Scientific report

concerning the implementation of the project

Data Assimilation Methods for Improving the Wave Predictions in the Romanian Nearshore of the Black Sea - DAMWAVE (PN-II-ID-PCE-2012-4-0089)

in the period September – December 2013

The objectives of this stage are:

1. Prediction of the wave climate in the basin of the Black Sea by performing simulations with the wave modelling system for a 10-year period.
2. Comparison of the data provided by the numerical wave model with satellite data for a 10-year period and analysis of the systematic errors.

Introduction

The climatology data on the medium and long term concerning the sea states present a high importance from both scientific point of view as also for a large range of marine practical applications. The climatology studies can be accomplished on the basis of the in situ measurements, which are usually limited to a few locations, or on the bases of the simulations with numerical wave models that provide information on large geographical spaces. In order for the numerical wave predictions to become more reliable, the wave models are first calibrated and further on validations are also performed. Even in such conditions, several errors may occur as well as results with a reduced accuracy. This especially concerns the extreme events which are usually more difficult to be modelled and predicted. A viable solution to improve the estimations of the sea states is the application of data assimilation (DA) techniques through which the wave model results are combined with measurements (either *in situ* and/or satellites). More recently, the increasing availability and on extended areas of the satellite date, which are more and more accurate, encouraged the studies concerning including of the DA schemes both in the operational wave models and in the hindcast databases.

As regards the Black Sea basin, little information is available in the public domain concerning the medium and long term characteristics of the sea states. Moreover, up to the present only limited validations of the wave model simulations are available (only of the order of some months). These are in general based on some in situ buoy measurements and no DA technique is considered. From this perspective, the main objective at this stage of the project is to perform numerical simulations with the wave prediction model for a 10-year period and to verify the accuracy of the wave predictions against satellite data. The results of the above numerical simulations were used to perform climatology analysis and will be further considered for implementation of some DA schemes.

The wave prediction in the Black Sea basin

In order to reach this objective, simulations with the SWAN (Simulating Waves Nearshore) spectral phase averaged model have been performed for a period of 10 years, which is closer to the present day. Considering the main characteristics specific to the wave climate of the Black Sea, in order to force the wave model wind fields with an increased resolution in space and time are necessary. Wind data to satisfy such request are available on the web page NCEP-CFSR (United States National Centers for Environmental Prediction, Climate Forecast System Reanalysis) http://rda.ucar.edu/datasets/ds093.1/. The above wind fields considered cover a 10-year period (1999-2008) and are related to the entire Black Sea basin, but also the basin of the Caspian Sea. The data are available in NetCDF format (Network Common Data Form), but in order to generate the wind data file, used as input for SWAN, it was necessary to convert this data into ASCII format (American Standard Code for Information Interchange). The spatial resolution is 0,312ºx0,312º while the temporal resolution is of 3 hours. The above information already processed is kept in the data base of the DAMWAVE project, both in numerical form and in images. Some examples are presented in Figure 1, which illustrates the wind field over the basin of the Black Sea for an extreme situation that corresponds to the time frame from January 2004 (Figure 1- left side) and a case with medium wind intensities, corresponding to

a situation encountered in march 2004 (Figure 1- right side). In order to enlarge the database concerning the wind characteristics, data from various meteorological stations have been also obtained.

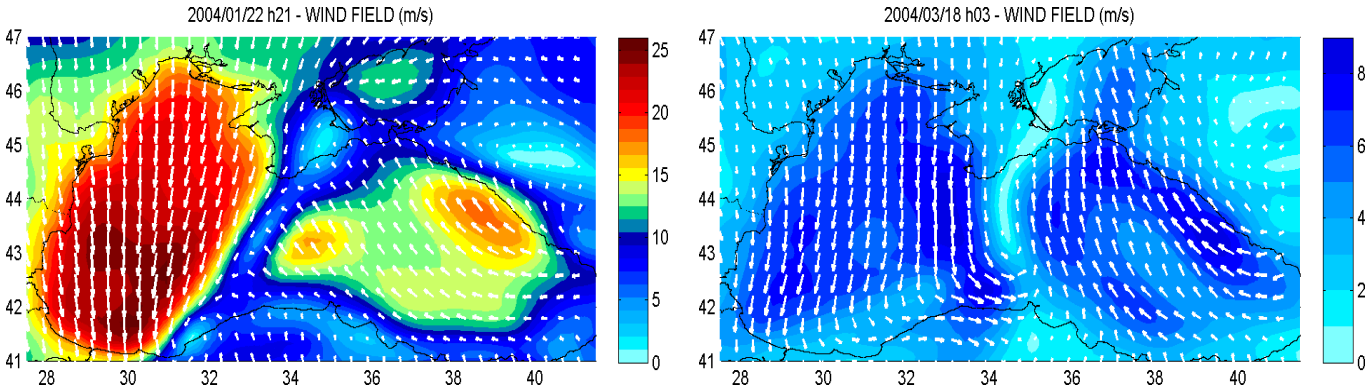

Figure 1 Wind fields corresponding to an extreme (a) and average situation (b) for the time frames 2004/01/22-h21 and 2004/03/18-h03, respectively.

A calibration of the wave modeling system has been first performed. This covered a 3-month period at the beginning of 1999 considering in situ measurements coming form Gloria drilling unit and the directional buoys Gelendzhik and Hopa. Satellite data have also been considered in this step.

Two different computational levels have been defined (**1-Global,** covering the entire basin of the Black Sea and **2-Costal,** covering the Romanian nearshore). The characteristics of these two domains are presented in Table 1. Other domains with higher resolution will be further implemented considering the ´*nesting*' procedure. After finishing the calibration process, considering the wind fields that were processed, numerical simulations with the SWAN model have been carried out for the first computational level (Global) covering the entire 10-year period (1999-2008). In all the grid points, the values of the following wave parameters have been generated: significant wave height (*Hs*), mean period (*Tm*), peak period (T_p), mean wave direction (*Dir*), wave energy (*Etr*) and direction of the wave energy transport (*Dtr*).

Table 1 Characteristics of the two SWAN computational levels

Level	Δx × Δy	Δt (min)	Nr frequencies	Nr directions	ngx × ngy = np	Origin (long/lat)
1-Global	0,08º × 0,08º	10 (non-stat)	30	36	176 × 76 = 13376	27,5 E / 41,0 N
2-Coastal	0,02º × 0,02º	10 ((non-stat)	30	36	101 × 101 = 10201	28,5 E / 43,5 N

In this way a database has been generated considering the results of the numerical simulations for the entire time interval considered. This contains reliable information concerning the main wave parameters in the Black Sea basin. This information is kept in binary format (format Matlab) and contain the values of the above wave parameters with a 3-hour resolution. For the significant wave heights images have also been generated. On this basis the average climatology values have been estimated for the entire Black Sea basin, covering each year, each season, and monthly average values. The above results clearly indicate that the western side of the sea is in general more energetic. Some examples are presented in Figure 2, which illustrates the average *Hs* values for each season, total time and only for the month of January (which is usually more energetic) corresponding to the time interval 1999-2008. In the above analyses the winter time represents the period from October to March, while the summer time is the rest.

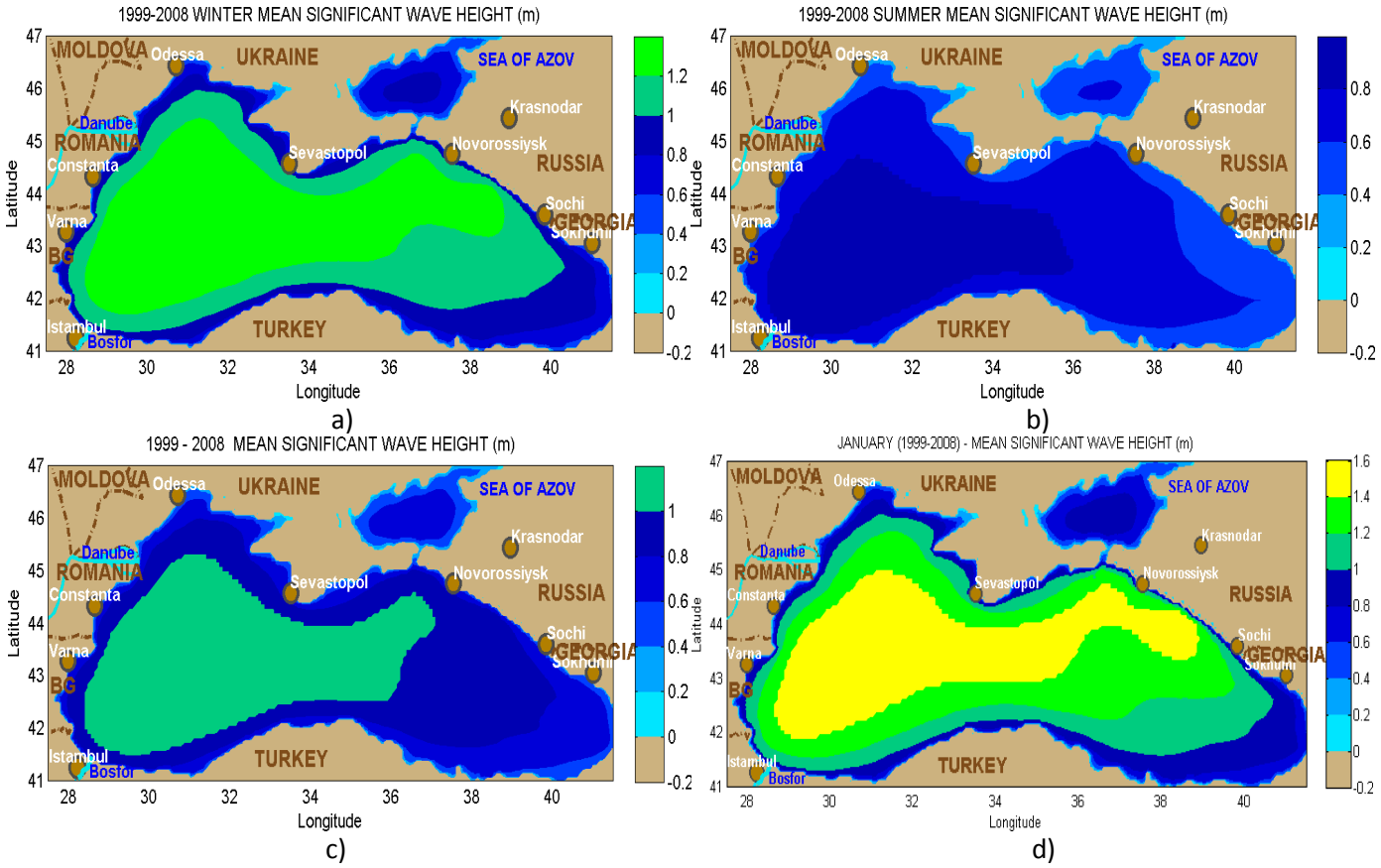

Figure 2 Significant wave height fields, average values for the interval (1999-2008) SWAN simulations for: a) winter time, b) summer time, c) total time, d) January months.

Comparison of the wave predictions with the satellite data and analysis of the systematic errors

The positive contribution of the satellite data in the validation of the numerical wave models was clearly established by several wave prediction centers that operate with global wave models and accomplish in these days of large scale such validations. Such data allow also an evaluation of the wave predictions in the basin of the Black Sea.

In order to perform such comparison, satellite data from the several bases have been considered (in principal http://cersat.ifremer.fr/ and http://www.aviso.oceanobs.com) covering data for the 10-year time interval (1999-2008). These are related to the *multi-mission* that contains measurements coming from more satellites: ERS-2, ENVISAT, TOPEX, Poseidon, JASON-1, JASON-2, GEOSAT Follow-On (GFO). In parallel with the significant wave height, the values of the wind velocities and the trajectories of the satellites over the Black Sea basin have been kept. In this way a consistent database has been generated for the period (1999-2008) as regards the wave and wind measurements.

The evaluation of the SWAN results against the satellite data presents the advantage that offers a much larger perspective than the comparisons performed against in situ measurements. In order to perform these comparisons interpolations in time and space have been performed in order to fit with the altimetric data. In this way the spatio-temporal correspondence between the SWAN simulations and the altimeter data has been accomplished.

The main statistical parameters computed are the mean measured and simulated values of the significant wave height, bias, mean absolute error, RMS error, scatter index (*SI*), correlation coefficient (*R*) and the regression slope (*S*). These statistical parameters were evaluated on several levels and categories, as annual, seasonal, monthly values, for each satellite separately and for all together. Also, for all comparisons scatter diagrams have been also designed.

The above mentioned statistical results are presented in Table 2 (*N* represents the number of data points considered). For each altimeter the period considered in the 10-year interval (1999-2008) it was also specified.

Table 2 *Hs* statistical results (separately for each altimeter and also for all together), SWAN simulations against satellite data for the entire Black Sea basin, covering the 10-year time interval (1999-2008).

Satellite / Time period	*MeanObs* (m)	*MeanSim* (m)	*Bias* (m)	*MAE* (m)	*RMSE*	*SI*	*R*	*S*	*N*
ERS-2 (10-year)	0,98	0,95	-0,03	0,32	0,43	0,44	0,82	1,00	190341
ENVISAT (from 14-05-2002)	1,12	1,08	-0,04	0,27	0,37	0,33	0,88	1,00	101660
TOPEX (until 08-10-2005)	0,93	0,94	0,01	0,24	0,34	0,37	0,88	1,03	142337
Poseidon (untill 08-10-2005)	0,88	0,92	0,04	0,29	0,39	0,44	0,78	1,01	3840
Jason-1 (from15-01-2002)	1,13	1,10	-0,03	0,28	0,38	0,34	0,87	1,02	132266
GFO (07-01-2000 - 07-09-2008)	1,22	1,23	0,01	0,27	0,39	0,32	0,87	1,04	112297
Jason-2 (from 04-07-2008)	1,08	0,97	-0,11	0,28	0,37	0,34	0,87	0,94	9472
All satellites	1,06	1,04	-0,02	0,28	0,39	0,37	0,86	1,02	**692213**

Table 2 shows that the number of data points is relatively large (*N* = 692213), a fact that offers an increased reliability of the results. In general the above results show that it exists a good correlation between simulations and measurements (*R* greater that 0,85), a bias in general smaller than 0.05m and *S* with values close to 1. The *SI* are not very small, but this is in line with the results of the studies performed in some other enclosed seas as the Mediteranean and the Adriatic seas. The scatter diagrams are presented in Figure 3.

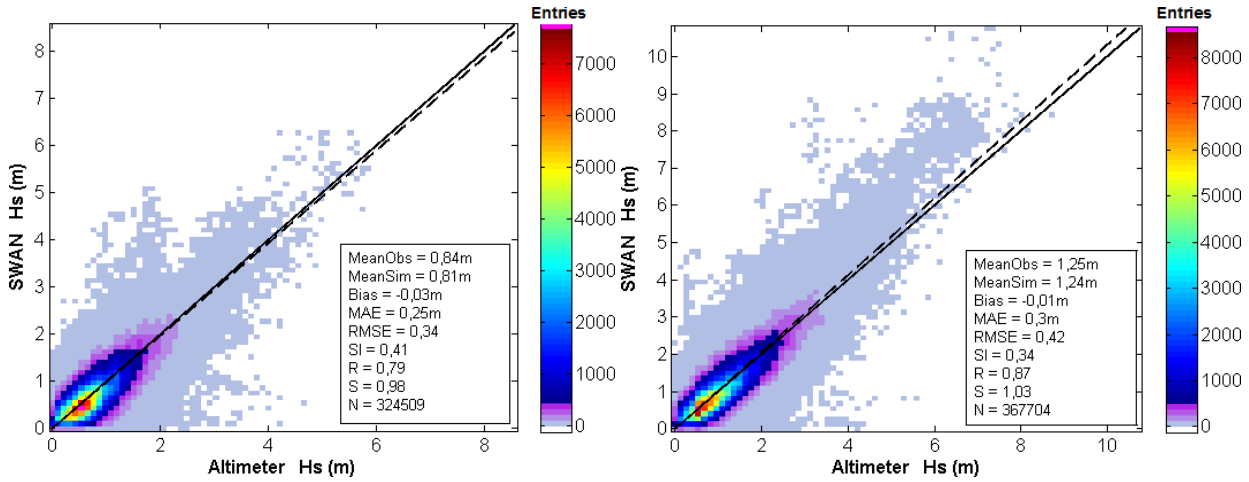

Figure 3 Scatter diagrams for summer time (left) and winter time (right) corresponding to the time interval 1999-2008.

From the analysis of the SWAN results in the entire basin of the Black Sea for the period 1999-2008 and correlating these analyses with the satellite data some specific situations have been considered for both average energy situations and for the extreme storms. Figure 4 illustrates two average to high energy situations (corresponding to the time frames 2001/08/02-h21 şi 2002/01/21-h21) and two storm situations (2001/12/09-h06 şi 2001/12/30-h12).

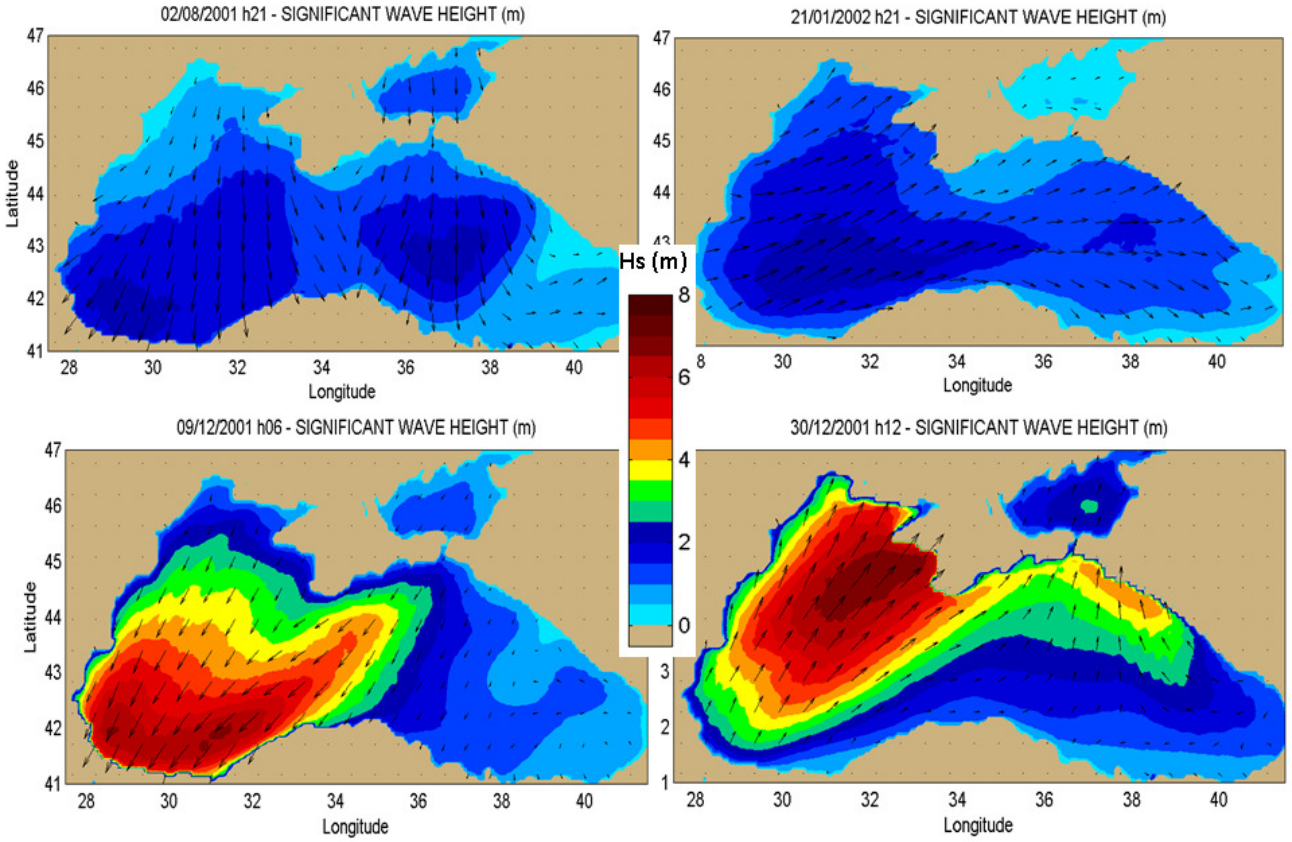

Figure 4 Significant wave height scalar fields and wave vectors, SWAN simulations for average to high wave conditions and also for storm conditions.

In order to perform comparisons with some other enclosed seas, which are very similar to the Black Sea, an analysis has also been carried out for the Caspian Sea basin. This covers the time interval 2005-2010. An example is presented in Figure 5, where an average to the high energy situation is illustrated in Figure 5a while a storm situation is illustrated in Figure 5b. As illustrated by the results, the conditions in the two enclosed seas are rather similar but as regards the storm conditions these are stronger in the Black Sea.

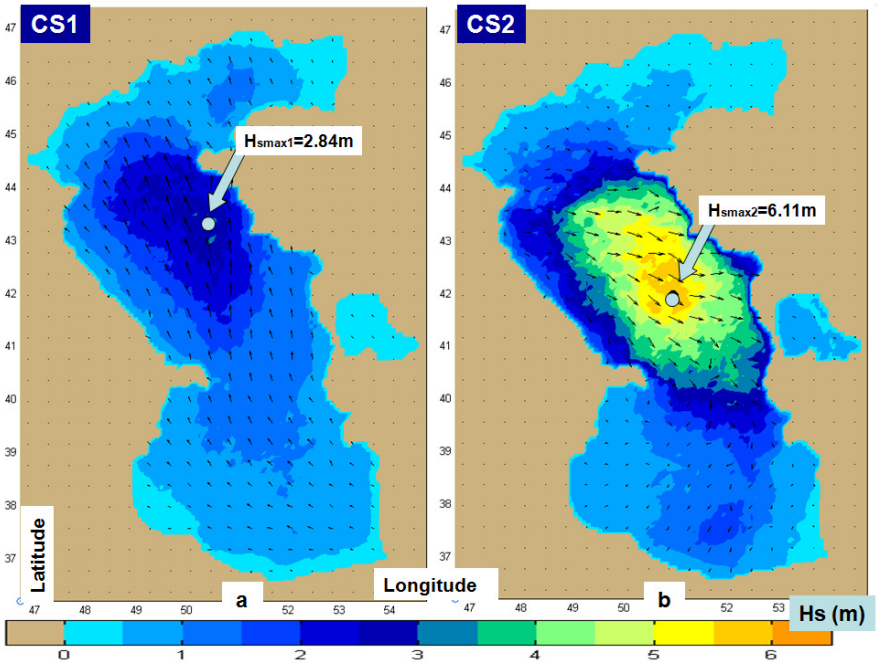

Figure 5 Wave climate in the Caspian Sea, significant wave height scalar fields and wave vectors, SWAN simulations (results published in Rusu & Onea 2013), CS1 – average to high wave conditions (corresponding to the time frame 2009/10/02/h18), b) CS2 – storm conditions (corresponding to the time frame 2009/11/27/h03).

Concluding remarks

We can conclude that we succeeded to achieve all the objectives proposed for this stage. The database concerning the wave and wind parameters covering the entire basin of the Black Sea with a resolution of 0.08° in both longitude and latitude and a spatial resolution of 3 hours has been made. Based on these data a climatology analysis has been carried out covering various time periods. On the other hand, this database represents the starting point for the next stages of the DAMWAVE project with the target of implementing DA schemes in order to improve the wave predictions based on the numerical wave models in the entire basin of the Black Sea as well as in the high resolution computational domains.

Dissemination of the results

Some of the results have been disseminated by publication of 2 papers in international journals, one of them in the prestigious journal *Energy* with ISI index (IF=3.651), and the second in *International Journal of Geosciences* indexed in international databases. Also, oral presentations have been performed in International Conferences as follows:

- International Conference Danube - Black Sea 3E - Energy, Environment & Efficiency (IWEEE2013), Interdisciplinary Researches in the Danube and Black Sea areas, Galati 18-21 September 2013 www.iweee.ugal.ro/documente/Program_final.pdf - oral presentation (invited conference) and other 8 papers published in the conference volume edited in ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI MATHEMATICS, PHYSICS, THEORETICAL MECHANICS FASCICLE II, YEAR V(XXXVI) 2013, No. 2 (B+), ISSN 2067-2071.
- The 4th Black Sea Scientific Conference, 'Black Sea - Challenges Towards Good Environmental Status', the papers being presented in: Symposium "Protection and sustainable management of the Black Sea ecosystem, third millennium imperative" Sixth Edition, and Workshop "Sustainable development and energy use in the Black Sea", 29 – 31 Octombrie, Constanța, Romania - 2 oral presentations and a poster. http://www.blacksea-commission.org/Downloads/BS-GES-2013-Conference_Program_18.10.pdf .

Also the paper "Analysis of the extreme storm events in the Black Sea considering the results of a five-year wave hindcast", authors Liliana Rusu, Dorin Butunoiu, Eugen Rusu, has been accepted to the International Conference AQUALIRES2014 http://www.incdpm.ro/en/news/events/222-aqualires-2014-en

Finally, it can be also mentioned that the web page of the DAMWAVE project has been designed in advance (this was previewed to be made at the beginning of 2014) http://www.im.ugal.ro/DAMWAVE/index.htm

Budget 2013: 85.100 lei

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