Numerical Modelling of the White Sea

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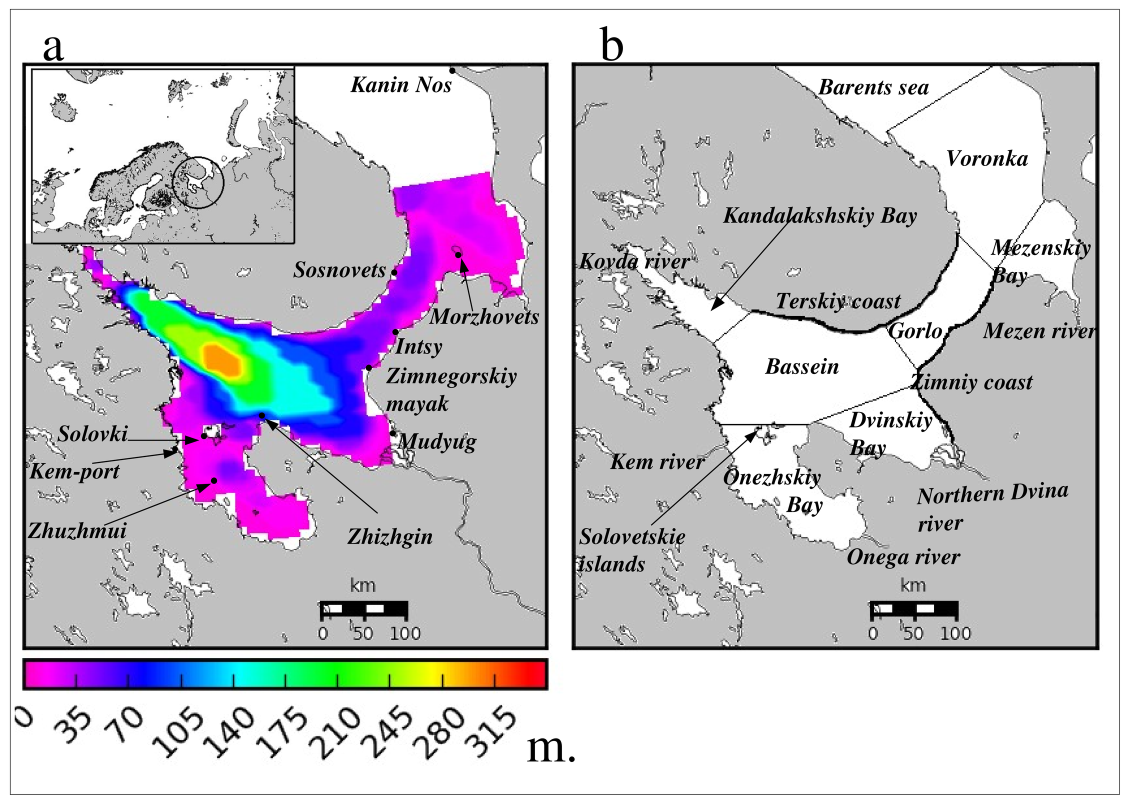
The White Sea

The White Sea is a small sea, completely within Russian territory. Influenced by strong tidal mixing, sea ice dynamics, and significant interactions with terrestrial inputs, it covers $\approx 91'000$ km^2 and is relatively shallow, with an average depth of 67 m and a maximal depth of 340 m. The White Sea is semi-enclosed. The water mass circulation is dominated by high tides incoming from the Barents Sea. The White Sea is ice-covered from late autumn to late spring and ice-free in summer. The area is important due to a number of human activities including fisheries, mollusk farms, mining, tourism, and maritime shipping. The Northern Sea Route begins in the White Sea, and tidal energy plants take advantage of the extremely high tides in some of its bays (e.g., 11 m in Mezenskiy Bay). Furthermore, the effects of climate change and anthropogenic activities on the ecosystem are still a matter of debate. Numerical modelling and computer simulations are able to answer questions that are hardly possible to be studied in any other way. Given the extreme conditions of the area and the difficulty of making field observations, especially during winter, numerical models can be useful tools for investigating the physical and biogeochemical properties of the White Sea and the spatial and temporal variability of those properties. Besides, "What if" numerical experiments can be made, including various scenarios of climate change and anthropogenic influence of the marine ecology.



(a) a) Bathymetry of the White Sea; data collecting stations are shown by circles. b) Sub-basins, rivers, and coasts of the White Sea.

Collaboration

Modelling is a meeting point for fruitful collaboration:

- IAMR & NWPI of Karelian Research Centre
- Marchuk Institute of Numerical Mathematics (Moscow)
- Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (Trieste, Italy)
- Institute of Oceanology (Moscow)
- Zoological Institute (St.-Petersburg)
- Biological department of Moscow State University
- SYKE, Helsinki, Finland
- etc

Simulation results

Surface Temperature & Salinity

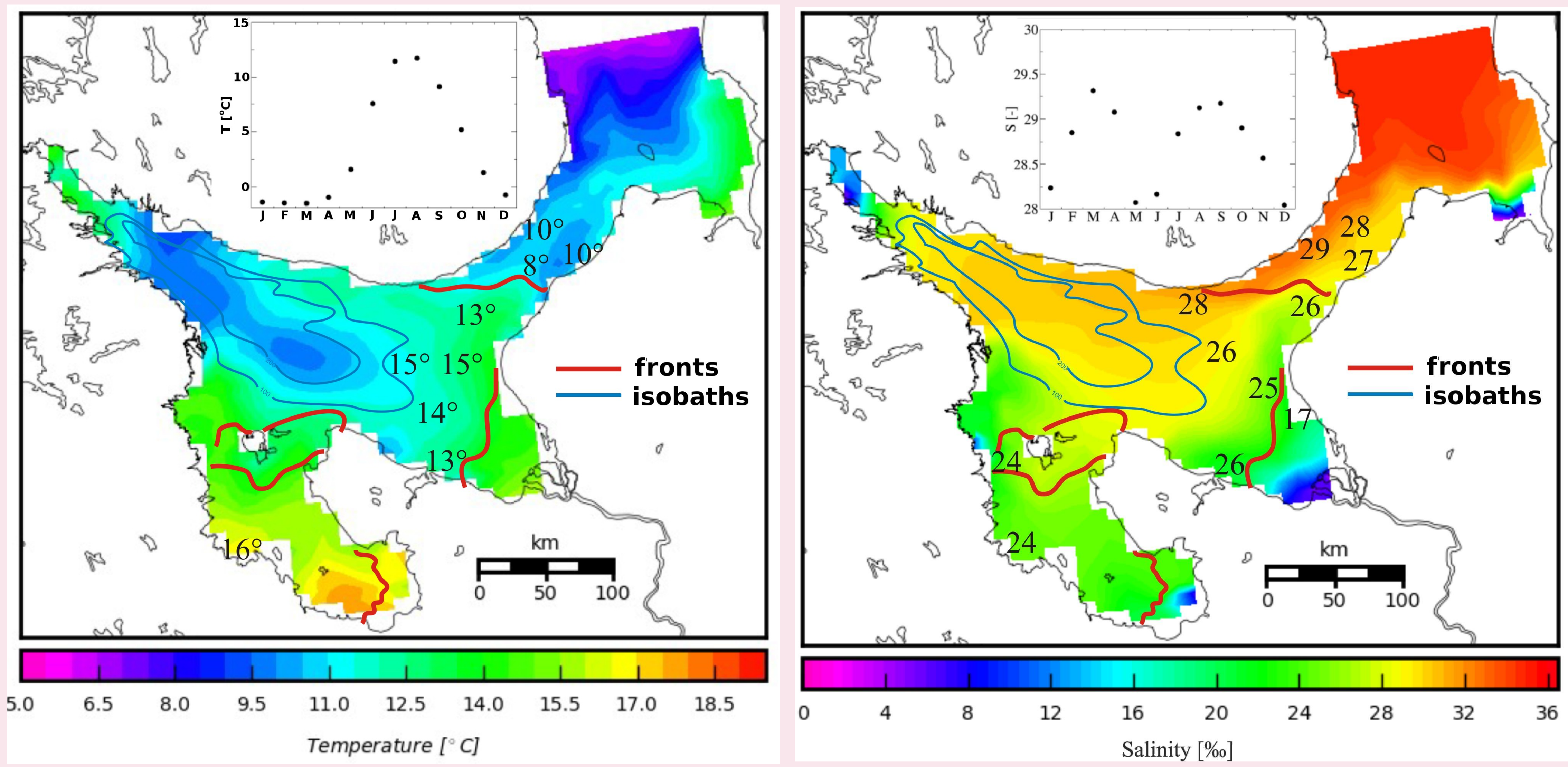


Figure: Sea surface temperature and salinity maps according to the color scale for the climatological August over the 2003–2012 period (model data); numbers show the sea surface temperature and the salinity measurements obtained in August 2013. The insets in each map show the seasonal cycle of the horizontally averaged field.

Pelagic Biogeochemical Phenomena

Temporal and spatial dynamics of nutrients, chlorophyll, plankton biomass, primary production agrees well with measurements. Benthic exchange is important due to low depth. Precise description of sea ice is crucial.

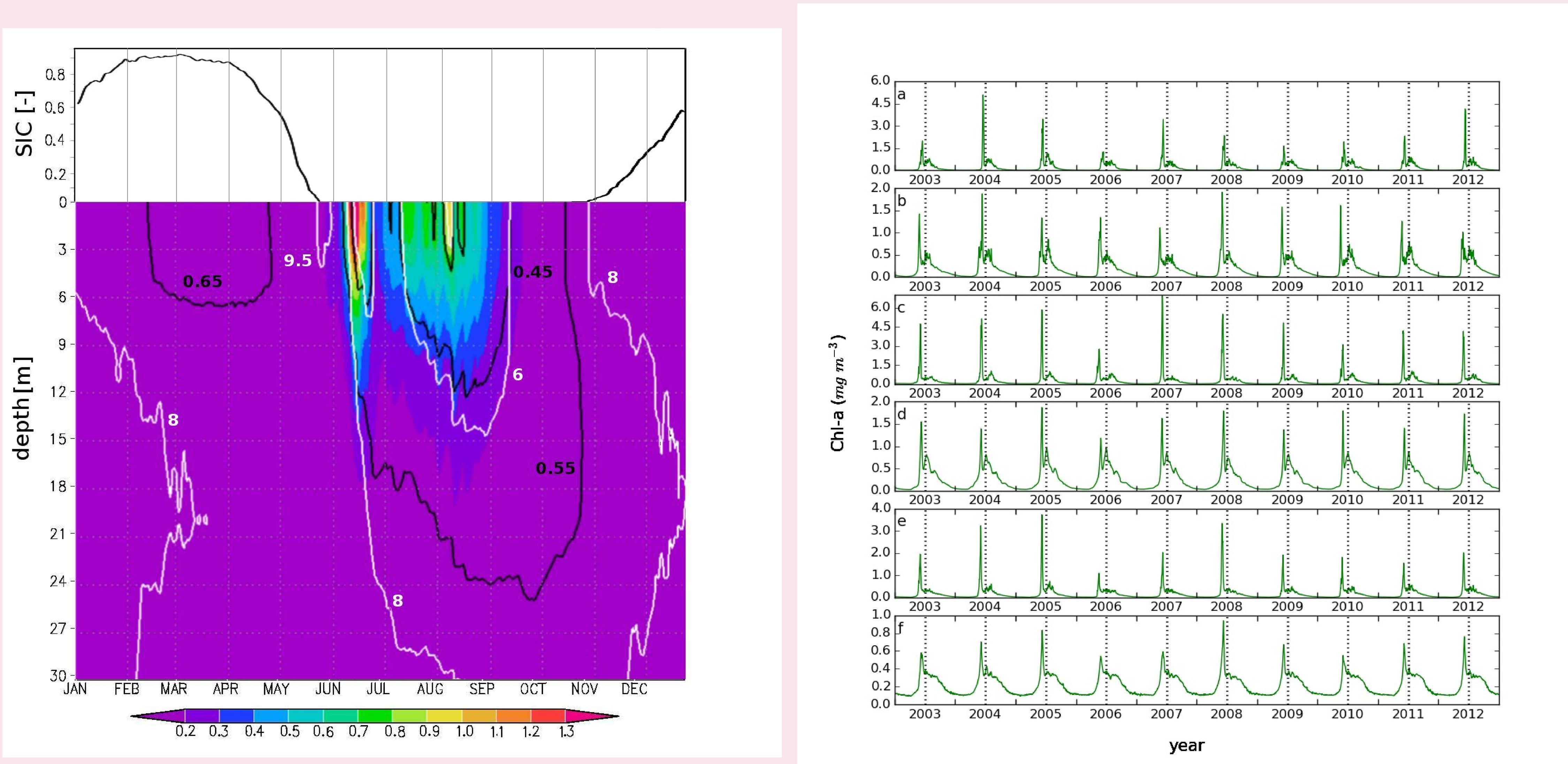
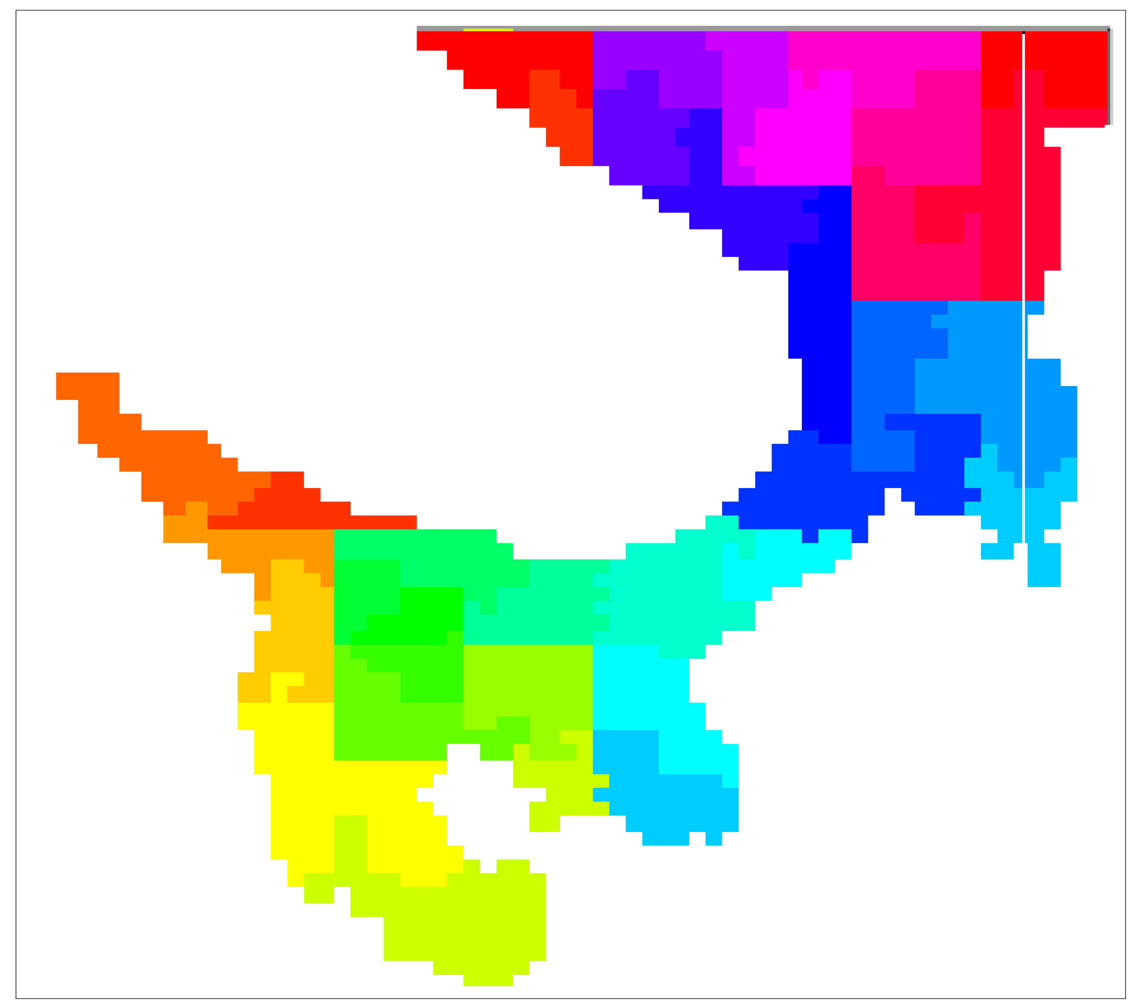


Figure: Left: Daily averages for 2007 of modeled Sea Ice Concentration (SIC, top panel), chlorophyll-a (mg/m^3, color scale), and nutrients (mmol/m^3, shown as contour lines; NO_x in white and PO_4 in black). Right: Time series of modeled surface chlorophyll-a horizontally averaged over the White Sea sub-basins: a) Kandalakshskiy Bay, b) Onezhskiy Bay, c) Dvinskiy Bay, d) Mezenskiy Bay, e) the Bassein, f) the Voronka. Ticks mark January 1; dotted vertical lines mark July 1. Note that the y-axis scale differs among panels.

The model

The JASMINE system is based on the FEMAO (Finite-Element Model of the Arctic Ocean by prof. N.G. Iakovlev) hydrodynamical model that includes both ocean and sea ice dynamics. Both are primitive equation finite-element numerical models of the Arctic Ocean, and the White Sea, respectively. The biogeochemical submodel is the Biogeochemical Flux Model (BFM). The BFM is a biomass-based numerical model that simulates the biogeochemical fluxes of carbon, phosphorus, nitrogen, silicon, and oxygen characterizing the lower trophic level (producers, consumers, and recyclers) of the marine ecosystem. The model includes four phytoplankton functional types (diatoms, flagellates, picophytoplankton, and dinoflagellates), bacteria, heterotrophic nanoflagellates, microzooplankton, and carnivorous and omnivorous mesozooplankton. Phytoplankton functional types are also described in terms of 124 Chlorophyll-a content; for diatoms, the silicon component is also included. Particulate and dissolved organic matter is taken into account, with the latter variable being partitioned into labile, semi-labile, and semi-refractory phases. The multi-CPU exchange library with load balancing by P. Perezhogin has linear scalability to at least 900 CPU.



(a) Decomposition for multiprocessor simulation

Main Publications

- Perezhogin et al. Advanced parallel implementation ... Geosci. Model Dev. 14, 843–857, 2021.
- Chernov et al. Hydrodynamical and biogeochemical ... J Marine Syst, 187, 2018, 23–35.
- Chernov, Tolstikov. The White Sea: Available Data ... Geosciences, 2020, 10, 46.