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 threefold: 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. 3) To give the perspective of developed methodology application to study global environment change including radiative forcing problem related to the carbon cycle.

Keywords: remote observations, expert system, global ecodynamics, data processing, scenarios

1. The technology of Geoinformation Monitoring

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 [1-10].

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.

2. 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 shown in Fig. 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.

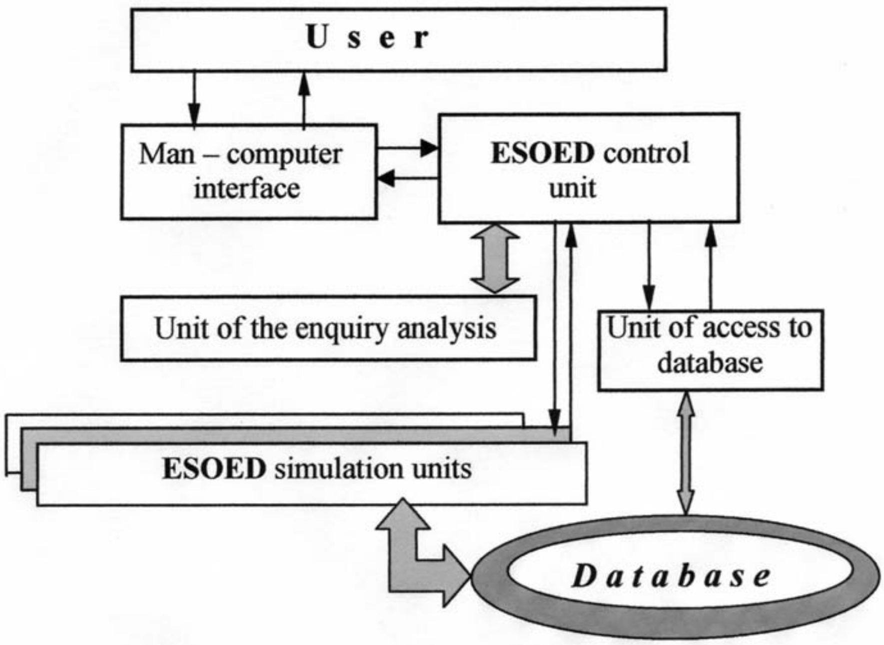

Figure 1. ESOED information units.

3. 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 charecterisatics. 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 of Fig. 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 $\Omega_{ij} = \{(\varphi,\lambda): \varphi_i \le \varphi \le \varphi_i + \Delta\varphi_i, \lambda_j \le \lambda \le \lambda_j + \Delta\lambda_j\}$. The choice of the the pixels size is defined by set of the conditions, definied 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 $\Omega_{ijk} = \{(\varphi,\lambda,z): (\varphi,\lambda) \in \Omega_{ij}, z_k \le z \le z_k + \Delta z_k\}$ are formed. All elements of Ω_{ijk} are considered as uniform. Finally, atmosphere above the pixel Ω_{ij} are descretized by the height in accordance with the atmospheric pressure levels, or on typical layers by height.

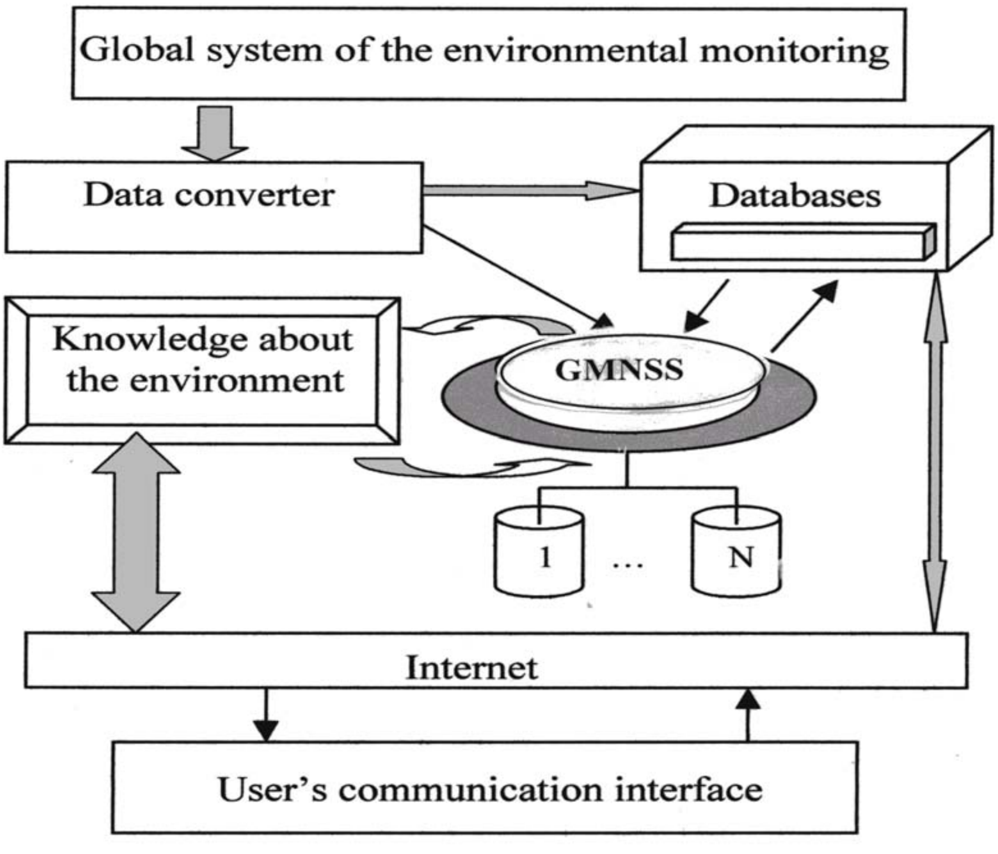

Figure 2. Conceptual block-diagram of geoinformation monitoring and use of the global model of *Nature-Society* system (GMNSS).

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 [7]. In [8,9] adaptive procedure for global model fitting in the geoinformation monitoring system is offered. This procedure is characterized by scheme represented in Fig. 3.

Approach of the moment of the natural catastrophe arising is characterized by hit of the vector $\{x_i\}$ in a certain claster 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 [6]. 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 permetted by the applied technical means;
2) recording suspecious 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 suspecious element to make a statistical decision about its noise or signal character and in the latter case the rest of the suspecious 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 occurence with the transmission of information to the respective environmental control services;
5) iterative procedure to locate an anomaly.

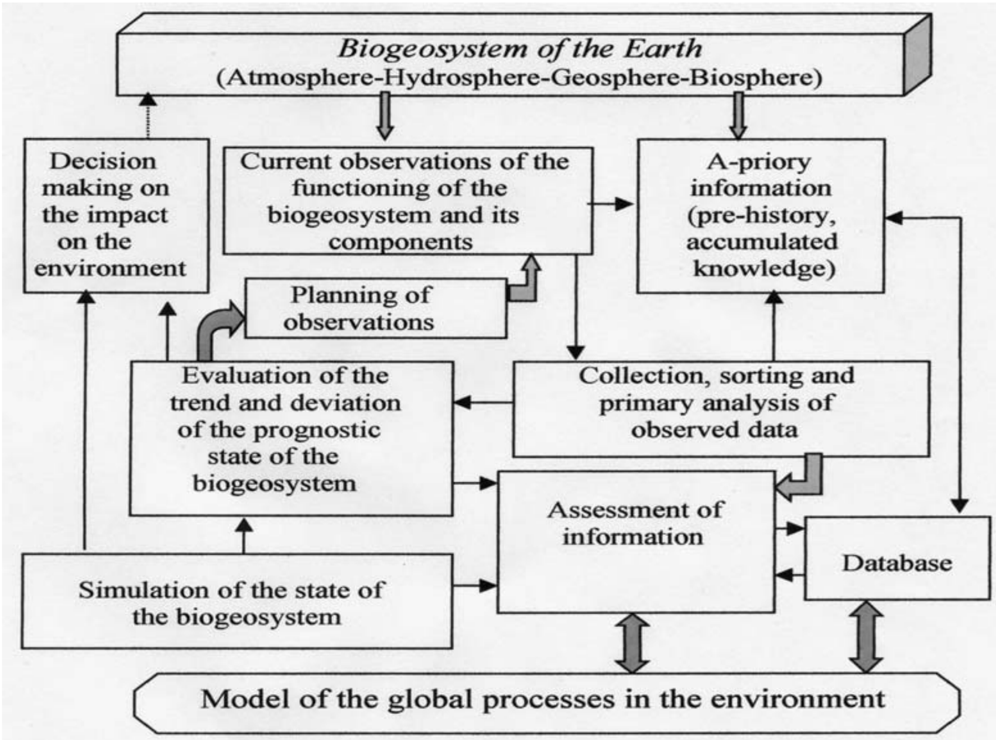

Figure 3. Concept of the ESOED adaptation procedure.

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 in accordance with scheme of Fig. 3.

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, expositio 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.

4. The ESOED Related to the Global Carbon Cycle Problem

The solution of the majority of applied problems within global carbon cycle 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. 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.

As is noted in [2], 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 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 [1-5,10].

One prospective approach to the solution of the problems arising here is GIMS-technology. 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 reliability of the assessment of the role of CO_2 in the greenhouse effect formation depends on a detailed consideration of the global biogeochemical carbon cycle dynamics in the models and on the accuracy of the assessment of its characteristics. The accuracy of estimates of carbon fluxes in the terrestrial part of the biosphere is the function of a detailed quantization of the SVS types and accuracy of the parameterization of the biocenotic processes. In this connection the world map of SVS is given in [7]. An exemplary scheme of carbon flux in this model is characterized in Fig. 4 and Table 1.

The vegetation cover parameters change during the year depending on the weather situation. The specific biomass Q_i of the *i*th type of vegetation at time *t* can be parametrized by means of the following equation:

$$\partial Q_i / \partial t = R_i - M_i - E_i$$

where R_i is the biomass productivity and M_i and E_i are the biomass losses at the expense of withdrawal and transpiration, respectively.

The function $M_i(\varphi, \psi, t)$ reflects the set of natural M_{Ni} and anthropogenic M_{Ai} processes leading to vegetation biomass losses ($M_i = M_{Ni} + M_{Ai}$):

$$M_i(\varphi, \psi, t) = \mu_i(t) Q_i(\varphi, \psi, t),$$

where φ, ψ are the latitude and longitude, respectively.

The flux E_i is calculated by means of the formula [10]:

$$E_i(\varphi, \psi, t) = \frac{\rho c_p \left[e^*(T_c) - e_a \right]}{\gamma_p (r_c + r_b)},$$

where $e^*(T_c)$ is the saturated vapor pressure inside the canopy foliage (in units of Pa), e_a is the vapor pressure in the canopy air space (Pa), r_c is canopy resistance (sm^{-1}), r_b is the bulk leaf boundary layer resistance of the canopy (sm^{-1}), ρ is air density ($kg \cdot m^{-3}$), c_p is the air specific heat ($J \cdot kg^{-1} \cdot K^{-1}$) and γ_p is the psychrometric constant ($Pa \cdot K^{-1}$).

The actual plant productivity is approximated as follows:

$$R_i = \delta_C^i \left(1 + \alpha_T^i \cdot \Delta T / 100 \right) \exp\left(-\beta_i / Q_i \right) \min\left\{ \delta_e^i, \delta_Z^i, \delta_W^i, \delta_B^i \right\},$$

where α_T^i and β_i are indices of dependence of production on the temperature variation ΔT and biomass Q_i, respectively; δ_ζ^i is the index of limitation of production by the factor ζ: e = illumination, Z = pollution, W = soil moisture, B = nutrient salts of the soil and c = atmosphere CO_2 concentration. The δ^i_ζ functions actually used in the framework of real situations are calculated based on existing or preliminary receiving data. Thus, the role played by the atmospheric CO_2 concentration C_A in photosynthesis is described by the relation $\delta^i_c = b_i C_A / \left(C_A + C^i_{0.5}\right)$, where $C^i_{0.5}$ is the CO_2 concentration for which $\delta^i_c = b_i / 2$. The influence of the solar radiation intensity $e(\varphi,\psi,t)$ on photosynthesis is parametrized by the relation $\delta^i_e = \delta^*_i \exp(1-\delta^*_i)$, where $\delta^*_i = e / e^*_i$ and e^*_i is the optimal illuminance for ith type of plant. A more detailed description of the correlations between the biocenotic processes is given in [8,9].

Fig. 4 represents the World Ocean as a complex hierarchic system. Modelling the organic carbon cycle in this system and *atmosphere-ocean* exchange processes are described by the 3-D model of oceanic ecosystem. Different items of this model were described in [6-9].

Following Nitu *et al.* [9], by the depth z the ocean was divided into four basic layers: photic to well-heated depths ($\Omega_U = \mathrm{U}[z_i, z_{i+1}]$, $z_0 = 0$; i=0,1,...,m-1); intermediate ($\Omega_P = \mathrm{U}[z_i, z_{i+1}]$, $i = m,...,m+n-1$); deep ($\Omega_L = \mathrm{U}[z_i, z_{i+1}]$, $i = m+n,..., m+n+l-1$), and bottom Ω_F. By the hydro-physico-ecological characteristics the layer Ω_U as a function of latitude φ, longitude ψ, and season t can be attributed to warm or cold waters, the layer Ω_P is photic but always with low water temperatures, in the layer Ω_L the phytoplankton is not produced. Finally, the layer Ω_F plays the role of a boundary layer.

The vertical CO_2 transport in the ocean is determined by advective fluxes $H^C_{19,ij}$ and gravitational sedimentation of dead organic matter (the flux $H^C_{20,ij}$). An advective transport from the i-th into the j-th reservoir of the ocean is considered proportional to the concentration of carbon in the respective reservoirs: $H^C_{19,ij} = \lambda_{2,ij} C_{a,i}$ ($a = U,P,L$), where $\lambda_{2,ij} = V_{ij} / V_i$, V_{ij} is the water volume transported per unit time from the i-th reservoir into the j-th reservoir; V_i is the volume of the i-th reservoir.

The following algorithm is used for a parameterization of the process of carbon sedimentation. The flux under unit area of the ocean is supposed to decrease exponentially with depth. If we denote the inflow of organic matter in the i-th reservoir as g_i and the net outflow of organic matter from the water surface as $H_{20\mathrm{T}}$, we obtain:

$$H^C_{20,1} = H_{20,T}\,;\; H^C_{20,i} = g_{i-1}(\sigma_i/\sigma_{i-1})exp[-(z_i - z_{i-1})/D_s]\,,\; (i=2,...,m+n+l),$$

where σ_i is the area of the i-th reservoir, D_s is the characteristic time of the organic matter particles sedimentation before their decomposition. The rate of decomposition in each reservoir is equal to: $R_{D,i} = H^C_{20,i} - H^C_{20,i+1}$, ($i$ = 1,...,$m+n+l$); $R_{D,F} = H^C_{20,m+n+l} - H^C_{16}$. However, if the time of the transition of the organic matter particles from one layer to another is short compared to D_s, then it is better to take $H^C_{20,i} = \lambda_1 C_{a,i}$, $H^C_{16,i} = \lambda_4 C_{F,i}$. In addition to these fluxes one should take into account the fluxes of detritus decomposition, solution of bottom sediments, and carbon consumption in the process of photosynthesis: $H^C_{17,i} = Const.$, $H^C_{18,i} = \lambda_3 D_{L,i}$, $H^C_{22,i} = \lambda_3 D_{U,i}$, $H^C_{21,i} = C_{31} R_{\Phi,i}$.

One of the promising results of modelling the effect of "fertilization" due to changing concentrations of atmospheric CO_2 has been discussed by Alexandrov and Oikawa [1] who, based on the TsuBiMo model, obtained a globally-distributed estimate of the contribution of various types of vegetation to the change of CO_2 flux on the "atmosphere-land" interface. To compare this result with the global simulation model (GSM) [7] and mathematical model of biosphere (MMB) [9] data, Fig. 5 presents curves of the dependence of pure primary production of the surface vegetation on changes of the atmospheric CO_2 partial pressure. The difference between these curves shows that a consideration in GSM and MMB of additional feedbacks compared with a simple TsuBiMo model specifies this dependence and recommends a more thorough structure of the MMB units as the GSM modernized version. Nevertheless, it should be borne in mind that despite an apparent simplicity of the parametric descriptions assumed in TsuBiMo, the result obtained with its use is reliable due to a detailed description of the spatial structure of vegetation covers (50×50 km).

Therefore the strategy of the modelling of the global carbon dioxide cycle should follow a paradigm of the complete description of all direct interconnections and feedbacks with the use of a set of functional dependences, the choice among which is made in the process of an adaptive-evolutionary numerical experiment.

Fig. 6 shows dependence of atmospheric CO_2 (C_a) dynamics on the different spatial resolution for SVS. As we see there exist some reserve in the precision of CO_2 forecasting. Curve 4 was received with additional correction of soil moisture as input data for the MMB item that parametrizes the SVS production as function of

CO_2 concentration, soil moisture and temperature [8]. It demonstrates the microwave radiometry role in the increase of precision of vegetation model under the evaluation of CO_2 sinks related to the concrete spatial resolution. Really a consideration of satellite (for example, from EOS-Aqua) data about soil moisture with spatial resolution 1°×1° or 0.5°×0.5° will permit to have more precise estimations for spatial distribution of CO_2 sinks and sources on the land. This study will be possible in the framework of the Global Carbon Project (GCP) [2].

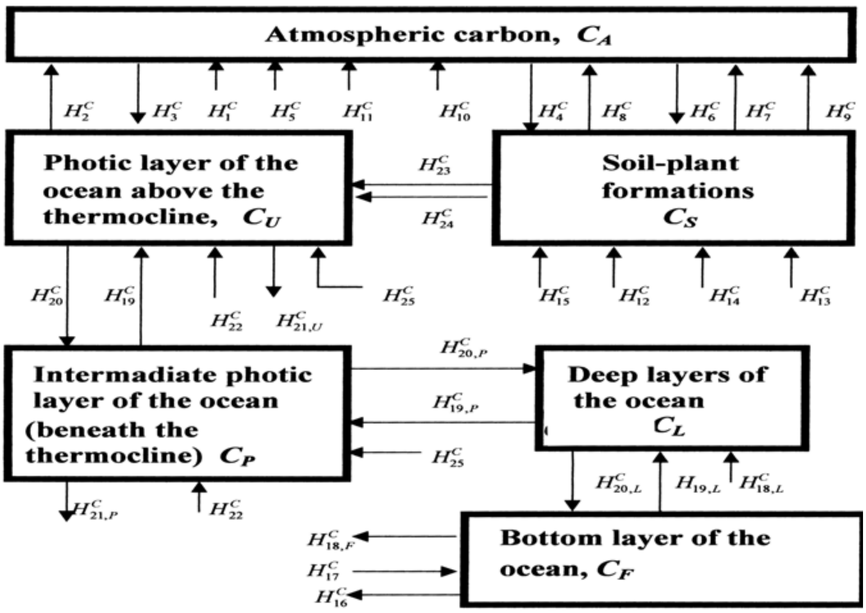

Figure 4. The block diagram of the global biogeochemical cycle of carbon in the *atmosphere-land-ocean* system as the ESOED item. The CO_2 reservoirs and fluxes are described in Table 1.

Table 1. Carbon flows included in Fig.4.

Flow	Origin of flow	Flow	Origin of flow
H_1	Fuel burning	H_{12}	People vital functions
H_2	Desorption	H_{13}	Animal vital functions
H_3	Sorption	H_{14}	Mortality of plants
H_4	Rock erosion	H_{15}	Secretion by roots
H_5	Volcanic emission	H_{16}	Deposition
H_6	Photosynthesis in the ocean	H_{17}	Ocean depositions dissolving
H_7	Respiration of plants	H_{18}	Detritus decomposition
H_8	Burning of plants	H_{19}	Water rising
H_9	Decomposition of humus	H_{20}	Water descending and sedimentation
H_{10}	People activities	H_{21}	Photosynthesis on land
H_{11}	Vital functions of biota in the ocean	H_{22}	River flow

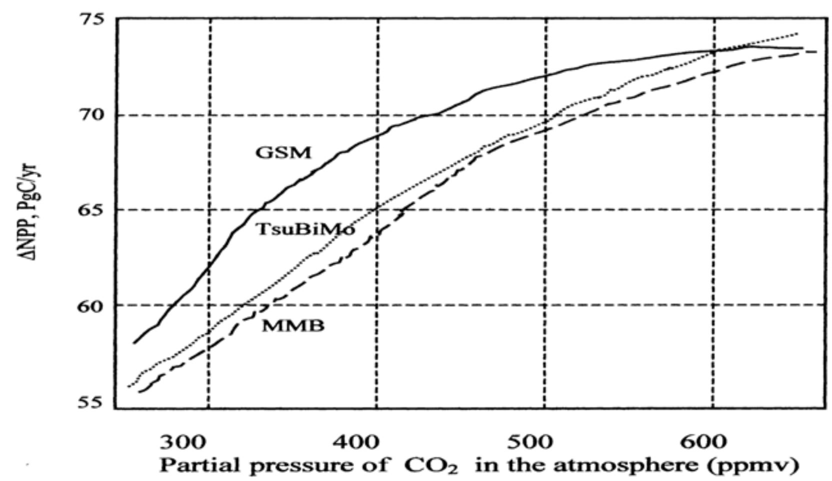

Figure 5. Comparison of three models of the global carbon cycle to assess the response of net primary production of vegetation to changing concentrations of atmospheric CO_2. Notation: TsuBiMo – Tsukaba Biosphere Model [1].

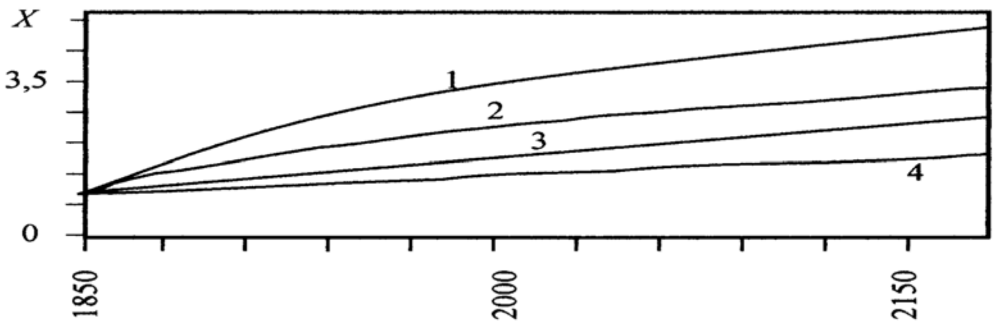

Figure 6. Model results for scenario IS92a with different spatial resolution in the SVS distribution ($\Delta\varphi,\Delta\lambda$)**: 1-**(10°,10°)**, 2-**(7.2°,9.0°)**, 3-**(4°,5°)**, 4-** (4°,5°) **with the correction of soil moisture. The ordinate $X=C_a(t)/C_a(1850)$.**

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