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44 Years Hindcast of the sea level and circulation in the Baltic Sea

J. Jędrasik [a,*], W. Cieślikiewicz [a], M. Kowalewski [a], K. Bradtke [a], A. Jankowski [b]

[a] Institute of Oceanography, University of Gdańsk, Al. Marszałka Piłsudskiego 48, 81-378 Gdynia, Poland
[b] Institute of Oceanology of PAS, Powstańców Warszawy 55, 81-712 Sopot, Poland

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ABSTRACT

The subject of the investigation was the multiyear hindcast of the sea level elevations and currents over the Baltic Sea. The approach follows to the HIPOCAS project conception and contained the 3D hydrodynamic model using boundary conditions from the atmosphere and catchment for 44-year period referring to the second half of the 20th century.

The sea level fluctuations and current hindcast were performed by the M3D_UG model based on the POM. The evaluations of hindcast accuracy were done by comparison of the modelled simulations to field observations. Their results were presented as statistical measures cored on the mean and integral square errors. The model results compared to the observed data agreed well and confirmed usefullness of the used model for hindcast.

Except for the hindcast quality evaluations, both observed and modelled sea level elevations were analyzed by the spectral and principal component analysis methods for singling out the components of its variability. The research proved at least two opposite trends — decreasing at the northern coast and increasing in the southern ones. Moreover, three temporal components of their variability were revealed. Due to vectorial and modular average of currents, annual circulation patterns in the Baltic Sea have been obtained. Using of long term sequences of the current fields, inter annual changes of averaged velocity and their increasing trend were evaluated.

1. Introduction

HIPOCAS strategic objective was obtaining 40 years' hindcast of wind, sea level and currents climatology for European seas (for future application in coastal and environmental decision processes). The Baltic Sea was one of the included seas in the project. To accomplish such a goal scientific tasks were assumed. Activity of international group was concentrated on modelling with high spatial and temporary resolution of winds, waves, sea levels and currents to generate 40 years' wind data set, wave and current hindcast for European seas. Part results of these hindcast were provided for producing of the Atlas of Met-Ocean Data for European Waters and Coastal Seas in digital and paper form for dissemination of achievements.

To carry out 44 Years Hindcast of the sea level and circulation in the Baltic, hydrodynamic model and meteorological data were necessary. The meteorological forcing data provided by GKSS (Germany) to be appropriate for our models, was transformed and interpolated. Another boundary condition required preparing discharges of main rivers into the Baltic Sea (runoff from land). Application of model called for numerical assumptions. Preliminary set up models were run for a test period of 5 years by the circulation model. Following these stages that model generated 44 years' (1958–2001) sea level and current hindcast. Simulation results were subjected to validation. The validation of modelled sea level was based on data of Permanent Service for Mean Sea Level (PSMSL). Shortage of current measurements for comparison to modelled simulations brought about that for indirect estimation of flows vertical distribution of temperature and salinity were utilized. Such a replacement allowed one to conclude indirectly about barotropic and baroclinic currents. Hindcast quality evaluation was carried out by using the statistical measures.

The first aim of this paper is to present of ability for reconstruction of the sea level variations and circulation on the long term scale. The other one refers to determination of annual and seasonal mean circulation patterns of the Baltic Sea based on the long term atmospheric forcing. Another goal was concerned to components of sea level variability.

At the beginning of the paper hydrodynamic model for the Baltic Sea is applied. Next validation and evaluation of the hindcast uncertainty appear. Sequence part contains principal components of modelled time series variability. Seasonally, annually and inter annually circulation patterns in the Baltic Sea ending the elaboration and finally conclusion sum up of the paper.

2. Application of the hydrodynamic model for the Baltic Sea

The M3D_UG (three-dimensional hydrodynamic model), developed at the Institute of Oceanography, Gdansk University model was applied to 44-years' simulation (1958–2001) of circulation in the Baltic

* Corresponding author.
E-mail address: janj@sat.ocean.univ.gda.pl (J. Jędrasik).

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Sea. Calculations of the sea level oscillations, currents, temperature and salinity were conducted using metrological conditions. The last ones were obtained from the atmospheric REMO model (REgional MOdel; Jones, 1998, 1999; Jacob and Podzun, 1997; Von Storch et al., 2000; Feser et al., 2001; Guedes Soares et al., 2002). The hydrodynamic model was based on the Princeton Ocean Model (POM), described in detail by Blumberg & Mellor (1987) and Mellor et al. (1994). In relation to the POM the applied model differed in advection numerical scheme and the way of climatic field calculations (Kowalewski, 1997).

2.1. Model setup, numerical assumptions

The applied model used Arakawa C grid defined in geographical coordinate system with steps: dφ=5', dλ=10'. The model comprised the whole Baltic Sea area with the Danish Strait (Fig. 1). The applied sigma-transformation produces in every point of the sea a vertical profile that could be evenly stratified regardless of its depth. Thus, both a better representations of the near-bottom layer as well as a simplified calculation according to numerical scheme can be achieved. However, the particular layers are not exactly horizontal resulting in some discrepancies in calculations of the horizontal pressure gradients (Haney, 1991) and the horizontal diffusion. Therefore, the discrepancies cause some errors in the calculated flows. To minimize such errors, a technique of subtraction of the area-averaged density was applied prior to density gradient evaluation (Gary, 1973; Mellor et al., 1994). 18 layers of different thickness were assumed. For a better representation of the surface and near-bottom layers, their thickness were smaller than other layers.

The bathymetric grid was worked out based on the nautical charts of the Baltic and smoothed to eliminate large depth differences, which would cause the considerable errors in calculated currents in consequences of the calculation errors of the horizontal gradients of pressure (Mellor et al., 1994).

Calculations of currents, temperature and water salinity were evaluated at every time step of internal mode of the model (20 min.), but the sea level oscillations were calculated with shorter, external mode time step (1 min.).

2.2. Initial and boundary conditions

The initial three-dimension temperature and salinity distributions were interpolated by DAS (Data Assimilation System) system (Sokolov et al., 1997) based on the data from Baltic Environmental Database (http://www.ecology.su.se/models/bed.htlm), obtained during observations carried out in 1970–1998. The zero level of the Baltic as well as the lack of currents in initial moment were accepted.

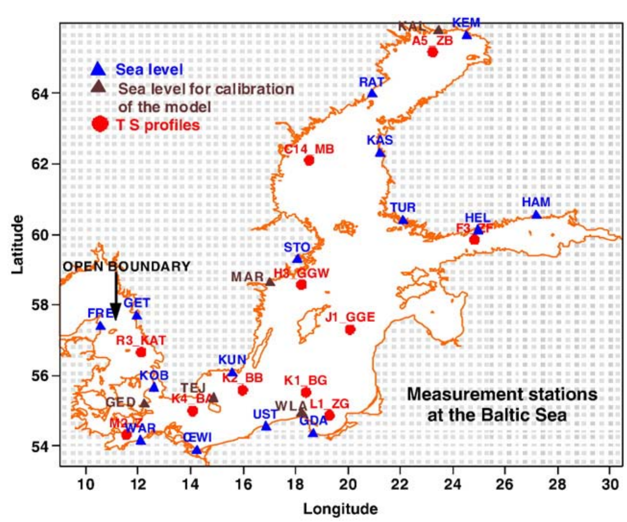

Fig. 1. Location of measurement stations of the sea level and vertical profiles of temperature and salinity (full name of coastal stations there are in Tables 1 and 2).

The characteristic distribution of salinity in the Baltic Sea is the result of water exchange with the North Sea and the inflow of fresh waters from land. The right reconstruction of salinity distribution is the condition of the correct calculation of currents and in consequence the sea level. Therefore, the inflow of 125 largest rivers were included. The monthly averaged inflows of individual rivers were calculated based on the data in the period for 1970–1990 taken from NEST database.

The open boundary was located between Kattegat and Skagerrak where the exchange of waters with the North Sea took place. Monthly averaged sea level at Göteborg station was assumed as the open boundary. A radiation boundary condition was applied for averaging vertical flows:

$$V = \frac{C}{h}(\zeta - \zeta') \tag{1}$$

where: $C = \sqrt{gh}$,

h	the water depth,
ζ'	a free surface elevation in the vicinity of an open border,
ζ	the values of free surface elevation for the grid points around the open border, calculated using the continuity equation.

If the momentary value of the free surface elevation (ζ) is larger than the adopted value (ζ'), the outflow of waters from the Baltic occurs proportionally to the difference between these values. On the contrary, when the sea level in Kattegat is lower — the inflow of waters from Skagerrak takes place.

On the open boundary the monthly averaged vertical distribution of salinity was applied, which means that the waters flowing from the North Sea to the Baltic have a climatic vertical distribution of salinity. However, the waters out flowing from the Baltic have the same distribution as the one found for the grid points closest to the open boundary. The assumption was made, that both the water flowing out of the calculation area and the water flowing into it have the same temperature, which was calculated as a result of model simulation near the open boundary.

2.3. Boundary conditions at the sea surface

The energy exchange between the atmosphere and the sea was concerned. Components of the surface wind stresses vector, τ_{ox} and τ_{oy}, were computed according to the formulas:

$$\tau_{0x} = C_D \rho_{atm} \sqrt{U_{10}^2 + V_{10}^2 U_{10}} \tag{2a}$$

$$\tau_{0y} = C_D \rho_{atm} \sqrt{U_{10}^2 + V_{10}^2 V_{10}} \tag{2b}$$

where:

ρ_{atm}	density of the atmosphere,
C_D	drag coefficient,
U_{10}, V_{10}	components of the wind velocity at 10 m height over sea level

The meteorological forcing data, used within the project, are 1-hourly grided wind velocity fields. The wind velocity hindcast covering the period 1958–2001 was performed in GKSS (Germany) with the atmospheric REMO model (REgional MOdel; Jones, 1998, 1999; Jacob and Podzun, 1997; Von Storch et al., 2000; Feser et al.,