Scientific Report

concerning the implementation of the project

Assessment of the Climate Change effects on the WAve conditions in the Black Sea - ACCWA

in the period July – December 2017

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

1. Evaluation of the wind fields provided by the regional climatic models
2. Performing model simulations for the past
3. Analysis of the wave climate in the Black Sea
4. Dissemination of the results

1. Evaluation of the wind fields provided by the regional climatic models

1.1 Analysis of the wind fields and establishing of the periods considered for model simulations in the Black Sea basin

In the framework of the EURO-CORDEX experiment (Jacob et al., 2014; Kotlarski et al., 2014; see http://www.euro-cordex.net/), the European branch of CORDEX (Coordinated Regional Downscaling Experiment), high-resolution wind fields are provided (Jones et al., 2011; Giorgi & Gutowski, 2015). The Regional Climate Models (RCMs) have an important role in the wave model simulations by providing projections with much greater detail and a more accurate representation of the localized extreme events. These wind fields with a fine resolution of 0.11 degrees (EUR-11, ~12.5km), carried out over the European domain by the CORDEX RCM simulations, are considered in this project. Their results are distributed free via the Earth System Grid Federation (ESGF) archives, being available predictions up to the year 2100.

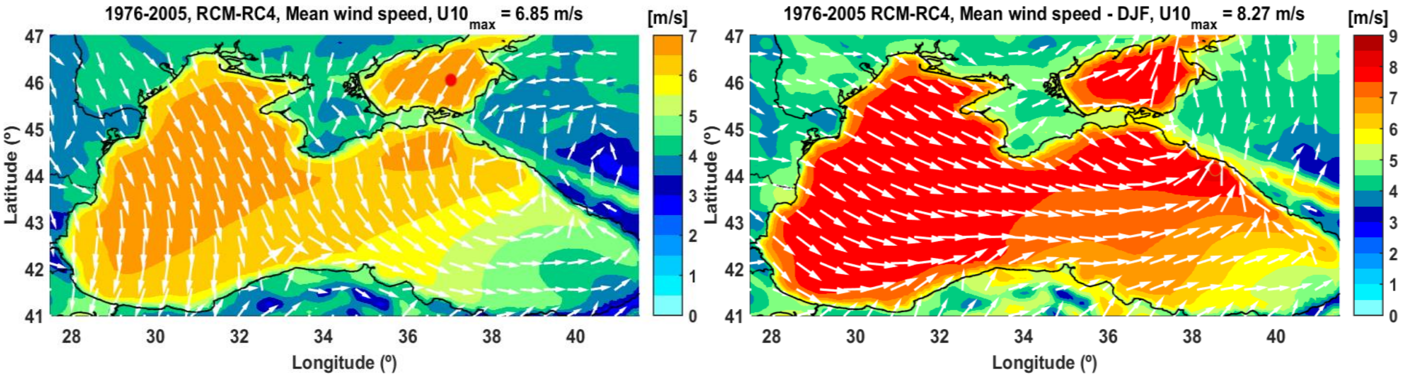
Starting from the fact that different projections of the wind climate are available, the first target was to assess what RCM wind fields simulated by the same RCM (forced by the same GCM - Global Climate Model) are available both in the recent past ('control' period) and for future projections, considering the two scenarios to be analysed in the project, namely RCP4.5 and RCP8.5 (RCP - Representative Concentration Pathways, Moss et al., 2010). The wind fields considered for the numerical simulations with the wave model should have a spatial resolution as high as possible and also high time step. On this basis, the wind fields available on EURO-CORDEX have been analysed.

From the analysis performed it was noticed that the simulations made by SMHI (Swedish Meteorological and Hydrologic Institute) with the RCA4 model (Rossby Centre regional climate model) fulfil the criteria established. This model was run with various boundary conditions as provided by 9 GCM models. In this respect we noted that the climate sensitivity defined as the transient climate response (TCR) in the GCMs used range from 1.3 to 2.5°C at the time of CO_2 doubling. Taking into account the fact that the EC - EARTH model (Hazeleger et al., 2010) considers an average temperature value of 2°C, at the same time being one of the most used model that covers an extended period for all RPCs, it was decided to use in the wave model simulations the wind fields produced by RCA4 forced with ICHEC-EC-EARTH (EC-EARTH operated by the Irish Centre for High-End Computing).

The above considered wind fields cover the entire European continent, including also the Black Sea basin. 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). As above mentioned, the spatial resolution is 0.11° (EUR-11 ~ 12.5 km) while the temporal resolution is 6 hours. The above information already processed is kept in the data base of the ACCWA project.

Thus, the data considered are wind fields produced by the regional climate model RCA4, forced with the global model EC-EARTH, and covers a 30-year period from the past (1976-2005), which is called also ‚control period'. This represents the historical data. The next data set covers 30 years from the near future (2021-2050) and furthermore another 30-year period for the future (2071-2100). The wind fields corresponding to the future cover both scenarios. Additionally, in relationship with the project proposal, there was downloaded 30-year of data from the near past (1980-2009), these being wind fields simulated with RCA4, forced by reanalysis data from ERA-Interim. These data can be used in the evaluation of the RCM model.

Figure 1 illustrates the average wind fields as resulted from the simulations with the RCA4 model computed for the period 1976-2004 (total time), as well as for the winter time periods.



a) b)

Figure 1. The average wind fields as resulted from the simulations with the RCA4 model computed for a) the period 1976-2004 (total time), b) the winter time periods (DJF).

1.2 Comparisons with other databases

For the control period of 30 years (1976-2005), reanalysis data are also available. These cover various periods. Before performing simulations with the wave model, various comparisons have been performed between the average values of the wind fields, as resulted from the simulations with the RCA4 model and those existent in databases that contain reanalysis data frequently used in wave hindcast. These are ERA-Interim, ECMWF (European Center for Medium-Range Weather Forecasts) and NCEP-CFSR (United States National Centers for Environmental Prediction, Climate Forecast System Reanalysis).

ERA-Interim data are available starting with 1979, they have a spatial resolution of 0,75° and a temporal resolution of 6 hours. For this reason, the average wind fields over the Black Sea basin was computed for the period 1979-2005, as they are presented in Figure 2.

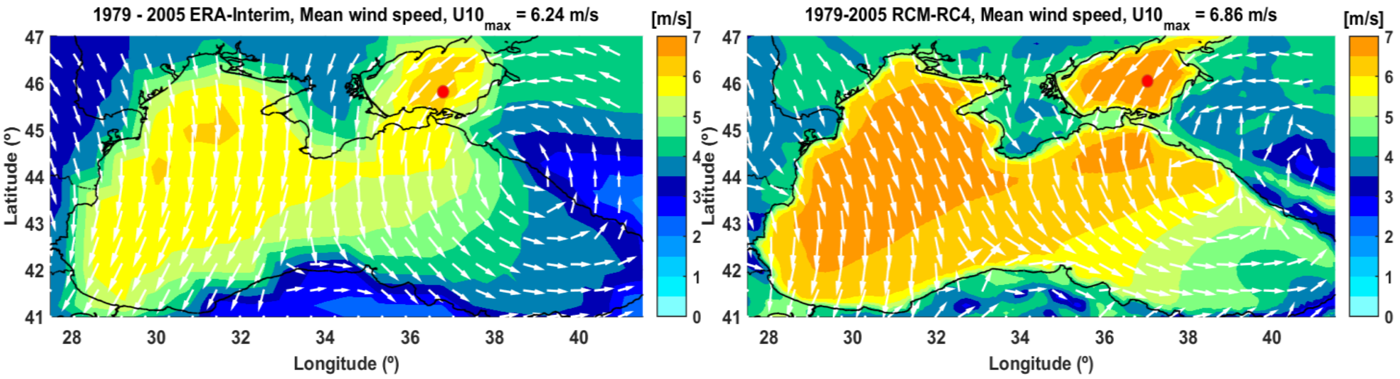


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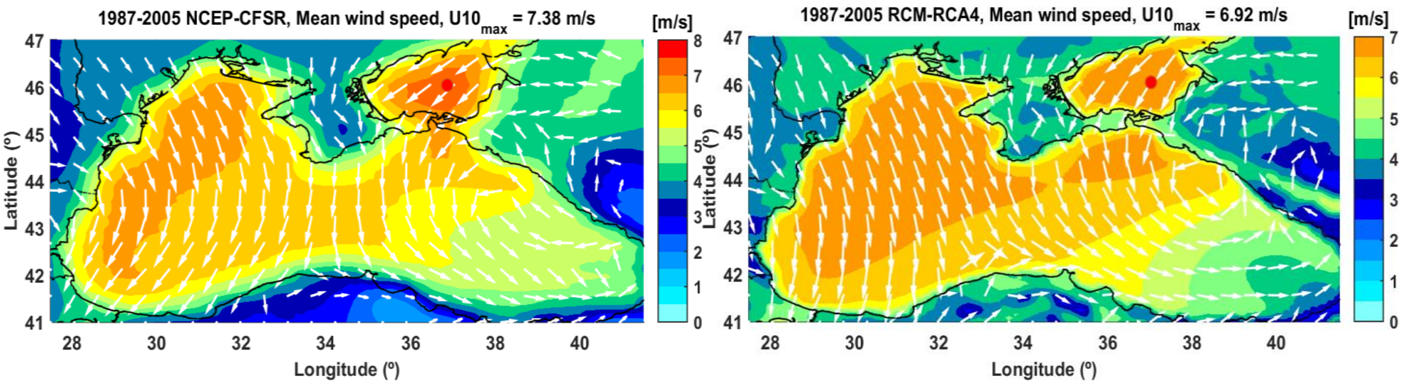
Figure 2. The average wind fields computed for the period 1979-2005; (a) ERA-Interim, (b) simulations with RCA4 model.

From the comparison of the spatial fields presented in Figure 2, it was noticed that in general the average values of the wind speeds coming from the RCA4 simulations are higher with about 0.5 m/s and up to 1 m/s. On the other hand, it is also known that in general the ECMWF reanalysis data provide lower values, especially for the case of the extreme conditions.

In the framework of the DAMWAVE project- Implementation of data assimilation methods to improve the wave predictions in the Romanian nearshore, CNCS – UEFISCDI, project number PN-II-ID-PCE-2012-4-0089, http://www.im.ugal.ro/DAMWAVE/index_engleza.htm, which was leaded by the same project director as ACCWA project, it was initiated the development of a database, extended also after 2016, when the DAMWAVE project was finalized. This database covers the 30-year period (1987-2016) and comprises wind fields from NCEP-CFSR processed into a format accessible for rapid visualizations/analyses as well as for simulations with the wave modeling system in the Black Sea basin. Comparisons have been also performed between the average values of the wind fields NCEP-CFSR against RCA4 for the period 1987-2005. At this point, it has to be also highlighted that the NCEP-CFSR data have a spatial resolution of 0.312°x0.312° and a temporal resolution of 3 hours.

In Figure 3 there are presented the maps of the two wind fields. Thus, it can be noticed that in the basin of the Black Sea, the average values of the wind field evaluated considering the two different databases are quite similar. The spatial distribution of the wind fields presents also a similar structure. Nevertheless, it can be also noticed that the NCEP-CFSR data show higher values in the area of the Sea of Azov. On the other hand, the average wind values resulting from RCA4 located in the range 6-7 m/s can be noticed on an extended surface in the western side of the basin in comparison with the data from NCEP-CFSR. It can be noticed also a slight modification of the wind direction, especially in the south and in the west of the basin.



a) b)

Figure 3. Average values of the wind field computed for the interval 1987-2005 (a) NCEP-CFSR; and (b) RCA4 model.

2. Simulation of the wave conditions for the 'control' period (1976-2005)

The wave conditions for the control period (1976-2005) have been simulated with the SWAN model (Simulating WAves Nearshore, Booij et al., 1999), forced with the wind fields provided by the RCA4 model. At the same time, it has to be mentioned that SWAN has been calibrated and validated over the basin of the Black Sea in the framework of the DAMWAVE project. Using the same physical parameterization and settings for SWAN over the same computational domain (Table 1), simulations for the entire control period have been carried out.

Table 1. Characteristics of the computational domain and the settings used in the SWAN simulations.

Computational grid	Δx × Δy	Δt (min)	Nr frequencies	Nr directions	ngx × ngy = np	Origin (long/lat)
Black Sea basin	0,08° × 0,08°	10 (non stationary)	30	36	176 × 76 = 13376	27,5 E / 41,0 N

Taking into account the fact that the model simulations for a 30-year period had to be performed in a relatively short time (4 months), it has to be mentioned the effort for processing the wind fields used as input for SWAN. Thus, initially the simulations have been carried out on two existing workstations, but in such conditions only for one year of SWAN simulations the requested computer time was of about 34 hours. After the new computing systems were acquired (the final of October) the average computer time decreased about 4 times. Under such conditions, it was possible to finalize the simulations corresponding to the first stage of the project implementation.

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*). On this basis, the climatology analysis has been performed by evaluating the average values for total time, seasons and months, respectively corresponding to the entire basin of the Black Sea. All these data have a spatial resolution of 0.08°and a time step of 3 hours.

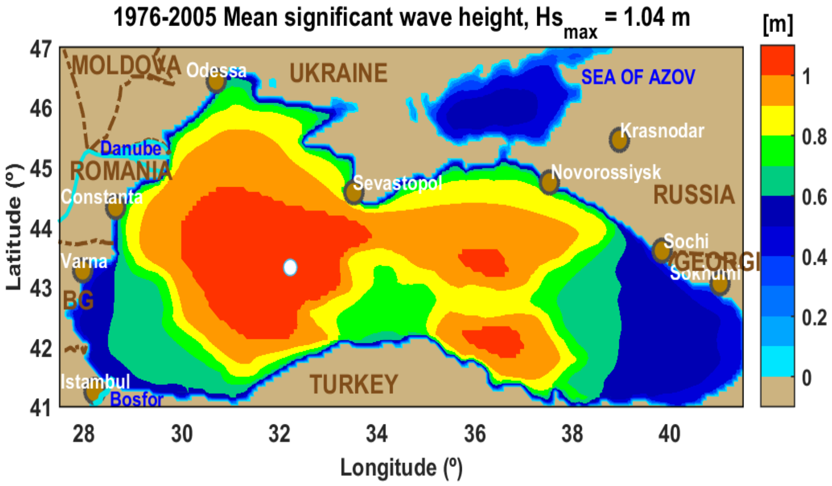


Figure 4. Average *Hs* fields resulted from the SWAN simulations forced with the RCA4 wind model. Results corresponding to the 30-year time interval (1976-2005).

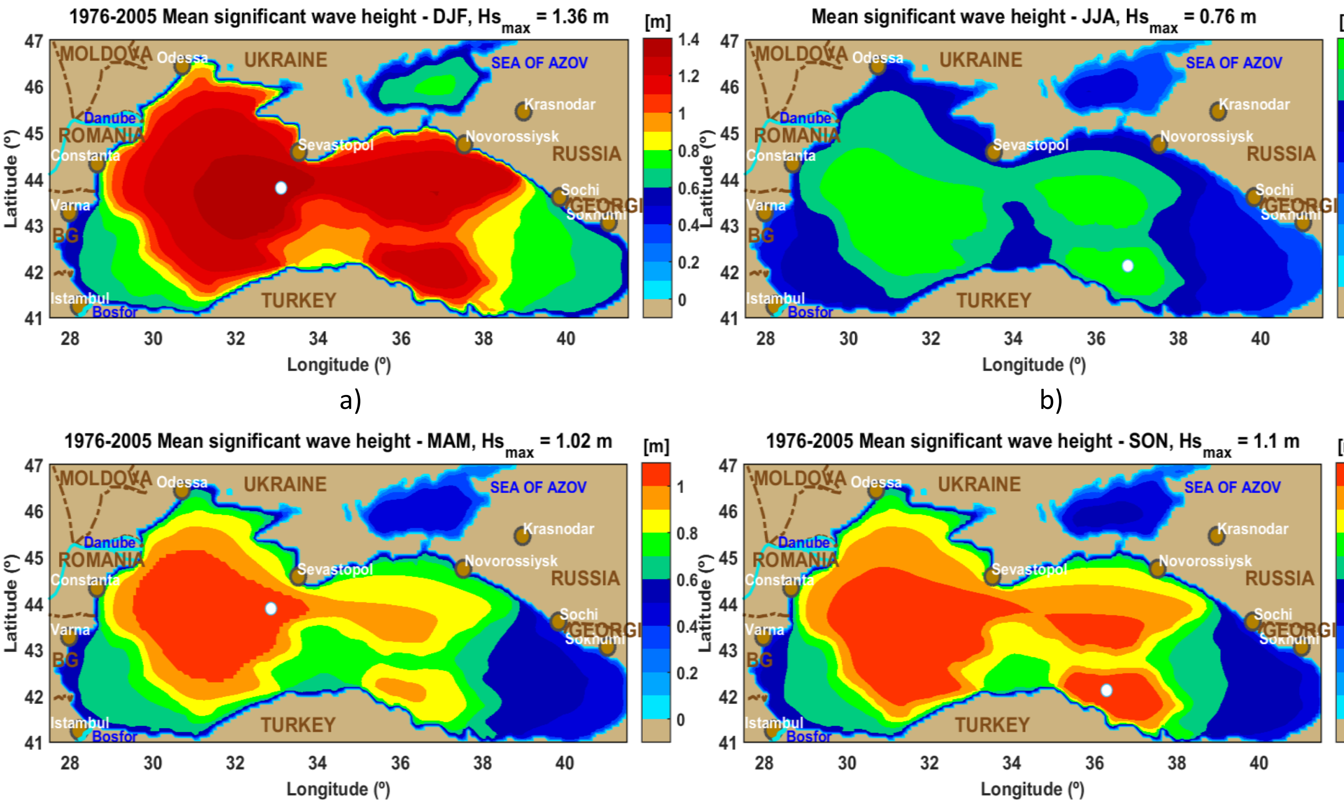


Figure 5. Seasonal average *Hs* fields resulted from the SWAN simulations forced with the RCA4 wind model. Results corresponding to the 30-year time interval (1976-2005): a) Winter; b) spring; c) summer; d) autumn.

Figure 4 presents the spatial distribution of the average *Hs* values resulted from the SWAN simulations while in Figure 5 the same *Hs* fields corresponding to the seasons have been represented. The information necessary to compute the average seasonal values was extracted from the total amount of data following the seasonal partition: winter - DJF (December-January-February), spring - MAM (March-April-May), summer - JJA (June-July-August) and autumn - SON (September-October-November).

For the period 1987-2005, information concerning the wave conditions in the basin of the Black Sea can be also found in the database of the DAMWAVE project. These results have been compared with the wave conditions resulted from the wave simulations performed considering the RCA4 wind model. For this period the *Hs* spatial distributions are presented in Figure 6. The maximum *Hs* values are very close (1.05m against 1.06m). However, in the spatial distribution some differences can be noticed. This is probably due to the differences that occur in the wind directions. The Black Sea is an enclosed basin and thus having a limited fetch in comparison with the open ocean, the influence of the wind on the waves is very high. From this perspective, a supplementary analysis will be necessary by comparing also the results of the wave model simulations for the period 1980-2009, considering in parallel RCA4 and ERA-Interim wind fields.

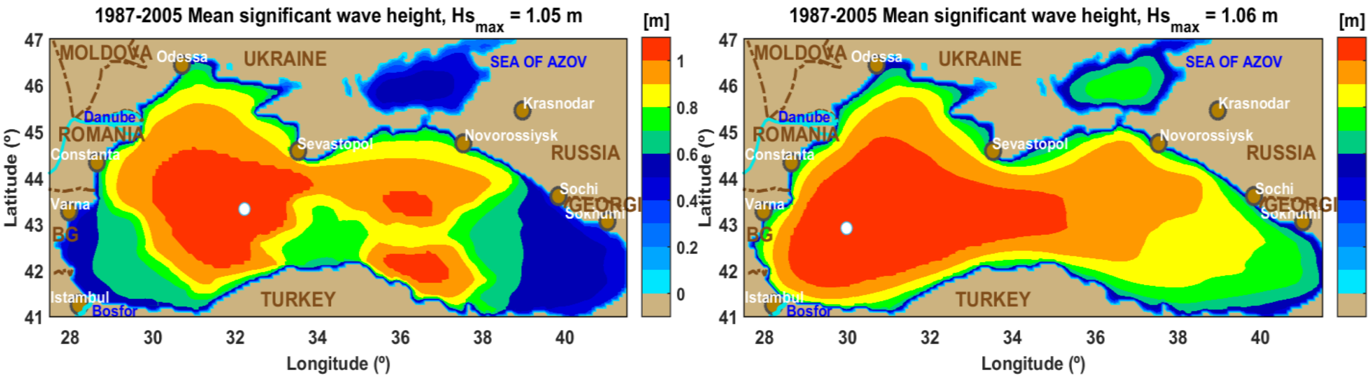


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Figure 6. *Hs* spatial distributions, average values corresponding to the time interval (1987-2005) resulted from the SWAN simulations forced with the wind fields from: a) RCA4 model; b) reanalysis NCEP-CFSR data.

3. Analysis of the wave climate in the Black Sea

In the framework of this first stage of the project, an analysis of the wave climate in the Black Sea has been performed considering data from more sources. Thus, such a long term evaluation of the wave climate in the basin of the Black Sea has been made by Onea & Rusu (2017). Figure 7 presents the map of the Black Sea, and also the reference points considered for assessment. These were equally divided between four sectors, denoted with I, II, III and IV. The evaluation of the wave conditions in the vicinity of the shoreline is made possible throughout the A-group points (A1, A2, …, A12).

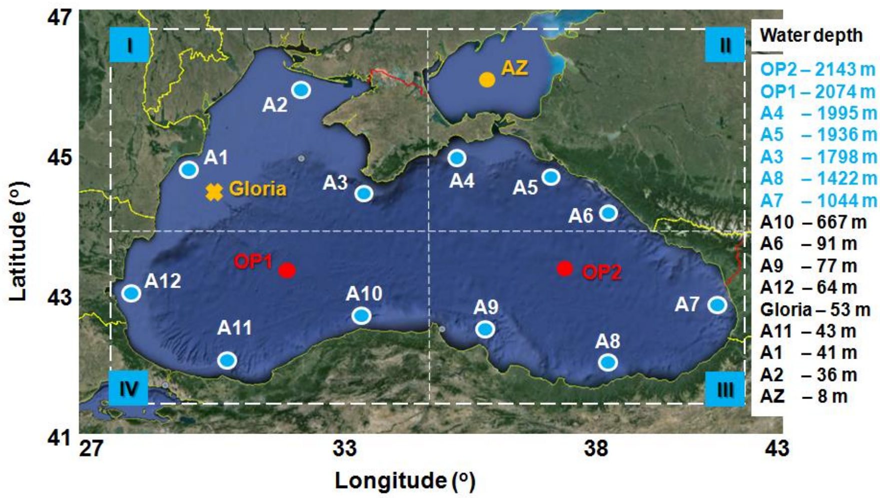


Figure 7. Location of the reference points considered in the Black Sea area. Figure processed from Google Earth (2017). The water depths correspond to the values reported by the NOAA bathymetric database (https://maps.ngdc.noaa.gov/viewers/bathymetry/), (Onea & Rusu, 2017).

The point Gloria is related to a drilling platform located in the vicinity of the Romanian nearshore (44°31'N/29°34'E), which will be considered to assess the local wave conditions throughout *in situ* wave measurements reported for the interval 2003-2009. In order to identify the wave variations in the offshore areas, two reference points (OP1 and OP2) were defined in the western and eastern parts of the sea, respectively.

In order to assess the long term variations of the Black Sea wave conditions, in this section the 38 years of ECMWF data (1979-2016) will be considered for evaluation. Figure 8 illustrates the distribution of the mean values reported on inter-annual scale for various time intervals (total and winter time). In Figure 8a, there are presented the differences reported between the maximum and minimum annual values corresponding to the interval 1979-2016.

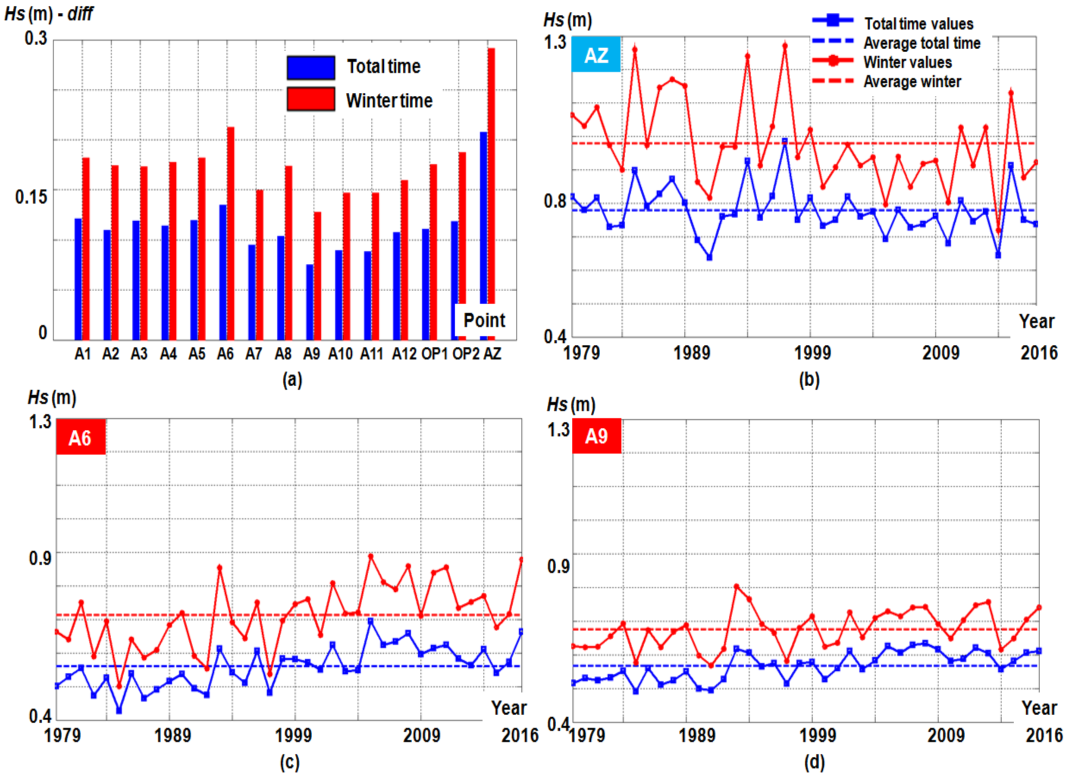


Figure 8. Inter-annual distribution of the average values based on the ECMWF data as indicated for the time interval 1979-2016. The results are related to: a) normalized values reported between the maximum variation and the average value; b), c) and d) annual variations computed for the total and winter time, respectively, by considering the points AZ, A6 and A9, (Onea & Rusu, 2017).

Furthermore, a spatial analysis of the wind and wave climate for the 20-year period 1997-2016 has been performed in the framework of the ACCWA project (Rusu et al., 2017), considering the data available from the DAMWAVE database. The corresponding results are presented in Figure 9.

Another important aspect is represented by the accuracy of the numerical models on the spectrum concept based (as the SWAN model is) to predict the storm conditions in the Black Sea (Rusu, 2017). The direct comparison simulations against measurements is shown in Figure 10a during the storm events registered in the period 22-23 December 1999. There is a quite good correlation between measurements and simulations, even if the measurements illustrate a greater variability, which was not entirely reflected by the simulations. On the other hand, the extreme values were predicted with a reasonable accuracy. The geographical distribution of the storm conditions was also determined through the computation of the percentage of the waves characterized by significant wave heights greater than 3 m. The corresponding results are illustrated in Figure 10b and they show in the western part of the basin an extended area where higher waves can be found.

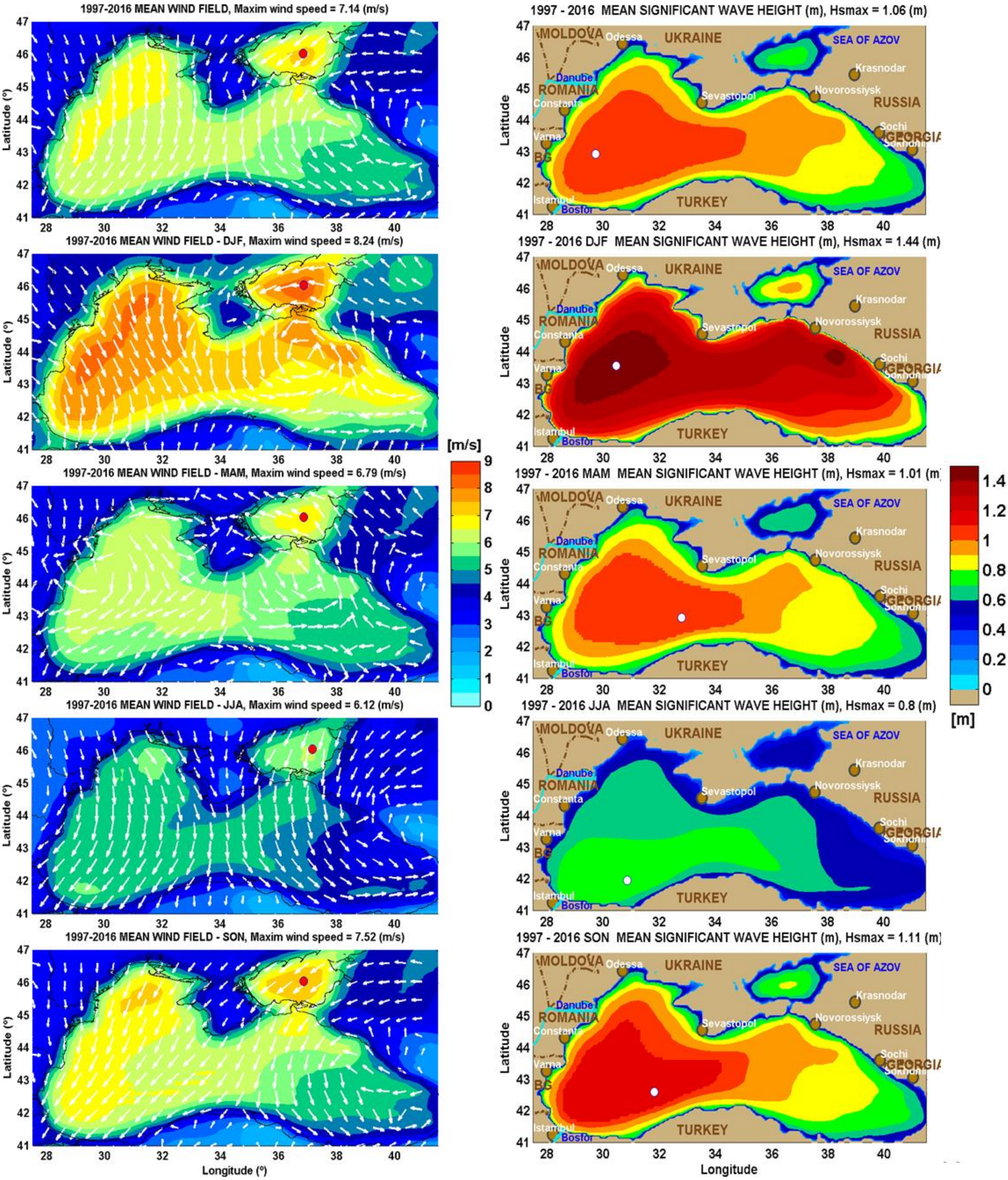
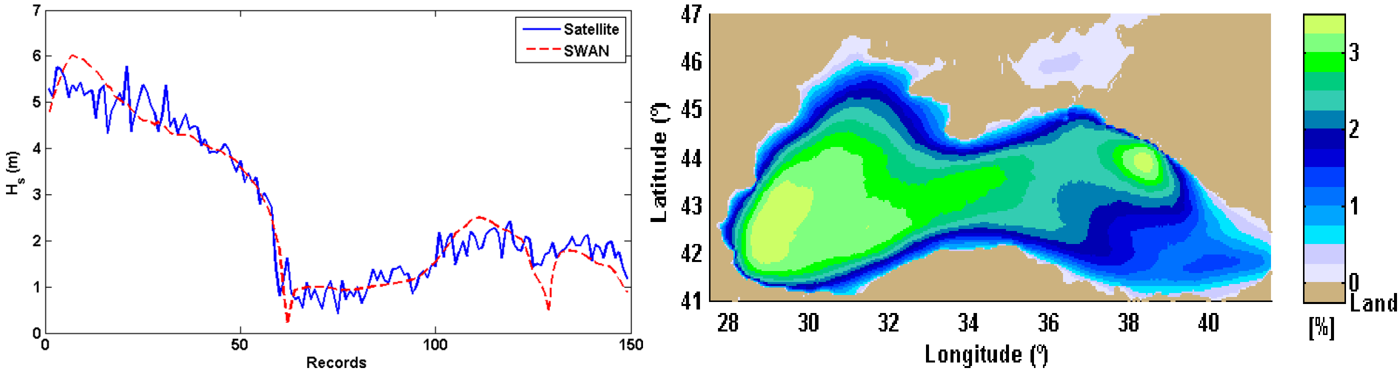


Figure 9. The spatial distribution of the mean wind fields (left panels) and the mean significant wave height fields (right panels) for the entire 20-year period 1997-2016 (first line), and for each season: winter (DJF) – second line, spring (MAM) – third line, summer (JJA) – fourth line, autumn (SON) – last line, (Rusu et al., 2017).



a) b)

Figure 10. Comparison of H_s simulated by SWAN against the corresponding wave parameters measured from different satellite missions along the track segments during the storm events in the Black Sea: 22-23 December 1999 (first line);Figure 1. The geographical distribution of the storm conditions in percentage (significant wave heights greater than 3 m) as resulted from 20-year wave simulations (1997–2016), (Rusu, 2017).

4. Dissemination of the results

4.1 Preparation of the scientific articles, a monograph, oral presentations and posters to disseminate the results

- Publications in international journals with ISI quotation (2)

1. Onea, F., Rusu, L., 2017. A long-term assessment of the Black Sea wave climate. *Sustainability* 9(10), 1875. (IF = 1,789) http://www.mdpi.com/2071-1050/9/10/1875 http://dx.doi.org/10.3390/su9101875
2. Rusu, L., Ganea, D., Mereuță, E. (2017). A joint evaluation of wave and wind energy resources in the Black Sea based on 20-year hindcast information. *Energy Exploration & Exploitation*, 17 pag, in press. (IF = 0,963) http://journals.sagepub.com/doi/full/10.1177/0144598717736389 -

- Publications in national journals indexed in international databases (3)

1. Anton, C., Rusu, E., Mateescu, R., 2017, "An Analysis of the Coastal Risks in the Romanian Nearshore", Journal of Mechanical Testing and Diagnosis, ISSN 2247–9635, 2017(VII), Volume 1, pp. 18-27, http://www.om.ugal.ro/mtd/download/2017-1/V2-2%20MTD_2017_Volume%201_Rusu%20xx.pdf
2. Rață, V., Gasparotti, C., Rusu, L., 2017, "The Importance of the Reduction of Air Pollution in the Black Sea Basin", Journal of Mechanical Testing and Diagnosis, ISSN 2247–9635, 2017 (VII), Volume 2, pp. 5-15, http://www.im.ugal.ro/mtd/download/2017-2/1_MTD_Volume%202_2017%20Rata%20Rusu.pdf
3. Anton, C., Carmen Gasparotti, Răileanu, A., Rusu, E., 2017. Towards an Integrated Management and Planning in the Romanian Black Sea Coastal Zones. Acta Universitatis Danubius. Œconomica, Vol. 13, no 5, pp 59-71. http://journals.univ-danubius.ro/index.php/oeconomica/article/viewFile/4381/4208

- Publications in the proceedings of international conferences (2)

4. Rusu, L., 2017. Evaluation of the accuracy of the spectral models in predicting the storm events in the Black Sea. Presented at the 17th International Congress of the International Maritime Association of the Mediterranean - IMAM 2017, Lisbon, Portugal, 9 - 11 October 2017, published in *Developments in Maritime Transportation and Harvesting of Sea Resources – Guedes Soares & Teixeira (Eds)*), Taylor & Francis Group, London, Vol. 2, 1105-1117. (ISI – indexed) http://www.imamhomepage.org/imam2017/ https://www.routledge.com/Developments-in-Maritime-Transportation-and-Harvesting-of-Sea-Resources/Guedes-Soares-Teixeira/p/book/9780815379935
5. Vlăsceanu, E., Buzbuchi, N., Rusu, E., "Application of Numerical Hydrodynamic Models in the Study of Waves and Curents in Romanian Black Sea Area", The International Symposium "Protection of the Black Sea

Ecosystem and Sustainable Management of Maritime Activities - PROMARE 2017", 8th Edition, 7-9 September 2017, Constanța, România - Poster

4.2 Designing the web page (Ro-En) and continuous updating of the project ACCWA site

It was designed the web page for the dissemination of the ACCWA project results http://193.231.148.42/accwa/index_en.php. During the project unfolding this web page was updated with the activities and the publications corresponding to this first stage of the project and it will be periodically updated also from now on.

5. Concluding remarks

We can conclude that we succeeded to achieve all the objectives proposed for this stage. All the activities included in the plan of achievement were accomplished.

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Giorgi, F., & Gutowski Jr, W. J. (2015). Regional Dynamical Downscaling and the CORDEX Initiative. *Annual Review of Environment and Resources*, 40(1), 467-490.

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