

The Baltic Sea coupled ice-ocean model

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Abstract: Community Earth System Model (CESM) is a coupled climate model that consist of five separate components with additional central coupler which controls time, exchanging data, domains, grids and other model data. Here CESM was adopted for the Baltic Sea and called 3D-CEMBS. This is not fully coupled configuration. In our case we have been taken into account ocean (POP model, version 2.1) and ice (CICE model, varsion 4.0) models which are forced by atmospheric data model (datm7). Other models are turned off in our configuration. However the main task of the datm7 is to interpolate data on model domain, we have interpolated data outside of the models. As an external forces daily-averaged forty-years reanalysis data derived from European Centre for Medium-range Weather Forecasts (ECMWF, ERA-40 reanalisis) has beed used. Currently in pre-operational state 3D-CEMBS is using 48-hour atmospheric forcing data from ICM-UM model (University of Warsaw). 3D-CEMBS model has also ecosystem part (currently work in progress).

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Keywords: Baltic Sea, 3D model, hydrodynamic variables

1. Introduction

In 2011, the operational ecohydrodynamic model (3D CEMBSv2 - new version) was launched at the Institute of Oceanology PAS in the parallel version on the 2 km grid with rivers and the open boundary for the hydrodynamic module http://deep.iopan.gda.pl/CEMBaltic/new_lay/index.php.

Therefore, the following works were completed:

- a new version of the model was launched (3D CEMBSv2), which includes the ocean-ice module POP-CICE (POP, version 2.1, the ice module CICE, version 4.0) and the ecosystem module (Fig.1):
 - compilation of the 2 km bathymetric grid,
 - adaptation of the model to meteorological data UM (ICM UW),
 - compilation of a data set with meteorological forecasts (UM) from 2010 and 2011 in the required format, preparation of the initial fields for the Baltic area in the 2 km grid,
- development of the operational system for data retrieval necessary for the model 3D CEMBSv2,

- development of the operational ecohydrodynamic model (3D CEMBSv2) in the parallel version on the 2 km grid with rivers and the open boundary:
 - compilation of climatic river discharge ,
 - compilation of climatic conditions along the open boundary.

This paper presents an integrated, operational model of the Baltic ecosystem – the hydrodynamic part, the ocean-ice module POPCICE (version 2.1 and 4.0) and the initial verification, the comparison of the obtained results with data from other models and measurements in situ.

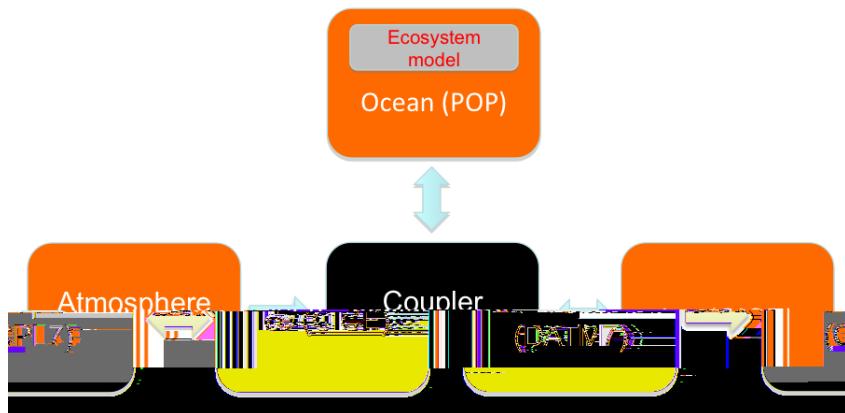


Fig. 1. Schematic presentation of the Baltic model

2. 3D-CEMBSv2 MODEL

CCSM4.0/CESM1.0 (the Community Climate System Model/Community Earth System Model) consists of five separate elements with an additional coupler (CPL7), which monitors the time, exciting forces, domains, grids and exchange of information between models. The central part of the model is based on MCT (The Model Coupling Toolkit) – which is a parallel tool providing a number of services, such as a register of particular components of the model, descriptors of the domain distribution into processes, communication, redistribution of data and other very helpful tools. For our purposes, CESM was adapted for the Baltic Sea and was called 3D-CEMBS. However, it is not an entirely active configuration. The ocean model (POP, version 2.1) and the ice model (CICE, version 4.0) work in the active mode, and they are imposed by the model of atmospheric data (datm7). Other models are excluded from this configuration (the stub mode). The main task of datm7 is interpolation of atmospheric data into the domain of the model. External forces are daily-averaged for the period of forty years, which come from the ECMWF re-analysis (ERA-40). At present, in the operational mode, 48-hour atmospheric forecasts are used, which are supplied by the UM model of the Interdisciplinary Centre for Mathematical and Computational Modelling of the Warsaw University. 3D-CEMBS Model is also equipped with the ecosystem module, on which works are being currently carried out in order to incorporate it into the operational mode.

POP

The ocean model is based on the Parallel Ocean Program (POP, [7]) from the National Laboratory in Los Alamos (LANL), which is derived from the global ocean model ([6]) with additional conditions for free surface. This is a model of 'z' type (identical thickness of layers for every cell); the three-dimensional equations describing the behaviour of the stratified ocean are solved by parametrization. Numerically the model defines spatial derivatives in the spherical coordinates using the method of finite elements. Physical quantities of the model are embedded in the spherical grid of Arakaw B ([1]). The barotropic equation is solved by 'preconditioned conjugate gradient solver' (PCG), and advection is determined by a centred differential. Parametrization of horizontal mixing is accomplished by a biharmonic operator, and vertical turbulence is determined by KPP parametrization. The equation of state, introduced by McDougall et al. ([5]), is also used.

POP is a three-dimensional hydrodynamic model derived from the ocean model created in the late 1960s by Kirk Bryan ([3]) and Michael Cox from the NOAA Geophysical Fluid Dynamics Laboratory in Princeton. The model was later modified and adapted by Semtner ([6]) for vector processors. The whole class of models from which POP is derived are of Brayan-Cox-Semtner type (B-C-S). The code of the model is adapted *inter alia* for supercomputers, but is well adaptable (*porting*) also for machines of different architecture, such as cluster types. The code of the POP model is characterised by good numerical performance and is well scalable on a large number of O(1000) processors. A special feature of the POP code (written in Fortranie 90) is orientation to parallel machines and the use of MPI (Message Passing Interface) or SHMEM (Shared Memory) libraries to communicate between processors. And therefore, the most technologically advanced machines can be used to perform calculations and to solve major computational problems.

CICE

CICE (Community Ice Code) is based on *elastic-visco-plastic* (EVP) rheology ([4]). It is designed to work in accordance with the POP ocean model using the parallel computing machines. It consists of several interactive elements: the thermodynamic model, which computes local growth rates of snow and ice owing to vertical conduction of energy and momentum fluxes. It also defines velocity of each ice cell based on wind and ocean velocity. It has a few vertical categories, so that the stress distribution is much closer to the real one.

CICE was applied worldwide in different configurations. It was used to study the variability and the impact of ice on the processes occurring in the atmosphere and the ocean in time scales ranging from decades to hundreds of years ([2]). It is used in regional models and global applications. Incorporation of the CICE model (version 4.0) into the regional POP model (version 2.1), completed within the scope of the research grant (No NN305111636 – the Polish State Committee for Scientific Research), is the first application of such an advanced ice model for the Baltic Sea.

Ecosystem

The ecosystem model consists of 11 main components: zooplankton, small phytoplankton, diatoms, cyanobacteria, two types of detritus deposits (fraction of dissolved DOM and molecular POM detritus), dissolved oxygen, and components of nutrients, such as: nitrates, ammonia, phosphates and silicates. The class of small phytoplankton should reflect nano- and picophytoplankton, and can be limited by nitrates and phosphates. The class of larger phytoplankton is represented by diatoms and can be limited by the aforementioned factors, as well as by silicates. The growth rate of cyanobacteria may depend on phosphates and the available light. Many biotic and detrital compartments contain multiple elemental pools as we track carbon, nitrogen, phosphorus and silicon through the ecosystem.

3D-CEMBS model is currently configured at two horizontal resolutions of 9 km and approximately 2km ($1/12^\circ$ and $1/48^\circ$ respectively). The model bathymetry is represented by 21 vertical levels and the thickness of the first four surface layers was five metres. The bottom topography is based on ETOPO1 1 arc-minute global relief model

(<http://www.ngdc.noaa.gov/mgg/global/global.html>, National Geophysical Data Center). The bathymetric data were interpolated to the model grid using the kriging method. The initial state of the ocean model was prepared using temperature and salinity climatic data. The ocean surface level (5m deep) is restored based on the monthly timescale to the monthly average T and S climatology, as a correction term to the explicitly calculated fluxes and overlying atmosphere or sea ice. The restoring time was set to 30 days at the surface and 10 days at the domain boundary. 3D-CEMBS model domain is based on stereographic coordinates, but the equator of these coordinates is in the centre of the Baltic Sea (so we actually use rotated stereographic coordinates) and we can assume that shape of the cells is square and they are identical.

The current calculations are performed on supercomputers of cluster type, Galera, which is located at TASK (the Academic Computer Centre in Gdańsk).

The time needed for computing 1 model year, for the ecohydrodynamic model, for resolution of 9km, is 30 h on 16 processors, and for resolution 2km – 120 h on 256 processors.

3. Results

In the first half of 2011, the new CESM model (Community Earth System Model - UCAR/NCAR USA) was adapted for the Baltic domain.

Models have been adapted and work properly (see the website). The results of simulations for 48-hour forecast are presented for the model with resolution of 9 km and 2 km.

Select 2km forecast for the area or the point (Fig. 2).

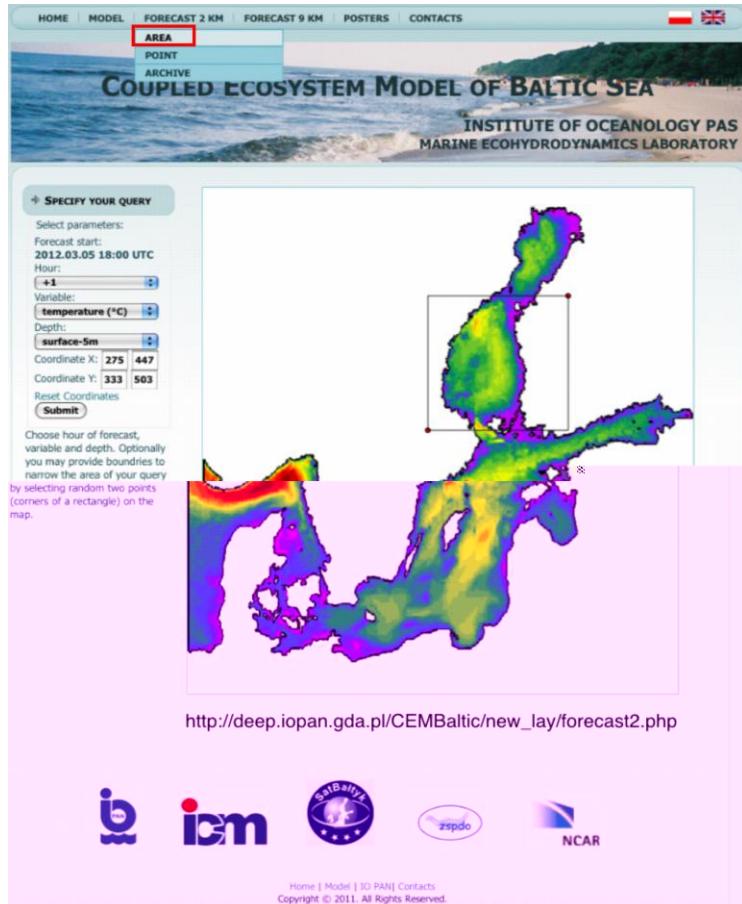


Fig. 2. Select 2km forecast for the area.

Simulations for 48-hour forecast for 2 km:

Forecast for the area:

- select the time of forecast (48-hour forecast) (Fig. 3a),
- select a required variable (temperature, salinity, currents, sea surface height, ice cover area) (Fig. 3b),
- select the depth, one of the ten layers for which you would like to see the model results (Fig. 3c),
- optionally you may provide boundaries to narrow the area of your query by selecting two random points (corners of a rectangle) on the map (Fig. 3d),
- to change coordinates x and y of selected points, press: Reset Coordinates (Fig. 3e),
- after all parameters are selected, press: Submit (Fig. 3f).

a

b

c

d

e

f

Fig. 3. Forecast for the area. Choose parameters of forecast for 05.03.2012.

The example is presented below for the following situations:

1. Forecast start: 2012.03.05, 18:00 UTC (Fig. 4)

Select forecast parameters: hour: +6 (forecast is for 2012.03.06, 00:00 UTC), variable: currents (cm s^{-1}); depth: 20-26 m (5th layer), coordinate X: 187 to 425, coordinate Y: 32 to 168. After selection of parameters, press: Submit and the screen will show a drawing with results of the model.

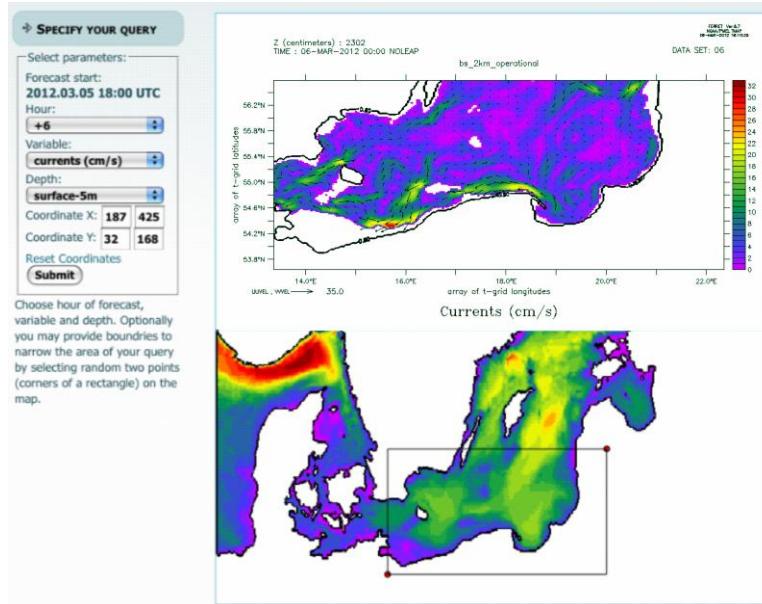


Fig. 4. Forecast for the area.

Forecast for the point :

- select the depth,
- select a point on the map to get 48 h time series,
- to change coordinates x and y of selected points, press: Reset Coordinates,
- after selection of all parameters, press: Submit

The example is presented for the following situation: forecast start: 2012.03.05, 12:00 UTC (Fig. 5).

4. Conclusion

The work presents the idea of a three-dimensional Coupled Ecosystem Model Baltic Sea version 2 (3D CEMBSv2) – a hydrodynamic part, which determines the main physical parameters of the environment: horizontal components of the velocity u, v and the vertical component of velocity w , pressure p , density ρ , temperature T and salinity S of water. Variables presented on the website for 48-hour forecast are as follows: temperature, salinity, currents, sea surface height and ice area cover.

The 3D CEMBSv2 model (at present – the hydrodynamic module) is a suitable tool for studying the annual, seasonal, monthly and daily variability of environmental parameters in the southern Baltic Sea. It can therefore be applied in the forecasting of ecological changes in the Baltic.

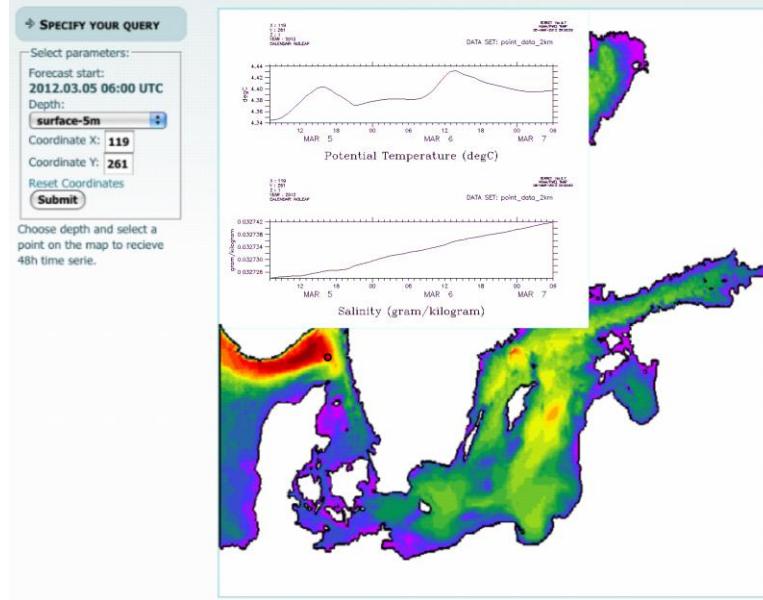


Fig. 5. Forecast for the point..

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