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Impact of weather conditions on winter and summer air quality

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Abstract. The impact of major meteorological elements on the concentration of sulfur dioxide, nitrogen dioxide, particulate matter, and ozone in the extreme conditions of winter and summertime was determined. It was observed that weather conditions significantly contributed to elevated concentrations of the all analyzed pollutants. The impact of the wintertime weather was most pronounced in southern Poland, whereas in the summer – also in the central and NE parts of Poland. The adverse conditions of anticyclone weather observed in January 2006 had a stronger effect on the concentrations of gaseous pollutants, whereas in July – on tropospheric ozone and particulate matter. Air quality primarily depended on air temperature and wind speed. Air temperature most often explained the variability of summertime ozone and particulate matter immission, as well as wintertime sulfur dioxide. However, the role of wind speed as a dispersing factor most affected nitrogen dioxide immissions in both seasons, and particulate matter during the winter.

Keywords: season weather conditions, gaseous pollutants, ozone, particulate matter, air quality

INTRODUCTION

Air quality is determined not only by the amount of emissions, but also by current and preceding meteorological conditions. The effect of weather on dispersion of gases and particulate matter (PM10), and on their deposition within the ground layer of air, has been demonstrated in a number of studies (Czarnecka and Nidzgorska-Lencewicz, 2008; Elminir, 2005; Jacob and Winner, 2009; Malek *et al*., 2006). Episodes of sudden intense air pollution, referred to as smog, which occur within large urban agglomerations and industrial areas, pose a serious threat to human health. The negative impact of high pollutant concentration on environment has been thoroughly studied and widely documented (Amann *et al*., 2008; Filleul *et al*., 2006; Fischer *et al*., 2004; Stedman, 2004; WHO, 2006). In August 2003, a very high level of tropospheric ozone (O_3) was recorded across Europe (Solberg *et al*., 2008), which, in conjunction with other pollutants and a heat wave, resulted in a considerable increase in mortality. Filleul *et al*. (2006) demonstrated that between the 3rd and the 17th of August 2003, the risk of death due to high 8 h concentrations of O_3 in connection with high temperatures increased from 10.6% in Le Havre to 174.7% in Paris.

The so-called black smog occurring in winter and the photochemical smog observed in spring and summer are both correlated with anticyclone weather, vertical thermal structure of the atmospheric boundary layer, and the type of circulation (Godłowska, 2004; Malek *et al*., 2006; Niedźwiedź and Ustrnul, 1989; Walczewski, 1997). Topography that hampers natural air circulation of a city, can contribute to the rise, buildup, and duration of smog episodes. Tall, tightly-packed buildings present an additional barrier to the dispersion of pollutants in metropolitan areas (Xie *et al*., 2005). Because air pollution is affecting an increasing number of people worldwide, especially in urban areas, continuous air quality monitoring is a necessity. Forecasting is also important since it enables early warning of high pollution levels and allows more time to prepare and reduce exposure (Krupa *et al*., 2003; Ma *et al*., 2004; Schicker and Seibert, 2009; Walczewski, 1997). During the winter and summer of 2006, extreme weather conditions in Poland led to an increase in concentrations of some pollutants beyond the limit level.

The aim of this study is to evaluate the effect of major meteorological parameters on elevated and limit-exceeding concentrations of pollutants affecting air quality.

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MATERIALS AND METHODS

This study was based on data recorded by the automatic air quality monitoring system of National Environment Monitoring. The data comprised hourly concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), PM10, and O_3, collected during winter (December 2005 to February 2006) and summer (June to August 2006) from immission stations operating in 12 places of Poland (Fig. 1). The primary selection criterion for a station was the completeness of measuring immissions and meteorological data. All of the stations are located in urban area. The meteorological data collected by automatic stations located near the immission stations included total radiation, air temperature, atmospheric pressure, relative air humidity, and wind velocity. Hourly and daily concentrations of the analyzed air pollutants were evaluated according to the standards.

The effects of these meteorological parameters on the concentrations of the analyzed pollutants were estimated using correlation analysis, as well as, single and multiple regression, including stepwise analysis. The analysis was performed at significance levels of $\alpha = 0.05$ and $\alpha = 0.01$.

RESULTS

In 2006, the mean annual temperature in Poland was 0.8ºC higher than the long-term average, and the annual precipitation was approx. 96% of the average for the period between 1971 and 2000 (Bulletin, 2006). However, both thermal patterns and precipitation demonstrated very strong fluctuations between the seasons and between consecutive months. The greatest difference in weather was between winter and summer, and, in particular, between January and July. In terms of temperature and precipitation, January and July clearly deviated from their respective monthly means of previous years (Fig. 2). Most days in January the weather was characterized by an extensive Russian high pressure area which brought mass amounts of frosty, dry air to Poland. The mean temperature for the month typically ranged from -4 to -8.5ºC and was more than 5ºC lower than the long-term average in the majority of cities. July was extremely hot and dry. The mean temperature for July in whole Poland ranged from 21 to 25ºC, which exceeded the average by 3 to 6ºC. Precipitation in July 2006 was merely 25% of the long term average. In both months, under anticyclone weather conditions, the mean monthly wind speed in the urban areas did not exceed 1.5 m s^{-1}, which considerably reduced natural dispersion of polluted air.

Fig. 1. Location of urban immission stations considered in the study.

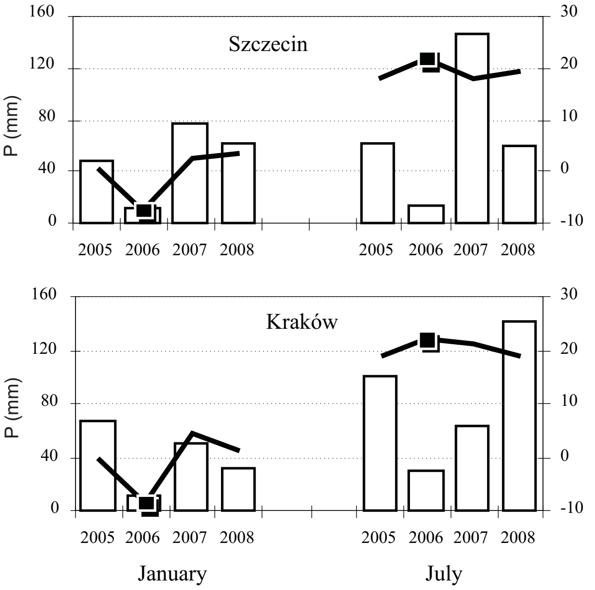

Fig. 2. Air temperature (T) and total precipitation (P) in January and July in Szczecin and Kraków during 2005-2008.

Due to severe frosts in January 2006, an increase in the use of heaters occurred in urban and residential areas. Poor air circulation in these areas resulted in considerably higher immission of the main pollutants, especially in southern Poland. The mean monthly concentrations of SO_2 ranged between 15 and 50 µg m^{-3}, while concentrations of PM10 usually ranged between 50 and 150 µg m^{-3}. The highest mean concentrations of SO_2 and NO_2 was recorded in the Dąbrowa Górnicza, while PM10 was highest near Kraków. In January 2006, mean monthly concentrations of SO_2 were twice as high, and PM10 were three times higher then the averages for 1993 to 2002 (Czarnecka and Kalbarczyk, 2004), and still much higher compared with adjacent years (Fig. 3). Air quality across the country fell well below standards, especially regarding the 24 h concentrations of PM10. The highest daily PM10 concentrations were recorded in the last ten days of January. In northern Poland (Szczecin, Gdańsk), the concentrations of PM10 were six times that of the acceptable 24 h limit, and in the south (Kraków), more than ten times (Fig. 4). In most of the analyzed cities, alarm levels of concentrations were exceeded, meaning the mean hourly

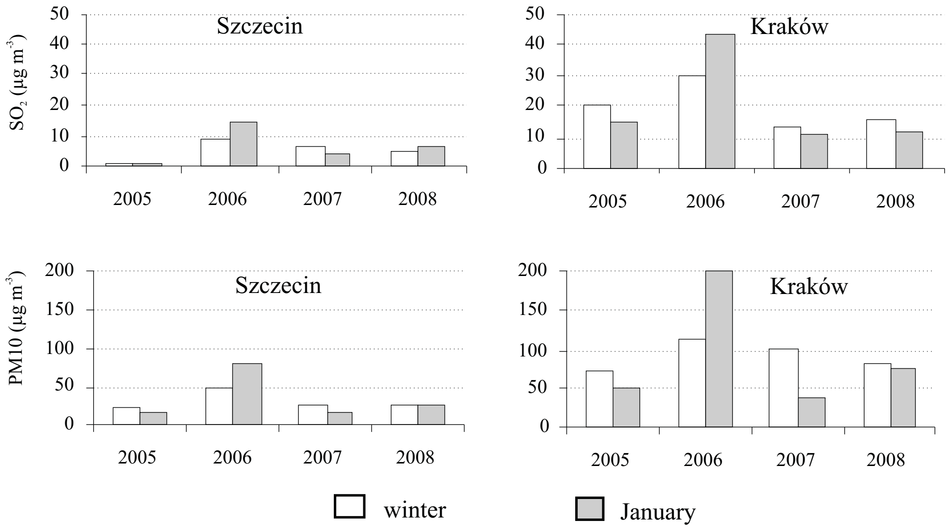

Fig. 3. Mean concentrations of particulate matter (PM10) and sulfur dioxide (SO$_2$) during wintertime of 2005-2008 in Szczecin and Kraków.

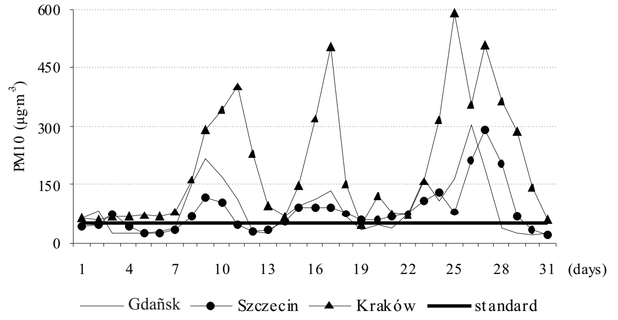

Fig. 4. Mean 24 h concentrations of particulate matter (PM10) in January 2006 in selected cities of Poland.

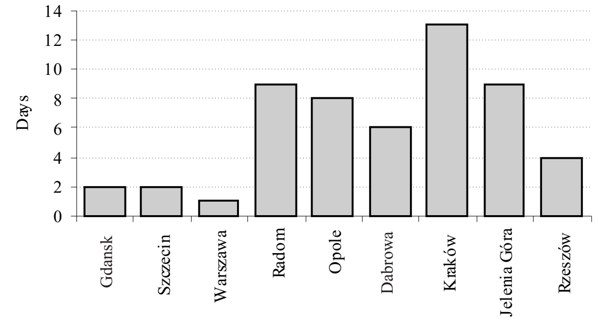

Fig. 5. Number of days in January 2006 when alarm (hourly) levels of PM10 were exceeded.

values were exceeded by 2 to 13 days (Fig. 5). These anomalies were the most frequent in Kraków, where the hourly PM10 concentrations on January 17, 25, and 27 of reached 505, 592, and 507 μg m^{-3}, respectively. These concentrations exceeded the maximum smog episode concentrations for January 2006 by 100 to nearly 200 μg m^{-3} (Mira-Salama *et al.*, 2008).

In July 2006, the level of PM10 dust was considerably elevated compared to previous years. O$_3$ levels were also high, but they did not differ much from O$_3$ levels in 2005 (Fig. 6). Nevertheless, immission levels of all pollutants oscillated below the allowable threshold. Only in Jelenia Góra, Dąbrowa Górnicza, and Radom, did the hourly O$_3$ concentrations exceed the level of 180 μg m^{-3}, on 20-21 July, which, according to the alarm rule, requires that the public be informed about a high risk of a smog event.

The impact of weather conditions on the variability of pollutant levels in 2006 was demonstrated using the coefficients of determination, in most cases statistically significant at $\alpha = 0.01$ (Table 1). Over the entire country, and in both winter and summer, the coefficients ranged between 10 and 30%, reaching, however, much higher values in most cities. The impact of the 2005/2006 winter weather was slightly stronger in relation to the immission of PM10 and SO$_2$, and weaker in relation to NO$_2$ (Table 1). In most of the cities, the role of inclement weather in the pattern of changes in pollutant immission was more apparent in January than in the overall winter of 2005/2006, particularly in relation to NO$_2$. The impact of the winter weather conditions was most apparent in southern Poland. The highest coefficients of determination for SO$_2$ and PM10, approx. 83 and 70%, respectively, for January were recorded in Radom. On the other hand, the impact of weather on NO$_2$ immission changes was most evident within the local topography of Jelenia Góra, where January R^2 reached nearly 71%.

The meteorological conditions of summer 2006 best described the variability of O_3 and PM10 concentrations, and were much less responsible for the levels of NO_2. In many cities, however, the adverse effect of weather on NO_2 immission was most pronounced in July. Extremely high July coefficients of determination, as compared with the entire summer, were observed in Olsztyn, Radom, and Rzeszów. The most apparent effect of weather on tropospheric O_3 concentrations ($R^2 \sim 70\%$) was demonstrated in Łódź and Jelenia Góra. However, in Dąbrowa Górnicza the relationship between the weather and PM10, as well as NO_2, was the strongest. In general, the variability of PM10 concentrations depended on bad weather conditions stronger in the summer of 2006 than in the winter; however, the parameter varied between regions and, in some of the cities, the relationships were not significant.

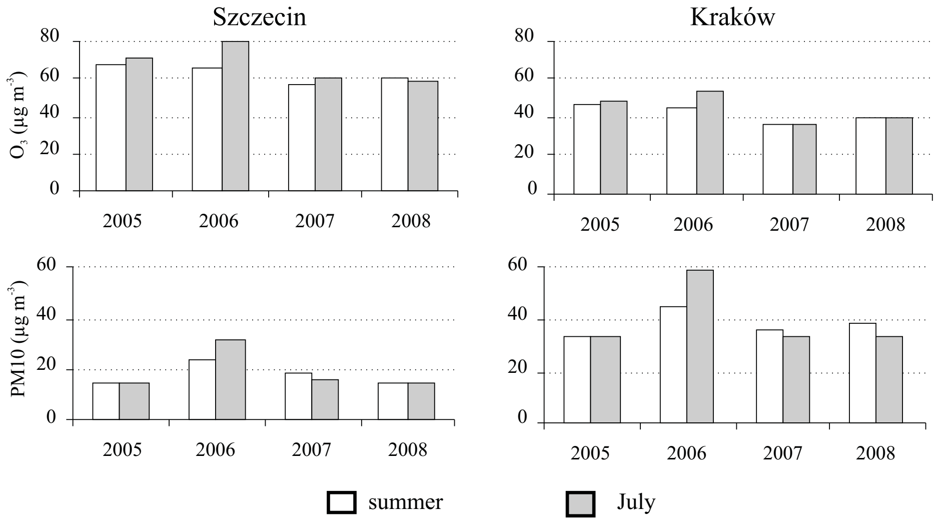

Fig. 6. Mean concentrations of particulate matter (PM10) and ozone (O_3) during summertime of 2005-2008 in Szczecin and Kraków.

Table 1. Coefficients of determination (%) for the relationship between SO_2, NO_2, PM10 (2005/2006) and O_3, NO_2, PM10 (2006) concentrations *versus* nominated meteorological components

City	2005/2006						2006					
	SO_2		NO_2		PM10		O_3		NO_2		PM10	
	winter	January	winter	January	winter	January	summer	July	summer	July	summer	July
Szczecin	40.5	44.7	38.8	54.2	52.1	52.5	56.3	42.9	20.9	n.s.	53.7	11.6
Gdańsk	51.2	53.4	33.6	48.9	33.2	36.8	28.5	22.9	13.3	29.2	34.2	56.2
Olsztyn	26.4	40.0	22.5	39.3	35.2	15.3	25.6	35.3	9.8	56.5	46.1	55.5
Warszawa	26.9	21.9	38.4	53.5	45.6	48.2	58.8	42.2	27.1	28.4	49.9	71.3
Łódź	29.4	32.7	26.8	49.6	40.6	51.1	72.5	68.8	14.6	31.4	59.3	43.8
Poznań	10.9	25.8	5.0	38.8	5.3	36.5	63.7	54.2	18.7	20.2	42.7	37.3
Jelenia Góra	63.8	67.4	52.4	70.7	45.2	49.0	54.7	70.8	23.4	34.6	48.3	41.4
Opole	33.6	17.1	38.4	46.2	29.7	25.3	*	*	18.2	28.5	50.6	52.0
Dąbrowa Górnicza	50.8	43.8	41.6	57.2	45.7	49.6	50.4	42.8	50.3	61.4	73.0	74.8
Kraków	41.5	19.7	37.6	41.5	57.0	49.7	*	*	9.7	33.7	44.4	n.s.
Radom	68.5	83.4	46.7	68.8	57.0	69.6	61.0	46.6	4.7	33.1	64.4	74.5
Rzeszów	45.1	75.9	25.3	53.8	54.4	64.0	*	*	15.5	40.9	22.0	n.s.
Poland	23.7	16.0	24.5	22.7	33.7	28.7	*	32.0	7.8	12.8	32.0	18.6

*lack of data, n.s. – non significant relationships at $\alpha = 0.05$.

The air quality in Poland during winter and summer 2006 depended mostly on air temperature and wind speed. The role of these factors in the variability of immission, as expressed by the coefficient of partial determination, differed depending on the type of pollution and the season (Fig. 7). In the winter, SO_2 immission was primarily determined by air temperature, whereas NO_2 was most affected by wind speed. The most similar coefficients of partial determination for both meteorological components were estimated for PM10 dust; during the entire winter, air temperature was more important in explaining its concentrations, and wind speed in January alone. An increase in the concentrations of O_3 and NO_2 in July 2006 was in large part due to air thermal conditions. Air temperature and wind speed played an important role in the pattern changes of PM10 particulate matter immission. In July, the impact of both was nearly the same, while if we look over the entire summer period, air temperature was the main factor underlying the immission increase.

Adverse weather conditions that significantly influenced the levels and variability of SO_2, NO_2, and PM10 concentrations in selected cities of Poland in 2006 most often represented two meteorological components at a time, nominated using the stepwise procedure of regression analysis. Air temperature and wind speed were most frequently nominated, similar as in the scope of the entire country; however, also relative humidity, pressure, and total radiation represented the variables accounting for the magnitude of immission (Fig. 8). These elements are commonly named in the literature as major factors that lead to air quality deterioration, also in different climatic zones. The role of thermal conditions as the main factor increasing the emission and, in consequence, the immission of major wintertime pollutants, in association with anemometric conditions, was demonstrated by many authors, including Godłowska (2004), Majewski and Przewoźniczuk (2006), Malek *et al.* (2006), Mira-Salama *et al.* (2008), Schicker and Seibert (2009), usually basing on a detailed analysis of occurrence of certain smog episodes or their models. Air temperature and wind speed are also used for describing and forecasting high O_3 levels (Baran *et al.*, 1999; Palacios *et al.*, 2004).

The effect of temperature on pollution levels depended on the season. In winter, temperature increase resulted in a drop in the immission of all pollutants, whereas in summer, it contributed to an increase. Wind speed always positively influenced air quality, and even under anticyclonic weather conditions, regardless of the wind direction, the ventilation function of wind was apparent. Interestingly, total radiation frequently (>20% of cases) explained radiation and thermal conditions which deteriorate air quality. In the summer, however, such conditions were reflected only by the 24 h mean air temperature. Temperature was the most important variable explaining the flux in O_3 concentrations, which agreed with the results of Gzella and Zwoździak (2003), Elminir (2005) and Jacob and Winner (2009).

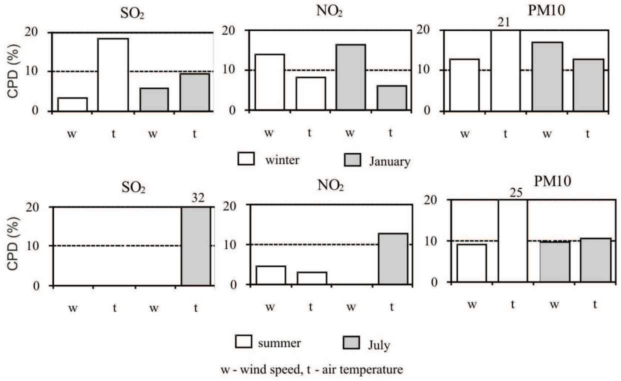

Fig. 7. Coefficients of partial determination (%) of meteorological components affecting the variability of pollutant concentrations during the winter and summer 2006 in the scope of the entire country.

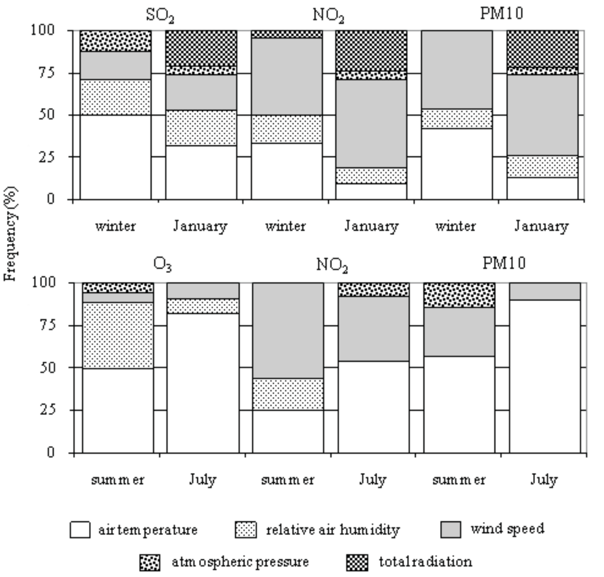

Fig. 8. Frequency of meteorological components (%) accounting for the concentration variability of the analyzed pollutants in the considered cities during the winter and summer 2006.

Air temperature most often accounted for the variability of O_3 and PM10 immission in summer, and, in July, in 80% of the cases. In winter, thermal conditions were the main factor explaining SO_2 concentration variability. In regression equations, which described immission of NO_2 and PM10, wind speed most frequently explained variability. Moreover, wind speed most often determined NO_2 concentrations during the summer. An increase in relative air humidity contributed to reduced immissions of all the analyzed pollutants during the winter. However, humidity most frequently *ie* in about 40% of the cases, significantly explained O_3 concentrations during the summer.

CONCLUSIONS

1. The meteorological conditions during winter and summer 2006, especially in January and July, were the fundamental cause underlying air quality decline in urban areas of Poland. During the winter of 2005/2006, the weather had the strongest impact on air quality in the cities of southern Poland; in summer 2006, also in the central and northeastern parts of the country were mostly affected.

2. Adverse anticyclonic weather in January 2006 had a strong impact on the concentrations of gaseous pollutants *ie* NO_2 and SO_2, and in July, on tropospheric O_3 and PM10.

3. The air quality in 2006 was determined mainly by air temperature and wind velocity. Air temperature most often accounted for the variability of O_3 and PM10 particulate matter immission during the summer, and SO_2 during the winter. However, concentrations of NO_2 in both seasons, and PM10 in the winter, were determined primarily by wind speed.

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