ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 44-45, 2011, 155-164

ASSESSMENT OF DAILY POACEAE POLLEN LEVELS BY LINEAR REGRESSION FOR TWO HUNGARIAN CITIES IN ASSOCIATION WITH DIFFERENT WEATHER TYPES

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Summary: Objectively defined clusters of meteorological elements and weather types described by weather fronts and precipitation occurrences are produced in order to classify Poaceae pollen levels. The Poaceae pollen concentration was then estimated one day ahead for each categories of days in Szeged and in Győr in Hungary. The database describes an 11-year period from 1997-2007. We find that both for Szeged and Győr, as well as both for the subjective and objective classifications, high daily mean Poaceae pollen levels are favoured by anticyclone ridge weather situations. Taking clusters into account, the objective classification for the original data, and the subjective classification for days with a warm front and precipitation were most effective.

Key words: Poaceae, grass pollen, pollination period, weather front, factor analysis, cluster analysis, ANOVA, linear regression

1. INTRODUCTION

Pollen allergy became a widespread medical problem by the end of the 20th century. Nowadays, some 20% of the inhabitants on average suffer from this immune system problem in Europe (D'Amato et al. 2007). In Hungary, about 30% of the population has some type of allergy and 65% has a pollen-sensitivity (Járai-Komlódi and Juhász 1993, Makra et al. 2004). The pollen from grasses (Poaceae) is one of the most important airborne allergen sources worldwide (Mohapatra et al. 2005). For sensitive people the threshold value is 30 grains·m^{-3}, above which the symptoms of pollinosis occur (Puc and Puc 2004). In many countries grass pollen is the main cause of pollinosis (Subiza et al. 1995). For example, 56.7%, 40.4% and 24% of people are allergic to grasses in Szeged in Hungary (Kadocsa and Juhász 2000), Thessaloniki in Greece (Gioulekas et al. 2004) and Hamburg in Germany (Nowak et al. 1996), respectively. The Poaceae pollen season usually begins when the average daily temperature exceeds 13.5°C (Peternel et al. 2006). In Hungary, Poaceae has the longest blooming period of all species: it lasts from the middle of April till the middle of October (Makra et al. 2006) and, after *Ambrosia*, discharges the second biggest amount of pollen of all taxa. The ratio of its pollen release to the total pollen release in Hungary is around 17% (Juhász 1996).

Poaceae pollen is considered to be the result of medium-range transport involving local pollen dispersion (Makra et al. 2010). The main grass pollen season is generally double-peaked. The pattern of successive flowering in grass species and meadow cutting dates appear to be the factors which cause the characteristic bimodal behaviour of the grass pollen season (Kasprzyk and Walanus 2010). In Hungary, the first peak occurs from February to April, while the second peak is from May to July (Juhász 1996).

Finding a connection between the daily Poaceae pollen concentration and daily meteorological elements is of great practical importance. Applying simple statistical analyses, several studies found significant positive correlations between daily Poaceae pollen concentration and daily maximum temperature (Valencia-Barrera et al. 2001, Green et al. 2004, Kasprzyk and Walanus 2010), daily minimum temperature (Green et al. 2004), daily mean temperature (Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010) and daily global solar flux (Valencia-Barrera et al. 2001, Kasprzyk and Walanus 2010). Relative humidity (Valencia-Barrera et al. 2001, Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010) and rainfall (Fehér and Járai-Komlódi 1997, Valencia-Barrera et al. 2001, Green et al. 2004, Puc and Puc 2004, Peternel et al. 2006, Kasprzyk and Walanus 2010), however, had a negative effect. Wind speed has an ambivalent role, partly having a positive impact by increasing pollen shed from the anthers, partly a negative association by diluting pollen from the air (Valencia-Barrera et al. 2001).

Meteorological elements affect pollen concentration not by means of their individual effects, but through their interrelationships and so it is useful to study the connection between daily Poaceae pollen concentrations and the daily values of meteorological elements as a whole. Only relatively few papers have reported results of approaches like these using multivariate statistical analysis techniques. Makra et al. (2006) objectively defined weather types with factor and cluster analyses in order to associate given daily pollen concentrations with their representative meteorological parameters. Hart et al. (2007) analysed the influence of weather elements on pollen concentrations for Sydney, producing a synoptic classification of pollen concentrations using principal component analysis and cluster analysis. Tonello and Prieto (2008) classified pollen data of 17 taxa and climate parameters using principal component analysis and cluster analysis to identify relationships between potential natural vegetation, pollen and climate.

The purpose of this paper is to determine the most homogeneous groups of meteorological elements by cluster analysis, and then Poaceae pollen levels are examined by conditioning on these clusters. Another aim is to utilise the possible information of meteorological elements on Poaceae pollen concentration when cold and warm weather fronts pass through a city. Furthermore, those days with a front but no rain and those days with rain but no front will also be considered. Lastly, we attempt to estimate the Poaceae pollen concentration one day ahead for each of the above day categories at Szeged and Győr. These medium-sized cities are located in South-eastern and North-western Hungary, respectively, about 340 km apart.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N, 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m asl. The city is the centre of the Szeged region with 203,000 inhabitants. The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Makra et al. 2010).

Győr (47.68°N, 17.63°E) lies in Northern Transdanubia, in Hungary. The city is located in the Rába valley with an elevation of 123 m asl at the confluence of the Rába, Rábca and Mosoni-Duna rivers. Győr is the sixth largest city in Hungary with a population of 132,000. The air sampler is situated on the roof of the Oncology Department building, Petz Aladár County Hospital, south of the centre of Győr, approximately 20 m above ground level.

Meteorological data were collected in monitoring stations (operated by the Environmental and Natural Protection and Water Conservancy Inspectorates of the Lower-Tisza Region, Szeged and Northern Transdanubia, Győr respectively) located in the downtown of Szeged and Győr at a distance of about 10 m from the busiest main roads.

For weather front recognition purposes, the ECMWF (European Centre for Medium-Range Weather Forecasts) ERA-INTERIM database was used on the grid network with a density of 1°x1°. Only those grid points (for Szeged: 46°N, 20°E; for Győr: 48°N, 18°E) were selected that were nearest to the geographical coordinates of both Szeged (46.25°N, 20.10°E) and Győr (47.68°N, 17.63°E). Meteorological parameters considered are as follows: RT 500/850 hPa relative topographies (for calculating the thickness of the air-layer), 700 hPa temperature fields (for calculating the temperature advection in order to determine the sign of the front) and 700 hPa wind fields (to include advection when calculating the Thermal Front Parameter, TFP).

In order to estimate actual daily Poaceae pollen concentrations, the previous-day values of five meteorological variables (mean temperature, mean global solar flux, mean relative humidity, mean sea-level pressure and mean wind speed) and previous-day Poaceae pollen concentrations as candidate predictors were applied. The statistical relationship between the predictors and the pollen concentration was conditioned on the clusters as well as frontal and precipitation information. The rationale behind this approach is that the existence of fronts and precipitation is forecasted at a high accuracy, but the forecast of the above meteorological variables is much less reliable. Hence, previous-day values were considered instead of their values forecasted for the actual days in question.

The longest pollination period of the two cities (April 4 – October 16, 1997-2007) was used for our study. This interval covers most of the Poaceae pollination period both in Szeged and Győr using the criterion of Galán et al. (2001). Namely, the start (end) of the pollen season is the earliest (latest) date on which at least 1 pollen grain m^{-3} is recorded and at least 5 consecutive (preceding) days also have 1 or more pollen grains m^{-3}. The mean of this annually varying period was selected for the 11-year period examined.

2.2. Objective identification of weather fronts

The objective identification of weather fronts is a difficult task due to the lack of a unique definition described in mathematical terms. In addition, different fronts can be characterised by different sets of meteorological parameters. The contribution of Renard and Clarke (1965) is a classic advance in this area. They analysed the horizontal gradient of magnitude of the horizontal potential temperature gradient at an air pressure of 850 hPa. Later, Hewson (1998) improved the procedure, resulting in a quantity called the Thermal Front Parameter (TFP). Using this methodology, Yan et al. (2008) produced an automatic weather system identification method that can identify weather systems with 80-100% accuracy and provide objective information on identifying and positioning weather systems. There is a clear relationship between the TFP as frontal analysis parameter and the well-known basic front definition that fixes a cold front where the temperature begins to fall and a warm front where the rise in temperature ends. This definition corresponds to the maximum of the TFP.

Frequently the relative topography is used for simplicity (www.satreponline.org) instead of the potential temperature. This is because there is a close connection between the thickness and the average potential temperature of an air-layer. Therefore, the relative topography (RT 500/850 hPa) was used in our calculations. The algorithm was run for 6-hourly datasets within the period examined for both cities. Dates when fronts passed through the cities were thus produced with a 6-hour resolution.

2.3. Statistical methods

Factor analysis (FA) explains linear relationships among the variables examined and reduces the dimensionality of the initial database without a substantial loss of information. In particular, the 6 variables (5 climate variables and the previous-day pollen concentration) were trasformed into *m* number of factors. These factors can be viewed as the main latent variables potentially influencing daily pollen concentration. The optimum number *m* of the retained factors is defined such that the total variance of the *m* factors reaches a prespecified portion (80% in our case) of the total variance of the original variables (Jolliffe 1993).

A cluster analysis was applied to the original data sets that objectively classifies the days of the given groups with similar climate conditions. We applied hierarchical cluster analysis using Ward's method on the climatic variables of the period April 4 – October 16 over the 11-year period examined. Ward's method attempts to minimise the sum of squares of elements within clusters forming at each step during the procedure (Ward 1963). The procedure works with the Mahalanobis metric, which is deemed better than the Euclidean metric (Mahalanobis 1936). The Mahalanobis metric takes into account the different standard deviations of the components of the vectors to be clustered as well as the correlations among the components. We select the number of clusters under possible cluster numbers from 3 to 30 so as to ensure nearly uniform occurrence frequencies of the clusters. Intuitively, the final system of clusters produces a small variation of occurrence frequencies of the clusters constrained on forming these clusters by Ward's method (Anderberg 1973, Hair et al. 1998).

Another classification is based on frontal information. In particular, the following six weather types were defined: warm front with rain, warm front with no rain, cold front with rain, cold front with no rain, no front with rain, no front with no rain.

The one-way analysis of variance (ANOVA) was then used to decide whether the inter-cluster variance was significantly higher than the intra-cluster variance of daily Poaceae concentrations. A post-hoc Tukey test was applied to find the clusters which differ significantly from others (Tukey 1985) from the viewpoint of the cluster-dependent mean pollen levels.

A further task was to establish a relationship between the predictors and the pollen concentration. As both kinds of variables exhibit annual trends, standardised data sets were used. Denoting an underlying data set by x_t, $t = 1, \dots, n$ the expected value function $m(t)$ of x_t is approximated by a linear combination of cosine and sine functions with periods of one year and one half year. (Note that the latter cycle was introduced to describe the asymmetries of the annual courses.) Namely, $m(t) = a_0 + a_1 \cos(w_1 t) + a_2 \cos(w_2 t) + b_1 \sin(w_1 t) + b_2 \sin(w_2 t)$ with $w_1 = 2\pi/365.25$ and $w_2 = 2w_1$. Unknown coefficients in this linear combination were estimated via the least squares technique. Then the standardised, and thus annual course-free data set is $y_t = (x_t - m(t))/d(t)$, $t = 1, \ldots ,n$, , where the unknown coefficients in $d^2(t) = a_0 + a_1 \cos(w_1 t) + a_2 \cos(w_2 t) + b_1 \sin(w_1 t) + b_2 \sin(w_2 t)$ were estimated like those in $m(t)$, except that x_t was replaced by $x_t^* = (x_t - m(t))^2$, $t = 1, \ldots ,n$ when applying the least squares technique. Linear regressions for both the entire data set and data sets corresponding to both systems of weather types were performed. The order of importance of predictors in the formation of pollen concentration was determined by the well-known stepwise regression method (Draper and Smith 1981). The mean squared error obtained for the entire data set was compared to the weighted sum of mean squared errors obtained for the weather types. The weights were the relative frequencies of these types.

3. RESULTS

3.1. Cluster analysis and ANOVA

The days of the 11-year period for both Szeged and Győr (Tables 1a and 2a) were classified into the above-mentioned six categories (warm front with rain, warm front with no rain, cold front with rain, cold front with no rain, no front with rain, no front with no rain). Afterwards, cluster analyses were carried out for the two cities using the original and standardised data sets. Hence altogether 4 cluster analyses were performed. The mean values of the 6 influencing variables (5 meteorological and 1 pollen variables) and the resultant variable (Poaceae pollen level) for both the frontal categories and the clusters are tabulated in Tables 1 and 2.

The analysis of variance revealed a significant difference at least at a 95% probability level in the mean values of Poaceae pollen levels among the individual clusters. For Szeged, using frontal categories, the pairwise comparisons of the cluster averages found 2 significant differences among the possible 15 cluster pairs of 6 clusters (13.3%). In this case, only the mean values of clusters 4 and 5, as well as 4 and 6 differed significantly from each other. The clustering of original variables resulted in 14 significant pairwise differences among the mean pollen levels of all 21 cluster pairs of 7 clusters (66.7%). Clusters defined with standardised variables revealed 7 significant differences among the possible 21 cluster pairs of 7 clusters (33.3%). The role of Cluster 2 is important because its average differed significantly from those of the remaining clusters.

For Győr, using frontal categories, only 3 significant differences were found among the possible 15 cluster pairs of 6 clusters (20%). An objective classification of original variables resulted in 7 clusters. Here, with the exception of clusters 2 and 5, 2 and 6, as well as 4 and 7, the means of all remaining cluster pairs notably differed from each other (85.7%). For standardised variables, 6 objective clusters and 11 significant pairwise differences among the mean pollen levels of all 15 cluster pairs (73.3%) were obtained.

Below only clusters of the significantly different cluster averaged pollen levels will be considered and analysed in detail, principally the clusters with extreme pollen levels

(Tables 1a-b and 2a-b). Comparing the results obtained by frontal categories (Table 1a) and objective clusters (Table 1b) defined on the original data for Szeged, the following key conclusions can be drawn. The category (cluster) displaying the highest mean pollen level includes a medium (fewest) number of days. The frontal category (cluster) involving the highest mean pollen level includes (does not include) extreme values of the influencing variables. For the subjective classification, the category of the highest mean pollen level (class 4: cold front with no rain) is influenced by high previous-day mean Poaceae pollen concentration, the highest mean values of temperature and air pressure, as well as low relative humidity and the lowest wind speed. These values of the meteorological parameters assume an ante – cold front weather situation that is a possible anticyclone ridge weather situation which facilitates high pollen levels (Table 1a). For the objective classification, the cluster of the highest mean Poaceae pollen concentration (cluster 5) is affected by the highest previous-day pollen level, low temperature, as well as high global solar flux, relative humidity, air pressure and wind speed. These values suppose a weak anticyclone ridge weather situation promoting the enrichment of Poaceae pollen (Table 1b). A similar comparison for Győr (Table 2a-b) reveals the following main points. The subjective category involving the highest mean pollen concentration occurs frequently, while the frequency of the objective cluster having the highest mean pollen level is the smallest. The subjective category having the highest mean pollen level is associated with the second highest previous-day mean Poaceae pollen concentration, while the objective cluster displaying the highest value of the resultant variable involves the highest mean previous-day pollen level as its apparently most important influencing variable. For the subjective classification, the category of the highest mean pollen level (class 2: warm front with no rain) is influenced by the highest temperature and wind speed, high global solar flux and air pressure, as well as low relative humidity. These values assume an ante – warm front weather situation that is possibly again an anticyclone ridge weather situation that aids high pollen levels (Table 2a). For the objective classification, the cluster of the highest mean Poaceae pollen concentration (Cluster 3) is probably mostly affected by the highest previous-day pollen level, since no meteorological variables have extreme values. Nevertheless, the temperature and global solar flux are high, while the relative humidity is low; furthermore air pressure and wind speed assume medium values. Accordingly, this cluster is supposed to be prevailed by a weak anticyclone ridge weather situation that assists the enrichment of Poaceae pollen (Table 2b).

Table 1a Mean values of the meteorological and pollutant parameters, according to subjective categories for Szeged, original data (**bold:** maximum; *italic:* minimum)

Cluster	1	2	3	4	5	6
Parameter			**Mean values**			
Total number of days	123	320	*46*	203	211	**484**
Frequency (%)	8.9	23.1	*3.3*	14.6	15.2	**34.9**
Temperature (°C)	19.4	20.8	19.0	**20.9**	*17.8*	19.5
Global solar flux (Wm^{-2})	259.3	**361.6**	270.1	340.5	*250.1*	357.5
Relative humidity (%)	75.2	*63.7*	77.6	64.7	**80.7**	65.8
Air pressure (hPa)	1000.6	**1006.1**	1002.1	**1006.1**	*1001.1*	1004.5
Wind speed (ms^{-1})	**1.1**	1.0	**1.1**	*0.9*	1.0	1.0
Poaceae pollen, previous-day*	16.7	14.7	**18.2**	17.7	14.5	*14.4*
Poaceae pollen, same day*	15.8	15.9	17.2	**17.7**	*13.2*	14.6

1: warm front with rain; 2: warm front with no rain; 3: cold front with rain; 4: cold front with no rain; 5: no front with rain; 6: no front with no rain; *: (pollen·m^{-3}·day^{-1})

Table 1b Cluster-related mean values of the meteorological and pollutant parameters, Objective clusters for Szeged, original data, whole database (**bold:** maximum; *italic:* minimum)

Cluster	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Parameter				**Mean values**			
Total number of days	174	249	232	137	*82*	**343**	170
Frequency (%)	12.5	18.0	16.7	9.9	*5.9*	**24.7**	12.3
Temperature (°C)	**22.4**	16.2	*15.8*	22.3	19.3	23.3	18.2
Global solar flux (Wm^{-2})	285.7	*165.3*	386.3	349.1	350.5	**413.5**	329.9
Relative humidity (%)	54.8	**89.5**	64.4	*49.5*	68.3	69.3	72.3
Air pressure (hPa)	**1012.7**	1000.3	1007.5	*997.1*	1005.0	1003.2	1003.9
Wind speed (ms^{-1})	0.9	0.9	*0.8*	1.0	1.0	0.9	**1.7**
Poaceae pollen, previous-day*	14.7	*8.7*	9.1	12.1	**66.6**	14.7	13.2
Poaceae pollen, same day*	14.9	*8.4*	10.8	12.9	**55.3**	15.4	14.9

*: (pollen·m^{-3}·day^{-1})

Table 2a Mean values of the meteorological and pollutant parameters, according to subjective categories for Győr, original data (**bold:** maximum; *italic:* minimum)

Cluster	**1**	**2**	**3**	**4**	**5**	**6**
Parameter			**Mean values**			
Total number of days	90	264	*53*	145	168	**416**
Frequency (%)	7.9	23.2	*4.7*	12.8	14.8	**36.6**
Temperature (°C)	17.8	**19.9**	18.1	19.8	*16.6*	18.7
Global solar flux (Wm^{-2})	*145.1*	196.5	154.7	193.8	149.0	**201.7**
Relative humidity (%)	72.8	*60.7*	69.8	60.4	**74.8**	61.2
Air pressure (hPa)	1002.2	1004.8	1003.5	1005.1	*1001.7*	**1006.1**
Wind speed (ms^{-1})	**1.2**	**1.2**	**1.2**	*1.1*	**1.2**	*1.1*
Poaceae pollen, previous-day*	7.1	7.7	**9.3**	7.7	*5.8*	6.1
Poaceae pollen, same day *	6.6	**7.9**	6.2	7.4	*5.2*	7.0

1: warm front with rain; 2: warm front with no rain; 3: cold front with rain; 4: cold front with no rain; 5: no front with rain; 6: no front with no rain; *: (pollen·m^{-3}·day^{-1})

Table 2b Cluster-related mean values of the meteorological and pollutant parameters, Objective clusters for Győr, original data, whole database (bold: maximum; italic: minimum)

Cluster	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Parameter				**Mean values**			
Total number of days	214	102	*80*	139	195	**217**	189
Frequency (%)	18.8	9.0	*7.0*	12.2	17.2	**19.1**	16.6
Temperature (°C)	20.1	17.3	20.6	*14.1*	18.2	**23.6**	15.3
Global solar flux (Wm^{-2})	**295.8**	168.6	224.2	118.3	178.7	187.0	*105.2*
Relative humidity (%)	59.8	69.2	61.9	75.6	*49.9*	60.2	**78.9**
Air pressure (hPa)	1008.2	999.5	1004.3	**1012.8**	1003.7	1003.9	*999.1*
Wind speed (ms^{-1})	*1.0*	**1.9**	1.2	1.1	1.1	1.1	1.1
Poaceae pollen, previous-day*	7.1	3.9	**37.2**	*2.3*	5.4	4.1	3.5
Poaceae pollen, same day*	10.0	5.0	**24.6**	*2.2*	6.9	5.0	2.7

*: (pollen·m^{-3}·day^{-1})

3.2. Linear regression

Predictors significant at least at a 90% level were retained and evaluated. These include previous-day pollen concentration, previous-day mean temperature and previous-day mean global solar flux for Győr, but only previous-day pollen concentration for Szeged when the entire data set was used. The previous-day concentration is apparently the best predictive parameter for both locations and for each weather type defined either by clustering or fronts with rain occurrences. The rank of importance of temperature and global solar flux for Győr is variable under both sets of clusters and even the wind speed has a slight (although statistically significant) role in types with fronts.

The ratio of the variance explained by these variables to the variance of the pollen concentration is 12.8% and 29.9% for Győr and Szeged, respectively, using all the data sets. With cluster-dependent regressions, Győr provides an explained variance of 27.9%, 17% and 16.3% using clusters with original data, clusters with standardised data and subjective weather types, respectively. The most effective classification is, therefore, the clustering with original data. A subjective classification and clustering with standardised data do not make any substantial difference. The corresponding values for Szeged under cluster-dependent regressions are 31%, 29.6% and 29.7%. Here, the different classifications perform quite similarly, especially the subjective classification and clustering with standardised data. Note that the estimation of daily Poaceae pollen concentration is more reliable for Szeged than for Győr because it has a warmer and dryer climate. However, the cluster-dependent regression for Szeged, in contrast to Győr, yields only a slight gain under clustering with original data and yields no gain under subjective classification and clustering with standardised data.

For the subjective classification, the best estimates can be obtained for days of warm front with precipitation (39% and 70.4% explained variance for Győr and Szeged, respectively), while the poorest estimates occur on days of cold front with no precipitation. Under this type, the mean squared error is larger than this quantity defined for the entire data set (by 20% and 13% for Győr and Szeged, respectively). For clustering with original data, the best estimates can be obtained for Cluster 4 and Cluster 3 for Győr (42.8% explained variance and Szeged (74.6% explained variance), respectively. The poorest estimates are associated with Cluster 3 for Győr and Cluster 7 for Szeged. The corresponding mean squared error increases by 106.5% (Győr) and 55.4% (Szeged) relative to the quantity defined for the entire data set.

The variability of mean pollen concentrations among clusters is wider than the similar range under subjective weather types. This is due to the fact that a subjective grouping might consider fewer influencing variables or selects the types arbitrarily, while an objective classification makes it possible to select an optimum number of groups of weather types, providing a higher explained variance of the pollen level (Makra et al. 2009). The category of warm front with precipitation involves very similar days of a relatively stable weather situation. Though the wind speed is high, the influencing variables display a small variablity, producing a higher explained variance of the Poaceae pollen concentration. On the contrary, on days of cold front with no rain in spite of low winds the higher variability of the influencing variables involves a lower explained variance of the pollen level (Tables 1 and 2). The estimation of the pollen level for Szeged is more reliable than for Győr. The warm and temperate climate (Köppen's Ca type) of Szeged fits the climate optimum of Poaceae better than temperate oceanic climate (Köppen's Cbfx type) of Győr (Köppen 1931). This is why the explained variance of the 6 influencing variables to the variance of the pollen level is higher for Szeged than for Győr.

4. CONCLUSIONS

Both for Szeged and Győr, as well as for the subjective and objective classifications, high daily mean Poaceae pollen levels are facilitated by anticyclone ridge weather situations, as we expected.

When estimating Poaceae pollen level, the previous-day pollen concentration, previous-day mean temperature and previous-day mean global solar flux for Győr, but only previous-day pollen concentration for Szeged were significant at least at a 90% level using the entire data set. As regards clusters with original data, clusters with standardised data and subjective weather types, the objective classification with original data proved the most effective.

For the subjective classification, the best estimates can be obtained for days of warm front with precipitation for Győr and Szeged, respectively. The poorest estimates are obtained on days of cold front with no precipitation. The ratio of the variance explained by the 6 variables to the variance of the pollen concentration was higher for the objective than for the subjective classification of the weather types, which confirms our expectations. The difference between explained variances of the Poaceae pollen concentration under the category of warm front with precipitation and under cold front with no precipitation can be explained by the different variability of the influencing variables. The estimates of the pollen level for Szeged is much more reliable than those for Győr, since the warm and temperate climate of Szeged fits the climate optimum of Poaceae better than the temperate oceanic climate of Győr.

The above-mentioned relationship between the pollen level and the six influencing variables allow us to perform a preliminary, cluster related analysis of variable dependencies for the pollen level. In order to get a reliable forecast of the Poaceae pollen concentration a more advanced methodology will be needed. However, both the objectively and subjectively defined weather types produce useful information on the accuracy of the forecast. For instance, the Poaceae pollen concentration following a warm front with rain can be accurately forecasted, while a cold front with no rain involves highly uncertain factors.

Acknowledgements: The European Union and the European Social Fund provided financial support for the project under the grant agreement no. TÁMOP 4.2.1/B-09/1/KMR-2010-0003 and TÁMOP-4.2.1/B-09/1/KONV-2010-0005.

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