

ORIGINAL PAPER

The long-range transport of birch (*Betula*) pollen from Poland and Germany causes significant pre-season concentrations in Denmark

C. A. Skjøth*, J. Sommer†, A. Stach‡, M. Smith‡,§ and J. Brandt*

*Department of Atmospheric Environment, National Environmental Research Institute, Roskilde, Denmark, †The Asthma and Allergy Association, Roskilde, Denmark,

‡Laboratory of Aeropalynology, Adam Mickiewicz University, Poznań, Poland and §National Pollen and Aerobiology Research Unit, University of Worcester, Worcester, UK

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Summary

Background Birch pollen is highly allergic and has the potential for episodically long-range transport. Such episodes will in general occur out of the main pollen season. During this time, allergy patients are unprotected and high pollen concentrations will therefore have a full allergenic impact.

Objective To show that Denmark obtains significant quantities of birch pollen from Poland or Germany before the local trees start to flower.

Methods Simultaneous observations of pollen concentrations and phenology in the potential source area in Poland as well as in Denmark were performed in 2006. The Danish pollen records from 2000 to 2006 were analysed for possible long-range transport episodes and analysed with trajectories in combination with a birch tree source map.

Results In 2006, high pollen concentrations were observed in Denmark with bi-hourly concentrations above 500 grains/m³ before the local trees began to flower. Poland was identified as a source region. The analysis of the historical pollen record from Copenhagen shows significant pre-seasonal pollen episodes almost every year from 2000 to 2006. In all episodes, trajectory analysis identified Germany or Poland as source regions.

Conclusion Denmark obtains significant pre-seasonal quantities of birch pollen from either Poland or Germany almost every year. Forecasting of birch pollen quantities relevant to allergy patients must therefore, take into account long-range transport. This cannot be based on measured concentrations in Denmark. The most effective way to improve the current Danish pollen forecasts is to extend the current forecasts with atmospheric transport models that take into account pollen emission and transport from countries such as Germany and Poland. Unless long-range transport is taken into account, pre-seasonal pollen episodes will have a full allergic impact, as the allergy patients in general will be unprotected during that time.

Keywords allergy, atmosphere, emission, forecasting, phenology, trajectories

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Correspondence:

Carsten Ambelas Skjøth, Department of Atmospheric Environment, National Environmental Research Institute, Frederiksborgvej 399, PO Box 358, DK-4000 Roskilde, Denmark. E-mail: cas@dmu.dk

Introduction

In central and northern Europe, *Betula* pollen is considered to be one of the most important allergenic pollen types [1–4]. In Denmark, pollen allergy among the Copenhagen population has increased from 12.9% in 1990 to 22.5% in 1998 [5, 6]. Allergic Rhinitis (AR) is closely associated with asthma, suggesting the theory of ‘one airway, one disease’ [7, 8]. Among people with AR, 20–30% either suffer from asthma or will develop asthma

later on [9, 10]. AR is associated with sinusitis and inflammation of the middle ear [11] and has a significant impact on quality of life (QOL), alters social life, disturbs sleep and affects performance in school and at work [10, 12]. Medical treatment of pollen allergy is documented to improve the overall health of the patients during the pollen season [9, 10, 12, 13]. In order for medication to be an effective protection against episodes of high pollen concentration, allergy patients need to plan their medical intake and protection in advance [10, 14, 15]. This

planning requires knowledge of the pollen levels. Reliable forecasts several days ahead are therefore needed. Owing to this need, pollen forecasts are prepared every day during the pollen season in Denmark (<http://hoefeber.astma-allergi.dk/regado.jsp?type=page&tid=29>). In Denmark, the official reported pollen prognosis is based on the daily weather forecast, the pollen calendar [16] and local 24-h measurements. The prognosis forecasts the pollen levels above certain daily average thresholds, which are 30 and 100 birch pollen grains/m³. These thresholds are based on correlations between pollen allergy symptoms among Danish hayfever patients and measured pollen concentrations [17, 18]. Forecast methods based on local measured pollen concentrations, the daily weather forecasts and clinical thresholds are also used in other countries such as Spain [19, 20], France [21] and Switzerland [22]. Such forecasts are unlikely to include episodes of long-range transport of birch pollen.

Air pollutants such as PM_{2.5} and PM₁₀ are known to have the potential for long-range atmospheric transport up to 1000 km or more [23]. The main reason for the long-range transport potential is the small weight of the particles resulting in a corresponding low gravitational settling. Birch pollen is approximately 22 µm in diameter [24] and therefore larger than PM_{2.5} and PM₁₀. It has an almost spherical form and a density of approximately 800 kg/m³ [24]. Form, size and density for a particle can be used to calculate the deposition velocity using particle deposition theory [25]. For birch pollen, this deposition velocity is approximately 1 cm/s. During the pollen season, birch pollen is especially released during hot sunny weather [22]. This weather type is associated with large atmospheric instability where the vertical winds may exceed several metres per second. Despite their gravitational settling, pollen may be caught by these vertical winds and transported up into the atmosphere and will be found throughout the atmospheric boundary layer [24, 26]. Removal from the atmosphere will be either by wet deposition, direct transport to the surface or gravitational settling. Pure gravitational settling takes several days from the top of an atmospheric boundary layer of 1–2 km. Birch pollen therefore has the potential during certain meteorological conditions to be transported long distances from one region to another.

Birch trees are found in most of Europe and the timing of pollen release is primarily related to local accumulation of heat from winter to spring [4, 22, 27–30]. Spring mainly advances from the south to the north and the release of birch pollen therefore follows the same pattern. As a consequence, birch pollen will be released in countries south of Denmark such as Poland and Germany before the season in Denmark begins. Many regions in Poland and Germany have a high density of birch trees [31, 32] and depending on the weather conditions, pollen from these countries may end up in Denmark through atmospheric

transport. If so, pollen levels could reach the threshold levels of 30 grains/m³ daily average and could cause symptoms of allergy before the Danish trees even begin to flower. Whether the pollen reaches Denmark in significant quantities to cause allergic symptoms is not known. We therefore formulated the hypothesis that Denmark receives birch pollen in quantities above 30 grains/m³/day almost every year from either Poland or Germany, before the pollen season due to local flowering trees is initiated in Denmark.

In 2006, we had the opportunity to test this hypothesis by using a combination of phenological observations and pollen measurements in Poland (Poznań) and Denmark (Copenhagen), and trajectory calculations of air masses from Poland to Denmark. Furthermore, we test our hypothesis by identifying possible long-range transport episodes in the Danish measurements during the period 2000–2006. All these episodes will be investigated with respect to source regions using trajectory analysis and a source map.

Materials and methods

Sites and observation methods

The observations in this study are obtained from two sites: Copenhagen and Poznań. Copenhagen is the capital of Denmark and the surrounding areas are mainly urban, bordered by the coast to the east. Continuous monitoring of the seasonal pollen content of the air has been performed by a Burkhard volumetric spore trap of the Hirst design [33] in Copenhagen since 1977. Here, we used bi-hourly pollen data from *Betula* collected during the period 2000–2006. The trap was sited on the roof of the Danish Meteorological Institute (55°43'N, 12°34'E) in the centre of Copenhagen at a height of 15 m above the sea level. Daily and diurnal variations in *Betula* pollen are expressed as grains/m³. Collection of pollen and preparation of slides are performed according to Goldberg et al. [34]. Pollen is counted at ×640 magnification on 12 transverse strips every 2 h, according to Kämpylä and Penttinen [35]. Pollen from *Betula* is identified to generic genus.

Poznań is the capital of Wielkopolska, an agricultural region situated in mid-western Poland [36]. In 2006, daily average *Betula* pollen data were collected in Poznań by a Burkard volumetric spore trap of the Hirst design [33]. The trap was sited on the roof of a 13-storey university students' dormitory (Esculap) at a height of about 33 m (52°24'N, 16°53'E), approximately 1 km south-west of the city centre. Pollen is counted according to a description by Corden et al. [37].

During the last 2 weeks of April, phenological observations were performed at both locations. Several phenological stages were identified during the flowering process [38]. Start of flowering was defined as a few open

inflorescences to 25% and the term full flowering was used for the period when 25–75% of the flowers were open. End of flowering was used to describe the period when the last 25% of catkins were open. In Poznań the phenological observations were performed two to three times a week at Cytadela Park situated in the centre of the city (52°25'N, 16°56'E). In Copenhagen, the observations were performed daily at residential areas in or near Copenhagen: Taastrup (55°38'N, 12°16'E) and Hedehusene (55°39'N, 12°11'E). The Copenhagen phenological observations were performed similar to the study by Jato et al. [39], where they randomly chose individual three trees at each location and selected 20 catkins for investigation. In Copenhagen, we chose three trees at each location. On each tree, four branches were selected, choosing north, west, south and east direction, if possible. On each branch, five catkins were investigated, totalling 20 catkins. It is assumed that these observations were general for the Copenhagen region.

Birch pollen pre-seasonal analysis

Temporal (seasonal and diurnal) variations in *Betula* pollen counts at Copenhagen during the period 2000–2006 were examined with the aim of identifying pre-seasonal *Betula* pollen episodes originating from long-range transport. The 2.5% accumulation method [34] has been used for identifying the start of the season. If the daily pollen count exceeded 30 grains/m³ either before the season began or at the actual start day, the episode was chosen for investigation with back trajectory analysis.

Back trajectory calculations and source location map

A map of potential sources of birch pollen covering Poland and Germany has been produced using national statistics, forest inventories [31, 32] and detailed land cover information from the Corine Land Cover Classification [40]. The land cover classification is available as irregular units with a minimum size of 25 ha and a minimum width of 100 m. The Corine Land Cover classification distinguishes between 44 different land-use classes including broad-leaved forest, coniferous forest and mixed forest. The National Forest inventories for Germany [32] and Poland [31] are used for calculating the resulting birch tree density in the forests. Back trajectories are calculated using nine trajectories for each arrival time using a method described by Stach et al. [41] as an indication of possible source areas.

Results

Daily pollen counts and phenological observations in 2006

Birch pollen concentrations in Poznań peaked between the 20th and 28th of April, with daily average birch pollen

concentrations of between 739 and 2167 grains/m³ (Table 1). The phenological observations in Poznań show that the flowering season was at its peak during this period (Table 1). Birch pollen concentrations in Copenhagen show three daily average pollen concentrations above 30 grains/m³. The values are 108, 244 and 41 for the 23rd, 26th and 27th of April, respectively (Table 1). The phenological observations during the period showed that the anthers opened between the 1st and 2nd of May (Table 1).

Diurnal birch pollen variations based on 2-hourly measurements displayed as a time series (Fig. 1) show that the first birch pollen in Copenhagen in 2005 was observed on April 23. The amount of birch pollen peaked sharply during the middle of the day on the 23rd and decreased again in the evening. From the 24th to the 26th of April bi-hourly measurements showed either low concen-

Table 1. Daily pollen count and phenological observations in Copenhagen and Poznań in the period 18th of April to the 2nd of May 2006

Date	Birch pollen count Copenhagen		Birch pollen count Poznań	
	(pollen grains/m ³)	Phenology Copenhagen	(pollen grains/m ³)	Phenology Poznań
18.04	0	Closed	7	Start of flowering
19.04	1	Closed	13	Start of flowering
20.04	0	Closed	917	Start of flowering
21.04	0	Closed	1011	Full flowering
22.04	0	Closed	2167	Full flowering
23.04	108	Closed	2123	Full flowering
24.04	4	Closed	1064	Full flowering
25.04	10	Closed	974	Full flowering
26.04	244	Closed	1395	Full flowering
27.04	41	Closed	1203	Full flowering
28.04	8	Closed	739	Full flowering
29.04	2	Closed	32	End of flowering
30.04	7	Closed	89	End of flowering
01.05	77	Anthers opening	23	End of flowering
02.05	118	Start of flowering	80	End of flowering

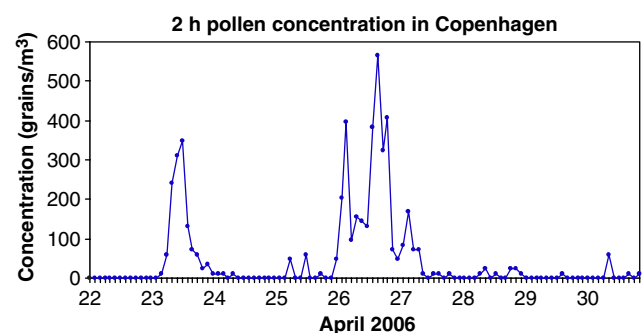


Fig. 1. Bi-hourly birch pollen concentrations in Copenhagen in April 2006.

trations (< 50 grains/m³) or no birch pollen. The bi-hourly concentration of birch pollen on April 26 rapidly increased from zero to above 400 grains/m³ early in the morning. The concentration decreased from 08:00 to 16:00 hours in the afternoon, but a second peak was recorded between 16:00 and 22:00 hours, where the highest observed concentration reached 564 grains/m³. After this second peak, the concentration decreased again to between 48 and 168 grains/m³. From the 27th of April to midday on the 1st of May, few birch pollen grains were recorded (< 50 grains/m³ per 2-h transect).

Detailed weather and trajectory analysis for the period 23rd–28th of April 2006

The synoptic situation in northern Europe from the 22nd to the 28th of April 2006 was governed by two low-pressure systems: one located over Iceland and one located between Greenland and Norway. A high-pressure area located in the southern part of Norway on the 22nd of April moved during the period to Finland and Russia. During the 22nd and 23rd of April, the high-pressure area over Norway produced a south-easterly wind that moved from Poland to Denmark. On the 24th and 25th of April, a small low-pressure system passed north of Poland, creating westerly winds over Denmark. This system dissolved between the 25th and 26th of April. From the 26th to the 27th of April, the low-pressure system located north of Iceland gave air mass transport to Denmark from the south and south-east. On the 28th of April, a high-pressure area west of the British Isles in combination with a low-pressure system between Greenland and Denmark resulted in wind from the north-east. The trajectories for these days were examined in detail (examples shown in Fig. 2).

The trajectories show that the air masses arrived directly from Poland on April 23rd (Fig. 2a) and that the air mass took approximately 1 day to move from the Poznań area to Denmark. During the period 24th–26th of April, the air masses arrived from the Baltic Sea and north of Poland, passing Denmark and arriving in Copenhagen from the west (Fig. 2b). On April 26th, the air masses again arrived directly from Poland, and took 1 day of atmospheric transport (Fig. 2c). From April 27th, the origin changed again: first to the north of Poland and the Baltic Sea and then to origins from the north-west (Fig. 2d).

Pre-seasonal birch pollen counts in Copenhagen 2000–2006

The beginning of the season based on the 2.5% method varies from the beginning of April to the beginning of May (Table 2). The annual accumulated pollen count also varies from 3409 in 2005 to 21142 in 2006. Eleven possible long-range transport episodes with records be-

tween 35 and 244 grains/m³ have been identified. Three of these were in 2006. All possible long-range episodes were investigated with trajectories for the main synoptic observation periods: 00 UTC, 06 UTC, 12 UTC and 18 UTC. In all investigated episodes, the air masses arrived in Copenhagen directly from Germany or Poland, travelling between 12 and 30 h. Except for the trajectories on the 15th of April 2005 (18 UTC), all trajectories arrived from within German or Polish land territory. The trajectories calculated for 18 UTC on the 15th of April 2005 arrived partly from northern Poland and partly from the Baltic Sea area between Denmark and Poland. In three of the episodes, the nine trajectories dispersed over all of Germany or Poland (see Fig. 3a), but in 29 episodes the nine trajectories did not disperse but followed the same path, e.g. the 2nd of April 2002, 12 UTC (Fig. 3b).

Broad-leaved trees are found in all regions of Germany and Poland with varying density (Fig. 4). The highest forest density is found in the central part of Germany, but high densities are also found in parts of eastern Germany, as well as parts of western and eastern Poland. Low forest densities are found in southern Germany, north-western Germany and central Poland. The birch tree density in the broad-leaved forests varies from 1% to 44% between the different regions in the two countries (Fig. 4). The highest birch tree densities are found in Poland and the eastern part of Germany. The lowest densities are found in south-eastern parts of Poland and the central and southern parts of Germany.

Discussion

The present experiments support the hypothesis that Denmark receives significant quantities of birch pollen from Poland and Germany, before the pollen season is initiated in Denmark.

The phenological observations in Copenhagen have shown that the local birch trees started flowering in the beginning of May 2006. Assuming that the observations were general for the region, then the pollen grains recorded in Copenhagen in April must have originated from another area. Pollen counts and phenological observations recorded in Poznań show that the birch pollen season was at its peak due to local emission in this area between the 20th and 27th of April. Trajectories for the investigated period show that air masses arrived in Copenhagen from several locations during the period. When the air masses arrived from Norway, Sweden or Denmark, few or zero pollen counts were recorded. When the air masses arrived from the Poznań region (or other Polish areas), high pollen counts were recorded in Copenhagen. During the transport from Poland, the air masses crossed the Baltic Sea where there are no pollen sources. This suggests that the pollen measured in Copenhagen in April 2006 were of Polish origin.

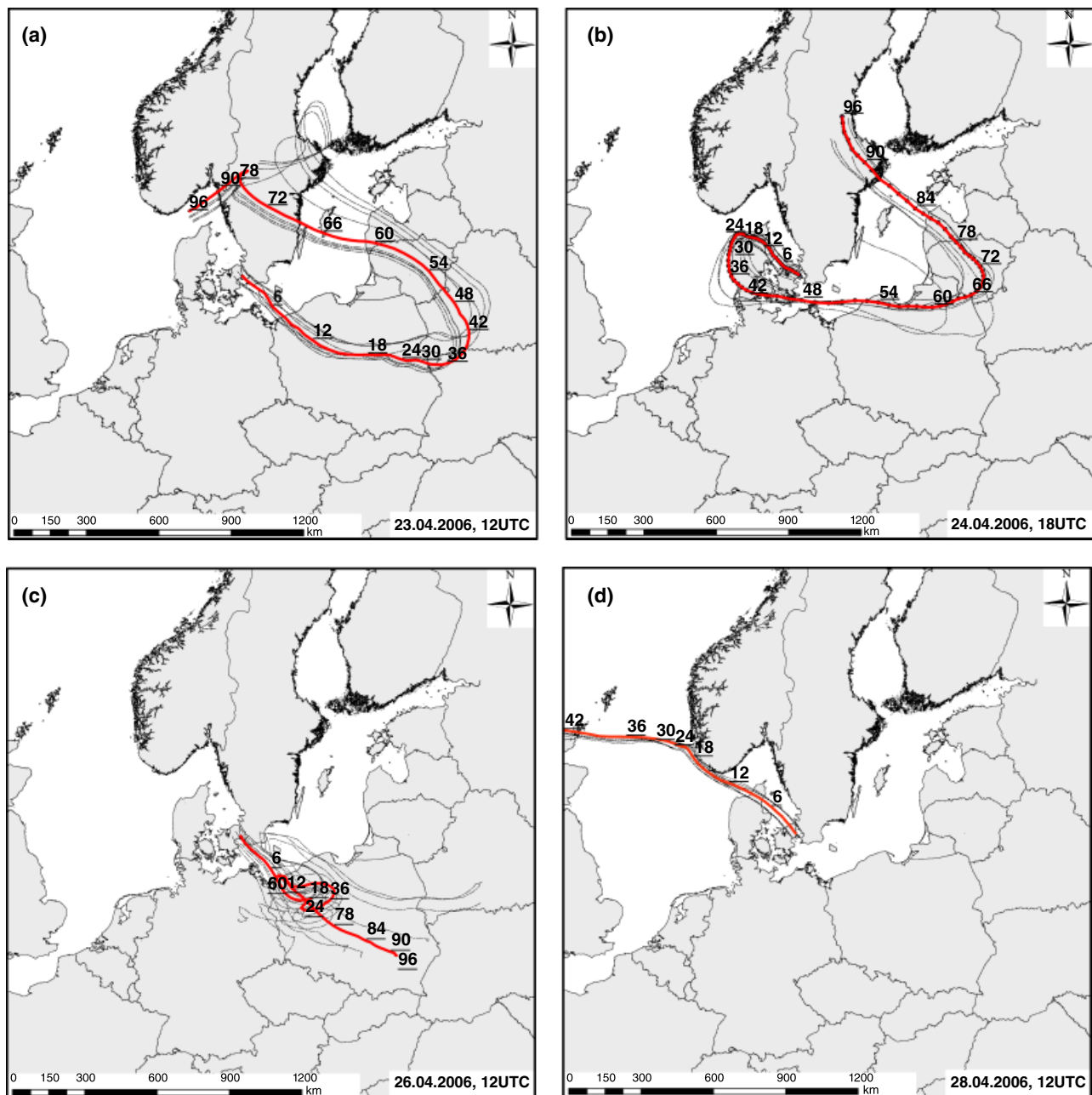


Fig. 2. Trajectories for (a) the 23rd of April, 12 UTC, (b) the 24th of April, 18 UTC, (c) the 26th of April, 12 UTC and (d) the 28th of April, 12 UTC. The trajectory marked with a thick red line corresponds to the pollen trap in Copenhagen and the trajectories marked with thin lines correspond to the surrounding receptor points.

Analysis of the period 2000–2005 showed several episodes with significant levels of (possible) pre-seasonal long-range transport almost every year. Daily phenological observations were not available for those years. However, trajectory analyses showed that, in all cases, the air masses arrived from either Germany or Poland, where the season generally starts earlier than in Denmark. It is also shown that Germany and especially Poland contains significant quantities of birch trees capable of acting as a source for pre-seasonal pollen in Denmark. The use of a simple trajectory model showed that there were no other

potential source regions apart from Germany and Poland. This strongly indicates that pre-seasonal long-range transport with significant quantities of pollen occurs almost every year, from sources in either Germany or Poland.

Long-range transport of pollen from other birch tree-rich regions such as Finland or the Baltic countries may also arrive in Denmark. Owing to a more northern location, the birch pollen season in Finland or the Baltic countries starts later than the German and Polish birch pollen season. Transport from Finland or the Baltic

countries is therefore more likely to occur during the season or after the main season in Denmark has finished. As a result, these episodes could potentially increase the overall pollen level in Denmark or extend the period with high pollen counts.

This paper extends other studies that have shown pre-seasonal long-range transport from the Baltic countries to Finland. Koivikko et al. [42] identified a period before the 'real' birch pollen season when the occurrence of pollen in the atmosphere could only be explained by long-range

Table 2. Season start, annual pollen count and possible long-range transport episodes to Denmark during the period 2000–2006

Year	Season start (2.5%)	Total annual pollen count	Possible long-range transport episode Date and daily pollen count
2000	18.04	4999	17.04 – 35 grains/m ³ 18.04 – 190 grains/m ³
2001	25.04	6686	25.04 – 55 grains/m ³
2002	02.04	6886	01.04 – 129 grains/m ³ 02.04 – 92 grains/m ³
2003	22.04	4559	–
2004	15.04	9189	04.04 – 67 grains/m ³ 05.04 – 56 grains/m ³
2005	15.04	3409	15.04 – 55 grains/m ³
2006	02.05	21142	23.04 – 108 grains/m ³ 26.04 – 244 grains/m ³ 27.04 – 41 grains/m ³

The possible long-range transport episodes are investigated using trajectory analysis according to the hypothesis.

transport, and Hjelmroos [43, 44] demonstrated, through the use of back-trajectories, how *Betula* pollen was transported to Fennoscandia before the start of the main pollen season. Furthermore, our study also extends previous findings because it investigates another geographical area, and because it is the first study to include simultaneous phenological observations and measurements of pollen concentrations in both the source and receiving regions.

The map used to establish Germany and Poland as potential source regions only took into account broad-leaved forests. A complete inventory should also take other sources into account such as mixed forest, shrub and ornamentals. This, however, only increases the source strength and the importance of Germany and Poland as source regions. Even though the map only covers the contribution from broad-leaved forest, it disagrees with a recently published map covering Northern Europe [43], which shows birch tree density below 0.1% for most of Poland and Germany. The map presented in this paper is based on the CLC2000 dataset [40] and national forest inventories compared with the map by Sofiev et al. [45] which is based on data with a lower spatial resolution, assumptions with respect to birch fraction and regional-scale extrapolations.

This study has shown that daily averages of the individual long-range transport episodes vary from 35 to 244 grains/m³. The 2006 results also show that bi-hourly concentrations from long-range transport exceed 400 grains/m³ several times. These peaks of relatively short duration exceed the daily thresholds of 30 and

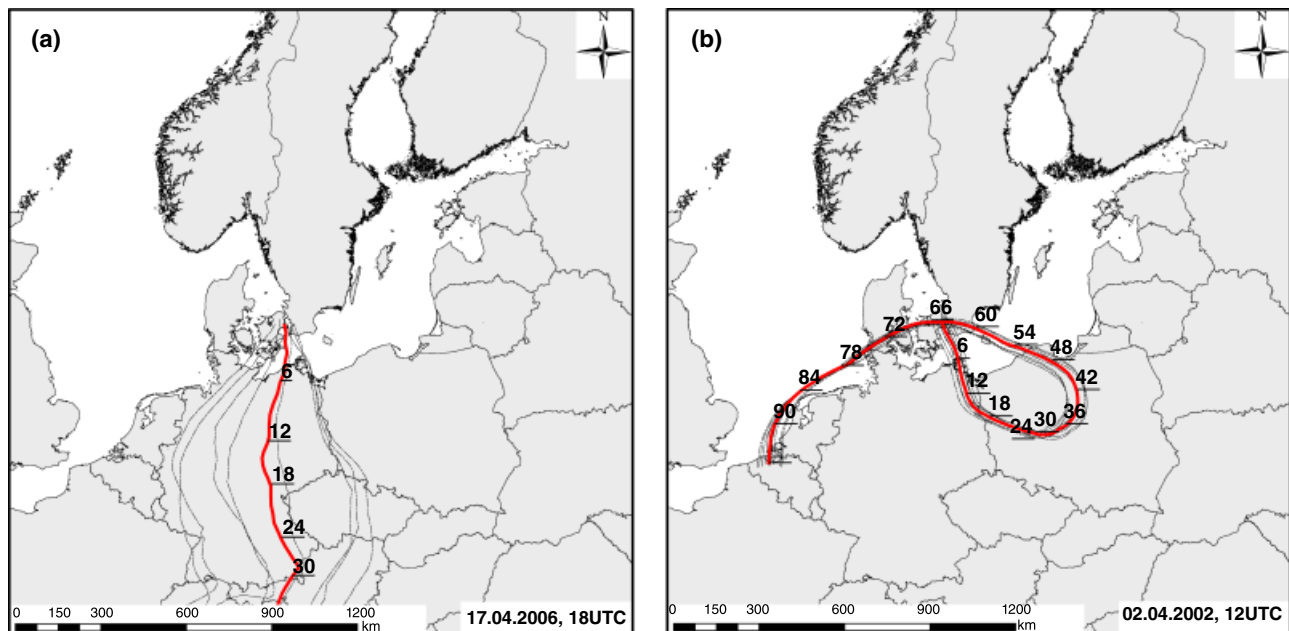


Fig. 3. Trajectories for (a) the 17th of April 2000, 18 UTC and (b) the 2nd of April 2002, 12 UTC. The trajectory marked with a thick red line corresponds to the pollen trap in Copenhagen and the trajectories marked with thin lines correspond to the surrounding receptor points.

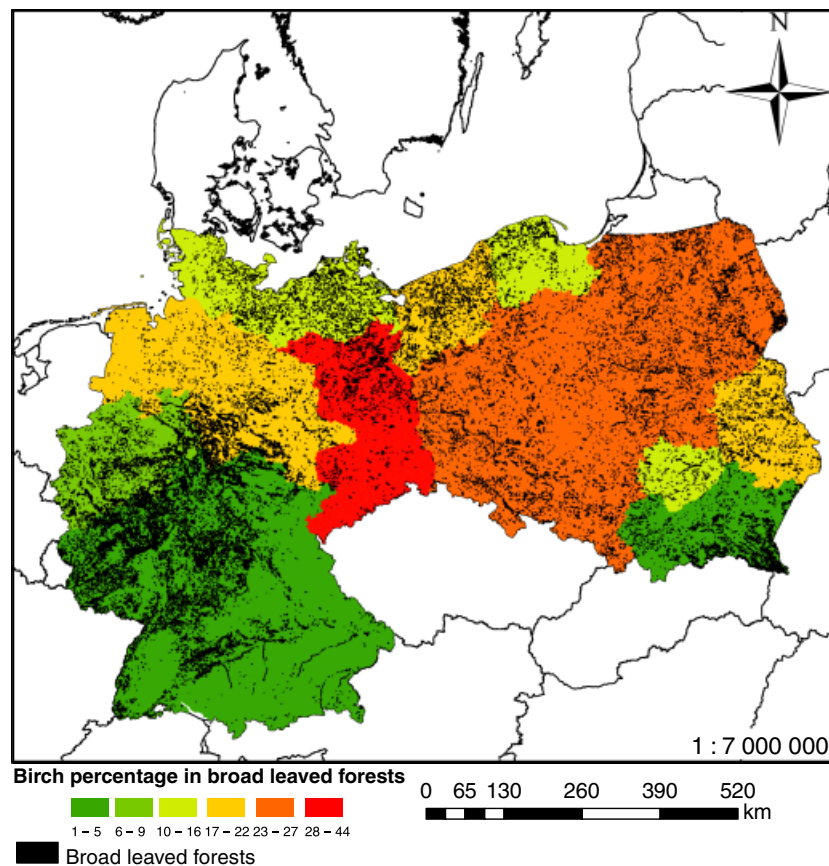


Fig. 4. Map covering Germany and Poland showing broad-leaved forests and birch tree density within broad-leaved forest.

100 grains/m³ to a large degree. This indicates that long-range transport may have a significant impact on health during these episodes and that such short-term variations should be taken into account in exposure studies and warnings to the public. The resulting pollen concentration in Denmark is, to a large degree, dependent on the meteorological conditions during transport and the pollen emission strength in the source region. The results show that there is a large variation in the distribution of broad-leaved trees and relative percentage with respect to birch trees in Germany and Poland. The results also show that even when series of trajectories are used to account for uncertainty, the air masses usually arrive from a relatively confined region. This indicates that the source regions for each episode have a limited spatial coverage. Differences in the measured pollen concentration in Copenhagen due to long-range transport are therefore partly related to the density of birch trees in the Polish and German regions. Furthermore, the timing and magnitude of the birch pollen season varies annually. Birch trees frequently have alternating cyclic rhythms of high and low years of pollen production [1, 46–49] and this study has shown that the start of the birch pollen season can vary annually by as much as a month (Table 2). The results also show that the main season in Poznań was about 8 days long. The short

duration of the main season and the inter-annual differences in the flowering season has several consequences: firstly, forecasts for long-range transport episodes from Germany and Poland must take into account annual variations in pollen production. Secondly, the forecast must take into account the uneven distribution of sources in the countries. Thirdly, the forecast must take into account the annual differences in the onset of flowering.

Current air quality transport models can be considered mature with respect to transport of air pollutants. These air quality models may be extended to deal with the atmospheric transport of pollen [45, 50–53] including forecasting of pollen concentrations three or more days ahead. It has been argued that data assimilation of real-time pollen measurements or phenological observations into air quality models would improve forecasting [45]. However, for the Danish area, the source areas in Poland and Germany are between $\frac{1}{2}$ and $1\frac{1}{2}$ days away with respect to atmospheric transport. Pollen measured in Poland or Germany may therefore be transported to Denmark in less than 1 day. Data assimilation with local observed pollen concentrations will, in these cases, provide less than 1 day's forecast, provided that these measurements are available online. As current pollen counting methods are retrospective, pollen may arrive in Denmark before

the local pollen count in Poland is performed. Therefore, supplementing air quality forecast models with pollen forecasts covering 3 or more days ahead would require local and regional forecasts of the pollen emission.

The results also show that the levels of birch pollen in Poznań were generally between 1000 and 2000 grains/m³ during the season. Atmospheric transport resulted in episodes in Copenhagen of a few hundred grains/m³. This indicates that diffusion and deposition during transport have decreased the concentration. However, compared with Copenhagen many Danish areas are much closer to Germany and Poland. Therefore, these areas are likely to receive larger quantities of pre-seasonal pollen than Copenhagen.

The findings have several implications. Firstly, forecasting of birch pollen quantities relevant to allergy patients in Denmark must take into account long-range transport. This cannot be based on measured concentrations in Denmark alone. Secondly, pre-seasonal pollen episodes will have a full allergic impact, as the allergy patients in general are unprotected during this time. Studies have shown that, at the beginning of the birch pollen season, 90% of the patients with birch pollinosis reported mild symptoms above 80 grains/m³. However, during the late season 80% of the patients remained symptomatic at a level below 30 grains/m³ [4, 42, 54]. Severe pre-seasonal birch pollen episodes early in the spring may have a similar effect as high-magnitude *Alnus* pollen seasons (the major allergens of *Alnus* and *Betula* cross-react) by priming sensitive individuals, eliciting stronger reactions to birch pollen and effectively extending the birch pollen season [4, 39, 55]. Allergy patients need a warning several days ahead to plan their medical intake. The most effective way to improve the current Danish forecast is therefore to extend the current forecast with dynamical models that take into account pollen emission and atmospheric transport from countries such as Germany and Poland. The old studies by Petersen and Munch [17] and Weeke [18] are more than 25 years old and still form the basis for the current operational pollen counts and operational pollen forecasts in Denmark. Linneberg *et al.* [5, 6] have shown that the part of the Danish population that suffers from hayfever have increased from 12.9% in 1990 to 22.5% in 1998. The background for defining the thresholds reported in 1981 is therefore most likely different today.

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References

- 1 Spieksma FTM, Emberlin JC, Hjelmroos M, Jäger S, Leuschner RM. Atmospheric birch (*Betula*) pollen in Europe – trends and fluctuations in annual quantities and the starting dates of the seasons. *Grana* 1995; **34**:51–7.
- 2 Adams-Groom B, Emberlin J, Corden J, Millington W, Mullins J. Predicting the start of the birch pollen season at London, Derby and Cardiff, United Kingdom, using a multiple regression model, based on data from 1987 to 1997. *Aerobiologia* 2002; **18**:117–23.
- 3 Emberlin J, Savage M, Woodman R. Annual variations in the concentrations of *Betula* pollen in the London area, 1961–1990. *Grana* 1993; **32**:359–63.
- 4 Emberlin J, Mullins J, Corden J *et al.* The trend to earlier Birch pollen seasons in the UK: a biotic response to changes in weather conditions? *Grana* 1997; **36**:29–33.
- 5 Linneberg A, Jørgensen T, Nielsen NH, Madsen F, Frølund L, Dirksen A. The prevalence of skin-test-positive allergic rhinitis in Danish adults: two cross-sectional surveys 8 years apart. The Copenhagen Allergy Study. *Allergy* 2000; **55**:767–72.
- 6 Linneberg A, Nielsen NH, Madsen F, Frølund L, Dirksen A, Jørgensen T. Increasing prevalence of specific IgE to aeroallergens in an adult population: two cross-sectional surveys 8 years apart – The Copenhagen Allergy Study. *J Allergy Clin Immunol* 2000; **106**:247–52.
- 7 Bachert C, Vignola AM, Gevaert P, Leynaert B, Van Cauwenberge P, Bousquet J. Allergic rhinitis, rhinosinusitis, and asthma: one airway disease. *Immunol Allergy Clin N Am* 2004; **24**:19–43.
- 8 Grossman J. One airway, one disease. *Chest* 1997; **111**:S11–6.
- 9 Demoly P, Bousquet J. The relation between asthma and allergic rhinitis. *Lancet* 2006; **368**:711–3.
- 10 Bousquet J, Van Cauwenberge P, Khaltaev N *et al.* Allergic rhinitis and its impact on asthma. *J Allergy Clin Immunol* 2001; **108**:S147–334.
- 11 Spector SL Overview of comorbid associations of allergic rhinitis. *J Allergy Clin Immunol* 1997; **99**:S773–80.
- 12 Allergy – Living and Learning. A survey of 7000 allergy patients in 10 European countries. ALK Abelló, Not published, 2000. <http://www.alk-abello.com/cfca3d77-bd19-4654-b5fe-5840a2bd4830.W5Doc?mid=DE8CBA3-EF6D-4AB7-9C22-3B4041E0822C>
- 13 Tripathi A, Patterson R. Impact of allergic rhinitis treatment on quality of life. *Pharmacoeconomics* 2001; **19**:891–9.
- 14 Sabbah A, Daele J, Wade AG, Ben Soussen P, Attali P. Comparison of the efficacy, safety, and onset of action of mizolastine, cetirizine, and placebo in the management of seasonal allergic rhinoconjunctivitis. *Ann Allergy Asthma Immunol* 1999; **83**:319–25.
- 15 Stern MA, Darnell R, Tudor D. Can an antihistamine delay appearance of hay fever symptoms when given prior to pollen season? *Allergy* 1997; **52**:440–4.
- 16 Frøsig A, Rasmussen A. The new pollen calendar for Denmark (1984–2001). Abstract and poster at the Third European Symposium on Aerobiology, 30 August–4th September 2003, Worcester, UK, 2003.
- 17 Petersen N, Munch E. Anvendelse af aerobiologiske data. In: Pollen og Skimmelsvampesporer. Symposium om pollen og

- skimmelsvampesporers betydning ved allergiske sygdomme. Scanticon, Århus, Denmark. Red: Weeke, E. & Petersen, N.B. 1981.
- 18 Weeke E. Behandling af pollen- og skimmelsporeallergi. In: Pollen og Skimmelsvampesporer. Symposium om pollen og skimmelsvampesporers betydning ved allergiske sygdomme. Scanticon, Århus, Denmark. Red: Weeke, E. & Petersen, N.B. 1981.
 - 19 Cotos-Yáñez R, Rodríguez-Rajo FJ, Jato MV Short-term prediction of *Betula* airborne pollen concentration in Vigo (NW Spain) using logistic additive models and partially linear models. *Int J Biometeorol* 2004; 48:179–85.
 - 20 Castellano-Méndez M, Aira MJ, Iglesias I, Jato V, González-Manteiga W. Artificial neural networks as a useful tool to predict the risk level of *Betula* pollen in the air. *Int J Biometeorol* 2005; 49:310–6.
 - 21 Laaidi M. Regional variations in the pollen season of *Betula* in Burgundy: two models for predicting the start of the pollination. *Aerobiologia* 2001; 17:247–54.
 - 22 Clot B. Airborne birch pollen in Neuchatel (Switzerland), onset, peak and daily patterns. *Aerobiologia* 2001; 17:25–9.
 - 23 Hov O, Hjøllø BA, Eliassen A. Transport distance of ammonia and ammonium in northern Europe. 1. Model description. *J Geophys Res-Atm* 1994; 99:18735–48.
 - 24 Gregory PH. *The microbiology of the atmosphere*, 2nd Edn. Aylesbury, Bucks, UK: Leonard Hill, 1973; 1–307.
 - 25 Seinfeld JH, Pandis S. *atmospheric chemistry and physics – from air pollution to climate change*. New York: Wiley, 1998; 1–1326.
 - 26 Raynor GS, Hayes JV, Ogden EC. Mesoscale transport and dispersion of airborne pollens. *J Appl Meteorol* 1974; 13:87–95.
 - 27 Corden J, Millington W, Bailey J *et al.* UK regional variations in *Betula* pollen (1993–1997). *Aerobiologia* 2000; 16:227–32.
 - 28 Emberlin J, Detandt M, Gehrig R, Jaeger S, Noland N, Rantio-Lehtimäki A. Responses in the start of *Betula* (birch) pollen seasons to recent changes in spring temperatures across Europe. *Int J Biometeorol* 2002; 46:159–70.
 - 29 Rasmussen A. The effects of climate change on the birch pollen season in Denmark. *Aerobiologia* 2002; 18:253–65.
 - 30 Mendez J, Comtois P, Iglesias I. *Betula* pollen: one of the most important aeroallergens in Ourense, Spain. Aerobiological studies from 1993 to 2000. *Aerobiologia* 2005; 21:115–23.
 - 31 Budna E, Grzybowska L., Zytecka-Karolak M. Forestry 2005 (In Polish: Lesnictwo 2005). 1–261. 2005. Zakład Wydawnictw Statystycznych 00-925 Warszawa, Al. Niepodległości 208, Statistical Publishing Establishment, 00-959 Wasaw, al. Niepodległości 208.
 - 32 Bundesministerium für Ernährung LuV. Die zweite Bundeswaldinventur - BWI2 - Das wichtigste in Kürze. 2004. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, Berlin, Germany.
 - 33 Hirst JM. An automatic volumetric spore trap. *Ann Appl Biol* 1952; 39:257–65.
 - 34 Goldberg C, Buch H, Moseholm L, Weeke ER. Airborne pollen records in Denmark, 1977–1986. *Grana* 1988; 27:209–17.
 - 35 Kämpylä M, Penttinen A. An evaluation of the microscopical counting methods of the tape in Hirst-Burkard pollen and spore trap. *Grana* 1981; 20:131–41.
 - 36 Stach A. Variation in pollen concentration of the most allergenic taxa in Poznań (Poland), 1995–1996. *Aerobiologia* 2000; 16: 63–8.
 - 37 Corden JM, Stach A, Millington WM. A comparison of *Betula* pollen seasons at two European sites; Derby, United Kingdom and Poznań, Poland (1995–1999). *Aerobiologia* 2002; 18:45–53.
 - 38 Łukasiewicz A. Need to standardize phenological methodology in Polish botanic gardens and arboreta. *Botanic News* 1984; 28:153–8.
 - 39 Jato V, Méndez J, Rodríguez-Rajo J, Seijo C. The relationship between the flowering phenophase and airborne pollen of *Betula* in Galicia (N.W. Spain). *Aerobiologia* 2002; 18:55–64.
 - 40 European Commission. Image2000 and CLC2000 *Products and Methods*. Maria Vanda Nunes de Lima. 1–152. 2005. European Commission, Joint Research Center (DG JRC), Institute for Environment and Sustainability, Land Management Unit, I-21020 Ispra (VA), Italy
 - 41 Stach A, Smith M, Skjøth CA, Brandt J. Examining Ambrosia pollen episodes at Poznań (Poland) using back-trajectory analysis. *Int J Biometeorol* 2006; 51:275–286.
 - 42 Koivikko A, Kupias R, Makinen Y, Pohjola A. Pollen seasons – forecasts of the most important allergenic plants in Finland. *Allergy* 1986; 41:233–42.
 - 43 Hjelmroos M. Long-distance transport of *Betula* pollen grains and allergic symptoms. *Aerobiologia* 1992; 8:231–6.
 - 44 Hjelmroos M. Evidence of long range transport of *Betula* pollen. *Grana* 1991; 30:215–28.
 - 45 Sofiev M, Siljamo P, Ranta H, Rantio-Lehtimäki A. Towards numerical forecasting of long-range air transport of birch pollen: theoretical considerations and a feasibility study. *Int J Biometeorol* 2006; 50:392–402.
 - 46 Ranta H, Oksanen A, Hokkanen T, Bondestam K, Heino S. Masting by *Betula*-species; applying the resource budget model to north European data sets. *Int J Biometeorol* 2005; 49:146–51.
 - 47 Dahl Å, Strandhede SO. Predicting the intensity of the birch pollen season. *Aerobiologia* 1996; 12:97–106.
 - 48 Spiekma M, Corden JM, Detandt M *et al.* Quantitative trends in annual totals of five common airborne pollen types *Betula*, *Quercus*, *Poaceae*, *Urtica*, and *Artemisia*, at five pollen-monitoring stations in western Europe. *Aerobiologia* 2003; 19:171–84.
 - 49 Emberlin J. Grass tree and weed pollen. In: Kay AB, ed. *Allergy and Allergic Diseases*. UK: Blackwell Science, 1997; 835–857.
 - 50 Helbig N, Vogel B, Vogel H, Fiedler F. Numerical modelling of pollen dispersion on the regional scale. *Aerobiologia* 2004; 20:3–19.
 - 51 Kawashima S, Takahashi Y. An improved simulation of mesoscale dispersion of airborne cedar pollen using a flowering-time map. *Grana* 1999; 38:316–24.
 - 52 Schueler S, Schlunzen KH. Modeling of oak pollen dispersal on the landscape level with a mesoscale atmospheric model. *Env Model Assess* 2006; 11:179–94.
 - 53 Pasken R, Pietrowicz JA. Using dispersion and mesoscale meteorological models to forecast pollen concentrations. *Atmos Env* 2005; 39:7689–701.
 - 54 Viander M, Koivikko A. Seasonal symptoms of hypo-sensitized and untreated hay-fever patients in relation to birch pollen counts – correlations with nasal sensitivity, prick tests and rast. *Clin Allergy* 1978; 8:387–96.
 - 55 Rodríguez-Rajo FJ, Dopazo A, Jato V. Environmental factors affecting the start of pollen season and concentrations of airborne *Alnus* pollen in two localities of Galicia (NW Spain). *Ann Agric Environ Med* 2004; 11:35–44.