A NEW TECHNOLOGY OF VEGETATION MICROWAVE MONITORING

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Abstract.*The objective of this paper is threefold: 1) To present a working methodology for the combined use of modeling technology and microwave remote sensing measurements in the assessment of attenuation of electromagnetic waves by the vegetation cover; 2) To illustrate this methodology with computer calculations of the attenuation for various soil-plant formations; 3) To give a perspective of the developed methodology applied to the study of global environmental change, including the radiative forcing problem.*
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Introduction

The solution of the majority of applied problems within agrometeorology, forestry, animal husbandry, and other areas of human activity directed toward the protection of nature is difficult for the reason that effective methods of control of the *soil-vegetation* system (SVS) are insufficiently developed.

During the last few years, the global carbon cycle problem has acquired a special significance because of the greenhouse effect. Knowledge of the state of the SVS allows one to have a real picture of the spatial distribution of the carbon sinks and sources on the Earth's surface.

As is well known, among the types of remote sensing techniques, microwave radiometry proves effective for observations of SVS environmental parameters [1-10]. However, these observations are a function of different environmental conditions mainly depending on the SVS type. That is why it is necessary to develop data processing methods for microwave monitoring that allow the reconstruction of the SVS characteristics with consideration of the vegetation types and that provide the possibility of synthesizing their spatial distribution.

Technology of Vegetation Microwave Monitoring

As is noted in [4], the problem of microwave remote sensing of the vegetation cover requires the study of the attenuation of electromagnetic waves (EMW) within the vegetation layer. The solution of the problems arising here is made possible by the combination of experimental and theoretical studies. The vegetation cover commonly is characterized by varied geometry and additional parameters. Therefore, a knowledge of the radiative characteristics of the SVS as functions of time and spatial coordinates can be acquired by means of a combination of on-site measurements and models. General aspects of such an approach have been considered by many authors [1-10]. But these investigations were mainly restricted to the investigation of models describing the dependence of the vegetation medium on environmental properties, as well as the correlation between the morphological and biometrical properties of the vegetation and its radiative characteristics.

One prospective approach to the solution of the problems arising here is GIMS-technology (GIMS=GIS+Model) [7]. A combination of an environmental acquisition system, a model of the functioning of the typical geoecosystem, a computer cartography system, and a means of artificial intelligence will result in the creation of a geoinformation monitoring system for the typical natural element that is capable of solving many tasks arising in the microwave radiometry of the global vegetation cover. The GIMS-based approach, in the framework of the EMW attenuation by the vegetation canopies, allows the synthesis of a knowledge base that establishes the relationships between the experiments, algorithms and models. The links between these areas have an adaptive character giving an optimal strategy for experimental design and model structure. The goal of this paper is to explain and assess the application of the GIMS method to the tasks of reconstructing the spatial and temporal distribution of the SVS radiative characteristics.

Many investigators support a constructive technology for microwave monitoring of vegetation covers. But greater accuracy of this technology is required for the reason that the various vegetation covers, especially vegetation canopies, are very dynamic and complicated for experimental study or model parametrization. In this respect, there are two aspects. One is connected with the creation of a highly productive technology to estimate the land cover characteristics. The other is connected with the climate change problem through the greenhouse effect [7]. In these cases the GIMS-technology recommends a balanced scheme for the solution of problems of land cover monitoring. As follows from Fig.1, a combination of experimental and theoretical studies of attenuation of microwave radiation by vegetation cover is required. It is actually possible to synthesize the experimental dependence between attenuation and a restricted set of vegetation parameters. An estimation of attenuation of microwave radiation by vegetation cover in real time is possible only with the application of microwave models and interpolation algorithms.

From the point of view of microwave remote sensing, a knowledge of the water content of the vegetation is an important element to be used for the synthesis of a model of attenuation of microwave radiation by the vegetation. This knowledge can be acquired by making use of the fact that water absorption features dominate the spectral reflectance of vegetation in the near-infrared spectrum . Using such indexes as the normalized difference vegetation index (NDVI), plant water indexes (PWI), the leaf area index (LAI), the simple ratio vegetation index (SRVI), and the canopy structure index (CSI) it is possible to determine the canopy structure and photosynthetic tissue morphologies. The correlation between the leaf water content and the leaf-level reflectance in the near-infrared has been successfully studied by many authors that linked the leaf and canopy models to study the effects of leaf structure, dry matter content, LAI, and canopy geometry. As a result, it is possible to parametrize the forest structure including the canopy and crown closure, stem density, tree height, crown size, and other forest parameters.

Quantitative information about SVS properties may be obtained by means of different remote sensing techniques based on passive microwave data [1]. This approach is particularly effective under an estimate of the hydraulic parameters of the soil-plant formations. The knowledge of these parameters allows one to parametrize the water balance of the territory occupied by vegetation of a given type and to model the growth of the plants. Under this approach a comparison of remote data registered at different EMW ranges may provide a high precision of estimates of the water content in the various layers of the SVS (canopy, trunks, stalks, and soil). Moreover, the combination of data analysis with remote sensing allows one to estimate the parameters of the ground vegetation cover and its role in the fluxes of sensible and latent heat from the surface to the atmosphere.

Thus, a set of vegetation-related parameters are to be generated with specific time and space resolutions to use as the basis for the calculation of EMW attenuation by the vegetation layer. Available remote monitoring data are to be used as input information for algorithms and models to synthesize the spatial-temporal distribution of the attenuation effects.

Field observations are the initial stage to determine the important properties of the vegetation cover. Many problems exist in providing the model descriptions of biological and physical processes which operate on different timescales. The tasks of describing EMW attenuation by the vegetation cover has timescales ranging from less than a second to hours or days and also has various spatial scales. Consequently, a parametrical description of the EMW attenuation by the vegetation cover demands an enormous number of experimental observations, the planning of which depends on the model type and the vegetation component under investigation. That is why the effective synthesis of the final results into given space-time scales may be realized by application of GIMS-technology [1,7, 8-10]. This allows one to solve the problem of scaling the *soil-vegetation-atmosphere* model and to describe the radiative transfer processes on a scale from that of individual plants or small plots to large-scale biomes.

As was mentioned above, the satellite data can be used to calculate many parameters of the vegetation cover, including unstressed stomatal conductance, photosynthetic capacity, the fraction of photosynthetically active radiation absorbed by the green portion of the vegetation canopy, canopy reflectance, transpiration, and other important environmental characteristics. These data and the results of field experiments allow one to generate model experiments.

The GIMS-based method uses a priori information to start the model experiment. Under this procedure, a set of algorithms operate over the whole data set and determine the input parameters of the model used. The model structure and its coefficients are changed depending on the fluctuation of the difference between the experimental and model estimations of the EMW attenuation effect. Usually, the central part of the model describes the fundamental processes within the SVS, such as the radiation balance, water circulation (evapotranspiration, root water uptake), photosynthesis and mortality.

Methods of local environmental diagnostics can not give complex estimations for the state of natural objects or processes, especially in the case when the environmental element occupies an enormous area. Any technical means of environmental data collection provides information that is spotty in time and fragmentary in space. In particular, microwave radiometric systems of remote sensing, widely used as the equipment of airborne laboratories and satellites, give data sets that are connected geographically along the traces.

Reconstruction of the information within the inter-trace space is possible only by applying spatial-temporal interpolation algorithms (the development of which is a specific problem).

One effective technique is a combination of monitoring data and a model describing the functioning of the environmental system within the studied area. Such an approach to environmental monitoring problems is developed in the framework of ecoinformatics [7]. Ecoinformatics suggests the development of a set of models for various processes in the biosphere, taking into account their spatial inhomogeneity, and the combination of existing databases with already functioning systems for environmental observations. This allows one to answer the following questions:

- 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 into consideration between the information contents and the costs of on-site and remote-sensing data?
- what kind of mathematical models can be used for both data interpolation and their extrapolation in terms of time and space in order 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?

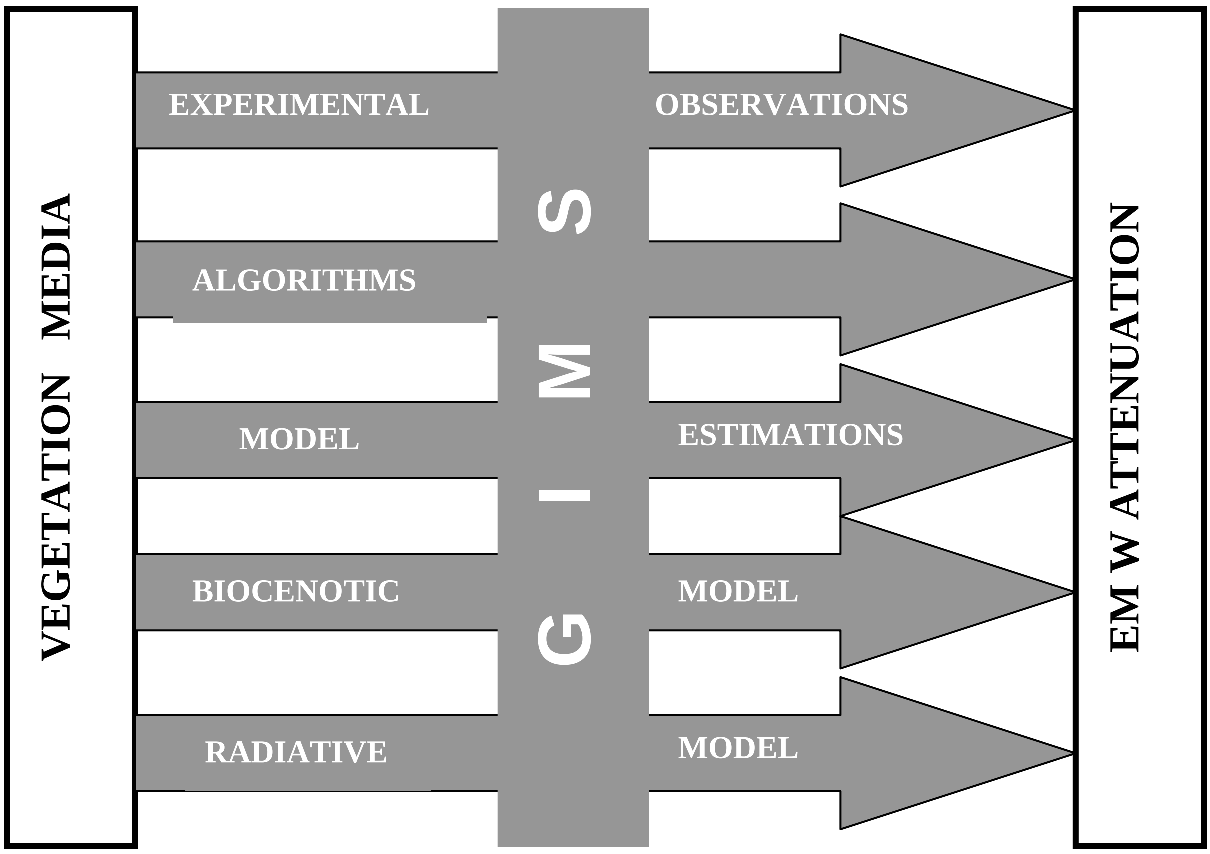

Fig. 1. Schematic showing the relationship between different kinds of procedures of the GIMS-based method for the assessment of EMW attenuation by vegetation media.

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. This unification forms the new information technology called GIMS-technology. The term *GeoInformation Monitoring System* (GIMS) is used to describe the formula mentioned in the introduction of this report. The relationship between GIMS and GIS is described in [2]. 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 in [1-10].

Conclusions

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. A model is created describing this interaction and the functioning of different levels of the spatial and temporal 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.

References

[1] Armand N.A., Krapivin V.F., and Mkrthyan F.A. (1987) *Methods for data processing in the radiophysical investigation of the environment.* Science Press, Moscow, 270 pp. (in Russian)

[2] Armand N.A., Krapivin V.F., and Shutko A.M. (1997) *GIMS-technology as a new approach to the informational service of environment study* // Problems of Environment and Natural Resources, 3: 31-50 (in Russian).

[3] Chukhlantsev A.A. and Shutko A.M. (1988) *Microwave radiometry of the Earth's surface: effect of vegetation* // Research of the Earth from Space, 2: 67-72 (in Russian).

[4] Chukhlantsev A.A., Shutko A.M., and Golovachev S.P. (2003) *Attenuation of electromagnetic waves by vegetation canopies in the 100-1000 MHz frequency band.* ISTC/IRE Technical Report, #2059-1, 59 pp.

[5] Del Frate F., Ferrazzoli P., and Schiavon G. (2003) *Retriveing soil moisture and agricultural variables by microwave radiometry using neural networks* // Remote Sensing of Environment, 84(2): 174-183.

[6] Ferrazzoli P. and Guerriero L. (1996) *Passive microwave remote sensing of forests: a model investigation* // IEEE Trans. on Geosci. And Remote Sensing, 34(2): 433-443.

[7] Kondratyev K.Ya., Krapivin V.F., Phillips G.W. *Global environmental change: Modeling and Monitoring. Springer*, Berlin, 319 pp.

[8] Krapivin V.F. and Shutko A.M. (2002) *Investigations in the field of microwave monitoring of land covers* // Problems of Environment and Natural Resources, 4:44-53 (in Russian).

[9] Krapivin V.F. and Shutko A.M. (1989) *Observation and prognosis of the state of environmental resources, ecological and meteorological situations by geoinformational monitoring system.* The Fourth Int. Symposium on Okhotsk Sea & Sea Ice. Abstracts. 5-7 February, Mombetsu, Hokkaido, Japan, pp. 1-4.

[10] Krapivin V.F., Shutko A.M., and Ivanov D.S. (2002) *New technology for the synthesis of environment monitoring system* // Problems of Environment and Natural Resources, 4: 2-7 (in Russian).

[11] Nitu, C., Krapivin, V. and Bruno, A. (2000) *System modeling in ecology.* Printech, Bucharest, 260 pp.

[12] Nitu, C., Krapivin, V. and Bruno, A. (2000) *Intelligent technics in ecology*, Printech, Bucharest, 280 pp