Comparison of objective air-mass types and the Péczely weather types and their ability to classify levels of air pollutants in Szeged, Hungary

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Abstract: This paper compares the efficiency of a system of objective air-mass types and the Péczely's weather types in classifying pollution levels over the Carpathian Basin for the winter and summer months. Based on the ECMWF data set, daily sea-level pressure fields analysed at 00 UTC were related to the levels of air pollutants for both the objective air-mass types and the Péczely-types in Szeged. The data base comprises daily values of 12 meteorological and eight pollutant parameters for the period 1997–2001. Mean sea-level pressure fields of the Péczely-types show higher independence from each other than those of the objective clusters in both seasons. In the winter months, anticyclonic types are mostly favourable, while cyclonic ones are mostly negligible in classification of pollutant levels both for the objective and the Péczely-types. In the summer months, neither the objective nor the Péczely classifications are effective in categorisation of pollutant concentrations.

Keywords: objective air-mass types; Péczely's weather types; air pollution; ANOVA; analysis of variance; weather classification.

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1 Introduction

Air pollution has become a very important environmental problem, mostly in densely populated cities. The emission sources can be transportation, industrial processes, solid waste disposal and others. These harmful particles in the air may affect human health, vegetation and the environment in general. The degree of the damage caused largely depends on the concentration and the duration of the exposure. Air quality and the pollutant concentrations are influenced by several natural conditions (physical, chemical, meteorological and geographical processes) and social factors, as well. For example, anticyclonic weather conditions can significantly influence the rise of extreme concentration rates of pollutants in the air (De Nevers, 2000; Mayer, 1999).

In Europe, numerous air pollution studies have appeared in the international literature, see for example, Kambezidis et al. (2001) and Sindosi et al. (2003) for Athens, Dirks et al. (2003) for London, McGregor and Bamzelis (1995) for Birmingham, Péczely (1959) for Budapest, Makra et al. (2006) for Szeged, etc.

In Athens, for example, due to its long summer with undisturbed irradiation and calm or weak breeze, the mountains which surround the city from the north, east and west, favour extreme accumulation of air pollutants (Kambezidis et al., 1998). In Budapest (Péczely, 1959), air pollution tends to have peak values during extensive anticyclonic events characterised by weak easterly breeze prevailing over the city. Conversely, air pollution is relatively lower during the prevalence of cyclonic weather systems characterised by strong and turbulent air currents prevailing over the Carpathian Basin (Figure 1(a)), especially when Hungary lies in the rear part of the cyclone.

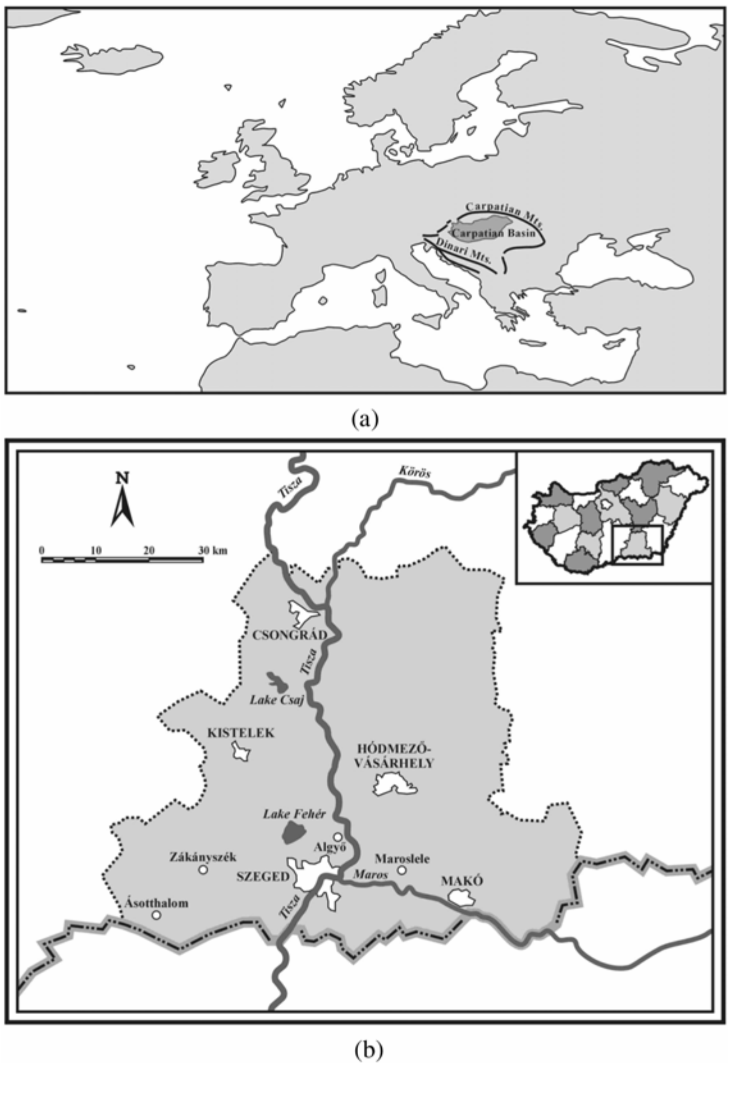
Studies on the relationship between synoptic weather conditions and pollution levels are carried out by either using objective multivariate statistical methods or subjective classifications based on the long experience of meteorologists. Examples of objective approaches are the works of McGregor and Bamzelis (1995), Sindosi et al. (2003) and Makra et al. (2006) who classified air-mass types (in fact weather types) and then investigated the corresponding Main Air Pollutants (MAPs) concentrations for Birmingham (UK), Athens (Greece) and Szeged (Hungary), respectively. On the other hand, Kassomenos et al. (1998a,b; 2001), Péczely (1957, 1983) and Károssy (1987, 2004) have given interesting results on weather categorisation and its applications for Athens and Budapest by using subjective methodologies. Nevertheless, comparisons of efficiency of objectively defined and subjectively determined weather classification systems to separate weather types with respect to pollutant levels have not been carried out sufficiently according to literature.

The primary aim of this study is to compare the efficiency of two systems in classifying levels of the MAPs for Szeged, Hungary; that is, a methodology which objectively defines air-mass types with the subjectively defined Péczely weather types. Another objective is to study the relation of the Péczely large-scale weather situations with respect to the meteorological elements; namely, to detect the most important climatic factors separating the subjectively-defined 13 Péczely weather types.

2 Topography of the Szeged area

The city of Szeged being the largest town in SE Hungary (20°06′E; 46°15′N) is located at the confluence of the Tisza and Maros Rivers characterised by an extensive flat landscape with an elevation of 79 m asl (see Figure 1(b)). The built-up area covers a region of about 46 km^2 with about 155,000 inhabitants. Szeged and its surroundings are not only characterised by extensive lowlands, but also they have the lowest elevation in Hungary and the Carpathian Basin, as well. This results in a 'double basin' situation. Due to the position of the city in a basin (a smaller one within a larger one), temperature inversions form more easily in the area and prevail longer than in flat terrain, leading to an enrichment of air pollutants within the inversion layer. The climate of Szeged is characterised by hot summer and moderately cold winter. The distribution of rainfall is fairly uniform during the year. The mean daily summer temperature is 22.4°C, whereas the mean daily winter temperature is 2.3°C. More details on the climatology and air quality of the Szeged area have already been presented in a previous work (Makra et al., 2006).

Figure 1 (a) Location of the Carpathian Basin and (b) location of Szeged in Csongrád county (centre); Csongrád county in Hungary (top right)



3 Data collection

The air pollution data base consists of 30-min datasets for winter (December, January and February) and summer (June, July and August) for the five-year period of 1997–2001. Daily values (average diurnal mass concentrations) of the following six pollutants have been used: CO (mg m^{-3}); NO (μg m^{-3}), NO_2 (μg m^{-3}), SO_2 (μg m^{-3}), O_3 (μg m^{-3}) and TSP (μg m^{-3}) as well as the daily ratios of NO_2/NO and the daily maximum concentrations of O_3 (μg m^{-3}).

The air pollution monitoring station is located in Szeged downtown at a crossroad with heavy traffic (Kossuth Avenue and Damjanich Street), about 10 m distance from the Kossuth Avenue. This is one of the busiest crossroads of Szeged. Data coming from this station are highly dependent on the traffic conditions and other local factors. Since urban background station does not exist in Szeged and the only one mentioned here is the traffic station, we are obliged to use its data. The monitoring station was put into operation on 1 September 1996. At a distance of 10 m from the station, a two-storey building is located, which affects wind and irradiance parameters. Sensors, measuring concentrations of the air pollutants, are placed 3 m above the surface.

The meteorological database consists of 30-min data sets also for winter (DJF) and summer (JJA) for the same period (1997–2001). Daily values of the following 12 meteorological parameters are used: mean temperature (T_{mean}°C), maximum temperature (T_{max}°C), minimum temperature (T_{min}°C), daily temperature range (DT = T_{max}–T_{min}°C), wind speed (WS, ms^{-1}), relative humidity (RH%), irradiance (I, MJ m^{-2} day^{-1}), saturation vapour pressure (E, hPa), water vapour pressure (VP, hPa), potential evaporation (PE, mm), dew point temperature (T_d°C) and atmospheric pressure (P, hPa).

Daily sea-level pressure fields measured at 00 UTC (UTC = Coordinated Universal Time) are taken from the European Centre for Medium-Range Weather Forecasts (ECMWF). Re-analysis ERA 40 project, in the frame of which daily data have been re-analysed since 1 September 1957. The investigated area is in the North-Atlantic–European region between 30°N and 70.5°N latitudes furthermore 30°W and 45°E longitudes. The grid network is selected with a density of 1.5° × 1.5°, which indicates 28 × 51 = 1428 grid points for the region.

4 Methods

4.1 Cartographical background

For the days classified in each objective type and the 13 Péczely weather types, average daily sea-level pressure patterns were constructed by applying the Surfer 7.00 contouring, gridding and surface mapping software. Isobars for an average day, that is, for an average objective or Péczely type, were drawn using 28 × 51 = 1428 grid data on the basis of the standard Kriging method without increasing data quantity and with a maximum smoothing (Makra et al., 2006).

4.2 The objective weather types

The objective definition of the characteristic air-mass types (in fact weather types) prevailing over Szeged, Hungary, was performed by Makra et al. (2006) by using Factor

Analysis (FA) and Cluster Analysis (CA). Firstly, the FA (varimax rotation) was applied on the data matrix in order to reduce the dimensionality of the interrelated meteorological parameters and then CA (hierarchical technique and average linkage method) on the factor scores time series in order to group objectively days characterised by similar weather conditions. Application of the hierarchical technique in this work aims to get defined objectively weather types which can be compared to the Péczely's large-scale weather situations. Here, the average linkage method is used since it produces more realistic groupings. These methods were applied to other similar works (e.g. Sindosi et al., 2003). According to the results, during the winter five air-mass types (clusters) were detected, while in the summer ten. For each of the derived clusters of days, the mean value for every meteorological and pollution parameter was computed. In this way, the relations between weather conditions and the corresponding concentration levels of air pollutants were revealed. Finally, for each weather type, the composite maps of the mean sea-level pressure distribution over the North-Atlantic–European region (00 UTC) were constructed revealing also the synoptic conditions associated with weather types and pollution levels in Szeged.

4.3 The Péczely large-scale weather classifications

Péczely (1957) defined 13 large-scale weather patterns altogether and for each of them he selected the most typical day. 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 in the North-Atlantic–European region by the Hungarian Meteorological Service. Péczely determined the daily catalogue of the 13 macrosynoptic types, at first, for the period 1877–1956 (Péczely, 1957) and later he completed it till the end of 1982 (Péczely, 1983). After his death in 1984, the daily classification of weather types was performed by Károssy (1987; 2004) with the same subjective methodology.

4.4 χ^2-test, independence analysis

In order to decide whether or not the sea-level pressure fields examined differ significantly from each other, the χ^2-test independence analysis was applied. This method determines whether or not two random variables (ξ and η) are independent. According to the 0-hypothesis, ξ and η are not independent.

4.5 ANOVA and Tukey's honestly significant difference test

When determining both the objective air-mass types and the Péczely's macrosynoptic types, only meteorological parameters are taken into account, excluding pollution data. Hence, the differences of the mean pollution levels calculated for both the objective air-mass types and each Péczely macrotype need a further statistical evaluation. This is performed by the method of one-way Analysis of Variance (ANOVA) for each pollutant. By using the method, significant differences in pollutant concentrations of both the different objective air-mass types and the Péczely weather types can be determined. Finally, the Tukey's honestly significant difference test is applied in order to quantitatively compare the mean air pollution levels between each pair of both the objective types and the Péczely's macrotypes (pairwise multiple comparisons) (Makra et al., 2006; McGregor and Bamzelis, 1995; Sindosi et al., 2003).

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

5 Results

5.1 Characteristics of the objective air-mass types and the Péczely macrosynoptic types in winter

5.1.1 Independence analysis

Mean sea-level pressure fields for the objectively defined cluster of days and the 13 Péczely weather types were compared on the basis of the used grid values (see Section 4.1) in both seasons of the period examined.

In order to decide whether the mean sea-level pressure fields of the five clusters, on the one hand, and the 13 Péczely weather types on the other hand, differ significantly from each other in the winter, the χ^2-test was applied. The 0-hypothesis means that there is no significant difference between the mean sea-level pressure fields of the objects compared.

On the basis of our computations, 80% of all possible objective pairs (8 out of $\binom{5}{2}$ = 10 cases) differ significantly from each other. While considering the subjective classification, all the pairs of the 13 Péczely types (78 pairs out of $\binom{13}{2}$ = 78 cases) differ significantly from each other. We note that it must be kept in mind that Péczely (1957, 1983) and then Károssy (1987, 2004) classified pressure patterns directly, while Makra et al. (2006) classified weather conditions in Szeged and then they presented the corresponding pressure patterns. Thus, under the same classification of Péczely, distinct areas in Hungary may have different prevailing weather conditions.

5.1.2 Basic statistical parameters

For the objective classification, considering the basic statistical parameters of the pollutants, variation coefficients (standard deviation expressed in the unit of the average) for NO and SO_2 are twice as high as those for other contaminants examined, which denote their higher variability. The difference of |median – average| remains within the so-called interquartile half extent (the interval given by the lower quartile and the upper quartile) for each pollutant.

For Péczely's classification, the variation coefficients for NO_2 and SO_2 are one and half times as high as those for other contaminants examined. The highest values occur during anticyclonic (type 12) and anticyclonic ridge (types 9 and 10) weather patterns. The difference of |median − average| is found beyond the interquartile half extent in a small percentage of the Péczely types for each pollutant: CO (in 15.4% of the Péczely types), NO (7.7%), NO_2 (7.7%), NO_2/NO (23.1%), O_3 (15.4%), O_{3max} (7.7%), SO_2 (15.4%) and TSP (15.4%).

SO_2 indicates the highest variation coefficient of all pollutants both in the objective and the Péczely classification. While the difference of |median − average| remains within the interquartile half extent for each pollutant in the objective types, it is found beyond the above interval, that is, 7.7–23.1% of the Péczely types.

5.1.3 ANOVA statistics

For winter, in order to determine the influence of the five objective air-mass types and the Péczely synoptic types on pollutant levels, ANOVA were performed on the pollutant parameters. It was found that, except for NO_2/NO, both the objective weather types (for all the pollutants) and the Péczely types (for only the primary pollutants) show significant inter-weather type differences in mean concentration values at the 99% probability level. On the other hand, for the secondary pollutants, the above differences are significant only at the 89% (O_3) and 66% (O_{3max}) probability levels, respectively. Considering that differences are found among the mean pollutant levels, Tukey's tests were applied in order to receive a pairwise multiple assessment of the differences.

It is calculated that four out of the ten pairs of the objective types (40.0%) differ significantly for four or five pollutants (mostly for CO and TSP), whereas four out of the 78 pairs of the Péczely types (5.1%) differ substantially for 3–5 pollutants (mostly for CO, NO, NO_2 and TSP). Generally, objective types 3–4 and Péczely types 6–9 can be considered to be mostly different, since the levels of most pollutant pairs (5 pollutant pairs for both cases) show substantial differences. This can mainly be explained by the fact that both the objective types 3–4 and Péczely types 6–9 show almost the highest difference in wind speed.

Furthermore, *cluster* 2 in the objective types and Péczely types 3, 7, 8 and 13 (with 3 or less pairwise differences) seem to be intermediate types considering pollution. Objective types 1 (an anticyclone over the Carpathian Basin), 3 and 4 (anticyclone ridge types) (with more than 10 pairwise differences) are found to be the most definite in classifying pollutants. On the other hand, the Péczely types 6, 9, 11 and 12 indicate more than 10 pairwise differences. Hence, considering the 13 subjective types, they are the most characteristic in classifying air pollutants. Among them, type 6 is a cyclonic, whereas the others are anticyclonic ridge (types 9 and 11) or anticyclone centre (type 12) situations.

5.2 Characteristics of the objective air-mass types and the Péczely macrosynoptic types in summer

5.2.1 Independence analysis

According to the χ^2-test, 2.2% of the mean sea-level pressure fields of the cluster pairs (only 1 out of the $\binom{10}{2}$ = 45 cases) shows significant difference. On the other hand, considering the Péczely types, 70.5% of the mean sea-level pressure fields of their all possible pairs (55 out of the $\binom{13}{2}$ = 78 cases) indicate significant difference from each other. Hence, the Péczely types indicate much higher independence than the objective clusters.

5.2.2 Basic statistical parameters

Considering the objective air-mass types, the variation coefficients for O_3 and O_{3max} decreased substantially compared to their values for the winter months. The difference of |median – average| for NO_2/NO is found beyond the interquartile half extent in 60% of the clusters, while for TSP and SO_2 only in one cluster. This indicates that the distribution functions of the pollutant concentrations in the clusters mentioned above are distorted; namely, the means of the samples are not representative for the datasets.

Regarding the Péczely types, the variation coefficients for O_3 and O_{3max} decreased to half of those measured for the winter months. Highest values occur under the same macrosynoptic types as in the winter; namely, when an anticyclone (type 12) or anticyclonic ridges (types 9 and 10) exert influence over the Carpathian Basin.

The difference of |median–average| is found beyond the interquartile half extent for CO (in 23.1% of the Péczely types), NO (15.4%), NO_2 (23.1%), NO_2/NO (15.4%) and SO_2 (23.1%). This indicates that the distribution functions of the pollutant concentrations are distorted when an anticyclone (type 12) or anticyclonic ridges (types 2 and 11) dominate the region of the Carpathian Basin. The only exception is type 6 (a Mediterranean cyclone with its centre over the Adriatic Sea influencing the weather of the Carpathian Basin). Namely, during these types the means of the samples are not representative for the data sets.

5.2.3 ANOVA statistics

Similar to the winter months, the significance of inter-air-mass type/Péczely inter-weather type differences in pollutant levels was determined by ANOVA. As a similarity, mean concentrations of CO, NO, NO_2 and TSP present significant inter-weather type differences at 99% confidence level for both classification systems. On the other hand, the above mentioned significance for NO_2/NO, SO_2, O_3 and O_{3max} differs in the two classifications. The lowest confidence level (86%) was derived by mean concentrations of O_{3max} for the Péczely inter-weather type differences.

Performing the pairwise comparisons (Tukey's significant difference tests), there are no two objective types/Péczely types for which inter-weather type differences in concentrations of all the eight pollutants considered are significant. The highest inter-weather type difference is indicated by four or five pollutants for all 11 pairs of the objective types (24.4 %) and only three pairs for the Péczely types (3.8%).

In general, objective types 6 and 10, as well as Péczely types 2, 5 and 8 differ a lot from the others, since the pairwise multiple comparisons detected significant differences in levels for them of the most pollutants. On one hand, the reason might be the fact that objective types 6 and 10, as anticyclone ridge types show a considerable difference in wind speed. On the other hand, the wind speed of the Péczely types 2, 5 and 8, being anticyclone ridge types, is the same. However, lowest levels of pollutants in type 2 can be explained by the relatively more intense vertical air currents caused by unstable atmosphere attributed to the lowest minimum temperature. The Péczely type 5 is warm and dry with high humidity and clear weather, which favours high values of the air pollutants. The Péczely type 8, with its high irradiance and clear weather, is beneficial to higher ozone levels. At the same time, the objective type 5 and the Péczely type 7 seem to be intermediate types, since they show fewer (or hardly any) pairwise differences than the others.

5.3 ANOVA statistics for the Péczely weather types

When objective weather types were defined for Szeged, Hungary (Makra et al., 2006), 12 meteorological parameters were used in order to determine groups of days with similar weather in Szeged and then, the corresponding pressure patterns were constructed. On the other hand, the base of the subjective classification of Péczely's (1957, 1983) large-scale weather situations was the sea-level pressure maps constructed at 00 UTC for the North-Atlantic–European region.

So, the ANOVA tests, which have been performed on the MAPs (Makra et al., 2006) are now applied to the above-mentioned 12 meteorological parameters. If differences are found among the mean levels of the climatic elements, the Tukey's honestly significant difference tests are applied in order to receive a pairwise multiple assessment of the differences, which aims to detect the most important climatic factors to separate the subjectively defined 13 Péczely weather types.

5.3.1 Winter months

According to ANOVA, all the meteorological parameters present significant inter-Péczely type differences in the mean concentration values at the 99% confidence level (see Table 1). Therefore, Tukey's tests were applied to get pairwise multiple assessments of the differences (see Figure 2). According to this, none of the 78 pairs of the Péczely types showed significant differences in mean values of all the 12 meteorological parameters considered. The highest inter-Péczely type difference is expressed by eight meteorological parameters between Péczely types 6–12 and by seven parameters between Péczely types 2–7, 7–10 and 7–12 (see Figure 2).

At least five meteorological parameters presented significant differences in their mean values for altogether nine pairs of Péczely types. In general, Péczely types 6, 7, 9 and 12 differ mostly from the others, since the pairwise multiple comparisons detected significant differences for them in mean values of the most meteorological elements. Namely, these types can be considered as the most specific ones in the winter (see Figure 2 and Table 2). Both the most important and the negligible meteorological elements in classifying Péczely types are listed in Table 3.

5.3.2 Summer months

The mean values of the majority of the meteorological parameters show significant inter-Péczely type differences at the 99% confidence level, except for VP (87%), T_d (84%) and T_{min} (63%) (see Table 4). Performing the pairwise comparisons, namely the Tukey's tests, the statistically significant differences are presented in Table 3 at the 95% and 99% confidence levels, respectively. According to this, no pairs of Péczely types are found for which inter-Péczely type differences in mean values of all the 12 meteorological parameters considered are significant. The highest inter-Péczely type difference is indicated by eight meteorological parameters between Péczely types 1–12 and 12–13. Since no pairwise comparison of Péczely type 7 shows significant differences in mean values of meteorological parameters, this seems to be a clear intermediate type (Figure 3).

Table 1 ANOVA statistics for the Péczely inter-weather type comparison of meteorological parameters' values, winter months (December, January and February)

	T_{mean}	T_{max}	T_{min}	*DT*	*E*	*VP*	*PE*	T_d	*RH*	*I*	*P*	*WS*
Mean square between groups	101.88	78.85	50.08	27.23	24.59	16.83	0.84	102.82	229.21	15352.35	1645.98	0.83
Mean square within groups	25.77	19.27	11.59	9.50	6.35	3.37	0.35	21.79	77.02	2790.94	53.34	0.23
F-ratio	3.95	4.09	4.32	2.87	3.87	4.99	2.37	4.72	2.98	5.50	30.86	3.63
Confidence level (%)	99	99	99	99	99	99	99	99	99	99	99	99

Notes: T_{mean}: mean temperature; T_{max}: maximum temperature; T_{min}: minimum temperature; DT = (T_{max}–T_{min}): daily temperature range; WS: Wind Speed; RH: Relative Humidity; *I*: Irradiance; *E*: saturation vapour pressure; VP: water vapour pressure; PE: Potential Evaporation; T_d: dew point temperature; *P*: atmospheric pressure.

Figure 2 Péczely weather type – meteorological element difference matrix. Each matrix cell represents the comparison between two Péczely types. Parameters appearing in the matrix cells indicate significant difference in their values between two given Péczely's weather types according to Tukey's Honestly Significant Difference Test, winter months (December, January and February) (plain characters: 95 % of confidence level; italic characters: 99 % of confidence level)

	1	2	3	4	5	6	7	8	9	10	11	12
2	T_{mean} VP T_{min} T_d *P*											
3												
4		*P*										
5	*P*			*P*								
6	I	T_{min} *I* *VP* T_d *P*	I		*P*							
7		*T_{mean}* *T_{max}* *T_{min}* *VP* *Td* *E* *P*			VP T_{min} *P*							
8	*P*	PE E		I *P*		*RH* *I* DT *P*	*P*					
9	*P*	*T_{mean}* *T_{max}* T_{min} VP *T_d* *E*		WS *P*	T_{max}	*I* *DT* *P*	*P*					
10	T_d *P*		P	I *P*		VP *I* *Td* *P*	T_{mean} *T_{max}* T_{min} *VP* *T_d* E *P*		*T_{max}* VP T_d			
11	P			*P*		P						
12	*WS* VP T_{min} *T_d* *P*		P	*WS* I *P*		*WS* *VP* RH *T_{min}* *I* *T_d* DT *P*	*T_{mean}* T_{max} *T_{min}* *VP* *T_d* *E* *P*		T_{mean} T_{max} T_{min} *VP* *T_d* E			
13		*P*			*P*			*P*	*P*	*P*	*P*	*P*

Note: T_{mean}: mean temperature; T_{max}: maximum temperature; T_{min}: minimum temperature; DT = (T_{max}–T_{min}): daily temperature range; WS: Wind Speed; RH: Relative Humidity; *I:* Irradiance; *E*: saturation vapour pressure; VP: water vapour pressure; PE: potential evaporation; T_d: dew point temperature; *P*: atmospheric pressure.

Table 2 The most different and the intermediate Péczely types

	Winter	*Summer*
Most different Péczely types	6, 7, 9, 12	5, 6, 12, 13
Intermediate Péczely types	3, 5, 11, 13	4, 7, 9

Table 3 The most important and the negligible meteorological elements in classification of Péczely types

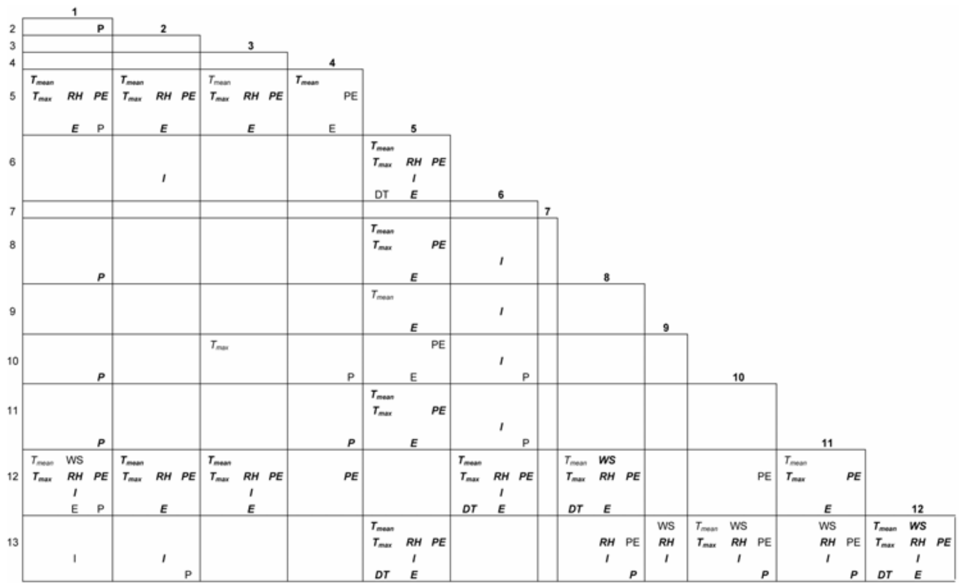
	Winter	*Summer*
Significant meteorological elements	*P*	T_{mean}, T_{max}, RH, *I*, *E*, PE, *P*
Negligible meteorological elements	PE; RH, DT, WS	T_{min}, VP, T_d

Table 4 ANOVA statistics for the Péczely inter-weather type comparison of the meteorological parameters values, summer months (June, July and August)

	T_{mean}	T_{max}	T_{min}	*DT*	*E*	*VP*	*PE*	T_d	*RH*	*I*	*P*	*WS*
Mean square between groups	76.90	138.15	48.08	165.08	256.77	17.31	37.00	11.76	848.11	34766.30	206.29	0.62
Mean square within groups	11.29	17.29	44.27	45.25	36.11	11.65	3.67	8.34	91.05	4607.24	30.67	0.17
F-ratio	6.81	7.99	1.09	3.65	7.11	1.49	10.08	1.41	9.31	7.55	6.73	3.57
Confidence level, %	99	99	63	99	99	87	99	84	99	99	99	99

Notes: T_{mean}: mean temperature; T_{max}: maximum temperature; T_{min}: minimum temperature; DT = (T_{max}–T_{min}): daily temperature range; WS: Wind Speed; RH: Relative Humidity; *I*: Irradiance; *E*: saturation vapour pressure; VP: water vapour pressure; PE: Potential Evaporation; T_d: dew-point temperature; *P*: atmospheric pressure.

Figure 3 Péczely weather type – meteorological element difference matrix. Each matrix cell represents the comparison between two Péczely types. Parameters appearing in the matrix cells indicate significant difference in their values between two given Péczely weather types according to Tukey's Honestly Significant Difference Test, summer months (June, July and August) (plain characters: 95% of confidence level; italic characters: 99% of confidence level)



Note: T_{mean}: mean temperature; T_{max}: maximum temperature; T_{min}: minimum temperature; DT: (*T*–*T*): Daily Temperature range; WS: Wind Speed; RH: Relative Humidity; *I:* Irradiance; *E*: saturation vapour pressure; VP: water vapour pressure; PE: Potential Evaporation; T_d: dew point temperature; *P*: atmospheric pressure.

The pairwise multiple comparisons indicated significant differences in mean values of at least five meteorological parameters for altogether 14 pairs of Péczely types. Generally, Péczely types 5, 6, 12 and 13 differ mostly from the others, since the pairwise multiple comparisons detected significant differences for them in mean values of the most meteorological elements. Namely, these types seem to be the most specific ones in the summer (see Figure 3 and Table 2). Both the most significant and the negligible meteorological elements in grouping Péczely types are found in Table 3.

6 Discussion

This paper compared the efficiency of classification of pollutant levels in Szeged for days characterised by specific weather, defined objectively and the days characterised by a common pressure pattern over Europe according to the subjective classification of Péczely's weather types over the Carpathian Basin. Specific types both for the winter and summer months were found to play a significant role in the pollutant concentrations in Szeged.

Overall, in winter, objective types 1, 3 and 4 are favourable, while types 2 and 5 are less characteristic in the classification of pollutant levels. Namely, types with anticyclonic character are mostly favourable, while those with cyclonic character are mostly negligible in classification of pollutant levels. At the same time, in the summer, objective types 6, 8 and 10 (all with anticyclonic character) are effective, while intermediate type 5 is inefficient in categorising pollutant concentrations (Makra et al., 2006).

Concerning the individual Péczely situations in winter, types 6 (CMw), 9 (Ae), 11 (AF) and 12 (A) are favourable, while types 3 (CMc), 7 (zC), 8 (Aw) and 13 (C) are negligible in classification of pollutant concentrations. On the other hand, in the summer, Péczely types 1 (mCc), 2 (AB), 4 (mCw), 5 (Ae) and 8 (Aw) are favourable, whereas types 3 (CMc), 6 (CMw), 7 (zC), 9 (As), 10 (An), 11 (AF), 12 (A) and 13 (C) are negligible in categorising pollutant levels. Namely, in winter, anticyclonic types are mostly favourable, whereas cyclonic ones are mostly negligible in the classification of pollutant levels. On the other hand, in summer, none of them is predominant. Hence, the Péczely large-scale weather situations cannot be considered as an overall system in categorisation of the pollutant concentrations. On one hand, they have an emphasised role in winter and, on the other, they are inefficient in summer.

In winter, 90% of the pairs of the five objective types and 65.4% of the pairs of the 13 Péczely types and in summer 83.3% of the pairs of the 10 objective types and 19.2% of the pairs of the 13 Péczely types indicated significant differences in the levels of one or more pollutants. Namely, efficiency of air pollution-related objective classification of air-mass types seems to be effective in both seasons, while a substantial decrease for the Péczely's classification can be observed only in summer. Hence, the Péczely types seem practically useless in classifying air pollutants in summer.

7 Conclusions

Mean sea-level pressure fields of the Péczely types show higher independence from each other than those of the objective clusters in both seasons. This difference in the two classifications is especially striking in the summer, when independence of the 10 objective clusters determined can practically be neglected, while, at the same time, more than two-third of the Péczely types are independent.

Prevalence of the anticyclone centre and anticyclonic ridge situations are observed both for the objective (winter (79.8 %)) (see Table 5), summer (85.2%) (see Table 6)) and for the Péczely classification types (winter (69.0 %), summer (69.8 %) (Table 7)), in the period examined. The frequency (in percentage) and persistence (average length in days) of the objective and Péczely types with anticyclonic character for summer and winter are given in Tables 5–7. Persistence of the types with anticyclonic character is significantly higher for the objective types in winter, as well as for the Péczely types both in winter and summer. On the other hand, persistence shows higher standard deviation in summer than in winter both for the objective and the Péczely types (see Tables 5–7).

It should be stressed that Péczely first and Károssy afterwards classified pressure patterns directly, while Makra et al. (2006) classified weather conditions in Szeged and they presented the corresponding pressure patterns. Thus, different areas in Hungary may have different weather conditions under the same pattern of Péczely.

Table 5 Frequency and persistence (average length) of the objective types in the winter

Objective type	*Frequency (%)*	*Persistence (day)*
1 (Anticyclone centre type)	12.5	2.3
2 (Anticyclonic character)	30.0	2.8
3 (Anticyclonic character)	16.3	2.8
4 (Anticyclonic character)	21.0	2.0
5 (Cyclonic character)	20.1	2.5
Anticyclonic types, total	79.8	2.5

Table 6 Frequency and persistence (average length) of the objective types in the summer

Objective type	*Frequency (%)*	*Persistence (day)*
1 (Anticyclonic character)	6.1	1.6
2 (Anticyclonic character)	8.7	1.3
3 (Anticyclonic character)	12.6	1.5
4 (Anticyclonic character)	16.5	1.6
5 (Intermediate type)	3.7	1.3
6 (Anticyclonic character)	10.0	2.4
7 (Anticyclonic character)	15.7	1.8
8 (Anticyclonic character)	10.2	1.3
9 (Intermediate type)	11.1	1.4
10 (Anticyclonic character)	5.4	1.9
Anticyclonic types, total	85.2	1.7

Concerning the relation of the Péczely large-scale weather situations with respect to the meteorological elements in Szeged, the most specific Péczely macrotypes differ more definitely from each other in summer than in winter. Péczely types 12 and 6 are found to be characteristic weather situations in both seasons. Furthermore, Péczely macrotypes 7 and 9 in winter and types 5 and 13 in summer are considered to be the most specific ones.

In winter, the role of atmospheric pressure (P) is the most definite among the 12 meteorological parameters in representing the differences in the Péczely weather types. On the other hand RH, DT and WS have practically no influence on separating the Péczely types. As a result, the most specific winter types (12, 6, 7 and 9) differ from each other as well as from the other types mostly with respect to P. Besides, type 7 differs from the others mostly with respect to I, as well. At the same time, Péczely macrotypes 3, 5, 11 and 13 can be considered intermediate.

In summer, T_{mean}, T_{max}, RH, I, E, PE and P are the most definite in representing the differences of the Péczely's weather types. While PE shows the highest load, T_{min}, VP and T_d have no role in separating the Péczely types. Considering the most specific summer types (macrotypes 12, 6, 5 and 13), type 12 differs from the other ones mostly with respect to PE, T_{mean}, T_{max} and E; type 5 differs from the others mostly in E, T_{mean} and PE;

Péczely type 13 differs mostly with respect to *I*, RH and PE, while type 6 differs from the other ones mostly in *I*. At the same time, Péczely types 7, 4 and 9 can be considered intermediate.

Table 7 Frequency and persistence (average length) of the Péczely types in the extreme seasons

Péczely type	*Winter months*		*Summer months*	
	Frequency (%)	*Persistence (day)*	*Frequency (%)*	*Persistence (day)*
1 (mCc) cyclonic type	9.3	1.5	15.4	1.6
2 (AB) anticyclonic ridge type	7.8	1.9	9.8	1.8
3 (CMc) cyclonic type	0.7	1.0	1.1	1.0
4 mCw (cyclonic type)	5.5	1.3	3.0	1.1
5 (Ae) anticyclonic ridge type	14.4	2.0	8.5	1.6
6 (CMw) cyclonic type	9.1	1.4	3.5	1.1
7 (zC) cyclonic type	4.2	1.4	0.4	2.0
8 (Aw) anticyclonic ridge type	14.9	1.9	16.5	1.7
9 (As) anticyclonic ridge type	8.4	1.3	4.4	1.4
10 (An) anticyclonic ridge type	5.5	1.3	8.0	1.6
11 (AF) anticyclonic ridge type	1.8	2.0	9.1	2.5
12 (A) anticyclone centre type	16.2	1.7	13.5	1.8
13 (C) cyclone centre type	2.2	1.3	6.7	1.2
Anticyclonic types, total	69.0	1.7	69.8	1.8
Cyclonic types, total	31.0	1.3	30.2	1.3

Relation of both the objectively determined air-mass types and the subjectively- defined Péczely weather types on the one hand and air quality in Szeged, on the other, detected that pollution levels can be connected to different pressure patterns ruling the region examined. Hence, in view of the weather forecast, expected pollution levels can be indicated and abatement of severe air pollution episodes can be considered. However, it has to be underlined that atmospheric circulation is not the only factor controlling air pollution in Szeged. The revealed pressure patterns can only influence the concentration of the pollutants, which are mostly of human origin. Thus, for a precise air pollution forecast, apart from a good weather forecast, a good knowledge of human habits is necessary.

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