Microwave Radiometry Technology for the Nature - Society System Biocomplexity Assessment

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***Abstract* – The problem of biocomplexity in global Nature - Society System (NSS) is considered in the framework of complex hierarchical systems theory. The interactions between the NSS elements having different spatial and temporal scales are modelled in the terms of information value, diversity of elements, dynamical stability of biogeochemical cycles, and relations between the spaces of elements. Simulation-methodical model of biocomplexity dynamics founded on the correlations between basic elements of the NSS is synthesized. Mechanisms of living processes regulation and presence of restriction by the environment quality are taken into consideration. Principal aspects of the NSS model are formulated, and analysis of corresponding knowledge base is given. Interconnection between the criteria of the NSS biocomplexity, stability and survivability are analysed.**

This report is oriented on the development of biocomplexity indices basing on the remotely measured environmental characteristics. Microwave radiometry is used as effective technique to assess the land cover parameters. Other ranges help to form input information for the NSS Biocomplexity Model that will be developed in the framework of this work.

Keywords - Biocomplexity, Nature - Society System, microwaveradiometry, global model

I. INTRODUCTION

Biocomplexity refers to phenomena that result from dynamic interactions between the physical, biological and social components of the Nature-Society System (NSS). The investigations of the processes of interaction between the Society and Biosphere are, as a rule, targeted at understanding and estimating the consequences of such interactions. The reliability and precision of these estimations depend on criteria founded on conclusions, expertise and recommendations. At present, there is no unified methodology for selection between the set of criteria due to the absence of a common science-based approach to the ecological standardization of anthropogenic impacts on the natural environment. After all, the precision of the ecological expertise for the functioning and planning of anthropogenic systems, as well as the quality of the global geoinformation monitoring data, depend on these criteria.

The processes that have their origin in the environment can be presented as a combination of interactions between its subsystems. The human subsystem is a part of the environment and it is impossible to divide the environment into separate subsystems such as Biosphere and Society. The problem is to search for methodologies to describe existing feedbacks between Nature and Humanity and to simulate reliably the dynamic tendencies in the NSS. Unfortunately, the part of the NSS that is responsible for the quality of modelling the climatic processes introduces instability in the modelling results. That is why it is supposed below that the NSS climatic component is replaced by a scenario describing stable climatic trends during the time interval of investigation. What is actually studied is the NSS.

We are introducing the scale of biocomplexity ranging from the state where all interactions between the environmental subsystems are broken to the state where they correspond to natural evolution. In this case, we have an integrated indicator of the environmental state including bioavailability, biodiversity and survivability. It reflects the level of all types of interactions among the environmental subsystems. In reality, specific conditions exist where these interactions are changed and transformed. For example, under the biological interaction of the type consumer/producer or competition-for-energy-resources there exists some minimal level of food concentration where contacts between interacting components cease. In the common case, physical, chemical and other types of interactions in the environment depend upon specific critical parameters. Environmental dynamics is regulated by these parameters and the main task is in the parametrical description of it. Biocomplexity reflects these dynamics.

II. BIOCOMPLEXITY MODEL

The NSS consists of subsystems $B_i (i = 1,..., m)$ the interactions of which are formed during time as functions of many factors. The NSS biocomplexity reflects the structural and dynamic complexity of its components. In other words, the NSS biocomplexiry is formed under the interaction of its subsystems $\{B_i\}$. In due course the subsystems B_i can change their state and, consequently, change the topology of the relations between them. The evolutionary mechanism of adaptation of the subsystem B_i to the environment allows the hypothesis that each subsystem B_i, independently from its type, has the structure $B_{i,S}$, behaviour $B_{i,B}$ and goal $B_{i,G}$, so that $B_i = \{B_{i,S}, B_{i,B}, B_{i,G}\}$. The strivings of subsystem B_i to achieve certain preferable conditions are represented by its goal $\hat{A}_{i,G}$. The expedience of the structure $B_{i,S}$ and the purposefulness of the behaviour $B_{i,B}$ for subsystem B_i are estimated by the effectiveness with which the goal $B_{i,G}$ is achieved.

As an example, we consider the process of fish migration. The investigations of many authors revealed that this process is accompanied by an external appearance of purposeful behaviour. From these investigations it follows that fish migrations are subbordinated to the principle of complex maximization of effective nutritive ration, given preservation of favourable environmental conditions (temperature, salinity, dissolved oxygen, pollution level, depth). In other words, the travel of migrating species takes place at characteristic velocities in the direction of the maximum gradient of effective food, given adherence to ecological restrictions. That is why we can formulate that the goal $B_{i,G}$ of the fish subsystem is toward the increase of their ration, the behaviour $B_{i,B}$ consists in the definition of the moving trajectory securing the attainability of the goal $B_{i,G}$.

Since the interactions of the subsystems $B_i (i = 1,..., m)$ are connected with chemical and energetic cycles, it is natural to suppose that each subsystem B_i realizes the geochemical and geophysical transformation of matter and energy to remain in a stable state. The formalism of approach to this process consists in the supposition that the interactions between the NSS subsystems are represented as a process whereby the systems exchange a certain quantity V of resources spent in exchange for a certain quantity W of resources consumed. Represent this process by the name (V,W)-exchange.

The goal of the subsystem is the most advantageous (V,W)-exchange, i.e. it tries to get maximum W in exchange for minimum V. The quantity W is a complex function of the structure and behaviour of interacting subsystems, $W=W(V,B_i,\{B_k, k\in K\})$, where K is the space of subsystem numbers interacting with the subsystem B_i.

Designate $B_K=\{B_k, k \in K\}$. Then the following (V,W)-exchange is the result of interactions between the subsystem B_i and its environment B_K

$$\begin{aligned} W_{i,0} &= \max_{B_{ii}} \min_{B_K} W_i\left(V_i, B_{i,opt}, B_{K,opt}\right) \\ W_{K,0} &= \max_{B_K} \min_{B_i} W_k\left(V_K, B_{i,opt}, B_{K,opt}\right) \end{aligned} \tag{1}$$

Figure1 represents a block-scheme for the global model of the NSS (GMNSS). The synthesis of the GMNSS is based on its consideration as a self-organizing and self-structuring system, in which the elements are coordinated in time and space by the process of natural evolution. The anthropogenic constituent in this process breaks this integrity. Attempts to parameterize, on a formal level, the process of co-evolution of nature and humans, as elements of the biosphere, are connected with the search of a single description of all processes in the NSS, which would combine all spheres of knowledge in perceiving the laws of the environment. Such a synergetic approach forms the basis of numerous studies in the field of global modelling [1,2].

All of this corroborates the fact that biocomplexity is related to categories which are difficult to measure empirically and to express by quantitative values. However, we will try to transfer the truly verbal tautological reasoning to formalized quantitative definitions. For the transition to gradations of the scale Φ with quantitative positions it is necessary to postulate that relationships between two values of Φ are of the type $\Phi_1<\Phi_2$, $\Phi_1>\Phi_2$ or $\Phi_1\equiv\Phi_2$. In other words, always there exists a value of the scale ρ that defines a biocomplexity level $\Phi\rightarrow\rho = f(\Phi)$, where f is a certain transformation of the biocomplexity concept to a number. Let us attempt to search for a satisfactory model with which to reflect the verbal biocomplexity image onto the field of conceptions and signs, subordinating to the formal description and transformation. With this purpose m subsystems of the NSS are selected. The correlations between these subsystems are defined by the binary matrix function: $X = \| x_{ij} \|$, where $x_{ij}=0$, if subsystems B_i and B_j do not interact and $x_{ij}=1$, if subsystems B_i and B_j are interacting. Then any one point $\xi \in \Phi$ is defined as the sum $\xi = \sum_{i=1}^{m} \sum_{j>i}^{m} x_{ij}$. Certainly there arises the need to overcome uncertainty for which it is necessary to complicate the scale Φ; for example, to introduce weight coefficients for all NSS subsystems. The origin of these coefficients depends on the type of subsystem. That is why three basic subsystem types are selected: living and nonliving subsystems and vegetation. Living subsystems are characterized their density, estimating by numbers of elements or by biomass value per unit area or volume. Vegetatio n is characterized by the type and portion of occupied territory. Nonliving subsystems are measured by their concentration per unit square or volume of the environment. In the common case, certain characteristics $\{k_i\}$, corresponding to the significance of the subsystems $\{B_i\}$, are assigned to every subsystem $B_i(i = 1,..., m)$. As a result we obtain more closely the definition of the formula to move from the biocomplexity concept to the scale Φ of its indicator:

$$\xi = \sum_{i=1}^{m} \sum_{j>i}^{m} k_j . x_{ij} \tag{2}$$

It is clear that $\xi = \xi(\varphi,\lambda,t)$, where φ and λ are geographical latitude and longitude, respectively, and t is the current time. For the territory Ω the biocomplexity indicator is defined as mean value:

$$\xi\Omega(t) = (1/\sigma) \int_{(\varphi,\lambda)\in\Omega} \xi(\varphi,\lambda,t) d\varphi d\lambda \tag{3}$$

where σ is the area of Ω.

Thus the indicator $\xi_\Omega(t)$ is the integrated NSS complexity characterization reflecting the individuality of its structure and the behaviour at each time t in the space Ω. According to the natural evolution laws a decrease (increase) in ξ_Ω will correspond to an increase (decrease) of biocomplexity and the survivability of the nature-anthropogenic systems. Since a decrease of biocomplexity disturbs the exclusiveness of the biogeochemical cycles and leads to a decrease of stress on the nonrenewal of resources, then the binary structure of the matrix X is changed in the direction to intensify the resource-improverishment technologies. The vector of energetic exchange between the NSS subsystems is moved to the position where the survivability level of the NSS is reduced.

$$\xi = \sum_{i=1}^{m} \sum_{j>i}^{m} k_j . x_{ij} \qquad (4)$$

It is clear that $\xi = \xi(\varphi, \lambda, t)$, where φ and λ are geographical latitude and longitude, respectively, and t is the current time. For the territory Ω the biocomplexity indicator is defined as mean value:

$$\xi\Omega(t) = (1/\sigma) \int_{(\varphi,\lambda)\in\Omega} \xi(\varphi, \lambda, t) d\varphi d\lambda \qquad (5)$$

where σ is the area of Ω.

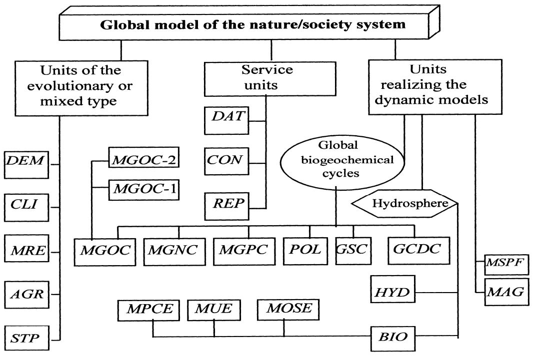

Fig. 1. Structure and items of the GMNSS. List of items is given in Table 1

TABLE I. A DESCRIPTION OF THE ITEMS IN FIGURE 1

Item	An item description
DEM	A set of demographic models that parametrize the population dynamics
WITH	The consideration of age structure
CLI	A set of climate models with various spatial resolution
MRE	Model for the control of mineral resources
AGR	Model of agriculture production
STP	Model of science-technical progress
DAT	Controlling procedure of interface between the MGNSS items and database
CON	Informational procedure for the MGNSS items adaptation to
THE	Simulation experiment conditions and its control
REP	Reporting and visualization procedure
GCDC	Model of global carbon dioxide cycle
GSC	Model of global sulphur cycle
MGOC	Model of global oxygen (MGOC-1) and ozone (MGOC-2) cycles
MGNC	Model of global nitrogen cycle
MGPC	Model of global phosphorus cycle
POL	A set of models parametrizing the pollutant kinetics within different medias
BIO	A set of models parametrizing the aquatic ecosystems in different climatic zones
HYD	Model of global hydrodynamic processes and the biosphere water balance
MSPF	A set of biocenotic models describing different classification of soil-plant formations
MAG	Model of the magnetosphere processes related to the global biogeochemical cycles
MUE	Typical model of the upwelling ecosystem of the World Ocean
MOSE	Model of the Okhotsk Sea Ecosystem
MPCE	Model of Peruvian Current Ecosystem

III. BIOCOMPLEXITY OF THE OKHOTSK SEA

Trophical piramid Of the Okhotsk Sea ecosystem is described by the matrix $X = || x_{ij} ||$, where x_{ij} is binary value equaled to «1» or «0» under existence or absence of nutritive correlation between the ith and jth components, respectively. Define the biocomplexity as function:

$$\xi(\varphi, \lambda, z, t) = \sum_{i=1}^{20} \sum_{j=1}^{19} x_{ij} C_{ij} \qquad (6)$$

$$x_{ij} = \begin{cases} 1, \text{ if } B_m \geq B_{m,\min} \\ 0, \text{ if } B_m < B_{m,\min} \end{cases}$$

Where: φ and λ are geographical latitude and longitude; t is current time; $C_{ij} = (k_{ji} B_{i,*} / \Sigma_{j+})$ is the nutritive pressure of the jth component upon the ith component; z is the depth; $B_{m,min}$ is the minimal biomass of the mth component consumed by other trophic levels; $\Sigma_{i+} = \sum_{m\in S_i} k_{im} B_m$ is real food storage which is available to the ith component; $B_{m,*} = max\{0, B_m - B_{m,min}\}$; $k_{im} = k_{im}(t, T_W, S_W)(i = 1, .., 17)$ is the index of the satisfaction of nutritive requirements of the ith component at the expense of the mth component biomass; k_{im} (i=18,19) is the transformation coefficient from mth coponent tothe ith component; $k_{i\ 20}$ is the characteristic of anthropogenic influence on the ith component; $S_i = \{i: x_{ij} = 1\ j = 1, \dots, 19\}$ is the food spectrum of the ith component' T_W is water temperature; S_W is water salinity.

Maximal value of $\xi = \xi_{max}$ (≈ 20) is reached during spring-summer time when nutritive relations into the Okhotsk Sea ecosystem are extended, the intensity of energetic exchanges is increased, horizontal and vertical migration processes are stimulated. In the winter time value of ξ is changed near ξ_{min}(≈8). Spatial distribution of ξ reflects a local variability of food spectrum for the components. Calculations show that basic variability into the $\xi^* = \xi/\xi_{max}$ is caused by migration processes. Under this the quick redistribution of interior structure of matrixes X and $\|C_{ij}\|$ are occured. Many fishes during spring time migrate to the shelf zone, and during winter time they move to the central aquatories of sea. Therefore value $\xi^* \to 1$ during spring and $\xi^* \to 0.6$ during winter for the shelf zone, respectively. It means that biocoplexity of Okhotsk sea ecosystem in the shelf decreases by 40% in winter in comparison with spring. For the central aquatories the ξ^* is changed near 0.7 during year. Such stability of biocomlexity indicator is explained by the balance between nutritive correlations and productivity during spring, summer and winter times.

It can be to establish that variability in the ξ^* reflects the changes of fish congestions which are controlled by environmental conditions. Specifically, during spring time *Clupeapallasi escapes* occupy the area with the T_W <5°C. Other fishes have the elective depth for their feeding and spawning. All these processes influence on variability of the ξ^*. A more detail investigation of correlations between value ξ^* and structural and behavioral dynamics of Okhotsk Sea ecosystem demands additional studies.

Spatial distribution of the indicator of biocomplexity Okhotsk seas in the spring-and-summer period, designed by a technique described in section 2. (Fig. 2).

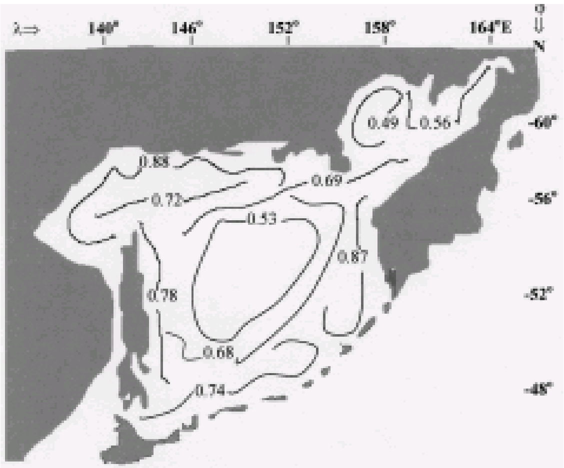

Fig. 2. Spatial distribution of the indicator of Biocomplexity Okhotsk See.

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Biocomplexity is clearly important characteristic of the NSS dynamics. It has importance for complex study of interactions between living and non-living elements of environment and, more significantly, it is can use make valuable contributions to the understanding and solution key socio-economic and environmental problems. It is reasonable to expect that over the nearest time the biocompexity will be to use as informative indicator analogous to such indicators as normalized difference vegetation index (NDVI), leaf area index (LAI) etc. [3]. It appears that the only satisfactory way to develop an appropriate definition of biocomplexity indicator is to summarize the many structural ideas in the forms of a series of global biospheric models. The synthesis of these models requires not only their coexistence with global databases, but also the interconnections between different sources of data. This paper proposes global model and biocomplexity indicator only one category in which biospheric processes are considered as predominating. Further study is to be oriented on the expansion of information taking into account in the global model and it is necessary the correlation dependencies between socio-economic and biospheric components make more precise.

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