ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 36 no. 4 pp. 55 - 66 2010

PL ISSN 0324-8461

RELATIONS BETWEEN CIRCULATION AND WINTER AIR POLLUTION IN POLISH URBAN AREAS

JOLANTA GODŁOWSKA*, ANNA MONIKA TOMASZEWSKA

Institute of Meteorology and Water Management, Krakow Branch, Poland
Department of Monitoring and Modelling Air Pollutions
Piotra Borowego str. 14, 30-215 Kraków
* Corresponding author e-mail:zigodlow@cyf-kr.edu.pl

Keywords: Urban air pollution, circulation, urban boundary layer, sodar, ground inversion, elevated inversion.

Abstract: We determined the performance of different Circulation Type Classifications (CTCs) to stratify air pollutants concentrations in Polish cities in winter. Our analysis is based on 15 CTCs calculated by COST 733 as well as on 5 manual universally used manual weather type classifications. For this purpose we compared and tested the explained variation (EV) and within-type standard deviation (WSD) methods. Finally, EV method has been chosen for evaluating classifications for daily values of SO2, NO2, PM10 and CO as well as vertical dispersion conditions obtained from SODAR data. We also presented the methodology of choosing smog episode days based on 90-percentile values. For the winter smog episodes data from Krakow different classifications have been compared using Gini coefficient method. The best results for separate air pollution data series as well as for smog episode days were obtained for Hess-Brezowski Großwetterlagen classification (HBGWL). Moreover, good results were obtained for the based on principal component analysis PCACA classification, Polish Niedzwiedz TCN21, modified Polish Litynski LITTc, modified Lamb LWT2, and three modified HBGWL (GWTC26, OGWL, OGWLSLP) classifications. The same classifications except for HBGWL are good for SODAR data. For the best CTCs, the differences between various classes are visible, however a big scattering is still observed. Main urban air pollution problems arise in situations when flow with Southerly component is observed. Correlations between air pollution data and SODAR data (calculated for marginal means obtained for different classes) confirm a negative role of both low height of the ground-based inversion and long duration of the low-level elevated inversion in urban areas.

INTRODUCTION

Urban areas are characterised by both large heterogeneity of emission and spatial variability of roughness. Turbulence induced by merged interactions of temperature, wind and friction causes some homogenization of the air. However, physical, chemical and meteorological parameters characterizing air conditions change inside cities [6, 24]. Nevertheless, a similar day by day variability of different pollutants measured in different places inside a city is observed. It shows that there is some outside factor which influences this common changeability. Air pollution concentration depends on both emission and dispersion [8]. As emission usually does not change quickly with time (except for daily variability), weather conditions connected with dispersion play the crucial role in changing pollutants concentration [9]. Nowadays, means of transport and heating systems based on coal burning are the main sources of winter air pollution in Polish urban areas. As these sources of emission are situated near the ground level, mainly in urban canopy layer or just above it, meteorological conditions such as wind speed and thermal structure of urban boundary layer, play a key role in displacing pollutants outside the city. The ground – based inversion of temperature causes the accumulation of pollutants in low-lying layer. Moreover, the area accessible for vertical mixing becomes smaller as a result of the blocking caused by the elevated inversions. This reflects the behaviour of air pollution concentrations that are the highest when low-lying elevated inversion can be found [11]. A connection between synoptic situation and air quality in Upper Silesia and Kraków was originally examined using Niedzwiedz classification [21, 22]. Later research showed that the increase of air pollution concentrations in Krakow is observed for Litynski SWA and OOO classes [10]. For these classes frequent low-lying elevated inversions are also seen. The connection between high PM10 concentration and circulation classified by Niedzwiedz was also confirmed in Katowice agglomeration [2]. In this paper, the usefulness of different circulation type classifications for winter urban air pollution is examined.

DATA AND METHODS

A key goal of this paper is to compare the performance of different Circulation Type Classifications (CTCs) to stratify concentrations of air pollution in winter. The analysis is based on catalogues of atmospheric circulation types that have recently been made available within the COST 733 action of the European Science Foundation (www.cost733.eu). We use the release 1.1 and 1.2 of circulation type classifications catalogue [4]. Comparison between CTCs with different number of classes is difficult, so we analyse only the subset of collection with about the same number of classes (about 27). Finally, 15 "objective", i.e. computer-assisted methods of classification developed using the ECMWF ERA-40 dataset and 5 manual, universally used, CTCs are used. The catalogues used are listed in Table 1. For a thorough description of CTCs see [23, 12]. The classification procedures used within COST 733 action are applied on Pan-European scale (large domain) as well as on scale of a few countries (ten sub-domains). In this paper objective CTCs from domain D07 (3°E–26°E, 43°N–58°N) are used (Figure 1). Additionally, Polish Niedzwiedz's (TCN21 – 21 classes) classification [19, 20] is analysed.

The analysis has been made using daily mean of SO_2, NO_2 and PM10 as well as maximum daily 8 – hour mean of CO from Warsaw, Krakow, Upper Silesia, Lodz and Wroclaw. Research has been conducted for winter air pollution data (December, January, February) from 1997 to 2002 with the exception of Krakow, where data from 1994 to 2002 have been analysed. Air pollution data come from the AIRBASE database [1]. Meta - information from AIRBASE database concerning stations (type of area, type and altitude of station) and amount of missing data was used. Moreover, on the basis of the SODAR data from Krakow, the relation between boundary layer conditions and circulation was examined. The SODAR data come from December, January and February of between 1994 and 1999. Different parameters characterising thermal structure and variability of Urban Boundary Layer were determined. For each day a mean height of convection (C), ground-based inversion (GI) and elevated inversion (EI) were calculated. Moreover, we specified the number of hours when each of these boundary layer phenomena was observed.

Previously, the relationship between the atmospheric circulation and the surface environment was determined mainly on the basis of the Pearson correlation coefficient, main square error, and root main square error [27, 5]. In this paper, two new methods suggested by COST733 action such as Explained Variation (EV) and Within – type Standard Deviation (WSD) [15] are tested and used to establish separability and within-type variability characterizing different classifications. Apart from these methods, the Gini coefficient method [7] is used to determine which one of CTCs is the best for determination of smog days.

Usage of EV (EV = 1-WSS/TSS) is based on the fact that for a grouped random variable, the sum of squares of deviation from the overall mean (TSS) can be divided into two parts: the sum of squares based on the within-group variability (WSS) and the sum of squares based on the between-group variability (BSS) [3]. The best CTC for stratifying air pollution data ought to have the lowest WSS. This gives rise to conclusion that the best CTC is connected with the highest values of EV. Within – type Standard Deviation $WSD = \frac{1}{k}\sum_{i=1}^{k} SD_i$ measures average within-type standard deviation after partitioning data into k classes (where SD_i is the standard deviation in i class). For this method, the problem of comparing different CTCs correctly will arise, if we have different number of cases in different classes. Higher separability and smaller within-type variability are connected with lower WSD values. Both methods were tested on the basis of COST 733 classification catalogue data (cost733cat-1.1) and winter air pollution data (1999 – 2002) from Upper Silesia. The relationship between the number of classes and evaluation of different CTCs is observed for both parameters (Fig. 1 – the left and middle).

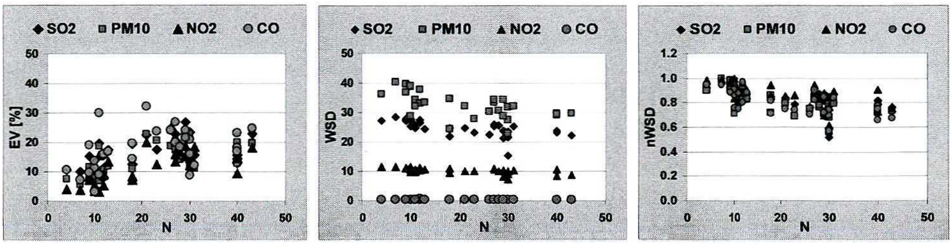

Fig.1. Relation between number of classes N for different classifications and EV (the left), WSD (in the middle) and nWSD (the right)

Moreover, WSD values depend on the kind of pollutants. It is very inconvenient and made us normalize WSD by dividing it by standard deviation calculated for all data (nWSD – Fig. 1 – the right).

The best classification chosen by nWSD is ESLPC30, while EV favours LWT2 and HBGWL (Fig. 2).

The comparison between expected marginal means of SO2 for ESLPC30, LWT2 and HBGWL led us to choose EV parameter for evaluation of CTCs as classification with higher separability is preferred by EV (Fig. 3).

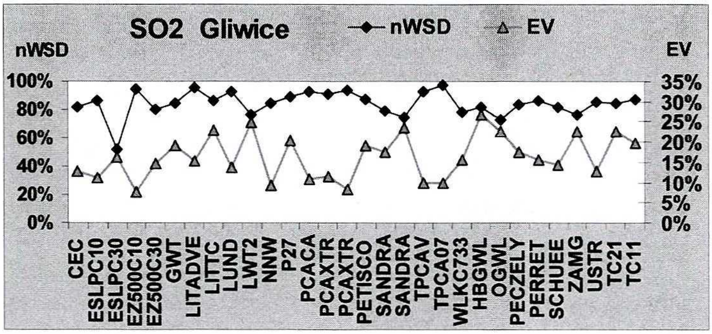

Fig. 2. Comparison between EV and nWSD values calculated for CTCs from catalogue 1.1 and daily SO2 in Gliwice

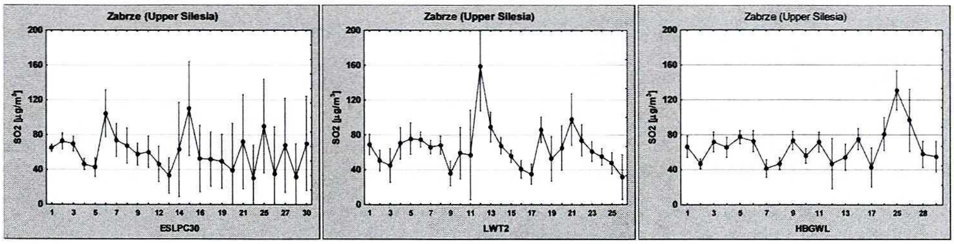

Fig. 3. Expected marginal means of SO2 for ESLPC30 classification (chosen by WSD and nWSD methods - on the left) as well as for LWT2 and HBGWL classifications (chosen by EV method – the middle and the right).Confidence interval 95% is marked

The third method allows to observe how different CTCs separate days when air pollution thresholds are exceeded for many pollutants and stations. In this case evaluation methods proposed by COST733 cannot be used and as a result we applied the Gini coefficient method [7] based on the Lorenz curve [18]. In this method only two numbers for each class characterise every classification – a number of days meeting our criteria (e.g. smog days) and total number of days for each class. In order to calculate Gini coefficient G for a classification, the probability $p_i = m_i/n_i$ of occurrence days with some characteristic (e.g. high pollution concentration, large precipitation, fog) for each class ought to be calculated and finally sorted according to rising p_i.

Then

$$G = 1 - \sum_{k=0}^{L} (x_k - x_{k-1}) \cdot (y_k + y_{k-1})$$

$$\text{for } x_k = \sum_{i=0}^{k} (n_i) / N \text{ and } y_k = \sum_{i=0}^{k} (m_i) / M$$

where n_i is a total number of days for class i (after sorting), m_i is a number of days meeting our criteria for class i, N is a total number of days for all classes, M is a total number of days meeting our criteria for all classes and L is a number of classes.

RESULTS

Daily values of SO2, PM10, NO2 and CO in different Polish cities

In order to determine separability of pollutants' concentrations by circulation types we used EV values calculated for different CTCs from catalogue 1.2. A similar EV variability (Table 1 – top) according to CTCs for the same pollutant measured in different places is observed. However, the mean EV level is neither the same for each pollutant nor for each city. Probably it is because of monitoring stations' localisation and irregular distribution of emission sources. A low level of EV values is observed for both NO2 and CO, which have mainly their origin in traffic. The largest EV values for these pollutants are achieved by Polish Niedzwiedz TCN21 classification in Krakow. This is the best classification for this city. EV values for SO2 in Gliwice (Upper Silesia) and EV values for PM10 in Wroclaw are greater than EV values in other cities. Each classifications has been ranked by number of EV > 0.3 and number of data series ranking high on the EV list (classifications which are first or second on the list EV for each data series). German, universally used manual classification the "Hess-Brezowski Großwetterlagen" HBGWL [12] is a good classification for most cities and pollutants.

Classification calculated on the base of Principal Component Analysis PCACAC27 and Polish classification TCN21 also rank high. Apart from these classifications good results are obtained for modified (according COST 733 arrangements) Litynski classification LITTc [17], objective version of Lamb-Weather types [16] LWT2 and for three objectivized versions of the Hess and Brezowsky Großwetterlagen (GWTC26, OGWL, OGWLSLP) [14].

For the best classifications we drew the Box-Whiskers plots of pollution concentration (SO2 Gliwice – HBGWL, PM10 Wroclaw – PCACA, NO2 Krakow – TCN21 and CO Krakow – LWT2) for different classes (Fig. 4). Differences between various classes are visible, however big scattering is still observed. Nevertheless, the Analysis of Variance conducted for all data series points out that for most classifications the marginal means for different classes vary at a significant level $p < 0.01$.

Smog days in Krakow

Because of irregularly situated emission sources (industrial, traffic, unorganized) research concerning relation between air pollution and boundary layer meteorology is difficult. The analysis based on air pollution measured only in one site might be distorted by the influence of isolated sources. Moreover, the analysis based only on days when air pollution norms are exceeded omits pollutants without norms. To solve these problems, the analysis based on exceeding 90-percentile (calculated for each month of the year and for each pollutant separately) is carried out. Days when 90-percentile is exceeded for at least 50% different air pollutants as well as for at least 50% sites inside agglomeration are chosen and called "smog days".

The Gini coefficients, calculated on the basis of air pollution data from Krakow, show that the best classifications are HBGWL, PCACAC27, LWT2 and TCN21 (Table 1 - the middle). They are the same CTCs as chosen by EV parameter calculated for each data series separately. This fact points out the consistency of both methods.

Table 1. Comparison of EV values for SO2, PM10, NO2 and CO measured in different Polish urban areas (at the top) as well as Gini coefficients for smog days occurrence in Krakow (in the middle) and EV of some boundary layer thermal structure characteristics (at the bottom) calculated for different CTCs. Correlations in 1st and 2nd places for each data series are printed in bold. EV greater than 0.3 as well as Gini coefficients greater than 0.5 are marked

METHOD		CLUSTER						LEADER			PCA		THRESHOLD				SUBJECTIVE				POLISH
	STATIONS	SANDRASC27	SANDRAC27	PETISCOC27	**PCACAC27**	NNWC27	CKMEANSC27	KHC27	ESLPC27	LUNDC27	TPCAC27	P27C27	WLKC28	**LWT2**	**LITTC**	GWTC26	**HBGWL**	OGWL	OGWLSLP	PERRET	**TCN21**
Air Pollution EV Rank		1 (1)	1 (0)	0 (0)	**2 (7)**	0 (0)	2 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	2 (0)	**2 (4)**	2 (2)	1 (2)	**5 (11)**	2(1)	**2 (5)**	0 (0)	**4 (5)**
Smog Days Gini Rank		0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1
Vertical Dispersion EV Rank		0 (0)	2 (1)	0 (0)	**2 (4)**	0 (0)	**2 (5)**	0 (0)	0 (0)	1 (0)	0 (0)	1 (0)	0 (0)	2 (1)	2 (1)	1 (0)	0 (2)	0 (0)	0 (1)	0 (1)	2 (0)
EV PM10	Warszawa	0.21	0.16	0.15	**0.24**	0.14	0.21	0.17	0.18	0.19	0.17	0.17	0.19	0.23	0.21	0.13	**0.32**	0.23	0.16	0.14	0.18
	Kraków	0.21	0.21	0.17	**0.24**	0.19	0.19	0.21	0.17	0.21	0.20	0.20	0.23	**0.24**	**0.24**	0.23	0.21	0.19	0.18	0.16	**0.29**
	Wrocław	0.27	0.34	0.25	**0.44**	0.23	0.31	0.27	0.30	0.30	0.34	0.35	0.40	**0.41**	0.40	0.34	0.38	0.34	0.34	0.29	0.34
	Gliwice	0.19	0.24	0.18	**0.28**	0.20	0.21	0.24	0.23	0.21	0.22	0.23	0.20	0.25	0.23	0.19	**0.27**	0.24	0.22	0.17	0.26
EV NO2	Warszawa	0.20	0.15	0.11	0.17	0.08	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.18	0.15	**0.28**	0.17	**0.21**	0.15	0.11
	Łódź	0.13	0.14	0.08	**0.17**	0.14	0.13	0.09	0.14	0.09	0.1	0.12	0.11	0.15	**0.17**	0.10	**0.24**	0.15	**0.17**	0.14	0.13
	Kraków	0.11	0.19	0.20	0.23	0.13	0.20	**0.25**	0.15	0.23	0.22	0.23	0.19	0.24	0.24	**0.25**	0.12	0.15	0.15	0.13	**0.33**
	Wrocław	0.12	0.18	0.10	0.19	0.10	0.17	0.11	0.16	0.16	0.13	0.14	0.09	0.19	0.16	0.16	0.13	**0.21**	**0.20**	0.15	0.17
	Gliwice	0.14	0.22	0.15	0.19	0.10	0.22	0.14	0.14	0.22	0.21	0.17	0.17	**0.23**	0.15	0.13	**0.28**	0.14	0.15	0.15	0.18
EV SO2	Warszawa	0.22	0.18	0.12	0.21	0.07	0.23	0.14	0.19	0.22	0.18	0.15	0.2	0.18	0.21	0.11	**0.35**	0.24	**0.26**	0.15	0.17
	Łódź	0.15	0.18	0.11	0.16	0.12	0.19	0.16	0.19	0.16	0.12	0.15	0.15	0.16	0.18	0.12	**0.31**	0.20	**0.21**	0.13	0.16
	Kraków	**0.22**	0.19	0.12	0.21	0.13	0.17	0.15	0.19	0.17	0.18	0.16	0.16	0.17	0.21	0.13	**0.25**	0.21	0.21	0.15	**0.22**
	Wrocław	0.24	0.21	0.17	**0.27**	0.11	0.22	0.18	0.21	0.22	0.18	0.26	0.19	0.21	0.23	**0.27**	**0.28**	0.26	0.22	0.18	0.20
	Gliwice	0.30	0.27	0.25	**0.34**	0.18	0.30	0.31	0.28	0.28	0.28	0.29	0.31	0.31	0.31	0.27	**0.48**	0.32	0.33	0.24	0.33
EV CO	Warszawa	**0.23**	0.20	0.14	0.21	0.16	0.19	0.17	0.14	0.14	0.17	0.16	0.19	0.19	0.19	0.18	**0.24**	0.15	0.14	0.13	**0.23**
	Kraków	0.15	0.20	0.20	0.23	0.11	0.21	0.22	0.15	0.22	0.20	0.19	0.22	**0.24**	0.21	0.21	0.21	0.18	0.15	0.14	**0.30**
GINI coef. Smog Days	Kraków	0.47	0.46	0.43	**0.52**	0.42	0.49	0.48	0.44	0.46	0.49	0.41	0.48	**0.52**	0.47	0.42	**0.51**	0.47	0.47	0.37	**0.51**
EV Mean Height of:	Convectin	0.12	0.11	0.10	0.13	0.11	**0.16**	0.05	0.11	0.14	0.12	0.12	0.08	0.14	0.12	0.12	**0.16**	0.12	0.09	0.15	0.12
	Ground Inv.	0.24	**0.37**	0.24	**0.41**	0.19	0.36	0.21	0.27	0.31	0.26	0.34	0.22	0.33	0.34	0.31	0.29	0.25	0.28	0.23	0.35
	Elev.Inversion	0.12	0.16	0.14	**0.18**	0.09	**0.17**	0.12	0.13	0.13	0.09	0.14	0.11	0.15	0.15	0.10	0.16	0.13	0.11	0.09	0.14
EV Persistance:	Convectin	0.09	0.11	0.08	0.12	0.08	**0.17**	0.07	0.08	0.06	0.07	0.12	0.11	0.11	0.14	0.10	**0.17**	0.16	**0.18**	**0.17**	0.12
	Ground Inv.	0.09	0.10	0.12	**0.16**	0.07	**0.18**	0.08	0.14	0.11	0.11	0.12	0.13	0.10	0.09	0.11	0.14	0.11	0.13	0.11	0.11
	Elev.Inversion	0.26	0.30	0.19	**0.33**	0.27	**0.31**	0.23	0.26	0.26	0.27	0.28	0.22	**0.31**	**0.31**	0.29	0.18	0.24	0.22	0.18	0.30

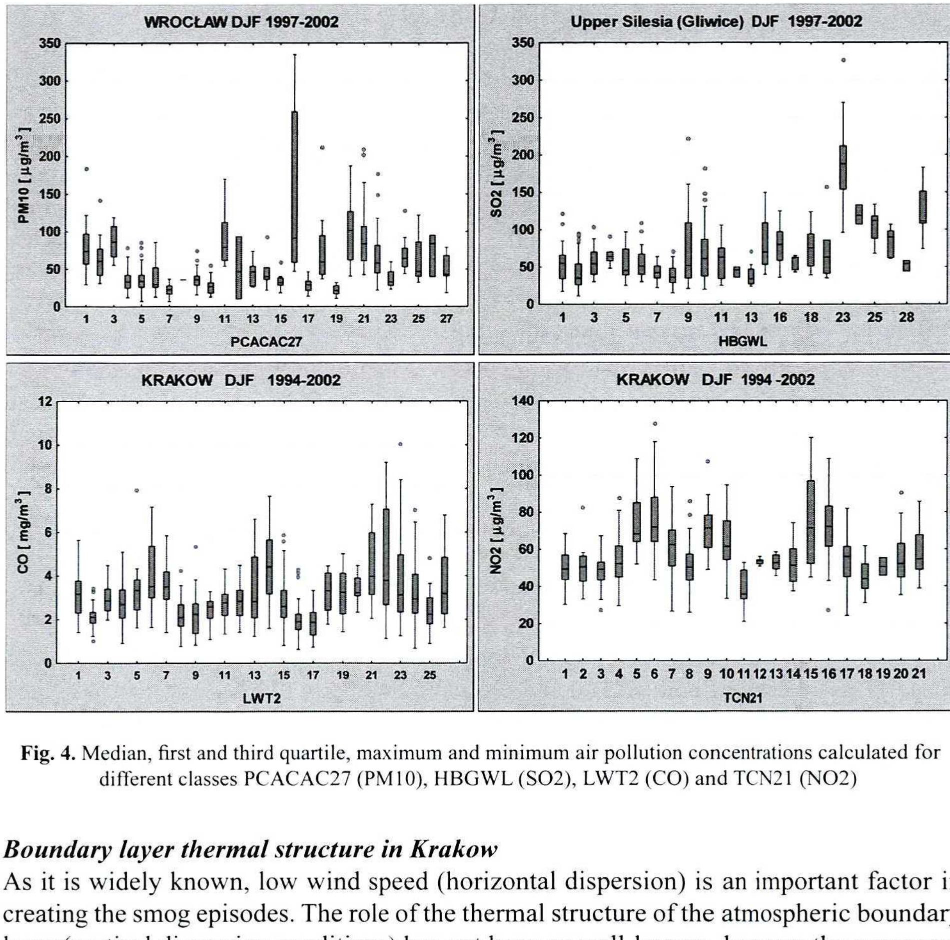

Fig. 4. Median, first and third quartile, maximum and minimum air pollution concentrations calculated for different classes PCACAC27 (PM10), HBGWL (SO2), LWT2 (CO) and TCN21 (NO2)

Boundary layer thermal structure in Krakow

As it is widely known, low wind speed (horizontal dispersion) is an important factor in creating the smog episodes. The role of the thermal structure of the atmospheric boundary layer (vertical dispersion conditions) has not been so well-known, because the necessary data have been hardly available. The Boundary Layer in Krakow has been continuously monitored since the beginning of the last decade of the 20th century with use of vertical sounding sodar SAMOS-4C (the improved version of earlier applied sodars) [25, 26]. This remote-sensing device emits sound waves of the precisely chosen parameters. Some part of the acoustic signal is backscattered by the thermal heterogeneity of the atmosphere. The received part of the backscattered signal is analyzed and presented in the graphic form – the sodarogram. To determine the power of the relation between SODAR data and CTCs, the values of EV are used (Table 1 – the bottom). The biggest EV values for all classifications are observed for ground-based inversion height and the number of hours of elevated inversion presence. These parameters play a crucial role in air pollution concentration in Krakow [11, 10]. The best results (EV = 0.41 for GI height and EV = 0.33 for EI presence) are obtained for PCACAC27 classification. LWT2, and LITTC classifications also rank high.

DISCUSSION

Taking all the obtained results into consideration it seems that winter air pollution as well as vertical dispersion conditions are connected with circulation. The best CTCs in diversifying air pollution conditions in urban areas are based mainly on earlier used methods. Only PCACA classification has no connection with old, climatological research. The best results for separate air pollution data series and for smog episode days are obtained for Hess-Brezowski Großwetterlagen classification (HBGWL). Moreover, good results are obtained for principal component analysis based on PCACA, Polish Niedzwiedz TCN21, modified Polish Litynski LITTc, modified Lamb LWT2, and three modified HBGWL (GWTC26, OGWL, OGWLSLP) classifications.

The same classifications apart from HBGWL are good for air pollution and dispersion. The power of this relation is not very big. Only for a few CTCs, EV values exceed 0.3, mainly for SO2 and PM10 data as well as for both ground inversion height and elevated inversion presence. The greatest values of Gini parameter do not exceed 0.6. The biggest SO2 marginal mean is obtained for 23rd class of HBGWL (HNFZ – high over Northern Sea – Fennoscandia, cyclonic). A similar behaviour of SO2 and PM10 for different cities is observed. Composite plot prepared by WG2 COST 733 shows that this class is characterised by the lack of precipitation, high level pressure and a very low temperature accompanied with meridional SE flow over the territory of Poland (Fig. 5).

Both LWT2 and TCN21 classifications prefer two classes: Anti-cyclonic South-Westerly (6th class for both CTCs) and Cyclonic Southerly (22nd class for LWT2 and 15th class for TCN21). Moreover, high air pollution concentration is observed for both 14th (Unbiased South-Westerly) and 21st (Cyclonic South-Easterly) LWT2 classes and for 5th (Anti-cyclonic Southerly), 6th (Anti-cyclonic South-Westerly), and 16th (Cyclonic South-Westerly) TCN21 classes. Finally we can conclude that main urban air pollution problems arise when the flow with Southerly component is observed.

Correlations between expected marginal means of air pollution and marginal means of both GI height and EI presence, calculated only for CTCs with EV (air pollution) > 0.3

Table 2. Correlations between marginal means of air pollution concentrations and marginal means of chosen SODAR parameters (calculated for different classes CTCs). Only CTCs with EV > 0.3 for air pollution data are shown. Correlations at significant level $p < 0.05$ are shown in bold

Method	CTC's	ELEVATED INVERSION PRESENCE				GROUND INVERSION HEIGHT			
		CO	PM10	SO2	NO2	CO	PM10	SO2	NO2
CLUSTER	SANDRAC27	0.67	0.82	0.75	0.55	-0.14	-0.45	-0.50	-0.17
	PCACAC27	0.64	0.79	0.71	0.53	-0.29	-0.54	-0.69	-0.10
	CKMEANSC27	0.56	0.76	0.68	0.52	-0.11	-0.39	-0.59	-0.02
LEADER	LUNDC27					-0.18	-0.47	-0.53	-0.53
PCA	P27C27					-0.15	-0.44	-0.52	-0.10
THRESHOLD	LWT2	0.77	0.90	0.82	0.58	-0.27	-0.40	-0.52	-0.10
	LITTC	0.66	0.87	0.74	0.55	-0.27	-0.55	-0.69	-0.12
	GWTC26					-0.21	-0.35	-0.40	-0.40
POLISH	TCN21	0.77	0.82	0.79	0.70	-0.16	-0.32	-0.42	-0.05

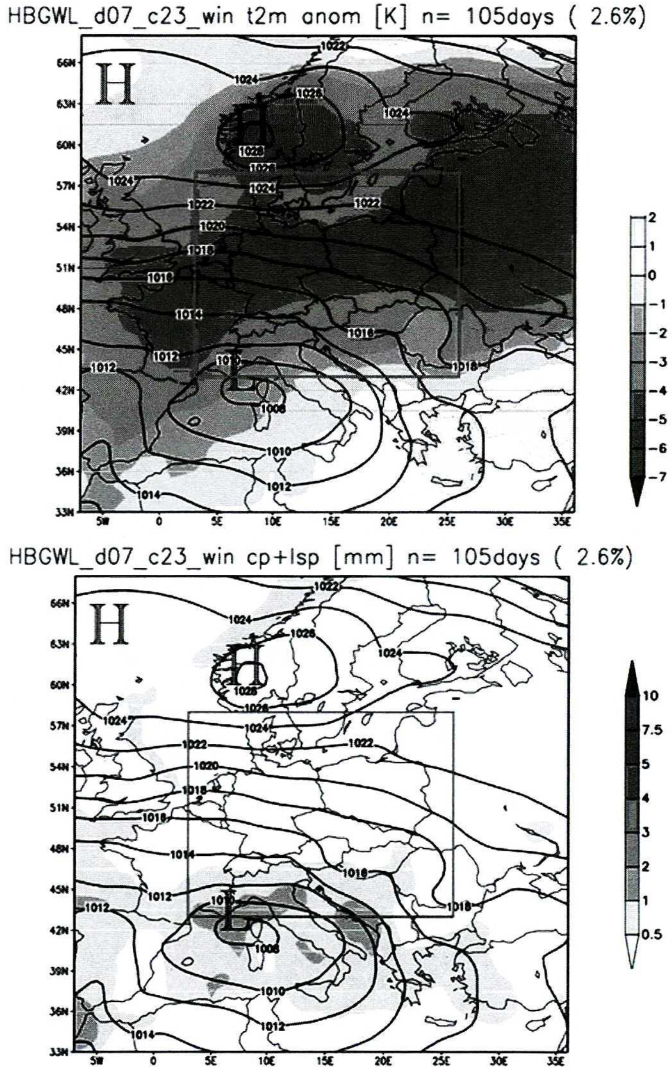

Fig. 5. Composite plot prepared by WG2 COST 733 (average situation in December, January and February in 1957-2002) for 23rd class of HBGWL (HNFZ class - high over Northern Sea - Fennoscandia, cyclonic)

(Table 2) suggest that air pollution in Krakow (especially for PM10 and SO2) depends on boundary layer conditions.

Negative correlations between pollutants' concentration and GI height confirm that shallow ground-based inversions in urban areas are connected with harmful air pollution conditions (Fig. 6).

Additionally, positive correlations between pollutants' concentrations and the number of hours with EI presence show that long duration of low-level elevated inversion causes the escalation of air pollution problems in urban areas (Fig. 7).

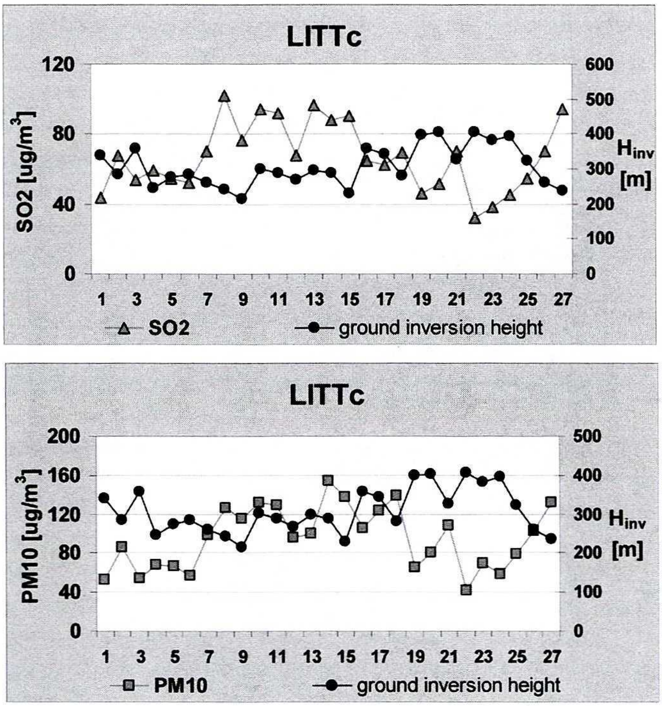

Fig 6. Comparison between marginal means of SO2 (top) or PM10 (bottom) and marginal means of ground-based inversion height calculated for LITTc classification on the basis of data from Krakow

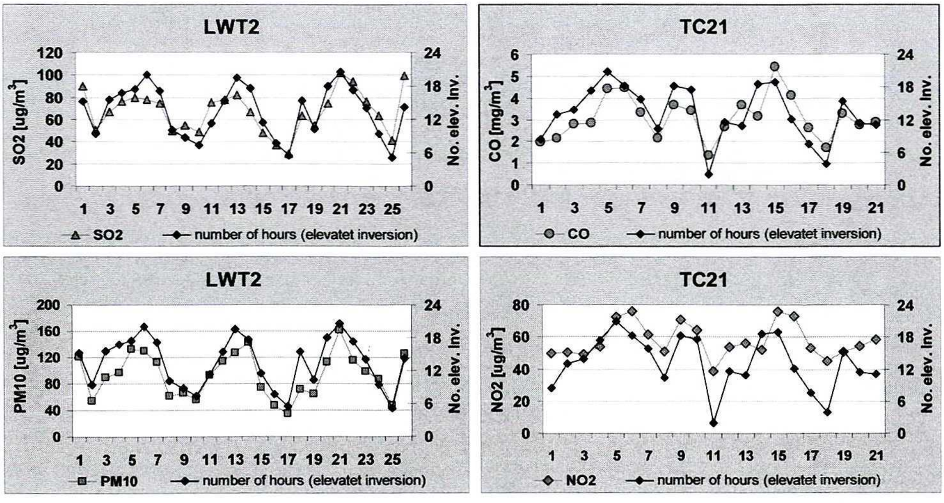

Fig. 7. Comparison between marginal means of SO2 (top left), CO (top right), NO2 (bottom right) PM10 (bottom left) and marginal means of elevated inversion presence calculated for LWT2 (SO2 and PM10) and TCN21 (NO2 and CO) classifications on the basis of data from Krakow

Acknowledgements
This work was supported by the Ministry of Science and Higher Education under the Project No. 147/COS/2006/01.

REFERENCES

[1] AIRBASE – European Air Pollution database: http://air-climate.eionet.europa.eu/databases/EuroAirnet/

[2] Blazek Z., L. Ośródka, K. Korbek, M. Wojtylak: *Concentration of suspended dust PM10 in Katowice agglomeration and Ostrava-Karvino agglomeration versus the meteorological conditions,* Wiadomości IMGW, XXIII(XLIV), **3**, 53-69 (2000).

[3] Brandt S.: *Statistical and computational methods in data analysis (Ed 3)*, Springer Verlag, New York 1997.

[4] Catalogue of the circulation type classifications of COST733 Action – http://geo21.geo.uni-augsburg.de/cost733wiki.

[5] Comrie, A.C. and B. Yarnal,: *Relationships between synoptic-scale atmospheric circulation and ozone concentrations in metropolitan Pittsburgh, Pennsylvania,* Atmos. Environ., B, 26B, **3**, 301-312 (1992).

[6] Fisher B., S. Joffre, J. Kukkonen, M. Pringer, M. Rotach, M. Schatzmann (ed.): *Meteorology Applied to Urban Air Pollution Problems – Final Report COST Action 715*, Demetra Ltd Publishers, Bulgaria 2005.

[7] Gini, Corrado: *Measurement of Inequality and Incomes,* The Economic Journal **31**: 124–126 (1921).

[8] Godłowska J., A.M. Tomaszewska: *Imisja wybranych zanieczyszczeń powietrza a procesy w warstwie granicznej - analiza statystyczna,* Wiadomości IMGW, XXIII(XLIV), **3**, 47-52 (2000).

[9] Godłowska J.: *The particulate matter PM10 air pollution in Cracow*. Wiadomości IMGW, XXVII(XLVIII), 1, 79-90 (2004).

[10] Godłowska J.: *Wpływ cyrkulacji atmosfery (wg Lityńskiego) na występowanie podwyższonych stężeń zanieczyszczeń i niekorzystnych warunków wentylacji w Krakowie,* [w:] Ekstrema pogodowe w Polsce – obserwacje, pomiary; Instytut Meteorologii i Gospodarki Wodnej, Seria: Monografie, Warszawa2008, 82-98.

[11] Godłowska J., A. M. Tomaszewska, M. Hajto: *Związek wysokości imisji zanieczyszczeń w Krakowie z warunkami w miejskiej warstwie granicznej, określonymi na podstawie danych sodarowych,* [in:] Klimat i bioklimat miast; Wyd. Uniw. Łódz., Łódź 2008, 455-465.

[12] Hess P., H. Brezowsky: *Katalog der Grosswetterlagen Europas*, Ber. dt. Wetterdienst in der US-Zone, **33**, 5, 1-39 (1952).

[13] Huth R., C. Beck, A. Philipp, M. Demuzere, Z. Ustrnul, M. Cahynová, J. Kyselý, O.E. Tveito: *Classifications of atmospheric circulation patterns: recent advances and applications*, [in:] L. Gimeno, R. Garcia Herrera, R.M. Trigo (Eds.): *Trends and Directions in Climate Research*, Ann. NY Acad. Sci., **1146**, 105–152, Wiley-Blackwell (2008).

[14] James P.M.: *An objective classification for Hess and Brezowsky Grosswetterlagen over Europe.* Theor. Appl. Climatology., **88**, 17-42 (2007).

[15] Kalkstein L.S., G. Tan, J. A. Skindlow: *An Evaluation of Three Clustering Procedures for Use in Synoptic Climatological Classification,* Journal of Climate and Applied Meteorology, **26**, 717–730 (1987)

[16] Lamb H.: *British isles weather types and a register of the daily sequence of circulation paterns, 1861-1971.* Geophysical Memoirs, **116**, 1-85 (1972).

[17] Lityński J., *Liczbowa klasyfikacja typów cyrkulacji i typów pogody dla Polski.* Prace Państwowego Instytutu Hydrologiczno-Meteorologicznego, **97**, Warszawa 1969.

[18] Lorenz M. O.: *Methods of measuring the concentration of wealth*, Publications of the American Statistical Association, **9**, 209–219 (1905).

[19] Niedźwiedź T.: *Kalendarz sytuacji synoptycznych dla dorzecza górnej Wisły (1951-1985)*, Zesz. Nauk. UJ, Prace Geogr., **71**, 37-86 (1988).

[20] Niedźwiedź T.: *Calendar of Circulation Types for Southern Poland 1873-2009.* Computer File Available at Department of Climatology, University of Silesia. http://klimat.wnoz.us.edu.pl (2010).

[21] Niedźwiedź T., Z. Ustrnul: *Influence of synoptic situations on the occurrence of weather types favorable to concentration or dispersion o fair pollution above the Upper Silesia Industrial Region,* Wiadomości IMGW, **12** (1-2), 31-39 (1989). (in Polish, summary in English).

[22] Niedźwiedź T., Z. Olecki: *Influence of synoptic situations on the air pollution in Krakow.* Zeszyty Naukowe UJ, Prace Geograficzne, **96**, 55-67 (1994). (in Polish, summary in English).

[23] Philipp A., J. Bártholy, C. Beck, M. Erpicum, P. Esteban, X. Fettweis, R. Huth, P.M. James, S. Jourdain, F. Kreienkamp, T. Krennert, S. Lykoudis, S. Michalides, K. Pianko, P. Post, D. Rassilla Álvarez, A. Spekat,

F.S. Tymvios, in press. *COST733CAT – a database of weather and circulation type classifications*. Physics and Chemistry of the Earth (2010).

[24] Piringer M., Joffre S. (ed.): *The Urban Surface Energy Budget and Mixing Height in European Cities*: Data, Models and Challenges for Urban Meteorology and Air Quality. Final Raport of Working Group 2 of COST-715 Action. Demetra Ltd Publishers, Bulgaria (2005).

[25] Walczewski J.: *Application of Sodar in Urban Air-Quality Monitoring Systems. Acoustic Remote Sensing Applications*. S.P.Singal, Springer Verb. - Narosa Publ. H., New York-New Delhi, 385-394 (1997).

[26] Walczewski J.: *Application of Acoustic Remote Sensing in Air Quality Monitoring*. Proc. Fourth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe Warsaw'98, September 1998, Warsaw, Poland. CD-ROM, Florida State University, Institute for International Cooperative Environmental Research (1999).

[27] Yarnal, B.: *Synoptic Climatology in Environmental Analysis*. Belhaven Press. London, UK. (1993).

Received: March 8, 2010; accepted: July 15, 2010.

ZWIĄZEK POMIĘDZY CYRKULACJĄ ATMOSFERY I ZANIECZYSZCZENIAMI POWIETRZA W OBSZARACH ZURBANIZOWANYCH NA TERENIE POLSKI

Określono ocenę przydatności różnych klasyfikacji typów cyrkulacji (CTCs) do różnicowania stężeń SO2, NO2, PM10 i CO w zimie w polskich obszarach zurbanizowanych. Analiza bazuje na 15 nowych klasyfikacjach obliczonych w ramach Akcji COST 733 oraz pięciu powszechnie stosowanych klasyfikacjach historycznych. Porównano i przetestowano trzy metody oceny jakości klasyfikacji: EV - wyjaśnianej wariancji, WSD - wewnątrzklasowego odchylenia standardowego i metodę Giniego. Ostatecznie ocenę jakości CTCs dla zróżnicowania dobowych wartości stężeń zanieczyszczeń a także warunków dyspersji pionowej przeprowadzono opierając się na metodzie EV, zaś ocenę przydatności klasyfikacji do prognozowania wystąpienia epizodów smogowych w Krakowie wykonano stosując metodę Giniego. Zaprezentowano także metodologię wyboru dni z epizodami smogowymi opartą na wartości 90 percentyla stężeń.

Najlepsze rezultaty, dla pojedynczych serii danych a także dla epizodów smogowych, otrzymano dla klasyfikacji Hess-Berezowski (HBGWL). Ponadto dobre rezultaty uzyskano dla opartej na analizie składowych głównych klasyfikacji PCACA, klasyfikacji Niedźwiedzia, zmodyfikowanych w ramach Akcji COST 733 klasyfikacjach Lityńskiego LITTc, Lamba LWT2 i HBGWL (GWTC26, OGWL, OGWLSLP). Te same klasyfikacje, z wyjątkiem HBGWL i jej modyfikacji, są dobre dla różnicowania danych sodarowych. Dla najlepszych klasyfikacji różnice średnich stężeń dla różnych klas są widoczne, jakkolwiek duży rozrzut wewnątrz klas jest ciągle obserwowany. Najwyższe stężenia zanieczyszczeń obserwowane są dla adwekcji mas powietrznych z kierunków SE, S i SW. Korelacje pomiędzy wielkością imisji i danymi sodarowymi, obliczone dla średnich brzegowych uzyskanych dla różnych klas, potwierdziły negatywną rolę zarówno niskiej wysokości przygruntowej inwersji, jak i długotrwałego utrzymywania się niskich inwersji wzniesionych.