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Effect of cloudiness on the vertical distribution of chlorophyll *a* and zooplankton in Barguzin Bay of Lake Baikal: a numerical experiment

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ABSTRACT. The objectives of this article are to describe the effect of cloudiness on the content of chlorophyll *a* and zooplankton on an example of Barguzin Bay of Lake Baikal using mathematical modeling. In this study, numerical experiments with various values of cloud coverage have been implemented. Simulations demonstrate that cloudiness essentially influences the vertical distribution of chlorophyll *a* and zooplankton in the open lake.

Keywords: numerical modeling, cloudiness, chlorophyll *a*, zooplankton, Lake Baikal

1. Introduction

As a weather-forming factor, cloudiness plays an important role in the physical and biological processes occurring in water bodies. The extent of cloud coverage influences the amount of solar radiation incoming on a water surface, which, in turn, affects the rate of photosynthesis and temperature regime of a lake.

The purpose of this work is to study the effect of cloudiness on the distribution of chlorophyll *a* (the basic pigment essential for photosynthesis in plant cells) and zooplankton by numerical modeling methods on an example of Barguzin Bay of Lake Baikal.

2. Material and methods

The coupled model used in this study was developed on the basis of a thermodynamic model (Tsydenov, 2019) and biological models of Fasham et al. (1990), Fennel et al. (2006), Hofmann et al. (2008), and Gan et al. (2014). The biological model developed includes 10 prognostic variables: nitrate, phosphate, ammonium, chlorophyll *a*, phytoplankton, zooplankton, small nitrate detritus, large nitrate detritus, small phosphate detritus, and large phosphate detritus.

The vertical cross-section of Barguzin Bay of Lake Baikal was taken for this study. The origin of the coordinate system coincides with the mouth of the Barguzin River (53°25′30″ N and 108°59′50″ E). The bottom topography of the lake was taken from Ueno et al. (2005). The atmospheric data including air temperature, relative humidity, atmospheric pressure, and wind speed and direction available from the Goryachinsk weather station archive from August 1–31, 2018, (https://rp5.ru/) were used to calculate heat flux components at the water–air interface. The parameter of cloudiness was taken into account in calculations of fluxes of shortwave (solar) and longwave radiation (Tsydenov, 2018). The initial temperature field in Barguzin Bay was set to 4.5 °C. The water temperature in the mouth of the Barguzin River increased from 12 °C to 15 °C. The river flowed into the lake at a velocity of 0.5 cm/s. Water mineralization in Lake Baikal was 96 mg/kg (Shimaraev et al., 1995), in the Barguzin River it was set to 128.2 mg/kg, which is the mean value for all tributaries of Lake Baikal (Votintsev, 1978).

Initial conditions for biological variables of the model were the following:

- values of the nitrate, phosphate, ammonium, chlorophyll *a*, and zooplankton concentrations were set at 5.0, 4.0, 0.4, 0.3, and 0.3 mmolN/m^3, respectively;
- the concentration for all detrital components was 1.0 mmolN/m^3.

Boundary conditions at the river inflow area for biological variables coincide with their initial conditions.

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3. Results and discussion

To evaluate the extent of the impact of cloudiness on the development of biological processes in the lake, numerical experiments with the following values of cloud coverage (0 – clear sky, 1 – completely overcast) were implemented:

1. C = 0 (experiment no. 1);
2. C = 0.5 (experiment no. 2);
3. C = 1 (experiment no. 3).

Findings of modeling demonstrated that the high concentrations of chlorophyll *a* are observed in the near-mouth area of the lake. Analysis of water samples (Ueno et al., 2005) also indicates a high level of chlorophyll *a* in the vicinity of the Barguzin River inflow in a summer season. The difference between the results simulated is noticeable in the open lake, where the concentrations of chlorophyll *a* have the horizontally homogeneous distribution. At a distance of 15 km from the river mouth, the maximum content of chlorophyll *a* in experiment no. 1 was registered at the depth of 22 m, in experiment no. 2 at the depth of 18 m, and in experiment no. 3 at the depth of 13 m (this results qualitatively agree with the vertical distribution of chlorophyll *a* determined spectrophotometrically in the central part of Barguzin Bay in August 2002: the peak value of chlorophyll *a* was detected at the depth of 10 m (Satoh at al., 2006)). At completely overcast weather (C = 1), the chlorophyll concentration at the surface of the lake was greater than 80% in comparison with the case of C = 0.

The growth of zooplankton biomass occurs in the upper 20 m level of the lake. There is the inverse relationship between the depth and the amount of zooplankton (the maximum concentration of zooplankton was observed in the near-surface layer). The peak value of zooplankton concentration was 0.9 mmolN/m^3 in experiment no. 1, 0.84 mmolN/m^3 in experiment no. 2, and 0.4 mmolN/m^3 in experiment no. 3. It is also important to note that the lower the degree of cloud cover, the wider the range of variation of the amount of chlorophyll *a* and zooplankton in a vertical direction.

4. Conclusions

Numerical modeling of the physical and biological processes on an example of Barguzin Bay of Lake Baikal has highlighted the influence of cloudiness on the vertical distribution of chlorophyll *a* and zooplankton in the open lake. The maximum content of chlorophyll *a* was observed at the depth of 22 m for clear sky and the depth of 13 m for completely overcast weather. With the increase of the depth, the zooplankton biomass decreases. At greater cloud coverage, the amount of chlorophyll *a* is higher and the concentration of zooplankton is lower in the near-surface zone of the lake.

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