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Relationship between the Péczely's large-scale weather types and airborne pollen grain concentrations for Szeged, Hungary

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Abstract

This paper discusses a subjectively defined system of air mass types, the 13 Péczely's large-scale weather situations over the Carpathian Basin in relation to the detected airborne pollen grain concentrations. Based on the ECMWF (European Centre for Medium-Range Weather Forecasts) sea-level pressure data set, daily sea-level pressure fields analyzed at 00:00 UTC were prepared for each Péczely's weather types in order to relate the sea-level pressure patterns with the average pollen levels in Szeged. The data basis for this study comprises daily values of 12 meteorological parameters and daily average pollen concentrations for 24 species in a 5-year period (1997–2001). It was found that Péczely's anticyclonic ridge types 2 and 11 as well as cyclonic types 4 and 7 are favourable for pollen production and dispersal unlike the cyclonic types 3 and 13. Hence, the Péczely's large-scale weather situations cannot alone be considered as an overall system in predicting pollen concentrations.

Keywords: *Péczely's large-scale weather situations, pollen, ANOVA weather classification*

Studying the relationship between airborne pollen concentrations and meteorological parameters has a practical importance because of health issues due to pollen allergies. In recent decades, the prevalence of allergy and asthma has increased worldwide (D'Amato et al., 1998; Traidl-Hoffmann et al., 2003). A possible cause for increased pollen allergy may be global warming, since greater concentrations of carbon dioxide and higher temperatures may increase pollen quantity and induce longer pollen seasons. Pollen allergenicity can also increase for the same reason (Wan et al., 2002; Beggs, 2004; Beggs & Bambrick, 2005). Air pollution can also contribute to increased pollen allergy and is more frequent in industrial (Obtulowicz et al., 1996) and urban (Charpin, 1996) regions, while in the rural regions patients showed only small predisposition to allergy. According to Hjelmroos et al. (1999) and Wyler et al. (2000), there is an indication that traffic related air pollution modifies the composition of pollen grains. This could facilitate an interaction between pollen and pollutants in the atmosphere outside the organism, which in turn may affect allergy-relevant phenomena (Emberlin, 1995; Behrendt et al., 1997; D'Amato et al., 2005). A striking difference in the prevalence of respiratory atopic diseases was found when comparing populations of Eastern and Western Europe with their different patterns of air pollution. Eastern Europe was found to have a lower prevalence than Western Europe. It is hypothesized that the western way of life, including a lower rate of recurrent early childhood infections, and a higher allergenic exposure could explain these differences (Charpin, 1996; Behrendt et al., 1997).

About one-third of Hungary's inhabitants experience some type of allergy, two-thirds of them have pollen sensitivity and at least 60% of this

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pollen-sensitivity is caused by *Ambrosia* pollen (Mezei et al., 1992; Járai-Komlódi, 1998). The number of patients with registered allergic illnesses has doubled and the number of cases of allergic asthma has become four times higher in Southern Hungary by the late 1990s compared to the last 40 years (Mezei et al., 1992; Farkas et al., 1998). *Ambrosia* represents 47% of the total airborne pollen detected between 1990 and 1996 in Southern Hungary (Juhász, 1995; Makra et al., 2004; 2005*a*). Although this ratio highly depends on yearly meteorological factors (in 1990 this ratio was 35.9%, while 66.9% in 1991), ragweed can be considered the main aero-allergen plant in Hungary (Makra et al., 2004; 2005*a*), clinical investigations also have proved that ragweed pollen is the major reason for serious and long-lasting pollinosis in Hungary (Gönczi et al., 1997; Dervadis et al., 1998).

Depending on the phenological phase of a given plant the occurrence of pollen grains is seasonal and is also influenced by meteorological parameters. Pollen concentrations have been shown to have significant positive correlations with temperature parameters (Jato et al., 2002; Gioulekas et al., 2004; Makra et al., 2004; Rodríguez-Rajo et al., 2004*a*; Stennett & Beggs, 2004). Significant negative correlation was found between pollen concentration and air pressure (Stennett & Beggs, 2004). Increased relative humidity or rainfall generally results in decreased airborne pollen concentrations (Gioulekas et al., 2004). Pollen levels have proved to have significant positive correlation with wind speed (Gioulekas et al., 2004; Stennett & Beggs, 2004) and wind direction (Damialis et al., 2005), illustrating the importance of wind persistence in pollen transport. Convective storms potentially can transport pollen over considerable distances (Mandrioli et al., 1984; Hjelmroos, 1991; Hjelmroos & Franzen, 1994). Rousseau (2003, 2004, and 2005) has found that a regular pattern of air masses is responsible for the transport of pollen grains from eastern North America to Southern Greenland.

Long-lasting clear weather situations, with undisturbed irradiation and calm or weak breezes are favourable for studying relations between pollen levels and meteorological elements. In Europe, the Mediterranean is considered to be such a region (Kambezidis et al., 1998; 2001; Adamopoulos et al., 2002; Vázquez et al., 2003; Rodríguez-Rajo et al., 2003; 2004*a*; Gioulekas et al., 2004; Damialis et al., 2005).

Péczely defined 13 large-scale weather situations relative to the region of the Carpathian Basin (Péczely, 1957) and for each of them he selected and defined a typical day (Appendix I, II; Péczely, 1957, 1983). The daily catalogue of Péczely's macrosynoptic types was first determined for the period 1877–1956 (Péczely, 1957), and was later extended till the end of 1982 (Péczely, 1983). The daily classification of weather types was compiled later by Károssy (1987; 2004), with the same subjective methodology.

Pairwise comparisons of the Péczely's weather types regarding their efficiency in enriching or diluting airborne pollen concentrations have not yet been made. The aim of this present study is to assess the usefulness of the subjective Péczely's classification system for specifying airborne pollen levels. The severe health impact of pollen and the worldwide increasing tendency of pollen related diseases, including pollen allergenicity, which is potentially related to global warming, mean that this kind of research is of practical importance for predicting pollen loads. This study investigates the possibility of predicting pollen levels belonging to the different Péczely's weather types in the high pollen season, which may help patients to prepare for periods of extreme pollen release.

Material and methods

The city of Szeged (20°06′E; 46°15′N), the largest city in south-east Hungary, is located at the confluence of the Tisza and Maros Rivers, and is characterized by an extensive flat landscape (79 m a.s.l.; Figure 1). The urban area covers a region of about 46 km^2 with about 155 000 inhabitants. The extensive lowlands do not only characterize Szeged and its surroundings but they have the lowest elevations in Hungary and the Carpathian Basin (Figure 1). This results in a "double basin" situation. Due to the position of the city in a basin, temperature inversions form more easily in the area and last longer than on a flat terrain, leading to an enrichment of both physical and chemical air pollutants as well as bioaerosols within the inversion layer.

The majority of Hungary is characterized by temperate-warm climates with an even distribution of precipitation [*Cf* climate zone of Köppen (1931)] corresponding to the Trewartha's *D.1* climate zone characterized by continental climates with long warm summers (Trewartha, 1943).

A more detailed, higher resolution climatic classification of Hungary is based on the mean temperature values of the growth season (T_{VS}) and the aridity index (H) [$H = S/(L \cdot C)$; where S is the annual mean radiation balance at the surface, L is the latent heat of vaporization and C is the total annual mean precipitation]. Based on the climatologic characteristics for the period of 1901–1950 (Table I), the climate of Szeged can be considered as *warm-dry* with $T_{VS} > 17.5$°C and $H > 1.15$ (Péczely, 1979).

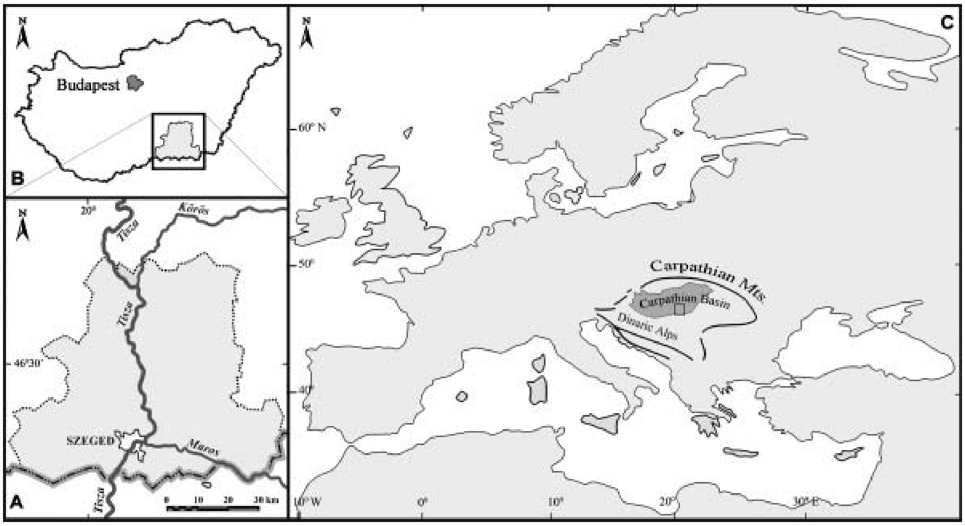


Figure 1. **A**. Location of Szeged in Csongrád County; **B**. The Csongrád County within Hungary outline map. **C**. The Carpathian Basin with Hungary outlined.

The range of the aridity index is between 0.81 and 3.45 while the index in an average year is 1.25. The typical vegetation type for the most arid year is desert, while that of the most humid year is woodland; the typical vegetation in an average year is steppe. Consequently in some years Szeged area may belong to the vegetation belt of desert ($H > 3$; e.g., years 1952–1953), while in other years this region is influenced by semi-desert conditions ($2 < H < 3$; e.g. 1954–1956) (Makra et al., 1985). Analysis of Palmer drought severity index time series of five meteorological stations in East Hungary, including the Szeged area, for the growing season between 1901 and 1999 detected a significant increasing trend for dry periods (Makra et al., 2005*b*).

A "Hirst-type" (Hirst, 1952) pollen trap (Lanzoni VPPS 2000; Lanzoni s.l.r., Bologna, Italy) has been used to collect airborne pollen in Szeged since 1989. The air sampler is placed on the roof top of the Faculty of Arts, University of Szeged (20 m above the ground level). Daily pollen data were obtained according to the recommendations of Käpylä & Penttinen (1981). The data consists of daily mean pollen counts (expressed as pollen grains $\times$ m^{-3} of air) for 24 species (Table II) over a 5 year period (1997–2001: from 1 February to 31 October).

The classification of the days into homogeneous groups of Péczely-types, i.e. into groups of days with the same weather, was performed based on the sea-level atmospheric pressure only and not on pollen parameters. Pollen were examined in the second stage of the work and therefore the results were not affected by pollen distribution in time. Since pollen dispersion of the 24 species, owing to the different phenological phases, is not observed each day of the period 1 February–31 October, the mean daily pollen concentrations of the species within the individual Péczely-types are calculated for only those days, when pollen release of the species examined was detected (Table II). Therefore, the number of days with dispersion of any specific pollen is not higher than that belonging to a given Péczely-type (Table II).

Meteorological data

The meteorological data consist of data set from 1997 to 2001 measured every 30 min intervals at the

Table I. A summary of meteorological data at Szeged for the study period (mean of 1901–1950).

	Winter	*Summer*	*Annual*
Temperature (℃)	2.3 (January: −1.2)	22.4 (July: 22.4)	11.2
Irradiance (MJ m^{-2})	4.2	20.2	
Most frequent wind direction	SSE (32.6%)	NNW (42.3%)	
	NNW (30.8%)	SSW (24.0%)	
Wind speed (m s^{-1})	2.8	3.5	3.2
Precipitation (mm)			573.0
Relative humidity (%)			71.0
Sunshine hours			2102.0

Table II. Meteorological parameters and pollen concentrations (pollen grains × m^{-3} of air) for the days belonging to the 13 Péczely's weather types (mean of data from 1997 to 2001).

Péczely-type	1	2	3	4	5	6	7	8	9	10	11	12	13
Case no (days)	166	92	11	68	137	52	26	153	48	102	92	138	52
Frequency (%)	14.6	8.1	1.0	6.0	12.1	4.6	2.3	13.5	4.2	9.0	8.1	12.1	4.6
T_{mean} (°C)	16.7	15.5	12.8	13.5	17.7	13.8	15.7	15.3	15.9	15.5	17.9	16.1	17.4
T_{max} (°C)	21.7	20.3	17.5	18.4	23.6	17.8	21.4	20.2	21.8	20.6	22.9	22.1	21.6
T_{min} (°C)	9.9	9.2	7.9	7.7	10.3	9.6	10.3	9.5	8.4	9.6	10.4	8.4	12.8
$\Delta T = T_{max} - T_{min}$ °C	11.8	11.1	9.6	10.7	13.3	8.2	11.1	10.7	13.4	11.0	12.5	13.7	8.8
WS (m s^{-1})	1.2	1.1	1.0	1.2	0.9	1.1	1.0	1.0	0.8	1.0	0.9	0.7	1.2
RH (%)	72.2	68.9	78.4	74.7	65.2	79.8	73.4	68.5	69.4	67.6	66.6	64.3	79.9
I (MJ m^{-2})	20.1	24.7	20.4	17.5	23.2	13.6	17.8	22.6	21.3	23.8	24.4	25.9	16.9
E (hPa)	27.7	26.1	22.1	22.3	30.3	22.7	25.5	26.6	26.5	26.9	30.1	28.3	28.3
VP (hPa)	19.3	17.6	17.1	16.3	18.8	17.6	18.1	17.6	17.5	17.6	19.3	17.2	21.6
PE (mm)	3.6	3.6	2.4	2.7	4.6	2.5	3.2	3.7	3.7	3.8	4.4	4.4	3.0
T_d (°C)	11.6	9.7	9.1	8.9	10.9	10.2	10.9	9.4	10.1	9.4	11.4	9.1	13.7
P (hPa)	1010.6	1017.6	1009.5	1008.0	1017.0	1009.9	1008.2	1017.8	1016.3	1019.0	1017.2	1020.0	1009.1

Taxa	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+	p*	d+
Acer	7.2	18	2.9	7	0.0	1	20.6	11	3.1	16	1.4	5	3.3	3	4.6	11	4.8	4	2.9	11	6.2	6	5.5	2	16.0	4
Alnus	14.8	24	13.3	8	9.5	2	7.1	10	24.7	13	20.6	5	32.4	8	26.1	26	7.0	8	19.0	9	1.0	4	26.9	20	1.5	2
Ambrosia	107.9	67	63.6	31	133.5	2	94.6	23	48.0	69	47.0	24	6.3	11	65.5	63	113.6	9	93.2	51	119.5	55	62.3	59	111.2	26
Artemisia	6.5	60	8.1	28	4.0	2	3.8	18	8.6	57	7.2	19	2.3	6	9.4	55	14.1	9	11.8	48	9.4	46	14.6	50	10.2	21
Betula	21.2	31	13.5	10	17.7	3	39.3	21	14.8	23	22.4	14	78.0	1	44.6	13	22.7	3	8.9	13	10.7	9	11.5	13	26.9	9
Cannabis	4.3	33	4.2	21	8.3	3	13.0	2	5.0	20	4.4	7	11.5	2	5.2	50	3.8	5	3.8	17	5.9	25	5.8	38	4.2	18
Carpinus	12.3	24	7.7	7	11.0	1	35.0	19	8.8	13	9.0	13	3.0	1	7.5	10	11.7	3	9.1	10	6.3	6	7.6	11	11.9	9
Chenopodium	6.3	76	7.0	40	9.3	3	4.5	24	8.0	66	4.5	24	2.1	9	7.2	73	4.9	16	11.0	55	9.5	58	11.0	60	7.8	34
Corylus	7.8	26	1.5	2	2.5	2	2.5	13	20.2	12	10.0	5	27.6	8	18.3	27	11.8	9	12.1	9	1.5	4	24.6	19	2.0	2
Fraxinus	10.8	15	2.3	4	11.0	2	13.0	14	9.7	15	4.5	6	0.0	0	15.2	10	0.0	1	9.3	7	9.7	3	5.8	5	9.3	4
Juglans	6.7	20	5.5	14	13.0	2	3.0	2	10.1	18	10.2	9	3.0	1	4.6	5	7.3	6	5.1	8	7.5	10	17.5	11	8.1	8
Morus	10.6	21	16.0	10	17.0	2	1.0	2	25.4	17	12.6	8	4.0	1	9.5	4	45.6	5	8.6	8	8.7	10	45.3	12	9.7	7
Pinus	15.1	24	10.0	31	18.5	2	11.8	4	13.6	25	6.5	8	33.0	1	8.7	12	14.8	13	15.0	15	14.0	13	10.5	18	8.7	15
Plantago	3.7	39	4.5	30	6.0	4	2.8	5	6.1	22	7.0	7	0.0	0	3.2	45	4.3	11	3.1	24	5.9	32	4.4	33	3.5	21
Platanus	16.0	20	6.3	6	19.5	2	19.0	6	10.5	12	14.5	10	0.0	1	8.5	4	14.3	4	3.2	5	8.0	7	8.1	9	30.6	5
Poaceae	12.5	113	16.2	69	18.6	7	6.8	36	13.0	94	6.8	36	3.7	12	10.9	91	16.2	28	14.2	68	14.6	79	13.0	84	14.8	46
Populus	61.9	19	14.0	1	10.7	3	63.2	16	25.3	21	2.3	3	112.0	2	47.8	15	92.0	3	10.2	13	11.0	4	85.6	10	187.5	2
Quercus	7.9	27	4.9	14	5.7	3	9.6	13	6.4	17	11.6	13	17.5	2	8.3	14	9.5	2	9.5	11	5.6	7	8.9	14	11.0	8
Rumex	6.2	39	8.2	37	10.8	4	6.4	7	6.8	29	8.0	6	0.0	2	2.8	42	5.4	15	5.3	18	11.9	19	3.7	33	6.2	25
Salix	10.2	25	6.3	11	16.5	2	17.3	17	10.4	21	6.0	10	20.0	4	13.3	19	9.7	3	5.9	12	6.3	6	12.4	7	27.8	4
Taxus	9.3	23	1.0	8	1.0	3	8.5	13	9.4	18	3.0	5	9.3	8	9.0	23	9.4	8	7.9	12	1.5	2	14.6	20	13.0	2
Tilia	5.3	18	2.9	28	5.0	3	3.8	6	4.6	14	3.0	5	0.0	0	6.5	17	6.0	12	4.0	14	7.6	7	3.3	12	7.6	9
Ulmus	9.7	22	4.7	12	3.5	2	7.7	10	9.7	12	4.8	5	13.5	8	8.3	23	11.0	8	9.4	8	7.7	6	7.8	18	0.0	1
Urtica	10.2	82	13.2	50	12.8	5	6.7	20	11.8	70	9.0	20	2.0	7	15.0	75	8.8	20	12.5	49	12.2	60	14.5	66	7.6	37

T = temperature (°C); ΔT = daily temperature range (°C); WS = wind speed (m s^{-1}); RH = relative humidity (%); I = irradiance (MJ m^{-2} day^{-1}); E = saturation vapour pressure (hPa), VP = water vapour pressure (hPa); PE = potential evaporation (mm); T_d, = dew point temperature (°C); P = atmospheric pressure (hPa); p* = pollen grains m^{-3} of air; d+ = number of days;

Table III. χ^2 test, independence analysis of the mean sea level pressure fields of the 13 Péczely-types, probability of the null hypothesis.

Péczely-type	1	2	3	4	5	6	7	8	9	10	11	12	13
1	–	0.0000	0.0000	1.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
2		–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3			–	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0525
4				–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5					–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
6						–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
7							–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8								–	0.0000	0.0000	0.0000	1.0000	0.0000
9									–	0.0000	0.0000	1.0000	0.0000
10										–	0.0000	0.0000	0.0000
11											–	0.0000	0.0000
12												–	0.0000
13													–

monitoring station, located in Szeged downtown and ca 500 m from the pollen monitoring site.

Daily sea-level pressure fields for the same period (1 February–31 October, 1997–2001) measured at 00.00 UTC come from the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis ERA 40 project (ECMWF, London, UK). The area for the pressure fields is between 30°N–70.5°N latitudes and 30°W–45°E longitudes. The grid network is selected with a density of $1.5° \times 1.5°$, which indicates $28 \times 51 = 1428$ grid points for the region.

The Hungarian Meteorological Service prepared the daily sea-level pressure maps, according to which Péczely's macrosynoptic types could be determined. Using the ECMWF database and applying the Surfer 7.00 software, we constructed average daily sea-level pressure maps for each Péczely-type in the period examined. Isobars for an average day, i.e. for an average Péczely-type, were drawn by using $28 \times 51 = 1428$ grid data on the basis of the standard kriging method without increasing element number of data and with maximum smoothing (Makra et al., 2006).

For each Péczely's large-scale weather situation (Péczely's macrosynoptic types) the concentration of pollen 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. The efficiency of the Péczely's weather types was statistically evaluated in grouping the total pollen grain concentration for each species.

Statistical 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 two random variables (ξ and η) are independent. According to the null hypothesis, ξ and η are not independent.

A One-way Analysis of Variance (ANOVA) was used to determine the significant differences in pollen concentrations between the different taxa. Tukey's honestly significant difference test was applied to quantitatively compare the mean pollen levels between each pair of synoptic type (pairwise multiple comparisons) (McGregor & Bamzelis, 1995; Sindosi et al., 2003).

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

Results

χ^2-test, independence analysis

On the basis of our computations, probability of the null hypothesis for each sea-level pressure field pairs compared was 0. The mean sea-level pressure fields of all the 13 Péczely-types differed significantly from those of the 13 typical days of the Péczely system and 90% of the pairwise mean sea-level pressure fields of the 13 Péczely-types differed significantly from each other. When the probability of the null hypothesis between the sea-level pressure fields of Péczely-types is 1, the sea-level pressure fields cannot be considered independent (Table III).

Statistical characteristics of the Péczely's macrosynoptic types

With reference to the 24 species (Figures 2, 3), basic statistical parameters of their pollen concentrations were calculated for the days within the individual Péczely-types. Of all pollen, the variance was proved to be the highest for *Ambrosia*, in agreement with the higher variability of its concentrations (Figure 3) followed, in decreasing order, by *Populus*, *Morus* and *Alnus*. Variation coefficient was highest for *Ambrosia* pollen concentration denoting its higher daily variability. However, it did not differ significantly from that of the other species. The difference of

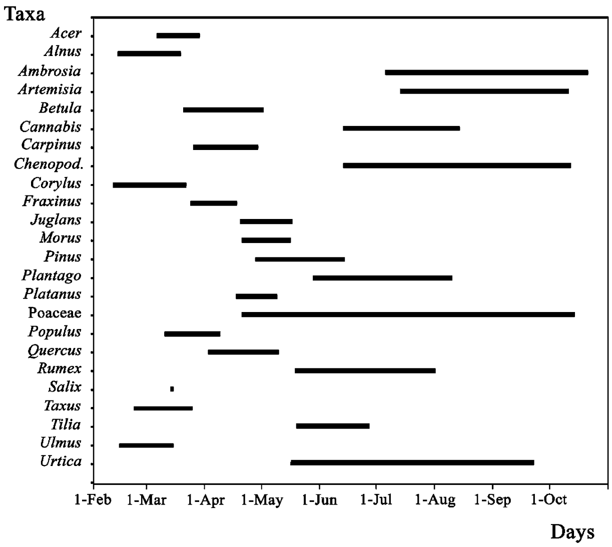


Figure 2. Investigated species with their main pollen seasons in Szeged (based on data from 1997–2001).

|*median*−*average*| remained within the interquartile half extent for each pollen type. The highest differences of |*median*−*average*| were detected for *Ambrosia* and *Alnus*.

Regarding the period examined (1 February–31 October), four groups of the Péczely's macrotypes are characteristic over the Carpathian Basin: 1) types connected with northerly current (23.7%); 2) types connected with southerly current (23.6%); 3) types connected with westerly current (20.0%) and 4) types connected with easterly current (17.1%). These weather types amount to 84.4% of the total number of days in this period of the year. Anticyclonic and anticyclonic ridge situations between 1 February and 31 October are predominant in the Péczely types (66.9%).

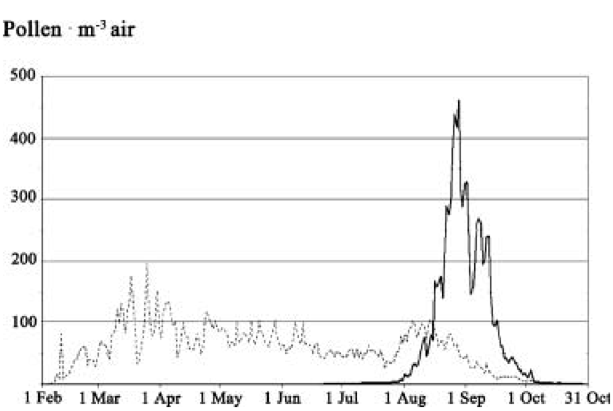


Figure 3. Mean daily pollen concentrations in Szeged, 1997–2001, 1st of February–31st of October.

ANOVA-statistics for the individual Péczely-types

All the investigated pollen types except *Alnus*, *Juglans*, *Morus*, *Pinus*, *Populus*, *Quercus*, *Taxus* and *Tilia*, presented significant Péczely's inter-weather type differences in mean pollen concentration values at the 99% probability level (Table IV). For *Alnus* (81%) *Juglans* (89%), *Morus* (85%) and *Quercus* (89%) the differences were significant below the 90% probability level. Because differences were found among the mean pollen concentrations, Tukey's tests were applied in order to apply a pairwise multiple assessment of the differences.

There were no two air mass types for which Péczely's inter-weather type differences in pollen concentrations of all the 24 species considered are significant. The pairs of Péczely-types 2–4, 4–11 and 4–10 differ significantly for nine, eight and seven species, respectively (Table V). The pairs of Péczely-types 4–9 differ substantially for six species and each of the pairs of Péczely-macrotypes 4–8, 4–12 and 7–11 show important differences for five species (Table V).

Significant differences for pollen levels of one or more species were found in 47.4% of the pairs of Péczely-types. The highest inter-air mass type difference is indicated by nine species for the types 2–4. No significant differences in pollen levels of any species could be found in 41 pairs (52.6%; Figure 4 & Tables II, V).

Péczely-type 3 shows pairwise difference only for *Corylus*. The cyclonic type 4 indicated 55 and type 7 showed 27 pairwise differences and anticyclonic type 11 indicated 20 parwise differences (Figure 4; Tables II, V).

Discussion

Studies on the relationship between synoptic weather conditions and air pollution levels are made either using objective multivariate statistical methods (McGregor & Bamzelis, 1995; Sindosi et al., 2003; Makra et al., 2006), or subjective classifications based on the long experience of meteorologists (Péczely, 1957, 1983; Kassomenos et al., 1998; Károssy, 1987, 2004). Efficiency of subjective weather types in enriching or diluting air pollutant concentrations (MAPs) were analyzed by Péczely (1959) and Kassomenos et al. (1998). However, the relationship of subjective weather types and airborne pollen grain concentrations has not yet been analyzed.

Pollen concentrations were analysed for subjectively defined large-scale weather situations. The base of the Péczely-classification is the same with the objective categorization: daily sea-level pressure

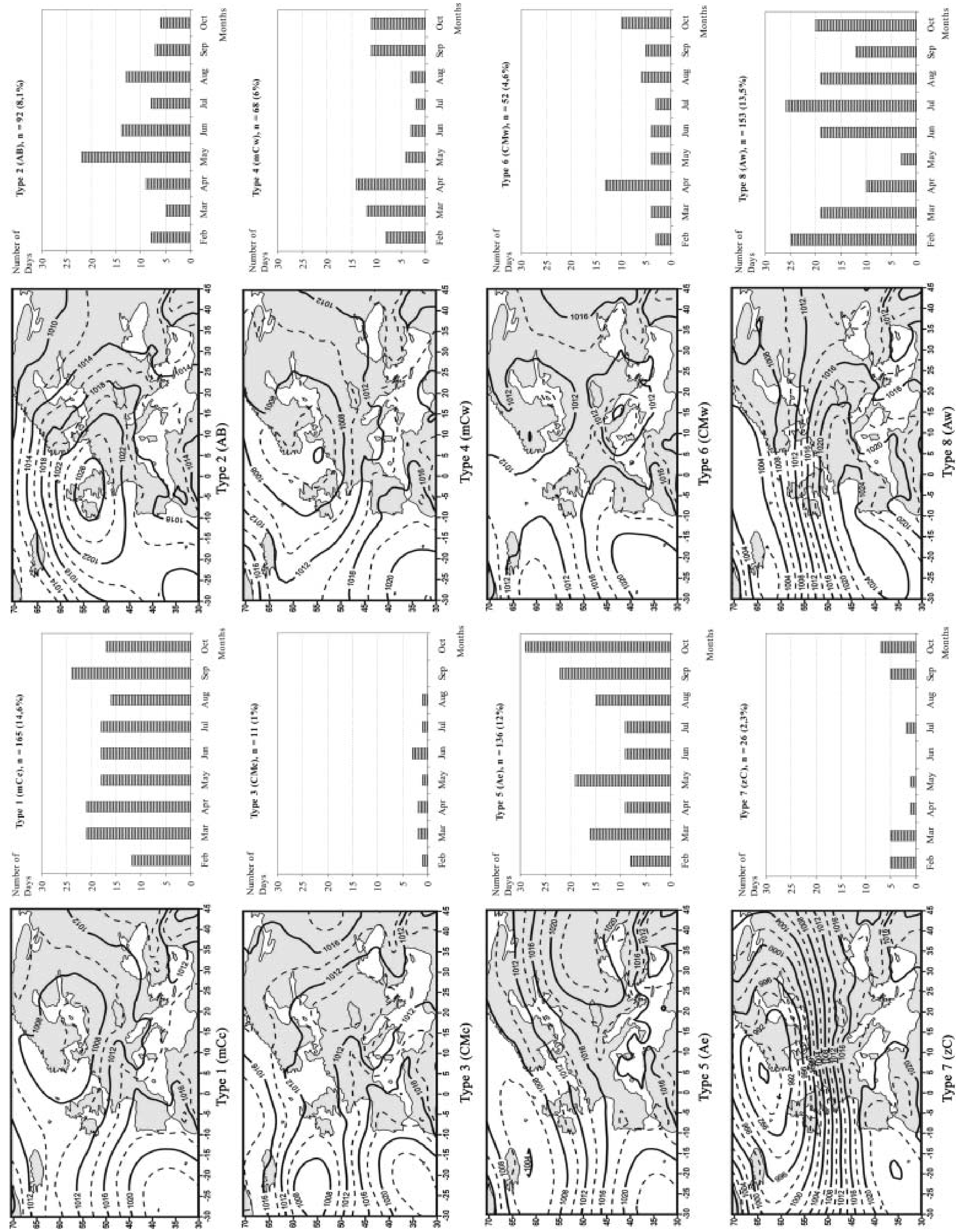
Table IV. ANOVA statistics for the Péczely's inter-weather type comparison of pollen concentrations (pollen grains × m^{-3} of air).

Taxa	Mean square between Péczely types	Mean square within Péczely-types	F-ratio	Level of significance (%)
Acer	52.49	12.20	4.30	99
Alnus	303.87	226.71	1.34	81
Ambrosia	30956.00	12907.49	2.40	99
Artemisia	196.83	81.55	2.41	99
Betula	670.37	197.18	3.40	99
Cannabis	23.23	9.69	2.40	99
Carpinus	530.50	137.65	3.85	99
Chenopodium	197.34	57.59	3.43	99
Corylus	361.23	83.42	4.33	99
Fraxinus	44.13	18.64	2.37	99
Juglans	25.04	16.39	1.53	89
Morus	254.75	178.90	1.42	85
Pinus	103.87	59.39	1.75	95
Plantago	20.21	7.16	2.82	99
Platanus	91.59	28.96	3.16	99
Poaceae	856.67	175.27	4.89	99
Populus	1388.82	846.38	1.64	93
Quercus	29.88	19.51	1.53	89
Rumex	71.57	21.34	3.35	99
Salix	124.19	39.90	3.11	99
Taxus	45.09	24.40	1.85	96
Tilia	11.66	6.67	1.75	95
Ulmus	37.93	17.60	2.16	99
Urtica	402.58	152.95	2.63	99

fields measured at 00 00 UTC. Generally, Péczely-types 2–4, 4–11 and 4–10 can be considered to be the most different. This can mainly be explained by their different sea-level pressure systems. On the one hand, during type 4 (mCw) air currents over the Carpathian Basin are directed by a cyclone found with its centre in north to north-west Europe and Hungary lies in the fore part of a Mediterranean cyclone, the warm front of which passes through the region. During type 7 (zC) fast cyclones pass through the Carpathian Basin. Both types induce very high wind speed with cloudy and rainy weather, which favour dilution of pollen levels. Type 8 (Aw), type 11 (AF) and type 12 (A) are anticyclonic weather situations, during which the Carpathian Basin is under the influence of a high pressure system. In this case, the region is characterized by a clear, undisturbed weather, which promotes accumulation of pollen (Figure 4A-C; Tables II, V).

Relation of the Péczely-types and pollen concentrations of the 24 species in Szeged detected that pollen levels can be connected to different prevailing pressure patterns in the region examined. The atmospheric circulation, based on the pressure patterns of the 13 Péczely-types, is not the only factor controlling the pollen concentrations in Szeged. The pressure patterns of these subjectively defined weather types can only partially influence the pollen levels. Pollen concentrations depend firstly on the phenological phase of the given species, and secondarily on the values of the meteorological elements.

Results revealed that pollen appear in higher concentrations when irradiance is high and light breezes occur (Table II). This is the situation, when anticyclonic ridges (Péczely types 8, 10, and 11) or an anticyclone centre type (Péczely type 12) influence the weather of the Carpathian Basin (Figure 4; Tables II, V). The lowest pollen concentrations are connected to type 2 (AB), as an anticyclonic ridge situation and type 4 (mCw), as a cyclonic type. The decreased pollen levels are due to the very high wind speeds, which are characteristic of both weather situations. This example of type 2 (AB) might indicate the ambivalent role of anticyclonic ridge types in pollen levels (Figure 4; Tables II, V). Besides, with more than 15 pairwise differences types 4, 7, 11 and type 2 are considered to be the most characteristic macrotypes in classification of pollen concentrations with 55, 27, 20 and 19 pairwise differences respectively. Among them, type 4 [with the most frequent pairwise differences of *Acer* and *Carpinus* (10 cases each)] and type 7 [*Corylus* (12 cases)] are cyclonic weather types, while type 11 [*Ambrosia* (5 cases)] and type 2 [*Poaceae* (4 cases)] are anticyclonic ridge types. Type 3 (with 1 pairwise difference) and type 13 (4) can be regarded as intermediate situations (Figure 4; Tables II, V).


Type 1 (mCc)
Type 1 (mCc), n = 165 (14,6%)
Type 2 (AB)
Type 2 (AB), n = 92 (8,1%)
Type 3 (CMc)
Type 3 (CMc), n = 11 (1%)
Type 4 (mCw)
Type 4 (mCw), n = 68 (6%)
Type 5 (Ac)
Type 5 (Ac), n = 136 (12%)
Type 6 (CMw)
Type 6 (CMw), n = 52 (4,6%)
Type 7 (zC)
Type 7 (zC), n = 26 (2,3%)
Type 8 (Aw)
Type 8 (Aw), n = 153 (13,5%)
Number of Days
Months
Feb Mar Apr May Jun Jul Aug Sep Oct

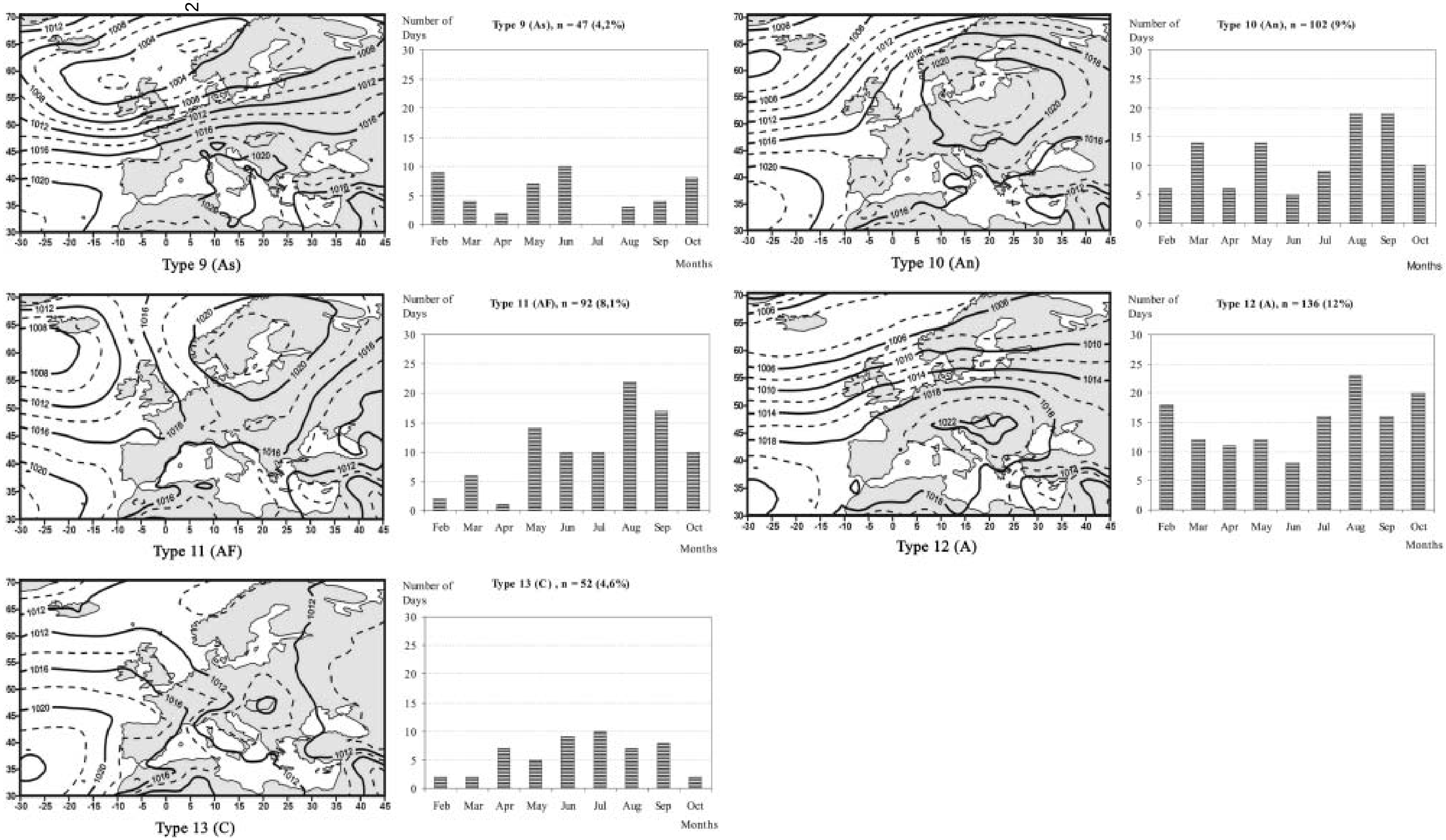


Figure 4. Monthly mean sea level pressure fields and the corresponding monthly average number of days for the 13 Péczely's weather types produced on data from the 5 year period (1997–2001: from 1st of February to 31st of October).

Table V. Péczely's weather type – pollen counts difference matrix. Each matrix cell represents the comparison between two Péczely's weather types. Species appearing in the matrix cells indicate significant inter – Péczely's weather type difference in pollen counts (pollen grains × m^{-3} of air) of the species considered according to Tukey's honestly significant difference test (light-faced characters: 95% of significance; **bold** characters: 99% of significance).

	1	2	3	4	5	6	7	8	9	10	11	12
2												
3												
4	**Ac Be Car S**	**Ac Be Car F Poa** Pop Plan R **S**										
5				**Ac Be Car S**								
6		Plat Poa		**Ac** Car S								
7	**Co**	**Co Poa Ul**	Co	Ac Car **Co**	**Co** Ul	**Co** Ul						
8		**R Poa**		**Ac Be Car S** Ur		**Plat**	**Co**					
9				**Ac Be Car** F Poa **S**			**Co** Poa	Pi				
10	Ch	R		**Ac** Ar **Be Car** Ch F **S**		**Plat**	**Co** Ul					
11	**Ch Plan**	Am		**Ac Be Car** Ch **F Plan Poa S**	**Am**	Poa	Am **Co** Plan **Poa Ul**	Am **Poa**				
12		**R**		**Ac Be Car F S**		Plat	**Co** Ul				Am	
13				Poa			**Co** Poa **Ul**					

Ac = *Acer*; Am = *Ambrosia*; Ar = *Artemisia*; Be = *Betula*; Car = *Carpinus*; Ch = *Chenopodium*; Co = *Corylus*; F = *Fraxinus*; Pi = *Pinus*; Plan = *Plantago*; Plat = *Platanus*; Poa = Poaceae; Pop = *Populus*; R = *Rumex*; S = *Salix*; Ul = *Ulmus*; Ur = *Urtica*

In this study two measures of classification were considered: a) for how many species the two Péczely-types compared differ significantly; b) how many significant pairwise differences belong to the given type. It was found that two anticyclonic ridge situations (Péczely-types 2 and 11) as well as two cyclonic types (Péczely-types 4 and 7) are favourable, while two further cyclonic types (Péczely-types 3 and 13) are negligible in classification of pollen levels. Hence, the Péczely's large-scale weather situations cannot be considered as an overall system in categorization of pollen concentrations.

Although some of the Péczely's weather types are characteristic in enrichment or dilution of pollen concentrations, the ones measured at any given location are also influenced by the dispersion or transport of pollen in the atmosphere, as well as by the pollen sources and sinks, that may have a complex spatial and temporal structure. In order to better characterize the pollen parameters for the Carpathian Basin, a transport model is needed for predicting the downwind rates of deposition and airborne concentrations of pollen grains. Local variables, including the prevailing climate (a total set of meteorological parameters) and topography should be considered for realistic estimates of pollen transport distances. The model accuracy could be improved by using the pollen data from all stations within the Hungarian pollen monitoring network.

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Appendix I

The 13 Péczely's large-scale weather situations

The 13 Péczely's large-scale weather situations with their typical days concerning their sea-level pressure maps constructed at 00 00 UTC for the North-Atlantic–European region are as follows (Péczely, 1957, 1983; Károssy, 1987, 2004):

Types connected with northerly current

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 current

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 current

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 current

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

Type 11 (AF). Anticyclone over the Fennoscandinavian region (typical day: 28 March, 1981)

Type of anticyclone centre

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

Type of cyclone centre

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

Appendix II

Description of the Péczely-types concerning the meteorological elements for the period examined (1 February–31 October, 1997–2001)

Type 1 (mCc). This pressure pattern is characterized by an extended low pressure system centred over Northern Europe and the Baltic region. The cold front of the cyclone passes through the Carpathian Basin. This macrosynoptic type, which causes windy, changeable and rainy weather, amounts to 14.6% of the total number of days and is associated with the following weather characteristics in Szeged: highest wind speed (1.2 m s^{-1}) and high temperature parameters (mean daily as well as maximum and minimum temperatures), as well as high humidity parameters (saturation vapour pressure, water vapour pressure and dew point temperature), while air pressure is low (Figure 4a; Table II).

Type 2 (AB). A highly developed anticyclone is found with its centre over the British Isles. Due to the fact that it blocks zonal air currents, *Type 2* favours meridional northerly currents over the Carpathian Basin. During this weather type, which mainly occurs in late spring and early summer, cold fronts pass through the Carpathian Basin, with fresh north to north-west winds. This type contains 8.1% of the total number of days, with high air pressure (Figure 4a; Table II).

Type 3 (CMc). A deep low west of the British Isles and a definite high pressure centre over the Azores are characteristic on its sea-level pressure map. September and October are completely free of this type, which has the lowest frequency (1.0%) of the total number of days. The Carpathian Basin is situated in the belt of cyclones. Both temperature and humidity parameters are low. In addition, mean and maximum temperatures as well as saturation vapour pressure and potential evaporation are the lowest (Figure 4a; Table II).

Type 4 (mCw). Cold air currents over the Carpathian Basin are directed by a cyclone found with its centre in north to north-west Europe causing the lowest minimum temperatures of all the types. This type is typical in spring and autumn with very low summer frequencies. It contains 6.0% of the total number of days (Figure 4a; Table II).

Type 5 (Ae). Its pressure pattern is characterized by a highly developed anticyclone in Eastern Europe, with its centre over Ukraine, inducing southern–south-eastern air currents over the Carpathian Basin. This weather type amounts to 12.0% of the total number of days. Being an anticyclone ridge situation for Hungary, this type involves light breezes only. Maximum temperature, saturation vapour pressure and potential evaporation are the highest (Figure 4a; Table II).

Type 6 (CMw). It contains 4.6% of the total number of days, with highest frequency in April and October. Air currents over the Carpathian Basin are ruled by a cyclone situated over the Italian Peninsula. The warm front of the cyclone passes through the Carpathian Basin, which might cause heavy precipitation. This type induces high wind speed with the lowest irradiance (13.6 MJ m^{-2}) (Figure 4b; Table II).

Type 7 (zC). This is a typical spring and autumn type (and winter, obviously), with casual summer occurrences. The pressure gradient is very high over the mid-latitudes of the temperate belt. From west to east fast cyclones pass through this zone including the Carpathian Basin. It is characterized by a changeable weather. Meteorological variables show medium values; at the same time, sea-level pressure is the second lowest (Figure 4b; Table II).

Type 8 (Aw). A highly developed anticyclone in south-west Europe, with its centre west of the Iberian Peninsula, is the most important characteristics of its pressure pattern. This type, which is the second most frequent of all, comprises

13.5% of the total number of days. Among meteorological variables temperature parameters are low and wind speed is high, while sea-level pressure is the third highest (1017.8 hPa) (Figure 4b; Table II).

Type 9 (As). A deep low is developed over the north-eastern part of the Atlantic Ocean. However, the weather over the Carpathian Basin is mainly influenced by a high pressure system found over the Mediterranean and the Carpathian Basin belongs to its northern ridge. It contains 4.2% of the total number of days with highest frequencies in February, May, June and October. Mean and maximum temperatures are higher than those in *Type 8*; on the other hand, daily temperature range (13.4°C) is the second highest and wind speed (0.8 m s^{-1}) is the second lowest (Figure 4b; Table II).

Type 10 (An). An anticyclone is found with its centre over the Baltic region and Poland, which, forming a high pressure ridge extends as far as Middle and Eastern Europe. This type contains 9.0% of the total number of days. Sea-level pressure is the second highest (1019.0 hPa) and, since it is an anticyclonic ridge situation, wind speed is high (0.8 m s^{-1}) (Figure 4b; Table II).

Type 11 (AF). Two formations are characteristic on its sea-level pressure map: a) an anticyclone with its centre over the Scandinavian Peninsula and the Baltic region and b) a low pressure centre south of Iceland. Among them, the Scandinavian anticyclone, forming a high pressure ridge, extends over the Carpathian Basin and Eastern Europe. This type rarely occurs in February, March and April and amounts to 8.1% of the total number of days. Mean temperature is the highest (17.9°C) and irradiance is the second highest (24.4 MJ m^{-2}) (Figure 4c; Table II).

Type 12 (A). An anticyclone stays, mostly for several days, with its centre over the Carpathian Basin. Due to orographic effects (Alps, Carpathians, and Dinari Mts.), the Carpathian Basin favours long-lasting anticyclones in the region. During this weather type undisturbed irradiance can be observed with its other typical meteorological characteristics: daily temperature range (13.7°C) and irradiance (25.9 MJ m^{-2}) are the highest, while wind speed (0.7 m s^{-1}) and relative humidity (64.3%) are the lowest, respectively. This type is the third most frequent, with 12.0% of the total number of days (Figure 4c; Table II).

Type 13 (C). The cyclone, relating to this type, comes mostly from the Mediterranean, originating from the Bay of Genoa and moves over the Carpathian Basin. It comprises 4.6% of the total number of days, with higher frequency in late spring and summer. This type has the most extremes of meteorological variables, which are typical to low pressure centre situations: minimum temperature (12.8°C), wind speed (1.2 m s^{-1}), relative humidity (79.9%), water vapour pressure (21.6 hPa) and dew point temperature (13.7°C) are the highest, while irradiance (16.9 MJ m^{-2}) and sea-level pressure (1009.1 hPa) are the lowest, respectively (Figure 4c; Table II) (Péczely, 1957, 1983; Károssy, 1987, 2004).