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Problems of Development of the Integrated Environmental Monitoring System and Approaches to Their Solution

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Abstract—The analysis is given of the present situation and current preparedness of available approaches to the implementation of the Roshydromet concept of the improvement of environmental pollution monitoring system taking into account differences in goals and objectives that different components of this system should achieve at the federal, regional, and local levels. The structure and functional scheme of the National environmental pollution monitoring system is discussed. The approximate allocation of functions is put forward among the monitoring system components of different levels as well as the distribution of responsibilities and powers among stakeholders to ensure the implementation of these functions. The key issues of establishing an integrated monitoring system are discussed. The network-centric approach to the system management organization is proposed. Specific goals, objectives, and strategies can be set for different components of this system which may differ in terms both of algorithms and actual parameters. The development of the main technological components of the integrated environmental monitoring system (monitoring networks and information systems) is considered.

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INTRODUCTION

The right of any citizen to the favorable environment is guaranteed by the Constitution of the Russian Federation. At the international level, the need in preserving the environment for the present and future generations was proclaimed in the declaration of sustainable development of the human civilization "The Future We Want" accepted at the Rio+20 conference in 2012 and in the Sustainable Development Goals officially known as "Transforming Our World: The 2030 Agenda for Sustainable Development" accepted by the United Nations General Assembly in 2015.

As the scales of economic activity increase, the rising anthropogenic load leads to unfavorable environmental changes accompanied by the depletion of mineral-raw, water, and biologic resources as well as by the degradation of natural complexes. The global climate change aggravates the mentioned problems. The need in reasoned decisions ensuring the balanced solution to socioeconomic problems and the preservation of favorable environment, biologic diversity, and natural resources causes the need in extensive, timely, and available information as well as in the estimates and forecasts of current and expected changes based on this information. Therefore, the problem of efficient informational support is becoming more and more topical. This support is related to the minimization of possible damage for the population and economic activity due to unfavorable environmental changes occurred under the influence of natural and anthropogenic factors.

This problem is solved on the basis of environmental pollution monitoring. To control economic activity, taking into account the characteristics of environmental conditions that determine the transport of pollutants in the atmosphere and hydrosphere as well as their migration in the soil, is extremely important. This fact was realized in the period of the intensive industrial development of society. In Russia the concept

and the term of "environmental monitoring" meaning the observation, analysis, and forecast of anthropogenic pollution was introduced by the academician Yu.A. Izrael [1].

At the same time, the practical need arose in the formation of the system of monitoring, assessment, and forecast of environmental changes occurred under the influence of increasing anthropogenic load. The specific knowledge, the experience in the development and use of the systems of hydrometeorological observations and information-measuring technologies, which were available in the Hydrometeorological Service of the USSR, formed the base for the establishment of the National Service for Pollution Monitoring and Control (NSPMC) in 1970–1980s.

In the following years, some federal laws and decrees by the Government of the Russian Federation [2–4, 7–9] required the obligatory consideration of climatic and hydrometeorological parameters for the substantiation and implementation of any pollution-related economic activity; the computation of potential pollution levels based on these data (and, proceeding from background and maximum permissible concentrations of pollutants, the determination was required of standards for the permissible emissions and discharges) was also required.

According to the above regulatory framework, the state authorities of the Russian Federation are currently working on the implementation of the national environmental monitoring by creating and developing monitoring systems as well as providing their operation based on a wide range of observation networks and information resources including the State Database of National Environmental Monitoring (SDNEM).

The national monitoring of environmental pollution is one of the most important components of the national environmental monitoring. It aims to provide actual data on current environmental conditions and on the level of pollution of the atmosphere, soil, surface waters of water bodies (including hydrobiological parameters), ozone layer, ionosphere, and near-Earth space as well as the results of estimation and forecasting of their variations under the influence of natural and anthropogenic factors. The monitoring should basically be implemented in the framework of the national observation system of environmental conditions (hereinafter, NOS). The NOS information should be presented to the population, state authorities of all levels, and organizations and should be stored in the Roshydromet Unified State Database and SDNEM.

As a result, the regulatory framework was created for the operation of the integrated environmental monitoring system. The major practical task is to widen the monitoring data use in the national system of assessment and control of environmental quality; it includes the operational informing of population about environmental quality, especially in case of the risk of high pollution levels, and the assessment of efficiency of pollution control measures.

The present paper provides the analysis of current preparedness of available approaches to the improvement of the national environmental monitoring system developed by Roshydromet taking into account differences in goals and objectives that different system components achieve at the federal, regional, and local levels. The potential of numerical models in simulating the pollution transport in different environments is assessed as well as the possibility of obtaining the maximum reliable estimates of the pollution level based on the assimilation of the data of instrumental observations using these models. Special attention is given to the issues concerning the construction of the unified integrated environmental monitoring system based on the network-centric approach [10].

COMPOSITION AND FUNCTIONS OF THE NATIONAL SYSTEM OF ENVIRONMENTAL CONDITIONS OBSERVATION

In accordance with the federal law [7], the national environmental pollution monitoring is carried out by the authorized organizations (monitoring stakeholders) by creating and ensuring the operation of observation networks and information resources as NOS subsystems. NOS includes (Fig. 1) the state observation network of the federal level whose operation is provided by Roshydromet as well as regional systems for observation of environmental conditions whose formation and operation are provided by the executive authorities of the subjects of the Russian Federation. All NOS subsystems should be connected functionally in the framework of the unified information system to allow data exchange between the subsystems, potentially in the automatic real-time mode.

When forming NOS, the stations and systems of environmental observations are taken into account in the areas where such objects are located that negatively affect the environment and whose owners provide the monitoring of environmental pollution in the zone of their impact (hereinafter, local observation systems) according to the federal laws. The informational interaction and the data exchanges with them should also be established.

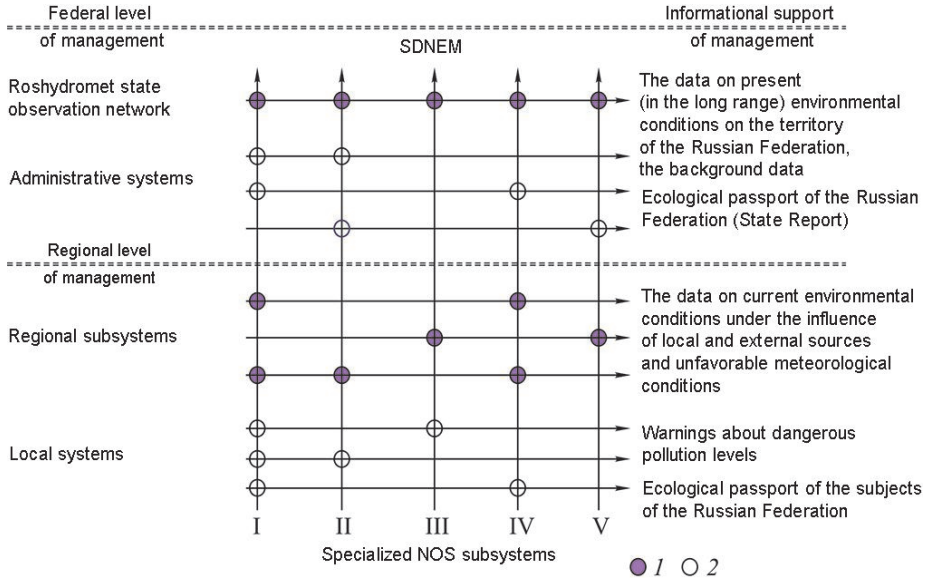

Fig. 1. The functional scheme of the national environmental pollution monitoring. (I) Monitoring of the unique ecosystem of Lake Baikal; (II) Air monitoring; (III) Monitoring of exclusive economic zone; (IV) UNASRM; (V) Monitoring of inland sea waters and territorial waters. (*1*) Information coupling with NOS. (*2*) Information interaction with NOS.

If federal executive authorities (ministries and departments) conduct the observations of environmental pollution, the informational interaction should be established with their observation subsystems. The regulations of such interaction are stipulated in the framework of separate agreements. The list of federal executive authorities and organizations established by the Government of the Russian Federation for providing the national monitoring of environmental pollution is presented in [7].

The monitoring stakeholders can also take part in providing the operation of specialized monitoring subsystems within NOS. According to [3], Roshydromet must provide the operation of specialized NOS subsystems implementing the national monitoring of the atmosphere, inland sea waters and territorial waters of the Russian Federation, exclusive economic zone, continental shelf, and the unique ecosystem of Lake Baikal. In addition to that and in accordance to [2], the Unified National Automated System of Radiation Monitoring (UNASRM) may be considered as a specialized NOS subsystem.

It is noted in [7] that the powers of Roshydromet, other federal state authorities, and the executive authorities of the Russian Federation subjects are realized in accordance with their competence. However, the allocation of functions among the monitoring system components of different levels as well as the distribution of responsibilities and powers of stakeholders to ensure their implementation have not been established yet.

According to [7], Roshydromet coordinates the agreed operation of the mentioned observation systems in order to provide the necessary completeness and reliability of environmental data as well as to obey the clauses on the uniformity of measurements and on the comparability of the data obtained on the whole territory of the country.

These powers implemented in the framework of the Roshydromet national observation network can be formulated in the expanded form as follows:

—the acquisition of objective, reliable, and comparable information from the whole territory of the Russian Federation;

—the organization of the coordinated operation of the national observation network, regional environmental observation systems, and local observation systems to provide the desired completeness and reliability of environmental data, the comparability of these data throughout the country, and the optimization of using the ground-based, aviation, and space remote observation systems;

—scientific and technical support of regional and local monitoring systems;

—long-term observations of variations in the global and regional background levels;

—development of models for assessing and forecasting environmental conditions and the assessment of their applicability;

—performance of international treaties and the organization of coordinated operation of the national monitoring system with similar international systems.

Regional systems interact with the Roshydromet national observation network and, in accordance to the regulations, generalize the environmental pollution data obtained from the certain territory and transmit them to SDNEM.

The function of local observation systems is the control of the normalized parameters of negative effects. These systems also provide that the activity of technical and economic objects is consistent to the requirements of environmental permits. The conclusion that an object keeps the prescribed standards of emissions and discharges of pollutants is made on the base of the information obtained.

Data from local systems are acquired and analyzed by regional systems and, together with the data of regional and federal monitoring systems, are used both for compiling the ecological passports of territories and for solving the problems related to the operational response to significant changes in environmental conditions and pollution. The main functions of regional monitoring systems are the reception and analysis of information on the territory of the Russian Federation subject and the maintenance of the ecological passport of a territory; the revelation and estimation of contribution of pollution sources in the framework of the state environmental control; the assessment of efficiency of environmental measures; the ecological support of socioeconomic development of territories and informing the population.

Currently, the environmental quality management system is implemented in the Russian Federation subjects for air and water bodies. In the majority of cases the quality management is implemented at the enterprise level and includes the normalizing of emissions (discharges) of pollutants to the atmosphere (water bodies) and establishing the standards of the maximum permissible emission (discharge). Summary calculations of joint influence of the set of industrial sources on the air are provided in several big cities only. The influence of mobile sources of air pollution and the possible influence of several sources on a water body pollution are not taken into consideration.

Such practice has developed, in particular, due to the absence of efficient information exchange between different levels of NOS. For example, information about the regional background levels and the data of the pollutant transport simulation in the environment are needed to assess the impact of industrial objects. In turn, to fulfill the regional-level functions, data are needed on the pollution sources and their influence on the environment on the territory of the Russian Federation subject and on the regional background; also, the results of the modeling of transport and transformation of pollutants are required.

However, the integration of data is considerably complicated because each monitoring subsystem has its specific regulatory and methodical framework and its specific features of organization of observation programs, the use of observation instruments and methods, and methods of integration and comprehensive analysis of observational data. The problem is aggravated by the insufficient development of modern hierarchical systems of data processing, storage, and presentation in the area of environmental monitoring and control. As a result, in many cases the data of the state environmental monitoring do not allow identifying the source of excessive pollution and providing the valid quoting of emissions or discharges.

To ensure the necessary completeness and reliability of environmental data and their comparability on the whole country territory, the coordinated operation of the above observation systems should be organized. This may be done by the joint analysis and processing of all data received from the Roshydromet national observation network and regional and local monitoring systems, satellite data, outputs of numerical models, and other available data on a uniform technological basis. This means that the efforts should be focused on the development of the integrated system of national environmental monitoring.

KEY ISSUES OF THE DEVELOPMENT OF THE INTEGRATED ENVIRONMENTAL MONITORING SYSTEM

The use of environmental monitoring data as a practical tool of the state environmental policy requires the improvement of the legislative framework, the scientific-methodical base development, and the creation of high-quality observation networks.

One of the instruments for the implementation of the state environmental policy is the control of target indicators of environmental quality. In the Russian Federation the major indicator is the maximum permissible concentration (MPC). However, the current practice of using MPC as a target indicator is incorrect when the systematic multiple exceeding of MPC for a number of environmental pollutants is observed on the country territory. The fact of the chronic multiple exceeding of MPC indicates that this parameter has

not become a real ground for setting the management task of environmental quality improvement on the specific territory.

The management task can be set if a clearly measurable and achievable target indicator is defined for it, and the terms of the widespread achievement of this target indicator on the territory under control are specified. Moreover, the application of MPC is not constructive in long-term prospective as this indicator is mostly considered as a hygienic parameter, and its quantitative values are defined by health authorities and can vary depending on the current opinion what damage one or another chemical causes to the human health.

Some critical values of pollutant concentration established taking into account a set of factors could be used as target indicators instead of MPC. These factors include the actual levels of environmental object pollution, the presence of technical, economic, and financial opportunities for taking measures on the reduction of anthropogenic load, the acceptability of established quantitative target indicators for business and society, and, finally, the feasibility to reach the prescribed target indicator by the given moment of time. This certainly complicates the problem of the state control of environmental quality, but, at the same time, is a powerful stimulus for the development of integrated environmental monitoring systems.

The existing programs of environmental observations are formed taking into account the established standards for MPC of pollutants. At present in our country the list of MPC standards includes more than 600 pollutants. This list does not stress the national priorities as it is done, for example, in the EU countries. As a result, due to the limitedness of the instrumental monitoring potential, routine observations may cover only a small part of pollutants from the list of MPC standards. Therefore, it is reasonable to investigate the issue of the regulatory limitation of the list of pollutants which are routinely monitored in the national observation system. The federal list should be limited by the most widespread pollutants, and regional lists may be established for each separate region depending on its specific features.

Taking into account the huge size of our country, it is economically unreasonable to try to cover its territory with instrumental observations with the sufficient spatial resolution. Therefore, to assess environmental conditions, to substantiate economic feasibility, and to establish target indicators of the environmental pollution level taking into account the concrete features of territories, there is an urgent need in developing computer technologies for the analysis of observational data jointly with the results of simulations of pollutant transport models which take into consideration data on emissions and discharges.

To progress in this direction, the legalization is needed of the methods of summary calculations of the impact that enterprises and mobile sources of pollution make on the environment. These calculations should be done at the regional level taking into account data of background monitoring and data on the volumes of emissions and discharges. The development of high-quality local observation systems by the owners of enterprises could form the required information base for making management decisions at the regional level and could significantly reduce the state costs of the development of the environmental monitoring system. The content and volume of observation programs of local systems should depend on the category of the objects exerting negative impact on the environment and should be coordinated with the allowances for emission, discharge, and waste disposal.

Concerning the problems of the development of high-efficiency observation networks, it should be noted that almost no routine observations are conducted in the Russian Federation for some pollutants belonging to the priority indicators of environmental quality: surface ozone, particulate matter (PM_{10} and $PM_{2.5}$), and persistent organic pollutants (dioxins and furans) which, according to the latest statements of the World Health Organization, exert the most dangerous influence on the human health.

In the current observation programs, there are many shortcomings in the sampling because the operating systems of air monitoring were created to reveal long-term trends in pollution but not high peak values.

The comparison of monitoring results based on discrete observations with the data of continuous monitoring corroborates the variable nature of pollution episodes which cannot be detected successfully from discrete sampling data. The frequency of measurements of three or four times a day is insufficient in the everyday air quality control, especially during the periods of adverse meteorological conditions.

SOME APPROACHES TO THE ORGANIZATION OF THE INTEGRATED ENVIRONMENTAL MONITORING SYSTEM OPERATION

The present paper considers the environmental pollution monitoring as a counteraction to the anthropogenic load on the environment carried out by monitoring stakeholders and by different means that are organized on the regional base and according to the type of actions taken. The grouping of means on the regional base implies that the means intended for the implementation of protective actions in the limits of the respective region are united into the single set. The grouping of means based on the type of actions

taken (special monitoring) presupposes that sets for taking certain protective measures are created both at the federal and regional levels.

From the technological point of view, the integrated environmental monitoring system is considered as "the system of systems" whose components consist of present and future monitoring systems of different levels used for different purposes which provide the reception of initial data, their acquisition, processing and modeling, and the output of information products. The observation networks keep their functions and departmental affiliation.

In the framework of such concept, it is reasonable to use the network-centric methods of management for constructing the integrated monitoring system. The network-centric features of monitoring organization are expressed in the fact that each component of "the system of systems" (a monitoring stakeholder) may have its specific objectives, tasks, and strategies which may differ both in terms of algorithms and actual technological solutions [10]. To ensure their operation, the man-machine object which could control this process is created in each component. Let us call such object "an agent" and consider it as a single unit not discriminating between the functions performed by the man (or group) and computer (or subsystem of information-measuring tools).

To implement its functions, the agent should have at least the following capabilities: to have the clearly formulated goal of operation; to operate in accordance with the rules and algorithms set in the process of its construction; to have the database containing needed information; to be able to use the concerning monitoring results and to respond to them; to take initiative; to send and receive messages from other agents and to interact with them.

In essence, the agent is a subsystem that makes or supports decisions. Such subsystems are united into the single "system of systems." On the one hand, each agent operates rather autonomously, i.e., it defines the type of the impact by itself; on the other hand, it is a component of the hierarchic management system and, in view of this, the actions of agents should be synchronized in time and agreed following the impact type.

The Roshydromet state observation network is of primary importance in the integrated system. It is responsible for the early detection of unfavorable changes in abiotic factors of the environment (air, surface inland water, soil, marine environment) before they lead to the economic damage and ecosystem destabilization and cause damage to the population health as a result of environmental pollution caused by anthropogenic activities. The Roshydromet monitoring system is declared a fundamental (base) part of the integrated system which defines the directions of the development of software, information, and technical tools.

Common technological elements of observation systems of all stakeholders of the environmental pollution monitoring are observation networks and the systems of data acquisition, processing, and presentation.

Observation networks provide the reception of actual data on the controlled parameters proceeding from the scales (global, regional, territorial, or local) and dynamics of possible changes (for example, the discreteness of measurements).

The priority direction of the development of observation networks is the development and implementation of methods and tools of automatic observations of environmental pollution both at the stationary and mobile base.

The experience of Roshydromet in using mobile automatic observation systems is of interest. In 2015, the trial operation of the mobile automatic station of water pollution control was carried out. Its results revealed that mobile stations can be used successfully as a moveable lower measuring link of automatic systems for the short-term (from 1 week to 2–3 months) monitoring of surface water quality. The trial operation revealed the unauthorized sewage discharges falling on weekends and the volley of sewage leading to the considerable water level rise in a river and to variations in its qualitative composition [6].

Another essential improvement of observation network operation efficiency is the development of remote sensing methods. The remote sensing data supplementing the data of instrumental observations collected using the surface monitoring may be of great importance for assessing and forecasting the spatial scales of pollution. At the federal level the modeling tools should be developed which allow extrapolating the monitoring data to the areas where observational data are absent (in order to cover the whole territory).

The observation network of the integrated monitoring system should be rather flexible to respond to new priorities and should be able to present the needed information for answering the most important questions about the dynamics and reasons for variations in environmental pollution. The flexibility of the system should be manifested relative to the measured environmental parameters (new substances and new requirements), measurement conditions (other natural environments), and new tasks.

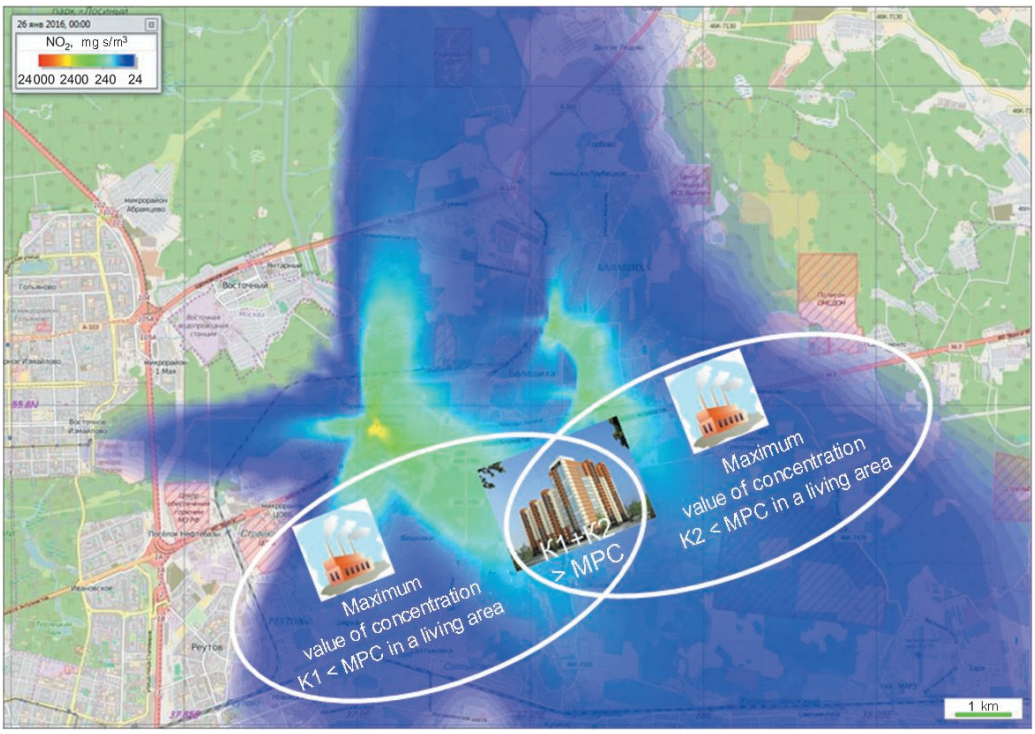

Fig. 2. An example of presentation of the data of computation of integral concentration of pollutants from several sources in the urban municipal unit.

An example of the emergence of new tasks is Roshydromet works on the monitoring of the Baikal natural territory (hereinafter, BNT). The survey of BNT [5] revealed that samples contained the significant number of persistent organic pollutants (POP) which were not produced and used on the territory of the Russian Federation or USSR (oxychlordane, mirex, and trans-nonachlor pesticides). Despite the absence of any evidence on the use of toxaphene-type pesticides (polychloropinene and polychlorocamphene) on BNT or in the neighboring areas, the compounds of this group of POP included to the Stockholm Convention list were detected in all BNT ecosystems. The concentration of this toxicant in the organisms of some fish species exceeds the concentration of metabolites of such well-known pesticide as DDT.

The monitoring of BNT revealed that the surface and deep waters of Lake Baikal are significantly polluted with PCB congeners and the concentration of these groups of toxicants is not reduced; moreover, it exceeds the levels registered by the researchers in the late 20th century.

The obtained data require the revision of the current programs of Lake Baikal monitoring.

The operation of the integrated monitoring system requires the preparation and implementation of technical regulations for the organization of regional and local observation systems and methodical documents including the requirements to the order of conduction of observations (typical orders) at the regional and local levels and to the use of methods and instruments of observations. The technical regulations for the organization of observations should include the orders of interaction between the observation systems of different levels and the regulations and forms (protocols) of data presentation and dissemination.

The systems of data acquisition, processing, and presentation are intended to ensure the required completeness and reliability of data on environmental pollution levels and their comparability on the entire territory of the country. This problem can be solved only in the presence of necessary organizational fundamentals and procedures of data integration including the creation of the universal standard of data description (metadata), the control of reception and quality of data, and the development of data assimilation methods using the numerical models of the environment. The development of regional information systems based on the local systems requires the development of methods of integration of observational data with the emission and discharge inventories using the pollutant transport models.

If the operational data on air pollution, meteorological data, and the data on the parameters of emissions of enterprises on the given municipal territory are available in the information system, the pollutant transport

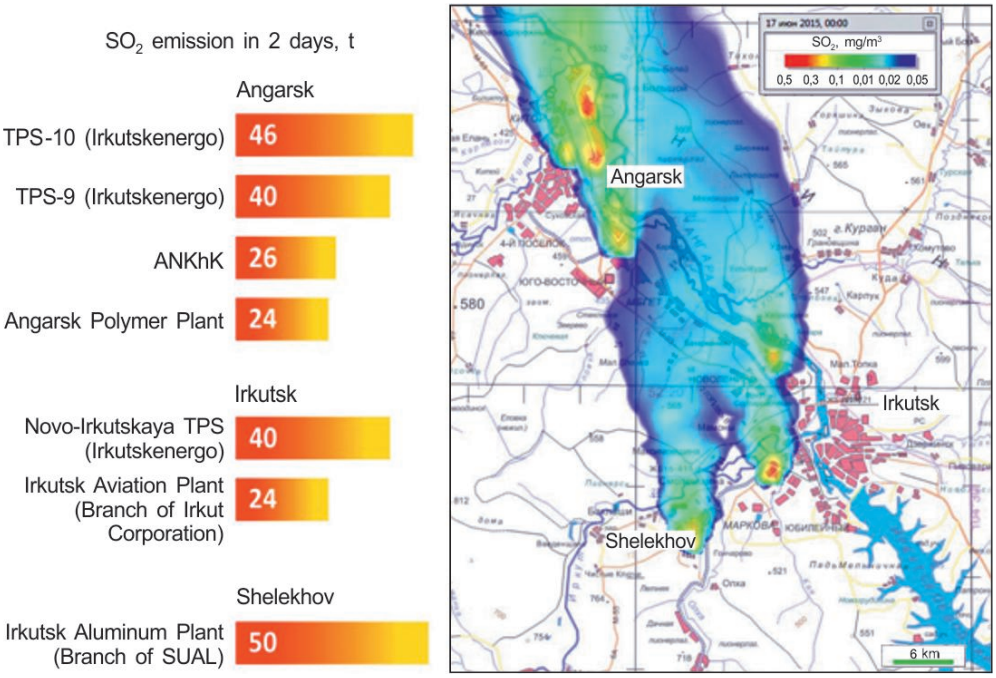

Fig. 3. The numerical forecast of environmental pollution (an example of simulation of SO_2 transport from a number of enterprises in Irkutsk, Angarsk, and Shelekhov on June 15–16, 2015; the simulation is provided by Roshydromet's Taifun Research and Production Association).

models can be used to prepare the maps of pollution levels specifying the areas where the MPC of pollutants for living areas is exceeded that indicates the need in measures on emission reduction (Fig. 2).

The presented example proves that the simulations by the numerical model of pollutant transport in the atmosphere can be used in the real time. These simulations take into account data on the emission parameters of the main sources of pollution for the whole municipal territory and are used for the operational control of emission reduction during the period of adverse meteorological conditions or for making a decision on the placement of a new industrial object.

At the regional scale the environmental pollution monitoring system can be used for assessing and forecasting air pollution in the areas of big industrial agglomerations (Fig. 3).

The observations in the framework of the BNT monitoring system are carried out in the continuous mode using automatic stations. This allows the real-time monitoring of pollutant concentration in the air in the areas of location of stations and the assessment of parameters of emission sources (industrial enterprises) which make the basic contribution to air pollution in the region under control. The concentrations of pollutants are computed for all territories of the region under control including the areas where the instrumental observations of air pollution are not carried out. The computations are based on operational data on the parameters of pollution sources, on meteorological data on the atmospheric surface layer conditions, and on the computer models of pollutant transport in the atmosphere. In case of weather changes in the region, the forecast of possible concentration of pollutants in the air is also computed with models if the volumes of pollutant emission from the main sources are known.

CONCLUSIONS

It is demonstrated in "The Concept of Improvement of Environmental Pollution Monitoring System Taking into Account the Concretization of Tasks of Federal, Regional, and Local Levels for 2016–2025" prepared by Roshydromet that the preparation and implementation of the integrated monitoring strategy is one of the priority directions which creates conditions for the coordination of activities in the framework of different specialized networks and monitoring systems and more efficiently implements the state environmental policy based on the objective data.

The necessary condition for the implementation of the proposed concept is the organization of the national environmental monitoring system based on integrated observations. The operation of the system should be implemented using the modern approaches some of which are provided in the present paper. The stepwise development of the integrated monitoring system should be implemented by the primary modernization and development of regional and local observation systems in the regions with the most unfavorable environmental conditions or on the territories which require the preservation of their natural uniqueness.

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