DEFINING THE NUMERICAL CONDITIONS FOR THE PASSIVE FLOW THROUGH THE SKAGERRAK STRAIT

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Abstract A closed boundary between the Baltic Sea and the North Sea applied in the model does not reflect the actual situation. In order to obtain the correct flows (including inflows into the Baltic Sea), a flow was created in the Skagerrak Strait, which depends on the model time. This paper presents the numerical conditions of the passive flow through Skagerrak, which determine the exchange of waters between the Baltic and the North Sea. CCSM4.0/CESM1.0 (Community Climate System Model/Community Earth System Model) is a coupled climate model that consists of five separate components: land, sea ice, land ice, atmosphere and ocean models. Our Baltic application 3D-CEMBSv2 MODEL currently consists of the Community Ice Code (CICE model, version 4.0) and Parallel Ocean Program (version 2.1). The models are coupled through CPL7, which is based on MCT (The Model Coupling Toolkit) routines. External forces are a daily-averaged forty-years period; reanalysis data are derived from the European Centre for Medium-range Weather Forecasts (ECMWF, ERA-40 reanalysis). Currently, in pre-operational state 3D-CEMBS, 48-hour atmospheric forcing data from ICM-UM model (University of Warsaw) are used.

RESULTS

The Baltic domain used both in the ice and ocean model is closed for the computing reasons at the junction between the Baltic and the North Sea, i.e. near Skagerrak. In order to obtain the correct flows (including inflows into the Baltic Sea), it is necessary to create a flow in the Strait of Skagerrak, which would depend on the model time. We can choose one of the following options [1]:

•Clamped LBC (lateral boundary conditions) [imposed shoreline conditions – classic Dirichlet's condition, which includes the external data]. The main disadvantage of this option is the inability to include the propagation of waves at the boundary and a wave often returns inside the domain, but this can be further minimize by applying the additional, different conditions.

•Zero gradient (classic Neumann condition):

$$\frac{\partial \eta}{\partial n} = 0$$

it results in rather unrealistic solutions

•Newtonian damping (restoring, spectral nudging). It should be emphasized that imposing of this condition may frequently hide mistakes of incorrect parametrization/coefficients due to location of the model within the area (set) of external data.

$$\frac{\partial \eta}{\partial t} = \left(\eta_r(t) - \eta\right) / T_d$$

•Sponge – entering high values of viscosity at the borderline, which results in the suppression of the whole structure at the domain's boundary

•Sommerfield radiation conditions

$$\frac{\partial \eta}{\partial t} + c\frac{\partial \eta}{\partial x} = 0$$

The equation of motion and continuity:

$$\frac{\partial u}{\partial t} = -g\frac{\partial \xi}{\partial x}$$

$$\frac{\partial \xi}{\partial t} = -\frac{\partial}{\partial x}\left(Hu\right)$$

one can obtain a relationship between the sea surface height and velocity:

$$u = \xi\sqrt{\frac{g}{H}}$$

where: u – velocity

ξ – sea surface height

g – gravitational acceleration

H – depth at a given point

Application of this formula to connect the Baltic Sea with the North Sea implies that everything what happens at the boundary between the North Sea and the Baltic Sea depends only on the Baltic, which is far from the actual situation.
In practice, each method has advantages and disadvantages, therefore it is good to use more than one method at the same time.
It was assumed that the passive flow will be applied in the eastern side of the North Sea (near the place where it is connected with Skagerrak). The region where boundary conditions are applied to determine the passive flow is presented in Figure 1 (the range of colours applies precisely to this area and at the same time presents the weights, which will be applied for particular portions of data).
Basically, three methods were combined in order to determine the correct flows:

- classic Dirichlet's condition that includes the external data
- Newtonian damping
- applying weights for model and external data

Such an approach allows to control the inflow of external and model data by time constants and statistical weight factors. Taking into account the above assumptions, one can say that for the whole domain:

$$d\eta = \frac{\eta_r(t) - \eta}{T_d} \times dt \quad and \quad \eta = \eta + d\eta \times mask$$

the above formula was written in the form of the Fortran code.
In the case of the Fortran code, it is written for active tracers (temperature and salinity). For the correct determination of passive flows, it should be applied for temperature, salinity, currents in U and V directions, and the sea surface height should be combined with currents. In such a case, all conditions necessary to define the artificial flow through Skagerrak are included. The developed formula allows to determine the flow through Skagerrak at any time.

CONCLUSION

In 2011 the ecohydrodynamic model 3D CEMBSv2 was launched – in the operational mode in the parallel version on the 2 km grid with rivers and the open boundary (details in the paper by [2]).Results from the model are delivered with an hourly time step and with 48-hour forecast, at present for the hydrodynamic unit (see http://deep.iopan.gda.pl/CEMBaltic/new_lay/forecast2.php).

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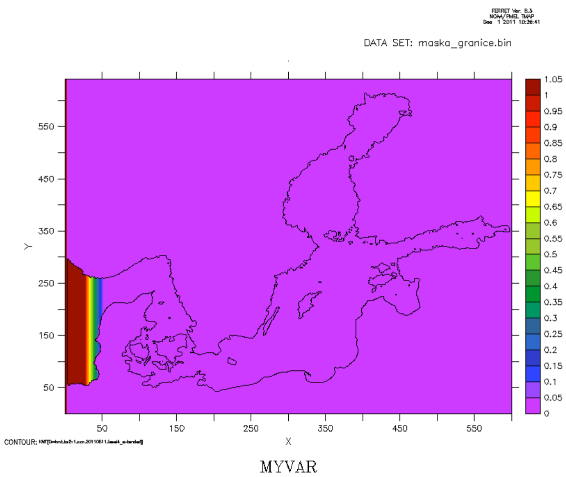

Figure 1. The region where the passive flow will be applied

References

[1] D. P Stevens. On open boundary conditions for three dimensional primitive equation ocean circulation models. *Geophysical Astrophysical Fluid Dynamics*, **51**(1-4): 103-133, 1990.

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