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EXPERIMENTAL AND MATHEMATICAL EVALUATION OF AIR THRESHOLD VELOCITY OF POLLINATION FOR SELECTED AEROALLERGENS

Jiri Pospisil and Miroslav Jicha

Brno University of Technology, Faculty of Mechanical Engineering, Technicka 2,
61669 Brno, Czech Republic

Abstract: Pollination (release of pollen grains) is generally influenced by temperature, daylight length, morning temperature gradient and relative humidity. The mentioned collection of parameters isn't complete for correct pollen production prediction without inclusion of the actual wind velocity. Results of in-situ measurements were used for carried out analysis of the relation between the wind velocity and the pollen concentration in an urban canopy layer. Subsequently, numerical modeling (CFD code StarCD) was used for the parametrical studies testing influence of the wind velocity on pollen release from the mother plant and subsequent pollen dispersion in a ground boundary layer.

Key words: *pollination, pollen release, threshold velocity of pollination, wind velocity*

INTRODUCTION

Temperature is the basic parameter for prediction of the beginning of the pollen season and identification days with good potential for pollen release. Different approaches are used for determination of the start of the pollen season: i) the sum of daily pollen counts = $\sum x$ criterion (Vliet 2002), ii) the mean temperature method during pre–defined period (Sparks, 2000), iii) the temperature sum method (Jones 1992). Other parameters influencing pollen release are: daylight length, morning temperature gradient, relative humidity. The mentioned parameters enable to create the "statistical" model for determination of timing of pollen potential release. But, the correct determination of pollen release timing is only the first step to correct prediction of pollen concentration in air. The above mentioned collection of parameters isn't complete for correct pollen production prediction without inclusion of the actual wind velocity. The wind velocity directly influences the pollen release rate from mother plants and subsequently transport of pollen grains. For this reason, influence of wind conditions has to be considered as exactly as possible in complex prediction models. Only a limited number of published papers deals with the relation between the wind velocity and the pollen concentration. In this paper, the authors present analysis of in-situ measurements and subsequent parametrical studies focused on the mentioned relation.

RELATION BETWEEN WIND VELOCITY AND AIR POLLEN GRAIN CONCENTRATION

Results of the in-situ measurements were used for the carried out analysis of the relation between the wind velocity and the pollen concentration in an urban canopy layer. The mean daily wind velocities and the mean daily pollen concentrations were used as the input data describing the pollen seasons 1998 - 2008 in an inner part of the city of Brno (pop. 400 000. The mean daily pollen concentrations were matched to the corresponding mean daily wind velocity and depicted in graphs. This procedure was done for all locally monitored aeroallergens, namely Alnus, Ambrosia, Betula, Artemis, Corylus, Fraxinus, Poaceae and Quercus.

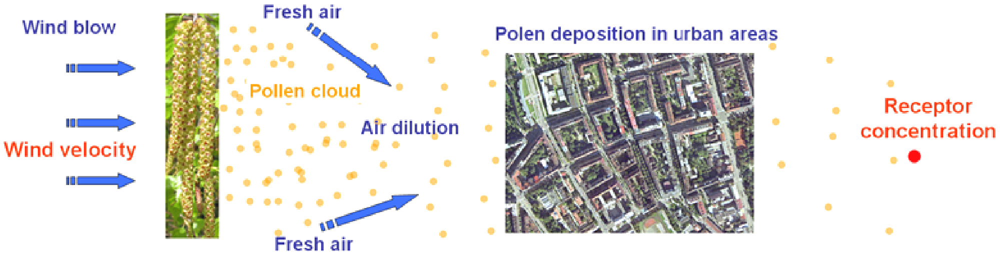
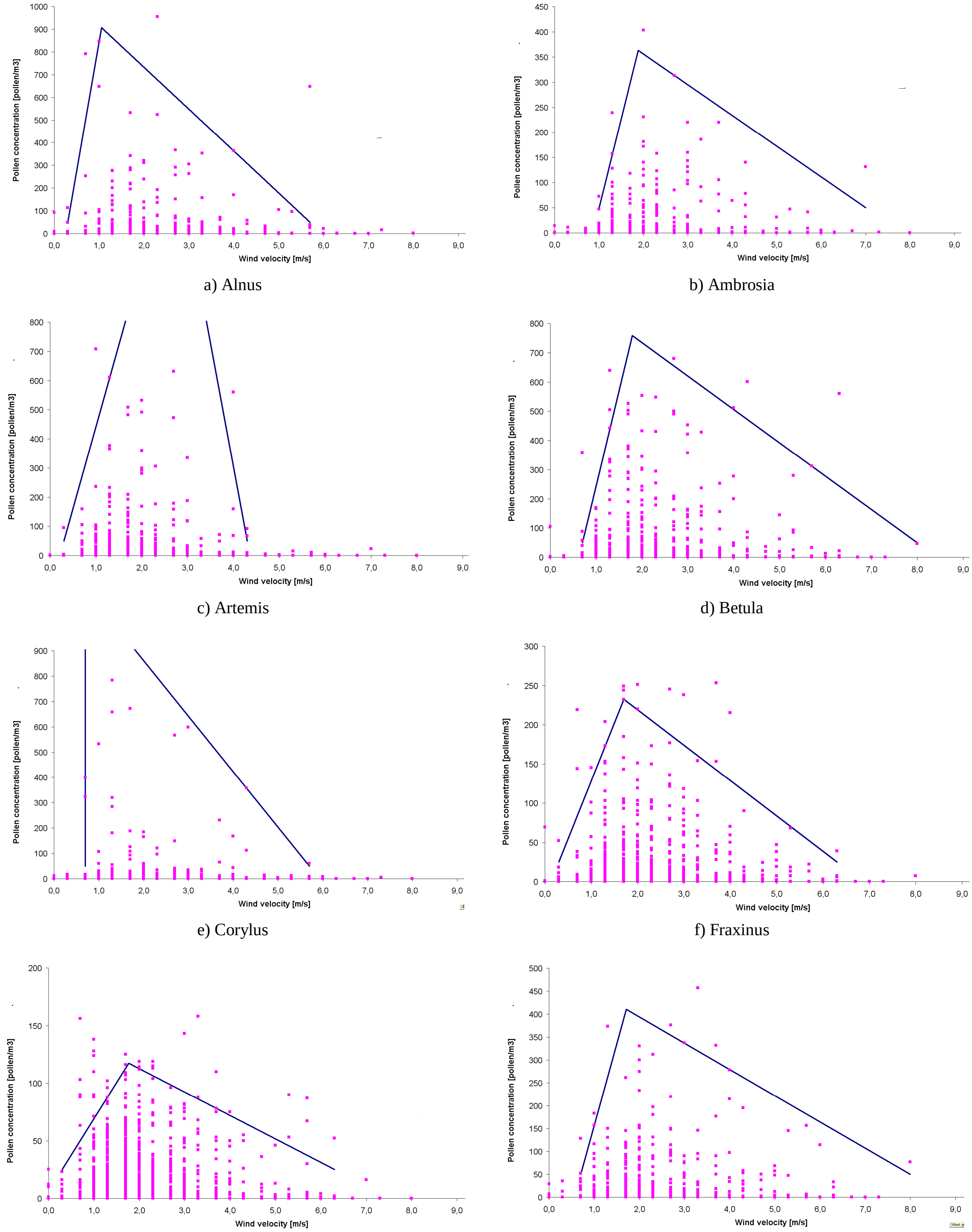


Figure 1. Pollen dispersion process considered in this contribution

The following subsequent steps were used for the raw data processing:
1. The unrealistic pollen concentration values above 600 polens.m^{-3}.24h^{-1} were excluded from the processing.
2. Only days with the pollen concentration above the threshold pollen concentration were considered for a detailed analysis. The threshold pollen concentration was determined as 5 % of the maximal pollen concentration obtained for the considered aeroallergen. The threshold pollen concentration determination enabled to exclude the zero-concentration days and very small concentration values that have great potential to be weighted by a significant relative error. The threshold pollen concentration was set to 25 pollen grains.m^{-3}.24h^{-1} for Fraxinus and Poaceae. The threshold pollen concentration for other monitored aeroallergens was set to 50 pollen grains.m^{-3}.24h^{-1}.
3. Determination of the threshold velocity of pollination. The threshold velocity of pollination is defined as the lowest wind velocity with evidence of the pollen concentration above the threshold pollen concentration.
4. Determination of the threshold maximal wind velocity with presence of the significant pollen concentration in the air. The threshold maximal wind velocity is defined as the highest wind velocity with evidence of the pollen concentration above the threshold pollen concentration.
5. As another step, the construction of two limit lines was done on the outskirt of the data plot (see Figure 2). The first point of the lower limit line was determined by the threshold velocity of pollination (defined in point 3) and the threshold pollen concentration. The first point of the upper limit line was determined by the threshold maximal wind velocity (defined in point

4) and the threshold pollen concentration. The trends of both limit lines were obtained by the interaction calculating process fulfilling the following requirements. The lower limit line and the upper limit line close the 90% of relevant records obtained from the long term measurement. Another 10 % of relevant records were split in two groups (each 5 % records). The first group of records is located on the left hand side from the lower limit line and another 5% group of records is located on the right hand side from the upper limit line. The second points of both limit lines were obtained in their intersection point. This intersection point was used for determination of the wind velocity corresponding to the highest pollen concentration. Figure 2 shows the raw data and the limit lines for all analyzed aeroallergens.



a) Alnus

b) Ambrosia

c) Artemis

d) Betula

e) Corylus

f) Fraxinus

g) Poaceae

h) Quercus

Figure 2. The relation between the wind velocity and the pollen concentration

Clear evidence of the wind threshold velocity of pollination appears in the carried out graphical expression of the in-situ measurement. The threshold velocity of pollination is the lowest wind velocity with significant concentration of pollen grains in the air. Wind velocity increase above the threshold velocity of pollination causes another increase in the pollen maximal concentration until reaching the highest concentration of the pollen season. This trend reflects increase in the total pollen release rate due to increase of the air velocity in deeper layers of vegetation and branch bundles. Another increase of wind velocity causes decrease of the maximal air pollen concentration due to “dilution” of the canopy layer by vast quantity of fresh air. The described "triangle" trend was confirmed for the majority of considered species. The particularly determined values are written in the Table 1 for the threshold velocity of pollination and the wind velocity corresponding to the maximal pollen concentrations.

The general equations used for mathematical expression of the limit lines can be written in following form:

- for the lower limit line $$c_1 = a_1 + b_1 u \, , \qquad (1)$$

- for the upper limit line $$c_2 = a_2 + b_2 u \, . \qquad (2)$$

The coefficients a_1, b_1, a_2, b_2 are written in the Table 1, u is the actual wind velocity, c_1 and c_2 are the limit concentration in the air.

Table 4. The threshold wind velocities and the limit lines coefficients obtained from the in-situ measurement for selected aeroallergens

Species	Threshold wind velocity of pollination (m/s)	Wind velocity corresponding to the maximal pollen concentration (m/s)	Coefficients of the limit lines			
			a1	b1	a2	b2
Alnus	0.3	1.1	-289.9	1133.0	1102.8	-184.7
Ambrosia	1.0	1.9	-305.9	355.9	478.1	-61.2
Artemis	0.3	2.7	-118.6	562.3	3672.1	-842.3
Betula	0.7	1.8	-407.8	653.6	961.1	-113.9
Corylus	0.7	0.7	-100332.0	1126769.0	1298.3	-219.0
Fraxinus	0.3	1.7	-19.4	148.1	309.0	-45.1
Poaceae	0.3	0.8	6.1	63.0	153.4	-20.4
Quercus	0.7	1.7	-199.7	356.3	509.1	-57.39

Note: The wind velocity mentioned in this paper is considered at height 10 m above the ground.

INFLUENCE OF THE WIND VELOCITY ON POLLEN RELEASE AND POLLEN DISPERSION

There is no clear evidence if the threshold velocity of pollination results from more intensive pollen grain production or if the air pollen concentration is increased due to more complex dispersion processes keeping pollen grains longer traveling in the air. Numerical modeling (CFD code StarCD) was used for parametrical studies testing influence of the wind velocity on pollen release from the mother plant and subsequent pollen dispersion in the ground boundary layer.

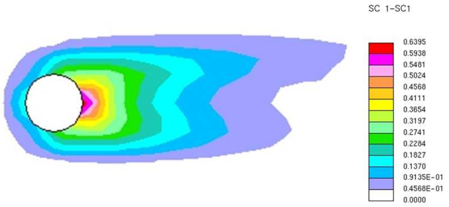
Pollen dispersion in free space

The first parametrical study was focused on small-scale modelling of pollen dispersion from a single ament located i) alone in free space, ii) in field of aments with regular span 50 mm. The aments had geometry of cylinder with diameter 10 mm and height 50 mm. The Figure 3 shows the results of calculation obtained from the numerical model of the alone ament. The figure 4 shows the result of calculation for same situations obtained in the regular field of aments.

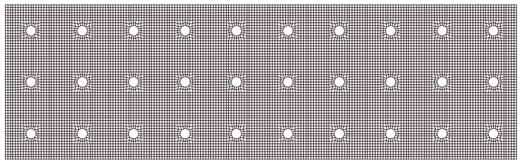
Circumfluence of the cylindrical ament is connected with significant instability in the flow pattern. The instability of flow pattern forms non-symmetric shape of pollen concentration field in the cross section done in the downstream direction from the ament. The cross section concentration field obtains more regular cycle shape features with increasing distance from the mother plant. The cross section pollen concentration field can be considered as regular cycle in the distance 1m downstream from the ament, see Figure 3b. The figure 3c shows the relation between the maximal pollen concentration in the cross section and the distance of the considered cross section from the initial ament. The series of calculations was carried out for different wind velocity boundary conditions. The presented results show the linear decrease of the maximal pollen concentration with increasing distance from the mother plant. Higher wind velocity causes more intensive decrease of the maximal pollen concentrations, the relationship remains in the linear trend.

Pollen dispersion in field of aments

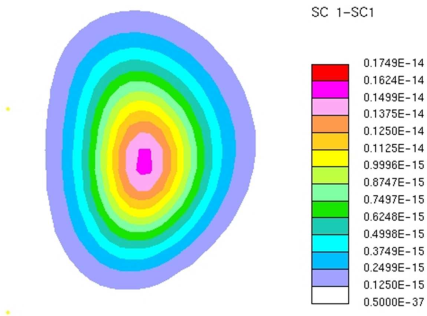
The second parametrical study was carried out on the numerical model of the field of the aments with the regular span, see fig 4a. Due to more complex flow pattern in the field of aments, the cross section concentration fields have more regular shape in comparison with the results obtained on the model of the single ament, see fig 4b. Intensive mixing processes encourage pollen dispersion. From this reason, the maximal pollen concentrations are lower in the field of aments in comparison with the single ament model. The Figure 4c shows the relation of the maximal pollen concentration and the downstream distance. There is rapid pollen concentration decrease in distance up to 5 cm from the initial ament. This trend results from the high pollen concentration in the close vicinity behind the ament and following rapid dilution of the pollen cloud in the distance of one regular span. Higher distances from the mother plant are connected with slow linear decrease of the pollen concentration in the field of aments.



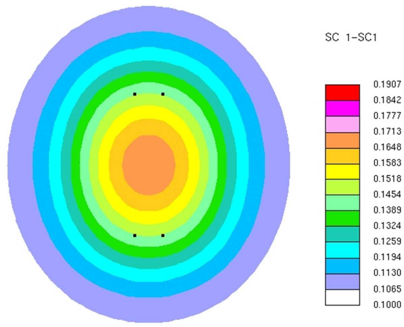
a) Horizontal pollen concentration field (g/m^3) in vicinity of the ament, wind velocity 0.3 m/s



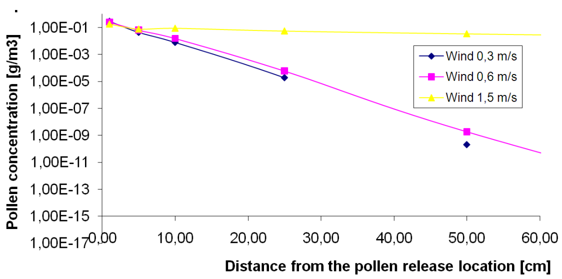
a) The mesh of control volumes in the field of the aments



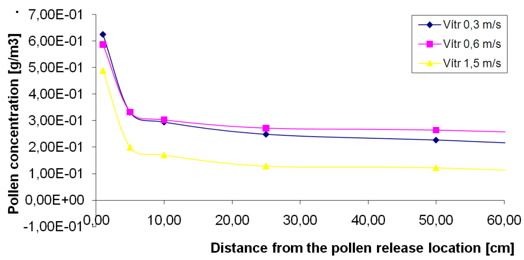
b) The vertical pollen concentration field (g/m^3) at the distance 100 cm from the initial ament, wind velocity 0.3 m/s



b) The vertical pollen concentration field (g/m^3) at the distance 100 cm from the initial ament, wind velocity 0.3 m/s



c) The relation between the maximal pollen concentration and the distance from the mother plant



c) The relation between the maximal pollen concentration and the distance from the mother plant

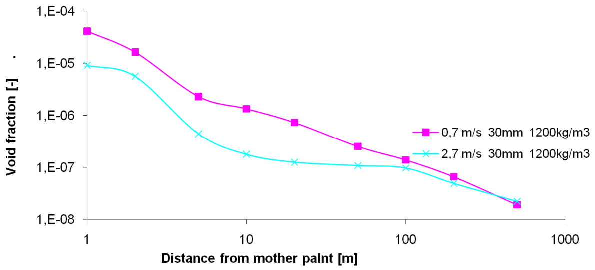
Figure 3. Pollen dispersion from single ament

Figure 4. Pollen dispersion in the field of aments

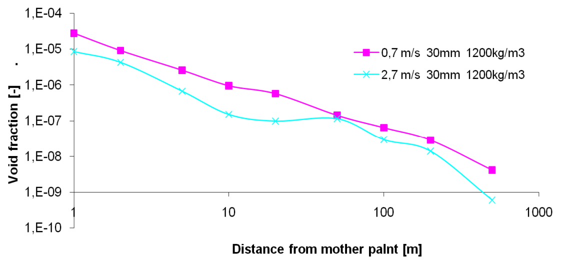
Influence of vertical distribution of pollen grains on space dispersion

Another parametrical study was focused on dispersion of pollens released in different heights above the ground. The different heights correspond to the different kinds of vegetation, namely trees (releasing height 4 m), bushes (releasing height 1 m) and grasses (releasing height 0,2 m). Three different numerical models were built up. The boundary condition “non slip wall” was used on the ground surface. The parametrical roughness was set to the ground surface to involve the influence of vegetation. Two different wind velocities were tested, namely 0.7 m/s and 2.7 m/s. The spherical pollen grains were considered with diameter 30μm and pollen density 1200 kg/m^3. The Lagrangien approach was used with detailed description of the interaction between the pollen grains and an ambient air.

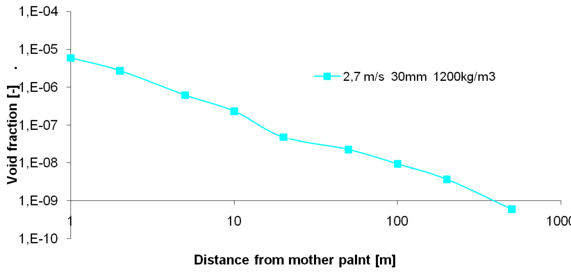
The Figure 5 shows results of carried out calculations in the form of the relation between the maximal pollen concentration and the distance from the mother plant. Each presented graph corresponds to the different pollen released height: Figure 5a - trees (4 m), Figure 5b - bushes (1m) and Figure 5c – grass (0,2m). The pollen grain release rate was identical for all tested situations. The presented results show decrease of the pollen concentration with the rising distance from the mother plant. The lower position of pollen release causes faster decrease of the pollen concentration due to more intensive deposition of pollen on the ground surface and the ground covering vegetation. The higher wind velocity causes more intensive decrease of the maximal pollen concentration in distances till 100 m from the mother plant. Another increasing of the distance brings near the maximal pollen concentrations obtained for the tested wind velocities.



a) Pollen released at the height 4m above the ground



b) Pollen released at the height 1m above the ground



a) Pollen released at the height 0.2m above the ground

Figure 5. The relation between the maximal pollen concentration and the distance from the mother plant

CONCLUSION

The pollen season prediction models are predominantly statistical models analyzing the actual meteorological conditions and their history. The simplest models are based only on air temperature monitoring. Other prediction models analyse other parameters such as daylight length, morning temperature gradient, relative humidity. The pollen season prediction models are capable of identifying the period with good potential for intensive pollination. The days with high concentration of pollens in the air alternate with the days with the low level of pollen concentration during the pollen season. This high variability of the pollen concentration in the air results from change of meteorological conditions, namely precipitation and wind velocity.

The detailed analysis carried out in this study showed some typical features in the relationship between the pollen concentration and the wind velocity. The data records of eight major aero-allergens were analysed through the period 1988-1998. The threshold velocity of pollination was determined for all analysed species as well as the wind velocity causing maximal concentration of pollen grains in the air. Another step of analysis was focused on determination of the pollen dispersion in a close vicinity to the mother plant.

The study confirmed significant influence of the wind velocity on the air pollen concentration. The now-a-days pollen season prediction models can be effectively improved by inclusion of the wind velocity monitoring and the wind velocity prediction. The correct air velocity prediction is the crucial point of such models and requires powerful computational methods (for example CFD) that become the common prediction tools of many meteorological models. Inclusion of the wind velocity between the monitored parameters of the pollination models enable to built up the correct prediction regional models with a high level of accuracy.

ACKNOWLEDGEMENT

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REFERENCES

Jones HG., 1992. Plants and Microclimate. Cambridge University Press, Cambridge, UK.

Sparks T., Jeffree CE, Jeffree EP, 2000. An examination of the relationship between flowering times and temperature at the national scale using long-term phenological records from the UK. Int. Journal of Biometeorology. 44, pp. 82-87.

Vliet A. J.H. V. a kol., 2002, The Influence of Temperature and Climate Change on the Timing of Pollen Release in the Neatherlends, International Journal of Climatology, vol. 22, pp. 1757-1757.

Vliet A. J.H. Van, Overeem Aart, Groot Rudolf S., Jacobs Adrie F. G., 2002. The Influence of Temperature and Climate Change on the Timing of Pollen Release in the Netherlands, International Journal of Climatology, 22, pp 1757-1767.