

## **Storm surges in the Oder Estuary in 2002-2003 – numerical study**

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### **Abstract**

The application of the 3-D operational hydrodynamic model, based on the POM model for the study and forecast of storm surges in 2002 and 2003 revealed its high usefulness. In case of high amplitude and significant water level fluctuations the model correctly approximated the changes of water level and reflected the hydrological situations properly. Potential users such as emergency command centres and services dealing with environmental and flood control as well as with the safety of navigation can take advantages from current 0-60-hour hydrological forecasts for the region of the Szczecin Lagoon and the Pomeranian Bay via a quick website access (<http://model.ocean.univ.gda.pl>).

Keywords: Storm surges; Numerical modelling; the Oder Estuary.

### **Introduction**

The Oder River forms one of the major estuaries in the southern Baltic Sea. In its downstream reach, the Oder opens first into the Szczecin Lagoon. Then it drains into the Baltic Sea through three straits: the Swina, the Dziwna and the Peenestrom. That shallow, coastal water body is exposed among others to storm surges. Caused by deep low-pressure systems passing the Baltic Sea the storm surges are the result of wind activity and changes of atmospheric pressure on the sea surface.

### **The description of the model**

In recent years numerical modelling has become an essential tool in the flood control of coastal areas (among others Funkquist, 2001; Kalas *et al.*, 2001). In our study a 3-D operational hydrodynamic model of the Baltic Sea, developed at the Institute of Oceanography, University of Gdansk, was applied to the study and forecast of storm

surges in the Oder Estuary (Kowalewski, 1997). 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 Blumberg and Mellor (1987). The model was adapted to the Baltic conditions and for the 48-hour numerical meteorological forecast of ICM (Interdisciplinary Centre of Mathematical and Computational Modelling, Warsaw University). Because of wind-driven back-up in the Oder mouth, a simplified operational model of river discharge based on water budget in a stream channel was developed. Linking the Oder discharge model with the Baltic Sea model as one system made possible to simulate operationally water levels and currents as well as water temperature and salinity in the Oder Estuary (Kowalewska and Kowalewski, 2004). The adequate fit between the predicted and observed water level series from the gauging stations on the Szczecin Lagoon and the Pomeranian Bay encouraged to apply the model to studying and forecasting storm surges in 2002 and 2003.

### Storm surges in the Oder Estuary

Fourteen storm surges were recorded in the Oder Estuary in 2002 and 2003. During three of them the typical wind-driven back-up in the Oder branches was observed. In those cases continuous increase of water level was observed, starting from the Pomeranian Bay and then within the whole estuary. Finally the continuous fall of water level was recorded. The negative phase of the wave caused by the changes of air pressure on the sea surface was clearly seen.

Six storm surges were observed during spring, melting season, while high water levels in the branches of the lower Oder were notified. In those cases the rise of water levels within the estuary caused by the passage of deep low-pressure system over the Baltic Sea was more intensive. Sometimes it resulted in flooding events like during storm surge from 19 to 27 February 2002 (Fig. 1). In Swinoujście, on 19 February, the water level decrease until 472cm was correctly approximated by the model. Then, sea level rise was observed till 635cm on 21 February as a result of low centre shifting over the Southern Baltic (overlapping of two effects: the strong north-easterly winds of 11°B and positive phase of baric wave). In Swinoujście, the maximum was predicted two hours before the real maximum in the forecast from 20 February and two hours after in the forecast from 21 February. The forecast of the rapid sea level fall to 415cm on 22 February, being the result of low shifting over Scandinavia (negative phase of baric wave), was accurate as far as the time and the minimum level are concerned. During that storm surge on the Szczecin Lagoon significantly weaker changes of water level were observed. In Trzebiez, the water level maximum of 596cm followed with 8-hour lag in comparison to the sea level maximum in Swinoujście. All the phases of the storm were properly approximated by the model as far as the time and the extreme levels are concerned.

Only two short-lived storm surges were recorded at the coasts of the Pomeranian Bay. They were the result of fast deep low shifting over the Baltic Sea like in the beginning of December 2003 (Fig. 2). Following the minimum water level of 459cm in Świnoujście on 5 December, correctly approximated by the model, the sudden rise of sea level began. It reached the maximum value of 594cm on 6 December. The forecast from 5 December overestimated the maximum and calculated it 6-hour earlier, however the forecast from 6 December underestimated it. The last one predicted the subsequent decrease of water level until the minimum on 7 December sooner as well. On the contrary, the forecast

from 7 December overestimated that fall of sea level. Because of the fast low passage on the Szczecin Lagoon significantly weaker fluctuations of water level were recorded, followed by a delay to sea level changes. It is because of too low flow capacity in the straits connecting the Szczecin Lagoon and the Pomeranian Bay. In Trzebież, the fluctuations of water level between 487cm on 5 December to 546cm on 7 December were properly predicted by the model.

Three storm surges were recorded caused mostly by the strong wind. In those surges both the increase and decrease phase of water level is slow and mild. The effect of the changes of air pressure is imperceptible. The raised water levels are observed within the whole estuary.

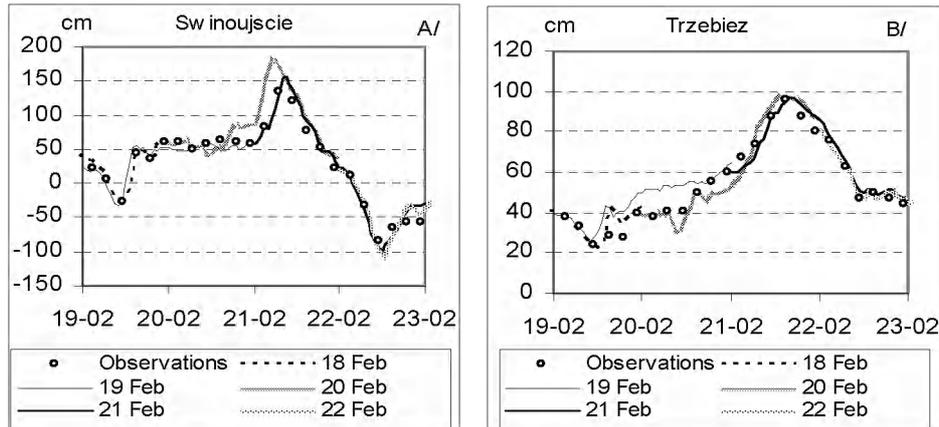


Fig. 1. Observed and predicted course of water level changes in Swinoujscie (A) and Trzebiez (B) during the storm surge in February 2002. In legend: forecasts from 18 to 22 February.

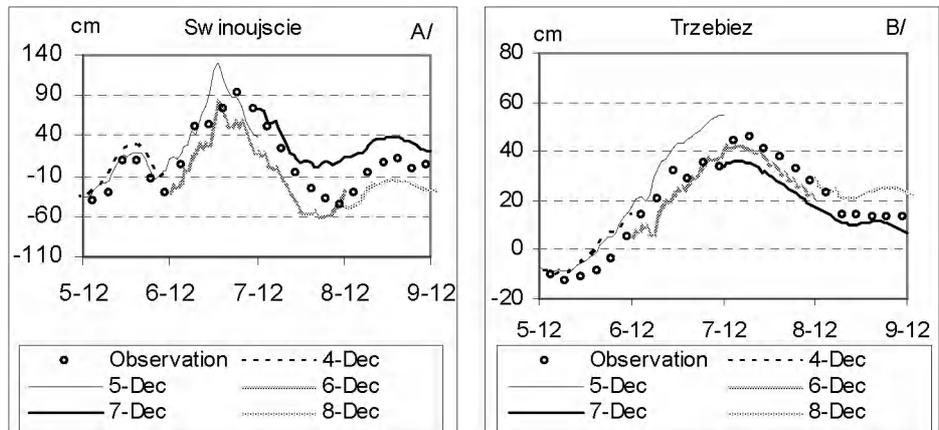


Fig. 2. Observed and predicted course of water level changes in Swinoujscie (A) and Trzebiez (B) during the storm surge in December 2003. In legend: forecasts from 4 to 8 December.

## Conclusions

The analysis revealed that the highest increases of water level were recorded in the cases of the movement of deep depression with a trajectory running close to the coasts of the Southern Baltic Sea (mainly the effect of air pressure) and strong northerly winds (damming up of waters close to the coasts). Overlapping of both factors caused the intensification and prolongation of the storm surge. In that case the reverse slope of water free surface was recorded. It resulted in the intrusion of brackish water from the Pomeranian Bay into the Szczecin Lagoon, reduced river outflow and rising of water levels within the whole estuary. Occasionally it resulted in flooding events like in February 2002.

Current 0-60-hour hydrological forecasts via a quick website access (<http://model.ocean.univ.gda.pl>) give potential users an opportunity to predict water level fluctuations, especially storm surges within the Szczecin Lagoon and the Pomeranian Bay. That information can be very important for emergency command centres and services dealing with environmental and flood control of coastal areas as well as with the safety of navigation and harbour operations. It may affect other areas of human life and activities, *e.g.* sport or recreation.

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