# Simulation of the dispersal of plants' pollen

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On the basis of analytical and numerical solutions of a semiempirical equation of turbulent diffusion the models of restoring the fields of the fallout of pollen of the plants in the neighborhood of the area sources are proposed. The methods of aggregation of the parameters in the problems under study are considered. Based on the proposed models, numerical experiments were conducted on restoring the pollen concentration fields of birch and chenopodium (kochia) from the data of profile observations.

## Introduction

Determination of regularities of the pollen dispersal in the air is very important for validation of the accuracy of spore-pollen analysis. Great interest has been expressed in this problem because a correct notion of the distance of pollen transfer in the air is a condition required for reconstructing the history of the vegetation cover based on the measurement data on the pollen grain concentration. For the major part of wood types it was revealed that the main body of pollen of such broad-leaved types as hornbeam, oak, beech, lime travels at limited distances although the far transfer of pollen of these plants, in small proportion, is not excluded. For small-leaved types (birch, alder) in the literature the pollen dispersal at long distance from the plants is noted. The birch pollen, in one quantity or another, can be determined almost in all the analyzed samples taken far from the limits of its areal, in the Caspian Lowland and in the Central Asia. The pine pollen can be transported by the air at long distances. The presence of the pine pollen was found in the spore-pollen spectra of surface samples of peat and soil from the regions of the Arctic, Taimyr Peninsula, Greenland, the Caspian Lowland, and other places. Under conditions of southern Kazakhstan the pine pollen in small proportion can be found at 1200 km distance from the nearest places of its habitat.

In the experimental investigations the notions are amalgamated about the limits of pollen transfer in the air and about the quantity of pollen, transported at long distance, that results in some contradictions in understanding the processes taking place. To solve a series of practical problems, it is important to determine the quantitative regularities of the pollen dispersal process through the air transfer. The problem on the limiting distribution is of secondary importance.

Dimensions of the pollen grains are within the limits from 2 to 250 μm.[1,2] The yield of pollen is tens and hundreds of kg/ha.[3,4] The dynamics of pollen crop is seasonal and daily that is directly connected with the periods of plant flowering and weather conditions. In this case the problem of adequate mathematical description of the pollen dispersal is quite difficult. One of the basic reasons of such a situation is insufficient experimental information about the spatiotemporal conditions of emission from pollen sources, the current meteorological conditions, aerodynamic characteristics of pollen grains, etc. In this connection, the use of direct simulation methods is too problematic. In our opinion, an approach is most effective, which is based on the statement of inverse problems of an impurity transfer.[5,6]

## 1. Experimental data

In Ref. 7 the experiment has been described on collecting the pollen of kochia in June 1952 in the Stalingradskaya Region. Kochia is a wind-pollinated plant of chenopodium family producing a great quantity of pollen and occupying large areas among complex vegetation within the desert steppe. The settling rate of pollen grains of kochia can vary within the limits from 3 to 7 cm/s. The plant height is low, about 10–15 cm.

As an object of research a saline spot of size 40×60 m overgrown by kochia was selected. Its flowering in this area was abundant. The observations were made on the lee side at the area where these plants were lacking. The profile of measurement was 200 m.

The pollen grains were sampled on the glass plates covered with glycerin-gelatin mixture and set up at 30–40 cm height at an angle of 45° against the wind at a definite distance from one another. The duration of exhibiting per day was 9 hrs 30 min. The wind velocity and direction were determined three times during the observation. Over the observation period the rate increased from 2.7 to 11.2 m/s. The results of pollen sampling based on the above profile are given in Table 1.

As the next object of numerical simulation the birch forest was considered.

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**Table 1. Measured and calculated values of kochia pollen concentration at sampling points**

| Point number | Distance from point 1, m | Number of pollen grains, % of the number of grains at point No. 1 | | |
|---|---|---|---|---|
| | | Measurement data | Calculation model for point | |
| | | | No. 1 | No. 2 |
| 1* | 0* | 100* | 100* | 100* |
| 2* | 11* | 50.6* | 51.6* | 50.4* |
| 3 | 45 | 10.9 | 11.3 | 12.3 |
| 4 | 79 | 6.2 | 4.9 | 5.6 |
| 5 | 99.4 | 4.7 | 3.3 | 4 |
| 6 | 172.4 | 6.4 | 1.2 | 1.6 |

* Points used for calculation.

**Table 2. Number of birch pollen grains sampled during florescence (May 13 to 15) at 1 cm$^2$ area of plate surface (in thousands)**

| Point number | Distance, m | Daily mean |
|---|---|---|
| 33–31 | 0 | 14 |
| 30–28 | 100 | 16.5 |
| 27 | 150 | 19 |
| 26 | 200 | 14 |
| 25 | 250 | 8 |
| 24 | 350 | 8 |
| 23 | 450 | 18 |
| 22 | 650 | 5 |
| 22a | 900 | 9 |
| 21 | 1150 | 6 |
| 20 | 1250 | 6 |
| 19 | 1350 | 4 |
| 18 | 1450 | 6 |
| 17 | 1550 | 3 |
| 16 | 1650 | 4 |
| 15 | 1750 | 5 |
| 14 | 1950 | 2 |
| 13 | 2150 | 2 |
| 12 | 2450 | 4 |
| 11 | 1150 | 6 |
| 10 | 2950 | 1 |
| 9 | 3150 | 1 |
| 8 | 3250 | 2 |
| 7 | 3350 | 1 |
| 6 | 3450 | 1 |
| 5 | 3660 | 2 |
| 4 | 3850 | 1 |
| 3 | 3950 | 4 |
| 2–1 | 4000 | 3.5 |

Reference 8 describes a series of experiments on the birch pollen sampling from the air. The experiments were carried out at a distance of 60 km to the south-east of Moscow during a period of mass birch flowering, on 13th, 14th, 15th of May 1955. The glass plates (9×12 cm), covered with glycerin-gelatin mixture, were set up in a treeless area and in the birch forest at different heights (1–3 m). The weather at that time was warm, sunny, without rain, the wind was from low (sometimes gusty) to moderate; the wind direction (from the south to the west) remained constant during the whole period. The pollen sampling was made along the profile of 4 km distance, from the birch forest to which the forest meadow is adjacent, along the ploughed field crossed at 400 m distance from the field by a copse, to small birch forest, which becomes, at 400 m distance from the edge, a large forest area, being leeward during the observation period. The results of investigations, using the above profile, are shown in Table 2.

## 2. Formulation of the inverse problems

Depending on the experimental information available and *a priori* data on the objects of research for describing the processes of pollen dispersal, it is profitable to use both the numerical and analytical solutions of the semiempirical equation of turbulent diffusion. The above-mentioned objects of pollen emission are the areal sources. For the sake of simplicity it is suitable to represent these objects as a sum of $N$ point sources. In this case the net concentration of pollen emission can be determined as a superposition of the fields created by point sources.

Periods of pollen sampling are long. Over a period of measurement an essential variation of dynamic characteristics of the atmospheric boundary layer can occur that makes the interpretation of the obtained experimental data difficult. Therefore, later, when analyzing the data, we will use some typical mean values of the meteorological quantities.

### a) Model 1

It is assumed that the area of the source being studied is approximated by a covering consisting of $N$ equal small squares. In their centers there are point sources having identical power. Assume that $x$ axis coincides with the wind direction and $y$ axis is in the transverse direction. Then the pollen concentration, produced by the areal source, is calculated by the following formula[9]:

$$Q(x, y) = M_0 \sum_{i=1}^{N} \frac{\exp\left(\dfrac{-(y-y_i)^2}{2\varphi^2 (x-x_i)^2}\right)}{\sqrt{2\pi}\ (x-x_i)} g_i, \tag{1}$$

where $q_i = q(x - x_i)$ is the surface pollen concentration, produced by a linear source, located along the line $x = x_i$, $M_0$ is the emission of admixture from the area unit, $\varphi$ is the variance of wind direction over the observation period.

The pollen concentration in the air from the point source is described using the semiempirical equation of turbulent diffusion

$$u(z)\frac{\partial q_i}{\partial x} - w\frac{\partial q_i}{\partial z} = \frac{\partial}{\partial z} m(z)\frac{\partial q_i}{\partial z} \tag{2}$$

with the boundary and initial conditions:

$$m(z)\frac{\partial q_i}{\partial z}\bigg|_{z=0, z=h} = 0,\ u(z)q_i\big|_{x=x_i} = M_0\,\delta(z-H), \tag{3}$$

where $z$ is the vertical coordinate, $w$ is the rate of pollen settling, $H$ is the effective height of the source connected with the plant height, $u(z)$ is the wind velocity, $m(z)$ is the coefficient of vertical turbulent exchange.

The wind velocity and the turbulence coefficient are described using Monin–Obukhov theory of similarity for the atmospheric boundary layer[10]:

$$u(z) = \frac{u^*}{0.35}\left[\log\left(\frac{z}{z_0}\right) + 4.7\,\frac{z - z_0}{L}\right],\quad m(z) = \frac{0.35\,u^*\,z}{1 + 4.7\,\dfrac{z}{L}}, \tag{4}$$

where $z_0$ is the parameter of roughness, $u^*$ is the dynamic velocity, $L$ is the Monin–Obukhov scale of length.

To calculate the function $Q(x, y)$ using Eqs. (1)–(4), a large number of parameters should be given. The most important characteristic is the value $M$ connected directly with the florescence. To estimate it, we need the data on the density of pollen fallout on the glass plates. Meteorological characteristics $u^*$ and $L$ affect the profile formation of pollen concentration along the wind direction. This effect manifests itself in the definite form and at this stage of the investigations it is sufficient to use their typical values in the numerical simulation. The quantity $\varphi$ is directly connected with the period of observations and to evaluate $\varphi$, it is also expedient to use the data on the density of the pollen fallout.

Assuming the density of the pollen fallout on the glass plates to be proportional to the pollen concentration in the air

$$P(x, y) = c\,Q(x, y),$$

we are led to the problem on evaluating the parameters $M = c\,M_0$, $\varphi$, and the function $P(x, y)$ based on the data of observations.

The parameters of $M$ and $\varphi$ can be evaluated using the method of least squares[11] with no less than two observation points.

### b) Model 2

Significant advantages, in solving the inverse problems of pollen dispersal, can be obtained using analytical solutions of Eq. (2) for light admixture when approximating the functions $u(z)$ and $m(z)$ by the power-law functions

$$u = u_1\left(\frac{z}{z_1}\right)^n,\quad m = \frac{k_1 z}{z_1}, \tag{5}$$

here $u_1$ and $k_1$ are the values of the wind velocity and the coefficient of vertical turbulent exchange at the height $z = z_1$.

In this case the problem stated by Eqs.(2), (3), and (5) allows the analytical solution, which can be presented in the following form[9]:

$$q(x - x_i,\ z)\big|_{z=0} = \frac{M_0}{(1+n)\,k_1\,(x - x_i)} \times$$
$$\times \exp\left(-\frac{u_1 H^{1+n}}{(1+n)^2\,k_1\,(x - x_i)}\right). \tag{6}$$

Then, taking into account expressions (1) and (5), the surface pollen concentration, produced by the areal source, is described by the formula[10]:

$$Q(x,y) = \Theta_0 \sum_{i=1}^{N} \frac{1}{(x - x_i)^2} \times$$
$$\times \exp\left(-\frac{2x_{\max}}{x - x_i} - \frac{(y - y_i)^2}{2\varphi^2\,(x - x_i)^2}\right), \tag{7}$$

where

$$\Theta_0 = \frac{M_0}{(1+n)\,k_1\,\varphi\sqrt{2\pi}},\quad x_{\max} = \frac{u_1 H^{1+n}}{(1+n)^2\,k_1}. \tag{8}$$

Analysis of Eq. (7) shows that the inversion of aggregated parameters $\Theta_0$ and $x_{\max}$ simplifies considerably the problem of assessment. It should be noted that $x_{\max}$ corresponds to the distance between the point source and the point of maximum ground concentration produced by this source. The quantity $x_{\max}$ is mainly determined by the source height and corresponds to the distances of 15–20 $H$, therefore one can previously be limited by this approximation.

Based on the proportionality of the pollen concentration in the air to the density of the pollen fallout, we are led to the problem on estimating the parameters $\Theta = c\,\Theta_0$, $\varphi$, and the functions $P(x, y)$ using the observation data.

## 3. Numerical experiments

Based on the models 1, 2, and on the data of sampling, the numerical reconstruction was made of the density of the kochia and birch pollen fallout according to the given profiles. The parameters $u^*$ and $L$ in the model 1 were selected from the range of permissible values corresponding to the current meteorological conditions, and the efficient height $H_{\text{eff}}$ of the pollen sources was given with the account of the plant height. Selection of the number of reference points – the points of sampling, using which the model parameters were reconstructed, was performed taking into account the level of noise in the observation data.

### a) Kochia (chenopodium)

Figure 1 and Table 1 show the reconstructed results on the density of kochia pollen fallout based on the proposed models. As reference points the points No. 1 and No. 2 were selected. Analysis of the data, given in Table 1 and Fig. 1, shows that the agreement of the calculations and the observation data at the reference points No. 3 to No. 5 is satisfactory. At the point No. 6 the difference is significant that, evidently, is due to the presence of foreign sources of pollen of chenopodium.

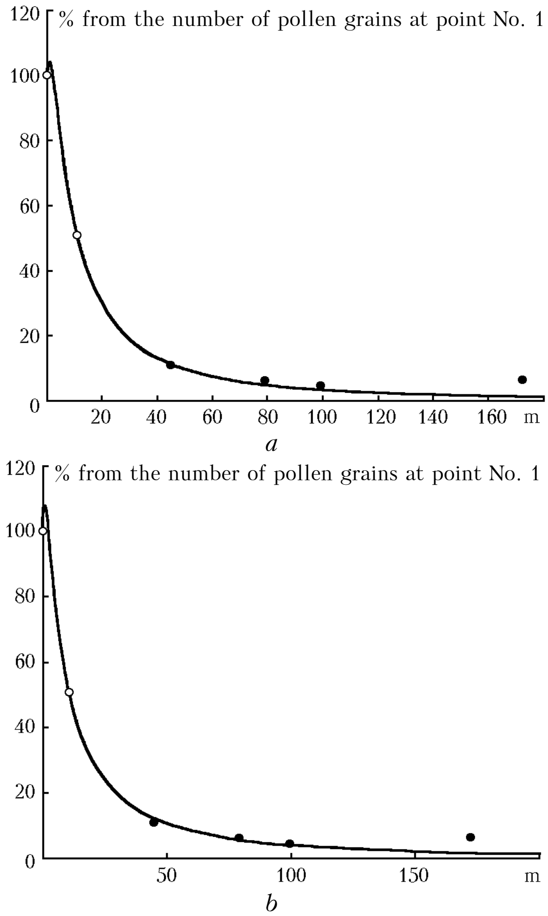


**Fig. 1.** Measured values of kochia pollen fallout density at sampling points and the density curve restored using model 1 (*a*) and model 2 (*b*). N – reference points; • – control points.

## b) Birch

Preliminary analysis of data given in Table 2 shows that the variation of the birch pollen fallout density with distance occurs nonmonotonically and points to the presence of a considerable noise due to additional sources and the inhomogeneity of the underlying surface. Therefore to increase the stability of reconstruction of the data, it is advisable to use a larger number of reference points.

The parameter Θ is determined by the following formula:

$$\Theta = K_{\exp}/K, \tag{9}$$

where

$$K_{\exp} = \sum_{X_i \in M_s} Q(X_i)(X_{i+1} - X_i), \quad K = \int_0^{X_S} Q_{\text{norm}}(x)\,\mathrm{d}x,$$

$$M_s = \{X_1, \ldots, X_s, 1 \le s \le 33\}$$

denote the set of points where the pollen sampling is made.

Figure 2*b* shows the reconstruction performed using Model 2 and sampling points from the nearest area (up to 800 m). Figure 2*a* shows the version of calculations at all points of observation and with the use of Model 1. Analysis of Fig. 2 shows that, in spite of a significant spread, the observation data are mainly grouped close to the reconstructed curves.

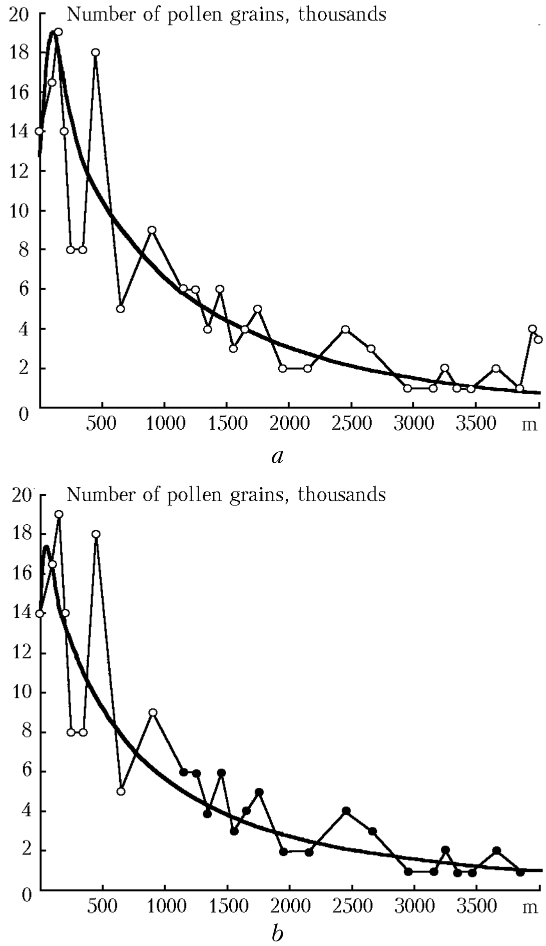


**Fig. 2.** The curve of the birch pollen fallout density restored using the model 1 with the use of all sampling points (*a*); restored using model 2 and the points located at distances ≤ 800 m from the birch grove (*b*) (N – reference points, • – control points).

# Conclusion

The above investigations show that in the framework of solutions of the semiempirical equation of turbulent diffusion an adequate interpretation of the observation data is possible on the pollen fallout of different plants based on the formulation of inverse problems of impurity transfer. The number of the parameters to be assessed is rather small and can vary depending both on the method of description of impurity transfer and on the availability of *a priori* data on the phenomena taking place.

Under definite conditions the use of analytical concept of the solution of impurity transfer equation gives significant advantages because it enables one to carry out an effective procedure of aggregation of the parameters. This makes it possible to use a limited number of reference points and opens opportunities for testing the adequacy of models.

Under inhomogeneous conditions for the dispersal of pollen the differential model becomes preferable.

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