GEOINFORMATION PRINCIPLES AND REMOTE METHODS OF REGIONAL GEO–ECOLOGICAL MONITORING

V.B. Malyshev, V.M. Mazikov, V.V. Egorov, M.A. Ermoshkina, N.S. Ozerov, and E.V. Smirnova

Institute of Geography of the Russian Academy of Sciences, Moskow
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Principles of organization of regional geographical information systems (GIS's) are considered by the example of the Aral region. It is shown that the GIS is the most important element of geo–ecological monitoring representing a specialized hierarchical system of repeated multistep observations. The results are given of the analysis of airborne spectral survey of the Aral coastal zone and of model calculations of the dynamics of the Aral water plane considered as the elements of the GIS information content and monitoring procedures.

At present the rates, scales, and consequences of the anthropogeneously and technogeneously stimulated changes of the geo–ecological situation requires the application of the routine methods of acquisition, processing, and analysis of different kinds of geo–ecological data, their systematization, and elaboration of the scientifically substantiated recommendations with respect to the rational exploitation of the nature and the environmental protection.

This point calls for the practical implementation of the specialized system of monitoring of these processes. In the process of development and implementation of this system it is necessary to apply the following principles:

First, the data obtained in the course of operation of the monitoring system must be processed and analyzed to provide monitoring and estimation of the states and the prediction of the change in the components of the environment.

Second, the monitoring system must provide the acquisition, processing, systematization, and analysis of the data of different scale obtained from aerospace means and ground–based measurements performed with the given periodicity in combination with geographical knowledge and thematic archive materials.

Third, the system must have the possibilities of the formation of the spatially distributed data bank and of the manipulation with the multilayer heterogeneous data.

These principles give the unique quality to the monitoring system, while its objectives define it as a specialized service. Therefore, the geo–ecological monitoring seems to be a specialized hierarchical system of repeated multistep observations oriented toward monitoring and estimation of the environmental state and toward the prediction of its changes and the elaboration of the recommendations with respect to the rational exploitation of the nature.

Monitoring including the use of the remote means makes it possible to obtain data over a short period of time in large territories thereby providing the solution of the problem of estimation and monitoring of the state from a local scale (city, district) to the regional one (region, republic, state or large physico–geographical region).

A number of principal conceptual points of the monitoring were formulated by Izrael' and Gerasimov.[1–3] Into the content and problems of monitoring of anthropogeneous changes of the environment Izrael' includes the following: (1) monitoring of the influencing factors and the environmental states, (2) prediction of the states of the biosphere, and (3) estimation of tendencies of evolution of the biosphere.

The concrete definition of the problems of anthropogeneous monitoring requires the determination of real objects and the methods of its realization. In the paper devoted to the scientific principles of modern monitoring of the environment Gerasimov suggested to separate monitoring into three principal steps or chapters, i.e., bio–ecological, geo–ecological, and biospheric. The general criteria of such a separation were the differences in the observed objects and influencing factors. In the process of implementation of all blocks and directions of monitoring and especially of development of regional and global monitoring, the state must be estimated both by individual parameters and indices and by integral criteria and characteristics. The integral criteria, particularly the remote aerospace data, play a special role in the estimation of large territorial units and complex natural–anthropogeneous systems.

The immediate problems appear in the process of design and development of the system of geo–ecological monitoring, i.e., the organization of different kinds of data into the corresponding spatially distributed structure and the creation of the spatiostructural model of the territory. These problems as well as the problem of the structural organization of the entire monitoring system are most effectively solved on the basis of the computer geographical information systems (GIS's).

This direction is being successfully and intensively developed abroad. In our country it has been developed in the last few years. For example, in 1985 a specialized geoinformation system was organized on the basis of the FAO database. The aims of this system were the analysis and recommendations with respect to the global and regional policy in the field of agriculture and the study of the growth of population and formation of the deserts.

However, the problem of the geoinformation–structural approach has its own peculiarities and requires the solution of a number of fundamental problems. First of all, these problems are connected with the peculiarities of different kinds of information belonging to different departments, i.e., geographical, statistical, and funded data. Second, they are connected with the necessity of structural organization and systematization of data and with the use of geographical knowledge in the form of territorial models and expert systems.

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We solved some of the above–enumerated problems in the integrated study of the Near–Aral territory with the aim of formation of the unified structure of the regional multipurpose geoinformation system on the basis of the application of remote methods. The system includes four main subsystems.

The first subsystem is the software of the database management system and provides the accumulation, storage, structural distribution, and manipulation with its different information layers. Operation of this subsystem is provided by the EPPL[7] (Environmental Planning and Programming Language) program package.

The second subsystem provides the selection and input of the thematic geographical data into the database, their system analysis, creation of the spatiostructural territorial model which is the basis for the formation of the unified geoinformation system (UGIS).

The third subsystem involves database and acquisition, processing, and analysis of the ground–based and remote data and estimate of the current values of the geosystem components.

The fourth subsystem is destined for the development and implementation of the models for estimation of the parameters of the geosystem states, modeling of the dynamic processes, and prediction of their evolution.

The proposed structure provides the unity of the system as a whole, the interconnection, and active operation of the above–indicated subsystems. The UGIS makes it possible to connect the thematic geographical information and aerospace data with spatially distributed quantitative and qualitative (biogeophysical, geochemical, etc.) data, provides the routine analysis of the data and the possibility of modeling on the basis of the available database. The system provides for the accumulation of data of different scale obtained with the given periodicity by means of the remote aerospace measurements in combination with the ground–based geographical investigations and the thematic archive data.

The territorial orientation of the study determines the basic parameters of the information system, i.e., the spatial resolution (two–dimensional size and types of the units of data acquisition), the scales of properties and relations (the dimension of the considered geosystems), the metric scales of the output cartographic documentation for implementation of monitoring.

In the integrated study of the territory of the Near–Aral region we solved the following problems:

– The thematic cartographic data which characterize the state of geosystems of the region, were acquired and analyzed, and the numerical database of the complex of thematic data and ground–based observations was formed.

– The matrix of the composition and state of the geosystem components was formed by means of overlay of the thematic charts, their superposition, and structure analysis of the combinations of the parameters of the geosystem state. Each cell of the obtained numerical matrix contained four informational layers about the soil cover, the salinization chemism, the salinization degree, and the geomorphology. The set of combinations of the geosystem components made it possible to pool the territories into classes on the basis of the homogeneity of qualitative–quantitative parameters of the state and the character of their interaction. The matrix was the basis for creation of a spatiostructural territorial model.

The spatiostructural territorial model is the result of the regional classification on the basis of the integrated system analysis of the multilayer information and reflects the degree of homogeneity and the character of interaction of the geosystem components. The territorial model is the basic block in the formation of the multipurpose geoinformation system of geo–ecological monitoring and is used for organization of the structure of acquisition of different kinds of data.

The network of the airborne route spectral observations was formed on the basis of the spatiostructural model. According to this network, measurements of the spectral characteristics of the geosystem classes were carried out from onboard the YAK–40 aircraft–laboratory by means of the spectral instrumentation complex. The instrumentation complex was capable of obtaining spectral and TV data along the measurement route in the regime of continuous spectral scanning in 0.4 s with 1 nm spectral resolution in the 0.4–0.85 μm wavelength range.

The problem of classification is of prime importance in estimation of the geo–ecological state of the territory and elaboration of the local spatiostructural model using the remote data. The degree of the structural homogeneity is one of the main parameters for solving the problem. It is estimated on the basis of the analysis of the amplitude–frequency characteristics of spectral data taking the Fourier transform.

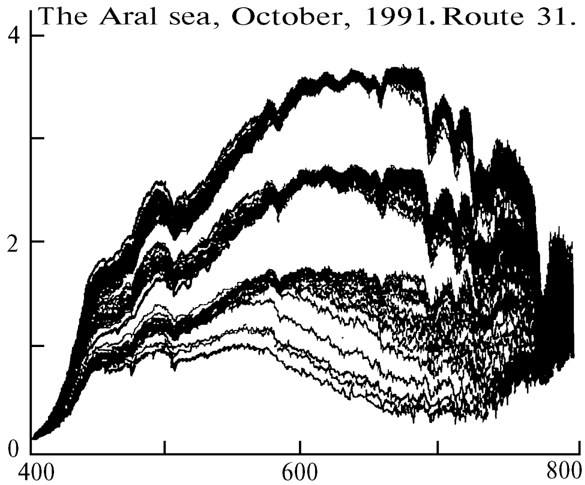

FIG. 1. Spectral power density of the energetic brightness (SPDEB) of the coastal zone of the Aral sea (October, 1991).

The results of the classification made on the basis of the analysis of the obtained spectral data along the predetermined airborne routes are shown in Figs. 1 and 2. The analysis of the spectral characteristics shows that the principal classes of the territorial model are inhomogeneous and can be divided into the subclasses. The number of subclasses is determined by different degree of salinization of soil. The Fourier analysis of the spectral data makes it possible to obtain the quantitative criteria which characterize the inner structure of each class. For example, the class formed by the spatially uniform combination of the main natural landscape components and including marine hydrogenous and residually hydrogenous coastal coquina–sand–clay deposits with high degree of salinization (marine chloride solonchak soils) was divided into three principal subclasses based on the results of the analysis of the spectrophotometric data (Fig. 1). The further analysis of each subclass structure with the help of the Fourier transform made it possible to select out eight individual clusters and to determine the relative contribution of each cluster (Fig. 2). It follows from the analysis of the results shown in Fig. 2 that five clusters incorporating the most part of the measured spectra make a principal contribution to the formation of the subclasses. The concrete identification of each subclass was made on the basis of the analysis of the ground–based field measurements and the available funded cartographic materials.

The results of spectral measurements make it possible to refine the quantitative and qualitative characteristics of geosystem states, to determine the degree of homogeneity of the available classes, and to characterize the inner structure of classes and subclasses. The obtained materials can be used as a new information layer for improvement and increase of the scale of the spatiostructural model of the territory.

The measured values of the radiometric characteristics, i.e., the spectral power density of the energetic brightness (SPDEB) and the coefficients of the spectral brightness (CSB), are used at the subsequent stages of formation of the information system for compiling the fields of the radiative characteristics, i.e., preparing the charts of the spectral brightness and of the spectral albedo, as well as for studying the state of the surface atmospheric layer in combination with the given type of the underlying surface and for calculating the atmospheric transmission function and the degree of smokiness.

The thematic cartography based on the satellite data is one of directions connected with the database for the geo–ecological monitoring system.

The computer decoding of the satellite photographies made in the spring and fall of 1990 was performed based on the analysis of the brightness characteristics of the surface and the ground–based measurements. The following objects were selected: open water surfaces, seasonally swamped sections (whose ground water level is 0–30 cm), seasonally moistened sections (30–50 cm), persistently hemihydromorphic sections (50–150 cm), and persistently automorphic sections (below 150 cm).

After decoding, two territorial models reflecting the actual geosystem state in spring and fall of one year were created. The comparison of the models shows the pronounced seasonal trends of the state of the components of the Amu–Darya delta geosystem. They can be especially clearly seen from the change of the flooded prodelta and from the significant increase of the open water surfaces in fall.

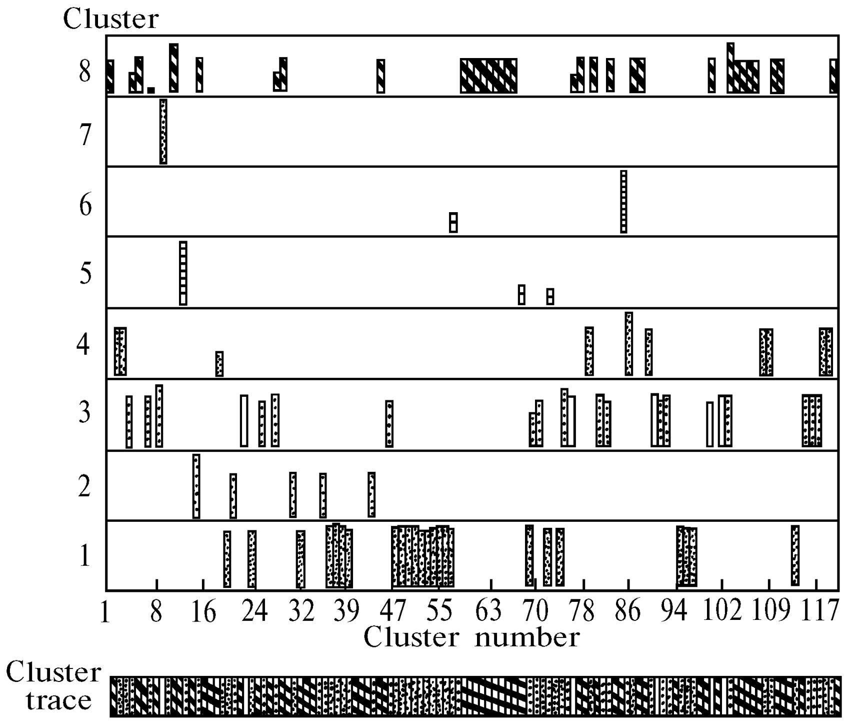

FIG. 2. Cluster distribution of the spectra shown in Fig. 1 as a result of the Fourier analysis. The column heights are inversely proportional to the distance from the cluster centre.

Based on the decoding results with their subsequent correction and selective ground–based observation, at the next stage of our work we plan to prepare the charts of the seasonal trends of the ground water level in the Amu–Darya delta. The component of the regional water budget can be calculated from the seasonal trends of the areas of the open water reservoirs. It can be the basis for preparing a series of the prognostic charts of this territory.

In our opinion, the method of the imitation computer modeling is the most adequate method of investigation of these processes under conditions of incomplete knowledge about the mechanism of the geosystem state dynamics. Its essence is the use of the system of two nonlinear differential equations of the form

$$x_i + A_i(x_i, t) = U_i(t) , \qquad i = 1, 2 , \qquad (1)$$

where x_i is the geosystem state parameter, $A_i(x_i, t)$ is the system of nonlinear differential operators, $U_i(t)$ is the source function, and t is time.

The system of equations (1) was solved for the example of the study of the dynamics of the Aral sea state.

The values of the sea level and the surface area of the Aral sea water plane were used as the parameters x_1 and x_2.

Model investigations include two stages: (1) the stage of teaching the model, i.e., parametrization of Eq. (1) consisting of approximation of $A_i(x_i, t)$ by the polynomial of the third degree and the determination of the coefficients a_{ij} of the power series as well as the determination of U_i and (2) the stage of estimation of the current Aral state and prediction of its changes.

The initial data for the modeling procedures were the following: the bathimetric chart of the Aral sea on a 1:500000 scale with 0.5–m depth resolution as well as the long–standing data (since 1925) of hydrological observations of the sea level and the water influx to the Aral.

The preliminary stage included digitalization of the bathimetric chart of the Aral and its coastal zone with display of the results on the screen in the form of the image 128×128 pixels in size. The system of equations (1) was solved for each pixel with subsequent reconstruction of the images at the selected interval.

The results of implementation of the model teaching procedure are shown in Fig. 3. It illustrates the accuracy of the approximation of the time series of hydrological measurements of the sea level.[4]

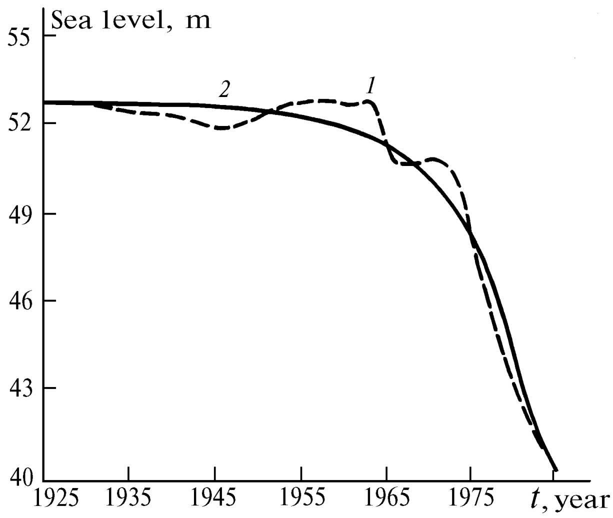

FIG. 3. Temporal behavior of the Aral sea level. Dashed curve shows the data obtained at the meteorological stations, and solid curve shows the model calculation (teaching).

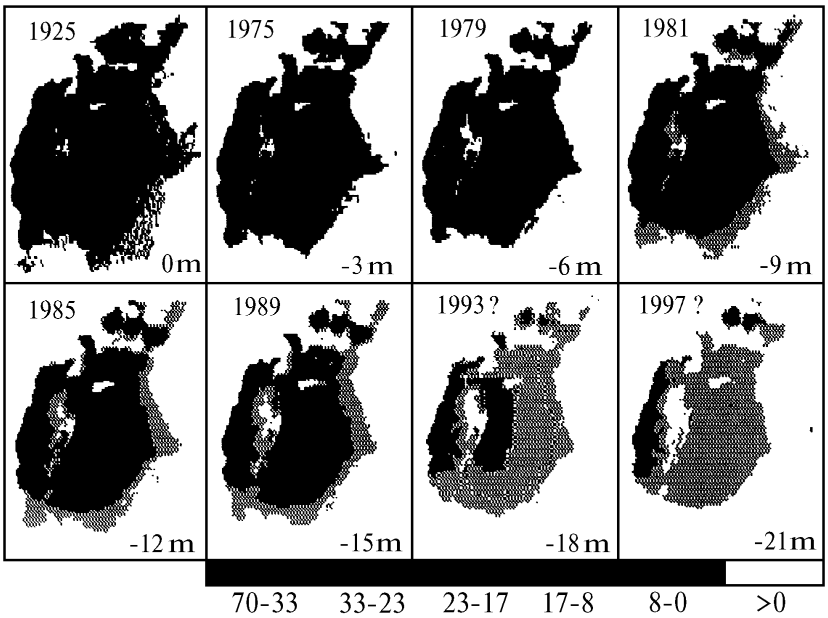

FIG. 4. The dynamics of the Aral sea water plane calculated by the model for 1925–1977. Numbers indicate the gradient of the sea level about the level of 1925. The scale of the sea depths (m) is given at the bottom of the figure.

The sequence of the model images of the Aral water plane since 1925 up to 1977 is shown in Fig. 4. The satellite photography of the Aral obtained in 1989 from onboard the Kosmos–1939 satellite was used as a reference image for verification of the model. The reference and model images of the water planes agree within an error of about 3%. This makes it possible to assert that the degree of adequacy of the model to the actual dynamics of the Aral is quite high and the water plane will change by the proposed scheme given that the present conditions (climate, water budget, structure of economic activity, etc.) remain unchanged. The program of calculation by Eq. (1) also makes it possible to model the diffusion processes, for example, the eolic transport of sand and salts and formation of barkhans, sand–bars, and other analogous objects and phenomena. However, the implementation of modeling of these processes requires a large base of the actual data and knowledge of the evolution and dynamics of the region under consideration.

In conclusion it should be noted that the performed work makes it possible to do the following:

1. To create the numerical computer base of the spatial distribution of the regional data. The base includes the multilayer structure of the thematic cartographic information, the satellite photographies, and airborne and ground–based data.

2. To create the spatiostructural model of the territory representing the basic block of the multipurpose geoinformation system. In the system of acquisition of the data on the territory, the created model makes it possible to take into account the landscape peculiarities as well as the structure of the regular network. This is the main distinctive feature of the principle of acquisition of the spatial data.

3. To estimate the seasonal trends of the state of the components of the Amu–Darya delta geosystem.

4. To develop the methods of imitation computer modeling of the dynamic processes and the principles of creating the prognostic models.

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