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Temporal variation of Black Carbon concentration using Aethalometer observations and its relationships with meteorological variables in Karachi, Pakistan

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ABSTRACT

Black Carbon (BC) mass concentration was measured continuously for every five-minute interval with ground-based Aethalometer at an urban site in Karachi for the period from 2006 to 2008. In this study, the temporal (diurnal, monthly and seasonal) variations of BC and its relationship with meteorological variables were analyzed. Monthly averaged concentrations of BC ranged from 2.2 to 12.5 μg/m^3, with maximum in the month of January 2007 and minimum in the month of June 2006. BC showed higher concentrations during the months of January, February and November while lower during the months of May, June, July and August throughout the years. It also displayed comparatively high concentrations during winter and postmonsoon, while moderate during premonsoon and low during summer. Diurnal analysis of BC concentration showed sharp peaks between 07:00 and 09:00 LST and again around 22:00 during all the months. Moreover, the relationship between BC concentration and meteorological variables such as Temperature (Temp), Relative Humidity (RH), Wind Speed (WS), Visibility (VIS) and RainFall (RF) was found and it was observed that BC concentration showed an inverse relationship with all these meteorological variables. Finally, the analysis of the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) cluster trajectories revealed that almost all the clusters were originating from southwest of the study site.

1. Introduction

Atmospheric aerosol or Particulate Matter (PM) is a complex mixture of tiny particles which consists of solid fragments and small liquid droplets. Black Carbon (BC) is one of the important light absorbing component (~ 90% in $PM_{2.5}$) of airborne PM, which is directly emitted from incomplete combustion of carbonaceous fuel (fossil fuel, biomass and agricultural waste and forest fire) (Cao et al., 2009; Tiwari et al., 2013; Guha et al., 2015; Li et al., 2016). BC emissions vary by changing use of fossil fuels and development of technology. In developing countries, the estimated emission of BC is the highest due to the fossil fuel (Novakov et al., 2003; Ramachandran and Kedia, 2010). The variation in fuel consumption has produced large temporal variations in the absorption of solar radiation by aerosols suggesting that absorbing aerosols in the atmosphere such as BC may have taken a significant part in global temperature variation in the last century (Sreekanth et al., 2007).

Much attention has been given to BC because it is a strong absorber of shortwave solar radiations and plays a significant role in the Earth's climate system by affecting the radiative balance of the atmosphere (IPCC, 2013; Wang et al., 2016). According to Petzold et al. (2013), almost all light absorbing carbonaceous elements present in the atmosphere can be qualitatively defines as BC. In fact, BC is considered to be the second strongest contributor to current global warming next to carbon dioxide (Bergstrom et al., 2007; Dumka et al., 2013; Surendran et al., 2013). It absorbs the incoming solar radiation, heats up the atmosphere and produces a heating effect in contrast to other aerosols (sulfates, etc.) which reflect solar radiations leading to a cooling effect (Bond et al., 2013; Adesina et al., 2015). BC causes harmful health effects, reduces crop yields, contaminates construction materials and adversely affects terrestrial ecosystems, because it absorbs toxic substances due to its porous and absorptive nature (Cao et al., 2009; Tiwari et al., 2013). Apart from this, it can also alter precipitation, cloud lifetime, reflectivity and melting of snow and ice (Dumka et al., 2013). The long lifetime (≳1 week in the lower troposphere (Babu and Moorthy, 2001) allows BC aerosols long-range transportation (Tiwari et al., 2013). BC aerosol particles are chemically

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inert and the main removal process is wet deposition due to its fine size (Aruna et al., 2013).

Interest in BC has increased because of its fine size, inert chemical characteristics and absorptive nature. These features combined with the growing sources of the BC, make it necessary to give proper and appropriate attention to the monitoring of these aerosols from different regions of South Asia. In recent years, carbonaceous aerosols have become one of the key research areas, as it has many climatic impacts. Therefore, numerous studies have been conducted related to BC aerosols over different regions of the world (Cao et al., 2009; Aruna et al., 2013; Tiwari et al., 2013; Wu et al., 2016), but very few studies could be traced regarding carbonaceous aerosols in Pakistan and these are conducted over a very short period of time (Husain et al., 2007; Dutkiewicz et al., 2009). Due to lack of ground observations, therefore, the present study has the potential to improve our knowledge about BC aerosols in different processes in Pakistan and also their impacts on regional and global climate change.

In this study, for the first time, we present a comprehensive datasets on BC aerosols, measured for period of three years (2006–2008) covering the four seasons (winter, summer, premonsoon and postmonsoon) for an urban site (Karachi). The temporal variations of BC concentration in diurnal, monthly, seasonal and scales were examined. These variations were explained on the basis of changing surface meteorological variables such as Temperature (Temp), Relative Humidity (RH), Wind Speed (WS), Wind Direction (WD), Visibility (VIS) and RainFall (RF) and the relationships between these variables and BC concentration were also analyzed.

2. Research methodology

2.1. Site description and local meteorology

Karachi is a major city of Pakistan situated (Lat 24° 51′N; Long 67° 02′E) on the coast of Arabian Sea. It has a large industrial base, with rapid urbanization and growing number of factories, vehicles as well as power plants, which are major sources of BC emission. The sampling site is northwest of Karachi Airport, which is located at the University of Karachi campus. Though moderate vehicular traffic is present in the campus, but the study area is adjacent to highways which have heavy traffic load. The region experiences four major seasons in each year: winter (December-February), pre-monsoon (March-May), summer (June-August) and postmonsoon (September-November). During winter, an increase in BC concentration occurs due to frequent burning processes mainly done by the local population for warmth against cold. The data of meteorological variables used in the present study were obtained from the Pakistan Meteorological Department, Karachi. Monthly averaged Temp, RH, RF and VIS are shown in Fig. 1. The monthly averaged Temp was in the range of 17–33 °C with high during the June-August and low during December-February. The monthly averaged RH showed strong monthly variability i.e. high during the summer months and low during winter months. The RH was lowest in January 2008 (43.1 ± 11.3%) and highest in August 2006 (81.5 ± 4.4%). It was observed that there was no prominent seasonal variation in VIS. The rainy season in Karachi is from July to September. During the study period from 2006 to 2008, the total RF was about 827 mm out of which 80% fall between July and September with maximum (250 mm) RF recorded in the month of August 2007.

Fig. 2(a–d) shows the averaged surface WS and WD during summer, winter, premonsoon and postmonsoon. The seasonal cycle of wind speed was significant with higher values during summer (4.5 m/s) and premonsoon (3.6 m/s) followed by postmonsoon (2.4 m/s) and weaker during the winter season (1.8 m/s). Analysis of these wind datasets revealed that the observational site was mostly under the influence of southwesterly winds. Whereas during winter, some of the wind patterns start shifting in the direction from southwest to northeast.

2.2. Aethalometer

The BC concentration measurements were obtained with a Magee Scientific Model AE21 Aethalometer, which was operated from a second floor window of the HEJ Research Institute of Chemistry building at the University of Karachi campus. Aethalometer measures BC using a light beam of high intensity at wavelengths of 880 and 370 nm by measuring the its attenuation caused by BC particles that accumulate on a rolled quartz filter strip with a cellulose fiber backing (Dutkiewicz et al., 2009). The mass concentrations were measured at 880 nm because BC is a major absorber at this wavelength and this wavelength signifies an accurate value of BC in the atmosphere. Aethalometer uses an optical transmission and continuous filtration method for the real-time measurement of BC concentration (Singh et al., 2010). A vacuum pump sucks air continuously for the particles accumulated on filter strip of Aethalometer. The light beam passes through the unloaded filter strip first and is then compared with the loaded filter. In this study, the measurement sampling interval was kept at five minutes from March 2006 to December 2008 at the 880 nm channel. BC concentration is calculated by measuring the change in the transmittance through the quartz filter at which the BC particles are deposited (Hansen et al., 1984). Attenuated light is linearly proportional to the concentration of BC, which is placed on filter. The Aethalometer was operated with a cyclone inlet (BGI corporation) equipped with an insect and rain guard at a flow rate of 4 l/min making the cut-point ~ 3.2 μm. It is noted that there are several systematic errors in filter based absorption methods used for the measurement of BC concentration that need to be corrected (Bond et al., 1999). The uncertainty in the measurement of BC concentration is ~ 10% (Babu and Moorthy, 2002) and particularly the absorption coefficient used for the 880 and 370 nm are 16.6 and 39.5 m^2/g, respectively (Dutkiewicz et al., 2009). The various uncertainties in the measurement of BC mass concentration using Aethalometer arises due to the changes in filter scattering occurs by aerosol loading and by increasing the filter loads, the Aethalometer measuring signals reduces i.e. BC concentrations (Ramachandran and Kedia, 2010).

3. Results and discussion

3.1. Temporal variation of BC concentration

BC aerosol mass concentrations measured for every five-minute interval within 24 h per day during each month were averaged for the entire study period (2006–2008) over Karachi. Monthly averaged BC mass concentration and associated standard deviation over Karachi for period 2006–2008 are tabulated in Table 1. Fig. 3 shows the monthly averaged BC concentration with maximum (12.5 $\mu g/m^3$) in the month of January 2007 and minimum (2.2 $\mu g/m^3$) in the month of June 2006. It is clear from the figure that overall concentrations were higher during the months of January, February and November while lower during the months of May, June, July and August throughout the years but with varying magnitudes. One of the reasons for high BC concentration is indoor heating due to coal burning activities (Cao et al., 2009). Moreover, local sources such as industrial and vehicular emissions also take part in high BC concentration (Safai et al., 2007). On the other side, the enriched wet deposition during monsoon rainfall is responsible for the low concentration of BC (Zhang et al., 2010; Lu et al., 2011; Li et al., 2016). Our results are comparable with the previous findings over Ahmedabad, in which monthly averaged BC concentration was enhanced in December (13.8 $\mu g/m^3$) and reduced in June (1.6 $\mu g/m^3$) (Ramachandran and Kedia, 2010). Dutkiewicz et al. (2009) also found higher values during November to February (~ 10 $\mu g/m^3$) and lower during June to September (~ 2 $\mu g/m^3$) over Karachi during 2006–2007. The results show that BC concentration increases year by year due to rapid increase in urbanization, vehicular emissions and deforestation. It is to be mentioned here that no measurements of BC concentration data were made for the months