

Examining high magnitude grass pollen episodes at Worcester, United Kingdom, using back-trajectory analysis

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Abstract

Trajectory analysis is a valuable tool that has been used before in aerobiological studies, to investigate the movement of airborne pollen. This study has employed back-trajectories to examine the four highest grass pollen episodes at Worcester, during the 2001 grass pollen season. The results have shown that the highest grass pollen counts of the 2001 season were reached when air masses arrived from a westerly direction. Back-trajectory analysis has a limited value to forecasters because the method is retrospective and cannot be employed directly for forecasting. However, when used in conjunction with meteorological data this technique can be used to examine high magnitude events in order to identify conditions that lead to high pollen counts.

Abbreviations: BADC = The British Atmospheric Data Centre; BAF = British Aerobiology Federation; BST = British Summer Time; ECMWF = European Centre for Medium Range Weather Forecasting; Mb = millibars

1. Introduction

Aerobiologists have regularly measured and reported quantities of airborne pollen (pollen counts) as a service to allergy sufferers (Larsson, 1993; Cariñanos et al., 2000; Portnoy, 2004). However, an increase in the prevalence of hay fever and asthma witnessed in some, but not all, European cities in recent years (Galan et al., 1995; D'Amato et al., 2001; Huynen et al., 2003) has led to an increased demand for accurate pollen forecasts for allergy sufferers, health care professionals and pharmaceutical companies (Emberlin et al., 1999).

In order to produce an effective forecast model for allergenic pollen it is necessary to

understand the relationship between atmospheric pollen concentrations and the environmental factors that influence them. Plotting the path along which a quantity or parcel of air travels during a definite time interval, which is known as trajectory analysis (Walker, 1995), is a valuable tool that has been used previously in aerobiological studies to investigate the movement of airborne pollen. For example, Hjelmroos (1991, 1992) used back-trajectory models to study the long-range transport of birch (*Betula*) pollen. The author showed that *Betula* pollen grains originating from distant source areas were transported to pollen monitoring sites by the passage of air masses, before local birch trees underwent anthesis.

Back-trajectory analysis has been used in this study to examine a number of high magnitude grass pollen episodes that occurred at Worcester, United Kingdom (UK), during the summer of 2001. This paper does not examine the long-range transport of grass pollen *per se*; instead, it looks at the effectiveness of using back-trajectory analysis to find possible sources of grass pollen that may have contributed to the airborne catch on the days in question and the usefulness of using back-trajectory analysis in respect to constructing forecast models for grass pollen. Pollen grains from the grass family (Poaceae) are the focus of this study because they are considered to be one of the most important aeroallergens in Europe (Sanchez Mesa et al., 2003).

2. Material and methods

2.1. Site

Daily average grass pollen counts were obtained from the National Pollen and Aerobiology Research Unit site at Worcester (Figure 1). The pollen-monitoring site is approximately 1.4 km from the centre of Worcester, which has a population of 93 358 (ONS, 2002). The City of



Figure 1. Pollen-monitoring site at Worcester.

Worcester is the administrative seat of the county of Worcestershire (area 176 100 hectares). Agriculture is a major activity in the county. Grassland (including temporary grassland less than 5 years old, permanent grassland and rough grazing) occupied approximately 50% of the total agricultural area in 2000 and 2001 (49.9% and 50.3% respectively) (DEFRA, 2004).

2.2. Grass pollen data

Grass pollen data has been collected in Worcester from 1995. The trap is situated on the roof of the main building of University College Worcester (52°11' N, 002°14' W) at a height of 10 m. The methodology used for collecting the grass pollen data followed the standard method of the UK National Pollen Monitoring Network described in the British Aerobiology Federation (BAF) guide for trapping and counting airborne pollen and spores (BAF, 1995). Grass pollen counts are expressed as grains/m³ and are a daily average taken from 09:00 to 09:00 hours. However, diurnal variations in grass pollen counts have also been examined in this paper. Grass pollen counts were recorded every 2 hours and are expressed as the number of grains counted per transect (field of view 0.55 mm diameter). Each transect represents 0.001% of the total volume of air sampled.

A detailed local phenological survey has not been carried out, however, a list of several grass species that are common to the region, that flower during the study period (June and July) and are believed to make a considerable contribution to the airborne catch has been compiled: *Agrostis capillaries*, *Agrostis stolonifera*, *Alopecurus pratensis*, *Anisantha sterilis*, *Anthoxanthum odoratum*, *Arrhenatherum elatius*, *Avena fatua*, *Brachypodium sylvaticum*, *Bromus hordeaceus*, *Cynosurus cristatus*, *Dactylis glomerata*, *Festuca pratensis*, *Festuca rubra*, *Holcus lanatus*, *Lolium multiflorum*, *Lolium perenne*, *Phleum pratense*, *Poa annua*, *Poa pratensis* and *Poa trivialis* (Fitter et al., 1984; Hubbard, 1992; Grime et al., 1996; Emberlin, 1997; Stace, 1997; Preston et al., 2002). In Worcester, pollen grains from cereals are not counted separately to other pollen from the Poaceae family. It is therefore difficult to determine the relative importance of cereals to the airborne catch. However, the pollen grains of cereals are reasonably large (> 45 µm), heavy and do not

become airborne easily (Subiza et al., 1992) and are generally not frequent in the catch.

The National Pollen and Aerobiology Research Unit uses the following thresholds when forecasting grass pollen counts: 0–29 grains/m³ low risk, 30–49 grains/m³ moderate risk, 50–149 grains/m³ high risk and ≥150 grains/m³ very high risk. The limits of the grass pollen season were calculated for this study by using the Threshold 30 method whereby, the start and end of the grass pollen season are defined as the first and last days when the pollen counts are ≥30 grains/m³ (Sanchez Mesa et al., 2003).

The 2001 grass pollen season at Worcester was the most severe since records commenced at the site. The season lasted for 54 days; with grass pollen counts exceeded 150 grains/m³ on 14 occasions (Figure 2). This analysis focuses for 4 days, which experienced the highest grass pollen counts of the 2001 season. These were the 10th June (367 grains/m³), 13th June (592 grains/m³), 18th June (507 grains/m³) and 1st July (410 grains/m³). The mean grass pollen count for the 2001 grass pollen season recorded at Worcester was 122 grains/m³.

2.3. Climate and meteorological data

The British Isles has a maritime temperate climate that is influenced throughout the year by low-pressure zones moving in from the Atlantic to the west (Goudie, 1996). In Worcester, the mean temperature (1971–2000 average) for January and

July is 3.5 and 16 °C respectively, and mean annual rainfall (1971–2000 average) is approximately 600 mm (METO, 2004).

The Met Office via the BADC supplied the meteorological data. Meteorological data came from the Met Office surface station at Great Malvern (52°7' N, 002°18' W) situated approximately 8 km southwest of Worcester. Data from a number of Met Office stations situated around the pollen-monitoring site were considered for this study. Great Malvern, although situated several kilometres away, had a complete dataset and meteorological data from Great Malvern were more highly correlated with grass pollen counts at Worcester than meteorological data taken from elsewhere.

2.4. Back-trajectory analysis

A number of grass pollen events, during the 2001 grass pollen season at Worcester, were investigated using back-trajectory analysis. The British Atmospheric Data Centre (BADC) Web Trajectory Service plotted the trajectories backward in time (back-trajectories) using operational and reanalysis data supplied by the European Centre for Medium Range Weather Forecasting (ECMWF). Back-trajectories were run for 2 days with 6 hourly steps. Three back-trajectories were run on each day: for 12:00, 18:00 and 00:00 hours BST (back-trajectories could only be run at 00:00, 06:00, 12:00 and 18:00 hours).

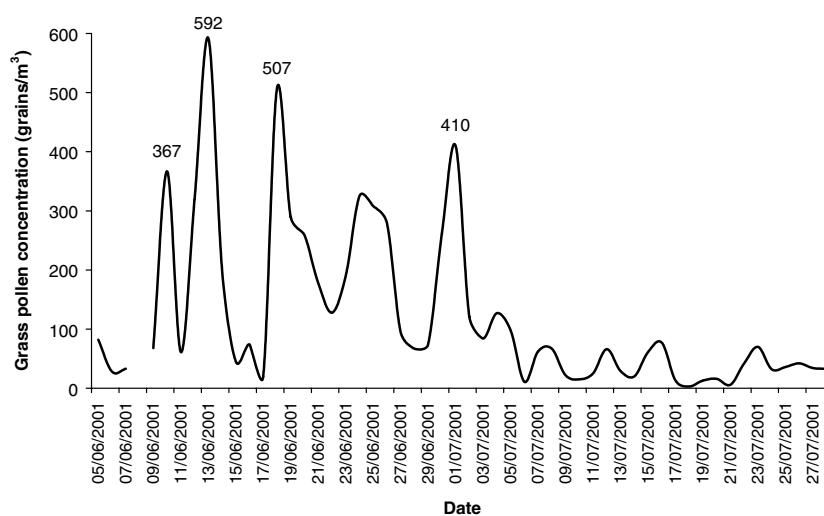


Figure 2. 2001 grass pollen season in Worcester. Start and end of the grass pollen season calculated using the Threshold 30 Method.

The vertical advection type selected for each back-trajectory run was pressure vertical velocity, Omega (3D). When using 3D advection, initial levels are entered as pressure in millibars (mb). The recommended pressure range for the initial levels is 950–10 mb. Ten millibar is the upper level of the ECMWF data used. Nine hundred and fifty millibar was chosen because this study concentrates on the low level transport of pollen. It is suggested that using pressures less than 950 mb often results in parcels going into the ground. In an attempt to determine whether any anomalies existed in the back-trajectory runs, clusters of back-trajectories were also plotted. The cluster consists of four points: one directly north, one directly east, one directly south and one directly west of the central parcel. The distance between the cluster points from the central point is determined by the cluster radius, which was entered as 100 km (BADC, 2002). No anomalies were discovered using cluster analysis and so only single back-trajectory runs have been included in this paper.

3. Results

3.1. Back-trajectory analysis for 10th June 2001

In the UK, June 2001 was a dry sunny month overall. Nationally, there were some outbreaks of rain or showers at the beginning of the month on the 1st and 2nd. This was followed by 2 days of quite cool, dry weather with sunny intervals. The period 5th–10th June 2001 was dominated by low pressure to the north or northeast and the weather was rather unsettled and wet as a result. In Great

Malvern, rainfall was recorded at the beginning of June 2001 on the 5th (0.1 mm), 6th (0.5 mm), 7th (1.3 mm) and 9th (1.4 mm), the 10th remained dry (0.0 mm). The average daily temperature recorded in Great Malvern for the 10th June 2001 (Table 1) was 3.5 °C below the 14.4 °C mean (1961–1990) for the month (BBC, 2001).

In 2001, the first grass pollen count in excess of 30 grains/m³ was recorded on the 5th June (82 grass pollen grains/m³). This was followed by daily average grass pollen counts of 28, 33 and 68 grains/m³ on the 6th, 7th, and 9th June respectively. No counts were available for 8th June 2001 because of trap failure. The grass pollen count then increased to 367 grains/m³ on June 10th. Back-trajectory analyses show that the air mass approached Worcester from a northwesterly direction (Figures 3–5).

3.2. Back-trajectory analysis for 13th June 2001

The period covering the 11th–13th June 2001 was rather cool and mostly cloudy, but generally dry apart from some isolated light showers. No precipitation was recorded in Great Malvern on the 11th and 12th June, although 0.1 mm was recorded between 15:00 and 16:00 hours on the 13th. The average daily temperature recorded at Great Malvern for the 13th June 2001 (Table 2) was 0.5 °C above the 14.4 °C mean (1961–1990) for the month (BBC, 2001).

Daily average grass pollen concentrations for the 11th and 12th June were 61 and 319 grains/m³ respectively. The highest grass pollen count recorded at Worcester in 2001 was on the 13th

Table 1. Weather data recorded at Great Malvern Met Office surface station on 10/06/01

	Daily measurement (09:00–09:00 hours)			Measurement
Maximum daily temperature	18.1			°C
Average daily temperature	10.9			°C
Daily rainfall	00.0			mm
	Time (hours)			
	12:00	18:00	21:00	
Air temperature	15.6	16.4	9.8	°C
Relative humidity	59.8	46.5	72.5	%
Wind speed	8.0	6.0	2.0	Knots
Wind direction	350	350	330	Degrees
Mean surface level pressure	1018.3	1020.0	1021.8	mb

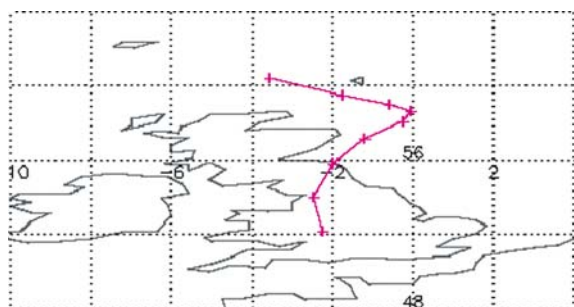


Figure 3. Back-trajectory analysis, start of run 12:00 hours on 10/06/01.

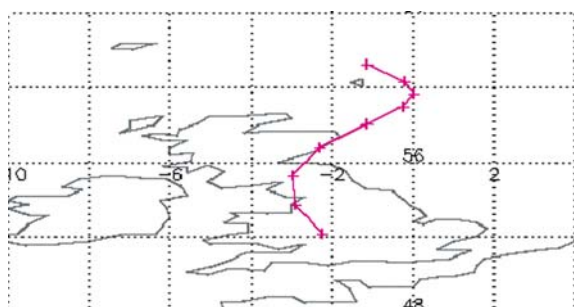


Figure 4. Back-trajectory analysis, start of run 18:00 hours on 10/06/01

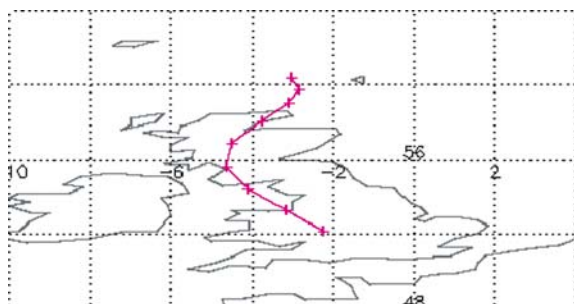


Figure 5. Back-trajectory analysis, start of run 00:00 hours on 11/06/01.

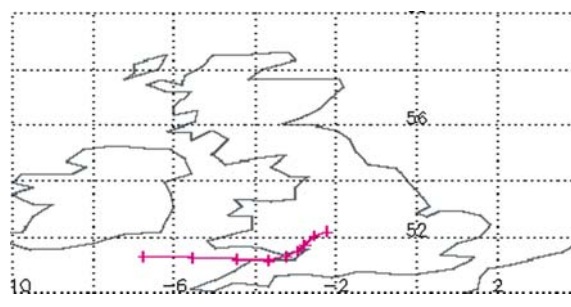


Figure 6. Back-trajectory analysis, start of run 12:00 hours on 13/06/01.

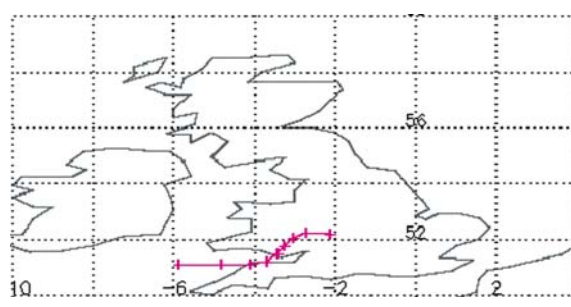


Figure 7. Back-trajectory analysis, start of run 18:00 hours on 13/06/01.

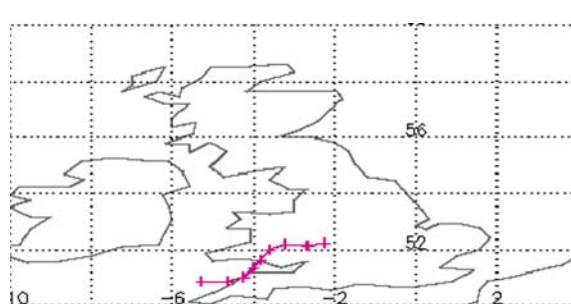


Figure 8. Back-trajectory analysis, start of run 00:00 hours on 14/06/01.

Table 2. Weather data recorded at Great Malvern Met Office surface station on 13/06/01

	Daily measurement (09:00–09:00 hours)			Measurement
Maximum daily temperature	21.0			°C
Average daily temperature	14.9			°C
Daily rainfall	00.1			mm
	Time (hours)			
	12:00	18:00	21:00	
Air temperature	19.0	18.0	14.9	°C
Relative humidity	57.1	66.7	79.6	%
Wind speed	3.0	0.0	2.0	Knots
Wind direction	340.0	0.0	350.0	Degrees
Mean surface level pressure	1014.7	1014.4	1015.0	mb

June (592 grains/m³), back-trajectory analyses for this day shows that the air mass approached Worcester from the south and west (Figures 6–8).

3.3. Back-trajectory analysis for 18th June 2001

The period from the 14th to 16th June was mainly cool and very wet, which was caused by a depression that remained stationary over southern England. Rain and showers (often thundery) broke out in many places. A drier regime prevailed from the 17th after the showers cleared. Daily amounts of precipitation recorded in Great Malvern for this period were 2, 1.5 and 19.7 mm for the 14th, 15th and 16th June respectively, the 17th and 18th were dry (0.0 mm). The average daily temperature recorded at Great Malvern for the 18th June 2001 (Table 3) was 2.1 °C above the 14.4 °C mean for the month (BBC, 2001).

Pollen counts decreased steadily from the 14th June, reaching a low of 20 grains/m³ on the 17th June (Figure 2). The grass pollen count then increased significantly to 507 grains/m³ on the 18th June. Back-trajectory analyses for the 18th June (Figures 9–11), again shows that the air parcels approached Worcester from a westerly direction.

3.4. Back-trajectory analysis for 1st July 2001

The period from the 18th to 26th June 2001 was virtually dry with high pressure producing long sunny spells in most parts. No precipitation was recorded at Great Malvern during this time. The weather then became cooler and more changeable, with sunny intervals and occasional outbreaks of

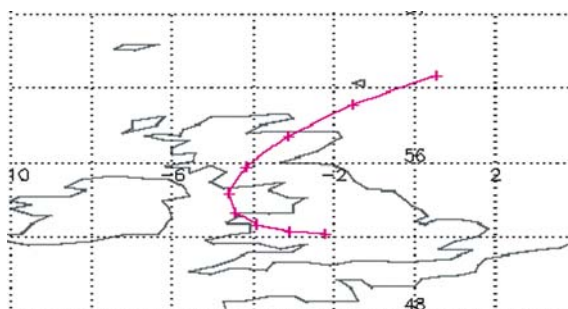


Figure 9. Back-trajectory analysis, start of run 12:00 hours on 18/06/01.

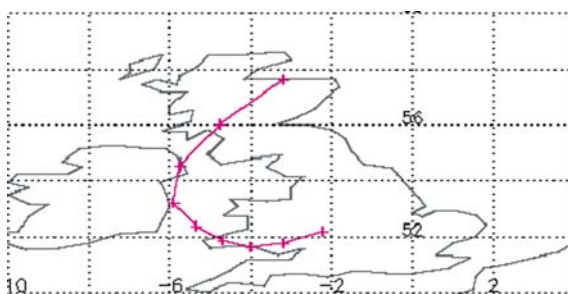


Figure 10. Back-trajectory analysis, start of run 18:00 hours on 18/06/01.

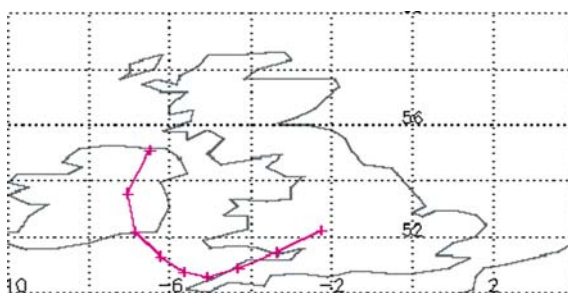


Figure 11. Back-trajectory analysis, start of run 00:00 hours on 19/06/01.

Table 3. Weather data recorded at Great Malvern Met Office surface station on 18/06/01

	Daily measurement (09:00–09:00 hours)			Measurement
Maximum daily temperature	19.9			°C
Average daily temperature	16.5			°C
Daily rainfall	00.0			mm
	Time			
	12:00	18:00	21:00	
Air temperature	17.6	17.9	16.2	°C
Relative humidity	56.3	59.1	64.5	%
Wind speed	3.0	5.0	3.0	Knots
Wind direction	230.0	220.0	240.0	Degrees
Mean surface level pressure	1027.6	1026.9	1027.7	mb

rain or showers occurring from the 27th June; 0.3 1.8 and 0.1 mm of precipitation were recorded on the 28th, 29th and 30th June respectively. The BBC (2001) describes the weather at the beginning of July as being hot and thundery. Although no precipitation was recorded at Great Malvern on the 1st July, maximum daily temperature was 25.7 °C and relative humidity (recorded at 21:00 hours) was 82.4% (Table 4). The average daily temperature was 2.7 °C above the (1961–1990) July mean (BBC, 2001).

Following the grass pollen count of 507 grains/m³ on 18th June, counts did not fall below 100 grains/m³ until the 27th (95 grains/m³). Grass pollen counts of 67 and 74 were recorded on the 28th and 29th June respectively, increasing again to 261 grains/m³ on the 30th. A grass pollen count of 410 grains/m³ was recorded on the 1st July. Back-trajectory analyses for this day (Figures 12–14) shows that before reaching

Worcester the air parcels spent less than 6 hours traversing Wales and parts of western England and a similar amount of time over southern Ireland.

3.5. Diurnal variations in grass pollen counts

Diurnal variations in grass pollen counts at Worcester were plotted for the 10th, 13th and 18th June and 1st July 2001 (Figure 15). The amount of grass pollen registered on the 13th and 18th June and 1st July 2001 started to increase considerably from about 14:30 hours onward. The grass pollen count on the 10th June started to rise slightly later, between 16:30 and 18:30 hours, and increased sharply to 345 grass pollen grains at about 20:30 hours. Grass pollen counts on the 18th June also peaked around 20:30, but the peak was much flatter. The 1st July had a low peak at 16:30 (142 grass pollen grains) followed by a slow decrease in pollen counts throughout the night.

Table 4. Weather data recorded at Great Malvern Met Office surface station on 01/07/01

	Daily measurement (09:00–09:00 hours)			Measurement
Maximum daily temperature	25.7			°C
Average daily temperature	19.4			°C
Daily rainfall	00.0			mm
	Time (hours)			
	12:00	18:00	21:00	
Air temperature	22.3	23.5	20.2	°C
Relative humidity	72.5	69.5	82.4	%
Wind speed	4.0	3.0	4.0	Knots
Wind direction	240.0	300.0	310.0	Degrees
Mean surface level pressure	1027.2	1027.5	1028.5	mb

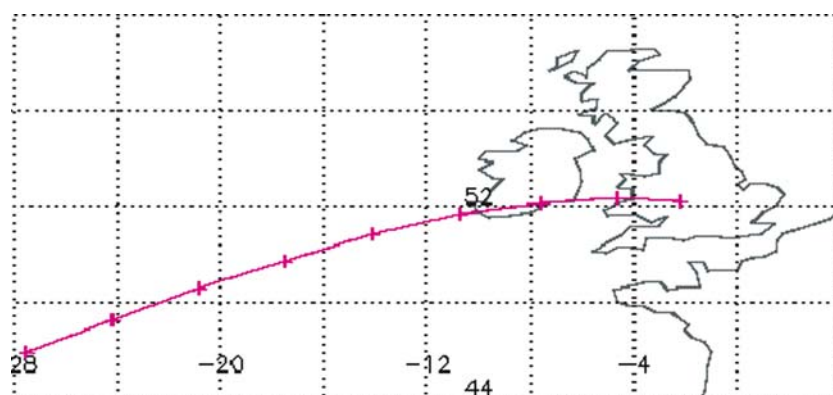


Figure 12. Back-trajectory analysis, start of run 12:00 hours on 01/07/01.

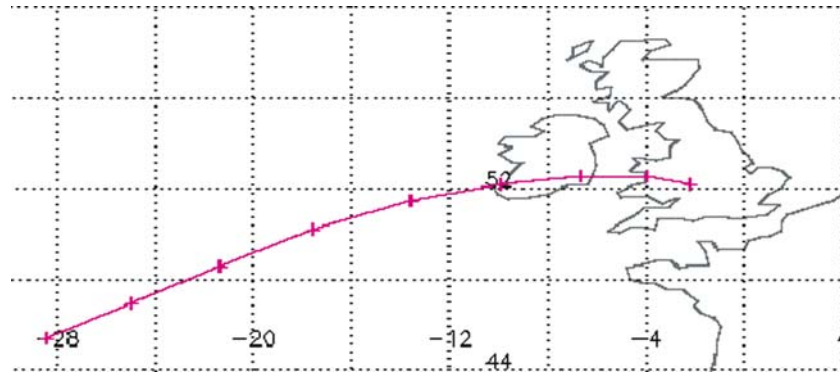


Figure 13. Back-trajectory analysis, start of run 18:00 hours on 01/07/01.

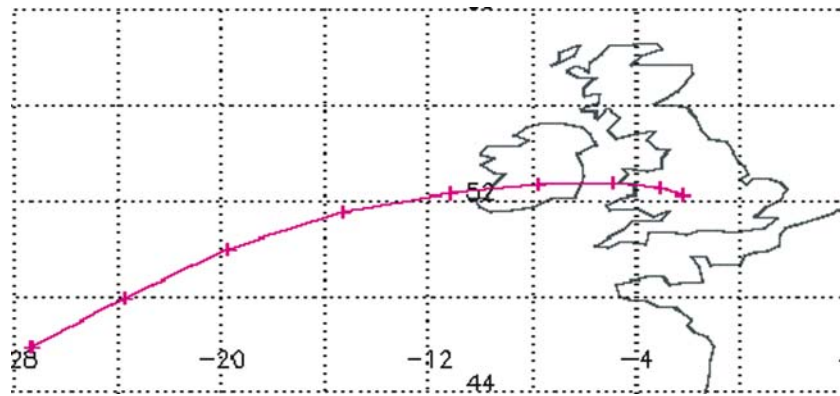


Figure 14. Back-trajectory analysis, start of run 00:00 hours on 02/07/01.

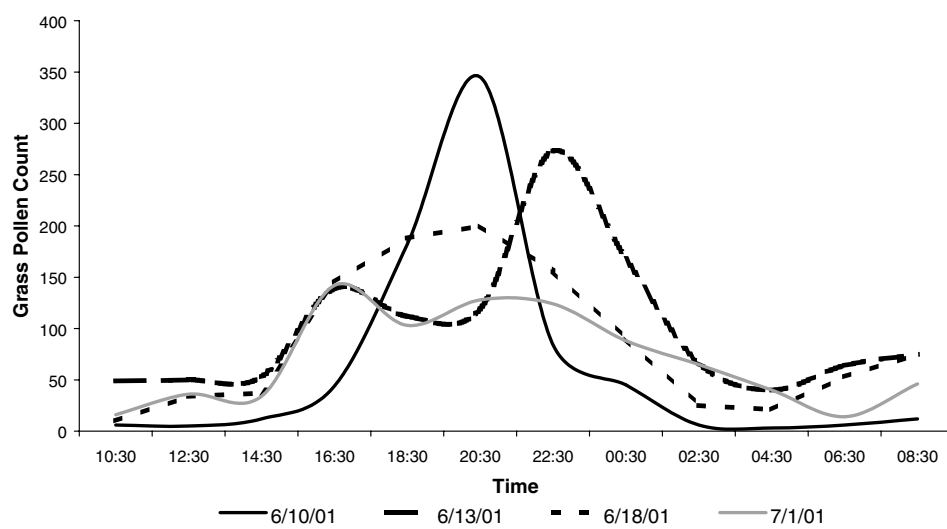


Figure 15. Diurnal variations in grass pollen at Worcester on the 10th, 13th and 18th June and 1st July 2001.

The 13th June also exhibited a low peak at around 16:30 hours. Interestingly, the grass pollen count for the 13th June also had a second, higher, peak around 22:30 hours. This second peak might have been caused by the long-range transport of pollen. The small amount of precipitation recorded at Great Malvern on the 13th June (0.1 mm) did not appear to affect the pollen count.

4. Discussion

This study has shown that back-trajectory analysis can be used to investigate specific pollen episodes in order to determine the direction taken by a parcel of air prior to arriving at a site. Back-trajectories run on the 10th, 13th and 18th June and 1st July 2001 show that the highest counts of the 2001 grass pollen season were reached when air masses arrived from a westerly direction. It should be noted, however, that the prevailing winds are from the west, it is to be expected therefore that pollen-bearing air masses will approach Worcester from this direction. The back-trajectories also show that the amount of time the air masses spent over land did not appear to significantly affect the amount of pollen recorded at the trap.

It is extremely difficult to identify possible sources of grass pollen because grasses are ubiquitous, and grow in a wide range of habitats including waste ground, roadside verges and agricultural land. Nevertheless, the results of this paper have produced some interesting results. For example, examination of diurnal variations in grass pollen at Worcester for 13th June 2001 (Figure 15) shows that the amount of grass pollen recorded during the day peaked around 22:30 hours. This late evening peak may have been caused by nighttime cooling, which deposited pollen grains that had been kept airborne during the day by convection. The maximum transport distance of individual pollen grains over a period of 1 day, which is normally the maximum lifetime of an individual pollen grain in the air, is approximately 50–100 km (Faegri and Iversen, 1992). Back-trajectory analyses for the 13th June show that the air masses arriving at Worcester at 18:00 and 00:00 hours were in South Wales (approximately 100 km away) around midday, about the same time that convection currents were forming (Figures 6–8). It is therefore possible that some of the grass pollen recorded at the trap originated in South Wales (Figure 1).

Examination of particular pollen episodes using back-trajectories and meteorological data can help to establish conditions that are favourable for high (grass) pollen counts. The results demonstrate the importance of temperature and rainfall on grass pollen counts. Three of the 4 days studied were warmer than the monthly mean (1961–1990) and dry (≤ 0.1 mm rainfall). Relative humidity was also important, but to a lesser extent. The 2001 grass pollen season had a mean midday relative humidity of 66.1%; yet very high pollen counts were recorded on the 1st July 2001 even though relative humidity at midday was higher than average (72.5%).

5. Conclusion

This study has shown that it is possible to carry out in-depth analysis, in conjunction with meteorological and pollen records, of particular pollen episodes using back-trajectory analysis. The principal aim of this investigation was to find possible sources of grass pollen that may have contributed to the airborne catch on the days in question. Examination of back-trajectories has shown that the highest grass pollen counts of the 2001 season were reached when air masses arrived from a westerly direction. However, any conclusions reached by this study should be regarded with caution because only a few days were studied. A thorough investigation into the relationship between the path taken by an air mass and grass pollen counts would require a more representative sample size covering several grass pollen seasons.

The main objective of this paper was to find out whether back-trajectory analysis could help the construction of forecast models for grass pollen. The value of back-trajectory analysis is limited by the fact that it is retrospective and cannot, therefore, be employed directly for forecasting. However, when used in conjunction with meteorological data this technique can be used to examine high magnitude events in order to identify conditions that lead to high pollen counts.

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