

Expert System for the Operative Environmental Diagnostics

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ABSTRACT

Expert system for the operative environment diagnostics (ESOED) that is here proposed realizes GIMS-technology (GIS+Model) combining the methodic and algorithms of mathematical modeling with the land and remote observations of the environment. Links between experiments, algorithms, and models of environmental processes and subsystems are developed to realize effective procedure for the operative control and diagnostics of the environment.

The objective of this report is twofold: 1) To present a working methodology for the combined use of modeling technology and microwave remote sensing measurements in the assessment of environmental processes and biospheric subsystems dynamics. 2) To illustrate this methodology with computer calculations of global change dynamics for the various scenarios.

INTRODUCTION

There are many parameters describing the environmental conditions on the Earth. Among them are soil moisture and moisture related parameters such as the depth of a shallow water table and contours of wetlands and marshy areas. The knowledge about these parameters and conditions is very important for agricultural needs, water management and land reclamation, for measuring and forecasting trends in regional to global hydrological regimes and for obtaining reliable information about the water conservation estimates (Alexandrov, Oikawa, 2002; Chuklantsev et al., 2003; Ferrazzoli et al., 1996; Kondratyev et al., 2002; Kondratyev et al., 2004).

In principle, the required information may be obtained by using on-site measurements and remote sensing and by getting access to a prior knowledge-based data in the GIS databases. But the problem which arises here consists of solving the following:

- what kind of instruments are to be used for conducting the so-called ground-truth and remote sensing measurements;
- what is the cost to be paid for the on-site and remote sensing information;
- what kind of balance is to be taken under consideration between the information content of on-site and remote sensing and the cost of these types of observations;
- what kind of mathematical models may be used both for the interpolation of data and the extrapolation of them in terms of time and space with the goals to reduce the frequency and thus the cost of the observations and to increase the reliability of forecasting the environmental behavior of the observed items.

These and other problems are solved by using a monitoring system based on combining the functions of environmental data acquisition, control of the data archives, data analysis and forecasting the characteristics of the most important processes in the environment. In other words, this unification forms the new information technology called the GIMS-technology. The term "GeoInformational Monitoring System (GIMS)" is used for the description of the formula: $GIMS = GIS + Model$. There are two views of the GIMS. In the first view the term "GIMS" is synonymous with "GIS". In the second view the definition of GIMS expands on the GIS. In keeping with the second view the main units of the GIMS are considered below.

The basic component of the GIMS is considered as a natural subsystem interacting through biospheric, climatic and socio- economic connections with the global *Nature-Society* system (NSS). A model is created describing this interaction and the functioning of various levels of the space-time hierarchy of the whole combination of processes in the subsystem. The model encompasses

characteristic features for typical elements of the natural and anthropogenic processes and the model development is based on the existing information base. The model structure is oriented to the adaptive regime of its use.

The combination of the environmental information acquisition system, the model of the functioning of the typical geoecosystem, the computer cartography system and the means of artificial intelligence will result in creation of the geoinformation monitoring system of a typical natural element capable of solving the following tasks:

- evaluation of global change effects on the environment of the typical element of the NSS;
- evaluation of the role of environmental change occurring in the typical element of climatic and biospheric changes on the Earth and in its territories;
- evaluation of the environmental state of the atmosphere, hydrosphere and soil-plant formations;
- formation and renewal of information structures on ecological, climatic, demographic and economic parameters;
- operative cartography of the situation of the landscape;
- forecasting the ecological consequences of the realization of anthropogenic scenarios;
- typifying land covers, natural phenomena, populated landscapes, surface contaminations of landscapes, hydrological systems and forests;
- evaluation of population security.

STRUCTURE AND FUNCTIONS OF THE ESOED

Construction of the ESOED is connected with consideration of the components of the biosphere, climate and social medium characterized by the given level of spatial hierarchy. It is based on the use of GIMS - technology.

Subsystem for Planning and Analysis of the Data Acquisition Systems

This subsystem solves the task of experimental planning by analysis of the structure of the environmental data acquisition system, making use of data from satellites, flying laboratories and movable and stationary ground observation means. The laboratories are equipped with the necessary software and hardware tools to allow determination of the degree of environmental contamination, of the ecological situation, mapping of the characteristic geological formations, detection of soil subsurface centres of ecological injury, performing the all-weather land-cover typification and detection of permafrost disturbances, oil spills, forest states and pollution of bodies of water.

Subsystem for Initial Data Processing and Data Acquisition

Methods and algorithms for synchronous analysis of aero-space information and ground measurements are realized using space-time interpolation methods. Retrieval of the data and their reduction to the common time scale is performed. Model parameters are determined. Thematic classification of the data is carried out and space-time combination is performed of images in the optical, IR and microwave ranges and of trace measurements obtained from devices of various types.

Subsystem for Computer Mapping

Algorithms are realized for creation of computer maps with characteristic markings for evaluating the ecological situation. Multilevel scaling and fragmentation of the territory is envisaged. The overlaying of output maps with the information needed by the user is provided through the user interface.

Subsystem for Evaluation of the State of the Atmosphere

Models of atmospheric pollution spread due to evaporation and burning of oil products, natural gas and other outputs of industrial enterprises are suggested. The problem of evaluation of the atmosphere

dust content is solved. The gas and aerosol composition of the near-earth atmospheric layer are provided and forecasting maps of their distribution over the earth's surface are created.

Subsystem for Evaluation of the State of the Soil-Plant Cover

This subsystem solves the following tasks:

- typifying of the floristic background taking into account the microrelief, soil type and its salinity, humidification and degree of soil brine mineralization;
- revealing of micro- and macrorelief peculiarities and subsurface anomalies;
- determination of the structural topology of the land cover;
- indication of forests, swamps, agricultural crops and pastures.

Subsystem for Evaluation of the State of the Water Medium

A complex simulation model of the territory is developed taking into account seasonal changes of surface and river runoff, the influence of snow cover and permafrost and the regime of precipitation and evapotranspiration. A model is constructed of water quality dynamics for the hydrologic network of the territory.

Subsystem for Risk Evaluation of the Ecological Safety and the Health of the Population

Algorithms are developed for evaluation of the damage to nature, economic stability and population health depending on changes in the environment connected with natural trends of meteorological, biogeochemical, biogeocenotic, micro- biologic, radiologic and other natural processes as well as the enhancement of environmental stress of anthropogenic origin.

Subsystem for Identification of Causes of Ecological and Sanitary Disturbances

The task of revealing the sources of environmental pollution is solved. This subsystem determines the source coordinates, the magnitude and the possible time of nonplanned introductions of contaminate substances. The dynamic characteristics of the pollution sources are given. A priori unknown pollution sources are revealed and the directions of possible transborder transfer of pollutants are determined.

Subsystem for Intelligent Support

Software-mathematical algorithms are realized for providing the user with intelligent support in performing the complex analysis of objective information formed in the framework of the simulation experiment. The necessary information for the objective dialogue with the global model is provided in a convenient form for the user. The introduction of data processing corrections is also provided. The knowledge base of anthropogenic, demographic and socio-economic processes on the territory is formed.

The ESOED functions include:

- Acquisition and accumulation of data by means of in-situ and remote methods and their analysis with the subsequent subject processing.
- Systematic observation and evaluation of the environment.
- Evaluation and synthesis of knowledge concerning the atmosphere, soil-plant cover, and water medium change.
- Predetermination of the forecasting diagnostics of the environment change under anthropogenic forcing.
- Analysis of the tendencies in the environmental processes when the anthropogenic scenarios are realized.
- Identification of causes of ecological disturbances and danger warning.

The user, following the hierarchy of the ESOED menu, can realize the following operations:

- to ask for data on any identifier (array) and to correct any of its fragments;
- to ask for estimates of all or part of the parameters of simulation units and to correct them;

- to select the sets of parameters and identifiers for a more prompt access to them;
- to synthesize a symbolic schematic map of the distribution of the estimates of the environmental characteristics;
- to predict the state of the environment down to a given depth or till accomplishing the a-priori formulated criterion of assessment of the state of the water environment.

Schematically it is (as illustrated by Figure 1). The user, through interface, sends a permission at each step of the command dialogue, which are assessed in the unit of the query analysis, and from its response, the controlling unit realizes a chain of needed actions of the system. Via return channels of query, the resulting prediction is arranged in the needed form, which can change in each cycle of service. The final result is presented in the form of the protocol with enumerated characteristics of the water environment by objects and territories as well as in the form of schematic maps or digital information combined with the map.

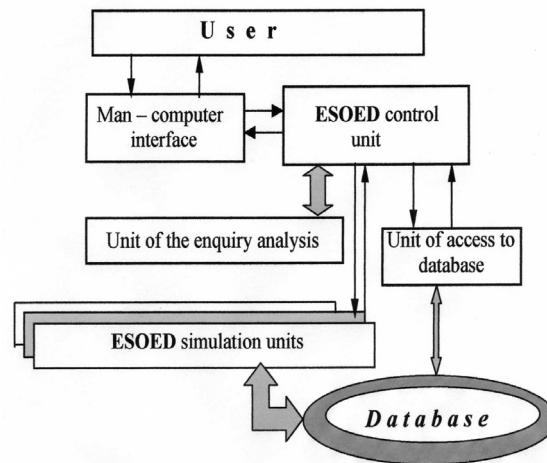


Figure 1: ESOED information units.

SEARCH AND DETECTION OF NATURAL DISASTERS

The ESOED allows to adjust its functions for the operative control of the environmental parameters in the regions where it is possible the natural disaster arising. It is realized by means of global model that parametrizes the dynamics of biospheric characteristics. Presence of the global database containing various information characteristics allows to consider and to evaluate the consequences of possible realization of the different scenarios of the NSS subsystems development. Traditional approaches to syntheses of the global models are founded on consideration of the collections of the balance equations, in which environmental parameters $\{x_i\}$ fall into the form of functions, arguments, factors and conditions of the transition between parametric descriptions of the environmental processes. As well as the other approaches are using based on the evolutionary and neuron-network algorithms. The organization of the NSS global model functioning can be presented in the manner of conceptual scheme (as illustrated by Figure 2). The realization of this scheme is performed by the introduction of the geographical cell $\{\varphi_i, \lambda_j\}$ with discretization steps $\Delta\varphi_i$ and $\Delta\lambda_j$ for the land surface and World Ocean by the latitude and longitude, respectively. So, all processes and NSS elements are

considered as uniform and are parametrized by point models within the pixel $\Omega_{ij} = \{(\varphi, \lambda): \varphi_i \leq \varphi \leq \varphi_i + \Delta\varphi_i, \lambda_j \leq \lambda \leq \lambda_j + \Delta\lambda_j\}$. The choice of the pixels size is defined by set of the conditions, defined by spatial resolution of the given satellite measurements and by presence of necessary global database. In the case of water surface, the water body of pixel Ω_{ij} is divided by depth z on the layers, i.e. three-dimensional volumes $\Omega_{ijk} = \{(\varphi, \lambda, z): (\varphi, \lambda) \in \Omega_{ij}, z_k \leq z \leq z_k + \Delta z_k\}$ are formed. All elements of Ω_{ijk} are considered as uniform. Finally, atmosphere above the pixel Ω_{ij} are discretized by the height in accordance with the atmospheric pressure levels, or on typical layers by height.

It is clear that creation of global model is possible only with attraction of the knowledges and data on given multidisciplinary level. Among ensemble of the global models the most making is a model, described in [4]. In [6, 7] adaptive procedure for global model fitting in the geoinformation monitoring system is offered.

Approach of the moment of the natural catastrophe arising is characterized by hit of the vector $\{x_i\}$ in a certain cluster of multidimensional space X_c . In other words, going from purely verbal discourses to quantitative determination of this process, we shall enter the generalised feature $I(t)$ of the natural catastrophe and shall identify it with graduated scale Ξ . Satisfactory model that transforms the verbal portrait of a natural disaster into notions and indicator subject to a formalized description and transformation is described in (Kondratyev et al., 2002). An introduction of the characteristic I enables one to propose the following scheme of monitoring and predicting natural catastrophes. Three are three levels in the system: recorder, decision maker, and searcher, whose units have the following function:

1. regular control of the environmental elements to accumulate data about their state in the regime permitted by the applied technical means;
2. recording suspicious elements of the environment for which the value of the indicator I corresponds to the interval of a natural anomaly danger of a given type;
3. formation of the dynamic series $\{I(t)\}$ for a suspicious element to make a statistical decision about its noise or signal character and in the latter case the rest of the suspicious element by criteria of the next level of accuracy (getting of the $\{x_i\}$ vector into the cluster, etc);
4. making the final decision about the approaching moment of a natural catastrophe occurrence with the transmission of information to the respective environmental control services;
5. iterative procedure to locate an anomaly.

Efficiency of such procedure depends on the parameters of the measuring technical facilities and algorithms for the data processing. The important role here plays the environmental model, used parallel with formation and statistical test of the row $\{I(t)\}$ and adapted to mode of the monitoring.

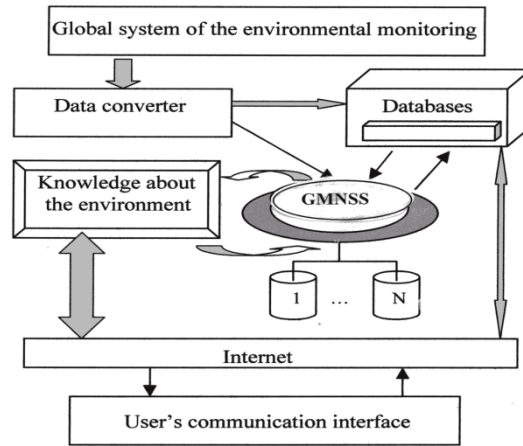


Figure 2: Conceptual block-diagram of geoinformation monitoring and use of the global model of *Nature-Society* system (GMNSS).

As seen from the introduced criterion of an approaching natural catastrophe, the form and behaviour of $I(t)$ are special for each type of the processes in the environment. One of the complicated problems consists in determination of these forms and their classification. For instance, such frequent dangerous natural events as landslips and mudflows have characteristic features, such as preliminary changing relief and landscape, which are successfully recorded from satellites in the optical range, and together with data of aerial photography and surface measurements of relief slopes, exposition of slopes and the state of the hydro-system make it possible to predict them several days beforehand. However, restricted capabilities of the optical range under conditions of clouds or vegetation cover should be broadened by introducing the systems of remote sensing in the microwave region of the electromagnetic spectrum. Then, in addition to the indicators of landslips and mudflows, one can add such information parameters as soil moisture and biomass, since a soil moisture increase leads to landslips, and an enhancement of biomass testifies to the growth of the restraining role of vegetation cover with respect to the dislocation of mountain rocks. Particularly this it is important when supervision is snowed-stone or simply snow avalanches. Making the catalogue of such indicators for all possible natural catastrophes and contributing their in knowledgebase of monitoring system is a necessary stage of increasing of its efficiency.

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