Ecoinformatics Tools and Gims - Technology in the Water Quality Monitoring

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Abstract **- Basic GIS imperfection consists in that it does not orient on multi-plane prognosis of the monitoring object evolution. With the help of technology modeling, the GIS can be extended to global information-modeling system (GIMS), modifying some functions of the user interface for computer cartographic systems, including forecasting assessments of conditions for environmental system functioning within predefined scenarios. Furthermore, these parametric changes can be used both for the evaluation of model coefficients and for the prognostic assessment of environmental dynamics based on the evolutionary modeling. Such a modification requires the support of combining mathematical modeling with remote sensing to solve many problems. 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. The GIMS provides remote sensing, on-ground (on-site) samplings, using GIS-information and mathematical modeling of physics-chemical processes in selected areas. GIMS-technology can effectively be applied for solving many agricultural, hydrological, environmental and many other Earth related problems. The MFIMS can used under the water media or other liquids quality control under the expedition conditions when chemical laboratory no exist**

Keywords - ecoinformatics, spectroellipsometer, water quality monitoring

I. Introduction

Numerous problems of the environmental monitoring are solved by means of the ecoinformatics technologies [1-18]. Global information systems (GIS) are the most developed elements 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 is 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.

In particular, the microwave remote-sensing systems that are widely used to equip the flying laboratories and the natural-resources satellites supply the data sets that are geographically distributed. Reconstruction of the information obtained is possible only by employing methods of spatial-temporal interpolation for the development of which several techniques and algorithms of simulation modeling have been used in the past [2, 7]. For example, the spatial modeling has been widely used for the interpretation of the data obtained by environmental instruments, which monitor the lithosphere, cryosphere, hydrosphere, vegetation interfaces and urban environments.

For the accomplishment of the complex task of the environmental diagnostics, it is necessary to built up a system that incorporates such functions, as well as data collection (by means of remote sensing and in-situ methods), their analysis and processing. A system of this type is capable to conduct systematic observations and assessments of the environmental state, to predetermine forecasting diagnostics of changes of the environmental elements (due to anthropogenic impacts) and to analyze the evolution of environmental processes, taking into account the anthropogenic scenarios. One of the system functions is to provide warnings about undesirable changes in the environment. Attainment of such functions for environmental monitoring is feasible with the use of simulation methods allowing the development of a model for the investigation of the natural subsystem.

The GIS tool guarantees the geographical data processing, the relation with existing databases and the topological representation for studied territories. With the help of technology modeling, the GIS can be extended to global information-modeling system (GIMS), modifying some functions of the user interface for computer cartographic systems, including forecasting assessments of conditions for environmental system functioning within predefined scenarios. Furthermore, these parametric changes can be used both for the evaluation of model coefficients and for the prognostic assessment of environmental dynamics based on the evolutionary modeling. Such a modification requires the support of combining mathematical modeling with remote sensing to solve the following problems [7, 8]:

- Forecast of the onset and the dangerous level of natural disasters, the emergency situations and the manmade catastrophes.
- Control of possible disasters and catastrophes (including complex meteorological conditions) with the provision of information for decision making.
- Impact assessment of disasters and catastrophes for cities, agricultural and forest areas, sea and coastal flora and fauna.
- Delivery plans for rescue operations.

II. NEW ECOINFORMATICS TOOL

Important step in the GIS-technology development was made in the papers [1-10] where new technology of the GIMS synthesis 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.

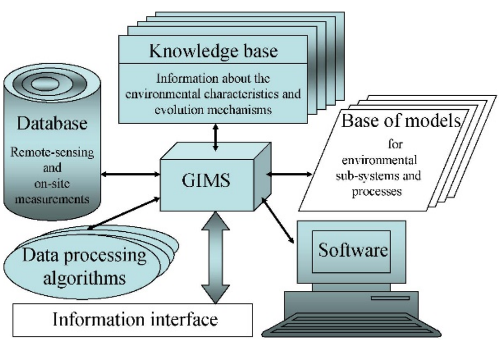

Fig. 1. Conceptual diagram showing the definition of the GIMS-technology architecture

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 hierarchical structure of environmental monitoring systems optimizes the use of financial resources with high quality of final results. This is the basic argument for the creation of geoinformation monitoring systems using the technology of hierarchical synthesis.

Fig. 2 shows an organizational structure of the GIMS-technology functioning and its position within the monitoring procedure. The GIMS-technology optimizes multi-channel informational structure of monitoring system and forms a current database that is the most keeping with solved environmental task.

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

- Remotely sensed microwave and optical data;
- In situ measurements;
- In situ measurements;
- GIS and other available data banks information;
- Mathematical modeling of spatial-temporal variations in physical and chemical parameters of the environment

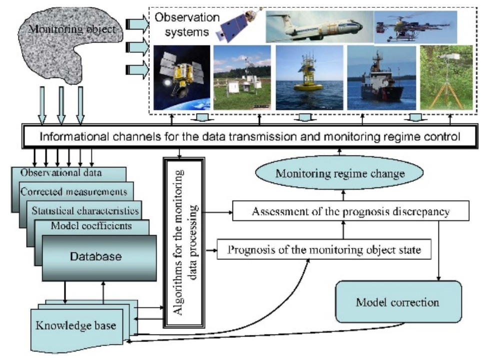

Fig. 2. Functional structure of global information-modeling system (GIMS). Principal scheme of the GIMS functioning in the regime of adaptive correction of the parametrical space and monitoring mode of operation

The GIMS structure includes series of blocks that solve specific tasks. As example, Fig. 3 and Tables 1 and 2 demonstrate one of such blocks. This block is multi-functional adaptive information-modeling system for hydrophysical and hydrochemical investigations. It is oriented on an assessment of physics-chemical characteristics of the water objects of different spatial scales.

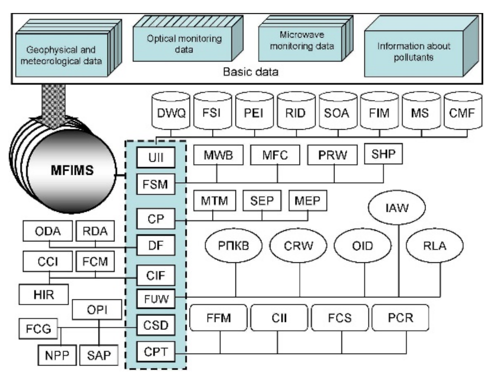

Fig. 3. A structure of multi-functional information-modeling system (MFIMS) for hydrophysical and hydrochemical investigations.

Notations are giwen in Tables 1 and 2.

TABLE I. THE FIRST LEVEL BLOCKS OF MULTI-FUNCTIONAL INFORMATION-MODELING SYSTEM FOR HYDROPHYSICAL AND HYDROCHEMICAL INVESTIGATIONS

Block	Block functions
UII	Universal information interface
FSM	Forming the simulation model of regional water balance. Control of models and algorithms used for the parameterization of hydrophysical and hydrological processes.

CP	Control of the parameterization of the energy and matter flows in the hydrophysical system. Realization of the transformation of chemical elements in the water medium.
DF	Database forming and synthesis of anthropogenic scenarios that can be realized in the area where hydrophysical system is functioning.
CIF	Control of information flows between the MFIMS blocks.
FUW	Forming and using the water quality criteria.
CSD	Control of statistical decision-making procedures.
CPT	Control of the phase transitions in the hydrophysical system.

TABLE II. A SECOND LEVEL BLOCKS OF MULTI-FUNCTIONAL INFORMATION-MODELING SYSTEM FOR HYDROPHYSICAL AND HYDROCHEMICAL INVESTIGATIONS

Block	Block function
FSI	Forming the subject identifiers for the MFIMS adaptation to the studied hydrochemical system configuration taking into account of its geophysical, ecological and social aspects.
PEI	Perception of experimental information and its scaling and recording to the GIMS database.
RID	Realization of the inquiries to the database. Operation with the regulation demands.
SOA	Support of the operator actions under the selection and change of information and user-defined interfaces.
FIM	Forming the information maps concerning water quality on the hydrophysical object territory.
MS	Modification of the scales for the cartographic information representation with selection of the hydrophysical object territory fragments.
CMF	Control of the MFIMS functions, the coordination of information flows within the MFIMS, detection of defect demands and massages, and help to the user.
DWQ	Detection of the water quality failure and the operator information about these failures.
MWB	A model of the water balance of the territory occupied by the hydrochemical system.
MFC	A model of the forming the complex multi-factor process of surface outflow taking into account of the reservoir topography and soil-vegetation cover.
PRW	Parameterization of the run-off water flows.
SHP	Simulation of the hydrophysical processes.
CWQ	Calculation of the water quality indicators.
MTM	Modeling the transformation mechanisms for the chemicals in the water.
SEP	Simulation of the exchange processes on the boundary of hydrophysical systems including tidal processes and interaction with the atmosphere.
MEP	Modeling the exchange processes by chemical elements between the atmosphere and water surface.
RDA	Renewed data archive including information about volumes and composition of pollutants released to the environment by agricultural and municipal systems, and industry in the hydrophysical object zone.
ODA	Official data adequacy delivered to the GIMS data archive.
FCM	Formation of the computer-based mode for the hydrophysical system.
HIR	Heterogeneous information reduction to the unique standard.
CCI	Co-ordination control of the inputs and outputs of the GIMS blocks and their communications with database.
CRW	Control for realization of the water quality criteria.
OID	Operative information documentation concerning the water quality.
RLA	Registration of the laboratory analyses for the water quality.
IAW	Integrated assessment of the water quality.
NPP	Neuman-Pearson procedure for statistical decision making.
SAP	Sequential analysis procedure for statistical decision making.
FCG	Functional control of the GIMS blocks.
OPI	Overcoming procedure of information uncertainty.
FFM	Forming the files of meteorological and geophysical characteristics.
CII	Calculation of instability indicators and biocomplexity concerning the hydrophysical system.
FCS	Forming the cluster space.
PCR	Percolation procedure realization.

III. THE GIMS-TECHNOLOGY FUNCTIONS

State of any geo-ecosystem 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. 4).

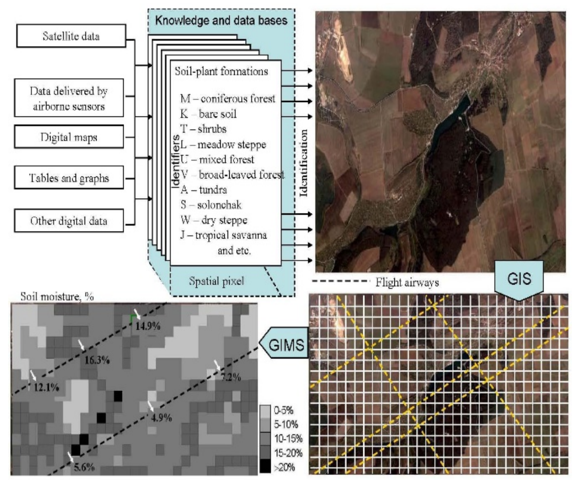

Fig. 4. Environmental data integration from different sources and in various forms. Arrows show a precision of the soil moisture reconstruction

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?
- 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 behavior 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;
- Modeling (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;
- 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.).

IV. THE GIMS-TECHNOLOGY PLATFORMS FOR MICROWAVE MONITORING

Series of mobile remote-sensing platforms for microwave monitoring of the environmental systems have been synthesized during last years [3-7]. 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 [3,7,11,13]. For instance, application of the non-contact technology allows the obtaining the 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 waterlogging of roads and railways, and the leakage across the dams are possible [4]. 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 times and regions [3-6, 19]:

- Flying laboratory IL-18 (Fig. 5).
- Airborne SAR complex IMARC (Intelligent Multi-frequency Airborne polarimetric Radar Complex) equipped by the radiometric complex of ranges: X(3.9 cm), L(23 cm), P(68 cm) and VHF(2.54 m) [3, 7].
- Miramap sensor aircraft-laboratory TwinCommander equipped by digital photo camera (visible 0.4-0.7 micron), lidar scanner (SW infrared 1064 nm), passive microwave scanner (2, 5, and 21 cm), and thermal camera (LW infrared 7.5-13 micron) [3-7].
- A manned "Rover" mobile type platform (Fig. 6) at a height of 2 m, which provides data at a ground resolution of 1.4 m and is equipped by radiometers of ranges: 6cm, 18cm, and 21cm [5].
- Fully autonomous unmanned aerial vehicle helicopter platform at an altitude of 30m, which provides data at a ground resolution of 20 m using one of microwave radiometers: 5cm, 18 cm or 21 cm (Fig. 7) [3-6].

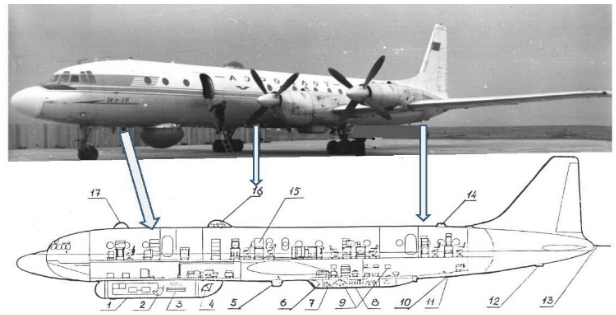

Fig. 5. Scheme of positioning the antenna systems and photo-hatches on-board of flying laboratory IL-18. Notation: Antennas: 1,3 – radiolocators with synthetic aperture, wavelengts – 2.0 and 10.0 cm; 2,6- trace polarimeters, wavelength – 0.8 and 2.25 cm; 4 – six-channel scanning polarimeter, wavelength – 0.8, 1.35, 2.25, 10, 20 and 27 cm; 7,9–precision altimeter and interferometer of side looking, wavelength – 2.2 cm; 13 – sub-surface sonding station of decimetric range; Photo-hatches:5,10,12 – large-format and frame TV, aero-camera; 11, 14 – radiometers of mm range; 16 – trace radiometers, wavelength – 0.8, 1.35, and 2.25 cm; 15 – gravimetric and inertial devices; 17 – astro-hatch

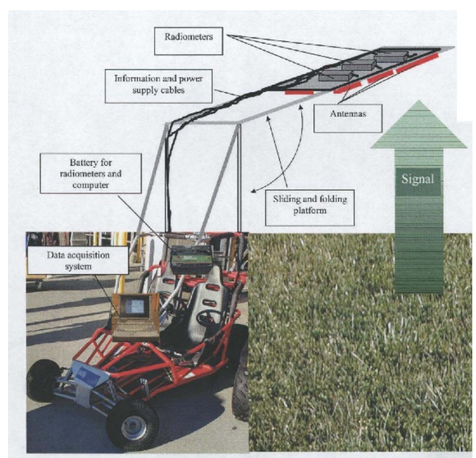

Fig. 6. Subsystems and microwave radiometers on the rover's mobile platform [7].

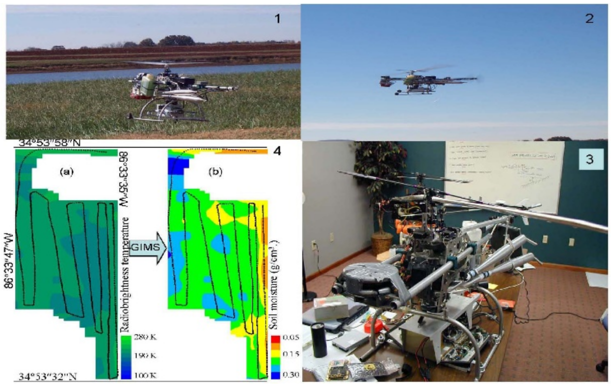

Fig. 7. Photographs of the unmanned aerial vehicle (UAV) helicopter "Microwave Autonomous Copter System" (MACS) equipped with a 6 cm radiometer, data acquisition system, GPS receiver and power supply battery [7]. Notation: 1 – general view of MACS during landing; 2 – MACS is in the flying; 3 – a design process; 4 – some results processing

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 unremovable information uncertainty using evolution modeling methods [6,9,10]. 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 [8,16,18].

V. INSTRUMENTAL TECHNOLOGY FOR THE DIAGNOSTIC OF LIQUID SOLUTIONS

During last time, optical devices are intensively used for the investigation of characteristics of liquid and solid mediums. It allows the operative diagnostic practically in real time mode. Spectroellipsometry is the peak of polarization optics. The creation of multichannel polarization optical instrumentation and use of spectroellipsometric technology are very important for the real-time ecological monitoring of the aquatic environment. Spectroellipsometric devices give us high precision of measurements. Spectroellipsometric and their multichannel measurements in an aquatic environment provide the basis for the application of modern algorithms for the recognition and identification of pollutants. Present multi-channel spectrophotometers and spectroellipsometers deliver spectral images of controlled objects with high speed and precision. Use different algorithms and models for the processing spectral images allows the adaptive identifier to synthesize that has principal difference from traditional approaches to the liquid solution control.

Combined application of instrumental tools and software for operative monitoring of the water medium on the Earth developed insufficiently on account of complexity of complex monitoring system synthesize. Tasks of the adaptation of algorithms and models to the specific monitoring system are complexity and sometimes contradictory. Krapivin et al. [10] proposed new universal technology for solution these tasks. This technology based on the precision compact polarimeters and the education algorithms for recognition of spectral images. Under this, a solution effectiveness of multi-parametrical tasks is mainly determined by the sensitivity and precision of sensors, their universality, and by using wide spectral bands.

Spectral measurements of the water medium deliver information for the using the proper algorithms and models of identification and recognition of pollutants. This is the first time the combined use of real-time spectroellipsometry measurements and data processing methods have been realized as different versions of an Adaptive Identifier (AI) (Fig. 8-12). Use of an acromatic compensator on the basis of Fresnel rhomb made of fused quartz that enhances the precision of measurements.

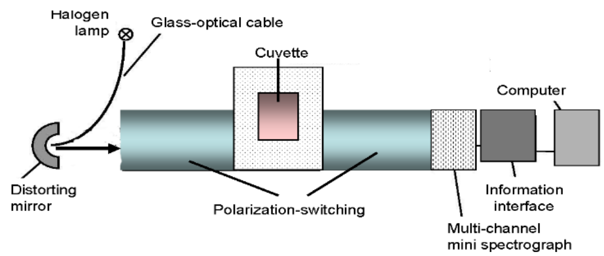

Fig. 8. Principal scheme of Adaptive Identifier (version 1) based on high precision real-time 128-wavelengths spectroscopic ellipsometer with binary polarization modulation. AI-1 characteristics are shown in Table 3.

Realized AI-1 version is shown in Fig. 9.

Fig. 9. Adaptive Identifier (version 1) based on the 128-channel spectroellipsometer and oriented to the laboratory analysis of liquid samples.

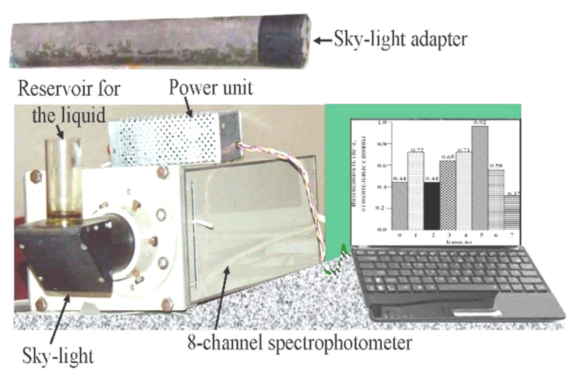

Fig. 10. Universal Adaptive Identifier (version 2) based on 8-channel spectrophotometer and fragment of its interface.

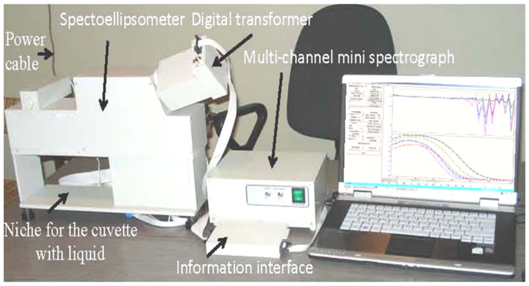

Fig. 11. Adaptive Identifier (version 3) based on the 35-channel spectroellipsometer

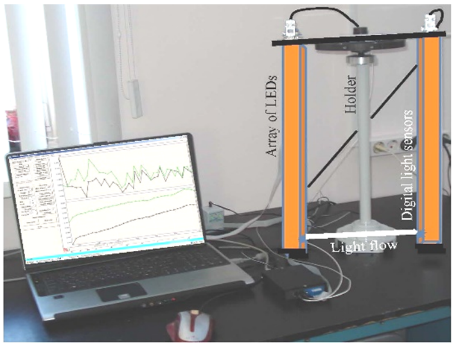

Fig. 12. Principal structure of multi-channel Adaptive Identifier (version 4). LEDs is light-emitting diodes

TABLE III. BASIC CHARACTERISTICS OF DIFFERENT VERSIONS OF ADAPTIVE IDENTIFIER.

Parameter	**Value**			
	AI-1	***AI-2***	***AI-3***	***AI-4***
Spectral range, nm	380-930		380-930	360-800
Minimal measurement time, s	0.5	1.0	0.6	3.0
Precision in Psi Delta	0.003 0.01	0.05 - -	0.003 0.01	0.003 0.01
Polarization rotation angle, degree	0.001	-	0.001	0.001
Long-term stability, degree	0.01	0.05	0.01	0.01
Weight of measuring device (kg): polarization block analyzer block	4.0 2.0 2.0	5.0 - -	4.5 2.3 2.2	3.0 1.5 1.5

VI. THE ECOINFORMATICS TOOLS AND 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. Krapivin and Shutko [7] give description of the GIMS experimental tests of which were realized in different climatic conditions. The some of platforms represented above 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 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.

TABLE IV. A PRECISION OF THE MFAIMS DIFFERENT VERSIONS UNDER THE DIAGNOSTICS OF SINGLE-COMPONENT LIQUID SOLUTIONS

Water solution	**The MFAIMS version and its error (%)**			
	MFIM S-128	***MFIM S-8***	***MFIM S-35***	***MFIM S-512***
$CuSO_4$	7.1	12.0	8.2	4.3
NaCl	6.5	9.1	7.3	4.3
$CaCl_2$	4.4	6.7	5.3	1.9
$AlCl_3$	4.6	6.8	6.1	1.8
$NaHCO_3$	5.4	8.7	7.2	2.3
NH_4OH	5.3	7.9	6.6	2.1
$ZnSO_4$	4.9	8.1	5.1	1.9
Furaciline	4.4	6.3	4.6	1.7
Bifidumbacterium	3.7	9.3	4.1	2.1
Potassium iodine	5.2	8.8	3.9	1.8
Nitrofural	5.1	8.7	5.4	1.8
$Al(NO_3)_3$	4.5	8.6	5.5	1.9
MgF_2	6.7	11.3	7.1	3.1
Na_3PO_4	3.3	10.2	3.9	2.7
$BaSO_4$	6.2	7.8	6.6	1.8
HgC_2O_4	5.6	8.5	6.3	1.3
$CaSO_4$	4.5	9.5	5.2	1.1
Propolis	3.8	4.9	5.0	0.9

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 modeling.
- Inventarization 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 modeling; 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. The MFIMS functions were controlled by comparison of real solutions and their assessments by means of optical and microwave measurements during series of ecological expeditions in different climatic zones [7,9,10].The measurements were realized in the laboratory conditions using a set of specific solutions and on-site under different climatic conditions. A learning procedure is in the database formation of spectral standards with digitization of chemical element concentration by ten sections in the range up to nontransparent state (saturated solution). For example, calcium sulfate solubility is restricted by 0.2036 g. per 100 ml of the water at 20C. CaSO4 was discovery on Mars in a vein of the surface. Barium sulfate and hydrogen oxalate are weakly soluble maximal solubility of which is 0.0015g/l and 0.107 g/l, respectively at 18C. Spectral images of every section memorize to the MFIMS database as spectral standards. The MFIMS precision was assessed as a result of recognition and concentration evaluation for new water solution. Several new water solutions were considered and final assessment of the MFIMS precision was made by the averaging the results. Table 4 characterizes the MFIMS precision.

ACKNOWLEDGMENT

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 [4-6] 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 (on-site) samplings, using GIS-information and mathematical modeling of physics-chemical processes in selected areas. GIMS-technology can effectively be applied for solving many agricultural, hydrological, 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 and 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.
- Basic functions of the MFIMS consist in the realization of following operations:
- Reduction to unique system of spatial information delivered by different sources: geographical maps, satellite images, remote-sensing and on-site measurements.
- Creation of geometrical description of the land surface within the compatible topological structures.
- Firming the series of models and software for the transformation between the vector and expanded data.
- Overcoming information uncertainties arising under the water quality assessment.
- Supporting the coordination geophysical and geochemical characteristics of the water system on each of its spatial level.
- Synthesis of symbolic map-scheme for the distribution of environmental characteristics.
- Forecasting the water system evolution with classification of its phases and detection of its critical states.

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