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IDENTIFICATION OF POLLEN SOURCES AFFECTING CATALONIA (SOUTH WEST OF EUROPE) USING SILAM MODEL IN ITS ADJOINT (INVERSE) MODE

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Abstract: Airborne pollen particles can be dispersed into the atmosphere and depending on the meteorological conditions can reach large distances (~10^3 km) and produce allergic symptoms in a part of the population sensitive to it. In this study, the System for Integrated modeLling of Atmospheric coMposition (SILAM) in its inverse mode (source apportionment problem) is applied to determine the main source areas of the episodes that produced high pollen levels in eight aerobiological stations of the Xarxa Aerobiològica de Catalunya (Aerobiological Network of Catalonia) during the years 2006, 2007 and 2008. Because of the low local contribution to birch pollen in Catalonia (NE of Spain), it is believed that the occasional birch pollen peaks observed each spring may come from pollen emitted in other European regions. The model SILAM (Sofiev et al, 2006 a) in its adjoint (inverse) mode has been widely applied to study the contribution of long-range transport to the observed pollen peaks in north Europe (Sofiev et al., 2006 b; Siljamo et al., 2008; Veriankaite et al., 2010) and in this work it has been applied to the South of Europe.

***Key words*: Birch pollen, LRT, SILAM model, aerobiology, footprint.**

INTRODUCTION

Most of allergenic pollens (particles related to the reproduction of flowering plants) are anemophilous (wind-pollinated) and can be transported by the air-masses thousands of kilometers. The use of dispersion models giving to the pollen grains a similar treatment to that of the particulate matter is a good tool to study and understand the mechanisms that contribute to abrupt high concentrations of pollen grains in areas with usual low local influence. One of the species causing allergenic effects is birch tree, mostly in Northern Europe, due to the abundance of birch trees in forests. Nevertheless, punctual peaks are observed in Southern Europe (Catalonia) due to the long-range transport from North to South under concrete meteorological circumstances. We will focus to the study of birch pollen season in Catalonia in 2006, 2007 and 2008. In this study, the System for Integrated modeLling of Atmospheric coMposition (SILAM) in its inverse mode (source apportionment problem) is applied to determine the main source areas of the episodes that produced high pollen levels

MATERIAL AND METHODS

A. Pollen sampling

Airborne pollen data were recorded by the Aerobiological Network of Catalonia (XAC) at eight aerobiological stations located in the Catalan localities of: Barcelona, Bellaterra, Girona, Lleida, Manresa, Roquetes, Tarragona and Vielha. Samples were obtained daily from Hirst samplers (Hirst, 1952) -the standardized method in European aerobiological networks and analyzed following the standardized Spanish method (Galán et al. 2007).

Figure 2. Catalonia (NE of Spain) and the 8 localities of the pollen monitoring stations

B. Modelling

SILAM model version 4.5.1 (Sofiev et al., 2006a; 2006b) (http://silam.fmi.fi) was applied in its forwards and backward mode, in the domain with longitudes comprised between -12º and 18º and latitudes between 35º and 60º. The grid resolution was 15 km. The meteorological input data were from ECMWF. The study periods extended from 1st March to 15th June 2006, from 1st March to 15th May 2007 and from 1st March to 8th May 2008.

The adjoint mode, which is also called inverse or backward, is characterized by the inverse direction of time, the method is based on numerical solution of the adjoint (inverse) dispersion equation and it explicitly computes the sensitivity of the observed values to meteorological processes that can affect each particular observation. Initial conditions are the pollen concentrations in the measurement sites. Results from adjoint simulations are the footprints in the area under study that show the sensitivity of each region to be the potential source for the measured pollen concentrations. Thus, the footprint represents the potential contribution of each surface element of the upwind area to a measured value at the monitoring site. Regarding to the study of long-range transport of pollen, some of the uses that can be attributed to the adjoint mode are:

1. To study the footprint (source area) for an observed peak of pollen. The method will consist in running an inverse simulation starting on the day of the peak with the values of the measured peaks as input in their locations and backward in

time 2 or 3 days depending on the estimation about the permanence of the pollen in air.

2. To study the footprint (source area) for a modeled peak of pollen. An inverse simulation starting on the day of the peak with the values of the modeled peaks as input in their locations and backward in time 2 or 3 days depending on the estimation about the permanence of the pollen in air.

3. To study the failure of the model to predict an observed peak of pollen. An inverse simulation starting on the day of the observed peak with the values of the subtraction of the observed and the modeled values as input in their locations and backward in time 2 or 3 days depending on the estimation about the permanence of the pollen in air.

RESULTS AND DISCUSION

A. Pollen dynamics

In 2006, the beginning of the birch pollen detection was 20th March in Vielha and 24th March in Bellaterra, as can be seen in Figure 3. With the exception of Vielha, the rest of stations started birch pollen season with low values (< 20 grains/m^3) but they increased considerably around 26th -27th April and 29th April (30th in Barcelona and Bellaterra). These peaks are attributed to long-range transport because of their huge value in comparison with the precedent days and the simultaneity in the whole territory.

In 2007 (Figure 4), first detection of birch pollen was on 10th March in Manresa (not shown in the graphic), but it was not until 27th March (not shown in the graphic) that the values became continuous in time. As in 2006, low values were measured with the exception of some days. The days that have been attributed long-range transport were 15th and 19th-20th April. In 2008 (Figure 5), birch pollen detection was in most of the stations after the first half of March. Low values were measured with the exception of Vielha station where measurements reached 333 pollen/m^3 on 25th April. It was on 7th, 25th and 26th of April that relative peaks were observed in several stations and they were again attributed to long-range transport, although the quantities observed were low compared with the values of the precedent years.

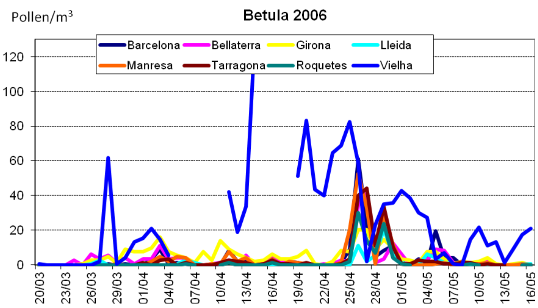
B. Direct pollen simulations

SILAM was first run in direct mode (forward) using data from the Third National Forestry Inventory (IFN3) to update the birch tree distribution in the Iberian Peninsula. SILAM was executed for the entire pollination periods. After that, the results for the different stations for the peak days were extracted and are shown in Table 1 (2006), table 2 (2007) and table 3 (2008).

C. Inverse pollen simulations

After identifying the peaks to be studied in terms of footprints (see Table 1), different simulations were made in inverse mode. Identification of the peaks was done based on observed punctual high concentrations with relation to the precedent days, simultaneously in several stations.

In order to present results for the global Catalonia region, footprints from similar input sources have been multiplied and added. When footprints are multiplied, only the areas where all footprints have a probability nonzero appear; thus, the no coincident areas are removed in the final combined footprint. While adding footprints, common areas have higher values than the regions that are not common, but the final footprint conserves all the areas. Only the footprints with similar origin or at least a similar behavior on the XAC observations have been considered together. In figures 6, 8 and 9 color scale from 10^{-5} to 10^6 .



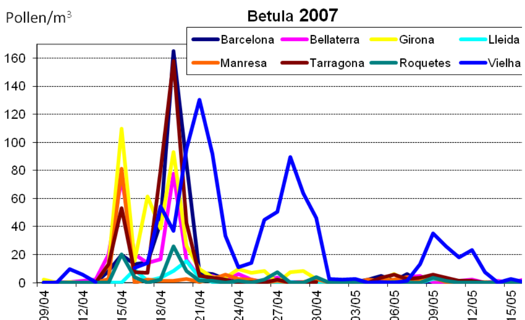


Fig. 3 (Left) Mean daily airborne birch pollen concentration in the stations for 2006, from 20th March to 16th May
Fig. 4 (Right) Mean daily airborne birch pollen concentration in the stations for year 2007, from 9th April to 15th May.

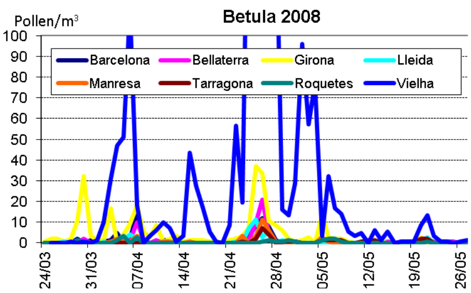


Fig. 5 Mean daily airborne birch pollen concentration in the Catalan stations for year 2008, from 24th March to 30th May.

Table 1. Birch pollen peaks in 2006, 2007 and 2008

2006	26th April, 27th April, 29th April
2007	15th April, 19th April, 20 th April
2008	7th April, 25th April, 26th April

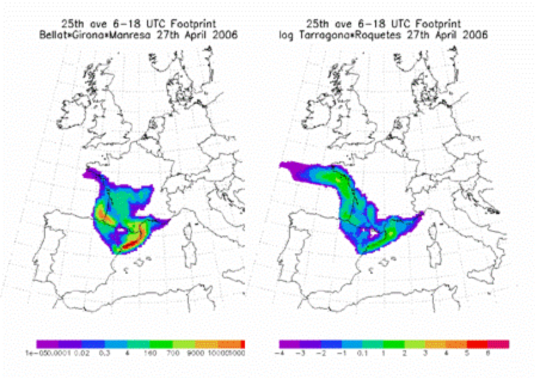


Figure 6. The average footprints on 25th April 2006 on Bellaterra, Girona and Manresa (left panel) and Tarragona and Roquetes (rigth panel) where averaged footprints had been multiplied to show the most probable common area of the emissions causing the peaks on 27th April 2006.

Case 1. Study of the footprint for the observed peak of pollen on 27th April 2006 and 29th April 2006

The failure of the model to predict the peak observed on 27th April 2006 has been analyzed with the inverse simulation for 72 hours starting at 24h of that day. The input file for the inverse simulation was de differences between the measurements and the model results in direct mode (difference between columns Xac and Silam for 27th April, Table 1). Figure 6 shows the average footprint, after multiplication, from Bellaterra, Girona and Manresa (left panel) on 25th. The scale used is logarithmic. The stations located in the south of Catalonia (Tarragona and Roquetes) have also a similar footprint (right panel), that becomes more different when increases the distance to the station sites. Results show the most probable area of emissions as a local region in the coast, but this is not consistent because birch trees are not abundant in that area (figure 1). The other regions that appear in footprints are west Pyrenees and south of France. Only in Pyrenees there is some fraction of birch trees, but most of pollen is still in the catkins as can be seen in Figure 7, right down panel, which shows the percentage of pollen delivered from catkins. This can be the reason of the low values obtained in the forward simulation in comparison with the observed ones. Thus, contrasting the footprint area with the emissions on 26th April 2006 (Figure 6), we can conclude that, with the exception of some grid cells in the Pyrenees, most of the footprint area had no emissions on that day.

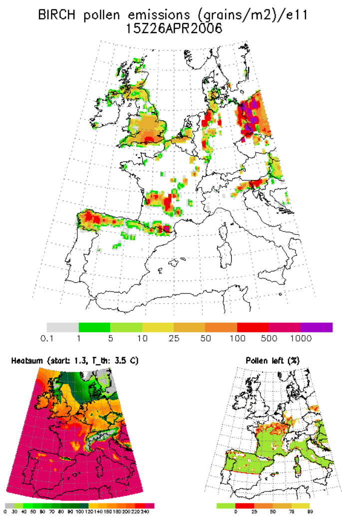
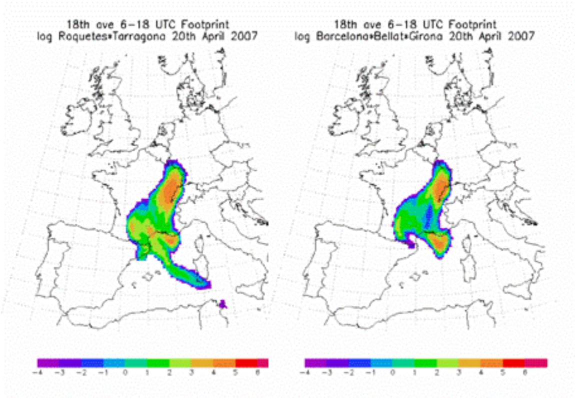


Figure 7. Emissions on 26th April 2006 at 15UTC, central panel, heatsum in left panel, and percentage of pollen delivered from catkins in right panel.

The cause for the discrepancy between de observation and the forward model simulation can be the same for 29th April. The footprint on 27th April corresponded to a narrow area extending over western France from north to south (not shown). Emissions map showed that, similarly than in the previous case, even small amount had been released in this area on 27th April (not shown).

Case 2. Study of the footprint for the modeled peak of 20th April 2007

The study of the footprint for a modeled peak of pollen has been applied to 20th April 2007. Figure 8 shows the results from the inverse simulation on 18th April 2007, being, in this case, the output from the forward model simulation the values used as input data in the inverse simulation. The figure shows the multiplication of the average footprints from 6UTC to 18UTC for Bellaterra, Girona and Barcelona (right panel) and for Tarragona and Roquetes (left panel), in logarithmic scale. The emissions causing the peak are situated in the north-east of France, extending towards the Alps, and Western Switzerland, on 18th April.



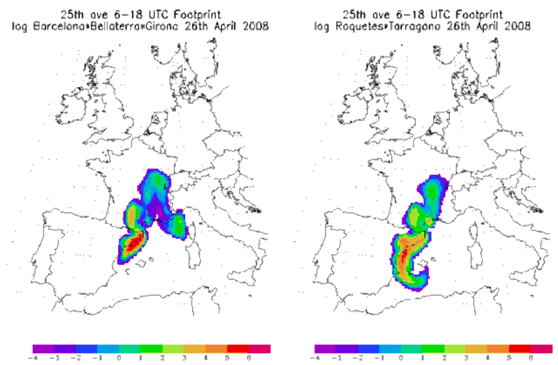


Figure 8. (Left) The average footprints on 18th April 2007 on Tarragona and Roquetes (left panel) and Barcelona, Bellaterra and Girona (rigth panel) where averaged footprints had been multiplied to show the most probable common area of the emissions causing the peaks on Catalonia on 20th April 2007.

Figure 9. (Right) The average footprints on 25th April 2008 on Barcelona, Bellaterra and Girona (left panel) and Tarragona and Roquetes (rigth panel) where averaged footprints had been multiplied to show the most probable common area of the emissions causing the peaks on Catalonia on 26th April 2008.

Case 3. Footprint for the observed peak of 26th April 2008

Finally, we used the XAC observations as inputs to the inverse modeling on 26th April 2008. Figure 9 shows the results of the multiplication of the 6-18 UTC averaged footprints for Barcelona, Bellaterra and Girona (left panel) and Roquetes and Tarragona (right panel). Simulation shows emissions in east of France the 25th April as the most probable source area for the peak registered in Catalonia on 26th April 2008 (figure 9).

CONCLUSIONS

SILAM pollen simulations have been used to study the behavior of birch pollen in South of Europe. Three years were modeled in terms of forward Eulerian modeling and in inverse Eulerian modeling. The forward modeling reproduced enough accurately the local season, but some problems were observed in punctual peaks attributed to long-range transport. The inverse modeling has been applied to study those peaks.

The main application of the inverse modeling was to identify the failure of forward modeling, in the location of the most probable source areas of the emissions causing the peaks in the Catalan stations. Inverse simulations were done for 2 days backward in time. Most of the results show different regions of France as the source area. Since there is a great uncertainty in birch fraction map in France, it seems that an improvement in that quantity could affect considerably to the reproduction of the peaks by the model.

Other applications for the inverse modeling have been the identification of the source areas for some modeled and observed peaks, using the output of forward model and the XAC measurements as inputs in the source file, respectively.
In terms of analysis, the average in daily hours for one day or for two days before the occurrence of the peak had been used individually for each station or combined by addition or by multiplication of the footprints for different stations. It seems that multiplication of the footprints gives the common area of the combined footprints, what is easy to interpret. But it can be dangerous to combine too many stations since they can have totally different footprints depending on the meteorological situation affecting to the different points.

Other considerations in the figures showing the average for the inverse model results are that the quantities shown are only representative in terms of comparison inside the figure, but they cannot compare with other figures since the values represented has not sense because they have not been properly scaled. They represent a sensitivity function ranged with the source input magnitude, but it should be scale to represent the probability, anyway the higher values show the most probable sources areas.

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