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Assessment of phytoplankton productivity using satellite data for Peter the Great Gulf

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Abstract: The biological productivity of ecological systems is very important characteristic for study of the natural environment. For aquatic ecosystems the biological productivity can be determined on the base of phytoplankton productivity.
The distribution of phytoplankton in a vertical column of water under the influence of sun intensity, temperature and mineral content is simulated. Change in the concentration of mineral substances and phytoplankton is influenced by diffusion. Photosynthetic activity radiation and temperature of water satisfy the climatic conditions typical of Peter the Great Bay.
A remote sensing data probing the seas and oceans plays an important role in the study of the status and functioning of phytoplankton. In particular, satellites provide data on the content of minerals and chlorophyll in the surface layer. Data on chlorophyll content make it possible to estimate the phytoplankton and to give a rough estimate of primary production (Shushkina et al. 1997).
This paper uses a model of phytoplankton activity in the vertical column of water to assess its condition and to obtain the dynamics of changes in key parameters on the basis of satellite melon of the ocean in the Gulf of Peter the Great.

***Keywords**: Mathematical model, chlorophyll, phytoplankton, diffusion.*

1. Introduction

Evaluation of the biological productivity of ecological systems has great importance for the study of the natural environment and opportunities for environmental management. The biological productivity for aquatic ecosystems can be determined on the basis of phytoplankton productivity (Jorgensen, Legovich, Fath, 2008; Jorgensen, 2010).
The monitoring of seas and oceans has an importance in the research of the status and functioning of a phytoplankton. Satellite data on chlorophyll, physical and chemical characteristics on the surface layer are used in this research. Data on chlorophyll content allow an estimate of the phytoplankton status and of the primary production of aquatic ecosystems (Shushkina et al., 1997).
A model of phytoplankton activity in the vertical column of the water is used in this paper to research its status and to supervision of the dynamics of basic parameters with use of the satellite data on the surface layer of the ocean in the Gulf of Peter the Great.

2. Basic model

We simulate the phytoplankton distribution in a vertical column of water under the influence of light, temperature, mineral content. The model is reduced to a system of partial differential equations of parabolic type with nonlinear functional part. Concentrations of mineral substances and phytoplankton are changing under influence of diffusion. Phytoplankton is considered as a multi-species community with competitive relationships between them. Photosynthetic activity radiation (PAR)

and temperature are modelled according to the seasons of the annual cycle and conform to the climatic conditions typical for Peter the Great Gulf.
The model describes the biomass dynamics for basic species of the phytoplankton in dependence of environmental factors with spatial distribution in vertical column of water in ocean. The growth of the phytoplankton biomass arises from photosynthesis process. The PAR I and the mineral nutrient z are basic sources of biomass growth. We allow for these parameters. The depth x profile $I(t,x)$ of PAR I is important. We show all processes at time t.
Function $z(t,x)$ is concentration of a mass of mineral nutrition. Vector-function $y(t,x)$ is vector of biomass concentrations of phytoplankton groups. For example, the phytoplankton has three groups of species specifically for our research: cold-resistant species, immediate species and thermophilic species (see below). The change of biomass concentration of phytoplankton depends from temperature $\theta(t,x)$ of water. The depth is measured in meters (m), the concentration of mass is measured in grams (g) per cubic meter (g/m^3).
Biomass dynamics model has form:

$$\begin{cases} \dfrac{\partial y_i}{\partial t} = k_i^{(y)} \dfrac{\partial^2 y_i}{\partial x^2} + \mu_i(z,I,\theta) y_i - e_i(y) y_i \\ \dfrac{\partial z}{\partial t} = k^{(z)} \dfrac{\partial^2 z}{\partial x^2} - \sum_{i=1}^{n} \gamma_i \mu_i(z,I,\theta) y_i + \sum_{i=1}^{m} \beta_i e_i(y) y_i \end{cases}, \quad i = 1,\dots,m. \qquad (1)$$

It is “diffusion-reaction” model with describing of nutrient resource (Okubo, Levin, 2002). Mineral nutrient and phytoplankton have passive motion under diffusion processes. The phytoplankton functioning is described with help of specific speed μ_i of growth of phytoplankton biomass and specific speed e_i of phytoplankton elimination. Parameters β_i describe the back coming of the mineral substances from deadly organic with help of the bacteria. Parameters γ_i describe a part of the mineral substances absorbed by phyto-organisms. There is inequality $\beta_i \le \gamma_i$. The function of PAR has form: $I(x,t) = I_0(t)\exp(-\alpha x)$. The parameter α denotes the specific weakening rate for PAR in water.
The growth parameters have some independence factors: $\mu_i(z,I,\theta) = \mu_i^{(0)} \cdot \mu_i^{(z)}(z) \cdot \mu^{(I)}(I) \cdot \mu_i^{(\theta)}(\theta)$. The dependence from mineral nutrient has form of Michaelis-Menten: $\mu_i^{(z)}(z) = \dfrac{z}{z_i^{(0)} + z}$ (Droop, 1974; Murray, 1993).
Function of the biomass growth has exponential dependence from PAR: $\mu^{(I)}(I) = I\exp(-\delta I)$. This function may be more complex form (Platt, Gallegos, Harrison, 1980) but our form gets a good approximation for complex form. The parameter δ defines a best level of PAR for phytoplankton.
The dependence from water temperature has exponential form: $\mu_i^{(\theta)}(\theta) = \exp\left(-\dfrac{(\theta - \theta_i^{(0)})^2}{2\tau_i^2}\right)$ with use of the selectivity about temperature for phytoplankton group number i. Parameter $\theta_i^{(0)}$ defines a best level of water temperature for phytoplankton, the parameter τ_i denotes a dispersion of the temperature.
The elimination rate $e_i(y)$ is the linear function of the phytoplankton concentration $e_i(y) = e_{i0} + e_{i1} y$ for group number i.

3. One year life period. Test calculations

We show one year period: $t \in [0, T]$, $T = 365$ days. The year begins on January, 1st. The phytoplankton has three groups of species: cold-resistant species, immediate species and thermophilic species. The water column has 1 per relative unit of depth: $x \in [0,1]$. It is phaopelagial. The temperature has specific forms for each season (Figure 1).

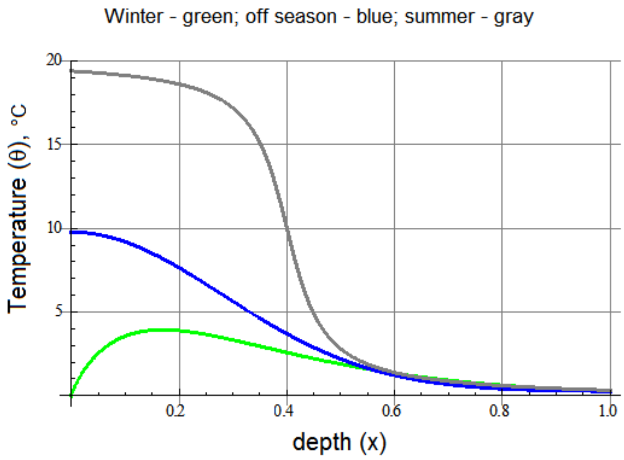

Figure 1. Temperature distribution on depth. Temperature on vertical axis in Celsius units. The per unit depth is in horizontal axis.

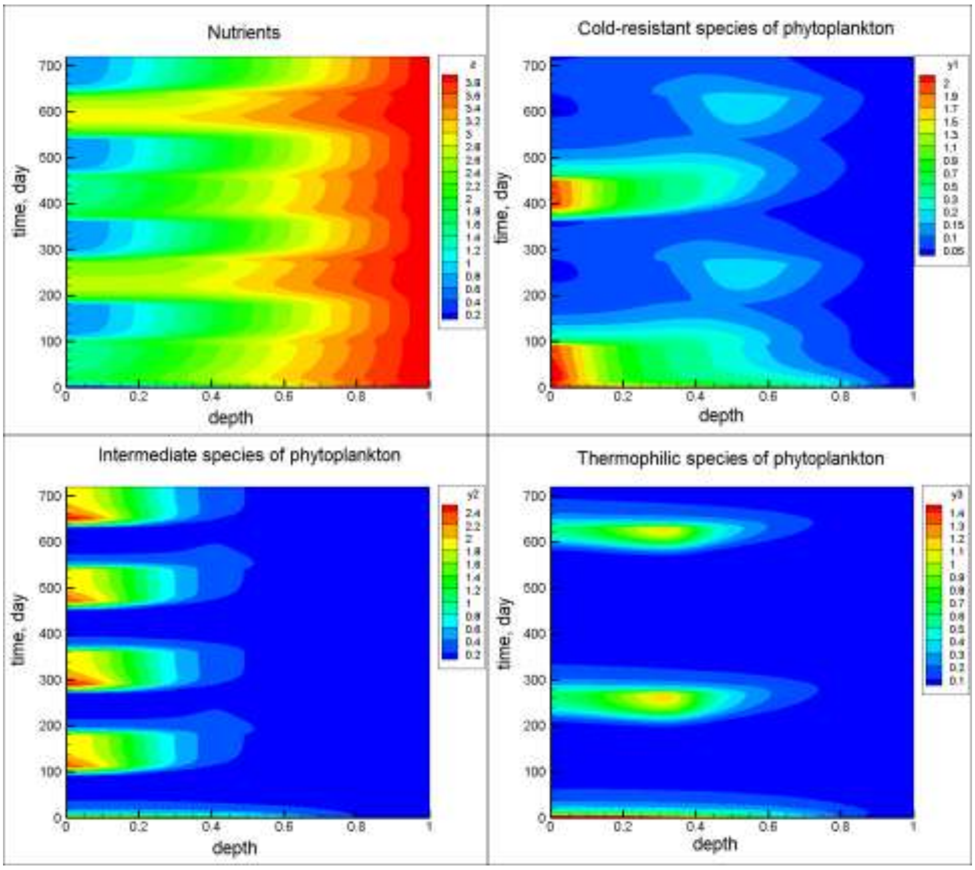

Figure 2. Modelling concentration (g/m^3) of mineral nutrient and phytoplankton groups.

The PAR changes periodic at days and at seasons in surface layer. This function has two periods. First period equals one day. Second period equals one year.
We separate the phytoplankton on three groups on the base of relation to temperature of water. Organisms of the first group “cold-resistant species” prefer the the cold temperature. Organisms of the second group “intermediate species” prefer the average temperature. Organisms of the third group “thermophilic species” prefer the warm temperature. The modelling calculations show the dynamics of groups concentrations and mineral concentration (figure 2).

4. Results for Peter the Great Gulf on satellite data

The information about surface of the ocean was received in our Institute from satellite OrbView-2 with sensor SeaWiFS at 1998 to 2007 years. It is the data about average daily chlorophyll concentration for surface of Peter the Great Gulf. Data source is website http://oceancolor.gsfc.nasa.gov/cgi/13. Definition is 9 km for pixel; data format is HDF-EOS. Basic level is “Level-3”. This information is used as boundary conditions for model (1).
A parameter for conversion from chlorophyll to phytoplankton is taken from results of previous paragraph. We postulate defined proportions between different groups of the phytoplankton on the base of research of the previous paragraph too. The temperature and PAR data were taken on base of our expert estimations of average monthly rate for Peter the Great Gulf.
We have calculated the phytoplankton abundance on the base of theoretical modelling (see previous paragraph). Calculations are made for deep-sea region (figure 3) of Peter the Great Gulf at each month in average.

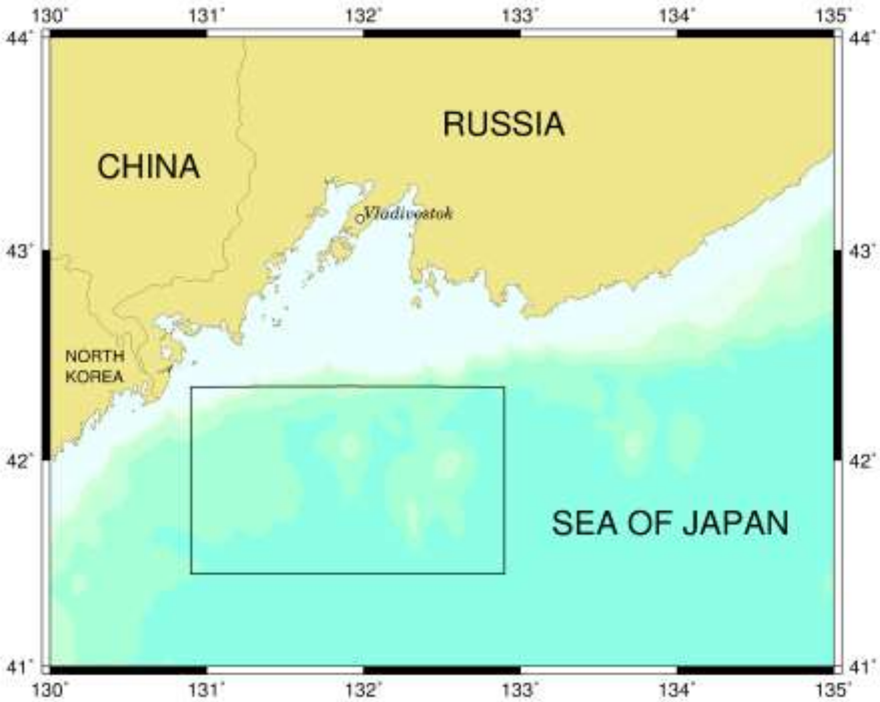

Figure 3. The deep-sea region near Peter the Great Gulf under consideration.

This region is divided on small separate pieces. We calculate by model (1) the phytoplankton concentration in vertical water column for every piece on base of satellite data. The integral on depth from phytoplankton concentration is phytoplankton content under square meter (g/m^2) of the surface layer for this piece.

We gave the modelling results for each month in average at 1998 – 2007 years. Total result for our region is shown at figure 4.

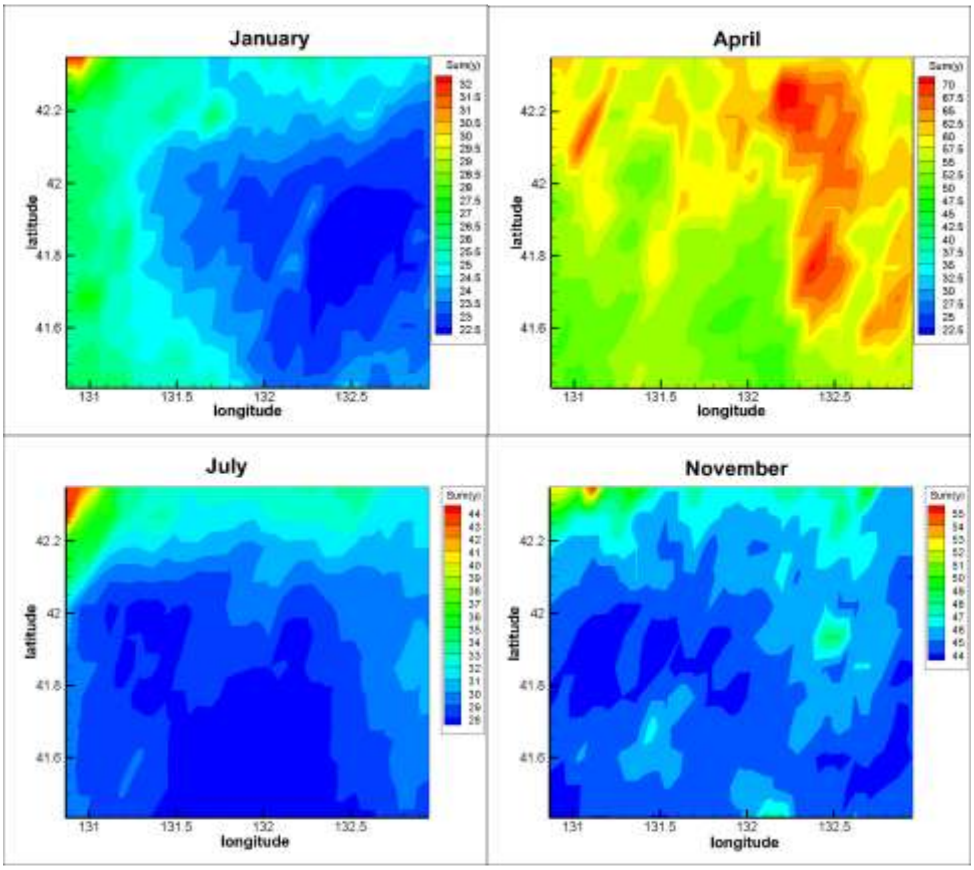

Figure 4. The phytoplankton content under square meter (g/m^2) of surface layer.

We have a phytoplankton bloom in spring (April). Separate outbreaks are in winter (January) and in autumn (November). Summer high concentration is in north part of the region.

5. Conclusion

The mathematical modelling of complex aquatic ecosystem is shown. The simulation results are applied to estimate the biological productivity of Peter the Great Gulf using data from satellite monitoring.

The model (1) can restore the phytoplankton content in ocean by the satellite data about surface layer. The modelling estimates of the phytoplankton content are made on base of a satellite data of surface layer of Peter the Great Gulf. This modelling experiment is based on data at 1998 – 2007 years. We show through calculation the season effects of phytoplankton functioning. The feature of spring bloom for phytoplankton is shown.

Our model gives a way for estimation of phytoplankton content on the base of satellite data. We calculate the phytoplankton content in ocean by the data of remote sensing. The biological productivity of marine ecosystems can be calculated with help of this model.

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