

Parameterization of the birch pollen diurnal cycle

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Abstract The purpose of this study was to investigate the patterns of birch pollen counts over a diurnal cycle and propose a parameterization that is useful for inclusion into operational and research short- and long-term modeling for birch pollen atmospheric transport and deposition at different spatial scales. The evaluation of patterns of diurnal cycles on monthly and interannual bases has been done based on analysis of a 26-year time series of birch pollen counts from the Danish pollen measurement site in Copenhagen. The suggested parameterization, based on a simple trigonometric function, includes dependencies on the time of birch pollen maximum and minimum occurrence on a diurnal cycle, averaged concentration at the end of the previous day, and time shift.

Keywords Birch pollen · Time series · Parameterization · Diurnal cycle

1 Introduction

In the modeling of atmospheric transport and deposition of birch (*Betula*) pollen, the released amount of pollen particles depends on a number of parameters

related to meteorological conditions (WHO 2003). These include the accumulated heat sums, start and end dates of the pollinating season, mean climatological rate of release, correction functions related to wind, temperature, humidity, and precipitation, and the diurnal cycle of the birch pollen (Sofiev 2007). Currently, Denmark has only two measurement sites located in Copenhagen (55°43'N, 12°34'E) and Viborg (56°27'N, 09°24'E), where the long-term measurements were conducted. At these stations, situated at a distance of approximately 220 km from each other, the routine monitoring of airborne pollen is performed. In Denmark, the birch pollen season is relatively short, being up to 1.5–2 months, and birch pollen data has an episodic character (Rasmussen 2002).

In forecasting, in order to estimate the possible emissions of birch pollen, the mentioned parameters should be evaluated in any selected grid cell of a modeling domain (Helbig et al. 2004; Mahura et al. 2006; Sofiev et al. 2006). It is a task of the emission module where all parameters contribute to the resulting emission rate. According to Sofiev (2007), at each time step, the emission rate, $E(t)$, at least, is a product of several functions: F_{start} (function of the start of the flowering season), F_{end} (function of the end of the flowering season), F_{temp} (temperature-related function), F_{wind} (wind-related function), F_{precip} (precipitation-related function), F_{humid} (humidity-related function), and F_{dc} (diurnal cycle-related function):

$$E(t) = F_{\text{start}} \cdot F_{\text{end}} \cdot F_{\text{temp}} \cdot F_{\text{wind}} \cdot F_{\text{precip}} \cdot F_{\text{humid}} \cdot F_{\text{dc}}$$

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In computations, in each grid cell, the resulting birch emissions are calculated by the multiplication of the estimated emission rate by the birch trees fraction and area of the cell. All of the mentioned parameters, except the diurnal cycle variability of the birch pollen, are parameterized in forecasting applications, and, therefore, the focus of this study is to identify a simple and useful parameterization of the birch pollen cycle suitable for such an emission module. So, based on the analysis of the 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 modeling.

2 Methodology

2.1 Time series of birch pollen counts at the Copenhagen measurement site

The Copenhagen original dataset (representing the time series) of birch pollen counts (in the number of birch grains/particles counted at the transverse strips of the Burkard traps corresponding to a specific constant volume of air pumped through the measuring device) included bi-hourly measurements performed during the pollinating seasons of 1980–2006. Note that meteorological factors might have an impact on the results obtained, since this trap is not isokinetic. Standard methods are used to count the birch pollen (Käpylä and Penttinen 1981). In total, there are 17,328 records available for analysis for the Copenhagen measurement site. Each record consists of the birch pollen count value with the corresponding day, month, year, and local time. Two types of new datasets have been constructed for evaluation. The first dataset includes birch pollen counts observed within the pollen season period in Denmark (excluding short periods at the beginning and end of the pollen season), as well as omitting 269 cases that corresponded to elevated birch pollen counts associated with long-range transport events (Mahura et al. 2007). In the second dataset, only cases with pollen events were considered, i.e., all values corresponding to zero were excluded from the analysis. This was done in order to obtain a more clear signal of the amplitude of the birch pollen diurnal cycle. Note that the zero values accounted for 8,939 records, i.e., 52% of the datasets

(with almost 60% of these during night hours). Due to the large number of zeros, the results of the analysis would be significantly biased toward the low values. Furthermore, the contribution from other months, except April and May, to the birch pollen season is approximately 8%. Since the analysis showed that these do not influence the diurnal cycle behavior, therefore, only 2 months of the birch pollen season, April and May, having the highest contribution to the time series of birch pollen counts, were considered in more detail. Moreover, it is important to note that there might be other contributions due to long-range transport as well (but not associated with the above-mentioned elevated cases) from remote sources, e.g., predominantly from the Scandinavian and Eastern European countries (Mahura et al. 2007), where more birch trees are present compared to Denmark.

3 Results and discussions

3.1 Birch pollen diurnal cycle

For the Copenhagen site, the diurnal cycle of birch pollen counts for two datasets, firstly including all available data and secondly excluding zero values, is shown in Fig. 1a. On a diurnal cycle, the mean birch pollen concentration is almost two times higher for the latter, as well as the amplitude. As seen in Fig. 1b, the mean diurnal cycle of May has lower amplitude and variability compared with April. Moreover, although during June the birch pollen counts are still continued at the measurement site, there is no significant signal. The lower mean values correspond to the early morning hours, and the higher values are observed during midday hours. On average, the means are 1.7 times higher for April compared with May, although in 1999, as an extreme, this difference is sixfold. During April, the largest mean and maximum both occurred at 13.00 h Local Standard Time (LST). During May, the largest mean and maximum shifted by 2 h and both occurred at 17.00 h LST due to the increase of sunlight hours and local temperature patterns. On the other hand, during both months, the lowest mean and maximum occurred between 05.00 and 07.00 LST. Analysis of the interannual variability showed a similar pattern for both of these months, although the birch pollen season can start at the end of March and extend to early June.

3.2 Parameterization of the birch pollen diurnal cycle

The analysis of diurnal cycles of birch pollen counts by years and months (for the time series of 1980–2006) at the Copenhagen site showed some possibilities of parameterization. In general, different polynomials can be used to fit the data, but these are valid only for a particular type of distribution and, hence,

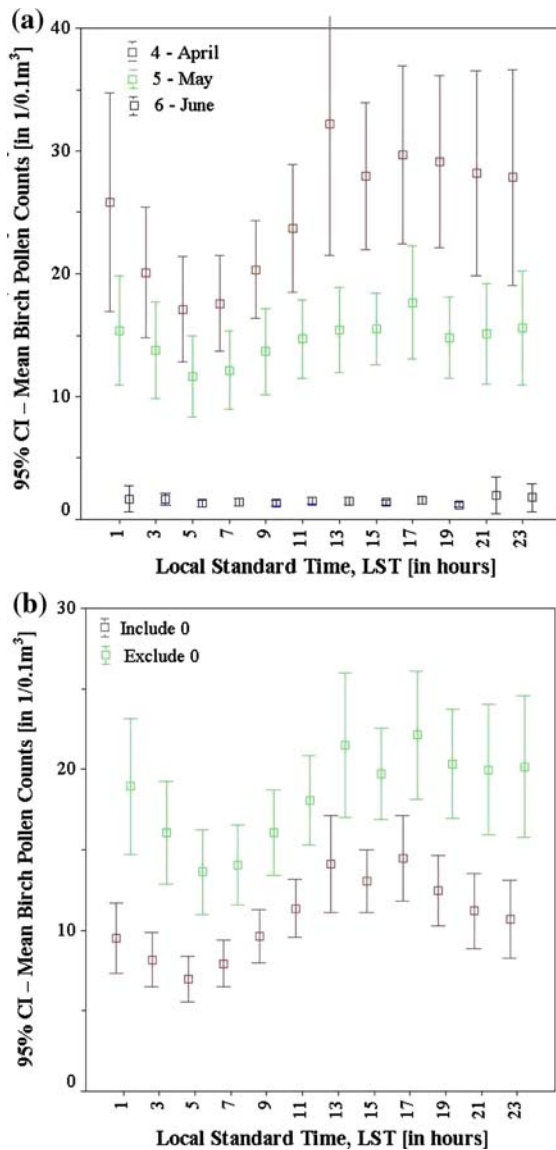


Fig. 1 Diurnal cycle of the mean birch pollen counts (at the 95% confidence interval [CI]) for the Copenhagen site based on 1980–2006 data for: **a** months of April–May–June and **b** datasets with excluded and included zero values

cannot be used in the operational modeling of atmospheric pollen transport and deposition. The applied polynomials of the third and larger orders can be used to fit birch pollen data. In particular, the fourth- to fifth-order polynomials showed a relatively good fit to the data, although the coefficients in such equations are fixed constants for a particular type of diurnal cycle and will not represent a wide range of possible hour-to-hour and day-to-day variabilities. Therefore, these polynomials were again used to find a best fit to birch pollen long-term data by applying trigonometric functions. The multiple evaluations of the fitting curves have been done in order to obtain a continuous function representing relatively smoothed

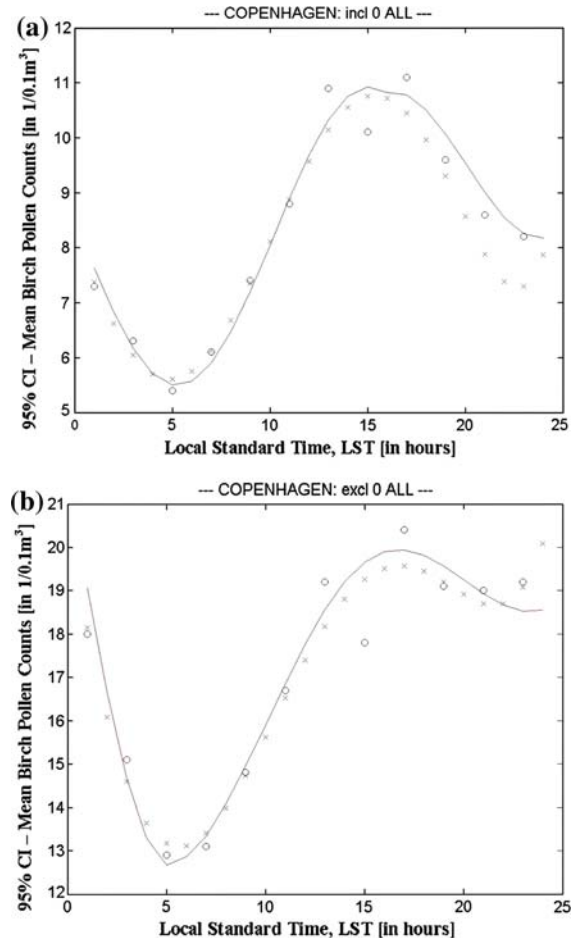


Fig. 2 Parameterization of the diurnal cycle of birch pollen at the Copenhagen measurement site for the dataset with: **a** all data included and **b** excluded zero values (circles mean observed; crosses best fit with polynomial; solid line best fit with trigonometric function)

diurnal cycle variability. The best curve representing the diurnal cycle was selected depending on a minimal difference between the mean observed birch pollen values versus fitted values of polynomials and trigonometric functions. Further, such a function might be identified as a simple and useful variant of parameterization describing a common behavior of birch pollen diurnal variability. The result of such curves with the best fit to birch pollen data based on a trigonometric function is given in Fig. 2 for the Copenhagen site.

For the dataset (*with all values included*) based on polynomial fits (third to sixth orders) to diurnal cycles and a set of corresponding equations describing the fits to the birch pollen data, the diurnal cycle at the Copenhagen site can be proposed to be parameterized in the following form:

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

$$(1b)$$

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

$$(1d)$$

where:

$C(t)$	Birch pollen count/concentration (in the number of particles per volume, $1/\text{m}^3$) at time t on a diurnal cycle
$C(t_0)$	Birch pollen count/concentration at the beginning of the diurnal cycle (i.e., at 00.00 hours local time) or at the end of the previous day
$\Delta C(t)$	Change of birch pollen count/concentration due to the diurnal cycle
t	Time (in h)
t_{shift}	Time of shift (in h)
a_0	Constant equal to 2.7183 or e^1
A, B	Empirical coefficients (dimensionless)
$t_{\text{bp max}}$	Time of occurrence of maximum birch pollen count on a diurnal cycle (at the Copenhagen site, such a maximum occurred

during 15.00–17.00 LST, i.e., let us select $t_{\text{bp max}} = 16.00$ LST)

CDF Conversion dimensional factor (equal to 1) and having units of C

TDF Time-dimensional factor (equal to 1) and having units h^{-1}

Evaluation of the parameterization by fitting it to the diurnal cycle showed that a good fit might be observed when the A and B coefficients vary within a range of 0.75–1.25 (with the finest fit when $A = B = 1$; see Fig. 2a). Since an analysis of residuals (i.e., difference between the measured and predicted data) is a measure of the goodness of the fit, therefore, in our study, the residuals for various fits (based on combinations of A and B coefficients) were compared. The results showed that the lowest difference between residuals (0.2–0.5) is characteristic for the selected combinations and 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 requires additional study). The time of shift varies within 24–26 h (with a maximally best fit at $t_{\text{shift}} = 25$ h). The second term (Eq. 1a) shows a dependence on the time of the maximum occurrence on the diurnal cycle at the site.

Moreover, 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 following form:

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

$$(2b)$$

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

$$(2d)$$

where $C(t)$, $C(t_0)$, t , t_{shift} , a_0 , A , B , CDF , and TDF have similar definitions as previously, and $t_{\text{bp min}}$ is the time of occurrence of the minimum birch pollen count on a diurnal cycle (at the Copenhagen site, such a minimum occurred during 05.00–07.00 LST, i.e., let us select $t_{\text{bp min}} = 06.00$ LST).

Evaluation of the parameterization by fitting it to the diurnal cycle showed that a good fit might be observed when the A and B coefficients vary within the ranges: $0.50 \leq A \leq 0.75$ and $2.75 \leq B \leq 3.25$ (with the finest fit when $A = 0.75$ and $B = 3$; see Fig. 2b). Similarly to the 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 higher for all others. The time of shift is also varied within 24–26 h (with a maximum best fit at $t_{\text{shift}} = 25$ h). The second term (Eq. 2a) shows a dependence on the time of the shift (in hours) after the occurrence of the minimum on a diurnal cycle at the site.

4 Conclusion

In our study, based on analysis of the long-term time series of birch pollen counts at the Copenhagen measurement site, we suggested a parameterization of the birch pollen diurnal cycle. Such a parameterization can be tested and applied for the operational and research modeling of atmospheric birch pollen transport and deposition. Due to the fact that there are only two birch pollen measurement stations in Denmark (Copenhagen and Viborg) located at a relatively short distance (~ 220 km) from each other, the additional testing of the parameterization would be needed, together with the evaluation of the coefficients' variability and limits. In particular, within the POLLEN project, at least, the birch pollen data from the

Finnish and German measurement sites might be used for the verification and identification of the latitudinal versus longitudinal dependancies. Moreover, during the birch pollen seasons of 2007–2008, a special Danish program of measurements will be conducted at four additional stations in the Copenhagen metropolitan area and surroundings, with a focus on obtaining detailed spatial distributions of pollen, and this was used for further analysis and improvement of the local-, meso-, and long-range dispersion modeling.

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