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Forecasting the onset of an allergic risk to poaceae in Nancy and Strasbourg (France) with different methods

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Key words

Poaceae, Forecast method, Meteorological data, Allergic risk

Summary

Pollens of Poaceae are among the most allergenic pollen in Europe with pollen of birch. It is therefore useful to elaborate models to help pollen allergy sufferers. The objective of this study was to construct forecast models that could predict the first day characterized by a certain level of allergic risk called here the Starting Date of the Allergic Risk (SDAR). Models result from four forecast methods (three summing and one multiple regression analysis) used in the literature. They were applied on Nancy and Strasbourg from 1988 to 2005 and were tested on 2006. Mean Absolute Error and Actual forecast ability test are the parameters used to choose best models, assess and compare their accuracy. It was found, on the whole, that all the models presented a good forecast accuracy which was equivalent. They were all reliable and were used in order to forecast the SDAR in 2006 with contrasting results in forecasting precision.

Introduction

Grass pollen is considered to be one of the most important aeroallergens in Europe (1) affecting, for example, 20% of pollen-allergic people in Denmark and 80% of pollen-allergic people in France or in the Netherlands (2). A calendar of the pollen average season is often used for forecasting the Starting Date of the Allergic Risk linked to Poaceae (SDAR). Because of the high variability of the SDAR from one year to the next, one this calendar is not suitable for an accurate prediction. Many models were produced to forecast the SDAR using only temperatures like the Growing Degree Days (GDD), the Lejoly-Gabriel and the Q_{10} sum methods presented in this paper. But, in the case of Poaceae, rainfall is also a significant factor in the prediction of the starting date of pollination (3) and this parameter is generally associated with temperature in a multiple regression analysis (4). This last method is chosen in order to predict the SDAR in Nancy and Strasbourg. With regression analysis, in addition to temperature and rainfall, we can introduce relative humidity, sunshine duration and underground temperature. These three last meteorological data were previously used to forecast the starting date of pollination of other herbaceous plants like ragweed (5).

Materials and methods

Climate and pollen monitoring sites

Nancy and Strasbourg are located in the north-eastern part of France; they are characterized by a climate with continental influences. Nancy is situated at 212 m above

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sea level (48°41' N, 6°11' E) and Strasbourg at 142 m (48°35' N, 7°45' E). In Nancy, mean temperatures for January and July are approximately 1.2°C and 18°C respectively, mean annual rainfall is about 759.3 mm and mean annual duration of sunshine is 1651.5 hours (1961-1990 average). With regard to Strasbourg mean temperatures are 0.9°C for January and 19.1°C for July; mean annual rainfall and the amount of sunshine recorded annually are lower than Nancy values (610.5 mm and 1636.9 hours respectively).

The pollen grains were sampled by Lanzoni-Hirst-type (6) volumetric traps placed on the roof of the Faculties of Medicine of Nancy and Strasbourg, 18 and 50 m above ground level respectively. They were calibrated to handle a flow of 10 litres of air a minute, which roughly corresponds to human breathing, and a built-in vane ensured that they were permanently oriented in the direction of the wind. Pollen grains sucked into the trap impacted on a cylindrical drum covered by a plastic film coated with a uniform layer of silicone solution and rotated by 7-day clockwork at a speed of 2 mm/h (7, 8). The methodology employed is common for this type of sampling. Every week, the strip was removed and cut into seven equal segments corresponding to the 7 days of the week. Each segment was mounted between slide and coverglass. Then it was examined by light microscopy and pollens were counted on 2 or 3 equal-distanced horizontal lines. The results were expressed as the number of pollen grains per cubic metre of air.

Grass pollen data

Grass pollen data were supplied by the French aerobiological network (RNSA) which managed 59 pollen traps in 2006. This study used two historical databases of 19 years for Nancy and Strasbourg; the dataset ranged from 1988 to 2005.

Various thresholds were found in literature in order to define the starting date of pollen season. For example Laaidi (4) used a relative threshold those origin is graphical (9). It corresponds to the day when the daily pollen concentration first reaches 1% of the annual sum, the accumulated concentration up to this day being at least 5% of the same annual sum. This procedure eliminates the long tails of very low values at the start of the season, which may not accord with local phenology (4). But these relative thresholds, inevitably, correspond to different counts according to the inter-annual variability of pollen amounts. This method is, therefore, not very suitable for a forecast intended for allergy sufferers. Furthermore missing values were found in the Nancy and Strasbourg datasets during the grass pollen season, so total grass pollen amounts could not be known for some years. In England, a Threshold 30 method was used (10) which is defined as the first day when the pollen count is greater than or equal to 30 grains/m^3. This method is based on the results of several clinical studies that indicate that this is the average concentration at which hay fever patients are likely to experience symptoms (11, 12).

In France, the RNSA has developed a risk index for each allergenic pollen (13, 14). This index ranges from 0 (no risk) to 5 (very high level of risk). For Nancy and Strasbourg, we chose the first day when the daily average Poaceae pollen count reached 10 grains/m^3 followed by a four-day period which reached, at least, 40 grains/m^3. Moreover, three days of the total five-day period had to reach the daily average threshold. Ten grains/m^3 correspond to level 3 in the risk index applied to Poaceae (medium risk) and the following conditions have the advantage of eliminating isolated days when the daily average grass pollen count reached the medium risk level.

Meteorological data

Meteorological data were supplied by Météo France. The following variables, from the sites of Nancy-Essey and Strasbourg-Entzheim, were used for this study:

- minimum, maximum and mean daily temperatures.
- daily rainfall.
- daily sunshine duration (in minutes).
- minimum, maximum and mean daily relative humidity.

In addition to these classical meteorological parameters, the number of days with rainfall (above or equal 0.1, 1 and 5 mm respectively), the number of days where minimum, maximum and mean temperatures were lower than 0°C and the temperature 10 cm and 20 cm under ground were included.

In literature the use of 10-day periods or decade-of-days is a standard method employed in meteorological and aerobiological works (15-20) but many of these periods are overlapping two months; the reading is, consequently, not very practical. To a straightforward reading we chose fortnightly periods, based on monthly division, which are the followings: 1 to 15 January (symbolized by 01a), 16 to 31 January (01b), 1 to 14 February (02a), 14 to 28 or 29 February (02b), 1 to 15 March (03a), 16-31 March (03b), 1 to 15 April (04a) and 16-30 April (04b). Variables were taken from 1 January because this is the onset date used

in papers about grass pollen forecast (10, 21). The earliest SDAR occurred at the beginning of May, therefore meteorological parameters recorded after the 30 April were excluded.
Because of the different lengths of these periods, all the factors were converted in fortnightly and monthly averages. Because of the variable length of the second fortnight of February, the number of rainfall days and negative temperatures days were taken over from the frequency of these days during the under consideration period.

Forecasting methods

Three temperature accumulation methods are presented in here part:

- Growing Degree Days (GDD) method was developed, originally, for the calculation of heat units in pest management (22). Degree-days are calculated by a single triangle and a single sine method. Minimum and maximum temperatures are accumulated depending on an upper and a lower threshold. Many combinations are therefore possible according to the position of minima and maxima in relation to values of the two thresholds. Many papers used the triangle method, or the sine one, in order to predict the starting date of pollen season of different species like olive tree (23) and oak (24, 25). But authors only used the lower threshold, according to a paper of Snyder et al., because: "it was assumed that development is negligible when the temperature is below the lower threshold and that there is no further increase in developmental rate when air temperature is above an upper threshold temperature" (26). GDD are calculated as following:

  $GDD = 0$ when $x \geq Tx$

  $GDD = [(Tx - x)/2]\,[(Tx - x) / (Tx - Tn)]$ when $Tn < x < Tx$

  $GDD = Tm - x$ when $x \leq Tn$

  Tn, Tx, Tm = minimum, maximum, mean temperature; x = threshold temperature

- Lejoly-Gabriel method (9) is a simpler version of GDD method. Originally, mean temperatures are accumulated above a certain threshold, but the use of maximum temperature appeared to be more efficient to predict the beginning of the pollen season linked to the appearance of an allergic risk. This method is, above all, used in French publications (4, 27, 28). The formula is the next one:

  Lejoly = when $Tx > x$

  Tx = maximum temperature; x = threshold temperature

- Q_{10} is, originally, a notion which corresponds to a constant for given vegetal specie. Analogically with Van't Hoff's law in chemical kinetic, Q_{10} (t) is identified to the existing link between the growth speed for T temperature and those would be observed for the temperature T+10°C. Q_{10} sum method, which results from it, allows the growth and development of a plant to be adjusted to an exponential temperature law (4). It corresponds, there, to the "Warm Effect" (WE) method (29), generally used in French articles notably for the Poaceae forecast (4, 30), which formula is the next one:

  $$WE = Q_{10}^{Tn/10} + Q_{10}^{Tx/10}$$

  Tn, Tx = minimum, maximum temperature

Contrary to GDD and Lejoly-Gabriel methods, where temperatures are summed above a certain threshold, the Q_{10} sum method gives us the ability of using all the temperatures of the period preceding SDAR.
In order to forecast the SDAR from many meteorological data like temperature, rainfall or relative humidity, linear multiple regression analysis is the most appropriate method (4, 5). A forward stepwise multiple regression was applied on all the meteorological data of each fortnightly period; the most non-colinear significant correlated variables with SDAR, at a p level of 0.05, were established. The operation was therefore repeated eight times (once for each fortnightly period from the 1st January to the 30th April).
Variables selected by each forward stepwise regression were included in a standard linear multiple regression as the next example:

$$SDAR = a_1x_1 + a_2x_2 + \ldots + b$$

Standards of choice of best models

GDD and Lejoly-Gabriel methods consists of cumulatively summing the daily average values, peculiar to each method, from a statistically determined date, above a

thermal threshold and until the SDAR previously calculated. Several dates were tested in order to determine the best one for starting the sum calculation. These dates ranged from 1 January to 30 April, in steps of one day. Different thermal thresholds, above which the daily temperature is effective, were also tested, from 0 to 20°C, in steps of 0.5°C. The same process was applied for the Q_{10} sum method but, instead of thermal thresholds, different Q_{10} coefficients were tested from 1 to 12, in steps of 0.1.

The best starting date and the more appropriate threshold were those that minimized the Mean Absolute Error (MAE) which is a good indicator of mean errors of prediction. The MAE is calculated as:

$$\left|MAE\right| = \frac{1}{N}\sum_{i=1}^{N}\left|x_i - \hat{x}_i\right|$$

N = Number of observations; x_1= estimated value;
$\hat{x}_1$ = predicted value

In the case of several date/threshold combinations with the same MAE value, those that minimized the Root Mean Square Error (RMSE) were chosen.

As regards linear multiple regression analysis, variables selected by each forward stepwise regression were included in a standard linear multiple regression. They were resulted from different periods and therefore they were physically independent because maximum temperatures of the second fortnight of April, for example, could not be predicted according to mean relative humidity of the first fortnight of February. But, in most cases, a statistical multi-colinearity, which affects the quality of models, exists between these variables. In order to compensate for this, the use of an Actual forecast ability test (Af test) is appropriate. This test is stemmed from the coefficient of determination (R^2) which takes into account the number of variables used and the number of available observations. Smaller the gap between Af value and R^2 is, better the model is.

The Af test is calculated as:

$$Af = R^2 - 2\left[(M/N) + (1 - R^2)\right](1 - M + N)$$

R^2 = coefficient of determination; M = number of variables in the equation; N = number of observations

Therefore, only the variables without multi-colinearity were kept in the equations of regression. These variables were, of course, significantly correlated with SDAR at a *p* level of 0.05.

Results

SDAR for each town and each year are presented in Table 1 in number of days from 1st January. In Nancy the average SDAR is approximately on 10th May (day 130 from 1st January) for a no-leap year (9th May therefore for a leap year). The standard deviation reaches 5.96 days. The earliest SDAR occurred on 2nd May in 1999 and 2003 and the latest in 1991 (23rd May).

The average SDAR occurs 3 days later in Strasbourg i.e. the 13th May for a no-bissextile year which corresponds to the 133rd day from 1st January. The standard deviation reaches 5.20 days. The earliest SDAR took place on 4th May in 2003 and the latest in 1996 on the 142nd day of the year (21st May).

According to the *W* test of Shapiro-Wilks, which evaluates the normality of a distribution, the series of SDAR of Nancy and Strasbourg presented a Gaussian distribution with *p* values of 0.1454 and 0.6611 respectively. So, in this case, the comparison between the two series could be done with the *t* test of Student, and linear correlation between data of Nancy and Strasbourg could be realized. The *p* value of the *t* test were 0.162 and the coefficient of

Table 1 - Starting Dates of the Allergic Risk in Nancy and Strasbourg (number of days from 1st January): annual values, average and standard deviation

Year	Nancy	Strasbourg
1988	128	127
1989	134	132
1990	133	133
1991	143	141
1992	134	135
1993	125	135
1994	129	128
1995	125	127
1996	142	142
1997	131	135
1998	129	130
1999	122	130
2000	123	126
2001	128	131
2002	127	133
2003	122	124
2004	132	136
2005	130	140
Average	129,83	132,5
σ	5,96	5,2

correlation reached a value of 0.78 ($p<0.001$). So SDAR of Nancy and Strasbourg were statistically similar, despite a gap of 2.7 days between both averages, and followed the same trend during the 1988-2005 period.

Following the determination of the Starting Date of the Allergic Risk for each station, the next results presented were resulted from models established from 1988 to 2005. The year 2006 was deliberately removed of the development of models in order to test the accuracy of the different models in a forecasting context.

The best combinations between date and threshold in order to minimize the mean absolute error for the three cumulative methods are given in Table 2.

We can notice that the starting dates are late and all occur during the second part of April except for Q_{10} method in Nancy. The latter we start the summing, the better are the forecasts in Strasbourg, but it is not the case in Nancy. Thresholds are various but they are almost identical for the Lejoly-Gabriel method.

Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) associated to the date/threshold emerging from Table 2 are presented in Table 3.

All the models present a good accuracy with a mean absolute error lower than 2.6 days. We can notice, here, that Lejoly-Gabriel is the best cumulative method to predict the SDAR in Strasbourg and Q_{10} method is the most accurate for Nancy. But, overall, the results are equivalent; all the methods are valid even they were elaborated according to different processes and hypothesis.

As regards linear multiple regression analysis, variables significantly correlated with SDAR at a *p* level of 0.05 are collected on Table 4.

Table 2 - Starting dates of summing temperatures, thresholds and sums to reach in order to forecast the Starting Date of the Allergic Risk of the most accurate models for each cumulative method and each station (1988-2005)

	Method	Date	Threshold	Sum
Nancy	GDD	25 april	7.5°C	77.62°D
	Lejoly-Gabriel	29 april	16.5°C	135.57°C
	Q_{10}	4 january	3.2	734.83 unités
Strasbourg	GDD	30 april	8.5°C	73.36°D
	Lejoly-Gabriel	30 april	17°C	183.94°C
	Q_{10}	30 april	3.2	224.51 unités

GDD = Growing Degree Days method. Lejoly-Gabriel and Q_{10} are the name of the other ones

Table 3 - Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), in days, corresponding to date/threshold combinations of each cumulative method presented in Table 2 (1988-2005)

	Method	MAE	RMSE
Nancy	GDD	2.50	3.34
	Lejoly-Gabriel	2.56	3.38
	Q_{10}	2.33	3.25
Strasbourg	GDD	2.39	3.34
	Lejoly-Gabriel	1.94	2.66
	Q_{10}	2.28	3.36

GDD = Growing Degree Days method. Lejoly-Gabriel and Q_{10} are the name of the other ones

The main characteristic of this table is the important rule played by the variables of the second fortnight of January in Nancy and Strasbourg. Temperature and rainfall are significantly and negatively correlated with SDAR. Early SDAR seems to be linked to mild temperatures and rainy weather during this period. Temperature is the most recurrent variable and has the same influence for all the periods where it appears:

- negative correlations with thermal values.
- positive correlations with number of days where temperature (minimum, maximum or mean) are lower than 0°C.

Two equations, where the gap between R^2 and *Af* test values are minimized, are resulted from these correlations:

$SDAR_{NANCY} = 1.059*\mathbf{T0\_01b} - 1.308*\mathbf{Tn\_04b} + 131.622$
$R^2 = 0.7724$ ($p < 0.001$) $Af = 0.7326$ MAE = 2.28 RMSE = 2.77

$SDAR_{STRASBOURG} = 0.798*\mathbf{T0\_01b} + 1.120*\mathbf{T0\_03a} + 127.790$
$R2 = 0.5794$ ($p = 0.0015$) $Af = 0.5168$ MAE = 2.82 RMSE = 3.30

T0 = number of days where mean temperature is lower than 0°C; Tn = minimum temperature; 01b = 16-31 January; 03a = 01-15 March; 04b = 16-30 April

Mean Absolute Error associated to these equations is a little upper than MAE of models resulted from cumulative methods. However, the accuracy is good especially for Nancy. We can notice that the use of the Actual forecast

Table 4 - Significant correlations between fortnightly meteorological variables and the Starting Date of the Allergic Risk at the 0.05 level

Station	Variable	Period	Significance
Nancy	rainfall	16-31 January	-0.4715
	rainfall days > 0 mm		-0.5299
	rainfall days > 0.9 mm		-0.4733
	rainfall days > 4.9 mm		-0.5357
	minimum temperature		-0.6466
	maximum temperature		-0.7063
	mean temperature		-0.6874
	number of days where minimum temperature < 0°C		0.6998
	number of days where maximum temperature < 0°C		0.6526
	number of days where mean temperature < 0°C		0.7727
	ground temperature (-10 cm)		-0.5765
	ground temperature (-20 cm)		-0.5413
	minimum relative humidity		0.4864
	number of days where minimum temperature < 0°C	01-14 February	0.5114
	number of days where mean temperature < 0°C		0.4731
	ground temperature (-10 cm)		0.479
	ground temperature (-20 cm)		0.4973
	minimum temperature	16-30 April	-0.5772
Strasbourg	rainfall days > 0 mm	16-31 January	-0.4883
	rainfall days > 0.9 mm		-0.5531
	maximum temperature		-0.5025
	mean temperature		-0.4905
	number of days where minimum temperature < 0°C		0.6166
	number of days where maximum temperature < 0°C		0.5457
	number of days where mean temperature < 0°C		0.6443
	number of days where minimum temperature < 0°C	15-28 (29) February	0.5172
	minimum temperature	01-15 March	-0.4743
	number of days where mean temperature < 0°C		0.5475

ability test conducts to equations with only two predictive variables which are not affected by multi-colinearity.

2006 forecasts

In 2006, the Starting Date of the Allergic Risk (SDAR) occurred on the 12th of May in Strasbourg and on the 15th of May in Nancy. The different models presented before are used to predict the SDAR for this year. Results are presented in Table 5.

The SDAR forecasted in Strasbourg always occurs before the observed SDAR with a very small gap for models re-

Table 5 - Predicted Starting Date of the Allergic Risk in 2006 and gap, in days, between predicted and observed value for each cumulative method presented in Table 2 and the linear multiple regression

Year	Nancy	Strasbourg
GDD method	6 may (-9)	11 may (-1)
Lejoly-Gabriel method	7 may (-8)	10 may (-2)
Q_{10} method	14 may (-1)	11 may (-1)
Linear multiple regression	11 may (-4)	20 may (+8)

sulting from cumulative methods. Results are contrasting in Nancy with very accurate forecasts using model of Q_{10} method, while the SDAR predicted by the three others occur later than the real one. In order to initiate a preventive treatment against pollen allergy, too earlier forecasts (however without large gaps) are less prejudicial than too later ones.

Discussion and conclusion

We presented different methods: their main characteristic was their equivalent forecast ability with a similar accuracy demonstrated by the use of the Mean Absolute Error. Recently, a study of Laaidi was done on the forecast of Poaceae for four Burgundian stations (4) during the periods 1996-1998 (Montbard, Dijon and Mâcon) and 1995-1998 (Chalon-sur-Saône) where forward stepwise regression analysis, Lejoly-Gabriel and Q_{10} methods were used. With regard to models which result from Lejoly-Gabriel method, Mean Absolute Error values ranges from 0.33 day (Montbard and Mâcon) to 3 days (Dijon). As for Q_{10} method, models give the exactly starting date of Poaceae season for three sites except for Chalon-sur-Saône where MAE is equal to 3 days. The comparison between these and Nancy and Strasbourg data is impossible because of the differences in series lengths and geographical location. However, for the four sites taken as a whole, MAE linked to each cumulative method is globally similar and shows their equivalent ability in forecasting the SDAR; a fact which is confirmed in the present paper. Multiple regression analysis was performed with 10-day meteorological data and the four periods were grouped together in a fictive 13-year dataset because of the small size of the samples in each site (4). MAE of the equation resulting from this dataset is 4.54 days. These quite bad results might come from the process used and put forward that model accuracies are better when they are elaborated from dataset of one site.

The parallel established between our results and the study upon Burgundian sites allows verifying that different types of forecast methods can be used with similar results. Multiple regression is as reliable as the more classical cumulative methods but its approach is different using other meteorological data than air temperature.

The main objective of this paper was to construct forecast models from different methods and several meteorological variables. Using underground temperature, number of days of rainfall or number of days where air temperature is below 0°C is an uncommon approach. The use of winter averages of the NAO (Northern Atlantic Oscillation), not tested here, seems as well to be useful in the forecast of pollen counts (10, 12). There is probably a place here for further investigation in the SDAR forecast.

The ability to predict the first day when occurs a medium-level allergic risk for Poaceae up to one month and half before the SDAR will be of assistance to the medical profession, including allergists planning treatment and physicians scheduling clinical trials. Such information will also be useful for pharmaceutical companies and the health care industry that market and stock hay fever treatments (19).

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