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Synoptic and meteorological characterisation of olive pollen transport in Córdoba province (south-western Spain)

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Abstract The main goal of the present study was to provide a detailed analysis of olive pollen transport dynamics in the province of Córdoba (south-western Spain) by applying back-trajectory analysis. Pollen data from 2006 and 2007 were analysed at four monitoring sites: Córdoba city in the centre of the province, Baena and Priego de Córdoba located in the south, and El Cabril reserve (Hornachuelos Natural Park) in the north. Particular attention was paid to nine episodes of high pollen counts. Synoptic surface maps were used, and kinematic back-trajectories (3D) were computed using the hybrid single particle Lagrangian integrated trajectory model (HYSPLIT) at 500 m above ground level, run with a time-step of 6 h over a period of 36 h. Findings were analysed in conjunction with daily and bi-hourly airborne pollen data, field phenological data and hourly surface meteorological data recorded at nearby stations: temperature, relative humidity, rainfall, wind direction and wind speed. The results identified two pollen source areas over the Córdoba province, the largest one located in the south, affecting

Baena, Priego de Córdoba and Córdoba city, and one smaller located in the west, which determines mainly the pollen cycle over the north of the province, El Cabril. In addition, two air mass circulations were found, one coming from the south and crossing the main olive pollen sources very close to the surface and being frequently associated with higher pollen counts, and the other coming from the west and, in the episodes investigated, influencing mainly the north of the province.

Keywords Aerobiology · Olive pollen · Back-trajectory · Synoptic conditions · Meteorological conditions

Introduction

Airborne biological particles are affected by a number of aerobiological processes, including release, dispersal and/or transport, and deposition. Once released into the air, particles are exposed to the horizontal and/or vertical movement of air masses in the atmosphere, which may encourage their transport, confinement or dispersal.

There is a well-documented direct correlation between pollen counts and certain weather-related parameters. Temperature and relative humidity are among the most critical meteorological values in determining olive-pollen counts in a given area (Fornaciari et al. 1998; Vázquez et al. 2003). These parameters are relevant mostly for determining the time and intensity of flowering. But olive-pollen dynamics are also affected by wind and rainfall, which may lead to the presence of pollen from remote areas (Bullock and Clarke 2000).

A combined study of potential pollen sources and back-trajectory air mass calculations could improve the identification of actual pollen source areas and transport dynamics.

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Back-trajectories chart the path travelled by an air mass over the days prior to its arrival at a given site. They provide information on the possible local, regional or long-distance transport of pollen, as well as on the origin of airborne pollen. In recent years, a number of papers have highlighted the value of this tool in aerobiological studies (Stach et al. 2007; Skjóth et al. 2008; Smith et al. 2008).

Since the southern Spanish region of Andalusia is the world's leading olive-oil-producing region, the study of olive-pollen transport dynamics is of considerable economic importance. Spain produces 33% of the world's olive oil, and Andalusia accounts for 80% of total Spanish output. The largest olive-growing areas are concentrated in the provinces of Jaén and Cordoba. The use of airborne pollen data as an indicator of final olive harvest has proved valuable. A number of published studies have charted the relationship between pollen release and olive production in Andalusia (Galán et al. 2004, 2008) and also in both central Italy (Fornaciari et al. 2002), and Portugal (Ribeiro et al. 2007).

In Cordoba province, the main olive-pollen season runs from April to June. Weather conditions prior to flowering govern the pollen-season start-date, as well as its duration and intensity, but this date also depends on the topographical location of pollen sources. In the city of Cordoba, located in the Guadalquivir valley, airborne pollen counts are characterised by a number of peaks forming a seasonal curve. Previous studies in the province, based on field phenological and aerobiological data, have sought to clarify the real contribution of the various olive-growing areas to airborne pollen counts. The results obtained suggest that crops located far from the trap (over 50 km) may contribute to the pollen curve on days with favourable winds during the flowering period (Fornaciari et al. 2000).

The main goal of the present study was to provide a detailed analysis of olive-pollen transport dynamics in the province of Córdoba, using daily and bi-hourly airborne pollen data obtained from four traps located in different areas of the province, together with field phenological data of the areas around the traps. High pollen count episodes recorded in 2006 and 2007 were examined using back-trajectory analysis, with a view to charting the previous path of air masses and their possible influence on pollen counts.

Material and methods

Four pollen sites were studied: Cordoba, in the Guadalquivir river valley, Baena and Priego, in the Subbética Mountain Chain, and the “El Cabril” reserve in the northern part of the Hornachuelos Natural Park, Sierra Morena Mountain Chain (Fig. 1a, Table 1). It should be noted that data from Priego were available only during 2007. Figure 1b shows a south–north gradient of *Olea* pollen sources across Cordoba

province, highlighting the minimal presence in the north and a large source area located in the south.

Olive-pollen counts from 2006 and 2007 were obtained using Hirst-type volumetric traps (Hirst 1952). Standardised data management procedures followed the rules laid down by the Spanish Aerobiology Network (REA; Galán et al. 2007). For the purposes of the present study, “episode days” included days on which peak pollen counts were recorded, and also days on which high pollen counts were recorded outside the typical hours reported by Galán et al. (1991) in a study of the intradiurnal pattern for airborne olive pollen counts in Cordoba, which noted maximum values between 11:00 UTC and 17:00 UTC. Weekly field phenological data were recorded for olive-groves surrounding the traps at Córdoba, Baena and Priego. The phenological key developed by Maillard (1975) was used to identify the main stages in floral phenology.

Back-trajectory analysis was carried out using the HYSPLIT model (hybrid sail-particle Lagrangian integrated trajectory) Version 4 (Draxler and Hess 1998; Draxler et al. 2005). This model was developed by the Air Resources Laboratory (ARL) at the US National Oceanic and Atmospheric Administration (NOAA). Of the various types of back-trajectory available depending on the calculated conditions (e.g. kinematic 3D, isentropic, isobaric, sigma), the kinematic 3D trajectory was selected as being more accurate when vertical wind fields are present. The weather data used for the computation of trajectories came from the FNL and GDAS archives maintained by ARL. This kinematic back-trajectory seems to have an error of 20% of the distance travelled (Stohl 1998).

Back-trajectories of 36 h with a time-step of 6 h were calculated at different hours at all sites on episode days, in order to detect possible links between the variability and pathways of air mass trajectories and the pollen counts recorded. This temporal coverage of each back-trajectory was decided after testing a range from 24 to 96 h. The results obtained suggested that the most suitable tool for charting local/regional transport from nearby pollen sources was a back-trajectory of 36 h. Moreover, given the topography of the area (Fig. 1b) and the need to calculate trajectories close to the ground due to the low height of pollen displacement, a preliminary study was performed to determine any anomalies in the back-trajectory calculation with respect to height. Back trajectories were plotted at all sites during each episode at heights ranging from 100 m a.g.l. (metres above ground level) to 800 m a.g.l., at 100 m intervals (not shown). The results showed that a single trajectory at 500 m a.g.l. could be taken as representative; therefore, one single trajectory is shown for each episode. It should be noted that, despite this validation, differences might still exist between air mass arrival and the wind direction registered at ground level due to the spatial resolution of the

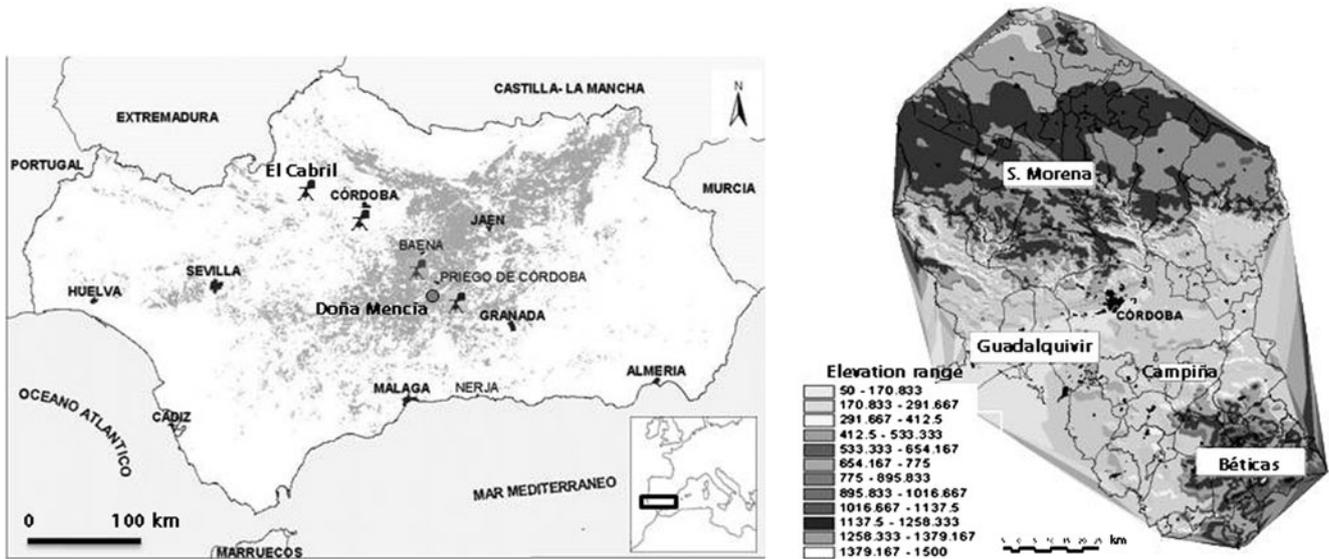


Fig. 1 a) Location of the study sites and meteorological stations in Andalusia, representing grey areas the olive crop distribution. b) Orography of the Córdoba province

model and the particular topography of the area (Fig. 1a). However, these potential differences did not alter the value of the trajectories, which in this study were intended to provide information on possible pollen routes rather than on wind conditions at a particular point.

Weather characterisation focussed mainly on identifying the synoptic situations associated with high-pollen-count episodes in conjunction with local weather data such as relative humidity, temperature, rainfall, wind speed and wind direction. Data were subjected to Pearson’s correlation test in order to chart the relationship between meteorological parameters and pollen counts. Three conditions were considered when selecting weather stations: closeness to pollen traps, representatives of the temporal and spatial meteorological environment, and availability of data during episode days. The weather stations selected were: Córdoba and Priego, belonging to the Spanish Meteorological Agency (AEMET); Baena, belonging to the Andalusia Government Agroclimatic

Information Network (RIA); and El Cabril, belonging to the ENRESA company (Fig. 1a; Table 1).

Results

Temporal pollen-count variations

Curves for daily average airborne olive-pollen counts at monitoring stations in 2006 and 2007 are shown in Fig. 2. In both years, the highest pollen counts were recorded at Baena, located inside the large olive-pollen source area (Fig. 1a). In general, curves displayed an irregular pattern, with peaks that tended to coincided in time but vary in magnitude. The main flowering period at each site, as identified using field phenological data, is also shown in Fig. 2. In some cases, main pollen peaks did not coincide with the local flowering period.

Table 1 Monitoring sites used in this study. *a.m.s.l.* Above mean sea level

Stations	Site	Latitude	Longitude	Altitude a.m.s.l.
Meteorology	Córdoba	37° 50' N	4° 51' W	91
	Baena	37° 41' N	4° 18' W	334
	Doña Mencía (Priego de Córdoba)	37° 33' N	4° 21' W	650
	El Cabril	38° 4' N	5° 24' W	450
Pollen	Cordoba (COR)	37° 50' N	4° 45' W	123
	Baena (BAE)	37° 37' N	4° 19' W	363
	Priego de Córdoba (PRI)	37° 26' N	4° 11' W	650
	El Cabril (CAB)	38° 4' N	5° 24' W	450

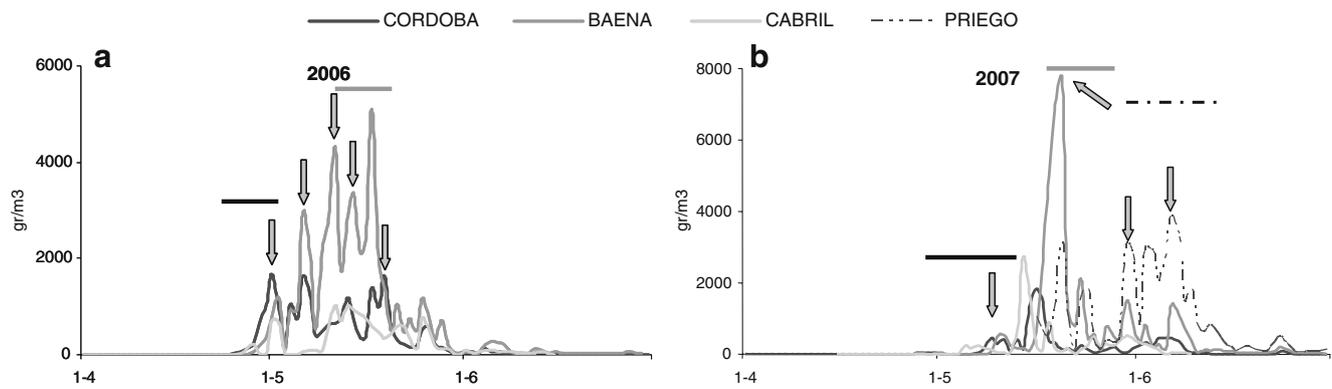


Fig. 2 Olea pollen daily evolution from April to June in each measurement station in 2006 (a) and 2007 (b). Horizontal bars Time period of full flowering in each area detected from field phenological observations. gr/m^3 Pollen grains per cubic metre

Analysis of episodes

Episode days were analyzed in order to determine which weather conditions might favour higher pollen counts, and to trace the potential origin of non-typical intra-diurnal patterns. Bi-hourly pollen measurements at each site during episode days are shown in Figs. 3 and 4.

Nine episodes, all occurring in May and June of 2006 and 2007, were selected for characterisation using kinematic 3D back-trajectories, isobaric surface maps and weather data recorded on the episode day (Table 2). To reduce the number of plots, isobaric maps representing the typical synoptic configuration on the episode day are shown at the end of the weather analysis.

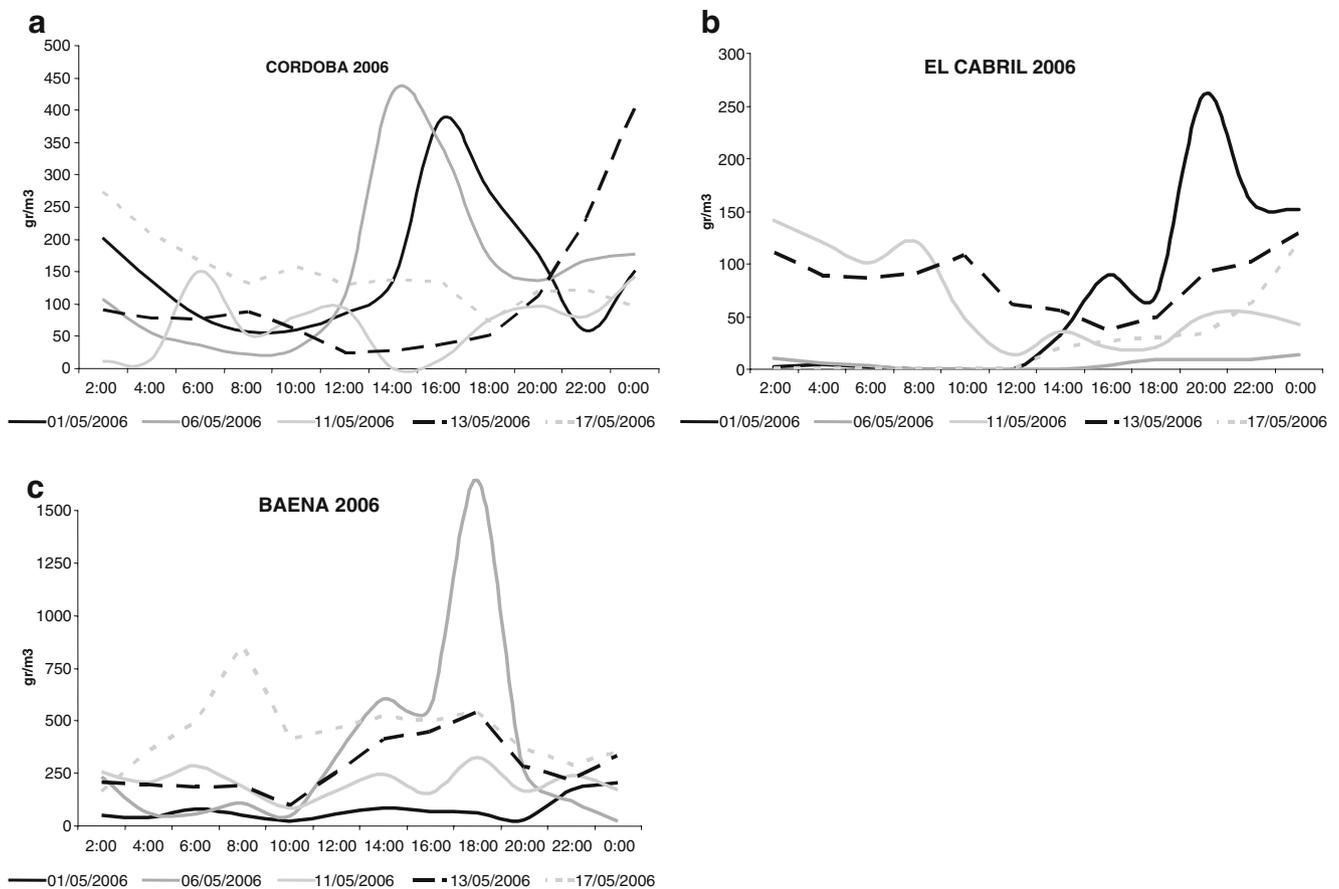


Fig. 3 Bi-hourly olea pollen counts registered in each episode at a Cordoba, b El Cabril and c Baena stations during 2006

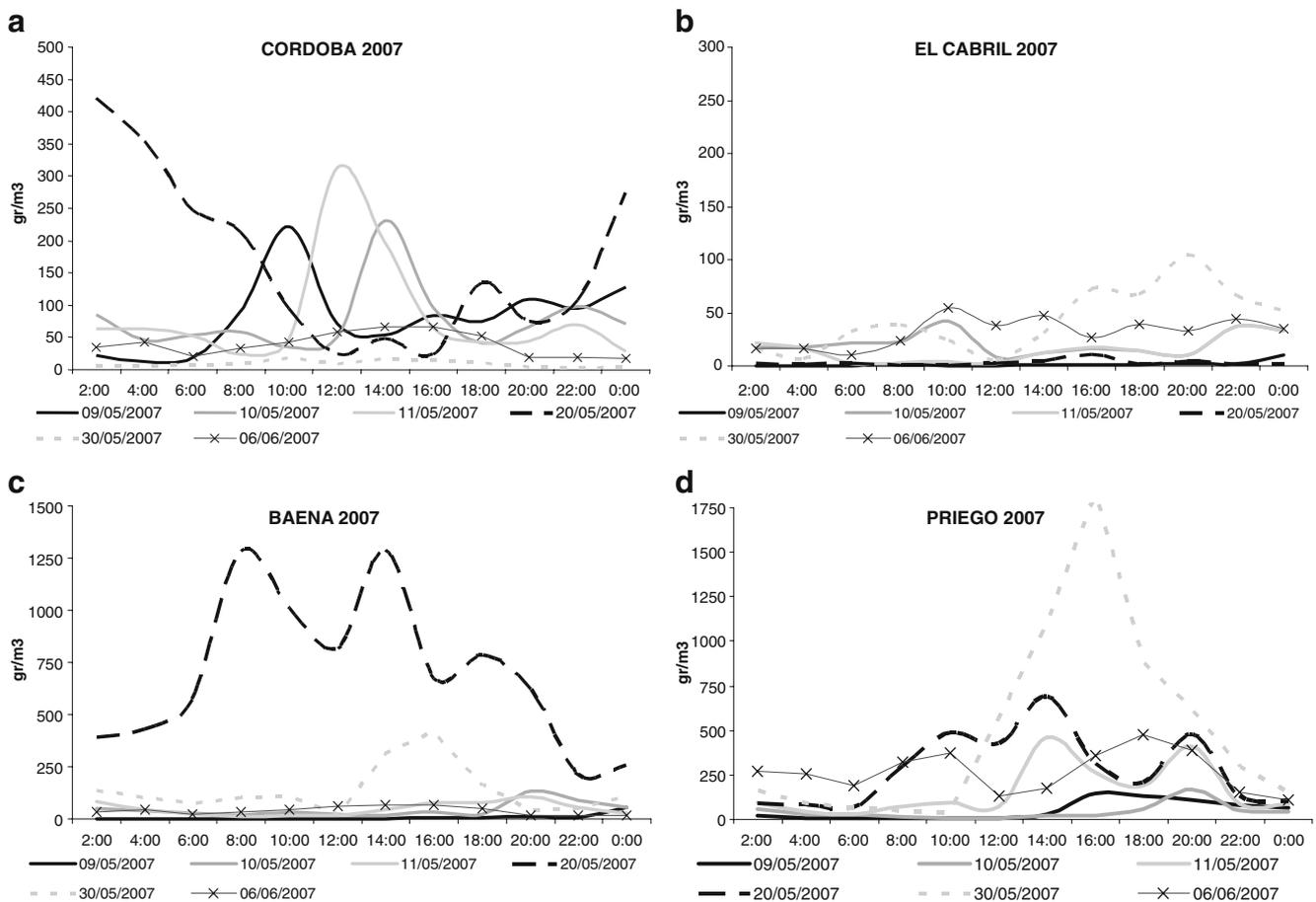


Fig. 4 Bi-hourly olea pollen counts registered in each episode at **a** Cordoba, **b** El Cabril, **c** Baena and **d** Priego de Cordoba stations during 2007

Episode 1: 1 May 2006

The maximum daily pollen count in Cordoba during 2006 was recorded on 1 May [1,668 grains(gr)/m³; Fig. 2) with a peak at 16:00 UTC (Fig. 3a). Pollen counts on that day were lower at Baena and El Cabril (793 gr/m³

and 713 gr/m³ respectively), and peaked later at El Cabril, where an increase was noted from 12:00 UTC onwards (Fig. 3b).

The synoptic configuration was characterized by the absence of any large pressure gradient over the Iberian Peninsula, with weak low-level African troughs affecting

Table 2 Daily mean, maximum and minimum temperature (T_{mean} , T_{max} , T_{min}) and relative humidity (RH_{mean} , RH_{max} , RH_{min}) data recorded in the nearest meteorological station during each episode

Episode date	Site	Temperature (°C)			Relative humidity (%)		
		T_{max}	T_{mean}	T_{min}	RH_{max}	RH_{mean}	RH_{min}
1 May 2006	Córdoba	29.0	20.4	11.7	92.2	60.2	32.5
6 May 2006	Baena	25.6	19.1	13.0	89.0	63.8	39.9
11 May 2006	Baena	18.1	15.2	13.7	89.2	76.3	57.5
13 May 2006	Baena	32.0	27.7	15.8	82.7	65.5	29.9
17 May 2006	Baena	40.8	29.7	18.4	75.2	37.3	10.6
10 May 2007	Baena	30.9	23.0	14.8	61.3	40.2	15.5
20 May 2007	Baena	30.1	17.5	12.7	82.5	61.0	43.5
30 May 2007	Priego de Córdoba	24.8	18.9	12.9	57.0	42.5	29.7
6 June 2007	Priego de Córdoba	28.5	21.6	15.9	54.7	43.1	32.2

the southern part of the region. This stable synoptic situation favoured mesoscale processes over Cordoba, with prevailing southwesterly winds, thus contrasting with the southerly synoptic flows recorded over subsequent days. The wind recorded during the episode at El Cabril ranged from southerly to south-westerly.

The set of back trajectories displayed a different air-mass path between Cordoba-Baena and El Cabril (Fig. 5), combining a slight air-mass movement close to the surface during the preceding hours, heading from the south inland

into central Andalusia for Córdoba-Baena, with a northerly flow veering southwesterly for El Cabril.

The daily average temperature and relative humidity in Córdoba were 20.4°C and 60.2%, with maxima of 29.0°C and 92.1%, respectively (Table 2). There was no rainfall on that day; however, rains and intense wind on 3 May prompted a considerable drop in airborne pollen counts at all stations (Fig. 2).

Since these stable weather conditions did not favour long-distance pollen transport, this high-pollen-count episode in

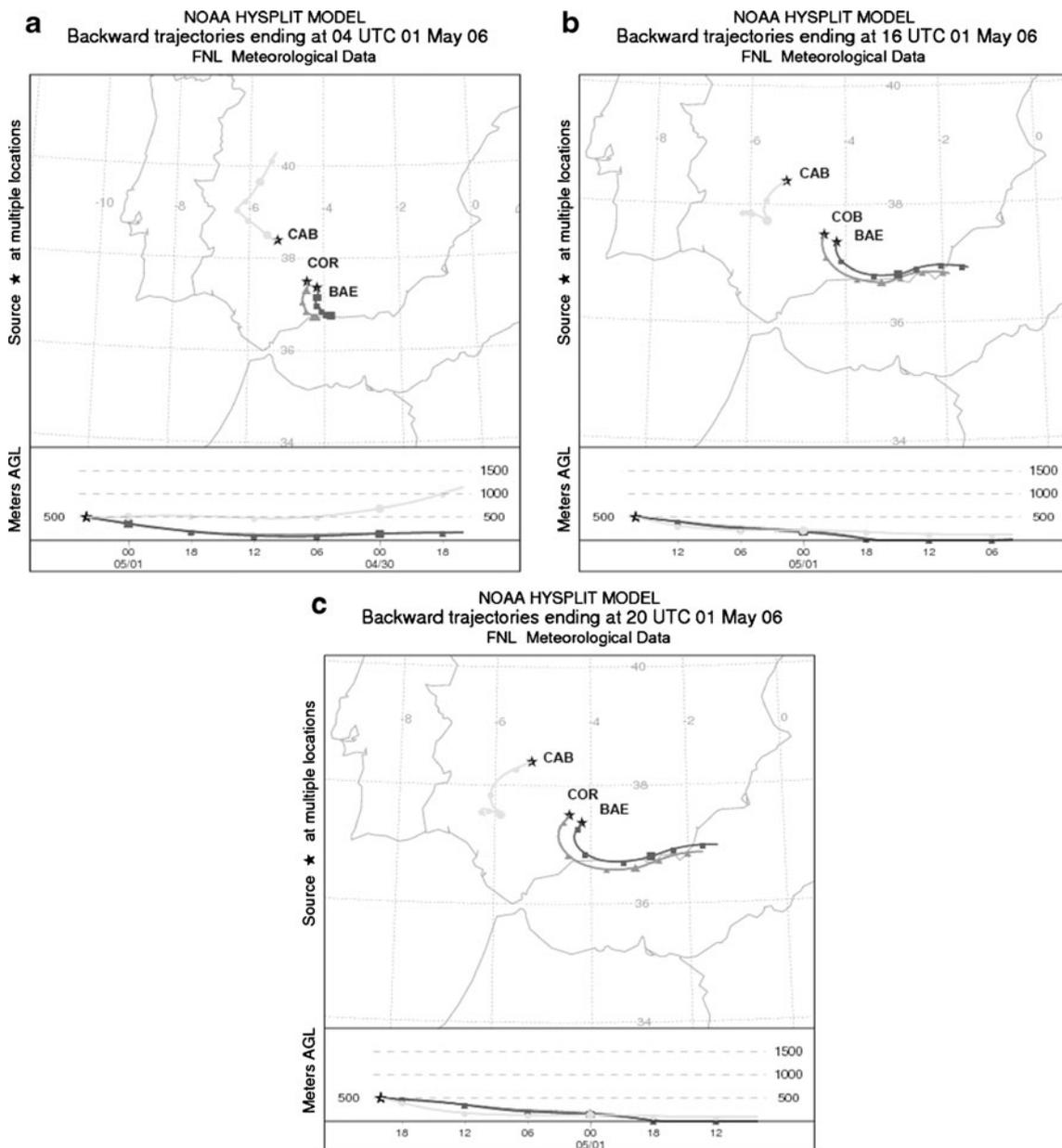


Fig. 5 Maps showing 36-h back trajectories at a final height of 500 m at **a**) 04:00, **b**) 16:00 and **c**) 20:00 UTC on 1 May 2006 at the Córdoba (Cor), El Cabril (Cab) and Baena (Bae) sites

Cordoba might be attributable to pollen-sources on the outskirts of Cordoba city, located beside the river and in lowland arable areas, coinciding with the full flowering period detected by the field phenological survey (Fig. 2). This hypothesis is borne out by the intra-diurnal pollen pattern for Córdoba (Fig. 3a), and the absence of peak counts at Baena (Fig. 3c). In contrast, at El Cabril the increased pollen count was associated with external sources located to the southwest, and was clearly attributable to the change in back-trajectory movement over the course of the day, with whose timing it coincided (Figs. 3b, 5).

Episode 2: 6 May 2006

Pollen counts at the study sites differed considerably: 2,967 gr/m³ at Baena, 1,633 gr/m³ at Córdoba and 59 gr/m³ at El Cabril (Fig. 2). However, these counts were associated with peaks at various times in the course of the day in Cordoba (Fig. 3a) and Baena (Fig. 3c), but not in El Cabril (Fig. 3b).

The synoptic configuration displayed a weak pressure gradient, with a low-pressure system to the north and a high to the west. At Baena and Cordoba, back trajectories showed a progressive change towards a path close to ground level (i.e. below 500 m) as far as the Mediterranean east coast and finally moving up the natural channels connecting the Mediterranean coast with the Guadalquivir valley, crossing the olive pollen source close to Baena (Fig. 6). At El Cabril, by contrast, air-mass movements remained westerly/northwesterly (Fig. 6).

On the episode day, an increase in pollen counts was recorded at all sites. The increase was especially marked at Baena (Fig. 2), coinciding with a weak mesoscale wind regime characterized by southwesterly/westerly flows in the afternoon. In Córdoba, wind direction was also southwesterly. Daily mean temperature was 19.1°C, with a mean relative humidity of 63.8% (Table 2).

The similar timing of peaks in Baena and Cordoba (Fig. 3a–c), taking into account back-trajectory circulation and the stable weather conditions, indicates that, in both cases, peaks were probably attributable to local pollen sources or to regional transport from sources near the Baena trap. However, while the peak count in Córdoba was recorded at 14:00 UTC (Fig. 3a), in Baena it was registered at 18:00 (Fig. 3c), by which time pollen counts in Córdoba had dropped down to an intermediate range. The lower pollen counts at El Cabril (Fig. 3b) are attributable to air mass circulation over areas where olive-pollen sources are minimal.

Episode 3: 11 May 2006

During the preceding days, a slight increase in pollen counts at Córdoba and El Cabril contrasted with the

considerable, though gradual, rise in counts at Baena, to 4,303 gr/m³ on 11 May 2006, coinciding with the local flowering season (Fig. 2). No clear sharp intradiurnal peaks were detected in Cordoba (Fig. 3a) or Baena (Fig. 3c), where pollen counts were similar at certain times; by contrast, at El Cabril there was a more marked difference between morning and afternoon counts (Fig. 3b).

Weak high and low pressure systems affected the Iberian Peninsula (range 1,010 to 1,015 hPa), with an intensive low pressure system situated in the west. This led to relative instability, temperatures ranging between 18.1°C and 13.7°C, and relative humidity averaging 76.3% (Table 2).

Similar air-mass movements were detected at all three sites in the morning; masses travelled close to the ground, heading south over the Mediterranean as far as the Andalusian coast, where they moved inland at the tip of the Andalusia (Fig. 7). While this wind path was maintained over Baena and Cordoba, data logged at El Cabril indicated a greater influence of westerly air masses (Fig. 7). Surface data indicated a shift from southerly to westerly flux.

Pollen counts over the course of the day were thus determined by wind behaviour in two different ways. First, similar intradiurnal curves were recorded at Baena and Córdoba, with unexpected drops at 12:00 UTC in Baena and 2 h later in Córdoba, suggesting regional transport of air mass containing high pollen counts from the area around Baena towards Cordoba (Figs. 3a–c, 7). A similar air-mass movement was observed at El Cabril, with higher counts until midday, when a change in the air mass pathway causing a rapid decline in the pollen count (Figs. 3b, 7).

Episode 4: 13 May 2006

Daily pollen counts ranged between 2,874 gr/m³ at Baena, and 1,007 gr/m³ at El Cabril, the count in Córdoba being 1,178 gr/m³ (Fig. 2). However, there were greater differences in intradiurnal patterns, with a marked increase in counts from 12:00 UTC to 20:00 UTC in Baena (Fig. 3c), and from 18:00 UTC onwards in Cordoba (Fig. 3a), while lower pollen counts were registered in El Cabril during the central hours of the day (Fig. 3b).

The progressive westward shift of the low-pressure system prompted relatively stable weather conditions. Average meteorological data were moderate: temperature 27.7°C and relative humidity 65.5% (Table 2).

As in the previous episode, the air mass came inland over the Mediterranean coast through the valleys connecting the two areas (Fig. 8). Back trajectories suggested that the movement was very close to the ground (i.e. lower than 100 m) over Cordoba and Baena, but higher over El Cabril, where the air mass continued to arrive from the west throughout the day. This difference in wind dynamics across the province was confirmed by surface wind data.

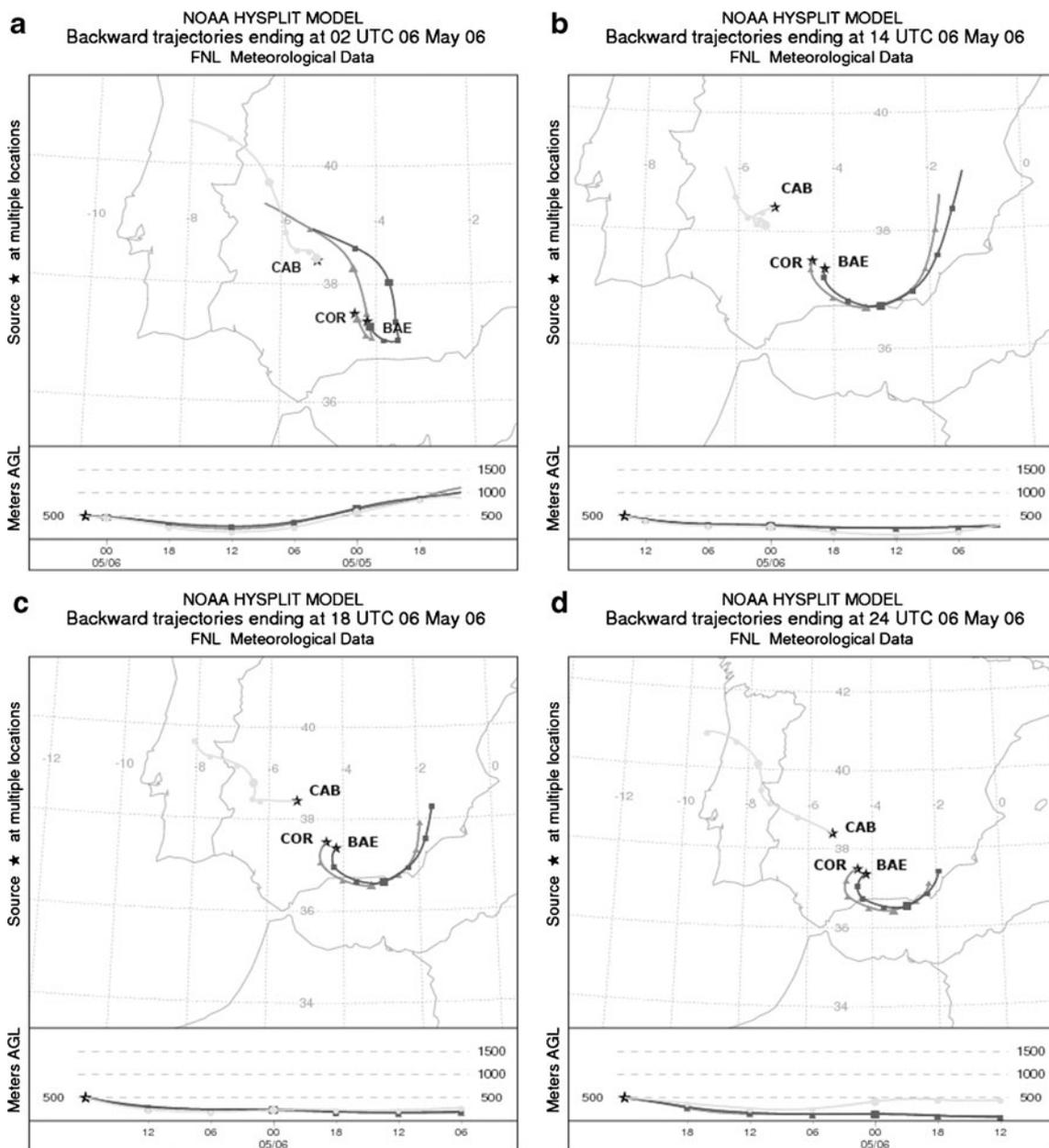


Fig. 6 Maps showing 36-h back trajectories at a final height of 500 m at **a)** 02:00, **b)** 14:00, **c)** 18:00 and **d)** 20:00 UTC on 6 May 2006 at the Córdoba (Cor), El Cabril (Cab) and Baena (Bae) sites

This episode coincided with the full flowering period (field phenological data) in Baena (Fig. 2), suggesting that the high pollen counts were due to local transport from nearby sources. Moreover, the intradiurnal curve at Córdoba, an unusual peak during the night, and the time difference between peaks registered in Córdoba and Baena (Fig. 3a–c), could indicate that pollen counts at Córdoba were due to regional transport from the Subbética Mountains. Airborne pollen counts at El Cabril were again clearly influenced by olive sources outside the province (Fig. 8).

Episode 5: 17 May 06

A marked difference was observed between Baena and the other weather stations (Fig. 2): pollen counts in Baena reached 5,109 gr/m³ on 17 May, peaking at 8:00 UTC (Fig. 3.c). By contrast, counts remained low in Córdoba (1,393 gr/m³) and El Cabril (588 gr/m³), peaking in the morning and at night, respectively (Fig. 3a–b).

The synoptic situation was marked by the absence of a pressure gradient over the Iberian Peninsula, where high warm-air masses led to predominantly stable weather

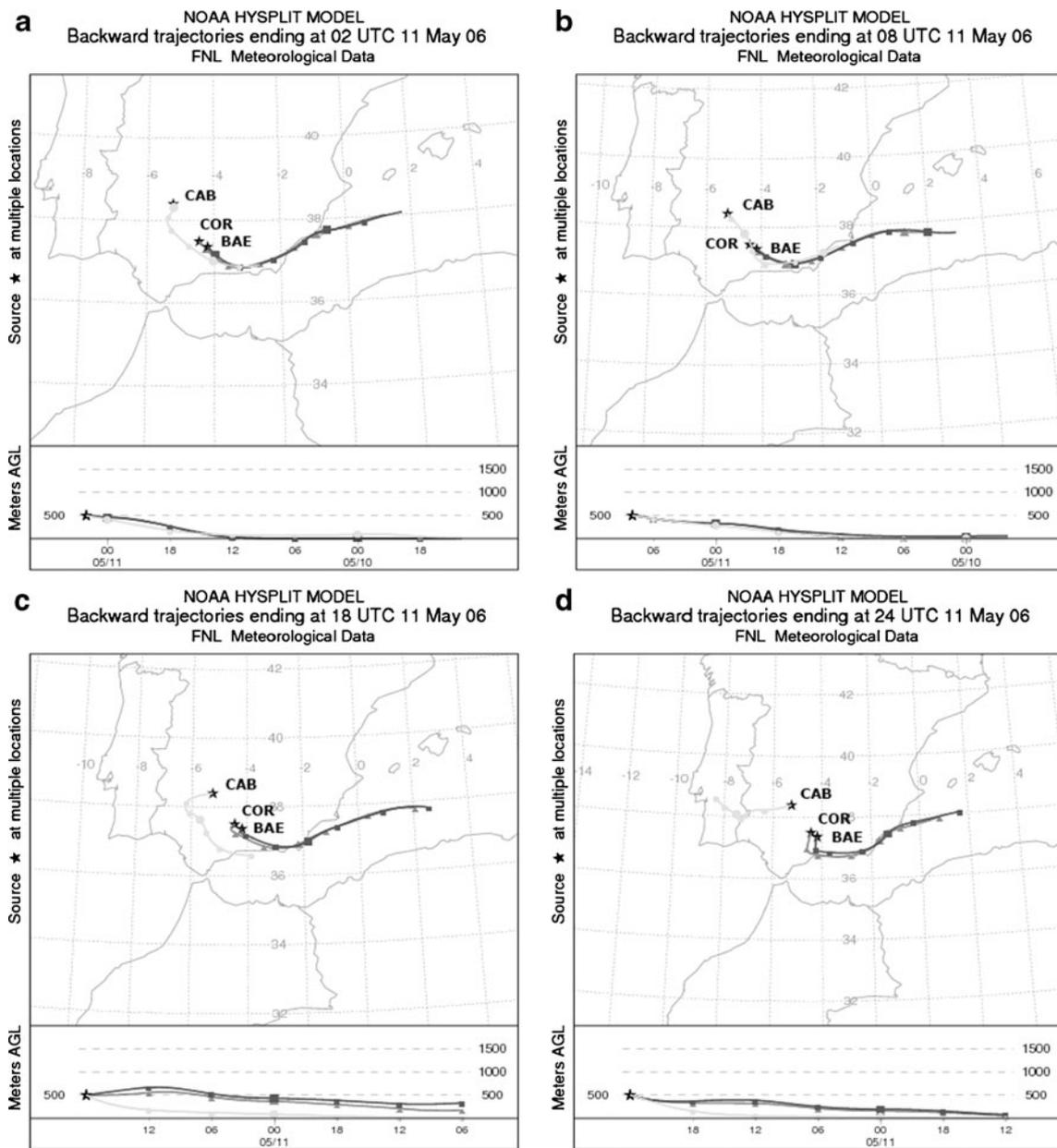


Fig. 7 Maps showing 36-h back trajectories at a final height of 500 m at **a**) 02:00, **b**) 08:00, **c**) 18:00 and **d**) 24:00 UTC on 11 May 2006 at the Córdoba (Cor), El Cabril (Cab) and Baena (Bae) sites

conditions. Back trajectories calculated from Cordoba and Baena (Fig. 9) showed high-level air-mass movements from North Africa in the early hours of the day, dropping gradually to around 500 m over the Mediterranean and moving northwards towards central Andalusia. At El Cabril (Fig. 9), air-mass movements shifted from southerly to northerly over the province, leading gradually to a cyclonic gyre with air-mass input from the west, of south-westerly continental origin.

The temperature ranged between a maximum of 40.8°C and a minimum of 18.4°C; mean relative humidity was 37.3%, and there was no rainfall (Table 2). The wind was

variable in the morning over Baena and Cordoba, and by afternoon was blowing from southwest/west. At El Cabril, there was a progressive change in wind direction.

Since olive-groves were still flowering (Fig. 2), pollen counts at Baena—considerably higher than those recorded at other sites—were probably attributable to local release and transport from nearby sources. However, taking into account the back-trajectory (Fig. 9) and peak-detection time (Fig. 3c), inputs from sources located in North Africa cannot be ruled out. The pollen cycle in Cordoba (Fig. 3a) displayed an intradiurnal curve with maximum values at night, probably due to stable wind conditions prompting

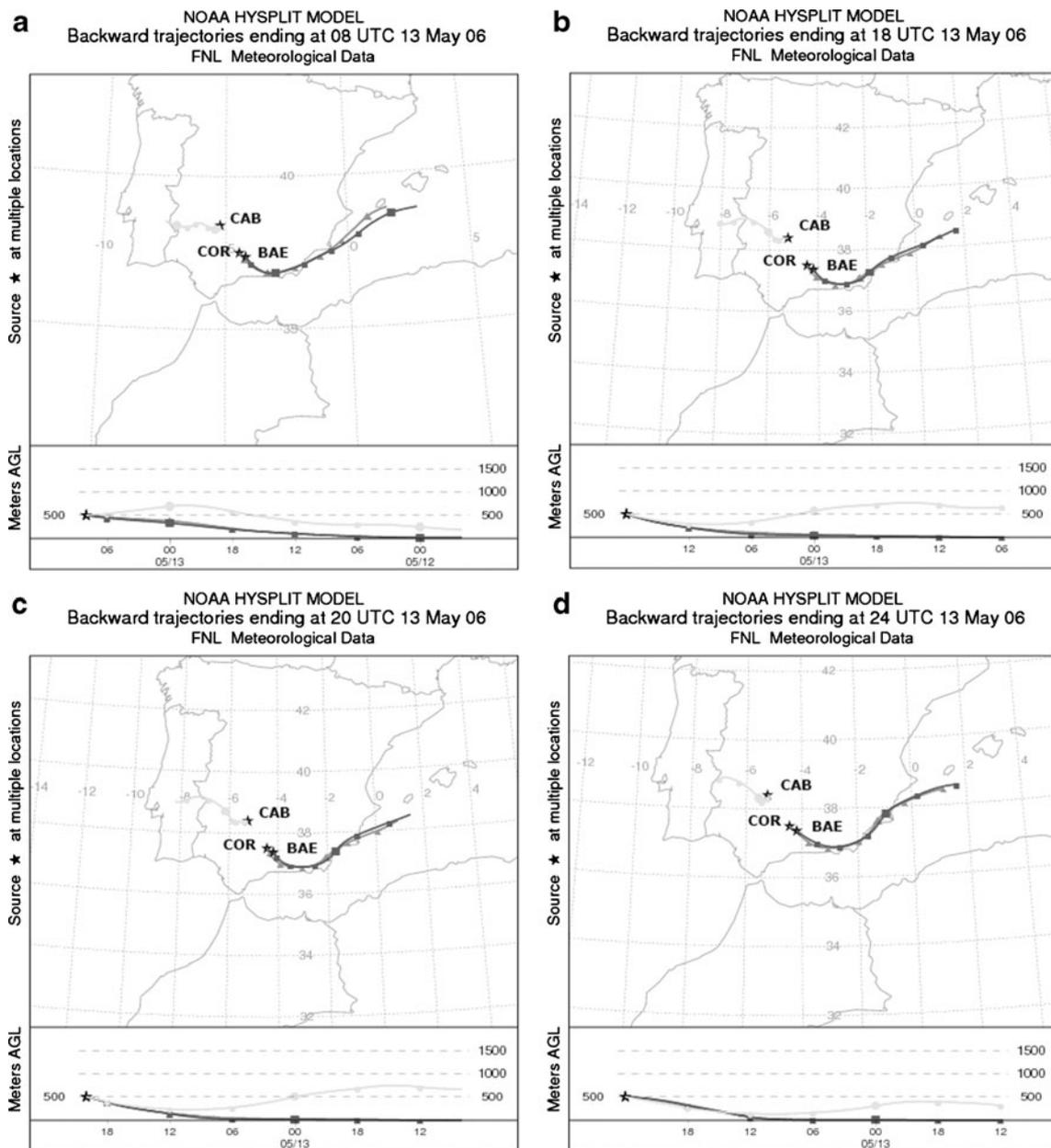


Fig. 8 Maps showing 36-h back trajectories at a final height of 500 m at **a)** 08:00, **b)** 18:00, **c)** 20:00 and **d)** 24:00 UTC on 13 May 2006 at the Córdoba (Cor), El Cabil (Cab) and Baena (Bae) sites

katabatic flows or possibly—as in Baena—to external pollen sources outside the province. Comparison of air-mass variability and pollen counts at El Cabil indicated that rising pollen counts from 14:00 UTC (Fig. 3b) were attributable to external pollen sources located to the southwest.

Episode 6: 9–11 May 2007

From 9 to 11 May 2007, pollen count patterns differed between stations. While in Cordoba a single daily peak was detected at different times (Fig. 4a), the other sites

displayed no major peaks, apart from one in Priego at 10:00 UTC on 10 May 2007 (Fig. 4d).

The back trajectories reflected a shift occurring over that period, as initially stable atmospheric conditions over the Iberian Peninsula, due to the influence of a high-pressure system in the Azores, gave way to instability associated with the progressive approach of a low pressure centre in the north. This gave rise to a constant change in wind origins and paths (Fig. 10); air masses initially moved from north to south across the Iberian Peninsula, but westerly winds blowing in from the Atlantic eventually prevailed. Predominantly local wind regimes were observed in

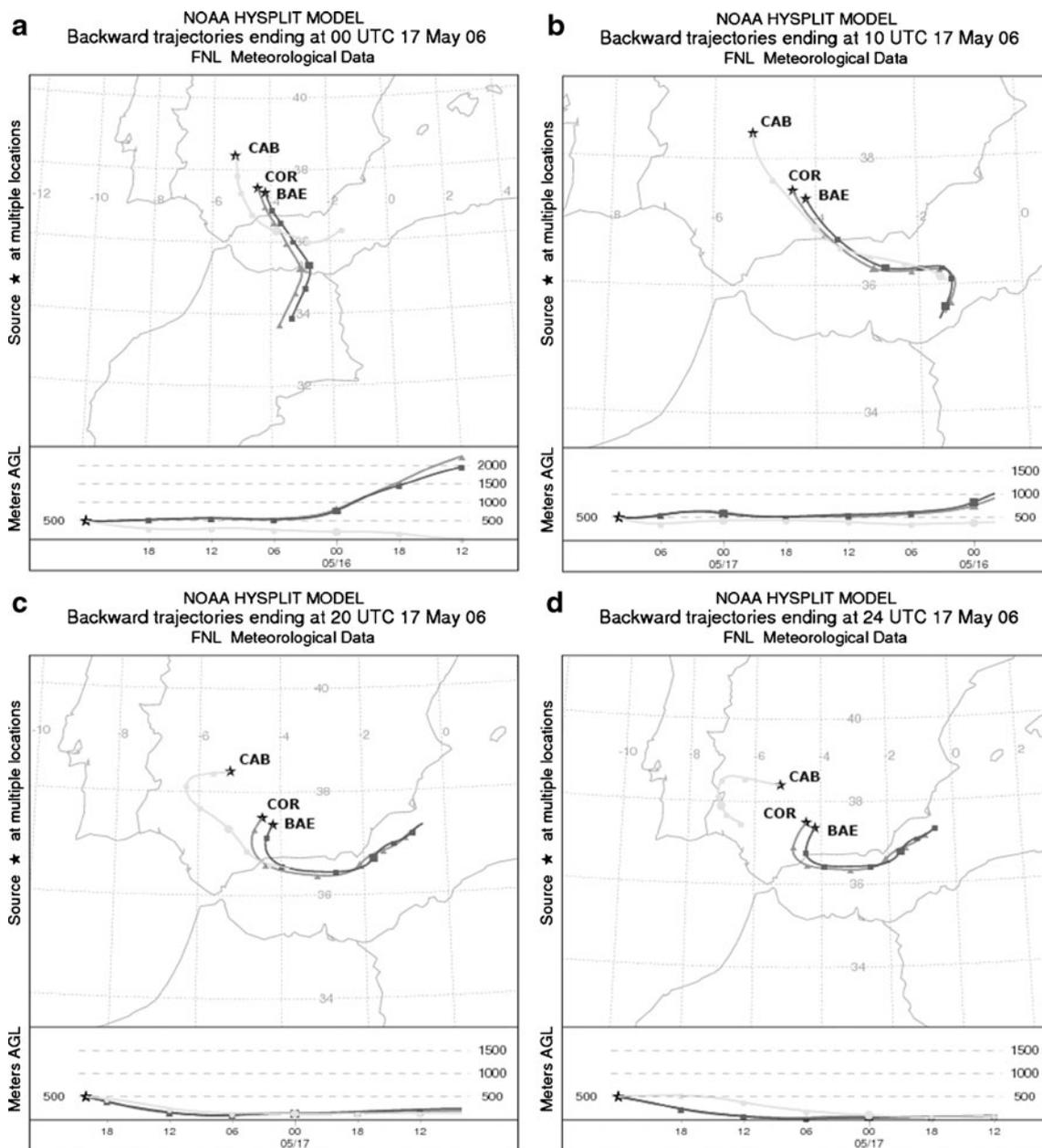


Fig. 9 Maps showing 36-h back trajectories at a final height of 500 m at **a**) 00:00, **b**) 10:00, **c**) 20:00 and **d**) 24:00 UTC on 17 May 2006 at the Córdoba (Cor), El Cabril (Cab) and Baena (Bae) sites

southern Andalusia, crossing pollen sources. Temperatures were moderate (minimum 14.8°C, maximum 30.9°C), and relative humidity remained below 61% throughout the 3-day period (Table 2).

In view of these weather conditions, two major pollen origins were identified. The peaks recorded in Córdoba on 9 and 10 May (Fig. 4a) were attributed to local pollen sources, since there were no matching peaks at other stations. Pollen counts at El Cabril increased on 10 May at 10:00 UTC (Fig. 4b), but the back-trajectory suggests that pollen may have been transported from an external source. The peaks observed in Priego and Córdoba on 11 May (Fig. 4a–d) may

be due to pollen contributions from outside the province, given the air-mass data and the fact that peaks occurred simultaneously at the two sites. This hypothesis is borne out by a peak detected at 20:00 UTC in Priego (Fig. 4d).

Episode 7: 20 May 2007

The highest pollen count of all the episodes studied was recorded at Baena (7,724 gr/m³; Fig. 2), where two major peaks were observed in a single day at 8:00 UTC and 14:00 UTC (Fig. 4c). Elsewhere, counts were considerably lower (3,123 gr/m³ at Priego, 1,540 gr/m³ at El Cabril and

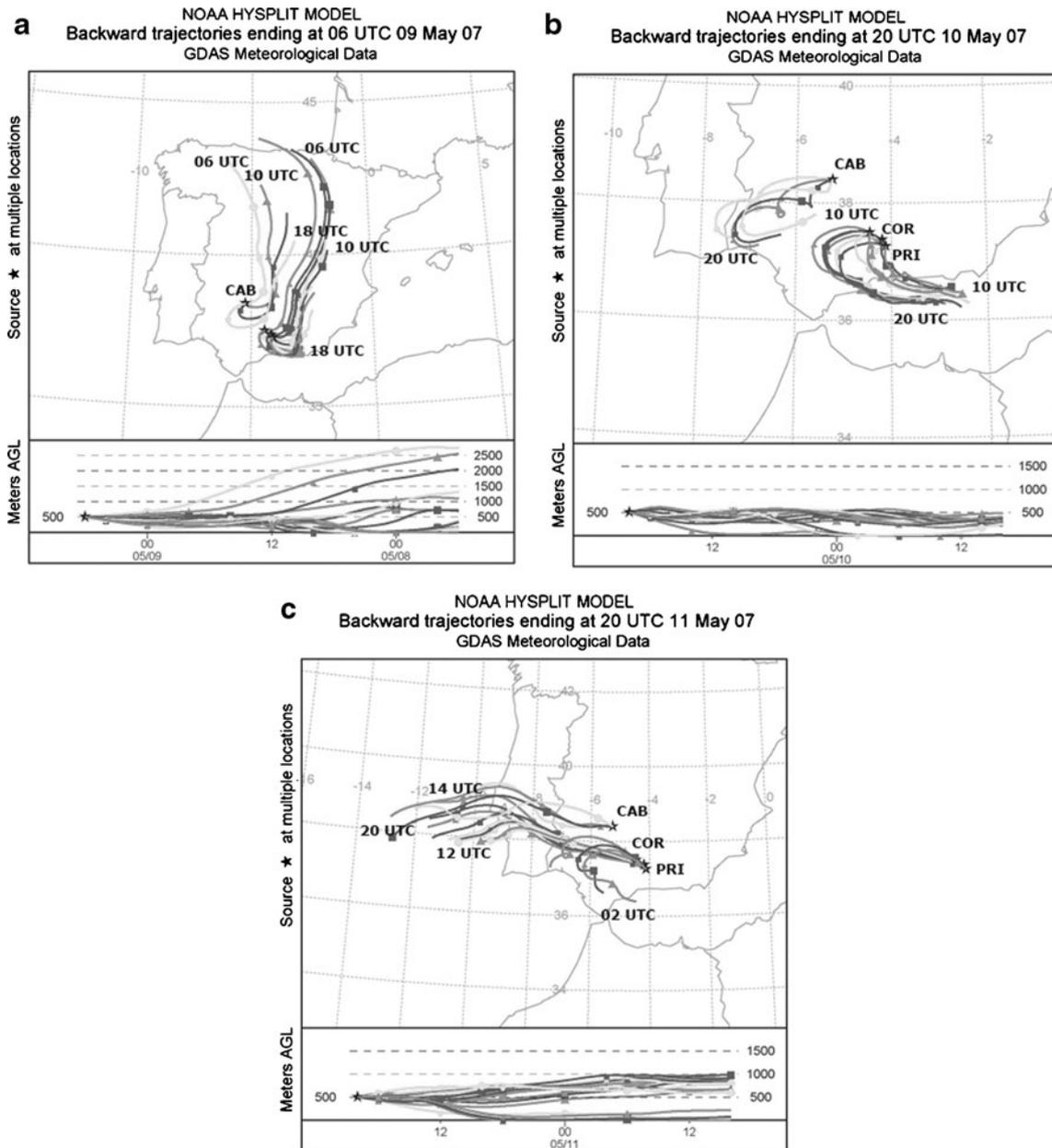


Fig. 10 Maps showing 36-h back trajectories at a final height of 500 m and at different hours on a) 9 May, b) 10 May and c) 11 May 2007 at the Córdoba (Cor), El Cabril (Cab), Baena (Bae) and Priego de Cordoba (Pri) sites

124 gr/m³ at Córdoba). However, while in El Cabril no intensive peak was detected (Fig. 4b), in Cordoba higher counts were recorded during the early hours and in the late afternoon (Fig. 4a). Similar pollen counts to those registered in Baena were also recorded in Priego but of a lower magnitude (Fig. 4c–d).

The synoptic configuration showed a weak surface pressure gradient, together with relatively unstable conditions at higher levels, associated with the growing influence of a low located in the northwest of the Iberian Peninsula. In these conditions, a local wind regime developed over the days prior to the episode day, prompting

a gradual increase in pollen counts. By the end of the day, however, an incipient westerly synoptic wind led to a sharp drop in pollen counts across the whole province. Temperature ranged between 30.1°C and 12.7°C and relative humidity between 82.5 % and 43.5 % (Table 2).

Back trajectories originated mainly over the Mediterranean, arriving though the valleys that connect the Guadalquivir valley and the Mediterranean area; the height of air mass movement varied considerably, generally remaining relatively far from the ground except over El Cabril (Fig. 11). By the afternoon of that day, however, a strong southwesterly wind prevailed over the whole province.

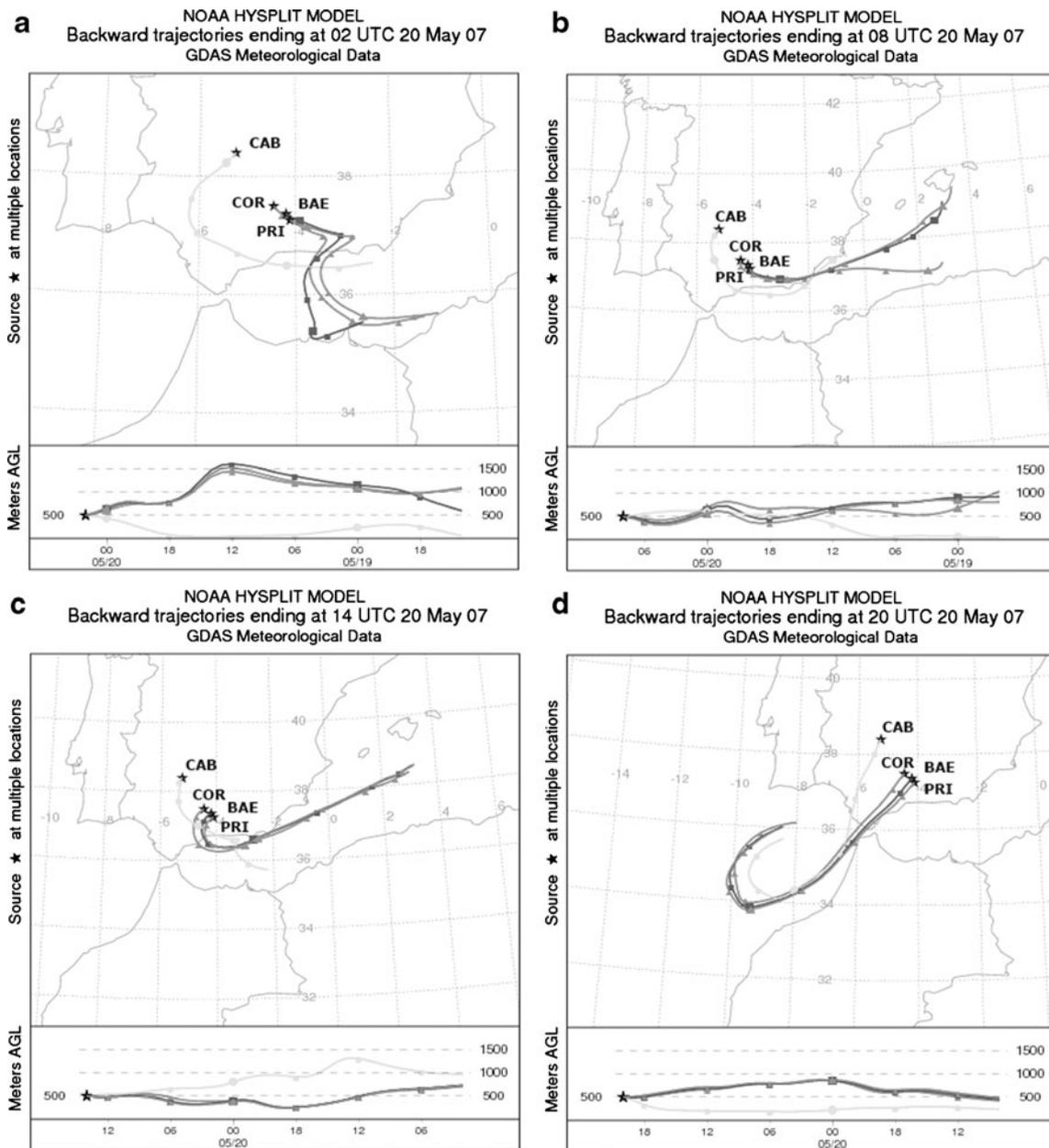


Fig. 11 Maps showing 36-h back trajectories at a final height of 500 m at **a**) 02:00, **b**) 08:00, **c**) 14:00 and **d**) 20:00 UTC on 20 May 2007 at the Córdoba (Cor), El Cabril (Cab), Baena (Bae) and Priego de Córdoba (Pri) sites

Given these weather conditions, there are two possible explanations for the high pollen counts and the difference in their timing from one site to another. Due to the progressive increase in pollen counts during the preceding days, the elevated counts recorded in the course of the morning (until 10:00 UTC in Cordoba, at 8:00 UTC in Baena and at 10:00 UTC in Priego) were probably due to residual airborne pollen from local sources, counts being higher in Baena and Priego owing to the presence of larger local pollen sources. At the same time, there was evidence of regional pollen transport from south to north; a correlation was apparent between the drop in counts in Baena and Priego at 12:00

UTC, and an increase in counts in Córdoba by 14:00 UTC (Fig. 4c–d). Later in the day, this correlation disappeared due to the southwesterly synoptic wind, which probably transported pollen from other sources; this would account for the sharp decrease in pollen counts in Baena and Priego, and slight increase in Cordoba (Fig. 4a). Thus, pollen counts on this episode day reflected both local and regional transport.

Episode 8: 30 May 2007

The outstanding feature of the 30 May episode was the high pollen count recorded at Priego (3,044 gr/m³), which was

twice that at Baena (1,497 gr/m^3) and much higher than the count recorded in El Cabril (478 gr/m^3) and Cordoba (51 gr/m^3). Significantly, these high values were the result of a sudden and rapid change in daily pollen counts, coinciding with the flowering season (Fig. 2).

The confluence of two pressure centres, a ridge of high pressure in the east and a low in the north-western Iberian Peninsula, prompted by the arrival of the synoptic wind from the west, was reflected in the wind regime recorded at Priego.

The back-trajectory revealed an air mass moving in from the west of the Iberian Peninsula, gradually falling towards the end of the day (Fig. 12). Weather data were typical for the season; temperatures ranged between 24.8°C and 12.9°C, and relative humidity between 57.0% and 29.7% (Table 2).

In view of the synoptic wind regime, the marked increase in pollen counts at 16:00 UTC in Priego (Fig. 4d) was probably caused by the arrival of air masses from external sources, probably from near Baena, containing a considerable amount of pollen. However, this external input was probably supplemented by pollen from local sources, coinciding with the full flowering period in phenological surveys. Similar causes may account for the peak recorded at El Cabril at 20:00 UTC, which was lower than that observed in the south of the province (Fig. 4b). However, pollen counts in Córdoba were very low, with no marked intradiurnal curve (Fig. 4a).

Episode 9: 6 June 2007

Probably associated with the full flowering period in olive groves to the south of the province, pollen counts ranged

from 3,800 gr/m^3 in Priego to 1,387 gr/m^3 in Baena, while values were considerably lower in Córdoba and El Cabril. At 442 gr/m^3 and 343 gr/m^3 , respectively (Fig. 2).

The synoptic situation was characterized by an undefined pressure gradient over the Iberian Peninsula and by low pressure troughs over Africa. This prompted local wind flows during the episode day; the back-trajectory showed air-mass movements at 500 m, along the Mediterranean as far as the Andalusian coast, then moving along the coastline and finally into inland Andalusia via natural channels (Fig. 13). Surface weather data were typical for spring; mean temperature and relative humidity were 28°C and 43%, respectively (Table 2). The considerable difference between the amount of pollen recorded at Priego and the other sites (Fig. 4a–d) may be due to the proximity of the Priego trap to olive-pollen sources, reflecting the influence of local wind flow regimes associated with the occurrence of peaks at different times during the day. The lower pollen-count peaks recorded at El Cabril highlight the effect of a shift in the back-trajectory from southerly to northerly (Figs. 4b, 13).

Synoptic charts

A synoptic overview reveals a number of common features that serve as the basis for an initial hypothesis regarding the weather conditions responsible for high pollen counts in the province of Córdoba. In general terms, it was found that there was no well-defined predominant pressure gradient on episode days due to the influence of high pressure prompting stable conditions (Fig. 14a). This led to local mesoscale wind flows, as recorded at the various weather

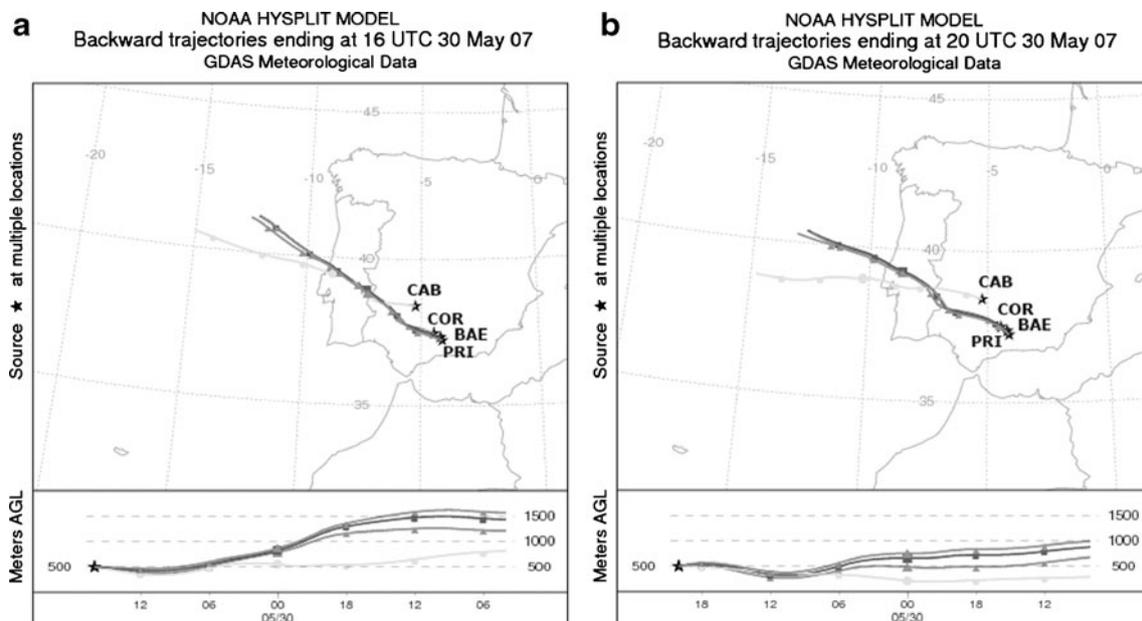


Fig. 12 Maps showing 36-h back trajectories at a final height of 500 m at **a**) 16:00 and **b**) 20:00 UTC on 30 May 2007 at the Córdoba (Cor), El Cabril (Cab), Baena (Bae) and Priego de Córdoba (Pri) sites

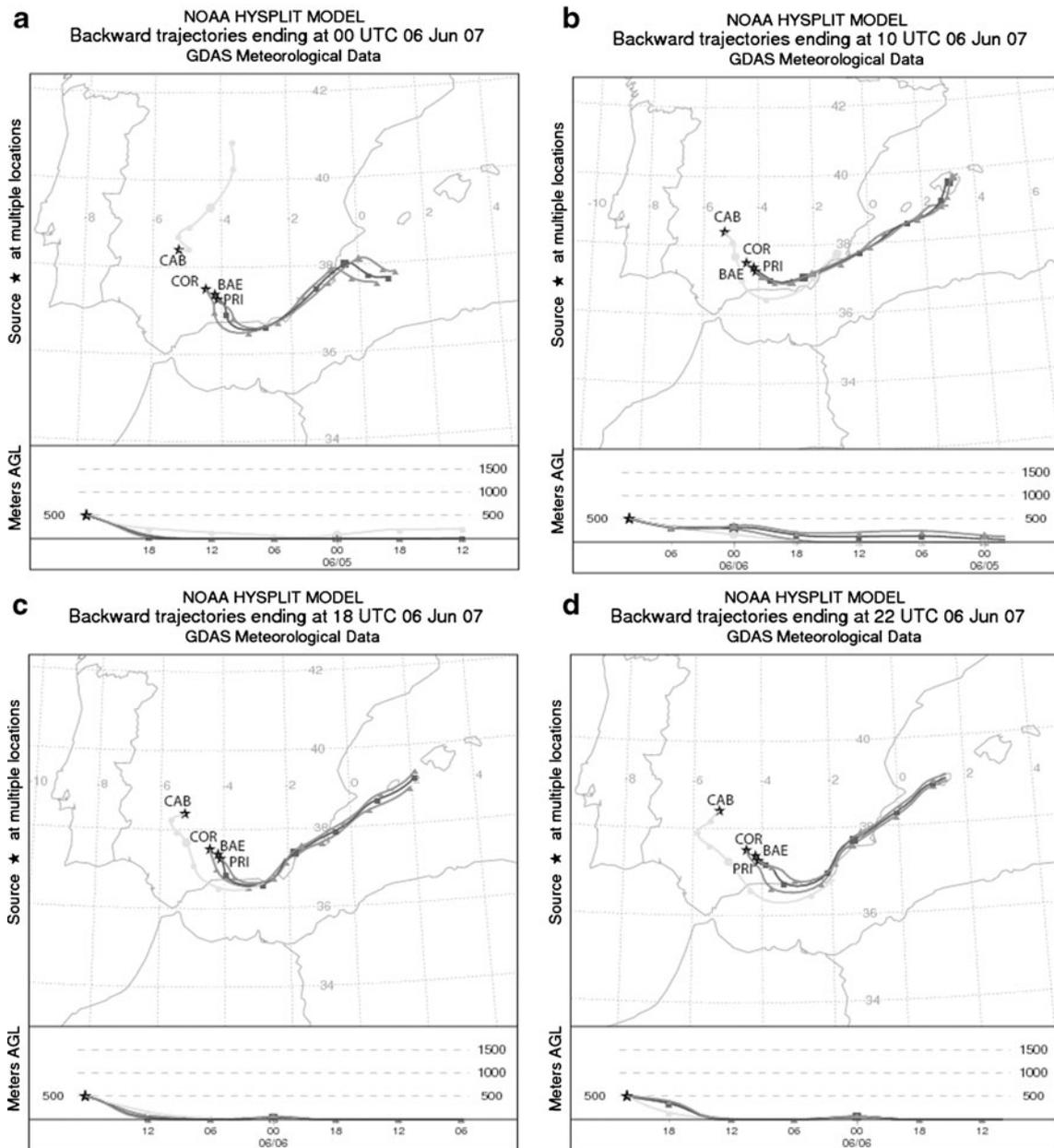


Fig. 13 Maps showing 36-h back trajectories at a final height of 500 m at a) 00:00, b) 10:00, c) 18:00 and d) 22:00 UTC on 6 June 2007 at the Córdoba (Cor), El Cabil (Cab), Baena (Bae) and Priego de Córdoba (Pri) sites

stations. However, certain episodes coincided with predominantly unstable conditions (Fig. 14b), reflected in the establishment of a synoptic flow (Priego, 30 May).

Discussion

The results obtained confirm the importance of a detailed knowledge of source locations and meteorological conditions, including wind regime, in order to understand spatial variations in pollen counts in a given area. Mean pollen counts were higher at sites located in the south of the

province, Baena and Priego, coinciding with the most extensive olive crop areas and therefore *Olea* pollen sources. The highest daily count for the study was recorded at Baena on 11 May 2006. The Córdoba site may be seen as intermediate, recording occasional high counts and also low values; in most episodes, counts were lower than those obtained in the south of the province. At the El Cabil site, in the north of the province, pollen-count peaks were consistently lower due to the scarce olive crop areas in the vicinity of the trap; moreover, due to its geographical location, this site is less influenced by pollen sources located in the south, and more affected by smaller sources

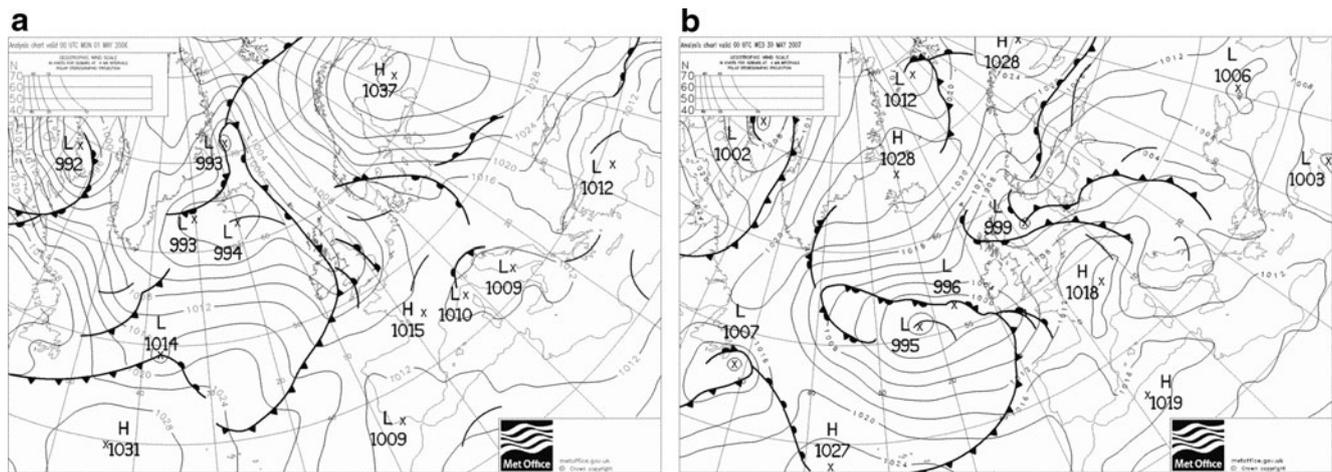


Fig. 14 Examples of the two main synoptic configurations associated to the set of the *Olive* pollen episodes over Córdoba province. **a**) 1 May 2006 and **b**) 30 May 2007

located outside the province to the southwest. Thus, Córdoba province can be divided into two pollen areas as a function of the sources areas identified as responsible for higher pollen counts in the province.

However, the correlation between pollen counts and distance of sources is also influenced directly by weather conditions (Latatowa et al. 2002; Kasprzyk 2008). The results obtained here highlight the importance of studying data on trap location in conjunction with particle sources and meteorological data from different sources (e.g. time series, maps, back trajectories) in order to interpret particle counts in a given area, regardless of the type of area or the biological particles concerned.

Knowledge of weather conditions in the upper atmosphere is essential, given their influence on the behaviour of various weather-related parameters including temperature, wind and relative humidity. Analysis of weather data for all episode days showed that the average daily temperature ranged between 15°C and 30°C, while relative humidity varied from 31% to 76%. In general, correlations between pollen counts and both temperature and relative humidity values (maximum, minimum and mean) were not particularly strong; correlation coefficients for all possible combinations never exceeded 0.4 (data not shown).

The synoptic configuration determines both horizontal and vertical movements of air masses (Kalkstein et al. 1998) and therefore their transit over different types of sources. Two configurations were observed during high-pollen-count episodes: one led to stable conditions favouring the development of local dynamic processes, while the other was associated with continuous, intense flows that enhanced both transport and dispersal over greater distances.

The low-altitude movement of air masses from the south of the province—the most common feature of the episodes described here—favoured the dragging of biological par-

ticles close to ground level and was associated with stable synoptic conditions. This circulation largely determined daily pollen counts in stations located in the south (Baena, Priego) and in Córdoba city. By contrast, the air mass coming from the southwest/west mainly determined pollen counts over El Cabril. To a lesser extent, this was also observed in the south of the province, although under unstable synoptic configurations hindered identification of inter-site pollen transport.

The relationship observed between back trajectories and olive pollen episodes agrees with others obtained elsewhere in Europe, including grass pollen in the United Kingdom (Smith et al. 2005) and Ambrosia pollen in Poland (Stach et al. 2007).

Córdoba city has recorded some of the highest *Olea* pollen counts in Spain (Díaz de la Guardia et al. 1999). This has traditionally been attributed in part to the regional transport of pollen from different areas of the province—a finding based on the results of field phenological surveys (Fornaciari et al. 2000). The *Olea* pollen curves examined here (2006–2007) displayed different peaks, described in detail for each “episodes” above. Back-trajectory analysis in conjunction with hourly wind data showed that, on days when high *Olea* pollen counts were recorded in the city, air masses tended to come in from the southeast of the province. This information, combined with intradiurnal pollen-count variations and field phenology data, suggests that *Olea* pollen counts recorded in Córdoba over the latter part of the season may originate from sources close to Baena and, at a later stage, to Priego.

The importance of the correlation between weather data, back-trajectory analyses and pollen counts is highlighted in the intradiurnal pollen curve for Córdoba, which, despite the predomination of a typical trend with peak counts between 11:00 and 17:00 hours (Domínguez et al. 1993),

displayed considerable variation in daily peaks. In some cases (e.g. 6 June 2007), counts increased constantly throughout the day, while in others (13 May 2006 and 20 May 2007) peak daily values were recorded in the late evening rather than earlier. This enables some differentiation between local and external contributions. The contribution of local pollen is dependent on local dynamics and on the environment immediately surrounding the trap, whilst contributions from remote sources are favoured by air-mass transport, leading to high pollen counts at unexpected times.

Previous studies of olive-pollen transport in the province of Cordoba based on aerobiological and field phenological data reported considerable regional transport. Here, trajectory analysis indicated that some of the high-pollen-count episodes reflected the local transport of olive pollen within the province. This type of analysis should be taken into account when producing pollen forecasts for Cordoba city, since episodes of this kind are to be expected when weather conditions favour wind flows from the south, mainly with stable synoptic configurations.

Conclusions

High pollen counts in stations across Cordoba province were influenced mainly by large pollen sources situated in the south of the province and, to a lesser extent, by small external sources located to the west, prompting a gradient from south to north. Two main air-mass paths were identified: winds from the south exerted greater influence on pollen counts in Baena, Priego and Cordoba city, while southwest/west flows were the prevailing influence at El Cabril. Wind flow from the south/southwest prompted high pollen counts in Cordoba province, regardless of whether these were associated with a mesoscale wind regime due to a stable synoptic configuration. However, intensive pollen peaks were also detected in association with westerly synoptic flows under unstable conditions. The difference between the two dynamics was more evident in daily pollen curves, when synoptic flows were associated mainly with peaks at unexpected times. Pollen counts at Baena and Priego were influenced strongly by nearby pollen sources, most high-count episodes being linked with local wind configurations.

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