RELATIONSHIP BETWEEN THE PÉCZELY'S LARGE-SCALE WEATHER TYPES AND AIR POLLUTION LEVELS IN SZEGED, SOUTHERN HUNGARY

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SUMMARY

This paper determines the 13 Péczely's large-scale weather situations over the Carpathian Basin with the levels of the main air pollutants for the winter and summer months. Based on the ECMWF data set, daily sea-level pressure fields analysed at 00 UTC were prepared for each Péczely-type in order to relate their sea-level pressure patterns to the levels of air pollutants in Szeged. The database comprises daily values of 12 meteorological and 8 pollutant parameters for the period 1997-2001. Concentration of air pollutants occured exclusively during anticyclonic conditions, or anticyclone-ridge situations. Their dispersion can be experienced not only during cyclonic, but also anticyclone-ridge weather types. CO, SO_2 and TSP were sensitive to Péczely's weather classification, while NO_2/NO, O_3 and O_{3max} were completely insensitive. After all, anticyclonic weather types are determinant in winter, while their role in classifying concentrations of the air pollutants is less predominant during summer.

KEYWORDS: Péczely's large-scale weather situations, air pollution, ANOVA, weather classification, Szeged, Hungary.

INTRODUCTION

Though levels of some pollutants have already shown moderately increasing trends [1, 2], or in some cases, due to local regulation policy, decreasing trends [3], air pollution remains a global environmental problem until using organic-based energy sources.

In Europe, many of air pollution studies, especially for Athens, have appeared in the international literature, due to its long summers with undisturbed irradiation and calm or light breezes. The weather of Athens and the presence of mountains to the north of the city, favour the extreme accumulation of air pollutants [4-10]. In Budapest, according to Péczely's observations [11], air pollution levels tend to have peak values during extensive anticyclone events characterized by light easterly breezes prevailing over the city. Conversely, air pollution levels are relatively low during the prevalence of cyclonic weather systems, characterized by strong and turbulent airflow prevailing over the Carpathian Basin (Fig. 1), especially when Hungary was in the rear part of the cyclone.

Studies on the relationship between synoptic weather conditions and pollution levels are carried out either using objective multivariate statistical methods, or subjective classifications based on the long experience of meteorologists.

Examples of objective approaches are the works of Kalkstein & Corrigan [12], McGregor & Bamzelis [13], and Sindosi et al. [14], who classified air mass types (in fact, weather types), and then investigated the corresponding Main Air Pollutant (MAP) concentrations for regions of the US, Birmingham (UK) and Athens (Greece), respectively.

On the other hand, subjective methodologies were also used by several authors producing subjective weather classifications (e.g. Baur [15], Dzerdzeevski [16], Girs [17], Hess & Brezowsky [18], Károssy [19, 20], Kassomenos et al. [21-23], Pasquill [24], Péczely [25, 26] and Turner [27]). Studies on the topic, however, even in the form of papers [12-14] did not completely elaborate the role of weather types in classifying air pollutants, and they have only partly solved the task. The present study, contrary to those, aims at fully detecting the relationships between the Péczely's weather-types and the levels of air pollutants. Furthermore, the daily mean pollutant levels were classified for the first time in the region of the Carpathian Basin based on Péczely's weather-types.

The aim of the present study was to analyze whether the subjective classification system of weather types established by Péczely for the Carpathian Basin [25, 26], being

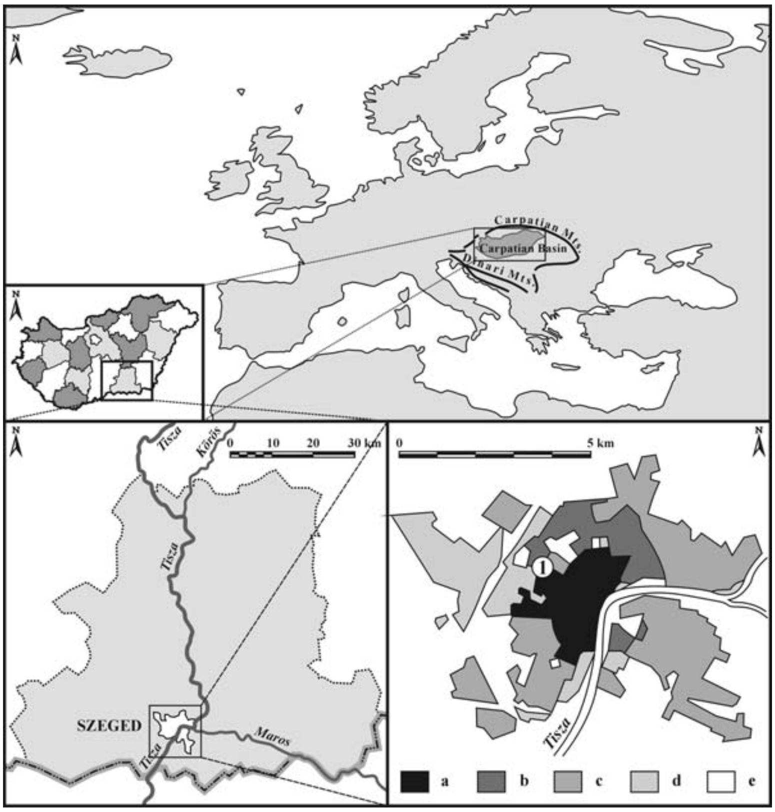


FIGURE 1
Location of the Carpathian Basin (upper large panel), Csongrád county in Hungary (upper panel, low left), Szeged in Csongrád county (low left panel) and the urban web of Szeged (low right panel):[a: centre (2-4-storey buildings); b: housing estates with prefabricated concrete slabs (5-10-storey buildings); c: detached houses (1-2-storey buildings); d: industrial areas; e: green areas, (1): monitoring station].

characteristically over Szeged, Hungary, is suitable for classifying air pollution levels. The basis of classifying weather types is the position, extension and development of cyclones and anticyclones relative to the Carpathian Basin considering the daily sea-level pressure maps available at 00:00 UTC (Universal Time Centre) in the North-Atlantic–European region [25, 26].

MATERIALS AND METHODS

Topography and data collection

The city of Szeged (20°06' E; 46°15' N) is the largest town in southeast Hungary, and located at the confluence of the Tisza and Maros rivers. It is characterized by an extensive flat landscape with an elevation of 79 m a.s.l. (Fig. 1). The built-up area covers a region of about 46 km^2 with about 155,000 inhabitants. The climate of Szeged is characterized by hot summers and moderately cold winters. The distribution of rainfall is fairly uniform during the year. The mean daily summer temperature is 22.4 °C, while that of winter is 2.3 °C. Based on the climatological characteristics of the period 1901-1950, the climate of Szeged can be considered to be warm-dry [28].

The air pollution database used consists of 30-min data sets for winter [December, January and February (DJF)] and summer [June, July and August (JJA)] over the 5-years period 1997–2001. Daily values (average diurnal mass concentrations) of 6 pollutants [*CO* ($mg \cdot m^{-3}$); *NO* ($\mu g \cdot m^{-3}$), NO_2 ($\mu g \cdot m^{-3}$), SO_2 ($\mu g \cdot m^{-3}$), O_3 ($\mu g \cdot m^{-3}$) and total suspended particulates (*TSP*) ($\mu g \cdot m^{-3}$)] have been used, together with the daily ratios of NO_2/NO and the daily maximum concentrations of O_3 ($\mu g \cdot m^{-3}$).

The air pollution monitoring station is located in downtown Szeged, at one of the busiest crossroads with heavy traffic. A 2-storey building is located at a distance of 10 m from the monitoring station, which affects wind and irradiance parameters. Sensors measuring the concentrations of air pollutants are placed 3 m above ground surface.

The meteorological database used consisted of 30-min data sets for winter (DJF) and summer (JJA) for the above-mentioned 5-years period. Daily values of the meteorological parameters were used [mean temperature (T_{mean}, °C), maximum temperature (T_{max}, °C), minimum temperature (T_{min}, °C), daily temperature range ($\Delta T = T_{max} - T_{min}$, °C), wind speed (WS, $m \cdot s^{-1}$), relative humidity (RH, %), irradiance (I, $MJ \cdot m^{-2} \cdot day^{-1}$), saturation vapor pressure (E, hPa), water vapor pressure (VP, hPa), potential evaporation (PE, mm), dew point temperature (T_d, °C) and atmospheric pressure (P, hPa)].

On the basis of daily sea-level pressure fields plotted at 00 UTC from the ECMWF (European Centre for Medium-Range Weather Forecasts) Re-Analysis ERA 40 project, daily data have been re-analyzed since September 1st, 1957.

The investigated area covers the North-Atlantic- European region between 30° N–70.5° N latitudes and 30° W–45° E longitudes. The grid network was selected with a density of 1.5° x 1.5°, which indicates 28 x 51 = 1428 grid points for the region.

The Péczely's large-scale weather situations

The daily catalogue of the 13 large-scale weather types was first determined by Péczely for the period between 1877- 1956 [25], and later completed by him, till the end of 1982 [26]. After the death of Péczely in 1984, the daily classification of weather types was performed by Károssy [19, 20], with the same subjective methodology. The relation of Péczely's weather types with air pollution levels has already been studied as an application of the Makra-test [29]. The Makra-test was suitable for detecting whether a given individual Péczely type is favourable for significant accumulation or dilution of a given pollutant. Nevertheless, comparison of the efficiency of Péczely weather types in enriching or weakening pollutant concentrations, as an overall analysis of the above object, has not yet been performed. For each Péczely's large-scale weather situation (Péczely macrosynoptic type), the concentration of the main air pollutants in the area of Szeged was calculated in order to reveal the possible relationship between the prevailing atmospheric conditions and the spatial distribution of mean sea-level pressure fields. Furthermore, when characterizing the Péczely's large-scale weather types, their efficiency was statistically evaluated in grouping pollutant concentrations.

Péczely defined 13 large-scale weather situations [25], selecting and presenting the most characteristic (i.e. typical) day for each of them. The classification was based on the position, extension and development of cyclones and anticyclones relative to the Carpathian Basin, considering the daily sea-level pressure maps constructed at 00 UTC over the North-Atlantic–European region. The daily sea-level pressure maps, which Péczely used in order to determine his large-scale weather types, have been prepared by the Hungarian Meteorological Service.

The 13 weather types with their typical days are the following [25, 26]:

Types connected with northerly airflow

Type 1 (mCc): Hungary lies in the rear part of an East-European cyclone (typical day: 28 August, 1981)

Type 2 (AB): anticyclone over the British Isles (typical day: 6 April, 1981)

Type 3 (CMc): Hungary lies in the rear part of a Mediterranean cyclone (typical day: 17 December, 1981)

Types connected with southerly airflow

Type 4 (mCw): Hungary lies in the fore-part of a West-European cyclone (typical day: 20 September, 1981)

Type 5 (Ae): anticyclone east of Hungary (typical day: 15 February, 1982)

Type 6 (CMw): Hungary lies in the fore-part of a Mediterranean cyclone (typical day: 14 January, 1981)

Types connected with westerly airflow

Type 7 (zC): zonal, cyclonic (typical day: 4 February, 1981)

Type 8 (Aw): anticyclone extending from the west (typical day: 22 August, 1982)

Type 9 (As): anticyclone south of Hungary (typical day: 22 November, 1981)

Types connected with easterly airflow

Type 10 (An): anticyclone north of Hungary (typical day: 26 February, 1981)

Type 11 (AF): anticyclone over Fennoscandia region (typical day: 28 March, 1981)

Types of pressure centres

Type 12 (A): anticyclone over the Carpathian Basin (typical day: 14 January, 1982)

Type 13 (C): cyclone over the Carpathian Basin (typical day: 2 January, 1982)

In the present study, the Péczely classification is used for each winter and summer day studied during 1997-2001. The classification [20] was based on the 00 UTC sea-level pressure maps over North Atlantic and Europe, produced by the Hungarian Meteorological Service. Afterwards, using the ECMWF database, the pressure patterns of the days belonging to each of the 13 categories were averaged. Thus, mean daily sea-level pressure maps for the 13 Péczely types were constructed and used as new basis for further analyses.

Cartographical background

Maps of the mean sea-level pressure fields belonging to the Péczely's weather types, contrary to those in other papers, were prepared by using the database of the ECMWF Re-Analysis ERA–40 project, with the help of the standard Kriging method and the Surfer 7.00 software for the North-Atlantic – European region in the examined period. As a result, a precise analysis of the macrosynoptic background of the 13 Péczely's weather types was able to be carried out. Isobars for an average day, i.e. for an average Péczely-type, were drawn by using 28 x 51=1428 grid data.

Statistical tests

In order to decide whether the sea-level pressure fields differ significantly from each other, the χ^2-test was applied.

This method determines whether two random variables are independent. According to the null hypothesis, they are not independent.

Péczely determined his 13 large-scale weather types on the basis of daily sea-level pressure fields at 00 UTC, excluding pollution data. Hence, the differences of the mean pollution levels calculated for each Péczely's large-scale weather type need a further statistical evaluation. This was performed by the method of one-way analysis of variance (ANOVA) for each pollutant. By using this method, significant differences in pollutant concentrations in the different Péczely's weather types can be determined. Finally, Tukey's honestly significant difference test was applied in order to compare the mean air pollution levels between each pair of the Péczely's large-scale weather types quantitatively (pairwise multiple comparisons) [13, 14].

All statistical computations were performed with SPSS (Version 9.0) software.

RESULTS

χ^2-test, independence analysis

Mean sea-level pressure fields for the 13 Péczely's weather types were compared on the basis of the used grid values. In order to decide whether the mean sea-level pressure fields of the 13 Péczely types differ significantly from the 13 typical days of the Péczely types, respectively, the χ^2-test was applied. The null hypothesis implied that there is no significant difference between the sea-level pressure fields compared.

In the winter months, the probability of the null hypothesis for each sea-level pressure field pair was 0. This means that all the 13 Péczely types differed significantly from the corresponding 13 typical days of the Péczely types. Furthermore, the mean sea-level pressure fields of all the 13 Péczely types differed significantly from each other.

In the summer months, all the 13 Péczely types were also found to differ significantly from the corresponding 13 typical days of the Péczely-types.

On the other hand, 70.5 % of all the possible pairs of the mean sea-level pressure fields of the 13 Péczely-types differed significantly from each other. Besides, sea-level pressure fields of all the 13 typical days of the Péczely-types also differed significantly from each other.

Péczely characterised his 13 weather types on the sea-level pressure maps of their typical days. However, our analysis concerns mean daily sea-level pressure fields for the summer and winter months, between 1997 and 2001. According to the above results of this chapter, the sea-level pressure fields of all the 13 Péczely types both in winter and summer months, were significantly different from those belonging to the corresponding typical days of the Péczely types. Hence, further climatic analyses of the 13 Péczely types for the period indicated are required.

Characteristics of the Péczely's large-scale weather types in winter

The main characteristics of the 13 Péczely's weather types involving the prevailing ones are shown in Table 1, presenting the mean values of their meteorological parameters, as well as those of the corresponding pollution parameters. Considering the basic statistical parameters of the pollutants, the standard deviations from the means for NO_2 and SO_2 are 1.5-fold those of the other pollutants. The highest values occurred during anticyclonic (type 12) or anti-cyclonic-ridge (types 9 and 10) weather situations. The difference $|median - average|$ in Péczely types remained within the

TABLE 1 - Mean values of the meteorological and air pollution parameters for the days belonging to the 13 Péczely's weather types, winter months (DJF), 1997-2001.

Péczely-types	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of cases (days)	42	35	3	25	65	41	19	67	38	25	8	73	10
Freqency (%)	9.3	7.8	0.7	5.5	14.4	9.1	4.2	14.9	8.4	5.5	1.8	16.2	2.2
T_{mean} (°C)	3.7	0.3	0.8	3.4	4.9	3.1	6.0	2.8	4.1	0.2	-5.0	0.8	4.1
T_{max} (°C)	7.6	2.8	4.9	6.8	3.9	5.4	10.1	6.3	9.7	1.2	-2.4	3.6	5.4
T_{min} (°C)	1.1	-3.3	-3.0	0.1	-2.6	0.7	2.6	-0.9	1.0	-3.9	-7.8	-2.4	0.8
$\Delta T = T_{max} - T_{min}$, (°C)	6.5	6.1	7.9	6.7	6.4	4.7	7.5	7.2	8.7	5.1	5.4	6.0	4.6
WS (m s^{-1})	0.9	0.8	1.2	0.9	0.6	0.9	0.8	0.6	0.6	0.6	0.6	0.4	0.5
RH (%)	79.6	82.1	83.3	81.3	82.4	81.9	82.1	74.5	77.8	80.8	87.5	77.4	82.2
I (MJ m^{-2})	7.5	9.0	14.8	6.7	6.4	4.7	5.0	10.3	9.1	8.8	12.2	8.9	7.4
E (hPa)	11.1	8.7	9.7	10.8	9.1	10.7	12.9	10.8	11.3	8.7	6.0	9.1	11.5
VP (hPa)	8.8	7.1	8.4	8.8	7.3	8.8	10.7	7.9	8.7	7.1	5.2	6.9	9.5
PE (mm)	1.1	0.8	0.8	1.0	0.9	1.0	1.2	1.3	1.3	0.9	0.4	1.0	1.1
T_d (°C)	0.7	-2.2	-1.4	0.7	-2.0	0.5	3.3	-1.2	0.6	-2.7	-6.6	-2.6	1.6
P (hPa)	1009.1	1025.8	1011.2	1011.7	1026.1	1011.6	1014.7	1023.8	1024.4	1027.5	1026.3	1028.5	1005.2
CO (μg m^{-3})	640.2	654.6	521.0	674.1	819.8	723.3	947.5	729.8	1001.0	701.3	743.5	979.2	817.3
NO (μg m^{-3})	22.7	22.0	25.9	30.6	27.1	22.0	36.8	29.6	42.2	14.2	10.6	35.1	26.8
NO_2 (μg m^{-3})	39.2	33.8	38.2	40.1	38.4	34.4	41.1	44.3	49.6	32.8	11.1	46.1	37.6
NO_2/NO	1.7	1.5	1.5	1.3	1.4	1.6	1.1	1.5	1.2	2.3	1.0	1.3	1.4
O_3 (μg m^{-3})	27.3	28.4	39.7	29.3	24.3	23.9	23.0	24.1	19.0	26.3	22.9	23.0	28.1
O_{3max} (μg m^{-3})	47.7	48.3	81.0	45.8	46.7	39.6	46.0	45.5	41.0	43.5	42.5	46.3	41.9
SO_2 (μg m^{-3})	9.5	11.6	9.1	10.4	12.4	9.5	10.5	12.8	10.0	14.8	22.4	11.4	12.8
TSP (μg m^{-3})	38.8	49.0	57.0	39.4	60.6	41.2	55.0	51.4	66.2	50.8	56.7	61.1	44.1

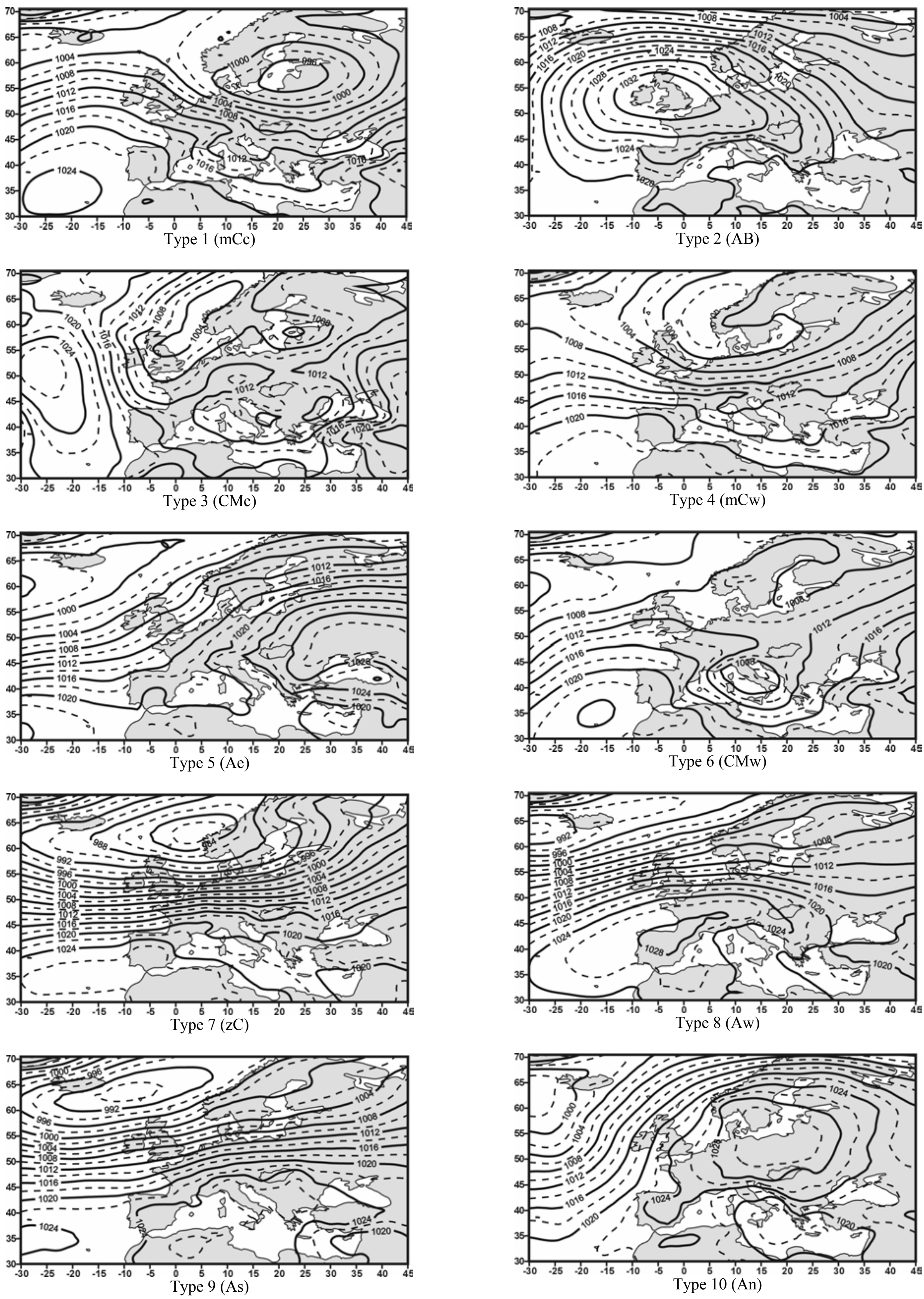
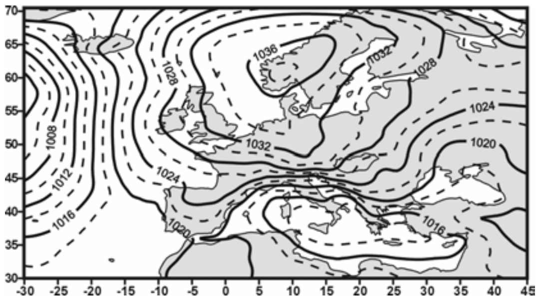
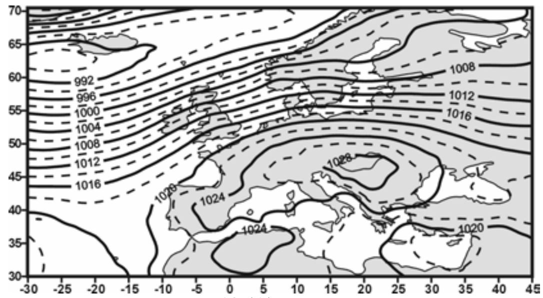


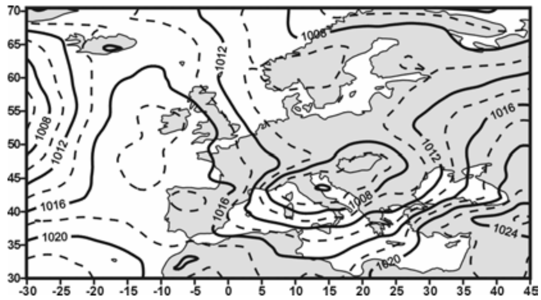
FIGURE 2a - Mean sea-level pressure fields belonging to the 13 Péczely's weather types, North-Atlantic – European region (winter months (DJF), 1997-2001).



Type 11 (AF)



Type 12 (A)



Type 13 (C)

FIGURE 2b - Mean sea-level pressure fields belonging to the 13 Péczely's weather types, North-Atlantic – European region (winter months (DJF), 1997-2001).

TABLE 2 - ANOVA statistics for the Péczely's inter–weather type comparison of air pollutant concentrations (winter months (DJF), 1997-2001).

	CO	NO	NO_2	NO_2/NO	O_3	O_{3max}	SO_2	TSP
Mean square between groups	633403.69	2019.87	1528.32	351.92	308.07	576.47	156.31	2976.86
Mean square within groups	135843.81	612.13	240.57	207.28	200.14	513.27	66.85	510.32
F-Ratio	4.66	3.30	6.35	1.70	1.54	1.12	2.34	5.83
Level of significance, %	99.00	99.00	99.00	94.00	89.00	66.00	99.00	99.00

inter-quartile half extent (the interval given by the lower quartile and the upper one) for each pollutant. How-ever, there are characteristic types for which the mentioned difference was found beyond the inter-quartile half extent: type 4 (CO, NO_2/NO, TSP), type 9 (NO_2/NO, O_3, SO_2), and type 12 (all pollutants). During clear-sky conditions, the levels of each pollutant seemed to increase considerably. The mean sea-level pressure distributions belonging to the 13 Péczely's weather types are shown in Figs. 2a-b.

ANOVA-statistics for the individual Péczely types: In order to determine the influence of the Péczely's weather types on pollutant levels, an analysis of variance (ANOVA) was performed on the pollutant parameters. The results are shown in Table 2. It can be observed that, except for NO2/NO, all the primary pollutants presented significant Péczely's inter–weather type differences in means at the 99 % probability level. However, for the secondary pollutants, the above differences were significant only at the 89% (O3) and 66% (O3max) probability levels, respectively. Considering that differences are found among the mean levels of the primary pollutants, Tukey's test was applied in order to receive a pairwise multiple assessment of the differences.

The statistically significant differences are shown in Table 3 at 95 and 99 % probability levels, respectively. It can be seen that the pairs of Péczely types 6-9 differed significantly for five pollutants (CO, NO, NO_2, NO_2/NO, TSP) of the eight, while the types 6-12 differed substantially for four pollutants (CO, NO_2, NO_2/NO, TSP). Furthermore, types 1-9 and 2-9 showed important differences for three pollutants (CO, NO, TSP and CO, NO, NO_2, respectively) (Table 3). Generally, the Péczely types 6 and 9 can be considered to be the most different ones, since levels of the most pollutant pairs showed substantial differences for them (Table 3). This can mainly be explained by their different sea-level pressure systems. On the one hand, during type 6, the Carpathian Basin lies in the front part of a Mediterranean cyclone. This type induces high wind speed with cloudy and rainy weather, which favor dilution of air pollutants. On the other hand, type 9 is an anticyclonic ridge situation, when the Carpathian Basin lies under the northern ridge of an extended high pressure system over the Mediterranean. In this case, the region is characterized by clear, undisturbed weather, which favors extreme accumulations of the air pollutants (Figs. 2a-b; Tables 1 and 3). Furthermore, Péczely type 3 seems to be an intermediate type considering pollution, since it shows no pairwise differences (Table 3).

Characteristics of the Péczely's large-scale weather types in summer

The main characteristics of the 13 Péczely's large-scale weather situations are shown in Table 4, which presents the mean values of both their meteorological variables and those of the corresponding pollution parameters.

TABLE 3 - Péczely's weather type – air pollution difference matrix. Pollutants appearing in the matrix cells indicate significant differences in their concentrations between two given Péczely's weather types according to Tukey's Honestly Significant Difference Test (winter months (DJF; normal characters: 95 % of significance; bold characters: 99 % of significance).

	1	2	3	4	5	6	7	8	9	10	11	12
2												
3												
4												
5	**TSP**			**TSP**								
6					NO_2 vsNO **TSP**							
7						NO_2 vsNO						
8												
9	**CO** NO **TSP**	**CO** NO **NO_2**		CO **TSP**		CO NO_2 vsNO NO **NO_2** **TSP**		CO				
10									**NO** **NO_2**			
11	**NO_2** **SO_2**	NO_2 SO_2		**NO_2** SO_2	**NO_2**	**NO_2** **SO_2**	**NO_2** SO_2	**NO_2**	**NO_2** **SO_2**	NO_2		
12	**CO** **TSP**	**CO** **NO_2**		CO TSP		CO NO_2 vsNO **NO_2** **TSP**		**CO**		NO NO_2	**NO_2** SO_2	
13											NO_2	

TABLE 4 - Mean values of the meteorological and air pollution parameters for the days belonging to the 13 Péczely's weather types (summer months (JJA), 1997-2001).

Péczely-types	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of cases (days)	71	45	5	14	39	16	2	75	20	37	42	62	31
Freqency (%)	15.5	9.8	1.1	3.1	8.5	3.5	0.4	16.3	4.4	8.1	9.2	13.5	6.6
T_{mean} (°C)	21.7	20.8	18.4	22.3	24.8	20.9	22.1	22.6	23.1	23.2	22.2	23.5	20.6
T_{max} (°C)	28.2	25.9	22.3	28.5	31.5	25.3	27.2	27.8	29.8	29.1	27.7	30.5	24.6
T_{min} (°C)	17.3	15.2	15.8	16.4	19.4	16.5	16.2	17.4	16.6	17.7	16.2	17.2	16.2
$\Delta T = T_{max} - T_{min}$, (°C)	10.9	10.7	6.5	12.1	12.1	8.8	11.0	10.4	13.2	11.4	11.6	13.3	8.4
WS ($m\ s^{-1}$)	1.1	1.0	1.0	0.9	1.0	1.4	1.0	1.0	0.8	0.8	1.0	0.8	1.3
RH (%)	71.3	65.8	82.3	68.7	64.3	73.3	75.5	68.2	66.3	65.6	66.9	61.2	74.6
I ($MJ\ m^{-2}$)	20.1	25.2	12.3	21.5	21.5	17.6	20.4	22.8	25.7	21.7	22.2	25.9	15.9
E (hPa)	36.1	34.3	28.9	37.7	44.4	34.5	36.9	38.4	40.0	39.7	37.1	40.8	34.0
VP (hPa)	25.7	22.5	23.7	25.9	27.7	24.7	27.7	25.9	26.3	25.6	24.5	24.5	24.8
PE (mm)	4.5	4.8	2.6	5.0	6.5	4.2	4.2	5.2	5.6	5.7	5.1	6.3	4.0
T_d (°C)	16.6	14.5	15.6	16.6	17.9	16.1	18.0	16.7	16.9	16.7	15.9	15.9	16.1
P (hPa)	1010.7	1018.7	1015.6	1014.0	1017.3	1011.7	1013.8	1016.0	1014.6	1017.2	1016.7	1017.8	1009.1
CO ($\mu g\ m^{-3}$)	361.5	253.1	390.1	346.8	496.5	296.7	385.9	323.0	354.8	407.3	340.2	392.5	328.9
NO ($\mu g\ m^{-3}$)	7.3	4.6	7.2	6.7	10.4	5.5	10.3	5.1	8.6	8.7	6.5	8.0	6.4
NO_2 ($\mu g\ m^{-3}$)	27.1	18.7	27.8	25.8	34.9	25.3	36.9	24.1	30.9	26.6	23.8	29.2	25.9
NO_2/NO	3.7	4.1	3.9	3.9	3.4	4.6	3.6	4.7	3.6	3.1	3.7	3.7	4.0
O_3 ($\mu g\ m^{-3}$)	55.5	54.1	58.7	55.7	60.9	53.6	59.0	63.1	57.1	58.2	55.1	63.2	61.8
O_{3max} ($\mu g\ m^{-3}$)	99.0	94.8	107.7	94.8	105.4	97.4	116.4	106.9	103.6	106.1	102.5	112.0	101.7
SO_2 ($\mu g\ m^{-3}$)	4.5	3.6	3.5	4.3	6.2	2.9	1.9	3.9	6.1	4.4	3.3	5.0	4.1
TSP ($\mu g\ m^{-3}$)	36.2	33.8	26.3	34.2	50.8	39.1	40.2	36.5	40.6	39.4	39.3	41.5	32.6

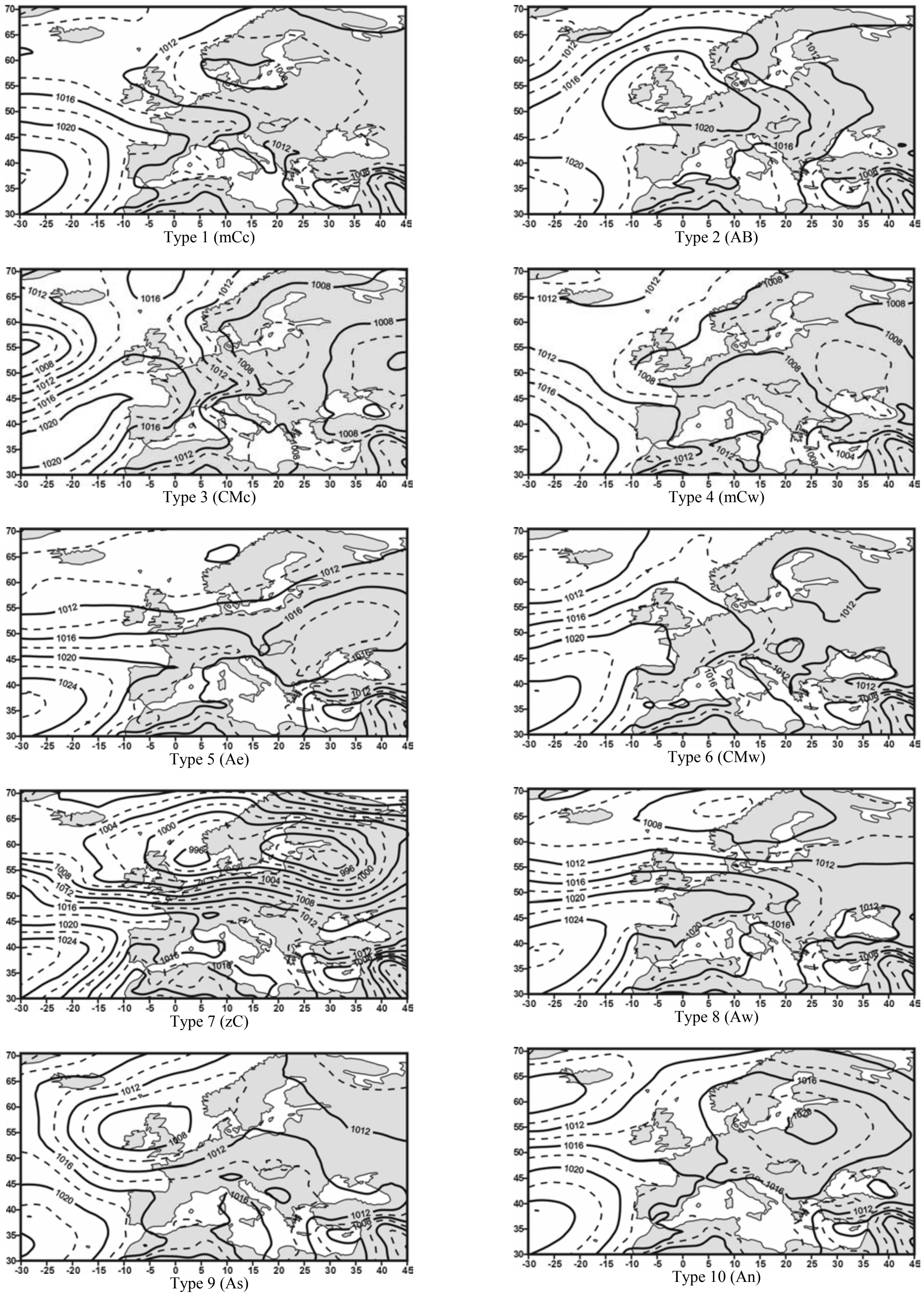


FIGURE 3a - Mean sea-level pressure fields belonging to the 13 Péczely's weather types, North-Atlantic – European region (summer months (JJA), 1997-2001).

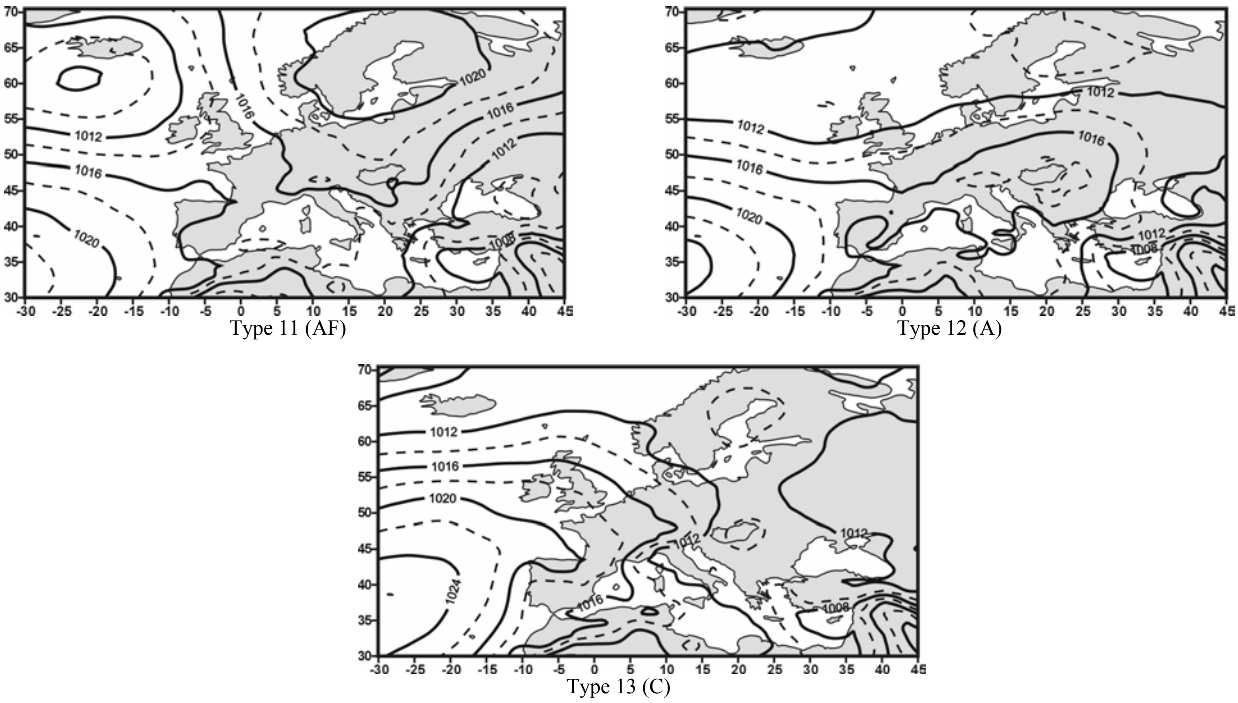


FIGURE 3b - Mean sea-level pressure fields belonging to the 13 Péczely's weather types, North-Atlantic – European region (summer months (JJA), 1997-2001).

Basic statistical parameters of the pollutants were calculated for the summer months, too. Variation coefficients for O_3 and O_{3max} decreased to half of their values measured in winter months. Highest values occurred under the same large-scale weather types than in winter; namely, when an anticyclone (type 12) or anticyclonic ridges (types 9 and 10) ruled the Carpathian Basin.

The characteristic types, for which the difference $|median - average|$ was found beyond the inter-quartile half extent, are as follows: type 2 (CO, NO, NO_2), type 6 (CO, NO_2/NO, SO_2), type 11 (NO_2, O_3, SO_2), and type 12 (CO, NO, NO_2, NO_2/NO, SO_2). This indicates that distribution functions of the pollutant concentrations are distorted when an anticyclone (type 12) or anticyclonic ridges (types 2 and 11) control the weather in Carpathian Basin region. The only exception is type 6 (a Mediterranean cyclone with its centre over the Adriatic Sea influencing the weather of the Carpathian Basin), and, namely during these types, the means of the samples are not representative for the data sets.

The mean sea-level pressure distribution over the North-Atlantic–European region belonging to the 13 Péczely's large-scale weather types examined and the variation of the number of days within the summer season are presented in Figs. 3a-b.

ANOVA-statistics for the individual Péczely types: Similarly to winter months, significance of Péczely's inter-weather type differences in pollutant levels was determined by ANOVA (Table 5). Means of CO, NO, NO_2, SO_2 and TSP present significant Péczely's inter-weather type differences at the 99 % probability level, while NO_2/NO at the 97, O_3 at the 98, and O_{3max} at the 86% levels, respectively.

Performing the pairwise comparisons (Tukey's honestly significant difference tests), the statistically significant differences are presented in Table 6 at 95 and 99 % probability levels, respectively. There are no two weather types for which Péczely's inter-weather type differences in concentrations of all 8 pollutants are significant. Moreover, in the summer months, the Péczely types seem not to characterize the classification of air pollutants, as in winter. While in the winter months 34.6 % of the pairs of the Péczely types indicated significant differences for one or more pollutants, in the summer months this value was only 19.2 %. The highest inter-weather type difference was indicated by five pollutants (CO, NO, NO_2, SO_2, TSP) for the types 2-5 and 5-8, and by four pollutants (CO, NO_2, SO_2, TSP) for types 5-11. Of the total 78 pairs of Péczely types, 63 pairs (80.8 %) were most similar, since no significant differences in the levels among the pollutants can be detected (Figs. 3a-b; Tables 4 and 6).

Generally, Péczely types 2, 5 and 8 differed mostly from the others, since pairwise multiple comparison between Péczely types 2-5 and 5-8 showed significant differences for the levels of 5 of the 8 pollutants examined (Table 6). All these 3 types were anticyclonic ridges, and their wind speed was the same. However, the lowest levels of pollutants in type 2 can be explained by the relatively more intense vertical airflows caused by an unstable atmosphere attributed to the lowest minimum temperature. Type 5 was warm and dry with high humidity and clear weather, favoring highest air pollutant values, but type 8, with its high irradiance and clear weather, was beneficial to higher ozone levels (Figs. 3a-b; Tables 4 and 6).

At the same time, type 7 seemed to be an intermediate situation considering pollution, since no pairwise differences could be detected (Table 6).

TABLE 5 - ANOVA statistics for the Péczely's inter–weather type comparison of air pollutant concentrations (summer months (JJA), 1997-2001).

	CO	NO	NO_2	NO_2/NO	O_3	O_{3max}	SO_2	TSP
Mean square between groups	146098.66	116.11	655.43	1904.14	552.24	1128.35	30.98	949.66
Mean square within groups	25056.82	38.09	133.99	941.22	271.83	760.90	11.47	167.06
F-Ratio	5.83	3.05	4.89	2.02	2.03	1.48	2.70	5.68
Level of significance, %	99.00	99.00	99.00	97.00	98.00	86.00	99.00	99.00

TABLE 6 - Péczely's weather type – air pollution difference matrix. Pollutants appearing in the matrix cells indicate significant difference in their concentrations between two given Péczely's weather types, according to Tukey's Honestly Significant Difference Test (summer months JJA; normal characters: 95 % of significance; bold characters: 99 % of significance).

	1	2	3	4	5	6	7	8	9	10	11	12
2	CO **NO_2**											
3												
4												
5	**CO** NO_2 **TSP**	**CO** **NO** **NO_2** SO_2 **TSP**	**TSP**	**TSP**								
6	NO_2 vs NO				**CO** SO_2							
7												
8					**CO** **NO** **NO_2** SO_2 **TSP**							
9		**NO_2**										
10		**CO**			**TSP**							
11					**CO** **NO_2** **SO_2** **TSP**							
12		**CO** **NO_2**			TSP							
13					**CO** **TSP**							

DISCUSSION

This paper has analyzed the levels of air pollutants in Szeged, in relation to the sea-level pressure based on the subjectively defined Péczely's weather types over the Carpathian Basin. Specific large-scale weather situations both for winter and summer months were found to play a significant role in the pollutant levels in downtown Szeged. Since no ozone parameters showed significant Péczely's inter-weather type differences in mean concentrations, neither in summer nor in winter months, the secondary pollutants were omitted from further consideration.

The analysis was focused on two extreme seasons, winter and summer, showing the most distinct difference in atmospheric circulation over the Carpathian Basin. Based on the Péczely's large-scale weather types, determined daily for the 103-years period (1881-1983), in summer the subtropical (Azores) anticyclone of the Atlantic is the most dominant of all the circulation types, with 19.5 and 26.5 % frequencies, respectively [26]. Northerly airflows are also characteristically because of blocking anticyclones. In winter, southerly airflows are the most characteristic ones, followed by the westerly ones. In both seasons, anticyclonic weather conditions are the most frequent ones over the Carpathian Basin, prolonged and enhanced from the basin character of the region [26].

In the winter, the mean sea-level pressure fields of the 13 Péczely types indicated a more definite difference than in summer. This might be explained by the fact that in winter the sea-level pressure patterns were much more characteristically due to higher pressure gradients. Hence, the large-scale weather types can be distinguished more clearly. This result is in accordance with that received when seasonal sea-level pressure maps of objectively defined weather types were compared. Nevertheless, it should be noted that either in winter or summer, mean sea-level pressure fields of the 13 Péczely types determined for the period examined differed significantly from the 13 typical days of the Péczely types, respectively. This means that though a daily sea-level pressure map at 00 UTC in the North-Atlantic–European region can be identified as a given Péczely type, it may significantly differ from that of its typical Péczely type. This is a deficiency of the procedure and can be attributed to the subjective weather typology. On the other hand, an objective classification of weather types may lead to similar results [30; 31].

Results for the winter months revealed that the primary pollutants appeared with higher concentrations when both cloudiness and wind speed were low (Péczely types 9 and 12; Figs. 2a-b; Tables 1 and 3). This was the case when an anticyclone ruled the region south of Hungary influencing the weather of the country, which corresponded to an anticyclonic ridge situation (type 9; Fig. 2a; Tables 1 and 3), or an anticyclone situation over the Carpathian Basin (type 12; Fig. 2b; Tables 1 and 3). Low concentrations of primary pollutants were detected when Hungary lied in the front part of a Mediterranean cyclone (type 6; Fig. 2a; Tables 1 and 3). This type induced high wind speed with cloudy and rainy weather, which favored dilution of air pollutants. Furthermore, type 6 (12 pairwise differences), type 9 (18), type 11 (18) and type 12 (15) were found to be the most important large-scale weather types in the categorisation of pollutant concentrations. Among them, type 6 [with the most frequent pairwise differences of NO and NO_2 (3-3 cases)], is a cyclonic weather type, while type 9 [CO, NO, NO_2 (4-4 cases)] and type 11 [NO_2 (10 cases), SO_2 (6 cases)] are anticyclonic ridges, and type 12 [CO (5 cases)] is an anticyclone centre situation. On the other hand, type 3 (with 0 pairwise difference), type 7 (3), type 8 (3) and type 13 (1) can be regarded as intermediate situations. Hence, their role is negligible in classification of pollutant levels (Figs. 2a-b; Tables 1 and 3).

Results for the summer months indicated that the primary pollutants showed higher levels when cloudiness was low and light breezes occurred (Péczely types 5 and 8; Figs. 3a-b; Tables 4 and 6). This was the situation, when anticyclonic ridges influenced the weather over the Carpathian Basin. Namely, during type 5, an anticyclone was found with its centre east of the region, while during type 8 an anticyclone from the Azores extended over the Carpathian Basin. The lowest concentrations of the primary pollutants were connected to type 2, when an anticyclone was found with its centre over the British Isles. This is an anticyclonic ridge type with relatively low temperature and humidity values, undisturbed irradiance and light breezes. This example might hint the ambivalent role of anticyclonic ridge types in air pollutant levels (Fig. 3a; Tables 4 and 6). Besides, type 1 (6 pairwise differences), type 2 (9), type 4 (10), type 5 (25) and type 8 (5) are considered to be the most characteristic large-scale weather types in classifying the pollutant concentrations. Among them, type 1 [with the most frequent pairwise differences of CO and NO_2 (2-2 cases)] and type 4 [TSP (4 cases)] are cyclonic weather types, while type 2 [NO_2 (3 cases)], type 5 [TSP (9 cases)] and type 8 [CO, NO, NO_2, SO_2, TSP (1-1 case)] are anticyclonic ridge types. On the other hand, type 3 (with 1 pairwise difference), type 6 (3), type 7 (0), type 9 (1), type 10 (2), type 11 (4), type 12 (3) and type 13 (2) can be regarded as intermediate situations. Namely, their role is negligible in categorising the pollutant levels (Figs. 3a-b; Tables 4 and 6).

On the basis of the mean values of the air pollutants for the days belonging to the 13 Péczely types (Tables 1 and 4), and the Péczely's weather type-air pollution difference matrices (Tables 3 and 6), the following characteristics of their inter-relationships were observed:

In winter, types 9, 12 and 11 are the most efficient in enriching the air pollutants, while (in decreasing order) types 11, 6 and 1 in their dilution. The dubious role of type 11 can probably be attributed to the fact that on the days belonging to this type substantially different wind speeds might occur. In the summer, the role of type 5 is exclusive (78.1 %) in enriching the pollutants, but at the same time, types 2, 8, 1 and 11 are the most important in their dilution (Table 7).

During the study period, the number of industries around and inside the city, as well as that of cars, have not altered substantially, and, therefore, the emissions can be considered to be stable. Thus, the findings of this study imprint relatively well the influence of the atmospheric circulation in the air quality of Szeged. This would not be the case, if some large industrial units had started or ceased operation in the neighbouring countries, and thus the long-range transport of pollutants had modified the pre-existing atmospheric situation in Szeged. However, such great changes, according to our knowledge, did not occur during the study period.

On the basis of previous works [30-32], relation of both the objectively determined air-mass types and the subjectively defined Péczely's weather types, on the one hand, and pollen grain and chemical pollutant concentrations in Szeged, on the other hand, detected that pollen and chemical pollutant levels can be connected to different pressure patterns ruling the region examined.

When considering pollen release of the species in pollination period, both the objective and subjective weather types are partly favourable and partly negligible in classification of pollen levels. On the other hand, when analysing levels of the chemical pollutants: (1) objective types with anticyclonic character are mostly favourable both in winter and summer, while those with cyclonic character are mostly negligible in winter; (2) Péczely's anticyclonic types in winter are mostly favourable, while cyclonic ones are mostly negligible in classification of pollutant levels. At the same time, in summer none of them is predominant. Hence, while the objective weather types have a significant role, the Péczely's large-scale weather situations cannot be considered as an overall system in categorization of pollutant concentrations.

Accordingly, to categorize pollen release of the species, neither the cyclonic nor the anticyclonic weather types show a clear character within objective and subjective weather classifications systems. On the other hand, for classifying the chemical pollutants, the objective types with anticyclonic character are effective in both extreme seasons, while the Péczely's cyclonic and anticyclonic types have an emphasized role only in winter, whereas they are inefficient in summer.

When disregarding anticyclonic and cyclonic character of the weather types, and taking into account pairwise comparisons for each type, efficiency of the pollen-related objective air mass types seems to be much higher, than that of the Péczely's weather types. Furthermore, efficiency of the chemical pollutant-related objective types seems to be significant in both seasons, while a substantial decrease can be observed for the Péczely's classification in summer months. Hence, the Péczely types seem practically to be useless in classifying air pollutants in summer.

As a result of the above, the objective air mass types are more efficient than the Péczely's weather types in classifying either biological or chemical air pollutants, and they can be used more efficiently in air pollution forecast [30-34].

TABLE 7 - Ranking and ratio of the Péczely's weather types in enrichment/ dilution of the air pollutants (%), and air pollutants are considered together, 1997-2001.

Péczely-type	levels of the air pollutants in the pairwise comparisons of the Péczely-types are							
	[1] enriched				[2] diluted			
	ranking		%		ranking		%	
	winter	summer	winter	summer	winter	summer	winter	summer
1 (mCc)	6-10	2-3	2,0	6,3	3	3-4	13,2	12,9
2 (AB)	6-10	7-13	2,0	0,0	4-5	1	11,3	35,5
3 (CMc)	12-13	7-13	0,0	0,0	12-13	7-9	0,0	3,2
4 (mCw)	6-10	7-13	2,0	0,0	4-5	7-9	11,3	3,2
5 (Ae)	5	1	7,8	78,1	11	10-13	1,9	0,0
6 (CMw)	4	4-6	9,8	3,1	2	5-6	17,0	6,5
7 (zC)	12-13	7-13	0,0	0,0	7	10-13	5,7	0,0
8 (Aw)	6-10	7-13	2,0	0,0	8-10	2	3,8	16,1
9 (As)	1	4-6	31,4	3,1	8-10	10-13	3,8	0,0
10 (An)	6-10	4-6	2,0	3,1	6	10-13	7,5	0,0
11 (AF)	3	7-13	13,7	0,0	1	3-4	20,8	12,9
12 (A)	2	2-3	25,5	6,3	8-10	7-9	3,8	3,2
13 (C)	11	7-13	1,8	0,0	12-13	5-6	0,0	6,5

[1](1 = mostly enriched; 13 = least enriched); [2](1 = mostly diluted; 13 = least diluted)

CONCLUSIONS

Summarizing the results of the inter-relationships of the Péczely's weather types and daily mean levels of the air pollutants, the enrichment of the latter (either in winter or summer; either considering the pollutants together or separately) occurs exclusively during anticyclone centre or anticyclone ridge weather situations. On the other hand, their dilution can be experienced not only during cyclonic but also anticyclone ridge weather types. Efficiency of the objective weather classification, performed for the same period, is almost one order of magnitude higher than that of the Péczely's weather types in classifying the air pollutant levels [33, 34]. CO, SO_2 and TSP are sensitive to the Péczely's weather classification, while NO_2/NO, O_3 and O_{3max} are completely insensitive.

In winter, anticyclonic types are mostly favourable, whereas cyclonic ones are mostly negligible in classification of pollutant levels. On the other hand, in summer, none of them are predominant. Hence, although they play a clear role in winter, the Péczely's large-scale weather situations cannot be considered as an overall system in categorization of pollutant concentrations, as they are especially inefficient in summer.

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