Operational hydrodynamic model as an environmental tool in the Oder Estuary

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Abstract

The Oder Estuary with a large Szczecin – Swinoujscie port is both of significant economical and recreational importance. So in the region it is important to improve safety of navigation and work in ports as well as protect against ecological hazards. To fulfil these tasks it is necessary among others to possess current information on hydrological conditions in the estuary. So a 3-D operational hydrodynamic model, developed at Institute of Oceanography, Gdansk University was applied in order to forecast hydrological conditions in the estuary. The model was based on the coastal ocean circulation model known as POM (the Princeton Ocean Model), which was adapted to the Baltic conditions and for the 48-hour digital meteorological forecast of ICM (Interdisciplinary Centre of Mathematical and Computational Modelling, Warsaw University). Because of backwater occurrence in the Oder mouth there was developed a simplified operational model of river discharge based on water budget in a stream channel. Linking the Oder discharge model with the hydrodynamic model of the Baltic Sea as one system made possible to simulate operationally hydrological conditions in the Oder Estuary. The model enables to forecast water levels, currents, water temperature and salinity in the estuary. Good agreement between observed and computed data allowed to consider the model as a reliable environmental tool. Quick access for hydrological forecast (on a website) allows potential users to take a lot of advantages of it in different areas of living.

1 Introduction

1.1 The research area presentation

The Oder Estuary, situated at the southern Baltic Sea, is of significant economical importance. The location of the large Szczecin – Swinoujscie port in the mouth of the Oder River and the convenient system of waterways linking Silesia with the Baltic Sea offer an excellent transportation opportunity. Navigation of ships and barges, the port operations such as transport, freight handling and storage of goods depend to a large degree on actual local weather conditions. The area is exposed among others to storm surges caused by fluctuations of the large-scale wind field over the Baltic. Thus forecasts of water level, currents as well as water physical features are crucial for emergency command centres and services, responsible for safety of navigation and work in ports, flood protection of coastal areas, especially protection of depression areas, polders and areas close to river.

On the other hand the region is of vital recreational importance because of seaside resorts situated along the inner and especially outer coasts of the estuary. But the area is exposed to increased water pollution introduced by the Oder River. This results that the estuary is one of the most polluted coastal waters of the southern Baltic Sea. As good water quality is an important factor for further tourism development the estimation of ecological hazards in the estuary is essential.

Numerical modelling became an essential tool in coastal management and environmental protection of the Oder Estuary. Generally the modelling is carried out for two sub-areas: the lowest part of the Oder River and the Szczecin Lagoon – the Pomeranian Bay (Jasinska et al. 2003). For describing

water flow and levels in the branches and channels of the Lower Oder 1-D model was applied successfully by Ewertowski (1988). For describing hydrodynamic regime of the Szczecin Lagoon – the Pomeranian Bay area mainly 3-D models have been used. IBW PAN in Gdansk developed a three-dimensional model known as ESTURO (Jasinska & Robakiewicz 1999). The Warnemünder Ostee Model (WOM) based on the GFDL ocean circulation model was also set up successfully (Lass et al. 2001). A 3-D operational numerical model HIROMB was developed in BSH in Hamburg, and then extended in cooperation with SMHI in Norrköping (Funkquist 2001). Maritime Institute of Gdansk built up the model for the Polish zone (Kalas et al. 2001). Hydrodynamic forecast, realized on the base of the meteorological analysis and the 48-hour forecast, is given for the whole Baltic Sea and its particular parts.

1.2   3-D operational hydrodynamic model of the Oder Estuary

In our study a three-dimensional operational hydrodynamic model, developed at Institute of Oceanography, University of Gdansk was applied in order to forecast hydrological conditions in the Oder Estuary. Theoretical and numerical solutions of the model were based on the coastal ocean circulation model known as POM (the Princeton Ocean Model), described in detail by Blumerg & Mellor (1987) and Mellor (1996). The model (Fig. 1) was adapted to the Baltic conditions and for the 48-hour digital meteorological forecast of ICM (Interdisciplinary Centre of Mathematical and Computational Modelling, University of Warsaw). To parameterize vertical mixing processes, the scheme of second order turbulence closure was used as in POM (Mellor & Yamada 1982). Firstly the model was designed for the whole Baltic Sea and the Gdansk Bay as a part (Kowalewski 1997). To obtain a proper approximation of water exchange with the North Sea, the Baltic comprises also the Danish Straits. The open boundary was situated between the Kattegat and Skagerrak where radiation boundary conditions were accepted for flows.
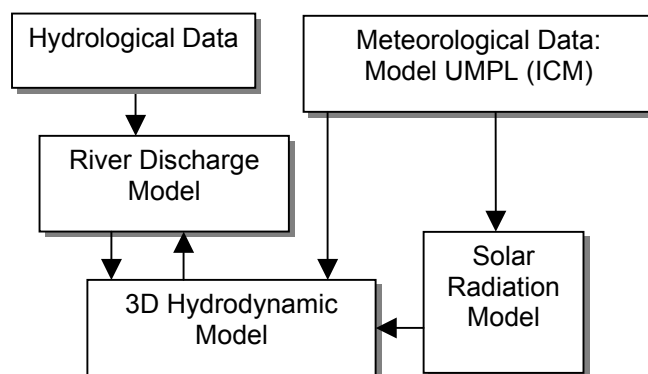

Figure 1: The scheme of 3-D operational hydrodynamic model of the Oder Estuary.

In order to obtain a proper resolution and reliable data two grids with different spatial steps were applied: 5 nautical miles for the Baltic Sea and 0.5 NM for the second region that comprises the Pomeranian Bay, the Szczecin Lagoon to Police at the Oder mouth. The computational grid can be denser for some regions like for Szczecin-Swinoujscie shipping channel. Because of backwater occurrence in the Oder mouth in addition a simplified operational model of river discharge based on water budget in a stream channel was developed. Discharge calculations are performed automatically assimilating water level data from three gauging stations situated in the Oder mouth (Gozdowice, Widuchowa and Szczecin), published on the website of Institute of Meteorology and Water Management (IMWM). Linking the Oder discharge model with the hydrodynamic model of the Baltic Sea as one system made possible to simulate operationally hydrological conditions in the Oder Estuary and give 48-hour forecast for the Oder Estuary. The model forecasts water levels, currents, water temperature and salinity in the Pomeranian Bay as well as in the Szczecin Lagoon with special

emphasis put on the Szczecin – Swinoujscie Fairway. The results of the model are given day by day on websites of University of Gdansk and Szczecin.

Verification of the model was based on empirical and calculated series of water level, currents, water temperature and salinity in the Pomeranian Bay as well as in the Szczecin Lagoon. The empirical series of data from 2002 were taken from websites of IMWM (Poland) and BSH (Germany). In addition the observations of meteorological and hydrological conditions along the Szczecin-Swinoujscie Fairway obtained from Master's Office of Szczecin-Swinoujscie Harbour as well as IMWM (Poland) were included.

2   Results

For the given observations and numerical simulations of water level, water temperature and salinity as well as currents standard statistical parameters as average value (AVG), maximum value (MAX), minimum value (MIN), standard deviation (STD) and variation coefficient (VS) have been calculated. Additionally t-test for independent samples was carried out and correlation coefficient (R) was computed between empirical and predicted data. The calculated statistics for observed and calculated series of water level and water temperature are given in Table 1.

A/ Water level								
Location	**Type of data**	**N**	**AVG**	**MIN**	**MAX**	**STD**	**VS**	**R**
Swinoujscie	Observation	2189	505.10	413.00	633.00	22.370	0.044	0.939
	Model	2189	505.36	417.16	649.99	21.220	0.042	
Trzebiez	Observation	2185	510.72	458.00	596.00	22.190	0.043	0.955
	Model	2185	511.58	454.59	593.08	21.030	0.041	
Koserow	Observation	6389	506.71	428.00	639.00	22.220	0.044	0.946
	Model	6389	503.17	421.89	644.81	20.780	0.041	
B/ Water temperature								
Location	**Type of data**	**N**	**AVG**	**MIN**	**MAX**	**STD**	**VS**	**R**
Swinoujscie	Observation	365	10.41	0.00	22.00	7.273	0.699	0.991
	Model	365	10.02	-0.20	21.28	7.103	0.709	
Trzebiez	Observation	365	11.33	0.00	23.20	7.815	0.690	0.987
	Model	365	10.98	-0.10	24.05	7.566	0.689	
Ueckemuende	Observation	1819	14.32	2.90	24.40	7.794	0.544	0.994
	Model	1819	13.88	3.09	23.11	7.377	0.531	
Oder Bank (Depth 3m)	Observation	1920	11.06	0.02	21.75	6.733	0.609	0.996
	Model	1920	11.04	0.25	20.11	6.131	0.555	
Oder Bank (Depth 12m)	Observation	1799	11.78	1.06	20.33	6.085	0.517	0.996
	Model	1799	11.67	0.33	19.44	5.763	0.494	

Table 1: Basic statistical parameters for observed and modelled series of water level and water temperature.

The comparison between observed and predicted data of water level showed that the average values of observed and computed data series were almost the same for Swinoujscie gauging station. For all the locations variation coefficient values were very low however both standard deviation and

variation coefficient values were larger for empirical data than for modelled ones. The highest correlation coefficient between empirical and modelled values was achieved for Trzebiez gauging station, but it should be emphasised that calculated correlation coefficients (between 0.94 and 0.96) were highly statistically significant for all the stations.

Comparing empirical with modelled data of water temperature one can see very good agreement between them. Calculated basic statistics and achieved highly statistically significant correlation coefficients (R exceeded 0.99) prove it. As for water level standard deviation and variation coefficient values were insignificantly higher for empirical data than for modelled ones.

Modelled salinity and current values (at the Swina mouth) were weaker but of statistically significant importance (0.566-0.727 and 0.663 adequately).
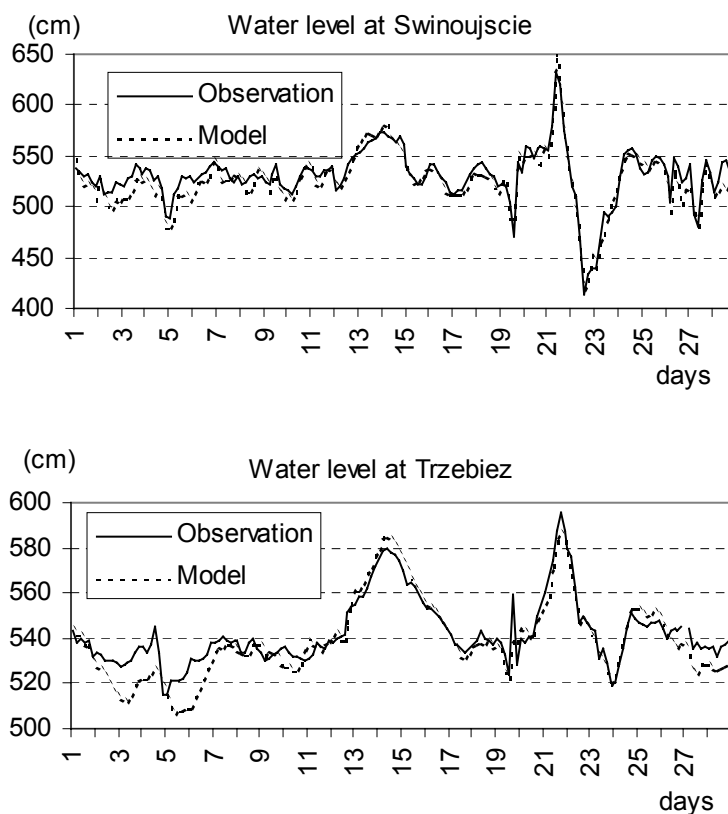

Figure 2: Comparison between modelled (dash line) and observed (solid line) water level as measured at Swinoujscie and Trzebiez gauging stations during storm surge in February 2002.

Good agreement between empirical and predicted data encouraged to check accuracy of the model during extreme events in 2002. From 19 to 27 February 2002 the significant storm surge at the coasts of the Southern Baltic Sea was observed, which caused invasion of sea waters inland and flooding event in some seaside towns (Swinoujscie, Lübeck). The surge was the result of low-pressure systems passage over the Baltic Sea. On 19th February there was observed the decrease of water level in Swinoujscie until 472 cm caused by the prevailing south to west winds (Fig. 2). From 20th February sea level began to rise and on 21st February it reached the value of 635 cm as a result of the shifting of deep low centre over the Southern Baltic Sea (Fig. 3). On that day the flooding event in Swinoujscie occurred. Next the low went away over Scandinavia and joined with other lows over the Northern Atlantic Ocean and caused the rapid fall of sea level in Swinoujscie to 415 cm on 22nd February. On 23rd February the system of lows over Western Europe came together and one extended system over Northern Scandinavia occurred causing only slight changes of sea level.
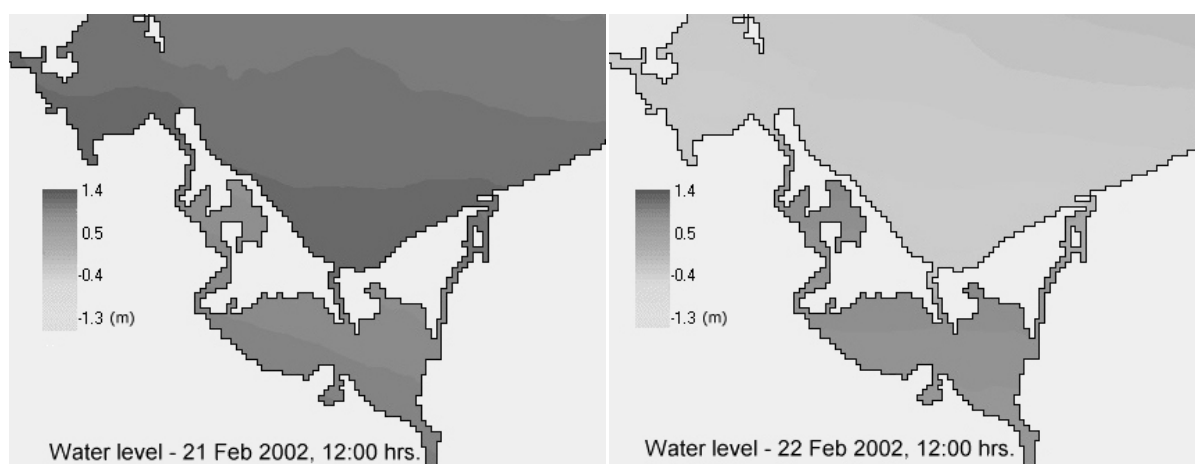
Figure 3: Simulation results with the 3-D operational numerical model of the Oder Estuary during the storm surge in February 2002 (on left – the surge, on right – the fall of water level).

During that storm surge at Trzebiez (the Szczecin Lagoon) there were observed significantly weaker changes of water level. From 19th to 21st February the systematic increase of water level was recorded until the maximum value of 596 cm. The increase of water level followed with 8-hour lag in comparison to sea level maximum in Swinoujscie. Then water level in the Oder Estuary systematically lowered till 24th February. During next few days in the estuary only slight changes of water level were recorded. We conclude that our model correctly approximates the changes of water level and reflects properly all the phases of that storm at both gauging stations (Fig. 2 & 3).

3   Discussion

Linking the Oder discharge model with the hydrodynamic model of the Baltic Sea as one system made possible to simulate operationally hydrological conditions in the Oder Estuary. The model enables to forecast water levels, currents, water temperature and salinity in the Pomeranian Bay as well as in the Szczecin Lagoon.

The best agreement between observed and computed data series was achieved for water level and water temperature of the Pomeranian Bay as well as the Szczecin Lagoon. Modelled salinity and current values (at the Swina mouth) were of weaker but statistically significant importance.

Good agreement between observed and computed data allowed to consider the model as a reliable environmental tool for forecasting the extreme events like storm surges. In the situations of high amplitude and rapid changes of water level like in February 2002 the model reflects properly the hydrological situation.

Quick website access to the hydrological forecast allows potential users to predict day by day processes that may affect different areas of living and can be useful for improvement of safety of navigation and work in ports, flood protection of coastal areas as well as for studying coastal processes in the estuary. Further improvement of the model will be performed in order to acquire better agreement between observed and computed data.

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