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ORIGINAL PAPER

Elevated birch pollen episodes in Denmark: contributions from remote sources

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Abstract The purpose of this study was to investigate the relationship between possible long-distance transport of birch pollen and episodes of elevated concentration in Denmark. By analysis of a twenty-six year (1980–2006) time-series of bi-hourly birch pollen counts from two sites (Copenhagen and Viborg) episodes of elevated counts (more than 100 grains) were identified in fewer than 2% of cases. Trajectory analysis showed that such episodes are primarily associated with long-distance transport from Eastern Europe and Scandinavia (43 and 33% of events, respectively); the lowest contribution originated from the British Isles. Long-term episodes (as in 1993 and 2006) occurred when atmospheric conditions favored long-distance transport from several source regions in succession.

Keywords Birch pollen · Elevated concentration episode · Source region · Trajectory modeling

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1 Introduction

In recent decades pollen-related allergic reactions have attracted increased attention in European countries. Because of the wide distribution of birch trees (*Betula*) in Northern Europe, birch pollen is regarded as a main aeroallergen triggering springtime asthma and rhinitis (OECD 2003). In a future warmer climate the distribution is likely to widen as tree-lines extend northwards by several hundred kilometers, while contraction is expected in the south of the Northern Hemisphere (Emberlin 1994). During the last 30 years the length of the growing season has increased by 10–11 days (WHO 2003) and, therefore, analysis of long-term (18–30 years) birch pollen data from several European stations has revealed a weak trend of increasing annual totals (Spieksma et al. 2003; Frei 1998). Such trends were also found for Denmark in a study of the period 1977–2000 (Rasmussen 2002), and could be related to increasing air temperatures arising as a result of anthropogenic activity (Menzel 2000).

It is well known that atmospheric variables, for example temperature, wind, humidity, cloud cover, and precipitation, affect the production, emission, transport, and deposition of birch pollen. In particular, an increase in the strength of the Atlantic westerlies over northwestern Europe might enhance long-distance transport to the Scandinavian countries (Emberlin 1994). The phases of the North Atlantic oscillation correlate strongly with a timing of the growing season at middle and high latitudes and in the pre-seasonal months (January–March) may reach −0.92 for Denmark (D'Odorico et al. 2002).

The effect on human health is strongest during episodes of elevated concentration. According to clinical threshold standards number concentrations of more than 100 grains cause strong allergic reactions (Viander and Koivikko 1978). The observed mean diurnal cycle is primarily related to local sources, well below threshold values, but significantly elevated concentrations may arise when remote sources are superposed on the local effect. The purpose of this study was to investigate the relationship between possible long-distance transport of birch pollen and episodes of elevated concentration.

2 Methods

2.1 Birch pollen measurements in Denmark

The Nordic pollen-monitoring network has more than 30 sampling sites (WHO 2003). Only two of these are located in Denmark—Copenhagen (55°43 ′N and 12°34 ′E) on Zealand and Viborg (56°27 ′N and 09°24 ′E) on Jutland. These perform routine monitoring of airborne pollen. At Copenhagen and Viborg birch pollen is sampled with Burkard Traps located 15 and 21 m, respectively, above ground. Because the distance between the sites is approximately 220 km, statistically significantly different information on pollen measurements can be obtained (Comtois 1998). Standard methods are used to count the birch pollen (Kapyla and Pentinen 1981). Pollen grains are counted in twelve transverse strips and the generic genus is then identified. Counts are expressed in number of grains per specific volume corresponding in our study to approximately 0.1 m^3 during 2 hour interval. Because birch pollen data are episodic in character and continue for a few weeks only during the year, special treatment must be used for data analysis.

2.2 Data treatment

The Copenhagen and Viborg original datasets (representing time series) of birch pollen counts include bi-hourly measurements performed during the pollinating seasons of 1980–2006. A total of 17,328 and 14,703 records from the Copenhagen and Viborg sites, respectively, are available for analysis. Each record consists of the site identifier, day, month, year, local time, and birch pollen count.

Exploratory analysis showed the diurnal cycle for birch pollen counts (when all measurements were included) had a relatively similar shape at both locations (with a minimum in the early morning) but was characterized by slightly lower amplitude and a time shift of an hour in the occurrence of the maximum at Viborg compared with Copenhagen. This is related to specific local meteorological conditions, because the Viborg site is located much further inland than the Copenhagen site, which is close to the seashore, and because of the lower proportion of birch trees in the area. During the period studied bi-hourly mean birch pollen counts were 8 (7) grains, and on an inter-annual scale the largest mean value was 28 (27) grains in 2006 for the Copenhagen (Viborg) site.

For the 26-year period all birch pollen counts higher than 100 were grouped in a separate dataset. For Copenhagen, this included 274 records (with the largest numbers of such measurements in 1993 and 2006) corresponding to 62 days in the 26 years. For Viborg this included 152 records (with the largest number of such measurements during the same years as for the Copenhagen site) corresponding to 49 days during the same period.

The distribution of these cases (accounting for less than 2% from 1980 to 2006 data) as a function of the diurnal cycle is shown in Fig. 1, where the lowest number of such cases corresponds to the early morning (a minimum of 13 cases at 0700 local standard time (LST) and a flat maximum of 28–29 cases between 1300 and 1900 LST). For Viborg, the lowest number of such cases corresponds to the night hours (a minimum of seven cases at 0100 LST and a maximum of 24 cases at 0900 LST).

2.3 Trajectory modeling

Backward trajectory modeling is widely used for evaluation of possible atmospheric transport to geographical locations where short or long-term measurements of chemical or biological species/agents are conducted. Tracking of the positions of air parcels in the atmosphere during such transport can enable

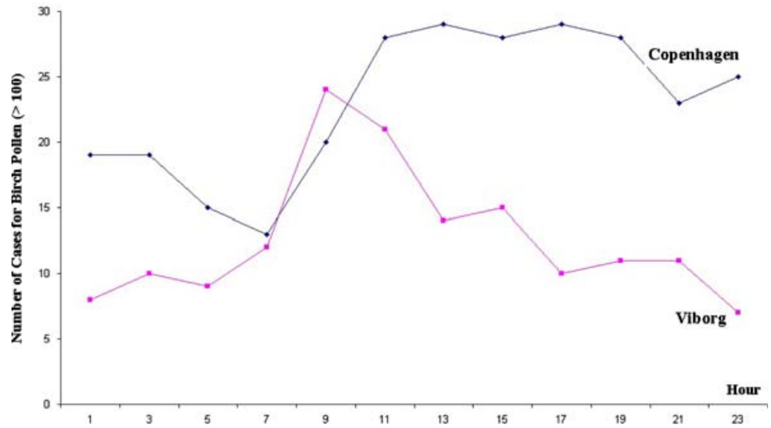

Fig. 1 Distribution of specific cases of birch pollen counts (≥ 100) as a function of diurnal cycle

identification of potential paths and regions from where pollution can be transported and with which it can be associated.

In our study we used the NOAA on-line transport and dispersion HYSPLIT 4.5 model available interactively at http://www.arl.noaa.gov/ready/open/hysplit4.html. This model, called the hybrid single-particle Lagrangian integrated trajectory model (Draxler and Rolph 2003; Rolph 2003) computes both forward and backward types of trajectory by use of several methods. To drive such simulations over a 26-year period the gridded meteorological dataset—Global Reanalysis 1948–2006—was selected.

Each computed trajectory (274 and 152 for the Copenhagen and Viborg sites, respectively) was associated with the corresponding elevated birch pollen measurement. For simplicity, only one trajectory arriving at the measurement site at ground level for the period with the highest concentration was computed backward in time for up to 72 h (3 days) using the vertical motion calculation method. This duration was selected because, according to Sofiev et al. (2006), small grains such as birch pollen can stay in the atmosphere for a few days, leading to typical atmospheric transport of 1,000 km. A set of meteorological data was also extracted along each trajectory at 1-h intervals. This included terrain height, potential temperature, air temperature, precipitation, relative humidity, and mixing layer height. Because there is a difference of 1 h between the universal coordinated time (UTC) and Danish LST, the trajectories were computed for even hours to fit the corresponding measurements made at odd local times. Trajectories were then grouped depending on pathway of atmospheric transport and area from where the trajectories arrived.

3 Results and discussion

3.1 Elevated pollen counts from remote sources

Depending on the pathways of atmospheric transport the simulated trajectories were divided into four sectors/potential regions from which they had originated. Analysis of meteorological data along trajectories showed that trajectories mostly traveled within the boundary layer and without wet removal during transport (no precipitation observed).

The northern sector. Scandinavian sources of birch pollen are divided into two potential regions. The first involves atmospheric transport from Finland and northern parts of the Scandinavian peninsula (Fig. 2 a) and is characterized by relatively rapid atmospheric transport, i.e. air parcels originating over the potential pollen-source region traveled a longer distance before arrival at the measurement site. The second is related to atmospheric transport from southern parts of the Scandinavian Peninsula (Fig. 2 b) and is characterized by a slow motion of air parcels and a longer time to travel to Denmark.

The eastern sector. Eastern European sources include the Baltic States, Belarus, Ukraine, and Russia. During atmospheric transport pollen from all these always passes over Poland before arrival at the measurement sites (Fig. 2c, d).

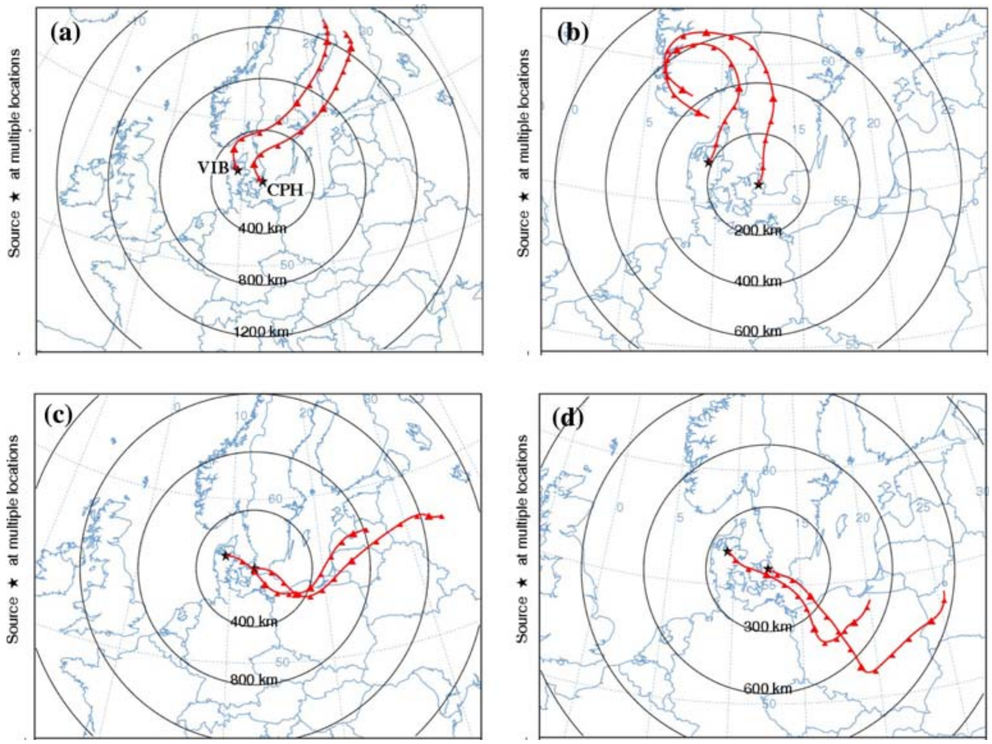

Fig. 2 Backward atmospheric trajectories (calculated by use of the NOAA HYSPLIT model) arriving at the Copenhagen (CPH) and Viborg (VIB) measurement sites from the northern sector at (**a**) 0800 UTC on 28 Apr 1995 and (**b**) 2200 UTC on 10 May 2001, and from the eastern sector at (**c**) 1800 UTC 27 Apr 2004 and (**d**) 1600 UTC 16 Apr 2004

The southern sector. Western European sources are usually Germany and the Benelux countries, and countries south of Germany (Fig. 3a), but also, on occasion, France (when backward trajectories originated and traveled initially above the boundary layer).

The western sector. British sources, i.e. trajectories initially originating over the Atlantic Ocean and then passing over the UK before arrival at the Danish sites (Fig. 3b).

During elevated pollen-concentration episodes a clear signature of a substantial contribution from Danish local birch pollen sources was identified on five occasions only for the Copenhagen site (Fig. 3c). A very rare situation, when transport occurs from different source regions, is shown in Fig. 3d. The calculated trajectory arriving at the Viborg site from the north originated over Germany (southern sector). The trajectory arriving at the Copenhagen site from the east originated over Poland (eastern sector).

As shown in Table 1, elevated counts at both sites were because of atmospheric transport from the eastern sector on 43% of occasions. Levels at Viborg were higher than at Copenhagen when transport was from the southern sector and lower than at Copenhagen when transport was from the western sector. The northern sector had similar effects at both Viborg and Copenhagen but rapid transport (25%) from this sector resulted in a dominant effect at Copenhagen compared with Viborg. The lowest mean of 157 was found for the Danish sources. Among sectors, for both sites the highest maxima and means of elevated counts are for the eastern sector, i.e. this sector makes a greater contribution than the others to Danish birch pollen measurements. For 90 cases elevated counts were observed simultaneously at both locations, moreover, i.e. the birch pollen source region is considered to be the same. Among these, 74 cases are represented by two long-term episodes. Such episodes (continuous duration of several days) have the

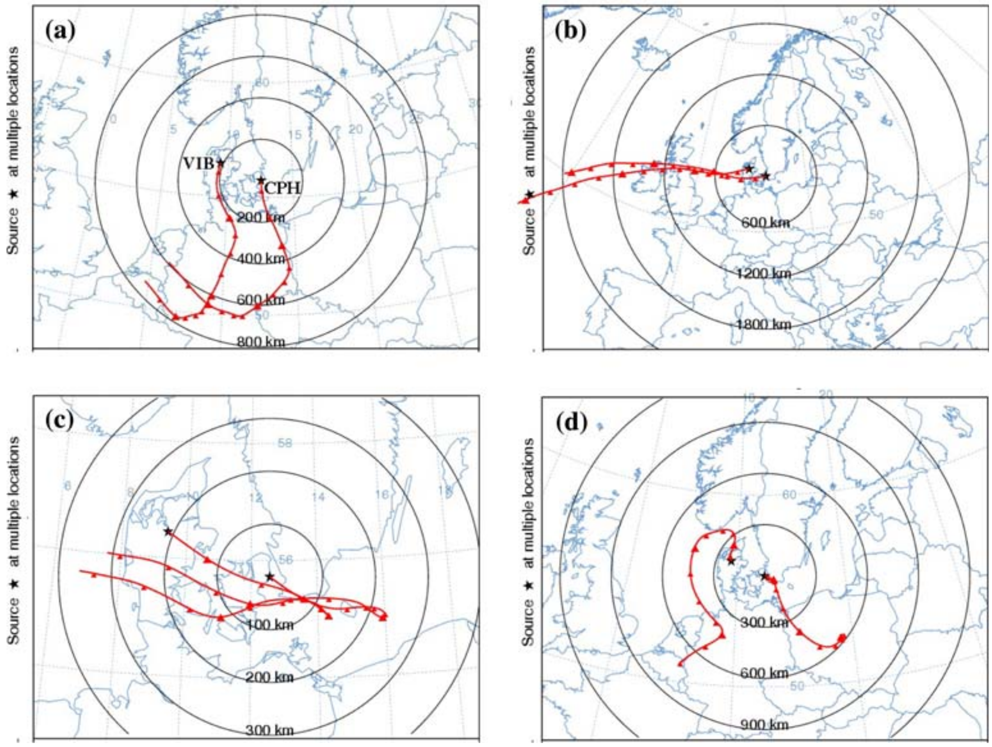

Fig. 3 Backward atmospheric trajectories (calculated by use of the NOAA HYSPLIT model) arriving at the Copenhagen (CPH) and Viborg (VIB) measurement sites from (**a**) the southern sector at 1400 UTC 14 Apr 1990, (**b**) the western sector at 2200 UTC 01 May 1997, (**c**) Danish local sources at 0400 UTC 03 May 1986; and (**d**) different source regions at 1200 UTC 24 Apr 2000

Table 1 Summary of trajectories corresponding to the elevated birch pollen concentrations and their means and maxima by sectors in respect of the Copenhagen and Viborg measurement sites (based on 1980–2006 data)

Site sector	Copenhagen				Viborg			
	N	%	Mean	Max	*N*	%	Mean	Max
Northern	93	33.9	187	647	50	32.9	174	426
Fast transport	68	24.8	222	647	12	7.9	176	295
Slow transport	25	9.1	152	243	38	25.0	172	426
Eastern	117	42.7	213	1,080	64	42.1	189	689
Southern	38	13.9	175	460	32	21.1	177	373
Western	21	7.7	181	646	6	3.9	165	226
Local Danish	5	1.8	157	212	–	–	–	–
Total cases	274				152			

greatest effect on health and should, therefore, be evaluated in more detail.

3.2 Long-term episodes with elevated pollen counts

For the time series studied there were two episodes during which elevated counts of birch pollen were observed almost simultaneously at both sites for a relatively long time:

1. 25–30 April 1993 (33 cases); and
2. 3–10 May 2006 (41 cases).

In 1993 the birch pollen flowering dates corresponding to 2.5 and 97.5% of the seasonally accumulated amount were 23 April and 11 May, respectively, for Copenhagen, and 24 April and 10 May, respectively, for Viborg. In 2006, these dates were 2 May and 14 May, respectively, for Copenhagen, and 3 May and 11 May, respectively, for Viborg. The time series of the birch pollen concentrations at both sites are given in Fig. 4 and the sequences of trajectories arriving at these two locations during these periods are shown in Fig. 5.

3.2.1 Episode from 25–30 April 1993

For the first episode, for Viborg (Fig. 5b), trajectories showed that atmospheric transport from the southern sector (dominated by Germany) initially had the largest effect. This was followed by input from the eastern European countries (dominated by Poland).

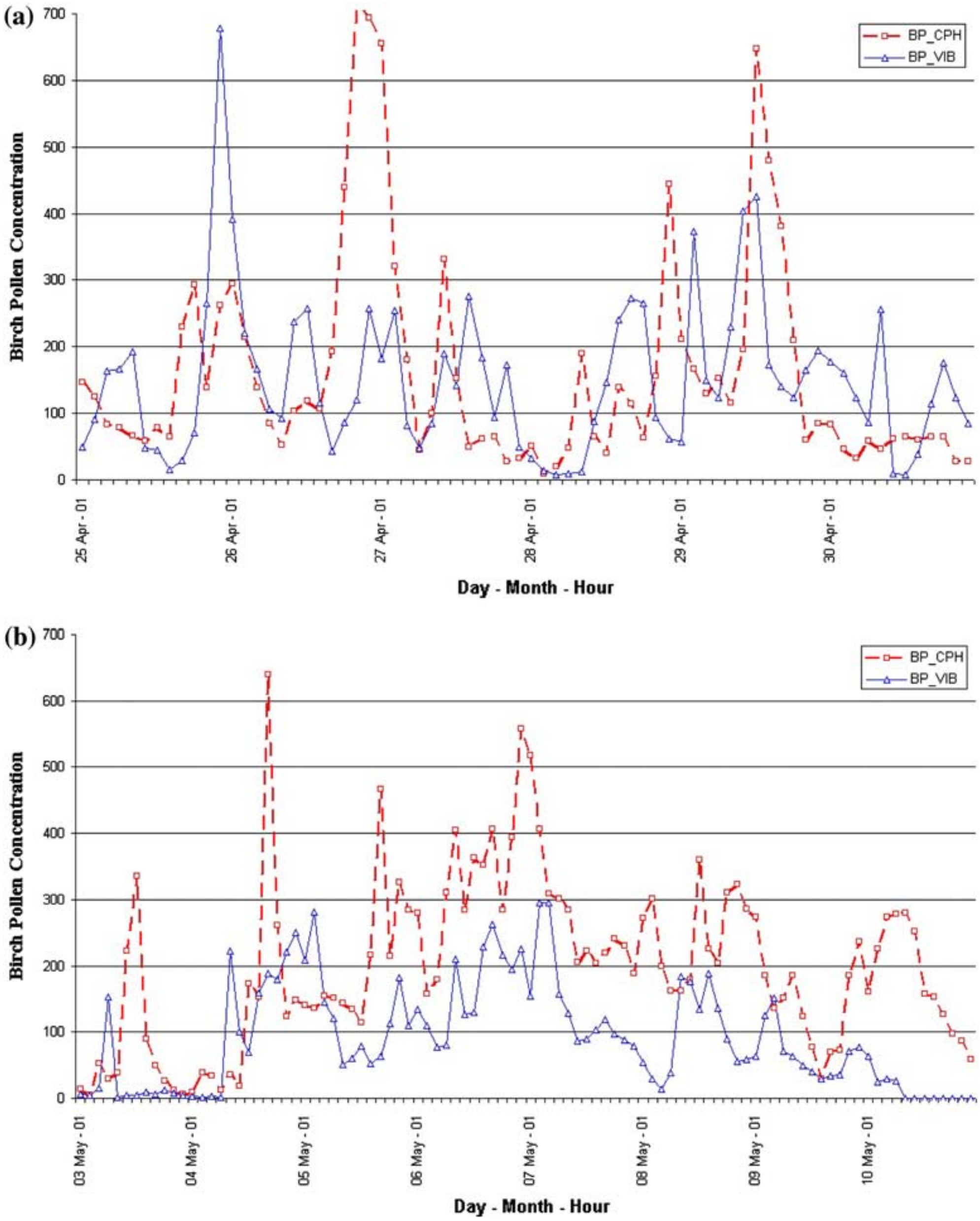

Fig. 4 Times series of birch pollen concentrations (counts per 2 hour intervals) for the Copenhagen (CPH) and Viborg (VIB) measurement sites for the long-term episodes (**a**) 25–30 Apr 1993 and (**b**) 3–10 May 2006

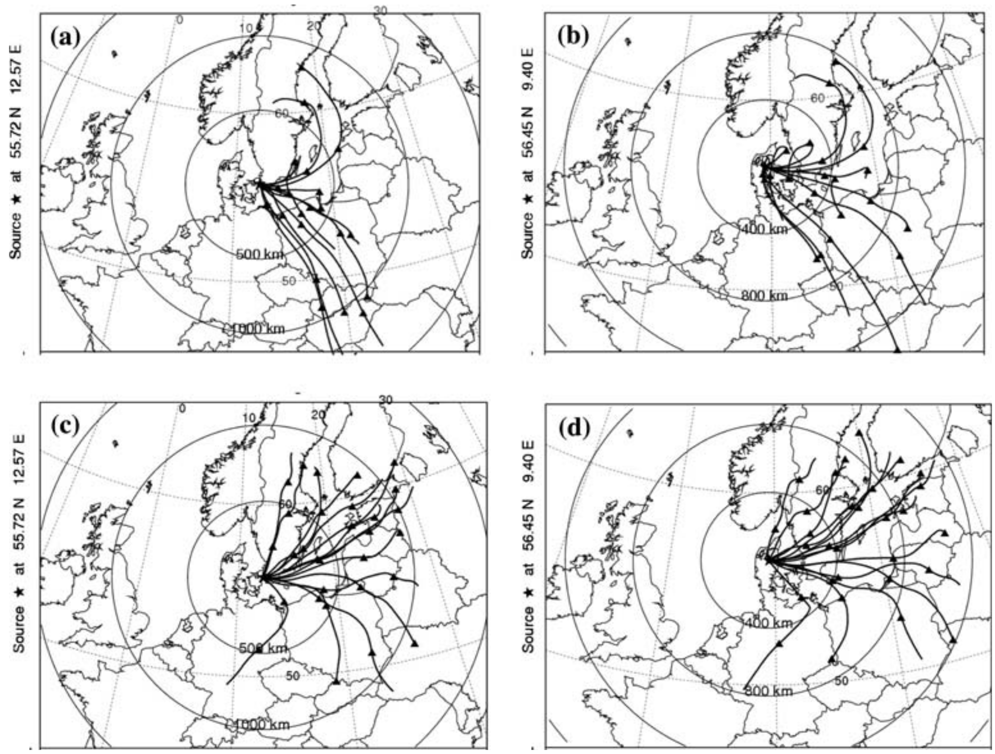

Fig. 5 Backward atmospheric trajectories (calculated by use of the NOAA HYSPLIT model) arriving at the Copenhagen (**a**, **c**) and Viborg (**b**, **d**) measurement sites during long-term episodes characterized by continuous elevated birch pollen concentrations: (**a**, **b**) 25–30 Apr 1993 and (**c**, **d**) 3–10 May 2006. The plotted trajectories are shown at 12-h intervals

Finally, during 29–30 April 1993, the effect of the Scandinavian sources became more visible. For Copenhagen, for the same episode, the effect of German sources was minimal (Fig. 5a). On average, the mean elevated counts at the Copenhagen and Viborg sites were 228 and 210 grains, respectively.

At the Copenhagen site the mean elevated counts transported from the eastern and northern sectors were 233 and 226 grains, respectively. The maximum values of 716 and 647 grains were observed at 2100 LST on 26th April and at 1300 LST on 29th April, respectively, because of transport from the same sectors. At the Viborg site the mean elevated counts transported from the eastern and northern sectors were 219 and 187, respectively. The maximum values of 678 grains and 426 grains were observed at 2100 LST on 25th April and at 1100 LST on 29th April, respectively, because of transport from the same sectors.

3.2.2 *Episode from 3–10 May 2006*

A similar dependence on source regions was identified for the second episode. As seen in Fig. 5c, d, for both sites, during the first day atmospheric transport occurred from Germany. Then, until the end of 5th May 2006, it was dominated by the effect of eastern sector sources. From 6th May until the end of 10th May 2006 the elevated concentrations depended on birch pollen transport from countries in the Scandinavian peninsula (dominated by Finland), and especially from territories north of 60° N. The mean elevated counts were 258 and 166 grains at the Copenhagen and Viborg sites, respectively.

At the Copenhagen site the mean elevated counts transported from the eastern and northern sectors were 255 and 242 grains, respectively. The maximum values of 639 and 558 grains were observed at 1700 LST on 4th May and at 2300 LST on 6th May, because of transport from the eastern and northern sectors, respectively. At the Viborg site the mean elevated counts transported from the eastern and northern sectors were 191 grains and 170 grains, respectively. The lowest mean of 134 grains was for the southern sector. Maximum values of 281 grains and 295 grains were observed at 0300 LST on 5th May and at 0300 LST on 7th May, because of transport from the eastern and northern sectors, respectively. For both sectors, comparable maximum values were observed with a time delay of several hours at Viborg compared with Copenhagen.

For both episodes contributions of birch pollen from several potential source regions were readily identified. At both Danish sites the mean and maximum elevated counts of birch pollen were always higher for the eastern sector than for the other sectors. The contribution from German sources (southern sector) was the lowest. Such long-term episodes are very useful for verification of off-line and on-line modeling of birch pollen atmospheric transport and deposition, for example by the DMI-ENVIRO-HIRLAM modeling system (Chenevez et al. 2004).

4 Conclusions

Analysis of time series (1980–2006) of short-term and selected long-term episodes with elevated birch pollen counts from two Danish measurement sites (Copenhagen and Viborg) showed that these events can be associated with long-distance atmospheric transport from potential sources of birch pollen. During this period, in 43 and 33% of the episodes such atmospheric transport occurred from the eastern sector, which comprises the eastern European countries, the Baltic States, the Ukraine, Belarus, and Russia, and from the northern sector, which comprises the countries of the Scandinavian peninsula. These sectors are characterized by rapid and slow atmospheric transport, respectively, to the sites. The means (maxima) were 213 (1080) and 187 (647) grains per specific volume corresponding to approximately 1.0 m^3 during 2 hour interval for the eastern and northern sectors, respectively. The lowest contribution was found to be from the western sector, associated with British sources.

Although the Danish sites are not far from each other (220 km), atmospheric transport associated with episodes of elevated concentration were different at the sites. This was especially apparent for the northern sector, for which slow atmospheric transport dominates rapid transport by a factor of approximately 3 at the Viborg site compared with Copenhagen, and vice versa.

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