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REVIEW OF THE BLACK SEA WAVE SPECTRUM

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Abstract: This paper is focused on the improvement of the SWAN (Simulation of Waves Nearshore) numerical model in order to be better adapted to the specific conditions of the Black Sea Littoral. As coupling conditions – for North, East and South, excepting West boundaries which are represented by land – were used data from the Gloria Meteorological Station. The ALADIN wind field generated by the National Meteorological Administration was used on the southern parts of the Romanian littoral. The first SWAN simulations were performed with SWAN theoretical spectra: JONSWAP and Pierson-Moskowitz. After that, a previously built one-dimensional Black Sea wave spectrum was introduced into the model. Since the numerical model uses a directional 2D spectrum, a methodology proposed by the CERC Shore Protection Manual was applied to transform the initial frequency spectrum into a directional one. This one constructs the two-dimensional spectrum starting from the directional spreading cosine method.

By considering the specific local conditions, the results of this new parameterization are promising, suggesting that the improved SWAN model could be used for the Black Sea nearshore wave forecasting.

1. INTRODUCTION

The numerical wave-forecasting models in coastal areas need, in general, two-dimensional spectra. The utilization of directional spreading within numerical models is important for the increasing of their accuracy and for in situ oceanographic buoy calibration. If there are no available buoy data, the numerical model could be realized by combining the spreading function with an existing spectrum such as: JONSWAP (JOint on North Sea WAve Project) (Hasselmann, 1973) for deep water applications, TMA Shallow-Water Spectrum (Hughes, 1984) for nearshore waves or the sea spectrum, as it is presented in this paper, namely the Black Sea wave spectrum.

For short period waves – which are specific for closed seas, such as the Black Sea – a larger frequency domain is chosen simultaneously with reduced resolution ; larger breadths are also adopted in these cases for spectral directions. The directional spreading of spectral energy determines the directional spreading coefficient. Knowing its evolution in shallow waters is important for coastal engineering which will adopt in this way more accurate wave predictions for the computations. Collins (1981) establishes that the use of spectral models which neglect the directional spreading of wave energy could overestimate up to 20% the significant wave heights, having therefore implications on coastal structures regarding raw material. Forristall (1978) shows that not considering directional spreading leads to the overestimation of storm-wave speeds. For this reason, the realistic models of coastal processes are the spectral ones, having as input data the directional spectrum established for deep-water conditions.

Various oceanic models have been developed by oceanographic institutions such as:

-MEDATLAS (The MEDAR Group, 2002) is a climatologic marine model applied to the Mediterranean Sea;

-GOTM–General Ocean Turbulence Model (www.gotm.net) is a one-dimensional numerical model of simulation of vertical processes in marine environment;

-MOM–Modular Ocean Model (www.gfdl.noaa.gov/~smg/ MOM /MOM.html);

-POM–Princeton Ocean Model (www.aos.princeton.edu/WWWPUBLIC/ htdocs.pom/), but neither of these models are fully spectral wave ones.

The one-dimensional Black Sea spectrum for Lebada region, was elaborated by Bondar (1989). Using this spectrum, Trusca (2005) developed a two-dimensional spectrum for the Black Sea. The Romanian Black Sea wave simulations were presented by Trusca (2003, 2004), using the most advanced third-generation, numerical, high-resolution, fully spectral, near-shore wave model SWAN (Simulation of Waves Nearshore) developed at Delft University of Technology, the Netherlands, which could obtain realistic estimates of wave characteristics in shallow waters from given wind, bottom and current conditions (Booij, 2004). In this paper, an improvement of the SWAN model obtained by a two-dimensional spectrum is presented. Section 2 presents the physics of the SWAN model and the method of turning a one-dimensional spectrum into a two-dimensional one , followed by a review of the Black Sea wave spectrum (construction and validation of the two-dimensional spectrum) shown in Sections 3 and 4. Conclusions are presented in Section 5.

2. METHODOLOGY

2.1. Physical basis of SWAN

In SWAN (Simulating WAves Nearshore), the wave description is given by two-dimensional wave action density spectrum $N(\sigma,\theta)$ equal to energy density divided by relative frequency σ (as obtained in a frame of reference moving with the action propagation velocities):

$$N(\sigma,\theta)=E(\sigma,\theta)/\sigma \qquad (1)$$

The second independent variable is wave direction θ (the direction normal to the wave crest of each spectral component).

The evolution of wave spectrum is described by the spectral action balance equation:

$$\frac{\partial}{\partial t}N+\frac{\partial}{\partial x}c_xN+\frac{\partial}{\partial y}c_yN+\frac{\partial}{\partial \theta}c_\theta N=\frac{S}{\partial} \qquad (2)$$

In the left-hand side of this equation, the first term represents the local rate of change of action density in time, the following two terms represent the propagation of action in the geographical space (with propagation velocities c_x and c_y , in x- and y-space, respectively). The next term represents the shifting of relative frequency due to variations in depths and currents (with propagation velocity c_σ in σ-space). The last term in the left-hand side of equation represents the depth-induced and current-induced refraction (with propagation velocity c_θ in θ-space).

The term S is the source term opposing spectral energy density and wave action which bring together the effects of dissipation by bottom friction, dissipation by depth-induced wave-breaking, dissipation by whitecapping and generation by wind:

$$S(\sigma,\theta)=S_{ds,b}(\sigma,\theta)+S_{ds,br}(\sigma,\theta)+ \\ +S_{ds,w}(\sigma,\theta)+S_{in}(\sigma,\theta) \qquad (3)$$

In fact, energy is re-distributed, without altering the total quantity.

2.2. Turning a one-dimensional spectrum into a two-dimensional one

In the initial wave generated stage, crests are very short and for this reason propagation takes place on several directions differing from that of the wind. As wind waves travel over longer and longer distances, they catch mainly the wind direction , but there still exists a spreading energy around the mean advancing direction. Later on, as wind waves are transformed into swell, the energetic dispersion cone becomes more and more limited.

The spatial spectral approach supposes the introduction of directional spreading of wave energy in relation to the mean propagation direction, especially in the case of wind waves with a large width development of wave front, different from the swell ones, which already have an almost compact as well as a right well-defined wave front with a reduced directional spreading.

Considering wave energy in one arbitrary point, it has not only an angular distribution but also one covering a frequency domain (CERC, 1984). The 1D spectrum only describes the wave energy distribution depending on frequency; in addition, the 2D spectrum is also connected to the mean wave propagation direction and its adjacent directions up to:

$\pm\left(90° - \frac{1}{2}\cdot\frac{360°}{n}\right), n$ being the number of discretization directions (CHETN-I-64, Smith, 2001).

The spatial representation which includes frequency distribution as well as the angular spreading of wave energy is named directional spectrum. Its representation function is determined by the adopted number of spectrum frequencies ; while the use of a smaller number of frequency steps reduces the numerical model resolution, a higher one increases the computational time of applications. It was remarked that it is recommended to choose frequency domain so that peak spectrum reaches only one third of the domain (Booij, 2004).

For long-period waves, fine discretizations starting from much lower frequencies are adopted. For short-period waves – which are specific to closed seas, such as the Black Sea – a larger frequency domain is chosen, which corresponds at the same time with a decreased resolution; larger breadths are also adopted in these cases for spectral directions.

The directional spreading of spectral energy determines directional spreading coefficient (DSPR). Knowing its evolution in shallow waters is important for coastal engineering, which will adopt in this way more accurate wave predictions for computations. For this reason, the realistic models of coastal processes are the spectral ones, having as input data the directional spectrum established for deep-water conditions.

The spreading parametrical functions (CETN, 1985) describe directional one peak spectrum and consist of the product of two functions:

$$E(f,\theta) = E(f)\cdot D(f,\theta) \qquad (4)$$

where: $E(f,\theta)$ – directional spectral density function

$E(f)$ – spectral energy density function given by frequency field dimension

$D(f,\theta)$– angular spreading function

f – frequency in Hz; θ – direction in radians.

Since total directional spectral energy must be the same with that described by the 1D spectrum, the resulting equality is:

$$\int_{0}^{\infty}\int_{-\pi}^{\pi} E(f)D(f,\theta)d\theta df = \int_{0}^{\infty} E(f)df \quad (5)$$

This parameterization represents the directional nature of wave field in the absence of influences given by major changes in wind direction and of swell propagation into the wave generated area, which could lead to a bimodal spectrum. The **cos-squared function** used for 2D spectra is given by:

$$D(\theta)=\begin{cases}\frac{2}{\pi}\cos^2(\theta-\theta_0), for \\ \left(-\frac{\pi}{2}+\theta_0\right)<\theta<\left(\frac{\pi}{2}+\theta_0\right) \\ 0, otherwise\end{cases} \quad (6)$$

This function does not depend on frequency or wind speed but only on θ_0 mean wave direction.

where: $\overline{E}=\frac{\rho g\overline{H^2}}{8}$ represents mean specific energy of wave field (kJ·m^{-2})

$\varpi = 2\pi/\overline{T}$ mean angular frequency (rad·s^{-1});

ω – angular frequency (rad·s^{-1});

ρ – water density, considered on the analyzed area: 1012 kg·m^{-3};

$\overline{H}$ – average wave height (m).

Considering approximately 21 thousand recorded waves from the multi-annual period 1971÷1994, the Black Sea specific wave energy ranged between 0.05 and 44.6 kJ·m^{-2}, from which 88.9% belonged to the 0.7÷3.7 kJ·m^{-2} interval.
By applying the cos-squared spreading function (6), to the existing spectrum (7), the ***Black Sea 2D spectrum (MarNeRo)*** is obtained (Trusca, 2005):
where θ_0 mean wave direction is expressed in radians.

$$S_{MN}(\omega,\theta)=\begin{cases}2.202\left(\frac{\overline{E}}{\varpi}\right)\cdot\left(\frac{\varpi}{\omega}\right)^{6.9285}\exp\left[-0.3883\left(\frac{\varpi}{\omega}\right)5.9285\right]\cdot\frac{2}{\pi}\cos^2(\theta-\theta_0), for\left(-\frac{\pi}{2}+\theta_0\right)<\theta<\left(\frac{\pi}{2}+\theta_0\right) \\ 0, otherwise\end{cases}$$

(kj·m^{-2}s) (8)

3. TURNING THE BLACK SEA SPECTRUM INTO A TWO-DIMENSIONAL ONE

The Black Sea one-dimensional spectrum for Lebada region, situated offshore the Romanian coast, was elaborated by Bondar (1989), using the following relation :

$$S\eta(\omega) = 2.202\cdot\left(\frac{\overline{E}}{\varpi}\right)\cdot\left(\frac{\varpi}{\omega}\right)^{6.9285} \exp\left[-0.3883\cdot\left(\frac{\varpi}{\omega}\right)^{5.9285}\right] \quad (7)$$

Knowing that : $\overline{E}=\frac{\rho g\overline{H}}{8}=\frac{\rho g H_s^2}{16}=\frac{E}{2}$ (9)

where: H_s– represents the significant wave height (m);

E – specific energy of wave field, by considering H_s (kJ·m^{-2});
Simplifying, the ***2D Black Sea wave spectrum*** becomes :

In order to be introduced within the numerical model SWAN, the wave energy (variance) will be expressed in m^2, instead of energy density in kJ·m^{-2}, so that by dividing by:

$\rho g \approx 10000$ kg $m^{-2} \cdot s^{-2}$, the coefficient 1.101 will become 0.1101 because:

$$1 \cdot \left[\frac{kJ}{m^2}\right] = 1000 \cdot \left[\frac{N \cdot m}{m^2}\right] = 1000 \cdot \left[\frac{kg \cdot m \cdot m}{m^{2 \cdot s^2}}\right] = 1000 \cdot \left[\frac{kg}{s^2}\right] \qquad (11)$$

and θ_0 mean wave direction will be expressed in nautical degrees.

4. BUILDING THE 2D BLACK SEA WAVE SPECTRUM

Trusca (2005) developed a software to calculate the two-dimensional Black Sea wave spectrum. The required input data are: offshore significant wave heights, their periods and clockwise directions (covering up to one month) as they are communicated at 6-hour intervals from the Gloria Meteorological Station.

For every discrete time, the spectral matrix was built by considering on its columns the 30 logarithmic discretizated frequencies from the lowest to the highest of them (as in table 1) for the user-imposed 0.0566÷1 s^{-1} interval .

On the spectral matrix (as in table 2), in which the frequencies run from top to bottom and directions from left to right, respectively, the non-null values corresponding to wave energy are only indicated on their mean propagation direction and in addition to the adjacent ones up to ±85° – according to the Smith formula (CHETN-I-64, 2001), by considering: n=36 the number of discretization directions .

$$S_{MN}(\omega,\theta) = \begin{cases} 1.101\left(\frac{E}{\varpi}\right) \cdot \left(\frac{\varpi}{\omega}\right)^{6.9285} \exp\left[-0.3883\left(\frac{\varpi}{\omega}\right)5.9285\right] \cdot \frac{2}{\pi}\cos^2(\theta-\theta_0), for\left(-\frac{\pi}{2}+\theta_0\right) < \theta < \left(\frac{\pi}{2}+\theta_0\right) \\ 0, otherwise \end{cases}$$

$$(kj \cdot m^{-2} s) \qquad (10)$$

In order to be introduced into the SWAN model (Booij, 2004), the directly obtained spectral matrix values must be factorized so that the value 9901 corresponds to energy peak and the other elements become proportionally related to this maxim by the integer values within the [0, 9901) interval.

The matrix columns which contain exclusively noughts symbolize wave energy absence behind their advancing front, namely outside the above-mentioned directions.

The null values from the rows are disposed absolutely outside the spectrum frequencies , thus a more or less energetic spectrum will be emphasized according to the null allocation on the upper or lower matrix rows, a more energetic spectrum occupying the first spectral matrix rows.

For the initial SWAN grid boundaries, the obtained matrix constitutes input data, this time defined by spectral conditions instead of the offshore wave parametrical ones such as wave heights, wave periods or directional spreading.

Table 1. The spectral matrix frequency discretization in 30 logarithmic intervals

Frequency (s^{-1})										
f1÷f10	0,0566	0,0625	0,0690	0,0762	0,0841	0,0929	0,1025	0,1132	0,1250	0,1380
f11÷f20	0,1524	0,1682	0,1857	0,2051	0,2264	0,2500	0,2760	0,3047	0,3365	0,3715
f21÷f30	0,4102	0,4528	0,5000	0,5520	0,6095	0,6729	0,7430	0,8203	0,9057	1,0000

4.1. Verifying the *MarNeRo* spectrum

In a SWAN output subroutine, *Hs* (input) with the significant wave heights from offshore boundaries, is always displayed. After SWAN is run using the MarNeRo spectrum, the output value of significant wave height (11.00 m in our case) was equal to the one used in formula 10 to generate the spectrum shown in table 2, which really shows that the methodology is correct.

For the exemplified case of a representative storm, on 23.01.2004, 6:00 UTC (figure 1), the offshore significant wave height registered at the Gloria Weather Station (shown as maximal value on the left top side of the figure and also encircled) was of 11 m and wave period was 8.9 s. The ALADIN (Aire Limitée Adaptation Dynamique développement Inter-National) (Radnoti, 1995) wind field was provided by the National Meteorological Administration, Bucharest, Romania.

Table 2. MarNeRo spectral matrix (with frequencies on ordinate and directions on abscissa)

```
20040123.060000          time
1.761085E-04             factor

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    1    1    1    2    2    2    2    2    2    1    1    1    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  2   16   44   80  122  163  200  227  242  242  227  200  163  122   80   44  16   2
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 21  181  483  891 1353 1816 2223 2525 2686 2686 2525 2223 1816 1353  891  483 181  21
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 58  510 1360 2505 3907 5109 6254 7104 7556 7556 7104 6254 5109 3907 2505 1360 510  58
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 76  668 1782 3282 4988 6695 8195 9308 9901 9901 9308 8195 6695 4988 3282 1782 668  76
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 65  573 1527 2813 4275 5737 7023 7977 8485 8485 7977 7023 5737 4275 2813 1527 573  65
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 44  388 1033 1904 2893 3883 4753 5399 5742 5742 5399 4753 3883 2893 1904 1033 388  44
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 26  230  613 1130 1717 2304 2821 3204 3408 3408 3204 2821 2304 1717 1130  613 230  26
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 14  127  338  623  947 1271 1556 1768 1880 1880 1768 1556 1271  947  623  338 127  14
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  8   67  179  330  502  674  825  937  996  996  937  825  674  502  330  179  67   8
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  4   35   93  171  260  349  427  485  516  516  485  427  349  260  171   93  35   4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  2   18   48   88  133  178  218  248  264  264  248  218  178  133   88   48  18   2
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1    9   24   44   68   91  111  126  134  134  126  111   91   68   44   24   9   1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1    5   12   22   34   46   56   64   68   68   64   56   46   34   22   12   5   1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    2    6   11   17   23   28   32   34   34   32   28   23   17   11    6   2   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    1    3    6    9   12   14   16   17   17   16   14   12    9    6    3   1   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    1    2    3    4    6    7    8    9    9    8    7    6    4    3    2   1   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    1    1    2    3    4    4    4    4    4    4    3    2    1    1   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    1    1    1    2    2    2    2    2    2    1    1    1    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    1    1    1    1    1    1    1    1    1    1    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    1    1    1    1    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   0   0
```

The *MarNeRo* spectrum described by equation (10) reached a maximum value of 17.31 kJ·m^{-2} (1.74 m2 with the factor 1.74 / 9901=1.761·10^{-4}).

Due to refraction, as waves approach nearshore one could remark a spectral peak displacement from the initial direction of 0° towards values of nearly 90° (figure 2).

When SWAN program is run over a large area within the southern parts of the Romanian littoral – a marine area (figure 3) of 42x42 km^2 described by *168x105* meshes of *250 mx400 m* each, containing Gloria data as coupling boundary conditions for North, East and South – another spectrum, named *MarNeRo* (Romanian translation for – Romanian Black Sea), is obtained. It contains new boundary conditions for a succession of equidistant locations situated on the nested grid outline.

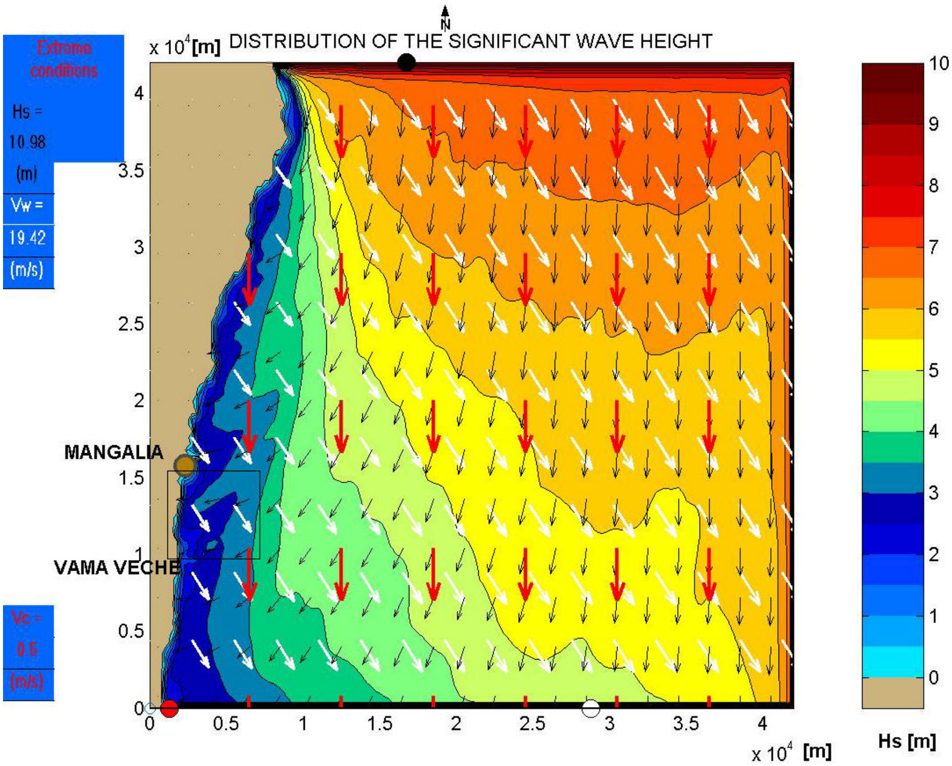

Figure 1. Field distribution Hs(m)-wave (black arrows), wind (white), current (red) on coarse grid on 23.01.2004, 6:00 UTC

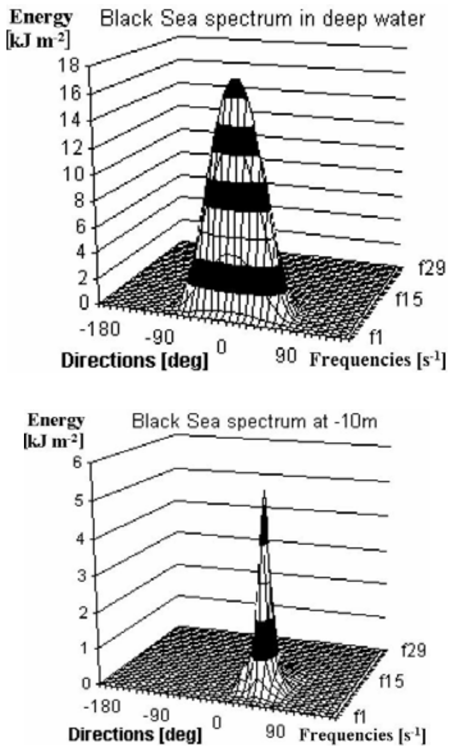

Figure 2. Deep and shallow water spectra in the Black Sea

Waves generated in the Western Black Sea basin do not dissipate almost at all their energy till they arrive at the Romanian offshore platform in less than 50 meters depth. This is the reason why the adopted offshore boundary of the

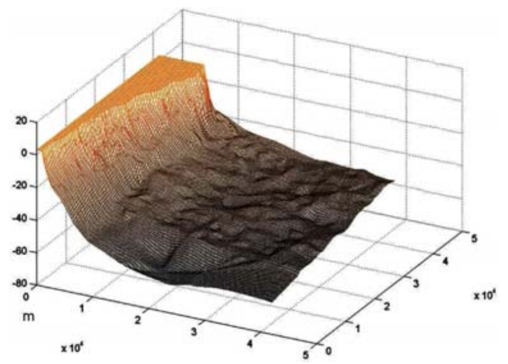

Figure 3. Bottom configuration – coarse resolution grid

extended area has greater values, up to 69 meters in the North. Considering the registered data from Gloria station as coupling boundary conditions for the extended south-eastern SWAN area, is a good choice since most of the year, the waves are coming from the north-east .

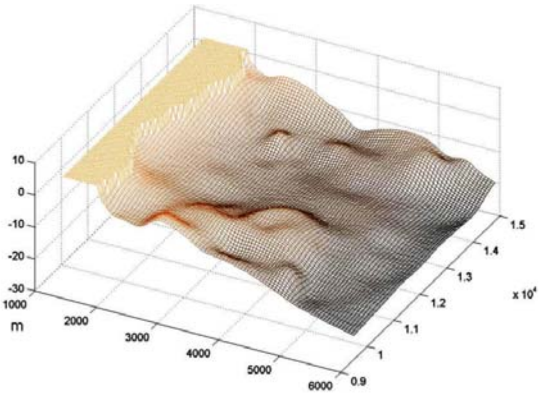

Figure 4. Bottom configuration – fine resolution grid

The obtained SWAN grid maps are based on the "Bathymetric Charts of the Black Sea" edited in 2002 by the Maritime Hydrographic Directorate Constanta.

The nested grid (figure 4) within the larger one (figure 1), is a high littoral area resolution of only 50 m in both directions, having 5x5 km^2, which contains the towns of Vama Veche and 2 Mai. Usually, the initially constant conditions of the extended area induce some errors concerning specially the North coupling boundary (from where the waves propagate), but due to the SWAN capabilities, the nesting procedure eliminates most of them since the un-constant coupling conditions of small areas – obtained after the first set of SWAN runs – replace the initially fixed ones.

Obviously, there are not spectral matrices for the inland points, energetic variance density being null for these geographical locations. By utilizing the justly obtained spectrum instead of theoretical spectra such as JONSWAP or Pierson-Moskowitz (1964), the SWAN has been improved, being therefore better adapted to the specific Black Sea conditions .

Choosing from the new spectrum a coastal location placed at 10 m depth, a significant decrease in spectral peak is noticeable; passing on shallow waters to near 5.41 m peak decrease in relation to the initial offshore conditions will be less than 25 times.

To validate the results of *MarNeRo* spectrum, simulated runs for an entire month (January 2004) were carried out . They were compared with the default theoretical SWAN spectra: JONSWAP and PM (Pierson-Moskowitz) obtained from parametrical boundary conditions. Choosing SWAN linear interpolation , the transformed coastal wave parameters were obtained every 3 hours instead of 6-hour intervals for input data. The January 2004 Gloria wind data could be considered representative for the entire analyzed area because: "In conditions of strong winds (with speeds greater than 10 m/s), due to the relatively small area of the Romanian shore, wind speed and direction fields are almost the same across the entire littoral" (Bondar, 1973). In addition, during the 21-24.01.2004 storm , it was also used the ALADIN-forecasted 10 m wind speed as forcing model across the entire southern part of the Romanian littoral as well as across the nested area. Usually, wave statistics (Rusu, 2003) was computed in order to evaluate the SWAN performances such as: mean values – for significant wave heights and periods, bias and RMSE (root-mean-square-error).

A comparison (figures 5 and 6) between results of nested SWAN runs and in situ data from Mangalia provided by the National Institute for Marine Research & Development "Grigore Antipa" reveals slightly better results from using the Black Sea two-dimensional spectrum (see tables 3 and 4). Thus, a reduced overestimation of significant wave heights is achieved as against those described by JONSWAP and Pierson-Moskowitz spectra.

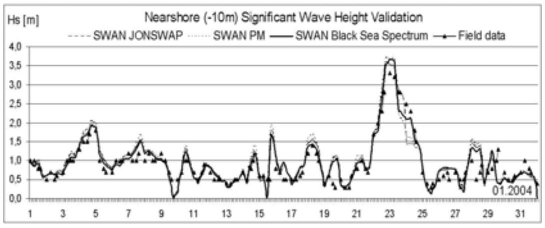

Figure 5. Validation of significant near-shore wave heights: 1÷31.01.2004

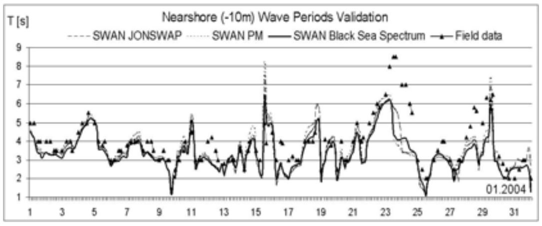

Figure 6. Validation of near-shore wave periods: 1÷31.01.2004

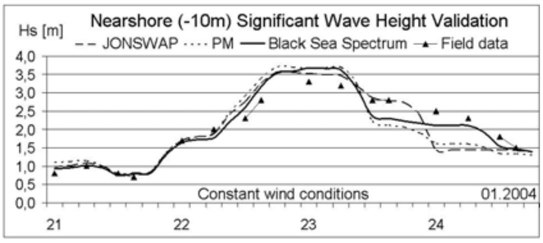

Figure 7. Validation of significant near-shore wave heights during storms in the Black Sea: 21÷24.01.2004, when the wind is considered to be constant

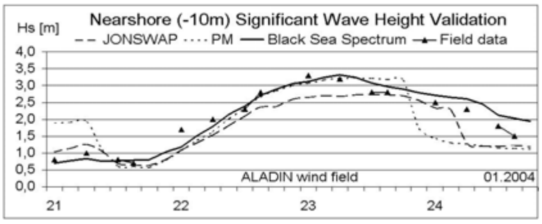

Figure 8. Validation of significant near-shore wave heights during Black Sea storms: 21÷24.01.2004, using the ALADIN wind field

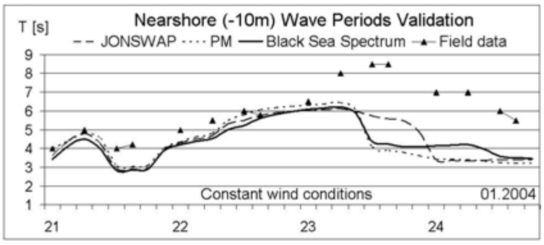

Figure 9. Validation of near-shore wave periods during Black Sea storms : 21÷24.01.2004, when the wind is considered to be constant

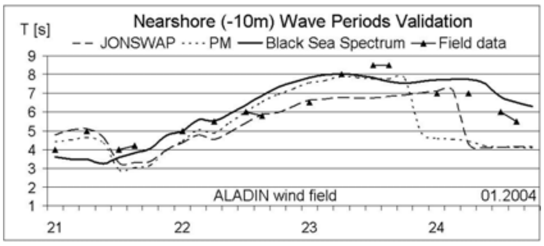

Figure 10. Validation of near-shore wave periods during Black Sea storms: 21÷24.01.2004, using the ALADIN wind field

As it can be noticed in figures 7, 8, 9 and 10 of accurate nested cases, during

Table 3. Hs statistics : 2004/01/01/h00÷2004/02/01/h00

Source data	Hsmed m	Bias m	RMSE m
SWAN JONSWAP	0,972	-0,035	0,277
SWAN PM	0,996	-0,057	0,307
SWAN MarNeRo	0,963	-0,025	0,245
Field data	0,923	–	–

Table 4. Wave period statistics : 2004/01/01/h00÷2004/02/01/h00

Source data	Tmed s	Bias s	RMSE s
SWAN JONSWAP	3,450	0,510	0,983
SWAN PM	3,535	0,414	1,066
SWAN MarNeRo	3,377	0,578	0,990
Field data	3,947	–	–

storms , considering the ALADIN wind field instead of the Gloria constant wind leads to more accurate simulation results. In this way, maximum storm intensity is not overestimated and its decrease is gradual when using *MarNeRo* spectrum instead of the other theoretical spectra.

5. CONCLUSIONS

Starting from the one-dimensional spectrum of the Black Sea established by Bondar (1989), the present paper describes its turning into a two-dimensional one which shows better the frequencies and energetic directions covering the Black Sea waves.

For the Romanian littoral, using the two-dimensional *MarNeRo* spectrum for numerical wave models – like SWAN – instead of theoretical ones such as JONSWAP or Pierson–Moskowitz, leads to an increase in the accuracy of results when considering the wave characteristics for the analyzed area.

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