The influence of the inverse character of the weather on concentrations of black carbon

M Kucbel¹,², B Svedova²,³, H Racalvská²,⁴, K Racalvský², J Ruzickova² and D Juchelkova³

¹Institute of Environmental Engineering, Faculty of Mining and Geology, VSB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic
²ENET Centre-Energy Units for Utilization of Non-traditional Energy Sources, VSB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic
³Department of Power Engineering, Faculty of Mechanical Engineering, VSB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic
⁴Institute of Geological Engineering, Faculty of Mining and Geology, VSB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic

Abstract. Black carbon (BC) is a product of incomplete combustion of fossil fuels, biomass and other fuels. The study is focused on the influence of an inverse character of the weather on the BC concentrations in the city of Ostrava during the period 2012–2016. The continuous measurement of daily concentrations of BC were performed by the portable Aethalometer, and PM₁₀ by the DustTrak aerosol monitor. The average concentrations of BC and PM₁₀ during the days with an inversion character of the weather, compared with the days without inversion, were increased up to 3.8 times and 3 times, respectively.

1. Introduction

Black carbon (BC) particles are an integral part of dust particles (PM) [1]. The BC concentration in Central Europe averages 5% in PM₂.₅ for rural areas, 14% in PM₂.₅ in urban areas, and 21% in PM₂.₅ near roads [2]. Black carbon is generated by the incomplete combustion of fossil fuels, biomass, and other carbonaceous fuels [3]. BC adversely affects the environment, human health, and influences the climate [4]. PM and BC air pollution in urban environment varies, depending on the distance of industrial sources, traffic density, and other factors (population density, housing development, etc.). Meteorological factors also have a significant influence [5].

The highest PM₁₀ concentrations occur during winter months due to frequent inversion situations [6]. Temperature inversion is a natural phenomenon of a change in the normal tendency of air temperature to fall at higher altitude, as compared to normal in the troposphere with the temperature increasing with altitude [7]. During thermal inversions, atmospheric convection occurs; dispersion of pollutants is limited, local emission sources increase the concentration of pollutants [8]. Inversion represents a stable equilibrium of the atmosphere that prevents vertical movements in the atmospheric boundary layer [9]. In urban environment inversion there is a significant increase in BC concentrations over a few hours up to maximum levels. Explaining the causes of BC peak contrast occurrence can lead to better characterization of air pollution gradients, source identification, and assessment of meteorological impact on urban BC concentrations [8].
Measurement of the BC concentration took place in the Ostrava-Zábřeh urban district (Moravian-Silesian Region, Czech Republic). The influence of geomorphology of the area in combination with metallurgical production and numerous temperature inversions during the autumn and winter months leads to a high load of pollutants in Ostrava during the autumn and winter periods [10].

In Ostrava-Zábřeh, the permissible number of days exceeding the limit value for PM$_{10}$ concentration is exceeded annually (daily value of 50 μg/m$^3$ may be exceeded 35 times per year according to the Act on Air Protection 201/2012 Coll. [11] the average annual air pollution PM$_{10}$ limit is 40 μg/m$^3$). At the locality of Ostrava-Zábřeh, the daily PM$_{10}$ air pollution limit value was exceeded in 2012 in 66 cases, 107 cases (2013), 92 cases (2014), 54 cases (2015), and in 2016, this air pollution limit value was exceeded in 48 cases [12]. In 2012, in the Ostrava-Karviná agglomeration, a smog situation was announced 7 times for a total duration of 985 hours, in 2013, a smog situation was announced 5 times (425 hours), in 2014, 5 times (240 hours), in 2015, in total 3 times (124 hours), and in 2016, twice (297 hours) [12].

The aim of the work is to determine the influence of the inverse character of the weather on the concentration of black carbon and PM$_{10}$ in Ostrava-Zábřeh in 2012-2016.

2. Methods and samples
Ostrava-Zábřeh represents an urbanized part of the town, with typical panel buildings and houses on the outskirts. Measurement took place at Průkopnická Street, see figure 1. North of the measuring point, there is a major traffic artery - road no. 11 (Rudná) connecting the city of Ostrava with surrounding villages, and the D1 motorway in the western direction. In the east, Arcelor Mittal Steel metallurgical complex is located 7 km away, and Vítkovice Steel is located in the north-east. Black carbon concentrations were measured daily between 8-9 p.m. in the period from 9th January 2012 to 31st December 2016 (in total 1761 measurements) by optical method using the Magee Scientific Company AE-42 Aethalometer with a flow rate of 2 l/min. The concentration of BC was calculated from the optical attenuation measured at seven wavelengths caused by BC particles deposited at a filter tape, during 5-minute intervals. The concentrations of dust particles (PM$_{10}$) were determined by optical method, using the DustTrak™ aerosol monitor model 8535 (TSI).

![Czech Republic](image1.jpg)

**Figure 1.** Situation of the Ostrava-Zábřeh sampling point.

3. Results
According to the Decree of the Ministry of Industry and Trade No. 194/2007 Coll. [13], the measurement period 2012-2016 was divided into heating season (September-May) and non-heating season (June-August). According to the Decree, the heating season begins on 1st September and ends on 31st May. The average BC concentration for the whole reporting period from 2012 to 2016 was 3.16 ± 3.79 μg/m$^3$, and PM$_{10}$ concentration was 45.8 ± 36.5 μg/m$^3$. The PM$_{10}$ concentration exceeded the average annual PM$_{10}$ limit value (40 μg/m$^3$) permitted by legislation.
The observed BC concentration is common for the urbanized environment with industrial activity, and it is comparable, for example, to Poland. In Zabrze (Poland), the average BC concentration of 4.4 µg/m³ was found in 2009-2011 [14].

The average BC concentration for the heating season (2012-2016) was 3.87 ± 4.14 µg/m³ and the average PM$_{10}$ concentration was 51.9 ± 39.9 µg/m³. During the heating season, BC showed a normal distribution. 78% of all measured BC concentrations were less than 5 µg/m³ and only 8% of BC concentrations were higher than 10 µg/m³. BC in the non-heating season showed a different distribution, 99.8% of the measured BC concentrations were in the range of less than 5 µg/m³, of which 57% of the BC concentration values were less than 1 µg/m³ and only 0.2% occurred in the range of 5-10 µg/m³). The average BC and PM$_{10}$ concentrations for the non-heating season (2012-2016) reached the values of 1.05 ± 0.61 µg/m³ and 27.8 ± 11.5 µg/m³, respectively.

Black carbon concentrations were found in 2011: in Racibórz (Poland), the value was 4.56 µg/m³ during the heating season, and 0.99 µg/m³ during the non-heating season [15].

![Figure 2. Variability of BC concentrations for the heating and non-heating season of the individual years.](image)

![Figure 3. Average concentrations of PM$_{10}$ including the standard deviation, for the heating and non-heating season.](image)

The BC concentrations for the heating and non-heating season are shown in figure 2 and the average PM$_{10}$ concentrations in figure 3. The ratio values of BC and PM$_{10}$ concentrations (2012-2016) in the heating season and in the non-heating season were 3.69 and 1.87, which is due to the more frequent occurrence of impaired scattering conditions and increased combustion of fossil fuels and biomass in local furnaces. The ratios for the BC concentrations during heating and non-heating seasons ranged from 3.18 to 4.16, and the largest difference for the BC concentrations was recorded in 2014 (3.43 µg/m³). The regression analysis between BC and PM$_{10}$ showed a significant correlation dependence $r_s = 0.83$ during the heating season (2012-2016), in the non-heating season, it showed a mean dependence with $r_s = 0.48$. The contribution of combustion during the heating season from large energy, industrial, and transport sources, as well as from local heating plays a significant role in the BC and PM$_{10}$ concentrations, and the origin of the particles is the same.

During the warm season of the year, dust particles of PM$_{10}$ grain size are largely made up of biogenic organic particles, resuspended particles, etc. The origin of PM$_{10}$ and BC particles is therefore not entirely identical during the summer months, but the particles come from many different sources. The average percentage contributions of BC in PM$_{10}$ for the period of 2012-2016 were 6.7 ± 3.1% in the heating season and 4.1 ± 2.7% in the non-heating season. The heating season of 2012-2016 was then divided into days with inversion (PM$_{10}$ > 50 µg/m³) and days without inversion (PM$_{10}$ < 50 µg/m³). It turned out that in 35% of cases, days with inverse character of the weather were recorded in the heating season (450 days with inversion character of the weather out of the total of 1302 days within the heating season). The distribution of the BC and PM$_{10}$ concentrations for days...
with inversion and without inversion for the whole period of 2012-2016 is shown in figure 4; table 1 shows BC and PM$_{10}$ concentrations for the individual years.

**Table 1.** Average BC and PM$_{10}$ concentrations and standard deviation (S.D.) for the inverse character of the weather and no inversion in the heating season from 2012 to 2016.

| Years | Days with inverse character of the weather | | | Days without inverse character of the weather | | |
|-------|------------------------------------------|---|---|------------------------------------------|---|
|       | BC [μg/m$^3$] | S. D. | PM$_{10}$ [μg/m$^3$] | S. D. | BC [μg/m$^3$] | PM$_{10}$ [μg/m$^3$] | S. D. |
| 2012  | 8.39 ± 5.11 | 100.3 ± 46.1 | 2.05 ± 1.21 | 28.0 ± 10.9 |
| 2013  | 8.00 ± 4.92 | 104.1 ± 47.6 | 2.04 ± 1.14 | 31.8 ± 10.1 |
| 2014  | 7.95 ± 5.75 | 88.7 ± 44.5 | 2.07 ± 1.33 | 31.5 ± 10.3 |
| 2015  | 5.70 ± 3.03 | 80.6 ± 32.6 | 1.70 ± 0.99 | 30.3 ± 9.5 |
| 2016  | 6.27 ± 5.01 | 83.6 ± 45.0 | 1.84 ± 1.33 | 32.0 ± 9.6 |

The inverse character of the weather in the heating season 2012-2016 was recorded in 35% of cases. The average PM$_{10}$ concentration in the heating season of 2012-2016 for days with the inverse weather was up to 3 times higher (92.0 ± 44.6 μg/m$^3$) than for days without inversion (30.7 ± 10.17 μg/m$^3$). The ratio the average BC concentrations for days with inversion (7.36 ± 5.02 μg/m$^3$) and without inversion (1.94 ± 1.22 μg/m$^3$) was even more significant (3.8).

In Athens from December 2013 to February 2014, the BC concentrations for inversion days (4 μg/m$^3$) were found to be almost three times higher (2.7 times) than for non-inversion days (1.5 μg/m$^3$) [16].

The average percentage of BC in PM$_{10}$ was slightly higher (7.8 ± 3%) for days with inverse weather patterns (range 1.4 - 19.2%) than for days without inversion (6.2 ± 3.1%) ranging from 1.2% to 29.9%. During the inverse character of the weather, a significant correlation relationship between BC and PM$_{10}$ has been demonstrated with a Spearman correlation coefficient ($r_s$) of 0.77* and for days without inversion ($r_s = 0.70$*), which refers to the common origin of BC and PM$_{10}$ emissions from combustion sources.

**Figure 4.** Distribution of PM$_{10}$ and BC concentrations for the inverse weather and non-inverse days in the 2012-2016 heating season.

**Figure 5.** The course of 5 min BC concentrations during the period from 21 to 25 November 2016.

The study Klejnowski and Błaszczyk, 2012 [14] in Zabrze (Poland) has shown that the daily pattern of BC levels is bimodal, with two peaks at equal level in the non-heating season, while in the heating season, the evening mode outreaches the morning peak approximately by about 2 μg/m$^3$.

In the period from 21st to 25th November 2016, a continuous day-long measurement was carried out showing the beginning of the inverse character of the weather (from 22 November), see figure 5. The average BC concentration in the period from 21st to 25th November 2016 was 2.73 ± 2.20 μg/m$^3$ with the minimum BC concentration of 0.261 μg/m$^3$ up to the highest BC concentration of 11.40 μg/m$^3$. On 21st November, BC concentrations were more than twice lower compared
to the other days of inversion. In figure 5, two very distinct peaks may be observed during the morning hours (approximately from 4:00 a.m. to 10:00 a.m.) and during afternoon to evening hours (approximately 4:00 p.m. to 10:00 p.m.) and the total increase in BC concentrations throughout the day. Increased concentrations of BC are caused by morning and afternoon traffic peaks and the need for heating in local furnaces due to the drop in outdoor temperature and impaired scattering conditions.

The morning increase in BC concentrations is caused by emissions from road transport. The main source of high BC concentration in the evening hours observed in Warsaw and Racibórz are emissions from local heating [15]. During evening hours, the BC concentration increases faster in an inverse situation than in another part of the day, which is related to lower wind speeds [6].

4. Conclusions

The heating season of 2012-2016 in Ostrava-Zábřeh is characterized by an average 3.7 times higher contribution of the BC concentrations than in the non-heating season. The average PM$_{10}$ concentrations are also up to three times higher in the heating season compared to the non-heating season. It turned out that in 35% of cases, days with inverse character of the weather were recorded in the heating season. During the inverse character of the weather, BC concentrations were almost 4 times higher than during days without inversion. The inverse character of the weather was found mainly in the autumn and winter months. Combustion sources, in particular, local furnaces, contribute significantly to the BC emissions; their effect is particularly evident at the time of inversion during the evening hours.

Acknowledgement

This study was supported by the research projects of the Ministry of Education, Youth and Sport of the Czech Republic: The National Programme of Sustainability LO1404 – TUCENET, and SGS 2017/35 Research in Selected Areas of “Smart Energy” of 21st Century, and SP2017/116 “Research of Various Types of Material, their Properties and Application Potential”.

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