Project: **1206**

Project title: **High-resolution modeling of the interaction of physical and biogeochemical processes in the Kara Sea**

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The current project is aimed on the study of hydrodynamics and biogeochemical processes of the Kara Sea by means of numerical modeling. We use a MITgcm-based (Marshall et al., 1997) regional high-resolution **Ka**ra **S**ea **M**odel (**KASM**) with effective horizontal resolution of 1500 m, which allow to resolve the first baroclinic Rossby radius and simulate the mesoscale eddy dynamics explicitly almost everywhere in the Kara Sea except for the vicinity of the Ob and Yenisei estuaries.

According to the Project's roadmap, during the current third stage we were predominantly working with a marine biogeochemical module applied to the Kara Sea, since the basal coupled physical ocean–sea ice model was successfully configured and verified for the conditions of the Kara Sea during the previous stages of the current Project. The biogeochemical module of KASM called "ECO7" is an original 7-component model that describes evolution of the following biogeochemical state variables: Phytoplankton, Zooplankton, Detritus, Dissolved Inorganic Nitrogen (DIN), Total dissolved Inorganic Carbon (DIC), Detritus hard parts ($CaCO_3$) and Total Alkalinity (TA). Although ECO7 model is a rather simple model compared to other multi-phytoplankton and multi-nutrients models, it was shown that it can capture the main large-scale features of phytoplankton bloom in Arctic marginal seas, provided it has been thoroughly tuned (Martyanov et al., 2017, 2018).

The work plan for 2023 included: (1) Adding a benthic sub-model to the KASM's biogeochemical module. (2) Calibration of biogeochemical module of KASM. (3) Continuation of the study of the interaction of physical and biogeochemical processes in the Kara Sea.

<u>In the following we briefly report our main results obtained during the current stage of the Project:</u>

We have added a simple benthic sub-model to the ECO7 biogeochemical model in order to investigate the impact of pelagic–benthic exchange of nutrients in the Kara Sea during the process of detritus remineralization. The Kara Sea is known for its strong vertical stratification due to the considerable inflow of riverine fresh waters. This freshened 10-20 meters thick upper sea layer, and a corresponding underlying pycnocline, dramatically decrease the flux of nutrients coming to the surface layers from the deeper layers. Thus, the upward flux of nutrients and its model simulation is of crucial importance to realistically simulate the phytoplankton primary production in the Kara Sea. As was shown previously, KASM realistically simulates the horizontal and vertical thermohaline structure of the Kara Sea, including the depth of pycnocline (MLD). Still, new results of coupled physical-biogeochemical simulations suggest that the model somewhat underestimates the total phytoplankton biomass in the Kara Sea compared to the satellite data (Fig. 1). In this regard, the addition of a simple benthic sub-model, unfortunately, could not enhance the performance of ECO7.

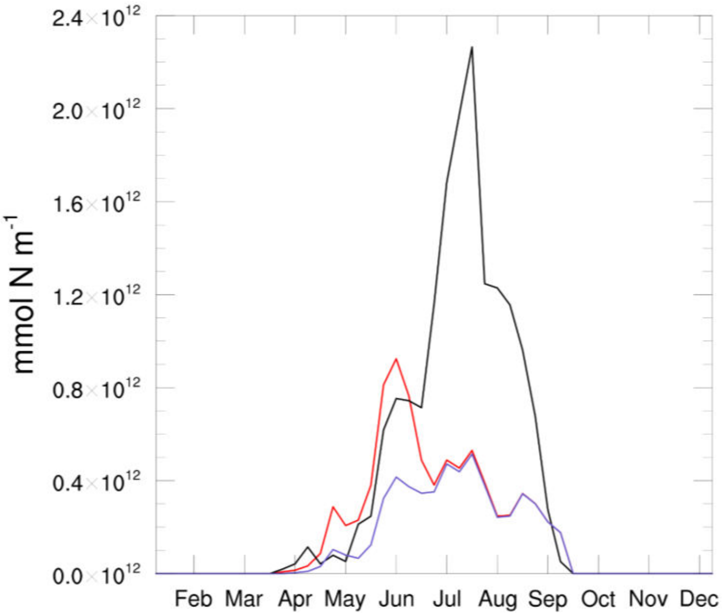

Fig. 1. Intra-annual time series of total phytoplankton biomass in the upper sea layer in 2015 based on S-NPP satellite data (black curve) and on KASM results (red curve – for the entire Kara Sea, blue curve – for the ice-free area only).

It is obvious from the Fig. 1 that the first stage of the phytoplankton bloom in the Kara Sea is simulated relatively well by the ECO7 model: the moments of beginning of the bloom coincide both in satellite data and in model results. Moreover, the further simulated phytoplankton growth has a relatively same rate compared to the satellite measurements. Unfortunately, after the first peak occurred in June (both in satellite measurements and model results), the total simulated phytoplankton biomass starts to decrease, while the satellite data demonstrate a significant growth of phytoplankton biomass, with an absolute peak being in the second part of July. This second peak of biomass is also present in the model results, but has a dramatically lower absolute value. The end of phytoplankton growth season in the Kara Sea in the late September 2015 is reliably simulated with the model.

Taking into account that the coupled model KASM+ECO7 is forced with the ERA5 meteorological fields, which can be treated as more or less reliable external meteorological data, and also that KASM realistically simulates the sea-ice cover spatial and temporal distribution (which is responsible for PAR penetration into the water), the main internal reasons for the above-mentioned discrepancy between the modeled phytoplankton biomass and satellite data may be either problems with nutrient supply and recirculation, or the structure of the biogeochemical model itself that cannot capture the main mechanisms of the functioning of lower trophic level of the Kara Sea ecosystem, though both reasons are somewhat linked through the formulation of the ECO7 model. Also, it should be noted that the comparison of modeled and measured phytoplankton concentration in terms of nitrogen units is a tricky task since the satellite measures not the content of dissolved nitrogen directly but chlorophyll concentration, which is, in turn, calculated based on optical characteristics. Thus, any conversion between chlorophyll concentration and nitrogen/carbon units is a very complex task since it employs carbon-to-chlorophyll ratio. The C:Chl ratio was taken as a constant during the ECO7 verification due to the lack of field data, but it is well-known that in reality the C:Chl ratio is a variable ranging from app. 20 to 200 in northern seas. Unfortunately, precise values for the Kara Sea or even its range are not known nowadays.

During the ECO7 calibration process we also noted that the problem with the underestimated phytoplankton biomass may also be due to the lack of other phytoplankton functional type in the model. Figure 1 suggests that the highest biomass peak in satellite data may be caused by another phytoplankton functional group (say, dinoflagellates, etc) that blooms later in summer. Thus, our model results may mean that we have correctly calibrated only one phytoplankton type for the Kara Sea (and the only one currently existed in the ECO7 model, which can be attributed to diatoms), but the lack of another phytoplankton functional group in the model, which has a large impact on Kara Sea primary production, led to the discrepancy seen in Fig. 1. Concluding, it turns out that a simple NPZD marine biogeochemical model that uses only one type of nutrients and only one type of phytoplankton, cannot be successfully configured to capture the main features of the Kara Sea phytoplankton growth due to, presumably, a change in phytoplankton species during the vegetation period (succession).

References:

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