Numerical simulation of turbulence in ocean circulation problems

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splitting method for *turbulence model equations*

All the required grid functions have been solved by OCM INMOM at current time moment. *Using the splitting method, it is now necessary* to solve a set of equations for the turbulent exchange with assumptions:

$$\frac{\partial u, v, w, \rho}{\partial t} = 0,$$

First Stage of Splitting: transport and vertical diffusion

$$D_t k = \frac{1}{H}\frac{\partial}{\partial\sigma}\frac{\nu_u}{\sigma_k}\frac{\partial k}{\partial\sigma},\ D_t\omega = \frac{1}{H}\frac{\partial}{\partial\sigma}\frac{\nu_u}{\sigma_\omega}\frac{\partial\omega}{\partial\sigma}.$$

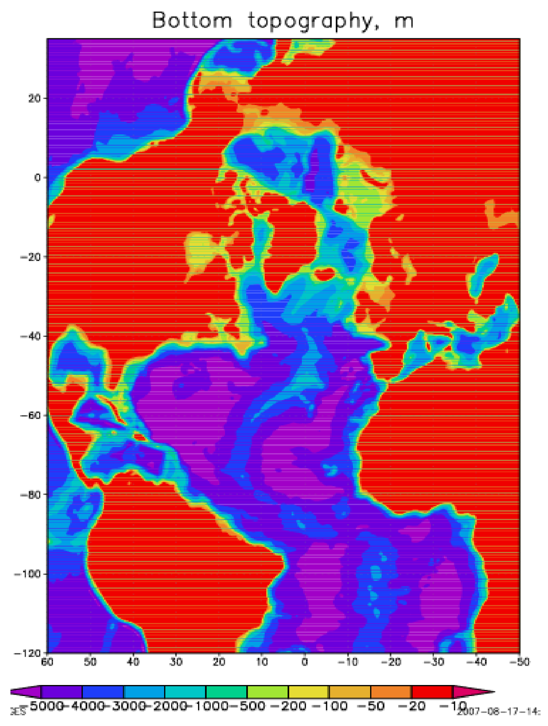
Second Stage of Splitting: generation – dissipation turbulence energy

$$\frac{d\omega}{dt} = B - C\cdot\omega^2, \qquad \frac{dk}{dt} = \left(\frac{A}{\omega} - D\cdot\omega\right)\cdot k,$$

$$A = G^2 - N^2/\mathrm{Pr},\ B = \left(c_1^{\omega}G^2 - c_3^{\omega}N^2/\mathrm{Pr}\right),$$

$$C = c_2^{\omega}\cdot\left(c_S^0\right)^4,\ D = \left(c_S^0\right)^4.$$

k – *turbulence energy*,
ω – *a frequency characteristic of the turbulence decay process*
,
N, G – *buoyancy and shere frequencies*;
$\sigma = z/H$,
z – *geopotential vertical coordinate*,
H – *ocean depth*, $\nu_u = k/\omega$,
$\nu_\rho = \nu_u/\mathrm{Pr}$,
$\mathrm{Pr} = f(Ri)$ – *Prandtl number*,
$Ri = N^2/G^2$,
$c_S^0, c_{1,2,3}^{\omega}$ – *parameters*

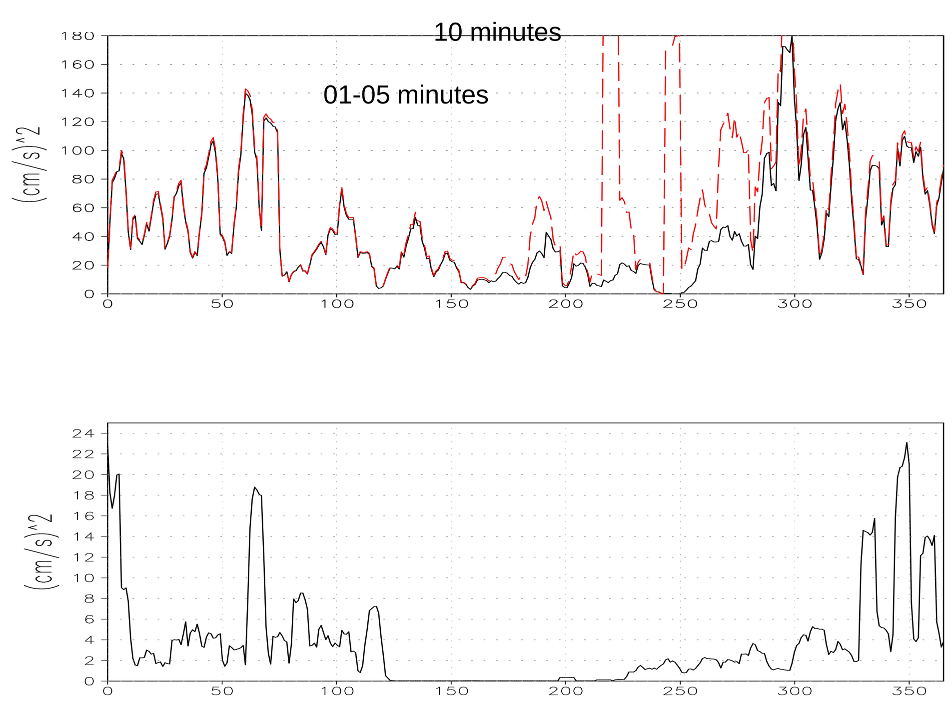


Experiments

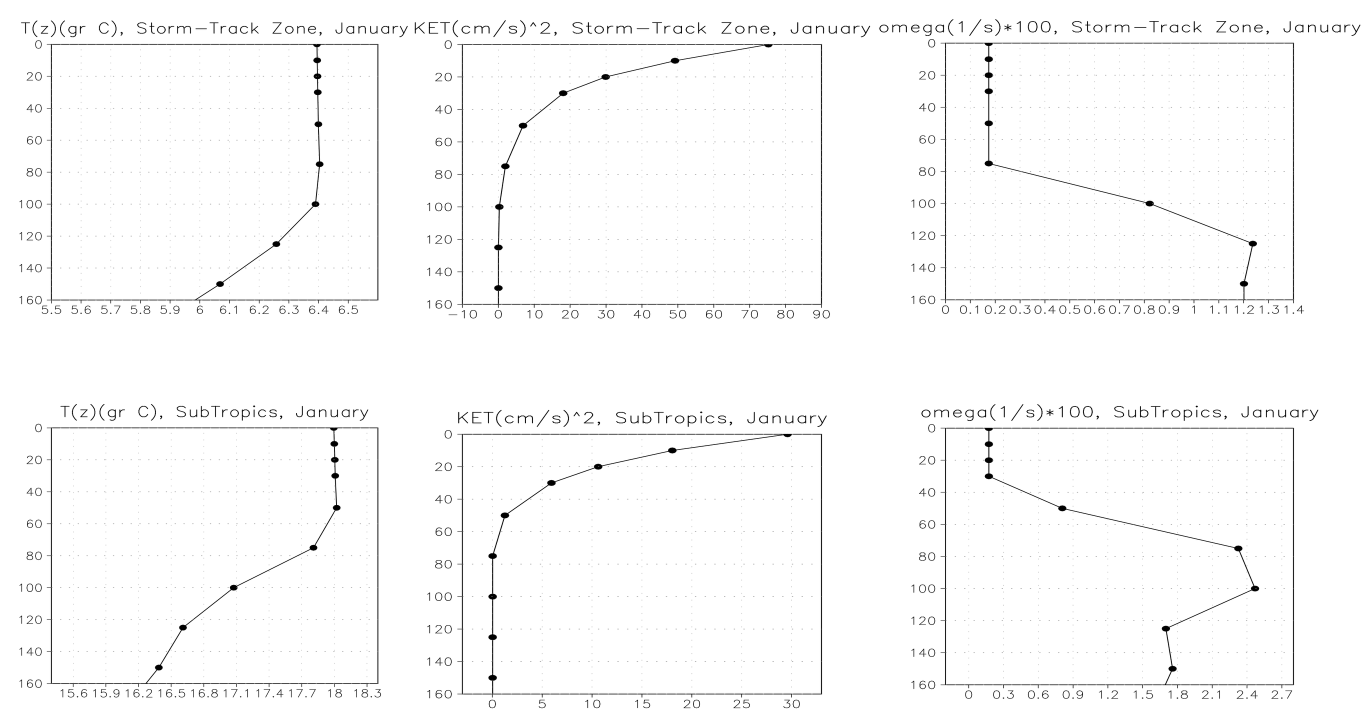
The numerical experiment was carried out with Ocean Circulation Model INMOM using atmosphere forcing CORE (1948-2007 years: heat, salt and momentum fluxes at the sea surface and year mean river runoff). Domain: North Atlantic (open boundary at 30°S, including Mediterranean, Black and Baltic Seas) - Arctic Ocean – Bering Sea. Time step: 1 hour. Multicomponent splitting method with respect to the physical processes and space coordinates. A rotation of the model grid (model North Pole is located at geographical equator, 120°W). 1/4° horizontal eddy-permitting resolution is used (620x440 grid points) and 40 unevenly spaced vertical levels. The EVP (elastic- viscous- plastic) dynamic - thermodynamic sea ice model is embedded. Experiments were carried out in two variants: with Pacanovsky-Philander (1981) mixing parameterization and with two equations turbulence model (full evolutionary equations for turbulence kinetic energy and a frequency characteristic of the turbulence decay process) based on the **multicomponent splitting method upon physical processes and spatial coordinates**.

Turbulence Energy (**TE**) evolution (1979, North Atlantic, 3-days filtered) : Upper panel – Storm-track zone (OWS "C"). Low panel – Subtropics.

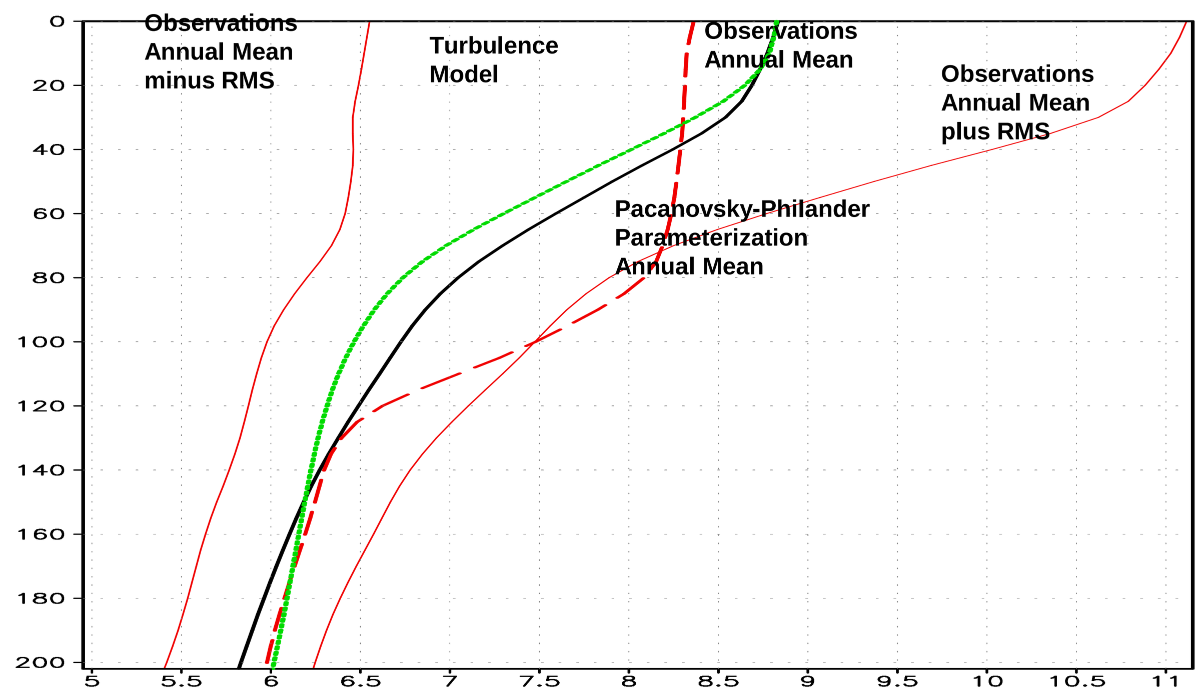
TM time steps:



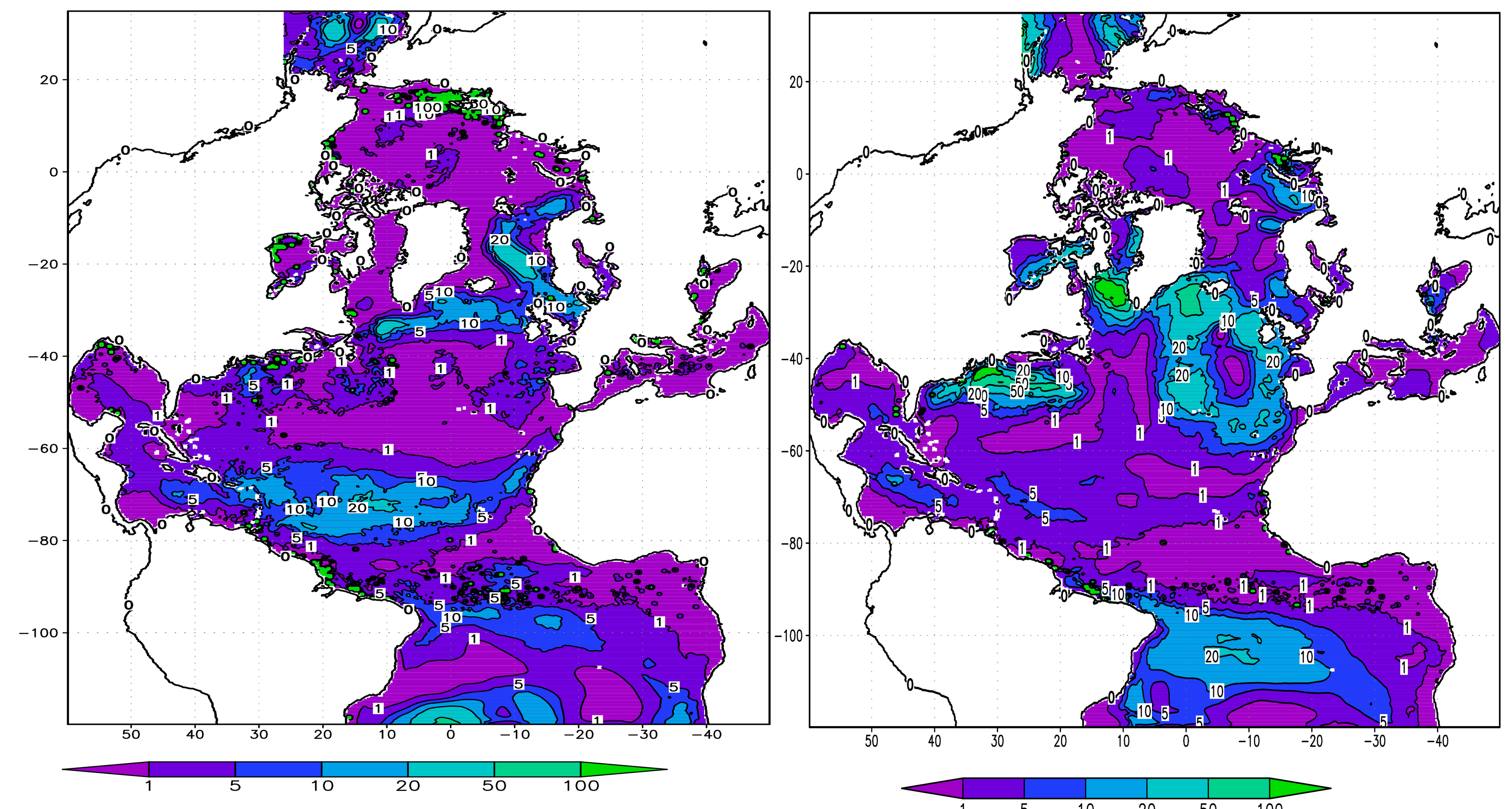
Typical profiles of the temperature, TE and frequency characteristic of the turbulence decay process in the storm-track zone and subtropics of the North Atlantic during free convection



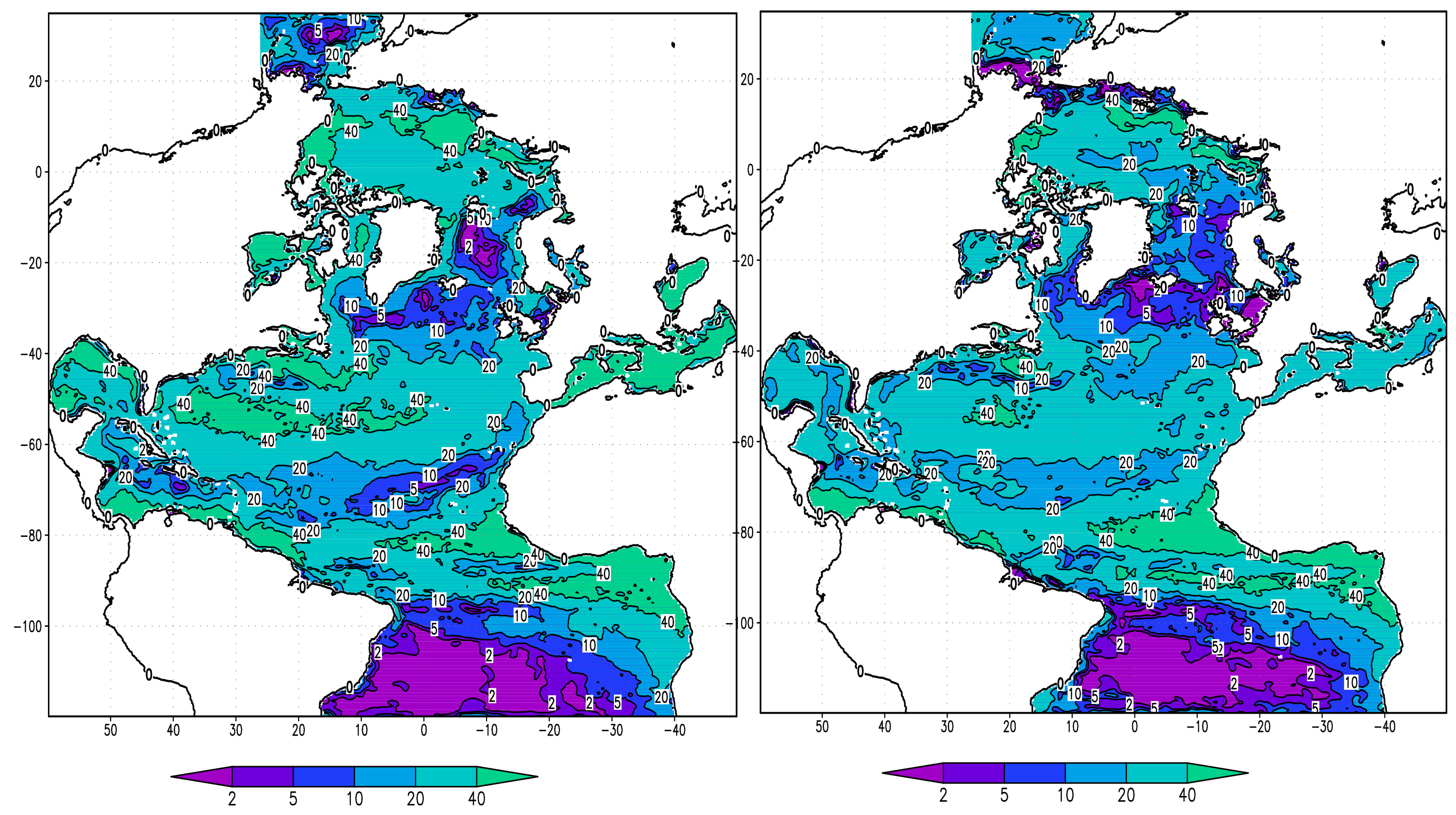
Potential Temperature Profiles. OWS "Charlie" (52.75N.,35.5W) 1979.



Turbulence Energy (cm^2/s^2, 0-50 m averaged, model coordinates).
Left panel: - 30.VI.1979; Right panel: -10.X.1979



Frequency "Omega" ($Hz*10^3$, 0-50 m averaged, model coordinates)
Left panel: - 30.VI.1979; Right panel: -10.X.1979

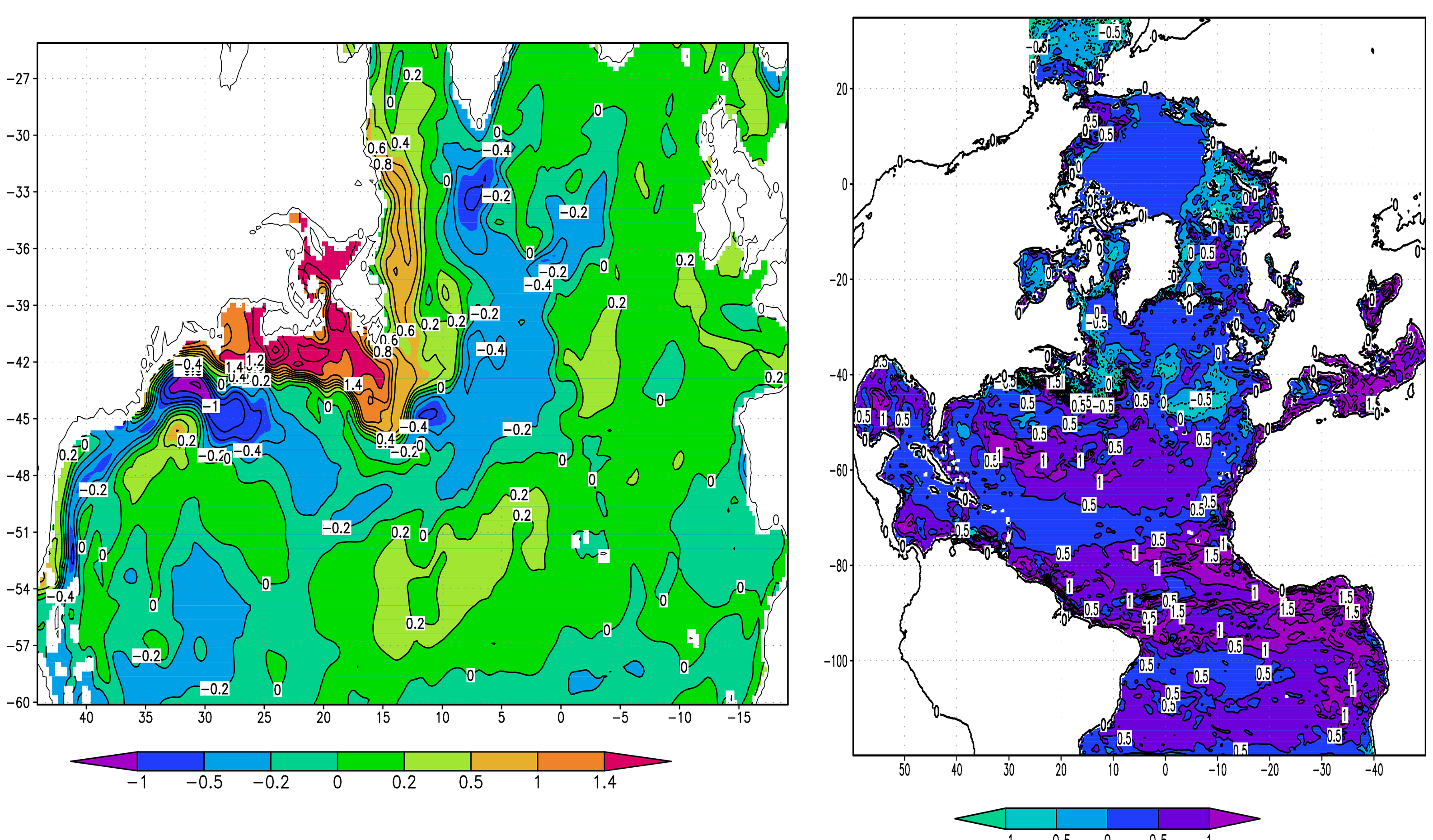


Differences between (**OCM INMOM. Model coordinates**)**:**

Left: Water potential density (kg/m^3 minus 10^3) (*Turbulence Model* minus *parameterization* Pacanovsky and Philander). North Atlantic. Layer 0-100 m. 1989-2007 years.

Right: SST (^0C) (Pacanovsky-Philander Parameterization minus Turbulence Model. *(10 October 1979).*

Compare with large-scale long-period SSTA!!

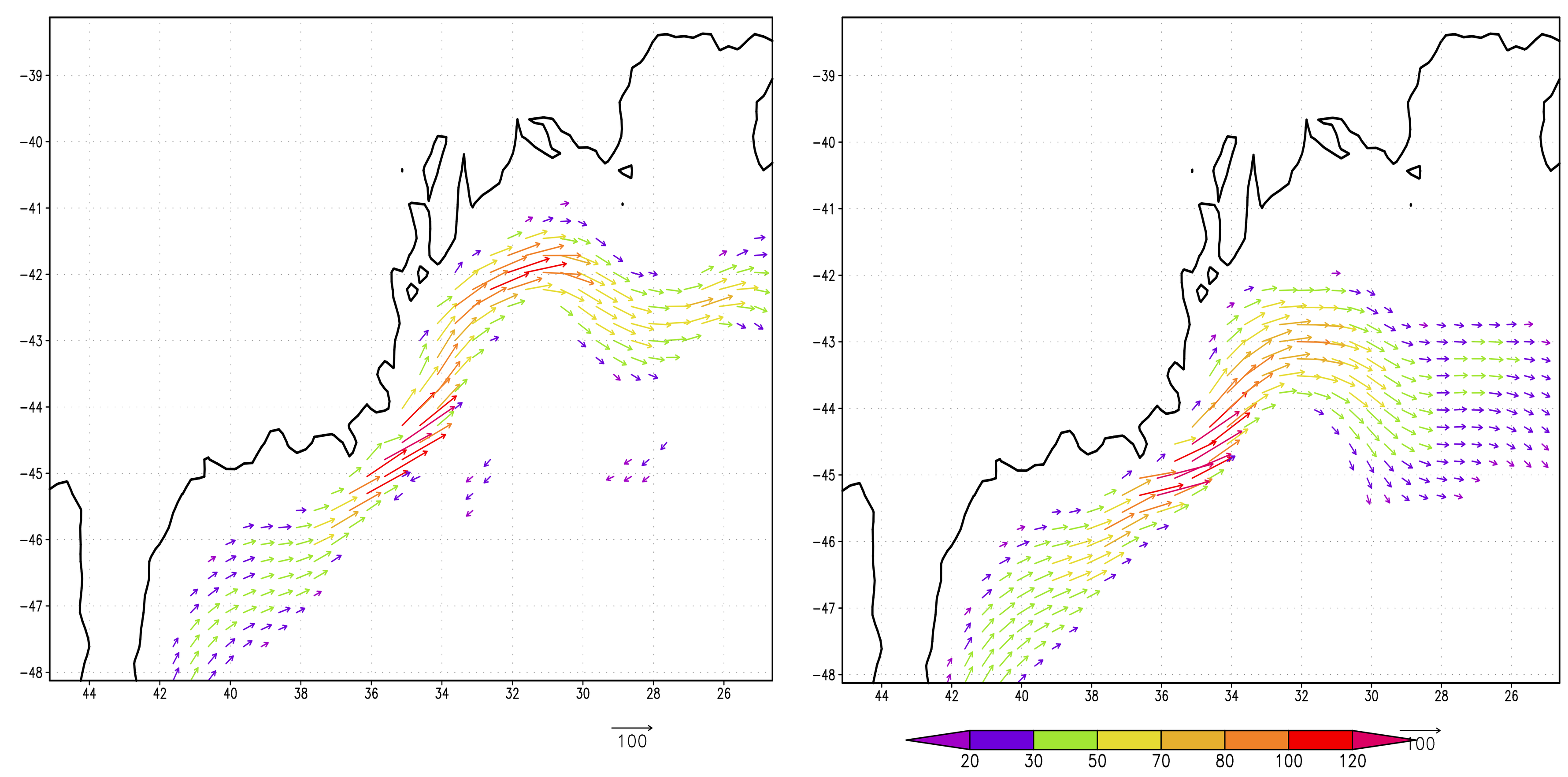


Gulfstream, 0-50m layer, mean for 2007

***Left- parameterization* Pacanovsky and Philander (1981)**

Right- Turbulence Model

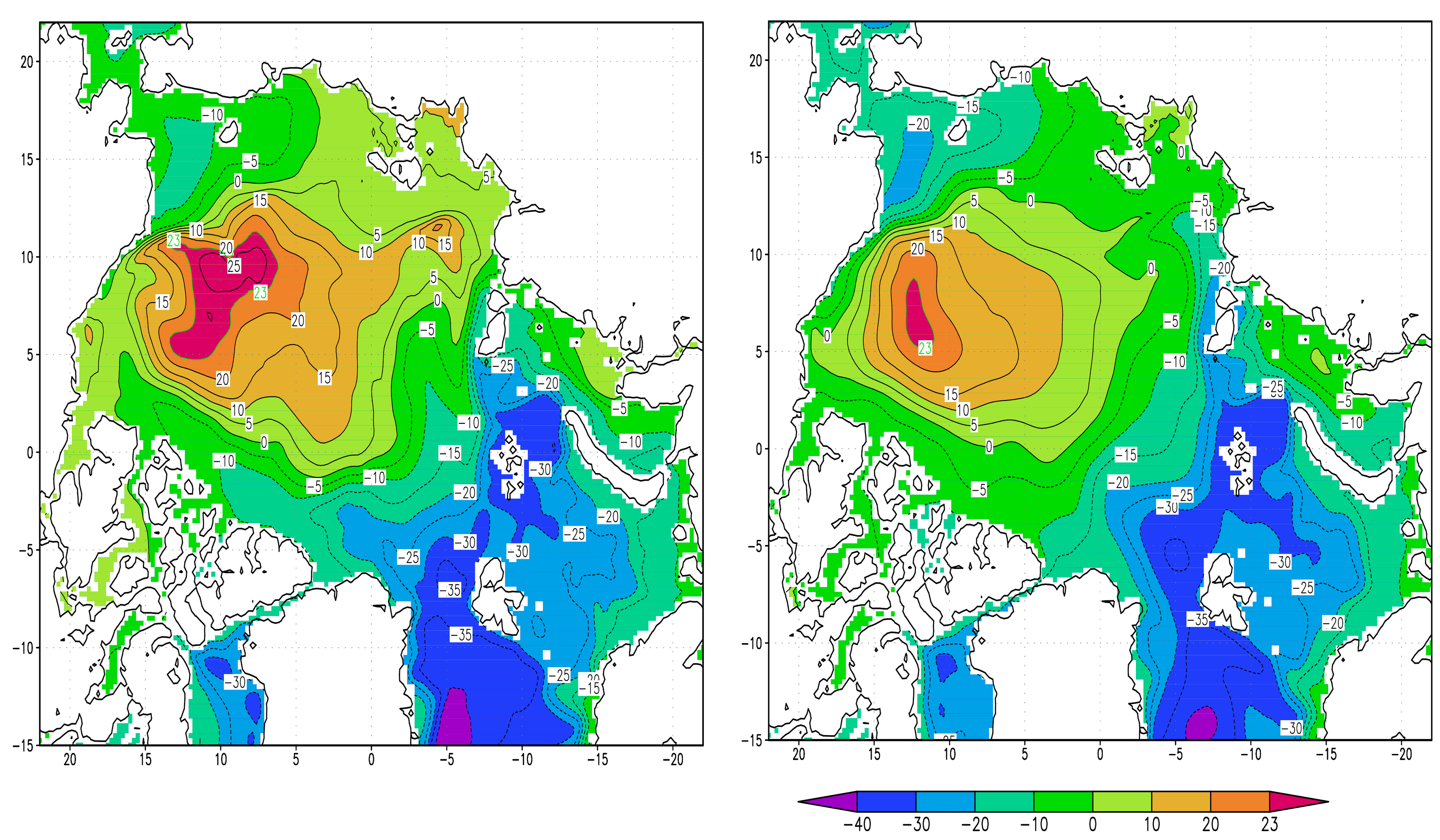
OCM INMOM. *Model coordinates: y = - 44 corresponds to Cape Hatteras.*



Arctic Ocean. Sea Surface Hight (cm):

Left- *parameterization* Pacanovsky and Philander. ***Right-*** *Turbulence Model*

Mean for 1957. *Model coordinates.* OCM INMOM



The splitting algorithm is developed for the turbulence model (TM) based on full evolutionary equations for turbulence kinetic energy (TKE) and turbulence dissipation frequency (TDF). The model numerical solution is based on multicomponent splitting upon physical processes and spatial coordinates [1]. The model proposed does not yield to the contemporary differential models of fully developed turbulence [2] with the respect to physical formulation, and its algorithms is characterized by rather higher computational efficiency. Transition from TKE dissipation rate to TDF allowed us to unite TKE generation and dissipation stages. In turn, it let us obtain the analytical solution for the stage, which cardinally transformed the TM numerical algorithm and made the TM more adaptive to the ocean circulation model (OCM). The case is found for degeneration of the general solution for TKE and TDF equations at the generation-dissipation stage (mixed layer formation). The analytical solution is obtained for this case. It let us make the model algorithm more efficient and aimed to using in three-dimension high resolution OCM. The verification is done for TM connected to INMOM (Institute of Numerical Mathematics Ocean Model) which has spatial resolution 0.25° in longitude and latitude, and 40 non-uniform σ-levels with refinement near surface. The simulation was made of seasonal cycle and climatic variability in 1948-2007 in Arctic and Atlantic Oceans. The results were compared with observations and simulations performed with using the simple asymptotical parameterization [3]. The TM demonstrated principally higher quality of reproducing ocean thermohaline and dynamical structure. The TM let us obtain both quantitative and qualitative improvement of the results. E.g., use of TM allowed us to improve qualitatively reproducing of key climatic features of circulation, for example, Gulfstream turn near Cape Hatteras in the Atlantic Ocean, and Beaufort Gyre in the Arctic Ocean.

Literature

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The research was supported by RFBR -grant 12-05-00814-a