Birch Pollen: Modelling, Spatial and Temporal Variability, Elevated Episodes, Potential Source Regions, Emissions Parameterizations, and Future Research

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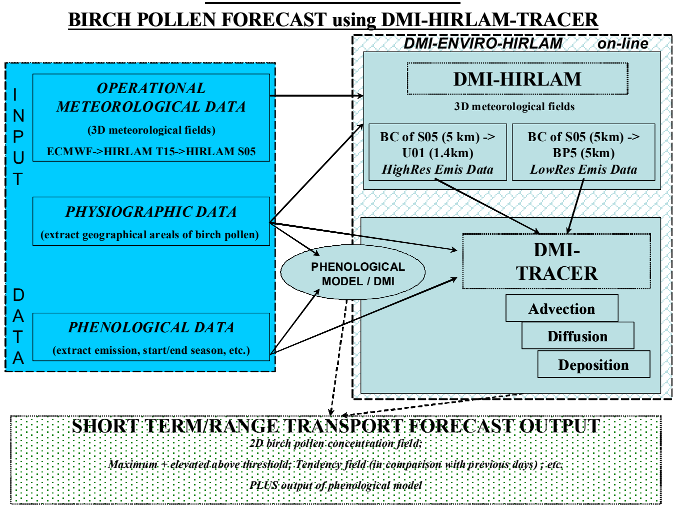
Introduction

Within recent decades pollen-related allergic reactions have received an increased amount of attention in the European countries. Due to the wide distribution of birch trees (Betula) in Northern Europe birch pollen is considered a main aeroallergen triggering spring-time asthma and rhinitis (*OECD, 2003*). The effect on human health is strongest during events of elevated concentrations above threshold standards causes strong allergic reactions. So, the forecasting of birch pollen concentration during pollinating season is important task for informing allergen-prone people and reducing possible health effects.

Birch Pollen Forecasting



DMI-ENVIRO-HIRLAM

BIRCH POLLEN FORECAST using DMI-HIRLAM-TRACER

DMI-ENVIRO-HIRLAM on-line

INPUT DATA

OPERATIONAL METEOROLOGICAL DATA
(3D meteorological fields)
ECMWF->HIRLAM T15->HIRLAM S05

PHYSIOGRAPHIC DATA
(extract geographical areals of birch pollen)

PHENOLOGICAL DATA
(extract emission, start/end season, etc.)

PHENOLOGICAL MODEL / DMI

DMI-HIRLAM
3D meteorological fields

BC of S05 (5 km) -> U01 (1.4km)
HighRes Emis Data

BC of S05 (5km) -> BP5 (5km)
LowRes Emis Data

DMI-TRACER
Advection
Diffusion
Deposition

SHORT TERM/RANGE TRANSPORT FORECAST OUTPUT
2D birch pollen concentration field;
Maximum + elevated above threshold; Tendency field (in comparison with previous days) ; etc.
PLUS output of phenological model

***Figure 1**. Scheme of birch pollen forecasting using phonological and dynamical approaches.*

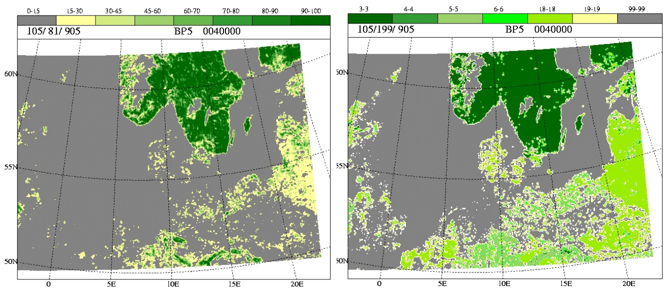


***Figure 2**. For the month of April — (left) Fractions (in %) of the forest tile; and (right) Types of land use classes (from available 20) for the forest tile - represented in the BP5 domain and generated for the ISBA land surface scheme.*

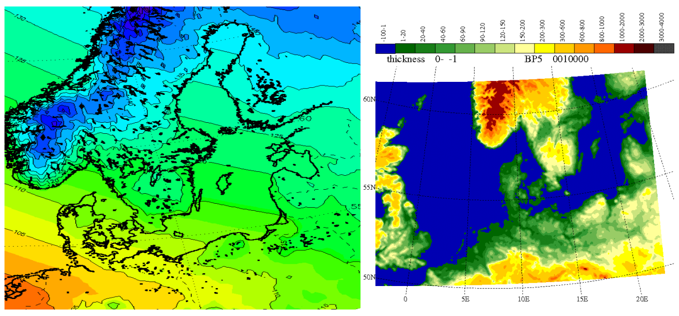


***Figure 3**. (left) Emission sources (derived from the SILAM input dataset on birch pollen emissions; contact M. Sofiev, FMI); and (right) terrain the in the BP5 domain.*

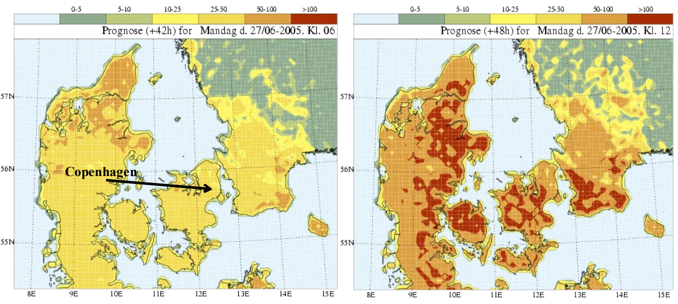


***Figure 4**. Test of pollen forecast using DMI pollen statistical model (normalized concentrations after (left) 42 and (right) 48 hours forecast.*

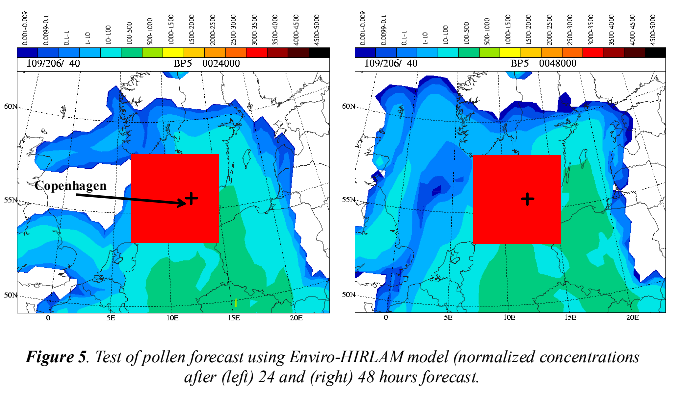


***Figure 5**. Test of pollen forecast using Enviro-HIRLAM model (normalized concentrations after (left) 24 and (right) 48 hours forecast.*

Acknowledgments

The authors gratefully acknowledge the Danish Asthma-Allergy Association for a long-term cooperation on pollen related monitoring, research, and forecasting in Denmark. The authors gratefully acknowledge the NOAA Air Resources Laboratory for the provision of the HYSPLIT transport and dispersion model and/or READY website (http://www.arl.noaa.gov/ready.html) used in this study. The research activities on the birch pollen related issues and forecasting for Denmark is also a part of the birch pollen modelling system developments (as a part of the Enviro-HIRLAM applications) as well as cooperation with the Finish Meteorological Institute on the POLLEN project.

Contribution of Remote Sources in Elevated Birch Pollen Events in Denmark

Birch Pollen Measurements

There are only two Danish sites with longest time-series of birch pollen measurements. The sites are located in 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 these measurement sites – Copenhagen and Viborg – birch pollen sampling is done using the Burkard Traps which are located at 15 and 21 m above ground, respectively. Pollen grains are counted in 12 transverse stripes and then identified to generic genus. Because birch pollen data has an episodic character and it continues only for a few weeks during year, a special treatment should be given to analyzed data.

Data Treatment

The Copenhagen and Viborg original datasets (representing time series) of birch pollen counts include bi-hourly measurements during the pollinating seasons of 1980-2006. In total, there are 17328 and 14703 records available for analysis for the Copenhagen and Viborg sites, respectively. Each record consists of the site identificator, day, month, year, local time, and birch pollen count. From the 26 year period all measurements with values of higher than 100 birch pollen counts were grouped into a separate dataset. For Copenhagen, it includes 274 records (with largest numbers of such measurements in 1993 and 2006) corresponding to 62 days during 26 years. For Viborg, it includes 152 records (with largest numbers during the same years as for the Copenhagen site) corresponding to 49 days during the same period. The distribution of these cases is shown in Fig. 6.

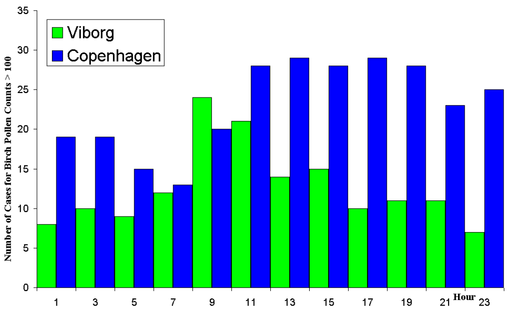


***Figure 6**. Distribution of specific cases of birch pollen counts (=100).*

Trajectory Modelling and Source Region Identification

The backward trajectory modelling is a widely used tool for evaluation of possible atmospheric transport to geographical locations where short- or long-term measurements of chemical or biological species/agents are conducted. Trajectories can allow identifying potential paths and regions from where pollution can be transported and associated. In our study, we used the NOAA on-line transport and dispersion HYSPLIT v4.5 (HYbrid Single-Particle Lagrangian Integrated Trajectory) model available in an interactive mode at web-site: http://www.arl.noaa.gov/ready/open/hysplit4.html (*Draxler & Rolph, 2003*). Each computed trajectory was associated with corresponding elevated birch pollen measurement. Trajectories (examples are shown in Fig. 7) were computed backward in time up to 72 h (3 days) using vertical motion calculation method. Then, depending on pathways of atmospheric transport trajectories were grouped into sectors/potential regions from which they had been originated (Tab. 1).

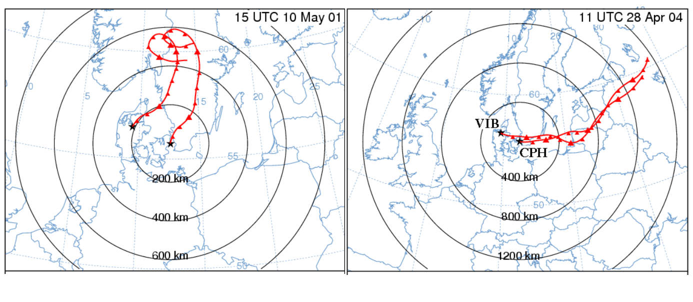


***Figure 7**. Backward atmospheric trajectories arriving at the Copenhagen (CPH) and Viborg (VIB) measurement sites from (a) northern sector; and (b) eastern sector.*

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	1080	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			

***Table 1**. Summary of trajectories corresponding to elevated birch pollen events and their means and maxima by sectors with respect to two measurement sites (based on 1980-2006 data).*

Summary

The analysis of time series with elevated birch pollen counts showed that these events can be associated with the long-distance atmospheric transport from potential source regions of birch pollen emissions. During this period, in 43% and 33% of the cases such atmospheric transport occurred from the eastern and northern sectors, which are consisted of from one side by the Eastern European countries, Baltic States, Ukraine, Belarus and Russia, and from another by the Scandinavian Peninsula countries. The latter is represented by the fast and slow atmospheric transport to the sites. The means (maxima) are 213 (1080) and 187 (647) grains for the eastern and northern sectors, respectively. The lowest contribution was found to be from the western sector associated with the British sources. Although the Danish sites are located not far from each other (220 km), the atmospheric transport associated with elevated concentration events showed some differences between the sites. It is especially seen for the northern sector where the slow atmospheric transport dominates over the fast ones by approximately factor of 3 for the Viborg site compared with Copenhagen, and vise versa.

References

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*Draxler R.R., Rolph G.D., **2003**: HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Lab, Silver Spring, MD.*

*Mahura A., A. Baklanov, A. Rasmussen, U.S. Korsholm, C. Petersen (**2006**): Birch pollen forecasting for Denmark. Abstracts of the 6th Annual Meeting of the European Meteorological Society (EMS), 3-7 September 2006, Ljubljana, Slovenia; Vol. 3, EMS2006-A-00495.*

*Mahura A., Korsholm U.S., Baklanov A., Rasmussen A., (**2007**): Elevated Birch pollen events in Denmark: Contributions from remote sources. Aerobiologia, Vol. 23, pp. 171-179.*

*Mahura A., Baklanov A., Korsholm U., (**2009**): Parameterization of the Birch Pollen Diurnal Cycle. Aerobiologia, Vol. 25, pp. 203-208,*

Parameterization of Birch Pollen Diurnal Cycle

In forecasting, in order to estimate possible emissions of birch pollen the mentioned parameters should be evaluated in any selected grid cell of a modelling domain . It is a task of the emission module where all parameters contribute into resulting emission rate. All mentioned parameters, except the diurnal cycle variability of the birch pollen, are parameterized in forecasting applications, and therefore, the focus is to identify a simple and useful parameterization of the birch pollen cycle suitable for such emission module. So, based on analysis of 1980-2006 time series of birch pollen counts performed at the Copenhagen measurement site, a parameterization is suggested to be used in applications for operational forecasting and research birch pollen modelling.

Diurnal Cycle

For the Copenhagen site, the diurnal cycle of birch pollen counts for two datasets, first, including all data, and second, excluding zero values, is shown in Fig. 8.

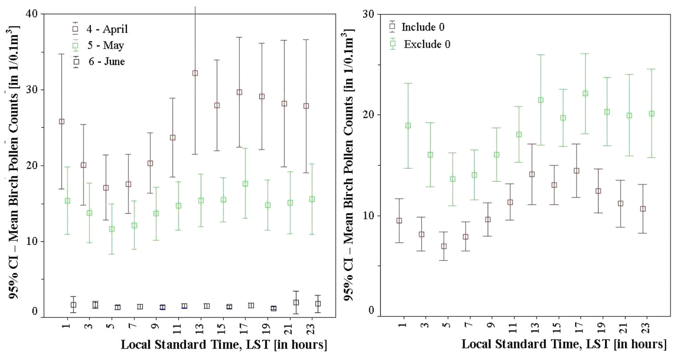

***Figure 8.** Diurnal cycle of the mean birch pollen counts (at 95% confidence interval) for the Copenhagen site based 1980-2006 data for (right) datasets with excluded and included zero values, and (left) for months of April-May-June.*

Including All Data

For the dataset (with all values included) based on polynomial fits (3-6th orders) to diurnal cycles and a set of corresponding equations describing the fits to birch pollen data, the diurnal cycle can be proposed parameterized in the form of Eqs. 1ab, where:

$C(t)$ – birch pollen count/concentration [in number of particles per volume, $1/m^3$] at moment of time t on a diurnal cycle;
$C(t_0)$ – birch pollen count/concentration at the beginning of the diurnal cycle (i.e. at 00 hours of the local time) or at the end of the previous day;
$\Delta C(t)$ – change of birch pollen count/concentration due to diurnal cycle;
t – time (in hours);
t_{shift} – time of shift (in hours);
a_0 – constant equal to 2.7183 or e^1;
A, B – empirical coefficients (dimensionless);
t_{bpmax} – time of occurrence of maximum birch pollen count on a diurnal cycle (at the Copenhagen site such maximum occurred during 15-17 LST, i.e. let us select t_{bpmax} = 16 LST);
CDF – conversion dimensional factor (equal to 1) and having units of C;
TDF – time dimensional factor (equal to 1) and having units of hour $^{-1}$.

$$C(t) = C(t_0) + \begin{cases} \Delta C(t) & \text{if} \quad C(t_0) > 0 \quad (1a) \\ 0 & \text{if} \quad C(t_0) = 0 \quad (1b) \end{cases} ;$$

$$\Delta C(t) = \begin{cases} CDF \cdot A \cdot a_0 \cdot \cos\left(\pi + \frac{(t - t_{shift}) \cdot TDF}{\pi}\right) + CDF \cdot \left(\frac{(t - t_{bp\,max}) \cdot TDF}{\pi}\right) & \text{if} \quad t \geq t_{bp\,max} \quad (1c) \\ CDF \cdot B \cdot a_0 \cdot \cos\left(\pi + \frac{(t - t_{shift}) \cdot TDF}{\pi}\right) & \text{if} \quad t < t_{bp\,max} \quad (1d) \end{cases} ;$$

$$C(t) = C(t_0) + \begin{cases} \Delta C(t) & \text{if} \quad C(t_0) > 0 \quad (2a) \\ 0 & \text{if} \quad C(t_0) = 0 \quad (2b) \end{cases} ;$$

$$\Delta C(t) = \begin{cases} CDF \cdot A \cdot a_0 \cdot \cos\left(\pi + \frac{(t - t_{shift}) \cdot TDF}{\pi}\right) + CDF \cdot \left(\frac{(t - t_{shift}) \cdot TDF}{\pi}\right) & \text{if} \quad t \geq t_{bp\min} \quad (2c) \\ CDF \cdot B \cdot a_0 \cdot \cos\left(\pi + \frac{(t - t_{shift}) \cdot TDF}{\pi}\right) & \text{if} \quad t < t_{bp\min} \quad (2d) \end{cases} ;$$

Evaluation of parameterization by the fitting to the diurnal cycle showed that a good fit might be observed when A and B coefficients vary within a range of 0.75-1.25 (with the finest fit when $A = B = 1$). Since an analysis of residuals (i.e. difference between the measured and predicted data) is a measure of the goodness of the fit; so, the residuals for various fits (based on combinations of A and B) were compared. It showed that the lowest difference between residuals (0.2-0.5) is characteristic for the selected combinations and it is higher for all others. The coefficients selected might be a function of the latitudinal and longitudinal location of the measurement site as well as the time of the beginning and the end of the birch pollen pollinating season (this issue require additional study). The time of shift varies within 24-26 h (with a max best fit at t_{shift} = 25 h). The 2nd term (Eq. 1a) shows a dependence on the time of the maximum occurrence on diurnal cycle at the site.

Excluding Zeros

For the dataset (with excluded zero values), based on the same order of polynomial fits and corresponding equations the diurnal cycle at the Copenhagen site, can be parameterized in the form of Eqs. 2ab; where:

$C(t)$, $C(t_0)$, t, t_{shift}, a_0, A, B, CDF, TDF – have similar definitions as above; and t_{bpmin} – time of occurrence of minimum birch pollen count on a diurnal cycle (at the Copenhagen site such a minimum is occurred during 05-07 LST, i.e. let's select t_{bpmin} = 06 LST).

Evaluation of parameterization by the fitting to the diurnal cycle showed that a good fit might be observed than A and B coefficients vary within ranges: $0.50 = A = 0.75$ and $2.75 = B = 3.25$ (with the finest fit when $A = 0.75$ and $B = 3$). Similarly to dataset with all values included, in this case the residuals for various fits (also based on combinations of A and B coefficients) were compared. It showed that the lowest difference between residuals (0.9-1.2) is characteristic for the selected combinations and it is higher for all others. The time of shift is also varied within 24-26 hours (with a max best fit at t_{shift} = 25 h). The 2nd term (Eq. 2a) shows a dependence on the time of the shift for hours after the occurrence of the minimum on a diurnal cycle at the site.

Future Plans

The overall further planned activities for improvement of birch pollen forecasting will include the following research and development topics:

spatial and temporal variability of birch pollen emissions – studies of relevant processes on diurnal cycle variability with respect to locations of stations and other physiographic parameters; accumulated heat sums for triggering the emissions vs. climatological variability; precipitation influence (intensity, type, clouds, etc.) on speed and tendency of temporary decrease of emissions during flowering season; wet & dry deposition, resuspension, and others - all leading to development of revised parameterizations;

long-term modeling studies - on meso- and regional scales for selected flowering seasons for identification of potential source regions, elevated concentration episodes, and better placement of pollen monitoring stations employing both forward and inverse trajectory and dispersion modeling approaches with cluster and probability fields analysis; as well as for studies of pollen influence on climatic changes/ variability employing adapted environmental climate model (such as Enviro-HIRHAM);

bio-chemical weather forecasting as for a newly emerging area of research – studying interactions between air pollution and birch pollen at multi-scales ranging from regional, urban to street levels (especially street canyon studies under different meteorological conditions estimating on how long pollen could remain within canyon and be influenced by pollution).