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Numerical simulation of Black Sea circulation and pollution propagation in coastal waters of the Great Sochi

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Outline:

- Institute of Numerical Mathematics Ocean Model (INMOM).
- Using INMOM for Black and Azov Seas operative circulation model.
- Using INMOM for simulation of Black Sea offshore regional circulation near Great Sochi.
- Comparison results from Black and Azov seas model and regional Great Sochi offshore model.
- Pollution spread near Great Sochi coast.
- Conclusions

INMOM multicomponent splitting includes

- Symmetrized forms of governing equations for energy conservation low.
- Multicomponent splitting into series of nonnegative subsystems.
- It allows to use implicit and semi-implicit schemes for time integration of these subsystems with long time step.
- Each separate subsystem has its adjoint analog. The adjoint model consists of the respective subsystems adjoint to the split subsystems of the forward model. This technique simplifies the construction a full adjoint model required for 4D-var data assimilation.

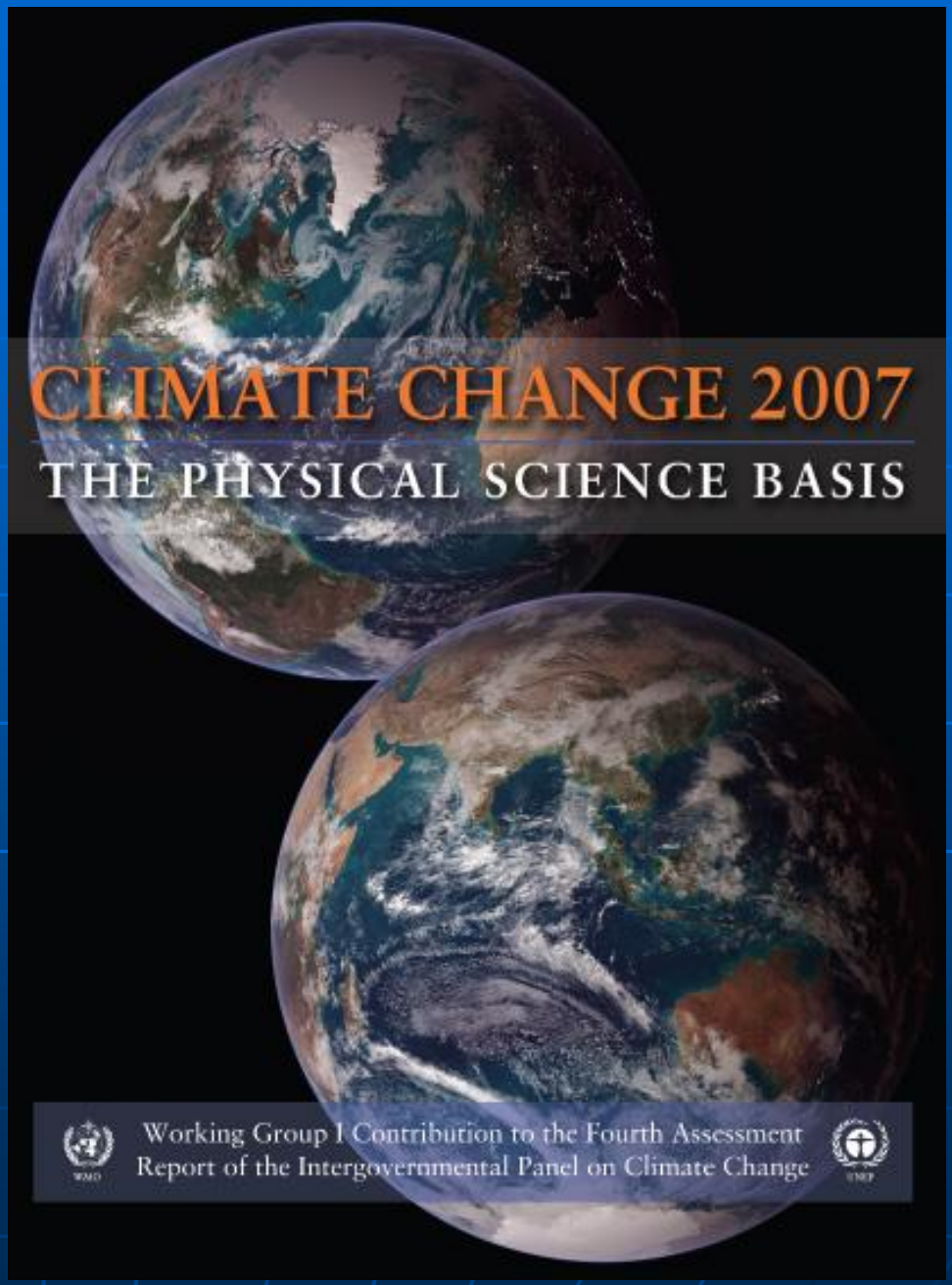
Physical parametrizations

- The EVP (elastic- viscous- plastic) dynamic - thermodynamic sea ice model (Hunke, 2001) is embedded.
- Philander-Pakanovsky, Monin-Obukhov or Mellor-Yamada parameterization of vertical mixing are used.
- A Laplacian operator along the geopotential or isopicnal surfaces is used for the lateral diffusion for T and S.
- A bilaplacian operator along sigma-surface is used for the lateral viscosity on momentum.

The global version of the INMOM is used as the oceanic component of the IPCC climate model INMCM (Institute of Numerical Mathematics Climate Model).

INMCM3 with INMOM of 2x2.5 deg. resolution is presented in the IPCC Fourth Assessment Report (2007).

INMCM4 with INMOM of 0.5x1 deg. resolution will be presented in the IPCC AR-5.



Two versions of INMOM for Black Sea circulation using:

1. Black and Azov Seas (BAS) model has uniform grid with ~4 km space resolution. It works in operative regime in State Oceanographic Institute, Moscow, Russia.

2. Regional Great Sochi offshore model has non-uniform spatial resolution up to 50 m near Great Sochi and about 5-9 km in the west part of Black Sea.

Conception. Operative model works every time. Regional model works if necessary starting from temperature, salinity, velocity and SSH fields interpolated from BAS model.

INMOM – Black and Azov Sea circulation model (BAS MODEL)

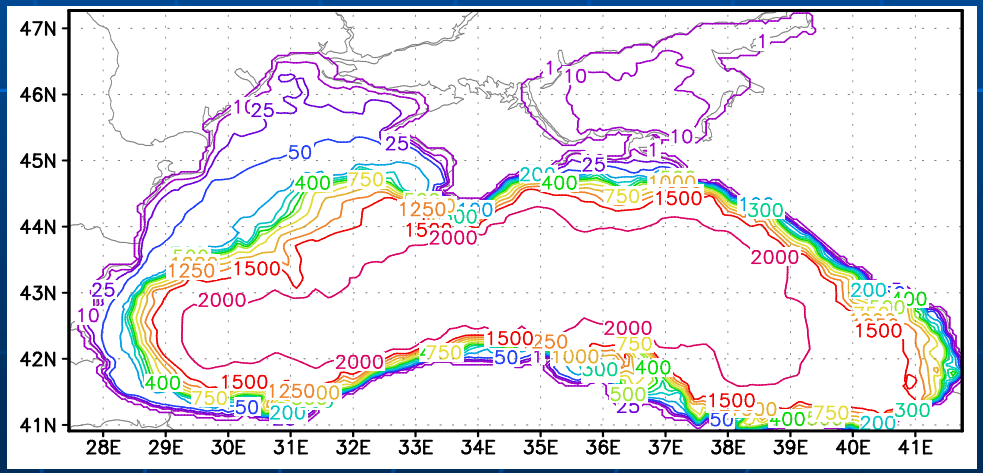
Grid domain:
- 287x160 horizontal resolution;
- 40 uniformly distributed vertical σ-levels, with condensation in the surface layer of 0 - 100 m;
- Time step 300 s;
- Longitude step: 0°3‘(~4.2 км);
- Latitude step: 0°2'24(4.44 км);

Grid boundaries:
- Longitude: 27°26'60” E - 41°45'00” E.
- Latitude: 40°54'36” N - 47°16'12” N

Topography based on:
- Black sea topography with spatial resolution 0°0'36"x0°0'36»;
- Azov Sea topography with spatial resolution 0°0'35.06"x0°0'35.06“;

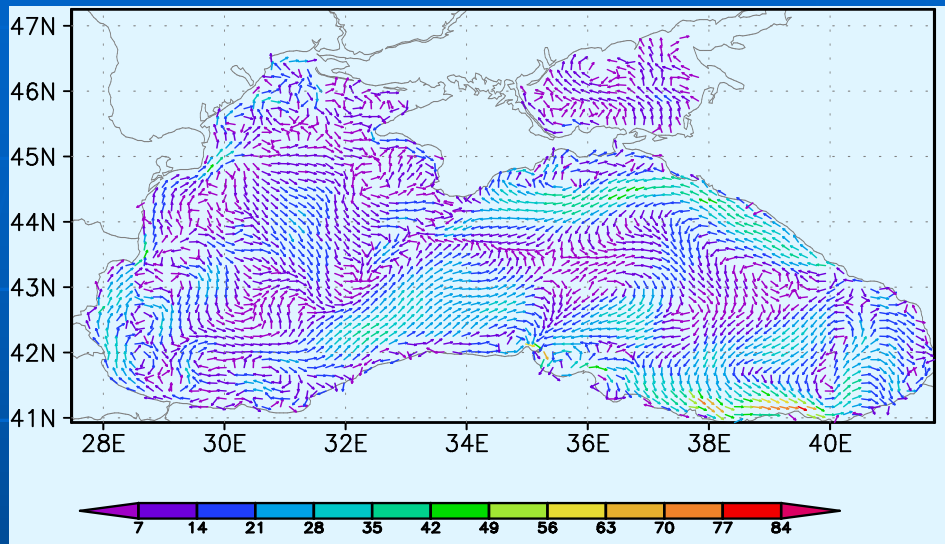
Temperature and salinity climate data based on climate fields are from Belokopytov atlas (MHI, Sebastopol)

Black and Azov Sea bottom topography [m]

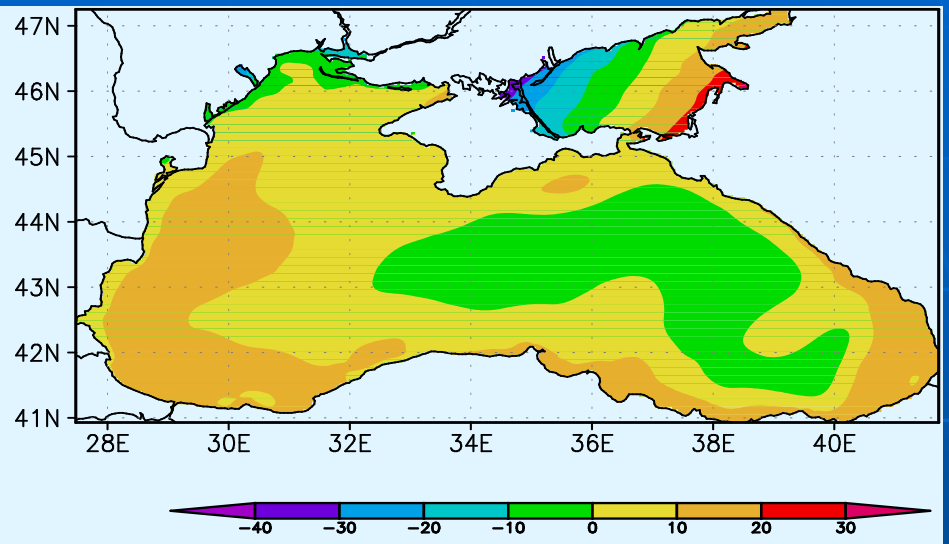


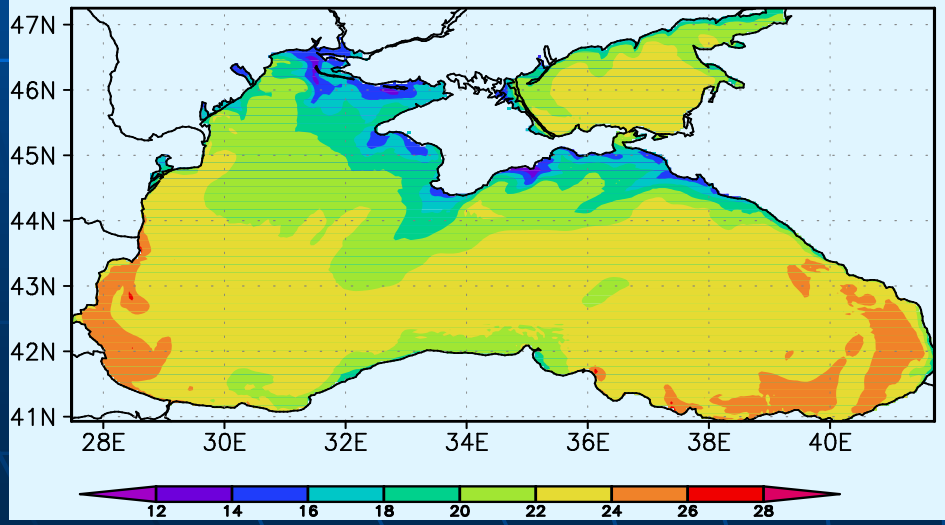
Примеры оперативной информации для Черного и Азовского морей на 12:00GMT 06.09.2013.

Скорость течений, м/с

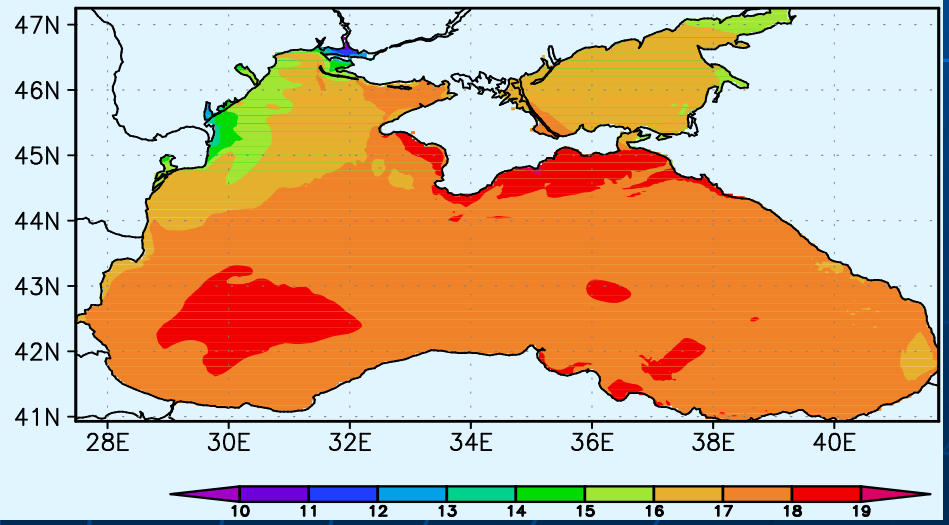


Уровень моря, см



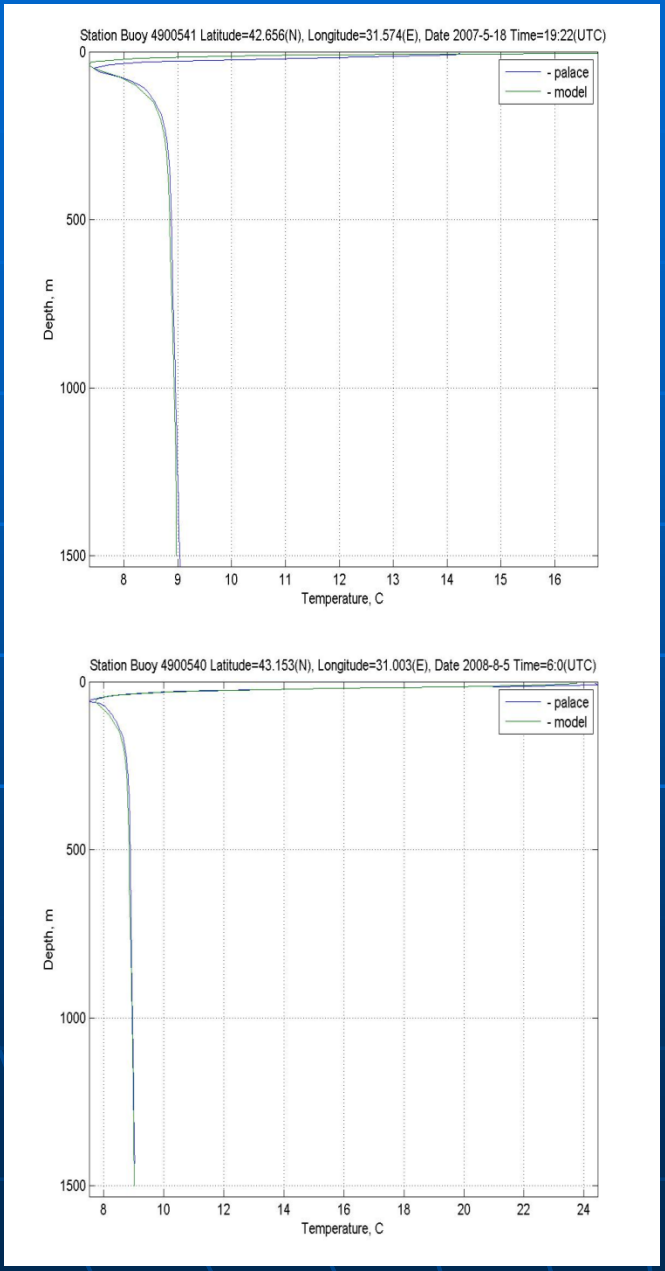


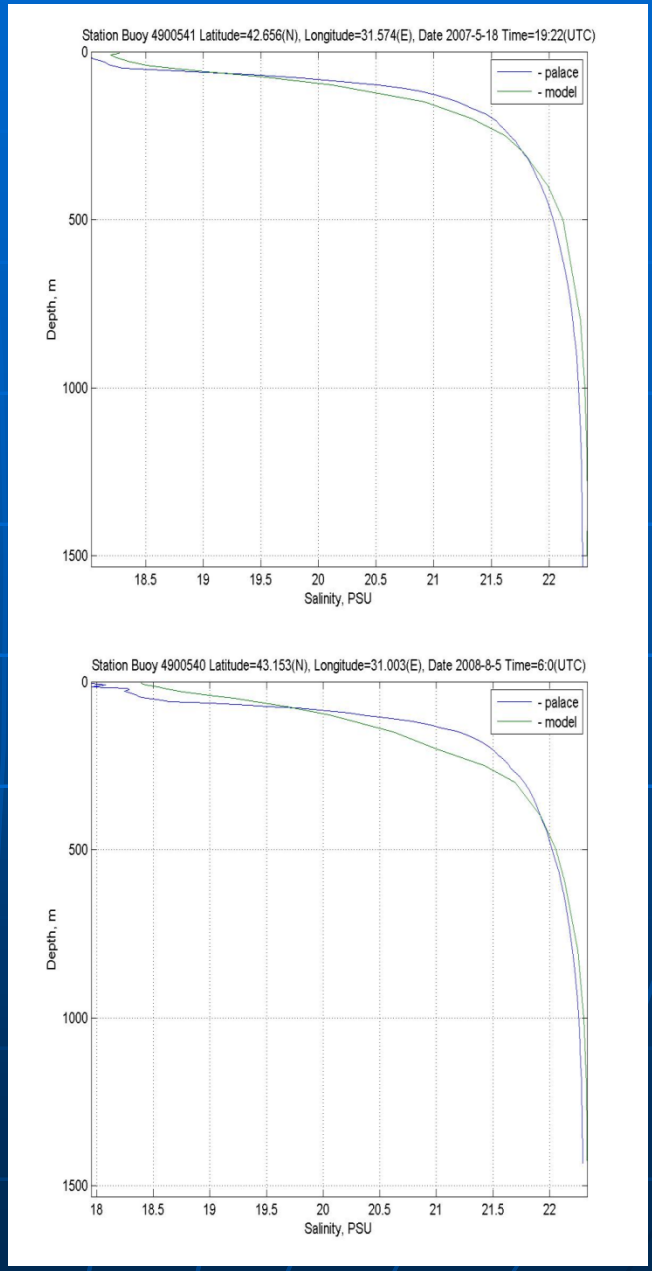
Температура, С



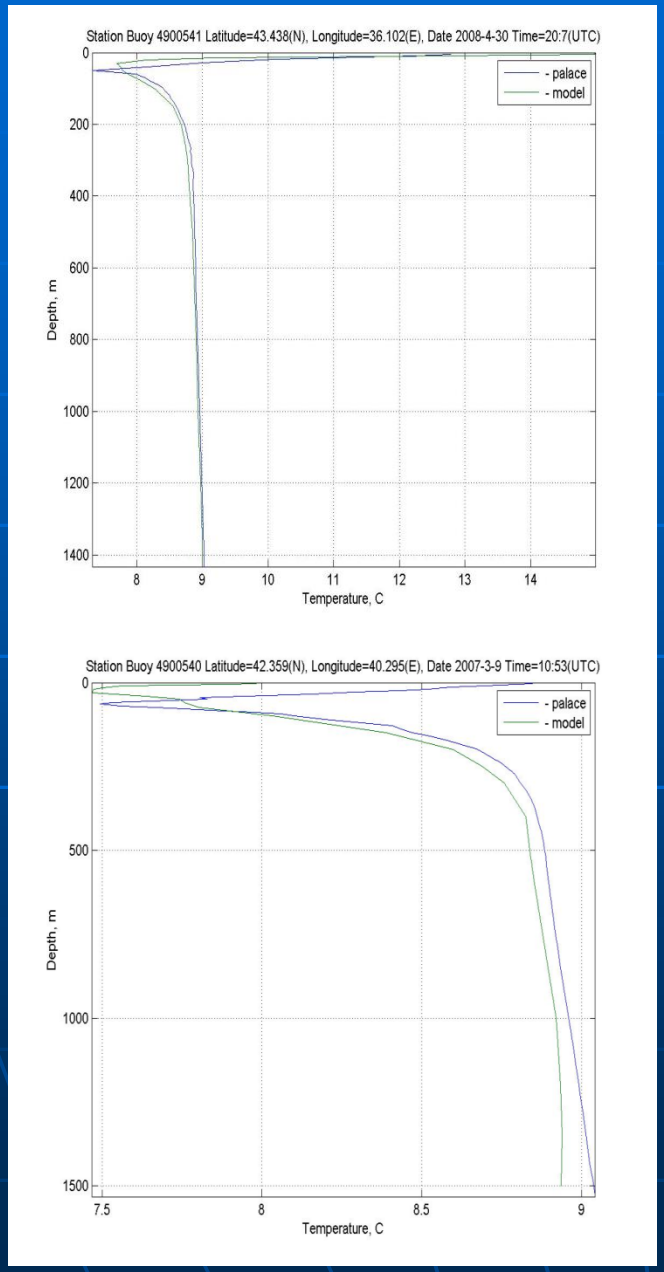
Соленость, PSU

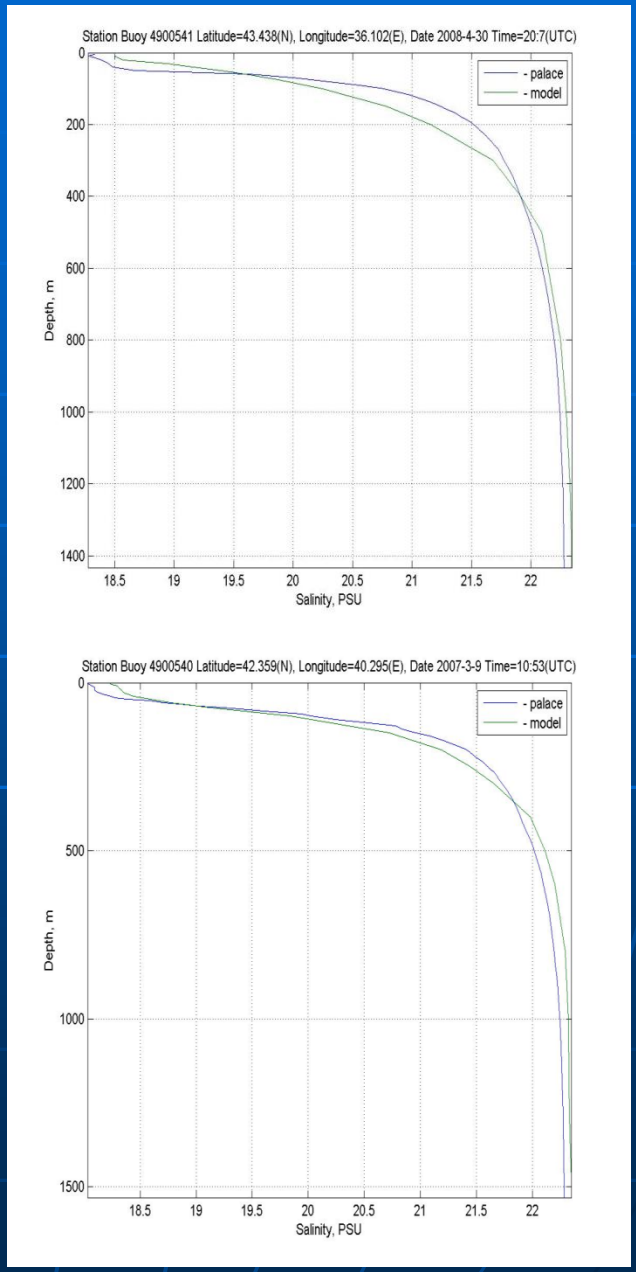
BAS model results vs ARGO project



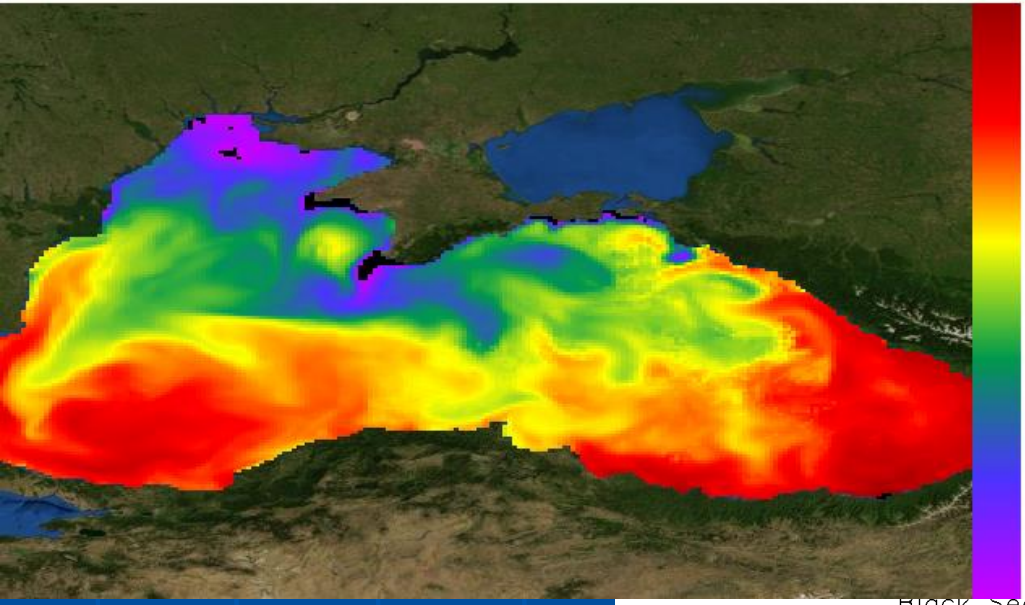


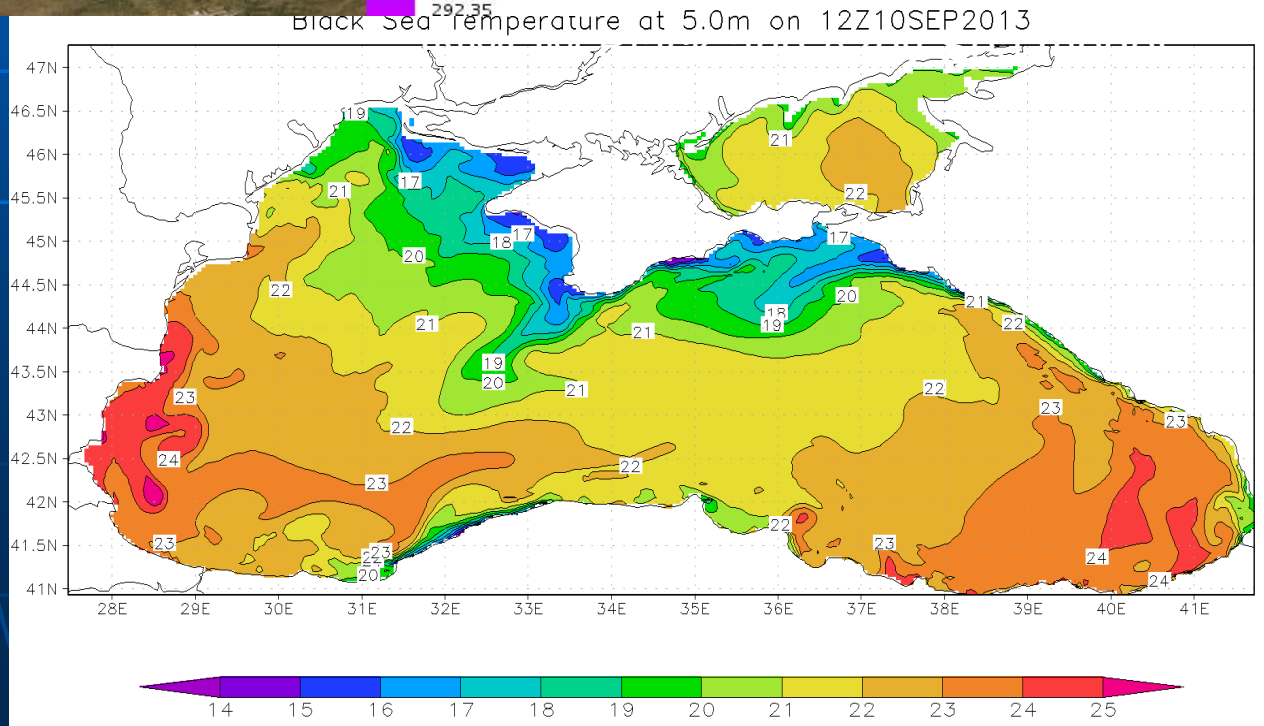
BAS model results vs ARGO project





Modelling of sea-water state for the Black Sea
↳sea_water_temperature
Time: 2013-09-10T12:00:00.000Z
Depth: 5meters





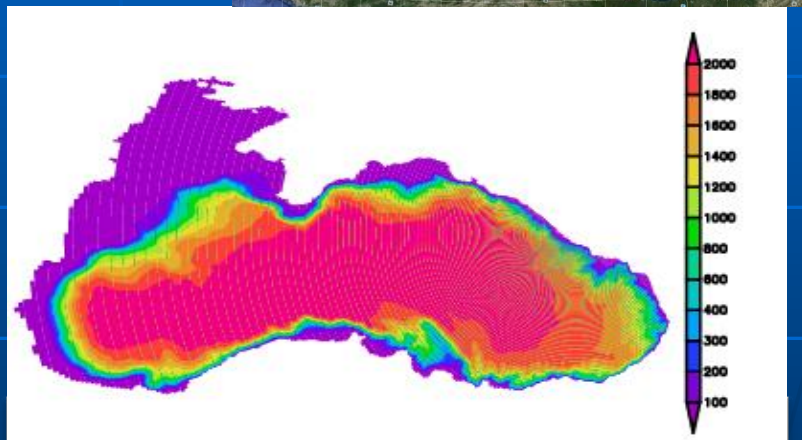
Regional version of INMOM for Great Sochi offshore

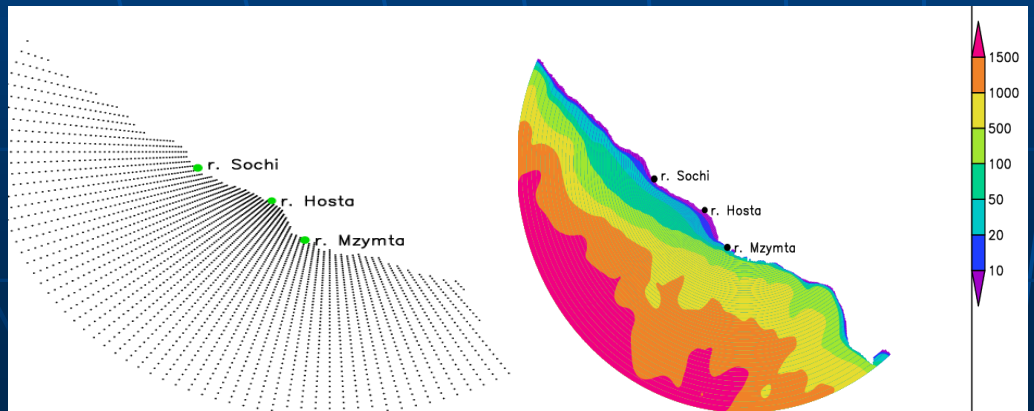
Grid:

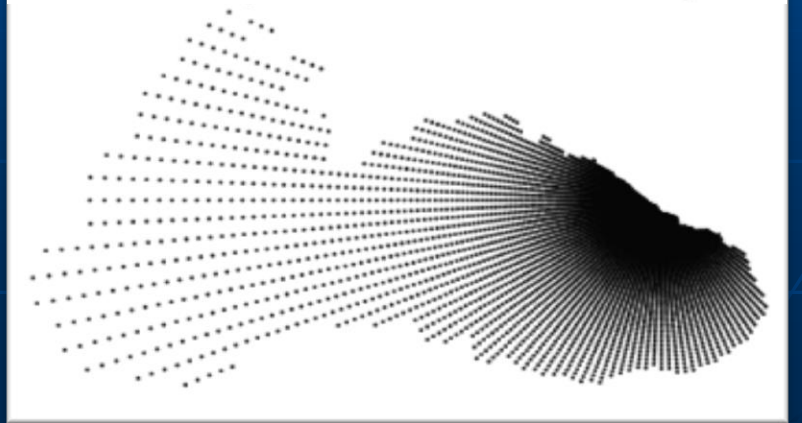
- Model north pole is set at village “Read Rock”
- Non-uniform spatial resolution up to 50 m near model north pole and about to 5-9 km in the west part of Black Sea.
- 759x600 – model grid
- 20 non-uniform sigma levels

Initial fields:

- GEBCO topography;
- Temperature and salinity distribution – results from BAS model or climate fields are from Belokopytov atlas MHI, Sebastopol

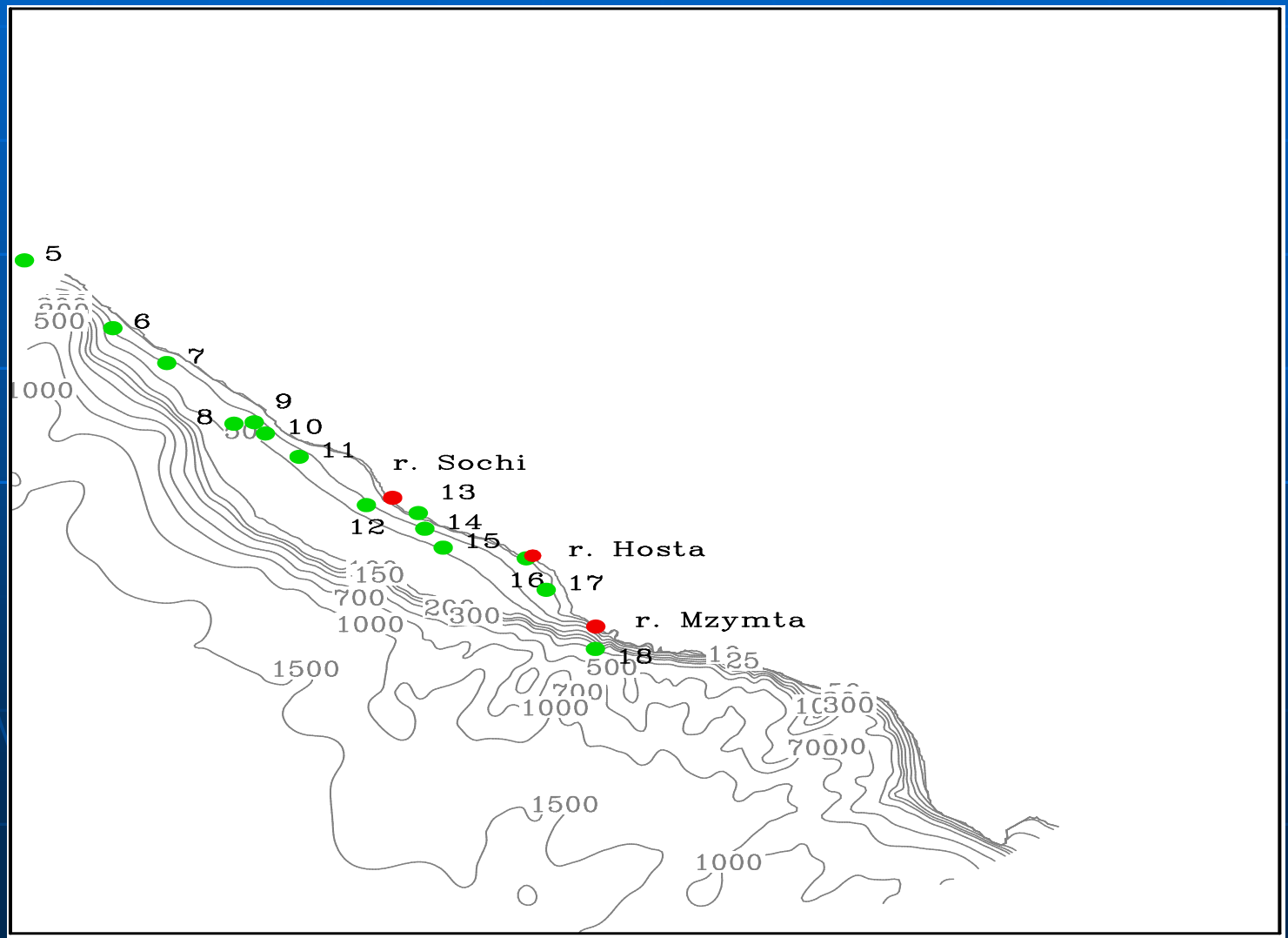




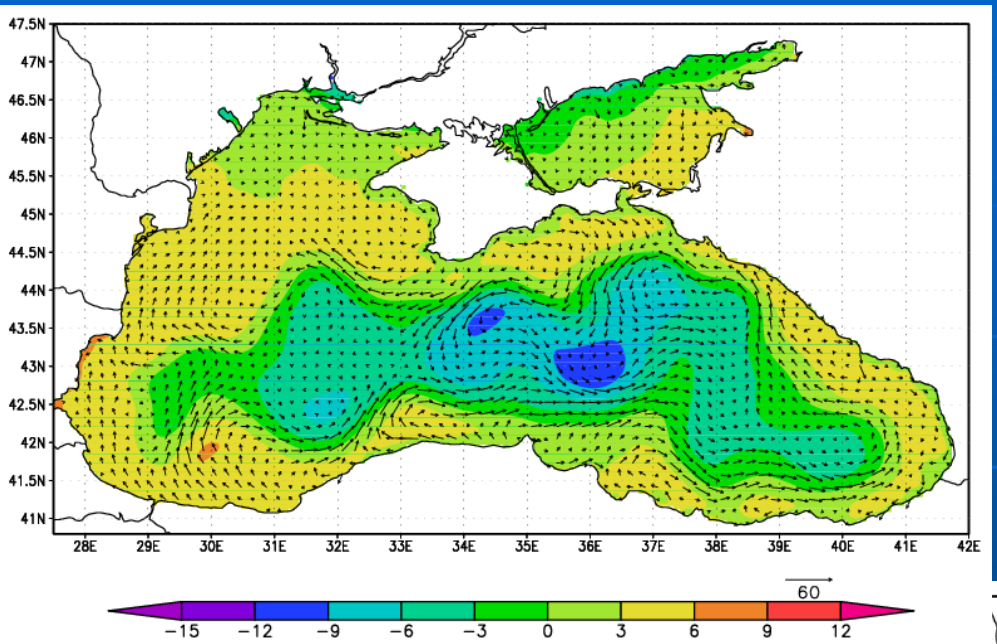


Experiment scenario

Pollutions flow from 18 sewage pipes and 3 rivers (Sochi, Hosta, Mzymta)
Initial hydrological fields are from BAS model
Duration – 1 month (April, 2007)/ Atmospheric forcing are from Era-Interim



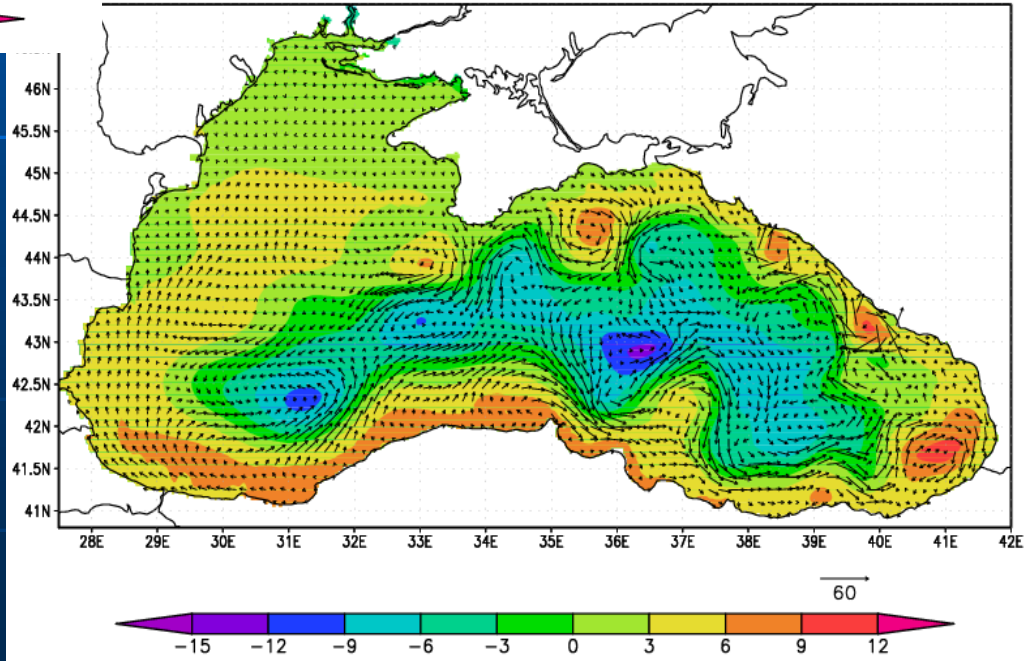
Black Sea velocity (vectors) and sea level height (color) calculated by BAS model, 15 April 2007



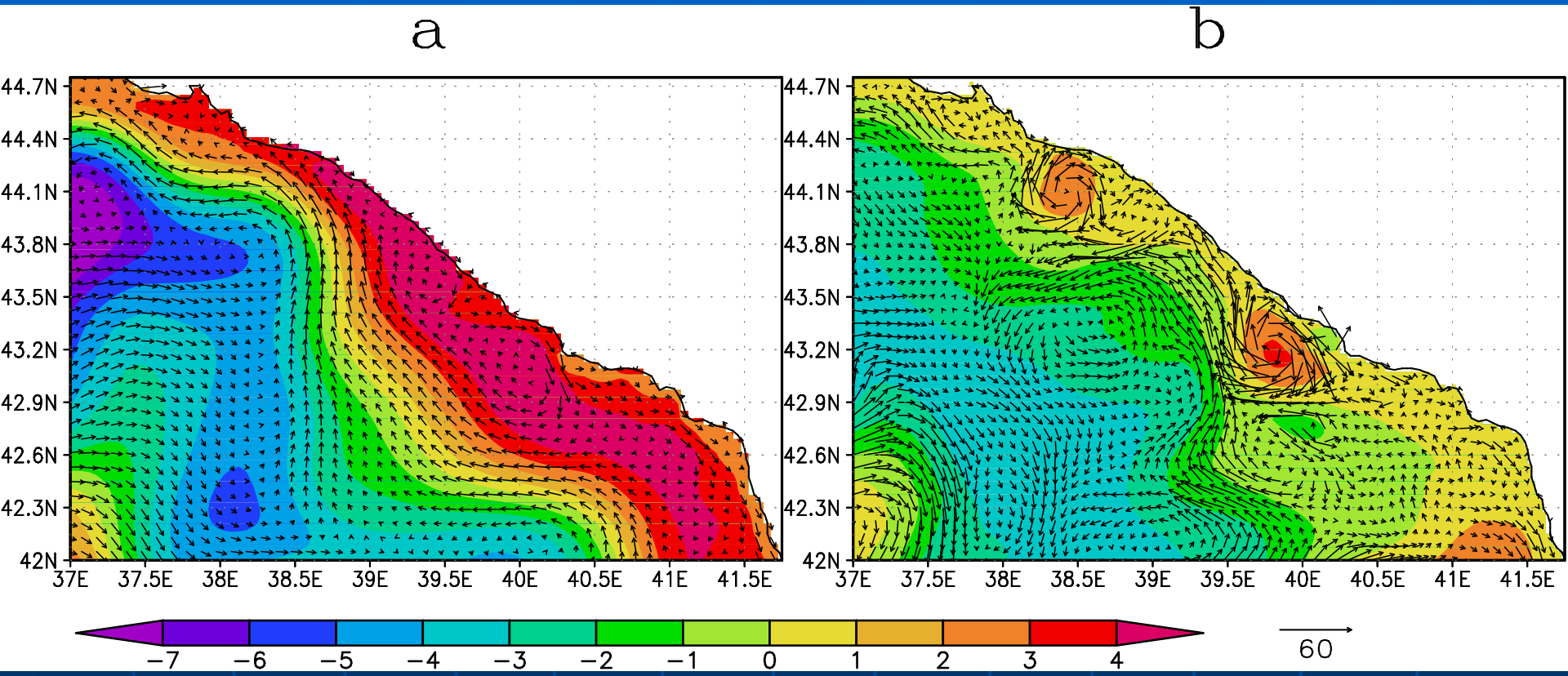
Major difference between BAS model and regional Great Sochi model is a horizontal spatial resolution. It can be concluded that for a good reproduction of Black Sea circulation we need to use the spatial resolution of about 1.5 km, which is achieved in regional model in the south-eastern part of the Black Sea.

Calculated by regional Great Sochi model sea level and velocity fields is more adequately reflect eddy circulation in the eastern part of Black sea (Batumi, Caucasus and Crimea anticyclonic eddies).

Black Sea velocity (vectors) and sea level height (color) calculated by Sochi model, 15 April 2007

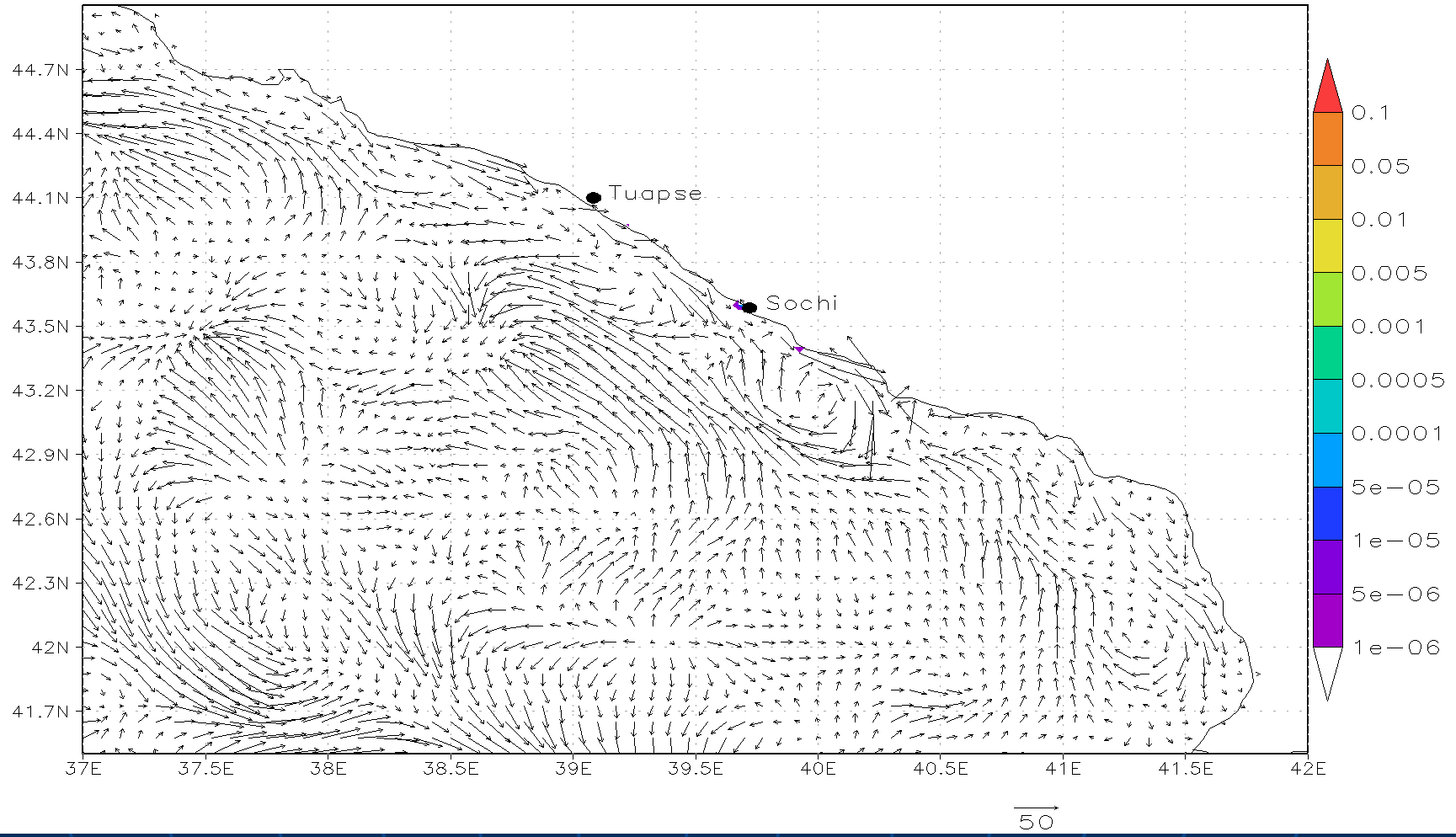


Black Sea velocity (vectors) and sea level height (color) calculated by BAS model (a) and regional Greate Sochi model (b) for the same time 15.04.2007

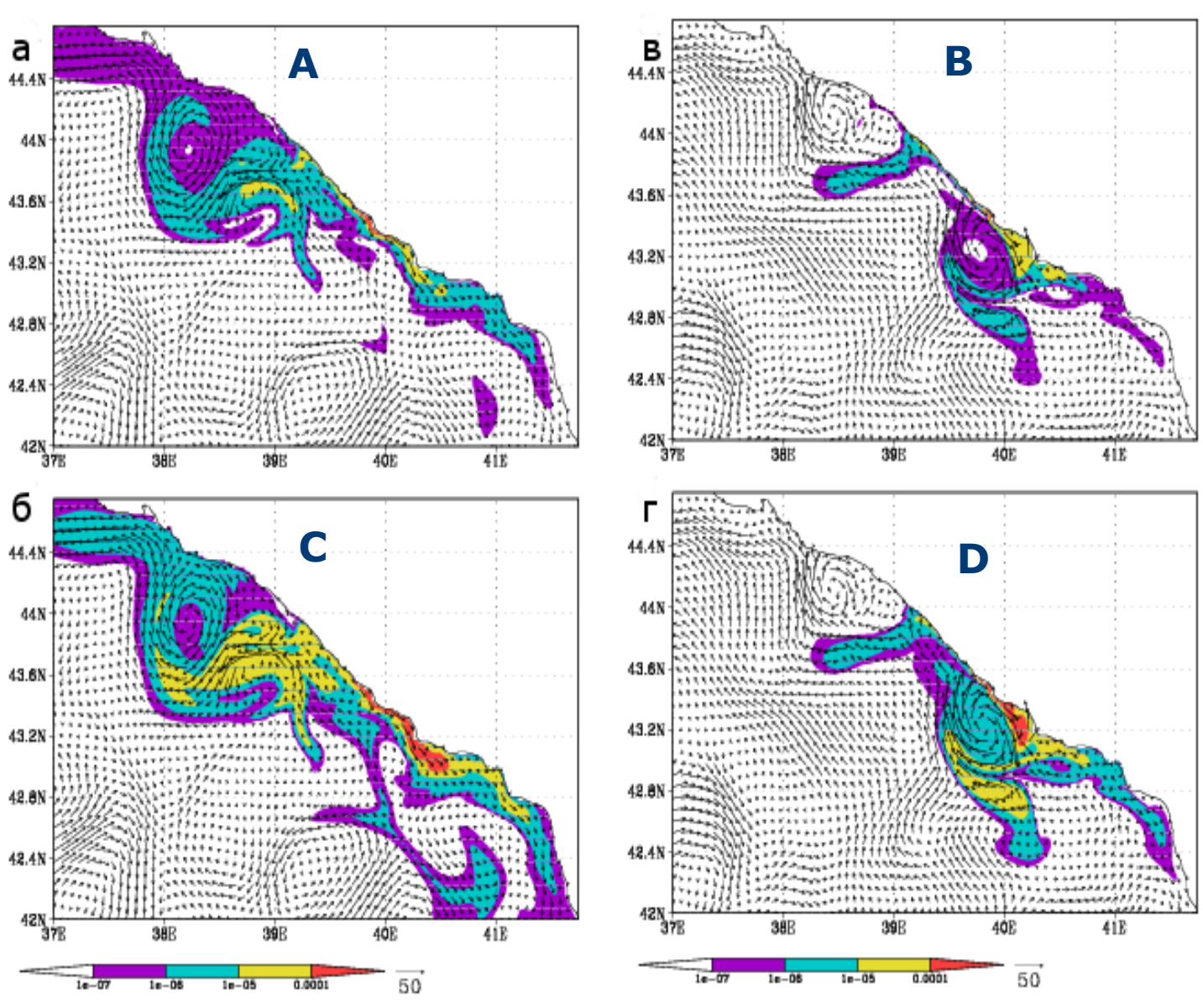


Both versions reveal complexity of the BS circulation nature, however, M2 more adequately reproduces eddy circulation due to higher horizontal resolution in its eastern part.

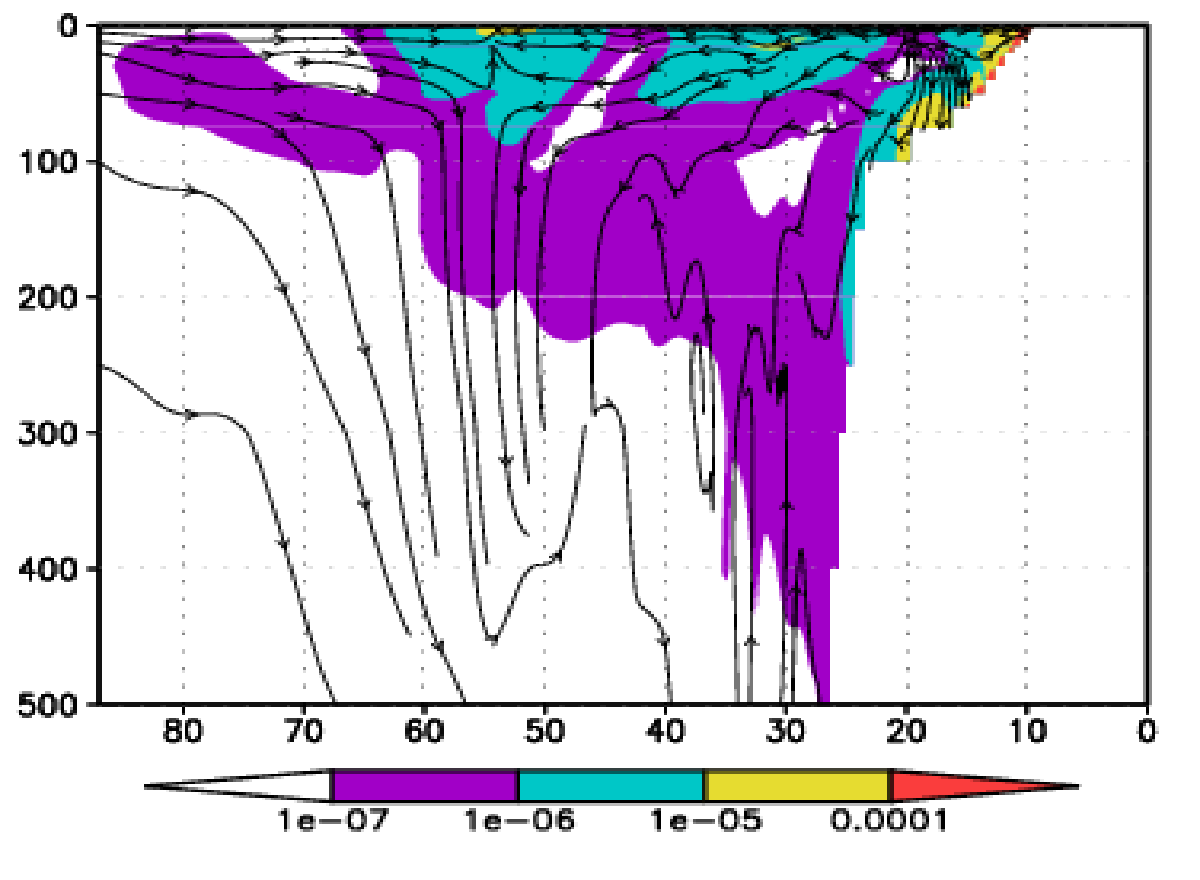
Pollution distribution near Big Sochi: April 2007, 1-25



Pollution distribution near Great Sochi from rivers(a,c) and tubes (b,d): 15 April 2007, 30 April 2007



Vertical section of total pollutant from tubes and rivers on 30.04.2007



The pollutants spread in the deep layers below 150 m occurs due to the vertical movement generated by the complex eddy structure of coastal currents in a coastal zone (50 km) over bottom slopping. The most important role in the flow of pollutants in deep layers (500 m) playing slope flow, which reaches for the vertical component of 0.02 cm/s.

Conclusions:

- Regional Great Sochi model more accurately reproduces eddy circulation in eastern part of Black Sea due to higher horizontal resolution.

- Adequate simulation of Black Sea eddy structure requires model resolution ~1,5 km. The major factor of quasistationary Batumi anti-cyclonic gyre formation is the topographical features in this part of the sea.

- The significant contribution to polluting substances distribution from punctual sources near Sochi is made by eddy mesoscale formations generating complicated 3-dimensional polluting substance distribution.