GEOINFORMATION APPROACH TO THE DEVELOPMENT OF AUTOMATED INFORMATION SYSTEMS OF REGIONAL AND LOCAL MONITORING OF ATMOSPHERIC POLLUTANTS

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The general principles of application of geoinformation technology to the solution of the problems in ecological monitoring of the atmosphere on regional and local scales are considered. The structure and functional capabilities of the geoinformation system intended to solve this class of problems are discussed. The principles of application of geoinformation technology to processing of the data of lidar sounding of the atmosphere under anthropogenic pollution conditions are also considered.

1. INTRODUCTION

In the period of scientific–technical progress anthropogenic impacts on the environment are getting progressively stronger and large–scale, while the environment itself is beginning to lose the unique property of self–purification. By now especially unfavourable ecological situation has been formed in the territory of Russia (particularly, in large industrial centers) owing to a number of reasons.

First, in the last decades in spite of the essential growth of ecologically dangerous production the problems of organizing the ecological monitoring (including local areas like an industrial center and a city) and the questions of ecological expert examination of the newly built objects of the national economy received serious attention only beginning in the 1980's when the law of the environmental protection was ratified in the USSR. And so it was natural since that time that the numerous publications on this subject has evolved, including fundamental papers (see, for example, Refs. 1–8) devoted to various aspects of ecological monitoring and environmental protection.

Second, to date the problems of spread and evolution of pollutants in the atmosphere as well as the influence of the existing and newly built industrial complexes on the atmospheric pollution have still received only insufficient study.

Third, up to now the reliable and efficient software needed for real–time pooling and processing of a large body of diverse ecologo–physical information obtained from different measuring systems and for modeling, diagnostics, and forecast of the atmospheric processes and the pollution parameters for the current and future states of the atmosphere to be estimated is lacking.

Fourth, our country has been falling behind (from the world level) in the field of development of modern automated systems of ecological monitoring intended for routine monitoring of atmospheric pollution of local territories and routine forecast of air pollution level. We know only one home–made system of this kind (ANKOS–AG system, see Ref. 9).

All things considered, in view of the large scales of the atmospheric pollution and the enormous economical damage resulting from daily activities of ecologically dirty production as well as from large industrial accidents and catastrophes (for example, in the Chernobyl' atomic power station) a broad spectrum of scientific and technical elaborations aimed at the development of an efficient system of environmental protection in Russia and at minimization of the environmental effect of man's economic activity is planned as part of the federal special–purpose integrated scientific–research program ECOLOGICAL SAFETY OF RUSSIA (1993–1995) (see Ref. 10). Among these elaborations is the development of the Unified State System of Ecological Monitoring (USSEM) that includes different systems of regional and local monitoring.

In our opinion, an automated system of ecological monitoring of local areas (ASEMLA) must be the most important element of the USSEM. This system, being developed on the basis of the advanced hardware and software, is to not only supplement and improve (at the expense of the development of new means of monitoring) the existing system of environmental monitoring formed by the network of ground–based stationary posts (of the Post–1 and Post–2 types) but also to provide the most comprehensive and objective real–time estimate and forecast of the level of environmental pollution on local and regional scales and on the basis of pertinent prognostic information to evaluate best ways of salvaging our environment.

In the design and development of the ASEMLA there are a number of important scientific–technical problems that must be solved for effective use of this system in routine ecological monitoring. These problems are to cover two directions of scientific applied researches. One of them centers around the development of the modern hardware of routine monitoring of the pollution of local air basin (a city or an industrial center). The second centers around the development of an automated information system (AIS) that must provide the intellectual support of the solutions of different concrete problems and, in particular, the problem of the local ecological diagnostics and ecological prediction of the level of the environmental pollution.

At present the active optical methods and especially methods and systems of laser sounding of the atmosphere are the most promising means of monitoring of the ecological state of air basin.[7,8] Unlike the existing methods[3,9] these methods yield the real–time data, with high spatiotemporal resolution, about the wide complex

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of the physical parameters of the atmosphere including the concentration of aerosol–gaseous pollutants of anthropogenic origin. They also provide a means for routine remote monitoring of the composition and amount of various pollutants emitted by point sources.

To process the data of ecological monitoring (including lidar monitoring), we formulated the concept of the development of the AIS based on the ideas and methods of geoinformatics being increasingly employed for solving the problems of environmental monitoring and rational exploitation of natural resources.

2. STATE AND DEVELOPMENT OF THE GEOINFORMATION TECHNOLOGY FOR SOLVING THE PROBLEMS OF ECOLOGICAL MONITORING

As a scientific lead geoinformatics was formed at interfaces of geography, cartography, and informatics proper. In the context of informatics the set of principles and methods is pooled to form the geoinformation technology or the technology of geoinformation systems (GIS's).

This is a computer technology of integrated processing of the spatially distributed information and includes the input, storage, conversion, analysis, modeling, forecast, and visual representation of the data about natural processes and fields that evolve in space and time.

The geoinformation technology goes back to the middle of the 60's when the Canada GIS was developed, which is one of the most effective systems of processing of large arrays of spatial information yet devised. In the 60's these systems were developed in the USA and Canada. As a rule, they were developed to order and tailored to the concrete user. The two–volume monograph,[11] published by the International Geographical Union (IGU) in 1972 summarized the development of the geoinformation technology in this period and contained systematic presentation of technical and methodological aspects of the development of the GIS's.

In the 70's the GIS technology begins to develop intensively in Europe, namely, in Sweden, Germany, Netherlands, France, etc. During the period under review the emphasis was on the development of the software of the GIS's. The universal general–purpose systems that needed no modifications on the user's part began to appear. In 1980 the IGU commission published the three–volume reference book[12] that contained specifications of all the programs being developed by that time and programs embracing all divisions of software and development and operation of the geoinformation systems. In the 80's the progress of methods of design and software and hardware for these systems was primarily due to a considerable advance in computing machinery, in particular, a wide distribution of mini– and microcomputers.

Analysis of a wide variety of the existing foreign GIS's (see Refs. 13–16) shows that the geoinformation technology received the greatest recognition in solving the problems centered around natural resource estimate and management when information may be effectively parametrized and represented in the cartographic form. It is explained by a number of reasons including the factors of the historical development of the geoinformation technology. The matter is that these systems were preceded by the systems of automated cartography, and so the geoinformation technology first gained acceptance in the fields with traditional cartographical data representation. In these systems the geographical objects are represented in a two–dimensional form that could be simply realized in mapping.

At the same time in solving numerous ecological problems centered around atmospheric monitoring when the processes and objects under study have a three–dimensional character neglect of one coordinate essentially distorts the results, and so the considerable potential of the geoinformation technology has yet to be realized. One reason of this is the lack of the methods describing the complicated atmospheric processes occurring near the ground and the lack of the integrated mathematical models for estimating the spatial distribution and evolution of pollutants entering the atmosphere from various sources of pollution.

At the same time developing the means of monitoring the atmospheric pollution (and primarily systems of laser sensing), refined knowledge of modeling of atmospheric processes under conditions of anthropogenic influence on the environment, the availability of the reach potential of the geoinformation technology, and practical requirements on the part of the services of ecological monitoring and environmental protection allow us to include in the agenda the question of the concepts of development and structure of the special–purpose systems for ecological monitoring of air basin in local territories.

3. PRINCIPLES OF DEVELOPMENT OF THE REGIONAL GEOINFORMATION SYSTEM OF ATMOSPHERIC POLLUTION MONITORING

Ecological monitoring of the atmosphere is a continuous process of monitoring the environmental pollution level in the region under study, recording and processing of the measurement data, real–time estimate and forecast of the level of pollution on their basis, and representation of the obtained results in the form that is convenient for the user. It requires for realization the corresponding software and the development of the modern automated information system capable of the effective intellectual support for solving these problems.

An analysis of present researches on this subject shows that, in spite of a number of existing scientific–methodical publications,[17–19] a standard automated system of ecological monitoring has yet to be developed (except for the ASKZA–AG experimental model). As to the ASKZA–AG system comprising an information–computer complex intended for real–time estimate of the level of atmospheric pollution in cities, it has limiting capabilities and is inconsistent in full measure with present–day requirements.

These state–of–the–art elaborations in the field of development of special–purpose automated information systems (AIS) were considered by us when we developed the basic principles of design of the regional system of atmospheric pollution monitoring.

In our opinion, this system is to implement the ideas and methods of the geoinformation technology. It must fit the following requirements:

1) geoinformation system must have a regional character and reflect the peculiarities of evolution of the atmospheric and ecological processes in the inspected physico–geographical region;

2) the GIS under development must have opportunities for integrating and processing diverse information from various measuring systems (contact and remote ones);

3) software for solving the problems of atmospheric monitoring must incorporate a complex of the databases

comprising the data about the atmospheric background (including the data on the concentration of harmful pollutants) and pollution sources as well as a certain mathematical polygon that includes a set of different models (hydrodynamic, physico–statistic, and photochemical) needed for objective estimate of the pollution level and its evolution in the inspected area;

4) geoinformation system of regional ecological monitoring of the atmosphere must have a ramified configuration with a computer network that provides on–line interface of a central working station, located in the data processing center, with remote measuring systems;

5) system architecture of the regional GIS of atmospheric monitoring must provide the multiple access of the users to the system resources, the opportunity of high–performance data processing, the solution of object–oriented problems, and the modular principle of structure of the geoinformation system to permit unobstructed subsequent integration of supplemental information and program modules;

6) architecture of the GIS of the regional ecological monitoring of the atmosphere must incorporate the box of expert systems (automated decision–making subsystem) that provides the powerful intellectual support for the solution of numerous problems centered around an analysis of the severe ecological situations, estimate of possible consequences of various scenarios of their evolution, and making substantiated decisions to minimize their severe impact on the population and environment;

7) this system must be capable of integrating in the information system of a higher level (up to a state or even a global level).

4. STRUCTURE AND MAIN FUNCTIONS OF THE REGIONAL GEOINFORMATION SYSTEM OF ECOLOGICAL MONITORING OF THE ATMOSPHERE

As mentioned above, the ramified configuration is one of the main requirements for the structure of the given system. Figure 1 shows that the central element of this configuration is a working station (of the YAX, HP Apollo, or Sun Microsystems type) that is connected with a number of microcomputers by means of a computer–information network. In its turn, these microcomputers are jointed with the measuring systems and sensors. The microcomputers of a lower level provide the collection of the measurement results in the inspected area, their conversion and preliminary processing. Then these data enter the working station for storage and processing of a higher level.

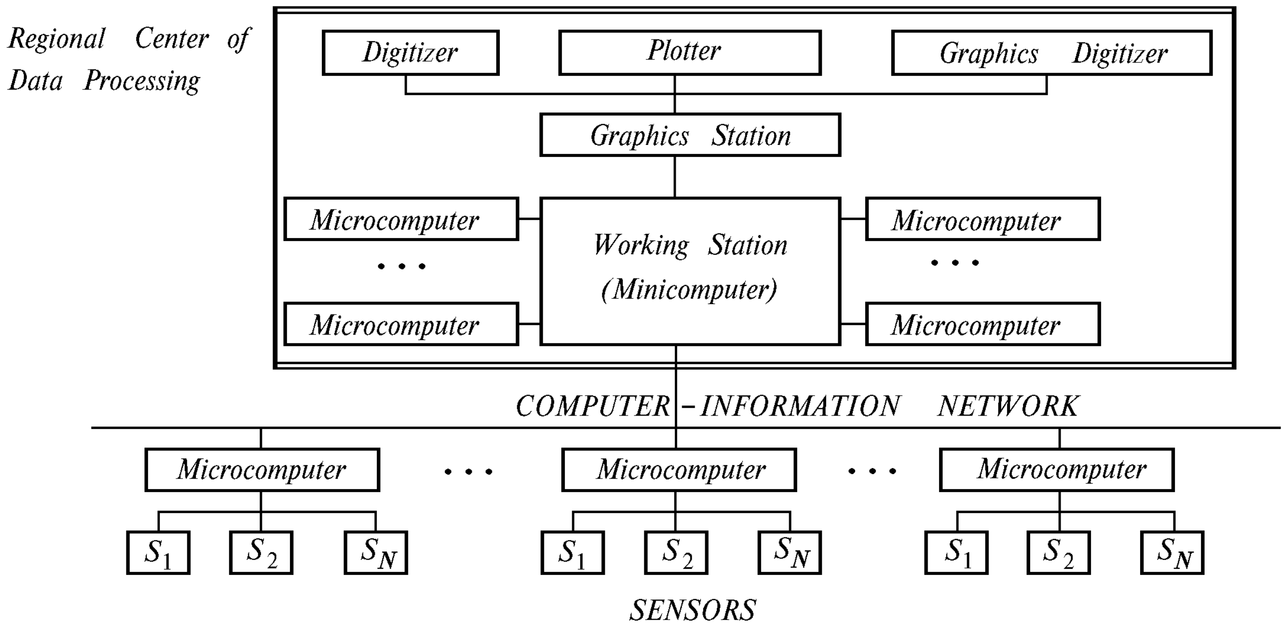

FIG. 1. Structure of the regional geoinformation system of ecological monitoring of the atmosphere.

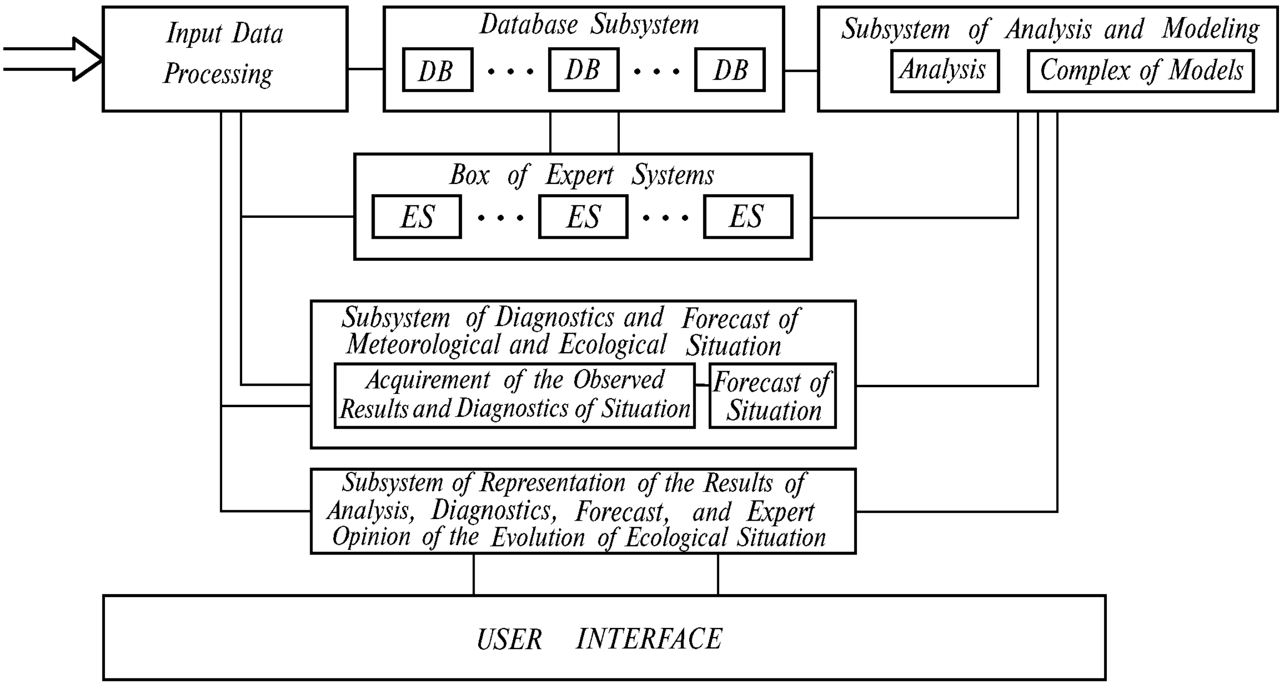

FIG. 2. Block diagram of the regional geoinformation system of ecological monitoring of the atmosphere.

We consider that the working station must be in a regional center of environmental monitoring or in an institution performing analogous functions. The interactive multiaccess regime on the basis of a local computer network provides the access to the information acquired in the course of ecological monitoring of the atmosphere. A graphics station on a computer microplatform is supposed to be placed at one node of the local network, which would provide all set of the input functions for cartographical and visual information. It also enables us to have the "hard" copies of the cartographical images using a plotter or analogous devices.

Now we consider the main functions that the regional geoinformation system must realize proceeding from the formulated problems. Figure 2 depicts the block diagram of the system. As seen from the figure, it consists of a number of modules (subsystems) each performs a specific set of functions.

1. *Subsystem of input data processing provides:*

– spatial coding, editing, conversion, and recording of the data of ecological monitoring of the atmosphere in required formats;

– interactive input, editing, and digitizing of cartographical data;

– interactive input, editing, and operation of images of aerosol formations (smoke plumes, etc.), meteorological objects and phenomena, and underlying surface.

2. *Subsystem of the information databases provides:*

– data archiving and effective access to the spatially distributed information about the physical state of the atmosphere and the underlying surface, acquired during the course of monitoring, as well as to the data about the sources of atmospheric pollution (their locations, strengths, composition of emitted pollutants, etc.);

– organizing the effective manipulation with the spatial data (conversion of the raster format to the vector one and back, data pooling, scaling, projections, and transformation of systems of coordinates, changing the spatial elements, overlapping (cartographical image coincidence), etc.).

3. *Subsystem of analysis and modeling provides:*

– multidimensional statistical analysis of ecologo–physical information from the spatially distributed sensors;

– imitation modeling based on the complex of models that characterize the formation and evolution of the ecological state of the atmosphere on the regional level;

– cartographical analysis and modeling of the atmospheric spatial processes and structures.

4. *Subsystem of solving the problems in atmospheric ecological monitoring provides:*

– acquirement of input information and experimental estimate of the level of the current pollution of the atmosphere;

– short–, medium–, and extended–range forecast of the evolution of the atmospheric pollutants based on the complex of prognostic (hydrodynamic, physico–statistical, and photochemical) models;

– evaluation of the error in the estimate of the level of atmospheric pollution using the data of independent observations.

5. *Subsystem of logical analysis and expert opinion (box of expert systems) provides:*

– organization of storage and effective access to the existing knowledge in the field of research of atmospheric and ecological processes that define the level and evolution of atmospheric pollution;

– acquiring the new knowledge using the expert opinion and friendly interface;

– acquiring the new knowledge as well as modification and extension of the available knowledge;

– intellectual support of the procedures of data processing and analysis of the diverse input information, diagnostics, and forecast of atmospheric pollution as well as making routine decisions providing safety of population in case of severe ecological situation.

6. *Subsystem of data representation provides:*

– visualization the results of analysis, modeling, diagnostics, and forecast of the physical characteristics and pollutants of the atmosphere;

– organizing the output of the graphical and thematic cartographical information;

– making reports and organizing the output of digital and textual information.

Thus the above–proposed structure and functions of the regional geoinformation system provide the effective solution of the problems in integrated ecological monitoring of the atmosphere and at a later time the underlying surface within industrial zone or in large industrial center.

5. SOME ASPECTS OF APPLICATION OF THE GEOINFORMATION TECHNOLOGY TO THE DEVELOPMENT OF THE AUTOMATED SYSTEM OF LASER ECOLOGICAL MONITORING OF THE AIR BASIN OF AN INDUSTRIAL CENTER

References 7 and 8 report that the problem in ecological monitoring of air basin in local areas (for example, industrial center) cannot be successfully solved without the automated systems of laser sounding of the atmosphere. These systems provide the data with high spatial resolution about the state and dynamics of the atmospheric air pollution in the boundary layer.

It is natural that in the course of ecological monitoring with the use of the systems of laser sounding a number of difficulties emerge connected with intellectual support of the solution of the arising applied problems (measurement data processing, estimate of the level of local pollution, objective display of the processes and fields under study). The methods of geoinformation technology can help to overcome these difficulties.

It should be emphasized that application of this technology to the system of laser monitoring of atmospheric pollution is a particular case of a more general concept based on the application of the principles and methods of geoinformatics to the systems of ecological monitoring. In view of the 3–D (rather than 2–D) estimate of the atmospheric pollution and high spatial resolution of lidar data, the local GIS of ecological monitoring must additionally have not only a cartographical information base but also means of 3–D display of the processes and fields under study. Since the spatiotemporal resolution of the systems of laser sounding of the atmosphere (in case of ground–based systems) corresponds to the processes of micro– and meso–scales, the cartographical base must comprise the "layers" that provide thematic mapping on 1:2 000 to 1:2 000 000 scales. In addition, to adequately estimate the level of the atmospheric pollution, the local GIS must receive real–time synoptical information and the data about the meso–meteorological processes on corresponding scale.

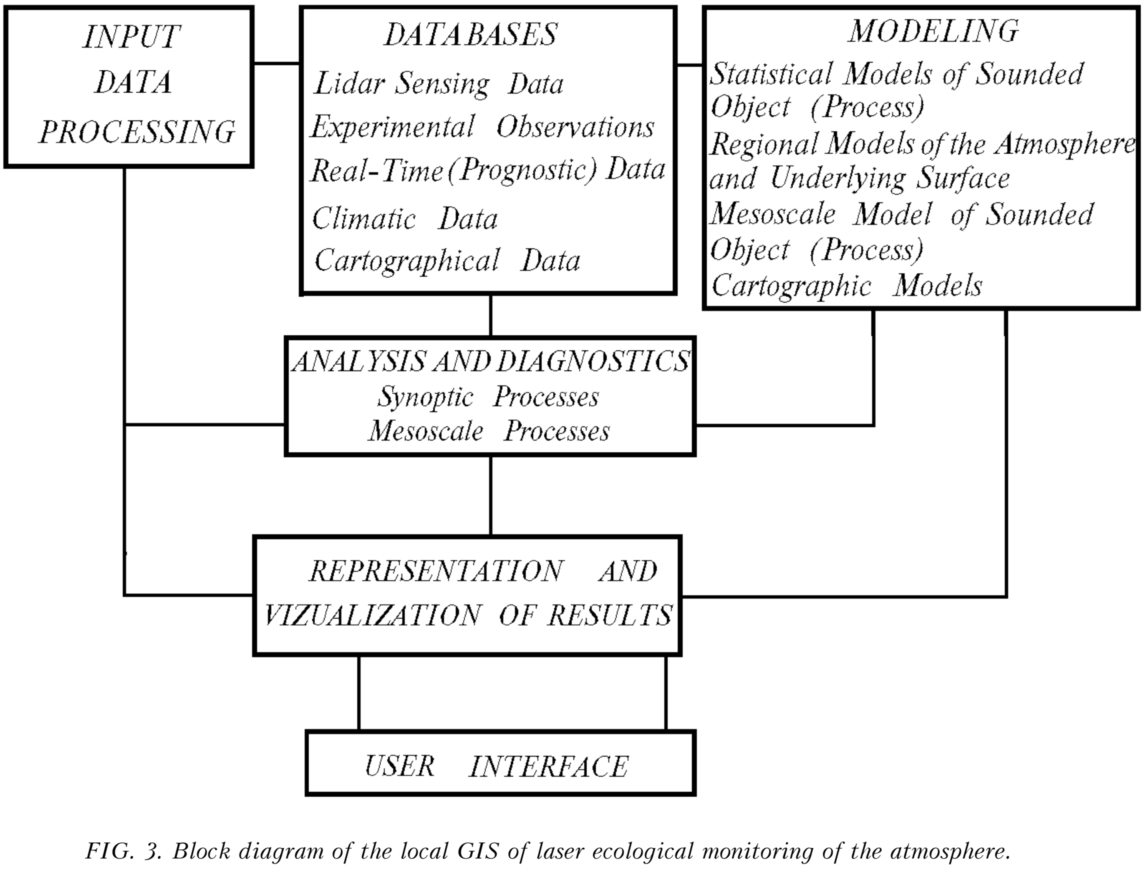

FIG. 3. Block diagram of the local GIS of laser ecological monitoring of the atmosphere.

Figure 3 shows the structure of the geoinformation system of local ecological monitoring that on account of the foregoing must comprise such subsystems:

1. *Subsystem of input data processing provides:*

– interactive input, editing, and conversion of the cartographical information in digital one;

– spatial coding, conversion, and recording of experimental data, obtained with the use of lidar and other systems of sounding and preliminary processed, in required format;

– input and editing of the routine and prognostic information that enters through channels of communication from other sources.

2. *Subsystem of database* is the key subsystem and contains the following databases: cartographical, lidar sounding, experimental observations, routine (prognostic) information, climatic data, etc. This subsystem executes conversion, archiving, and organizing the effective access to spatially distributed information about the concentration of pollutants as well as about climatic, current, and future states of the atmosphere and the underlying surface.

3. *Subsystem of modeling* provides a system character of the experimental data analysis and contains two complexes of mathematical models (statistical and imitational) intended to study the stochastic properties and physical laws defining the dynamics of atmospheric pollution and the complex of special models for cartographical analysis, modeling, and 3–D data conversion (pooling, scaling, projections, transformation of coordinate systems, etc.).

4. *Subsystem of diagnostics* is intended for acquirement of the input information transmitted through the communicating channels and collected from the other sources, analysis of this information, and diagnostics of the atmospheric state and the atmospheric pollution level in the inspected area (in the absence of the regional model of the atmosphere and meso–scale model of pollution, diagnostics can be carried out by synoptical methods).

5. *Subsystem of data representation provides:*

– visualizing the results of analysis, modeling, and diagnostics of the level of atmospheric pollution;

– output of the graphical and thematical cartographical information;

– presentation of reports and output of the textual information.

The user interface incorporated into the GIS provides the interactive regime of operation with the GIS.

The hardware of the local GIS of laser ecological monitoring must comprise, along with an IBM PC/AT–386/486 with graphical display, printer, scanner, digitizer, and plotter.

In conclusion we note that in case of further development of works in this direction this variant of the GIS provides a basis for the development of the systems of now–cast of the state of the atmosphere and the underlying surface on the basis of the remote sensing means including lidars, sodars, radars, etc.

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