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Dust transport from industrial cities to large distances*

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It is well known that industrial centers are powerful sources of emission into the atmosphere of lot of pollutants transported with aerosol particles. As a result, the formation of antropogenically changing bio-geochemical provinces takes place [1–3]. There are some examples of air pollution investigations in the vicinity of industrial centers, but unfortunately the quantitative regularities of these processes are not very well studied. There are a number of difficulties concerning mathematical description of the aerosol particles transport to provide the detailed picture of pollutant distribution.

According to the problems mentioned above it seems reasonable to distinguish the processes of local and regional transport. To describe a local contamination picture, the geometry of the source, the wind speed, and the vertical turbulence characteristics, a uniformity of the ground surface, etc., should be taken into consideration [4, 5]. However it has been shown, using theoretical and experimental data that for a weakly sedimentated impurity being removed from a pollution source at distances of 7–10 km these factors practically do not influence the deposition processes independent of the height. Therefore the non-sedimentated impurity transfer at the regional level may be described using a minimum number of parameters [6–8].

1. The regional level estimation of pollutions

Let the axis be oriented to the east, the axis y – to the north, S be a distributed source representing the town territory. The concentration of weakly sedimentated impurity from the point type source during a long period (month, season, year) may be expressed as:

$$q(x,y) = \frac{m(\xi,\eta)P(\phi+180^\circ)}{2\pi H\sqrt{(x-\xi)^2+(y-\eta)^2}}, \tag{1}$$

where (ξ,η) is the source coordinate, $(\xi,\eta) \in S$, $m(\xi,\eta)$ is the impurity emission from this point, $P(\phi)$ is the winds rose for the period under consideration u and H are the average wind speed and the height of the turbulence layer, respectively,

$$\phi(\xi,\eta) = \operatorname{arctg}\frac{y-\eta}{x-\xi}.$$

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It is supposed that the point (x, y) is moved off the source at a distance exceeding 7–10 km. In this case, equation (1) can be used to describe the process of the long-term contamination at these distances. If $m(\xi, \eta)$ is a function describing the emission of a weakly sedimenting impurity into the atmosphere of the city it is possible to present the impurity content with allowance for (1):

$$Q(x, y) = \frac{1}{2\pi H} \iint\limits_S \frac{m(\xi, \eta) P(\text{arctg}\, \frac{y-\mu}{x-\lambda} + 180°)}{\sqrt{(x-\lambda)^2 + (y-\mu)^2}}\, d\xi\, d\eta. \qquad (2)$$

Here it is also supposed that the point x is far enough from the multitude S. The function $m(\xi, \eta)$ is as a rule unknown or approximately known. In this case, it is very difficult to interpret experimental data using equation (2). But the situation becomes sufficiently better when it is transformed with the help of the integral theorem about average [9]. According to this theorem, for two continuous functions on a compact multitude the following equality takes place:

$$\iint\limits_S f(\xi, \eta) g(\xi, \eta)\, d\xi\, d\eta = f(\lambda, \mu) \iint\limits_S g(\xi, \eta)\, d\xi\, d\eta, \qquad (3)$$

where $(\lambda, \mu) \in S$ and it is also supposed that $g(\xi, \eta) \geq 0$ at the multitude S. In our case, when

$$g(\xi, \eta) = m(\xi, \eta) \quad \text{and} \quad f(\xi, \eta) = \frac{P(\text{arctg}\, \frac{y-\eta}{x-\xi} + 180°)}{\sqrt{(x-\xi)^2 + (y-\eta)^2}},$$

the following simple equation may be obtained:

$$Q(x, y) = \frac{\theta P(\text{arctg}\, \frac{y-\mu}{x-\lambda} + 180°)}{\sqrt{(x-\lambda)^2 + (y-\mu)^2}}, \qquad (4)$$

where $\theta = M/2\pi H$, $M = \iint_S m(\xi, \eta)\, d\xi\, d\eta$ is the summarized emission from the city territory.

To determine the function $Q(x, y)$ it is sufficient, according to (4) to estimate the unknown parameters M, λ, and μ using, for example, experimental data. The situation may be simplified for the case when the position of a predominant source of the point type at the city territory is known. In this case, $\lambda = x_0$, $\mu = y_0$, where (x_0, y_0) are the coordinates of the effective emission source.

2. Experimental

The sampling was done in February at the end of the 2000–2001 winter season in the vicinity of Iskitim (Novosibirsk region). The sampling points were arranged at distances not exceeding 15 km from the cement factory in

the northern part of the town. The town of Iskitim is situated to the south of Novosibitsk in the valley of the Berd river and is characterized by an elevated level of pollution as compared to other Russian towns. The main source of pollution is Chernorechensky cement plant. The northern part of the town is the most contaminated one. The high contents of benz(a)pyrene, carbon and dust were observed at distances up to 1500 m from the contamination source. According to the predominant south-west and the west wind directions [10] the sampling routs were oriented to the north-east (rout 1) and east (rout 2) at a distance of 6–15 km from the source on the flat and open surface.

3. Numbering modeling

Preliminary analysis of the climatic information about the average winter repeatability for the wind direction in the boundary atmospheric layer [9], the main sources of emission into the atmosphere in Iskitim city and experimental measurements of the pollutant's content in the snow cover have shown that the coordinates of the effective point type source should be localized on the cement factory territory. In this case, the task of the parameters determination in regression (4) becomes simpler and consists in θ estimation. The measurement data along the sampling rout at the base point may be used to calculate θ. The base points should be chosen not too close to a source to avoid the sufficient systematic error and not too far from it, because the accuracy of the estimation of parameters from (4) decreases with distance. The reconstructed curves for the dust and the sum of polyaromatic hydrocarbons (PAHs) in the east-north-east direction are presented in Figure 1. To estimate the parameters of regression, the experimental data of the winter season of 2001 have been used.

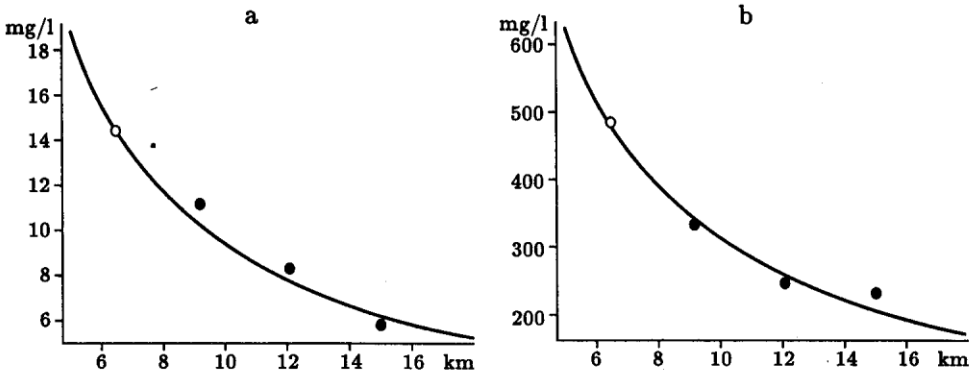

Figure 1. The distribution of dust (a) and the sum of PAHs (b) as function of the distance from the source along Rout 1. The white circles are test points, the black ones are experimental results

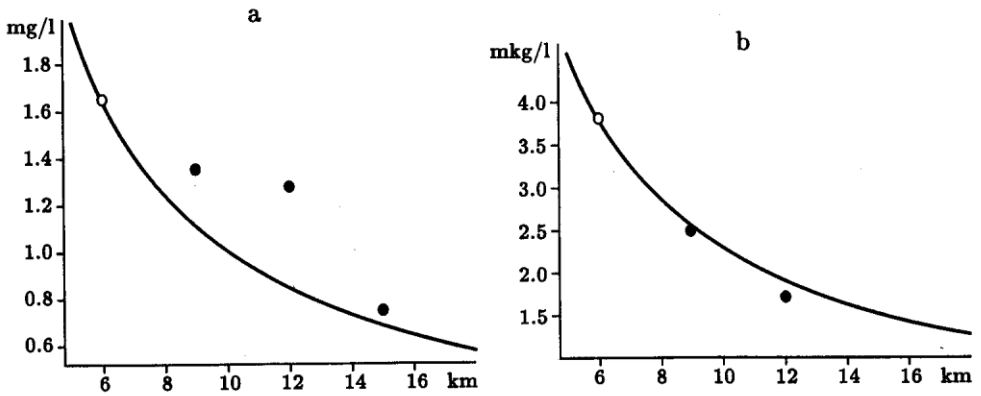

Figure 2. The distribution of water soluble Ca (a) and Cd (b) as function of the distance from the source along Rout 2

In Figure 2, the reconstructed picture of cadmium and water-soluble forms of calcium resulting from the data of the winter of 2000 is given. The points at distance about 6 km were used to estimate θ. It is seen that the experimental and calculated data are in good agreement.

From Table 1 it follows that while the height is increasing, redistribution of the wind directions repeatability takes place due to local (a city is situated in the valley) and global (the predominant west-eastern air mass transport) factors. Taking into account the repeatability in the boundary atmospheric layer it is possible to reconstruct the picture of contamination in the Iskitim vicinity and to estimate the summarized admixture of a source using the data of Table 2. It is interesting that at the height of 0.5 km the deposition along Rout 1 is much higher than that along Rout 2. This fact points out that the wind directions repeatability relative to Rout 1 is higher and the summarized dust admixtures in this direction had a maximum during 1999–2000 years.

Table 1. Winter repeatability (%) of the wind direction at different height

Wind direction	Height, km			
	weather-cock*	0.1	0.2	0.5
S–E	36	8	6	8
S	48	25	17	10
S–W	5	32	36	29
W	1	13	18	28

*January wind repeatability is given.

Table 2. θ-parameter estimation for Routs 1 and 2

Component	θ_1	θ_2	θ_1/θ_2
Dust	93.5	78.7	1.18
$\sum$ PAH	3100	2200	1.4
Cd	16.3	12.6	1.2
Ca^{2+}	12.5	9.9	1.26
NH_4 specific conductivity	16.1	12.6	1.27

4. Conclusion

The quantitative regularities of the distribution of dust, polyaromatic hydrocarbons, heavy metals and some other components at the remote distances from a distributed contamination source have been investigated. It has been shown that the re-distribution of the aerosol emission direction takes place from north and north-west to north-east and east when removing from the source. The connection of albedo with the level of snow contamination during the melting period as well as with variations of image densities of the contamination oriole on the aero- and satellite photopictures was established. Therefore the detected regularities can be used for the search of the correlation between the dust content and albedo for the snow cover. The use of the integral theorem about average value of a function gave us the possibility to transform the task with a very amount of unknown parameters to the task with a far less number of parameters.

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