# BLACK CARBON AND ITS CORRELATION WITH TRAFFIC

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**ABSTRACT:** Environmental pollution as a result of road transport is a pressing topic at the global level and is increasingly gaining importance at the local level. The main pollutant is carbon dioxide, and in the recent period, the so-called PM particles are also included, among which are also t. i. black carbon. We measured the black carbon concentrations at the Faculty of Logistics, in cooperation with Aerosol company and the Municipality of Celje, in the spring period of 2017 and in the winter period of 2018. The static measurements were carried out at various measuring points in Celje, which is known to be one of the most polluted Slovenian cities with the highest levels of PM particles. When analyzing measured values, results were compared to measured quantities of precipitation and wind speed, which were obtained from Slovenian Environmental Agency (ARSO). This was crucial because different environmental factors like precipitation and wind importantly affect fluctuation of BC's concentrations. One of BC's characteristics is seasonal fluctuation where concentrations of particles are higher in colder part of the year and lower in spring and summer time. Distance from the pollution source is also an important factor in BC's concentrations changes. With knowledge on BC's features and characteristics of seasonal fluctuation, we can significantly manage traffic flows and thus avoid the occurrence of excessive pollution in the city.

## INTRODUCTION

Black carbon, better known as soot, is a product of the incomplete combustion of carbon fuels or diesel fuels (Liu et al., 2018). It represents one of the most problematic pollutants, mainly due to its ability to absorb sunlight effectively, which consequently strongly influences climate change and alterations in the atmosphere. In addition, it has a long-term impact on human health (Rajesh and Ramachandran, 2018). Black carbon is produced both naturally and as a result of human activities in the incomplete combustion of fossil fuels, biofuels, and biomass. The main sources of pollution include transport, industry, burning of biomass and secondary sources (Pey et al., 2010).

The distribution of black carbon depends on several factors of natural or anthropogenic origin, such as its concentrations at source or distance from the source (Xing and Brimblecombe, 2017). Increased concentrations are mainly seen in winter, while in the warmer part of the year concentrations are usually lower (Virkkula et al., 2007). Seasonal fluctuations in concentrations are largely due to the burning of biomass, especially in the cooler part of the year, when, due to lower outside temperatures, the consumption of coal or wood is needed to heat the domiciles (Zhang et al., 2017).

Among the most important contaminants of anthropogenic origin is traffic. Black carbon emissions from vehicles, specifically diesel engines, account for up to 43% of all $PM_{2.5}$ particles.

When discussing carbon black emissions in transport, various factors must be considered, since the amount of fumes containing black carbon is not the same throughout the day, week, or year (Singh et al., 2018). On the movement of black carbon concentrations, urban traffic is mostly influenced by traffic density, which is the highest during peak hours. Traffic rush hours are usually made up of two parts: morning and afternoon peaks (Liu et al., 2017). The effect of the weekend in the alteration of black carbon concentrations in urban areas is also evident, which is reflected in reduced concentrations due to lower traffic density at weekends. In addition to the traffic density, the distance from the source of pollution (the main roads in the cities) and the presence or absence of canyons on the road (Nazzer Hussain et al., 2017) should also be considered. Various obstacles such as buildings, sound barriers and trees along traffic routes have significant influence on the spreading of concentrations (Hagler et al., 2012).

The wind also has a significant impact on black carbon concentrations, especially with its speed and direction. It has been proved that black carbon concentrations that occur near the ground level lower with increasing wind speeds (Baldwin et al., 2015). Also all types of precipitation have a noticeable effect on black carbon concentrations. The relationship between water and concentrations is determined by the hydrophobic character of freshly released particles and the intensity of precipitation (Kucbel et al., 2017).
In the Municipality of Celje (MOC), the main sources of pollution are industry, technological processes, industrial boilers, road transport, boilers for heating buildings and preparing the sanitary water. MOC's Environmental Report states that a more detailed analysis of sources from 2011 was carried out due to the exceeded number of permitted daily values of PM10 particles in the air in the MOC area. The analysis of the sources showed that as much as 31% of the emissions of dust particles are contributed by transport and industry. It also stated that the burning of biomass contributes up to 24% of the particles, 17% of which are of secondary origin, brought from elsewhere by local air masses. The road dust contributes approximatelly 9% of particles, and 19% of particulate sources are undefined (Report on the state of the environment in the Municipality of Celje, 2014).

## *Methodology*

Measurements of black carbon concentrations were carried out in several sections, them being the time of the spring period of 2017 and the winter period of 2017/2018. The first spring measurements took place between March 14$^{th}$ and April 14$^{th}$, 2017, and others between April 20$^{th}$ and 29$^{th}$, 2017. Winter measurements began in December 2017 and continued between 1$^{st}$ and 25$^{th}$ January 2018. Although the measurement period was not excessive, it was nevertheless sufficient to determine the basic patterns of black carbon distribution.

The measurements were made with several devices called the aethalometer. More specifically, Aethalometer® Model AE-33 (Magee Scientific, Aerosol d.o.o.) was used. The device works in such a way that the air is drawn through the filter, on which particles accumulate. The aethalometer then beams through the filter with a light source of different wavelengths and calculates the carbon black concentration (Tavčar, 2013) on the basis of the transmittance of the sample for light and changes in the intensity of light between the two measurements. Although the intervals of data capturing on the aethalometer were set to 1 minute, 30 second average of the measurements was taken into account when interpreting and comparing the results, as precipitation and wind data for comparison were provided to us in this form.

Data on the number of vehicles were obtained by the Directorate of the Republic of Slovenia for Infrastructure on behalf of the MOC. They were adapted on the basis of data obtained from individual hand counts of traffic and from automatic traffic counters across Slovenia. Manual traffic counting took place on an average working day between 5.30 and 21.30 nad it was executed in 15 minutes intervals. On the basis of data from the Statistical Office of the Republic of Slovenia, at the end of 2016, 54% of registered passenger cars had petrol engines and 46% had diesel engines (registered road motor vehicles and trailers, Slovenia, 2016).

Since the traffic flow consists of different types of vehicles, we have defined normalized number of vehicles (NNV) for easier comparisons. We defined the normalized number of vehicles by equating one bus or truck with four personal vehicles and calculated according to the formula NNV = (number of buses or truck numbers) × 4. This figure is due to the fact that fuel consumption and, consequently, emissions of buses and lorries are on average four times higher than for passenger cars, if they accelerate or drive at a steady rate (Jereb, Krumperščak & Bratina, 2018).

As already mentioned, measurements were made in the area of the Municipality of Celje and there were five static measuring points (A, B, C, D, and E). Aethalometers were installed at these points nad were continuously measuring black carbon concentrations. In addition to the mentioned static measuring points, data for the survey were also obtained from two measuring stations (measuring points F and G), which are included in the national measuring network. The measuring station Celje Hospital (measuring point F) provided the results on the degree of contamination in the urban background, while for the needs of this survey, data on the speed of wind and amount of precipitation were taken from the AMP Gaji measuring station (measuring point G). Otherwise, both measuring stations provide measurements and data on the overall level of air pollution and weather conditions in the MOC. The location of the measuring points on the map of Slovenia and in the MOC is shown in Figure 1.

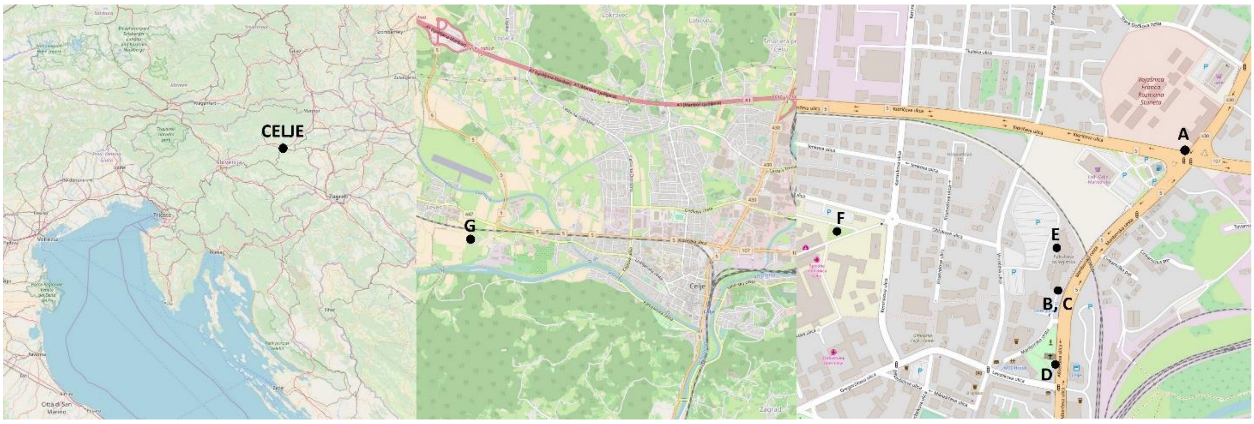


**Figure 1**: Measuring points on the map of Slovenia and MOC

- Measuring point A – the intersection of Mariborska Road and Kidričeva Street, which is also the biggest intersection in the MOC. Eight driving lanes converges here. The traffic at this intersection is very dense as 20,657 diesel vehicles passes through on the average working day. The Aethalometer was attached to a street lamp at a height of 3 m and the measurements took place in the spring and winter;
- measuring point B – ground floor of the building with approximate dimensions 20 x 110 m, where the aethalometer was attached at a height of 3 m. The measuring point was 20 m distant from the Mariborska Road, which ascends from the underpass. Because of it, a canyon is created here. Measurements at this site took place in the spring and winter, but the results of winter measurements were not authentic due to certain technical problems with the measuring device;
- measuring point C – 4th floor of the same building, where the aethalometer was installed exactly 18 m above the measuring point B. This layout was selected to observe changes in black carbon concentrations with increasing of the heights;
- measuring point D – a measuring point just along the Mariborska Road, where the aethalometer was attached to a road lamp 2 m away from the driving lanes and at a height of 3 m. Measurements at this site took place in the spring-time period only;
- measuring point E – ground floor on the other side of the aforementioned building with dimensions of 20 x 110 m, where the aethalometer was fixed at a height of 3 m. This layout was chosen because the building represents an anthropogenic obstacle, and one of the objectives of the study was to determine the impact of physical barriers on the distribution of black carbon. This point, however, is not located opposite the main road, but it overlooks a public parking lot for the building and an 80 m distant side road with low traffic density. At this point, measurements were made only in the springtime as well;

- measuring point F – measuring station Celje Hospital, which provides data on the degree of pollution in the urban background within the state measuring network. About 12,000 motor vehicles passes this measuring station on an average working day;
- Measuring point G – measuring station AMP Gaji, from which data on the wind speed and precipitation were obtained for the needs of the research.

## *Results and discusion*

### *Traffic*

Mariborska Road represents the main road in Celje. On an average working day 20,657 diesel vehicles passes measuring point A, of which 16,175 are diesel passenger cars, 233 buses, and 4,249 freight vehicles. On an average working day 12,920 diesel vehicles are passing the measuring point B, 10,011 of which represent diesel passenger cars, 204 buses, and 2,705 freight vehicles. The morning rush hour is most evident between 6 am and 8 am, when the number of cars increases most, as people migrate to work. Mariborska Road also represents the main bus line so in the morning the number of buses increases, especially during the school year. The afternoon peak is most distinct between 1 pm and 3.30 pm, when the number of cars increases most, as people leave their jobs. In the urban background, where measurements were made at the measuring point F, the traffic flow is considerably lower than at the measuring point A or B. On the average working day, there is a total of 5,655 diesel vehicles passing measuring point F, of which 5,286 are passenger cars, 93 buses, and 276 freight vehicles.

The morning rush hour is divided into two parts, between 6 am and 7 am and 7:30 am and 8:15 am. From 6 am to 7 pm, the number of cars increases the most, as this period represents the first wave of daily migrations. The period between 7.30 am and 8.15 am represents the second wave of people's daily migrations. During the school year, the number of buses increases as well in this time of the morning. Afternoon rush hour is also divided into two periods, between 10:30 am and 1 pm and between 1:45 pm and 3:15 pm. In both periods of the afternoon peak, the number of passenger cars increases considerably. The number of buses is also increasing, primarily during school hours, and there is also an increase in the number of trucks in both afternoon peaks. The reason can be assigned to delivery. The total number of vehicles on the average working day by individual measuring points is shown in Figure 2.

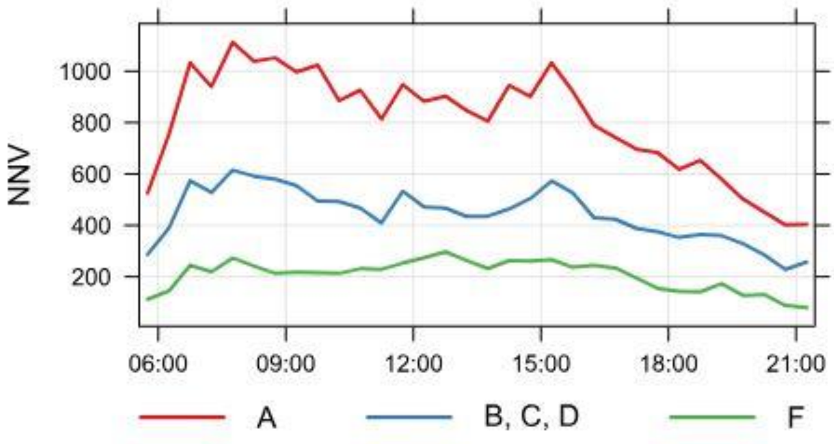


**Figure 2**: Normalized number of vehicles (NNV) on average working day by individual measuring points

### *Black carbon concentrations*

Black carbon concentrations have a characteristic seasonal movement with higher concentrations in the cooler part of the year and lower concentrations in the warmer part of the year. The seasonally higher concentrations in the colder part of the year are mainly affected by the level of black carbon emissions from burning of biomass, lower wind speeds and the occurrence of a temperature inversion which is typical for the Celje basin.

Black carbon concentrations at all measuring points are increased each day during the morning and afternoon peaks as a result of traffic. An important factor is also the day of the week, as the amount of traffic between weekends is lower than during working days. In the colder part of the year, the concentrations of black carbon coming from biomass burning increase mainly in the evening. The lowest concentrations of black carbon as a result of burning biomass were observed between 12 am and 5 pm. The velocity of the wind has a significant influence on the movement of concentrations. This was evident during periods of cloudlessness when the wind velocity was as high as 1 m/s, since the concentrations were then increasing, but began dropping during longer wind periods when the wind speed exceeded 2 or 3 m/s. In the windy periods, the carbon black concentrations were consequently lower during the morning and afternoon rush hours as well. The correlation between black carbon concentrations and the wind speed at measuring point A is shown in Figure 3.

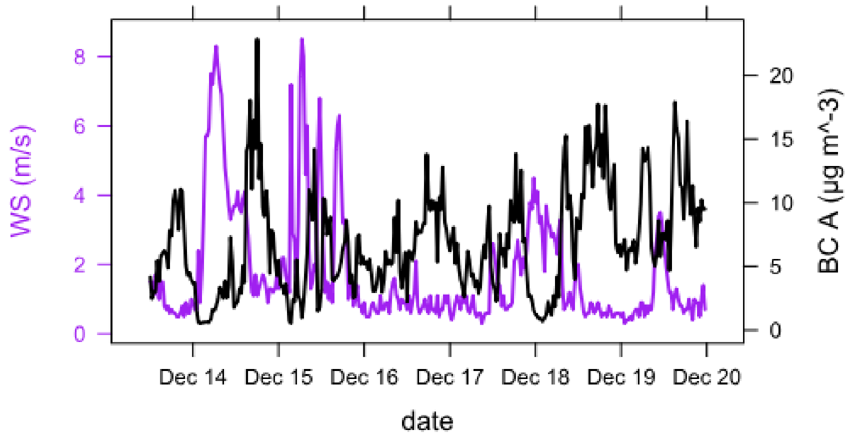


**Figure 3**: Correlation between black carbon (BC) and wind speed (WS) at measuring point A

Due to traffic load, black carbon concentrations, both in the cooler and warmer part of the year, are the highest at the measuring point A, located just at a traffic light, where vehicles stand and accelerate (7.48 ± 6.48 µg/m$^3$ during winter and 7.25 ± 6.06 µg/m$^3$ during spring). Correlation between the amount of traffic and black carbon concentrations at the measuring point A in the winter and spring periods is shown in Figure 4.

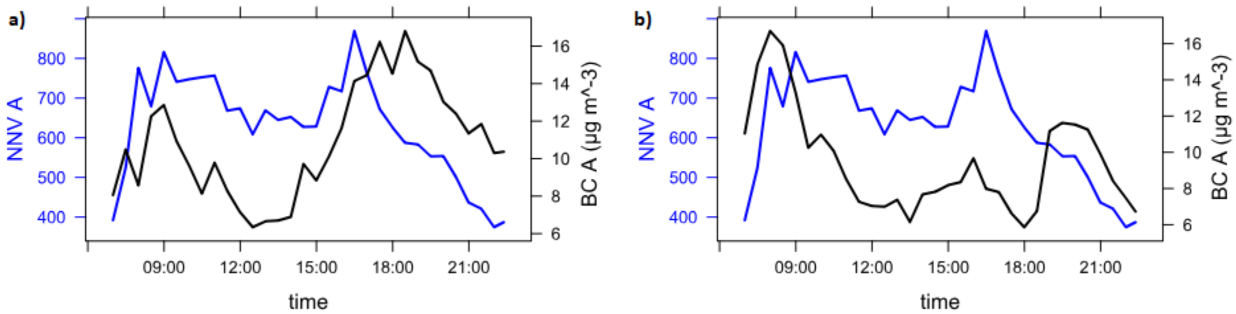


**Figure 4:** Correlation between the amount of traffic (NNV) and carbon black concentrations (BC) at the measuring point A in a) the winter period of measurements; and b) the spring period of measurements

In comparison with winter measurements, the concentrations decreased by 3% during the spring. In the urban background at the measuring point F, concentrations during the winter period averaged 5.86 ± 5.67 µg/m$^3$ in December and 3.31 ± 3.25 µg/m$^3$ in January, which is almost 50% lower in comparison to measuring point A. The reason for such a deviation between December and January are lower levels of carbon black emissions coming from the burning of biomass since January average temperature of the atmosphere was 2.2°C higher than in December. It is also necessary to take into account the difference in average wind speed in December, which was 1.91 ± 1.86 m/s, while in January it was 2.04 ± 1.70 m/s. A somewhat lower concentration was at the measuring point B located 2 m above the ground level and 20 m away from the Mariborska Road, which is lifting from the underpass at this point (6.20 ± 5.07 μg/m$^3$ in winter and 2,68 ± 2,65 μg/m$^3$ during the spring period). Compared to winter measurements, concentrations in the springtime decreased by more than 50% at this measuring point. In the spring period, measurements were also made at the measuring point C located on the fourth floor of the building, 18 m above the measuring point B. Concentrations were slightly higher here, namely, 2.75 ± 2.29 μg/m$^3$. Given the altitude difference of almost 20 m between the measuring points, the predictions dictated lower concentrations at the measuring point B. The average wind speed over a given period was 1.61 ± 1.27 m/s. On the basis of the results, it can be assumed that at a higher altitude, black carbon lasts longer than near the ground level. During the spring period, measurements were carried out on the other side of the building, at the measuring point E, where the public car park of the municipality of Celje is located. Black carbon concentrations averaged 1.67 ± 1.43 μg/m$^3$. At this measuring point, morning and afternoon tips do not have much influence on black carbon concentrations, and increased values in individual time periods can be attributed to the delivery and movement of vehicles in the parking lot. On the measuring point D, which was located 135 m from the measuring point B and 3 m from Mariborska Road, on average the black carbon concentrations in the spring period valued 2.50 ± 3.94 μg/m$^3$. Compared to the measuring point B, the concentrations are very similar, although the measuring point D stands at a traffic light, where vehicles stand and accelerate, and the number of vehicles passing both measuring points is the same. It should also be noted that at the measuring point D the area is more open than at the measuring point B, and the wind can also have a greater influence on black carbon concentrations even at lower speeds. The average values of black carbon concentrations, wind velocities and temperatures for measurement periods by individual measuring points are shown in Table 1.

**Table 1**. Average values of carbon black concentrations (BC), wind speed (WS) and temperatures for measurement periods by individual measuring points

| Measuring point | Winter measurements (December 2017–January 2018) | | | Spring measurements (March–May 2017) | | |
|---|---|---|---|---|---|---|
| | BC (µg/m$^3$) | WS (m/s) | T (°C) | BC (µg/m$^3$) | WS (m/s) | T (°C) |
| A | 7,48 ± 6,48 | 2,01 ± 1,84 | 2,91 ± 4,93 | 7,25 ± 6,06 | 1,91 ± 1,43 | 11,70 ± 6,47 |
| B | 6,20 ± 5,07 | | | 2,68 ± 2,65 | | |
| C | | | | 2,75 ± 2,29 | | |
| D | | | | 2,50 ± 3,94 | | |
| E | | | | 1,67 ± 1,43 | | |
| F | 3,31 ± 3,25 | | | | | |

## CONCLUSION

Static measurements of black carbon concentrations have shown that particle distribution depends on several factors. The study found that among the most frequent and most important factors are the annual time, the distance from the source of pollution, the anthropological influences (such as the heating of homes), the physical obstacles and wind speed.

A comparison of the results of black carbon concentrations at various sites in the MOC has shown that carbon black particles are increasing significantly in places where traffic is very dense. An example of such site in Celje is the intersection of Mariborska Road and Kidričeva Street, which is the busiest intersection of MOC. Concentrations have dropped significantly with distance from the main roads and black carbon concentrations almost halved in the urban background at the measuring point F. Measuring points B, C and D received the same amount of emissions from the traffic, so concentrations at these three measuring sites almost did not differ. In linkage to traffic, it does have a high impact. Especially in the rush hours thorughout the week, black carbon concentrations are on the rise, while they decrease on weekends. On graphs that simultaneously indicate NNV and black carbon concentrations, the trend of increasing particulate concentrations along the increase in traffic flow is clearly evident. Comparison of the anthropological effects on the distribution of black carbon and its

concentration has also shown a noticeable effect of physical barriers on the distribution of black carbon particles since the concentrations in front of a barrier (a building with dimensions of 20 x 110 m) were much higher than behind the obstacle.
The effects of natural phenomena on changes in black carbon concentrations were also found. A comparison of the number of particles in the warmer and colder part of the year is, in some ways, related to anthropological influences, as in winter, the concentration of black carbon increases greatly due to lower temperatures. In colder parts of the year people are forced into the heating of homes and other buildings, so the heating season is the main culprit for increased concentrations of black particles. Black carbon particles are part of the air masses, which are also influenced by the wind, as it allows mixing of air. This reduces the concentrations of black carbon particles. The results of the study show that the presence of the wind itself is not enough, but its velocity is also necessary to reduce concentration of black particles. Black carbon began to decline only when the wind reached a speed of at least 3 m/s, otherwise the black carbon concentrations were rising in the same way as when the wind was not present.

The results of this study demonstrate that control of airborne pollutants, such as black carbon, is not sufficient when focusing only on one influential factor. If we want to achieve improvement, all aspects of pollution need to be addressed and account must be taken on both - anthropogenic and natural influences. Still, we need to understand that we must only devote ourselves to those factors that can be controlled. The amount of black carbon generated as a result of traffic in the MOC could be significantly reduced by reorganizing traffic flows. Thus, the main road Mariborska Road would be palliated by constructing a bypass roads at the Celje West and Celje East motorway connections. Also, it would be necessary to build an out-of-level road on the Celje Center motorway that would take place above the Maribor road and connect it to the measuring point A or even at the very beginning of Mariborska Road, which would relieve the city center of Celje. A very good option for relieving the Mariborska Road is also the third development axis, which would primarily divert freight traffic and run outside the central part of Celje.

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