The Automatic Monitoring System for 3D-CEMBSv2 in the Operational Version

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Abstract: The objective of this paper is to present the development of an automatic monitoring system for the model 3D-CEMBSv2 (Coupled Ecosystem Model of the Baltic Sea, version 2) in the operational mode. The predictive, ecohydrodynamic model 3D-CEMBS will be used as an appropriate tool to control the conditions and bioproductivity of the Baltic environment and to forecast physical and ecological changes in the studied basin. 3D-CEMBSv2 provides hydrodynamic forecast of such variables as: temperature, salinity, sea surface height, currents, ice area cover and thickness. 3D-CEMBS model is also equipped with the ecosystem module that covers 3 phytoplankton groups, nutrients (nitrate, ammonia, phosphate, silicate), zooplankton, dissolved oxygen and small pelagic detritus. The automatic monitoring system also provides a 48-hour forecasts of above parameters that are available on the models website. Atmospheric forcing is supplied by the UM model of the Interdisciplinary Centre for Mathematical and Computational Modelling of the Warsaw University.

**Keywords:** Baltic Sea, ecosystem model, ice model, ocean model.

1. INTRODUCTION

One of the tasks associated with the project (No. NN305111636 funded by the Polish State Committee for Scientific Research) is to prepare the ecohydrodynamic model of the Baltic Sea – 3D-CEMBS for the operational mode. The detailed description of the 3D-CEMBS is presented in separate papers [1, 2]. Dzierzbicka-Głowacka and her co-workers published several papers respecting to modelling hydrodynamical and biological processes [3-7]. 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 discharge and the open boundary. To ensure the systematic operation of this model, it was necessary to prepare a fully automatic, supporting and monitoring system. This system consists of a few parts responsible for subsequent processes, including collection, processing and archiving of atmospheric data, preparation of relevant start-up files, launching and monitoring of the model's operation, retrieval of the results, storing the results in archives and on the website. Detailed description of the model operational system is presented in paper and summarized below.

2. MATERIALS AND METHODS

Ecosystem model 3D-CEMBSv2 is an appropriate tool to study the changes of biogeochemical and physical parameters of the Baltic Sea in real time and

48 hours ahead. It is based on CCSM4.0/CESM1.0 (the Community Climate System Model/Community Earth System Model) that consists of four separate elements with an additional coupler (CPL7), which monitors the time, exciting forces, domains, grids and exchange of information between models. For our purposes, CESM was adapted for the Baltic Sea and was called 3D-CEMBS (Figure **1**).
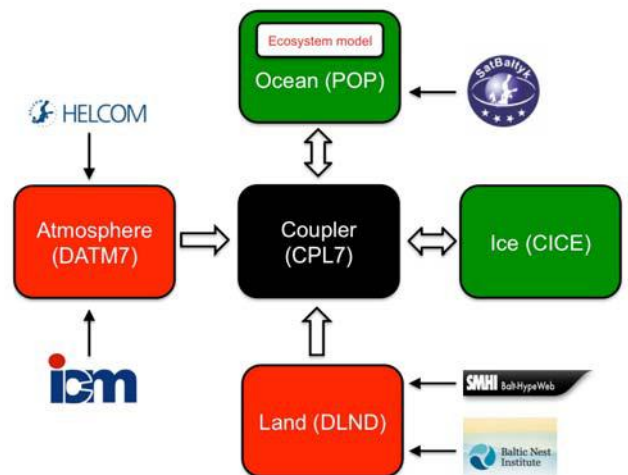
Figure 1: Model configuration diagram.

The ocean model (POP, version 2.1) and the ice model (CICE, version 4.0) work in an active mode (green). They are imposed by two data models (red):

- Atmosphere data model controls atmospheric forcing (data from ICM-UM University of Warsaw) and nutrient deposition data (data from Helcom).

- Discharge of freshwater (data from SMHI BaltHypeWeb hydrological model) and river nutrient

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deposition (data from Baltic Nest Institute) is processed by land model.

3D-CEMBSv2 model is configured at 2km resolution (1/48°). 21 vertical levels represent the model bathymetry and the thickness of the first four surface layers is five metres. The bottom topography is based on ETOPO1 1 arc-minute global relief model. 3D-CEMBSv2 model domain is based on stereographic coordinates, but the equator of these coordinates is in the centre of the Baltic Sea so we can assume that shape of the cells is square and they are identical. Currently, 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.

2.1. POP

The ocean model is based on the Parallel Ocean Program [8] from the National Laboratory in Los Alamos (LANL), which is derived from the global ocean model [9] with additional conditions for free surface [10]. POP is a 'z' type model, which means it has the same thickness of layers for every cell. Ocean circulation is described by a three-dimensional equations solved by a parameterization. The finite elements method is used to define spatial derivatives in the spherical coordinates. Physical quantities of the model are embedded in the spherical grid of Arakawa B [11]. The barotropic equation is solved by 'preconditioned conjugate gradient solver' (PCG), and advection is determined by a centred differential. A biharmonic operator accomplishes parameterization of horizontal mixing, and vertical turbulence is determined by KPP parameterization. The equation of state, introduced by McDougall [12] is also used.

2.2. CICE

CICE (Community Ice CodE) is based on *elastic-visco-plastic* (EVP) rheology [13]. It works in accordance with the POP ocean model on a parallel computing machines. It consists of several interactive elements, such as the thermodynamic model, which computes local growth rates of snow and ice owing. It also defines velocity of each ice cell based on wind and ocean velocity. Few vertical categories are included, to ensure that the stress distribution is preserved. 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.

2.3. Ecosystem

The ecosystem model [14] consists of 11 main components: zooplankton, small phytoplankton, large phytoplankton (mainly diatoms), summer species (mainly cyanobacteria), one detrital class, dissolved oxygen, and components of nutrients, such as: nitrates, ammonia, phosphates and silicates. The class of small phytoplankton should reflect nano- and pico- size phytoplankton, 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.

3. RESULTS

The developed system of an automatic monitoring consists of the main module and a few submodules responsible for particular operations related to the system operation. The whole system is written in such a way that no major changes are required if the system is transferred to another computer. Obviously it is necessary to install, on a given computer, all libraries used by the programs of the system. The following subfolders are located in the folder of the main system:

− execs: it contains scripts and executable files of all programs used for the system operation;

− in_files: it contains all the files required to run particular programs, including files with information about grids and files with weight matrices used for interpolation of data between grids;

− list_files: the folder contains list of files stored in the archive, time of the latest data update, performance status and restart parameters, as well as temporary system files;

− sources: it contains source codes of all the system's programs;

− storage: the directory where intermediate stages are stored in the process of atmospheric data processing.

Additionally, the system includes folders containing data available on the website and archives with data from the previous forecasts. Due to specification of the model, it is also necessary to store an atmospheric
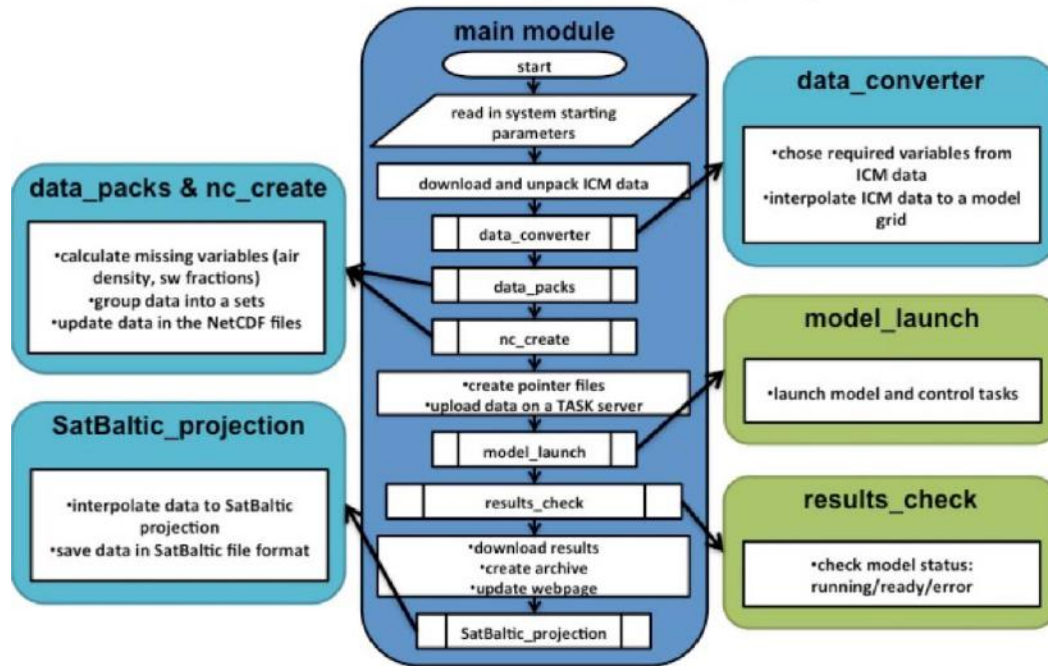
Figure 2: The block diagram presenting the system of automatic launching and operation of the 3D-CEMBSv2 model.

data set for the whole year. These data are stored on CI TASK servers, where the model is launched, and on local disks. The task of the main module consists in regular checking for new atmospheric data on the ICM server, transmission of data between servers, creating archives and launching other modules that prepare data for start-up and operational mode of the model. The other programs are responsible for subsequent steps of the system operation. Figure **2** shows the block diagram of the system structure.

3.1. Description of the Main Module

In order to automate the launching of the main module in the data acquisition system, the Launch Daemon service is used, which is available in the standard operating system Mac OS X. The information about the method and the time of script activation is stored in a special file, called Property List. At present, the main script is run every hour. At first it prepares new atmospheric data and updates archived data. Apart from downloading data to archives, the system performs subsequent operations presented in Figure **2**. After loading the boot parameters, including time of the latest updating, the performance status of the previous start-up, the current date and the hour, the system checks if available atmospheric data are complete and more recent than those used previously to run the

model. Data necessary to run the model are downloaded only when all required archives are on the server. As in the case of data downloaded to archives, each package is checked after downloading.

When all the files are downloaded and unpacked, the main script activates the next programs, which process the data. The process of data processing consists of:

− interpolation of data from the grid of the UM model used by ICM to the grid used in the 3D-CEMBSv2 model (data_converter),

− sorting the data in 48 packages containing consecutive hours of a forecast (data_packs),

− overwriting the relevant files in the NetCDF format, which contain atmospheric data stored on local disks with data from the latest forecast (nc_create).

If there are no errors in the prepared data, the system generates restart parameters of the model and sends the updated NetCDF files to CI TASK servers, replacing the existing ones. The ready NetCDF files are also additionally copied to the archive on another disk. If all operations are successful, the list of used files is updated, as well as the file with information about the latest update. The next step is to run the module

responsible for the start-up of the model and regular checking of the status (model_launch, results_check).

If any error occurs at this stage, the system interrupts the process and saves the relevant information in performance status files. In this way, when the system restarts, the redundant steps in the preparation of atmospheric data are skipped and restart of the model start immediately. If the model calculations are completed without any error, the system will proceed with the retrieval of data from the server CI TASK to the local disks. Next, the system checks whether all files were downloaded correctly. If not, the system will undertake three consecutive attempts to download them. If the operation fails, it means that an error may have occurred while the results of the model were saved and the system will restart the model at the next try, and the whole process will be repeated. After correct data retrieval, the system will make the data available on the website and store them in a relevant archive. Since the data take a lot of disk space, archives do not contain the complete 48-hour forecasts, but only every sixth hour from forecast. The last step is to prepare files with surface data in a format compatible with requirements of the SatBałtyk project. In the case of error-free completion of all steps of the system, information about the system status and the time of the latest update are updated. Whole system runs in background, without any interference from the user. Therefore in order to monitor the models status systematically, the log file containing a history of operations performed by the system is updated. Thus, any possible errors can be easily localized and eliminated.

3.2. Atmospheric Data Processing (Data_Converter, Data_Packs, NC_Create)

The first step in processing the retrieved data is their interpolation on the model's grid. Figure **3** presents examples of data obtained from ICM after interpolation onto the model's grid. Data available from ICM are the results of the UM model operating on the grid with the resolution of 4km and dimension of 615x448. At the moment, the grid with resolution of 2km and dimensions 600x640 is applied in the 3D-CEMBSv2 model. Bicubic interpolation was performed. Interpolation is not performed from the beginning every time. Weight maps were created for input and output grids containing weights for points from the input grid to be taken into account when transferring the values on the target grid. Weight maps were prepared in the program SCRIP developed by the Los Alamos National Laboratory (http://climate.lanl.gov/Software/SCRIP/). They are used in the first submodule included in the system of atmospheric data collection and processing – the program data_converter. The program divides the data obtained from ICM into scalars and vectors. Components of vectors are rotated from the ICM grid onto the actual system of coordinates, and then all variables are transferred to a new grid in accordance with the weight map and saved in binary files.

After termination, the system checks if everything proceeded correctly and if so, the data are transferred to the next program. From the data obtained in ICM, the program selects products used as variables in the model and products used for calculation of these variables. Variables are then stored in 48 files
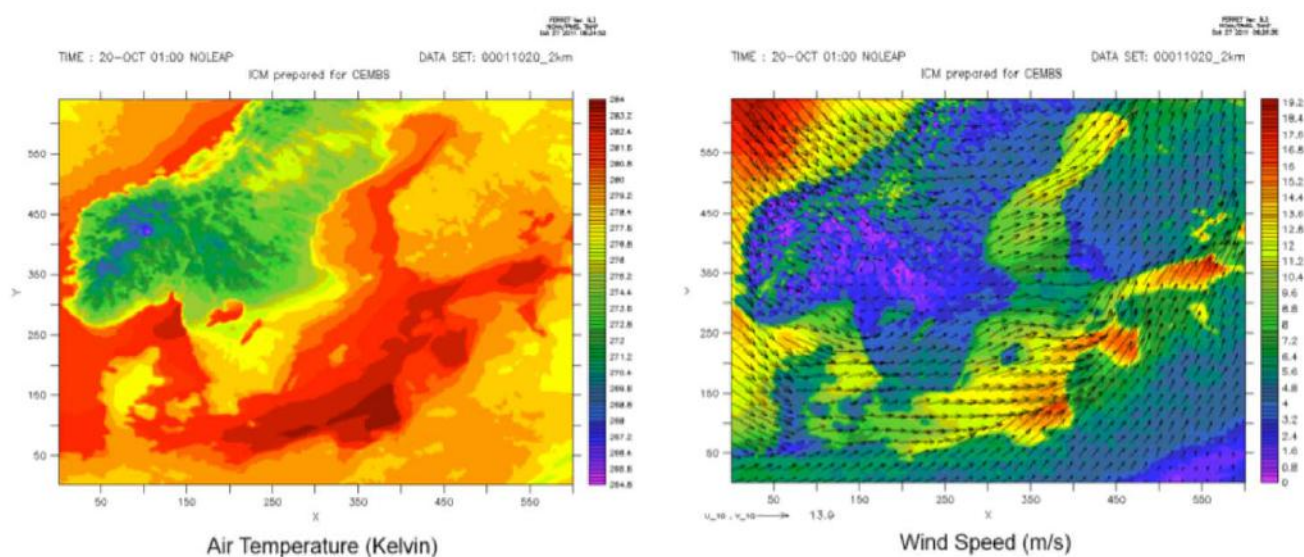

Figure 3: Temperature (**a**) and wind (**b**) obtained from ICM forecast after interpolation onto the grid of the 2km model.

corresponding to consecutive hours of a forecast. The final stage of data processing is to overwrite the files used by the model with new atmospheric data.

3.3. Launching and Monitoring of the Model (Model_Launch, Result_Check)

Launching and monitoring the model is done with a pair of scripts located on a local computer, on which also the whole system is installed, and on CI TASK servers. The task of each local script is to login on a server and to activate the corresponding script located there. The script model_launch located on CI TASK activates the model and creates control tasks, which check whether the model was completed correctly or not. It also creates files containing the IDs of these processes, which are used by the script results_check.

Depending on the performance status of the model, this script saves the information about the model, which is later transferred to the main module.

3.4. Conversion of Data to the Format Compatibile with the SatBałtyk Project

The last step is to convert the data to the format used in the SatBałtyk project. The project uses only the results from the surface. The data are then interpolated by the bi-cubic interpolation method (http://climate.lanl. gov/Software/SCRIP/) on the grid used in the project. Interpolation is carried out in the same way as interpolation of atmospheric data on the grid of the model, *i.e.* using the weight maps. These data are then saved as flat binary files and stored in the archive.
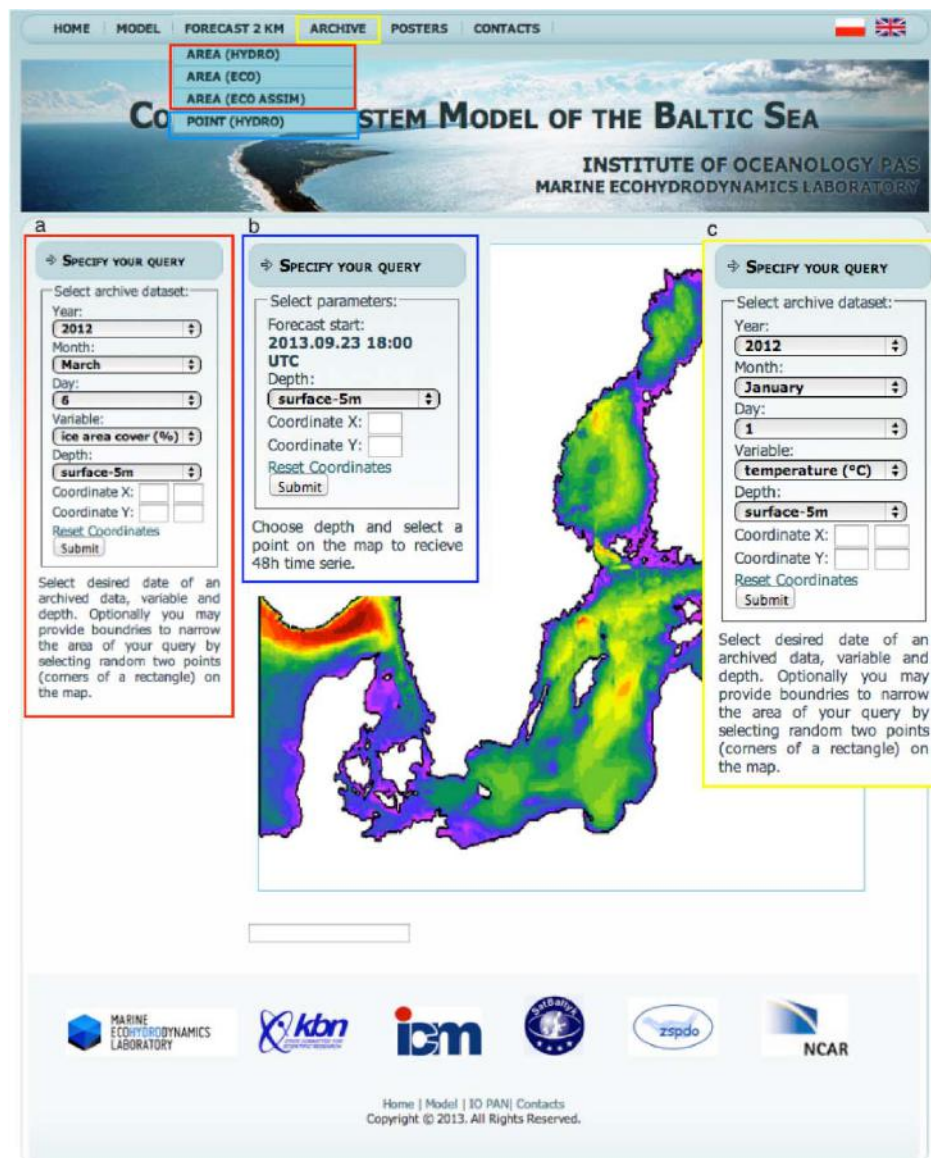
Figure 4: The selection page with results of 3D-CEMBSv2 model for the area (**a**), for 48 hours – point (**b**) and archival results (**c**).

3.5. Website

As previously mentioned, the results of the model performance are automatically placed on the website after each update of a forecast (http://deep.iopan.gda. pl/CEMBaltic/new_lay/forecast2.php). It consists of a few related bookmarks. Home page and model contain the description of the model, its individual components and configuration information. Bookmark called forecast 2km contain the current estimate of the model's selected parameters for the area (Figure **4a**) and 48-hour cycles for the selected point (Figure **4b**). Also archive data (since January 2012) are available on this level (Figure **4c**). In the near future, the

procedures supplementing the archival data backward will be launched.

In order to view a forecast for a given area, you should select this area on the map (Figure **5d**), then select a required hour of a forecast (Figure **5a**) in the left panel, then a parameter of the model (Figure **5b**) and depth of a layer (Figure **5c**) on which you want to see the results. After pressing the Submit button (Figure **5f**), a map with results appears.

Examples of the ice cover results for the whole domain of the model and chlorophyll a concentration results for the selected subarea from 3D-CEMBSv2 model are presented in Figures **6** and **7**, respectively.

Figure 5: Forecast for the area. Choose parameters of forecast for 04.01.2013.
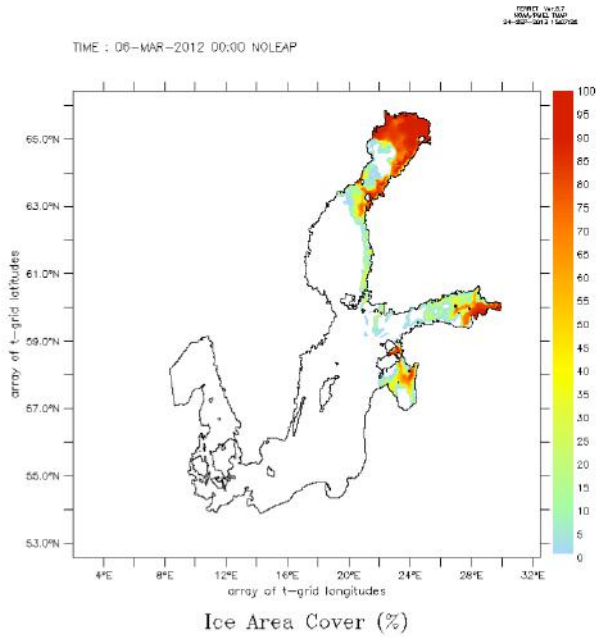
Figure 6: Examples of the ice cover results from 3D-CEMBSv2 model for the whole domain of the model.

At present, the following parameters are available:

- Hydrodynamical: temperature, salinity, water currents, the sea level and the ice area cover & thickness.

- Biogeochemical: small phytoplankton, diatom, diazotroph, nitrate, ammonia, phosphate, silicate, dissolved oxygen, small pelagic detritus.

In the case of 48-hour cycles, it is enough to select the depth of a layer and a point for which the results of the model are required. Figure **8** presents a graph with a 48-hour temperature and salinity cycle for a selected point. If archival data are selected, also a required date should be specified. The bookmark posters, contains posters from a conference during which the model was presented (the first version) and the performance results. The bookmark contact contains contact data of persons involved in the development and support of the model and the operational system.

4. DISCUSSION

3D-CEMBSv2 is the first parallel model in Poland that works in the operational mode providing hydrological, biogeochemical and ice forecasts for the whole Baltic Sea. There are several more models in Europe that also operates in this region such as: 'Baltic Sea Long-Term Large-Scale Eutrophication Model' (BALTSEM) [15-16], the 'Ecological Regional Ocean Model' (ERGOM) [17-18] and the 'Swedish Coastal and Ocean Model' coupled to the Rossby Centre Ocean Biogeochemical Model (RCO-SCOBI) [19, 20]. Since the time the 3D-CEMBSv2 operational system was launched, a number of changes have been implemented, which are designed to streamline and accelerate the system performance and to improve the error control performance. There are plans to implement several more changes that would improve
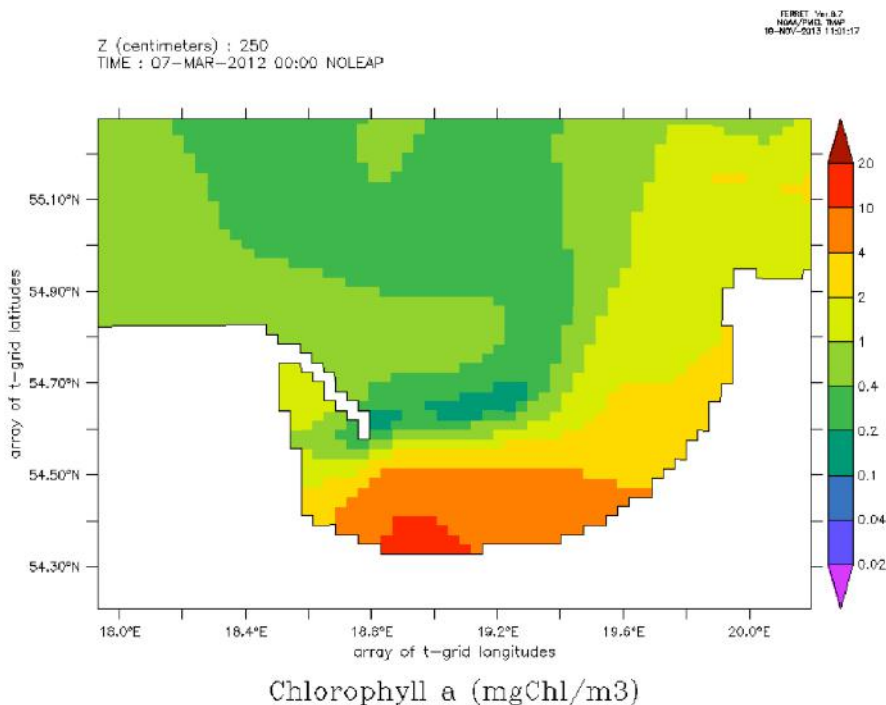
Figure 7: Examples of the chlorophyll a concentration results from 3D-CEMBSv2 model for the selected subarea.
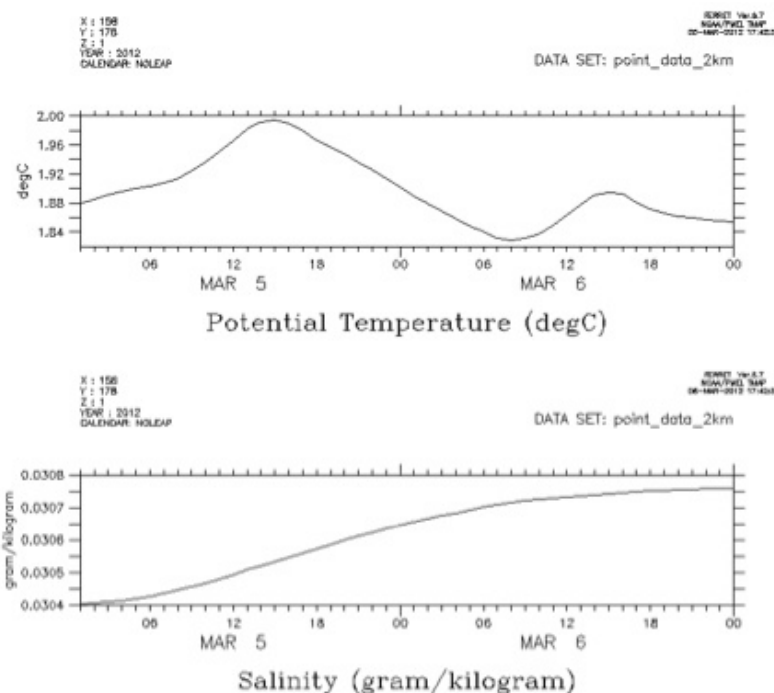
Figure 8: Sample results of 48-hour cycles for the selected point.

the performance and safety, although already in its present form the system is working in the operational mode. One of the planned improvements is to develop a method of storing the archival data, which will enable to store all the data while reducing the space occupied on disks. One of the major advantages of the system is its modular design, which makes it possible to easily add new modules in the future. The main task for now is to develop an efficient system for assimilation of satellite and in-situ data. There are already some programs that employ the satellite data assimilation using the Cressmann method, but they are not yet included in the operational system.

5. CONCLUSION

Automatic operational control system for the ecosystem model 3D-CEMBSv2 has been presented in this paper. 3D-CEMBSv2 was launched in the Institute of Oceanology Polish Academy of Sciences at the end of 2011. The 3D-CEMBSv2 model (new version, based on POP from 2010 year) works in the parallel, operational mode on the 2km grid with river discharge, atmospheric deposition and open boundary. The 3D-CEMBS model consists of ocean model which takes into account the hydrodynamic and biogeochemical modules and the ice model. The model results are produced as 48-hour forecasts with 1-hour time step. 3D-CEMBS is an appropriate tool to simulate the conditions and bioproductivity of the marine ecosystem

of the Baltic Sea and real-time forecasting of its physical and ecological changes.

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