near infra-red.

The AE-31 series adds analysis in the near-ultraviolet at 370 nm, which is found to respond with great sensitivity to aromatic organic species such as are found in tobacco smoke, wood fire smoke and fresh diesel exhaust. The AE-31 series performs optical analysis at seven different wavelengths from 370 nm to 950 nm and has found widespread application in studies of atmospheric optics, radiative transfer etc.

Aerosol Properties over Ranchi During Rainy Season: Measurements of Black Carbon Aerosols and have been carried out during July'10 to study the impact of wet conditions on black carbon concentrations over a typical urban environment of eastern region of India, Ranchi. Diurnal variations BC suggest that BC concentrations are high during morning (0600 to 0900 h) and evening hours (1900 to 2300 h) compared to afternoon hours. During early morning hours, high values of BC have been attributed to the turbulence set-in by the solar heating which breaks the night-time stable layer and aerosols in the nocturnal residual layer are mixed up with those near the surface. Low values of BC during afternoon hours have been attributed to the dispersion of aerosols, due to increase in boundary layer height. BC peaks during morning and evening have been attributed to the increase in traffic density and various activities during these hours.

Sensitivity studies of the accuracy of the inversion have shown ~± 2% errors in most situations for data. In order to screen out the effects of clouds, storm and clear sky weather all the data shown have passed a ~± 2% error self-consistency testing criteria. the black carbon (BC) concentration during the month of July during rainy season (July-10), shows similar pattern of increasing trend at morning and evening and decreasing at afternoon time in Figures (1.1). Figure (1.2) shows Comparison of BC during clear and rainy days has been done. The peak value of BC during clear days reaches upto (~29154 ng/m^3) at 00.45 hrs, while during rainy days

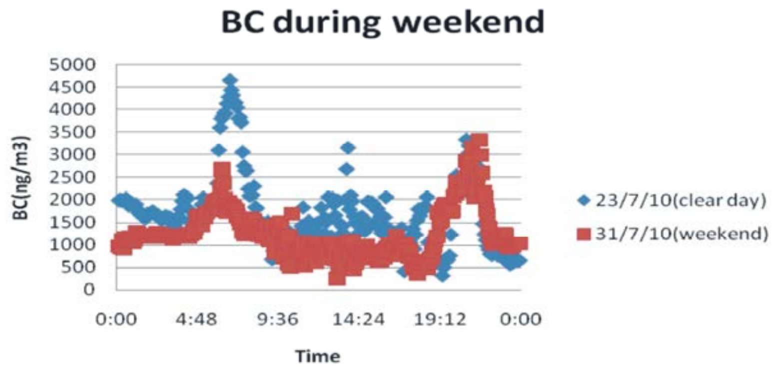


Fig. 1.3: Diurnal variation of BC during weekend & clear days

it reaches only upto (~5850ng/m^3) at 06:10 hrs. This may be attributed due to washout of BC due to rain. BC significantly reduces after rainfall due to scavenging process and also due due to reduction in the continental features conductive for aerosol generation by shifting the air mass [10]. During daytime from 12.30 to 17:30 hrs, high BC values are observed during rainy days in comparison to clear days; which may be due to cloud cover during rainy days in comparison to clear days; which may be due to cloud cover during rainy days because the boundary layer is reduced during rainy days. Similarly, a comparison of BC concentration during clear day and weekend has been done, In Figure1.3 which shows that on clear day has higher BC concentration is observed in comparison to weekend, because at weekend vehicular pollution and other daily buses of school and official vehicle has closed.. The peak value of BC during clear day reaches upto (~4658ng/m^3) at 0600 to 0900 hours while during weekend it reaches only upto (~2683ng/m3) at 0600 to 0900 hrs.

Aerosol and Black Carbon During Lighting Festival (Diwali) Using Aethalometer and Back Trajectory Datasets: In this section, Aerosol black carbon variation during Diwali festival which is celebrated in post-monsoon season during the month of October-November over the Indian region has been analyzed using ground-based measurements of Aethalometer and satellite data in order to understand the long-range transport of aerosol over this region.

The instrument was kept within the Institute Campus during Diwali, which is considered to be non-polluted region in comparison to the city area. Various types of chemical based fireworks used for the enjoyment and lighting. Therefore, the possible aerosol types present over the station could be a mixture of water soluble, dust like and soot-type aerosols.

Satellite-Based Measurements: Aerosol particles, such as black carbon soot, are visible from space, enabling a global estimate of the presence of a variety of pollutants using satellite data. TERRA/AQUA satellite-based MODIS instruments have been acquiring daily global data in 36 spectral bands from visible to thermal infrared. The MODIS sensor is onboard the polar orbiting NASA-EOS Terra and Aqua spacecrafts with equator crossing times of 10:30 and 13:30 local solar time, respectively. The data used in this study include Terra/Aqua satellite-based MODIS aerosol products.

Prevailing Meteorological Condition and Air Mass Back Trajectories: The prevailing meteorological condition during the study period over Ranchi was predominantly of calm synoptic conditions with weak winds, clear skies and absence of precipitation. No major weather systems or cyclonic depressions were encountered in the study area during the Diwali time in year 2010 at Ranchi station. Aerosol properties over semi-humid arid regions would be significantly modified by the advection of aerosols from adjoining Indo-Gangetic basin under favorable wind conditions. With a view to examine the effect of air mass trajectories, which act as potential conduits for aerosol transport, using HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model of NOAA (http://www.arl.noaa.gov/ready/hysplit4.html), seven-day back trajectories for all days during the study period were computed. Clusters of 7 days back trajectories arriving off Ranchi for 500m, 1000m and 2000m heights respectively, which are shown in the Fig. 2.1 for November 5th, 2010. It shows that the over the regional wind is influenced mainly due to the advection from the Indo-Gangetic plains of India at 2000m (Free Troposphere), whereas at lower levels, i.e. at 500 & 1000 mts., advection is mainly due to from continental region with very few trajectories up to Indo-Gangetic

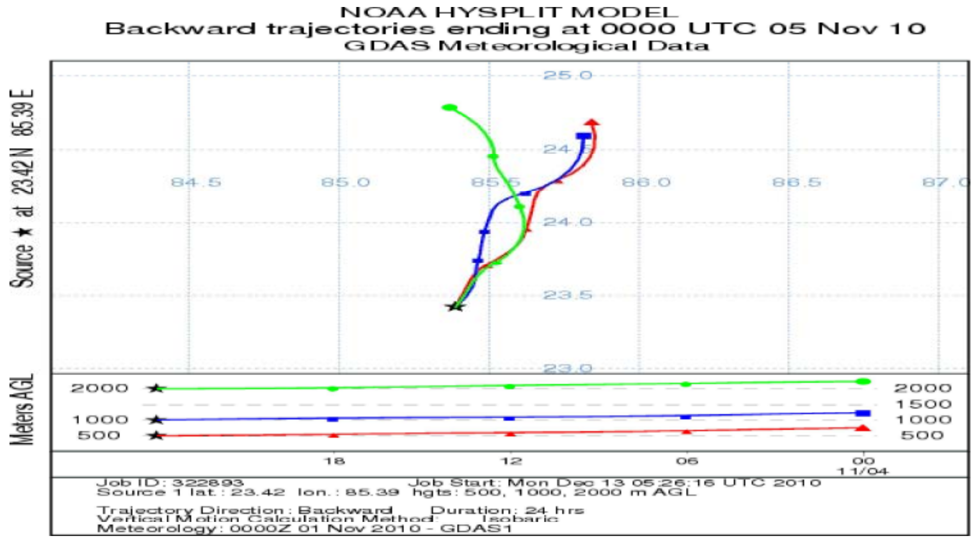


Fig.(2.1).-Backward trajectory of 5th Nov. 2010

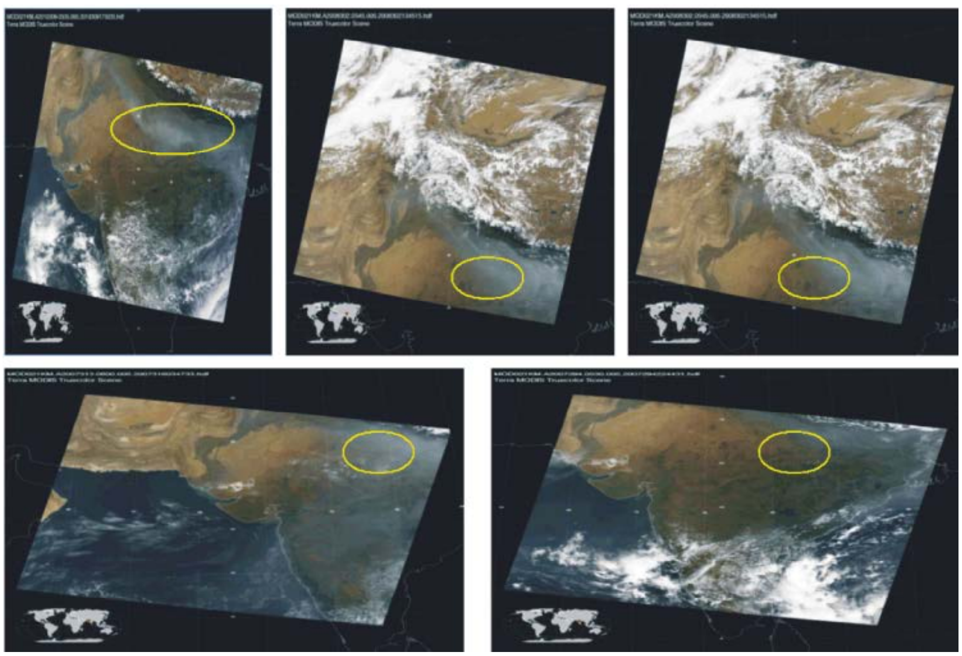
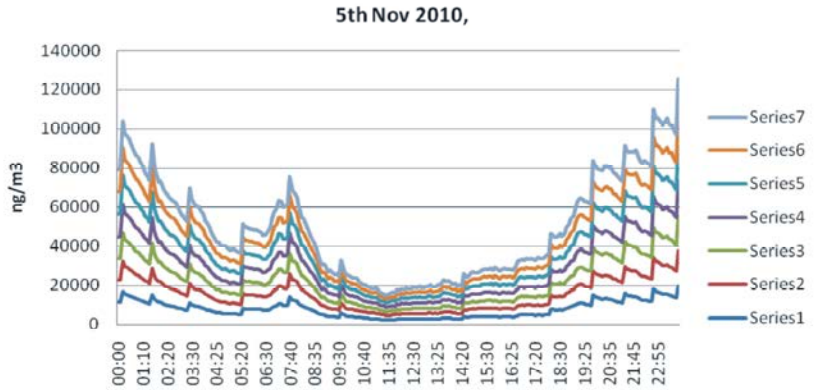


Fig. 2.2: Modis/Terra Image of Diwali for year 2010 (5th Nov), 2009 (17th Oct.), 2008 (28th Oct.), 2007 (9th Nov.), and 2006 (21st Oct.)

plain. We have characterized the impact of extensive anthropogenic activities associated with major Indian festival known as "Diwali", which was celebrated on 05th November, 2010. Figure – 2.3 shows aerosol concentration on Diwali 5th November, where as Figure-2.4 shows aerosol concentration before and after Diwali for all seven wavelength as conc (1)-370nm, conc (2)-470nm, conc (3)-520, conc. (4)-590, conc (5)-660nm, conc (6,black carbon)-880nm and conc. -950nm. On the festive day of 5th November, 2010 the sky was found to be hazy due to fireworks over India are clearly visible in Fig.2.2. High aerosol loading above the Indo-Gangetic Plains in post-monsoon is mainly attributed due to the long-range transport of continental anthropogenic aerosols due to fireworks associated with the festive activities of Diwali. It is clear from the Fig.2.2 image taken from Modis/Terra on Diwali festival of 2006-2010 that Indo-Gangetic plain was influenced by anthropogenic aerosol loading during the Diwali period. High levels of pollution are found over region due to extensive fireworks during the festival. It is



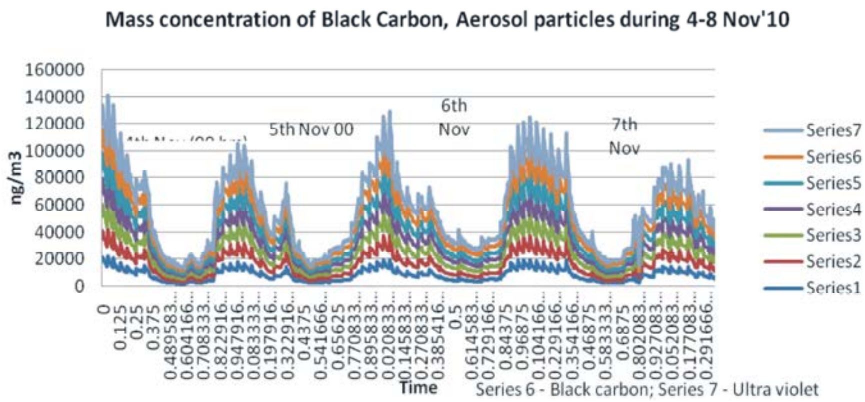


Fig. 2.3 & 2.4: Aerosol concentration on Diwali, before and after Diwali for all seven wavelengths (series6-black carbon)

clear from the figure that presence of aerosols remains in the atmosphere even after the festival and it reduces slowly.

Fig. 2.1 Shows the seven-days air mass back trajectories ending above the Ranchi (where high Aerosol value observed) during 5th November 2010. It is clear from Fig. 2.1 that, the air masses originated from the continental region enriched with aerosols and trace gases of anthropogenic origin.

Fireworks ignition during the Diwali festivities significantly affects atmospheric composition around the Indian subcontinent and oceanic region. In this study, it has been shown that the changes in atmospheric composition are even detectible by Aethalometer and back trajectory. Results of data analyses shows that-

The increase in the aerosol optical depth may have occurred due to coagulation of liquid water with aerosol basically in Post-monsoon season, thereby forming larger size aerosol which increase the residence time of fog over indo-Gangetic plains.

Local meteorological condition can not eliminated as the night on Diwali festival in which huge amount of firework of set off. Thus large amount of smog, sulphur dioxide and other gases released in the atmosphere might have converted into aerosols and black carbon. There was cooling of about 5°C to 6°C at surface due to which there was a suppressed level of atmospheric turbulence which may have also resulted in the increase residence time of fog in winter and aerosol optical depth.

Study of Aerosol Black Carbon and Aerosol Optical Depth During Winter: Each year, the northern part of India, especially the Indo-Gangetic Plains (IGP) region, suffers from intense aerosol, black carbon during winter season due to the typical meteorological, environmental and prevailing terrain conditions. The IGP region is highly influenced by western disturbances during Post-monsoon season, which provide ideal conditions for the accumulation of pollutants within the boundary layer and often results in fog formation [11-17].

The monthly variation of black carbon is presented in Fig. 3.1. Average monthly BC concentration varied from1.1 to 8.1 ng/m^3 from rainy season to maximum in winter followed by reducing trend in summer. The monthly variation results showed higher concentration during winter as compared to monsoon. This may be due to the decrease of the average temperature which causes the decrease in wind speed in

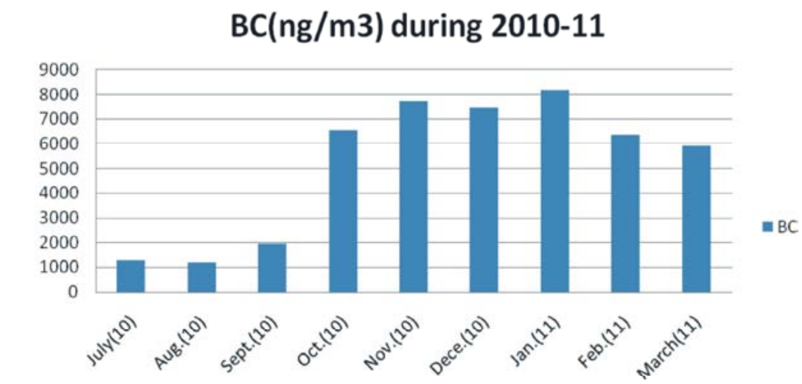


Fig. 3.1: Monthly average variation of black carbon aerosol during July-10 to March-11

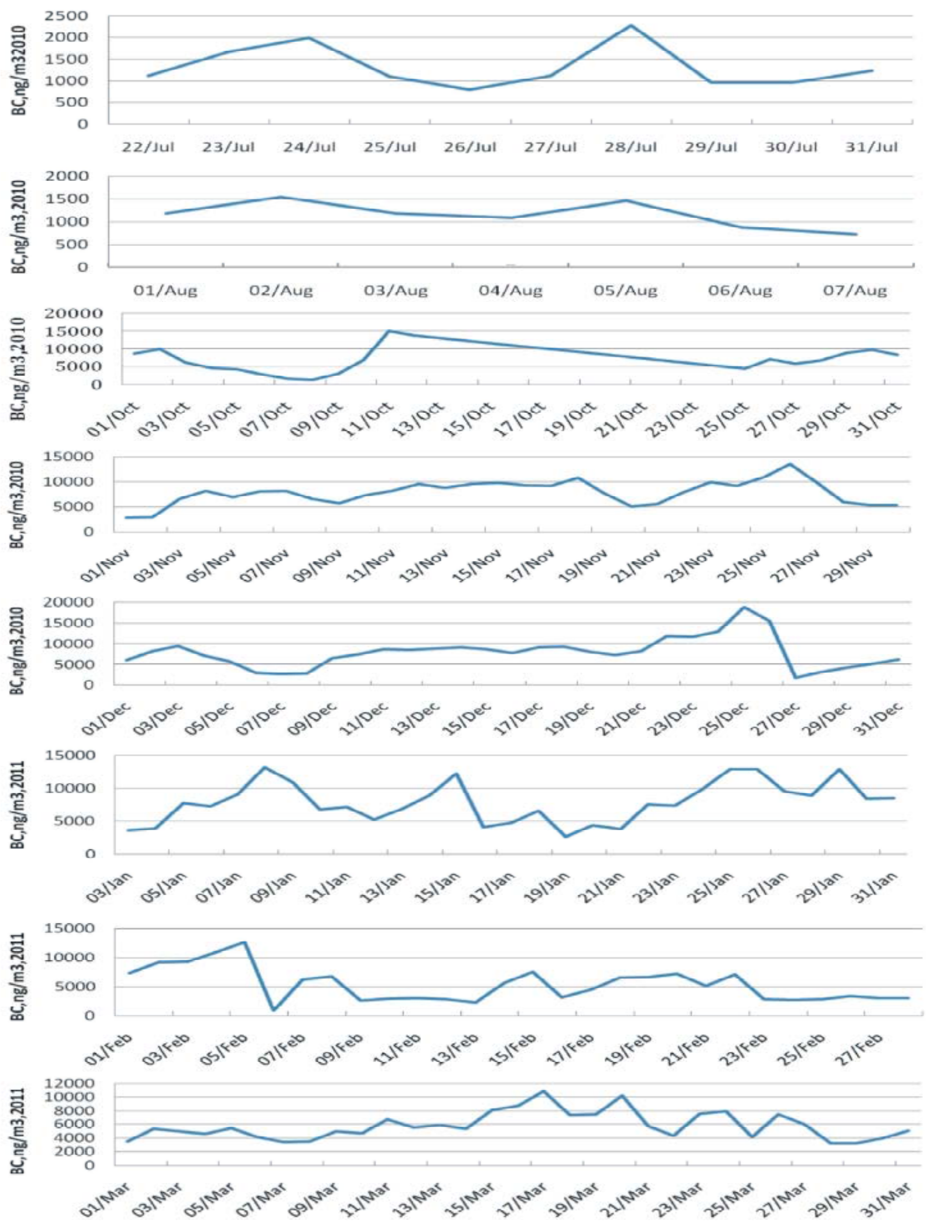
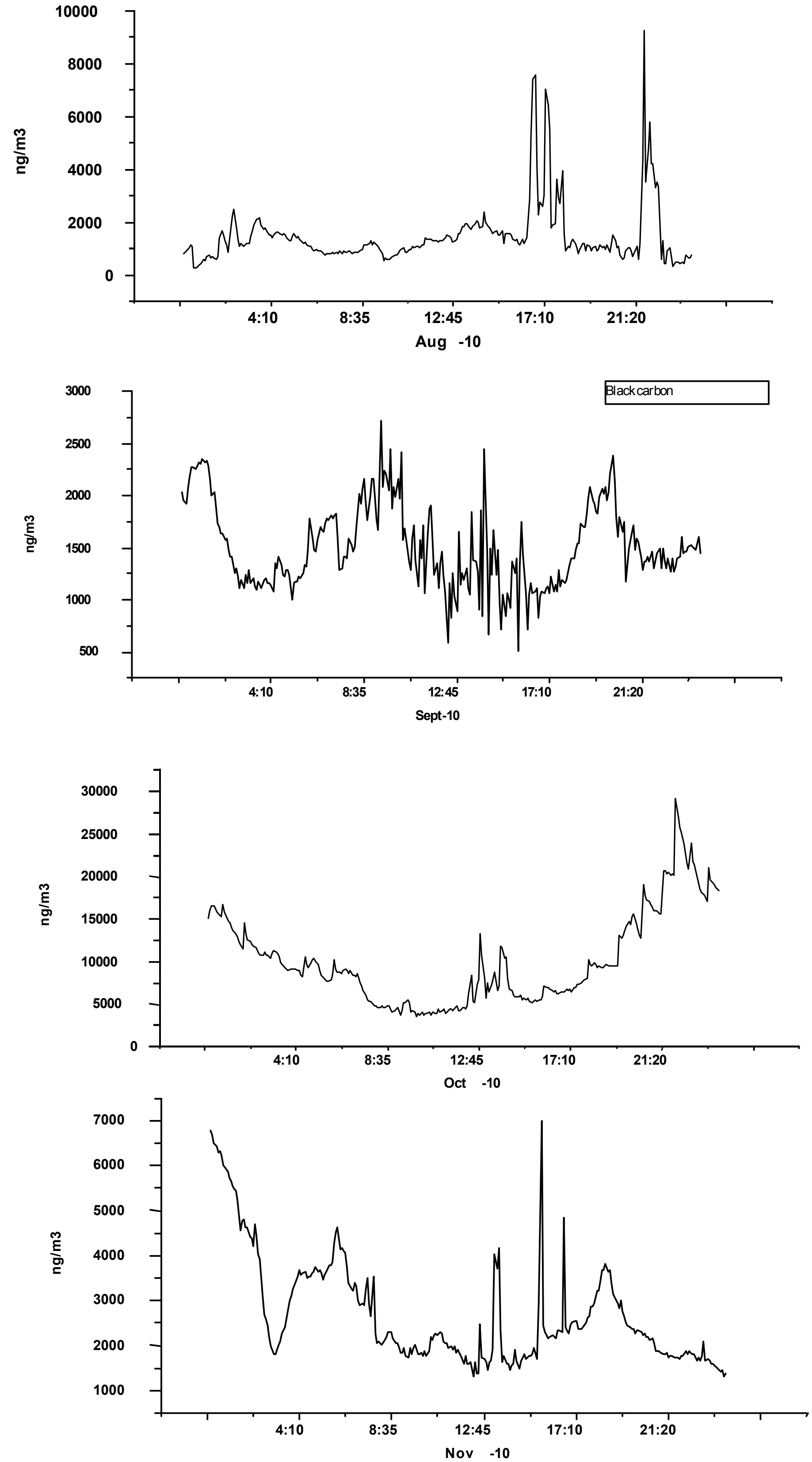


Fig. 3.2: Diurnal variation of BC concentration from July-2010 to March-2011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ng/m3
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8:35
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1500
1000
500
ng/m3
Black carbon
4:10
8:35
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Sept-10
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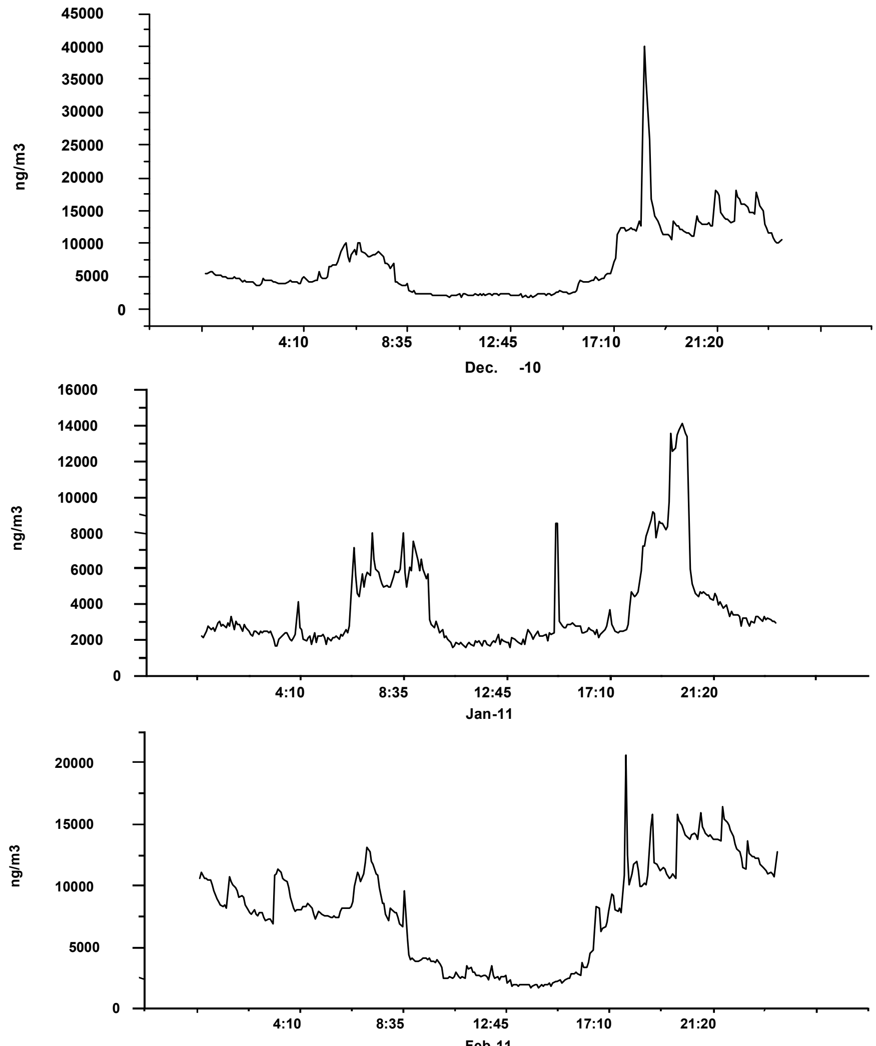

Fig 3.3: Hourly variation of BC concentration during different Month

turn resulted in low transport of the black carbon because of low dispersion. In 2010 and 2011 highest monthly average was found in the month of January, 2010. Daily variation of BC from July-2010 to March-2011are shown in Fig. 3.2. During the period of observation daily average value were found in the range of 1.0 to 18 μg/m^3.High BC concentration was observed during early morning and late night with some exceptions. During early morning hours, high values of BC may attributed to the turbulence set-in by the solar heating which breaks the nighttime's stable layer and aerosols in the nocturnal residual layer are mixed up with those near the surface. Low values of BC during afternoon hours may be due the dispersion of aerosols caused by increased in boundary layer height in addition to the low traffic density. But in the month of March 2010 Black carbon concentration high in the afternoon due to duststrom and transportation of aerosol from other location. In July, the black carbon concentration was low in noon as compared to the evening. High value of evening may also be because of the combustion of anthropogenic sources of fuel. In August, the BC concentration variation was similar but the concentration of the BC was slightly more than the July Fig. 3.2. In November, it was observed that the BC concentration was high at day fall and during night as compared to the concentration in day. The concentration is been increasing gradually from a low value during noon and attained peak during early morning. Diurnal variation of BC showed two peaks, one in morning and other in the evening. It indicate that the BC concentration is high during day fall and night due to prevailing low temperature, in turn making inhabitants to use anthropogenic sources for heating purposes. Above results/discussions are based on the assumption that the

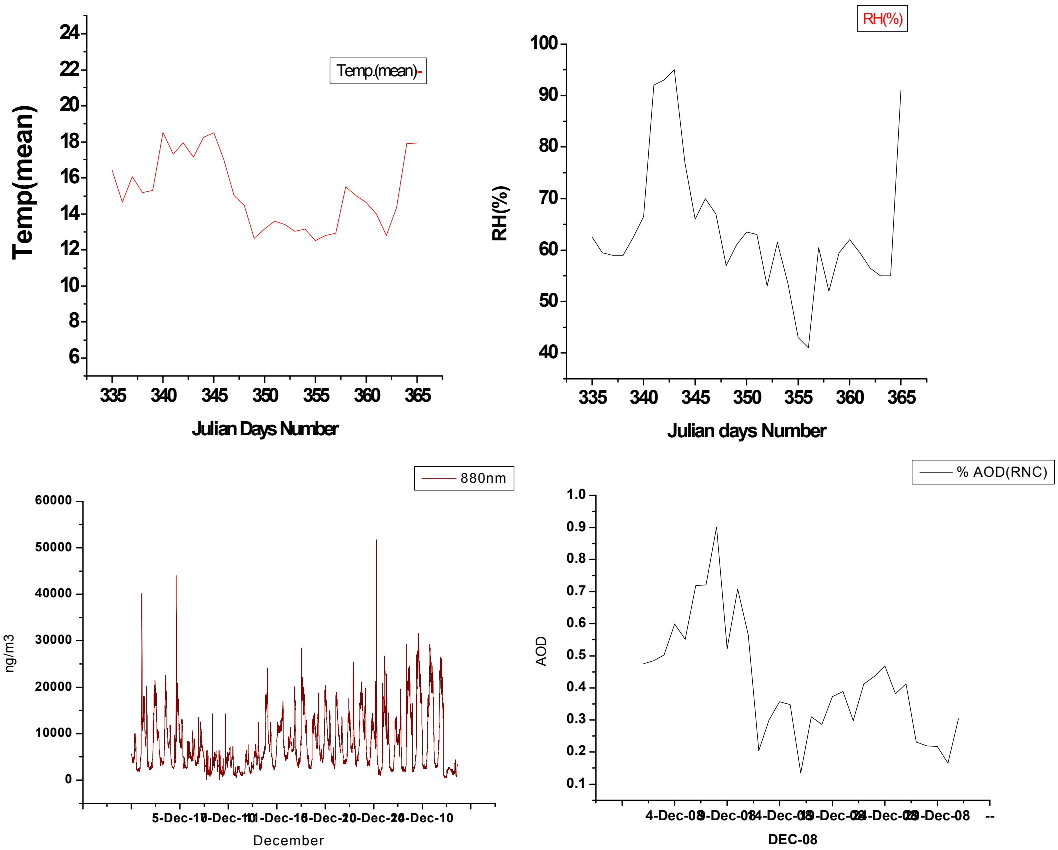

Fig. 3.4: Variation of BC concentration with respect to meteorological parameter (and AOD during month of December

Table 1: Black Carbon variation over different locations of India

Location	Period	BC concentration (µg/m^3.)
Ranchi	July10 to March-2011	1.0-18(Daily average),1.1-8.1(Monthly average)
Varanasi	Oct -08 to March-2010	2-40(Daily average),3.6-25.4(Monthly average)
Trivandrum	20 Feb.05 to 16 March 05	0.3-6
Hyderabad	Jan to July 2003	0.5-68(dry season),0.5-45(wet season)
Kanpur	Dec.2004	6-20
Pune	Jan.05 to Dec.05	4.1(average)
Anantapur	Jan-08 to Dec.09	2.74±0.63(annual average)
Northern BoB close to India	Oct.2003	1.8±1.6
Shillong	2008	~5(annual Mean)
Hanle in Himalaya	Aug.-Dec.2009	.06(Mean)
Dehradun	2007-2009	4.39(Mean)
Mohal-Kullu (H.P)	July09-March2010	2.7-8(Monthly mean)

sources will emit the black carbon with same rate and the quantitatively. Diurnal variation of BC is totally controlled by boundary layer conditions. Apart from this boundary layer variations, the effect of other factors may also be crucial factor such as fossil fuel burning and vehicular emission because are one of the major sources for black carbon aerosols. Fig. 3.3, Large variation of hourly variation of BC at afternoon time in Month of March due Storm.

Fig. 3.4. shows the variation of BC concentration with respect to meteorological parameters (temperature and relative humidity). The black carbon concentration was generally increased with increase in the relative humidity (RH) and decrease in the temperature but the variation was not consistent because of the influence of other parameters like wind speed and direction. The Aerosol optical depth was increasing with black carbon aerosol and decreasing with BC. Mean while the value of mass concentration of black carbon aerosol was also compared with other regions of India (Table.1). It was observed that average mass concentrations of BC in Ranchi are higher as compared to other city of India and other Indian continental locations.

CONCLUSION

- Monthly average BC concentration in Ranchi region is lower as compared to BC concentration reported from other location of India (Varanasi).
- BC showed well defined diurnal variations. This is due to local factors and boundary layer dynamics.
- High BC concentration was observed when the humidity of air was and high and vice versa.
- Average BC Concentration in Ranchi region is significantly large fluctuation in winter season (December) as compared to the temporal variation on that time.
- The aerosol number concentration and AOD measurements would be helps us to find the role of boundary layer dynamics in the above typical temporal and monthly variations of BC at BIT Mesra, Ranchi site. Moreover, it is proposed to study the impact of aerosols and trace gases on the biodiversity dynamics in and around Ranchi and other parts of Northern India.
- Winter season that may cause adverse effect to the agricultural crops and also to the human health. Increased aerosol loading may likely affect the rainfall which is responsible for the observed drought conditions over the Indian subcontinent. Detailed analysis of AOD, crop yields and rainfall data are required to understand the impact of increasing aerosol loading over the Northern India.
- Diurnal Variation of BC on clear day and weekend shows that high values of BC in the early morning 7:00 to 9:00h and a broad nocturnal peak from 21:00 to 1:00h.On other hand during rainy days the BC concentration is very low as the particles settle down due to rain.
- Fireworks ignition during the Diwali festivities significantly affects atmospheric composition around the Indian subcontinent and oceanic region. In this study, we have shown that the changes in atmospheric composition are even detectible by Aethalometer and back trajectory. Results of data analyses showed that-
  - The increase in the aerosol optical depth may have occurred due to coagulation of liquid water with aerosol basically in Post-monsoon season, thereby forming larger size aerosol which increase the residence time of fog over indo-Gangetic plains.
  - Local meteorological condition can not eliminated as the night on Diwali festival in which huge amount of firework of set off. Thus large amount of smog, sulphur dioxide and other gases released in the atmosphere might have converted into aerosols and black carbon. There was cooling of about 5?c to 6?c at surface due to which there was a suppressed level of atmospheric turbulence which may have also resulted in the increase residence time of fog in winter and aerosol optical depth.

- Summarizing, the first study on conc. distributions for the atmospheric column over Ranchi using Aethalometer have given great promise for future detailed studies of the origins of high pollution episodes in the region.

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