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 modelling. We use a specially-developed MITgcm-based 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 and submesoscale eddy dynamics explicitly almost everywhere in the Kara Sea.

During the current stage of the Project, we were predominantly working on the study of the various tidal forcings' impact on the KASM's simulation results, and also on the further tuning of our original biogeochemical module ECO7 coupled with KASM.

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

The circulation of the Kara Sea is significantly influenced by tidal dynamics, impacting currents, sea ice formation, and biogeochemical processes. The accurate numerical simulation of these phenomena depends on the selection of tidal forcing at the regional model's lateral open boundaries. In our study we have assessed three tidal models – TPXO9, FES2014, and Arc2kmTM – as sources of tidal boundary conditions for our high-resolution Kara Sea model.

Our findings indicate that although the FES2014 model's own solution matches most closely sea-level observations at the coastal gauges, and the Arc2kmTM model shows the worst results in the inner KASM's domain, the KASM's solution forced with the tidal boundary condition taken from these three external tidal models demonstrates another pattern (Fig. 1). The most accurate results for KASM have been achieved using the tidal forcing taken from Arc2kmTM model, followed by FES2014, and then TPXO9. Therefore, Arc2kmTM is recommended as a source of tidal forcing for KASM The tidal forcing from TPXO applied to KASM gave the worst results compared to other 2 tidal forcings.

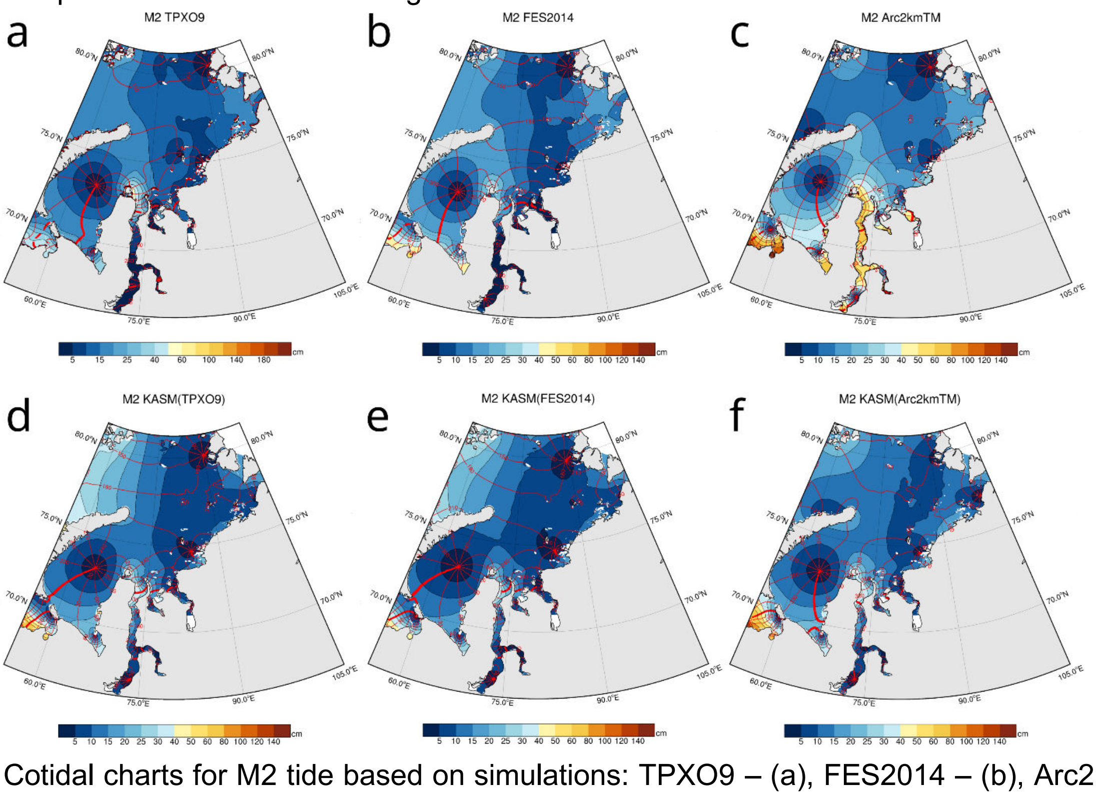

Fig. 1. Cotidal charts for M2 tide based on simulations: TPXO9 – (a), FES2014 – (b), Arc2kmTM – (c), KASM(TPXO9) – (d), KASM(FES2014) – (e), KASM(Arc2kmTM) – (f). Amplitudes are indicated with colour (in cm), while cotidal lines are represented with red lines (in degrees), the bold red line representing a zero phase.

A comparison of error metrics indicates that the dominant source of error in KASM is a slight phase shift in the tidal signal within the southwestern Kara Sea, in contrast to a more or less accurate reproduction of tidal amplitudes.

We have also evaluated the performance of our marine biogeochemical module ECO7 coupled to KASM. Previously we encountered some difficulties tuning it in order to correctly simulate the intra-annual phytoplankton primary production. After a large number of sensitivity experiments and analysis of published studies related to modelled-versus-observed phytoplankton data comparison, we have finally adopted an appropriate technique of comparison of the modelled phytoplankton biomass and observed chlorophyll-a concentration retrieved from satellite measurements for the Kara Sea. In our work, we use a regional algorithm based on the data obtained in expeditions to the Kara Sea conducted by the Shirshov Institute of Oceanology and presented by Vazyulya et al. (2024). We also use a ratio for a carbon-chlorophyll conversion of modelled phytoplankton biomass provided by Sathyendranath et al. (2009). Figure 2 shows an annual time-series of the total phytoplankton biomass in the upper one-meter layer of the Kara Sea based on the model results and satellite measurements for 2015.

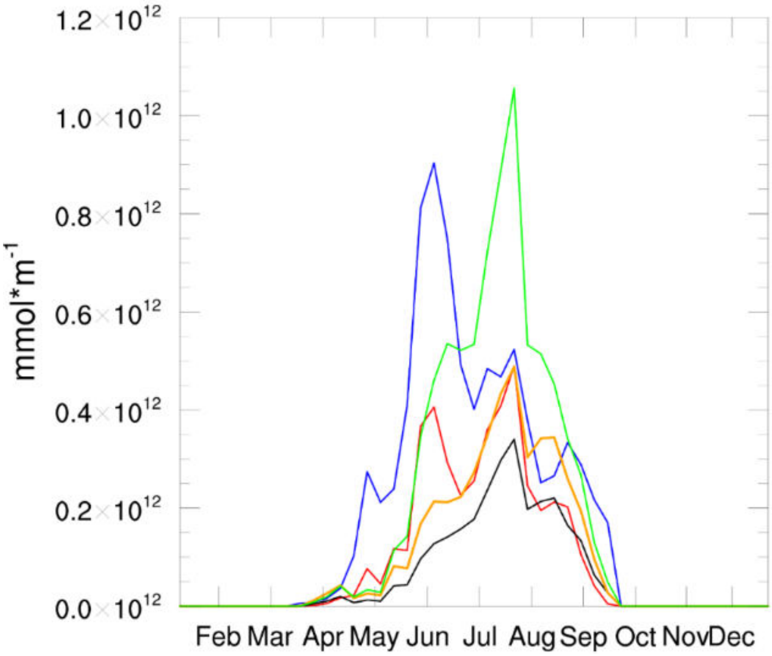

Fig. 2. Annual time-series of the total phytoplankton biomass (in nitrogen units) in the upper one-meter layer of the Kara Sea. KASM(open water) – Red curve; KASM(open water + MIZ) – Blue curve; Satellite(constant C-Chl ratio R=50) – Black curve; Satellite(Sathyendranath's ratio) – Orange curve; Satellite(exponent function of C-Chl ratio) – Green curve. Results for the year 2015.

When we use the satellite data of chlorophyll concentration, we should compare them against modelled results for water free of ice. It is clear that the adopted method has led to a much better agreement between modelled (red) and observed (orange) data. We can also conclude that the phytoplankton bloom in the Kara Sea observed in spring and summer, which occurs when the sea ice is still present and has intermediate compactness (app. 40–80%), is not efficiently captured by the satellite measurements, but is clearly observed in model results (blue curve).

References:

1. Marshall J., Adcroft A., Hill C., Perelman L., Heisey C. A finite-volume, incompressible navier-stokes model for studies of the ocean on parallel computers // J. Geophys. Res. 1997. 102(C3). P. 5753—5766.

2. Vazyulya S.V., Sahling I.V., Glukhovets, D.I. (2024). Regional Algorithms for Chlorophyll Concentration Estimation in the Kara Sea from MODIS Ocean Color Data // Atmospheric and Oceanic Optics. Vol. 37, Suppl. 1, S135–S143.

3. Sathyendranath S., Stuart V., Nair A. (2009). Carbon-to-chlorophyll ratio and growth rate of phytoplankton in the sea // Marine Ecology Progress Series. Vol. 383, 73–84.