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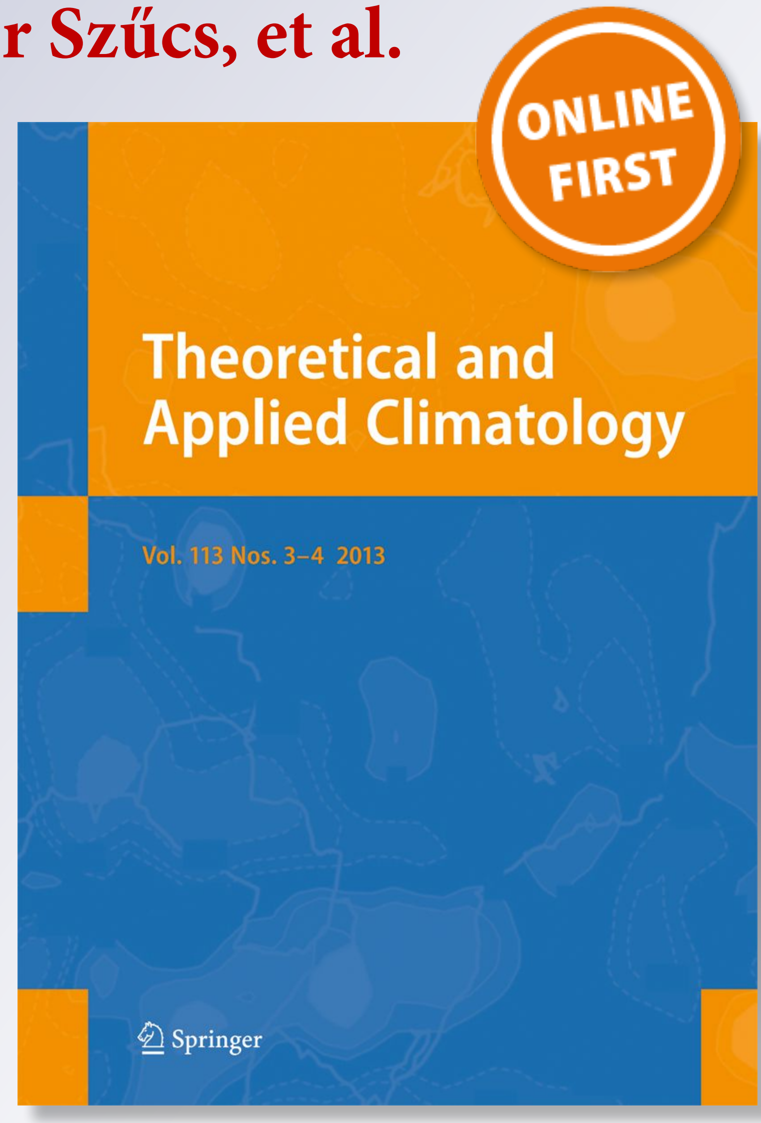

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ORIGINAL PAPER

Biogeographical drivers of ragweed pollen concentrations in Europe

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Abstract The drivers of spatial variation in ragweed pollen concentrations, contributing to severe allergic rhinitis and asthma, are poorly quantified. We analysed the spatiotemporal variability in 16-year (1995–2010) annual total (66 stations) and annual total (2010) (162 stations) ragweed pollen counts and 8 independent variables (start, end and duration of the

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ragweed pollen season, maximum daily and calendar day of the maximum daily ragweed pollen counts, last frost day in spring, first frost day in fall and duration of the frost-free period) for Europe (16 years, 1995–2010) as a function of geographical coordinates. Then annual total pollen counts, annual daily peak pollen counts and date of this peak were regressed against frost-related variables, daily mean temperatures and daily precipitation amounts. To achieve this, we assembled the largest ragweed pollen data set to date for Europe. The dependence of the annual total ragweed pollen counts and the eight independent variables against geographical coordinates clearly distinguishes the three highly infected areas: the Pannonian Plain, Western Lombardy and the Rhône-Alpes region. All the eight variables are sensitive to longitude through its temperature dependence. They are also sensitive to altitude, due to the progressively colder climate

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with increasing altitude. Both annual total pollen counts and the maximum daily pollen counts depend on the start and the duration of the ragweed pollen season. However, no significant changes were detected in either the eight independent variables as a function of increasing latitude. This is probably due to a mixed climate induced by strong geomorphological inhomogeneities in Europe.

1 Introduction

The prevalence of allergic respiratory diseases has increased over the last three decades, especially in industrialised countries (Asher et al. 2006; ARIA 2008). Based on clinical investigations in areas heavily invaded by *Ambrosia artemisiifolia*, among all airborne pollen types, pollen of ragweed (*Ambrosia*) is the most serious and persistent cause of allergy-associated respiratory diseases (Frenz 2001; Kadocsa and Juhász 2002; Harsányi 2009). Among allergy sufferers in Europe, sensitisation to ragweed pollen ranges from 2.5% in Finland to up to 60% in Hungary (Bullock et al. 2010; Burbach et al. 2009). Pollen concentrations as low as 5–20 pollen grains m^{-3} day^{-1} in the air have been reported to be sufficient for sensitised patients to display symptoms (Kadocsa et al. 1991; Oswalt and Marshall 2008). In addition, in other parts of Europe, apart from the Carpathian Basin, where pollen counts are substantially smaller, extremely low pollen loads (1–2 pollen grains m^{-3} day^{-1}) may also trigger mild allergic symptoms (Déchamp et al. 1997). Allergic responses comprise generally rhinitis, hay fever and, less commonly, dermatitis and asthma. The increase in ragweed pollen-related allergic diseases may be partly explained by changes in environmental factors. Urbanisation with the ever increasing levels of vehicle emissions (diesel exhaust can enhance IgE production: Peterson and Saxon 1996; Krämer et al. 2000) and changing lifestyles are linked to the rising prevalence of respiratory allergic conditions (D'Amato et al. 2005; Cecchi et al. 2010). In addition, ragweed pollen can be transported hundreds of kilometres by air masses and can cause allergic reactions at large distances from the location of pollen release (Bullock et al. 2010; Smith et al. 2014).

An analysis of a continental-scale pollen data set (Ziello et al. 2012) revealed an increasing trend in the annual amount of airborne pollen for many taxa including *Ambrosia* in Europe, which is more pronounced in urban areas than in semirural areas or rural areas. Ziska et al. (2011) reported that the recent increase in the duration of the ragweed pollen season in North America was greater further north. Latitudinal effects on increasing season length were associated primarily with a delay in first frost of the autumn season and lengthening of the frost-free period.

The accumulation of anthropogenic gases, especially CO_2, is likely (1) to have an indirect effect by increasing global mean surface temperatures with subsequent effects on the climate and (2) a direct effect due to the CO_2-induced stimulation of photosynthesis and plant growth (Rogers et al. 2006; Ziska 2014). Both effects, associated with urbanisation (Ziska et al. 2007), may also directly influence public health by stimulating the growth and pollen production of allergy-inducing species such as ragweed (Ziska and Beggs 2012). Anthropogenic climate change may be associated with transformations in the phenological and quantitative parametres of pollen dispersion from plant sources, including earlier pollen initiation (Rodríguez-Rajo et al. 2011), continuation into autumn/winter (Recio et al. 2010), and an overall longer season (Ariano et al. 2010), an increase in the total annual pollen load (Ariano et al. 2010; Bullock et al. 2010; Laaidi et al. 2011), as well as an increase in pollen-sensitivity throughout the year (Ariano et al. 2010). Recent models, in accordance with the warming global climate, predict an enlargement and a northward shift of potential range of ragweed habitats in Central and Northern Europe over the coming decades (Chapman et al. 2014, 2016; Storkey et al. 2014; Hamaoui-Laguel et al. 2015). A northernmost shift of ragweed is consistent with its phenological constraints, namely with its cold range margins. However, in Southern Europe, ragweed habitats occur only casually and are not expected to change due to drought stress in Spain and South Italy (Cunze et al. 2013; Chapman et al. 2014; Storkey et al. 2014). Hamaoui-Laguel et al. (2015) presented the first integrated modelling framework that incorporated ragweed phenology, pollen production, release and atmospheric transport to assess future changes in airborne pollen concentration under scenarios of climate and land-use changes and seed dispersal. Their simulations demonstrated that future ragweed airborne pollen loads are likely to increase in large parts of Europe owing to the synergistic effects of climate change on habitat suitability, pollen production, release and transport, and the infilling of existing suitable habitats due to seed dispersal. Furthermore, they estimated that seed dispersal accounts for about a third of the

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future airborne pollen increase, while climate change accounts for the other two thirds. Therefore, understanding the effects of climate on spatiotemporal patterns in ragweed pollen concentrations will be very important for managing the current and future public health challenges of ragweed invasion.

While there are several models for pollen production and atmospheric transport, they make a number of assumptions and therefore require statistical analyses of empirical data to determine the main drivers of spatial and temporal variation in ragweed pollen concentrations. Although it is expected that climate characteristics are largely driven by geographical coordinates, a somewhat different question is whether variations of annual total pollen counts and maximum daily pollen counts statistically depend on between-year variations of annual climate-related variables. The objective of the study is to analyse the change in the annual total ragweed pollen concentration, meteorological conditions (last frost day in spring, first frost day in autumn and duration of the frost-free period), as well as ragweed pollen-related features, namely phenological characteristics (start, end and duration of the ragweed pollen season) and quantity-related characteristics (maximum daily ragweed pollen concentration and calendar day of the maximum daily ragweed pollen concentration) for Europe as a function of geographical coordinates. Furthermore, we seek to study the Europe-scale regression of pollen-related variables on accumulated daily mean temperatures and precipitation amounts.

2 Materials and methods

2.1 A unique ragweed pollen data set for Europe

The most important distribution areas of common ragweed in Europe are the Rhône-Alpes region and the central areas in France (Chauvel et al. 2006; Gladieux et al. 2011; Thibaudon et al. 2014), the north-western part of the Po River valley, Lombardy in Italy (Bonini et al. 2014), the Pannonian Plain in the Carpathian Basin, in the south-eastern part of Central Europe including Hungary and some parts of Slovenia, Croatia, Serbia, Romania, Ukraine, Slovakia and Austria (Makra et al. 2005; Skjøth et al. 2010), along with the southern part of Ukraine (Rodinkova et al. 2012; Rodinkova 2014) and the south-western part of the European Russia (Reznik 2009).

In Europe, ragweed pollen concentration has been measured by 625 aerobiological stations; however, many of these stations no longer record ragweed pollen, while some of those that do have short data sets or have incomplete data. For instance, a number of stations that have been in operation since the 1980s in the western part of Europe ceased working, while all aerobiological stations in the Ukraine and the south-western part of Russia commenced operation only in 2010 or a few years before. This situation was an obstacle describing a satisfactory pollen portrait for Europe.

In order to overcome it, a trade-off among data coverage, number of stations and length of the study period is required. Here, we decided to select a joint period for those stations for which not more than 25% of the years (1995–2010) had data coverage less than 40% of a common study period (July 15–October 15) within the year for all stations (Makra et al. 2015). This period corresponds to *Ambrosia* airborne pollen season in the main distribution centres of ragweed in Europe. As a result, only 66 out of the existing 625 aerobiological stations were selected for a 16-year period from 1995 to 2010 (Fig. 1; Appendix, Table 3). Using similar arguments, 2010 representing the year with the most complete data set was also selected with 162 stations (Fig. 1; Table 4).

Hence, we produced two data sets from the data taken from the European Aeroallergen Network Pollen Database (https://ean.polleninfo.eu/ean), namely, (a) 16-year (1995–2010)

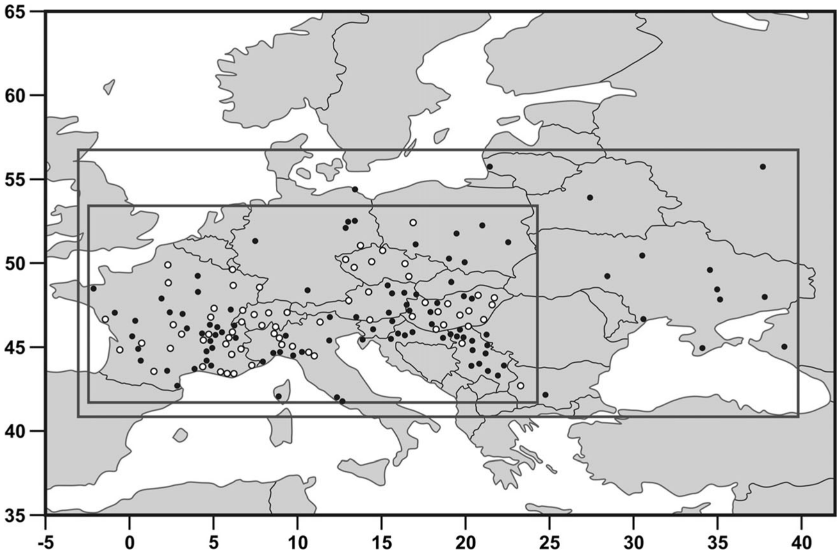


Fig. 1 Geographical positions of the aerobiological stations used in the study. *Empty circle*, 66 stations, comprising 16-year (1995–2010) annual total ragweed pollen counts; *empty circle + filled circle*, 162 stations, involving total annual ragweed pollen counts for the year 2010

annual total ragweed pollen counts for 66 stations and (b) annual total ragweed pollen counts for the year 2010 using data of 162 stations (Fig. 1). By doing this, we created the largest ragweed pollen data sets that have ever been used in ragweed pollen studies for Europe. Initially, the original 625 aerobiological stations measuring ragweed pollen concentrations had different operational terms and, in addition, almost all of them had incomplete data of different lengths year after year. In order to provide the mean of the annual total pollen counts, individual annual pollen concentrations were estimated for every year separately by fitting Gaussian curves to daily pollen concentration data for stations for which not more than 25% of the years (1995–2010) had data coverage less than 40% of a common study period (July 15–October 15) within the year for all stations (Makra et al. 2015). The regression model was validated by using the bootstrap technique; for more details, see Makra et al. (2015).

2.2 Spatiotemporal variation in pollen concentrations

The seasonality of daily ragweed pollen counts can be characterised by the start, end and duration of the pollen season as well as by the day of the maximum pollen count. Furthermore, quantitative parametres (i.e. value of the maximum pollen counts and annual total ragweed pollen counts) are analysed. These properties are affected by meteorological conditions like frost-related parametres, namely the last frost day in spring, the first frost day in autumn and the duration of the frost-free period (Ziska et al. 2011; Dahl et al. 2013). Frost day is defined as a day with minimum daily temperature <0 °C.

At the same time, when calculating phenological characteristics for all the stations in question, the pollen season of ragweed is defined by its start and end dates. For the start (end) of the season, we used the first (last) date on which at least 1 pollen grain m^{-3} of air is recorded and at least five consecutive (preceding) days also show 1 or more pollen grains m^{-3} of air (Galán et al. 2001). Evidently, the pollen season varies from year to year. The reason why we used the method of Galán et al. (2001) rather than the "percentage method" when the accumulated sum reaches 1% or more of the annual total (e.g. Nilsson and Persson 1981; Andersen 1991; Ziska et al. 2011) was the high allergenicity of *Ambrosia* pollen and thus significant sensitivity may be experienced already with very low (1–5 pollen grains m^{-3} day^{-1}) ragweed pollen concentration (Déchamp et al. 1997).

Airborne ragweed pollen grains are collected in Europe using 7-day Hirst-type (Hirst 1952) volumetric pollen traps (Thibaudon and Monnier 2015), manufactured by Burkard (UK) or Lanzoni (Italy) (https://www.polleninfo.org/BG/bg/allergy-infos/aerobiologics/methodik/pollen-traps.html). Pollen sampling and analyses are performed according to Käpylä and Penttinen (1981) and recommendations of IAA (Galán et al. 2014).

2.3 Meteorological data

We used three meteorological parametres, namely the daily mean air temperature (T_{mean}, °C), daily minimum air temperature (T_{min}, °C) (NOAA, National Climatic Data Center, http://www7.ncdc.noaa.gov/CDO/cdoselect.cmd), as well as daily precipitation data extracted from the 0.25 degree gridded E-OBS dataset v10 (http://www.ecad.eu/download/ensembles/ensembles.php) for the 16-year period 1995–2010.

In the first step, we looked for meteorological stations nearest to the above-mentioned 66 ragweed pollen stations. Two data sets were taken into account. One of them included data concerning the ragweed pollen stations with the coordinates of the stations in a WGS84 projection (Kumar 1988). The other data set included data concerning the meteorological stations where only cities of the stations were known but not their coordinates. To determine the coordinates of these meteorological stations, a procedure was developed based on the Google Maps online map system. Then for each ragweed pollen station, the nearest meteorological station was selected. To calculate distances, the "haversine" formula was applied that provided the shortest distance between two points on a great circle, which served as the distance as the crow flies between two points (Sinnott 1984; Gellert et al. 1989).

2.4 Methods

2.4.1 Linear regression

Consider observations (x_i, y_i), $i = 1,\ldots, n$, coming from the pair of a predictor and a predictand variable. Our goal is to estimate the unknown value y of the predictand at a given value x of the predictor. In the case of the linear regression, the relationship is modelled through a disturbance term or error ε_i, an unobserved random variable that adds noise to the linear relationship between the variables. Thus, the model takes the form

$$y_i = a + bx_i + \varepsilon_i, \quad i = l, \ldots, n,$$

where the term ε_i has a normal distribution with mean zero by assumption. The model can be validated by using Pearson's correlation test by rejecting the null hypothesis that the predictand and the predictor are independent. The fit of the model can be measured by the coefficient of determination $r^2 = 1 - \mathrm{SSR/SST}$, where SSR and SST are the residual and the total sum of squares, respectively.

2.4.2 Nonparametric regression

Linear and nonparametric regression was used to analyse relationships between *Ambrosia* pollen characteristics and meteorological parametres. One drawback of the linear

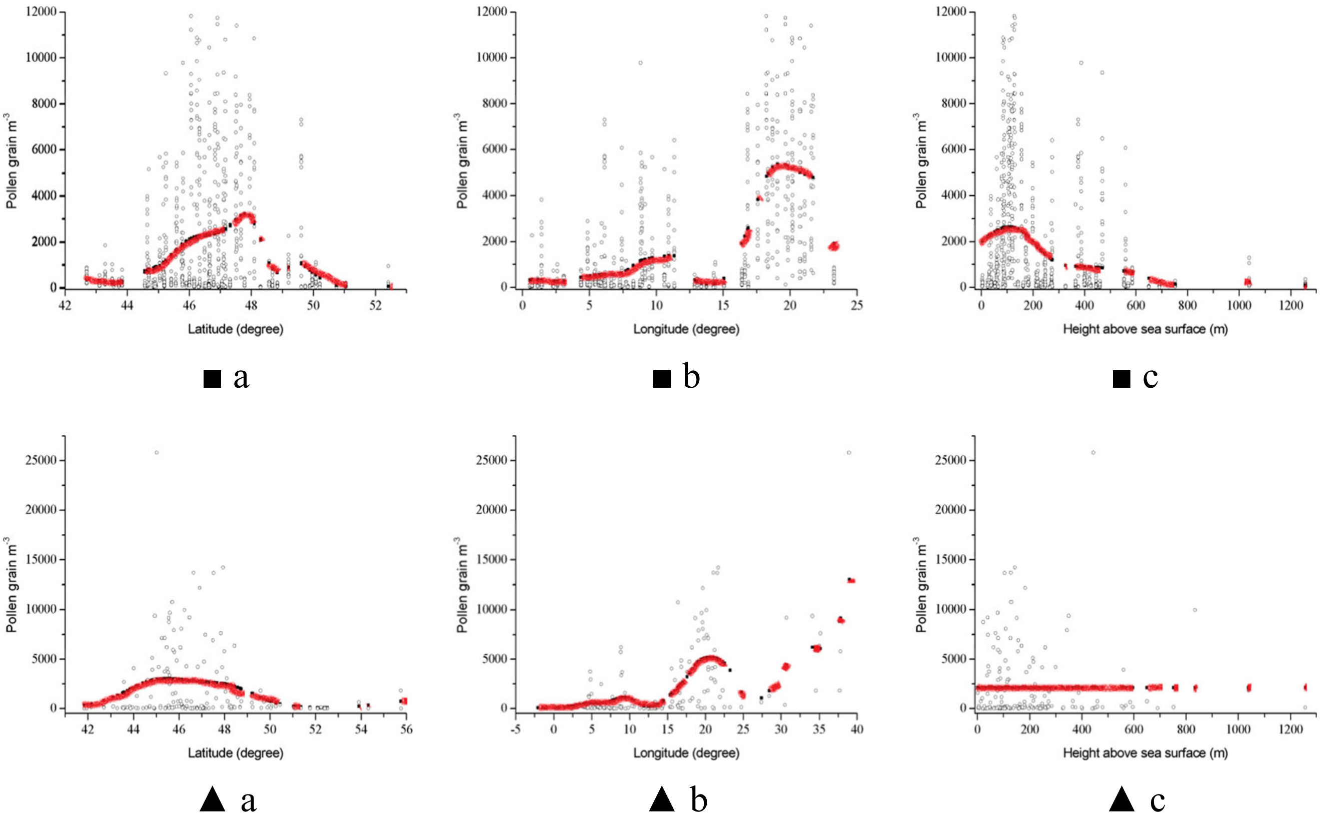


Fig. 2 Ragweed pollen counts indicated by *empty circles* and their regression curves (*filled squares in red*) against **a** latitude, **b** longitude and **c** height above sea level (*filled square*: 66 aerobiological stations, 16-year mean annual total, 1995–2010; *filled triangle*: 162 aerobiological stations, annual total, 2010)

regression is that it does not detect local trends. To overcome this problem, we can apply the model $y_t = g(x_i) + \varepsilon_i$, where $g(x)$ is a suitable regression function. Without assuming any analytical form for $g(x)$, the regression function can be estimated nonparametrically by using a local linear smoothing technique. The estimate of the predictand at a given arbitrary point x is $g(x) = a$ with an a and b that minimise the weighted sum of squares

$$\frac{1}{n}\sum_{i=1}^{n}\left(y_i - a - b(x_i - x)\right)^2 K\left(\frac{x_i - x}{h}\right)$$

The function $K(u) = 1/\sqrt{2\pi}\exp(-u^2/2)$ is the density function of the standard normal distribution. It is should be mentioned here that we cannot test any null hypothesis by applying this method, the nonparametric regression being only a curve fitting, a smoothing technique for the observations. Since we do not restrict ourselves to a given family of parametric curves, we do not get an explicit regression function, but local trends between the variables in subranges of the predictor can be detected more efficiently by plotting the predicted values. The bandwidth h plays a crucial role in the accuracy of the procedure. Large bandwidths that allow large amounts of smoothing produce small variances of the regression curve with possibly large biases of the pointwise estimations, while small bandwidths provide large variances of the curve with small biases. Asymptotically, this method produces the standard linear regression if $h \to \infty$, and we get the conditional mean of the predictand with respect to the predictor if $h \to 0$. For more details, see Lu and Chen (2002).

2.4.3 The binomial test

Let us assume that after n independent repetitions of an experiment, the number of occurrences of a given event A is k. Our goal is to test the null hypotheses that the unknown probability of the event A is equal to a hypothetical value $p \in (0, 1)$. Let X stand for a variable having a binomial distribution with parametres n and p, and consider integers c_α and d_α such that

$$P(X < c_\alpha) \le \frac{\alpha}{2} < P(X \le c_\alpha) \quad \text{and} \quad P(X > d_\alpha) \le \frac{\alpha}{2} < P(X \ge c_\alpha),$$

where α is the significance level. Then we can apply the binomial test, which rejects the null hypothesis if and only if k is lower than c_α or larger than d_α. The basic idea behind the test is that such a low or high number of occurrences contradicts the hypothetical probability p of the event. In this section, we present two regression models and a test of probability that are applied in our study (Siegal and Castellan 1998).

2.5 Application of the methods

2.5.1 Nonparametric regression

Nonparametric regression was used to draw the regression curves of the quantity related and phenological characteristics of ragweed pollen, as well as the frost-related characteristics as a function of the geographical coordinates (Figs. 2, 3, 4 and 5; Sections 3.1, 3.2, 3.3 and 3.4). Plotting interpolated 16-year mean annual ragweed pollen counts and spatiotemporal variation in pollen concentrations against geographical coordinates would require a four-dimensional figure that cannot be easily represented. Therefore, three panels for each characteristic show three possible two-dimensional cases where the interpolated values depend only on one of the three coordinates, namely on latitude, longitude and the height above sea level, respectively. We should again stress here that the two-dimensional representations show the spatiotemporal variation in pollen concentrations as simultaneous functions of all the three geographical coordinates. We applied the nonparametric regression method presented in Section 2. The bandwidth parametre h was equal to 2 when the regressor was the latitudinal or the longitudinal coordinate of the station, and h was 200 when the variables were plotted as a function of the height above sea level. We chose these bandwidths after plotting the results of several test runs, because these parametres provided the best balance between smoothing and unbiasedness. The value of r^2 lays between 0.16 and 0.54 when the regressor was the longitudinal coordinate, and it varied between 0.05 and 0.31 in the other cases.

2.5.2 Linear regression and the binomial test

Linear regression was used to model latitudinal changes in pollen-related characteristics (Fig. 6), while linear regression and the binomial test were used to determine regressions of pollen-related variables on climate-related variables (Table 2).

2.5.3 Temporal regression of pollen-related variables on climate-related variables

In order to clarify whether variations of annual total pollen counts and maximum daily pollen counts statistically depend on between-year variations of annual climate-related

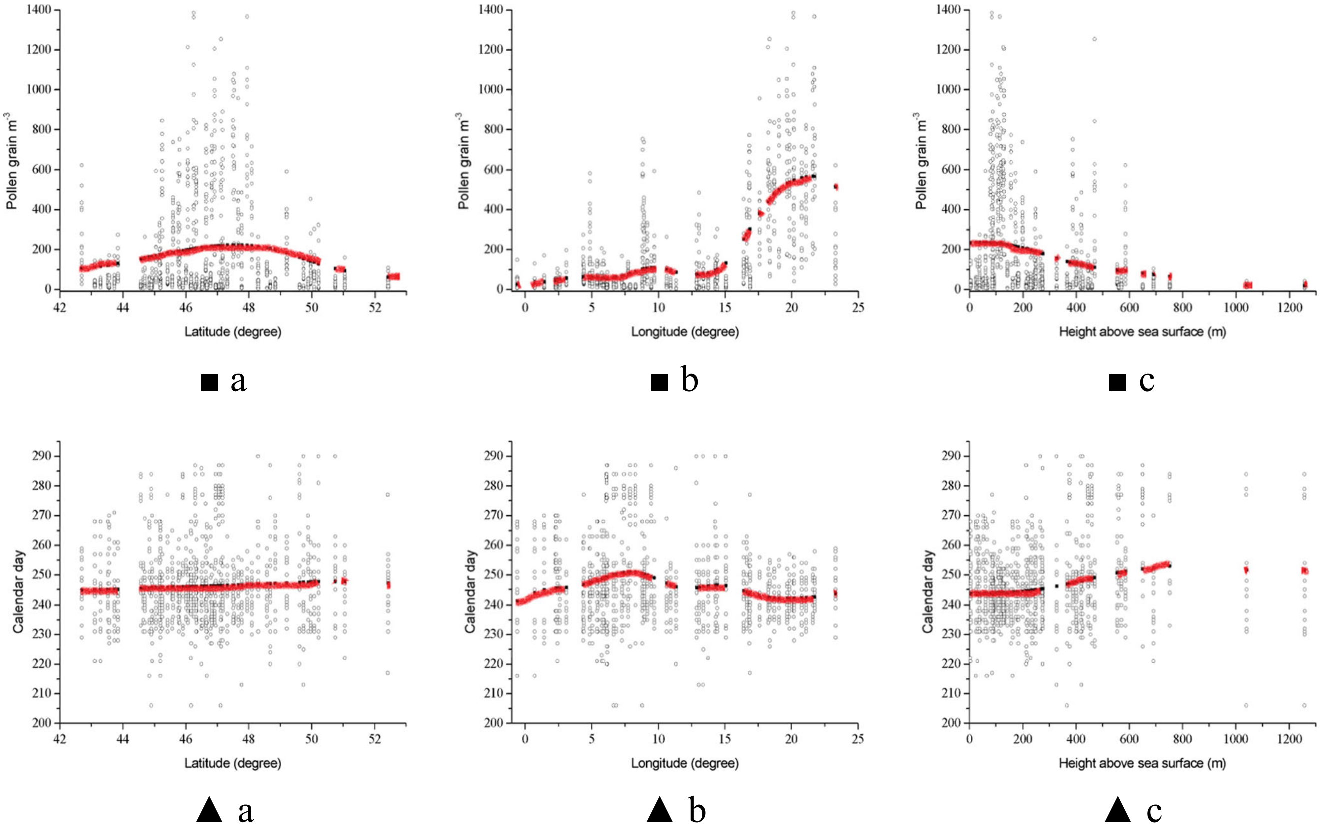
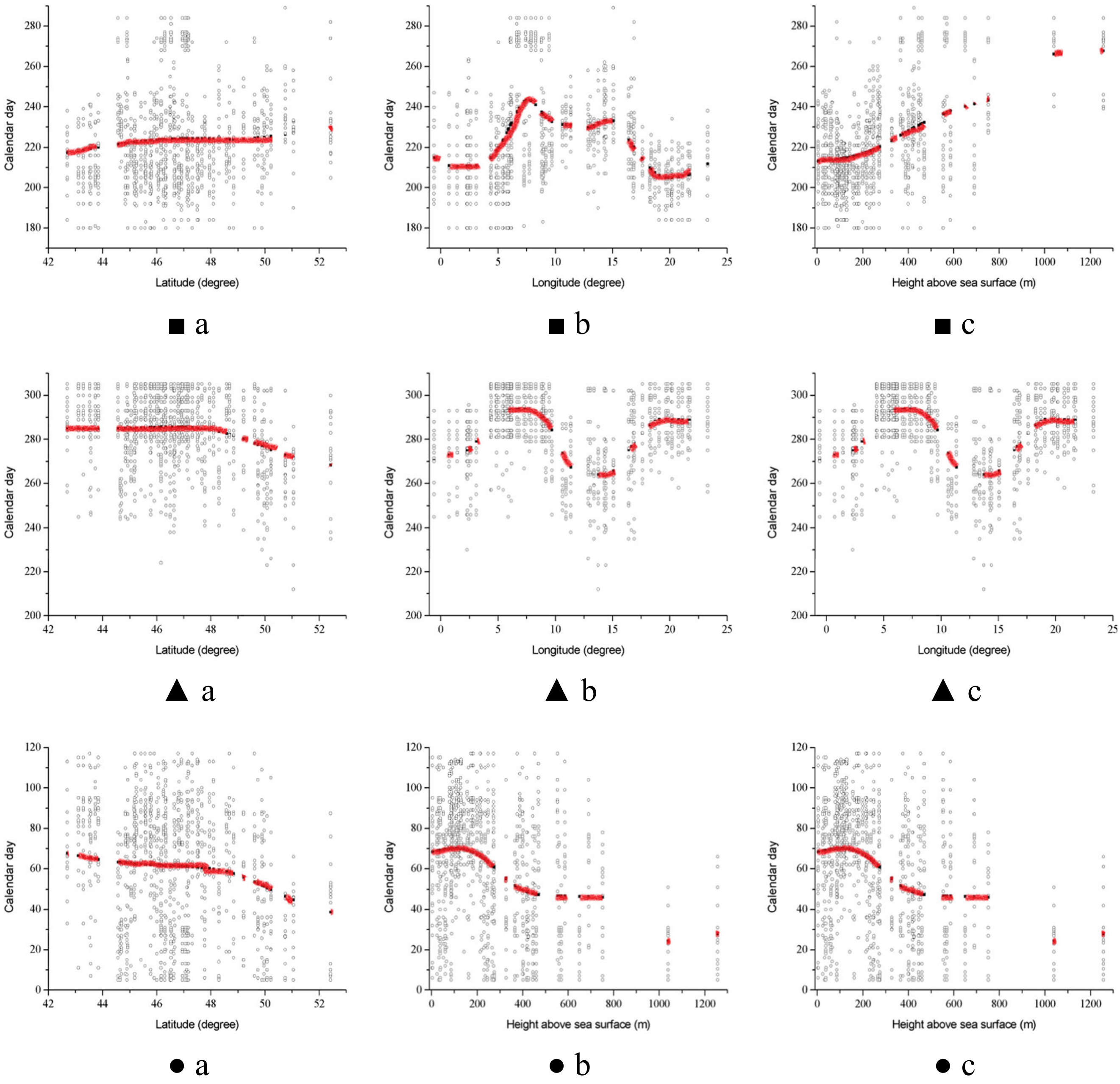


Fig. 3 Maximum daily ragweed pollen concentration (*filled square*) and calendar day of the maximum daily ragweed pollen concentration (*filled triangle*) indicated by *empty circles* and their regression curves (*filled squares in red*) against **a** latitude, **b** longitude and **c** height above sea level, 66 aerobiological stations, 16 years, 1995–2010



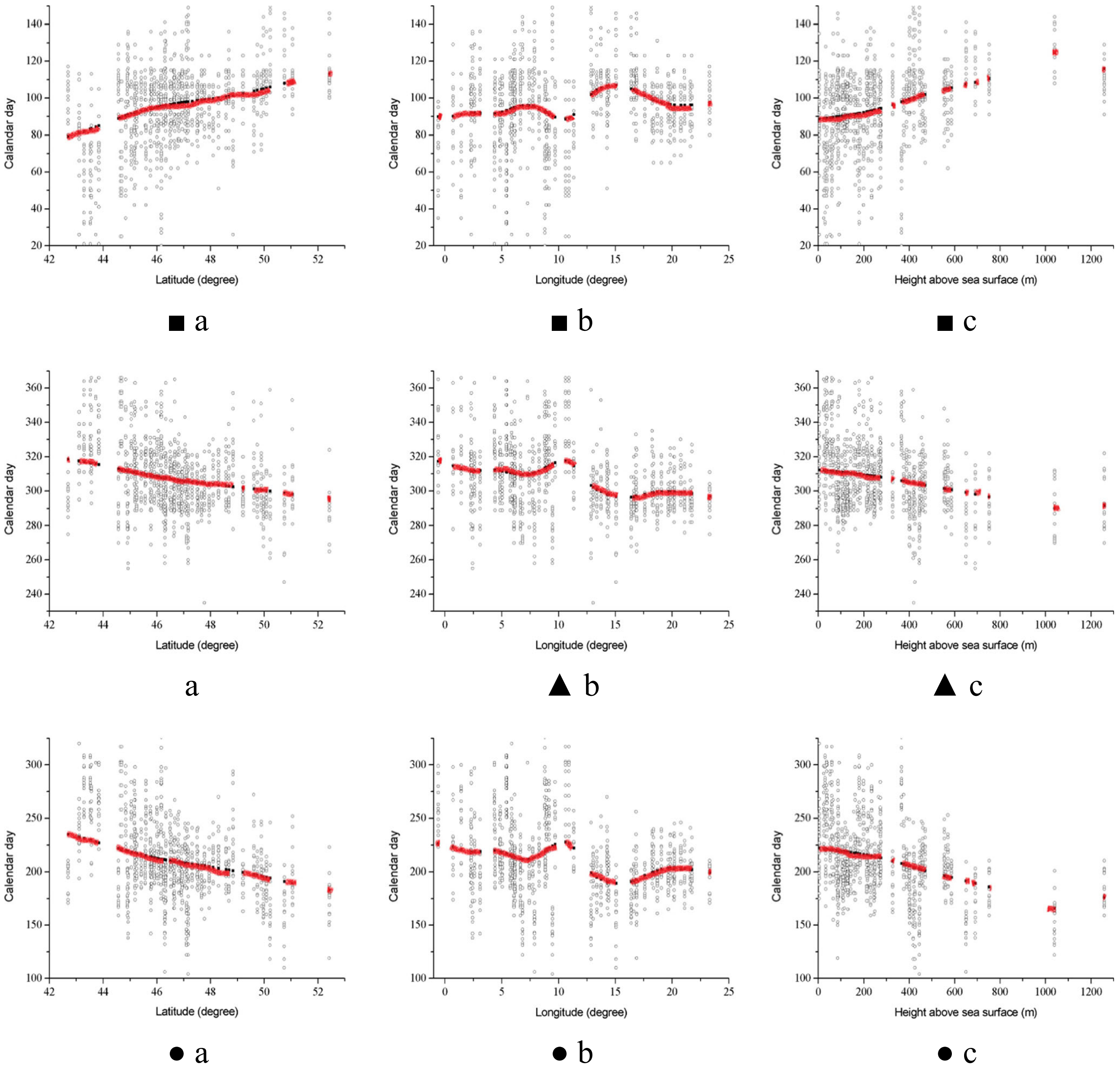
■ a ■ b ■ c

▲ a ▲ b ▲ c

● a ● b ● c

Fig. 4 Start (*filled square*), end (*filled triangle*) and duration (*filled circle*) of the ragweed pollen season indicated by *empty circles* and their regression curves (*filled squares in red*) against **a** latitude, **b** longitude and **c** height above sea level, 66 aerobiological stations, 16 years, 1995–2010

variables, we investigated several pollen-related and climate-related variables including first frost day, last frost day and the duration of the frost-free period of the year. It would seem natural to apply linear regression to test independence, but sample sizes per station are relatively small and the coefficients of the regression may vary from one station to the next, leading us to infer that no significant correlation may be found on the whole data set even if the variables are dependent in the case of every single station. To overcome this difficulty, we performed an experiment for each station separately by regressing annual total pollen counts, annual daily peak pollen counts and date of this peak against climate-related variables using 16 data based on the 16-year data set for the period 1995–2010. These variables include the first frost day, the last frost day, duration of the frost-free period of the year (Fig. 5), as well as daily mean temperatures and daily precipitation amounts cumulated over different periods of the year. Then we tested the independence at each station (Table 2). The significance level was $\alpha = 0.1$, and Table 2 contains the number of rejections for each pair of variables. Of course, the independence of a given variable with itself was rejected at each station, and the high rate of rejections was found



■ a ■ b ■ c

a ▲ b ▲ c

● a ● b ● c

Fig. 5 Last frost day in spring (*filled square*), first frost day in autumn (*filled triangle*) and duration of the frost-free period (*filled circle*) indicated by *empty circles* and their regression curves (*filled squares in red*) against **a** latitude, **b** longitude and **c** height above sea level, 66 aerobiological stations, 16 years, 1995–2010

corresponding to the phenological variables like the start and duration of the pollen season.

The number of rejections is positive in case of each pair of variables, but this fact does not imply that all the pairs are dependent because of the type I error of the tests. The independence of two variables can be rejected on the whole data set only if the independence the rejected at a large number of stations. If two variables are independent, then the independence is rejected with probability $\alpha = 0.1$ at each station. To test the independence on the whole data set, we tested this consequence by using the binomial test with parametre $n = 66$ and hypothetical probability $p = 0.1$. The corresponding critical values are $c_\alpha = 3$ and $d_\alpha = 10$. This means that if the number of rejections for a given pair of variables in Table 2 is lower than 3 or larger than 10, then the rejection probability is significantly different from 0.1, and the dependence of the variables is proved. These values are marked by an asterisk (Table 2).

We found that the variables which the total pollen counts depend on are the peak daily ragweed pollen counts and the start and the duration of the ragweed pollen season. The correlation coefficient of these variables

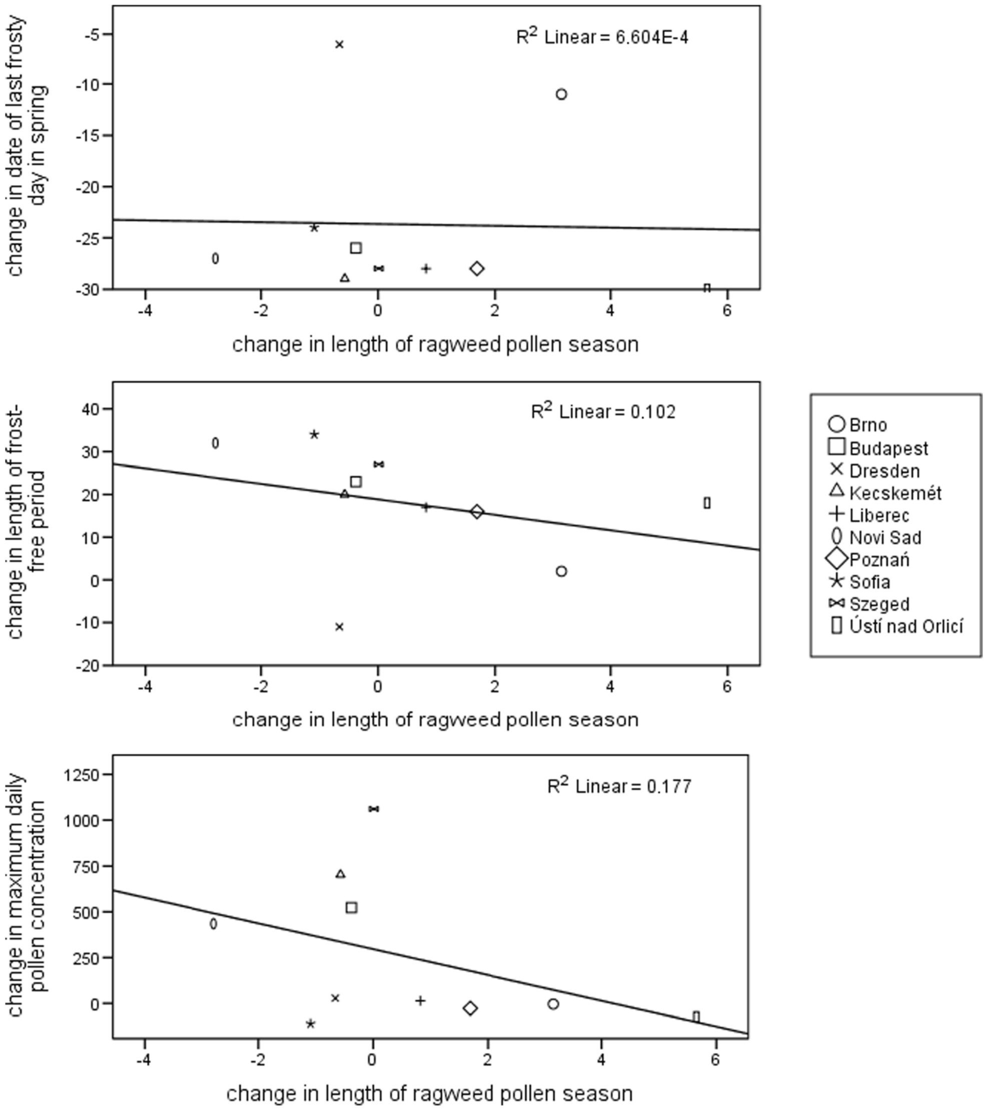


Fig. 6 Change in the length (days) of ragweed pollen season from 1995 to 2010 as a function of change in maximum pollen concentration, change in length of frost-free period and change in date of last frosty day in spring for 10 central European locations as a function of latitude. Data were calculated as a function of simple regression for each location. (Pollen data from Novi Sad are available for the 11-year period 2000–2010)

Table 1 Change in length (day of year, days) of the ragweed pollen season as a function of latitude for sites along a south-north latitudinal gradient

Location	Latitude	Start			End			Duration[a]
	(°)	*a*	Error	*p* value	*a*	Error	*p* value	
Sofia	42.70	0.64	0.75	0.41	−0.45	0.77	0.57	−1.09
Novi Sad[b]	45.25	0.78	0.52	0.17	−2.00	0.52	<0.01*	−2.78
Szeged	46.25	0.25	0.51	0.63	0.26	0.59	0.66	0.01
Kecskemét	46.92	0.85	0.44	0.07	0.28	0.53	0.60	−0.57
Budapest	47.50	0.45	0.67	0.52	0.07	0.56	0.91	−0.38
Brno	49.21	−1.70	0.60	<0.01*	1.46	1.00	0.17	3.16
Ústí nad Orlicí	49.97	−2.39	0.43	<0.01*	3.26	0.78	<0.01*	5.65
Liberec	50.75	0.73	2.04	0.73	1.55	2.45	0.56	0.82
Dresden	51.05	2.30	1.52	0.17	1.64	1.42	0.29	−0.66
Poznań	52.42	2.68	1.68	0.15	4.37	1.76	0.04*	1.69

Linear regression analysis was used to model the start and end day of the pollen season as a function of time at each location over the 16-year period (1995–2010), for which pollen data were available. Estimated coefficients (*a*) of the predictor, standard deviations (error) of the estimates and the corresponding *p* values are included in the table

*Significant values

[a] Corresponds to the independent variable (change in length of ragweed pollen season) in Fig. 6

[b] Pollen data are available for the 11-year period 2000–2010

varies from one station to the next, the means of the correlations being 0.34, −0.21 and 0.19, respectively. The peak daily pollen counts depend on the start and the duration of the pollen season, as well (Table 2). The mean correlation coefficients corresponding to these variables are −0.12 and 0.17. Here, no significant relationship was found between the daily mean temperature and precipitation, and none of the climate-related variables has an effect on the calendar day of the maximum pollen counts.

3 Results

3.1 Quantity-related pollen characteristics

3.1.1 Annual total ragweed pollen counts, 66 stations (16 years, 1995–2010) and 162 stations (2010)

The annual total ragweed pollen counts as a function of the geographical coordinates display the highest values between latitudes 45 and 48° N (Fig. 2, filled square, a; Fig. 2, filled triangle, a), between longitudes 18 and 23° E (with a much smaller secondary maximum between longitudes 10 and 12° E) (Fig. 2, filled square, b; Fig. 2, filled triangle, b) and between heights 0 and 200 m (Fig. 2, filled square, c).

3.1.2 Quantity-related pollen season characteristics, 66 stations, 1995–2010

Latitude-related characteristics: The maximum daily ragweed pollen concentrations occur between latitudes 46 and 49°, while the calendar day of the maximum daily ragweed pollen concentration does not actually change with increasing latitude (Fig. 3, filled triangle, a).

Longitude-related characteristics: The maximum daily pollen concentrations as a function of longitude display a barely visible, a slight and a strong peak at around 4–5° E, 9–11° E and 18–22° E longitude bands (Fig. 3, filled square, b). At the same time, the date of the maximum daily pollen concentration displays barely detectable peaks at longitudes 6–8° E and 13–15° E (Fig. 3, filled triangle, b).

Height-related characteristics: The maximum daily pollen concentrations slightly decrease over 100 m height above sea level. While this value may exceed 200 pollen grains m^{-3} of air at sea level, above a height of 1000 m practically no pollen is detected (Fig. 3, filled square, c). The calendar day of the maximum daily ragweed pollen concentration slightly shifts from day 245 at sea level to day 255 at the height of 800 m above sea level (Fig. 3, filled triangle, c).

3.2 Seasonality of daily ragweed pollen counts, 66 stations, 1995–2010

Latitude-related characteristics: A scarcely noticeable delay of the start date (Fig. 4, filled square, a) and a similar extension of the end date of the pollen season (Fig. 4, filled triangle, a) can be observed with different latitudes. The duration of the ragweed pollen season slightly decreases between latitudes 42 and 49° N; however, moving further northwards a more definite decrease can be seen (Fig. 4, filled circle, a).

Longitude-related characteristics: The earliest pollen season start appears in Western Europe, as well as in the south-eastern part of Central Europe including the

Table 2 Dependence of pollen-related variables on climate-related variables

Variable	Annual total pollen counts	Annual daily peak pollen counts	Date of annual peak pollen counts
Annual total pollen counts	68*	35*	6
Annual daily peak pollen counts	35*	68*	7
Date of annual peak pollen counts	12*	7	68*
Start of the ragweed pollen season	17*	11*	10
End of the ragweed pollen season	6	8	7
Duration of the ragweed pollen season	13*	17*	9
Last frosty day in spring	7	8	6
First frosty day in fall	7	5	7
Duration of the frost-free period	6	7	8
Daily mean temperature	6	9	7
Daily precipitation amount	8	10	8

*The given pairs of variables are not independent (probability level: $\alpha = 0.1$).

Pannonian Plain (Fig. 4, filled square, b). The pollen season lasts the longest at longitudes 7–8° E and 18–23° E, respectively. At the same time, local minima as the earliest end of the pollen release can be observed at longitudes around 0 and 14–15° E, respectively (Fig. 4, filled triangle, b). The longest duration of the pollen season can be seen at longitudes 3–5° E and 18–23° E, respectively (Fig. 4, filled circle, b).

Height-related characteristics: The start date of the pollen season gradually increases with the height above sea level up to 700 m above sea level (Fig. 4, filled square, c). The end of the pollen season displays a slight increase exceeding the height of 400 m. The regression curve for the height dependence of the length of the pollen season displays a marked decrease between 200 and 400 m height above sea level, while above this level, a constant length of the pollen season is seen up to 800 m in height (Fig. 4, filled circle, c).

3.3 Frost-related variables, 66 stations, 1995–2010

Latitude-related characteristics: Last frost day in spring gradually delays with increasing latitude (Fig. 5, filled square, a), while a clear, but slow linear decrease can be observed both for the first frost day in autumn (Fig. 5, filled triangle, a) and the duration of the frost-free period as a function of increasing latitude (Fig. 5, filled circle, a).

Longitude-related characteristics: Last frost day in spring indicates a clear cycle with a secondary and primary maximum between 6–8° E and 13–17° E longitudes, respectively (Fig. 5, filled square, b). The first frost day in autumn (Fig. 5, filled triangle, b) and the duration of the frost-free period (Fig. 5, filled circle, b) show again very similar cycles with the same two maxima at around longitude 0° and between longitudes 10 and 12° E, respectively.

Height-related characteristics: A clear increasing tendency of the last frost day can be seen (Fig. 5, filled square, c). The first frost day gradually occurs earlier with increasing height, displaying an almost linear relationship (Fig. 5, filled triangle, c), while the duration of the frost-free period indicates a slightly stronger decrease (Fig. 5, filled circle, c).

3.4 Changes and trends

3.4.1 The change of the pollen-related characteristics as a function of the change in the length of the ragweed pollen season

Longer pollen seasons associated with recent poleward and altitudinal warming (IPCC 2013) could induce elevational or latitudinal changes in pollen-related parametres (Ziska et al. 2011). We analysed the effect of the rise in global surface temperature on ragweed pollen counts and ragweed pollen-related characteristics at certain locations across Central Europe, as a function of latitude. Altogether, 10 locations were selected over an approximately south-north range from latitude of 42.70° N (Sofia, Bulgaria) to latitude of 52.42° N (Poznań, Poland) (Table 1; Fig. 6), in order to clarify whether the pollen season is lengthening and the annual pollen concentration is increasing going towards north due to the current climate warming. Aerobiological stations along this approximately south-north section from Bulgaria to Poland extended ≈1100 km.

Simple linear regressions were used to model the changes of the start and end dates of the ragweed pollen season as functions of time over the study period (16 years, 1995–2010) for each location. Using this method, long-term linear trends can be obtained by separating the random meteorological effects of the individual years. The estimated coefficients (a) of the predictor and the standard deviations (errors) of the estimates are included in Table 1. These coefficients can be interpreted as the average yearly increase of the start and end dates of the season corresponding to long-term effects, and the average yearly change in the duration of the pollen season can be obtained by calculating the difference of the coefficients. We also tested the null hypotheses whether the "true" values of the coefficients are equal to 0, that is, the theoretical start and end date of the pollen season did not change ($\alpha = 0.05$). p values of the t test can be found in Table 1, and significant values are marked by an asterisk. We found that the start date of the pollen season significantly changed in Brno and Ústí nad Orlicí, and the end date significantly changed in Novi Sad, Ústí nad Orlicí and Poznań.

Since among the examined ragweed pollen-related characteristics the date of the last frost day in spring, the length of the frost-free period and maximum daily pollen concentration indicate a significant association with latitude at the 5% probability level, the change of the above variables as a function of the change in the length of the ragweed pollen season was analysed in more detail. It was found that the change in the maximum daily pollen concentration and the change in the frost-free period were inversely associated, while the change in the date of the last frost day in spring showed no relationship with the change in the length of the ragweed pollen season. However, these associations were not significant at any reasonable probability level (Fig. 6).

3.4.2 Temporal regression of pollen-related variables on climate-related variables

We found that the variables which the total pollen counts depend on are the maximum daily ragweed pollen counts and the start and the duration of the ragweed pollen season. The correlation coefficient of these variables varies from one station to the next, the means of the correlations being 0.34, −0.21 and 0.19, respectively. The maximum daily pollen counts depend on the start and the duration of the pollen season, as well. The mean correlation coefficients corresponding to these variables are −0.12 and 0.17. Pollen-related variables showed no significant relationship with the daily mean temperature and precipitation, and none of the climate-related variables has an effect on the calendar day of the maximum pollen counts (Table 2).

4 Discussion

4.1 Phenology, quantity-related and frost-related characteristics as a function of the geographical coordinates

The regression curves of the ragweed pollen counts based on the 16-year annual total ragweed pollen counts (Fig. 2, filled square), and the total annual ragweed pollen counts for the year 2010 (Fig. 2, filled triangle) highlight the importance of the Pannonian Plain in the Carpathian Basin in the south-eastern part of Central Europe, along with Western Lombardy in Italy, while the Rhône-Alpes region in France is less obvious in the latitude–pollen counts and longitude–pollen counts representations. At the same time, height dependence can only be clearly manifested for the 16-year annual total ragweed pollen counts (Fig. 2, filled square, c). Values of frost-related variables are associated with changing climate as a function of the geographical coordinates, i.e. longer frost-free periods are due to the oceanic and the Mediterranean climate, while shorter frost-free periods are related to progressively colder climate with increasing latitude and altitude.

Change in phenology and quantity-related characteristics of ragweed pollen as a function of the geographical coordinates are not well known in the literature; in addition, this information is very rare for other taxa. As regards the height-related dependence of annual total ragweed pollen counts, for ragweed habitats 0–745 m altitudes are typical (Horváth et al. 1995; Deen et al. 1998; Mihály and Botta-Dukát 2004; Thibaudon et al. 2014; Karrer et al. 2015). At higher altitudes, the optimal heat requirement and daily maximum temperatures (26–32 °C) are usually not available for *Ambrosia*. What is more, above 1000 m altitude the daily maximum temperatures may remain below this range; nevertheless, late spring or early autumn frosts are much more common. Another aspect should also be considered here. Above the height of 1000 m, there are not even arable lands, or fallow land, or sandy soils, which favour the growth of ragweed. With higher elevations, pollen counts gradually decrease, and above the height of 1000 m above sea level, there is practically no ragweed pollen in the air (Silvers et al. 1992; Béres et al. 2005; Charalampopoulos et al. 2013). However, though ragweed does not grow or does not bloom above this height, ragweed pollen may occur there through long-range pollen transport (Makra et al. 2010). Note that with all northern areas of Croatia and Serbia, as well as 68% of Hungary in the Pannonian Plain, the key source areas of ragweed pollen for the data set are so-called perfect plains, below the height of 200 m (Bora and Nemerkényi 1994).

Ziska et al. (2011) found that duration of the ragweed (*Ambrosia*) pollen season has been increasing in recent decades in North America, as a function of latitude. An increasing season length was associated primarily with a delay in first frost of the autumn season and lengthening of the frost-free period. This is consistent with enhanced recent warming as a function of latitude. Furthermore, Leiblein-Wild and Tackenberg (2014) found that late growth and flowering phenology were highly correlated with latitude, i.e. individuals from northern populations grew smaller and flowered and dispersed their pollen and seed up to 5 weeks earlier than individuals from southern populations. In parallel to this, dates with maximum airborne pollen concentrations (peak dates) occurred earlier in the north than in southern latitudes (Frenz et al. 1995).

Over the mountainous Zugspitze area, phenological onset dates showed 6–7-day delay/100 m of elevation increase for grass species that could be interpreted as a temperature response rate varying between −9 and −10 days/1 °C of temperature decrease. Moreover, differences in exposure at the same altitude revealed large differences in the flowering dates of birch (Jochner et al. 2012). According to Charalampopoulos et al. (2013), the duration of the pollen season in Mt. Olympos (Greece) National Park decreases with elevation by on average 3 days for every 100 m of elevation increase, or by 5 days for every Celsius-degree of temperature decrease. In addition, they (Charalampopoulos et al. 2013) found that the pollen concentration in the air decreases with elevation for the lowland taxa.

Landscape variables, describing aspects of habitat availability (topography, soil, land use) may also significantly influence the current distribution of *A. artemisiifolia* (Essl et al. 2009). Thus, availability is found to vary throughout Europe and may to a large degree depend on the management of the landscape (Skjøth et al. 2010; Thibaudon et al. 2014). Chun et al. (2011) detected that abiotic conditions might exert selection pressure on *A. artemisiifolia* populations to differentiate adaptively, such that populations at higher altitude or latitude evolved greater reproductive allocation. And, as for invasive species, including *Ambrosia*, the level of invasion decreases with altitude (Pyšek et al. 2012; Nikolić et al. 2013), which is clearly seen in the study over France where 99% of all recorded ragweed habitats grew below 439 m (Thibaudon et al. 2014).

4.2 Comparison of the regression of the pollen-related variables on climate-related variables between Europe and the USA

Although our regression analysis between total annual pollen counts and the climate-related variables and the approach of Ziska et al. (2011) are different, it seems that a contradiction exists here. In order to better understand this contradiction, one should compare the geomorphology of the study areas (central North America and Europe). Central North America, with its relatively uniform surface, is a largely homogeneous area from south to north and from mid-west to east. This feature with a fairly high distance from the oceans together with the climate and vegetation makes possible an undisturbed climate on spatiotemporal variation in pollen concentrations and its phenology (Ziska et al. 2011). In contrast, Europe displays a quite different picture. Namely, this continent (1) has strongly rugged coastlines from south, west and north, and furthermore, (2) the surface of Europe is a mixture of high mountains with ridge lines of different orientation, medium altitude areas and perfect plains (below 200 m), as well as (3) frequently changing distance from sea with different climates. What is more, the Alps and the Carpathians, the highest and longest mountain ranges in Europe, are located at medium latitudes in the continent; hence, they significantly modify not just spatial ragweed pollen release, but its altitudinal distribution and even long-range ragweed pollen transport (Makra et al. 2010; Zink et al. 2012), as well. This geomorphological disturbance may be the main reason for the lack of any significant relationship among the above-mentioned variables for Europe.

5 Conclusions

In the study, regression curves of ragweed pollen-related features were analysed, namely phenological characteristics (start, end and duration of the ragweed pollen season), meteorological conditions (last frost day in spring, first frost day in autumn and duration of the frost-free period) and quantity-related characteristics (maximum daily ragweed pollen concentration and calendar day of the maximum daily ragweed pollen concentration) as a function of latitude, longitude and height above sea level. For the analysis, we created the largest ragweed pollen data sets to date that have ever been used in ragweed pollen studies for Europe.

The dependence of both categories of ragweed pollen counts on the geographical coordinates highlights the importance of the Pannonian Plain in the Carpathian Basin in the south-eastern part of Central Europe (in both a latitude–pollen counts and longitude–pollen counts representation) and the two additional highly infested areas, namely Western Lombardy in Italy and the Rhône-Alpes region in France (in a longitude–pollen counts representation). However, height dependence can only be clearly manifested for the 16-year annual total ragweed pollen counts. All the eight pollen-related characteristics are most sensitive to longitude that clearly distinguishes the three highly infested areas. They are also sensitive to height, due to the progressively colder climate with increasing altitude.

We found that the total pollen counts depend on the maximum daily ragweed pollen counts and the start and duration of the ragweed pollen season. At the same time, the maximum daily ragweed pollen counts depend on the start and duration of the pollen season.

Choosing an approximately south-north section from Bulgaria to Poland (covering a distance of around 1100 km), it was found that the change in the maximum daily pollen concentration and the change in the frost-free period were proportional, while the change in the date of the last frost day in spring was inversely associated with the change in length of the ragweed pollen season. However, these associations were not significant at any reasonable probability level.

At the same time, the regression of annual total pollen counts against climate-related variables (first frost day, last frost day, duration of frost-free period of the year, cumulated daily mean temperatures and daily precipitation amounts) produced no significant relationships. This is most likely due to strong geomorphological inhomogeneities (fragmented coastlines, high mountains and lowlands) in Europe.

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Appendix

Table 3 Abbreviations of the names and the geographical coordinates of the 66 stations used in the study, comprising 16-year (1995–2010) annual total ragweed pollen counts (stations are in longitudinal order)

Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)	Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)
1	FRBORD	−0.57[b]	44.84	25	34	CHLUGA	8.95	46.01	273
2	FRPERI	0.73	45.19	162	35	ITPAVI	9.17	45.17	88
3	FRTOUS	1.45	43.56	235	36	CHBUCH	9.47	47.17	445
4	FRAMIE	2.28	49.89	33	37	ITPIA1	9.70	45.05	61
5	FRPARI	2.31	48.84	53	38	ITREGE	10.62	44.70	61
6	FRAURI	2.43	44.93	691	39	ITMODE	10.93	44.65	38
7	FRMONT	2.61	46.34	219	40	ITBOLZ	11.34	46.50	275
8	FRCLER	3.09	45.78	400	41	CZKARL	12.87	50.22	418
9	FRNIME	4.36	43.84	39	42	ATSALZ	13.05	47.78	420
10	FRSTET	4.39	45.42	554	43	CZPLZE	13.37	49.74	327
11	FRCHAL	4.84	46.79	183	44	DEDRES	13.75	51.05	230
12	FRLYON	4.86	45.76	173	45	ATLINZ	14.28	48.30	266
13	FRDIJO	5.03	47.32	248	46	ATKLAG	14.31	46.63	446
14	FRMARS	5.40	43.29	31	47	CZPRAH	14.42	50.08	245
15	FRAIXP	5.45	43.52	180	48	CZLIBE	15.07	50.75	425
16	FRGREN	5.74	45.19	216	49	CZUORL	16.40	49.97	402
17	FRTOUN	5.87	43.11	5	50	CZBRNO	16.63	49.21	248
18	FRCHAM	5.92	45.57	272	51	HUZALA	16.83	46.83	156
19	FRGAP1	6.08	44.57	752	52	PLPOZN	16.88	52.42	86
20	FRANNE	6.13	45.91	454	53	HUGYOE	17.60	47.67	108
21	LULUXE	6.13	49.62	376	54	HUPECS	18.25	46.07	128
22	FRNANC	6.17	48.69	213	55	HUSZAB	18.37	47.12	470
23	FRBRIA	6.64	44.90	1257	56	HUSZEK	18.70	46.33	110
24	CHLAUS	6.65	46.53	570	57	HUPEST	19.07	47.50	105
25	CHLACH	6.83	47.11	1040	58	HUKECS	19.67	46.92	130
26	FRNICE	7.28	43.73	93	59	RSNOVI[c]	19.85	45.25	80
27	CHBERN	7.42	46.95	560	60	HUSZEG	20.17	46.25	85
28	FRSTRA	7.74	48.58	142	61	HUSZOL	20.20	47.17	89
29	CHVISP	7.88	46.30	650	62	HUMISK	20.75	48.10	119
30	CHLUZE	8.28	47.05	460	63	HUBEKE	21.08	46.65	90
31	CHLOCA	8.80	46.17	366	64	HUDEBR	21.58	47.53	120
32	ITVARE	8.83	45.80	388	65	HUNYIR	21.72	47.95	115
33	ITLEGN	8.92	45.60	199	66	BGSOFI	23.28	42.70	586

Selection criteria of the stations: not more than 25% of the years (1995–2010) had data coverage less than 40% of a common study period (July 15–October 15) within the year for all stations (Makra et al. 2015)

[a] First two letters: country code; remaining letters: city code according to the European Aeroallergen Network Pollen Database https://ean.polleninfo.eu/ean

[b] West longitude

[c] Pollen data are available for the 11-year period 2000–2010 (see Table 1)

Table 4 Abbreviations of the names and the geographical coordinates of the 162 stations used in the study involving total annual ragweed pollen counts for the year 2010 (stations are in longitudinal order)

Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)	Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)
1	ATALLE	15.37	48.69	596	82	FRVALE	4.89	44.93	120
2	ATGRAZ	15.43	47.06	365	83	FRVICH	3.42	46.12	162
3	ATKLAG	14.31	46.63	446	84	HRBJEL	16.84	45.9	108
4	ATLINZ	14.28	48.3	266	85	HRIVAN	16.39	45.71	130
5	ATPULL	16.5	47.5	251	86	HRKARL	15.56	45.49	119
6	ATSPIT	13.5	46.8	560	87	HROSIJ	18.66	45.56	150
7	ATSTPO	15.63	48.22	265	88	HRZAGR	15.98	45.82	115
8	ATWIEN	16.36	48.25	203	89	HUBEKE	21.08	46.65	128
9	BGPLOV	24.76	42.16	231	90	HUDEBR	21.58	47.53	105
10	BGSOFI	23.28	42.7	163	91	HUEGER	20.38	47.9	248
11	BYMINS	27.41	53.91	586	92	HUGYOE	17.6	47.67	85
12	CHBERN	7.42	46.95	126	93	HUKECS	19.67	46.1	110
13	CHBUCH	9.47	47.17	108	94	HUMISK	20.75	48.1	89
14	CHLACH	6.83	47.11	87	95	HUMOSD	18	46.35	214
15	CHLAUS	6.65	46.53	157	96	HUNYIR	21.72	47.95	143
16	CHLOCA	8.8	46.17	248	97	HUPECS	18.25	46.07	260
17	CHLUGA	8.95	44.42	327	98	HUPEST	19.07	47.5	156
18	CHLUZE	8.28	47.05	245	99	HUSALG	19.9	48.05	275
19	CHVISP	7.88	46.3	402	100	HUSZEG	20.17	46.25	835
20	CZBRNO	16.63	49.21	50	101	HUSZEK	18.7	46.33	42
21	CZPLZE	13.37	49.74	180	102	HUSZOL	20.2	47.17	41
22	CZPRAH	14.42	50.08	6	103	HUSZOM	16.63	47.24	1
23	CZUORL	16.4	49.97	270	104	HUTATA	18.32	47.64	19
24	DEBER1	13.38	52.53	33	105	HUVESZ	17.92	47.1	214
25	DEBERL	13.42	52.53	82	106	HUZALA	16.83	46.83	199
26	DEDRES	13.75	51.05	454	107	ITBOLZ	11.34	46.5	138
27	DEGARZ	13.35	54.32	440	108	ITBRUN	11.93	46.8	21
28	DEHAGE	7.45	51.37	691	109	ITGEN4	8.88	45.47	62
29	DEPOTS	13.07	52.4	25	110	ITGENO	8.95	46.01	153
30	DETREU	12.87	52.1	51	111	ITIMPE	8.01	43.87	64
31	DEZUSM	10.6	48.4	258	112	ITLASP	9.83	44.12	90
32	FRAGEN	0.62	44.2	40	113	ITLECO	9.4	45.85	388
33	FRAIXP	5.45	43.52	233	114	ITLEGN	8.92	45.6	37
34	FRAJAC	8.72	41.93	240	115	ITMAGE	8.88	44.71	376
35	FRAMBE	5.36	45.96	13	116	ITPADO	11.89	45.4	237
36	FRAMIE	2.28	49.89	1257	117	ITPARM	10.33	44.72	284
37	FRANGO	0.16	45.65	179	118	ITRHO1	9.03	45.53	187
38	FRANNE	6.13	45.91	183	119	ITROM5	12.6	41.85	197
39	FRANNM	6.2	46.19	272	120	ITROM6	12.45	41.96	101
40	FRAURI	2.43	44.93	90	121	ITVARE	8.83	45.8	86
41	FRAVIG	4.81	43.95	400	122	LTKLAI	21.13	55.76	106
42	FRBAGN	4.62	44.15	208	123	LULUXE	6.13	49.62	120
43	FRBESA	6.03	47.24	248	124	PLCRAC	19.95	50.05	86
44	FRBOBA	0.52	44.9	65	125	PLKATO	19.02	50.27	27
45	FRBOUB	5.23	46.2	752	126	PLLODZ	19.47	51.77	156
46	FRBOUJ	6.27	45.59	220	127	PLLUBL	22.54	51.24	80
47	FRBOUR	2.4	47.08	216	128	PLPOZ1	16.92	52.45	75
48	FRBRIA	6.64	44.9	4	129	PLPOZN	16.88	52.42	240
49	FRCAST	2.24	43.6	66	130	PLWARS	21	52.25	172
50	FRCHAL	4.84	46.79	173	131	PLWROC	17.03	51.12	160
51	FRCHAM	5.92	45.57	329	132	ROTIMI	21.25	45.75	80
52	FRCHOL	−0.88[b]	47.06	31	133	RSBEL1	20.47	44.82	212
53	FRCLER	3.09	45.78	49	134	RSBEL2	20.4	45.38	80
54	FRCOUX	4.62	44.77	219	135	RSCACA	20.35	43.89	105
55	FRDIJO	5.03	47.32	213	136	RSKRAG	20.93	44.01	86
56	FRDINA	−2.05[b]	48.45	180	137	RSKRUS	21.33	43.58	114
57	FRGAP1	6.08	44.57	93	138	RSKULA	19.53	45.61	78
58	FRGENA	5	45.73	39	139	RSNIS1	21.93	43.31	93
59	FRGREN	5.74	45.19	116	140	RSNOVI	19.85	45.25	127
60	FRLYON	4.86	45.76	93	141	RSPOZA	21.19	44.63	80
61	FRMACO	4.79	46.34	106	142	RSSOMB	19.11	45.78	344
62	FRMARS	5.4	43.29	9	143	RSSUBO	19.67	46.92	183
63	FRMONP	3.87	43.61	208	144	RSVRBA	19.64	45.57	23
64	FRMONT	2.61	46.34	554	145	RSVRSA	21.3	45.11	300

Table 4 (continued)

Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)	Serial no.	Station[a]	Longitude (°)	Latitude (°)	Height (m)
65	FRNANC	6.17	48.69	480	146	RSZAJE	22.29	43.91	272
66	FRNEVE	3.16	46.99	142	147	RSZREN	20.4	44.83	560
67	FRNICE	7.28	43.73	5	148	RUKRAS	38.98	45.03	445
68	FRNIME	4.36	43.84	235	149	RUMOSC	37.7	55.75	1040
69	FRORLE	1.9	47.91	105	150	SIKOPE	13.73	45.54	570
70	FRPERI	0.73	45.19	125	151	SILJUB	14.5	46.07	366
71	FRPERP	2.89	42.7	260	152	SIMARI	15.64	46.55	273
72	FRPOIT	0.34	46.58	39	153	SKBANS	19.15	48.74	460
73	FRREIM	4.06	49.24	48	154	SKBRAT	17.07	48.15	650
74	FRROCH	−1.12[b]	46.16	230	155	UADNEP	34.98	48.45	169
75	FRROUS	4.81	45.37	45	156	UADONE	37.81	48	155
76	FRSTET	4.39	45.42	98	157	UAKYIV	30.52	50.45	179
77	FRSTGE	4.49	45.71	81	158	UAODES	30.73	46.47	40
78	FRSTRA	7.74	48.58	70	159	UAPOLT	34.55	49.59	78
79	FRTOUN	5.87	43.11	460	160	UASIMP	34.1	44.95	350
80	FRTOUS	1.45	43.56	104	161	UAVINN	28.44	49.22	258
81	FRTROY	4.08	48.3	90	162	UAZAPO	35.15	47.85	70

[a] First two letters: country code; remaining letters: city code according to the European Aeroallergen Network Pollen Database https://ean.polleninfo.eu/ean

[b] West longitude

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