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Ambient Concentrations of Black Carbon Aerosol and Its Emission Sources in Bangkok Ambient Air

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Abstract: Black carbon aerosol (BC) or elemental carbon (EC) in the atmosphere is known that formed by the incomplete combustion of fossil fuels, biofuels, and biomass. BC plays an important role as the solar absorber. It is a short-lived climate forcer (SLCF) which has atmospheric lifetime days to weeks while CO_2 is more than 100 years. In addition, black carbon aerosol considers as air pollutant that affects human health and WHO support within its Health and Climate Change campaign "Road to COP21". Identification the situation and sources of black carbon aerosol in the atmosphere is important for air quality management. The objective of this study is to determine black carbon ambient concentrations in suburban area north of Bangkok and find out its emission sources. This study measured BC concentration continuously 24 hours every 6 days for 4 years from January 2014 to December 2017. A Nano-sampler was used to determine the size distribution and carbon composition of the samples, and meteorological data especially wind direction and rainfall, were conducted on-site. Sampling location was suburban area north of Bangkok at King Mongkut's University of Technology North Bangkok. BC concentration was measured by aethalometer. The results showed hourly BC concentrations had average value 1.84±0.21 ug/m3 to 3.72±0.65 ug/m^3 with peaks in the morning and evening related to traffic**.** Seasonal BC concentrations were 1.88±0.68 to 4.78±1.13 ug/m^3 during dry season (November to April) which higher than the concentration in the wet season (May to October) at valued of 1.46±0.14 to 2.85±0.95 ug/m^3. The highest concentration occurred in January each year, except in 2017 was February, with value of 5.82, 5.27, 4.83 and 3.20 μg/m^3, respectively. The results of 72-hour backward trajectories (NOAA Hysplit Model) in the months which had the highest and lowest value of BC concentrations, showed closely correlation of BC concentrations and wind directions. They showed that ambient air in Bangkok was affected not only from traffic in the city but also others activities such as biomass burning from neighboring province; east and northeast of Bangkok. Particle size distribution showed bimodal of particle sizes 0.5-1 μm and 2.5-10 μm. Mean ratio of OC: EC were range of 3.2-4.1 show signature of vehicle exhaust, biomass burning and may be the formation of secondary organic aerosol. In 2017, BC concentration had trend to decrease may be the effective measures of burning prohibiting.

Keywords: Black carbon aerosol; Bangkok ambient air; Elemental carbon; Char-EC; Soot-EC

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1. Introduction

Black carbon aerosol (BC) or elemental carbon (EC) in the atmosphere is known that formed by the incomplete combustion of fossil fuels, biofuels, and biomass. BC plays an important role as the solar absorber. Its global mean radiative forcing are around +0.34 to 1.0 W/m^2 compare to CO_2 value of +1.66(±0.17) W/m^2 (US EPA. 2012). It is a short-lived climate forcer (SLCF) which has atmospheric lifetime days to weeks while CO_2 is more than 100 years. It is the second largest anthropogenic contributor to global warming (Atlantic Consulting. 2009). In addition, black carbon aerosol considers as air pollutant that affects human health and WHO (2015) support within its Health and Climate Change campaign "Road to COP21". Identification the situation and sources of black carbon aerosol in the atmosphere is important for air quality management and mitigation for climate change.

Black carbon aerosol in the atmosphere was varied from place to place according to local source contribution and long-range transport. Ahmed et al. (2014) found that 27 years of BC measurements at rural Mayville in Western NY State from 1984 to 2010 had monthly average ranged from 0.01 to 0.9 μg/m^3 and showed decreasing trend with slope of -0.006 μg/m^3 per year, and a 32% decrease over the 27-year period. In urban central China, Zhang et al. (2015) found that annual BC concentration in an urban area of Hefei from June 2012 to May 2013 was 3.5±2.5 μg/m^3. The BC concentrations in Lahore, Pakistan from November 2005 to January 2006 were very high, ranging from 5-110 μg/m^3 with a mean value 21.7 μg/m^3 (Husain et al., 2007). In Thailand, Garivait and Chaiyo (2006) measured BC concentration at King Mongkut's University of Technology Thonburi, KMUTT (suburban area south of Bangkok) and a remote area of Pimai district (300 kilometers northeast of Bangkok). They found that at KMUTT the BC concentration ranged from 2.28 to 7.08 μg/m^3 with those in Pimai district ranging from 0.08 to 2.35 μg/m^3. Oanh et al. (2008) studied 6 Asian cities (Thailand, China, India, Indonesia, the Philippines, and Vietnam) from 2002 to 2008 and found that, in Thailand at Asian Institute of Technology campus 49 kilometers north of Bangkok, BC concentration ranged from 4 to 11 and from 2 to 10 μg/m^3 in dry and rainy seasons, respectively. Suwattiga (2012) studied BC concentration in suburban area north of Bangkok at King Mongkut's University of Technology North of Bangkok (KMUTNB) from November 2009 to October 2010 and found that BC concentration range from 4-22 and from 2-13 μg/m^3 in dry and wet seasons, respectively. Duangkaew (2013) measured BC concentrations at city center of Bangkok, Chulalongkorn University, and found that hourly BC concentration in dry season ranged from 2.33 to 5.50 μg/m^3 with a mean of 3.64 μg/m^3 and the results of OC to EC ratio in particulate matter (PM10 and PM2.5) showed traffic-related source. Quang Hung et al. (2014) studied black carbon at roadside sites and along vehicle roadway in Bangkok Metropolitan Region and found that the mean BC concentration at the Dindaeng roadside were 11.5-17.9 µg/m^3. These previous studies on BC concentration in Bangkok ambient air shown that BC concentration were around 2-22 µg/m^3. BC concentrations in the city center of Bangkok were lower than outer areas around Bangkok. These may be the inner areas was effected by vehicle exhaust dominantly. Sources of BC emission should be considered. Phairuang et al. (2016) studied the influence of agricultural activities, forest fires and agro-industries on air quality in Thailand and found that these activities were closely correlated to the monthly average ambient PM concentrations in the upper northern, lower northern and northeast in Thailand. Therefore, in northeast monsoon Bangkok may be affected.

The objective of this study is to determine black carbon ambient concentrations in suburban area north of Bangkok and identify its emission sources by using carbon composition; total carbon, organic carbon, elemental carbon; char-EC and soot-EC.

2. Methodology

This study measured BC concentration continuously 24 hours every 6 days from January 2014 to December 2017 including meteorological data especially wind direction and rainfall. Nano-sampler for size distribution and carbon composition analysis were measured in July 2014-April 2015 at the same time of BC measurement.

2.1 Sampling Location

Sampling location was suburban area north of Bangkok at King Mongkut's University of Technology North Bangkok (Figure 1). The sampling instruments were placed on the roof-top of the 10th floor building occupied by the Faculty of Applied Science. To determine the BC ambient concentrations representative of air-shed, the sampling location was located away from specific sources of air pollution including traffic and industrial emissions.

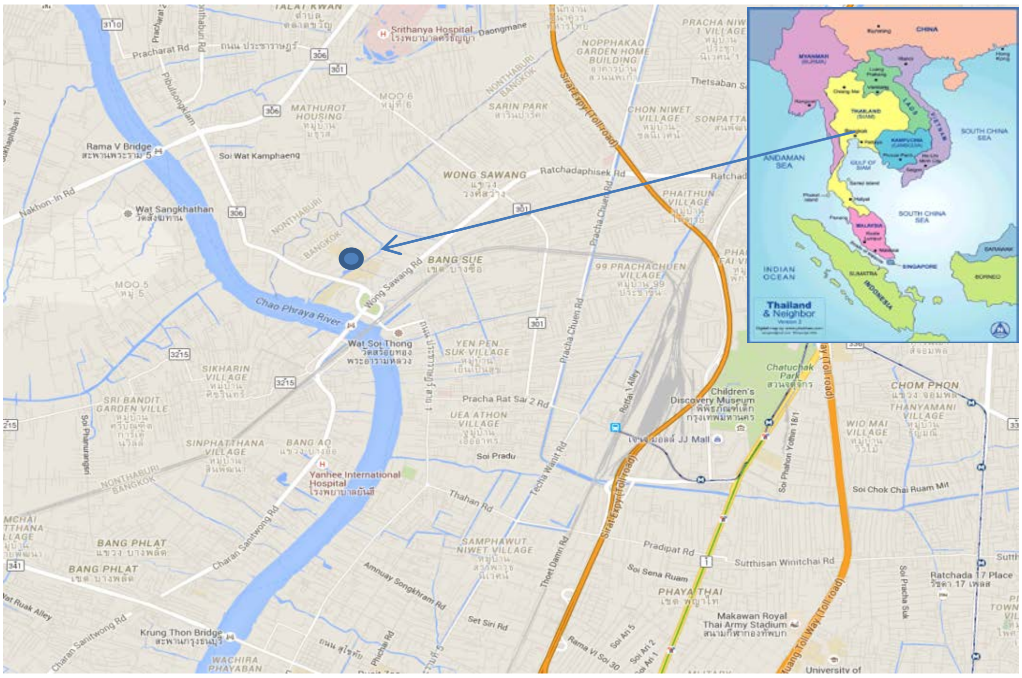


Figure 1 Sampling Location at King Mongkut's University of Technology North Bangkok

2.2 Measurement Methods

1) BC concentrations were measured by an aethalometer (MicroAeth®Model AE51, Magee Scientific). This instrument collects particulate matter via a filter and measures the infrared absorption value of the PM. The corresponding BC concentrations were determined and converted to µg/m3 (Figure 2). It's real-time analysis by measuring the rate of change in absorption of transmitted light due to continuous collection of aerosol deposit on filter. Measurement at the wavelength of 880 nm interpreted as concentration of Black Carbon (BC).

Figure 2 Aethalometer (MicroAeth®Model AE51, Magee Scientific)

2) A cascade impactor was used for collection of various sizes of particulate matter including PM <0.1, PM 0.5-1.0, PM 1-2.5, PM 2.5-10 and PM >10. The Nano sampler have 5 impaction stages as shown in Figure 3. It was operated at 40 liters/min.

Figure 3 The 5 stages Cascade Impactor (Provided by Kanazawa University)

3) The carbon compositions in particulate matter were analyzed for organic carbon (OC), elemental carbon (EC), char-EC and soot-EC. The samples collected on quartz-fibre filters were heated step by step from 500-850°C to remove all organic carbon and elemental carbon on the filter. Carbon compositions were analyzed at Kanazawa University using the OCEC Lab Instrument (Model 5, Sunset Laboratory Inc.)

4) Meteorological data: wind speed, wind direction, rainfall were recorded at this site.

All instruments; aethalometer and Nano-sampler were placed in housing as shown in Figure 4.

Figure 4 Sampling Site and all Instruments

3. Results and Discussion

The air samples were collected continuously for 24 hours every 6 days from January 2014 to December 2017. BC concentrations were measured by an aethalometer. The results showed average 24-hr BC concentrations have value 0.78 to 8.72 μg/m^3 with the high peak in January each year, except in 2017 was February (Figure 5).

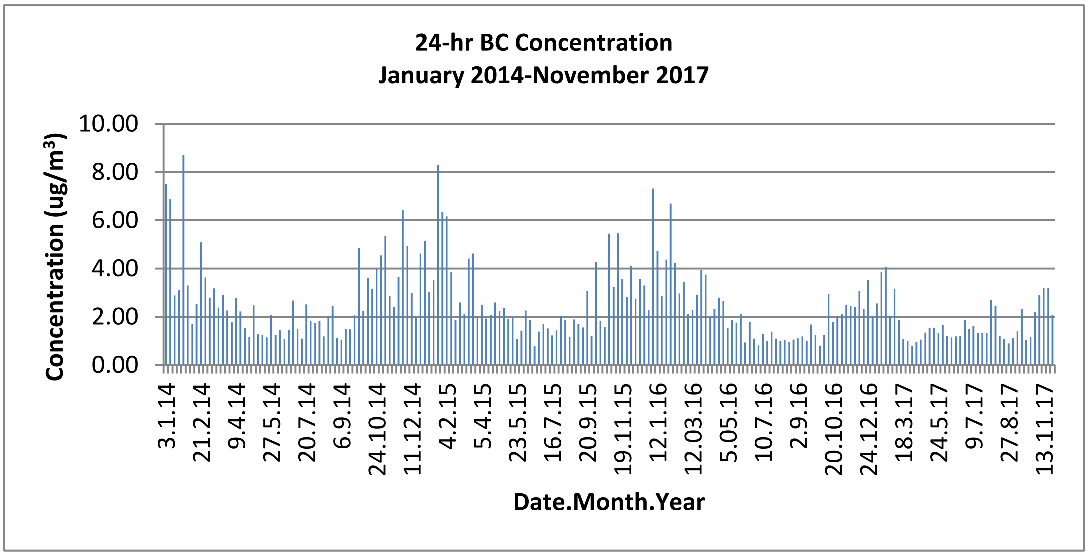


Figure 5 The 24-hr BC concentrations from January 2014 to December 2017

1) Diurnal BC Concentration

The 4-year mean of hourly BC concentrations have average value of 1.84±0.21 µg/m3 to 3.72±0.65 µg/m3 with peaks in the morning and evening related to traffic (Figure 6). According to the previous studies of Pongpiachan, et al. (2014) studied carbon composition in PM10 from 8 PCD monitoring stations in Bangkok and found the low OC to EC ratios which showed the influence of transportation and Quang Hung, et al. (2014) studied BC concentration along vehicle roadway and found that BC concentration from on-road traffic around Bang Sue area near KMUTNB sampling site had value at 25-30 g/m3. While, Suwattiga (2012) studied the ratio of OC/EC in PM10 at KMUTNB and found that the ratio of OC: EC showed contribution source of diesel vehicles.

The pattern of hourly BC concentrations also showed an accumulation of BC concentration in the mid night according to atmospheric stability.

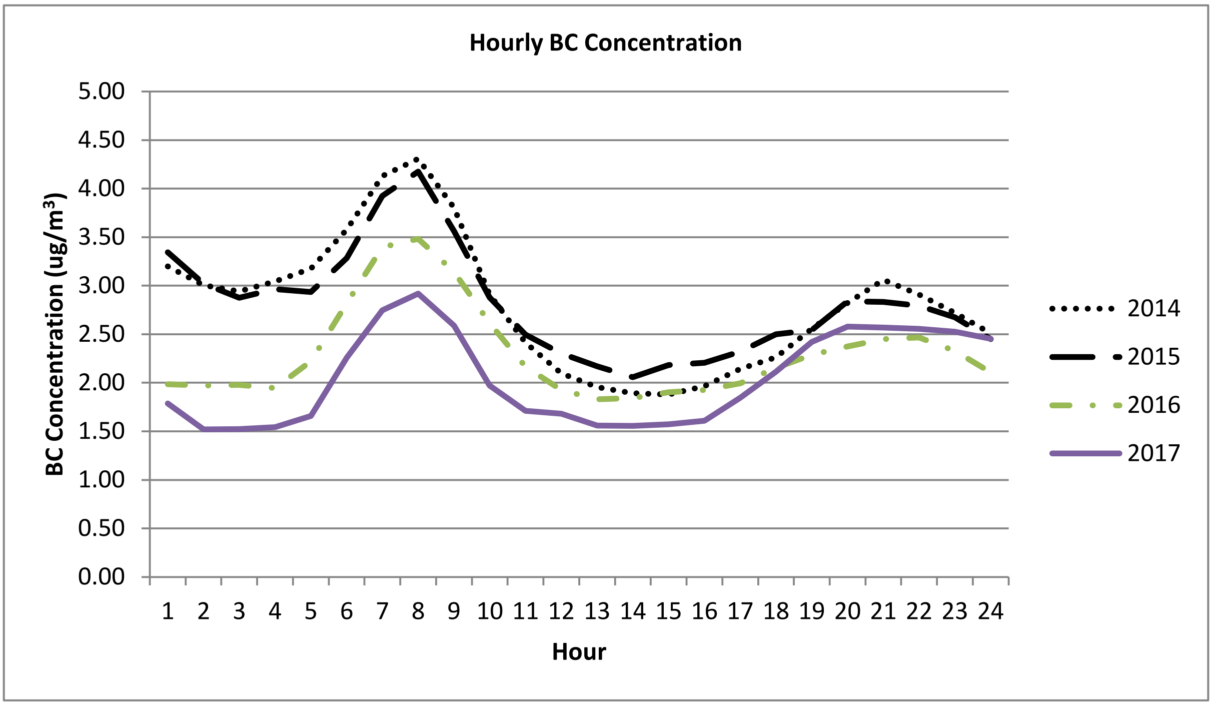


Figure 6 The Hourly BC Concentration

2) Seasonal BC Concentration

Monthly 24-hr BC concentrations showed seasonal variation (Figure 7). From meteorological data (Table 1), dry season was defined by rainfall value lower than 100 mm. Therefore, dry season and wet season were around November to April and May to October, respectively. Thailand was in effluence of northeast (NE) monsoon and southwest (SW) monsoon. Around October to January, the most of wind direction was N-NE-E and around February to September the most of wind direction was W-SW-S.

Mean of monthly 24-hr BC concentrations 2014-2017 showed that in the dry season (November to April) were 1.88±0.68 to 4.78±1.13ug/m3 higher than the concentration in the wet season (May to October) at valued of 1.46±0.14 to 2.85±0.95 ug/m3. The highest concentration occurred in January each year, except in 2017 was in February, with value of 5.78, 5.27, 4.83 and 3.20 ug/m3, respectively. Meteorological data at sampling site showed the strong influence of the wind direction on BC concentration more than an effect of wash out by rainfall. It showed that in SW monsoon the air mass from the sea to Bangkok is cleaner than the air mass from the east and northeast of Bangkok, NE monsoon.

Table 1 Meteorological Data at the sampling site: Rainfall and Wind Direction

Month	2014		2015		2016		2017	
	Rainfall (mm)	Mode of WD	Rainfall (mm)	Mode of WD	Rainfall (mm)	Mode of WD	Rainfall (mm)	Mode of WD
JAN	0.0	E	0.0	E	18.4	S	14.8	N
FEB	0.4	WSW	0.0	S	0.0	S	0.0	E
MAR	4.4	WSW	0.0	S	4.2	S	60.6	S
APR	10.0	S	0.0	S	0.0	S	98.2	S
MAY	129.6	S	99.8	S	56.2	S	438.4	S
JUN	192.4	SW	163.8	W	255.0	SSW	115.4	SSW
JUL	98.8	SW	89.4	WSW	127.6	W	147.6	WSW
AUG	225.6	SW	120.4	WSW	131.4	WSW	215.6	W
SEP	210.6	SW	236.4	W	279.6	W	87.2	W
OCT	149.7	E	229.2	E	190.0	W	244.6	NNE
NOV	46.6	NE	31.4	N	93.4	N	43.2	NNE
DEC	32.2	NE	5.2	N	0.0	NNE	3.6	N

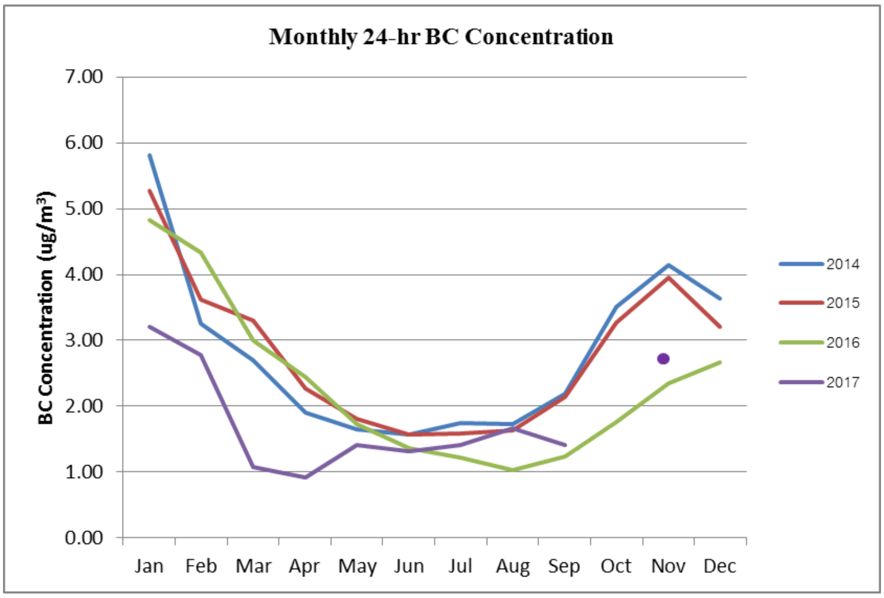
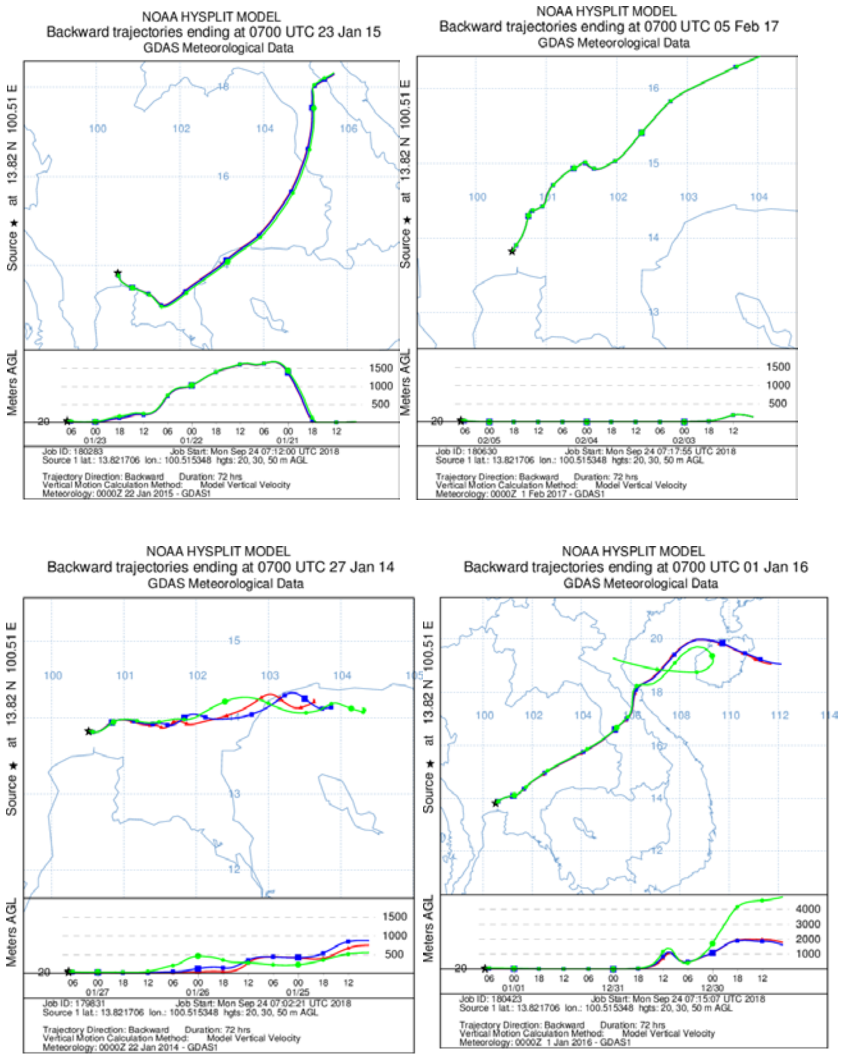


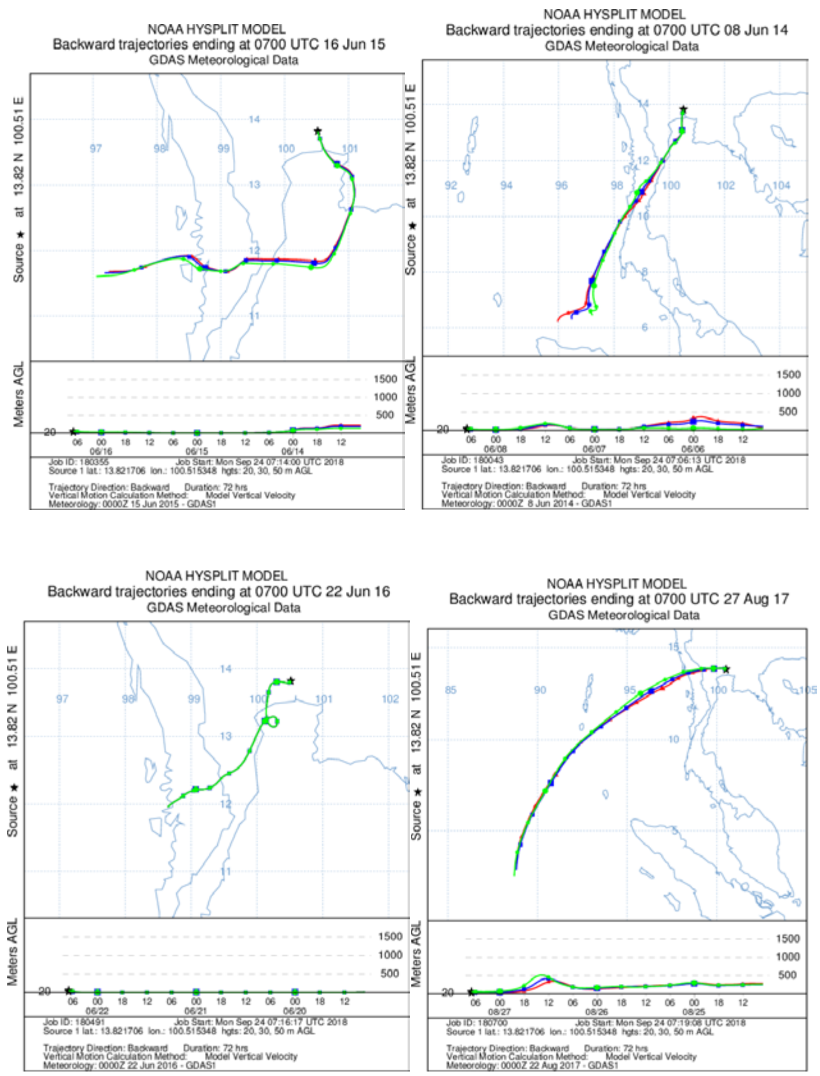
Figure 7 Monthly BC Concentration

According to the study of Phairuang et al. (2016) found the influence of agricultural activities, forest fires and agro-industries on air quality in Thailand and found that these activities were closely correlated to the monthly average ambient PM concentrations in the upper northern, lower northern and northeast in Thailand. The pictures of 72-hour backward trajectories (NOAA Hysplit Model) in January 2014-2016 and February 2017 and June 2014-2016 and August 2017 which had the highest and lowest value of BC concentrations, respectively showed closely correlation of BC concentrations and wind directions (Figure 8a,b). They showed that in the month with highest BC concentration, Bangkok was affected not only from traffic in the city but also others activities such as biomass burning (Phairuang et al. 2016) from neighboring province; east and northeast of Bangkok. Bridhikitti (2013) studied atmospheric aerosol layers over Bangkok Metropolitan Region (BMR) and found that biomass burning smoke layers were the most frequently observed and in dry seasons showed that the smoke layers with high AOD level were brought to the BMR via northeasterly to easterly prevailing winds. In June or SW monsoon, the air mass came from the sea to Bangkok. BC concentrations during SW monsoon were lower than BC concentration during NE monsoon.



Source: NOAA Hysplit Model

Figure 8a The 6-days backward trajectory trajectories in January 2014-2016and February 2017



Source: NOAA Hysplit Model

Figure 8b The 6-days backward trajectory trajectories in June 2014-2017

3) Particle Size Distribution

Particulate matter was collected; during July 2014-April 2015; at the same period of BC measurement by nano sampler provided by Kanazawa University. Results of Particle size distribution showed bimodal of particle sizes 0.5-1 μm and 2.5-10 μm (Figure 9). Particle size distribution between NE and SW monsoon was not much different except particle sizes 0.5-1.0 μm during NE monsoon were higher than during SW monsoon. They showed some additional sources of aerosol from the easterly and northeasterly wind according to Bridhikitti (2013) studied found that biomass burning smoke layers were the most frequently observed and in dry seasons and the smoke layers with high AOD level were brought to the BMR via northeasterly to easterly prevailing winds.

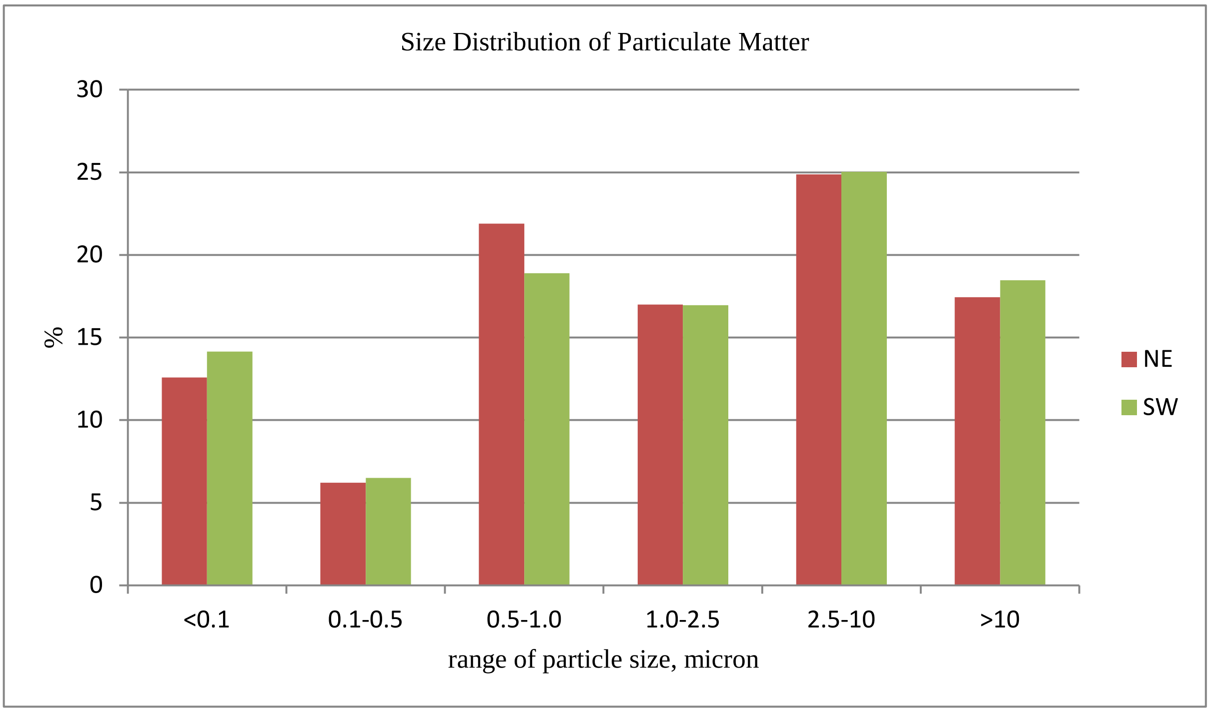


Figure 9 Particle Size Distribution

4) Carbon Composition

The carbon compositions; OC, EC, char-EC and soot-EC in each size range were analyzed at Kanazawa University. For particle size of 0.1-0.5 μm collected with filament material have not found the suitable method yet, therefore there was no result of carbon composition in that size. To identify source of particulate matter, the concentration of OC to EC and char-EC to soot-EC were used. Suwattiga, et al. (2007) found that in Thailand the ratio of OC : EC of gasoline vehicles were 1.0-2.7 while diesel vehicles were 0.2-0.3.

Mean ratio of OC : EC was very high at range of 3.2-4.1(Figure 10). Ratio of OC : EC greater than 2.0 indicated the formation of secondary organic aerosol (Chow et al., 1996). Mean ratio of char-EC : soot-EC of particle size smaller than 0.1 μm was 0.7 and particle size greater than 10 μm was 0.9 showed signature of motor vehicle emissions which have char-EC : soot-EC ratio lower than 1.0 (Han et al.,2010). Fresh diesel vehicle exhaust has particle size about 0.02-0.03 µm (Watson et al., 2005). The 3-range of 0.5-1.0, 1.0-2.5 and 2.5-10 µm have char-EC : soot-EC ratio at value of 4.3, 4.0 and 2.1, respectively. The ratio of these particle ranges showed the signature of biomass burning which have char-EC : soot-EC ratio about 2.0-5.0 (Chow et al., 2007).

The result of char-EC : soot-EC ratio showed emission sources of BC in Bangkok were vehicle exhaust and biomass burning dominantly.

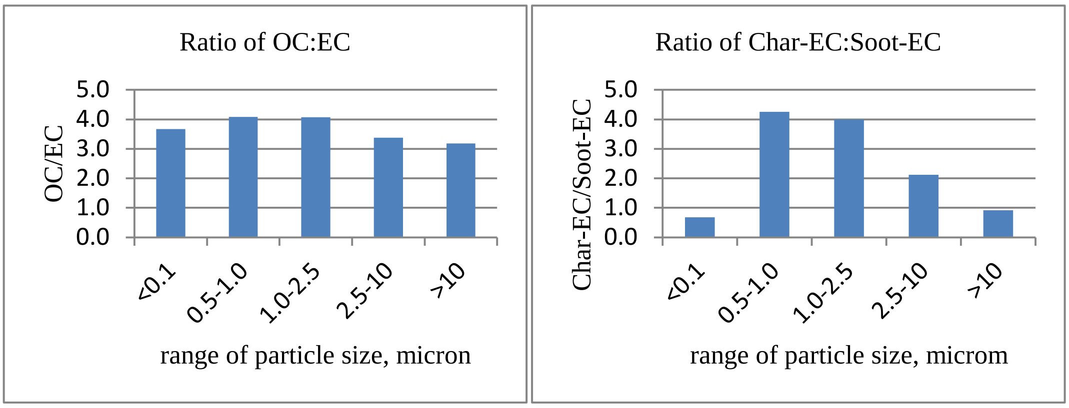


Figure 10 Ratio OC : EC and Char-EC : Soot-EC in Particulate Matter

4. Conclusions

BC concentrations in suburban area north of Bangkok showed diurnal variation had average value 1.84±0.21 µg/m^3 to 3.72±0.65 µg/m3 with peaks in the morning and evening related to traffic. This study also found seasonal BC concentration were 1.88±0.68 to 4.78±1.13 µg/m^3 during dry season which higher than the concentration in the wet season (May to October) at valued of 1.46±0.14 to 2.85±0.95 µg/m^3. The highest concentration occurred in January each year, except in 2017 was February, with value of 5.78, 5.27, 4.83 and 3.20 µg/m^3, respectively. The results of 72-hour back trajectory, OC to EC ratio and char-EC to soot-EC ratio showed that during northeast monsoon Bangkok ambient air were affected by biomass burning beside of transportation. The concentration of BC concentration in 2017 showed decreasing tend, may the effectiveness of biomass burning restriction.

“Stop burning” should be restriction policy of Thailand and Asian countries to reduce BC concentration in ambient air. It was a co-benefit to climate change and population health according to air pollution.

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