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Mobile remote-sensing platforms for environmental monitoring

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***Abstract*—Characteristic of series mobile remote-sensing platforms is given. These platforms are used to be as the base for microwave sensors under the organization of the monitoring of environmental objects. The structure of monitoring system synthesis is proposed with functions of decision making concerning the optimization of the data collection and processing. Technology of geo-ecological information-modelling system (GIMS-technology) synthesis is described. The questions are discussed related to the GIMS-technology use for the solution of tasks from the hydrology including a mapping the soil moisture and detection of critical situations in hydrological processes. It is shown that GIMS-technology makes more wide the GIS functions and makes easier the solution of task when it is needed to reconstruct two-dimensional distribution of the monitoring object characteristics basing on the data delivered by monitoring system irregularly at the time and fragmentary in the space. Specific characteristics of the GIMS-technology are marked and perspectives of its development are described.**

Keywords— microwave monitoring, model, prognosis, GIS, GIMS, soil moisture, algorithm

I. INTRODUCTION

Field of geographical information systems (GIS) is the most developed element of natural monitoring. GIS-technology has severe success and brings perceptible economic effects. GIS-technology is positioned in the interface of computer cartography, databases and remote-sensing. The GIS elements are computer net, database, data transmission net and a system for the reflection of real situation by means of computer display. Numerous GIS show that GIS-technology guarantees convenient tool for the masses use to control the monitoring object and is efficient mechanism for the integration of multi-factor information. However, GIS-technology has serious restrictions when complex environmental task are solved and when synthesis of dynamic image of the environment is needed on the database that is episodic at the time and fragmentary in the space. Basic GIS imperfection consists in that it does not orient on multi-plane prognosis of the monitoring object evolution.

Important step in the GIS-technology development was made in the papers [1-12] where new technology of the synthesis of geo-ecological information-modeling system (GIMS) was proposed. This technology eliminates many GIS imperfections and gives a possibility to synthesize the monitoring systems having prognosis function. Generally, principal GIMS-technology conception is represented in Fig. 1. Remote determination of highly possible of number of parameters for the model of controlled geo-ecosystem is key element of the GIMS-technology. Just, that sort of combination of empirical and theoretical functions of the GIMS-technology allows the operative assessment of current and prediction changes in the environment.

The GIMC-technology is based on a joint use of the following structural constituents:

- remotely sensed microwave and optical data;
- *in situ* measurements;
- GIS and other available data banks information; and
- mathematical modelling of spatial-temporal variations in physical and chemical parameters of the environment.

II. THE GIMS-TECHNOLOGY FUNCTIONS

State of any geoecosystem is characterized by large variety of parameters determining a dynamics of its functioning taking into account of the interaction with bordering territories. Some of these parameters characterize the soil and vegetation types, water regime of the territory, saline mixture of the soil-ground, position level of the subsoil waters, dislocation structure of the anthropogenic objects and many others. In principle, information needed about above parameters can be received with different reliability from in-situ and remote observations as well as from the GIS databases where a-priory information exists being accumulated during past years (Fig. 2). Problem arising before decision making person consists in the obtaining of answers on the following questions:

- What kind of instruments are to be used for conducting the so-called ground-truth and remote measurements?

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- What is the cost to be paid for the contact and remote information?
- What kind of balance between the information content of contact and remote observations and the cost of these types of observations is to be taken under consideration?
- 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 observations and to increase the reliability of forecasting the environmental behaviour of observed objects.

The GIMS-technology gives a possibility to answer on these questions using adaptation procedure to the prehistory of the monitoring object functioning. The GIMS structure includes series of blocks that realize the following functions:

- data collection (current information about the soil-canopy system: soil moisture, depth to a shallow water table, soil salinity, biomass of vegetation, rainfall rate, etc.);
- data preprocessing, sorting, and storing in the data bank;
- modelling (simulation) of different kinds of ecological, hydrological, agricultural, climatological processes in different geophysical and environmental systems (these blocks contain a variety of models of crop productivity, the functioning of irrigation systems, geo-ecology, and the epidemiology of certain vector-borne diseases, etc.);
- estimation of the current state of a specific geophysical system;
- forecasting the state of this system at a future time;
- feedback support, information deficit assessment, information optimization; and
- realization of specific operations to data processing in framework of the user needs (evaluation and prognosis of the object state when anthropogenic scenario is realized, etc.)

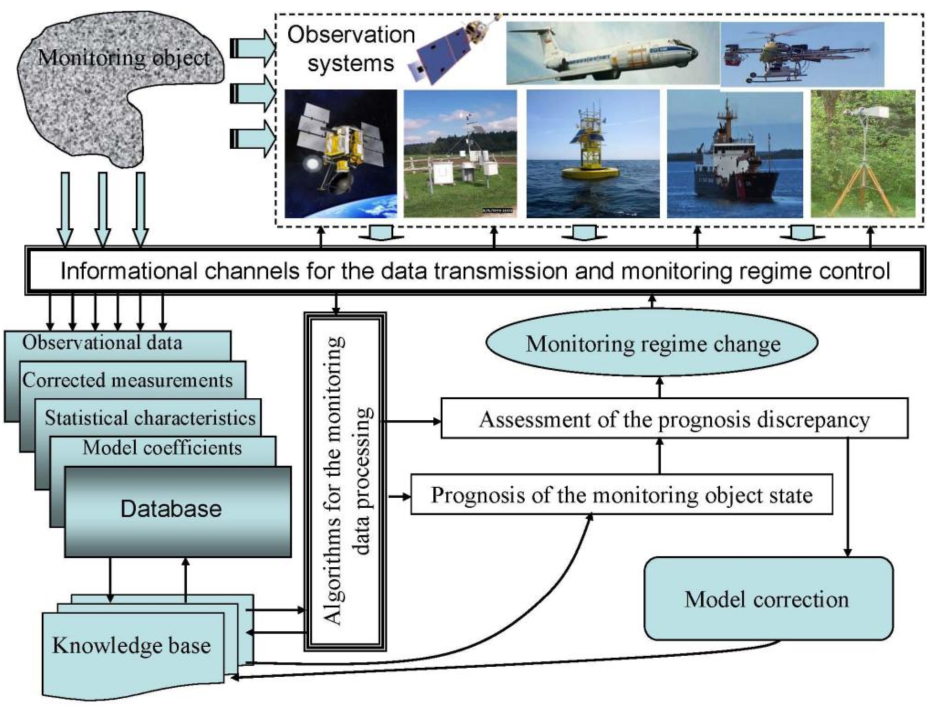

Fig. 1. Conception of the geoecological information-modeling system (GIMS). Principal scheme of the GIMS functioning in the regime of adaptive correction of the parametrical space and monitoring regime.

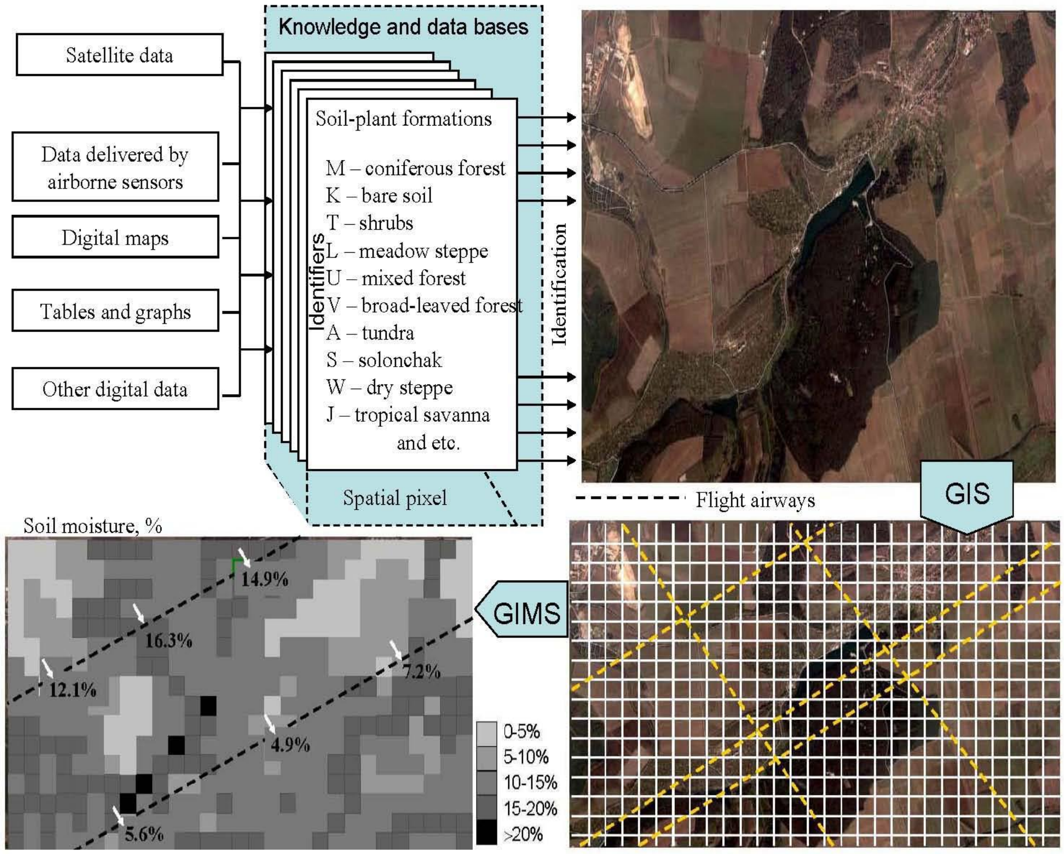

Fig. 2. Environmental data integration from different sources and in various forms

III. THE GIMS-BASED REMOTE-SENSING PLATFORMS PLATFORMS

Kotelnikov Institute of Radioengineering and Electronics of Russian Academy of Sciences and other Russian and foreign organizations have synthesized series of mobile remote-sensing platforms for microwave monitoring of the environmental systems. These platforms realize the GIMS functions for the solution of specific tasks of nature monitoring including man-made environmental systems such as related to the melioration, hydrology, oceanology, ecology, and epidemiology [1,3,7,10]. For instance, application of the non-contact technology allows to obtain operative data about the soil moisture, to assess a possibility of dangerous hydrological situations and to realize the monitoring of the state of hydro-technical structures in the regions where hydrological risk is higher. In particular, the GIMS-technology can give a reliable control of the zones where water-logging of roads and railways, and the leakage across the dams are possible [2].

Practical realization of the GIMS-technology is possible with the use of mobile platform equipped by the remote-sensing sensors. Such platforms were produced and tested in different regions [1-3]. Fig. 3-5 show the models of such platforms. Fig. 6 represents series of the radiometers that were used for the equipment of these platforms. In the all cases, the use of these platforms to assess regional geo-ecosystem state proposes a-priory data presence and realization of synchronous in-situ measurements. The GIMS-technology reconstructs spatial distribution of the geo-ecosystem characteristics basing on the data that are episodic in the time and fragmentary in the space. The GIMS-technology overcomes situations of irremovable information uncertainty using evolution modelling methods [4]. Use of optical sensors and spectroellipsometry technology gives a possibility to calculate the water quality indicators assessing the concentrations of chemicals in the water and distribution and parameters of the pollutant spots of the water surface [5,8,12,12].

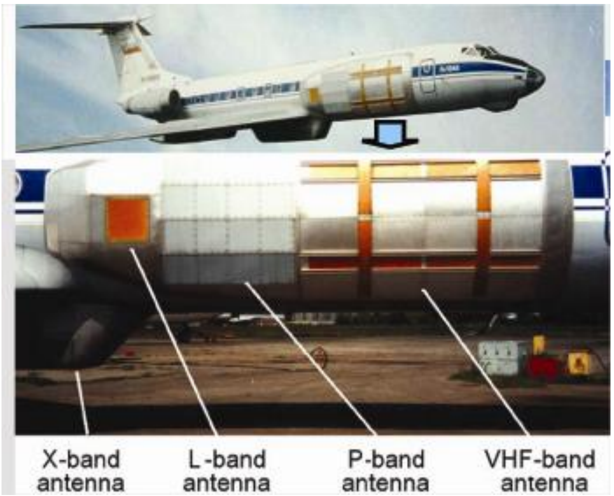

Fig. 3. Airborne SAR complex IMARC (Intelligent Multi-frequency Airborne polarimetric Radar Complex) showing how its antennas are deployed [1,3]. Ranges: X(3.9 cm), L(23 cm), P(68 cm) и VHF(2.54 m).

Fig. 4. Miramap sensor aircraft-laboratory TwinCommander and its microwave equipping [1-3].

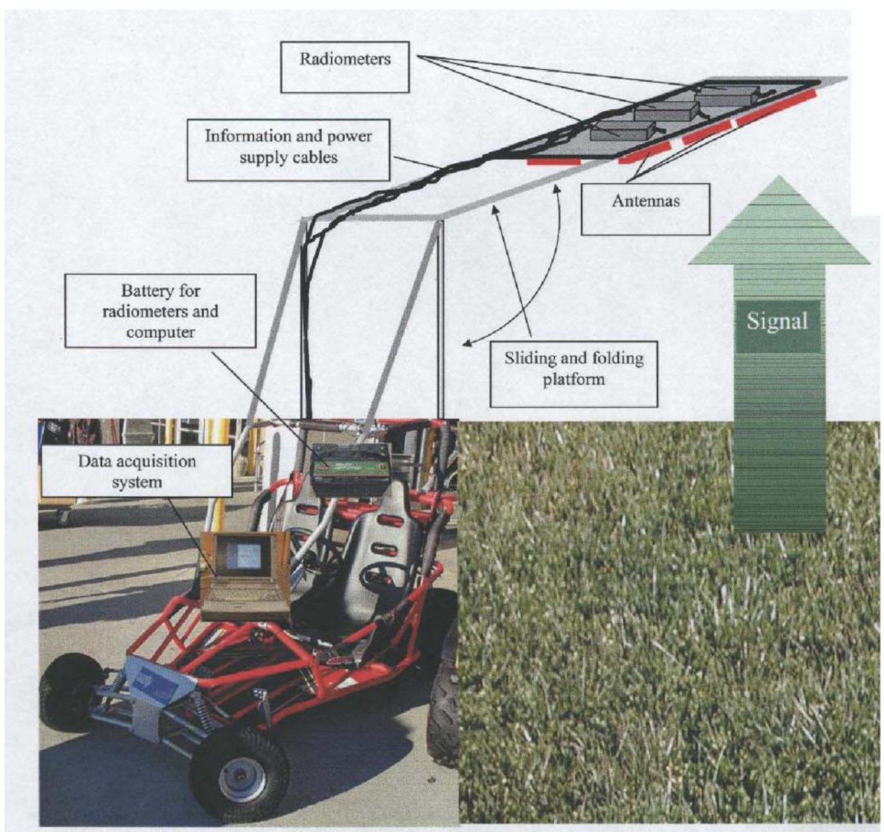

Fig. 5. Subsystems and microwave radiometers on the rover's mobile platform [3].

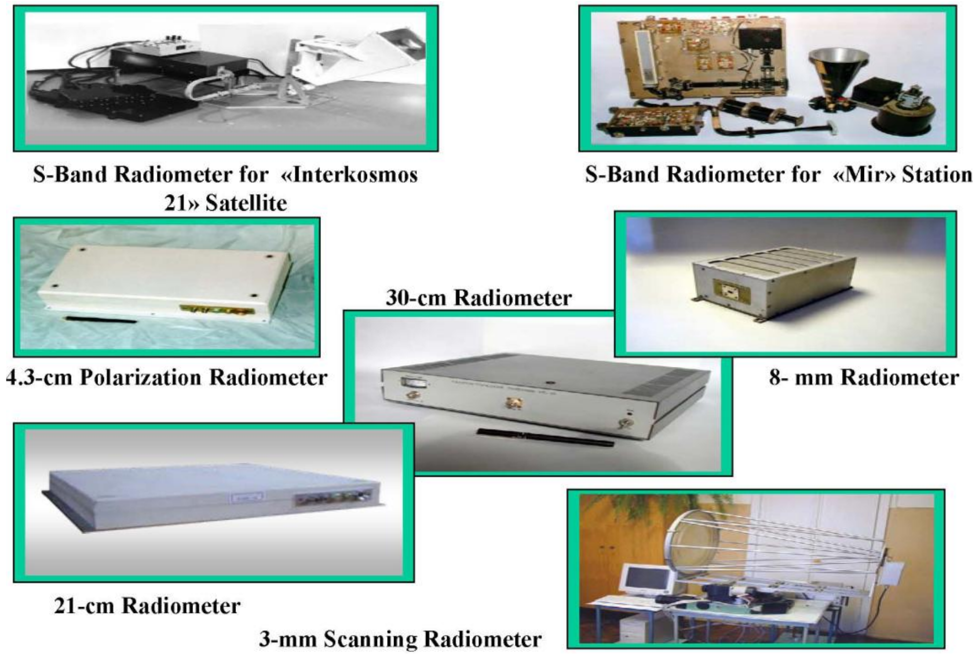

Fig. 6. Set of portable radiometers produced by the Special Design Office of the Kotelnikov Institute of Radioengineering and Electronics of Russian Academy of Sciences [1,3].

IV. THE GIMS-TECHNOLOGY TESTING

The main expected results of the GIMS-technology using consists in the development of the combined synergetic methods of microwave and optical remote sensing of the land terrain and GPS positioned prior knowledge-based information utilization which allow the user to increase through GIMS the information content, a spatial resolution of measurements and a probability of emergency situations. Table 1 gives short description of the GIMS experimental tests of which were realized in different climatic conditions. The platforms represented in Fig. 4 and 5 were used in these GIMSs. A control of the GIMS accuracy is realized by means of the comparison of remote sensing measurements and *in-situ* observations in the zones of testing arias. The GIMS adaptation to the regional geo-ecosystem was realized with the use of data archives related to the each spatial pixel and when these data are absent expert evaluations are used. Application of non-contact technology is seemed particularly actual, when operative data about the geo-ecosystem state are needed for the evaluation of dangerous situation possibility and when minimal in-situ observations are available.

Phases of the GIMS accomplishment include the following works.

- Inventarization of the available in geo-ecosystem region sources of aircraft and spacecraft information, and their incorporation into GIMS structure, its adaptation to the satellite observation regime; beginning some remote sensing, data acquisition and data processing instruments, software and algorithms purchase; beginning modelling.
- Inventory of the available in the geo-ecosystem region sources of GIS and *in-situ* information and their incorporation into GIMS structure; continuation of some remote sensing, data acquisition and data processing instruments, software and algorithms purchase; continuation of modelling; beginning some remote and on-ground measurements.
- Development of basic spatial-temporal models of geo-ecosystem and incorporation of these sources of information into GIMS structure, formation of GIMS knowledge base including the series of biospheric, climatic, and socio-economic connections/links and their parameterization.
- Organization of GIMS network; data collection and processing.
- Finalizing the GIMS structure taking into consideration of the hierarchy of its blocks.

Through both laboratory and field experiments it has been documented that the passive microwave radiometers and the processing/retrieval algorithms of the GIMS are feasible to determine the soil, water and vegetation related environmental parameters and conditions (see Table 2).

TABLE I. BRIEF CHARACTERISTICS OF THE GIMSS SYNTHESIZED IN THE KOTELNIKOV INSTITUTE OF RADIOENGINEERING AND ELECTRONICS OF RUSSIAN ACADEMY OF SCIENCES.

GIMS history	Description on the GIMS functions and references
GIMS-AY was created in the framework of the Contract with USA Department of Energy	It is calculated the influence of the Angara-Yenisey river system on the Arctic Basin pollution level by radionuclides, heavy metals and oil hydrocarbons [13].
GIMS-AC was created in the framework of collaboration with Georgetown University, Washington, USA	It is assessed the characteristics of the Aral Sea-Caspian Sea system hydrologic regime and prognosis of these characteristics is realized in framework of scenarios considering a possible climate change or anthropogenic impact on this system [14].
GIMS-GCC was created in the framework of collaboration with Tsukuba University, Japan	Fluxes of the atmospheric carbon to the hydrosphere, land, and geosphere are calculated taking into consideration of spatial distribution of soil-plant formations, heterogeneity of the World Ocean ecosystems and geospheric processes [3,4].
GIMS-AB was created in the framework of collaboration with Athens University, Greece	Spatial distribution of the pollutants in the Arctic Basin is calculated taking into consideration of river flow from all bordering continents and atmospheric transport from remote territories [15].
GIMS-Bulgaria was created at the instance of Bulgarian government.	Dynamics of soil moisture is evaluated basing on remote episodic microwave measurements and risks of dangerous situations in hydrophysical systems is assessed [1,2].

The GIMS-Bulgaria synthesis with control functions of hydrological processes in different regions has needed the realization of series of theoretical and experimental investigations.. A realization of the GIMS-Bulgaria during the first stage allows the demonstrational flights of aircraft-laboratory Twin Commander (Fig. 4) in several regions of Bulgaria and the procedure creation for computer mapping of soil moisture in territories with possible water-logging that are bordered with Danube River (Fig. 2). Initial data for the GIMS-Bulgaria were national database fragments concerning soil-plant formations and topography with spatial resolution by 9m×9m. White arrows in Fig. 2 show the comparison results of the GIMS results and in-situ measurements what gives a possibility to make the following conclusions:

- Practical use of the GIMS-Bulgaria needs the creation of the updatable archive of soil-plants reflecting spatial distribution of soils with their parameters and of vegetation covers with their biometric and production characteristics.
- Knowledge of the climate evolution characteristics and geophysical parameters is needed for all regions.

TABLE II. THE EXAMPLES OF OPERATING RANGE AND ERRORS FOR THE MAIN PARAMETERS THAT CAN BE ESTABLISHED WITH THE GIMS-TECHNOLOGY.

Parameter	Range and precision
Soil moisture content Operating range Maximum absolute error - vegetation biomass is less than 2 kg/m^2 - vegetation biomass is greater than 2 kg/m^2	0.02-0.5 g/cm^3 0.05 g/cm^3 0.07 g/cm^3
Depth to a shallow water table Operating range - humid, swampy areas - dry arid areas, deserts - maximum absolute error	0.2-2 m 0.2-5 m 0.3-0.6 m
Plant biomass (above wet soil or water surface) Operating range Maximum absolute error Salt and pollutant concentration of water areas (off-shore zones, lakes) - operating range - maximum absolute error - relative error	0-3 kg/m^2 0.2 kg/m^2 1-300 ppt 1-5 ppt 0.5 ppt

V. CONCLUSION

The questions discussed in this paper are some of part of numerous global ecodynamics problems a solution of which is barest necessity of today under rational management of natural systems. Basic defect of elaborated and used geo-ecological monitoring technologies consists in the efforts to do the integrating reasoning for the environmental system state on the base of study of separate systems. Therefore, many monitoring systems are not enough effective and non-informative. Set of the GIMS-technology authors focusing on this their attention [1-3] note it's the more universal character under the use of data and knowledge and a possibility to provide the most economical acquisition of new knowledge and data. This is achieved by means of adaptive package of technical and algorithmic tools harmonized by information content.

Thus, the GIMS provides remote sensing, on-ground (*in-situ*) samplings, using GIS-information and mathematical modelling of physics-chemical processes in selected areas. GIMS-technology can effectively be applied for solving many agricultural, hydrological, and environmental and many other

Earth related problems. In common, GIMS-technology solves numerous environmental tasks that GIS technology struggles with, such as:

- The study of environmental processes and systems that change quickly are unstable.
- Assessing the ecosystems in regions where monitoring systems do not exist.
- Optimization of the environmental monitoring systems.
- Reconstruction of spatial image of the system basing on the restricted information.
- Revealing the characteristic features of the environmental system evolution.

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