EVALUATION OF CITY POLLUTION FROM THE DATA OF SNOW COVER MONITORING

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Considered is the small-parameter model for evaluation of the state of long-time pollution of a city territory from the observation data. The problems of optimal location of sampling sites are discussed. The results of model testing using the observation data on snow cover pollution with benz(a)pyrene in Belovo city are analyzed.

INTRODUCTION

There exist a number of approaches to numerical description of the state of urban medium pollution.[1–3] The most of them are used for diagnostic and forecasting purposes at comparatively short time periods. Unfortunately, the common disadvantage of these models is their low accuracy caused by both difficulties in describing the physical mechanisms of pollutant spread in the city atmosphere and complexity of adequate statement of initial and boundary conditions inside a city. The situation is aggravated when performing calculations for long time periods (month, season, year) based on them.

In this paper, to evaluate the state of urban medium pollution, we use the approach based on solution of inverse problems of pollutant transfer in the atmosphere.[4,5] This approach allows us to directly close the information about the processes of pollutant spread and observation data on concentration fields within the framework of one model. The method used in Ref. 4 is mainly applicable to study of single aerosol sources. Its direct application to the case of a large number of sources can prove low-efficient, because the number of representative sampling sites is limited. In this connection, statements of problems with the small number of parameters to be estimated are discussed. Such possibilities arise, for example, when average intensity of sources are mainly known and the characteristics of pollutant sedimentation are determined.

The evaluation model was tested using the observation data on snow cover pollution within Belovo city of the Kemerovo region. Main sources of benz(a)pyrene are the boiler-houses situated within the city territory. Comparison of calculation results with the observation data at the control points demonstrated good agreement.

1. THE MODEL FOR RECONSTRUCTION OF LONG-TIME CITY POLLUTION

In Ref. 4, the inverse problem for determination of long-time pollution of a territory by an aerosol source was reduced to estimation, from observation data, of parameters of the following regression dependence:

$$p(r, \varphi, \theta) = \theta_1\, g(\varphi)\, r^{\theta_2}\, e^{-2r_m/r}\,, \qquad (1)$$

where $p(r, \varphi, \theta)$ is sediment density; r and φ are the polar coordinates of a point at the Earth's surface against the pollution source; $\theta = (\theta_1, \theta_2)$ is the vector of unknown parameters; $g(\varphi)$ is the probability of wind direction opposite to φ; r_m is the point of maximum surface concentration for weightless pollutant.

The unknown parameters θ_1 and θ_2 here are sufficiently cumbersome combinations of parameters dependent on meteorological conditions, source characteristics, pollutant interaction with the underlying surface.

In the case of a significant number of sources (typical enough situation for a city), estimation of sets of vectors θ_i, $i = \overline{1, k}$ can prove practically impossible by virtue of limited capabilities of the observation system. On our opinion, the way out of this situation is to invoke the additional *a priori* information about power of pollution sources and pollutant characteristics.

For example, if we take into account the following characteristics of lightly depositing pollutant:

$$\theta_{1,i} = S\, M_i\,, \quad \theta_{2,i} \to -2$$
$$\text{at } w \to 0; \quad i = \overline{1, k}\,, \qquad (2)$$

following from the results of Ref. 4, then solution of the inverse problem for estimation of the sum field of sediment density becomes much more simple. Here, M_i is source intensity; S is the coefficient depending on average meteorological conditions; k is the number of sources; w is the average rate of pollutant particles sedimentation.

With regard for Eqs. (1) and (2) the expression for density of sediment generated by the set of sources can be presented in the following form:

$$p(x, y, \omega) = S\, F(x, y) + \sum_{i=1}^{k_1} \theta_i\, p_i(x, y) \;, \qquad (3)$$

where $\theta_i = \theta_{1,i}$; $\omega = (S, \theta_1, ..., \theta_{k_1})$ is the vector of unknown parameters; k_1 is the number of sources, for which the average emission is uncertain;

$$F(x, y) = \sum_{i=k_1+1}^{k} M_i\, p_i(x, y) \;;$$

$$p_i(x, y) = \frac{g(\varphi_i(x, y))}{r_i^2(x, y)}\, e^{-2r_{m,i}/r_i} \;, \qquad (4)$$

where

$$\varphi_i(x, y) = \arctan \frac{y - y_i}{x - x_i} \;;$$

$$r_i(x, y) = \sqrt{(x - x_i)^2 + (y - y_i)^2} \;,$$

x_i, y_i are the horizontal coordinates of the sources; M_i, $i = \overline{k_1 + 1, k}$ are assumed given.

Then let us assume that observation data on sediment density have the form

$$g_n = p(x_n, y_n, \omega) + \xi_n \;, \qquad (5)$$

where ξ_n is normally distributed measurement error with the given variance σ_n, $n = \overline{1, N}$, N is the general number of observation sites.

With regard for Eqs. (3)–(5), estimations of the vector ω can be fund from the condition of minimum of the following square functional[5]:

$$J_n(\omega) = \sum_{n=1}^{N} \sigma_n^{-2}\, [g_n - p(x_n, y_n, \omega)]^2 \qquad (6)$$

provided that components of the vector ω are non negative.

The problem given by Eqs. (3)–(6) is the problem square programming, and its numerical realization can be performed using well known methods and algorithms.[7,8]

Remark 1. Since the parameter S is determined as the result of solution of the problem given by Eqs. (3)–(6), then with regard for Eq. (2) the unknown power M_i, $i = \overline{1, k_1}$ also can be estimated.

2. PLANNING OF OBSERVATIONS

To increase the accuracy of estimating the parameters of regression (3), it is appropriate to optimize the location of sampling sites. Since the dependence (3) is linear with respect to the sought parameters, then it is possible to preliminary numerically model the optimal plans of observation with regard for limitations to allowable areas for performing measurements. The methods and algorithms for numerical construction of plans for experiment can be found in Refs. 5 and 6.

Remark 2. Optimal plans of observation can be determined in explicit form for some particular cases:

a) Let $k_1 = 0$. Then the optimal plan contains a single point and is determined from the condition of maximum of the function $F(x, y)$;

b) If $k_1 = k$, then the points of the optimal plan correspond to positions of maximums of the function $p_i(x, y)$, $i = \overline{1, k}$.

3. EVALUATION OF SNOW COVER POLLUTION WITH BENZ(A)PYRENE IN BELOVO CITY

Main sources of snow cover pollution with polyaromatic hydrocarbons (PAH) in Belovo city of the Kemerovo region are small and medium boiler-houses situated at its territory. The number of boiler-houses only in the central part are several dozens.

The PAH amount entering the atmosphere depends not only on the type of used fuel, but mainly on technological processes of its processing and burning. PAH formation and degradation at high temperature are competitive processes, which intensity is determined by temperature mode, excess of air, recirculation of smoke gases, and other factors. Complexity of the running processes of PAH formation hampers direct determination of intensity of PAH emission into the atmosphere and calculation of pollution fields. In this connection, statement of the inverse problem of pollution field estimation is appropriate in the given situation.

Benz(a)pyrene (BP), being one of the most strong carcinogen, is accepted as PAH indicator. Snow in Belovo city was sampled in February of 1997. Sampling sites were chosen with regard for Point (a) Remark 2, because all the necessary information about boiler-houses was known,[9] that corresponds to the case $k_1 = 0$. The specific emission of BP was set in proportions:

1) to emission of dust-ash,[10]

2) to the volume of gas-air mixture coming from chimneys.[11]

Calculation of source functions $p_i(x,y)$, $i = \overline{1,63}$, was also performed in two versions: with use of Eq. (4) and on the base of GGO technique.[1]

The preliminarily performed estimates of the level of snow cover pollution with BP on the considered territory have shown that BP maximum concentration should be expected in the north-west part of the city. In this case, the location of the optimal plan point can be calculated before sampling. The sampling points are shown by stars in the presented plan of the city. The level of snow cover pollution with BP was reconstructed from the data of measurement at the point No. 1 located in the north-west part. The results of estimation of BP content at sampling points for both versions of specifying of relative emission of the sources and calculation of surface concentration are presented in the Table I. The Figure 1 shows the field of BP sediment density (ng/l) on the city territory reconstructed according to the second version using the GGO technique.

TABLE Ix Specific content of benz(a)pyrene in snow (ng/l).

Point No.	Measurement	Calculation			
		Equation (1)		GGO technique	
		Version**	Version***	Version**	Version***
1	124*	124	124	124	124
2	87	56	67	71	82
3	5	10	10	8	7
Estimation of the parameter S		0.32	0.99	$6.4{\cdot}10^{-5}$	$1.9{\cdot}10^{-4}$

* Was used for estimation of the parameter S.
** Dust-ash.
*** Gas-air mixture.

The analysis of calculation results shows the good agreement between the calculated and measured values at control points Nos. 2 and 3 for both versions of specifying of the BP specific emission from boiler-houses.

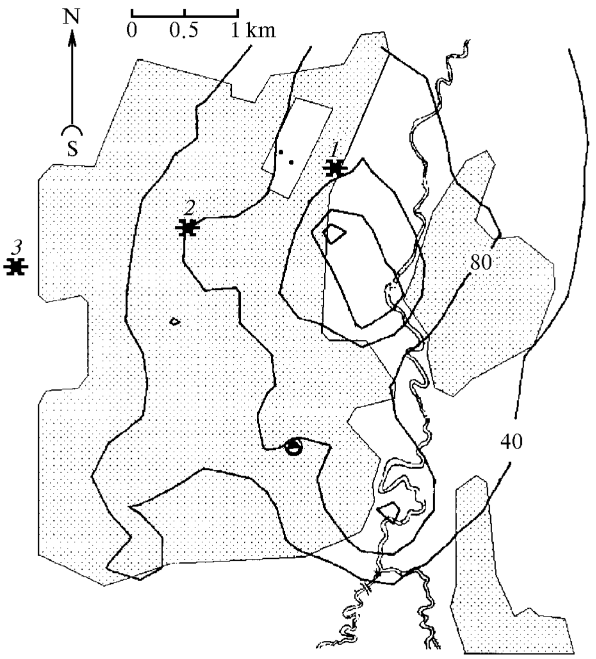

FIG. 1. The reconstructed field of benz(a)pyrene sediment density (ng/l) *in snow on the territory of Belovo city.*

The isolines of BP sediment density in snow presented in the city plan are in accordance with source positions and average winter repetition of wind velocity directions.

CONCLUSION

The model of pollution reconstruction proposed in this paper allows use of sufficiently limited observation system, that makes possible its practical application. The required input information about source parameters and climatic conditions of pollutant spread is quite available.

In spite of a small number of control points, the obtained agreement between calculation and observation data is not, in our opinion, accidental, but it reflects the character of internal connections in processes of city territory pollution with BP.

The model of pollution field estimation should be further tested taking into account peculiarities of a specific city, characteristics of pollution sources and emitted pollutants.

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