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Monitoring of aerosol (PM_{10} and Black Smoke) in a small rural settlement – the effect of local heating on air quality

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Abstract: Concentrations of particulate matter passing through a size-selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter (PM_{10}) were measured during one winter and two summer periods in a small mountain village, Albrechtice in the Jizerské hory Mts, Czech Republic. PM_{10} was measured by a photometer DustTrak (DT, 15-minute integrates) and by a Harvard Impactor (HI, 24-h integrates). Twenty four hour concentrations of the soot content were estimated by means of the OECD "Black Smoke" (BS) method. Comparison of 24-h PM_{10} data from Albrechtice with PM_{10} data from two nearby cities – Jablonec nad Nisou and Liberec – and one background site – Souš – showed that the average PM_{10} concentrations in Albrechtice were the highest during the heating season (37 μg m^{-3}). Average PM_{10} concentrations in the village were lower than the average concentrations in urban areas during both summer seasons. PM_{10} (measured by HI) and 24-h concentrations of BS strongly correlated during the heating season (0.89). The correlation coefficient dropped to 0.68 during the second summer period. Daily maximum concentrations were recorded mainly between 4 and 12 p.m. with a distinct peak between 8 and 10 p.m. showing a clear effect of evening lighting up stoves and household boilers. PM_{10} negatively correlated with temperature and wind velocity. The highest PM_{10} and BS concentrations were recorded when temperature was lower than 5 °C and wind velocity lower than 3 m s^{-1}, indicating that local sources and not long-range transport of pollutants were the most important factors for PM_{10} values in the village. The results of the study support the assumption that traditional local heating in small settlements including rural villages may cause an important local air quality problem.

Keywords: Black Smoke, DustTrak, Harvard Impactor, PM_{10}, rural air quality, solid fuel

INTRODUCTION

Aerosol particles are considered to be one of the major pollutants of the atmosphere. Data from epidemiological studies demonstrate associations between ambient particulate matter concentrations and increased morbidity and mortality (Pope et al 1991; Pope et al 1995; Schwarz et al 1993). The available data mostly characterize rural locations as cleaner than urban or industrial areas. Whereas the most important sources of aerosol particles are industrial activities and traffic, it is generally assumed that the concentration of particles in urban and industrial areas is higher than in rural areas (Monn et al 1995; Hoek et al 1997; Zee et al 1998; Cheng et al 2000). Measuring stations are thus preferably situated in urban and industrial areas with high population densities, or in relatively clean areas with no direct impacts of pollution sources to obtain background values.

The situation in these populated areas has improved due to conversion of heating from coal to gas, but heating in most small towns and villages in the Czech Republic and in other Central and East European countries is still based on combustion of wood and low quality coal (Data from census 2001). Studies describing air quality in settlements are scarce. However, a substantial portion of the population lives in these areas (Demographic Yearbook of the Czech Republic 2009). In a previous study (Braniš and Domasová 2003), it was observed that particulate pollution in a village often reached higher values than in the Czech capital – Prague. However, the selected village was situated not far from larger cities in the central part of the Czech Republic, and thus the effect of regional transport of pollutants could not be ruled out.

The aim of this study was to characterize PM_{10} and BS in a small village in a mountainous area, where the effect of industrial and traffic sources is supposed to be negligible and local heating is assumed to represent the main air quality problem. We hypothesized that, under favourable conditions (low temperature and low wind velocity), when the local inhabitants heat their homes using solid fuels (coal, wood), the PM concentrations would be similar or even higher than in larger urban areas situated under the mountains.

SITE AND METHODS

A village named Albrechtice in the Jizerské hory Mts, Czech Republic (50°45′29.000″ N, 15°17′30.000″ E, 610 m a.s.l.) with approximately 300 inhabitants, with 160 permanently inhabited family houses and over 300 recreation houses, situated in a slightly inclined valley between Tanvaldský Špičák Mountain (831 m a.s.l.) and Mariánská hora Mountain (874 m a.s.l.), was selected. The site is considered a clean forested recreational resort. The site was selected to minimize the influence of transport of pollutants from industrial or urban areas. No local industry or enterprise is present in the village and the only one local road leads through the village. The only local source of air pollution particularly in the winter is supposed to be domestic heating, mostly based on brown coal and wood combustion.

The measurements were carried out during a 15-month-long measuring campaign (27 June 2005 – 21 September 2006) covering both winter (heating) and summer (non-heating) seasons. The seasons were divided according to the average monthly temperatures. The period when the average monthly temperature did not exceeded 6 °C (November 2005 to April 2006) was marked as the heating season. The non-heating period of 2005 includes June 2005 – October 2006 and the non-heating period of 2006 May 2006 to September 2006.

Mass concentrations of PM_{10} and black smoke (BS) were measured. The 15-minute integration time data for PM_{10} were collected by using a DustTrak (TSI) photometer. Since the DustTrak instrument does not provide exact gravimetric output, but systematically overestimates these concentrations, DT was used mainly to record relative changes of PM_{10} concentrations. The 24-hour concentrations of PM_{10} were obtained using a low flow (10 l min^{-1}) Harvard Impactor. The aerosol was collected on 37 mm Teflon (PTFE) membrane filters with 2 μm pore size. The concentration of particles was determined by gravimetry. In addition, BS variable was also measured to ascertain the contribution of combustion aerosol.

The BS measurements were performed according to an OECD method. White Whatman No. 1 filters were exposed for 24 h in a low-volume sampler (flow-rate 1.4 l min^{-1}) and assessed by means of reflectance (M43D smoke stain reflectometer). Climatic indicators such as wind velocity, temperature and relative humidity were also measured.

The aerosol concentrations in the village were compared with those from two nearby larger cities (Liberec and Jablonec nad Nisou) and with a nearby rural background measuring point (Souš) of the State Air Quality Monitoring System (AIM) operated under the Czech Hydrometeorological Institute. The Souš background measuring point (50°47′22.000″ N, 15°19′19.000″ E, 771 m a.s.l.) is situated 4 km from the small settlement. The measuring points in the two nearby cities are situated in residential areas (characterized as "urban background" locations). The sampling point in Liberec (50°45′54.000″ N, 15°3′23.000″ E, 350 m a.s.l.) is located 16 km and the point in Jablonec nad Nisou (50°43′38.000″ N, 15°9′50.000″ E, 500 m a.s.l) 10 km from the village.

To ascertain the heating characteristics, a questionnaire was distributed among local inhabitants containing questions on combustion habits, the amount of fuel consumed and the type of heating technology used in households.

Spearman correlation coefficients and the non-parametric Kruskal-Wallis test were used for numerical analysis.

RESULTS

Comparison of PM_{10} data from the small settlement of Albrechtice with PM_{10} data from two urban areas in Jablonec and Liberec and one background area at Souš showed, that during the whole campaign, the daily average concentrations of PM_{10} were in the range from 15 μg m^{-3} (Souš) to 30 μg m^{-3} (Jablonec). The third highest concentrations were measured in Albrechtice. Statistical analysis (Kruskal-Wallis test, $p < 0.05$) showed significant differences among all the locations except the two cities.

The average PM_{10} concentrations in the village were the highest of all during the heating season (37 μg m^{-3}) and the lowest concentrations were, as expected, observed in the rural background area – Souš (15 μg m^{-3}). The Kruskal-Wallis test showed that no statistical difference could be found between the two cities and the village site, while the background site concentrations were significantly ($p < 0.05$) lower than those in the other locations.

During both non-heating seasons, the highest concentrations of PM_{10} were measured in Jablonec, the second highest in Liberec, the third in Albrechtice and the lowest concentrations were recorded in Souš, as expected. Statistical analysis showed statistical differences (at $p < 0.05$) among all the locations except the two cities (Table 1).

During the whole period, the daily concentrations of PM_{10} from the above-mentioned locations were reasonably correlated. The lowest correlation was recorded between the village and the rural background area (0.45). The strongest association was found between the two cities (0.92). Concentrations of BS in Albrechtice were relatively strongly correlated with the PM_{10} concentrations in the two cities. However, the association between BS concentrations in Albrechtice and PM_{10} concentrations in the background area was rather low (0.34).

Tab. 1: 24-h concentrations of PM_{10} ($\mu g\ m^{-3}$) for all sites.
AV – arithmetic average; SD – standard deviation; W – whole period; H – heating period; S05 – summer 2005; S06 – summer 2006.

	Albrechtice	**Souš**	**Jablonec**	**Liberec**
	W/H/S05/S06	W/H/S05/S06	W/H/S05/S06	W/H/S05/S06
AV	26 / 37 / 23 / 18	15 / 15 / 14 / 15	30 / 33 / 29 / 26	28 / 33 / 28 / 24
SD	17 / 20 / 13 / 10	9 / 10 / 8 / 9	14 / 16 / 12 / 11	14 / 14 / 13 / 12
Median	22 / 32 / 19 / 17	13 / 14 / 13 / 13	27 / 31 / 27 / 25	26 / 32 / 24 / 23
Maximum	109 / 109 / 74 / 69	69 / 60 / 36 / 69	87 / 87 / 66 / 69	80 / 80 / 66 / 80
Minimum	2 / 3 / 2 / 4	1 / 1 / 1 / 2	5 / 5 / 6 / 10	5 / 5 / 5 / 8
N	432 / 166 / 127 / 139	487 / 181 / 125 / 181	469 / 171 / 127 / 171	459 / 166 / 127 / 166

During the heating period, closer relationships between the PM_{10} concentrations in Albrechtice and the compared cities Jablonec (0.68) and Liberec (0.62) than in Albrechtice and Souš (0.33) were found. Again, the strongest correlation was found between the two cities (0.93). In Albrechtice, the PM_{10} and BS concentrations were highly correlated during the heating season (0.89). The correlation between the BS (Albrechtice) and PM_{10} values was lower in the two large cities (Jablonec and Liberec) during the heating/winter season. Very low correlation was found between the BS concentrations in Albrechtice and PM_{10} concentrations in Souš. (For all the data, see Table 2.)

Tab. 2: Correlation coefficients among all the sites during the whole (first number) and the heating (second number) period 2005/2006.
All the correlation coefficients were found to be statistically significant ($p < 0.05$).

	Albrechtice (PM_{10})	**Albrechtice (BS)**	**Souš (PM_{10})**	**Jablonec (PM_{10})**
Albrechtice (BS)	0.87 / 0.89			
Souš (PM_{10})	0.45 / 0.33	0.34 / 0.15		
Jablonec (PM_{10})	0.67 / 0.68	0.58 / 0.65	0.60 / 0.44	
Liberec (PM_{10})	0.66 / 0.62	0.66 / 0.63	0.61 / 0.41	0.92 / 0.93

Tab. 3: Correlation coefficients ($p < 0.05$) for all the sites during the summer period of 2005 (first number) and the summer period of 2006 (second number).
(X – data are not available.)

	Albrechtice (PM_{10})	**Albrechtice (BS)**	**Souš (PM_{10})**	**Jablonec (PM_{10})**
Albrechtice (BS)	X / 0.68			
Souš (PM_{10})	0.73 / 0.53	X / 0.51		
Jablonec (PM_{10})	0.66 / 0.68	X / 0.59	0.71 / 0.66	
Liberec (PM_{10})	0.61 / 0.62	X / 0.64	0.72 / 0.69	0.92 / 0.92

During both non-heating periods, the daily concentrations of PM_{10} from the compared locations were relatively highly correlated and all the correlations were found to be statistically significant at $p < 0.05$. The strongest association was again found between the two cities. In the first summer period, a closer relationship between the PM_{10} concentrations in Albrechtice and Souš was found. In the second summer period, the situation was different and a closer relationship was found between the village and Jablonec. The correlation between the PM_{10} and BS concentrations in Albrechtice dropped to 0.68 during the second summer period (Table 3).

Comparison of the average daily PM_{10} concentrations with the meteorological characteristics revealed that wind velocity and temperature were very important factors. The highest concentrations of particles were observed at low temperatures and low wind velocities. With increasing temperature and wind velocity, the concentrations of particles decreased. At wind velocities above 3.5 m s^{-1}, the concentrations of PM_{10} did not exceed 30 µg m^{-3}, and at temperatures above 20 °C, the concentrations of PM_{10} exceeded 35 µg m^{-3} only once (Fig. 1).

The 15-minute concentrations of PM_{10} (averaged over the whole period of measurement) recorded in the village by the DustTrak instrument showed that daily maxima in the small settlement were observed mainly between 4 p.m. and 12 p.m., with a peak between 8 p.m. and 22 p.m. This peak was recorded in 61% of the days monitored. For comparison, in the background area, the daily maxima between 4 p.m. and 12 p.m. were recorded only in 31% of the days. A daily minimum in Albrechtice was observed mainly during the early morning hours (Fig. 2).

To characterize the emission of particles by the fuel type and the quantity used for household heating, a questionnaire was designed and distributed among the villagers. The results of the questionnaire showed that 62.6% of the households used both coal and wood, 19% mainly wood, 9.2% mainly coal and only 3% used electricity for heating. Of the coal used,

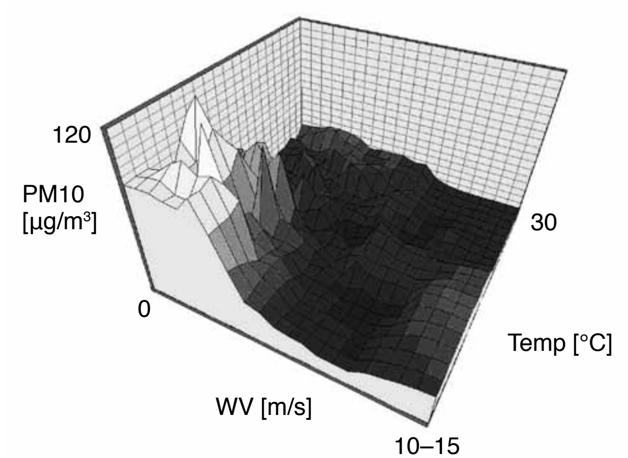

Fig. 1: The relationship between daily average concentration of PM_{10}, daily average temperature (Temp) and daily average wind velocity (WV) during the whole period in the village.

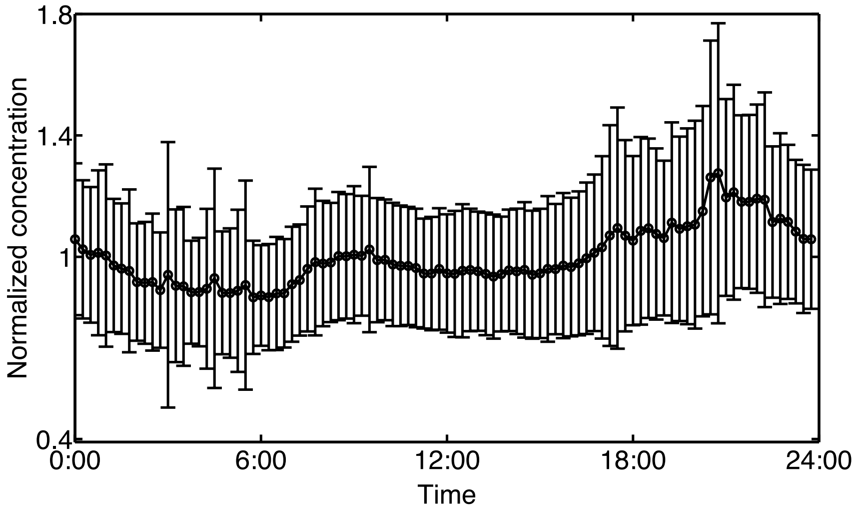

Fig. 2. Daily averages of 15 minute concentration during the whole period with standard deviations (normalized data).

about 75.4% was low-grade brown coal, while the rest was black coal of higher quality. Of the total number of households, 34.5% were connected to the natural gas network.

DISCUSSION

During the whole period, the average PM_{10} concentration in the village was 26 µg m^{-3}. During the 2005/2006 heating season, the average concentration was slightly higher and equalled to 37 µg m^{-3}. This corresponds with the values published by Braniš and Domasová (2003), who recorded during a two-year study performed in a small settlement in the central Bohemian Basin average PM_{10} concentrations of 38 µg m^{-3} and 41 µg m^{-3} in the first and the second heating periods, respectively.

Our results obtained during both non-heating periods (2005 and 2006) in Albrechtice also showed slightly lower PM_{10} concentrations than those from the central Bohemian Basin. The average daily concentrations in our case were 23 µg m^{-3} (2005) and 18 µg m^{-3} (2006), compared to the previous values (26 µg m^{-3}). The reason for the higher concentrations recorded in the central Bohemian village was most likely related to the geomorphology of the landscape. The central village was situated on the bottom of a river valley while the settlement in Albrechtice was spread over a hill saddle (at the top of a valley), where better dispersion of air pollutants can be expected.

Major changes in PM_{10} concentrations during the year at all the locations were observed in Albrechtice. During the heating season, the average daily concentration was almost double than in the non-heating season. A similar difference was observed in the settlement in the Central Bohemian Basin by Braniš and Domasová (2003). Seasonal variability was also recorded in three small settlements in Eastern and Southern Bohemia by Kotlík et al (2005). In contrast, Gomiščček et al (2004) did not find any seasonal air quality differences in a rural area in Austria. According to our results for the difference between the summer and winter PM_{10} concentrations in our locality (Albrechtice), the seasonal difference was between 40 and 50% for the first and the second non-heating periods, respectively. In both nearby cities, Jablonec and Liberec, the average winter PM_{10} concentrations were only about 20% higher (or less) than in the summer periods. In the rural background area Souš, the concentrations of PM_{10} during the heating and non-heating seasons were almost the same, which corresponds with the findings of Gomiščček et al (2004).

Our results do not correspond with the general assumption, that urban areas are more polluted by PM_{10} particles than rural areas. The same results were found by Braniš and Domasová (2003) and Kotlík et al (2005). In contrast, 13% differences in PM concentrations between urban and rural areas were observed by Zee et al (1998) in the Netherlands. During the PEACE study, Hoek et al (1997), who compared more than 10 Europe locations, found that the differences among these locations were even greater, reaching over 20%. Monn et al (1995), who measured the air quality in various locations in Switzerland, found that the PM concentrations observed at rural locations are about a third lower than those in urban areas. Cheng et al (2000) also found much lower concentrations in Canadian rural areas than in urban areas. Our results showed that in the heating season, the quality of air in the rural location was comparable or even worse than in the two larger urban areas and that the air in the small settlement was contaminated mainly by emissions from local heating. Interestingly, in spite of the fact that a large number of the houses (over one third) are connected to the natural gas network, only a few houses use this fuel for heating, while the vast majority prefers cheap, low-quality fossil fuel because of the high price of gas.

Although we have not carried out a detailed analysis of sources and have not determined their contribution to the level of local aerosol concentrations, we can speculate about the source apportionment in the studied region. The relatively high correlation coefficients between the air pollution variables in the two cities and in the village might suggest that the main source of PM in Albrechtice is not the local heating but the long-range transport of urban pollutants from the nearest cities. However, the values measured in the background location Souš (which is much closer to our location than the two cities) were dramatically different. The Souš locality is situated less than 4 km away, while Jablonec lies approx. 10 km and Liberec 16 km from Albrechtice. Interestingly, Souš is located closer to both cities (9 km from Liberec and about 13 km from Jablonec in approximately the same direction as Albrechtice), but the correlation coefficients between Souš, the two cities and our rural location were very low, suggesting very low mutual influence among the urban and rural localities. Based on this assumption, we suggest that the strong association between the cities and the village reflected a similar behaviour of sources and similar meteorological conditions rather than the long range transport of pollutants.

The results of the present study support the idea that, under current trends in fuel prices, improvements in the air quality in many rural Czech locations (and similarly in other Central and East European countries) may be delayed and that traditional heating in small settlements including rural villages may, similarly as in large towns, represent an important local air quality problem.

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