Poll Res. 41 (1) : 328-334 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i01.048

INTRA-SEASONAL AND SEASONAL TRANSITION VARIATION OF AEROSOL BLACK CARBON OVER HIGH ALTITUDE REGION OF SOUTHERN INDIA, OOTY, TAMILNADU

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(Received 2 May, 2021; Accepted 11 June, 2021)

ABSTRACT

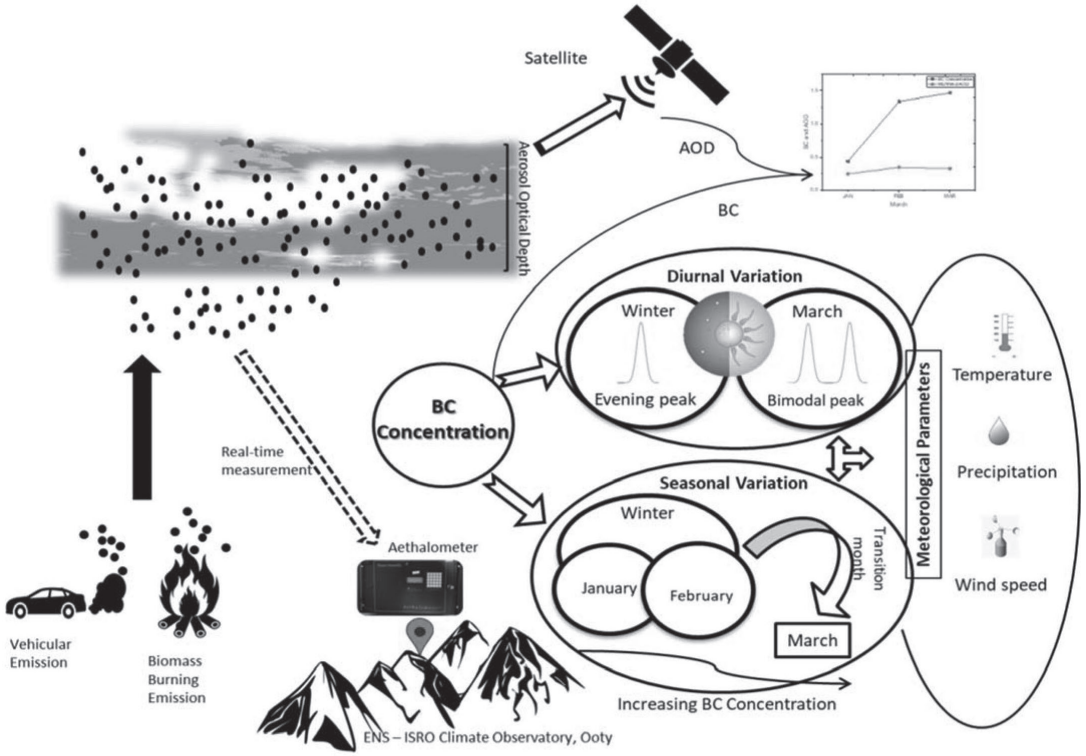
The Black carbon is the aerosol particle that has been produced from the incomplete combustion of carbonaceous fuels. The concentration of the Aerosol Black Carbon (ABC) was measured by using the Aethalometer (Magee Scientific Model AE-31) at high altitude region, Ooty. This study has measured the diurnal and seasonal variation of ABC concentration for the winter and transition month of March (winter to summer), 2021. They were also influenced by the local meteorological conditions. The average winter (January-February) and March month concentration were recorded as 0.89±0.26 µg m^{-3} and 1.46±0.62 µg m^{-3} respectively, and it shows significant variation at diurnally during the winter as well as in transition month. Aerosol Black carbon concentration attains the peak during evening hours (17:00 to 20:00 LT) in winter and follows the bimodal peaks in morning (09:00 LT) and late evening hour (21:00 LT) during March month. The ABC concentration was significantly related with the Aerosol optical depth which denotes that the ABC is one of the contributors to the atmospheric aerosols. The results showed that their nature tend to change with the local meteorological conditions and to the seasonal variation.

KEY WORDS : Aerosol Black carbon, Winter season, Transition month, Diurnal variation, Monthly variation, MERRA-2.

INTRODUCTION

Aerosols were produced from different natural and man-made activities (Ranjan *et al.*, 2007). In recent years, the aerosol concentration in atmosphere has increased, due to the increased loading of atmospheric pollutants associated with the rapid industrialization, growing population and modernization of cities and rural areas that makes the Asian continent as a hub for carbonaceous aerosols emission (Oshima *et al*., 2012). Among those aerosols, Aerosol Black Carbon (also known as soot particles) has gained significant scientific interest among the scientists because of its unique nature in terms of its fine size (sub-micron size), inert chemical character, short atmospheric lifetime (days to weeks), and high solar radiation absorbing potential (Singla *et al*., 2019). Aerosol Black carbon has originated from the incomplete combustion of fossil fuels or biomass (carbonaceous fuels), which is the second most contributor for the global warming next to the CO_2. The major sources for the black carbon are; i) fossil fuel burning, ii) biomass burning, iii) naturally occurring forest fires Hansen, 2005. Aerosol black carbon has high radiation absorbing attribute over a wide range of wavelengths from UV to IR which leads to the global warming (Kowsalya *et al*., 2020) and exerts a positive direct radiative forcing on Earth's climate between +0.08–1.27 W/m^2 (Bond *et al*., 2013). Paliwal *et al*. (2016) noted that the national BC emission for the year of 2011 was 901 ± 152 Gg yr^{-1} attributed with the domestic fuels as a

GRAPHICAL ABSTRACT



major contribution (~47%). Aerosol Optical Depth (AOD) is an important optical parameter that measures the aerosol loading in the atmosphere, which has been considered for assessing the impact of aerosols and to understand their characteristics over the atmosphere, spatially and temporally (Kuniyal *et al.*, 2009). In this paper we present the results for the Black carbon concentration over a high altitude region over the period of winter and the starting of summer season (meant for the transition month) and their variability in respect with the meteorological parameters.

MATERIALS AND METHODS

Study site

The study site "Ooty" 11.42° N, 76.72° E located from 2520m AMSL near to the Doddabetta peak belongs to the Western Ghats of South Indian peninsular region (Fig.1). This site has been highly excluded from the human activities, attributed with dense tropical forest, grasslands, plantations and mountain coverage. The study site is located near Ooty town, where the population is 88430 (as per the Census 2011), which is the very important tourist place consisting of botanical garden, conservation parks, sanctuaries and biosphere reserve.

Instrumental Measurement

ABC mass concentrations were measured by the Magee Scientific Model AE-31 Seven-Channel Aethalometer with the flow rate of 4 LPM and the data was recorded at the interval of five minutes. The instrument measures attenuation of optical beam at seven different wavelengths *viz.*, 370, 470, 520, 590, 660, 880 and 950 nm. Among those wavelengths BC is the chief absorber at 880nm and hence this wavelength has commonly considered for the ABC concentration measurement (Kowsalya *et al.*, 2020). The ABC concentration is measured by the variation of optical transmittance and the optical attenuation of the beam that has been transmitted through the particles deposited quartz filter paper. The attenuation of radiations is linearly proportional to the accumulated concentration of ABC on the filter (Zeb *et al.*, 2020).

The empirical formula to calculate the true ABC mass concentration (M_{BC}) is

$$M_{BC} = M^{*}_{BC}\left[\frac{P_0 T}{P T_0}\right]^{-1}$$

where,

M^{*}_{BC} - Raw mass concentration of ABC measured at ambient condition

P_0 and P - Standard and Ambient pressure

T_0 and T - Standard and Ambient temperature

Satellite Retrieval – MERRA-2 Model

NASA's global Earth system model MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, Version 2) was used to study the Aerosol component which gives the vertical profile of aerosol species at 0.5° × 0.625° resolution (Sun *et al*., 2019). The monthly averaged MERRA 2 data was downloaded for the study period (January to March, 2021) at 550 nm wavelength from the data file M2I3NXGAS 5.12.4 at MDISC site (https://disc.gsfc.nasa.gov/datasets?project=MERRA-2), managed by the NASA Goddard Earth Sciences (GES) Data and Information Services Centre (DISC). The GIS tool was used to extract the data value from the netCDF format data file to the specific study site coordinates.

Local Meteorology

To the entire study period meteorological parameters like Air temperature, Relative Humidity, Rainfall and Wind speed has been studied. The average air temperature and relative humidity for the entire winter month was 12.6 °C and 79.02 % with the maximum recorded readings of 14.9 °C and 100 %, respectively. Similarly, the maximum rainfall and wind speed were recorded as 20.6 mm and 12.8 kmph with the cumulative rainfall of 71.2 mm and average 5.3 kmph, respectively. Wind speed plays a major role in the transport of aerosols and their loading in the atmosphere, in which the maximum recorded wind speed was in line with the major direction of south westerly convection. The meteorological parameters for the transition month of March (starting of summer season) was also recorded as following, average temperature 14.2 °C, average relative humidity 66.6%, cumulative rainfall 34.7 mm and average wind speed 5.8 kmph. On comparing these three months March has been recorded with high temperature, whereas the rainfall and relative humidity was higher in January than other months. Notably there has no rainfall recorded during the February month.

Fig. 1. Study site Location (11.42° N, 76.72° E Altitude 2520 AMSL)

RESULTS AND DISCUSSION

ABC Monthly variation

The concentration of the ABC shows its heterogeneity *i.e.* increasing trend over the subsequent months throughout the study period. During the winter months (January and February), the average ABC concentration was 0.89±0.26µg m^{-3}. The concentration during the February month has shown increasing trend with the value of 1.34±0.52 µg m^{-3} over January month (0.44±0.32 µg m^{-3}), which could be due to the increased anthropogenic activities at the near Ooty town. This was in accordance with the results obtained by Dumka *et al*. (2010) in his study at the Manora peak (1958 amsl). The transition month (March) has recorded higher ABC concentration (1.46±0.62 µg m^{-3}) than the winter season which was due to the increased radiation convection that lead to the lofting of aerosols and make them spatially dispersed by the activity of prevailing winds across the study site. This makes the concentration high during the advent of the summer season which was in line with the Udayasoorian *et al*. (2014). Comparing the three months of study period the ABC concentration seems to have increasing trend due to the increased anthropogenic activities. Since the rainfall occurrence has reduced after January month, there was no chance for the wet removal of aerosols.

ABC Diurnal Variation

ABC concentration has been continuously measured and their variation in diurnal and seasonal transition was noted (Fig. 2). In the entire winter season, the concentration of ABC was normal and tends to

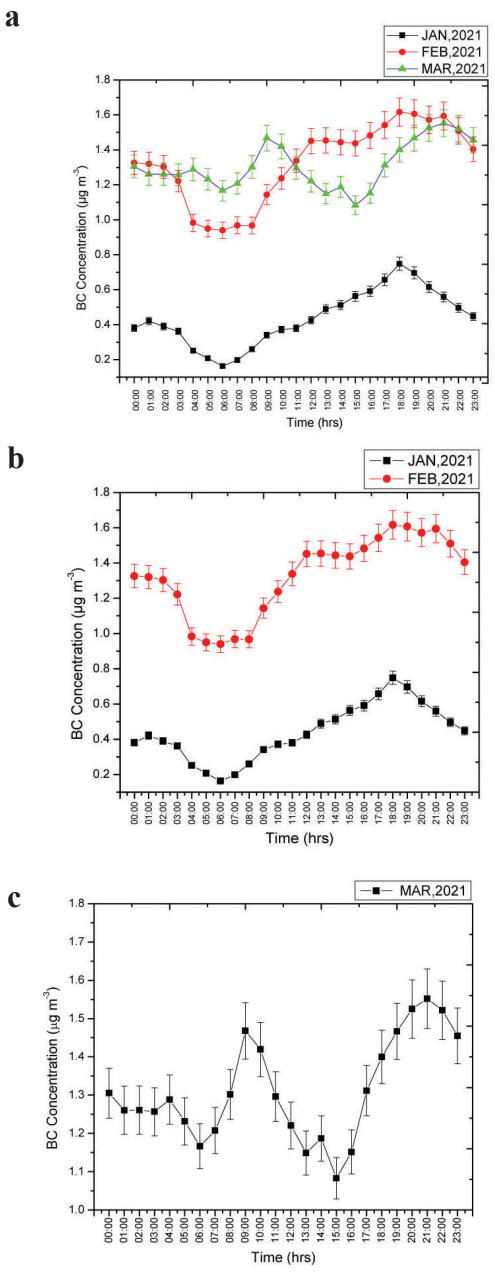


Fig. 2. Diurnal Aerosol Black Carbon Variation during a) Entire study period, b) Winter, c) March

decrease during the early morning hours (01:00 to 04:00 LT) and morning hours (05:00 to 08:00 LT) because our study site was far from the industrialized and urban location and hence there is no chance for concentration soaring in the morning hours. However at the end of morning hours, the concentration showed increasing trend due to the increase in air temperature that lofted the surface aerosols which was confined in the lower atmospheric boundary layer during the night hours (Fig. 2b). The ABC concentration has been increasing from forenoon hours (09:00 to 12:00 LT) till evening hours (17:00 to 20:00 LT) due to the thermal build up along with the increased anthropogenic activities and it has attained the peak during the evening hours (17:00 to 20:00 LT). The linear peak has continued to the end of evening hours due to the decreased atmospheric boundary layer near to the study site (Sarkar *et al*., 2015). In the entire season peak has attained during the mid-evening hours (18:00-19:00 LT) due to the cooking activities and biomass burning. During the night hours (21:00 to 23:59 LT) the concentration of ABC decreased because of diminishing anthropogenic activities. The low value of the ABC concentration during night and early morning hours of winter season was due to subdued anthropogenic activities along with the low ambient air temperature than the normal, and the nocturnal boundary layer was very low during these hours which have proven the findings of Dumka *et al.* (2010).

In the transition month of March (advent of the summer) the ABC concentration follows the bimodal peak (Fig. 2c). The concentration decreased during the early morning hours (01:00 to 04:00 LT) and recorded low concentration during the morning hours (05:00 to 08:00 LT), and reached the peak suddenly during the early forenoon hours (09:00 LT). Thereafter, the concentration tends to decrease towards the end of afternoon hours (16:00 LT), but the value showed increasing trend during the evening hours (17:00 to 20:00 LT) and attained the peak during the night hours (21:00 LT) and again decreased towards the end of night hours. The morning first peak occurred due to the thermal build up at that time period, which was followed by the decreasing trend during the noon hours. This was due to the increased solar radiation that deepens the diurnal atmospheric boundary layer and lofted aerosols were spatially dispersed by the activity of prevailing winds which makes the low ABC concentration around the study site, despite the occurrence of strong convection. Kant *et al*., 2012 and Ramachandran and Rajesh (2017) also reported similar results in their study.

The ABC concentration attained the peak in the night hours due to the increased anthropogenic activities during the afternoon and evening hours along with the formation of shallow boundary layer that traps the aerosols near the surface. The boundary layer has formed because of the surging in temperature during the late evening hours. Thus the ABC concentration was significantly varied in the

transition month from the winter months at the study site (Fig.2a).

Effect of Meteorological parameters on the ABC concentration

The prevailing local meteorological conditions *viz.*, Temperature, Wind speed and Rainfall has significantly affected the black carbon concentration. The ABC concentration has positively correlated with the temperature at both winter season (R = 0.81) and transition month (R = 0.85) (Fig. 3), meanwhile the Wind speed has positively correlated during the transition month (R = 0.77) (Fig. 4b), but it has negatively correlated during the winter season (R = - 0.86) (Fig. 4a). In the winter season, the ABC concentration was high due to the stable boundary layer and air temperature Guha *et al.*, 2015. However the high wind speed reduces BC mass concentration due to the ventilation effect and hence the ABC mass concentration has been negatively correlated with the wind speed which was similar to the findings of Kumar *et al.* (2011) and Wang *et al.* (2011).

In the transition month (March), high wind speed and temperature increased the ABC concentration which was due to the ventilation coefficient that disperse and carries the aerosols to our study site during the summer season. Hence the temperature and wind speed has been positively correlated with BC concentration during the transition month. This result was supported by the findings given by Udayasooriyan *et al.* (2014) and Latha and Badarinath (2005). The rainfall has been recorded during the early winter alone *i.e.* January, thereafter no rainfall had been recorded, and so it was negatively correlated (Fig. 5) with the early winter ABC concentration (R = - 0.68). These results showed that the ABC concentration has been decreased due to the rainfall which washout the aerosols from the atmosphere through wet deposition (Vijaybhaskar *et al.*, 2018). Black Carbon was a hydrophobic and sub-micron aerosol, hence

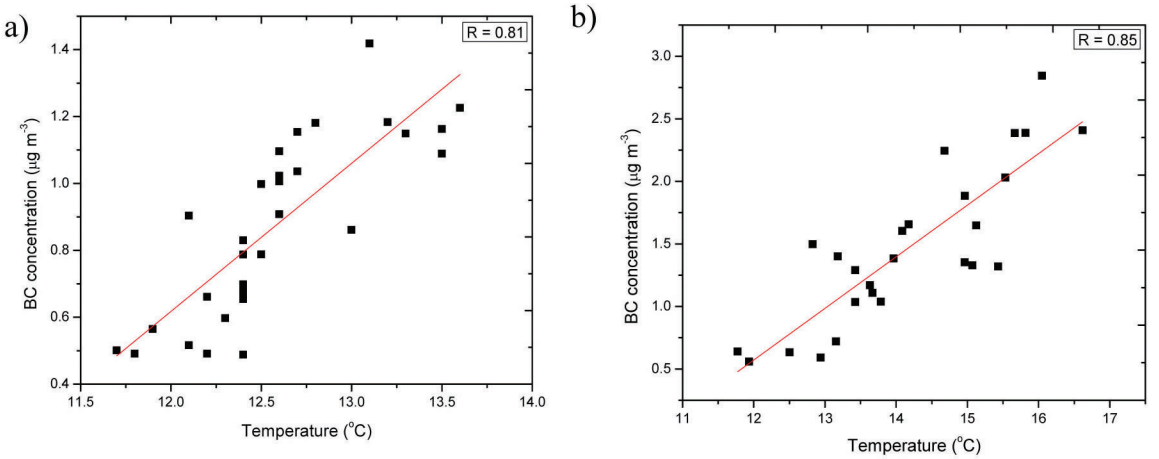


Fig. 3. Correlation of ABC Concentration with the Temperature during the a) Winter, b) March

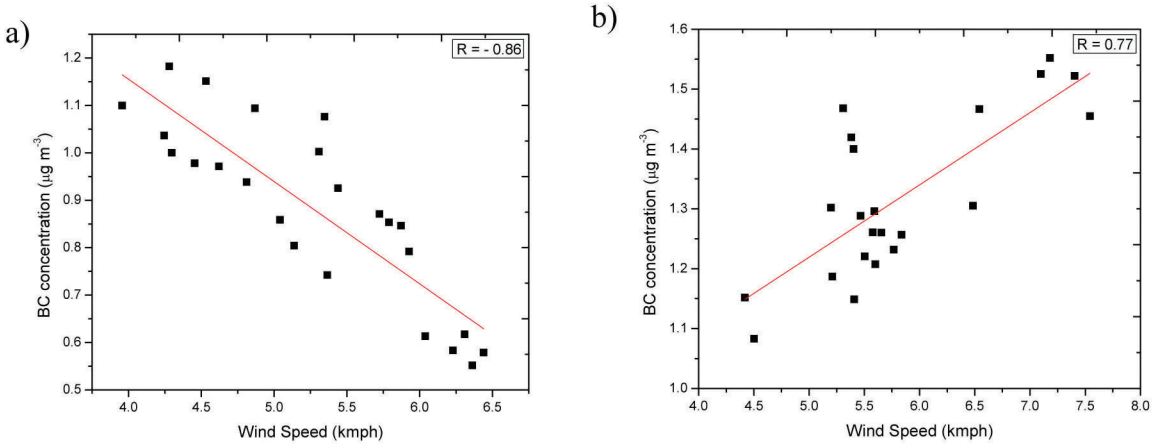


Fig. 4. Correlation of ABC Concentration with the Wind speed during the a) Winter, b) March

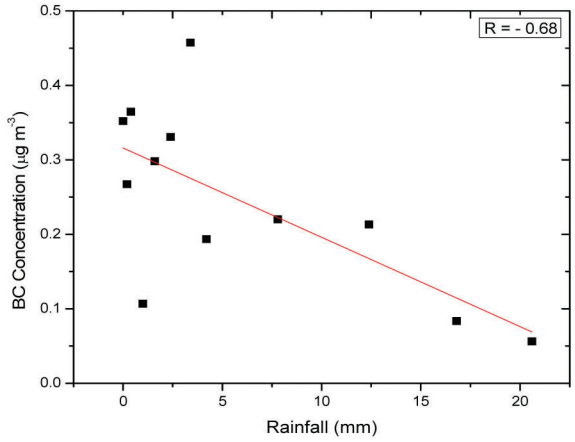


Fig. 5. Correlation between the Rainfall and ABC Concentration during the early Winter season (January)

there is no correlation were found between the relative humidity and Black carbon concentration, this is in line with the Ramachandran and Kedia (2010), Babu and Moorthy (2002) and Reddy *et al*., (2012) findings.

Aerosol Optical Depth and Aerosol Black Carbon Concentration

The monthly average of the AOD was retrieved from the MERRA-2, which was compared with the monthly average ABC concentration for the study period (Fig. 6). The study shows that the ABC concentration has increased with the increase in AOD which denotes that the Black carbon was one of the possible contributors to the atmospheric aerosols over the study region. This result corroborated the findings of the Kumar *et al*. (2011). The AOD value reveals that our study site is fairly clean during the winter as well as in the transition month.

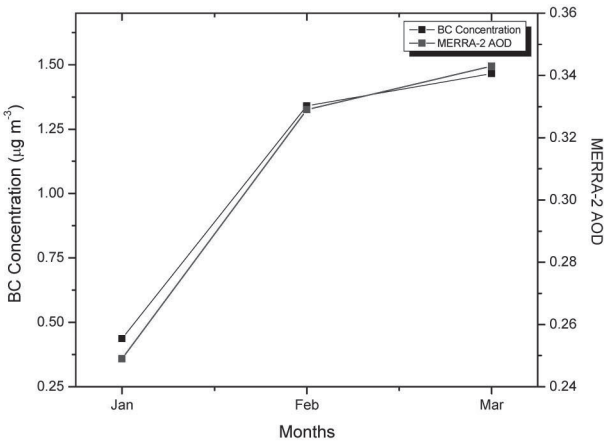


Fig. 6. Comparison of AOD and ABC concentration

CONCLUSION

The present study addresses the diurnal variation of the Black carbon concentration during the entire winter season and the seasonal transition month at the high altitude region, Ooty. The results of this study concluded the several findings that are;

1) The average ABC concentration during the winter season was 0.89±0.26 µg m^{-3} and for the March month it has recorded as 1.46±0.62 µg m^{-3}
2) Aerosol Black carbon concentration shows the significant diurnal variation over the season and they are influenced by the local meteorological conditions, especially the temperature plays a major role in loading and build-up of concentration in the atmosphere at this high altitude region.
3) Besides the temperature, parameters like wind speed, rainfall also affects the concentration, and notably wind speed plays a major role in dispersion of the aerosols during the winter season, which has been one of the reasons for the low concentration during this period.
4) Contrarily, in the transition month (March) the high wind speed increased the concentration of the Aerosol Black carbon at the study site.
5) Rainfall occurrence is the major factor in reducing the ABC concentration during the early winter season, the nature of the ABC does not allowed it to affect by the Relative humidity, so there is no correlation has studied for this parameter.
6) AOD value increased in line with the increased ABC concentration that shows the Black carbon was one of the significant contributors in the total atmospheric aerosols.

ACKNOWLEDGEMENT

This study was carried out under the Aerosol Radiative Forcing over India (ARFI) project of the Indian Space Research Organization – Geosphere and Biosphere Programme (ISRO-GBP) funded by Space Physics Laboratory, Vikram Sarabhai Space Centre (VSSC). The authors are grateful to the Indian Space Research Organization (ISRO) to the opportunity of working as a part of their research project, and for their assistance in terms of providing fund and support for this research.

Conflict of Interest

The authors declare that they have no conflict of interest.

Abbreviations

ABC : Aerosol Black Carbon
AOD : Aerosol Optical Depth
LT : Local Time
μg m^{-3} : microgram per cubic metre

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