Analysis of scales of the anthropogenic impacts in the atmosphere

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The scenarios approach is proposed to the preliminary assessments of the scales of possible anthropogenic impacts on the climate system. The modeling scenarios presented are realized based on a complex of models of the hemispheric transport of pollutants in the atmosphere. To be as close to reality as possible Reanalysis NCEP/NCAR (U.S.A.) data are used in designing the atmospheric circulation scenarios. The paper presents the results of numerical experiments demonstrating possible scales of the polluted areas in the atmosphere of the Northern hemisphere by the sources located in Serbia.

Introduction

The events of the last year over the course of the past millennium have substantiated our conclusion that at the present stage of social development the ecology in the industrialized regions becomes one of the most important socio-economic and geopolitical factors.[1] In reality, with the increase of technical complexity and specific power of production and power objects the menace of large-scale technological catastrophes is still serious, which, in turn, can result in severe ecological consequences. The tendency toward resolving international and home conflicts by force with the use of ecologically dangerous means and systems of armaments is now clearly recognized. The latest conception of military operations appeared using the intentional guided stimulation of ecological catastrophes by destroying ecologically dangerous civil objects. The realization of this idea has already been demonstrated to the world community in actual practice when performing the anthropogenic field experiments under real conditions.

How shall we inform the public and the specialists concerned about the possible ecological results of such experiments?

We can solve this problem by formulating typical tasks of the environmental protection. The above problems can be solved using mathematical simulation in the framework of the scenario approach. To form the scenarios we propose to use the retrospective natural information about the hydrometeorological processes.

The following two conceptions explain the strategy of the investigations we have chosen based on the typical scenarios. First, the field experiments under real conditions are irreversible. It is impossible to repeat them in nature due to the variability of processes. Second, when forecasting the possible development of the situation the problems arise caused by the uncertainty in *a priori* setting of the sources of actions and with the ability of forecasting using prognostic methods and models.

Clearly, this raises the question on the development of the information–modeling system for such situations using the mathematical models. The results of these calculations can be used for forecasting possible consequences of the anthropogenic effects. Such a multifunctional system is being developed at the Institute of Computer Mathematics and Mathematical Geophysics SB RAS in cooperation with other research groups.

The paper describes an example of solution of the typical problem from the class being considered. As the sources of anthropogenic effects in this problem we took the aggregation sources of pollutant and heat emissions. In this case we were interested in the situation in Central Europe during the NATO operation in Serbia.

The modeling scenarios, presented in the paper, were realized based on the hemispheric complex of models[1] including the pollutant transport model in the atmosphere and the information model of generation of hydrodynamic background using the model of hydrothermodynamics of the atmosphere[2] and the database of life information in the assimilation regime. To be close to practice for the formation of scenarios of atmospheric circulation we used the data of Reanalysis NCEP/NCAR, USA.[3] The system of data preparation, included in the complex of models, is described in Ref. 4.

1. Statement of the problem and the model structure

Now we turn our attention from the political problems and consider the natural-scientific aspects of the problem of anthropogenic effects. In this case the most urgent tasks consist in estimating the ecological prospects with different versions of anthropogenic

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effects against the background of natural course of processes in a climate system. For this purpose it is necessary, above all, to assess the spatiotemporal scales of interactions in this system. They determine the dimensions of ecologically significant results of the influence of one or another source.

Mathematical statements of these problems can be referred to the class of problems of the "source–detector" type. The initial information in these problems is the data on the parameters of operating sources. As a detector-zone, which is also denoted in the input data, serves a selected region exposed to the sources through the processes realized in the climate system.

Because the contribution from a power source is, as a rule, relatively small, as compared with the power of the atmosphere, we shall consider the processes connected with the transport and transformation of pollutants assuming, in the first approximation, that the effect of a power source on the climate system is negligible.

Equations of the pollutant transport and transformation model are written for the spherical Earth. The vertical coordinate is a hybrid "p-sigma" system consisting of isobaric coordinates above the 500-mb level and following the Earth's surface relief below this level.[2] Such a system is suitable both for work with the Reanalysis data and for taking account of the Earth's surface relief. The set of equations used is as follows:

$$\frac{\partial \pi c_i}{\partial t} + \mathbf{L}(\pi c_i) - \mathrm{div}\, \mu\pi\, \mathrm{grad} c_i + (\pi \mathbf{B}(\mathbf{c}))_i = f_i\,,$$

$$i = \overline{1, n}\,,\ n \ge 1.$$

Here $\mathbf{c} = \{c_i(\mathbf{x}, t),\ i = \overline{1, n}\} \in Q(D_t)$ is the vector-function of the state, c_i is the concentration of ith impurity, n is the number of different substances; $\mathbf{f} = \{f_i(\mathbf{x}, t),\ i = \overline{1, n}\}$ are the functions of sources; $\mathbf{L}(\mathbf{x}, t)$ is the pollutant transport operator against the background of atmospheric motions at the velocity $\mathbf{u} = (u, v, \dot{\sigma})$ (the gravitation precipitation of pollutants is allowed for in the vertical component of the velocity vector $\dot{\sigma}$); $\mathbf{B}(\mathbf{c})$ is the operator of the pollutant transformation[5]; π is the pressure function, its form depends on the choice of the coordinate system; $\mu = (\mu_1, \mu_2, \mu_3)$, μ_i $(i = \overline{1, 3})$ are the coefficients of the turbulent exchange along the coordinates x_i $(i = \overline{1, 3})$; $D_t = D\times[0, \bar{t}]$; D is the domain of space coordinates variation $\mathbf{x}$, and $[0, \bar{t}]$ is the interval of time variation; $Q(D_t)$ is the space of the state functions satisfying the boundary conditions at the domain boundary D_t. The turbulence coefficients are calculated from data on fields of meteorological elements: wind velocity, temperature, geopotential, surface pressure. The horizontal coefficients μ_1, μ_2 by analogy with Refs. 6, 7, and the vertical coefficients μ_3 are parameterized according to the definitions of K-theory of the turbulence taking into account the temperature stratification and the vertical shift of the horizontal velocity vector.

B o u n d a r y c o n d i t i o n s. At the upper boundary of air mass ($p = p_T = 10$ mb) it is assumed the absence of pollutant fluxes. At the lower boundary of air mass ($p = p_s(\mathbf{x}, t)$) the pollutant precipitation is taken for the boundary condition. The precipitation velocities are parameterized with consideration of aerodynamic, molecular, and surface resistances for pollutants in gas and aerosol state over the thermally and orographically inhomogeneous Earth's surface. Because the problem is considered on a sphere, then along the longitudinal coordinate the conditions of periodicity of all the fields are used. In a hemispherical version on the equator we assume the condition of the absence of pollutant fluxes from the southern hemisphere to the northern one.

2. Formation of scenarios

To realize the modeling scenarios there is a need to set the values of wind velocity, temperature, air humidity, geopotential, the surface pressure, and solar radiation fluxes at the level of the Earth's surface. As mentioned above, these values are calculated based on data of Reanalysis NCEP/NCAR using the system described in Ref. 4. For calculations we can use the data over 38-year period since 1961 until 1998. The initial and final moments of the time interval and the sampling time Δt to integrate the model in time as well as the structure of the grid area are determined when assigning the input data.

Thus the goal of scenarios is to evaluate the character of propagation and scales of the areas of the Earth's atmosphere where pollutants from the sources come as a result of anthropogenic catastrophes and military conflicts (in this case as a result of destruction of ecologically dangerous objects on the territory of Serbia).

It should be noted that these calculations are not the forecast or a diagnosis of the specific situation but a hypothetical scenario of the development of events on the background of real atmospheric processes in the past. Thus we try to answer a question of principle about the scales of a possible ecological catastrophe.

The calculations were made for several scenarios for one and the same calendar period at different years. One of the first scenarios, presented at the International Conference "Physics of Atmospheric Aerosol" held in Moscow, 12–17 April 1999, was calculated at the very beginning of the conflict. No current meteorological information and especially the forecast were available at that time. In accordance with our conception, we took the data on the atmospheric circulation for the period of 12–28 April 1996. The final date of the scenario was chosen arbitrarily. In reality the conflict proved to be more extended and was beyond the period of time we have chosen for our study. Later on the scenarios have been calculated over the same period using the data collected in 1994 and 1998.

It was assumed that the aggregation pollutant sources on the territory of Serbia would be chemical and biochemical objects, oil refineries, oil tanks and gasholders, nuclear reactors, and so on. Processes of pollutant transformation and mechanisms of secondary pollution of the environment by the transformation products were not considered because of the lack of information about the pollutant composition and the mechanisms of substance transformation in the atmosphere, although there is a possibility in principle of the forecast of chemical situation using our complex of models.[5] The results presented in this paper refer to the trace experiments with the passive impurities.

Because the destructions produced were due to the use of explosive substances initiating the fires it was also assumed that the pollutant emissions were accompanied by intense emissions of heat. The assessments, obtained on the basis of calculations using the mesoscale models of hydrothermodynamics in the nonhydrostatic approximation,[7] demonstrate that at rather long heat and pollutant emission from such objects, aerosol clouds with highly toxic impurities together with heated air masses can, depending on weather conditions, rise up to altitudes of 5 km above the Earth's surface and appear in the system of atmospheric circulation on the mesoregional and global scales. Therefore, the pollutant sources were set by the corresponding vertical profiles up to the level of 500 mb. In the scenarios it is assumed that the heat and pollution sources operate from 00:00 a.m., on April 12 to 00:00 a.m., on April 29.

The peculiarity of the region under study, including Serbia, known *a priori* is the fact that this region is under the influence of the Mediterranean cyclogenesis. It is characterized by high intensity and variability of natural processes and it means that this region belongs to the objects of high ecological risk both for itself and for the neighboring territories.

3. Calculated results

Results of calculations of the scenarios were represented visually as computer films demonstrating two-dimensional horizontal profiles of the pollutant concentration fields at 10 levels from the Earth's surface up to 20-mb level with the time discreteness of 30 min. Comparative analysis of all the scenarios favors the viewpoint that this region lies in the area of intense atmospheric processes. Nevertheless, we have managed to discover the common properties in the character of pollutant propagation. The scales of intense pollution areas and the total concentration fields over the entire period of modeling remain approximately of the same size, although their configurations in the space-time dynamics have their own characteristic properties.

This paper presents the results on the scenario calculated based on the data acquired in 1998. It should be noted that the dominating factor in this and other scenarios is the eastward transport of air masses, which alternates with the motions of the meridian circulation. Figures 1 and 2 show in the polar-stereographic projection of the northern hemisphere the fragments of the scenario, namely, the two-dimensional horizontal profiles of concentration fields close to the Earth's surface. Fig. 1 shows the measurement data taken at 12:00 a.m. on April 15, 1998, and Fig. 2 – at 12:00 a.m. on April 26, 1998. The concentrations are normalized to the maximum value calculated over all fields in time. The isolines in the figures are marked by figures and the isostrips are marked with the gradations of black color. The scale of values is given at the bottom. The contours of continents are marked on the map of the hemisphere for convenience.

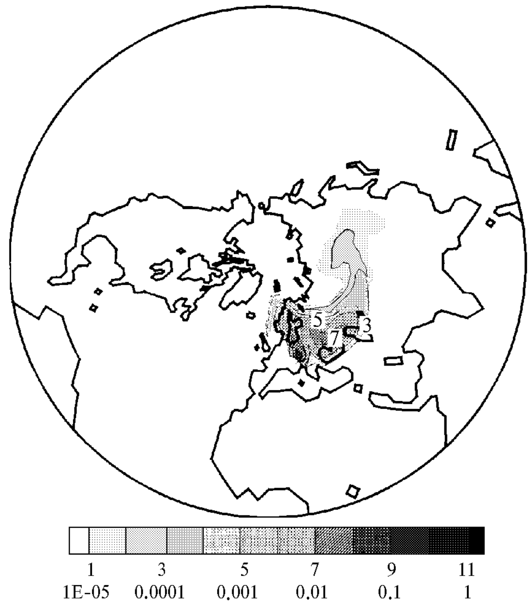


Fig. 1. The concentration field in the near-ground layer (April 15, 1998).

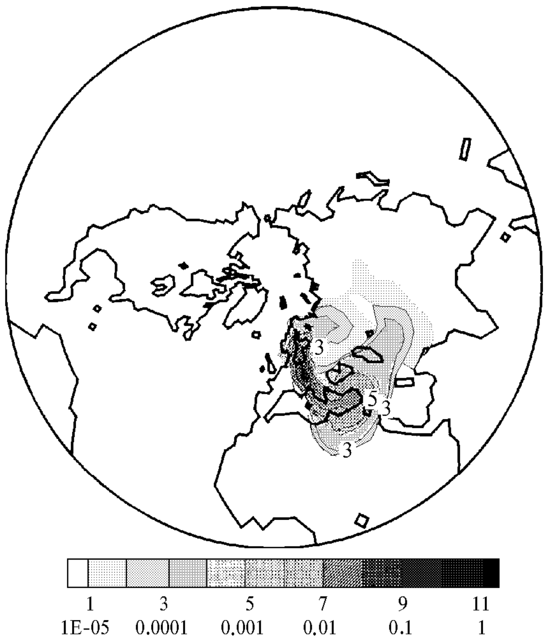
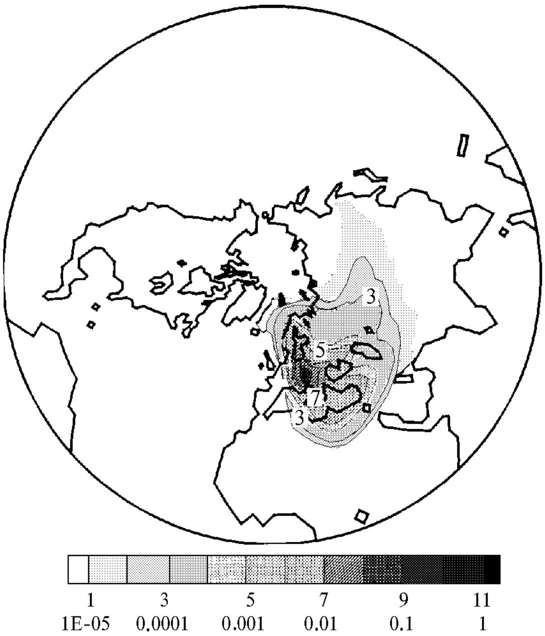


Fig. 2. The concentration field in the near-ground layer (April 26, 1998).

A comparison of Figs. 1 and 2 shows a considerable variability of concentration fields caused by a substantial variability of hydrometeorological conditions observed in the period considered.



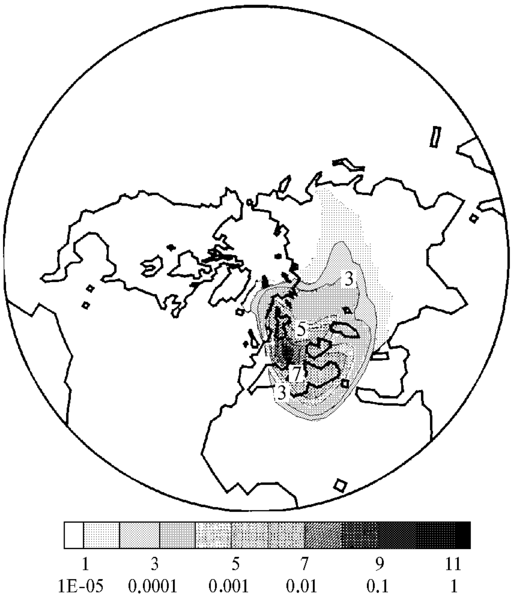
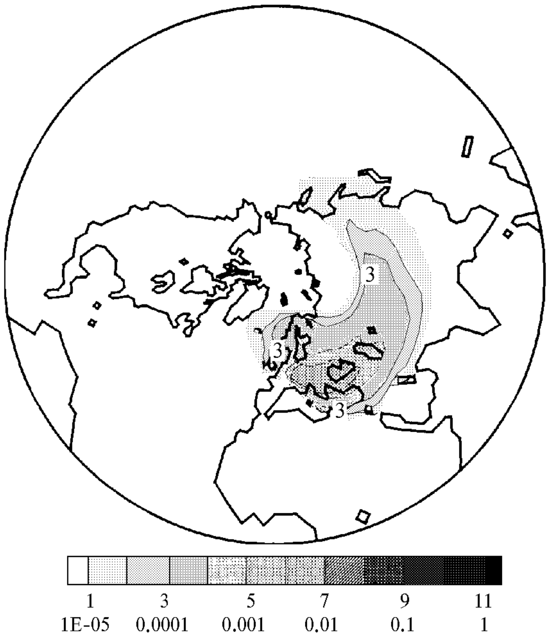


Fig. 3. The net concentration in the near-ground layer over a period from 12 to 28 April 1998.



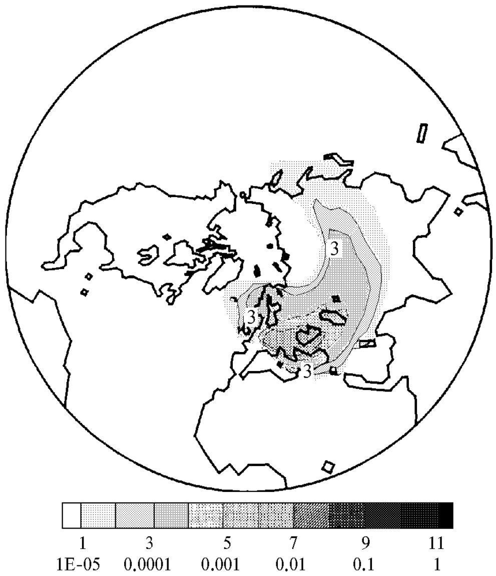


Fig. 4. The net concentration at 20-mb level over a period from 12 to 28 April 1998.

Figure 3 shows the concentration field of the total atmospheric pollution over a period of the action of sources (from 12 to 28 April 1998) at the level of relief of the Earth's surface and Fig. 4 shows the concentration field of total atmospheric pollution in the stratosphere at about 20-mb level. The concentration values in these figures are given in relative units normalized to the maximum value of three-dimensional total fields. The impurities were transported to the upper atmospheric layers by convection. Although the magnitude of pollutant concentrations in the stratosphere is small as compared with maximum, the concentrations are still significant and can be a cause of ecological consequences.

The figures clearly demonstrate large scales of pollutant propagation calculated in the scenarios. Such phenomena can be classified as the large-scale ecological catastrophe.

In this paper, we did not discuss such problems as chemical pollution and the possibility of secondary contamination of the atmosphere due to the processes of impurity transformation. In fact, as to the ecological aspect, these problems can appear to be more important for the human health and the quality of the environment than simple dispersal of pollutants in the atmosphere. For example, it has been known that reactions can yield more toxic products of transformation than the initial emissions can form.[5,7] The fact points to the complexity of this problem that chemical reactions proceed in different ways depending on the presence or absence of the sun light.

Thus in this paper we tried only to define the problem on the assessment of the consequences of anthropogenic impacts under specific conditions of technological catastrophes and military conflicts as well as to demonstrate one of the aspects of the application of the information–modeling system developed by the authors.

Conclusions

1. The localization of polluted areas in the environment is not clearly defined. At least, the regional pollution scale is assured in the cases when the pollution emissions are accompanied by intense thermal emissions.

2. If owing to the conditions of the catastrophe and the peculiarities of atmospheric circulation the pollutant transport to the stratosphere occurs then the dimensions of polluted areas increase substantially. This is especially dangerous in the case of damage of nuclear reactors and radioactive wastes storages.

3. In the scenarios with Serbia, which is located geographically in the area of Mediterranean cyclogenesis, practically the entire Europe appeared to be under the atmospheric anthropogenic impact.

4. It might be worthwhile to evaluate transboundary transports of pollutants and possible damages from the environment pollution due to the above pollutant transports (in our scenarios, for example, for CIS countries).

5. It is necessary to assess the typical scales of pollution areas using the global models. The details must be refined using mesoregional models with high spatial and temporal resolution.

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