Coupled numerical simulation of geophysical and biogeochemical processes in ice-covered seas and oceans

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Modeling the biogeochemistry

What are the distribution of chemical elements in the ocean, how they change and why.

Typical questions are

- What are the mean concentrations and why are they such
- How are they distributed in space
- How do they change in time

Substances of interest are those influenced by biological processes.

First of all, this is carbon.

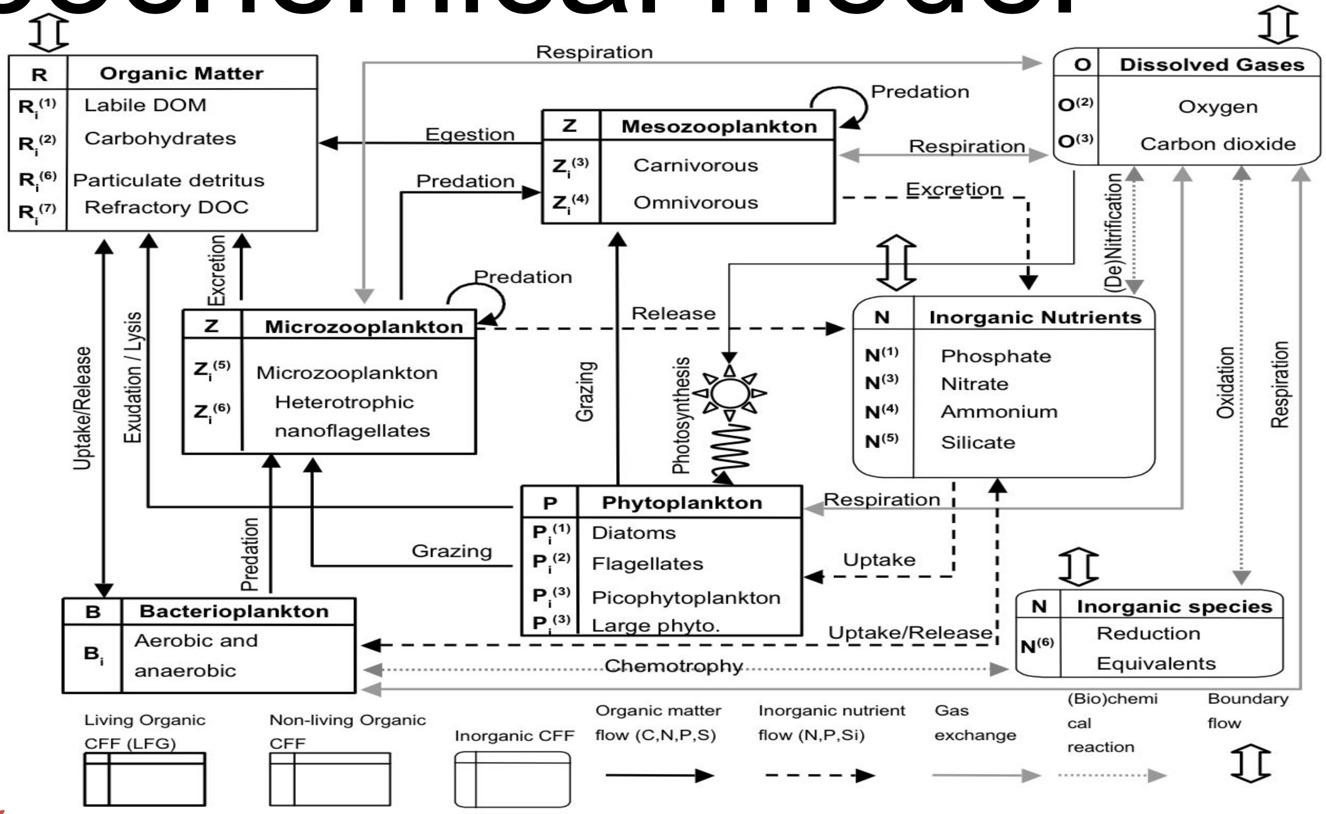
Also nitrogen, phosphorus, silicon, oxygen etc.

BFM: a pelagic ecosystem model

- Biogeochemical Flux Model developed by the consortium:
  - Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)
  - Dipartimento di Fisica e Astronomia, Alma Mater Studiorum Università di Bologna (UNIBO DIFA)
  - **Istituto Nazionale di Oceanografia e di Geofisica Sperimentale** (OGS)
  - Department of Oceanography, University of Cape Town (UCT)
  - Finnish Environment Institute (SYKE)
- Used for various scales and climatic regions:
  - Adriatics, Mediterranian;
  - Atlantic Ocean, Global Ocean;
  - Included into NEMO, MITgcm, POM
  - Used in the projects: MyOcean, GREENSEAS, GEOCARBON, MEECE etc.
- Contains the sympagic component
- Contains several benthic models
  - Though we use a simple exchange description

Biogeochemical model

- ✓ **Multielement description (C, P, N, Si, Chl*a*)**
- ✓ **Trophic net The classical and the microbial loop**
- ✓ **4 groups of phytoplankton**
- ✓ **4 gropups of zooplankton**



✓ **Vichi et al., 2013**

The page prepared by Paolo Lazzari, OGS, Trieste, Italy

Benthic exchange

- some components sink wrt water:
  - detritus (5 m/day)
  - phytoplankton (variable speed)
- Purely pelagic model also works (matter in the bottom layer)
- Sinking matter is accumulated “on the bottom”
- 25% slowly remineralized matter (C,N,P), 75% is quick.
- Rate is proportional to the amount
- And exponentially on the temperature
- Inorganic return is used by the diffusion.

Model can be tuned

- Stoichiometric concentrations for some groups: N=N(C), P=P(C)
- Join, split, exclude, or add groups.
- Turn a cycle on/off
- Diagnostic variables are functions of the phaze vector: numerous!
- Submodels of sea ice and benthic ecosystems

Interaction of GOCMs and BFM

- Process splitting
- Advection, rivers, flux from atmosphere, diffusion, sinking all come from GOCM
- Time derivative of the phaze vector and diagnostics for each node provided by BFM
- Environment parameters GOCM -> BFM (T, S, $\boldsymbol{\rho}$, light, wind, CO_2, ...)
- Amount of plankton may be used for sea optics (feedback!)
- Advection is the most costly!

General ocean circulation models

INMCM - The Earth system model of INM RAS, the ocean component.

- sigma-variable
- Sinking is separate. No benthos: just bury the matter.
- Rivers, precipitation provided by other components.

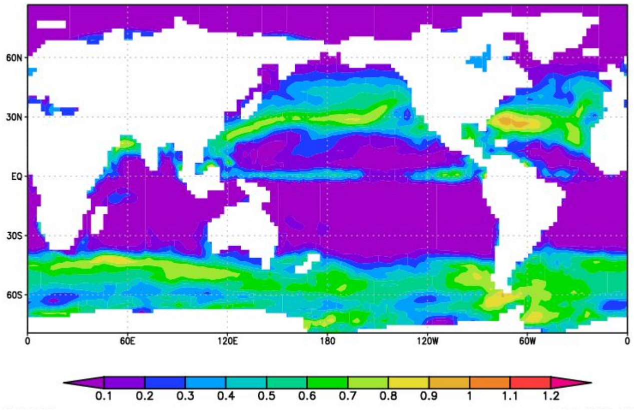
JASMINE - The White Sea model based on the FEMAO for the Arctic Ocean

- z-coordinate
- Several ice thickness levels
- Exchange with the bottom (the Sea is pretty shallow!)

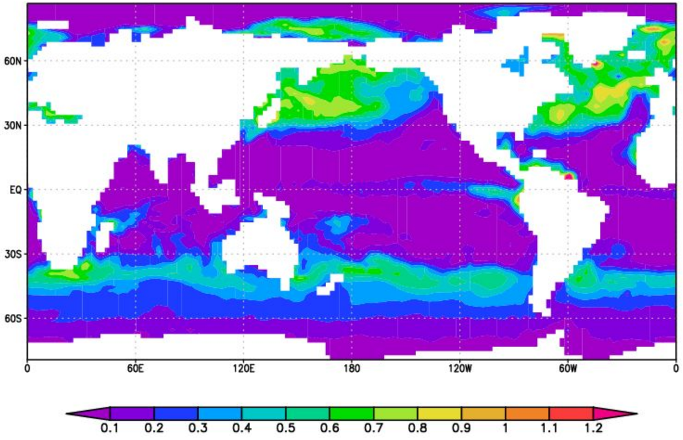
What can be calculated?

- Daily average chlorophyll for the sea or a bay
- Biomass of plankton or its group
- Primary production, net or gross, for each group.
- Redfield ration, limiting factor
- Spatial and temporal variability
- Inner variability of the system
- Numerical experiments

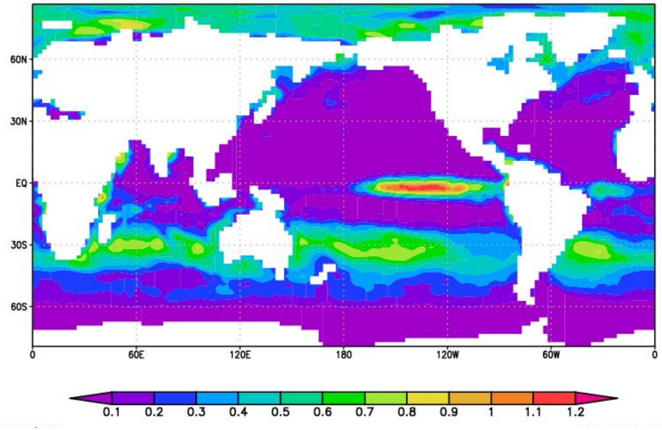
First results: chlorophyll



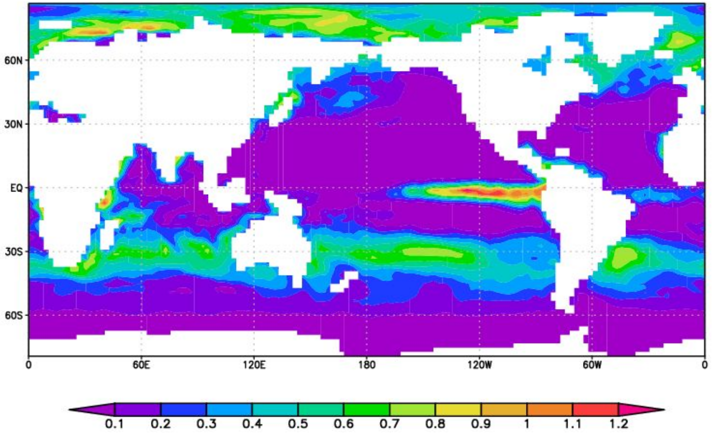
Jan



May

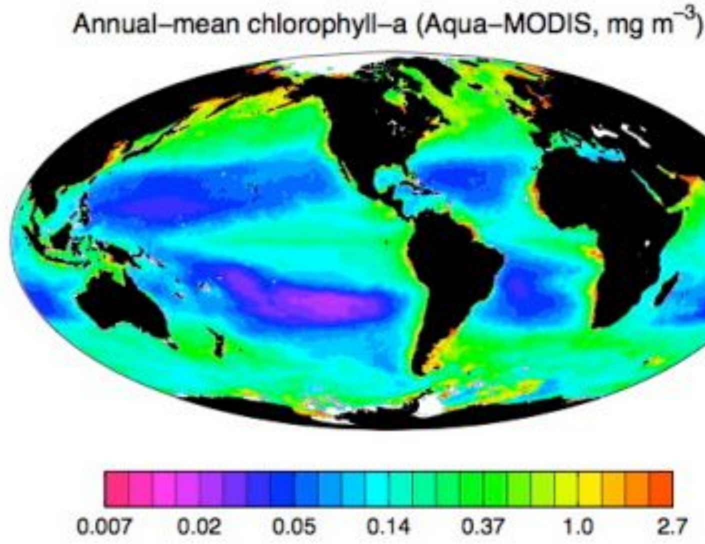


Aug

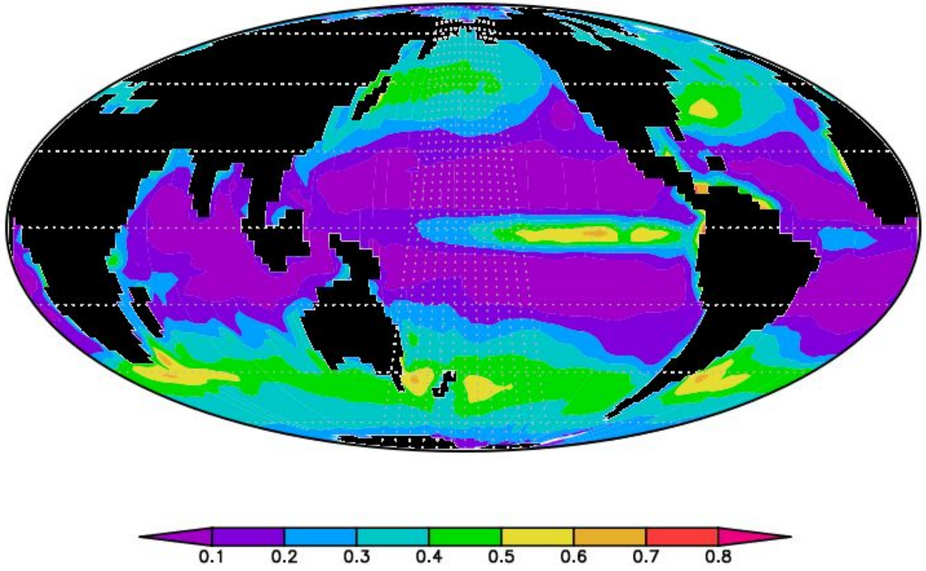


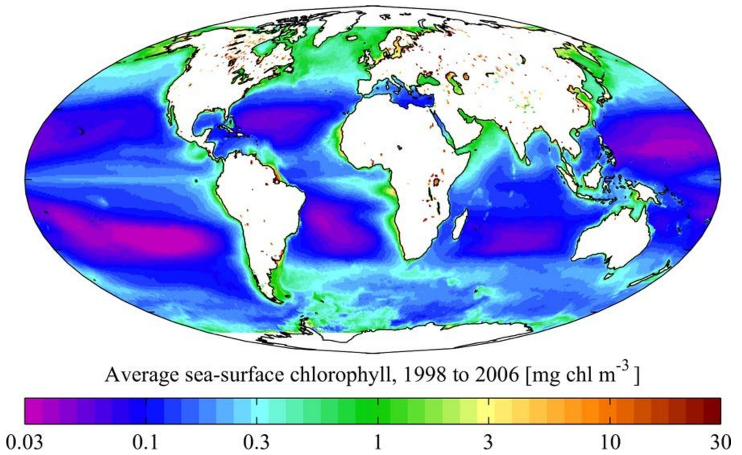
Oct

First results: chlorophyll



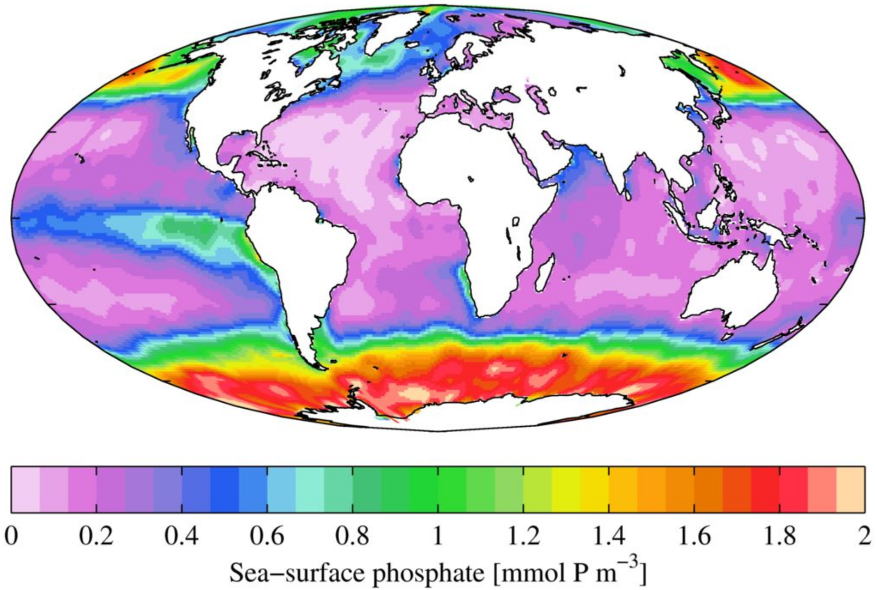
https://www.liverpool.ac.uk/climate/research/newbiogeo/

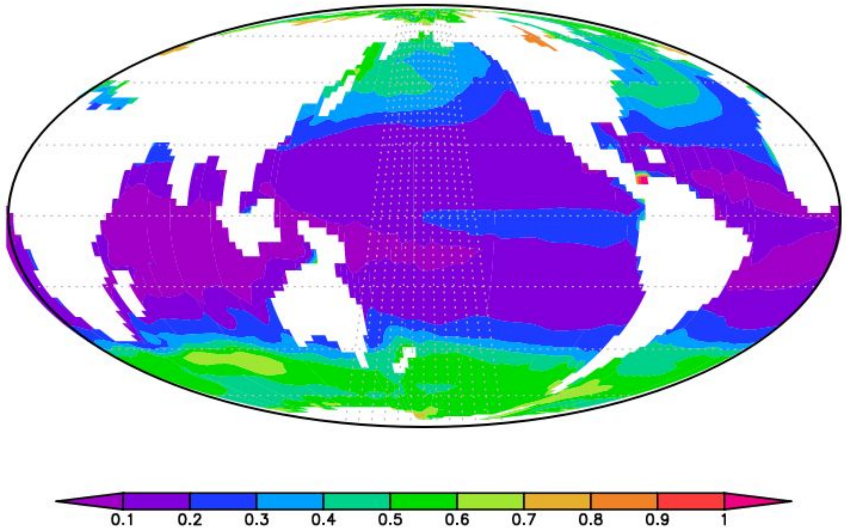




https://dabrownstein.com/category/plankton-maps/

First results: phosphates



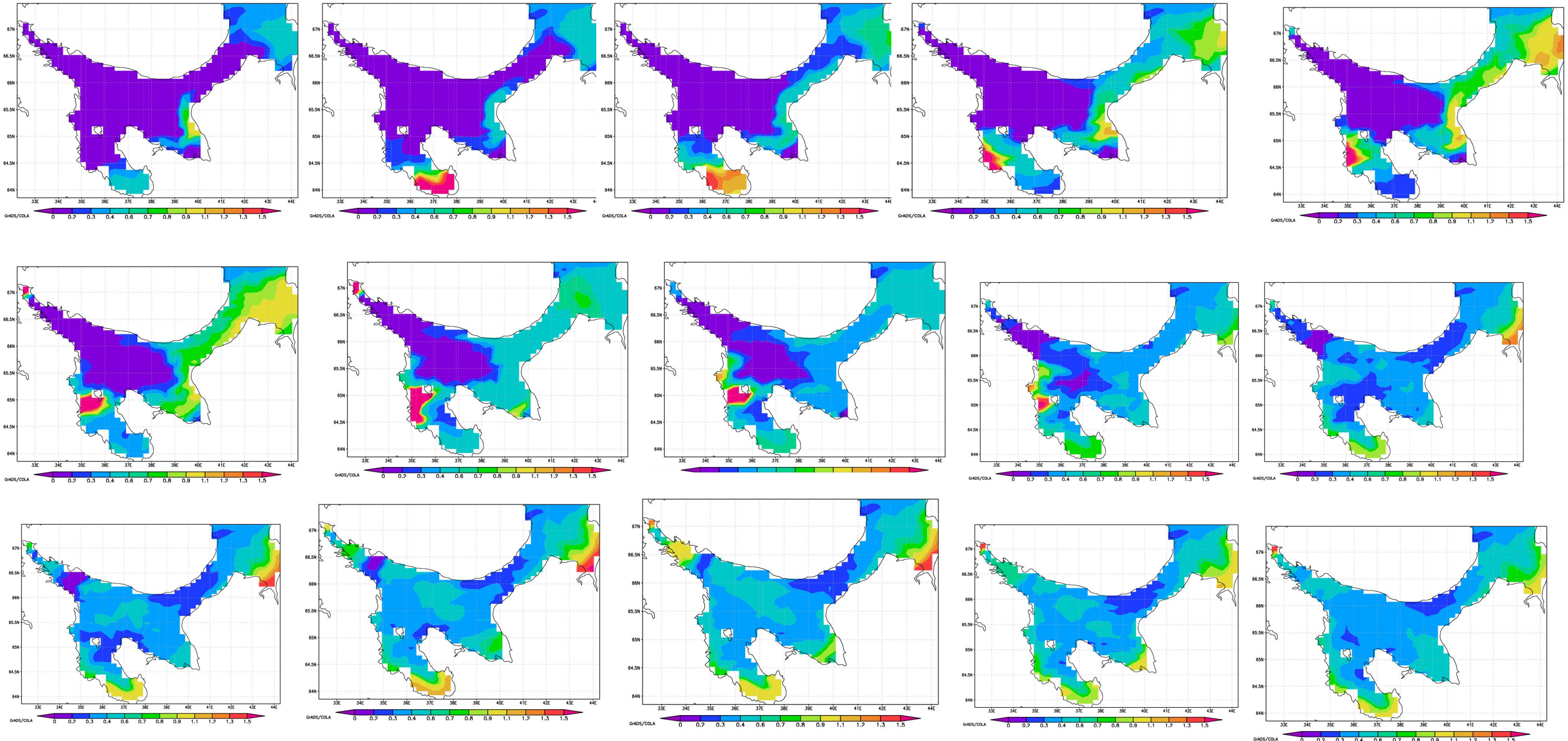


World Ocean Atlas

The White Sea

- Size ~500 км,
- Mean/max depth: 67/340m,
- Strong tidal motion
- Strong river discharge
- Ice-free in summer

The White Sea, chlorophyll, 10.05.2006 - 19.07.2006



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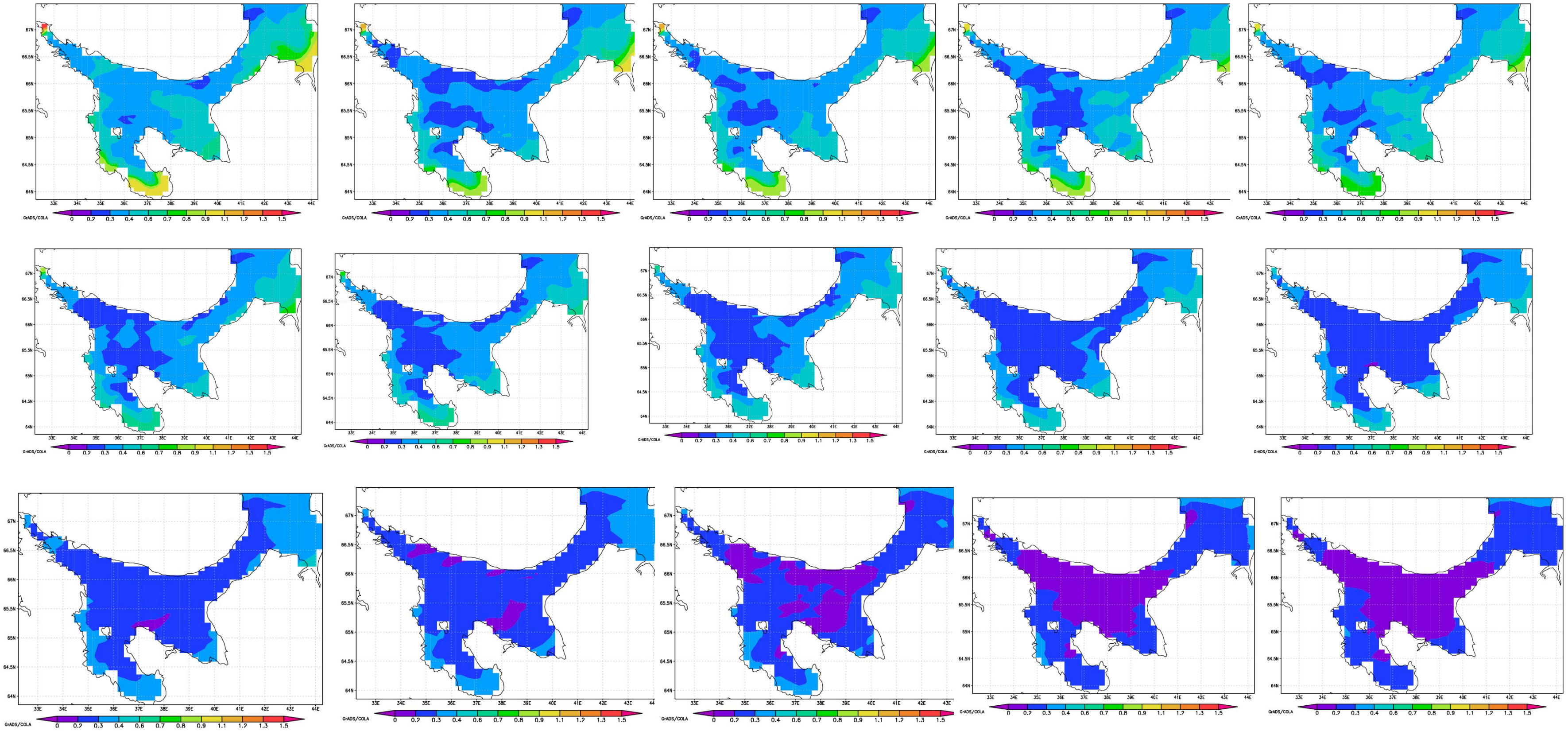
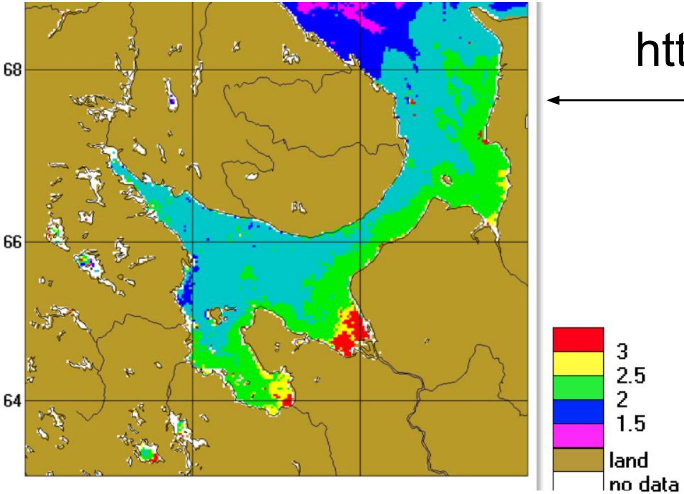
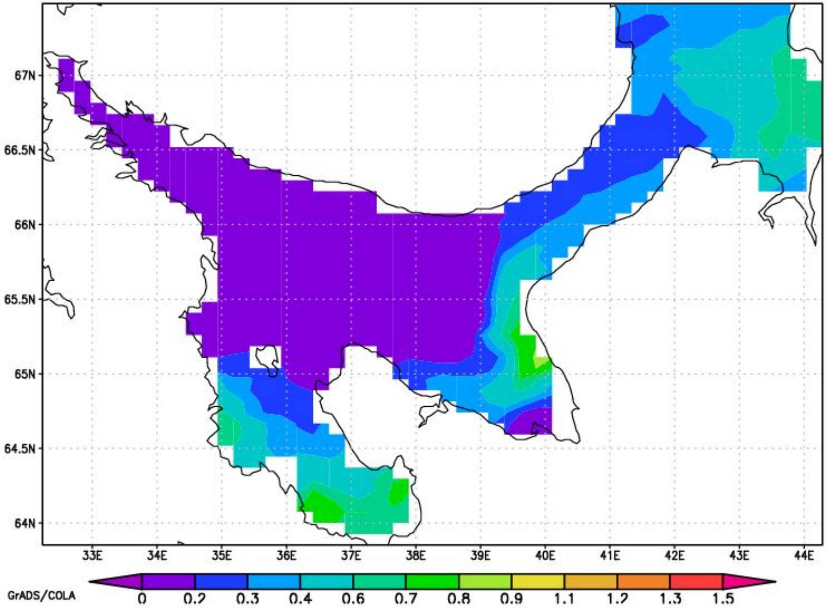
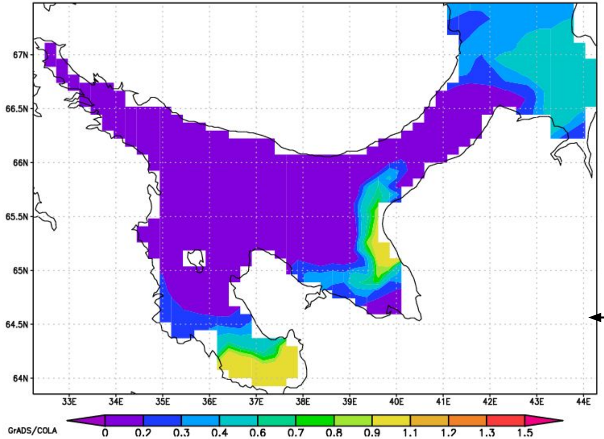


Chlorophyll distribution in May, multi-year average

http://optics.ocean.ru



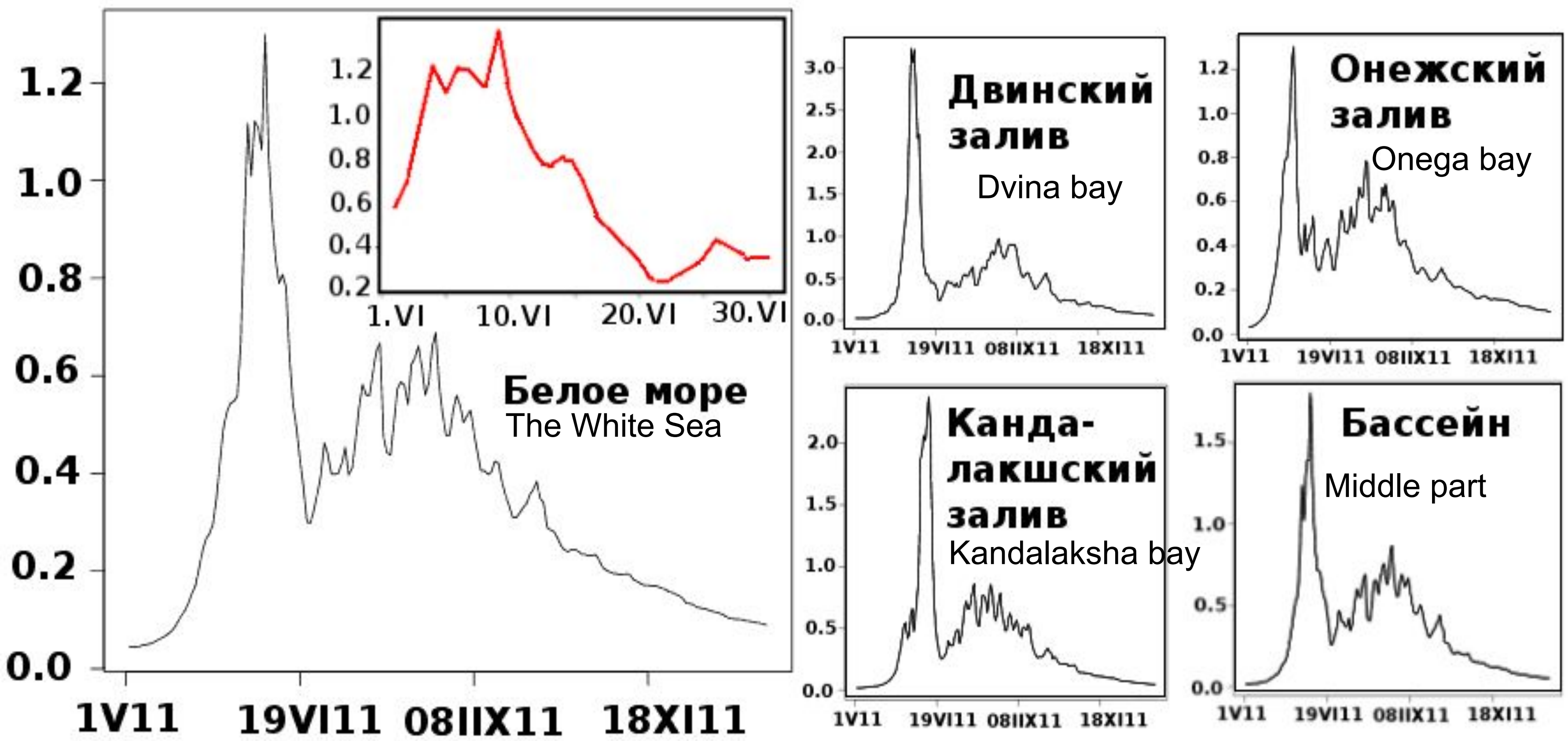




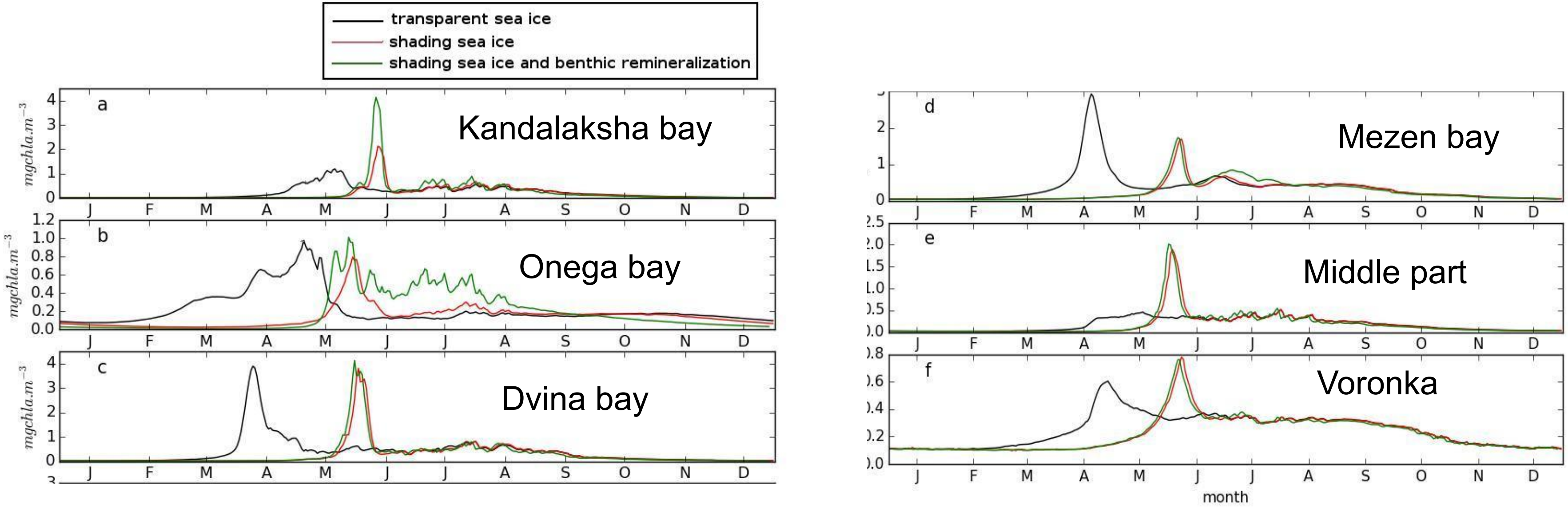
Model, May 13

Total chlorophyll in May, mg/m3

Area-mean chlorophyll

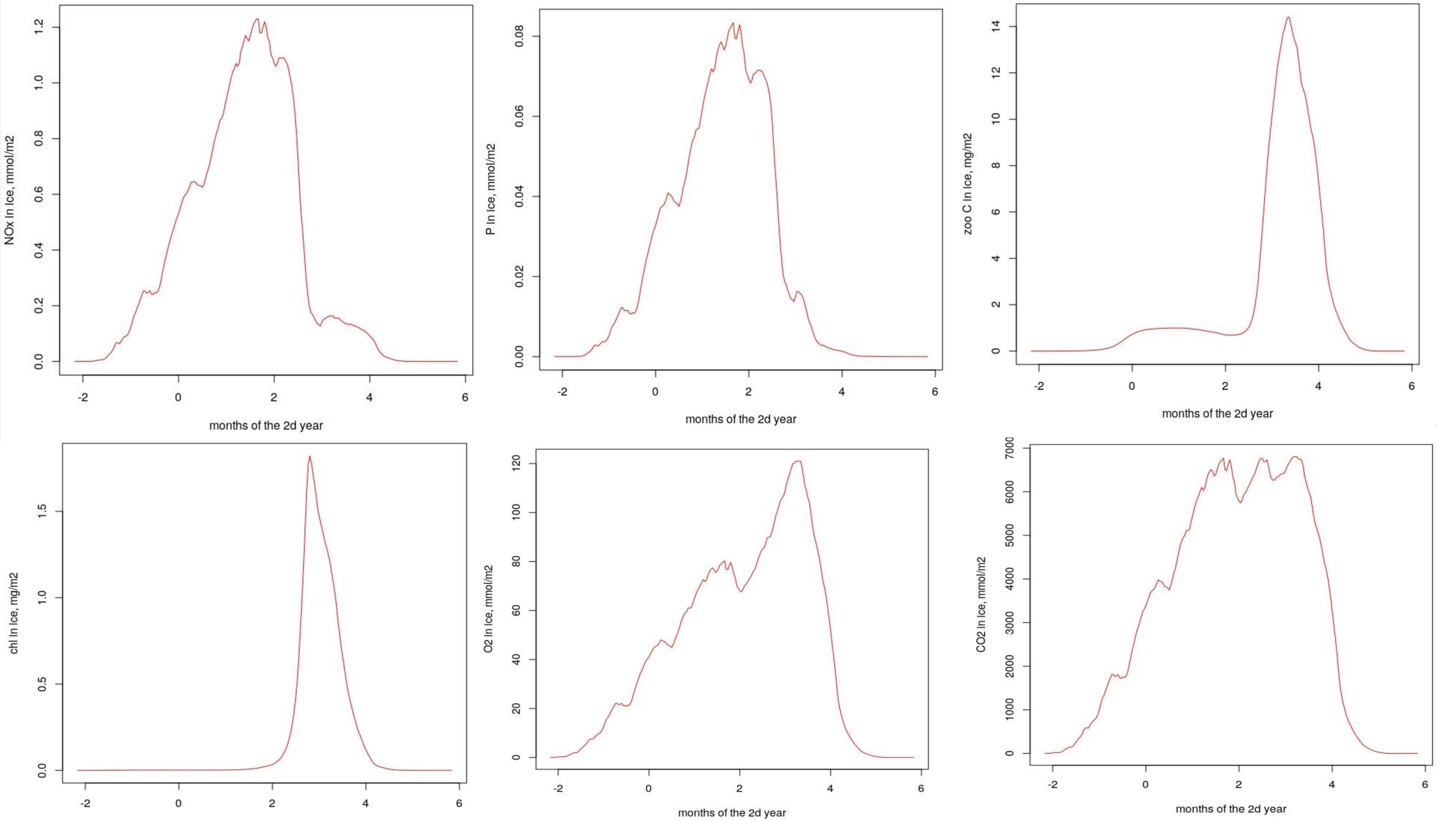


Influence of light and bottom



Sympagic ecology

- Letizia Tedesco, SYKE (Helsinki)
- Ice contains brine-filled pores with plankton
- Phytoplankton is surviving and ice-specific; zooplankton; bacteria; matter.
- Single 2D bioactive layer
- Light, T, S, ice thickness, and its speed taken from the GOCM
- Pelagic values from the BFM
- Advection by the GOCM
- Ice growth -> capturing stuff from water
- Melting -> release of matter and/or organizms to water, the flux used by diffusion


NOx In Ice, mmol/m2
months of the 2d year
P In Ice, mmol/m2
months of the 2d year
zoo C In Ice, mg/m2
months of the 2d year
chl In Ice, mg/m2
O2 In Ice, mmol/m2
months of the 2d year
CO2 In Ice, mmol/m2
months of the 2d year

Thank You for Your attention!