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

in the period January – December 2014

In the second stage of the project implementation carried out in the period above mentioned, the specific objectives of the project were pursued:

1. Implementation of a data assimilation scheme (DA-Data Assimilation) based on sequential or variational methods for hindcast simulations.
2. Validation of the results obtained by applying the DA methodology for hindcast, the period 1999-2008.
3. Results dissemination.

1. Implementation of a data assimilation scheme (DA-Data Assimilation) based on sequential or variational methods for hindcast simulations.

1.1. Analysis of the main DA schemes applied in wave prediction systems.

In the first stage, in order to implement the most appropriate data assimilation schemes in the wave predictions with spectral numerical models, an exhaustive analysis of the main DA schemes currently applied in the wave predictions, was made. Some important aspects on the results of this analysis are summarized in this section.

As it is known, the main purpose of the data assimilation is to reduce the systematic errors that occur in the predicted results provided directly by the numerical models, taking advantage of the existing measurements availability in the area of interest. The basic philosophy of the data assimilation is to combine the complementary information from measurements and the results of the numerical models into an optimal estimate of the geophysical fields of interest (Kalnay, 2003; Reichle, 2008). In doing so, data assimilation systems use the observations and provide complete estimates at the scales required by the application – both in time and in the geographical space. The optimal combination of the measurements with the model information takes into consideration of the uncertainties that come with the observations and the model estimates. Whenever and wherever highly accurate remote sensing data are available, the assimilation estimates will be close to these observations. All data assimilation methods share the basic principle of merging models and observations, but the sophistication of merging algorithm varies widely from one to another data assimilation technique. Important differences also remain between the specific methods that are most suitable for a given application.

The assimilation of wave data is usually performed in terms of significant wave height (H_s), measurement of this wave parameter is available locally (generally come from buoys) and widespread (altimeter data). Assimilation techniques for the wave predictions are commonly classified in two categories: sequential methods and variational methods.

The sequential methods combine all the observations falling within a particular time window and update the model solution without reference to the model dynamics. The most widely adopted DA schemes are based either on instantaneous sequential procedures, like Optimal Interpolation (OI) (e.g. Daley, 1991; Lionello et al., 1992; Abdalla et al, 2005), or successive correction method (SCM) (e.g. Thomas, 1988). These methods are attractive, especially due to their lower computational demands, DA schemes based on OI being the most used in the major centers for wave forecasting.

Other DA schemes are based on the application of the Kalman filter, this method is multi-level in time. The problem of implementing these techniques arises from the dimension of the error covariance matrix and for this reason some simplifications are necessary (see Voorrips, 1999). Recently, techniques that combine the Kalman filters and techniques for improving the accuracy of the DA simulations of the wave models were tested (Emmanouil et al., 2012). Specifically, systematic deviations of the wave model results are minimized by using Kalman filtering algorithms in areas with continuous observations. Then, the improved results are assimilated during the period of the wave model predictions using OI schemes to expand the impact of assimilation in time and space. It should however be noted that the proposed methodology can be applied successfully only when continuous time series of the measured data exist (e.g. buoy data), which is quite difficult.

Advanced methods based on variational schemes can take also into account the history of the observations under the constraints of the wave model dynamics. Nevertheless, the high computational demands of these methods have slowed down the speed of their development in the field of the wave forecasting. A comparative study with an OI based method has been carried out by Voorrips and de Valk (1997) for the sea states dominated by wind-sea waves (sch sea sate conditions are typical in the Black Sea), but no advantage was found for the variational methods. The results obtained after DA are then translated into the corresponding distribution in the spectral domain (Lionello et al., 1992; Greenslade, 2001; Emmanouil et al., 2007).

Nowadays, most of the weather prediction centers with wave modelling capabilities are assimilating altimeter measurements, respectively H_s, using assimilation procedures based on the OI or SCM techniques. At the seminar *Use of Satellite Observations in Numerical Weather Prediction* http://www.ecmwf.int/en/seminar-2014-use-satellite-observations-numerical-weather-prediction organized in September 2014 by one of the most important centers of global weather prediction, respectively European Centre for Medium-Range Weather Forecasts (ECMWF), discussions were held on data assimilation in wave models, both in this center and other centers for weather prediction (it is worth mentioning that two members of the research team of DAMWAVE project participated at this seminar). The most effective DA method (considering the calculation time vs. the accuracy of the results) for H_s still seems to be the OI method. Some relevant information on how the OI method is applied to the ECMWF can be found in the presentation *Active techniques for wind and wave observations: scatterometer, altimeter, SAR* (for waves starting with the slide 39) http://www.ecmwf.int/sites/default/files/AS-presentation_DeChiara_Abdalla.pdf.

1.2. Identification and implementation of a DA methodology in which a balance between the numerical accuracy of the results and the computation time exists.

1.2.1 A DA methodology to improve the local predictions in the Romanian coastal zone

Since the main objective of the project is to improve the wave predictions in the Romanian economic zone of the Black Sea, the first part of the research conducted in the framework of the DAMWAVE project was focused on improving the local wave predictions in the Romanian coastal zone. This was accomplished by assimilating in situ wave data measured at the Gloria drilling platform. The local data assimilation was performed at two different levels: assimilation in the time domain and assimilation in geographical space (which was subsequently transferred in the spectral space).

- DA scheme in time domain

The DA scheme adopted in this work is based on a successive correction algorithm. For every day ***d***, the predictions produced by the wave model at the location of the Gloria Platform are corrected in relationship with the measurements recorded in the same place with a time resolution of 6 hours, in terms of significant wave height and mean period. Using the ensemble of the measurements and the corresponding predictions produced in the previous **d-n** days (denoted training period), the goal was to find the parameter values (the least-squares intercept, β_0, and the slope, β_1) for a linear regression which best fits the data set. These parameters were then used to correct the predictions produced at day *d*, which represents the assimilation period. The regression parameters are estimated by using the Ordinary Least-Square method and they are obtained with the following relationships:

$$\beta_1^d = \frac{\sum_{i=1}^{k}(m_i - \overline{m})(p_i - \overline{p})}{\sum_{i=1}^{k}(m_i - \overline{m})^2} \quad \text{și} \quad \beta_0^d = \overline{p} - \beta_1^d \overline{m}, \tag{1}$$

where the superscript *d* indicates the day when the DA is applied, *p* represents the wave parameter (H_s or T_m) predicted by the wave model, *m* is the measured wave parameter (H_s or T_m), $\overline{m}$ and $\overline{p}$ denote the mean values of the variables *m* and *p*, while *k* represents the valid number of measurements performed in the training period considered. A schematic representation of the method application is illustrated in Figure 1 while the detailed theoretical background of this method is presented in Wilks (2006) or Soukissian și Kechris (2007). Thus, the corrected values p_a^d of the predicted wave parameters for the day *d* are given by the regression equation (2):

$$p_a^d = \beta_1^d p^d + \beta_0^d, \tag{2}$$

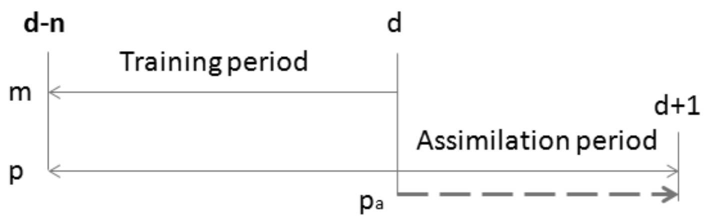


Figure 1. Graphical display of the time period considered for calculation and application of the linear regression parameters.

The results presented above were published in Rusu (2014). The DA scheme described was successfully implemented, allowing a substantial improvement of the wave predictions (the wave parameters considered were significant wave height and mean wave period) at the location of the Gloria platform. But, to improve the wave predictions with numerical spectral models, it is very important to implement in the Romanian coastal zone a DA scheme for the entire geographical area corresponding to the Romanian nearshore.

- DA spatial scheme

In order to propagate the corrections from the location of the Gloria drilling platform throughout the geographic area of the Romanian coastal zone, an original DA scheme has been developed and implemented based also on the successive corrections method. In this case, the geographical correction is followed by a correction in the spectral space in points located on the boundary of computational domain and then, the SWAN model simulations are completed. The DA procedure assumed to be implemented is also suggested in Figure 2 and considers the use of the in situ measurements performed at the Gloria drilling unit in order to correct the wave predictions in the coastal level computational domain.

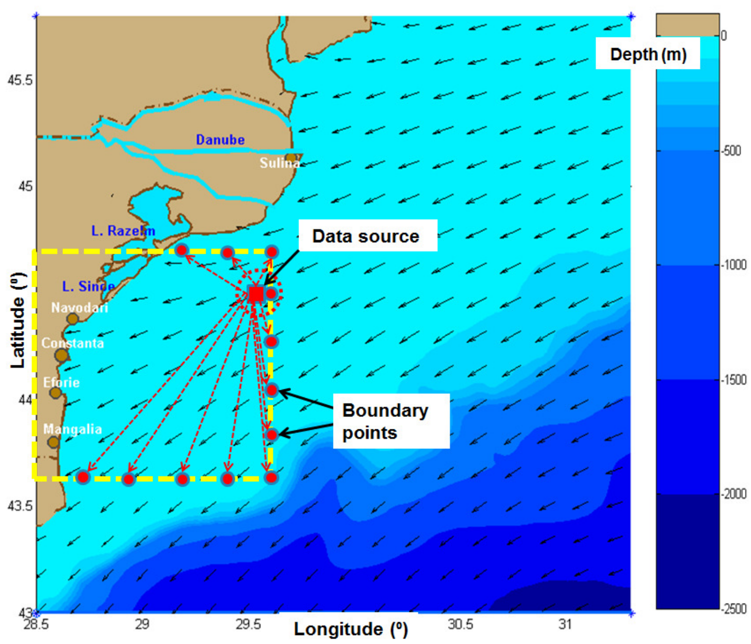


Figure 2. The computational domain (marked with yellow line) and the DA scheme considered for improving the wave predictions in the Romanian nearshore, in the background the bathymetric map is illustrated together with the most common pattern for the wave propagation.

The proposed method propagates the correction between the measurements at Gloria and the results of the SWAN simulations corresponding to the same location and time frame in the geographical space and particularly in the boundary points of the higher resolution computational domain that focuses on the Romanian harbors. Thus, in a point *B* (from the boundary) the assimilated value of the significant wave height corresponding to the simulation performed for the time frame *Tf* $\left(H_{sBTf}^{Assim}\right)$ is computed with the following relationship:

$$H_{sBTf}^{Assim} = H_{sBTf}^{Sim} + C_1(B,Tf)\left(\Delta H_{sGTf}\right), \tag{3}$$

H_{sBTf}^{Sim} represents the model predicted value of the significant wave height in the point *B*, ΔH_{sGTf} is computed as the difference between the measured and the simulated values of H_s at the buoy location and the correction $C_1(B,Tf)$ was defined as:

$$C_1(B,Tf) = \frac{H_{sBTf}^{Sim}}{H_{sGTf}^{Sim}}. \tag{4}$$

After performing the H_s corrections in the points *B* that control the variable boundary conditions of the coastal level domain, the next step is to transfer this correction in the spectral space. Further information on the implementation of this method in the Romanian coastal zone are provided in Butunoiu and Rusu (2014).

As a further step is expected the coupling of the two schemes, which would allow the development of a complete wave prediction system focused on the Romanian coast.

1.2.2 DA Methodology for the entire Black Sea basin

In addition to the improving of the local wave predictions, an important step is represented by the implementation of a DA scheme for the entire basin of the Black Sea based on satellite data, data that in recent years have a better resolution and accuracy.

Following the bibliographic study on the DA methodologies applied to perform wave predictions on large areas, and after the analyzing the advantages / disadvantages, it was decided to be applied in the Black Sea the algorithm based on OI techniques, formulated in the observational space, with the following definitions (Kalnay, 2003):

$$x_a = x_b + \mathbf{P}_b\mathbf{H}^T[\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}[y - H(x_b)] \tag{5}$$

where

y	Observation vector
x_b	Background vector
x_a	Analysis vector
H, **H**	Forward operator, Matrix
R	Observation Error Covariance
$\mathbf{P}_b$	Background Error Covariance
$y-H(x_b)$	Innovation vector
$y-H(x_a)$	Residual vector
$x_a - x_b$	Increment vector

The *Forward Operator H* is a method of converting a forecast model variable to an observed variable. In our case, the observations and predicted variables are the same (H_s), and *H* reduces to a spatial interpolation of the predictions to the observation locations. The analysis increment is equivalently defined by the relationship $\mathbf{P}_b\mathbf{H}^T[\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}[y - H(x_b)]$, where the quantity $\mathbf{P}_b\mathbf{H}^T[\mathbf{H}\mathbf{P}_b\mathbf{H}^T + \mathbf{R}]^{-1}$ is the weight matrix (also commonly called the Kalman gain matrix). Therefore, $\mathbf{H}\mathbf{P}_b\mathbf{H}^T$ is the background-error covariance between the observation locations, and $\mathbf{P}_b\mathbf{H}^T$ is the error covariance between observation and grid locations. The horizontal correlation computed with the relation $C_h = \exp(-s_h / L_{\max})$ where s_h is the horizontal distance between two locations (observations or observation and a grid point) and $L_{\max}$ is the correlation length of the prediction errors for H_s (Lionello et al., 1992).

Various studies (such as that achieved by Greenslade and Young, 2005) indicate that $L_{\max}$ at 45° latitude (Black Sea area is centered on this latitude) is around 400 km, which is about 4° degrees. First, this value was used, but since in the Black Sea, the wind-sea waves are predominant, it was considered necessary to be tested also lower values for $L_{\max}$ and to calculate the statistical results obtained after the DA application.

Improving the estimates of the sea state across the Black Sea by applying the DA methodologies is highly dependent on the number of the H_s data measured that are assimilated. For large areas the only available measurements are from satellites, which in the recent years have become increasingly more precise and representing a viable source for the use in the DA implementation.

The DA algorithm implemented in the Black Sea uses the database made in the first stage of the project. This contains information on the results of numerical simulations for a period of 10 years (1999-2008) about the H_s values simulated with the SWAN wave model (Simulating Waves Nearshore) on the entire Black Sea basin. Also, the H_s measurements are available from multiple satellites whose path crossed the Black Sea in the mentioned period, respectively ERS-2, ENVISAT, TOPEX, Poseidon, JASON-1, JASON-2, GEOSAT Follow-On (GFO).

The assimilation of the altimeter measurements is applied to a window of 24 hours (1 day), as shown schematically in Figure 3.

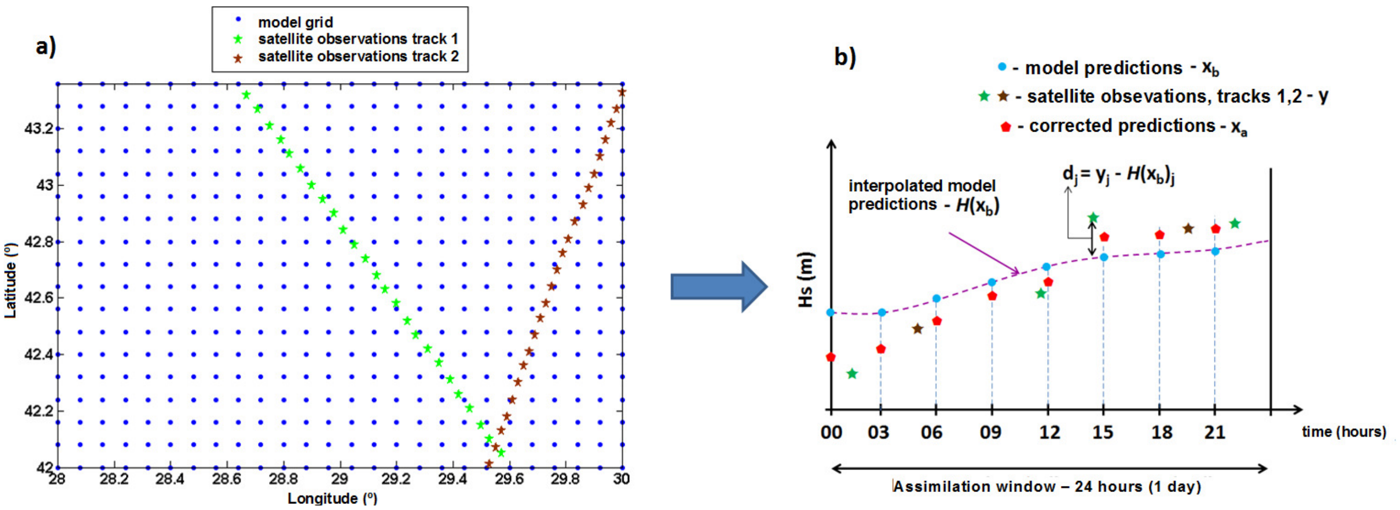


Figure 3. Schematic presentation of a computational domain for which wave model predictions exist in the grid points and the satellite tracks crossing the area in 24 hours (a); Calculation of the difference d_j between the observation y_j and the prediction interpolated to the observation position $H(x_b)_j$ made at the time of observation, considering the values of the observations recorded in the assimilation window (b).

2. Validation of the results obtained by applying the DA methodology for hindcast, the period 1999-2008.

Comparisons and statistical analysis to validate the DA methodology applied to the hindcast data obtained for the period 1999-2008 (numerical simulations for a period of 10 years).

The database achieved in the first stage of the project DAMWAVE implementation contains the values of H_s simulated by the SWAN model and covers a 10-year period. It should be noted that there are not available in the public domain buoy measurements in the Black Sea basin covering the entire period in several locations. The only source of measurements fulfilling both requirements (10 years of measurements and various locations in the area of interest) is the satellite observations from the multi-mission system, comprising measurements from seven satellites: ERS-2, ENVISAT, TOPEX, Poseidon, JASON-1, JASON-2 și GEOSAT Follow-On (GFO).

Thus, for a more efficient evaluation of the impact of the DA on the H_s predictions it was proceeded to divide the satellite data (a process similar to that used by Skandrani et al., 2004) trying as the percentage of treated data to be > 50% of the available observations (such as annual and entire period). This balance was possible to be accomplished using for validation the observations provided from ENVISAT and TOPEX, and for DA, the measurements from the other five satellites available in the period 1999-2008 were used. Information on the number of existing observations in the period under consideration are provided in Table 1.

Table 1. Information on the number of existing observations in the period under consideration, the number of observations used for assimilation and validation.

Year/Satellite	ERS-2	ENVISAT	TOPEX	Poseidon	JASON1	GFO	JASON2	Total	Assim	Valid	Assim/Total
1999	19393		17804	1601				38798	20994	17804	54,11%
2000	19293		19051	1362		11257		50963	31912	19051	62,62%
2001	19172		20244	560		15156		55132	34888	20244	63,28%
2002	19198	6040	19631	298	15889	13788		74844	49173	25671	65,70%
2003	11000	10183	21977		16615	11619		71394	39234	32160	54,95%
2004	12329	11650	18563		16980	11632		71154	40941	30213	57,54%
2005	17638	11069	15345		17243	14503		75798	49384	26414	65,15%
2006	17154	10783			15636	11163		54736	43953	10783	80,30%
2007	17322	18320			16790	7638		60070	41750	18320	69,50%
2008	18367	18634			16199	4937	9435	67572	48938	18634	72,42%
Total								**620461**	**401167**	**219294**	**64,66%**

The statistical parameters used to analyze the influence of the DA methodology on the quality prediction of H_s 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.

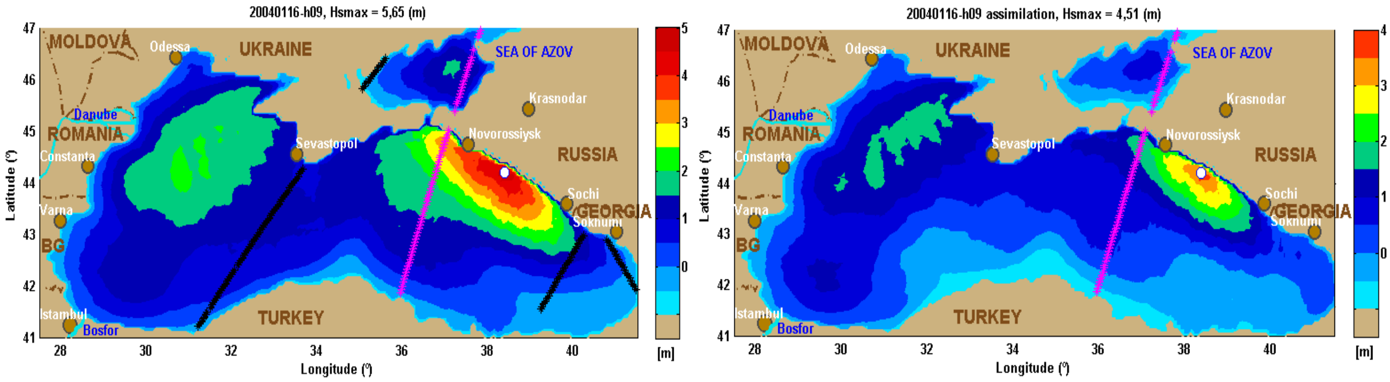
First, the statistical parameters corresponding to the comparison between the H_s simulated by SWAN (Hs-SWAN) and the altimeter measurements considered for validation (ENVISAT and Topex) were calculated. These statistical results are considered as reference to evaluate the influence of the DA on the quality of the predictions and they are presented in Table 2 (N is the number of pairs of data used in the statistical calculation). As stated above, other values were tested for L_{max} and in Table 2 statistical results obtained after applying the DA with L_{max} values of 4 ° (DA1) and 3.2 ° (DA2) are presented.

The statistical analysis of the results presented in Table 2 clearly show that by applying DA schemes improve all the statistical parameters, significant improvements in terms of MAE, RMSE, SI and R are noted. The change of L_{max} is without significant variations of the statistical parameters. To assess the robustness of the DA algorithm, the statistical parameters were analyzed at several levels or categories: each month, year, season and total data. The comparisons with benchmark results show consistently the improvement of the wave prediction quality after the DA application.

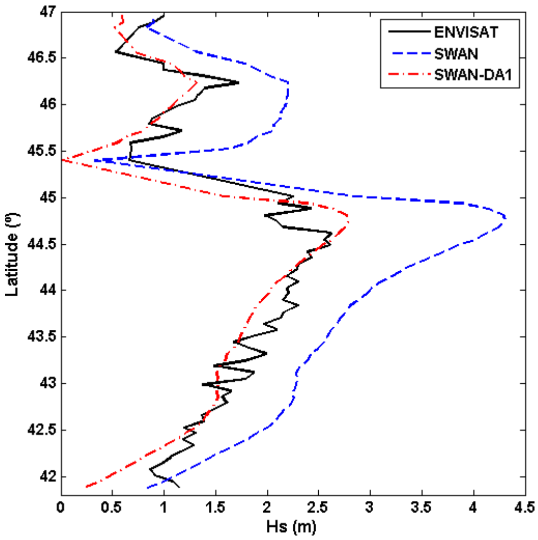
Table 2. Statistical results obtained for the *Hs* values simulated with SWAN and the *Hs* values obtained after the DA method application, against altimeter measurements (ENVISAT and Topex) across the Black Sea, the time interval (1999-2008).

Parameter	***MeanObs*** (m)	***MeanSim*** (m)	***Bias*** (m)	***MAE*** (m)	***RMSE***	***SI***	***R***	***S***	***N***
$H_{s\text{-SWAN}}$		0,978	-0,031	0,249	0,345	0,342	0,885	1,002	
$H_{s\text{-DA1}}$ (L_{max} = 4°)	1,009	1,011	0,002	0,188	0,268	0,266	0,925	1,006	219294
$H_{s\text{-DA2}}$ (L_{max} = 3,2°)		1,009	0,000	0,187	0,267	0,265	0,925	1,005	

In Figure 4a the results of the simulations with SWAN on the Black Sea are presented for the time frame 2004.01.16-H09. Figure 4b shows the new significant wave height scalar fields obtained after applying the DA method (DA1) using the satellite measurements on the 16 of January (black lines).



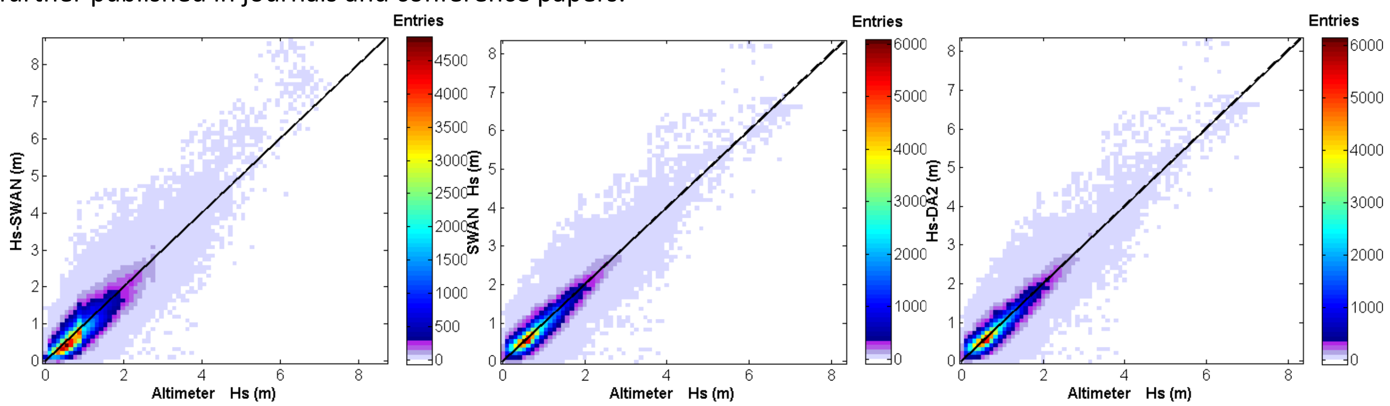
a) b)



c)

Figure 4. Significant wave height scalar fields simulated with SWAN on 2004.01.16-h09, the tracks of the satellite data used in the DA for the day 16 of January are marked with black, and the track of ENVISAT data used for validation is marked with magenta color (a). Significant wave height scalar fields obtenaided after DA1 aplication (b). Comparison between measured H_s, H_s simulated with SWAN and H_s obtained after applying DA1 along the track of ENVISAT.

Also, for all the comparisons the scatter diagrams were made (Figure 5) from which there can be observed the differences between the *Hs* measurements, and the simulations without DA and with DA. Note that after the DA application the data are grouped along the perfect line adjustment. The results obtained in this section will be further published in journals and conference papers.



a) b) c)

Figure 5. Scatter diagrams for the *Hs*, simulations (SWAN, DA1 and DA2) and measurements, the time interval 1999-2008.

3. Dissemination of the results

The dissemination of the results through scientific publications followed in the first phase the use of all the results obtained in the first stage of the project. Thus, a first direction followed in the dissemination is related to a complete analysis of the data coming from various sources (numerical models, satellite measurements or data coming from various prediction centers) and that were included in the database of the DAMWAVE project. For a better understanding of the wind and wave climate, the analyses were not limited only to the basin of the geographical space of the Black Sea and comparisons have been made with several other areas from the marine an ocean environment. In parallel with the implementation of the DA methods to improve the wave predictions, a very important direction that was and that will be continuously followed in the framework of the DAMWAVE project is represented by performing several studies concerning the application of the numerical spectral models to support the human activities in the nearshore. Thus, some reference papers concerning the coastal protection have been made and published as well as papers concerning the enhancement of the safety of the navigation or the evaluation of the energy resources in the coastal environment.

3.1- Scientific articles published in ISI and BDI (international databases) journals

It has to be mentioned this point that in the project plan some parameters have been proposed concerning the publication of scientific articles, parameters that have been reached and substantially exceeded.

PROPOSED RESULTS THAT WERE FULFILLED

Rusu, L., Butunoiu, D., Rusu, E, 2014, Analysis of the extreme storm events in the Black Sea considering the results of a five year wave hindcast. Oral presentation at International Conference AQUALIRES2014 – New tools for sustainable management of aquatic living resources, Bucharest, Romania, 17-18 January 2014, http://aqualires.incdpm.ro/images/AGENDA.pdf, event included in the calendar of the European Environment Agency, http://www.eea.europa.eu/events/new-tools-for-sustainable-management

Rusu, L., Răileanu, A., 2014. Wave modelling to assess the storm conditions in the Black Sea. Poster presented at European Geosciences Union General Assembly 2014 (EGU2014), Vol. 16, EGU2014-2140, 27 Apr – 02 May, Vienna, Austria. http://meetingorganizer.copernicus.org/EGU2014/EGU2014-2140.pdf

Rusu, E., Zanopol, A., 2014. Modelling the coastal processes at the mouths of the Danube River in the Black Sea. Poster presented at European Geosciences Union General Assembly 2014 (EGU2014), Vol. 16, EGU2014-2154. 27 Apr – 02 May, Vienna, Austria. http://meetingorganizer.copernicus.org/EGU2014/EGU2014-2154.pdf

Rusu, L., 2014. A data assimilation scheme to improve the wave predictions in the western side of the Black Sea. In: *Proc. of 14th International Multidisciplinary Scientific GeoConference* (SGEM2014) – Marine and Ocean Ecosystems, 17-26 June, Albena, Bulgaria, Vol. II, 539-545. http://www.sgem.org/SGEMLIB/spip.php?article4517

Rusu, L., Butunoiu, D., Rusu, E, 2014. Analysis of the extreme storm events in the Black Sea considering the results of a ten-year wave hindcast, *Journal of Environmental Protection and Ecology*, 15 (2), 445-454, http://www.jepe-journal.info/vol-15-no-2-2014 (IF=0.338).

OTHER RESULTS (in addition to the parameters proposed)

Rusu, E., 2014. Assessment of the Wave Energy Conversion Patterns in Various Coastal Environments, *Energies 2014*, Special Issue Selected Papers from the 1st International e-Conference on Energies, 7(6) 4002-4018; http://www.mdpi.com/1996-1073/7/6/4002 (IF=1.6)

Butunoiu, D., Rusu, E., 2014. Wave Modeling with Data Assimilation to Support the Navigation in the Black Sea Close to the Romanian Ports, *International Conference on Traffic and Transport Engineering* (ICTTE2014), Belgrade, Serbia 27th -28th November, 2014 (indexata ISI).
http://www.ijtte.com/article/102/ICTTE_Belgrade_2014.html

3.2 Continuous updating of the project DAMWAVE site http://www.im.ugal.ro/DAMWAVE/index.htm

During the project unfolding the web page of the project was continuously updated with the activities and the results of the project.

3.3 Supporting young researchers

Collaboration and supervision of master and PhD students represents a continuous concern of the members of the research team, having as objective to develop studies directly related to the area of the project, but also with some related areas as navigation, offshore and harbor operations that are strongly dependent on the knowledge of the wind and wave conditions. It has to be mentioned also the fact in 2014 3 bachelor dissertations, 5 master dissertations and 2 PhD theses have been defended. The names of the students and their themes are presented on the web page of the project DAMWAVE. Also, a PhD with the theme: *Implementation of data assimilation methods to improve the wave prediction in the basin of the Black Sea* (drd. Ing. Alina Răileanu) has been started and it is currently ongoing, as well as more master themes that are directly related to the topic of the DAMWAVE project.

Thus, in the framework of the project an important number of works were young researchers are included have been published and a list is presented below.

OTHER RESULTS ACHIEVED IN THE PTOJECT WITH YOUNG RESEARCHERS CO-AUTHORS (also additional in relationship to the parameters proposed)

Publications in international journals

1. Zanopol, A., Onea, F., Rusu, E, 2014. Coastal impact assessment of a generic wave farm operating in the Romanian nearshore, *Energy,* 72*,* 652-670. http://www.sciencedirect.com/science/article/pii/S0360544214006604 (IF=4,16)
2. Zanopol, A., Onea, F., Rusu, E, 2014. Evaluation of the coastal influence of a generic wave farm operating in the Romanian nearshore, *Journal of Environmental Protection and Ecology,* 15 (2), 597-605, http://www.jepe-journal.info/vol-15-no-2-2014/597.pdf (IF=0,338)
3. Gasparotti, C., Rusu, L. , 2014. Prediction of the dynamic responses for two containerships operating in the Black Sea, *Journal of Naval Architecture and Marine Engineering,* 11, 55-68. http://www.banglajol.info/index.php/JNAME/article/view/17289
4. Zanopol, A., Onea, F., Rusu, E., 2014. Studies concerning the influence of the wave farms on the nearshore processes, *International Journal of Geosciences*, 5 (7), 728-738. http://www.scirp.org/journal/PaperInformation.aspx?PaperID=47121
5. Zanopol, A.T., Onea, F., Rusu, E., 2014. The Coastal Impact of the WEC Arrays Operating in the Coastal Environment of the Black Sea. *Marine Engineering Frontiers* 2 (2), 16-23. http://www.seipub.org/mef/paperInfo.aspx?ID=16614
6. Toderascu, R., Rusu, E., 2014. Implementation of a Joint System for Waves and Currents in the Black Sea. *International Journal of Ocean System Engineering* 4(1), 28-41, http://www.koreascience.or.kr/search/articlepdf_ocean.jsp?url=http://ocean.kisti.re.kr/downfile/volume/kcore/E1GPBT/2014/v4n1/E1GPBT_2014_v4n1_29.pdf
7. Zanopol, A.T., Onea, F., Rusu, L., 2014. Experimental results to evaluate the wave and currents conditions in the Romanian nearshore. Constanta Maritime University Annals - An XV, Vol. 21-2014, Sect. I, 71-78 (indexată BDI). http://www.cmu-edu.eu/anale/anale_engleza/anale.html

Publications in proceedings of international conferences

8. Zanopol, A., Onea, F., Rusu, E, 2014. Longshore curents evaluation along the Romanian Black Sea coas. In: *Proc. of 14th International Multidisciplinary Scientific GeoConference* (SGEM2014) - GEOCONFERENCE ON WATER RESOURCES. FOREST, MARINE AND OCEAN ECOSYSTEMS, 17-26 June, Albena, Bulgaria, Vol II, 637-644 http://sgem.org/sgemlib/spip.php?article4530 (indexată SCOPUS)
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4. Concluding remarks

In this final section, we can appreciate that all the proposed objectives for this stage have been reached integral, being implemented and validated various DA algorithms for hindcast, both at local levels and at the level of the entire basin of the Black Sea. The algorithm for the generation area, represented by the entire basin of the Black Sea has been validated for the entire 10-year period (1999-2008) and the statistical results obtained indicate with clarity that the implementation of the DA methods leads to a clear improvement of the results provided by the wave prediction system in the Black Sea.

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