Bull. Nov. Comp. Center, Num. Model. in Atmosph., etc., 15 (2015), 77–83

Analysis of satellite imagery and surface observations of snow cover pollution

T.V. Yaroslavtseva, V.F. Raputa

Abstract. Using the reconstruction models, the methods for the joint analysis of satellite and contact observations of the snow cover pollution ghosting in the vicinity of sources of dust have been developed. Based on numerical data analysis of the ground monitoring and satellite imagery, stable quantitative relationships between the falling dust fields and the intensity of a change in tones of gray in the radial direction relative to the main sources have been revealed.

Keywords: model, parameter, estimation, reconstruction, tone of gray, functional relation.

Introduction

On satellite images, the deposition on the snow cover of aerosols of the industrial origin are clearly manifested [1, 2]. The images of snow polluted sites look like darkish spots, and blackening the image is directly dependent on the degree of atmospheric dust and reflects the dynamics of the dust transport processes from a source, thus creating the possibility of their mutual quantitative interpretation.

Regularities of distribution in the atmosphere and deposition on the earth's surface of heavy impurities are of considerable interest for solving many practical problems and for studying turbulent atmospheric properties. The movement of the heavy particles clouds in the atmosphere is mainly determined by the two factors: the influence of gravity, combined with the forces of resistance from the air and the wind field. It should also be noted that increasing the deposition rate of the particles causes decreasing the influence of turbulent exchange coefficients. When the sedimentation rate of order 0.5–1 m/s is quite suitable for the use of kinematics fallout particles onto the earth's surface. In describing the propagation of smaller aerosol fractions one should take into account the effects of turbulent mixing in the atmosphere.

When carrying out the numerical modeling and interpretation of experimental research into the propagation of heavy impurities information on the distribution function of the particle size spectrum, which is usually absent is also required. In this case, there is a need to consider additional a priori data about the possibility of describing the distribution function of the spectrum of sizes and statements of the corresponding inverse problems of the impurity transport in the surface and in the boundary atmospheric layers.

1. A model for evaluation of prolonged dust fallouts

When constructing models for estimating the field of dust deposition it is quite possible to use the version of the "kinematic" scheme of particles propagation in the atmosphere, that is, ignoring their turbulent dissipation. In this case, the movement of particles in the wind field is a drop with the Stokes constant speed, and the transfer of impurities can be described by the following equation [3, 4]:

$$u\frac{\partial q}{\partial r} - w\frac{\partial q}{\partial z} = 0 \tag{1}$$

with the boundary condition

$$q|_{r=0} = \psi(z) \equiv Q\delta(z - H), \tag{2}$$

where $q(r, z)$ is the impurity concentration in the plane (r, z), u is the average horizontal wind speed in the direction of the axis r, w is the settling rate of the particles along the axis z, the axis z is directed vertically upwards, Q and H are the power and the effective height of the source, respectively, and δ is the Dirac delta-function.

Impurities transfer along the characteristics of equation (1), and the solution to problem (1), (2) is explicitly represented:

$$q(r, z) = \psi\Big(z + \frac{w}{u}r\Big). \tag{3}$$

The particle size spectrum $N(w)$ of polydispersed impurity in a source is described by the sedimentation rate using the following two-parameter function:

$$N(w) = \frac{n^{n+1}}{w_k\Gamma(n+1)}\left[\frac{w}{w_k}\exp\Big(-\frac{w}{w_k}\Big)\right]^n. \tag{4}$$

Then, using expressions (3), (4) and the delta function properties, the density of impurity deposition in the radial direction of the source is represented as follows:

$$\begin{aligned}\sigma(r, \vec{\theta}) &= \int_0^\infty w\, q|_{z=0} N(w)\, dw = \int_0^\infty w\frac{u}{r}\delta\Big(w - \frac{Hu}{r}\Big)N(w)\, dw \\ &= \frac{Hu^2}{r^2}N\Big(\frac{Hu}{r}\Big) = \theta_1 r^{-\theta_2}\exp\Big(-\frac{\theta_3}{r}\Big),\end{aligned} \tag{5}$$

where $\theta_1 = \frac{u}{\Gamma(n+1)}\big(\frac{nHu}{w_k}\big)^{n+1}$, $\theta_2 = n + 2$, $\theta_3 = \frac{nHu}{w_k}$.

The field of deposition density of heavy inhomogeneous impurities in the vicinity of the source is described by the relation

$$\Pi(r, \varphi, \vec{\theta}) = \sigma(r, \vec{\theta})\, P(\varphi + 180^\circ).$$

Here $P(\varphi)$ is the averaged recurrence of wind directions in the layer of settling.

The evaluation of an unknown parameter vector $\vec{\theta}$ in expression (5) can be carried out according to observational data of surface sludge concentration by the method of least squares.

2. Numerical analysis of the snow pollution in the vicinity of Novosibirsk electrode plant according to surface and satellite observations

Experimental research. The Novosibirsk Electrode Plant (NEP) is located in a flat area, 50 km south of Novosibirsk. The main production is based on the technology of pyrolysis graphite made from the Gorlovsky anthracite cut, coke, coal tar pitch, petrochemicals residues. Polycyclic aromatic hydrocarbons (PAHs) constitute a significant portion of the plant emissions into the atmosphere. The ejection of resinous substances including benzo[a]pyrene (BP) and other PAHs is formed mainly in a kilning shop and is released via two 180 meter long tube.

Sampling of snow around the NEP was made in two radial routes to the pipe directed to the north and north-east. The main fallouts of impurities in the winter period occur mainly in the north-eastern sector. The scheme of snow samples selection is shown in Figure 1. Sampling points were located on routes with allowance for preliminary information about the sources of PAH emissions, terrain conditions, the system of roads, the location of settlements and the forest plantations, the snow conditions, the climatic characteristics of repeatability and the wind speed in the winter period, etc. The presence of two routes can increase the accuracy of estimating the pollution fields of the snow cover.

Preliminary analysis of the data of the expeditionary and chemical-analytical investigation has shown that the concentration of benzo[a]pyrene in the snow, despite a considerable height of the pipe, rapidly decreases with the distance from the source. The character of a change in the concentration of BP with increasing the distance from the plant suggests that in this case the contribution of a part of small particles containing BP in the near deposition zone (up to 3 km) is relatively insignificant.

Thus, the main BP fallouts in the area within 3km from the pipe are associated with large composite particles and are due to specific features of occurring technological processes. To the north, in the vicinity of the plant,

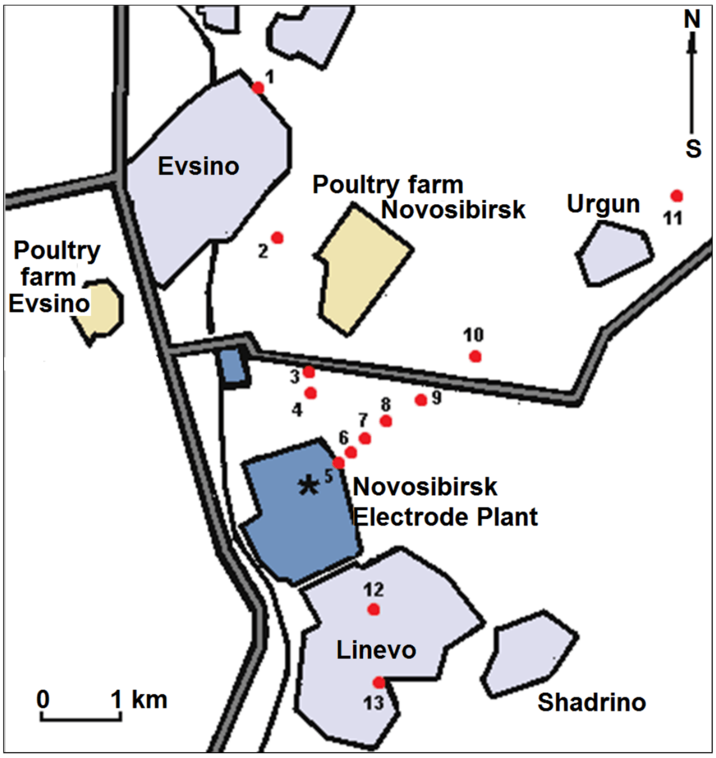

Figure 1. The scheme of snow samples selection near the NEP: $*$ is the main source of emissions of benzo[a]pyrene

a zone of very high concentrations has formed in accord with the directions of winds dominating throughout winter.

Numerical modeling. To evaluate three parameters in formula (5), it is necessary to use observations, at least, at three points along the route of snow samples selection. The selection of samples was carried out using the methods and algorithms for constructing locally optimal observation plans. Figure 2 shows the results of the recovery of BP concentration field at three reference points of measurements in the north-east direction from the source. Figure 2 reveals a satisfactory agreement between the measured and the calculated concentrations of various ingredients impurities at the control observation points.

The surface concentration maximum is attained at a distance of less than 1 km away from the pipe, thus indicating to a very high rate of particles sedimentation.

Digitization of pollution haloes. We used satellite snapshots obtained from the website of the company DigitalGlobe, which are freely available. As

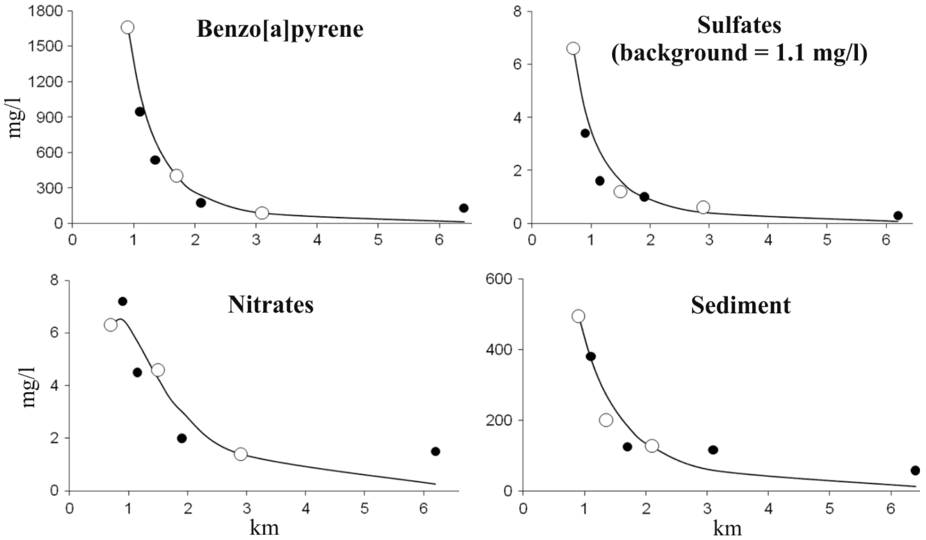

Figure 2. Numerically recovered concentrations of benzo[a]pyrene, sulfates, nitrates, dust in the snow on the north-east sampling route: ○ are bearing points, • are control observation points

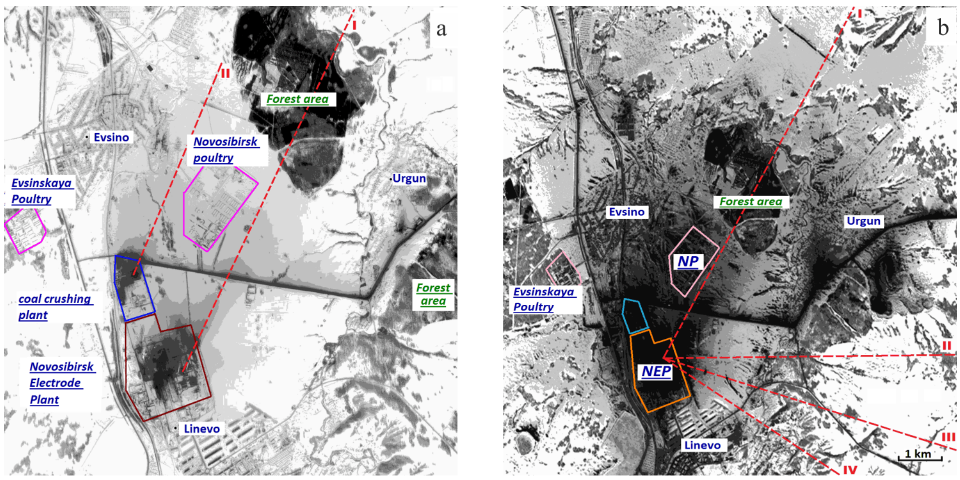

Figure 3. Dust deposition fields in the vicinity of the NEP digitized in the gray tones by satellite imagery of March 2, 2011 (a) and of March 31, 2009 (b); – – – are sections of dust deposition fields along the directions of the greatest removal

a result of image processing of March 2, 2011, and of March 31, 2009 we have obtained images of the NEP neighborhoods on which all color gradations were transferred to the gray tones. This decoding has allowed allocating the halo of pollution from the major foci of (refineries, coal crushing, and technological highway) in the directions.

Analysis of ground and satellite observations data. The results of analysis are shown in Figures 4–6.

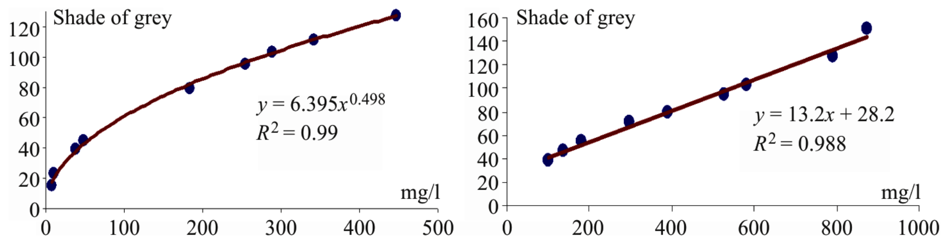

Figure 4. Functional connection in the north-east direction between the intensity of a change in the tones of gray (snapshot of March 2, 2011) and the fields of dust fallouts from the tall pipes of the roasting shop of NEP (a) and the coal crushing enterpriser (b)

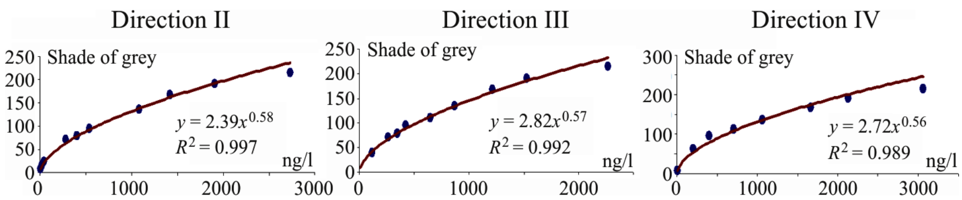

Figure 5. Functional relationship between the intensity of a changes in the gray tones (snapshot of March 31, 2009) and the fields of benzo[a]pyrene fallouts from tall roasting pipes of NEP in the directions II–IV

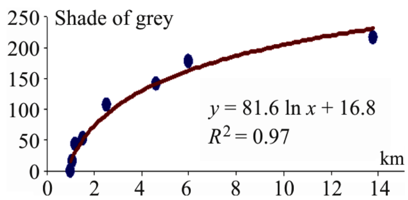

Figure 6. Functional relationship between the intensity of a change in the gray tones (snapshot of March 31, 2009) and the fields of benzo[a]pyrene fallouts from tall roasting pipes of NEP in the direction I

3. Conclusion

The results of the conducted research can significantly optimize the fulfilments of the ground pollution monitoring of the neighborhoods of industrial enterprises in the winter period. With the use of satellite data and relatively a small number of sampling points we have the possibility of restoring the snow fields multicomponent contamination of territories and estimating the total emission of contaminants.

References

[1] Prokacheva V.G., Usachev V.F. Snow cover as an indicator of the cumulative indicator of pollution in the sphere of influence of cities and roads // Meteorology and Hydrology.—2013.—No. 3.—P. 94–106 (In Russian).

[2] Vasilenko V.N., Nazarov I.M., Friedman S.D. Pollution Monitoring of Snow Cover.—Leningrad: Gidrometeoizdat, 1985 (In Russian).

[3] Berlyand M.E. Modern Problems of Atmospheric Diffusion and Air Pollution.—Leningrad: Gidrometeoizdat, 1975 (In Russian).

[4] Yaroslavtseva T.V., Raputa V.F., Turbinsky V.V., Shcherbatov A.F. Monitoring of snow cover dust pollution near a cement plant // Bull. Novosibirsk Comp. Center. Ser. Num. Mod. in Atmosph., Ocean, and Env. Studies.—Novosibirsk, 2014.—Iss. 14.—P. 105–111.