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# Boreal forests contribution to global seasonal dynamic of carbon dioxide in the atmosphere

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**Abstract**

Over the past few decades the global carbon cycle has become the topic of great interest and the role of $CO_2$ in the future climate changes has been extensively and contradictorily discussed. The most important objective of biosphere investigations is to assess how the continuously increasing human-caused inflow of carbon dioxide to the atmosphere will influence the climate system and biospheric processes. Our aim is to answer the important question – what is the contribution of boreal forests in total carbon circulation. The proposed global biota climate dynamics model gives a possible answer to this question. Verification of this model was based on the measurement data on the global dynamics of atmospheric carbon dioxide obtained in the Mauna Loa Observatory and on global net primary production (NPP) values obtained by remote sensing (model MODIS-NPP).



*Keywords: minimal computational model; net primary production (NPP); boreal forest*

## 1. Introduction

Extrapolation of the observed trends of global parameters to the future suggests that biospheric parameters and the Earth's climate can change significantly [1]: until 1750, atmospheric $CO_2$ levels had remained almost the same and then began increasing exponentially, 0.4% every year [8]; consumption of carbon fuels has doubled every decade (5-6 GtC/yr) [3]; since 1860, the average temperature at the Earth's surface has increased by about 0.5ºC [19]. Assessment of rates, scales, and irreversibility of these changes is certainly one of the most important tasks of modern science. Determining the key factors of

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global changes may provide a way to prevent the increasingly evident negative tendencies in the development of the biosphere.

At the present time, there is no unanimous opinion on the possible boreal forests influence on climate change. Investigations yield contradictory results. There is no definite answer to the question how global processes function and no quantitative data on variables involved in them. Some studies report correspondence of remote sensing data to climatic processes and global changes. Also, there are models studying climatic processes and global changes. This study unites these approaches by developing a minimal computational model of the global dynamics of biota and climate, using satellite monitoring data.

The model is designed to predict admissible limits of human impacts and to study principles of biosphere-climate interactions. The model is verified using the NPP (Net Primary Production), which is calculated from an array of satellite data. The investigations have demonstrated that remote sensing data can be used to construct not only distributed but also minimal models and assessment of the contribution of boreal forests in seasonal dynamics of carbon dioxide has also been done. By boreal forests we mean forests of the northern hemisphere from their nothern border with forest-tundra up to midlatitudes. Boreal forests grow primary in the cold, cold-temperate and temperate climate zones. They are mostly coniferous and also mixed coniferous-broadleaved in the south part of their spread. Area of boreal forests is in general between 40 and 70 degrees of northern latitude.

Over the past few decades the global carbon cycle has become the topic of great interest and the role of $CO_2$ in the future climate changes has been extensively and contradictorily discussed [1, 2]. The most important objective of these investigations is to assess how the continuously increasing human-caused inflow of carbon dioxide to the atmosphere will influence the climate system and biospheric processes. Some researchers underline the primary significance of biotic regulation processes as compared to the processes related to human-caused emissions of greenhouse gases. Practically speaking, they suggest that measures taken by the world community to reduce greenhouse gas emissions are of less importance than preservation of wild natural resources. However, it has been proven that global cycling of carbon as $CO_2$ and climate changes are related and this cannot but affect biodiversity too.

The carbon cycle is closely related to climate, the water cycle, cycling of biogenic elements, and photosynthesis production on land and in the oceans. Thus, no investigation of the global carbon cycle that does not take into account the combination of these relationships can yield even a nearly reliable assessment of the consequences that can be brought about by human-related carbon emissions into the environment. It is very important that the only tool of investigating biospheric processes is computational modeling. However, correction of model calculations and verification of models reproducing global processes cannot be performed without employing satellite monitoring databases. Many models use satellite measurements in the visible and near-IR spectra to determine PAR, vegetation indices, chlorophyll concentration in the oceans, soil moisture content, $CO_2$ concentration on leaf surface, temperature, etc. In this model, remote sensing data were used for parametric adjustment in order to minimize the discrepancy between the prediction and real measurements.

At the present time there are models that describe in more detail or in less detail distribution of carbon fluxes in space and their interactions. The authors of these models define biospheric sources and sinks of $CO_2$ as functions of environmental parameters and show the role of human-related processes [3, 4, 5]. Most of the researchers aim to answer the main question – assessment of boreal forests role in neutralizing excess of $CO_2$. The proposed model gives a possible answer to this question.

## 2. Materials and methods

This model is based on the notion of the closed-loop carbon cycle, taking into account intensity dynamics of human-made emissions of carbon to the biosphere [6, 7]. This dynamics is determined by the expected scenario of fossil fuel consumption by humanity. For the sake of definiteness, we chose the function corresponding to Scenario A2 [1]. The model takes into account dynamics of oceanic biota, and the integrated biotic reservoir is divided into latitudinal compartments: tropical (between 30ºS and 30ºN), southern (south of 30ºS), and northern (north of 30ºN). The land compartments include plant biomass and dead organic matter and the ocean ones – biomass of plankton and heterotrophic organisms. Model parameters (amounts of carbon in the land and ocean plants and in the soil, and rates of photosynthesis, respiration, and human-made emission) were taken from the literature. Based on them, oceanic biota was taken to assimilate 30 GtC/yr, its biomass being just 3 Gt. This can be accounted for by the high rates of phytoplankton growth and consumption, and oxidation of their remains and by the reverse ratio between autotrophic and heterotrophic biomasses, as compared to their land ratio. Reaction rate constants were selected in such a way that the biomass increase rate was equal to the published estimate – 50 GtC/yr – and the model free of the human-caused $CO_2$ inflow was in the steady state, with parameters corresponding to the real global parameters of the late 1950s [2, 5].

The model is represented by the following set of equations:

$$\frac{dA}{dt} = S(y,t) - P(x_w + x_s, A, t) \quad (1)$$

$$\frac{dx_s}{dt} = P(x_s, A, t) - D_s(x_s, t) \quad (2)$$

$$\frac{dx_w}{dt} = P(x_w, A, t) - D(x_w, t) \quad (3)$$

$$\frac{dB}{dt} = D(x_w, t) - D_b(B) \quad (4)$$

$$\frac{dy_s}{dt} = D(x_s) - S(y_s, t) \quad (5)$$

$$\frac{dy_w}{dt} = D_b(B) - S(y_w, t) \quad (6)$$

$$P_s(x, A, t) = V_p \cdot x \cdot (x_{\max} - x) \cdot V(A) \cdot fw_1(t) \quad (7)$$

$$V(A) = \frac{A}{K_A + A} \quad (8)$$

$$D(x,t) = V_d \cdot x \cdot fw_3(t) \quad (9)$$

$$D_b(B) = V_b \cdot B \quad (10)$$

$$S(y,t) = V_s \cdot y \cdot fw_1(t) \quad (11)$$

$$fw_1(t) = \omega_1 + k_1 \sin\left(\pi(t - t_{w1}) - \frac{\pi}{2}\right) \quad (12)$$

$$fw_2(t) = \omega_2 + k_2 \sin\left(2\pi(t - t_{w2}) - \frac{\pi}{2}\right)^4 \quad (13)$$

$$fw_3(t) = \omega_3 + k_3 \sin\left(2\pi(t - t_{w3}) - \frac{\pi}{2}\right) \quad (14)$$

where $A$ is the atmospheric carbon (GtC);
$x_s$, $x_w$ are the amount of carbon (GtC) in the biomass of the steppe and boreal forests compartments respectively;
$y_s$, $y_w$ – amount of carbon in dead biomass in steppe and boreal forest zones respectively (Gt);
*Vp,*– the scale factor (1/(GtC×year));
$x_{smax}$ , $x_{nmax}$– the limited amount of biomass of the north and south compartments respectively which depends on the limit of the density of vegetation cover (GtC), $x_0$ – the number of terrestrial plant biomass in the present;
*V(A)* - the growth of biomass in relation to the atmospheric concentration of CO2 in the form of well-known function of Monod.
*Vs* is the scale factor of carbon evolution from soil;
$P(x_n,A,t)$ - function of the growth rate of green plant biomass (GtC / year);
B – amount of wood in the biomass of boreal forests;
$K_A$ = 900 ГтС by experiment;
D(x,t) - extinction rate of biomass (GtC / year);
S(y,T,t) – the rate of soil respiration (decomposition of dead organic matter) and CO2 emissions in the atmosphere;
*fw*(t) – factors of seasonal oscillations of growing and decomposition processes for steppes and boreal forests

Verification of this model was based on the measurement data on the global dynamics of atmospheric carbon dioxide obtained in the Mauna Loa. The combustion function in the model was determined using historical and experimental approximation data from the Reports of IPCC [1, 2]. Observatory and on global net primary production (NPP) values obtained by remote sensing [8-10]. The latter parameter was chosen because NPP is of major significance for global carbon cycle studies. Different vegetation indices obtained as satellite data show only photosynthetic activity of plants, calculated from radiation received by the satellite sensor. They, however, cannot be used to immediately evaluate primary production, because plant growth is limited not only by absorbed solar radiation but also by a number of other factors such as humidity, mineral elements, temperature, etc. At the present time, there are several model used to calculate NPP from the satellite data [11-16]. We used results of evaluating NPP employing MODIS-NPP model [17]. MODIS-NPP is a model for calculating global NPP values. It is based on using empirical data for 15 plant biomes. In this model, respiration is temperature dependent, and, in addition to respiration of green phytomass, the model takes into account respiration of stems (for annual evaluations) and roots. For estimating NPP as boreal forests were the coniferous and mixed forests which are to the north from 40 degrees of northern latitude were taken [18].

Verification of the model was performed by comparing Mauna Loa in-situ measurements with the data obtained from the work of two model modifications, one of them taking into account the ocean part of the carbon cycle, the other ignoring it. Results of the comparison suggest that the model ignoring the oceanic compartments adequately describes the observed dynamics for short periods of time (seasons, decades). The differences between the data of the models compared are at a subpercent level. Thus, it is simpler and more effective to make calculations based on the six-equation model (two equations for living green plants for steppes and boreal forests respectively, two for two parts of soil for the same plant types, one for atmospheric carbon and the last one for carbon which is in lignified part of trees of boreal forests) than on the fourteen-equation, integrated. In the frames of the instant model, the main characteristic of boreal forests considered as the peculiarity of carbon flows in this territory. While in steppes zone all the grown plant biomass came in soil in autumn, and the main part of vegetative remains comes to the atmosphere. This process reflects in seasonal oscillations of NPP, increase in spring and summer and decrease in autumn linked with the end of vegetation period. In boreal forests zone, this cyclic seasonal process has the following feature. A part of the consumed by photosynthesis carbon comes not to the soil, but becomes a part of perenial wood biomass (3), (4), (10).

## 3. Results and Discussion

The difficulty of adjusting the model using NPP data was that the NPP curve can be variously shaped, depending upon the latitudinal compartment. For instance, it is so for the northern compartment, just where boreal forests are situated, with the largest seasonal variations of the study parameter. It remains to be investigated why this function is good for describing the data. Results of model verification based on satellite data on global NPP dynamics and global dynamics of carbon dioxide in the atmosphere are shown in Figures 1, 2. The fit of the model data to experimental measurements is evidently rather good.

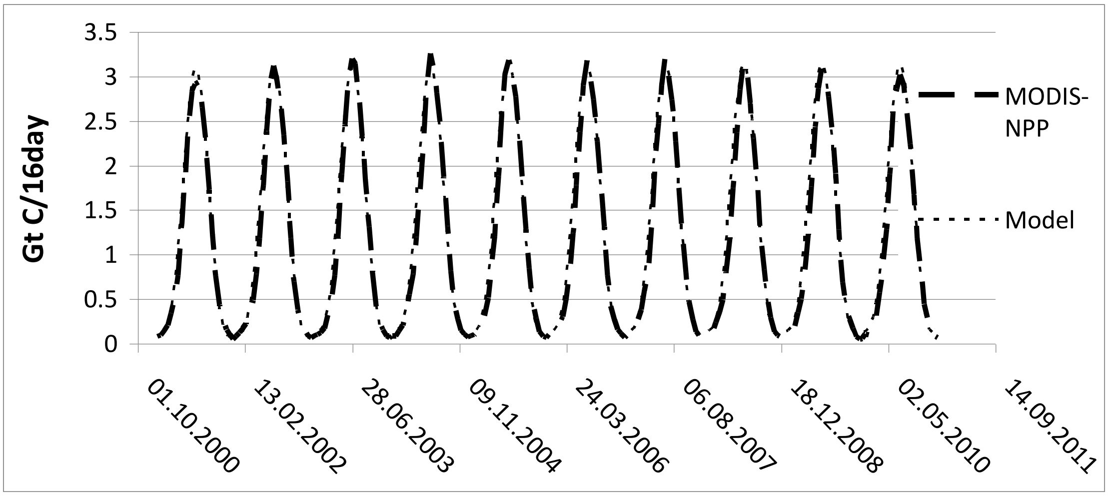


Fig. 1. Model results of calculating NPP of plants (solid line) vs. data obtained from satellite images (dashed line) in the northern geographic compartment – between 30°N and 90°N.

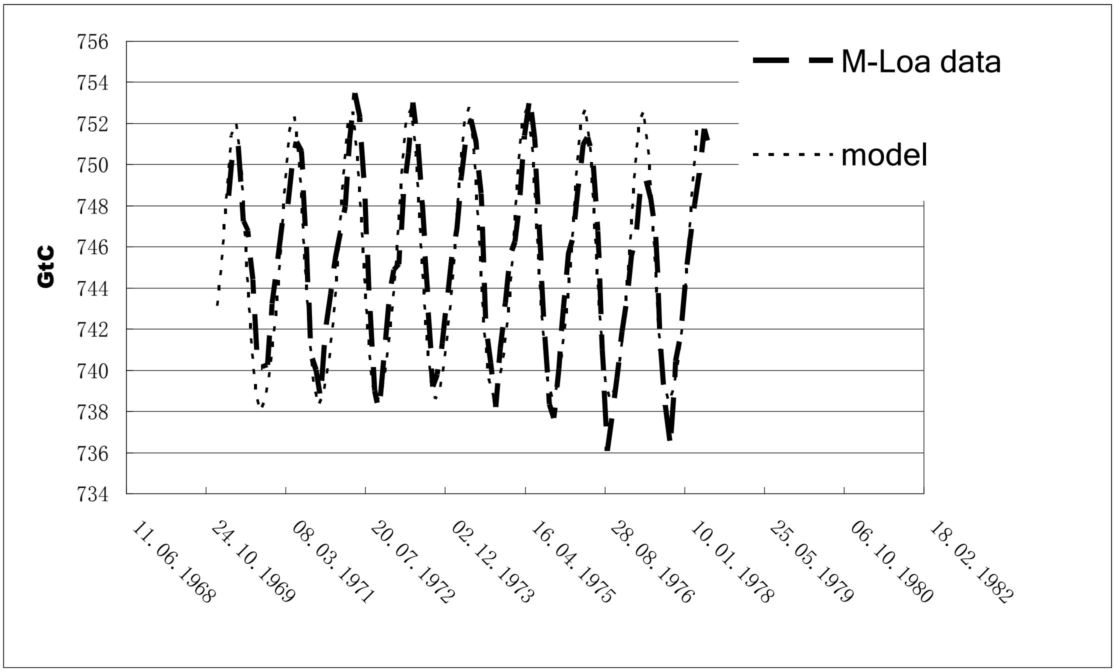


Fig. 2. Comparison with measured carbon dioxide dynamic

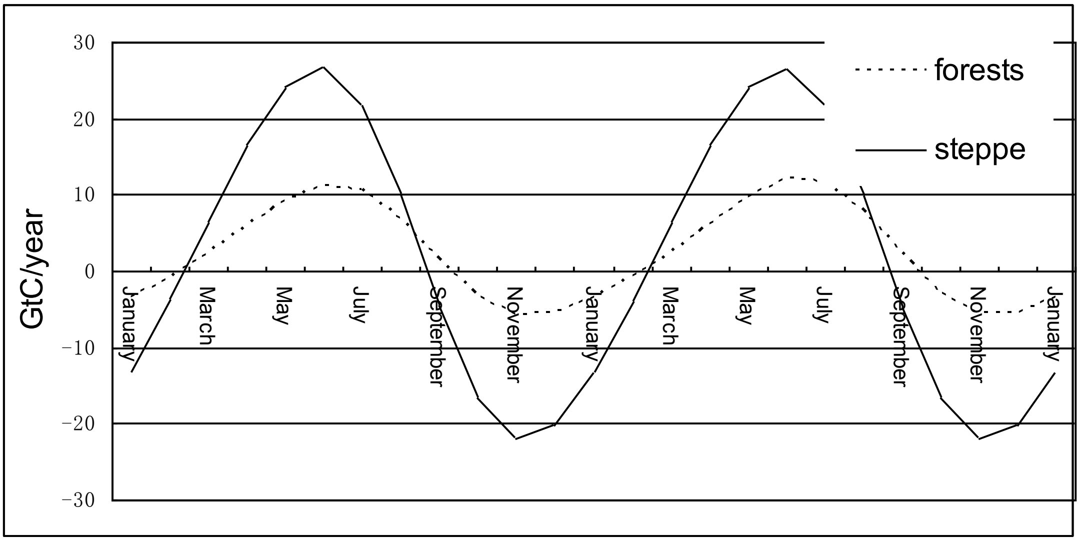


Fig.3. Seasonal dynamic of total carbon flows of boreal forests and steppe compartments.

To estimate the role of boreal forest in seasonal dynamics of carbon in atmosphere is possible due to the fact that the part of consumed carbon in timber varies dynamics of autumn decrease of NPP in comparison with the seasonal dynamics of carbon in steppe zone. The presence of pooling carbon in timber smoothes carbon flow that returns to atmosphere in the end of vegetation period therefore the amplitude of seasonal oscillations of NPP in the boreal zone less than in the zone of steppes (Fig.3). It can be seen that even though total flow of carbon through forest and steppe ecosystems are almost equal, the contribution of boreal forests into seasonal dynamics is approximately two times less than the one of steppe.

## 4. Conclusion

In the instant paper an important aspect of applying remote sensing data to estimate the role of boreal forests in seasonal variation of carbon dioxide concentration in the atmosphere is considered. Global biota and climate dynamics model act as converter and connecting link which binds remote sensing data with the biosphere processes taking boreal forests as an example. These are direct measurements of carbon dioxide concentration and global NPP values, which have been calculated from a set of satellite measurements. It was shown that remote sensing data can be used to configuring not only distributed but also minimal models. Cross-verification of environmental data of different nature allows to obtain some estimations of processes which are practically inseparable in experiment. The possibilities of this approach are shown on the example of evaluating the contribution of boreal forest and steppe ecosystems in global seasonal dynamics of atmospheric $CO_2$. It is shown that total contribution of forests and steppe into carbon exchange can be essentially differ than their contribution into seasonal dynamics.

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