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ORIGINAL ARTICLE

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An objective classification system of air mass types for Szeged, Hungary, with special attention to plant pollen levels

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Abstract This paper discusses the characteristic air mass types over the Carpathian Basin in relation to plant pollen levels over annual pollination periods. Based on the European Centre for Medium-Range Weather Forecasts dataset, daily sea-level pressure fields analysed at 00 UTC were prepared for each air mass type (cluster) in order to relate sea-level pressure patterns to pollen levels in Szeged, Hungary. The database comprises daily values of 12 meteorological parameters and daily pollen concentrations of 24 species for their pollination periods from 1997 to 2001. Characteristic air mass types were objectively defined via factor analysis and cluster analysis. According to the results, nine air mass types (clusters) were detected for pollination periods of the year corresponding to pollen levels that appear with higher concentration when irradiance is moderate while wind speed is moderate or high. This is the case when an anticyclone prevails in the region west of the Carpathian Basin and when Hungary is under the influence of zonal currents (wind speed is high). The sea level pressure systems associated with low pollen concentrations are mostly similar to those connected to higher pollen concentrations, and arise when wind speed is low or moderate. Low pollen levels occur when an anticyclone prevails in the region west of the Carpathian Basin, as well as when an anticyclone covers the region with Hungary at its centre. Hence, anticyclonic or anticyclonic ridge weather situations seem to be relevant in classifying pollen levels.

Keywords Air mass types · Plant pollen levels · Factor analysis · Cluster analysis · ANOVA weather classification

Introduction

Studying plant pollen levels in relation to meteorological elements is of high practical importance because of the implications for human health. About one-third of Hungary's inhabitants have some type of allergy, with two-thirds of these having pollen sensitivity. At least 60% of this pollen sensitivity is caused by *Ambrosia* (Járai-Komlódi 1998), with 50–70% of allergic patients being sensitive to ragweed pollen (Mezei et al. 1992). The number of patients with registered allergic illnesses has doubled, and the 40 years leading up to the late 1990s saw a 4-fold increase in the number of cases of allergic asthma in Southern Hungary. According to annual totals of pollen counts of various plants measured between 1990 and 1996 in Southern Hungary, *Ambrosia* is responsible for about one-half of the total pollen production (47.3%). Although this ratio is highly dependent on meteorological factors in any given year (35.9% in 1990, while in 1991 it was 66.9%), *Ambrosia* can be considered the main aero-allergen plant in Hungary (Juhász 1995; Makra et al. 2004a,b). Nevertheless, pollen sensitivity depends substantially on the individual.

Plant pollen, as a biological component of hazardous air pollutants [HAPs], is a seasonal air pollutant related to the phenological phase of the given plant and influenced by meteorological elements. In Szeged, Southern Hungary, the pollination term of indigenous species lasts from the beginning of February until the end of October.

Plant pollen levels and their relationship to meteorological elements have been studied by several authors. Pollen

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concentrations of the species examined showed significant positive correlations with temperature parameters [mean air temperature (Gioulekas et al. 2004; Stennett and Beggs 2004), minimum air temperature (Makra et al. 2004b; Rodríguez-Rajo et al. 2004a), maximum air temperature (Rodríguez-Rajo et al. 2004a), dew point temperature (Stennett and Beggs 2004)], and with duration of sunshine (Gioulekas et al. 2004), and significant negative correlations with atmospheric pressure (Stennett and Beggs 2004). However, the relationship of pollen levels to other meteorological parameters is less clear. While in one case daily grass pollen counts showed a significant negative correlation with precipitation (Green et al. 2004), in another case no correlation was found between pollen and relative humidity and rainfall (Gioulekas et al. 2004). Daily sums of precipitation are generally excluded from consideration (e.g. Giner et al. 1999), the reason being that the role of precipitation is complicated because of the opposing effect of rain intensity on pollen counts (Galán et al. 2000). Correlating rainfall and pollen concentrations is

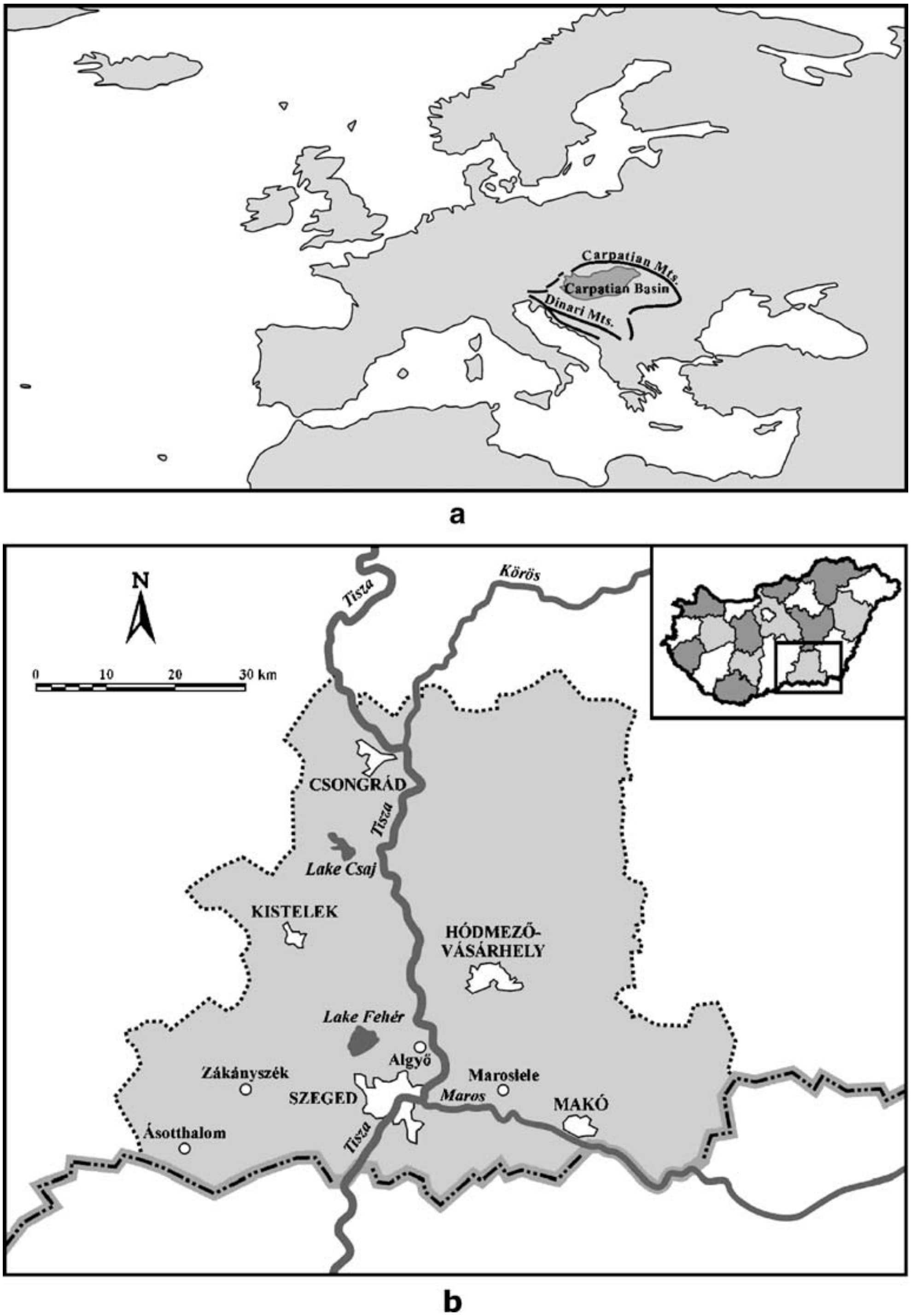


Fig. 1 **a** Location of the Carpathian Basin. **b** Location of Szeged in Csongrád county (*centre*); Csongrád county in Hungary (*top right*)

very difficult. On the one hand, the best correlation can be obtained by comparing pollen concentrations (Urticaceae) and meteorological parameters on non-rainy days (Fornaciari et al. 1992). On the other hand, pollen levels of species studied showed significant positive correlations with wind speed (Stennett and Beggs, 2004; Gioulekas et al. 2004) and wind components (Damialis et al. 2005), displaying the importance of wind persistence in pollen transport. However, Makra et al. (2004b) found significant correlation between daily pollen counts and wind speed with both signs, which seems to explain both high and low pollen concentrations as a consequence of high wind speed. This might indicate an ambivalent role of wind speed. Furthermore, the authors draw attention to their finding that if seasonality is subtracted, the explained variance of the regression decreases. One reason for this might be that a statistical description of pollen data simplifies complex processes such as phenology and dispersion of pollen in the air.

Long-lasting clear weather situations, due to long summers with undisturbed irradiation and calm or weak breezes, are favourable for studying the relationship of pollen levels with meteorological elements. In Europe, the Mediterranean is considered as such a region (Vázquez et al. 2003; Rodríguez-Rajo et al. 2003, 2004a; Gioulekas et al. 2004; Damialis et al. 2005). Athens, where the weather and the mountains that surround the city to the north favour extreme accumulation of both pollen levels and chemical air pollutants, seems to be an ideal place for such work (Kambezidis et al. 1998; Adamopoulos et al. 2002) and Thessaloniki (Gioulekas et al. 2004; Damialis et al. 2005). The position of Hungary, situated in the Carpathian Basin with long-lasting anticyclonic weather both in summer and winter, favours the enrichment of air with pollutants (Fig. 1a).

The major aim of the present study was to develop an objective, reliable classification system of air mass types prevailing over the city of Szeged during the pollination season, namely for the period between 1 February and 31 October, via the application of multivariate statistical methods. Then, for each air mass type characterised by homogenous temperature and humidity conditions, the pollen concentration of each species examined was estimated. Additionally, in order to reveal the possible relationship between the prevailing weather conditions, the spatial distribution of sea-level pressure fields, and the pollen concentration of species in the area of Szeged, mean sea-level pressure fields were calculated for the different air mass types for the North-Atlantic–European region.

Unfortunately, very few studies with such scope are known from the literature. The works of McGregor and Bamzelis (1995), Sindosi et al. (2003) and Makra et al. (2006) could be mentioned here as examples of similar analyses concerning the traditional main air pollutants (MAPs) as applied to Birmingham (United Kingdom), Athens (Greece) and Szeged (Hungary), respectively. Nevertheless, to our knowledge, pollen-related objective classification of air mass types has not been reported in the international literature. On the other hand, stability classes are often used, e.g. in air quality modelling, to classify whether the dispersion of air pollutants is high or low due to the prevailing meteorological conditions (determined empirically from wind speed, temperature gradient, cloud cover or solar radiation). However, these models classify only chemical air pollutants, disregarding biological agents (Pasquill 1962; Turner 1964; Golder 1972). The method used in our paper is an objective classification compared to the subjectively determined categories of Pasquill (1962) and Turner (1964). Furthermore, our method takes into account many more meteorological parameters in classifying air mass types, and the efficiency of the classes received in grouping plant pollen levels is statistically evaluated. This study represents an objective weather classification method, which might also serve as a starting point for the creation of a monitoring/forecasting system, with the ultimate goal of predicting plant pollen levels in the city of Szeged.

Topography, climatology, ecology, and pollen-related air quality of the Szeged area

Topography

The city of Szeged, the largest town in SE Hungary (20°06′E; 46°15′N), is located at the confluence of the Tisza and Maros rivers and is characterised by an extensive flat landscape with an elevation of 79 m a.s.l. (Fig. 1b). 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 they have the lowest elevations in Hungary as well as in the whole Carpathian Basin (Fig. 1a). 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 (e.g. due to cool air flow from the basin slopes) and prevail longer than in a flat terrain, leading to enrichment of air pollutants within the inversion layer.

Climatology

According to the climatic classification system of Köppen, the majority of Hungarian territory, including Csongrád county and the agglomeration of Szeged, belongs to the *Cf* climate zone characterised by temperate-warm climates and an almost even distribution of precipitation or to that of Trewartha's *D.1* climate zone, which is characterised by continental climates with long warm seasons.

The more detailed, higher resolution climatic classification of Hungary is based on the mean temperature values of the growing season (t_{VS}) and the aridity index (H) [where $H = Es\big/(L \cdot C)$ (E_S is annual mean radiation balance; L is latent heat of vaporisation and C is total annual mean precipitation)]. Based on the climatological characteristics of a 50-year period, the climate of Szeged can be considered as warm-dry with t_{VS} >17.5°C and H >1.15 (Péczely 1979).

The E_S energetic component of the aridity index (H) changes only slightly in Hungary. Its mean annual value is 1,760 MJ m^{-2} year^{-1} (Péczely 1979). On the other hand, the total amounts of annual precipitation for Szeged may fluctuate quite substantially. The average value is P_{mean} = 573 mm, with extreme values P_{min} =203 mm and P_{max} = 867 mm. On the basis of this information, the aridity index calculated for an average year is H =1.25, while for the most arid and most humid years the values are H =3.47 and H =0.81, respectively. The typical vegetation assigned to the most arid year value is desert, while that of the most humid is woodland. On the other hand, the typical vegetation belonging to an average year is steppe. Though persistence of high H values is not observed all-year or all-summer round, the climate of some summers inclines towards semi-arid or arid conditions in the Szeged area. This is also reflected in the composition of the natural vegetation. Several semi-desert species, such as needle grass (*Stipa stenophylla*), can be found as native plants in the southern part of the Great Hungarian Plain (Makra et al. 1985).

The climate of Szeged is characterised by hot summers and moderately cold winters. The mean daily temperature is 11.2°C over the year, 22.4°C in summer and 2.3°C in winter. The irradiance values also exhibit large-scale variances with an average of 20.2 and 4.2 MJ m^{-2} on summer and winter days, respectively. The most frequent winds blow along a NNW–SSE trajectory, with prevailing air currents arriving from NNW (42.3%) and SSW (24%) in the summer and from SSE (32.6%) and NNW (30.8%) during the winter. Due to its unique geographical position, Szeged is characterised by relatively low wind speeds, with average daily summer and winter values of 2.8 and 3.5 m s^{-1}, respectively. The highest hourly wind speeds have been recorded during the spring, with rates of up to 5 m s^{-1}. Finally, the mean annual values for relative humidity and sunshine duration are 71% and 2,102 h, respectively (Péczely 1979).

Ecology

The climate of the Great Hungarian Plains has been arid for several thousand years. Accordingly, xerophilous floras are native to this region [Illiric = species coming from Western Balkans; Pontian = species from the steppes arriving from the Black Sea region; Turanian (Aralo-caspian) = species coming from the region of the Aral and Caspian Seas; Sub-Mediterranean = species arriving from the regions bordering the Mediterranean areas of Southern Europe; Mediterranean = species coming from the region of the Mediterranean Sea (namely, species arriving from warmer and drier regions compared to the sub-Mediterranean conditions]. Most species of the above-mentioned floras immigrated to Hungary in the so-called “Hazelnut” era (between 7,000 and 6,000 BC). In addition, some species arrived in the Carpathian Basin even in recent times, namely during the last 2,000 years (mainly during warm-dry periods). Deforestation, drainage of swamps, and the comprehensive land drainage performed in the Great Hungarian Plains, which made the climate drier and warmer on a meso-scale, contributed to the settlement of the species mentioned above. According to the so-called “two-eras theory”, which is accepted among ecologists, long-lasting settlement of xerophilous species in the region can be attributed to two factors: the dry and warm climate in the Hazelnut era, and recent environmental changes, e.g. due to anthropogenic factors, that have resulted in climate change.

The dry and warm climate of the region is especially favourable for the Turanian (Aralo-caspian) semi-arid species. One of these groups consists of species that prefer extremely arid conditions, while species belonging to the other group indicate aridity, i.e. they are so-called xeroindicators (indicate long and dry periods in the climate). The Ellenberg’s indicator number (Ellenberg et al. 1991) for the one group is **1**, and for the other group is **2**. The lower the Ellenberg’s indicator number for a species (min =**1**), the more it prefers dry and warm climates. Similarly, the higher the number (max =**12**), the more the plant favours a humid environment. Hence, the Ellenberg’s indicator number is a 12-degree scale, first applied by Borhidi (1995) in Hungary, and introduced into the Hungarian literature as a WB (Water Borhidi)-value. The WB-value is a relative indicator number for groundwater or soil humidity. Borhidi also indicated the characteristic species of Hungarian flora, which did not feature much on the Ellenberg scale.

The native species of the Turanian (Aralo-caspian) semi-desert floras (with their Ellenberg’s indicator number) in the East Hungarian catchment area of the Tisza River are as follows: Crested Couch (*Agropyron pectinatum*) (**1**), Sea Buckhom (*Hippophaë rhamnoides* ssp. *carpatica* (**1**), Lying Broomgrass (*Kochia prostrata*) (**1**), Pepperwort (*Lepidium crassifolium*) (**1**), Wild Rye (*Secale sylvestris*) (**1**), Spring Speedwell (*Veronica verna*) (**1**), Sickle Buttercup (*Ceratocephalus testiculatus*) (**2**), Brush Orache (*Ceratoides latens*) (**2**), Bulbous Meadow-grass (*Poa bulbosa*) (**2**) and Prickley Saltwort (*Salsola kali* ssp. *Ruthenica*) (**2**) (Horváth et al. 1995).

The analysis is applied to the pollination term of species in Szeged; namely, for the period 1 February–31 October of the year.

Pollen-related air quality

Pollen levels are modified and influenced by prevailing atmospheric conditions, which are controlled by the prevailing meteorological parameters, mainly temperature and wind profiles, close to ground level.The city structure is a very simple one characterised by an intertwined network of boulevards, avenues and streets sectioned by the River Tisza, with the industrial area restricted mainly to the north-western part of the city.

In a detailed analysis of the quality of the environment and the level of environmental awareness, Szeged was ranked 32nd out of 88 Hungarian cities (the city ranked 1st was considered to have the best environmental conditions; Makra et al. 2002).

On the basis of the frequency of pollutant concentrations exceeding air quality limits, as measured at the Regional Immission Examining (RIE) network of stations for Hungary in 2001, the air quality of Szeged was listed as “polluted” (Mohl et al. 2002) according to a three-category classification system (satisfactory, moderately polluted, polluted).

The fact that Szeged was ranked 32nd out of 88 Hungarian cities gives the impression that this city has a rather moderate air quality. Therefore, categorisation of Szeged as “polluted” according to the RIE database seems surprising. In the above-mentioned analysis, the cities were ranked according to seven different categories (from 19 environmental indicators) as follows: water consumption (1), energy consumption (2), public utilities supply (3), traffic (4), waste management (5), settlement amenities factors (6), and air quality (7; with average concentration of particulates deposited, sulphur dioxide and nitrogen dioxide). As air quality is only one of the seven categories considered and is represented by only three parameters (environmental indicators), it carried little weight in the ranking of the cities. However, pollen levels were disregarded in the environmental indicators, owing to the lack of an overall pollen monitoring system in Hungarian cities.

Climatic parameters are favourable to pollen dispersion in the Carpathian Basin, especially in the Great Hungarian Plains. Considering the phenological phases of the 24 species examined, their pollination term lasts from the beginning of February until the end of October (Fig. 2). Daily mean pollen counts of these species are generally below 100 pollen grains/m^3 air. However, those of Acer (maple) (mean pollination term: beginning of March–end of March, Fig. 2) exceeds 100 pollen grains/m^3 air on some days (Fig. 3). Nevertheless, pollen dispersion of Ambrosia (ragweed) (mean pollination term: beginning of July–end of October, Fig. 2) is the most efficient of all species considered. On peak days its release (exceeding 450 pollen grains/m^3 air) is about one order of magnitude higher than that of the other species (Fig. 3).

Given its high pollen dispersion, the history, characteristics, and impact (Makra et al. 2004a), as well as the relation to meteorological elements (Makra et al. 2004b) of Ambrosia pollen have been analysed in detail. All the highest counts on peak days are reported from the Carpathian Basin, the southern part of the Great Hungarian Plains. The highest values observed in Szeged on peak days are about one order of magnitude higher than those in other European cities considered as highly polluted.

Pollen of the species examined, depending on individual sensitivity, may induce serious environmental-health problems. Nevertheless, *Ambrosia* pollen is the most aggressive of all pollens of plants in Hungary (Járai-Komlódi 1998). More and more people suffer from pollinosis and other allergic symptoms caused by this pollen in Hungary. High pollen levels of some species are

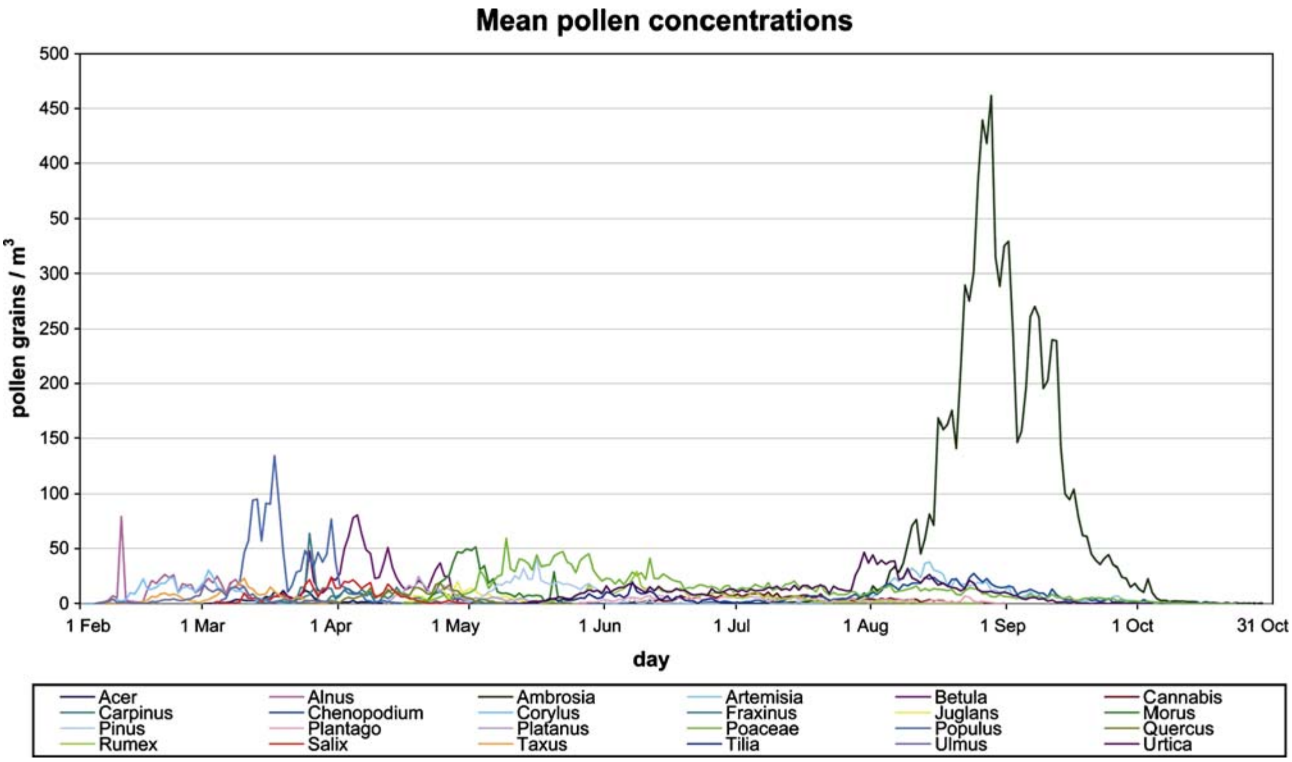


Fig. 2 Mean values of plant pollen counts of species considered, 1 February–31 October, 1997–2001 (pollen grains/m^3 air)

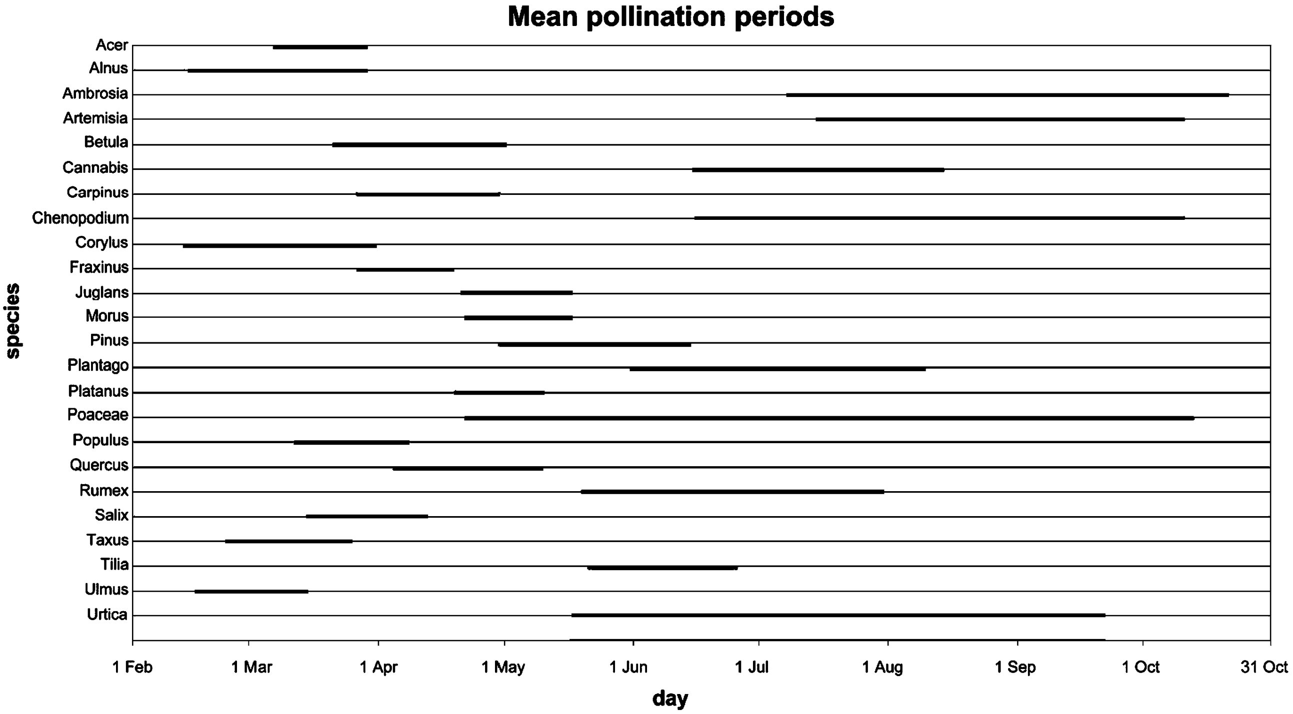


Fig. 3 Mean pollination periods of species considered, 1 February 1–31 October, 1997–2001 (days)

closely correlated with the development of respiratory diseases. Environmental pollution may also affect pollen allergenicity through a direct effect on the pollen grain itself. It has been shown that the prevalence of hay fever in the urban environment is twice of that in rural environments, even though pollen concentrations are higher in the latter (D'Amato 2000). Therefore, determining pollen threshold levels that elicit an allergic response is a complex task, since allergy depends on the combined effects of several factors: the patient, the allergens, the timing, the duration of exposure and elements of environmental quality (Geller-Bernstein et al. 1996, 2002).

The "double basin" situation of Szeged favours longer persistence of weather conditions both in the summer and the winter months, which contributes to an enrichment of not only MAPs (including sulphur dioxide, nitrogen dioxide, carbon monoxide, particles, lead and ozone) but also pollens as biological agents. The role and efficiency of objectively defined large-scale weather situations in grouping plant pollen levels was the main impetus behind the present work.

Materials and methods

Pollen data

In Szeged, the pollen content of the air has been examined with the help of a "Hirst-type" pollen trap (VPPS 2000; Lanzoni, Bologna, Italy) since 1989. The air sampler is located on top of the building of the Faculty of Arts, University of Szeged (20 m above the city ground level). The building is found in the downtown area, with its top level being one of the highest in the city. Daily pollen data were obtained by counting all pollen grains on four longitudinal transects (Käpylä and Penttinen 1981).

The database consists of daily mean plant pollen counts (pollen grains/m^3 air) of a total of 24 species from the 5-year period between 1997 and 2001, and for the pollination term 1 February–31 October. The species considered [with their Latin (English) names] were: *Acer* (maple), *Alnus* (alder), *Ambrosia* (ragweed), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), *Carpinus* (hornbeam), *Chenopodium* (goosefoot), *Corylus* (hazel), *Fraxinus* (ash), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (platan), *Poaceae* (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Salix* (willow), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm), *Urtica* (nettle).

Meteorological data

The database consists of 30-min data sets of 12 meteorological elements for the 5-year period 1997–2001 and for the pollination term 1 February–31 October. From these data, mean daily values are evaluated and utilised in the present work. The 12 meteorological parameters are: mean temperature (T_{mean}, °C), maximum temperature (T_{max}, °C), minimum temperature (T_{min}, °C), daily temperature range ($\Delta T = T_{\mathrm{max}} - T_{\mathrm{min}}$, °C), wind speed (WS, m s^{-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 come from the ECMWF (European Centre for Medium-Range Weather Forecasts) Re-Analysis ERA 40 project, in the frame of which daily data have been re-analysed since 1 September 1957. The procedure was performed using a uniform method with the data available from the investigated period. Data for the ECMWF Re-Analysis ERA 40 project are verified and dynamically correct, the pressure field is true even over the Atlantic Ocean, and there are no data lacking. When using the method, the measured false input data are omitted. On the other hand, if original station data are used, false data can frequently be encountered.

The investigated area covers the North-Atlantic–European region between latitudes 30°N and 70.5°N, and longitudes 30°W–45°E. The grid network is selected with a density of 1.5°×1.5°, which indicates 28×51=1,428 grid points for the region.

Cartographical background

For each objectively defined air mass type prevailing over Szeged, average isobar maps on the basis of daily sea-level pressure data calculated at each grid point of the investigated region were constructed by applying the Surfer 7.00 GIS software. Isobars for an average day, i.e. for an average objective type, were drawn by using 28×51=1,428 grid data on the basis of the standard Kriging method without increasing the number of data elements and with maximum smoothing. As a result of the procedure, the curved surface of the Earth—a spherical trapezoid with 40.5° difference of latitude and 75° difference of longitude—was transformed into a plane rectangle with equal spacing both horizontally and vertically. Isobar maps produced in this way can be fitted only to those informative background maps prepared with the same projection. For this reason, the background map of the investigated region was produced as an equidistant cylindrical projection. The major advantage of this map is that it is free from longitudinal distortion along each meridian and, therefore, the determination of the points of the compass is simple at any location of the map. Namely, the north-south and east-west directions are parallel with the vertical and horizontal sides of the rectangle; hence, geographical co-ordinates of various locations and air pressure formations can easily be determined with the help of the spaces indicated on the rectangle both horizontally and vertically (and, if required, by making linear interpolation). The only drawback of its use is that the background map becomes longer at higher latitudes in the east-west direction. The grid denotes a horizontal distance of about 107.3 km at a latitude of 50°N.

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 two random variables (ξ and η) are independent. According to the 0-hypothesis, ξ and η are not independent.

Factor analysis

In order to reduce the dimensionality of the above-collected meteorological data sets and thus to explain the relationships among the 12 meteorological variables, the multivariate statistical method of factor analysis is used. The main object of factor analysis is to describe the initial variables $X_1, X_2, \ldots, X_p$ in terms of m linearly independent indices ($m< p$), the so-called factors, measuring different "dimensions" of the initial data set. Each variable X can be expressed as a linear function of the m factors, which are the main contributors to the climate of Szeged:

$$X_I = \sum_{j=1}^{m} \alpha_{ij} F_j \tag{1}$$

where α_{ij} are constants called factor loadings. The square of α_{ij} represents the part of the variance of X_I that is accounted for by the factor F_j.

One important stage of this method is deciding on the number (m) of the retained factors. On this matter, many criteria have been proposed. In some studies, the Guttmann criterion or "Rule 1" is used, which stipulates that factors with eigenvalues >1 should be kept and those that do not account for at least the variance of one standardised variable X_{I} should be neglected. Perhaps the most common method is to specify a least percentage (80% in this paper) of the total variance in the original variables that has to be achieved (Jolliffe 1993; Sindosi et al. 2003). Extraction was performed by principal component analysis (kth eigenvalue is the variance of the kth principal component). There is an infinite number of equations that could be applied in place of Eq. 1. In order to select the best, or most desirable, of these, the so-called "factor rotation" is applied, a process that either maximises or minimises factor loadings to give better interpretation of the results. In this study, the "varimax" or "orthogonal factor rotation" is applied, which keeps the factors uncorrelated (Jolliffe 1990, 1993; Bartzokas and Metaxas 1993, 1995).

Factor analysis was applied to the data set, consisting of 12 columns (12 meteorological variables) and 1,366 rows (1,366 days) from 1 February until 31 October for each of the five examined years (1997–2001), in order to reduce the 12 interrelated meteorological parameters and reveal the main independent meteorological factors responsible for the formation of the weather in Szeged.

Cluster analysis

Cluster analysis is applied to the factor scores time series in order to objectively group days with similar weather conditions. The aim of the method is to maximise the homogeneity of objects within the clusters and also to maximise the heterogeneity between the clusters. Each observation (day) corresponds to a point in the *m*-dimensional space and each cluster consists of those observations that are “close” to each other in this space. The characterisation of a distance between two observations *k* and *l* as “close” or “far” is determined by the square of their Euclidean distance:

$$D_{kl}^{2} = \sum_{i=1}^{m} (x_{ki} - x_{li})^{2} \tag{2}$$

where x_{ki} is the value of the *i*th factor for the *i*th day and x_{li} is the value of the *i*th factor for the *l*th day.

There are two main clustering techniques: the hierarchical and the non-hierarchical. The basic difference between them is that in the non-hierarchical technique the number of clusters must be known a priori. On the contrary, in the hierarchical method the ultimate number of clusters is determined by a variety of statistical criteria. In this paper, the hierarchical technique is applied because of the lack of an objective classification of weather types for the Szeged region. The hierarchical technique can be applied by using various methods. Here, the “average linkage” method is used, since it does not depend on extreme values. In addition, it produces more realistic groupings and properly combines extreme weather days into distinct meteorological units (Anderberg 1973; Kalkstein et al. 1987; Hair et al. 1998; Sindosi et al. 2003).

For each of the derived clusters of days, the mean value for every meteorological parameter and the mean pollen concentrations of the species examined are then computed. In this way, the relationship between weather conditions and the corresponding plant pollen levels are revealed. Finally, for each weather type, composite maps of the mean sea level pressure distribution over the North-Atlantic–European region (00 UTC) are constructed. The aim of these maps is to associate atmospheric circulation patterns and plant pollen levels in the Szeged region. The classification of synoptic patterns into distinct groups used here enables us to describe the most important synoptic types from the point of view of the Szeged region.

ANOVA and Tukey’s honestly significant difference test

When determining the synoptic types, meteorological parameters only are taken into account, with pollen concentration data being excluded. Hence, the differences of the mean plant pollen levels calculated for each synoptic type require a further statistical evaluation. This is performed by the method of one-way analysis of variance (ANOVA) for each pollutant. Using this method, significant differences in plant pollen concentrations of different synoptic types (clusters) can be determined. Finally, Tukey’s honestly significant difference test is applied in order to quantitatively compare the mean plant pollen levels between each pair of synoptic type (pairwise multiple comparisons) (McGregor and Bamzelis 1995; Sindosi et al. 2003).

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

Results

The application of factor analysis to the time series of meteorological elements yielded five factors explaining 86.56% of the total variance (Table 1). Table 2 displays the factor loadings after orthogonal rotation.

Factor 1 explains 45.66% of the total variance (Table 1) and includes the three main air temperature variables (mean, maximum and minimum temperatures) and three important humidity parameters (saturation vapour pressure, water vapour pressure and potential evaporation). The high loadings of these temperature and humidity parameters show their strong relationship. Namely, the high loading of the water vapour pressure is due to the increase in vapour capacity of the atmosphere as the temperature rises (Table 2).

Factor 2 (13.88% of total variance; Table 1) includes daily temperature range with a negative sign and relative humidity. The high loadings of opposite sign indicate an inverse relationship between the two variables. Namely, high (low) daily temperature range is associated with low (high) relative humidity (Table 2). This ‘see-saw’ was expected since the minimum temperature range is recorded during overcast days, which are obviously characterised by high relative humidity values and vice versa.

Factor 3 explains 10.37% of the total variance (Table 1) and comprises atmospheric pressure only (Table 2).

Factor 4 (8.46% of total variance; Table 1) includes dew point temperature (Table 2).

Factor 5 is slightly weaker than Factor 4 and explains 8.19% of the total variance (Table 1). It comprises wind speed only (Table 2).

Table 1 Initial eigenvalues and variances, 1 February–October 31, 1997–2001

Component	Initial eigenvalues		
	Total variance	Relative variance (%)	Cumulative variance (%)
1	5.48	45.66	45.66
2	1.67	13.88	59.55
3	1.24	10.37	69.91
4	1.02	8.46	78.38
5	0.98	8.19	86.56
6	0.83	6.94	93.50
7	0.64	5.33	98.83
8	0.09	0.75	99.58
9	0.04	0.30	99.88
10	0.01	0.12	100.00
11	0.00	0.00	100.00
12	0.00	0.00	100.00

Table 2 Factor loadings for the period 1 February 1–31 October, 1997–2001

Meteorological parameters	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Mean temperature, T_{mean}	0.99				
Maximum temperature, T_{max}	0.98				
Minimum temperature, T_{min}	0.76				
Daily temperature range, $\Delta T = T_{\mathrm{max}} - T_{\mathrm{min}}$		−0.69			
Wind speed, WS					−0.67
Relative humidity, RH		0.78			
Irradiance, I					
Saturation vapour pressure, E	0.99				
Water vapour pressure, VP	0.90				
Potential evaporation, PE	0.91				
Dew point temperature, T_{d}				0.79	
Atmospheric pressure, P			−0.76		

Values higher than |0.12| are statistically significant at the 95% level; however, only those exceeding |0.60|are presented. This means that at least 36% of the total variance of a parameter can be explained by a single Factor

Irradiance (I) does not present high loadings in any factor. It appears that it is partially classified in more than one factor. In any case, this is not a problem since 86.56% is a high percentage and, in this work, factor analysis is used only as an intermediate data reduction tool before the application of cluster analysis.

Cluster analysis was applied to the five factor score time series and, as a result, nine homogenous clusters of days were revealed. The main characteristics of the nine clusters involving the prevailing air mass types are shown in Table 3, which presents the mean values of their meteorological parameters as well as the mean values of the corresponding plant pollen levels.

Here, we should note the following. Classification of the days into homogeneous groups, i.e. into groups of days with the same weather, was performed based on meteorological parameters only and not on pollen parameters. Pollen is examined in the second stage of the work. Therefore, the results are not affected by pollen distribution over time. Since, owing to the different phenological phases, pollen dispersion of the 24 species is not observed on every day of the period 1 February–31 October, the mean daily pollen concentrations of the species within the clusters are calculated only for those days when pollen release of the species examined was detected (Table 3). Therefore, the number of days belonging to a given cluster is generally higher than those with pollen release for the species in that cluster. The pollination terms of species for the days belonging to the nine dominant clusters is reported in Table 4.

Also, basic statistical parameters of the pollen concentrations of the 24 species are calculated for the days within the clusters when pollen release was observed. The variance for each cluster proved to be the highest for Ambrosia, in agreement with the higher variability of its pollen concentrations (Fig. 2). Variation coefficients (standard deviation expressed in the units of the average) for pollen levels of Alnus and Ambrosia are the highest, which denotes their higher variability. However, the difference is not significant compared to those of other species. 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 plant's pollen. The highest differences are detected for Ambrosia.

The mean sea level pressure distribution belonging to the clusters examined and the number of days in each cluster (air mass type) are shown in Fig. 4.

Mean sea-level pressure fields for the nine defined clusters were compared on the basis of the grid values used. In order to decide whether the mean sea-level pressure fields of the 9 clusters differ significantly from each other in the period examined, 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 clusters compared. On the basis of our computations, the probability of the 0-hypothesis for the period 1 February–31 October between the sea-level pressure fields of clusters 3–4, 3–7, 4–7, 6–7, 3–8, 6–8, 7–8, 3–9, 5–9, 6–9, 7–9 and 8–9 is 1. In other words, in these cases the mean cluster fields mentioned cannot be considered independent. On the other hand, the probability of the 0-hypothesis for all other cluster pairs (two-thirds of all cases) is 0, i.e. the mean cluster fields compared are in most cases considered to be independent (Table 5).

The nine air mass types and the corresponding pressure patterns with associated plant pollen levels are described as follows.

Cluster 1

This cluster comprises 8.8 % of the total number of days. The corresponding pressure pattern exhibits an extension of the subtropical anticyclone of the Atlantic (Azores anticyclone) up to central Eastern Europe. This situation appears more frequently in February, March and October, and the air masses prevailing over Szeged are associated with a weather type that could be characterised as 'calm weather'. Considering that this situation occurs mostly at the end of the winter and in autumn, temperature and humidity parameters, as well as irradiance and wind speed are lowest. It is in agreement with the general climate of the area. Pollen levels are also lowest, since the pollination term has mostly not yet started or has already finished (Fig. 4a; Table 3; Fig. 3).

Table 3 Mean values of the meteorological parameters and plant pollen counts (pollen grains/m^3 air) of the species indicated for days belonging to the nine dominant clusters, 1 February–31 October, 1997–2001

Clusters	1	2	3	4	5	6	7	8	9
Number of cases (days)	100	79	193	158	54	145	109	**251**	*47*
Frequency (%)	8.8	7.0	17.0	13.9	4.8	12.8	9.5	**22.1**	*4.1*
T_{mean} (°C)	*5.1*	6.3	14.4	12.1	16.8	16.9	20.0	23.0	**26.5**
T_{max} (°C)	*10.0*	11.4	18.6	16.7	21.6	22.6	25.7	28.6	**32.8**
T_{min} (°C)	*0.7*	1.0	10.7	6.6	11.8	11.3	13.2	17.3	**19.4**
$\Delta T= T_{\mathrm{max}}- T_{\mathrm{min}}$, (°C)	*9.3*	10.4	7.9	10.1	9.8	11.3	12.5	11.3	**13.5**
WS (m s^{-1})	*0.6*	0.7	0.9	1.6	**1.9**	0.7	0.9	1.0	1.0
RH (%)	73.4	59.0	**80.6**	70.3	57.6	68.6	67.4	69.8	*52.6*
I (MJ m^{-2})	*12.4*	18.5	10.8	14.5	19.8	18.8	18.2	22.3	**23.6**
E (hPa)	*12.4*	13.5	23.1	20.1	28.5	26.5	33.1	39.1	**48.4**
VP (hPa)	8.9	*7.7*	18.1	13.7	16.4	17.7	21.2	**26.3**	24.5
PE (mm)	*1.6*	2.3	2.4	2.7	4.7	3.7	4.8	5.3	**8.7**
T_{d} (°C)	0.8	*−1.2*	11.0	6.6	8.3	11.0	13.5	**17.1**	15.9
P (hPa)	1,021.9	**1,024.7**	*1,011.8*	1,012.1	1,019.3	1,018.7	1,013.6	1,015.5	1,017.8
Acer	3.2	4.2	8.9	9.2	3.0	7.0	**20.7**	*0.0*	*0.0*
Alnus	18.3	23.0	15.0	19.1	22.8	**28.0**	10.0	*0.0*	*0.0*
Ambrosia	1.2	*0.5*	66.9	107.4	**122.6**	51.3	108.1	98.1	59.0
Artemisia	*0.3*	*0.3*	4.7	8.4	16.1	6.1	9.8	9.5	**20.6**
Betula	19.5	10.3	16.4	26.9	16.3	36.0	**41.1**	3.0	*0.0*
Cannabis	*0.0*	*0.0*	5.3	4.8	3.8	**5.6**	**5.6**	5.0	5.1
Carpinus	7.0	11.8	12.7	12.6	8.3	9.7	**34.2**	3.0	*0.0*
Chenopodium	*0.3*	*0.3*	4.5	7.1	11.0	4.4	8.5	9.0	**16.0**
Corylus	8.0	18.7	7.1	19.2	12.6	**51.5**	5.0	*0.0*	*0.0*
Fraxinus	6.4	9.8	3.5	14.4	**18.8**	8.7	14.5	*0.0*	*0.0*
Juglans	2.0	*0.0*	7.7	9.6	**12.7**	7.4	11.8	5.4	6.8
Morus	*0.0*	*0.0*	11.4	13.2	28.3	13.5	**41.8**	17.2	21.0
Pinus	*0.0*	20.0	8.4	11.2	22.7	12.4	15.9	7.9	**29.5**
Plantago	*0.0*	2.0	4.2	2.2	3.4	3.5	3.9	4.7	**6.7**
Platanus	6.0	*0.0*	16.0	**19.7**	9.8	8.2	10.3	3.9	14.0
Poaceae	*0.1*	**23.8**	10.0	10.1	18.0	11.1	14.0	14.0	16.6
Populus	15.6	41.6	52.4	69.1	48.5	7.7	**92.0**	*0.0*	*0.0*
Quercus	6.6	5.5	8.3	9.7	7.0	**10.1**	8.9	3.1	*0.0*
Rumex	*0.0*	**12.5**	6.6	6.5	4.3	5.1	5.4	6.8	2.9
Salix	7.5	7.9	**14.8**	13.4	9.0	14.3	8.0	*0.0*	*0.0*
Taxus	4.9	12.0	6.2	9.6	**29.0**	7.5	17.2	*0.0*	*0.0*
Tilia	*0.0*	*0.0*	1.6	4.3	5.5	3.5	6.2	5.9	**9.0**
Ulmus	**10.8**	5.8	8.5	9.2	8.9	2.0	3.5	*0.0*	*0.0*
Urtica	*0.0*	7.5	5.7	6.2	14.0	7.7	12.4	14.8	**15.2**
Total mean pollen counts	*4,9*	9,1	12,8	17,6	19,0	13,4	**21,2**	8,8	9,0

Bold: maximum, *italic*: minimum

Cluster 2

The pressure pattern in this cluster of days (6.9% of the total number of days) is characterised by a high pressure system over Central Europe. The air mass types prevailing over Szeged under these conditions are associated with the following weather characteristics: high irradiance (mean value =18.5 MJ m^{-2}), low temperature parameters (T_{mean}, T_{max}, T_{min}), low (E, PE) or lowest (VP, T_{d}) values of humidity parameters and very low wind speed (0.7 m s^{-1}). Such weather conditions favour higher pollen concentrations. Values of meteorological parameters are similar to those in Cluster 1. However, irradiance is significantly higher, which is connected with higher declination and, hence, longer daylength of days belonging to Cluster 2. This may result in higher pollen levels (Gioulekas et al. 2004; Rodríguez-Rajo et al. 2004b). Pollen levels of Poaceae and Rumex reach their maximum values (Fig. 4a; Table 3; Fig. 3).

Cluster 3

This is the second most frequent type, with 17.1% of the total number of days. The ridge from Azores high pressure centre is not present in central Europe and, at the same time, a low pressure pattern deepens over

Table 4 Pollination term (days) of species considered for days belonging to the nine dominant clusters, 1 February–31 October, 1997–2001

Clusters	1	2	3	4	5	6	7	8	9
Number of cases (days)	100	79	193	158	54	145	109	251	47
Freqency (%)	8.8	7.0	17.0	13.9	4.8	12.8	9.6	22.1	4.1
Acer	17	27	21	23	7	1	3	0	0
Alnus	41	32	20	37	5	2	2	0	0
Ambrosia	16	10	82	28	24	77	50	164	39
Artemisia	4	3	68	23	23	74	43	142	39
Betula	11	18	40	47	15	15	13	3	0
Cannabis	0	0	16	13	14	10	30	121	37
Carpinus	8	8	28	44	8	18	11	1	0
Chenopodium	6	4	85	34	31	89	59	189	41
Corylus	38	35	21	34	5	2	3	0	0
Fraxinus	11	11	20	25	6	6	6	0	0
Juglans	2	1	28	18	9	21	16	14	5
Morus	0	2	27	16	9	21	15	14	3
Pinus	0	2	32	26	13	29	24	49	6
Plantago	0	1	21	22	14	26	38	129	22
Platanus	2	0	27	18	6	13	14	9	2
Poaceae	9	4	133	67	39	117	96	251	47
Populus	16	30	21	25	6	6	8	0	0
Quercus	5	8	34	40	15	24	10	8	0
Rumex	0	2	26	24	10	32	42	124	16
Salix	15	23	23	48	12	10	9	0	0
Taxus	37	32	28	38	3	2	5	0	0
Tilia	0	1	19	16	2	26	21	58	2
Ulmus	32	35	18	39	8	1	2	0	0
Urtica	0	2	75	38	27	69	73	234	43

Northern Europe reaching the Carpathian Basin. Consequently, irradiance is significantly lower and humidity parameters (RH, E, VP, T_d) are significantly higher than those in the former cluster. Since Cluster 3 comprises also summer days, temperature parameters (T_mean, T_max, T_min) and humidity variables (RH, E, VP, T_d), as well as pollen concentrations, are substantially higher than in Cluster 2 (Fig. 4a; Table 3; Fig. 3).

Cluster 4

The days of this type (14%) show a relatively uniform distribution in the months examined. Nevertheless, their frequency is higher in February, March and April. The sea level pressure pattern is similar to that of Cluster 3; however, low pressure develops over Northern Europe and, at the same time, the high pressure centre from the Azores gets closer to the Carpathian Basin. As a result of this, wind speed is much higher, while the other meteorological parameters are similar to those in Cluster 3. Pollen levels are higher than those in Cluster 3 (Fig. 4a; Table 3; Fig. 3). Since wind speed can show either significant positive (Stennett and Beggs 2004; Makra et al. 2004b) or negative (Makra et al. 2004b) correlation with pollen levels, the higher mean pollen count can be attributed to the different temporal distribution of days belonging to the two clusters.

Cluster 5

This is a very rare type (4.8%) with high standard deviation of its monthly occurrence. The high pressure centre from the Azores strengthens and extends over Central Europe, while the low pressure pattern in Northern Europe disappears. The Carpathian Basin is under the influence of the Azores high. Hence, irradiance is high, which involves an increase in the temperature parameters, and wind speed reaches the maximum of all clusters. This type comprises the second highest mean daily pollen levels, which is in accordance with the high temperature parameters (Gioulekas et al. 2004; Stennett and Beggs 2004; Makra et al. 2004b and Rodríguez-Rajo et al. 2004a) and high irradiance (Gioulekas et al. 2004; Rodríguez-Rajo et al. 2004b (Fig. 4a; Table 3; Fig. 3).

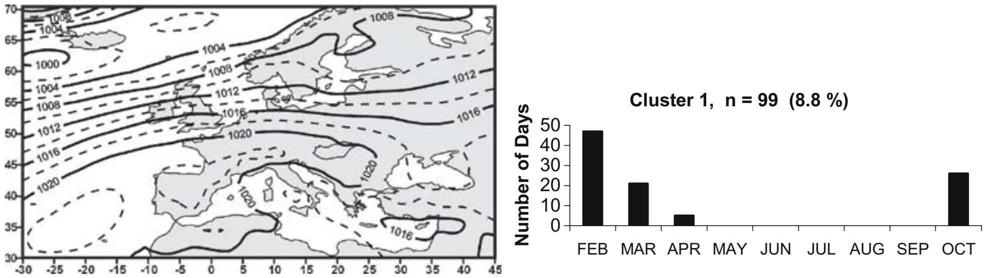
Cluster 6

This cluster consists of 12.8% of the total number of days. Except for Northern Europe, the continent is covered by an extremely large and uniform high pressure pattern, with a small pressure centre in Middle Europe. As the weather situation between Clusters 4 and 5 is very similar, with only minor differences in the meteorological parameters. However, pollen counts are lower than in Cluster 5. One reason might be that less summer days with higher pollen release belong to Cluster 6 than to Cluster 5 (Fig. 4b; Table 3; Fig. 3).

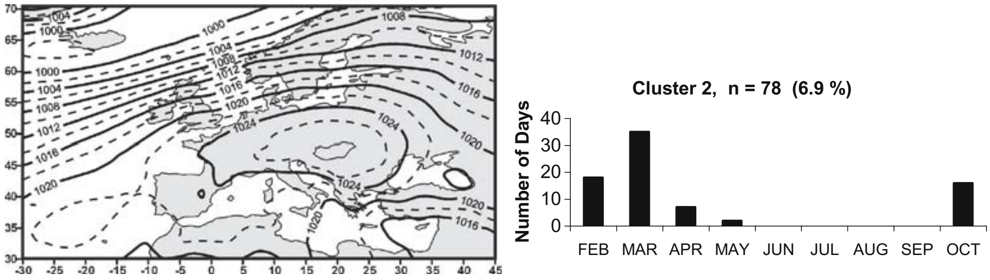
Cluster 7

This type comprises 9.5% of the total number of days. A narrow belt of the Azores high is extended as far as the Alps, while Northern Europe is prevailed by a uniform low pressure pattern. Also, the summer south west Asia low pressure system of thermal origin is well established. This is an anticyclonic ridge weather situation for the Carpathian Basin with calm or

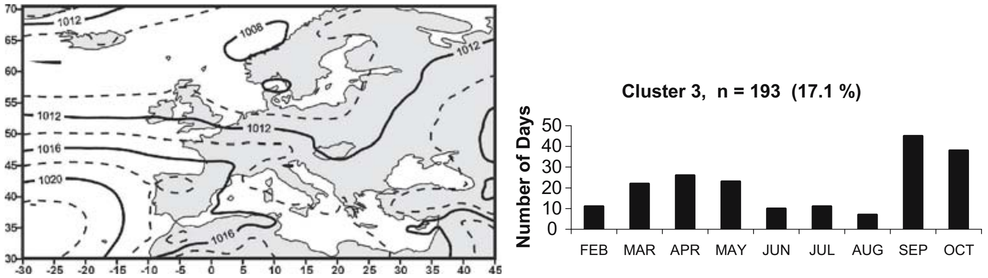
Fig. 4 **a**, **b** Mean sea-level pressure fields belonging to each air mass type (cluster), and monthly variation of the number of days belonging to them, North-Atlantic–European region, 1 February–31 October, 1997–2001



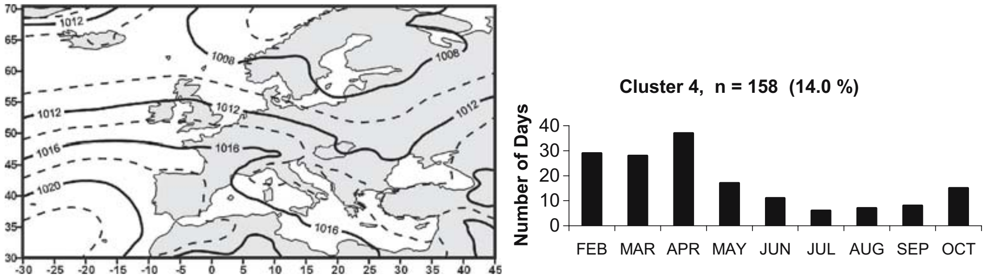
Cluster 1



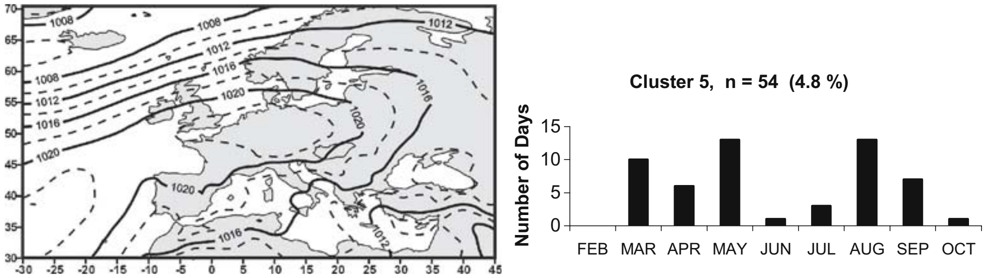
Cluster 2



Cluster 3



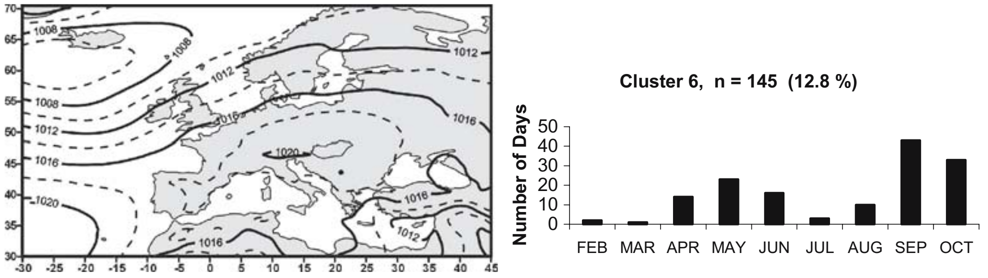
Cluster 4



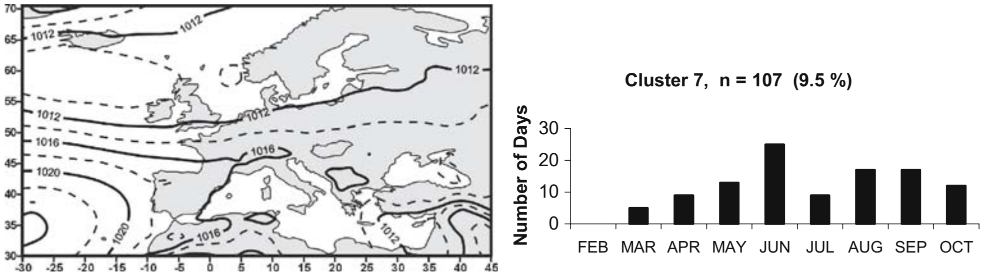
Cluster 5

a

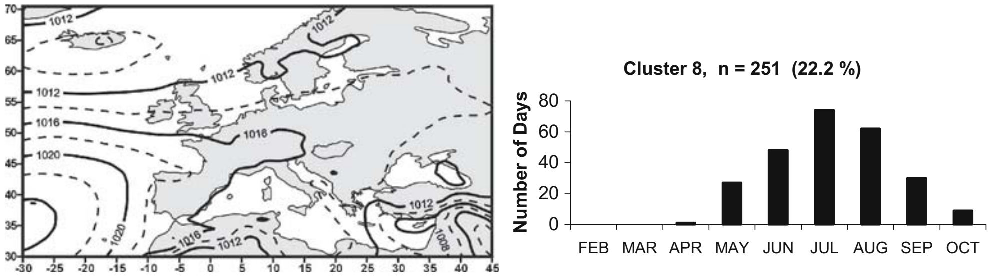
Fig. 4 (continued)



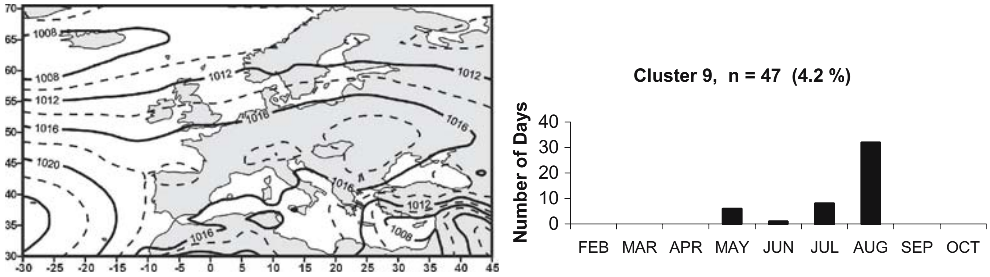
Cluster 6



Cluster 7



Cluster 8



Cluster 9

Table 5 χ^2–test, independence analysis of the mean sea level pressure fields for the nine identified clusters, probability of the 0-hypothesis, 1 February–31 October, 1997–2001

Cluster	1	2	3	4	5	6	7	8	9
1	–	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000	0.0000
2		–	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3			–	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000
4				–	0.0000	0.0000	1.0000	0.0001	0.0000
5					–	0.0000	0.0000	0.0000	1.0000
6						–	1.0000	1.0000	1.0000
7							–	1.0000	1.0000
8								–	1.0000
9									–

moderate winds. This cluster comprises both the highest pollen levels of all and the most peak values of the species. Temperature values are considerably higher than those in Cluster 6, which favours the highest pollen counts (Gioulekas et al. 2004; Stennett and Beggs 2004; Makra et al. 2004b, Rodríguez-Rajo et al. 2004a) (Fig. 4b; Table 3; Fig. 3).

Cluster 8

This is the most frequent type with 22.2% of the total number of days, and is characteristic only in the summer months. The pressure pattern could be considered as a typical middle summer situation with the Atlantic high and the south west Asia low fully developed. Both systems appear stronger than in Cluster 7. The meteorological parameters in Szeged are characterised by high temperature and irradiance, and moderate winds. Water vapour pressure and dew point temperature are highest of all clusters. On the other hand, pollen concentration is the second lowest. Higher temperatures and irradiance might involve higher pollen levels; however, surprisingly, this is not the case. One reason might be that days with low pollen release belong to this cluster (Fig. 4b; Table 3; Fig. 3). Furthermore, it could be argued that the high VP and T_d values indicate that many rainy days are also included in this cluster, and rainfall removes pollen from the atmosphere.

Cluster 9

This cluster comprises 4.2% of the total number of days. This is the rarest type, with typical occurrences in the summer. The high pressure centre of the Azores is very strong, extending as far as the Eastern European Plains, causing strong northerly summer winds (Etesians) in the Eastern Mediterranean. In Szeged, clear skies are responsible for the highest irradiance and, consequently, for the highest temperature values (including heatwaves), as well as high saturation vapour pressure and potential evaporation, and the lowest relative humidity. This situation favours the highest pollen concentrations for six of the species but it also exhibits zero concentrations for many others. It seems that these 0 values could be attributed to the limited temporal distribution of the few days of this Cluster (Fig. 4b; Table 3; Fig. 3).

In order to determine the influence of air mass types on pollen levels, ANOVA were performed on the pollen concentrations of the species (Table 6). Pollen counts of all species present significant inter-air mass type differences in mean concentration values at the 99% (for Carpinus only 98%) probability level. Considering that differences are found among the mean pollen levels (Table 3, last row), Tukey's tests were applied in order to obtain a pairwise multiple assessment of the differences.

Table 6 Analysis of variance (ANOVA) statistics for inter-air mass comparison of plant pollen counts (pollen grains/m^3 air) of species considered, 1 February–31 October, 1997–2001

Species	Mean square between groups	Mean square within groups	*F*-ratio	Level of significance (%)
Acer	41.01	12.43	3.30	99.90
Alnus	1,254.89	220.41	5.69	100.00
Ambrosia	75,160.88	12,667.18	5.93	100.00
Artemisia	1,802.63	70.59	25.54	100.00
Betula	1,001.32	196.66	5.09	100.00
Cannabis	188.50	8.57	21.99	100.00
Carpinus	342.61	140.47	2.44	98.71
Chenopodium	1,453.10	49.19	29.54	100.00
Corylus	728.79	81.86	8.90	100.00
Fraxinus	87.99	18.43	4.77	100.00
Juglans	52.50	16.24	3.23	99.88
Morus	482.31	177.71	2.71	99.42
Pinus	285.87	58.30	4.90	100.00
Plantago	120.41	6.50	18.54	100.00
Platinus	130.30	28.93	4.50	100.00
Poaceae	4,077.25	154.85	26.33	100.00
Populus	3,481.16	834.15	4.17	99.99
Quercus	101.93	19.05	5.35	100.00
Rumex	183.52	20.74	8.85	100.00
Salix	253.68	39.31	6.45	100.00
Taxus	241.42	23.13	10.44	100.00
Tilia	42.06	6.48	6.50	100.00
Ulmus	198.67	16.54	12.01	100.00
Urtica	4,716.59	123.23	38.27	100.00

The statistically significant differences are shown in Table 7 at the 95% and 99% probability levels, respectively. There are no two air mass types for which inter-air mass type differences in pollen concentrations of all the 24 species considered are significant. It can be seen that the pairs of air mass types (clusters) differ significantly for pollen levels of several species. Inter-air mass type differences are classified as follows: (a) highest difference indicated by 16–20 species is found only for one comparison: type 4–8 (20 species); (b) medium differences indicated by 11–15 species are found for types 1–7 (13 species), 1–8 (12), 2–7 (12), types 2–8 (15 species) and 4–9 (11); lowest differences indicated by 0–10 species are found for the rest of the comparisons. Air mass types 1–2 (2 species), 3–6 (0), 5–6 (1), 5–7 (0), 6–7 (2) and 7–8 (2) are the most similar, considering that very few significant differences in pollen levels (indicated by maximum 2 species) can be detected between them.

Frequency of plant species, indicating significant inter-air mass difference in pollen counts were calculated for each air mass type (Table 8). According to this analysis, types 8 (with 77 pairwise differences), 4 (64) and 2 (63) seem to be the most specific in classifying plants, since they show the highest frequency of species representing significant differences in pollen counts, whereas air mass types 3 (with 38 pairwise differences), 6 (34) and 5 (33) are the least important, indicating lowest differences.

The role of types 8, 4 and 2 are also emphasized by the fact that they comprise the least number of species with 0 significant inter-air mass difference in pollen counts (2, 3 and 6 species, respectively). On the other hand, types 5, 3 and 6 are also confirmed to be the least efficient by indicating the most number of species with 0 significant difference in pollen levels (11, 8 and 7 species, respectively) (Table 8).

Considering the total frequency of significant pairwise differences in pollen counts for all the nine air mass types, among the 24 species Poaceae (with 45 pairwise differences), Chenopodium (42) and Urtica (40) show the highest frequency. Cannabis (38), Artemisia (35), Plantago (32) and Ulnus (29) are also important species. On the other hand, Carpinus (with 2 pairwise differences), Morus (2) and Juglans (−) are considered the least characteristic in representing significant inter-air mass differences in pollen levels. Furthermore, with a frequency lower than 10, Betula (8), Populus (8) and Acer (6) can also be omitted from further consideration (Table 8).

Table 7 Air mass type– plant pollen counts difference matrix

	1	2	3	4	5	6	7	8
2	**Co** **Ta**							
3	Al Plat **Poa** **Ul**	**Al** **Co** Plat Poa **Ta** Ul						
4	Be Plat **Q** **S**	Co Plat Q **Ta**	Be **F** **S** Ul					
5	**Am** Ar **Ch** **Pi** **Poa** **Ur**	Am **Ar** **Ch** **Co** **Pi** **Poa** **Ta** **Ur**	**Ar** **Pi** **Poa** **Ur**	**Ar** Ch **Pi** **Poa** **Ur**				
6	**Al** Ch **Poa** **Ul**	**Al** **Co** **Poa** **Pop** **Ta** **Ul**		Ac **Co** F **Poa** Pop **S** **Ta** **Ul**	Pi			
7	Al **Am** **Ar** **Can** **Ch** M **Pi** **Plan** **Poa** **R** **Ti** **Ul** **Ur**	**Al** Am **Ar** **Can** **Ch** **Co** **Plan** **Poa** **Ta** Ti **Ul** **Ur**	**Can** Ch Plan **Poa** **Ti** **Ur**	**Can** **Ch** **Co** Plan **Poa** Q **S** **Ul** **Ur**		**Can** **Ur**		
8	**Al** **Am** **Ar** **Can** **Ch** **Plan** **Poa** **R** **Ta** **Ti** **Ul** **Ur**	Ac **Al** **Am** **Ar** **Can** **Ch** **Co** **Plan** **Poa** **Pop** **R** **Ta** **Ti** **Ul** **Ur**	**Ar** **Can** **Ch** **Plan** **Plat** **Poa** **Q** **R** **Ti** **Ur**	**Ac** **Am** **Ar** **Be** **Can** **Car** **Ch** **Co** **F** **Plan** **Plat** **Poa** **Pop** **Q** **R** **S** **Ta** **Ti** **Ul** **Ur**	**Can** F **Pi** Plan **R** Ti **Ur**	**Can** **Ch** **Plan** **Poa** Q **R** **Ur**	Plan **Ur**	
9	**Ar** **Can** **Ch** **Plan** **Poa** **Ul** **Ur**	Al **Ar** **Can** **Ch** **Co** **Plan** **Poa** **Ta** Ul **Ur**	**Ar** **Can** **Ch** **Plan** **Poa** **Ur**	**Ar** **Be** **Can** **Ch** **F** **Plan** **Poa** Q **S** Ul **Ur**	**Ar** **Can** **Ch**	**Ar** **Can** **Ch** **Plan** Poa **Ur**	**Ar** **Can** **Ch**	**Ar** Can **Ch** R

Ac = Acer; Al = Alnus; Am = Ambrosia; Ar = Artemisia; Be = Betula; Can = Cannabis; Car = Carpinus; Ch = Chenopodium; Co = Corylus; F = Fraxinus; M = Morus; Pi = Pinus; Plan = Plantago; Plat = Platanus; Poa = Poaceae; Pop = Populus; Q = Quercus; R = Rumex; S = Salix; Ta = Taxus; Ti = Tilia; Ul = Ulmus; Ur = Urtica

Each matrix cell represents the comparison between two air mass types. Plant species appearing in the matrix cells indicate significant inter-air mass difference in pollen counts (pollen grains/ m^3 air) of species considered according to Tukey's honestly significant difference test (light-faced characters: 95% of significance; **bold** characters: 99% of significance), 1 February–31 October, 1997–2001

Table 8 Frequency of plant species, indicating significant inter-air mass difference in pollen counts for each air mass type

Type	Ac	Al	Am	Ar	Be	Can	Car	Ch	Co	F	J	M	Pi	Plan	Plat	Poa	Pop	Q	R	S	Ta	Ti	Ul	Ur	Sum
1	–	4	3	4	1	3	–	5	1	–	–	1	2	3	2	6	–	1	2	1	2	2	5	4	52
2	1	5	3	4	–	3	–	4	8	–	–	–	1	3	2	6	2	1	1	–	8	2	5	4	63
3	–	2	–	3	1	3	–	3	1	1	–	–	1	3	3	6	–	1	–	1	–	2	3	4	38
4	2	–	1	3	4	3	1	4	4	4	–	–	1	3	3	5	2	5	1	6	3	1	4	4	64
5	–	–	2	4	–	2	–	4	1	1	–	–	6	1	–	4	–	–	1	–	1	1	–	5	33
6	1	2	–	1	–	3	–	3	2	1	–	–	1	2	–	5	2	1	1	1	2	–	3	3	34
7	–	2	2	–	3	6	–	5	2	–	–	1	1	5	–	4	–	1	1	1	1	3	3	4	45
8	2	2	3	5	1	7	1	6	2	2	–	–	1	7	2	5	2	3	7	1	3	5	3	7	77
9	–	1	–	8	1	8	–	8	1	1	–	–	–	5	–	4	–	1	1	1	1	–	3	5	49
Sum	6	18	14	35	8	38	2	42	22	10	–	2	14	32	12	45	8	14	15	12	21	16	29	40	455

Ac = Acer; Al = Alnus; Am = Ambrosia; Ar = Artemisia; Be = Betula; Can = Cannabis; Car = Carpinus; Ch = Chenopodium; Co = Corylus; F = Fraxinus; J = Juglans; M = Morus; Pi = Pinus; Plan = Plantago; Plat = Platanus; Poa = Poaceae; Pop = Populus; Q = Quercus; R = Rumex; S = Salix; Ta = Taxus; Ti = Tilia; Ul = Ulmus; Ur = Urtica

Concerning the frequency of significant pairwise differences in pollen levels for the individual air mass types, among the 24 species, Chenopodium, Poaceae and Urtica show the highest frequency of significant differences in pollen counts (at least three cases per each air mass type). On the other hand, Juglans, Carpinus and Morus are the least efficient, since they show no significant differences for 9, 7 and again 7 air mass types (Table 8).

The most important species (indicating the highest frequency of significant pairwise differences) are Poaceae (6) for type 1; Corylus (8) and Taxus (8) for type 2; Poaceae (6) for type 3; Salix (6) for type 4; Pinus (6) for type 5; Poaceae (5) for type 6; Cannabis (6) for type 7; Cannabis, Plantago, Rumex and Urtica (all with 7 significant pairwise differences) for type 8; furthermore Artemisia, Cannabis and Chenopodium (all with 8 significant differences) for type 9 (Table 8) are also important.

Discussion

In order to assess the effect of different air mass types on pollen levels in Szeged, objective multivariate statistical methods were applied to meteorological and pollen data. By defining objectively air mass types dominating in the Carpathian Basin, the pressure patterns over the North-Atlantic–European region associated with these air masses were determined.

The procedure itself has been applied in the literature (McGregor and Bamzelis, 1995; Sindosi et al. 2003; Makra et al. 2006). However, ours is a new approach for classifying air mass types in the region examined, since for Hungary only the subjective categorisation of the prevailing pressure patterns made by Péczely (1957, 1983) was previously known. On the other hand, to our knowledge, pollen-related objective classification of air mass types has not been reported in the international literature. The basis of Péczely's classification is the same as with the objective categorisation: daily sea-level pressure fields measured at 00 UTC. Péczely determined 13 large-scale weather situations for the Carpathian Basin. As regards the period examined (1 February–31 October), four groups of Péczely's macrotypes are characteristic over the Carpathian Basin: (1) types connected with southerly currents, (2) types connected with zonal westerly currents, (3) an anticyclone over the Carpathian Basin, and (4) an anticyclone north of Hungary. These weather types amount to 77.4% of the total number of days in this period of the year. On the other hand, the nine objective clusters detected in this paper are characterised mostly by anticyclonic pressure patterns (69.2% of the total number of days). In more detail they are as follows: an anticyclone extending from the west (considering the Carpathian Basin) [Cluster 1 (8.8% of the total number of days), Cluster 5 (4.8%), Cluster 6 (12.8%), Cluster 7 (9.5%), Cluster 8 (22.2%) and Cluster 9 (4.2)], an anticyclone over the Carpathian Basin [Cluster 2 (6.9%)], zonal cyclonic currents [Cluster 3 (17.1%) and Cluster 4 (14.0%)]. Anticyclonic and anticyclonic ridge situations between 1 February and 31 October are predominant both in the Péczely types (77.4%) as well as in the objective clusters (69.2%).

The air mass types determined for the period between 1 February and 31 October were also related to pollen levels in downtown Szeged.

If pollen-related analysis of air mass types are performed only for the independent cluster pairs (24 pairs of the total $\binom{9}{2}$ =36 cases), the result is similar to that obtained for the original 36 cluster pairs. Namely, types 1, 2, 4 and 8 are the most specific in classifying plants, since these types show the highest frequency of species representing significant difference in pollen counts, whereas air mass types 3 and 6 are the least important, indicating lowest differences (Table 9). Furthermore, Poaceae shows the highest, while Juglans, Carpinus and Morus the lowest total frequency of significant pairwise differences in pollen counts for all the nine air mass types (for the 24 independent cluster pairs). In addition, Poaceae shows the highest, whereas Juglans, Carpinus and Morus the lowest significant pairwise differences in pollen levels for the 24 independent air mass types (Table 9). Consequently, omitting non-independent cluster pairs only slightly modifies the results obtained for the significant pairwise differences of pollen counts for the rest of cluster pairs.

Correlating the objectively determined air mass types with pollen concentrations of the 24 species in Szeged showed that pollen levels can be connected to different pressure patterns ruling the region examined. We recently argued (Makra et al. 2006) that specific weather types favour high concentrations of pollutants assuming almost equal daily emissions (uniform distribution). However, it must be stressed that atmospheric circulation, based on the pressure patterns of the calculated nine clusters, is not the only factor controlling pollen concentrations in Szeged. The revealed pressure patterns can only partially influence pollen levels, which are basically of natural origin. In other words, pollen concentrations depend firstly on the phenological phase of the given species (seasonality) and the climate, and secondly on meteorological parameters. Hence, we must keep in mind that synoptic conditions do not influence concentrations of pollen as much as they influence the concentrations of the main air pollutants.

Thus, for a precise forecast of pollen levels, apart from a good weather forecast, a good knowledge of phenology is required. It might be that a statistical description of pollen data aimed at predicting pollen concentrations simplifies the complex process of phenology and dispersion of pollen in the air. Finally, another factor, which cannot be ignored either, is weather persistence. It must be kept in mind that the presence of pressure patterns favouring high pollen levels over a long period of time may cause even worse pollen conditions.

Conclusions

This paper reports an analysis of pollen levels in Szeged, Hungary, during characteristic sea-level pressure patterns over the Carpathian Basin. Specific air mass types given by the pressure patterns mentioned for the period between 1 February and 31 October were found to play a significant role in determining pollen concentrations in Szeged.

Overall, air mass types 8, 4 and 2, with the least number of species with 0 significant difference in pollen counts, differ most from the others, since pairwise multiple comparisons detected significant differences for these types (in decreasing order) in pollen levels of the most species. One reason for this might be the fact that these three types show a considerable difference in most meteorological parameters. At the same time, types 3, 5 and 6, with the most number of species with 0 significant difference in pollen levels, seem to be intermediate clusters, since they show fewer significant pairwise differences than the others. Analysing the total frequency of significant pairwise differences in pollen counts for all nine air mass types, among the 24 species Poaceae, Chenopodium, Urtica and Cannabis are the most important species, while Juglans, Carpinus and Morus are the least characteristic. As for the frequency of significant pairwise differences in pollen levels for the individual air mass types, Chenopodium, Poaceae and Urtica are the most efficient, whereas Juglans, Carpinus and Morus are negligible. Furthermore, the most efficient species, with 8 significant pairwise differences, are Corylus and Taxus for type 2, as well as Artemisia, Cannabis and Chenopodium for type 9, respectively. Independence of the cluster pairs only slightly modifies the results obtained for the significant pairwise differences of pollen counts for all the cluster pairs.

The results revealed that pollen appears with higher concentration when irradiance is moderate, while wind speed is moderate or high (air mass types 4, 5 and 7; Fig. 4, Table 3). Such conditions occur when an anticyclone prevails in the region west of the Carpathian Basin [Cluster 5 (4.8% of the total number of days), Cluster 7 (9.5%)] or when Hungary lies under the influence of zonal currents (wind speed is high) [Cluster 4 (14.0% of the total number of days)]. On the other hand, the sea level pressure systems belonging to low pollen concentrations are mostly similar

Table 9 Frequency of plant species, indicating significant inter-air mass difference in pollen counts for only the independent air mass types (see Table 5)

Type	Ac	Al	Am	Ar	Be	Can	Car	Ch	Co	F	J	M	Pi	Plan	Plat	Poa	Pop	Q	R	S	Ta	Ti	Ul	Ur	Sum
1	–	4	3	4	1	3	–	5	1	–	–	1	2	3	2	6	–	1	2	1	2	2	5	4	52
2	1	5	3	4	–	3	–	4	8	–	–	–	1	3	2	6	2	1	1	–	8	2	5	4	63
3	–	2	–	1	–	–	–	–	1	–	–	–	1	–	2	3	–	–	–	–	1	–	2	1	14
4	2	–	1	3	3	2	1	3	4	3	–	–	1	2	3	4	2	5	1	4	2	1	3	3	53
5	–	–	2	4	–	1	–	3	1	1	–	–	6	1	–	4	–	–	1	–	1	1	–	5	31
6	1	2	-	–	–	–	–	1	2	1	–	–	1	–	–	3	2	–	–	1	2	–	3	–	19
7	–	2	2	2	–	2	–	2	1	–	–	1	1	2	–	2	–	–	1	–	1	2	2	2	25
8	2	2	3	3	–	4	1	3	2	2	–	–	–	4	1	3	2	1	4	–	3	4	3	4	51
9	–	1	–	3	1	3	–	3	1	1	–	–	–	3	–	3	–	1	–	1	1	–	3	3	28
Sum	6	18	14	24	5	18	2	24	21	8	–	2	13	18	10	34	8	9	10	7	21	12	26	26	336

Ac = Acer; Al = Alnus; Am = Ambrosia; Ar = Artemisia; Be = Betula; Can = Cannabis; Car = Carpinus; Ch = Chenopodium; Co = Corylus; F = Fraxinus; J = Juglans; M = Morus; Pi = Pinus; Plan = Plantago; Plat = Platanus; Poa = Poaceae; Pop = Populus; Q = Quercus; R = Rumex; S = Salix; Ta = Taxus; Ti = Tilia; Ul = Ulmus; Ur = Urtica to those connected to higher pollen levels and arise when wind speed is low or moderate. Since these pressure patterns occur with highest frequency partly in February, March and October and partly in June, July and August, their temperature and humidity parameters cannot be compared. Low pollen concentrations are characteristic when an anticyclone prevails in the region west of the Carpathian Basin [Cluster 1 (8.8% of the total number of days), Cluster 8 (22.2%), Cluster 9 (4.2%) as well as when an anticyclone covers the region with Hungary at the centre [Cluster 2 (6.9% of the total number of days)]. Hence, anticyclonic or anticyclonic ridge weather situations seem to be relevant in classifying pollen levels.

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