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Master’s Thesis

Comparison of Black Carbon Mass Concentration and Absorption Coefficient Measured by Aethalometer and COSMOS

Aethalometer와 COSMOS를 통해 관측한 블랙카본 질량농도와 흡수계수 비교 연구

February 2013

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ABSTRACT

This study was carried out to investigate the contribution of volatile aerosols to aerosol absorption coefficients ($\sigma_{\text{abs}}$) and black carbon (BC) mass concentrations ($M_{\text{BC}}$) measurement by using the filter-based optical instruments (aethalometer, continuous soot monitoring system (COSMOS) and continuous light absorption photometer (CLAP)) at the Gosan Climate Observatory (GCO) from February to June, 2012. The $\sigma_{\text{abs}}$ and $M_{\text{BC}}$ measured by these three instruments were compared to estimate the contribution of volatile aerosols. Mean $\sigma_{\text{abs}}$ determined by aethalometer, COSMOS and CLAP at 565 nm were found to be $5.15 \pm 3.73 \text{ Mm}^{-1}$, $2.87 \pm 2.2 \text{ Mm}^{-1}$ and $5.64 \pm 4.24 \text{ Mm}^{-1}$, respectively and $M_{\text{BC}}$ were found to be $0.52 \pm 0.37 \mu\text{g m}^{-3}$, $0.29 \pm 0.22 \mu\text{g m}^{-3}$ and $0.56 \pm 0.42 \mu\text{g m}^{-3}$, respectively.

$\sigma_{\text{abs}}$ and $M_{\text{BC}}$ measured by aethalometer and CLAP showed almost identical values with a difference of 9% which is likely due to the instrument’s uncertainty. However, $\sigma_{\text{abs}}$ and $M_{\text{BC}}$ measured by COSMOS were found to be approximately 44% and 49% lower than those measured by aethalometer and CLAP, respectively. This difference is most likely attributed to the uncertainty caused by the volatile aerosols co-existing with the BC because, in case of COSMOS, the sample air is heated before the measurement is carried out that removes the volatile aerosols. After excluding the instrument uncertainty (i.e.,
9%), it was estimated that about 35 - 40% difference in the \( \sigma_{\text{abs}} \) and \( M_{\text{BC}} \) can be attributed to the removal of volatile aerosols. The difference of \( M_{\text{BC}} \) between aethalometer and COSMOS were found to be proportional to thermal organic carbon (OC) suggesting that the filter-based optical instruments without the use of the heater may include both volatile aerosols as well as BC in their ambient air sample, contributing to some portions of \( \sigma_{\text{abs}} \) and \( M_{\text{BC}} \) measurement.

**Keyword:** Black carbon, Aerosol light absorption, Organic aerosol, Filter-based optical instrument, Gosan Climate Observatory.

**Student number:** 2011-22824
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CHAPTER 1. INTRODUCTION

1.1 Background and motivation

In the atmosphere there are mainly three types of light absorbing aerosols; mineral dusts, brown carbon (BrC) and black carbon (BC). Mineral dusts refer to strong or weak light absorbers depending on their mineralogical composition (Linke et al., 2006). On the other hand, BrC is recently introduced name for a class of light-absorbing carbonaceous material, which refers to moderately-to-weakly light absorbing organic matter in the atmospheric aerosols of various origins with a brownish appearance (Andrea and Gelencsér, 2006). BC is operationally designed as the carbonaceous aerosol with a deep black appearance, based on the measurement of light absorption (Moosmüller, 2009).

Light absorption by BC has been recognized as a critical factor for assessing the effect of aerosols on global and regional climate, because BC is usually the most important light absorbing aerosol component in the visible wavelengths (Miyazaki et al., 2008). BC is formed by incomplete combustion of fossil fuels, biofuel and biomass. BC directly heats the air by absorbing solar radiation in the atmosphere. Also, BC absorbs and emits infrared radiation and adds to the atmospheric radiation and adds to the atmospheric warming (Ramanathan and Carmichael, 2008). High concentration of BC affects the human health, climate and visibility. BC may contribute up to 20-50% of atmospheric warming as by
Therefore, accurate determination of ambient BC mass concentrations is needed.

Currently, there are several measurement approaches for the quantification of aerosol absorption of solar radiation, among which filter-based optical methods are widely used due to their ease of operation. These instruments derive aerosol light absorption from the change in light transmission through a filter on which particles have been collected (Figure 1). These instruments give real-time measurements.

Some of the filter-based optical instruments include the particle soot absorption photometer (PSAP) (Bond et al., 1999), the continuous soot monitoring system (COSMOS) (Miyazaki et al., 2008), the aethalometer (Hansen et al., 1984), continuous light absorption photometer (CLAP; National Oceanic and Atmospheric Administration) and the Multi-Angle Absorption

\[ \text{CO}_2 \] (IPCC, 2007). Therefore, accurate determination of ambient BC mass concentrations is needed.

**Fig. 1.** Principle of the filter-based methods.
Photometer (MAAP) (Petzold et al., 2004). However, this approach inherently overestimates the aerosol light absorption due to filter loading error and multiple scattering of the light beam at the filter fibers. Bond et al. (1999), Arnott et al. (2005), Schmid et al. (2006), and Weingartner et al. (2003) are some examples used to correct these errors.

However, BC in the atmosphere does not exist as a single uniform entity. Atmospheric aerosol may consist of substantial fractions of organic matter whose properties and origin differ from that of BC. Filter-based optical instruments are incapable of distinguishing BC from the other light absorbing aerosols (Andreae and Gelencsér, 2006). So, filter-based optical instruments are capable of recognizing light-absorbing carbonaceous component of aerosols present in the filter, exclusively as BC.

1.2 Objectives of this study

The objectives of this study are as follows:

1. To investigate the aerosol absorption coefficient ($\sigma_{abs}$) and BC mass concentration ($M_{BC}$) measured by the filter-based optical instruments at Gosan Climate Observatory (GCO).

2. To estimate the contribution of volatile aerosols in light absorption.
CHAPTER 2. METHODOLOGY

2.1 Data

![Map showing Gosan climate observatory (GCO) at Jeju Island, South Korea](image)

**Figure 2.** Map shows the Gosan climate observatory (GCO) at Jeju Island, South Korea

In this study, the BC mass concentration and aerosol light absorption coefficient were measured using aethalometer, the continuous soot monitoring system (COSMOS), the continuous light absorption photometer (CLAP) and thermal organic carbon (OC) and thermal elemental carbon (EC) mass concentration were measured by Sunset OC/EC analyzer installed at the Gosan Climate Observatory (GCO) (33.17 N, 126.10 E, and 70 m ASL). The data analysis period was chosen from February to June, 2012.
2.2 Aethalometer

The aethalometer is designed to measure the particulate absorption of light and the corresponding BC mass concentration in the air continuously. The AE-31 series ‘Spectrum’ models of aethalometer use an optical source, which is mounted at the top of inlet piece which incorporates 7 wavelengths (370, 470, 520, 590, 660, 880 and 950 nm). Ambient air enters the inlet as an internally-mounted variable speed pump starts its action. It meets the small part of the quartz filter (Pallflex 250F) where it gets embedded. The remaining part of the filter is used as a reference for the optical measurement. A mass flow meter monitors the sample air flow rate, which in this case is 3.9 Lmin\(^{-1}\).

The two photo-detectors are mounted below the filter; one measures the light passing through the particle-laden sample spot, while the other measures the light passing through a particle-free reference part of the filter. The filter tape advances at the time of need. As a precaution, the electronics area is thermally insulated and its temperature is actively stabilized by a thermistor-controlled circuit. The temperature is stabilized at approximately 40\(^\circ\)C. This minimizes any possible effect of ambient temperature fluctuations (Hansen, 2005).
2.2.1 Principle of aethalometer

The ‘Optical Attenuation’ ATN is expressed as

\[ \text{ATN} = 100 \ln \left( \frac{I_o}{I} \right) \]  

(1)

where, \(I_o\) is the intensity of light transmitted through the reference portion of the filter and \(I\) is the intensity of light transmitted through the sample spot.

Attenuation coefficient \((\sigma_{\text{ATN}})\) is given as:

\[ \sigma_{\text{ATN}} = \frac{A}{100V} \frac{\Delta \text{ATN}}{\Delta t} \]  

(2)

where \(A\) is the filter spot area, \(V\) is the volumetric flow rate and \(\Delta \text{ATN}\) is the change in the attenuation during the time interval \(\Delta t\). Equivalent BC mass concentration \((\text{BC}_{\text{ATN}})\), \(\mu g\ m^{-3}\) is calculated using the following formula:

\[ \text{BC}_{\text{ATN}} = \frac{\sigma_{\text{ATN}}}{\alpha_{\text{ATN}}} \]  

(3)

where, \(\alpha_{\text{ATN}} = \frac{14625}{\lambda}\) is Spectral mass specific attenuation cross-section.

2.2.2 Schmid et al. (2006) correction scheme

In this study, multi-scattering error and filter loading error that arise in aethalometer is corrected by using corrected equation as proposed by Schmid et al. 2006,

\[ \sigma_{\text{abs.correct}} = \frac{\sigma_{\text{ATN}}}{\text{Cref} \left( \frac{1}{7-1} \left( \ln \text{ATN} - \ln 10 \right) \ln 50 - \ln 10 + 1 \right)} \]  

(4)
where, $\sigma_{\text{abs,correct}}$ is corrected absorption coefficient, $C_{\text{ref}}$ is Correction factor for multiple light scattering effects within the filter (Weingartner et al., 2003) and $R(\text{ATN})$ is correction for shadowing effect due to filter loading,

$$R(\text{ATN}) = \left[ \left( \frac{1}{f} - 1 \right) \frac{\ln \text{ATN} - \ln 10}{\ln 50 - \ln 10} + 1 \right]$$

(5)

where, $f$ is shadowing factor, $f = m (1 - \omega) + 1$

Corrected Mass concentration of BC is then obtained as:

$$M = \frac{\sigma_{\text{abs,correct}}}{\sigma_{\text{BC}}}$$

(6)

where, $\sigma_{\text{BC}}$ is Mass absorption coefficient in m$^2$ g$^{-1}$. Its value is taken to as 10 m$^2$ g$^{-1}$ (experimental value) as suggested by Miyazaki et al. (2008).

### 2.2.3 Interpolation method

In order to get the aerosol absorption coefficients at the same wavelength, it needs be interpolated or extrapolated to the matching wavelength with the aid of Ångström exponent (Backman et al. 2010). If the two parameters are measured at different wavelengths $\lambda_1$ and $\lambda_2$, Ångström exponent,

$$\alpha_{12} = -\frac{\log(\frac{\sigma_{1}}{\sigma_{2}})}{\log(\frac{\lambda_{1}}{\lambda_{2}})}$$

(7)
which describes the wavelength dependency of scattering or absorption. The Ångström exponent can be used to relate the data to the same wavelength ($\lambda_x$) with

$$\sigma_x = \sigma_1 \left( \frac{\lambda_1}{\lambda_2} \right)^{\alpha_{12}} \quad (8)$$

This requires the assumption that the spectral dependence of the Ångström exponent is constant. In this study, the light absorption data from the aethalometer were interpolated to the same wavelength as COSMOS measured the data in.

### 2.3 Continuous soot monitoring system (COSMOS)

COSMOS is designed to measure the particulate absorption of light and the corresponding BC mass concentration in the air continuously. This instrument basically combines the principle of the PSAP and aethalometer. Ambient aerosol is first introduced through an inlet line that passes through the PM 2.5 impactor and then is heated to 400°C using an electric jacket heater. Internally mounted pump is used as a suction of the sample air. The sampling flow rate is controlled by a mass flow controller. The aerosol is collected on a quartz-fiber filter (Pallflex E70-2075W) at a flow rate of 3.95 Lmin$^{-1}$. The filter rolls are handled by tape feeder which automatically advances the filter tape when the transmittance value recorded by the instrument falls below a pre-set value.
COSMOS uses a 565 nm LED as a light source focused by a double-convex lens (DCX). The sample air passes through the filter, while the LED illuminates it from above to detect the intensity light transmitted by a photo-detector mounted below. The air flow, which is particle-free after passing through the filter, is then introduced to the reference unit (Miyazaki et al. 2008).

2.3.1 Principle of COSMOS

The absorption coefficient ($\sigma_{\text{abs}}$) is determined using the following equation:

$$\sigma_{\text{abs}} = \left(\frac{A}{V}\right) \times \ln\left(\frac{I_i}{I_{i+1}}\right) \quad (9)$$

where, $A$ ($m^2$) is the area of sample spot, $V$ ($m^3$) is the air sample volume during the given time period and $I_i$ and $I_{i+1}$ are the average values of the filter transmittances during the prior and current time periods respectively.

2.3.2 Bond et al. (1999) correction scheme

Now, $\sigma_{\text{abs,correct}}$ is given by the following equation

$$\sigma_{\text{abs,correct}} = \sigma_{\text{abs,i}} \times \frac{F(T_{ri})}{K} \quad (10)$$

$$F(T_{ri}) = \frac{1}{2 \times (0.5398 \times T_{ri} + 0.355)} \quad (11)$$

where, $T_{ri} = \frac{1}{I_0}$ is the filter transmission and $K=1.22$ (Bond et al., 1999). Mass concentration of BC is then obtained by (6).
2.4 Continuous light absorption photometer (CLAP)

CLAP is another type of filter-based optical instrument similar to the PSAP. It monitors the light transmittance at three wavelengths (467, 528, 652 nm) operating at a volumetric flow of 1 Liter min\(^{-1}\). The inlet of CLAP has an impactor with a cut off size of PM 10 and PM 1. The aerosol absorption coefficient is measured using (9). The raw absorption coefficient of the CLAP includes the potential effects due to filter loading error. It is corrected using the Bond et al. (1999) correction as given in (10).

CLAP cycles through a filter in 10 different measurement spots. Eight of these 10 are sampling spots, with the remaining two as reference locations where only filtered air will pass through them. The sample flow is first run through the particle-loaded filter, with clean air then passing through the reference filter. The rotation of sampling sites allows for the ideal minimum transmittance of 0.7 to be achieved for eight times as long as the PSAP. It has and uses 47-mm diameter, glass fiber filters (Pallflex type E70-2075W) (NOAA CLAP User’s Manual). In this study, the light absorption data from the CLAP were interpolated to the same wavelength as COSMOS measured the data by using the (7) and (8).
2.5 Sunset OC/EC analyzer

Semi-continuous measurements of atmospheric organic and elemental carbon (OC and EC) were analyzed hourly using Sunset Laboratory Model-4 Semi-Continuous OC/EC Field Analyzer. This instrument is based on the National Institute for Occupational Safety and Health (NIOSH) Method 5040 (Birch and Cary, 1996). This is done by depositing particles in the quartz filter by heating the sample subsequently in two different atmospheres (helium and helium plus oxygen). In the pure He atmosphere the sample is heated in steps to evolve the collected OC via pyrolysis, thus making the filter darker while monitoring the filter transmittance. In the next step, the oven is cooled and EC and pyrolysed OC is exposed to He-O₂ mixture. From the detected combustion products, the amount of OC and EC can be determined. The instrument collects samples on the filter for 45 min and then analyzes carbons, producing hourly data for EC and OC masses.

2.6 Instrument Setup at GCO

The instrument setup at GCO is illustrated in Figure 3. Same inlet is shared by all the instruments used in this study. CLAP and COSMOS has impactor in their inlet of size PM1/PM10 and PM2.5, respectively. Likewise, Sunset OC/EC analyzer has PM2.5 cyclone in its inlet. However, in case of aethalometer, it
does not have any size cut, so the total suspended particle (TSP) is used as a sample for the BC measurement. In addition, COSMOS has a heater connected in between impactor and the instrument which heats the sample air to about 400°C. The other specific information among the instruments is listed in Table 1. Hourly data from these instruments were analyzed in this study for the data analysis period.

**Figure 3.** Instrument setup at GCO.
Table 1. Features of the filter-based instruments (Aethalometer, COSMOS and CLAP)

<table>
<thead>
<tr>
<th>Details</th>
<th>Aethalometer</th>
<th>COSMOS</th>
<th>CLAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelengths of the light source</td>
<td>370, 470, 520, 590, 660, 880, 950 nm</td>
<td>565 nm</td>
<td>467, 528, 652 nm</td>
</tr>
<tr>
<td>Filter type</td>
<td>Pallflex 250F</td>
<td>Pallflex E70-2075W</td>
<td>Pallflex E70-2075W</td>
</tr>
<tr>
<td>Temperature of the optical unit</td>
<td>~40°C</td>
<td>~50°C</td>
<td>~37°C</td>
</tr>
<tr>
<td>Filter advancement</td>
<td>Auto</td>
<td>Auto</td>
<td>Manual</td>
</tr>
</tbody>
</table>
CHAPTER 3. RESULTS

3.1 Comparison of aerosol absorption coefficient ($\sigma_{\text{abs}}$)

Figure 4 shows the temporal variation of hour averaged $\sigma_{\text{abs}}$ obtained by the CLAP, aethalometer, COSMOS at GCO for the study period from February to June, 2012. The data for aethalometer and CLAP were interpolated to 565 nm to match with COSMOS. It can be observed that the $\sigma_{\text{abs}}$ obtained by CLAP, aethalometer and COSMOS show similar temporal variation and they are well matched. $\sigma_{\text{abs}}$ obtained by CLAP appear to be highest among the three, closely followed by $\sigma_{\text{abs}}$ obtained by aethalometer. It is important to note that these two instruments are the ones that do not use the heater in their inlet. The possible reason for the difference between aethalometer and COSMOS could be due to instrument’s uncertainty, i.e., difference in their filter type, use interpolation to adjust the wavelength, and use of different correction methods. But, when $\sigma_{\text{abs}}$ obtained by these two instruments were compared with those by COSMOS (an instrument that uses heater in their inlet); it can be observed that COSMOS produces significant lower values of $\sigma_{\text{abs}}$. The average value of CLAP, aethalometer, and COSMOS are $5.64 \pm 4.24 \text{ Mm}^{-1}$, $5.15 \pm 3.73 \text{ Mm}^{-1}$, and $2.87 \pm 2.20 \text{ Mm}^{-1}$, respectively. Thus, the mean values of $\sigma_{\text{abs}}$ also suggest that aethalometer and CLAP produce almost similar values whereas, COSMOS produces comparatively lower values.
**Figure 4.** Temporal variation of hour averaged aerosol absorption coefficient (σ_{abs}) obtained by CLAP (green), aethalometer (black) and COSMOS (red) from February to June, 2012 at GCO.

Figure 5 shows the scatter plot of σ_{abs} obtained by COSMOS against those by aethalometer; 6 shows the scatter plot of σ_{abs} obtained by COSMOS against CLAP and 7 shows scatter plot of σ_{abs} obtained by aethalometer against CLAP. Firstly, Figure 5 shows a high correlation between σ_{abs} obtained by COSMOS and aethalometer (coefficient of determination, R^2 = 0.94) with a slope of 0.57. Similarly, Figure 6 also shows a high correlation between σ_{abs} obtained by COSMOS and CLAP (R^2 = 0.93) with a slope of 0.50. Hence, these scatter plots adds to the information that COSMOS produces lower values of σ_{abs} in comparison to aethalometer and CLAP. But then again, the slope of σ_{abs}
obtained by aethalometer and CLAP in Figure 7 is 0.86. This regression line is observed to be much closer to 1:1 line than the lines seen in Figure 5 and 6 and also with a good correlation ($R^2 = 0.95$). On average, $\sigma_{\text{abs}}$ obtained by the CLAP are found to be almost equal to those by aethalometer with a difference of about 9%. Whereas, $\sigma_{\text{abs}}$ obtained by COSMOS are approximately 44% and 49% lower than those by aethalometer and CLAP, respectively.

**Fig. 5.** Comparison of aerosol absorption coefficient ($\sigma_{\text{abs}}$) obtained by COSMOS and aethalometer from February to June, 2012 at GCO.
Figure 6. Comparison of aerosol absorption coefficient ($\sigma_{abs}$) obtained by COSMOS and CLAP from February to June, 2012 at GCO.

Figure 7. Comparison of aerosol absorption coefficient ($\sigma_{abs}$) obtained by aethalometer and CLAP from February to June, 2012 at GCO.
3.2 Comparison of BC mass concentration ($M_{BC}$)

Likewise, Figure 8 shows the temporal variation of hour averaged $M_{BC}$ measured by CLAP, aethalometer and COSMOS from February to June, 2012 at GCO. $M_{BC}$ measured by CLAP, aethalometer and COSMOS also show the similar temporal variation. Similar to the case of $\sigma_{abs}$, the values of $M_{BC}$ measured by CLAP and aethalometer are almost identical to each other, on the contrary, $M_{BC}$ measured by COSMOS shows significantly lower values than those measured by other two instruments. The mean values of $M_{BC}$ measured by CLAP, aethalometer and COSMOS are $0.56 \pm 0.42 \mu g \ m^{-3}$, $0.52 \pm 0.37 \mu g \ m^{-3}$ and $0.29 \pm 0.22 \mu g \ m^{-3}$, respectively. In addition to the temporal variation, these mean values also show that COSMOS produces lower values of $M_{BC}$ in comparison to other two instruments.
Figure 8. Temporal variation of hour averaged BC mass concentration ($M_{BC}$) measured by CLAP (green), aethalometer (black) and COSMOS (red) from February to June, 2012 at GCO.

Scatter plot shown in Figure 9 show the $M_{BC}$ measured by COSMOS against the $M_{BC}$ measured by aethalometer. The correlation is high ($R^2 = 0.94$) and the value of its slope is 0.57. In the same way, Figure 10 shows that the $M_{BC}$ measured by COSMOS is highly correlated to $M_{BC}$ measured by CLAP, but their slope is 0.50. However in Figure 11, when $M_{BC}$ measured by two instruments without heater are compared (aethalometer vs. CLAP), they not only show good correlation ($R^2 = 0.95$), but also has a slope of 0.86 which is much closer to 1:1 line. Thus, the $M_{BC}$ measured by aethalometer and CLAP are almost alike with difference of about 9%. However, $M_{BC}$ measured by COSMOS is inferior to aethalometer and CLAP by 44% and 49%, respectively.
**Figure 9.** Comparison of BC mass concentration ($M_{BC}$) measured by COSMOS and aethalometer from February to June, 2012 at GCO.

**Figure 10.** Comparison of BC mass concentration ($M_{BC}$) measured by COSMOS and CLAP from February to June, 2012 at GCO.
Figure 11. Comparison of BC mass concentration (M_{BC}) measured by aethalometer and CLAP from February to June, 2012 at GCO.
3.3 Potential contribution of volatile aerosols on light absorption measurement

Light absorption measurement by filter-based optical instruments is done by measuring the light attenuation by the aerosol particles deposited in the filter. BC cannot be considered as a single uniform entity. It also consists of substantial fractions of organic matter whose properties and origin differ from that of BC (Andreae and Gelencsér, 2006). Lack et al., 2008 reported that volatile aerosols can cause significant uncertainties to the BC measurements. Thus, filter-based optical instruments measure the total light absorption done by the aerosol particles present on the filter medium because they are incapable of distinguishing each particle. However, heating the aerosol will remove the volatile aerosols present along with the BC.

Kondo et al., 2009 also expressed the relationships between the mass of volatile components and heater temperature (30° - 480°C). The 50% (90%) evaporation temperatures of organic aerosols (OA), SO$_4^{2-}$, NO$_3^-$, and NH$_4^+$ were approximately 120 (300)°C, 200 (250)°C, 80 (120)°C, respectively. The volatile components evaporated almost completely at 400°C. It needs to be noted that BC cannot be volatilized at about 400°C, rather it needs a higher temperature (higher than 600°C). The difference in $\sigma_{\text{abs}}$ and $\mu_{\text{BC}}$ obtained by aethalometer
Fig. 12. Comparison of thermal OC measured by Sunset OC/EC analyzer and difference of BC mass concentration (MBC) measured by aethalometer and COSMOS February from June, 2012 at GCO. and COSMOS is likely due to thermal extraction unit connected to the inlet of COSMOS that heats the sample air to about 400°C and removes the volatile aerosols. It can also be illustrated by Figure 12, which shows the relation of thermal OC mass concentration measured by Sunset OC/EC analyzer with the difference of MBC measured by aethalometer and COSMOS from February to June, 2012 at GCO. It can be observed that differences of MBC measured by aethalometer and COSMOS linearly increased with increasing thermal OC mass concentration.

Figure 13(a) and 13(b) shows the plot for 21st to 25th March chosen from the total study period which is taken in addition help to explain the above result.
Figure 13(a) shows the $M_{BC}$ measured by aethalometer and COSMOS and Figure 13(b) shows the thermal OC/EC mass concentration measured by Sunset OC/EC analyzer. This is done to examine the relation of thermal OC mass concentration and $M_{BC}$ measured by aethalometer and COSMOS. It can be clearly identified that at the two points where there is a noteworthy increase of thermal OC mass concentration; at the same corresponding time frame, the difference of $M_{BC}$ measured by aethalometer and COSMOS also show remarkably large value. Similarly, the other points where there are comparatively lower values of thermal OC, the difference between the $M_{BC}$ measured by aethalometer and COSMOS is also smaller. Hence, it also suggests that the aerosol particles embedded in the filter of aethalometer not only contains BC particles but also other volatile aerosols. These volatile aerosols were removed while the sample air was heated in the inlet of COSMOS. Thus, it can be said that measurement of $M_{BC}$ could lead to over-estimation of $M_{BC}$. 
Figure 13. Temporal variation of (a) BC mass concentration (MBC) measured by aethalometer and COSMOS and (b) mass concentration of thermal OC and EC measured by Sunset OC/EC analyzer from 21st to 25th March, 2012 at GCO.
CHAPTER 4. SUMMARY AND CONCLUSION

Light absorption by BC has been recognized as a critical factor in the earth’s radiation budget. Filter-based optical instruments are most widely used to measure the light absorption by light absorbing aerosols. However, BC is not a single entity and these instruments are unable to distinguish BC and other aerosols.

In this study, filter-based optical instruments, i.e., aethalometer, COSMOS and CLAP were used to estimate the contribution of volatile aerosols to the light absorption measurement at GCO from February to June, 2012. Aethalometer and CLAP are the filter-based optical instrument that do not use heater in their inlet, whereas, COSMOS has a heater in its inlet. Based on the previously published methods, correction of the light absorption measurement data were accomplished for each instruments and were also interpolated to achieve data at identical wavelength. $\sigma_{abs}$ determined by Aethalometer, COSMOS and CLAP at 565 nm are found to be, 5.15 ± 3.73 Mm$^{-1}$, 2.87 ± 2.2 Mm$^{-1}$, and 5.64 ± 4.24 Mm$^{-1}$ respectively. Likewise, $M_{BC}$ measured by aethalometer, COSMOS, and CLAP at 565 nm are found to be 0.52 ± 0.37 $\mu$g m$^{-3}$, 0.29 ± 0.22 $\mu$g m$^{-3}$, and 0.56 ± 0.42 $\mu$g m$^{-3}$, respectively. Keeping that in mind, $\sigma_{abs}$ and $M_{BC}$ measured by the aethalometer and CLAP were found to have almost identical values with the difference of about 9%, which is likely
due to the instrument uncertainty. On the contrary, $\sigma_{\text{abs}}$ and $M_{BC}$ measured by COSMOS were found to be approximately 44% and 49% lower than those measured by aethalometer and CLAP, respectively. Aethalometer and CLAP measured the light absorption by total aerosol particles present on the filter, whereas COSMOS measured the light absorption by the aerosol particles present on the filter after it was burnt to about 400°C in the heated inlet. Excluding the instrument uncertainty, it can be concluded that relatively lower values of about 35-40% of $\sigma_{\text{abs}}$ and $M_{BC}$ measured by COSMOS can be attributed to the removal of volatile aerosols co-existing with BC. It can be further explained by examining the relation of $M_{BC}$ with thermal OC mass concentration. The scatter plot of thermal OC mass concentration and difference of $M_{BC}$ measured by aethalometer and COSMOS were plotted, which showed that the difference of $M_{BC}$ measured by aethalometer and COSMOS increased with increasing thermal OC mass concentrations. This is also explained by their temporal variation plot drawn for 21st to 25th March. In that figure, it can be clearly observed that the larger the difference of $M_{BC}$ measured by aethalometer and COSMOS corresponded to the peaks of thermal OC mass concentration measured by Sunset OC/EC analyzer. This suggests that co-existing volatile aerosols with BC are likely to enhance the light absorption measurement done by aethalometer and CLAP. Further studies on physical and chemical properties
of the aerosol are required to clearly understand the effect of volatile aerosols on light absorption at GCO.
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국문초록

Aethalometer와 COSMOS를 통해 관측한 블랙카본 질량농도와 흡수계수 비교 연구

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본 연구는 필터기반 광학 관측기기 (에셀로미터, COSMOS, CLAP)의 흡수계수 측정에 휘발성 에어로졸이 미치는 영향을 산정하기 위해 수행되었으며 고산기후 관측소에서 측정된 2012년 2월부터 6월 자료를 사용하였다. 휘발성 에어로졸의 영향을 산정하기 위하여 세 관측기기로 측정된 에어로졸의 흡수계수 ($\sigma_{abs}$)와 블랙카본 질량농도 ($M_{BC}$)를 비교하였다. 565 nm에서 관측된 에셀로미터, COSMOS, CLAP의 평균 에어로졸 흡수계수는 각각 $5.15 \pm 3.73 \, \text{Mm}^{-1}$, $2.87 \pm 2.2 \, \text{Mm}^{-1}$ 과 $5.64 \pm 4.24 \, \text{Mm}^{-1}$ 로 산정되었으며, 평균 블랙카본 질량농도는 $0.52 \pm 0.37 \, \mu\text{g m}^{-3}$, $0.29 \pm 0.22 \, \mu\text{g m}^{-3}$ 그리고 $0.56 \pm 0.42 \, \mu\text{g m}^{-3}$ 로 나타났다. 에셀로미터와 CLAP으로 측정된 에어로졸 흡수계수와 블랙카본 질량농도는 9%의 차이를 가지지만 거의 동일한 결과를
나타내는데 이 차이는 기기 관측오차로 인한 것으로 사료된다. 그러나 COSMOS로 측정된 에어로졸 흡수계수와 블랙카본 질량농도는 에셀로미터와 CLAP으로 측정된 것보다 각각 44%, 49% 낮게 측정되었는데 블랙카본과 함께 존재하는 휘발성 에어로졸로 인한 불확실성이 영향이 컸기라 사료된다. 기기관측오차 (9%)를 제거한 뒤에, 약 35 - 40 %의 에어로졸 흡수계수와 블랙카본 질량농도의 차이는 휘발성 에어로졸의 제거로 기인한 것으로 산정되었다. 에셀로미터와 COSMOS에서 측정된 블랙카본 질량농도의 차이는 유기탄소가 증가함에 따라 함께 증가하였다. 이것은 블랙카본 뿐만 아니라 휘발성 에어로졸들이 공기 샘플에 함께 포함되어있기 때문에 히터를 사용하지 않는 필터기반 광학기기들이 에어로졸 흡수계수와 블랙카본 질량농도를 과추정할 수 있다.

주요어: 블랙카본, 에어로졸 흡수계수, 유기탄소, 필터기반관측기, 고산기후관측소
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