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Global model of the carbon cycle as instrument of primary agriculture production assessment*

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Abstract - ***The role of agriculture and forest ecosystems in the climate change is considered. To understand the factors that determine the feedbacks in the global climate system of the cycles of carbon, a hierarchy of model units is constructed which parameterize a totality of physical and biogeochemical processes which are responsible for transport of various substances. In this paper an attempt has been made to assess the role of agriculture and forests in assimilation of carbon dioxide from the atmosphere, and to analyze the characteristics of forest ecosystems.***

Keywords: ***CLIMATE CHANGE, ECOSYSTEM, CARBON CYCLE, GREENHOUSE EFFECT, MODEL***

I. INTRODUCTION

The growing global size of population and the associated growing forcing of human activity on the environment and ecosystems have become not only the main threat to further sustainable development of civilization in the context of the global ecological safety but also reflect a dangerous disorder in the normal functioning of various systems of life support [6], [7]. In connection with the key role of the ecosystems in the processes of the natural regulation of environmental properties, of principal importance is an analysis of the available data on the global dynamics of ecosystems and an assessment of possible trends. Important information on these problems can be found, in particular, in recent publications by many authors, among which the most informative is the report prepared by the World Resources Institute (USA) supported by the UN Programme of Development, UNEP, and the World Bank [1].This report emphasizes a close relationship between the global ecosystems and the global population - a symbiosis, unique and extremely sensitive to external forcings. These presentations have been thoroughly substantiated by [3] in the form of a concept of biotic regulation of the environment. Monographs by Krapivin and Varotsos [6], [7] contain an analysis of the key aspects of the global changes from the viewpoint of functioning of the global systems of life support and requirements to an adequate ecological monitoring.

Global natural and regulated ecosystems play an important role as a factor of the environmental dynamics ranging from micro-scales (e.g., soil bacteria) to the whole planet and, on the other hand, are vitally important sources of drinking water, food, timber, paper, and other means of life support. As has been mentioned earlier [8], an urgency of the problem is that the world, on the whole, has already drawn near such limits to the impacts on the ecosystems, an exceeding of which is fraught with irreversible destruction of the global systems of life support, and from some indicators, these limits have already been exceeded, though the present enthusiasm for apocalyptic predictions is, so far, unfounded (this especially refers to the so-called "global warming").

An extreme complexity of the problem discussed is that it is necessary to explain (and, as far as possible, to predict) the dynamics of the interactive system "nature - society" (the society should be placed first here since its functioning determines its impact on nature) with its numerous feedbacks, nonlinear nature, and "surprises". Unfortunately, the present stage of studies of the system "nature - society" can be considered not more than initial and preliminary. This refers to even a simple description of the present condition of nature (global ecosystems), which results from the observational data deficit with an apparent abundance of some observational means (especially expensive space-borne means). Therefore the report of the Institute of World Resources (USA) is in many respects incomplete being concentrated only on consideration of five types of ecosystems (the share of land surface is given in brackets, except the Antarctic and Greenland occupied by the respective ecosystem): agricultural ecosystems (28%), coastal regions (22% within a 100-km band), forest (22%), fresh-water (< 1%), and grass (41%) ecosystems. An abandonment of the World Ocean is, of course, a serious, though justified (in view of information deficit) flaw. Special attention should be also paid to the soil ecosystems.These ecosystems are very important for the solution of various problems of human life support and regulation of the environmental conditions.

II. ANTHROPOGENIC IMPACTS ON LAND ECOSYSTEMS

The authors of the report of the World Resources Institute (USA) have briefly summarized the anthropogenic impacts on the ecosystems during the civilization development, beginning from an intensive application of the irrigation systems during the Shumer civilization, which had led to soil salination, to the present global processes of atmospheric pollution and the ozone layer depletion.

Examples of destructive (and even catastrophic) impacts on ecosystems and their economic consequences are numerous (see for details [4], [6], [7]). The collapse of cod catch in 1990 in the sea regions of Canada made about 30 thousand fishermen unemployed, and only in the region of Newfoundland brought forth serious economic difficulties in 700 settlements. Material losses in China reaching $11.2 \cdot 10^9$ \$US /year have resulted from a deficit of drinking water due to polluted river and sub-soil waters. In India, the commercial

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forest cutting and the transformation of the deforested lands into the agricultural ones have not only changed the traditional way of people's life but also caused a deficit of wood fuel and timber to the detriment of 275 millions of rural population.

As for the estimates of the consequences of the global anthropogenic impacts, the situation with the water resources is an example: about 28% of the global population have no access to pure drinking water; every year about 5 million people die because of a low quality of drinking water and anti-sanitary conditions; about 90% of wastes in the developing countries go to rivers, lakes, and coastal regions of the seas, etc. Intensified emissions of CO_2 into the atmosphere have caused considerable changes in the global carbon cycle [6]÷[8], [12].

The most important fact is that the levels of impact on the ecosystems have become of a global scale. About 75% of marine fish populations have either decreased due to violation of the permissible amounts of catch or come close to the threshold of their survival. An intensive forest cutting has almost halved the forested areas, and the construction of various economic infrastructures has caused a fragmentation of the forest cover. About 58% of coral reefs are seriously affected by fishery, tourism, and pollutions. Almost 65% of arable lands have partially lost their fertility. The scales of economic usage of ground waters exceed the rate of their natural recovery by at least 160·109 m3 /year. In most cases the anthropogenic load on the ecosystems has intensified. It is especially concerns the pasture ecosystems where the interference of the human's factor has reached the level of direct control [11].

It is well known that the main causes of ecosystems' degradation are the growing size of population and, respectively, increased needs for natural resources as well as enhancing loads on the environments. Concrete detailed data characterizing the present global situation can be found in numerous publications [12]. Note only that an extremely important feature of the growing scales of consumption is their strongest geographical non-uniformity reflecting the socio-economic contrasts in the world.

III. ECOSYSTEMS AND THE GREENHOUSE EFFECT

During the last years, the problem of the impact of atmospheric carbon dioxide on the global climate has been discussed both by scientists and politicians. Some people believe that humankind will inevitably change the climatic situation on the Earth due to enhanced greenhouse effect, which will change the life conditions and, probably, for the worst. And therefore it is necessary to reduce the industrial emissions of CO_2. Others, agreeing with the consequences of the greenhouse effect, deny the strategy put forward by the Kyoto Protocol and believe that the recommended reduction (quotas) will lead to an aggravation of economy in many regions of the globe, without solving the problem of the greenhouse effect, but further worsening the global ecological situation. The opponents to the Kyoto strategy think that the greenhouse effect can only be prevented by the correct management of the structure of surface covers and by introducing a strict control of the World Ocean pollution. In this connection, the Intergovernmental Panel on Climate Change (IPCC) at the 8th Session in June 1998 in Bonn and at the 14th Session in October 1998 in Vienna prepared a special report on the role of the strategy of using the surface covers (forests, in particular) in the global balance of CO_2. This report discusses the problems of interaction between the anthropogenic activity in the field of surface covers reconstruction and the distribution of CO_2 and other greenhouse gases in the biosphere. An assessment is given of various scenarios following from the Kyoto Protocol and concerning the problem of the impact of human society on the surface cover structure in general and on forested territories, in particular. A brief analysis of this report is given below.

IV. FORESTS AS SINKS FOR CARBON DIOXIDE

Item 3.1 and Appendix 1 of the Kyoto Protocol foresee a limitation and then a reduction of GHGs emissions during the period up to 2008-2012. Before this time some problems should be solved to assess the role of the use of the Earth's surface. In particular, among these problems is the problem of the formalized description of the processes of changes of the Earth covers' structure, such as afforestation, forest reconstruction, deforestation and the associated carbon supplies. Understanding of the meteorological processes as functions of greenhouse gases refers to one of the key problems of humankind in the first decade of the third Millenium. Only an adequate knowledge of the meteorological phenomena of various spatial-temporal scales in conditions of supplies of CO_2 and other GHGs will enable one to make correct and constructive decisions in the field of the global environment protection.

The dynamics of land ecosystems depends on interactions between biogeochemical cycles, which during the last decade of the 20th century suffered an anthropogenic modification. Especially this refers to the cycles of carbon, nitrogen, and water. The surface ecosystems, in which carbon remains in living biomass, decomposing organic matter, and soil, play an important role in the global CO_2 cycle. Carbon exchanges between these reservoirs and the atmosphere take place through photosynthesis, respiration, decomposition, and burning. Human interference into this process takes place through changing the structure of the Earth's covers, pollution of the water basins' surface and soil areas, as well as through direct emissions of CO_2 into the atmosphere [10], [13], [14].

The role of various ecosystems in the formation of carbon supplies in the biospheric reservoirs determines the rate and direction in changes of the regional meteorological situations and in global climate. An accuracy of assessment of the level of these changes depends on reliability of the data on the surface ecosystems inventory. The Table 1 data show that a considerable scattering of the estimates of carbon supplies in various types of vegetation suggests the conclusion that it is important to more specifically classify the surface ecosystems.

TABLE 1. CARBON STOCKS IN VEGETATION AND SOIL CARBON POOLS DOWN TO A DEPTH OF 1M [12].

Biome	Area, 10^9 ha	Carbon stocks (Gt C)		
		Vegetation	*Soil*	*Total*
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts and semideserts	4.25	8	191	199
Tundra	0.95	6	121	127
Weatlands	0.35	15	225	240
Croplands	1.60	3	128	131
Total	15.12	466	2011	2477

The anthropogenic constituent of the global carbon budget, beginning from the mid-19th century, increases the amplitude of the effect practically on its every natural element. From 1850 till 1998 about 270(±60)Gt C were emitted as CO_2 into the atmosphere due to fuel burning and cement production. About 136(±55)Gt C went to the atmosphere as a result of anthropogenic reconstruction of surface covers. This has led to an increase of atmospheric CO_2 by 176(±10)Gt C, that is, the partial pressure of carbon dioxide in the atmosphere has increased from 285 to 366 ppm (by 28%). In other words, during 148 years, 48% of emitted carbon remained in the atmosphere and were not assimilated by surface or ocean ecosystems (230(±60) Gt C were assimilated).

Some idea about the global carbon budget can be obtained from the data of Table 2. This table shows that the rates and trends of carbon accumulation in the surface ecosystems are rather uncertain. However, it is clear that the surface ecosystems are important assimilators of excess CO_2. Understanding the details of such assimilation is only possible through modelling the process of the plants' growth, that is, considering the effect of the nutrient elements of soil and other biophysical factors on the plants' photosynthesis.

TABLE 2. CHARACTERISTIC OF THE MEAN ANNUAL CO_2 BUDGET [12].

Characteristic	Estimate , Gt C/year	
	1980 - 1989	*1990 - 1998*
1) CO_2 emission due to fossil fuel combustion and cement production	5.5±0.5	6.3±0.6
2) CO_2 storage in the atmosphere	3.3±0.2	3.3±0.2
3) Oceans uptake	2.0±0.8	2.3±0.8
4) Net terrestrial uptake =(1) - [(2) + (3)]	0.2±1.0	0.7±1.0
5) CO_2 emission due to changes in the use of land resources	1.7±0.8	1.6±0.8
Residual terrestrial uptake = (4) + (5)	1.9±1.3	2.3±1.3

According to Table 1, the forest ecosystems and associated processes of natural afforestation, forest reconstruction, and deforestation should be studied in detail. The same has been emphasized in items 3.3 and 3.4 of the Kyoto Protocol, where the necessity is emphasized to determine national and international strategies of forest management. In a forest range, the volume of the reservoir for CO_2 coming from the atmosphere is a function of the density of its canopy, and in a time period, a change of this volume is determined by the level and character of the dynamic processes of the transition of a given type of forest to another state. The causes of this transition can be natural, anthropogenic, and mixed. Biocenology tries to create a universe theory of such transitions, but so far, there is only a qualitative description of the observed transitions. As mentioned in the Kyoto Protocol, of importance is the correct definition of the notions "afforestation, forest reconstruction, and deforestation". Afforestation means to forest a land area used before (for 20-50 years and longer) for other purposes. Usually this term determines the process of natural succession at the expense of propagation of forest over other territories without humans' interference [2]. The process of forest reconstruction is defined as planting trees. Deforestation is a substitution of the forest territory for another ecosystem. Thus two opposite processes are possible in the forest ecosystem dynamics that can be controlled by both nature and people. Each of these processes has its versions characterized by special dynamics of the vegetation over a given territory. Of special status is the process of foresting a territory where historically trees had never grown. In this case this territory immediately becomes important in the CO_2 dynamics.

Table 3 illustrates an impact of the afforestation/ deforestation processes on carbon supplies following the FAO scenario [12] where the forest is a land area not less than 0.5 ha, with trees more than 5 m high and the canopy covering more than 10% of the area. Deforestation is determined as a change of the surface cover with the canopy covering less than 10% of the area, as well as a change of the class of the forest with negative consequences (e.g., a decrease of productivity). Afforestation is the planting of trees over the area where trees had never grown. Note that "natural broadening" (i.e., propagation of forest over the agricultural territories without human interference) due to the FAO scenario isreferred also to the process of afforestation. Finally, the forest reconstruction is a direct planting of trees on the territories earlier covered with forest.

TABLE 3. ASSESSMENT OF THE CALCULATED CHAGE OF THE MEAN ANNUAL CARBON SUPPLY FOR THE AFFORESTATION/DEFORESTATION SCENARIO (Watson et al., 2000).

Region	RF	AF	TR		FR	
			A	*B*	*A*	*B*
Boreal	35	0.4÷1.2	0.5	0.1	-18	-185
Temperate	60	1.5÷4.5	2.1	1.9	-90	-501
Tropical	120	4÷8	13.7	2.6	-1644	-1352

Notation: A - deforestation; B - afforestation; RF - change of average carbon supply after deforestation, tC/ha;

AF - average rate of CO_2 assimilation at afforestation, tC/ha per year; TR -change of area (10^6ha/year) resulting from the deforestation-to-afforestation transition; FR - forecast of changes in carbon supplies (10^6 tC/year) in 2008-2012 after the FAO scenario.

The technology of considering the scenarios of the type given in Table 3 makes it impossible to choose the scenario to be recommended for use. An approach suggested in the Kyoto Protocol is oversimplified for reliable assessments of the CO_2 dynamics as a function of numerous natural and anthropogenic parameters.

V. MANAGEMENT OF THE ECOSYSTEMS

Let us return to the problem of anthropogenic changes of the structure of forest ranges. In the Kyoto Protocol its solution is connected with the problem of definition of such notations as forest, afforestation, tree planting, deforestation, biome, surface cover, land use, degradation, etc. Anyhow, a question arises here: to what extent is the use of either definition justified at making a decision and how does the result of its realization depend on their quality? The Kyoto Protocol not only does not answer this question, it even does not put it. In this respect, Table 4 is demonstrative and serves the basis for drawing various conclusions. In fact, a huge range of uncertainty exists here due to which the processes of afforestation and deforestation cannot be estimated uniquely. Clearly, a single correct way to solve the principal problem and the respective partial problems is to make a detailed inventory of the forest ranges and to use the obtained data in the global model. The specific features of this inventory should be determined in an adaptive regime of using the model, gradually changing the spatial-temporal scales, starting from the known model with a mean-annual time step and the geographical grid $4^o \times 5^o$. Some studies in this direction are being carried out within the framework of the International Programme “GlobalChanges”.

TABLE 4. DIRECTIONS OF CARBON SUPPIES CHAGES WITH DIFFERENT FORMS OF SOIL COVER RECONSTRUCTIONS (Watson et al., 2000).

Type of land cover reconstruction	**Direction of changes in C supplies**					
	Biomass		***Forest cover/wood***		***Q***	***M***
	A	***U***	***S***	***L***		
Cultivated land → forest	↑	↑	-	↑	↑	↑
Non-cultivated land→ forest	↑	↑	-	↑	?	↑
Forest → cultivated land	↓↓	↓	↓	↓	↓	-
Forest → grazing land	↓↓	↓	↑	↓	?	-

Notation: A - above ground; U - under ground; S - short-lived; L - long-lived; Q - organic matter; M - wood production.

VI. CONCLUSION

The problem discussed above is urgent from the viewpoint of the global changes of the environment both ecologically and economically. Combining these aspects, it is necessary to find an efficient mechanism of the global forestry management. This problem cannot be solved independent of other nature-protection problems. Apparently, even on a local level a decision about changing the Earth’s cover should be made on the basis of assessments of the global consequences in the future. The technology of making such well-considered decisions was proposed in [6], [7], [9] and was called GIMS - technology.

Coming back to the Kyoto Protocol, note that despite numerous quite acceptable conclusions and scenarios, recommendations to introduce quotas on GHGs emissions cannot be considered scientifically substantiated. After all, even the most optimistic assessments of the role of the forest ecosystems in CO_2 assimilation from the atmosphere scatter from 10 to 27%.

To solve the problem of the use of forests, coordinated with the dynamics of the global changes, is only possible with the use of GIMS-technology including the model of the forest dynamics, which describes changes of the structure of forest areas and temporal variations as a result of natural growth of plantations and a complex of external forcings.

From the viewpoint of humankind it would be worthwhile and advantageous to concentrate efforts of experts in different sciences dealing with the problem of global modeling, in a much better organized way than now [5].

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