

Forecast model of allergenic hazard using trends of *Poaceae* airborne pollen over an urban area in SW Iberian Peninsula (Europe)

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Abstract Cities are becoming bigger, being necessary the knowledge of associated natural hazards from organic and inorganic aerosols. This hazard could be included in the context of urban air pollution and climate change as environmental risk factors for allergy. Overall, grass pollens are the most important cause of pollinosis in Europe due to its high allergenicity and extensive distribution. The main objective of this work was to model daily average *Poaceae* airborne pollen concentrations from an urban area placed in a city in the SW of the Iberian Peninsula, taking into account the temporal distribution of five different meteorological variables from 23 years of continuous recording. This was achieved using a combination with the Shuffle Complex Evolution Metropolis Algorithm using as an optimisation function the root mean square error. Aerobiological sampling was conducted from 1993 to 2015 in Badajoz (SW Spain) using a 7-day Hirst-type volumetric sampler. The *Poaceae* Main Pollen Season lasted, on average, 89 days, ranging from 41 to 144 days, from April 17 to July 14. The model proposed to forecast airborne pollen concentrations is described by one equation composed of two terms. The first term represents the resilience of the pollen concentration trend in the air according to the average concentration of the previous 10 days, and the second term is obtained from considering the actual pollen concentration value, which is calculated based on the most representative meteorological variables multiplied by a fitting coefficient. The fit of the model was examined for a forecast horizon of 1, 7, 15 and 30 days. The R^2 values obtained were 0.70,

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0.69, 0.62 and 0.57, respectively, which show a trend in decreasing order. These results confirm the suitability of the proposed model.

Keywords Airborne natural hazards · *Poaceae* pollen · Allergy · Time series analysis · Forecasting · Temporal modelling

1 Introduction

A rise in the global average temperature happened between 1880 and 2012 and it has been anticipated that this trend will continue in the following years according to IPCC reports (2013). The impact of climate change has been studied with different natural indicators such as runoff and soil losses in a rainfed basin (Ramos and Martínez-Casasnovas 2015), vegetation and animal husbandry (Miao et al. 2016), weed pollen (Bogawski et al. 2014) and allergens and allergic diseases (Beggs 2014). There are several environmental factors related to plants such as temperature changes, the interaction with local meteorological parameters (mainly precipitation and wind) (Aboulaich et al. 2013; Myszkowska 2014), edaphic factors (Wielgolaski 2001) and photoperiod (Ibáñez et al. 2010). The backspin of climate on plant phenological response may be related by the impact of human activity on plant distribution with changes in land use. García-Mozo et al. (2016) have studied this relation for *Poaceae* pollen. García de León et al. (2015) have highlighted the *Poaceae* pollen dynamics and how climate change might impact the future evolution of airborne *Poaceae* pollen concentrations and thus the future evolution of related pollen allergies.

Poaceae family comprises more than 700 genera containing around 10,000 species (Wang et al. 2013), with over 420 of these occurring in Europe (Galán et al. 1989). Daily average grass pollen concentrations and features of the grass pollen season such as start date and intensity have been studied (Ugolotti et al. 2015; Zhang et al. 2015). Several papers have examined the relationship between airborne grass pollen concentrations with symptoms of allergic diseases (Annesi-Maesano et al. 2012; Erbas et al. 2012; Sánchez-Mesa et al. 2005) and the pollution air (Annesi-Maesano et al. 2012). Grass pollen is the main cause of pollinosis in several regions of the world, but its frequency may change between zones (Tormo-Molina et al. 2015). *Poaceae* pollen is one of the four major allergenic pollen families (Smith et al. 2014), inducing allergic rhinoconjunctivitis in Europe (D'Amato et al. 2007). A statement of the World Allergy Organization have discussed about meteorological conditions, climate change, new emerging factors and asthma and related allergic disorders (D'Amato et al. 2015).

Other papers have developed comparative studies examining temporal and spatial variations in *Poaceae* pollen counts (Galán et al. 1995; Smith et al. 2009, García-Mozo et al. 2009; Fernández-Rodríguez et al. 2015a), and have estimated of the potential allergy risk of a city (Rojo et al. 2016). Influence of *Poaceae* pollen in urban air has been also studied (Moreno-Sarmiento et al. 2016; Vesterberg 2001; Peel et al. 2014). Urban green infrastructure is a concept that includes not only ornamental street trees, but any area with natural vegetation in urban environments. It has been developed in the last two decades and it is clear that improves quality of life for citizens (Breuste et al. 2015). Due to demographic trends of population from rural to urban areas, cities are becoming bigger (Schmidheiny and Suedekum 2015), being necessary the knowledge of associated natural hazards from organic (fungal spores) (Srivastava et al. 2012) and inorganic aerosols

(Particulate Matter 10-PM₁₀) (Ambade 2016). This hazard could be included in the context of urban air pollution and climate change as environmental risk factors for allergy (35). In 1998, the Conference “Ragweed in Europe” was dedicated to pollen allergy of ragweed as natural hazard according UE ordinances (Comtois 1998; Jäger 1998; Járαι-Komlódi 1998; Makovcová et al. 1998; Peeters 1998; Thibaudon 1998).

Predicting the onset and duration of pollen season benefits allergic patients, providing information by forecasting pollen models and their levels at different spatiotemporal scales (Zhang et al. 2015). To forecast *Poaceae* pollen is necessary to consider daily values of airborne *Poaceae* pollen and the Season Pollen Index (SPI) (Ugolotti et al. 2015; Fernández-Rodríguez et al. 2016a; Kasprzyk and Walanus 2010; Piotrowska 2012; Puc and Wolski 2013), as well as trends in airborne related to climate change (Bogawski et al. 2014; Jato et al. 2009; Tormo-Molina et al. 2010; García-Mozo et al. 2010).

MATLAB (Matrix Laboratory) is a language of technical computing that has allowed to model green areas (Hao et al. 2015; Rivera et al. 2015) and pollen data (Gong et al. 2015; Senyuva et al. 2009) between time series of airborne pollen: *Cupressaceae* (Silva-Palacios et al. 2015), *Quercus* (Fernández-Rodríguez et al. 2016a) and *Olea* (Fernández-Rodríguez et al. 2016b) and meteorological parameters. This tool has verified the close agreement between observed and predicted mean concentrations. The statistical tools used to analyse pollen season trends have included time series analyses (Damialis et al. 2007), correlation with meteorological variables (Erbaş et al. 2007), regression analyses (Stach et al. 2008), process-based models (García-Mozo et al. 2009) and multiple regression (Myszkowska 2014; Brighetti et al. 2014; de Weger et al. 2014) for *Poaceae* pollen. Forecasting of *Poaceae* pollen has been widely developed in Europe: Spain (García-Mozo et al. 2009), France (Cassagne et al. 2008), Italy (Tassan-Mazzocco et al. 2015), Greece (Voukantsis et al. 2010), Turkey (Kizilpınar et al. 2011), UK (Smith and Emberlin 2005; Smith and Emberlin 2006) and Poland (Piotrowska 2012). Other tools used include methods based on artificial intelligence (AI) for *Poaceae* pollen applied to a coastal Atlantic climate region (Rodríguez-Rajo et al. 2010) and in polluted areas in Europe (Csépe et al. 2014).

The main objective of this work is to model daily average *Poaceae* airborne pollen concentrations from an urban area placed in a city in the SW of the Iberian Peninsula, in relation to the temporal distribution of five different meteorological variables from 23 years of continuous recording. This was achieved using a combination with the Shuffle Complex Evolution Metropolis Algorithm (SCEM-UA) using as an optimisation function the root mean square error (RMSE).

2 Materials and methods

2.1 Sampling site

Aerobiological samples were collected from 1993 to 2015 in Badajoz (SW Spain) using a 7-day volumetric sampler of the Hirst design (Hirst 1952) with an intake hole located 1.5 m above ground on an open terrace situated 6 m above ground at the Agricultural Engineering School of the University of Extremadura (38°53′45″N, 6°58′07″W). Petrolatum White (CAS number 8009-03-8) was used as an adhesive. Standardised data management procedures were used as described by the Spanish Aerobiology Network (REA) (Galán et al. 2007). The main pollen season (MPS) was determined using the 5–95 % range (Nilsson and Persson 1981) of the data. The data were used in the form of the Seasonal

Pollen Index (SPI), calculated as the sum of the daily average pollen counts recorded in each MPS for *Poaceae* pollen. Figure 1 includes a 12 × 10 km map with the main land uses located around the spore trap.

2.2 Climate data

Badajoz has a Mediterranean climate with the maximum rainfall in autumn and winter (AEMET 2016). The highest temperatures are recorded during the summer dry period. Annual values of rainfall (447 mm), mean temperature (17.1 °C) and relative humidity (64 %) were registered in the period 1981–2010. Wind data available (1993–2008) provide an average wind speed of 9.5 km/h with SW (35.4 %) and NW (26.4 %) winds being predominant. Climate data were obtained from Badajoz Airport (38°53'N, 6°49'W) (Fig. 1).

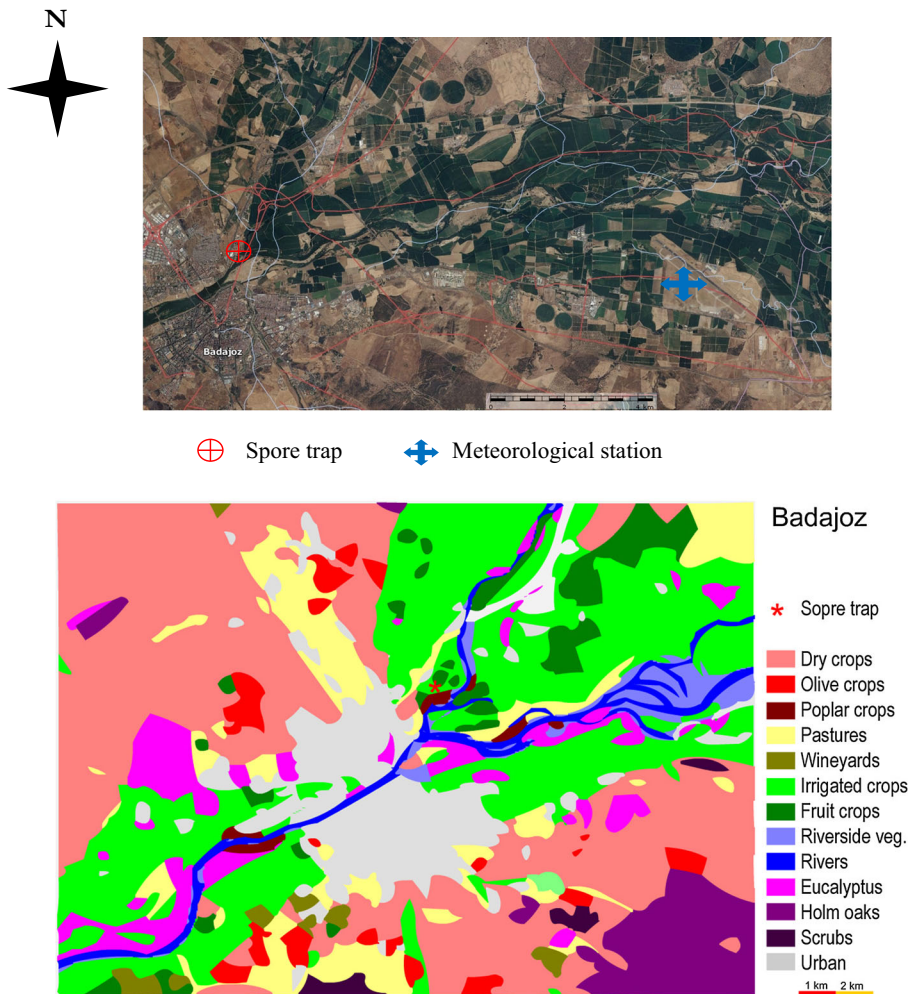


Fig. 1 Maps of location of spore trap and meteorological station and land use. Spore trap Meteorological station

2.3 Statistical analysis

The normal distribution of the data was tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. These tests showed that the daily data did not follow a normal distribution. The tests also showed that the log 10-transformed data also did not follow a normal distribution. A Spearman correlation test was then used to analyse associations between selected variables. The statistical analysis included the entire daily data set and was performed with the SPSS 15.0 statistical package. The use of meteorological information to predict the *Poaceae* pollen concentration was evaluated with a mathematical model. The model was calibrated using the Shuffled Complex Evolution Metropolis algorithm (SCEM-UA) with the root mean square error (RMSE) as the optimisation function. The suitability of the SCEM-UA has been previously verified in other areas of science, such as hydrodynamics (Vrugt et al. 2003; Efstratiadis and Koutsoyiannis 2010). This algorithm is based on an automatic search of the feasible parameter space and starts by generating random samples of unknown calibration parameters. From this search, the set of solutions that optimises the goodness-of-fit criterion is found. Meteorological parameters used were rainfall (R), relative humidity (RH), maximum (Tmax), mean (Tmean) and minimum temperature (Tmin). Probability distribution function of parameters and R^2 has been analysed by MATLAB.

The model proposed to forecast the airborne *Poaceae* pollen concentration (CP) is described by Eq. (1). This expression is composed of two terms: the first term represents the resilience of the pollen concentration trend in the air according to the average concentration of the previous 10 days; the second term is obtained based on the actual pollen concentration value, which is composed by the most representative climatic variables multiplied by a fitting coefficient. Finally, considering the effect of previous days on the daily value of each variable the average temperature and the cumulative rainfall of the previous 10 days to the equation:

$$\begin{aligned} \text{CP}^{t+\Delta t} = & a \cdot \frac{\sum_{i=t-10}^{i=t} \text{CP}^i}{10} \\ & + \text{CP}^t \left(b \cdot T_{\max}^t + c \cdot T_{\text{mean}}^t + d \cdot T_{\min}^t + e \cdot \frac{\sum_{i=t-10}^{i=t} T_{\text{mean}}^i}{10} + f \cdot R^t \right. \\ & \left. + g \cdot \sum_{i=t-10}^{i=t} R^i + h \cdot \text{RH}^t \right) \end{aligned} \quad (1)$$

where a, b, c, d, e, f, g and h are the coefficients to be calibrated for our time series of climatic and airborne pollen concentration and Δt is the time step considered for the forecasting process, which is fixed at 1 day. It is composed by the integration of different climatic variables for each time step regarding the actual airborne pollen concentration value joined to the mean concentration value of the previous 10 days for each time step. Besides the fact that the value of each variable is evaluated for every time step, the aggregated variables of the mean temperature for 10 previous days as well as the cumulative rainfall of the 10 previous days have been included to analyse the influence of the temporal variation of these variables over the airborne pollen concentration. Regardless of the fact that the degree of influence of some meteorological variables could be previously neglected by its apparently low relevance, it has been therefore considered appropriate to maintain them due to the fact that the range of variations are different among them as well

as its mean value. The fitting parameters for this model were estimated using the SCEM-UA algorithm.

3 Results

3.1 Trends

The *Poaceae* MPS lasted, on average, 89 days, ranging from 41 to 144 days, from April 17 to July 14 (Table 1). Not statistically significant correlation was found between the SPI and the number of days in the MPS ($r = -0.260$, $p = 0.232$) (Fig. 2). The mean daily average pollen concentration was 116 grains/m³, with a range of 26–303 pollen grains/m³. Figure 3 shows a trend towards a shorter pollination period by delaying the start day and advancing the last day of the MPS. The day with maximum concentration (day maximum) is progressively closer to the day end, and the correlation between the day maximum and day

Table 1 *Poaceae* pollen season characteristics (day start, day end, day maximum, number of days, daily average count and SPI)

	Day start (DOY)	Day end (DOY)	Day maximum (DOY)	Number of days (days)	Daily average count (pollen grains/m ³)	SPI (pollen grains)
1993	18-5	2-8	30-5	77	82	6345
1994	25-4	23-7	4-5	90	119	10,744
1995	27-3	23-7	17-5	115	46	5288
1996	15-4	18-7	31-5	95	185	17,571
1997	18-3	8-8	20-5	144	60	8572
1998	23-3	16-7	15-5	116	119	13,765
1999	24-4	29-7	25-5	97	68	6553
2000	12-5	13-7	18-5	61	281	16,613
2001	26-4	1-7	25-5	67	303	20,272
2002	27-4	1-7	20-5	66	152	10,051
2003	7-5	16-7	20-5	71	217	15,377
2004	23-3	11-7	26-5	111	108	11,970
2005	26-3	20-7	5-5	117	26	3004
2006	20-4	1-7	17-5	73	139	10,168
2007	25-3	3-6	19-5	80	134	10,681
2008	30-4	30-7	18-5	92	69	6366
2009	26-3	6-8	8-5	130	27	3481
2010	28-4	15-7	30-5	79	108	8526
2011	26-3	6-7	14-5	103	50	5122
2012	10-5	23-7	25-5	75	38	2882
2013	25-4	2-7	22-5	69	54	3750
2014	10-5	26-7	17-5	78	107	8364
2015	28-4	7-6	14-5	41	189	7731

Start, end and maximum dates of the *Poaceae* pollen season as day of the year (DOY)

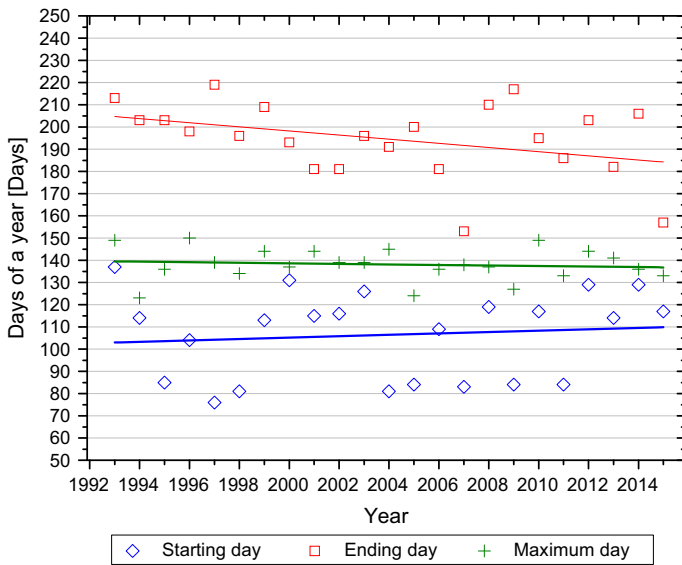


Fig. 2 Trends in the pollen season for *Poaceae* pollen

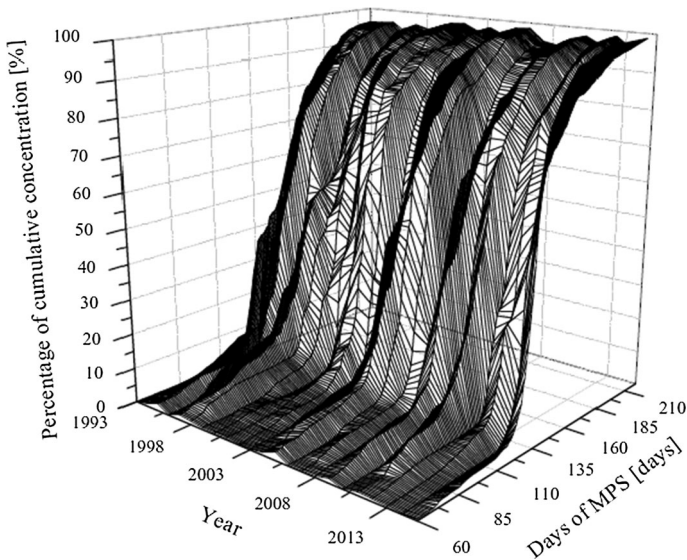


Fig. 3 *Poaceae* pollen season characteristics

start ($r = 0.336$, $p = 0.117$) is higher than between the day maximum and the day end ($r = 0.001$, $p = 0.995$). The number of days of *Poaceae* MPS is statistically significant correlated with day start ($r = -0.776$, $p = 0.001$), day end ($r = 0.599$, $p = 0.003$) and daily average concentration ($r = -0.596$, $p = 0.003$).

3.2 Relationship with meteorological variables

The first analysis performed was a Spearman correlation analysis of the relationship between the *Poaceae* SPI and the selected meteorological variables. Table 2 shows the results obtained in each year. Temperature (maximum, minimum and mean) and relative humidity were the meteorological variables with the highest positive correlation coefficient with the SPI. The correlation with relative humidity, rainfall and temperatures (maximum, minimum and mean) fluctuated between positive and negative values and was only significant for 1 year (1998). Nevertheless, 11 years showed a significance level greater than 95 % for the cumulative rainfall and temperature mean of 10 previous days. Separately, 15 and 17 years showed significance level for rainfall and temperature mean of 10 previous days, respectively. All years have shown significance level for cumulative *Poaceae* concentration of 10 previous days.

3.3 Model

In Table 3, the values obtained for each parameter for the 23 years analysed, and the value obtained from the coefficient of determination (R^2) is shown. The model has been validated

Table 2 Correlation coefficient between daily SPI and meteorological parameters

	$T_{\max}$	$T_{\min}$	T_{mean}	Rain	RH	Rain (10 days)	T_{mean} (10 days)	C_{Poa} (10 days)
1993	-0.383**	-0.433**	-0.474**	0.134	0.343**	0.664**	-0.767**	0.741**
1994	-0.259*	-0.283*	-0.302**	-0.095	-0.007	0.047	-0.399**	0.740**
1995	0.181	0.107	0.019	-0.105	-0.252**	0.218*	-0.036	0.737**
1996	0.034	0.052	0.037	-0.232*	0.056	-0.247*	-0.087	0.825**
1997	0.219 *	0.228**	0.079	-0.311**	-0.257**	-0.015	0.094	0.681**
1998	0.552**	0.548**	0.490**	-0.257**	-0.323**	-0.055	0.456**	0.852**
1999	-0.287 **	-0.341**	-0.381**	-0.189	0.027	0.343**	-0.596**	0.805**
2000	-0.219	-0.222	-0.184	0.138	0.230	0.630**	-0.731**	0.790**
2001	-0.178	-0.182	-0.191	-0.015	0.230	0.269**	-0.435**	0.808**
2002	-0.105	-0.163	-0.280*	-0.185	-0.077	0.467**	-0.614**	0.681**
2003	0.019	-0.131	-0.279*	-0.176	-0.465**	-0.363**	-0.501**	0.819**
2004	0.410**	0.466**	0.542**	-0.046	-0.217*	0.220*	0.407**	0.838**
2005	0.203*	0.151	0.094	0.070	-0.286**	0.114	-0.045	0.759**
2006	-0.165	-0.426**	-0.613**	-0.200	-0.309*	-0.450**	-0.740**	0.871**
2007	0.112	-0.103	-0.408**	-0.303*	-0.265*	-0.251*	-0.503**	0.767**
2008	-0.413**	-0.483	-0.521**	0.118	0.176	0.498**	-0.616**	0.750**
2009	0.115	0.132	0.101	-0.314**	-0.209*	0.092	-0.021	0.772**
2010	-0.231	-0.239*	-0.302*	-0.253*	0.038	-0.158	-0.552**	0.792**
2011	0.151	0.188	0.060	-0.332**	-0.099	0.246*	-0.042	0.678**
2012	-0.290*	-0.172	-0.093	0.205	0.323**	0.485**	-0.386**	0.807**
2013	0.045	-0.011	-0.244	-0.217	-0.180	0.053	-0.588**	0.559**
2014	-0.397**	-0.484**	-0.491**	-0.104	0.011	0.155	-0.645**	0.799**
2015	-0.285	-0.326	-0.213	0.000	0.086	0.577**	-0.650**	0.732**

* Significance at level 95 %; ** Significance at level 99 %

Table 3 Parameters and statistical analysis of the model proposed to predict airborne pollen concentration (D: previous day)

	Time prediction delay			
	1-day	7-day	15-days	30-days
Parameters				
<i>a</i>	0.491	1.286	0.941	0.819
<i>b</i>	0.006	0.074	−0.003	−0.003
<i>c</i>	0.082	−0.092	0.032	0.027
<i>d</i>	−0.066	0.061	−0.007	−0.007
<i>e</i>	−0.041	−0.079	−0.035	−0.028
<i>f</i>	−0.017	−0.015	0.001	−0.009
<i>g</i>	0.004	0.002	0.001	0.001
<i>h</i>	0.451	0.570	0.028	0.430
Comparison criteria				
R^2	0.704	0.689	0.622	0.573
RMSE	95.47	95.34	92.92	65.73
CC _{obs}	103.677			
CC _{sim}	100.869	98.194	82.279	68.370

for the last 5 years considering the rest of the data for the calibration process (Fig. 4), obtaining a correlation between the observed data (1993–2010) ($R^2 = 0.70$) and simulated data (2011–2015) ($R^2 = 0.69$). Moreover, Table 3 also includes the results obtained with a forecast time step of 1, 7, 15 and 30 days to examine the suitability of the model to predict concentrations for longer time gaps. For this purpose, Eq. (1) is modified with Δt equal to 7 for a forecast time step of 7 days, 15 for a forecast time step of 15 days and 30 for a forecast time step of 30 days. Parameter “*a*” had the highest value, showing the influence

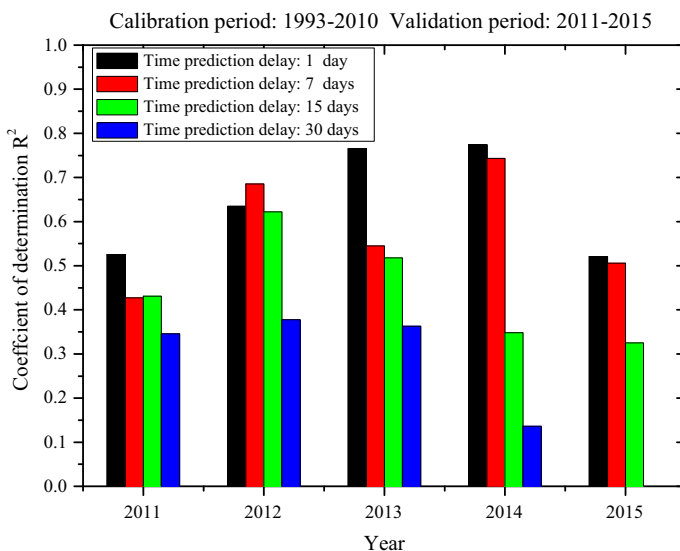


Fig. 4 Validation of the model for the last 5 year

of the previously explained trend in the pollen concentration. Among the parameters related to daily temperature, parameter “*b*” related to maximum temperature with the prediction to 7 days has shown the highest value; however, parameter “*c*” linked to mean temperature for forecast to 1 day was higher than 7, 15 and 30 days. Parameter “*d*” associated with minimum temperature showed the greatest value for 7 days as the mean temperature. Rainfall (parameter “*f*”) has shown lower values. The value of parameter “*g*”, linked to the average rainfall of the 10 previous days, was higher than “*f*” parameter for a forecast time step. Finally, the value of parameter “*h*”, which is linked to daily relative humidity, was the higher parameter. Figure 5 shows the posterior probability distribution function of all parameters (“*a*” to “*h*”) and R^2 . Red lines show the most accurate combination of parameters. The position of each red line is close to the value with higher probability for all parameters. Consequently, any variation around these values would not generate high differences in terms of R^2 .

4 Discussion

Badajoz is a historic city and is the urban centre most populated of SW Iberian Peninsula. Urban area extends about 8 km E–W and 6 N–S with approximately 18 km², river Guadiana crosses the city from NE to SW, and river banks were recently modified as green ornamental areas. Urban surrounding are covered by irrigated crops at NE and NW

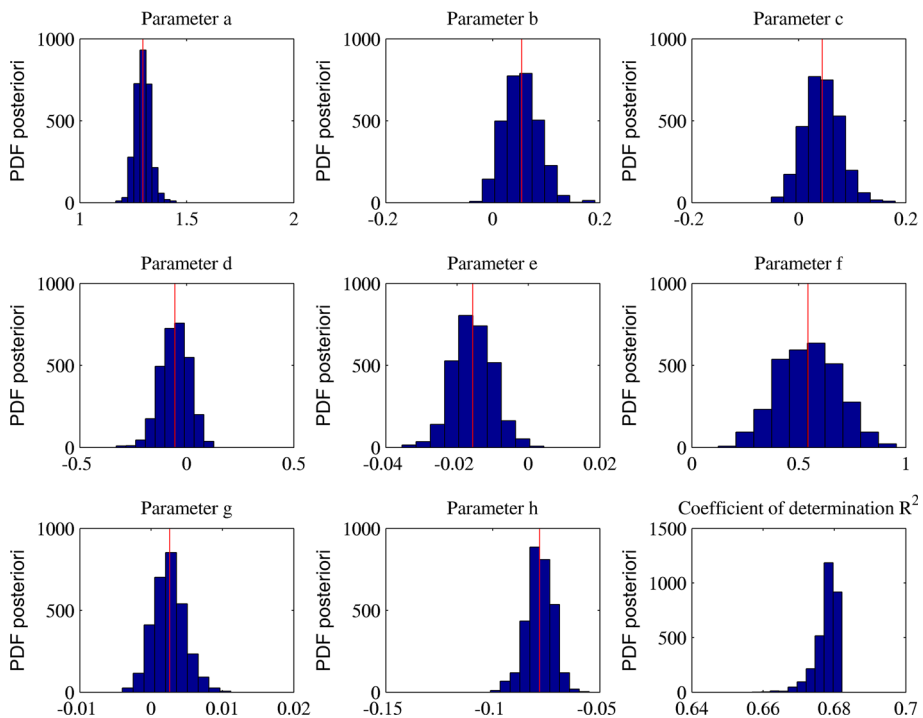


Fig. 5 Posterior probability distribution function of parameters (*a*, *b*, *c*, *d*, *e*, *f*, *g* and *h*) and R^2 . Red line means the more accurate combination of parameters

(cornfields, fruit trees crops and other vegetable crops); dried crops appear at S, N and NW (wheat and oats); some small areas of holm oak and cork oak dehesa appear mainly at S, some time shrubbery. Urban green areas represent 5.5 % of urban surface.

Recent papers have reported that airborne pollen recorded in Badajoz comes from median and distance sources. In Badajoz, Fernández-Rodríguez et al. (2015a, 2015c) have reported that airborne organic particles (fungal spores and pollen grains) recorded comes from local and regional sources with winds of West direction (Silva-Palacios et al. 2007). Grass pollen concentrations recorded in a site depends of environment specific conditions (Muñoz-Rodríguez et al. 2010), being representative emission sources up to 100 km around the sampler (Domínguez et al. 1993; Fornaciari et al. 2000). Phenology of wind-pollinated plants such as grasses is a tool to study aerobiological results (Tormo-Molina et al. 2015) and the relationship of spatiotemporal evolution of phenological phases, and pollen counts in sampling site (Tormo-Molina et al. 2011) allow a better knowledge of *Poaceae* pollen.

Trends in *Poaceae* pollen concentration displayed negative slopes, indicating a decrease in airborne grass pollen in Badajoz (SW Spain) as in Italy (Ugolotti et al. 2015) and in Poland (Stach et al. 2008), nevertheless not being in line with the trends in Andalucía (S Spain) (García-Mozo et al. 2010) and in the UK (Smith and Emberlin 2005). Changes in land use and a general reduction in grassland area have been used to explain a marked decrease in the length and severity of the grass pollen (Emberlin et al. 1993). A completely reverse effect of humidity was noted in the UK where in wetter years, grass pollen release was delayed (Emberlin et al. 1994). Smith et al. (2014) have showed that of the intensity of *Poaceae* pollen seasons has changed at several European cities, but this change was not consistent. The *Poaceae* MPS lasted about 2 months and, although trends are not statistically significant, it seems that there is a small delay trend in the pollination. This fact could be explained because the number of MPS days is correlated with the end day. The delay or advance in pollination differs from other studies and it is quite dependent on the years analysed. Barbosa et al. (2015) have shown the relationship between NDVI and rainfall might occur not in time neither in space, with a delay of both parameters. This fact could be justified by the fact that the occurrence of El Niño-Southern Oscillations (ENSO) events at the end of a year would cause decreased or increased rainfall in the rainy season. A delay was found of the pollen season in Extremadura for *Cupressaceae* pollen (Silva-Palacios et al. 2015), *Quercus* pollen (Fernández-Rodríguez et al. 2016a) and *Olea* pollen (Fernández-Rodríguez et al. 2016b). However, an advance of spring flowering days per decade was found in Europe for trees (Menzel et al. 2006) and of the pollen season in *Betula* (Zhang et al. 2013), *Olea* (Aguilera et al. 2015) and for herbs as *Poaceae* (Ugolotti et al. 2015; García-Mozo et al. 2010).

Not statistically significant correlation was found between the SPI and the number of days in the MPS; however, García-Mozo et al. (2016) recorded an increase in *Poaceae* pollen concentration for 15 years in Córdoba (S Spain). Piotrowska (2012) found a negative correlation between SPI and season duration, peak value and end date. On the other hand, we have found statistical significant trend in MPS length and day start, day end and daily average concentration. In contrast, García-Mozo et al. (2010) have found a lengthening mostly due to the advance of the pollen season start. A trend to appear earlier between onset and peak of pollination was found. This may be in line with other phenological studies of trees that display a general advance in flowering of *Poaceae* pollen (Myszkowska 2014; Stach et al. 2008). However, other studies have shown advance in the pollen season start (García-Mozo et al. 2010; Stach et al. 2007).

Grass pollen concentrations are greatly influenced by weather conditions (García-Mozo et al. 2009). The primary factors, prior to flowering, such as temperature, have influenced in plant growth. After, secondary factor such as rainfall and relative humidity influence pollen release (Laaïdi 2001). García de León et al. (2015) have reported that *Poaceae* development is influenced by exogenous perturbations, mainly temperature and rainfall. The positive relation between *Poaceae* pollen and temperature (maximum, minimum and mean) and rainfall is in consonance with previous papers (García-Mozo et al. 2010). Our study has shown a stronger relationship between *Poaceae* pollen and rainfall of 10 previous days. García-Mozo et al. (2010) have reported the influence with rainfall over the previous months. This fact has been explained because the growth of grasses is related to the water availability, particularly in Mediterranean regions (Clary et al. 2004). In relation to the wind, García-Mozo et al. (2010) claimed that the punctual influence of wind was not a significant factor to control temporal changes during a long term period, even though it is accurate for short analysis of pollen. For this reason, in this study we have not considered this meteorological factor.

It is widely known the relevance of models for predicting *Poaceae* pollen concentration as the forecast of start of the grass pollen season (García-Mozo et al. 2009; Chuine and Belmonte 2004) and daily grass pollen (Stach et al. 2008; Smith and Emberlin 2005; Smith and Emberlin 2006). Temperature and rainfall have been used in other studies (Zhang et al. 2015) to forecast pollen concentration. This study also takes into account pollen records from the 10 previous days, so the predictive value may be more accurate than using meteorological parameters alone. We have considered the more adjusted results to the real pattern of pollination. Relative humidity was the main meteorological factor considered in terms of its effect on the daily pollen forecast. The daily mean temperature and mean temperature of the previous 10 days were secondary factors that could modify this forecast. This fact could be explained due to that herbs and grasses can be less resilient to increases in temperature and relative humidity, unlike trees (Recio et al. 2010). Herbaceous plants such as grasses present more immediate response to meteorological conditions than tree species (Dahl et al. 2013).

To test the accuracy 1 day ahead forecast of these results, R^2 value (0.70) was estimated for the multiple regression model proposed, being a value higher than reported for the same time series for the pollen types; *Cupressaceae* pollen, 0.30 (Silva-Palacios et al. 2015) and 0.46 (Sabariego et al. 2012), *Quercus* pollen 0.58 (Fernández-Rodríguez et al. 2016a). A value closed, 0.77, was reported for *Olea* pollen (Fernández-Rodríguez et al. 2016b) in Badajoz. Other studies have reported forecast models for 7-day ahead forecast values between 0.62 and 0.47 (Smith and Emberlin 2005), and for 30 days ahead forecast, 0.62 (Smith and Emberlin 2006). Stach et al. (2008) have predicted the start of the grass pollen season to within 2 days and achieved between 60 and 70 % accuracy. Furthermore, for the analysis of the entire time period, the fit of the model was examined for a forecast horizon of 1, 7, 15 and 30 days. The R^2 values obtained were 0.70, 0.69, 0.62 and 0.57, respectively, which show a trend in decreasing order with accurate results in all cases. These results and the distribution of posterior probability parameters and R^2 have confirmed the suitability and the robustness of the proposed model.

5 Conclusions

This research highlights the importance to study the climate change as environmental risk factors for allergy and to quantify the natural risks hazards from organic aerosols, *Poaceae* pollen, as natural hazard in the context of urban air pollution as Badajoz (SW Spain).

Furthermore, these results obtained may be used for benefit allergy sufferers, medical professionals and those who produce and stock health care products in Badajoz. The model obtained provides a good level of confidence to forecast *Poaceae* airborne pollen concentration with an R^2 of 0.70, 0.69, 0.62 and 0.57 for a forecast horizon of 1, 7, 15 and 30 days, respectively. These results and the values of probability distribution function by parameters and R^2 have confirmed the suitability of the proposed model.

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