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Storm surges in the Western Black Sea. Operational forecasting.

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Abstract

The frequency of the storm surges in the Black Sea is lower than that in other regions of the World Ocean but they cause significant damages as the magnitude of the sea level set-up is up to 7-8 times greater than that of other sea level variations. New methods and systems for storm surge forecasting and studying their statistical characteristics are absolutely necessary for the purposes of the coastal zone management. The operational forecasting storm surge model of Meteo-France was adopted for the Black Sea in accordance with the bilateral agreement between Meteo-France and NINMH. The model was verified using tide-gauge observations for the strongest storms observed along the Bulgarian coast over the last 10 years.

Keywords: Storm Surge Model, Verification, Forecasting, Black Sea.

Introduction

The frequency of the storm surges in the Black Sea is lower than that in other regions of the World Ocean (RYABININ *et al.* 1996) but they cause significant damages as the magnitude of the sea level set-up is up to 7-8 times greater than that of the other sea level variations. Strong storm surges in the Western Black Sea along the Bulgarian Black Sea coast are usually observed from October to the end of March every winter. The highest storms are recorded in January and February.

The analysis of the longest Bulgarian tide-gauge records (1928-1998) in Varna and Burgas (MUNGOV *et al.*, 1994) shows that from 1928 to 1976 the amplitude of the storm surges did not exceed 50-60 cm. Several severe storms have been observed in the winter period since October 1976. These storms have caused serious damages to the ports, the various hydrotechnical constructions, the shore and the sand beaches, significantly increasing the coastal erosion. The sea water set-up does not often go up to or exceed 1 m above the mean sea level. It is about 8-10 times more than the amplitude of the maximum semi-duirnal tide observed in the central part of the Bulgarian shore and 2-3 times more than the "seasonal wave" in the mean sea level due to the seasonal variability of the Black Sea water balance. These strong storms could also cause serious ecological disasters because the shelf of the Bulgarian and Romanian sector of the

Black Sea has been carefully explored for oil and gas for several years and drilling platforms have been installed. For the purposes of the coastal zone management new methods and systems for forecasting storm surges and studying their statistical characteristics should be developed.

The previous investigations of the storm surges along the Bulgarian Black Sea coast were focused on the development of methods for their numerical modelling and forecasting and on the establishment of the extreme sea levels with low probabilities (MUNGOV, 1988; MUNGOV *et al.*, 1994). The model used in these studies was based on a rectangular grid with a spatial resolution of 9.000 and 9,333 km. This spatial resolution was relatively coarse and the important features of the coast, the shelf topography and the very steep Black Sea shelf slope were not well described. The advantages of the non-linear advective scheme were not entirely utilised either. These investigations pointed out that the semi-diurnal tide (resonant Kelvin travelling wave) should not be considered.

The numerical model of Meteo-France and its adaptation to the Black Sea

The operational forecasting storm surge model of Meteo-France was adopted for the Black Sea and the computational facilities of NIMH in accordance with the bilateral agreement between Meteo-France and NIMH. The operational model of Meteo-France is two-dimensional written in spherical co-ordinate system including advective terms, horizontal turbulence and non-linear bottom and surface friction (DANIEL, 1997):

$$\frac{\partial U}{\partial t} = f.V - \frac{g}{R.\cos\varphi}\cdot\frac{\partial\eta}{\partial\lambda} - \frac{1}{\rho.R.\cos\varphi}\cdot\frac{\partial P_a}{\partial\lambda} - \left(\frac{U}{R.\cos\varphi}\cdot\frac{\partial U}{\partial\lambda} + \frac{V}{R}\cdot\frac{\partial U}{\partial\varphi}\right) + \frac{\tau_{sx}-\tau_{bx}}{\rho.H} + A_H.\nabla^2 U \quad (1)$$

$$\frac{\partial V}{\partial t} = -f.U - \frac{g}{R}\cdot\frac{\partial\eta}{\partial\varphi} - \frac{1}{\rho.R}\cdot\frac{\partial P_a}{\partial\varphi} - \left(\frac{U}{R.\cos\varphi}\cdot\frac{\partial V}{\partial\lambda} + \frac{V}{R}\cdot\frac{\partial V}{\partial\varphi}\right) + \frac{\tau_{sy}-\tau_{by}}{\rho.H} + A_H.\nabla^2 V \quad (2)$$

$$\frac{\partial\eta}{\partial t} = -\frac{1}{R.\cos\varphi}\cdot\left[\frac{\partial}{\partial\lambda}(U.H) + \frac{\partial}{\partial\varphi}(V.H.\cos\varphi)\right] \quad (3)$$

The surface stress is obtained by quadratic relations:

$$\tau_{sx} = \rho_a.C_d.|W_{10}|.W_{10x} \qquad \tau_{sy} = \rho_a.C_d.|W_{10}|.W_{10y} \quad (4)$$

W_{10x}, W_{10y} are the horizontal components of wind velocity 10 m above the sea surface, □ is the air density and C_d is the drag coefficient calculated by the Smith and Banke formulation (SMITH et BLANKE, 1975):

$$\text{for } |W_{10}| < 25\ m/s \quad C_d = \left[0{,}63 + 0{,}066.|W_{10}|\right]10^{-3} \quad (5)$$

$$\text{for } |W_{10}| \geq 25\ m/s \quad C_d = \left[2{,}28 + 0{,}033.\left(|W_{10}| - 25\right)\right]10^{-3} \quad (6)$$

The bottom nonlinear stress is obtained by:

$$\tau_{bx} = \rho.C_b.\left(U^2 + V^2\right)^{\frac{1}{2}}.U$$
$$\tau_{by} = \rho.C_b.\left(U^2 + V^2\right)^{\frac{1}{2}}.V \quad (7)$$

The spatial discretisation is performed on lattice type "*C*" (MESINGER & ARAKAWA, 1976). Numerical integration is applied on three explicit steps (DANIEL, 1997) adopting the effective method described by Miller and PEARCE (1974), MATSUNO (1966).

In the first step the gravity waves and the Coriolis terms are treated. The second step is named "advective" and the non-linear terms are treated. In the third "physical" step the external stresses (surface and the bottom) and the atmospheric pressure gradient are included.

The hydrophysical fields □, □ and □ are smoothed with factor a ensuring the numerical stability.

The Black Sea area 27°E - 42°E and 47°N - 40°N, is approximated with a grid of 2'* 2' (x~2,528 km, 2y~3,704 km). This fine mesh contains about 42000 unit fields over the Black Sea and describes the main features of the shelf and the coastal line. The Black Sea bathymetry is characterised by deep central part up to 2245 m (Fig. 1), and a shallow continental shelf in the North West part of the sea between the Crimnea and the Romanian coast. The length of the shelf along the Bulgarian coast slowly reduces from North to South. The fine spatial discretisation and the big depths in the central part of the sea require small time step for the integration of the equations of motion and continuity and thus very serious requirements from computational point of view are set up. To overcome this problem and make the model convenient for operational applications the specific features of the stratification of the Black Sea waters and its seasonal dynamic were taken into account. The Black Sea has a very specific stratification and with some simplifications it can be treated as a three layered basin. The upper layer is very dynamic with lower salinity due to the significant fresh water inflow into the sea. The seasonal variations of the temperature additionally increase the density difference between the above and the below situated "cold intermediate layer". The rest of the basin that is below the cold intermediate layer is occupied by dense bottom waters. More detailed information about the Black Sea stratification and its driving mechanisms could be found in (OGUS *et al.*, 1993), (OZSOY, UNLUATA, 1997), "Hydrometeorology and hydrochemistry of the seas of the USSR. Vol. IV 'Black Sea'. Taking into account the described stratification we assume that the storm surge as long wave propagates in the upper dynamic part of the Black Sea. The test runs under the model validation and the comparison with the coastal tide gauge observations pointed out that for the winter stormy months the depth of this dynamic part could be accepted as equal to the "Mixed Layered Depths" - (OZSOY, UNLUATA, 1997). The bottom friction coefficient over the shelf was chosen as C_b=0.0015 and over "the liquid bottom" in the deeper parts of the basin as C_b=0.01*C_b.

The model computations start from "zero" initial conditions □=□=□=0. The same surface meteorological fields from the ARPEGE global operational model of Meteo-France are used as input data. The meteorological forcing on the fine computational mesh is obtained by applying biliner interpolation.

Model data and coastal observations

This model was adapted and verified using tide-gauge observations for the strong storms observed over the last 10 years along the Bulgarian coast. Next, the results from the hindcast computations for the strong storms from the period of 1986 - 1994 are

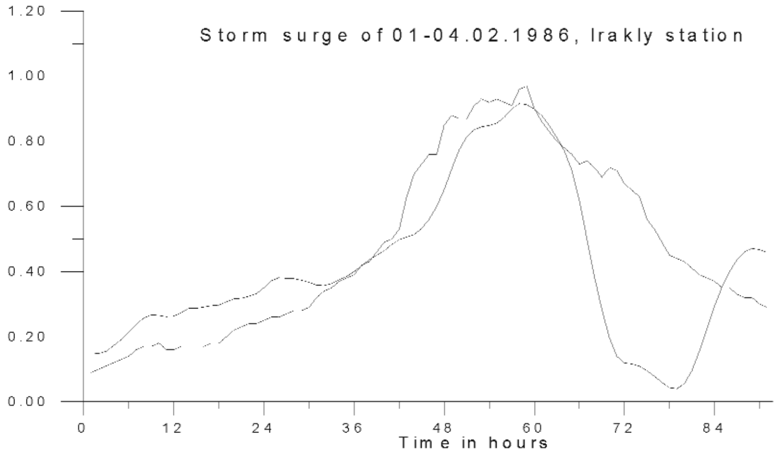

Fig. 1: Observed and model sea levels at Irakly tide-gauge staion for the storm of 01-04.02.1986.

TABLE 1
Data from coastal sea-level observations used for model verification.

N	Period of the storm data	days	Irakly	Ahtopol	maxDh (m)
1	1985.01.13 - 1985.01.17	3	x	x	0.70
2	1986.02.01 - 1986.02.04	3	x		0.90
3	1988.12.15 - 1988.12.18	4	x		0.75
4	1994.10.19 - 1994.10.23	4	x		0.80
5	1995.01.03 - 1995.01.06	4	x		0.70
6	1996.12.24 - 1997.01.14	22	x	x	1.00
7	1997.10.24 - 1997.10.30	8	x	x	0.80
8	1997.12.06 - 1997.12.19	14	x	x	1.30
9	1998.01.20 - 1998.02.08	20	x	x	0.90

shown in Table 1. Data from Irakly and Ahtopol tide-gauge stations is used. These two stations are located on the open sea shore and we consider them as being less affected by the local topography features. The data from the other two tide-gauges located in the two big bays-Varna and Burgas is scarce due to damages caused by the storms. Meteorological data from the global atmospheric model of Meteo-France "ARPEGE" is used in the model runs. During the model verification the following

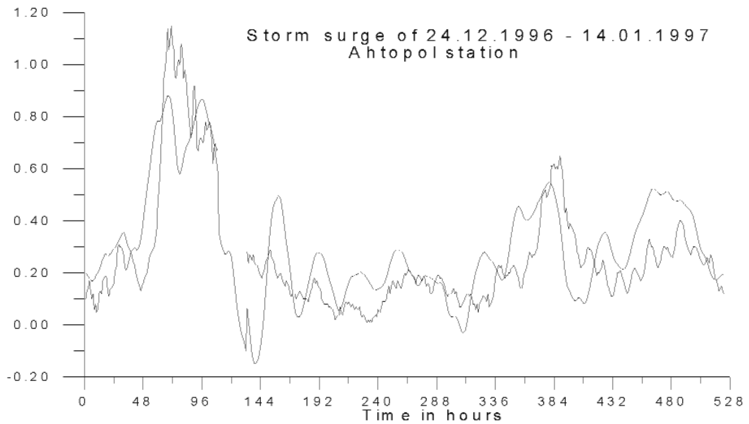

Fig. 2: Observed and model sea levels at Ahtopol for the storm of 24.12.1996 - 14.01.1997.

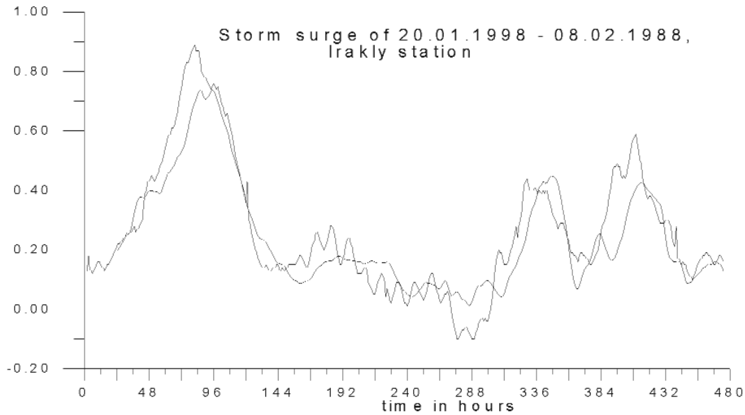

Fig. 3: Observed and model sea levels at Irakly for the storm of 20.01.1998 - 08.02.1998.

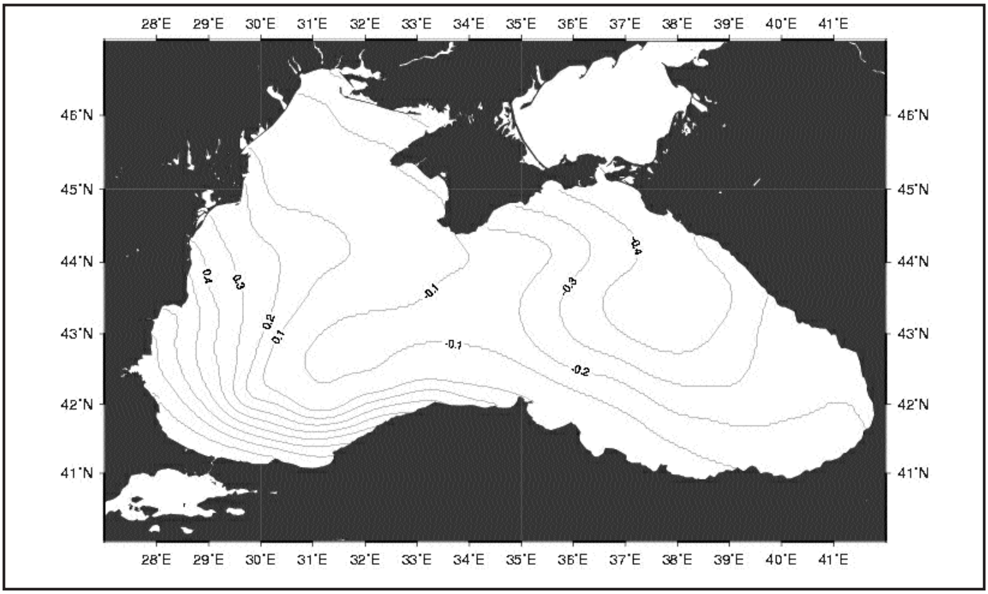

Fig. 4: Sea level topography for 12:00 of 03 January 1986.

parameters are calibrated:
- the surface friction coefficient is determined as 0,0016;
- the smoothing factor □= 0.975;
- the horizontal diffusion coefficient A_h=1500.

In Fig. 2 and 3 modelled and observed sea levels for the two recent storms of 24.12.1996 - 14.01.1997 and 20.01.1998 - 08.02.1998 are presented. As usual the computed sea levels are lower than the observed ones. We explain this with the specific bottom topography along the Bulgarian coast relatively narrow shelf and the need for more precise meteorological data from a fine mesh regional model. As shown in Fig. 4 the sea level set-up is realised over the shelf close to the shore where storm wind increase could be expected locally. At the present moment this local increase is not reproduced in the meteorological data we use. The described model is included in the operational system NIMH. It can be used for storm surge forecasting, mean currents computations in the surface mixed layer (an important “driving” factor in the oil drift model) determining the circulation and the dispersion of pollutants in the coastal zone, etc. The obtained results indicate that the developed version of the operational storm surge model of Meteo-France may be progressively applied for further studies of various Black Sea regions. It is a significant contribution to the modernisation of the operational activities of NIMH.

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References

DANIEL, P., 1997. Forecasting tropical cyclones storm surges at Meteo-France, Computer Modelling of Seas and Coastal Regions III, Computational Mechanics Publications, pp. 119-128.

Hydrometeorology and hydrochemistry of the seas of the USSR. Vol. IV "Black Sea. Hydrometeorological conditions." Gidrometeoizdat (in Russian), 1991.

LARGE, W. G., POND, S., 1981. Open ocean momentum flux measurements in moderate to strong winds. *J. Phys. Oceanogr.,* 11, 324-336.

MATSUNO, T., 1966. Numerical investigation of the primitive equations by a simulated back ward difference method. *J. Meteor. Soc. Japan, Ser.* 2, 44, 76-84.

MESINGER, F., ARAKAWA, A., 1976. Numerical methods used in atmospheric models. GARP Publ. Ser. N° 17, ICSU/WMO.

MILLER, M. J., PEARCE, R. P., 1974. Numerical model of a cumulonimbus. *Q. J. R. Meteorol. Soc.,* 100, 133-154.

MUNGOV, G., 1988. Numerical modelling of the storm surges along the Bulgarian shore. (in Russian). In Proceedings of the State Oceanograhic Institute, 189, 124-137.

MUNGOV, G., VESSELINOV, V., KORTCHEVA, A., KORTCHEV, G., 1994. "Sea level structure and their forecasting along the Bulgarian Black Sea coast", research contract with the National Science Foundation No. 53/1991, 70 p.

OGUS, T., LATUN, M.S, LATIF, M.A, 1993. Circulation in the surface and the intermediate layers of the Black Sea. *Deep-Sea Res.,* 40, 1597-1612.

OZSOY E., UNLUATA U., 1977. Oceanography of the Black Sea: a review of some recent results. ICTP, Trieste, April, 1997.

RYABININ E., ZILBERSTEIN, O., SEIFERT, W., 1996. Storm surges. WMO/TD NO. 779.

SMITH S., BANKE, E., 1975. Variation of the sea surface drag coefficient with wind speed. *Quart. J. Roy. Met. Soc.,* 101, 665-673.