

Non-native *Ambrosia* pollen in the atmosphere of Rzeszów (SE Poland); evaluation of the effect of weather conditions on daily concentrations and starting dates of the pollen season

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Abstract The investigated problem was whether and to what an extent the elements of weather conditions were associated with changes in the concentration of *Ambrosia* pollen in air. The study was carried out in the years 1997–2004 using the volumetric method. Ragweed did not occur in the flora of the town of Rzeszów and its vicinity, but every year its pollen occurred at concentrations considerably exceeding the threshold values for the allergic response. The pollen seasons usually began from near the end of August to the first part of September. The values of daily concentrations varied greatly: days without pollen grains being frequently noted while single grains occurred long before and after the season. The effect of the elements of weather on changes in the concentration of pollen in the air was slight. Taking into account all meteorological parameters, it can be stated that an increase in the number of pollen grains is connected with increased temperature and higher wind speeds, but negatively correlated with humidity and rainfall. These relationships can usually be explained by the effects of the type of weather taking place over the wider region. The analysis of the results showed that pollen was probably transported from distant regions. The mean angle at which the greatest pollen concentrations were recorded corresponded to the SE wind direction. The analysis of synoptic phenomena during the pollen season confirms the thesis about the long-distance transport from the south, southeast and southwest. A close dependence

was also found between the starting date of the season and the sum of maximum temperatures and the sum of differences between the maximum and minimum temperatures.

Keywords Aerobiology · Meteorological parameters · Long-distance transport · Pollen · Synoptic weather types

Introduction

The most frequently studied object in aerobiology is ragweed, *Ambrosia* sp., pollen (Dahl et al. 1999; Rybniček et al. 2000; Saar et al. 2000; Stepalska et al. 2002; Bartková-Ščevková 2003; Laaidi et al. 2003; Juhász et al. 2004; Puc 2004; Makra et al. 2004, 2005; Piotrowska and Weryszko-Chmielewska 2006). Produced in millions, it readily becomes a component of air. It contains very strong allergens which are apt to create cross-reactions with *Artemisia* allergens (Jäger 2000) and become a serious risk to human health in many countries. In some North America states and in central Europe, where the concentration of *Ambrosia* pollen are higher than those in other regions of the world, serious ragweed pollution occurs. *Ambrosia artemisiifolia* pollen is the most harmful to allergy sufferers *Ambrosia trifida* and *Ambrosia psilostachya* also produce allergens and potentially cause problems, but are rare in Europe at the present time (Járai-Kolmódi 2000; Makra et al. 2005).

Ragweed is tolerant of a wide range of environments due to its highly evolved reproduction strategies, which facilitate a rapid extension of range. The range has been observed to broaden from south to north across Europe since the First World War (Juhász 1998; Jäger 2000). Ragweed species thrive in regions with long warm and dry seasons. The limiting factor which determines the occur-

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rence of these plants is cool climates with high relative humidity. Hence, in northern European countries, their pollen has yet to present a serious allergological problem (Dahl et al. 1999; Saar et al. 2000).

In countries bordering southeastern Poland (Ukraine and Slovakia), ragweed occurs with variable intensity. In Slovakia, *Ambrosia artemisiifolia* (L.) is found most often in southern and eastern regions (Makovcová et al. 1998). In Ukraine, three species have been recorded: *A. trifida* (L.), *A. psilostachya* (DC.) and *A. artemisiifolia*. The first two species occur sparsely while the third has a considerably wider range and can be found almost throughout Ukraine with the exception of the Carpathian Mountains and the northwestern region of the country (Mosyakin and Yavorska 2002; Protopopova et al. 2003; Grygorak et al. 2004). Particularly favorable conditions for *A. artemisiifolia* are found in the zone of steppes and forest-steppes in the southeastern part of the country and in the Zakarpacie lowlands. There, the populations of this species densely cover many hectares and the height of individuals exceeds 1 m. Recently, the species has also been frequently recorded in the Podole region in the southwest (Y. Kobiv, personal communication). In Europe, the most ragweed-polluted region is the Carpathian Basin (Hungary), next is Croatia, then central France (the Rhône-Alpes region), followed by northern Italy (Juhász 1998; Juhász et al. 2004).

In the flora of Poland, three species of *Ambrosia* have been recorded: *A. artemisiifolia*, *A. psilostachya* and *A. trifida*. They are classified as synanthropic quarantine species occurring in habitats typical of ragweed: agrocenoses, in the vicinity of grain silos, ports, along road sides, and in ruderal sites. The genus has been recorded in Poland since the nineteenth century. However, the sites were found to no longer have ragweed in later floristic studies. This indicates the ephemeral character of these species (Malkiewicz and Wąsowicz 2003). The species *A. artemisiifolia* is more frequently encountered than any other in Poland; the greatest number of documented sites being found in the southwestern part of the country. *A. psilostachya* occurs in several scattered locations. The third species is very rare in Poland and owing to its ephemeral character it is difficult to document its distribution (Tokarska-Guzik 2001; Chłopek and Tokarska-Guzik 2006).

On account of the distribution of these species of this genus in Poland and in neighboring countries, its European range expanding from south to north, and the possibility of distant transport of pollen owing to the abundant production and small grain size, it was assumed that the pollen of this plant noted in the air of Rzeszów had originated from long-distance transport by air currents.

The aim of the work was to verify this hypothesis and answer the question whether and to what extent meteorological factors were associated with changes in the concentration of *Ambrosia* pollen in the air of Rzeszów.

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Materials and methods

Location of the city

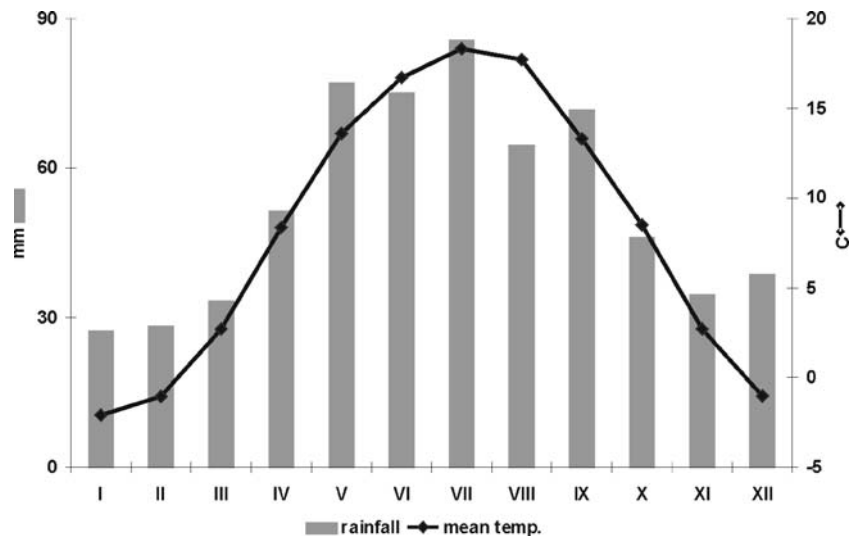
The town of Rzeszów lies in southeastern Poland at a distance of about 30 km north of the Carpathian Plateau (Fig. 1). The centre of the town lies in the valley of the River Wisłok at 200–215 m above sea level. Its climatic conditions are chiefly affected by polar maritime and polar continental air masses. In the years 1981–2000, the average annual total precipitation was 633 mm and the mean annual temperature 8.1°C. July is the warmest month (18.3°C) and usually has the greatest rainfall. In January, the lowest total of precipitation and lowest temperature (−2.1°C) are recorded (Fig. 2; Ochrona Środowiska 2001–2002). The vegetation growing period lasts 215–220 days.

The observed process of decreasing numbers of the native flora and vegetation in Rzeszów is due to anthropopressure. Synanthropic vegetation dominates in the town area. The green areas of the town also include numerous parks, lawns and home gardens. Rush and riparian vegetation is found along the river where some protected plant species can be encountered. In the vicinity of the town there are many hectares where wheat, rapeseed and root crops are planted, and also hay-growing meadows and cherry and apple orchards. In recent years, fallow fields and meadows are more and more commonly observed. The most frequent types of forest are pine, mixed and oak-hornbeam.



Fig. 1 Map of Poland with location of Rzeszów

Fig. 2 Climatic diagram for Rzeszów for years 1981–2000



Ragweed has not been recorded at any sites in the town and its vicinity. The two nearest sites of *A. artemisiifolia* have been observed about 80 km east and 100 km west of Rzeszów (Tokarska-Guzik 2001).

Methods of aerobiological investigation

Aerobiological monitoring was conducted continuously in the years 1997–2004. Because of irrelevant circumstances, the measurements were interrupted in 2000 and analyses did not cover that year. The volumetric method was applied in the investigation. The trap was set at a height of about 12 m. A microscopic slide was made for each day of measurements. Pollen grains were identified from 12 vertical strips of microscopic glass under 400× magnification. The width of each strip was 460 µm. Each strip corresponded to 2-h intervals, the obtained result showing the number of pollen grains in 1 m³/24 h.

Methods in the verification of results

Pollen seasons were distinguished using the 90% method, since the dates of starting and ending were characterized by the least variability coefficient in comparison to the 98% and 95% methods. The applied method eliminated single grains, which occurred outside the season during nearly the entire year, and in the case of low annual total numbers of pollen grains, they sometimes constituted a significant percentage. SPI (Seasonal Pollen Index) indicates the total pollen grains sum from the pollen season. Twenty is the number of *A. artemisiifolia* pollen grains in m³/24 h that was accepted as the threshold value responsible for triggering off an allergic reaction (Jäger 1998).

In order to obtain the normal distribution of samples, several techniques were used: $\ln(p+1)$, $\log(p+1)$, or a square root, where p was the daily number of pollen grains in 1 m³

of air. The distribution analysis was evaluated using the Shapiro–Wilk test. However, none of the techniques brought about an expected result and, hence, the results were calculated using non-parametric tests (Trigo et al. 2000). The relationships between the elements of weather conditions and the daily concentrations of pollen grains were verified using the Spearman test. On the basis of literature data (Stark et al. 1997; Bartková-Ščevková 2003; Laaidi et al. 2003; Makra et al. 2004), weather factors were selected which were most strongly associated with changes in the concentration of this airborne pollen, i.e., temperature (max., min., mean; °C), daily temperature range (°C), dew point temperature (°C), precipitation (mm), humidity (%), humidity deficiency (hPa), vapour pressure (hPa), sunshine duration (h), mean and maximum wind speed (m/s), and the direction of the prevailing wind. Following the suggestion of Makra et al. (2004), the relationship between the number of pollen grains and meteorological parameters was studied using numerical analysis. The standardized variables were compared using Factor Analysis. Each of the components carried independent information. In the result, several groups of examined factors were created and ranked according to their numerical importance. The first component gives the highest percentage of explained variance, but others can also stress additional, important information. The number of factors was chosen according to Kaiser's criterion.

The mean numbers of pollen grains were compared to the classes of maximum wind speeds given below and the mean concentrations of pollen grains during the pollen season, using a non-parametric alternative of variance analysis, i.e., the Kruskal–Wallis test, and appropriate statistics for multiple comparisons. The following classes of maximum wind speeds were established: 0–3 m/s, 4–5 m/s, 6–7 m/s, 8–9 m/s, 10–11 m/s, 12–13 m/s, and above 14 m/s. The method of circular statistics was used in

establishing the mean direction of wind from which the greatest numbers of pollen grains had been transported. The variability range and circular deviation were also computed (Zar 1999).

On the basis of synoptic maps of Europe, Niedźwiedz (1981) distinguished 11 circulation types taking into account the direction of air mass advection and the type of pressure pattern (a-anticyclonic, c-cyclonic). For the southeast of Poland, each day was described by types of circulation, air masses and fronts (Niedźwiedz 2004). The Kruskal–Wallis test was used to compare mean concentrations of pollen grains with 11 synoptic weather types and 7 types of air masses.

According to the literature and aerobiological and ecological data (Bartková-Ščevková 2003; Laaidi et al. 2003; Juhász et al. 2004; Makra et al. 2004; Peternel et al. 2005), temperature is the environmental factor which most strongly affects the generative and vegetative development and the occurrence of pollen in air. Thus, the significance of its effect on determining the starting date of the pollen season (SPS) was tested using linear regression (after the normal distribution was confirmed by the Shapiro–Wilk test), and the sum of effective temperatures (GDD°C). In the case of the latter method, several variants were checked in order to select a method with the least variability coefficient (Jato et al. 2000; Rodríguez-Rajo et al., 2003):

$-T_{\max}; T_{\max} - T_{\min}; T_{\text{mean}}$ above the threshold value.

The following threshold values were accepted: 0°C, 6°C, 7°C, 8°C, 9°C, 10°C, and 11°C. As proposed by Laaidi (2003), 1 April was the first day when temperatures were recorded; it is when the vegetation of plants usually begins growing (Juhász 1998). The statistical significance of all the tests was accepted at the level of $\alpha < 0.05$. The V , r and R^2 values were interpreted on the basis of Bogucki's work (1979). Statistical analyses were conducted using Statistica 7.1 and Excel programs. The meteorological data were supplied by the Rzeszów-Jasionka station established at the airport located about 7 km from the measurement station.

Results

Pollen seasons usually began in the second half of August and this date was characterized by low variability. Greater variability appeared at the ends of the pollen seasons, the variability coefficient reaching $V=3.1\%$. The earliest end of the pollen season was recorded on 31 August 2004 and the latest one on 23 September 2003. The lengths of the seasons were characterized by a high degree of variability: their mean length was 26 days, but pollen grains occurred at numerous intervals. The smallest number of breaks was observed in 2004 and the greatest one in 2003. On the basis of seven years results, no statistically significant tendencies were found in the starting date and the end of pollen seasons or in their length.

Ambrosia pollen was an important component of the pollen spectrum in Rzeszów. Each year, the SPI and percentage values varied considerably; the mean SPI number being 354 grains. In 1999, the greatest number of pollen grains throughout the year and the highest percentage contribution in the annual total number of all pollen grains were recorded. The maximum pollen concentrations usually occurred at the turn of August and September and their values varied considerably between years. In this respect, the highest concentration was also recorded in 1999 (Table 1).

The occurrence of *Ambrosia* pollen in air varied to a very high degree. Only in the year 2002 was the pollen season fairly consistent, as confirmed by the comparison of its length and actual frequency. In the remaining years, the seasons were more sporadic. The values of daily concentrations varied considerably and days without pollen grains were frequent and single grains appeared long before and after the season. The Kruskal–Wallis analysis of ranks showed significant differences between the years 2001–2002 and 2002–2003 in the mean concentration of pollen grains in the seasons ($H=19.146$; $\alpha < 0.0039$). In the remaining years, these values were not significantly different.

Table 1 Descriptive statistics. SPI Seasonal pollen index, f frequency

	SPI	%	Start 5%	End 95%	Duration	f	Maximum/data	Days > threshold
1997	163	0.8	21.08	13.09	24	19	34/23.08	3
1998	366	1.5	19.08	15.09	28	22	125/10.09	4
1999	807	2.2	26.08	21.09	27	25	319/4.09	6
2001	303	1.0	16.08	21.09	37	25	98/4.09	2
2002	411	1.4	27.08	9.09	14	13	98/5.09	6
2003	276	0.5	18.08	23.09	36	20	55/12.09	6
2004	152	0.3	13.08	31.08	18	11	42/30.08	3
Mean	354		232; 20.08	258; 14.09	26.3	19.3		4.3
$V\%$	62.6		2.1	3.1	32.3	28.5		39.5

Fig. 3 Diurnal variations of *Ambrosia* pollen on selected days with the direction of the wind

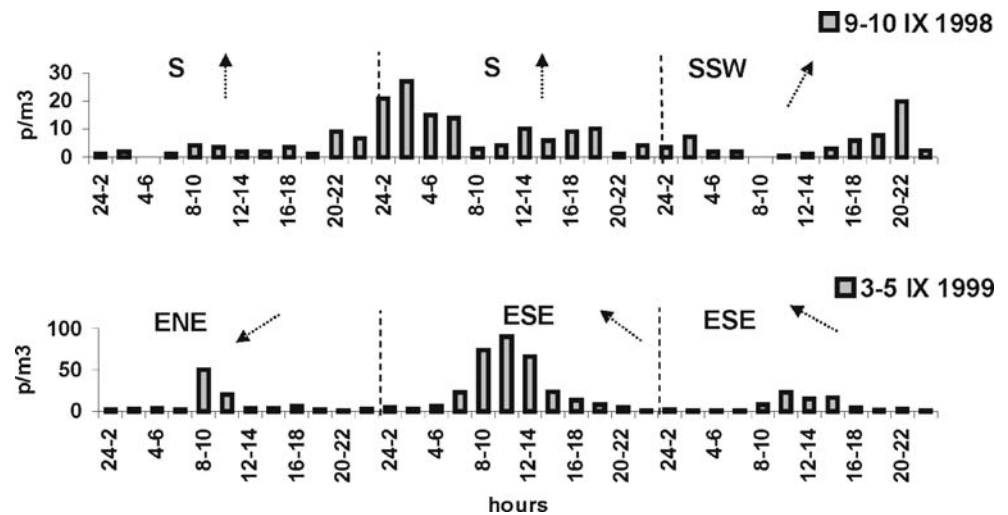


Figure 3 presents the diurnal variation of airborne pollen recorded over three selected days with the highest concentrations. In 1998, on these days the wind was blowing from the south and southwest, with the highest concentrations being noted during the night. In the following year, on days with southeastern and northeastern winds prevailing, the greatest number of pollen grains were noted during the day, at about noon.

The effect of weather conditions on the changing concentration of air pollen was slight. In 2001, 2002 and 2004, statistically non-significant dependences were found between each weather element and pollen concentration. In the remaining years, the correlation coefficients were only statistically significant in exceptional cases, e.g., when the

effect of some elements of weather on the number of pollen grains was moderate (relative humidity, humidity deficiency, dew point temperature, sunshine duration) or considerable (the maximum and the mean temperature). If all the years are taken into consideration, only five meteorological parameters showed an association with changes in the concentration of *Ambrosia* pollen in air. The maximum and mean temperature, dew point temperature and the daily temperature range correlated with an increase in the airborne pollen grains, while humidity was to a low degree correlated with its decrease (Table 2).

On the basis of Kaiser's criterion, three factors were chosen. The first factor explains 35.4% of the total variance. The daily pollen concentration and most of the

Table 2 Results of Spearman correlation between daily average of pollen grains in 1 m³ of air and the meteorological factors

	T _{max} (°C)	T _{min} (°C)	T _{mean} (°C)	ΔT (°C)	Dew point T (°C)	Rainfall (mm)	Vapour pressure (hPa)	Humidity deficiency (hPa)	Relative humidity (%)	Sunshine duration (hours)	Average wind speed (m/s)	Max. wind speed (m/s)
1997	0.647 ***	-0.195 NS	0.363 NS	0.611 *	0.030 NS	0.033 NS	0.026 NS	0.573 **	-0.396 NS	0.422 NS	-0.138 NS	-0.157 NS
1998	0.502 ***	0.374 *	0.619 ***	0.051 NS	0.558 **	-0.06 NS	0.431 *	0.442 NS	-0.391 *	0.007 NS	0.346 NS	0.377 *
1999	0.252 NS	-0.148 NS	0.003 NS	0.257 NS	0.550 **	-0.204 NS	-0.212 NS	-0.205 NS	-0.440 *	0.517 **	0.071 NS	0.136 NS
2001	0.135 NS	0.030 NS	0.083 NS	0.113 NS	0.097 NS	0.205 NS	0.049 NS	0.041 NS	-0.102 NS	-0.334 NS	-0.078 NS	-0.094 NS
2002	0.291 NS	0.244 NS	0.180 NS	0.433 NS	0.216 NS	0.034 NS	0.004 NS	0.044 NS	0.022 NS	0.142 NS	0.320 NS	0.517 NS
2003	0.309 NS	0.146 NS	0.265 NS	0.194 NS	0.282 NS	-0.142 NS	-0.113 NS	-0.106 NS	-0.392 *	0.393 **	0.148 NS	0.05 NS
2004	0.261 NS	0.111 NS	0.312 NS	0.190 NS	0.121 NS	0.149 NS	0.374 NS	0.375 NS	-0.112 NS	-0.115 NS	0.242 NS	0.141 NS
Seven years	0.368 ***	0.094 NS	0.292 ***	0.309 *	0.204 **	0.090 NS	0.061 NS	0.103 NS	-0.295 ***	0.194 NS	0.103 NS	0.003 NS

*** $\alpha < 0.001$; ** $\alpha < 0.01$; * $\alpha < 0.05$

meteorological parameters are statistically significant. The daily temperature range, sunshine duration and humidity contribute to the highest loadings. The results indicate the positive relationship between pollen concentrations with the daily temperature range, maximum, mean temperature, sunshine and the dew point temperature, and the negative relationship with minimum temperature, rainfall, humidity. The second factor explains 24.0% of the total variance, but the daily pollen concentration load is not statistically significant. The third factor explains 14.0% of the total variance. The daily pollen concentration load is significant. The parameters described are wind speeds: maximum and average indicate a positive relationship with the number of airborne pollen grains (Table 3).

Next, the daily mean pollen concentration was compared to the concentrations observed in the maximum speeds of the seven individual wind classes. No statistically significant differences ($H=1.766$; $\alpha>0.05$) were found. Because of the assumed hypothesis about the origin of the transported pollen, the direction of wind was taken into consideration. In each year, the mean angle at which the greatest concentration arrived from was noted, and although this angle varied slightly, in general it corresponded to a SE–E direction. Only in 1997 was it different, corresponding to ENE–E directions. The computed variability ranges are not wide, with the widest one being found in 2003 (Table 4). The mean angle for all the years of the investigation corresponded to a general SE direction, as confirmed by the rise in the pollen count (Fig. 4).

On days with either rising or falling barometric pressure and W–NW winds, the mean number of pollen grains was significant lower than in comparison with all other synoptic weather types. On days when air mass advection was noted from the E–SE and S–SW, high ragweed pollen counts were noted. On days with polar maritime or arctic air

Table 4 Results of circular statistic for daily average of pollen grains in 1 m^3 in air

	Mean angle $\bar{\alpha}$	Confidence limits/ range of wind direction	Angular deviation
1997	$83^\circ \pm 10^\circ$	73° – 93° ENE–E	53°
1998	$169^\circ \pm 4^\circ$	165° – 173° SSE–S	30°
1999	$102^\circ \pm 2^\circ$	100° – 104° E–ESE	25°
2001	$162^\circ \pm 7^\circ$	155° – 169° SSE	53°
2002	$173^\circ \pm 9^\circ$	164° – 182° SSE–S	61°
2003	$171^\circ \pm 21^\circ$	150° – 192° SE–S	71°
2004	$139^\circ \pm 15^\circ$	124° – 154° ESE–SSE	61°
Seven years	$160^\circ \pm 2^\circ$	158° – 162° SSE	64°

masses, the pollen count was statistically significant different, e.g., lower than on days with polar continental, polar maritime warm and polar maritime transformed (old) air masses (Tables 5 and 6).

In spite of the slight effect of weather on the concentration of airborne pollen count (Table 2), the low value of coefficient V describing the variability of starting dates of the pollen seasons in the investigated years (Table 1) justified the evaluation of methods used in determining the starting date of the season. A close dependence was found between the starting date of the season and the sum of maximum temperatures, and the sum of differences between the maximum and minimum temperatures. Regression equations were elaborated for these dependences (Fig. 5). The utility of these parameters in forecasting was confirmed by the lowest V values, as in the case of the method of summing effective temperatures, when $T_{\max}$ and $T_{\max} - T_{\min}$ was used. The remaining methods of sums of effective temperatures which were computed on the basis of threshold temperatures were characterized by a moderate variability (Table 7).

Table 3 Loads of variables for three factors (loads statistically significant are in bold)

Variables	Factor 1	Factor 2	Factor 3
Number of pollen grains	–0.327	0.082	0.307
$T_{\max}$	–0.693	0.663	–0.097
$T_{\min}$	0.239	0.869	0.181
T_{mean}	–0.375	0.898	0.033
ΔT	–0.848	–0.071	–0.267
Dew point	–0.735	0.454	0.044
Rainfall	0.525	0.200	0.076
Vapour pressure	0.113	0.944	–0.118
Humidity deficiency	–0.021	0.831	–0.047
Relative humidity	0.863	–0.053	–0.278
Sunshine duration	–0.881	–0.005	–0.014
Average wind speed	0.863	–0.053	–0.278
Max. wind speed	–0.881	–0.005	–0.014

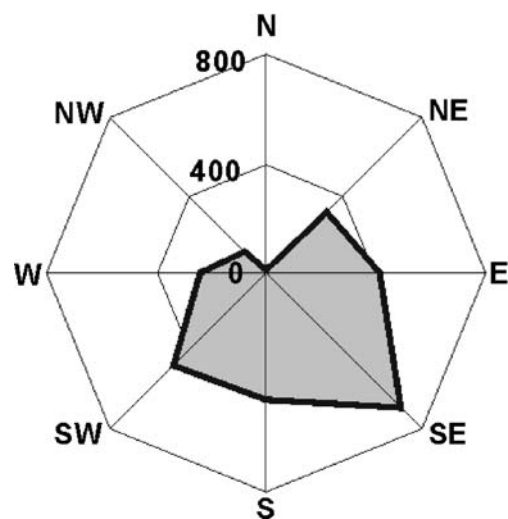


Fig. 4 “Pollen rose” of *Ambrosia* pollen concentrations for wind directions for the years 1997–1999 and 2001–2004

Table 5 Comparison of means number (Kruscal–Wallis test) with reference to 11 types of synoptic situations

	N+ NEa	E+ ESa	S+ SWa	W+ NWa	Ca+ Ka	N+ NEc	E+ SEc	S+ SWc	W+ NWc	Cc +Bc	x
N+NEa											
E+ESa				*					*		
S+SWa				*					*		
W+NWa		*	*					*		*	
Ca+Ka											
N+NEc											
E+SEc											
S+SWc				*							
W+NWc		*	*							*	
Cc+Bc				*					*		
x											

Capital letter: direction of air masses advection, geostrophic wind

a Anticyclonic situations; c cyclonic situations; Ca central anticyclonic situation; Ka anticyclonic wedge or ridge of high pressure; x unclassified situations

* $\alpha < 0.05$

Discussion

Seasonal pollen counts can be consistent or sporadic depending on the range of the taxonomic level of a pollen type, e.g., species, genus, family, the ecology of flowering, and the weather. In regions where ragweed commonly occurs pollen seasons are compact (Jäger 1998, 2000; Juhász et al. 2004; Peternel et al. 2005). In Rzeszów, the pollen seasons were rarely consistent and frequent breaks did not coincide with rainfall, showing that the sources of this pollen were probably scarce or pollen arrived by long-distance transport (Saar et al. 2000). The beginning of the pollen seasons hardly varied; no significant differences were found in the average daily concentration of pollen throughout the seasons over the years. This can suggest that in most years pollen was arriving from a constant source (Trigo et al. 2000). Over successive years, the values of SPI were characterized by diversity and differed from those

recorded in other Polish towns. In Wrocław (southwestern Poland; Malkiewicz and Wąsowicz 2003), Sosnowiec (south Poland; Chłopek and Tokarska-Guzik 2006) and Lublin (eastern Poland; Piotrowska and Weryszko-Chmielewska 2006), these values were relatively similar and higher in comparison with Kraków (southern Poland; Stepalska et al. 2002) and Szczecin (northwestern Poland; Puc 2004). In comparison with data from neighbouring countries, the obtained results are lower than in Slovakia and the Czech Republic (Makovcová et al. 1998; Rybniček et al. 2000) but higher than in Lvov (Ukraine; Weryszko-Chmielewska et al. 2003). In Hungary, the most ragweed-polluted region in Europe, seasonal total sums of pollen counts are almost 30 times higher than in Rzeszów and pollen seasons last about 3 times longer (Makra et al. 2005). Ragweed pollen is one of the more abundant pollen types in Croatia. In typical lowland rural areas, the daily maximum pollen counts and yearly total sums exceed 1,000 and 70,000, respectively (Peternel et al. 2005).

Numerous studies carried out in the several countries where ragweed commonly occurs showed close correlation between the concentration of airborne pollen and meteorological parameters, especially temperature, precipitation and humidity (Stark et al. 1997; Stepalska et al. 2002; Laaidi et al. 2003; Makra et al. 2004; Puc 2004; Peternel et al. 2005; Piotrowska and Weryszko-Chmielewska 2006). Only a few of the meteorological factors which are presented in this work produced correlation coefficients which were statistically significant. In spite of the high level of significance in some cases ($\alpha < 0.001$), the values of the correlation coefficients are low. The strongest dependences were related to maximum and average temperatures. The results of correlation analyses showed that the meteorological parameters had a weak effect on the airborne concentrations

Table 6 Comparison of means number (Kruscal–Wallis test) with reference to 7 types of air masses

	PA	PPm	PPms	PPk	PPmc	PZ	rmp
PA			*	**	**		
PPm			*	**	**		
PPms	*	*					
PPk	**	**					
PPmc	**	***					
PZ							
rmp							

PA Arctic air masses; PPm polar maritime (fresh); PPms polar maritime old (transformed); PPk polar continental; PPmc polar maritime warm; PZ tropical air masses; rmp various air masses

*** $\alpha < 0.001$; ** $\alpha < 0.01$; * $\alpha < 0.05$

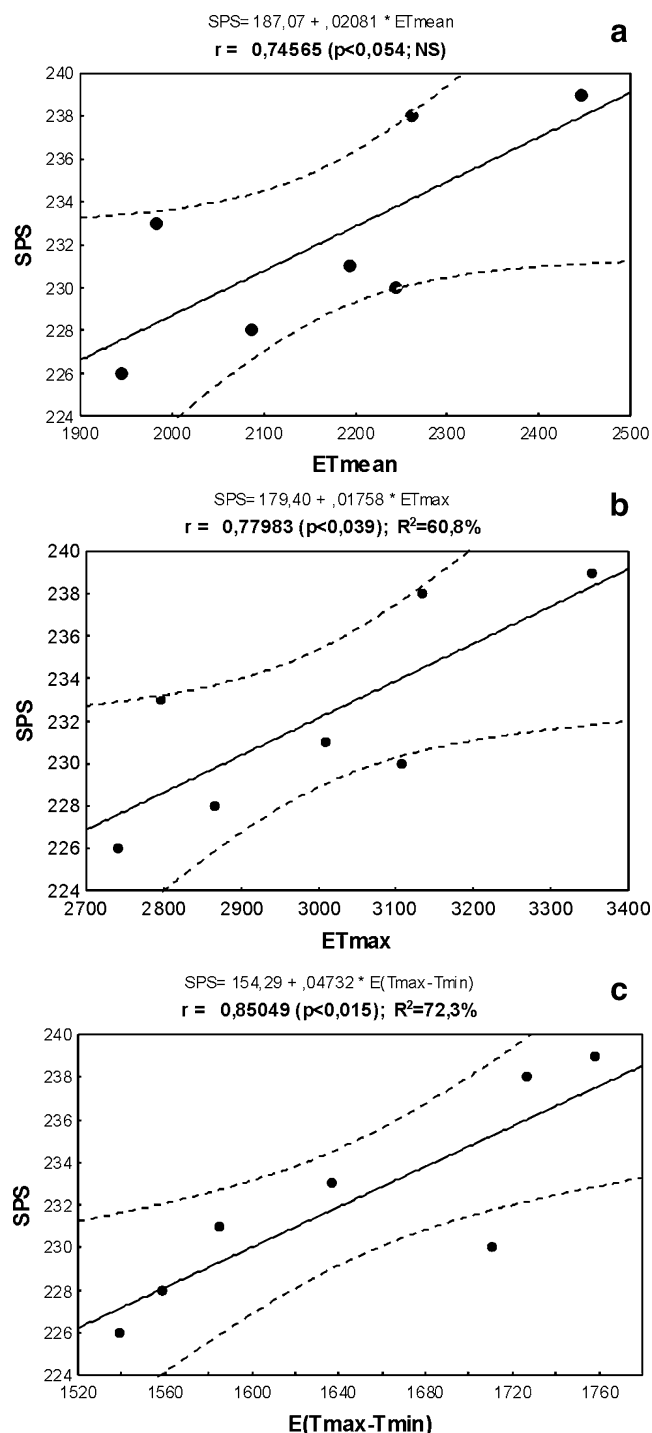


Fig. 5 Linear regression of the start of pollen season (SPS) with **a** $\sum T_{\text{mean}}$, **b** $\sum T_{\text{max}}$, and **c** $\sum (T_{\text{max}} - T_{\text{min}})$ for the years 1997–1999 and 2001–2004

of pollen. Plants produce millions of small pollen grains, which easily disperse over hundreds of kilometers. If the phenomenon of medium- to long-distance transport of *Ambrosia* pollen is noted, the question arises as to why there is no dependence on either the maximum or average wind speed (the Kruskal-Wallis analysis of means); no

statistically significant dependences in relation to the wind speed were confirmed. However, it should be stressed that in general, high concentrations of airborne pollen were noted when there were high winds. The relationship between the pollen counts and only one meteorological parameter is not a fully described phenomenon. Wind speed is a good example. The results of multivariate analysis indicate that maximum and average wind speed produces a marked increase in pollen counts, but considering this parameter separately, no significant relationships were found. However, wind can variably affect the airborne pollen concentrations. This effect depends on the speed, distance from the pollen sources, flowering phenophase and direction of wind. The wind can blow in pollen or bring about its thinning out; it is difficult to estimate its role independent of other environmental elements (Emberlin and Norris-Hill 1996; Palacios et al. 2000; Makra et al. 2004). Taking into account all meteorological parameters, it can be stated that an increase in the number of pollen grains is connected with increased temperature and higher wind speeds, but negatively correlated with humidity and rainfall. Similar results were obtained by Makra et al. (2005) and Piotrowska and Weryszko-Chmielewska (2006). The relationship between wind speed and pollen concentrations can confirm the hypothesis about long-distance transport of pollen grains occurring in the atmosphere of Rzeszów. The relationship which pollen has with temperature, especially its maximum, the temperature range and dew point is in agreement with the ecological requirements of the plant since these climatic elements are factors limiting the expansion of its distribution range. The relationships between the ragweed pollen count with some meteorological elements can usually be explained by the effects of the type of weather taking place over the wider region.

Comtois (1997), and Van de Water and Levetin (2001) showed that pollen from a distant transport could constitute a high percentage of the annual sum of pollen grains and this phenomenon should be taken into consideration when analyzing aerobiological data and in developing forecast models. Palacios et al. (2000) and Damialis et al. (2005) stress an important effect of the wind direction on the pollen count, particularly in the case of numerous pollen sources lying in one direction. As the results of wind direction showed, the sources of pollen were most probably lying to the south, southeast or southwest of the town. Since no ragweed sites were recorded in this region of Poland (Tokarska-Guzik 2001), it is most likely that the pollen was transported from abroad, particularly Ukraine or Slovakia, or even farther regions (Hungary, the Czech Republic, southeastern Russia west of the Urals, Moldova or Romania) where this plant is frequently encountered. The transport of pollen from these directions is possible owing to the characteristic topography of this area. In

Table 7 Values of GDD°C calculated using different methods and “threshold” temperatures [first 7 methods: $\sum(T_{\text{mean}} \text{ above } T_{\text{“threshold”}})$]

	>0°C	>6°C	>7°C	>8°C	>9°C	>10°C	>11°C	$\sum T_{\text{max}}$	$\sum T_{\text{max}} - T_{\text{min}}$
1997	1,983.4	1,957.0	1,931.8	1,924.7	1,882.4	1,834.6	1,803.1	2,796.0	1,637.1
1998	2,194.2	2,179.1	2,166.0	2,150.8	2,124.9	2,048.5	1,986.4	3,009.5	1,585.0
1999	2,261.1	2,256.2	2,235.8	2,205.5	2,120.4	2,063.4	1,936.8	3,134.5	1,726.5
2001	2,085.9	2,061.1	2,034.1	2,011.4	1,986.8	1,939.0	1,864.9	2,865.1	1,558.9
2002	2,446.8	2,430.6	2,430.6	2,430.6	2,379.7	2,342.0	2,288.5	3,352.5	1,758.4
2003	2,243.9	2,217.0	2,204.3	2,181.8	2,146.4	2,078.8	2,067.8	3,107.5	1,710.8
2004	1,945.0	1,922.9	1,896.5	1,845.1	1,784.1	1,736.3	1,662.9	2,740.3	1,539.0
mean	2,165.8	2,146.3	2,128.4	2,107.1	2,060.7	2,006.1	1,944.3	3,000.8	1,645.1
SD	174.8	178.9	187.7	197.0	196.0	195.7	200.4	216.5	87.7
V%	8.1	8.3	8.8	9.4	9.5	9.8	10.3	7.2	5.3

southern Poland, on the latitude line on which Rzeszów lies, a depression (the Beskid Niski range) is found between the Western and Eastern Carpathians while no natural barriers in the form of mountain ranges occur to the east. These characteristic landscape elements can favor the dispersal of ragweed pollen. A dependence between the occurrence of airborne *Ambrosia* pollen and winds blowing from the east, south and southeast was confirmed in Kraków, southern Poland (Stępalska et al. 2002), in Poznań, western Poland (Stach and Silny 1999), and also in the Baltic countries (Saar et al. 2000).

The relationship between synoptic phenomena and its effect on pollen counts has rarely been studied (Fehér and Járαι-Komlódi 1998; Saar et al. 2000). The analysis of synoptic phenomena during the pollen season confirms the thesis about long-distance transport from the south, southeast and southwest. During the year, a large variability in synoptic phenomena is observed. It is significant that a series of days with high pollen counts occurred when high pressure winds from the east and southeast occurred. In this case, wide high pressure areas is formed over eastern Europe which spread far across the west of the European continent and maritime air masses were blocked. In this situation, dry and warm air flows caused heat waves of at least 10 days and lack of clouds (Niedźwiedź 1981). Thirty-five percent of pollen season days from the 7 years under observation coincided with this synoptic weather condition. In 2002, polar continental air masses moved into southeast Poland over several days and on or about the same days (4–5 September), towns with aerobiological stations (Sosnowiec, Lublin) recorded their highest pollen counts of that season (Chłopek and Tokarska-Guzik 2006; Piotrowska and Weryszko-Chmielewska 2006). In Hungary, from 16 August to 13 September the average concentrations of ragweed pollen were significantly higher than the total from the other days of the pollen season combined (Makra et al. 2004). From near the end of August and into the first part of September, the highest ragweed pollen concentrations are usually noted in Croatia (Peternel et al. 2005).

The maximum diurnal ragweed concentrations in air are usually noted during the middle of the day. In the case of long-distance transport, the variation in the diurnal concentrations shows a characteristic pattern. The highest concentrations occur in the evening or at night, but not in the forenoon or about noon, when plants open their anthers (Juhász 1998; Jäger 2000; Makra et al. 2005). The results of diurnal analysis are unequivocal. On days when polar maritime air masses came from the south or southwest, the maxima appeared at night. When there were southeast or northeasterly wind and polar continental air masses, the highest concentrations were found to be in the middle of day. Similar results were obtained by Stach et al. (2007). Maximum pollen concentrations at night and in the early morning suggest that pollen was released during the preceding days. A midday maximum may indicate that the sources of pollen were not so far away as was previously assumed. Lack of natural barriers make pollen dispersal easier and, as Garcia-Mozo et al. (2004) stress, the definition and scale of aerobiological region can be interpreted differently. The next step of this research will be to conduct back-trajectory analysis, which will be helpful in better understanding the investigated phenomena and in solving the conundrum of long-distance transport. It seems that a detailed map of the distribution of ragweed pollen sources is essential to the further research and discussion of the obtained results.

The appearance of non-native *Ambrosia* pollen in air lengthened the entire pollen season of Rzeszów and hence prolonged the season of risk for allergy suffering people, as was the case with other non-native taxa in Catalonia (Belmonte and Vila 2004). However, aerobiological studies do not suggest that the problem of *Ambrosia* becomes serious in Poland. Clinical data show that patients react to these allergens (Obtułowicz et al. 1995), although the recorded concentrations rarely exceed the threshold values (Stępalska et al. 2002; Malkiewicz and Wąsowicz 2003; Puc 2004; Piotrowska and Weryszko-Chmielewska 2006). No statistically significant increase in the number of pollen

grains year-on-year is noted either in Rzeszów or in any other town in Poland. The climate of Poland, including the Rzeszów region, is not favorable for the generative development of this plant (seed production). However, a lot of habitats accessible to this species can be found. Intensive growth of ragweed occurs in June, and seed production in October–November. The variability of weather conditions in spring and cool, wet autumns detrimentally affects the growth of young plants and seed survival (Rich 1994; Juhász 1998). Piotrowska and Weryszko-Chmielewska (2006) suggest that in Lublin (about 200 km northeast of Rzeszów), airborne ragweed pollen may partly originate in vicinities close to the city while another part of recorded pollen results from long-distance transport. Detailed floristic investigations and local population control of the plant both seem to be necessary. The genetically variation with regard to phenology characterize many plant species including ragweed. The environmental stress (the lower temperature) can favor early flowering and rapid seed maturation. The expected warming climate is likely to allow ragweed seed to also ripen in the northern part of Europe (Dahl et al. 1999; Rich 1994).

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