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PhD THESIS

- ABSTRACT -

IMPLEMENTATION OF DATA ASSIMILATION METHODS TO IMPROVE WAVES PREDICTION WITH SPECTRAL MODELS IN THE BLACK SEA

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PREFACE

This paper contributes to a systemic and complex understanding of data assimilation methods, with applications to the prediction of wave climate in the Black Sea. The main purpose of the data assimilation method used is to develop and correct the results of the numerical model, taking into consideration more accurate initial conditions, thereby causing the model to move forward in a realistic direction. The thesis is a step forward in developing an operational wave model for the Black Sea, the research is focused on the western side of the basin and on the Romanian seaside.

I would like to express my sincere gratitude towards my scientific coordinator, Professor Eugen Rusu, for his constant guidance and support throughout the preparation of this paper as well as his absolute faith in me and in the direction of this work. I would like to specifically thank Professor Rusu for accepting to have me as one of the people who have had the privilege of benefiting from his guidance, for his patience during the long discussions we have had in these three years, for his advice and his constant trust in me.

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Furthermore, I would like to express my gratitude towards the members of the commission in charge with the guidance of this paper, for their suggestions and advice along the way. As part of this group, I would especially like to mention Professor Lorena Deleanu, Professor Stefan Dragomir and Associate Professor Nicoleta Talmaciu.

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Eng. Alina Beatrice RĂILEANU

SUMMARY

INTRODUCTION

Actuality and importance of the proposed them

Evaluation and waves predictions are an important aspect for planning activities in the marine, while long-term such data may indicate climatic trends that more clearly highlights the developments of coastal geomorphology. Currently, the best information is provided by *in situ* system measurements providing the disadvantage that only one location is covered. Moreover it is noted that in the event of storm conditions, these tools may provide incorrect values or, at worst, can be damaged. Studying wave climate in the Black Sea has become in the last decades an issue of increasing importance but, however, currently there is no network of *in situ* measurements in the area, if we consider the small number of buoys and the fact that most are nearshore located.

In order to identify the distribution of wave energy for a given sea area, it can be used data from numerical simulations or measurements provided by altimetry missions reported in that region. It should be noted that none of these data sources is perfect, each one defined by a low accuracy or simulation errors. If we consider numerical models, those are used successfully in the ocean areas, but when implemented within enclosed seas they can cause problems due to physical characteristics existing here. Regarding altimetry missions, they provide precise information about the distribution of waves in offshore areas, but for nearshore areas (land-water interface) they can report inaccurate or even missing values. These weaknesses can be offset by applying data assimilation techniques (DA) which envisages combining numerical simulations with *in situ* observations or satellite measurements in order to obtain a reliable wave prediction system, even for extreme weather conditions. Considering that satellite measurements are now available for large water surfaces and that there are performance computing systems, there are all prerequisites for the development of data assimilation schemes in operational models. Such an approach seems to be appropriate for the Black Sea, where there is limited information about the characteristics of wave fields. Much of the research focused on implementing wave patterns for various time intervals, which are validated with data from local buoys, but without taking into consideration DA techniques.

Research direction is topical addressed if we consider only the dynamics of freight traffic in the Black Sea through Pan-European transport corridors (e.g. IV, V and VII), where life safety and environmental protection play an important role. Considering that in the Black See basin there are also some protected areas such as the Danube Delta Biosphere, these studies become more important. By implementing an operational system we can obtain an obvious improvement of the wave predictions, information obtained is of interest to all those operating in the marine environment, from the tourism, fisheries, port activities or even to identify climatic tendencies.

In comparison with similar studies reported for this area, this work envisages achieving realistic results based on running SWAN (Simulating Waves Nearshore) based wave modelling system for long time periods (10-15 years), these results will be correlated with in situ measurements. The corrections resulting from this process are to be propagated in spectral and the geographical space, to finally obtain an optimum prediction of the sea condition. Based on simulation results reported for the entire Black Sea basin, in the western side, a higher resolution computational domain was nested in the large area, with special attention to Romanian nearshore.

Given that each calculation level considered has specific characteristics, both in terms of physical processes activated and the availability of in situ or satellite measurements, for each study were implemented specific simulations. Following the studies, it was considered useful to use a period of training for about 60 days, while DA methods most often addressed focused on the use of specific linear regression methods (e.g., Least-Squares) or on bias corrections.

Significant wave height (Hs) is considered relevant to describe conditions in the marine environment, so that it was considered most often in the process of assimilation. Using this parameter there is the advantage that the results can be corrected (or compared) with satellite measurements. By using altimetry measurements are obtained good results for large areas of water, while for smaller areas an improvement is seen only using in situ observations. In order to better evaluate the condition of the sea and wave energy it may be included in the process of assimilation also other parameters, such as for example the period and the direction of the wave, parameters which can be used for the transfer of information in the spectral domain using a theoretical spectrum. It is recommended to use a spectrum because, when there are corrections, wave heights can be adjusted without changing the shape of the spectrum. If we are talking about the Black Sea, for the spectrum corrections in points defining domain computing boundaries, it can be defined an equivalent JONSWAP spectrum that is used to describe an evolving sea conditions.

Objectives of the thesis

In this context, the researches are focused on the following objectives:

1. Providing an overview on the implementation of DA techniques that are becoming increasingly used in the modelling of physical phenomena involving numerical simulations. At this stage mentioning some examples that highlight the versatility and usefulness of these methods. Particular attention was given to identifying operational wave models that are currently used in major hydro-meteorological centres.

2. Description of the main DA Methods, in which were presented various techniques, such as those related to sequential or variational methods. Taking into account that one of the first techniques used was the Kalman filter, has been shown the main filters and their mathematical apparatus.

3. Identification of wave and wind conditions for the Black Sea basin considering data from numerical models or satellite measurements. As data sources, it may be mentioned reanalysis data from NCEP or ECMWF centres, while as satellite measurements were used observations from AVISO project. Data were analysed in terms of weather but also considering the potential of wave and wind resources to be used in renewable energy projects.

4. Implementation of data assimilation techniques for the Black Sea using spectral phase averaged wave model SWAN. Simulations were centred on the western side of the basin, focusing on the central part of the western side of the Black Sea (the Romanian nearshore).

5. Highlighting areas of activity where wave predictions are important. At this point it can be mention the dissemination of results which were centred on the implementation of DA techniques and the statistical analysis of specific parameters of the marine environment.

Structure of the thesis

PhD Thesis entitled ***Implementation of Data Assimilation Methods to Improve Waves Prediction with Spectral Models in the Black Sea*** is divided into eight chapters, as follows:

Chapter 1 achieved an introduction to data assimilation presenting different case studies of engineering, meteorology and medicine. Considering that currently the majority of studies involve the use of numerical simulations, the purpose of this chapter is to highlight the advantages of such techniques, aiming ultimately to achieve results closer to reality.

Chapter 2 deals extensively with key data assimilation techniques that were grouped into sequential and variational methods. Here it is presented the mathematical apparatus that underpinning techniques such as optimal interpolations or type 3DVAR variational methods that are most common in this area and have been implemented in this paper.

Chapter 3 describes the evolution of the Kalman filter and its applicability in systems defined by stochastic processes. Here is a theoretical presentation of the main existing filters, from discrete Kalman filter to some case studies to exemplify the implementation of these filters.

Chapter 4 presents general mechanisms underlying a wave model and highlighting the programs developed globally. Of these, particular attention was given to projects that provide global information (e.g. ECMWF and NCEP) and some regional models that can identify more precisely the sea state at the local level (e.g. NCOF - UK or DNMI - Norway).

Chapter 5 evaluate the wind and wave conditions in the Black Sea considering data from the re-analysis numerical models or altimetry missions. Based on this information are highlighted various seasonal trends manifested in this basin, with special attention to Romanian nearshore. They analysed the data of reported marine environment along the major waterway routes, while in some cases it was considered useful to compare the values obtained with those reported in the Caspian Sea basin.

Chapter 6 focuses on DA techniques implementation in the Black Sea, the methods used are adjusted according to the calculation domain and the physical processes enabled by SWAN model. Using in situ wave measurements, data from NCEP program and satellite measurements, the calibration and the correction of values provided by numerical simulations was realised, corrections obtained being propagated in spectral and geographic space. In order to estimate the impact of DA techniques on the accuracy of predictions provided, were used various statistical tools that have shown a significant improvement of the assimilated wave parameters.

Chapter 7 highlights the importance of wave predictions, showing the various areas that can benefit from an operational model. There are analysed various situations, such as research and search activities focus on the Black Sea. Whatever the analysed situation, it appears that time parameter stands out because sea conditions can change rapidly for different time frame, and the weather prediction can avoid (or minimize) the impact of extreme conditions.

Chapter 8 summarizes the main results obtained in this thesis, directly highlighting the elements of originality and the author contributions. Considering that the research domain is very dynamic, in this section are underline several directions of study that can contribute to implementation in a relatively short time of an operational wave model for the Black Sea, using a DA method. It is also mentioned scientific research activity of the author, which was completed and integrated into two projects:

a) Sectorial Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397.

b) Data Assimilation Methods for improving the WAVE predictions in the Romanian nearshore of the Black Sea - DAMWAVE (PN-II-IDPCE-2012-4-0089).

Chapter 1

APPLICABILITY OF DATA ASSIMILATION TECHNIQUES

1.1 Generale Aspects

Data assimilation (DA) methods aims to improve the results provided by a numerical model in order to obtain more lifelike results. This is achieved through the implementation of statistical methods that can adjust the results for different time intervals, namely: a) past - hindcast; b) present - nowcast; c) the future - forecast. One of the first methods was used in this field refer to the statistical interpolation, which is a basic element and is used successfully in the present [1, 2]. The first applications focused on reaction-geofluidelor, DA methods being implemented successfully in predicting weather or oceanographic, over time being adopted by other sectors such as aviation, agriculture or medicine respectively. They have a well developed mathematical foundation by applying their simulations tracking the calibration, monitoring of processes or possibly identify relationships that may exist between various physical phenomena [3].

Given that data processing is performed in a virtual environment depend on the quality of information obtained 'observations used to force a model and performance modeling software used. As in any field that involves processing databases or measurements, risk errors occur, which can be identified using techniques DA. In order to achieve quality results as needed depending on the physical phenomenon studied to find an optimal method that combines measurements DA with numerical simulations, aiming to finally calibrate the model and adjusting existing errors. The observations used have a better spatial resolution and temporary, the DA technique is more efficient and the results are more realistic [4, 5].

Data assimilation methods are characterized by a continuous dynamic, reaching nowadays the complicated techniques that can provide information on various parameters globally or in assembling databases covering decades. When you want to implement a complex methods and assimilating a larger number of parameters must be considered performance hardware systems, which for example where major hydro-meteorological centers can cover large areas of a building.

When taking into account the time parameter, can implement various techniques that comments be treated continuously both sequentially and considering different timeframes. This is illustrated in Figure 1.1, noting that currently seeks to assimilate real-time data using various techniques DA which vary by complexity, as can be seen in Figure 1.2.

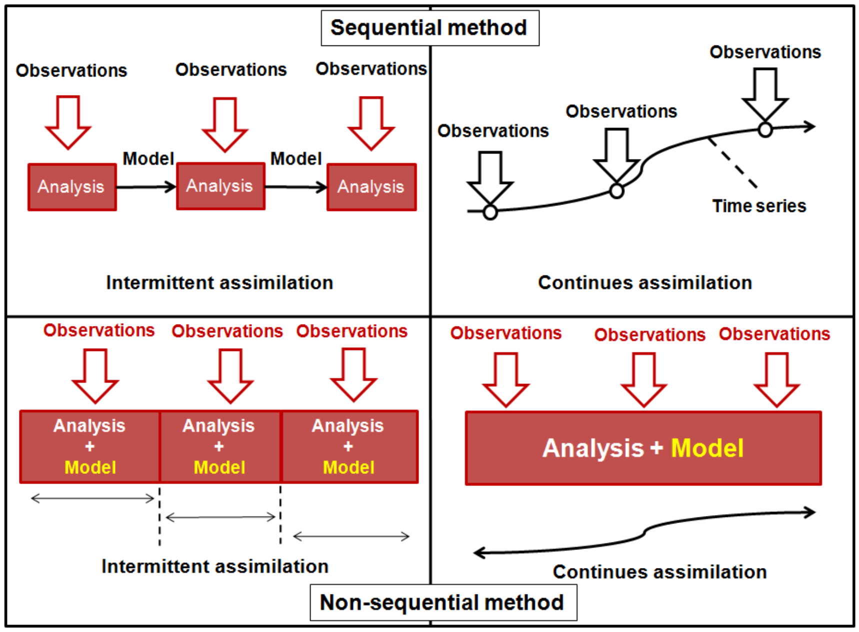

Figure 1.1. Clasifiction of DA techniques [6].

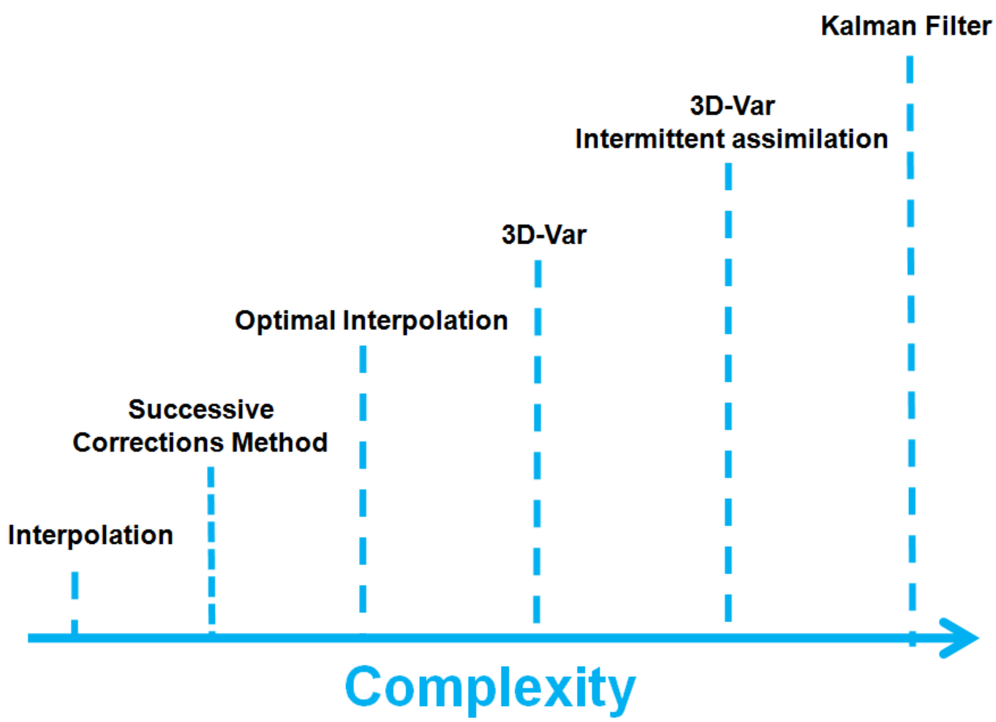

Figure 1.2. Complexity levels of DA techniques [6]

1.2 DA Systems Application Fields

Applications involving DA are already present in our lives, most relevant examples are predicting weather or mobile phones. Given that the purpose of assimilation techniques is to improve model predictions of further will present some applications in various fields in order to emphasize this.

1.2.1 Meteorology

Weather was one of the first areas where the DA techniques were used in order to forecast the dynamics of atmospheric conditions. The first case study is presented in Figure 1.3 where distribution was evaluated torrential rains reported near Beijing (China) for the date of 21.07.2012 [7]. For this type of study data were processed AMSU (Advanced Microwave sounding Kingdom) which have been assimilated into a numerical model that aims to simulate physical processes specific to the mezoscală. The results were compared with observations reported in situ study area, where the assimilation process was aimed at assessing areas of computing with spatial resolutions ranging between 3 km and 27 km. From the results provided results can be seen an improvement in predictions, especially for the case study focused on a spatial resolution of 27 km.

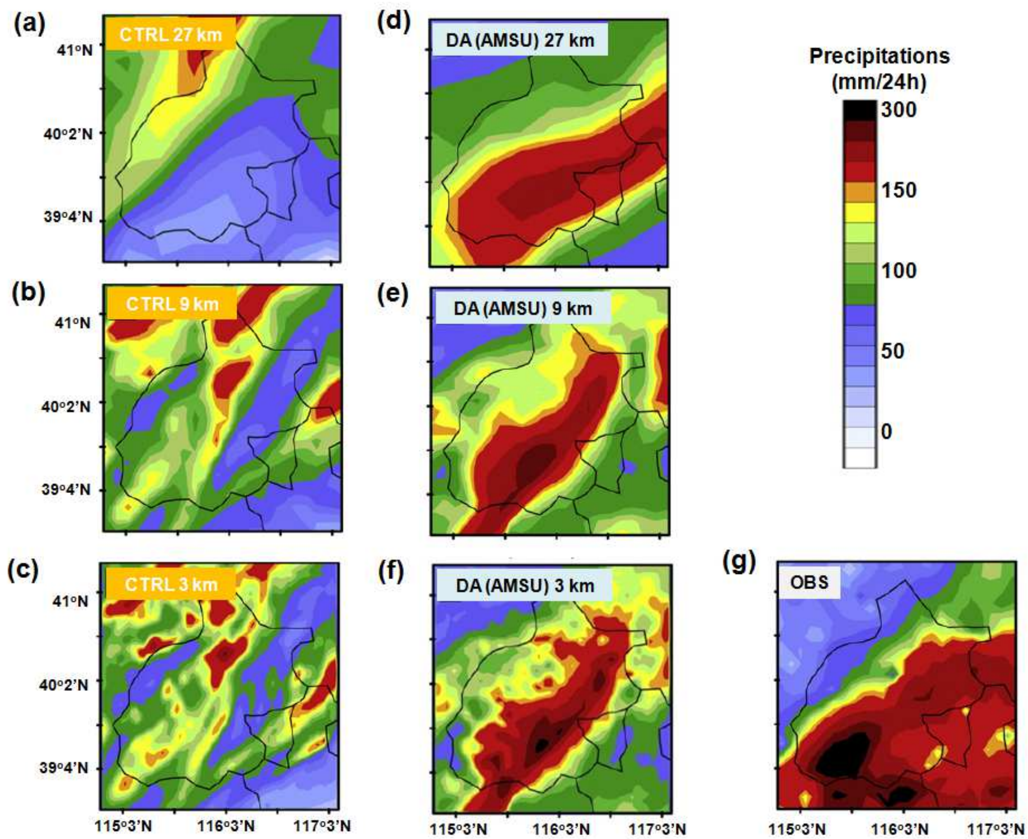

Figure 1.3. Analysis of the precipitations level reported near Beijing, where: a) - c) no assimilation; d) - f) DA related to AMSU data; g) *in situ* observations [7].

On the other hand, in arid and semi-arid rainfall it is much less so frequent sandstorms may occur that can affect health. A situation of this kind is shown in Figure 1.4, as identified in the Asia 10.05.2011-13.05.2011 considering the time [8]. The numerical simulations were done using the program MASINGAR mk-2 (Model of Aerosol Species ATMOSPHERE IN theGlobal Mark 2) that is based on modeling the movement of aerosols. The data come from the project assimilated MODIS/ Terra, while simulations performed was used indicator AOT (Aerosol Optical Thickness) and missing values were identified by black dots.

Assessing variations shown in Figure 1.4c may indicate that predictions made recorded a significant improvement, while they suggesting that the northern part of the target area seems to be most affected by this phenomenon. Distribution indicated in Figure 1.5 is particulate matter (PM10) to various cities in the geographical area assessed.

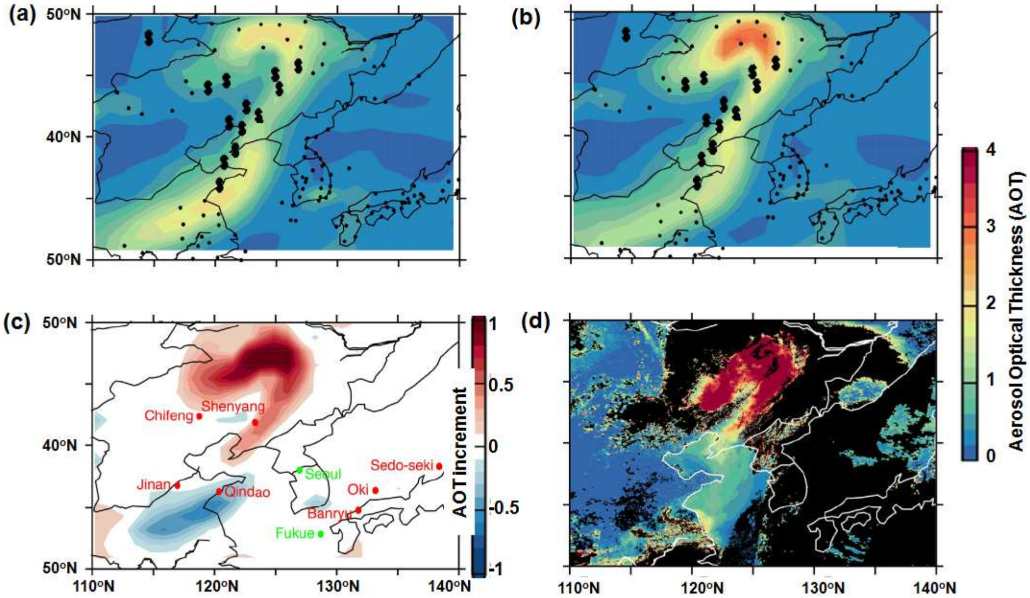

Figure 1.4. Estimation of AOT index at 12.05.2011, related to: a) no assimilation; b) DA prediction; c) differences (DA assimilation - no assimilation); d) MODIS/Tera measurements [8]

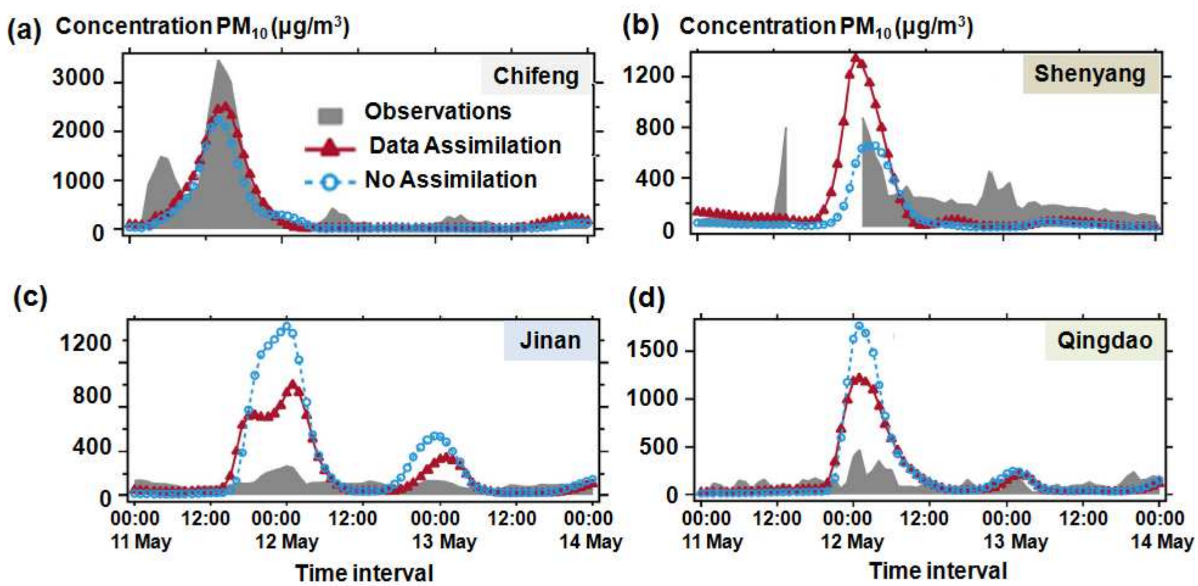

Figure 1.5. *PM_{10}* concentration reported for several cities located in the target area [8]

From these results it appears that the level is good Chifeng city, where there is a maximum concentration of 3000 mg / m3 at 12:00 (12.05.2011). Compared to these values, celelelate cities are even lower concentrations or missing values, such as in the case of Shenyang city. It may be observed that the numerical simulations have a good correlation with in situ measurements, accurately identifying and initiating sand storm.

Chapter 2

DATA ASSIMILATION - SEQUENTIAL AND VARIATIONAL METHODS

All DA schemes are processed sequential against time so that most assimilation methods presents common elements. The most common approach is that every observation of a sequence of variational problem solution be considered, where measurements butter used to adjust numerical simulations. Over time they developed various elements of theory and mathematical apparatus, which deals with the application of statistical principles generally able to reduce errors that may appear in the modelling [9]. The areas involving geo-fluids such as when predictions of atmospheric and ocean, focuses on the analysis of chaotic environment where it is important to establish the correct initial conditions in order to reduce error propagation from one simulation cycle to another or between different areas of computing. Most methods are the type of interpolations optimal DA (IO) that can be classified into type 1DVAR or 3DVAR scheme, existing and new schemes 4DVAR possibility of implementing that in addition to spatial characteristics taken into account during [4].

The successful implementation of DA methods and achieving realistic results it is important to consider the quality of databases used to force or validate numerical simulations. For the prediction of the waves, the most important factor is the wind that by its action on the air-water interface gives energy, this mechanism contributing to the emergence of wave heights. Given that ocean areas are characterized by large areas, currently the best contributor of mission's altimetry measurements provide easily covering these areas.

Considering all those, it still intends to present any fundamental underlying techniques DA.

2.1 Sequential Approach

These methods are based on differential equations with which information can be processed randomly distributed in time and space. For applications involving geofluide can go to the following relationship [10]:

$$s_k^p = \psi_{k-1} s_{k-1}^a \tag{2.1}$$

$$s_k^a = s_k^p + K_k (s_k^o - H_k s_k^p) \tag{2.2}$$

Where s indicates the state vector representing the variables included in the model as a grid points expressed either as finite elements or spectral elements. Considering predictions, they advance with a time step Δt to give the following shapes: a) $s_k = s(t_k)$; b) $t_k = k\Delta t$. In the above equations, the following parameters were indicated: p - prediction; o - observation; a - analyse; ψ - matrix indicating system dynamics; H_k - observations matrix.

If we refer to the finite element domain, Equation 2.1 become:

$$\psi_k^{(1)} s_k^p = \psi_{k-1}^{(2)} s_{k-1}^a \tag{2.3}$$

In view of the fact that the matrix $\psi_k^{(1)}$ it is irreversible, Equation 2.3 it can be written as:

$$\psi_{k-1} = [\psi_k^{(1)}]^{-1} \psi_{k-1}^{(2)} \tag{2.4}$$

For these relationships, the vector observations (s_k^o) is defined by a dimension p_k much smaller than dimension N feature parameters s_k^a and s_k^p. Matrix H_k is used for interpolating values from grid, the vector η_k (called *innovation* or *residue*) has the following representation:

$$\eta_k \equiv s_k^o - H_k s_k^p \tag{2.5}$$

Relation 2.2 is equivalent with the Equation 2.6 if: $y = s_k^p$, $z = s_k^o$ and $\alpha_2 = K_k$.

$$\bar{x} = y + \alpha_2 (z - y) \tag{2.6}$$

Parameter y refers to earlier observations based on its aiming at finally finding a gain matrix by which to identify optimal parameter values K_k. First step in this direction is to quantify the variation of geofluid (k_k^t) given by:

$$s_k^p = \psi_{k-1} s_{k-1}^t + b_{k-1}^t \tag{2.7}$$

In which, b_k^t refers to a sequence of white noise type that has the following form:

$$Eb_k^t = 0 \tag{2.8}$$

$$Eb_k^t (b_l^t) = Q_k \delta_{kl} \tag{2.9}$$

where: t - transposed column vector; δ_{kl} - Kronecker function.

If we include a constraint element (b_k) in Equation 2.1 it can be rewrite Equation 2.8 as [10]:

$$Eb_k^t = b_k \neq 0 \tag{2.10}$$

By implementing DA methods, in addition to obtaining gain matrix is envisaged the accuracy of numerical results compared with measurements:

$$s_k^o = H_k s_k^t + b_k^o \tag{2.11}$$

b_k^o indicates measurement error. Assuming that this parameter is a Gaussian sequence (type white noise), it appears the following form:

$$Eb_k^o = 0 \tag{2.12}$$

$$Eb_k^o (b_l^o)^T = R_k \delta_{kl} \tag{2.13}$$

In addition, it may indicate that the observations and the system noise are not correlated:

$$Eb_k^t (b_k^o)^T = 0 \tag{2.14}$$

On the basis of these simplified equations 2.7-2.14 mentioned in the variation over time can be estimated error covariance matrix:

$$P_k^{p,a} \equiv E(s_k^{p,a} - s_k^t)(s_k^{p,a} - s_k^t)^T \tag{2.15}$$

Where, s_k^a and s_k^p indicates that analysis and forecasting. This equation is also based on previous relationships that relate to:

$$P_k^p = \psi_{k-1} P_{k-1}^a \psi_{k-1}^T + Q_{k-1} \tag{2.16}$$

$$P_k^a = (I - K_k H_k) P_k^p (I - K_k H_k)^T + K_k R_k K_k^T \tag{2.17}$$

If we know the values $P_k^{p,a}$ according to $w_k^{p,a}$, it can be estimated qualitatively any state s_k^t for the value K_k. The optimal adjustment of the parameter K_k (reported at each time step) is identified by a reduction in error estimation:

$$R \equiv trP_k^a \equiv E(s_k^a - s_k^t)^T (s_k^a - s_k^t) \tag{2.18}$$

Equation 2.18 is adapted from 2.17, for matrix P_k^a when the derivatives item R in relation to the matrix K_k are null. Such an approach leads to obtaining a minimum value indicated by [10]:

$$K_k = K_k^* \equiv P_k^p H_k^T (H_k P_k^p H_k^T + R_k)^{-1} \tag{2.19}$$

Combining equations 2.1 and 2.2 to equation 2.19 specific to matrix optimal gain (K_k^*) we obtain a method of assimilation called Kalman filter. If we rephrase Equations 2.17 and 2.19 we can make a comparison between assimilation equations and the Kalman filter:

$$(P_k^a)^{-1} = (P_k^p)^{-1} + H_k^T R_k^{-1} H_k \tag{2.20}$$

$$K_k^* = P_k^a H_k^T R_k^{-1} \tag{2.21}$$

Analysing previous relationships it may indicates that the average variance is inversely proportional observations and assimilation is actually accurate forecasts in relation to the sum of current and past observations. If there is no information for a specific time k, parameters H_k and K_k^* are null.

The element P_k^a (Equation 2.17) can be brought to a simpler form if we consider $K_k = K_k^*$, situation in which the previous equations are:

$$s_k^p = \psi_{k-1} s_{k-1}^a \tag{2.22}$$

$$P_k^p = \psi_{k-1} P_{k-1}^a \psi_{k-1}^T + Q_{k-1} \tag{2.23}$$

$$K_k^* = P_k^p H_k^T (H_k P_k^p H_k^T + Rk)^{-1} \tag{2.24}$$

$$P_k^a = (I - K_k^* H_k) P_k^f \tag{2.25}$$

$$s_k^a = s_k^p + K_k^* (s_k^o - H_k s_k^p) \tag{2.26}$$

The advantage of this approach is the fact that it can reduce the error variance for the entire period of time that assimilation is reported, and not only in relation to a time step. Hence the name of the sequential method, because as current observations are processed, they are no longer included in the assimilation process [10].

Chapter 3

KALMAN FILTER

One of the first applications of Kalman filter was Apollo space program, which was taken to ensure an optimal trajectory and guidance to the aircraft. This was achieved by correlating information from various sources (e.g., radars, sensors, etc.) and solve potential errors series of measurements [11].

The equations for this filter are based on a set of relationships that are able to estimate the performance of a process by minimizing errors. It is used for a wide range of applications, from the type *hindcast* and reaching predictions that take into account the previous behaviour of the system [12]. A simplified diagram of such a filter is shown in Figure 3.1. The best representation of the state of a parameter can be achieved by means of measurements from measuring instruments, which have the disadvantage that are affected by errors and that may have different operating principles. Using a Kalman filter, you can group all available data on them and the initial conditions is possible to estimate an optimal states of a system.

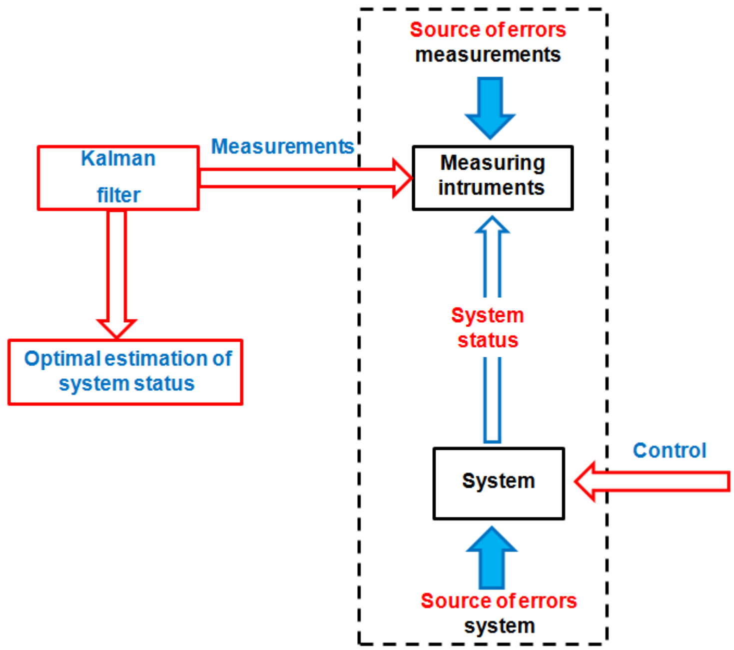

Figure 3.1. Kalman filter - main components [13].

3.1 Random Processes

These processes, which is also called stochastic and deterministic processes are completely opposite. A deterministic process aims to establish a single way of evolving a system, while in a random pattern may develop solutions. This is the fact that starting from an initial state can be assimilated many variables that increase the level of uncertainty of a problem [14].

Considering a dynamic process characterized by a differential equation (of order n), process dynamics can be described by [15]:

$$y_{i+1} = a_{0,i}y_i + ... + a_{n-1,i}y_{i-n+1} + u_i, i \geq 0 \tag{3.1}$$

where u_i refers to the autocorrelation function (mean value):

$$E(u_i, u_j) = R_u = Q_i\delta_{ij} \tag{3.2}$$

and parameters $y_0, y_{-1}, \dots, y_{-n+1}$ define initial values, which are relative to a covariance matrix (of size $n \times n$)

$$P_0 = E(y_{-j}, y_{-k}), j, k \in \{0, n-1\} \tag{3.3}$$

Simplifications can be also achieved, meaning that:

$$E(u_i, y_i) = 0 \qquad (pentru - n + 1 \leq j \leq 0) \qquad \text{and} \qquad i \geq 0 \tag{3.4}$$

and

$$E(u_i, y_i) = 0, i \geq j \geq 0 \tag{3.5}$$

By previous equations it entails identifying the noise, which is independent of the process we evaluate. This can be expressed mathematically as:

$$x_{i+1} \equiv \begin{bmatrix} y_{i+1} \\ y_i \\ y_{i-1} \\ \vdots \\ y_{i-n+2} \end{bmatrix} = \begin{bmatrix} a_0 & a1 & \cdots & a_{n-2} & a_{n-1} \\ 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 \end{bmatrix} \begin{bmatrix} y_i \\ y_{i-1} \\ y_{i-2} \\ \vdots \\ y_{i-n+1} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} u_i \tag{3.6}$$

Noting the first element as equal to *M*, the second to n_i, and the third with W, it can get a simplified form of Equation 3.6:

$$x_{i+1} = Mn_i + Wu_i \qquad \text{and} \qquad y_i = [1 \quad 0 \quad \dots \quad 0]n_i \tag{3.7}$$

or possibly in a more compact form:

$$x_{i+1} = Mn_i + Wu_i \tag{3.8}$$

$$y_i = D_i n_i \tag{3.9}$$

Using the relation 3.8 can establish a new state system x_{i+1}, resulting from the combination of the previous state (x_i) and noise Process (u_i), while 3.9 indicates how the relationship is processed observations y_i characteristic state x_i. Based on these relations further will achieve a more complete versions of the Kalman filter and its versions.

3.2 Discrete Kalman Filter (FKD)

If we aim to estimate a state $x \in \Re^n$ a process using a Kalman filter, we must resort to linear stochastic differential equations:

$$x_k = Ax_{k-1} + Bu_k + s_{k-1} \tag{3.10}$$

where $z \in \Re^m$, is a measurement defined as:

$$z_k = Dx_k + v_k \tag{3.11}$$

In the foregoing equations, the *A* and *B* connection state to said input current / previous state, while s_k and v_k refer to the process and measurement noise, and *D* is a matrix indicating the linear dependence of the output of the system. If we assume that the two variables (s_k and v_k) are independent and have the following probability distribution of:

$$p(w) \approx N(0,Q) \tag{3.12}$$

$$p(w) \approx N(0,R) \tag{3.13}$$

where *Q* and *R* refers to the covariance matrix of the process noise and the measurement in question, which for simplification are considered to be constant.

The element A ($n \times n$) switching from an earlier time (*k-1*) by a current moment *k*, without taking into account the input values u_k and w_k. Matrices *A* and *D* are updated each time step, but this case will be deemed to be constant.

By $\hat{x}\bar{k} \in \Re^n$ indicates a previous state system, which is actually estimation of a time *k* the system features known from previous steps. In addition, it also knows a state $\hat{x}_k \in \Re^n$ indicates for a moment k, which relates to comments z_k. Based on these relationships can be established errors *a priori* and *a posteriori* [15]:

$$\bar{e}_k \equiv x_k - \hat{x}_k^- \tag{3.14}$$

$$e_k \equiv x_k - \hat{x}_k \tag{3.15}$$

In this case, *a priori* error variance can be written as:

$$P_k^- = E[e_k^- e_k^{-T}] \tag{3.16}$$

and *a posteriori* error variance has the expression:

$$P_k = E[e_k e_k^T] \tag{3.17}$$

The next step is to identify the Kalman filter equations that define so it has established an equation for a state *a posteriori* ($\hat{x}_k$) combining an estimate a priori ($\hat{x}_k^-$) and relative differences between current measurement (z_k) and a prediction of the measurements ($H\hat{x}_k^-$).Such an equation may be:

$$\hat{x}_k = \hat{x}_k^- + K(z_k - D\hat{x}_k^-) \tag{3.18}$$

Differences reported $(z_k - D\hat{x}_k^-)$ define measurement *residue* or *innovation*. Parameter *K* ($n \times m$)It is called *gain*, an important factor that reduces variation error *a posteriori*. This minimization can be achieved by an adjusted matrix (K_k) to improve the equation of 3.16, as follow:

$$K_k = P_k^- D^T (DP_k^- D^T + R)^{-1} \tag{3.19}$$

Analysing the previous equation, it can be mentioned that when the measurement error variance (*R*) tends to zero, parameter K_k influencing residual have increasing values. This trend is indicated by:

$$\lim_{R_k \to 0} K_k = D^{-1} \tag{3.20}$$

Conversely, if the variance of the error for a state *a priori* (P_k^-) tends to zero, parameter K_k changes residue in the sense that its value increases with very small.

$$\lim_{P_k^- \to 0} K_k = 0 \tag{3.21}$$

Kalman filter is based on a process that takes into account the feedback generated in that predict a state model for a certain time and information while still taking shape measurements. Such equations of the filter are divided into two parts: a) time update equations; b) Update measurement equations, where the first category indicates the time evolution of the current state, while the rest of equations are considering obtaining information on reaction system by adding new measurements that improve next cycle predictions.

The equations of the first category are listed below:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_k \tag{3.22}$$

$$P_k^- = AP_{k-1}A^T + Q \tag{3.23}$$

while the measurement equations are:

$$K_k = P_k^- D^T (DP_k^- D^T + R)^{-1} \tag{3.24}$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - D\hat{x}_k^-) \tag{3.25}$$

$$P_k = (I - K_k D)P_k^- \tag{3.26}$$

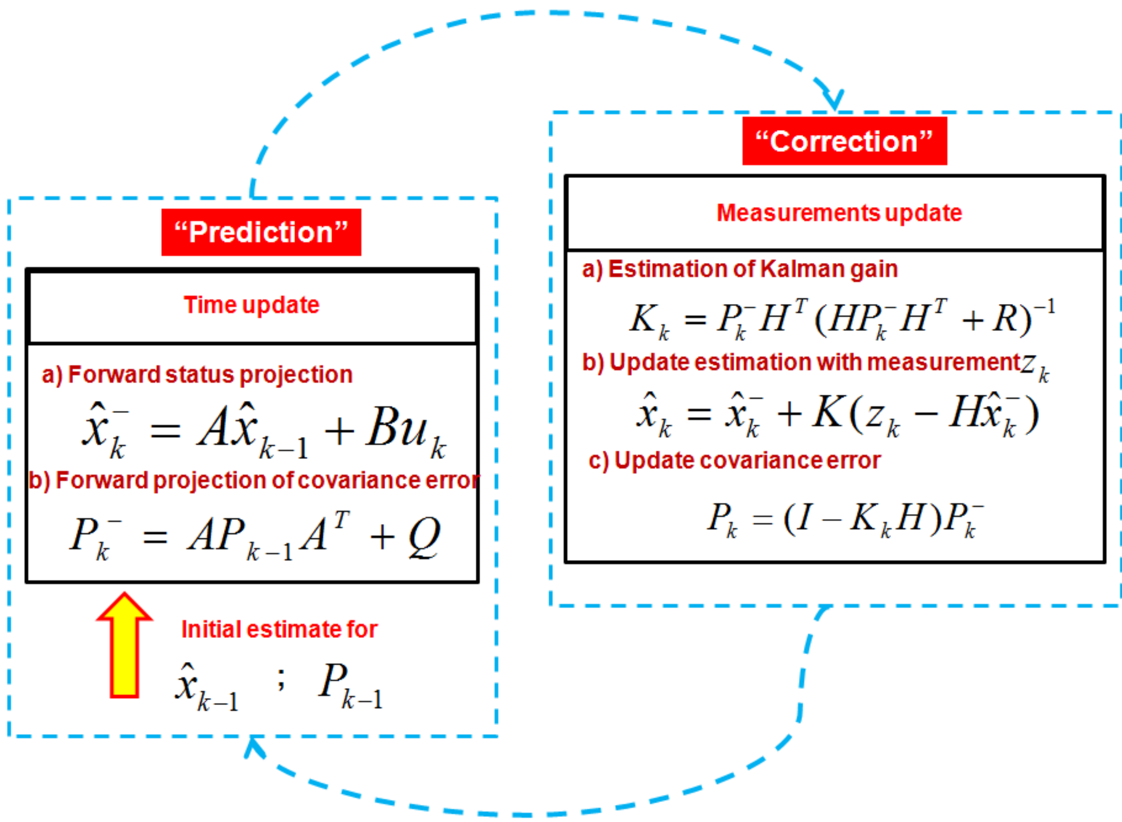

Figure 3.2. Simplified representation of the discrete Kalman filter [15].

Usually performed in pairs Update measurement time and this process is repeated with a priori values in order to establish a new estimate. This cycle of assimilation is shown in detail in Figure 3.2, which presents the main elements of a discrete Kalman filter.

Chapter 4

INTEGRATION OF DATA ASSIMILATION TECHNIQUES IN HYDRO-METEOROLOGICAL PREDICTION CENTRES

The dynamics of air masses and atmospheric influences and shapes our daily activities. In order to identify the evolution of these natural phenomena, it is important to use quality observations that can come both from in situ measurements (or satellite), or possibly considering datasets provided by numerical models globally or regionally. Based on this information can make various predictions that have application in various areas of interest, such as meteorology, renewable energy or search and rescue operations. Coastal probably the most important applications relate to the naval and offshore, a particular focus on identifying extreme conditions that may adversely affect these activities.

Over time numerical prediction models wave significant progress, significantly enhanced the accuracy of predictions provided by the application of data assimilation schemes. A more common procedure is the inclusion of satellite measurements in the stages of assimilation and validation, this data source is preferred because altimetry missions covering most areas of marine and resolution time domain pretty good [16].

Applying these computing models are desired a complete picture of the distribution conditions wave, both offshore and coastal using datasets that may be missing values or may be available only for certain time periods or geographical areas . Most often determining a physical parameter can be identified indirection development parameters such as for example the distribution of coastal currents or rate of coastal erosion. If we refer to the wave that provide predictive models globally, have stated that they provide better results compared to ocean areas closed basins where non-linear processes to identify regional patterns lend themselves better adapted to particular target areas. This is because in areas with shallow water and transfer processes dissipating wave energy are more complex, this category includes physical phenomena such as breaking waves, coastal currents or that influence the refraction of waves.

By using a grid computing, natural processes and dynamics of waves are measured more accurately by these numerical models that can provide a wider range of information than those from other sources that do not involve numerical simulations. Numerical simulations for marine areas seem more suited to identify the evolution of natural phenomena (e.g. storm), where for large areas of water can monitor (or simulate) the dynamics of an event.

The first wave patterns occurred in the early nineteenth century, being used during the Second World War for the development of marine forecasts for the period in which the Allied forces invaded Normandy have (June 6, 1944). Currently there are several operational models, among which may be mentioned` WAM (WAve Model) [17], SWAN (Simulating WAves Nearshore) [18] and WW3 (WAVEWATCH III) [19]. In addition to these models that have a global reach, there are programs that are designed predictions derived regional fields waves [20].

The waves are generated by the action of air masses, the amount of energy being transported directly influenced by wind speed and surface area on which it acts *fetch*. Therefore, special attention should be paid to the accuracy of wind data that are included in numerical simulations that can contribute a marine weather that are not covered in reality.

Figure 4.1 gives a general scheme underlying the wave patterns, indicating how different physical processes and phenomena are linked in order to simulate the changing digital wave. They cover the entire life cycle of waves begin generating waves and ending with increased dissipative phenomena that become more visible near the coastal areas. For the broad action of wind and nonlinear interactions between waves (e.g. triads) are most important, while nearshore wave energy is dissipated gradually in the surf zone. Globally implemented a significant number of operational models for predicting waves, a short presentation of them is presented in Table 4.1.

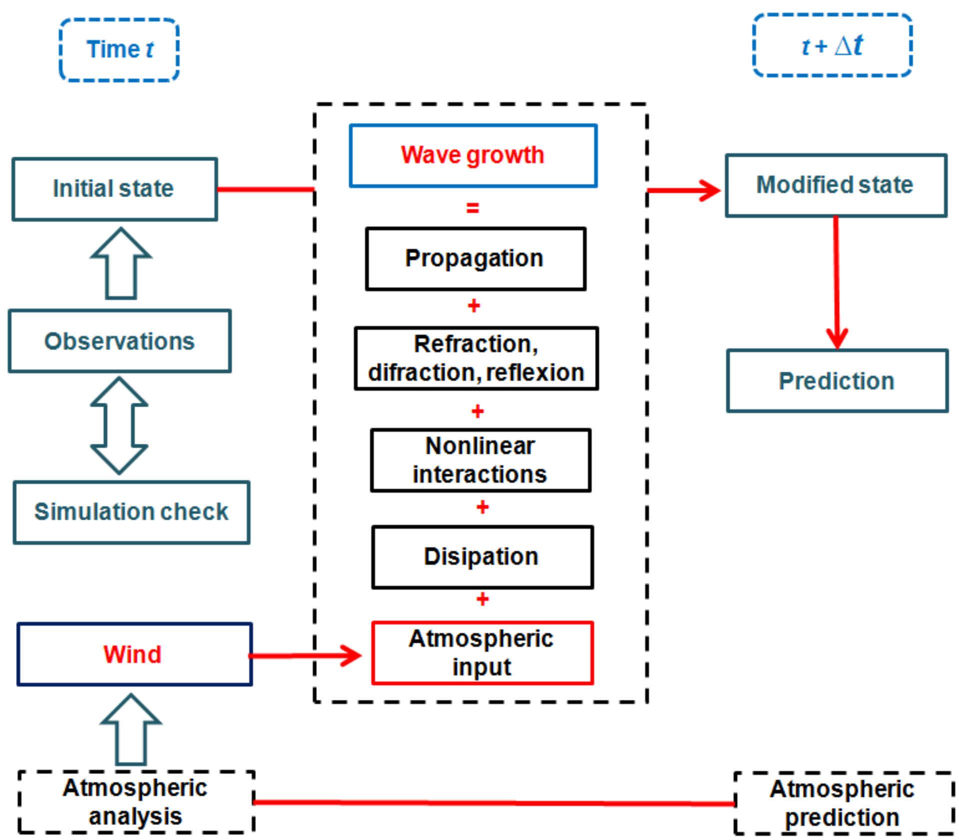

Figure 4.1. Structure of a wave prediction model [21].

Table 4.1. Numerical systems used for waves predictions [21].

Country	System	Region	Resolution	Area
Australia	WAM	Global	3° x 3° (lat/long)	offshore
	WAM	Australia	1° x 1°	offshore
Canada	Canadian Spectral Ocean Wave Model (CSOWM)	Atlantic Ocean (north)	1.08° long.	offshore
	CSOWM	Pacific Ocean (north)	1.08° long.	offshore
Europe	WAM	Global	1.5° x 1.5°	hybrid (offshore/ costal)
	WAM	Mediterranean Sea Baltic Sea	0.25° x 0.25°	-
France	VAGMED	Mediterranean Sea (West)	35 km polar	offshore
	VAGATLA	Atlantic Ocean (north)	-	offshore
Germany	Deutscher Wetterdienst	Atlantic Ocean (north)	-	offshore
	AMT für Wehrgeophysik	Norway Sea North Sea	50 km	continental
Greece	Model Mediterranean	Mediterranean Sea (centre and east)	100 km polar	offshore
Hong Kong	MRI-II	5°–35°N; 105°–135°E	-	offshore
	Costal model HK	Hong Kong	4.4 x 4.4 km	coastal
India	Sverdrup-Munk Bretschneider	local sea	2.5° x 2.5°-	offshore
Ireland	NOWAMO (adjusted model)	Atlantic Ocean (north)	-	hybrid
Japan	MRI-II	Pacific Ocean (north)	381 km 36 x 27	offshore
	MRI-II	local sea	127 km 37 x 31	offshore
	costal model	coastal area	10 km	hybrid
Malaysia	GONO	From Equator to 18°N; 110°–118°E	2° x 2°	hybrid
Netherlands	GONO	North Sea; Norway Sea	75 km	hybrid
Norway	WINCH	North Sea Norway Sea	75 km	offshore
Sweden	NORSWAM	North Sea	100 km	hybrid
UK	European model	Atlantic Ocean	0.25° x 0.4°	coastal
	Global model	Global	1.25° x 0.8333°	offshore
SUA	NOAA/WAM	Global	2.5° x 2.5°	offshore
	GWAM	Global	1° x 1°	offshore

4.1 Black Sea Area

Currently, there is interest from countries in the Black Sea region to develop regional models for predicting waves. From this point of view, the best results seem to be reported by researchers from Bulgaria who are considering implementing a model WAVEWATCH III operationally through IncREO project (Increasing Resilience through Earth Observation). To force model were considered wind data (reported by 10 m) from ALADIN project [22], the results are reported to satellite measurements. The region covers the area considered for implementation 40ºN - 47ºN; 27ºE - 42ºE, spatial resolution is set to the brink of 0.125º. It should also be noted that the numerical simulations is done hot, meaning that results in some previous runs are used to initiate new simulations [23].

A number of results are shown in Figure 4.2, which also shows the Jason-2 mission paths that are reported in the western basin for moments of time envisaged. Analysing these distributions may be mentioned that in May consistent Hs values are reported in the north-western sea which can reach maximum 7 meters if conditions more energy. Regarding the direction of wave propagation is observed that the vectors of direction are oriented from east to west, which means that air masses acting on an area fetch important, contributing to a concentration of wave energy in the Western basin.

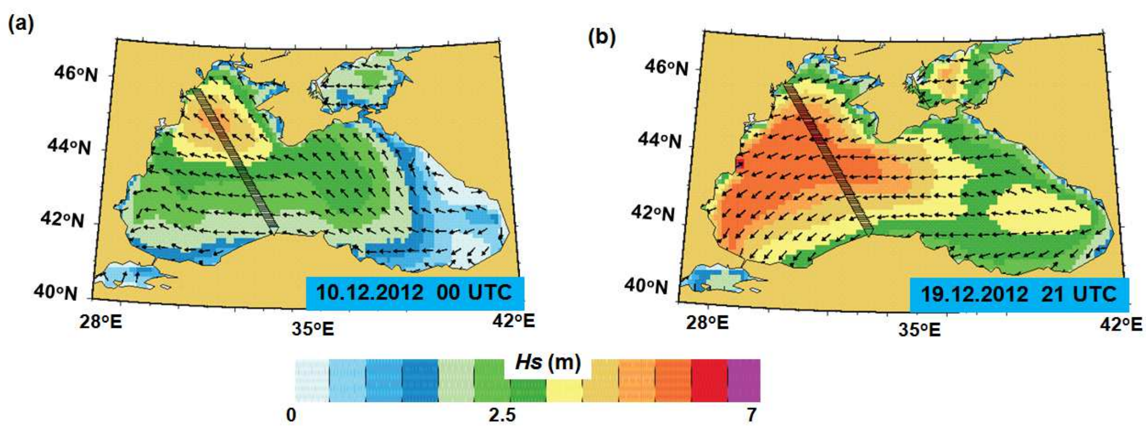

Figure 4.2. Spatial distribution of the *Hs* (m) values reported for the Black Se by the WAVEWATCH III model. Results available for: a) 10.12.2012; b) 19.12.2012 [23]

DA techniques are generally used for preparation of prediction or warnings present and future, but have the ability to generate database and reported in the past, so-called hindcast. Continue to be presented a study in which they used wind data covering a period of 60 years [24], given that improve marine forecasts in this region. Even if not related to the assimilation of data, taking into account the scope of this project results in this case can be used to implement an operational system. For this study was used SWAN model, results in Figures 4.3 and 4.4 were reported for Hs values estimated for the period 1949-2010, where to force the numerical model were used wind data from the program NCEP / NCAR.

Analysing the distribution of seasonal mean values in Figure 4.3 for the entire period of time considered, it can be mentioned that the most important values appear to be reported in the central Black Sea, which also covers a portion of the western side.

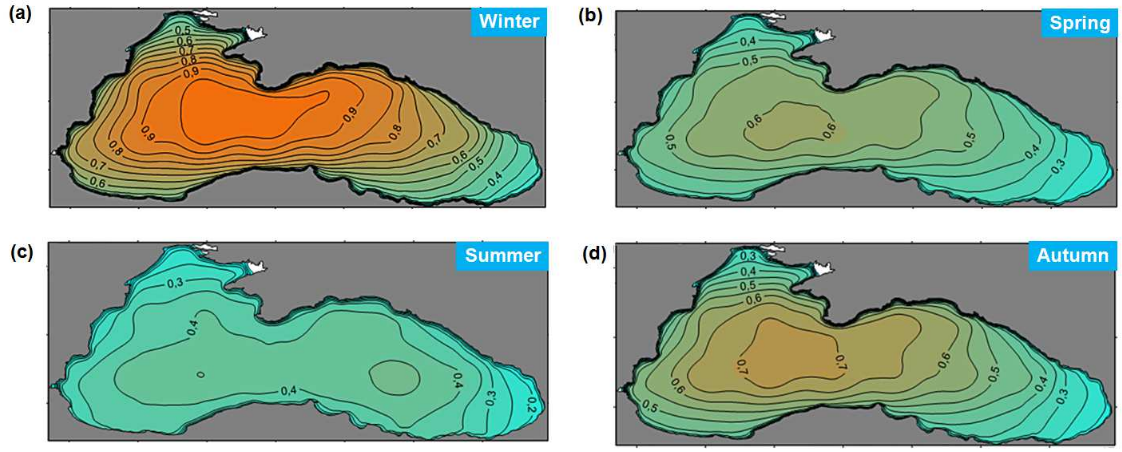

Figure 4.3. Spatial distribution of the *H*s parameter (average values), indicated by the SWAN model for the interval 1949-2010 [24]

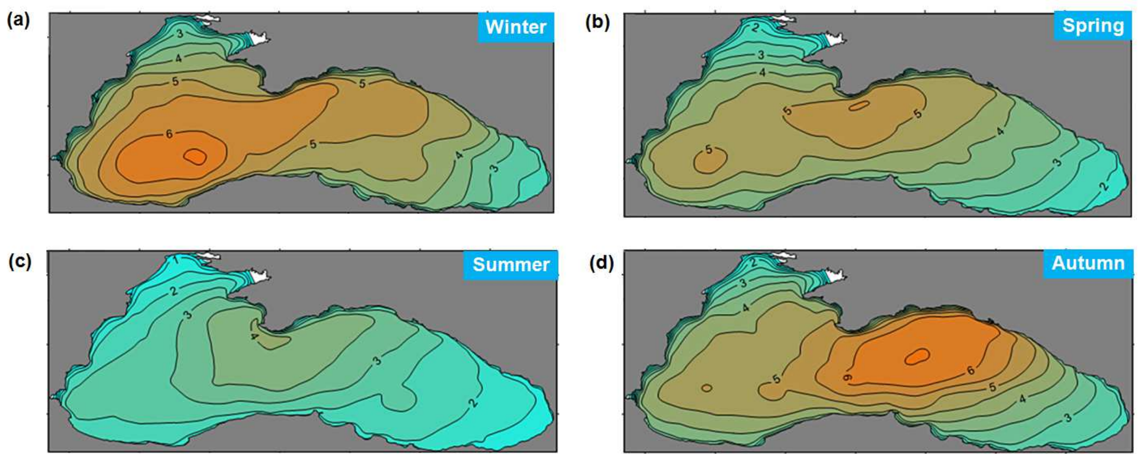

Figure 4.4. Spatial distribution of the *H*s parameter (maximum values), indicated by the SWAN model for the interval 1949-2010 [24]

Considering the distribution of the maximum values, it is noted that the central and western area presents significant values in winter and spring, compared to the eastern region where Hs in autumn highs can reach up to 6 m.

Chapter 5

EVALUATION OF WIND AND WAVE CONDITIONS IN THE BLACK SEA USING DATA FROM NUMERICAL MODELS AND SATELLITE MEASUREMENTS

Maritime activities are important for countries in the Black Sea region, especially by those related to port operations or navigation involving areas such as fisheries, transport or energy. To maintain safety in this area, it is important to understand and to estimate the extreme conditions in order to stop activities near shore when needed or to avoid areas of storm that may exist on the route ships in wide areas. Since all activities related to shipping involves large quantities of oil it should be noted that there is a risk in the event of storm conditions ships shipwreck, an event with negative consequences for flora and fauna of the marine environment [25]. This problem becomes even more important when discussing protected areas, such as for example when the Danube Delta located in the north-west of the Black Sea. In this region, the interaction of currents and waves generated by the Danube, serious problems can arise for local waterway given that here there is an important transport corridor (VII Pan-European) which connects the Black Sea to the North Sea, the Rhine axis Main-Danube. Even if no Black Sea energy conditions similar to those in ocean areas [26, 27], previous studies have suggested that wind and waves from this geographical area can reach significant values [28]. Considering these aspects, still there will be an overview of extreme conditions that may be encountered along the key shipping lanes in the Black Sea.

The distribution of the points of reference is shown in Figure 5.1. In order to identify the most relevant wind and wave conditions, we have identified three major transport routes. The first of them (denoted as Route A) defined between Odessa and Istanbul, along which there are defined three reference points (A1, A2, and A3). Another important route (route B) Kerch Strait linking Istanbul (Russia), where C starts route that ends in the coastal area of Georgia.

Another objective of the current study, is the assessment of natural conditions near coastal areas where these resources (wind and wave) are concentrated natural. One such area is situated near the Danube Delta, where interactions between waves and coastal currents may contribute to the occurrence of dangerous conditions [29].

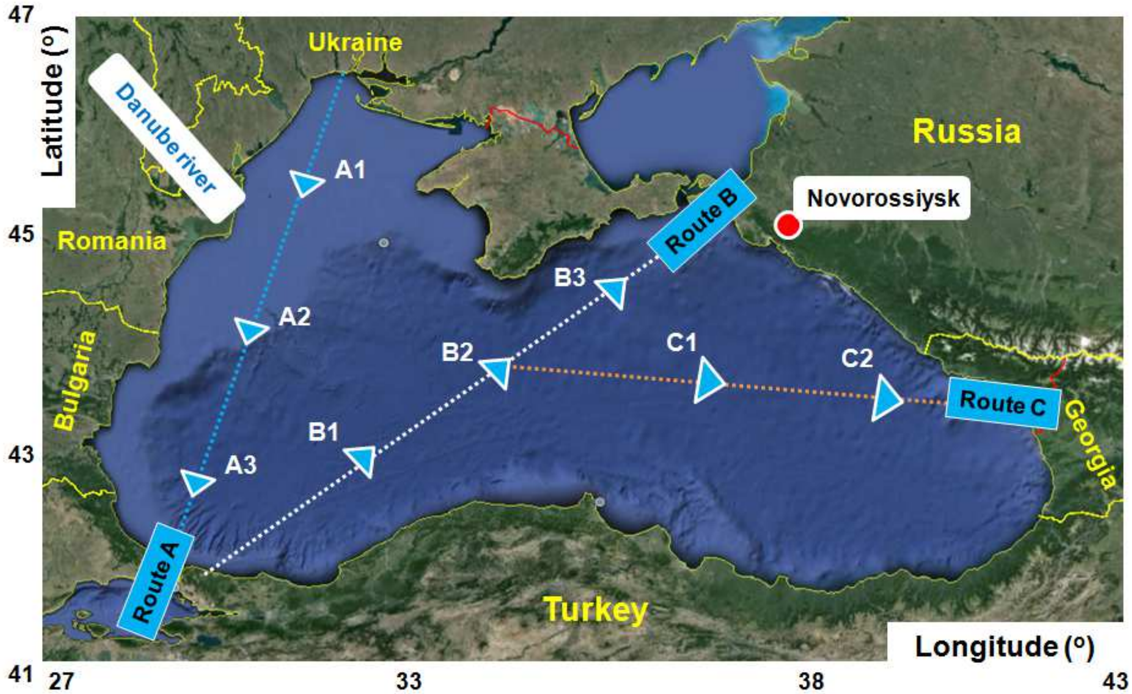

Figure 5.1. Distribution of the reference points along the Black Sea major navigation routes (A, B and C) [30]

Another interesting area is the same in the north-east of the basin, near the region of Novorossiysk (Russia), where at the air-dried form Bora wind. During this event, there may be comparable to those of a hurricane, if we take into account that wind speeds often exceed 50 m / s [31].

To analyse these environmental conditions in the Black Sea, they were considered two sets of data. The first of these comes from the platform AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic Data), which is a multi-mission project that collects data from several altimetry missions [32]. Satellite measurements (wind and wave) were processed for the period January 2010-November 2015, for which they were available on day one value relative to 00:00 UTC.

Variations in Marine were also analysed data from considering and incorporating ECMWF several databases reconsidered [33, 34]. For the current study, data were processed for the period January 2005 - December 2014, the values being reported to the brink of 6:00 (00: 00/06: 00/12: 00/18: 00 UTC). ECMWF data, the parameters taken into account marine accessories include: significant wave height (Hs), wave direction, wind speed reported at a height of 10 m (*U10*) and wind direction. Since the two databases envisaged (AVISO and ECMWF) are reported for different ranges is expected to register significant variations between results provided. A qualitative analysis of the two data sets is not a main point, the main objective consisting to identify extreme conditions that might occur in the Black Sea.

Figure 5.2 shows variations in parameter *U10* (maximum values) along the three main routes in the Black Sea (A, B and C).

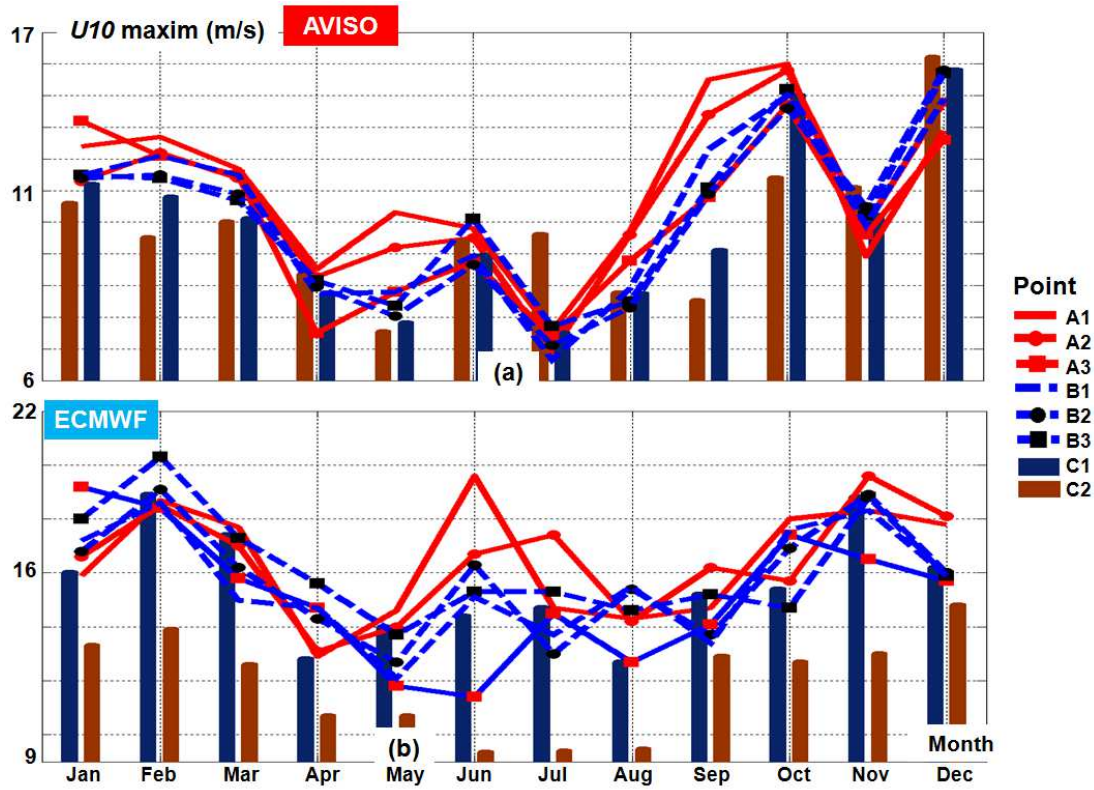

Figure 5.2. Monthly variations of the *U10* parameter (maximum values) reported by the reference points, based on: a) AVISO measurements; b) ECMWF data [30]

Regarding data AVISO, mention may be located on the route that points A and B have values consistent, particularly for the period: January-March (maximum: 14.2 m / s-A3); May (11.3 m / s - A1); August-September (15.5 m / s - A1). The analysis points C1 and C2, it can be seen that the maximum values are equally distributed, except that paragraph C1 may report a maximum of 16.2 m / s in December, compared to 15 m / s indicated by C2 in October. In general, higher values are reported in the October-December period, compared with the summer period when a minimum of 7.5 can record the route C.

Moving on to the ECMWF data (Figure 5.2b), it can be seen that the point group C are highlighted as well as less energy, except that this time the January-February period shows higher values. For this period of the year, a maximum of 20.3 m / s is indicated for B3, while a minimum of 11.8 m / s is the deposit of A3. A peak of 19.6 m / s is indicated for A1 (More) value that is similar to that reported for most points in November. C1 showing this time point values consistent, comparable to those reported along other routes. So near this point can register values of 18.8 m / s in February and November, while a minimum of 12.7 m / s is observed in April and August respectively. Much lower values are reported by point C2, which in winter (October to March) has a maximum of 14.8 m / s in December, while in summer the wind speed can atinge10.7 m / s except of September when there is a value of 12.9 m / s.

Figure 5.3 shows a similar analysis, this time centred on the distribution parameter Hs. Prima facie, it appears that the distribution of values is smoother being reported little difference between the reference points. Both sets of data indicate February as more energy, noting that AVISO reported between April to September constant values compared to ECMWF, where values rise gradually from June to September, leading ultimately to a value of 6.21 m (B3) for the month of December. Among the topics analysed can say that C2 is characterized by the lowest values, except for data that may indicate AVISO January and February a maximum of 3.89 m.

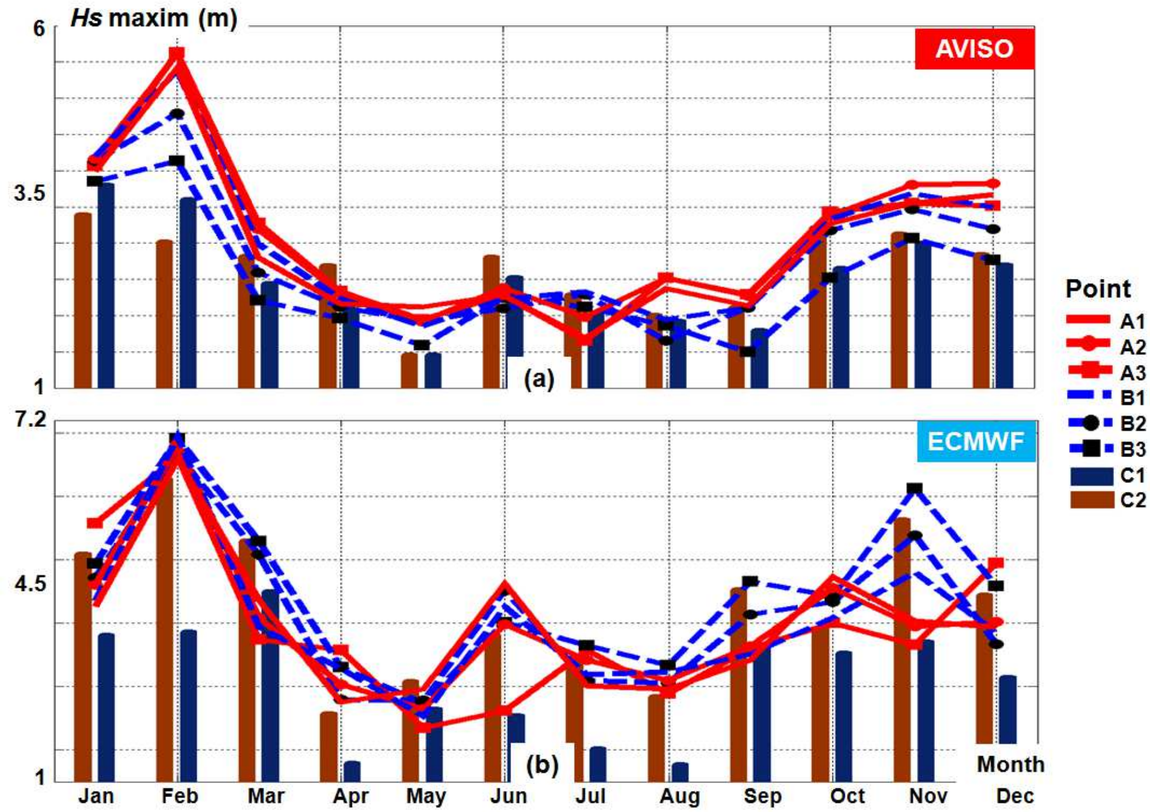

Figure 5.3. Monthly variations of the *Hs* parameter (maximum values) reported by the reference points, based on: a) AVISO measurements; b) ECMWF data [30]

In addition to the wave height, another important factor influencing navigation conditions is given by the direction of the propagating waves, this is shown in Figure 5.4 for various offshore points located on traffic routes A, B, or C. The analysis these results can be seen that there is no evidence a dominant direction, each zone being defined by specific characteristics. Near the A1 point, the direction from which the waves propagate changes significantly throughout the year, being the most common directions northwest and southeast, noting that in May the southern sector can be considered representative. If we refer to point A3 (located in the southeast), we can see that air masses reported in the northwest are dominant throughout the year, it is possible that between November to February to manifest conditions near the shoreline (South East).

For points B2, most values are concentrated along the east-west axis, with reports and several peaks in areas northwest and southeast, where the heights of the wave can reach up to 6 m. In August, craft flying near this point may encounter waves of the north, of which mention may be made bigger waves from the northwest. Regarding C2, it can indicate that the reported values of the West are the most common, except that in August the northeast sector appears to be more important. A similar trend is highlighted point A3, where between November to February is possible to record waves from the coastal area of Georgia (southwest).

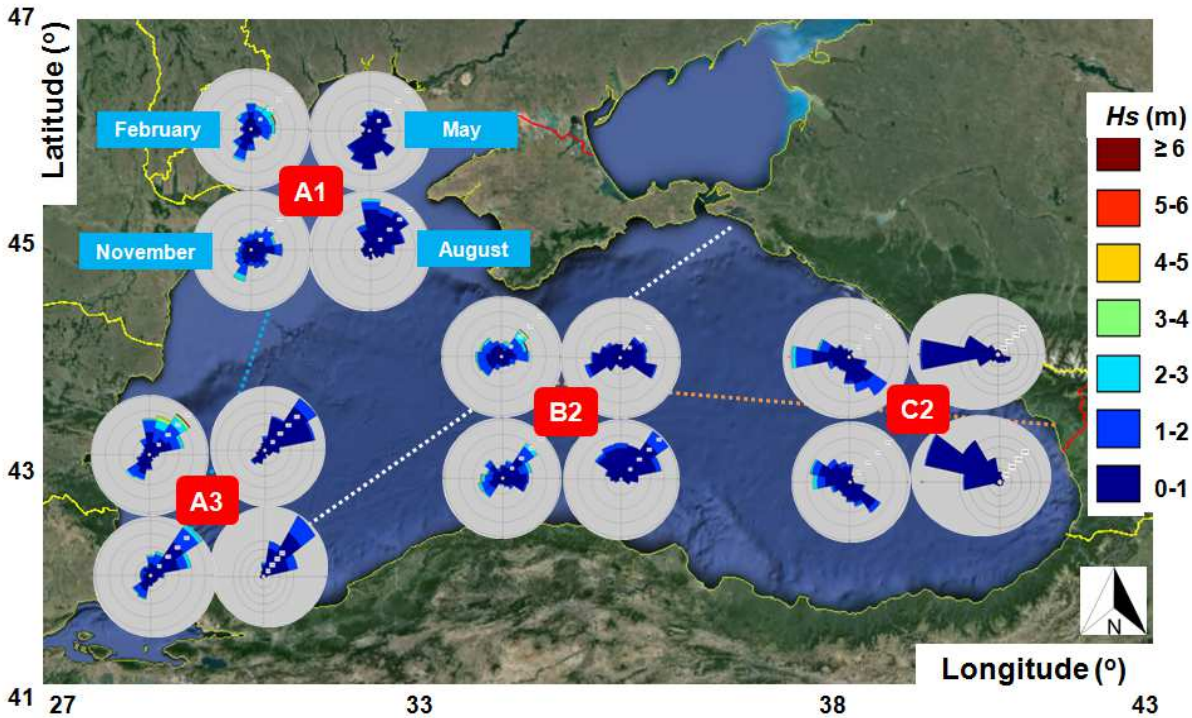

Figure 5.4. Wave roses reported by the ECMWF dataset for the interval January 2005-December 2014. Results reported for February, May, August and November taking into account only the points A1, A3, B2 and respectively C2 [30]

As near Delta may manifest significant environmental conditions in Figure 5.5 illustrates the distribution of wind and wave conditions for the period 2010-2015. *U10* time series parameter is shown in Figure 5.5a, which can be seen variations of the summer season (goals) and winter of each year considered. As expected, the most important values are reported in the winter, when values may reach a maximum of 16 m / s, while the inter-annual period 2014-2015 can specify that seems to present values consistent. Regarding parameter *Hs* (Figure 5.5b) revealed maxima varies around a value of 3 m, with an exception where there is a peak of 5.8 m in 2012.

Analysing time series, they were identified several instances where wind and wave energy higher values, as can be seen from Figure 5.11c and 5.11d. Regarding these spatial distributions, it can be seen that the extreme values reported by the two parameters that do not coincide timeframe.

Another important point was defined in the north-west region of the Black Sea near Novorossiysk (Russia) where extreme conditions can be reported, particularly in terms of wind speed. Such an analysis is shown in Figure 5.6, considering the maximum monthly data reported by AVISO and ECMWF parameters *U10* and *Hs* respectively. Based on these data it can be seen that the values indicated by ECMWF model are generally higher, notably in terms of *Hs* parameter.

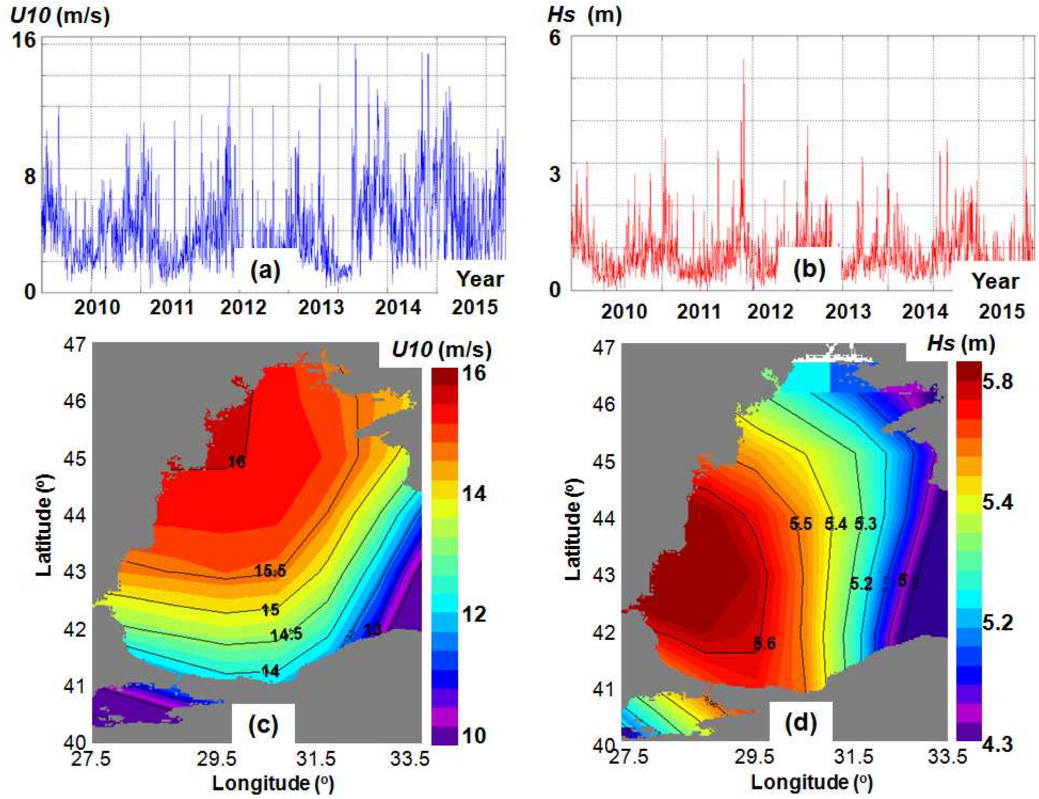

Figure 5.5. Distribution of the marine conditions from the north-western part of the Black Sea, where: a) and b) time series of the *U10* and *Hs* parameters reported close to the Danube Delta; c) extreme values of the *U10* parameter indicated for 20.10.2013; d) extreme values of the *Hs* parameter indicated for 8.02.2012. AVISO measurements processed for the interval 2010-2015 [30]

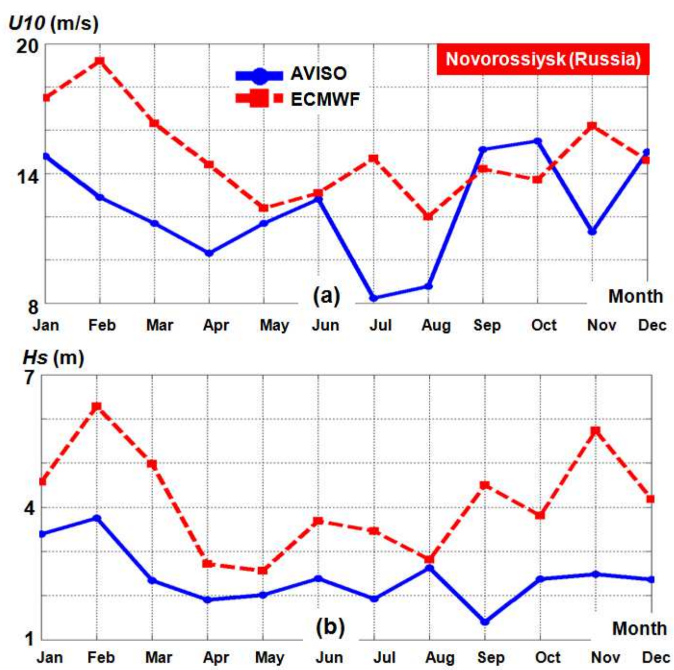

Figure 5.6. Monthly variations of the *U10* (figure a) and *Hs* (figure b) parameters reported for Novorossiysk (Russia), considering the AVISO data available for the interval 2010-2015 [30]

In terms of wind speed, ECMWF data indicates February as more important with a maximum of 19.2 m / s, while the period from May to December values may fluctuate in the range 12-16.2 m / s. An uneven distribution of values is indicated by measurements AVISO showing higher values for the period from September to December, when recording a maximum of 15.5 m / s. Here it should be noted that in November the values can achieve a minimum of 11.3 m / s. Much lower values are reported in the summer season (July and August), when a minimum of 8.22 m / s can be recorded.

Hs parameter distribution is shown in Figure 5.6b, of which one can observe a similar distribution of monthly values, indicating both databases February as more important, the reported values of 3.75 m (AVISO) and 6.28 m (ECMWF) . Values AVISO are relatively constant throughout the year, with the exception of September when recording a minimum of 1.4 m. Analysing the distributions of ECMWF, it highlights two periods where values tend to increase, namely: a) Mai (2.56 m) - July (3.46 m) - October (3.81 m) - December (4.18 m); b) April (2.71 m) - June (3.69 m) - September (4.5 m) - November (5.74 m).

Based on the above results, it can be concluded that although the Black Sea is an enclosed generally characterized by average values of environmental conditions, there may arise situations where extreme conditions that can restrict the activities of coastal or offshore.

Chapter 6

IMPLEMENTATION OF DATA ASSIMILATION TECHNIQUES IN THE BLACK SEA

6.1 Data assimilation using successive corrections method

This chapter considers the development and implementation of processes for data assimilation (DA) envisaged target area is located in the western part of the Black Sea, with special attention being paid to Romanian coastal zone. As can be seen in Figure 6.1, the first step is to implement these systems in the western basin calculation considering two areas: a) Level I - Basin; b) Level II - local.

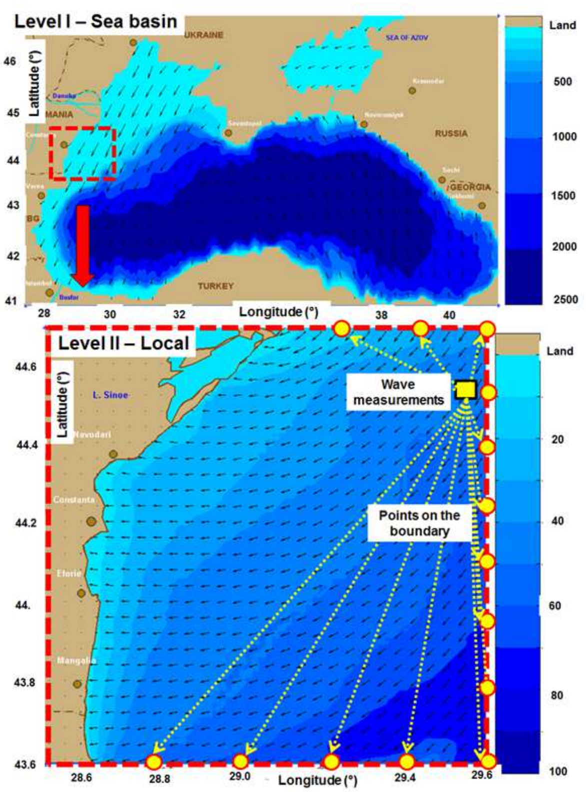

Figure 6.1. Computational levels considered for the SWAN simulation [35.

The Figure shows the general climate conditions wave (wave vector and scalar fields) that can be encountered frequently, while in the background one can see the pool closed bathymetry. Besides these elements are highlighted and border points used in simulations to model SWAN (Simulating Waves Nearshore) and Gloria platform that is an important source of in situ measurements. Regarding settings applied in numerical modelling, more details are provided in Table 6.1.

The SWAN was implemented considering the 36 directions and 30 frequencies which have a value between 0.12 Hz - 1.2 Hz, simulations were run in an unsteady characterized by a step for 20 minutes, the not-included effects of the presence of coastal currents. Black Sea was considered useful to use a number of iterations equal to 10, in order to achieve better accuracy of the results. Characteristics of the target zone and targeted physical processes in numerical simulations are also identified in Table 6.1.

Table 6.1. Main parameters and physical processes used for the SWAN simulations, indicated for each computational level [35]

<table>
<tr><th rowspan="2">SWAN</th><th colspan="12">Physical parameters</th></tr>
<tr><th colspan="2">Origin</th><th>Δx × Δy (º)</th><th>Δt (min)</th><th>Δθ (º)</th><th>Mod</th><th>nf</th><th>nθ</th><th colspan="4">ngx × ngy = np</th></tr>
<tr><td>Level I basin</td><td colspan="2">X_{O1}=-27.5°V
Y_{O1}=41°N</td><td>0.08× 0.08</td><td>20</td><td>10</td><td>Nestat</td><td>34</td><td>36</td><td colspan="4">176×76=13376</td></tr>
<tr><td>Level II Local</td><td colspan="2">X_{O2}=-28.5°V
Y_{O2}=43.6°N</td><td>0.005 × 0.005</td><td>20</td><td>10</td><td>Nestat</td><td>29</td><td>36</td><td colspan="4">75×90=6750</td></tr>
<tr><th rowspan="2">Input / Proc.</th><th colspan="12">Physical processes activated</th></tr>
<tr><th>Wave</th><th>Wind</th><th>Tide</th><th>Crt</th><th>Gen</th><th>Wcap</th><th>Quad</th><th>Tri</th><th>Dif</th><th>Mfr</th><th>Set up</th><th>Br</th></tr>
<tr><td>Level I basin</td><td>0</td><td>X</td><td>0</td><td>0</td><td>X</td><td>X</td><td>X</td><td>0</td><td>0</td><td>X</td><td>0</td><td>X</td></tr>
<tr><td>Level II Local</td><td>X</td><td>X</td><td>0</td><td>0</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
</table>

The parameters listed in Table 6.1 are indicated for: *Δx* and *Δy* - resolutions in the geographic space, *Δt* - resolution space of time, *Δθ* - resolution in space directions, *nθ* - number of lines in the spectral, *nf* - number of frequencies in the spectral, *NGX* - number of grid points after the *x*-axis, *NGY* - number of grid points *y* axis, *np* - total points. Among the physical processes enabled accessories include: waves - forcing waves, wind - forcing wind, gender - generation using wind, wcap - processes frothing, quad - interactions quadruple, triad - type interactions triad diff - diffraction Mfr - interaction seabed, set up - raise the water level, br - deferlare waves due to lower water depth.

In order to achieve better results in near-coast, it is important to use a bathymetry with a much higher resolution as the region in which propagates waves of wind (from deep water to shallow water) can vary widely. This can be achieved considering an unstructured grid resolution of which gradually increases the surf zone.

SWAN model using numerical simulations were conducted covering the entire Black Sea region for the period 2006/01 01-2006/ 07/01 (the first 6 months of 2006), the purpose being used fields of wind coming the NCEP-CFSR (United States National Centres for Environmental prediction, Climate Forecast system reanalysis) that are characterized by spatial resolution of 0.312º × 0.312º for which data were used in the system modelling of waves at an interval of 3:00 hours.

Using measurements of wave Gloria platform provided in Figure 6.2 was an analysis of the values obtained from numerical simulations of wave considering two parameters: a) significant height (Hs); b) wave period - Tp. In situ measurements provided by the platform covers the entire timeframe envisaged being reported daily at an interval of 6 hours. Given that the measurements recorded, approximately 92% is valid data via a method described in Makarinskyy et al., 2005 [36] were filled in missing values.

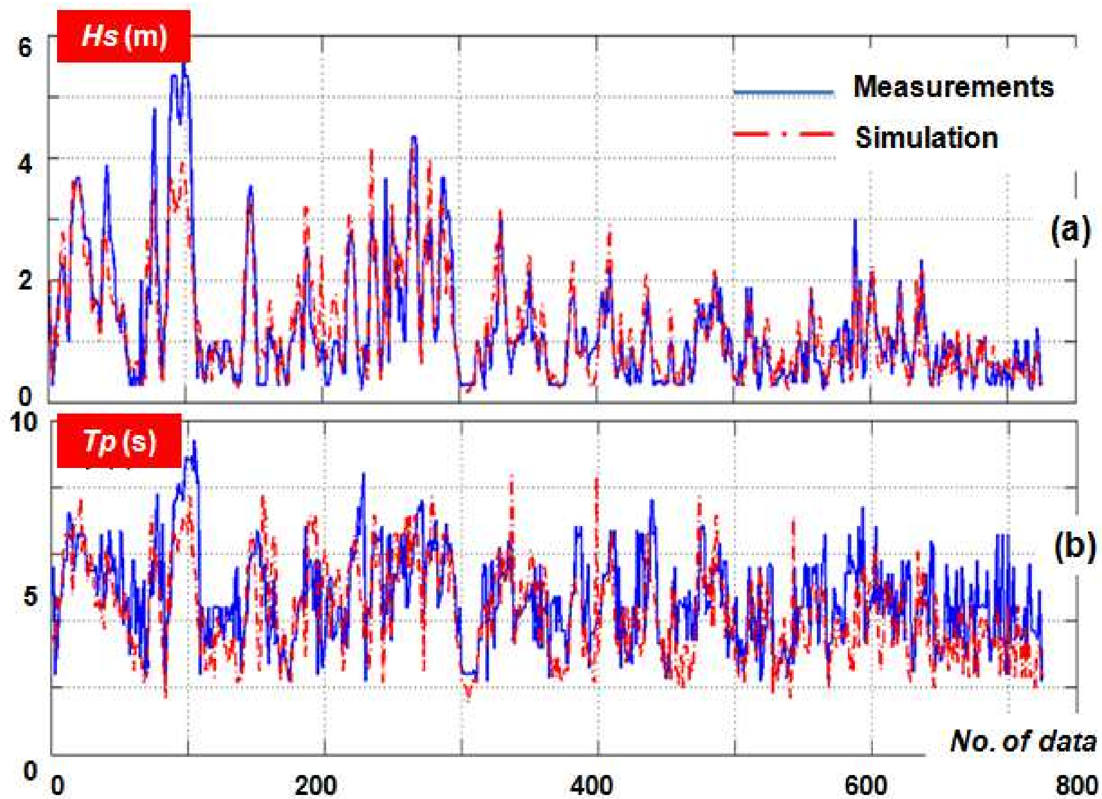

Figure 6.2. Time series of the *Hs* and *Tp* parameters, according to the wave measurements from the Gloria platform and SWAN simulations. Results reported for the time interval 2006/01/01-2006/07/01 [35]

Considering that for such studies it is very important to check the quality of numerical simulations, for this purpose were considered more numerical parameters whose mathematical equations defined below:

$$\text{Mean error: } Bias = \frac{\sum_{i=1}^{N}(X_i - Y_i)}{N} \tag{6.1}$$

$$\text{Mean absolute error: } MAE = \frac{\sum_{i=1}^{N}|X_i - Y_i|}{N} \tag{6.2}$$

Root mean square error: $RMSE = \sqrt{\frac{\sum_{i=1}^{N}(X_i - Y_i)^2}{N}}$ (6.3)

Scatter index: $SI = \frac{\sqrt{\sum_{i=1}^{N}(X_i - Y_i - Eroare)^2}}{\overline{X}}$ (6.4)

Linear correlation coefficient (*R*), also known as Pearson's Correlation Coefficient, is:

$$R = \frac{\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y})}{\left(\sum_{i=1}^{N}(X_i - \overline{X})^2 \sum_{i=1}^{N}(Y_i - \overline{Y})^2\right)^{\frac{1}{2}}} \quad (6.5)$$

Symmetric slope: $S = \sqrt{\frac{\sum_{i=1}^{N} Y_i^2}{\sum_{i=1}^{N} X_i^2}}$ (6.6)

In the above relationships *Xi* represent the measured values, *Yi* the simulated values, and are the mean measured and simulated values and *N*- the number of observations. For the time period analysed (2006/01/01-2006/07/01) were bought results from SWAN simulations with those measured by Gloria drilling unit. Statistical values obtained are shown in Table 6.2, while the scatter diagrams shown in Figure 6.3 are associated to the two main parameters (*Hs* and *Tp*).

Table 6.2. Statistical results of the wave conditions, reported between SWAN simulations and Gloria measurements, indicated for the time interval 2006/01/01-2006/07/01 (6 months) [35]

Parameter	Average measurements	Average SWAN	Error	MAE	RMSE	*SI*	*R*	*S*	*N*
Hs **(m)**	1.19	1.18	0.01	0.33	0.49	0.41	0.88	0.93	725
Tp **(s)**	4.61	4.21	0.40	1.07	1.41	0.31	0.55	0.92	725

Analysing the results shown in Table 6.2 and Figures 6.2 and 6.3, we can emphasize that the most important values are reported for 2006/01/25 / h12 when numerical simulations show much lower values for both parameters considered for evaluation. If we are talking about heights wave *Hs* is noted that the model reports a height of 3.82 m compared to 5.67 m indicated by measurements recorded in this way a relative error of 0.33% corresponding to an error absolute of 1.85 m.

Turning to the parameter *Tp* stands a maximum of 7.11 s (SWAN model) compared to 8.9 (measurements), which indicates an absolute error of about 1.8 s and a relative error of 0.2%. In addition to these aspects, it should be noted that the error reported is positive (*Tp* = 0.4 s; *Hs* = 0.01 m) while the slope distribution have values below 1 (*Tp* = 0.92 s; *Hs* = 0.93 m), these values indicating underestimation of the actual conditions of the simulations SWAN.

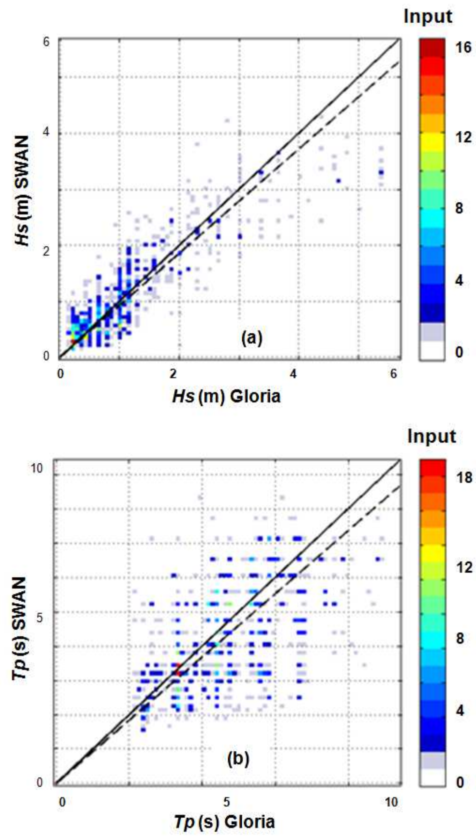

Figure 6.3. Correlation diagrams represented for *in situ* measurements (Gloria platform) and SWAN simulations, available for the interval 2006/01/01-2006/07/01 and the parameters: a) *Hs*; b) *Tp* [35].

Based on these results it can be stated that the values obtained from simulations seem to be quite precise target zone envisaged, given that climate modelling waves within closed seas are more difficult implemented compared to those reported in areas ocean. Also bear in mind that the performance of wave patterns reported in closed or semi-closed seas depend greatly on accurate wind fields used, which are characterized by lower quality due to influences arising from land-sea interface. To improve predictions of wave patterns is important to use databases with a higher resolution, plus and implementing type methods DA, these techniques are discussed below.

DA technique structure implemented in the target area is shown in Figure 6.1, implying the use of wave measurements from Gloria to adjust platform for the predictions obtained at coastal SWAN reported. Specifically, it is designed to provide corrections to platform measurements reported between Gloria and SWAN results, which were calculated for the same position and time series. They will be propagated in the geographic space, having a significant impact on demarcating the border crossings specific calculation of the west central area of the basin. It was initially thought to just assimilate procedure wave heights *Hs* and *Tp* period.

Generalizing, one can say that for an *F* (found on the border area with higher resolution), equivalent values for a parameter corresponding wave simulations relative to a time t is defined as:

$$X_{Ft}^{(A)} = X_{Ft}^{(E)} + K(F,t)(\Delta X_{Mt}), \tag{6.7}$$

$X_{Ft}^{(E)}$ represents the model predicted value at the point F, the coefficient is computed as the ratio between the model predicted values in the point F and that corresponding to the point M (at the location of the measurement), respectively, of the wave parameter considered:

$$K(F,t) = \frac{X_{Ft}^{(E)}}{X_{Mt}^{(E)}}. \tag{6.8}$$

By ΔX_{Mt} the difference between the measured and the predicted values of the wave parameter at the location of the measurement is denoted:

$$\Delta X_{Mt} = X_{Mt}^{(Ms)} - X_{Mt}^{(E)}. \tag{6.9}$$

In equations 6.7, 6.8 and 6.9, the superscript ***A*** indicates the assimilated values of the wave parameter, ***E*** the estimated values and ***Ms*** the measured values. The subscript ***F*** indicates the frontier point, while ***M*** is the point where the measurement is performed (in this case the location of the Gloria platform). A similar study was conducted by Rusu and Guedes Soares [37], which is reported to the Iberian peninsula, except that there is a major difference in the method used to transfer information in spectral space. Thus, in the previous study Hs parameter values propagated in space considering the spectral invariant normalized spectral matrix, this referring to the fact that the wave height is adjusted without changing the shape of the spectrum. In this situation, it was considered useful that wave spectrum to be replaced by an equivalent JONSWAP spectrum [38]. Other variants consist in using a type Pierson Moskowitz spectrum [39] or a spectrum with a Gaussian shape for implementing the SWAN model, defining the terms of spectral border with parametric values. To define a spectrum theory (e.g. JONSWAP or Pierson Moscovitz) may take into account four parameters wave, such as the height of the wave Hs, the maximum wave (or possibly the average), the direction of wave (Dir) and drift in space directional (DSPR). Of these, the first three parameters are considered to be standard, their expressions are described in the manual implementing SWAN [40].

The directional spreading represents the one-sided directional width of the spectrum (in degrees), defined and computed as conventionally for pitch-and-roll buoy data [41]:

$$\left(DSPR\frac{\pi}{180}\right)^2 = 2\left(1 - \sqrt{\left[\left(\int \sin\theta \frac{\int E(\sigma,\theta)d\sigma}{\int E(\sigma)d\sigma} d\theta\right)^2 + \left(\int \sin\theta \frac{\int E(\sigma,\theta)d\sigma}{\int E(\sigma)d\sigma} d\theta\right)^2\right]}\right) \tag{6.10}$$

By the method used in this study envisages a correction of the four indicators wave (*Hs*, *Tp*, *DIR*, *DSPR*), by replacing wave spectra of points located on the border area of computing, with a spectrum of parameters wave JONSWAP correct format. The benefits resulting from the proposed calculation scheme that can achieve a data assimilation technique of multi-parameter. The two techniques considered DA were analysed for different coastal areas, the results obtained indicate little difference between them [42, 43]. From the results, it seems near coastal areas, using parametric boundary conditions represent a sustainable approach to climate modelling waves.

Considering that the period considered (2006/01/01-2006/07/01), the platform of the measured parameters are only available Gloria values Hs and Tp in the first phase only these values will be considered in the assimilation. DA technique influence in the geographic space, is to be evaluated considering two separate case studies, which are indicated by: a) CS1 - 2006/01/19 / H00; b) CS 2 - 2006/01/20 / H00.

The Variations reported between the measured values and those from simulations SWAN (Gloria drill) are calculated as follows:

$$\Delta H_s = H_{sM}^{(M)} - H_{sM}^{(E)},\ \Delta T_p = T_{pM}^{(M)} - T_{pM}^{(E)}. \tag{6.11}$$

Figure 6.4 shows the development in the geographic space of two parameters, considering the situation in which they reported simulations SWAN with / without data assimilation, where they also mentioned the wind conditions local (speed and direction - averages) . In this case, it appears that the waves propagate in the southern sector, which is influenced by the wind direction acting on southwest with an average speed of 12 m / s. Analysing where CS1 is noted that over-assessing SWAN model real conditions, recording the following parameters variations of wave: $\Delta H_s = -0.69\,m,\ \Delta T_p = -2.41\,s$

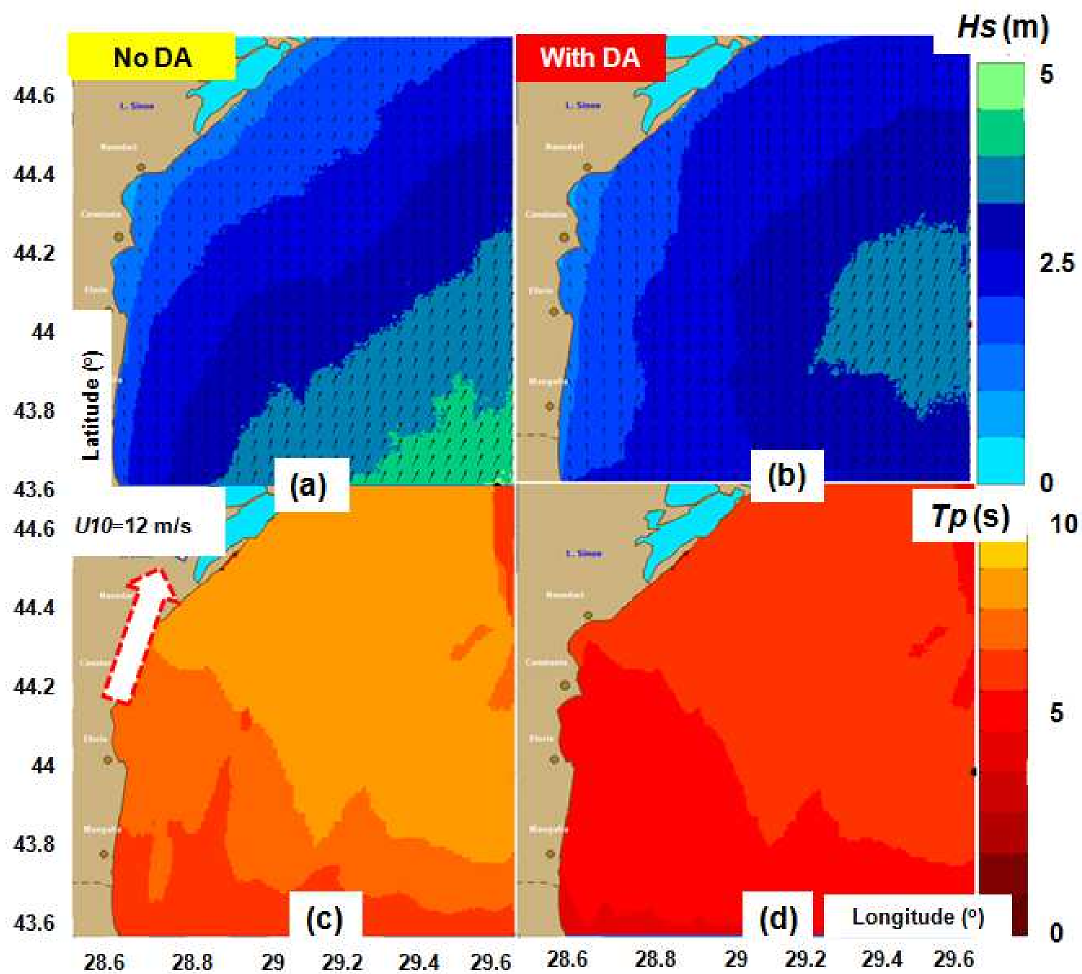

Figure 6.4. SWAN numerical simulations reported for the target area considering the case study CS1 (2006/01/19/h00). The wave parameters are: a) and b) *Hs* values - no assimilation and with DA; c) and d) *Tp* parameter - no assimilation and with DA [35].

Regarding the case study CS2, it can be seen that if there is a tendency numerical simulations to estimate values lower than the measurements recorded following differences: $\Delta H_s = 2.81m,\ \Delta T_p = 1.73s$. Distribution fields waves in the geographic area for this case study are shown in Figure 6.5.

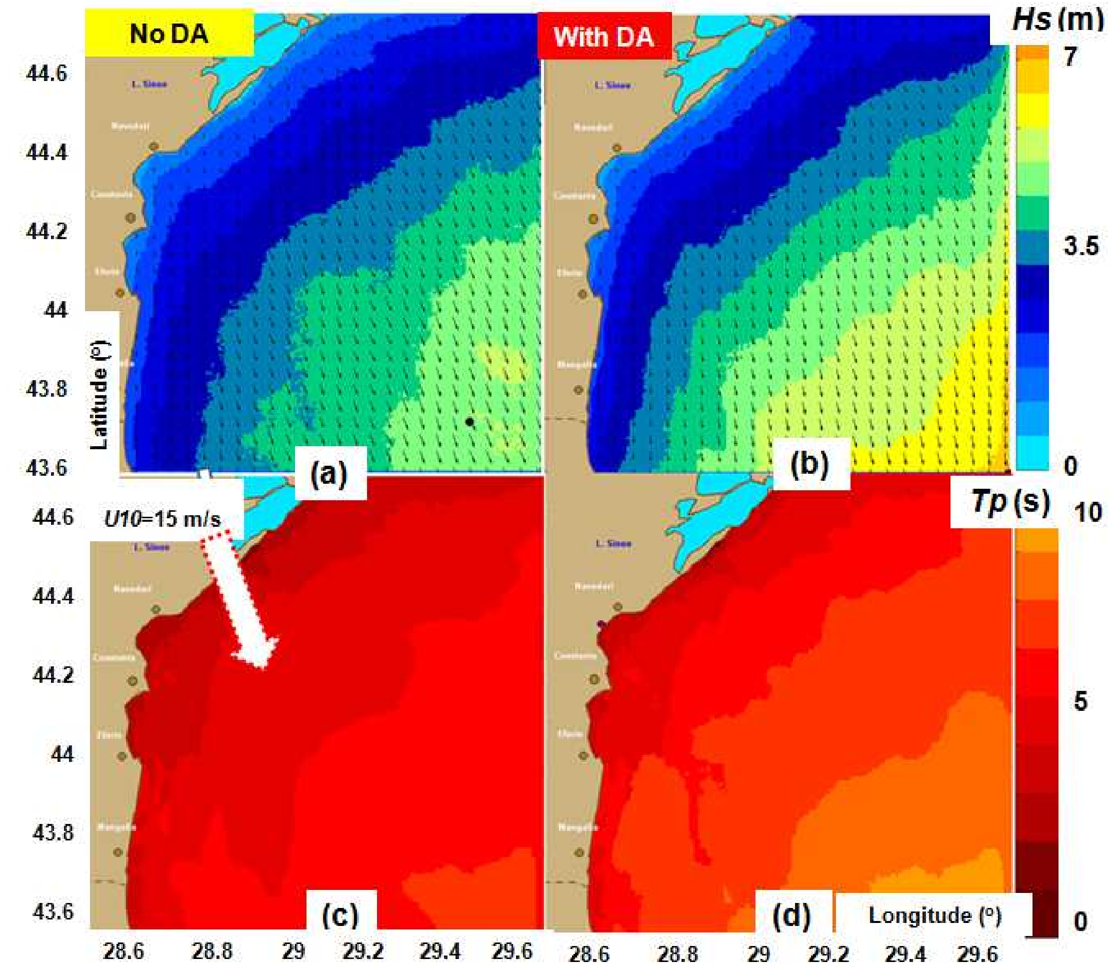

Figure 6.5. SWAN numerical simulations reported for the target area considering the case study CS2 (2006/01/20/h00). The wave parameters are: a) and b) *Hs* values - no assimilation and with DA; c) and d) *Tp* parameter - no assimilation and with DA [35]

For this situation, the waves enter the target area of the northwest, this direction similar to that of the wind, which for this moment of time can achieve an average speed of about 15 m / s. Analysing the results shown in Figure 6.4 and 6.5 can be stated that although the two case studies are separated by a span of 24 hours, they present distributions totally different both in terms of the direction of the waves and the values recorded between simulations SWAN measurements . Comparing the two distributions is observed that by using a technique DA is recorded improved results even for short periods.

A more detailed analysis of the impact of data assimilation is the wave predictions was achieved for the target area, analysing altimetry missions that were reported in this geographical area within 6 months considered for evaluation. To illustrate these trails, paths altimetry missions in the region are shown in Figure 6.6, considering only satellites registered in March 2006. Figure 6.7 is a comparison between satellite measurements and numerical simulations, considering Hs parameter which was analysed for all period of time (6 months → 2006/01/01-2006/07/01).

The analysis of these results, we can say that through the use of DA seems wave predictions are improving significantly. Analysing time series, highlights several energy peaks after the assimilation process variations reported more consistent in terms of wave height. These values are typical of January, during which significant changes are reported relative to a short amount of time. Looking at from another point of view, it is possible that these variations exist because of errors that can occur anytime in a set of measurements.

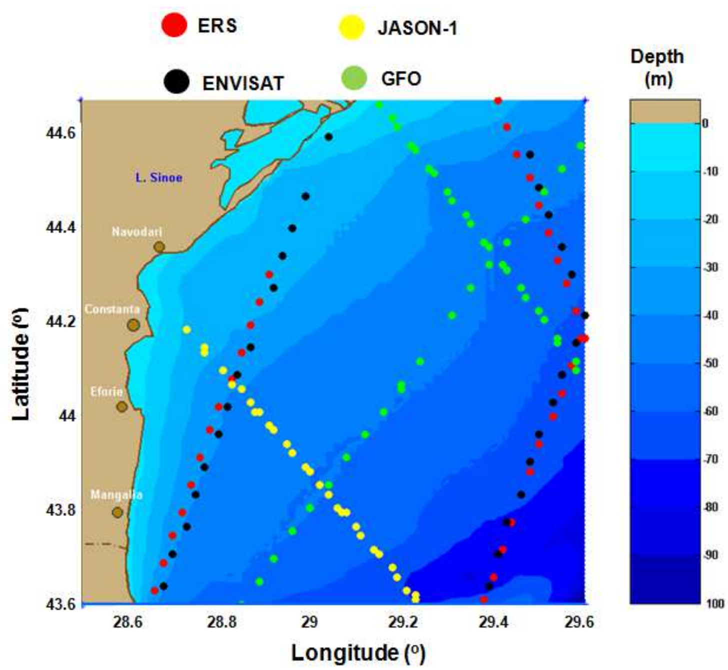

Figure 6.6. Altimeter mission tracks reported in the target area during March 2016 [35]

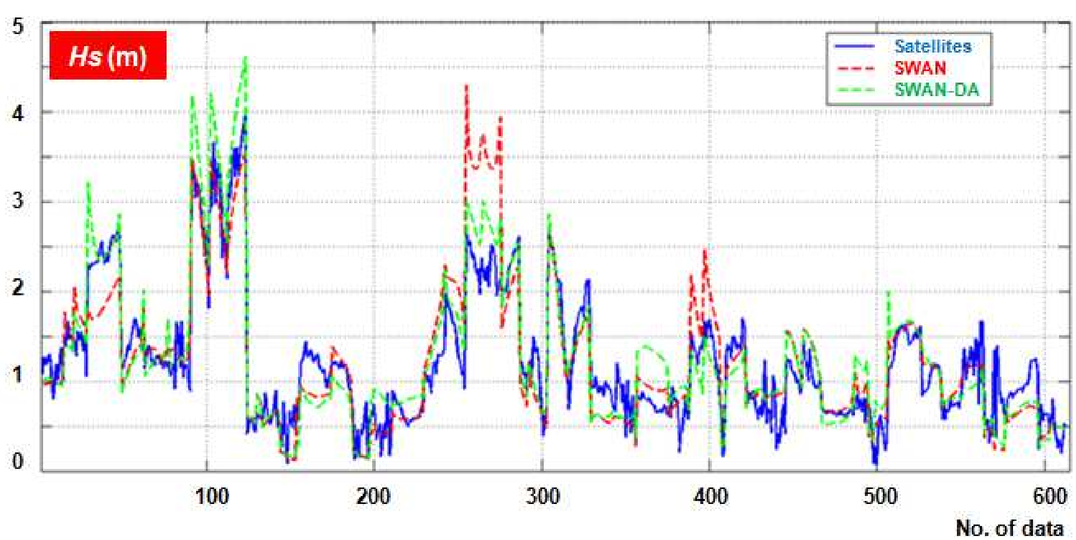

Figure 6.7. Time series of the *Hs* values, reported by the satellite measurements and by the SWAN simulations (no assimilation and with DA) for the interval 2006/01/01-2006/07/01 [35]

Statistical results reported heights Hs are shown in Table 6.3, the data being processed for the period 2006/01 / 01-2006 / 07/01. The numerical simulations were performed for the calculation characterized by better resolution, these results are presented in Figure 6.8 in the form of scatter diagrams.

Table 6.3. Statistical analysis of the *Hs* waves indicated for the computational field defined by a higher resolution. Numerical simulations (no assimilation and with DA) are compared with the satellite measurements available for the interval 2006/01/01-2006/07/01 [35].

Parameter	Average measurements	Average simulations	Error	MAE	RMSE	SI	R	S	N
$Hs_{\_SIM}$ (m)	1.21	1.22	-0.01	0.28	0.38	0.32	0.88	1.04	612
$Hs_{\_ASIM}$ (m)	1.21	1.24	-0.03	0.26	0.33	0.27	0.92	1.07	612

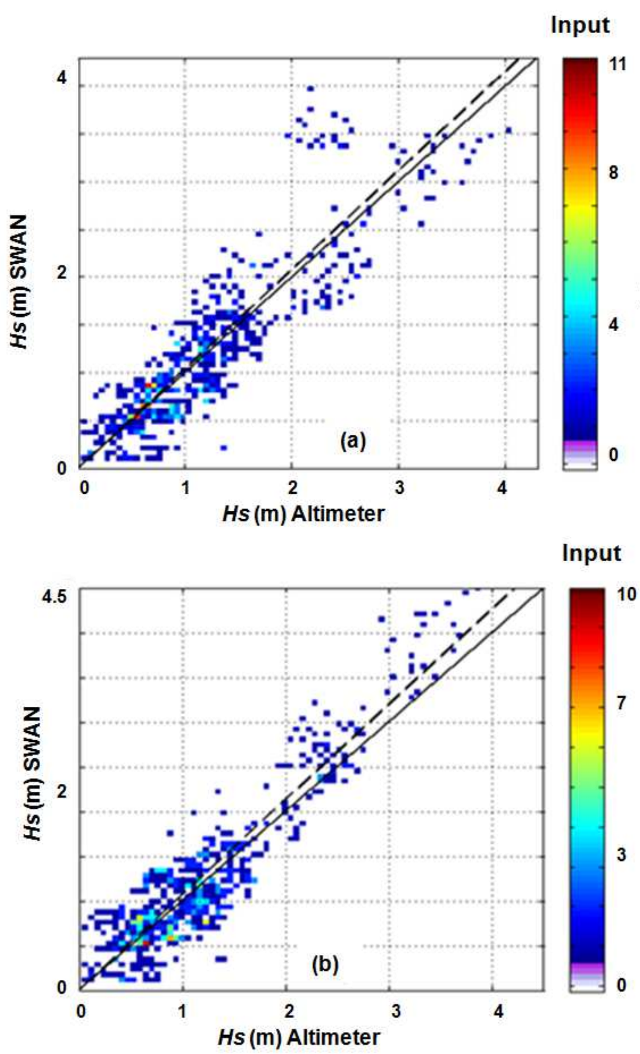

Figure 6.8. Correlation diagrams indicated for SWAN simulations and satellite measurements, available for the interval 2006/01/01-2006/07/01, where: a) no assimilation; b) with DA [35].

Taking into account previous results, it appears that by applying a technique DA can generate a prediction extended, which can contribute positively to the improvement of numerical simulations carried out for various coastal areas. Based on these results, the next step is to establish a DA techniques that will produce real-time information on the current state of the sea or to estimate its future development. To achieve this, the present study was considered pertinent to the achievement of key files at the end of each day, they are called *hot* file. They contain essential information related to the current state of the sea, being used as the base (input files) for subsequent simulations.

The analysis of these values were observed better quality outcomes, resulting from the evolution of the following statistical parameters: absolute error average (0.26 versus 0.28 previously) RMSE (0.33 to 0.38), SI (0.27 to 0.32) and coefficient correlation (0.92 to 0.88). Of the indicators contemplated symmetrical slope should be noted that not only has improved this recording 1.07 (compared with 1.04 previously).

With reference to these results we can say that the assimilation of other parameters of wave (e.g. DIR, DSPR) can significantly improve the quality of numerical simulations carried out using the SWAN model.

Once you have identified these files using the sea state, the next step is the correction of wave predictions for various points there are available in situ measurements, these adjustments being transferred to the geographical area using a method described in equations 6.7-6.9. This scheme used to improve the numerical simulations is based on an algorithm that includes successive corrections using linear regression method. Thus, for each day (***d***) are generated predictions for 00h and 18h hours that are characterized by a resolution of 6:00, which is designed to position drilling rig Gloria. These predictions are corrected considering the wave measurements reported for this position, assimilating being used height and wave period.

Based on predictions made for an interval ***d***-n days prior (determined according to the period of training) aimed at identifying values for linear regression to adjust in a simulated wave parameters conveniently. The resulting values will be deemed to modify predictions reported on ***d***, which is associated with the period of assimilation.

The results from (***a*** - slope ***b*** - intercept) are calculated using least squares (OLS -Ordinary Least-Square) which can be defined by:

$$a^d = \frac{\sum_{i=1}^{k}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{k}(x_i - \bar{x})^2} \quad \text{and} \quad b^d = \bar{y} - a^d \bar{x}, \tag{6.12}$$

where the superscript ***d*** indicates the day when the DA is applied, ***y*** - represents the wave parameter predicted by the wave model SWAN (*Hs* or *Tp*), ***x*** - is the measured wave parameter (*Hs* or *Tp*), $\bar{x}$ and $\bar{y}$ - denote the mean values of the variables *x* and *y*, while ***k*** - represents the valid number of measurements performed in the training period considered. A detailed theoretical background of this method is presented in technical literature [44].

The regression parameters are computed only if a minimum of 10 pairs of simultaneous observation/predicted values are available in the training period and their values are updated every time step represented by one day. Thus, the corrected (or assimilated) values of the predicted wave parameters for the day ***d*** are given by the regression equation:

$$y_a^d = a^d y^d + b^d, \tag{6.13}$$

If these conditions to assess regression parameters are not achieved or if the corrected values of parameters are negative wave will not apply any changes to the estimated values of the numerical model. This system of prediction of wave [45] together with a list assimilation of measurements the satellite [46], were used to achieve better results of numerical simulations made with the model SWAN, which were assessed in relation to the platform position Gloria. In view of these results in Table 6.4 have been identified various statistical results Gloria defined platform where *Hs* and *Tp* parameters were analysed for a period of nine years (1999-2007). Following these results, we can say that after a period of 60 days driving all statistical parameters showed an improvement in values.

Table 6.4. Statistical results reported for the Gloria position in terms of *Hs* and *Tp* wave parameters, evaluated for a 9-year interval (1999-2007). Results reported for the SWAN simulations without assimilation and with DA, where *N* correspond to the number of data [35]

N=12208	Average measurements	Average simulations	Error	MAE	RMSE	SI	R	S	Training interval
***Hs* (m)**	0.96	0.92	0.04	0.27	0.38	0.40	0.85	0.92	No assimilation
	0.96	0.95	0.00	0.27	0.38	0.40	0.85	0.95	20 days
	0.96	0.96	0.00	0.27	0.37	0.39	0.85	0.96	40 days
	0.96	0.97	-0.01	0.26	0.37	0.39	0.86	0.97	60 days
***Tp* (s)**	5.03	4.68	-0.35	1.24	1.63	0.32	0.39	0.94	No assimilation
	5.03	5.03	0.00	1.03	1.29	0.26	0.42	0.97	20 days
	5.03	5.03	0.00	1.00	1.26	0.25	0.45	0.97	40 days
	5.03	5.04	-0.01	0.99	1.25	0.24	0.45	0.97	60 days

Figure 6.9 shows a diagram for the implementation of DA technique for identifying a previous state of the sea (*hindcast*) and predictions for the future (*forecast*). In order to determine a current state can use either basic parameters (*Hs* and *Tp*), which can add other parameters (*DIR* and *DSPR*), which provides additional information, such as those related to the direction from which propagates waves.

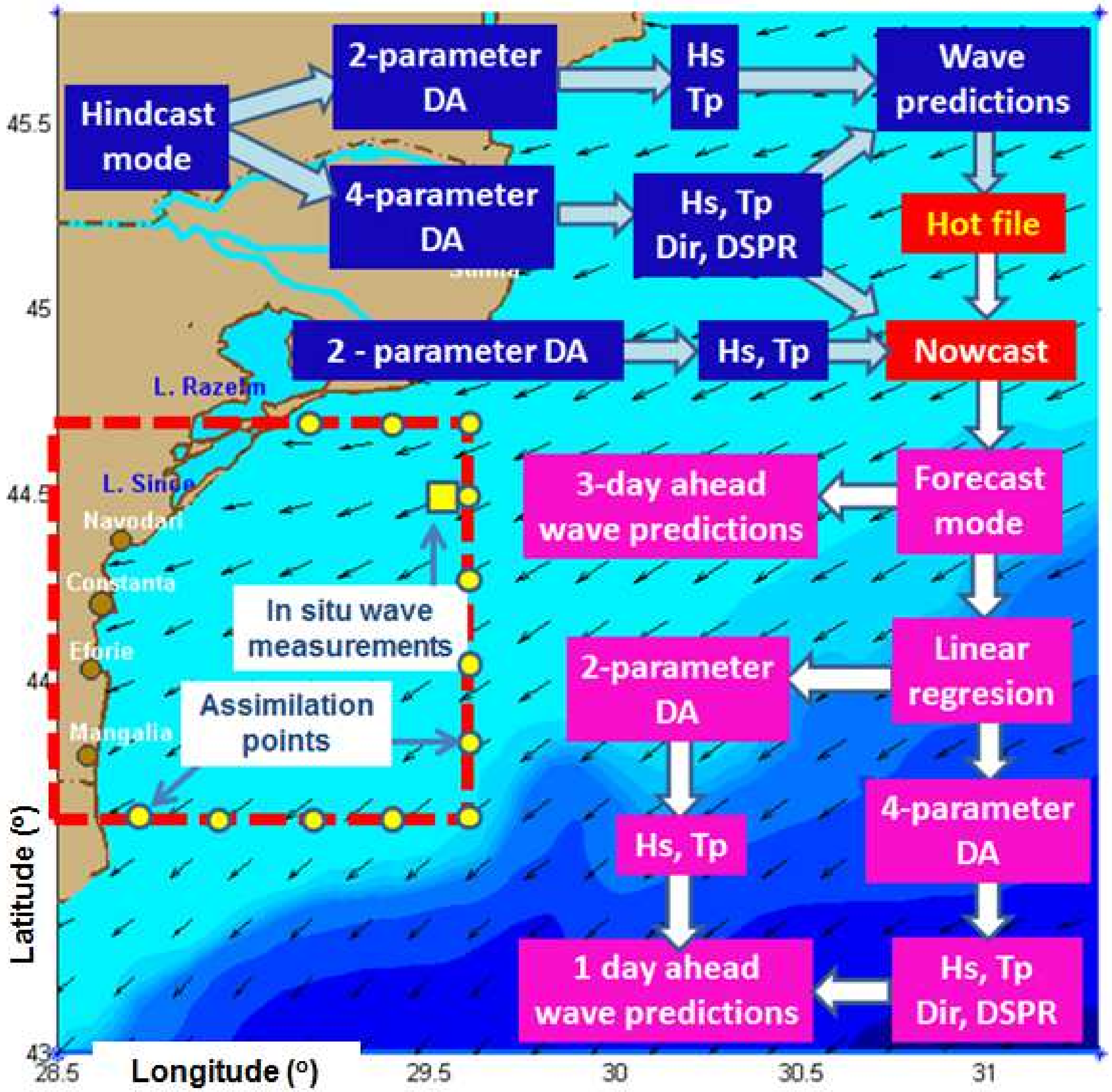

Figure 6.9. Implementation of the DA technique in order to estimate the past and future characteristics of the sea state [35]

An important role in this scheme is to identify steps from step to step the current forecast, where each day (end) goes envisages running a model *hindcast-nowcast* (*nowcast*- current state) in order to get those *key files* that underlie the initiation model for obtaining new predictions. Since the linear regression algorithm allows, boundary conditions can be adjusted using two parameters or in an ideal case, four wave parameters.

Chapter 7

APPLICATIONS OF NUMERICAL MODELS FOR WAVES

Sea state forecasts that estimated using numerical models are helpful for those who operate in marine areas. Depending on the existing requirements can provide information about the evolution of waves in the past (hindcast), present (nowcast) or future (forecast). Values reported in the past, usually to be achieved databases by identifying the different trends climatological, while values reported in the present (or future) aims at development of warnings on the occurrence of extreme conditions or to identify potential the energy of a region.

If we refer to the distance to shore, certainly for those offshore matters most predicting extreme conditions to be stable time window in which activities are not disturbed or endanger the safety of those working in such conditions. By using data assimilation techniques can achieve realistic results that can influence cost management, which, for example if a ship can be reduced significantly by identifying an optimal navigation routes.

Depending on the time window considered, the predictions may be used for warning of short-term (hours or days), while in the case of simulations complex can be achieved database covering tens of years (e.g., database ECMWF) that can be used successfully to develop climatological studies (Figure 7.1).

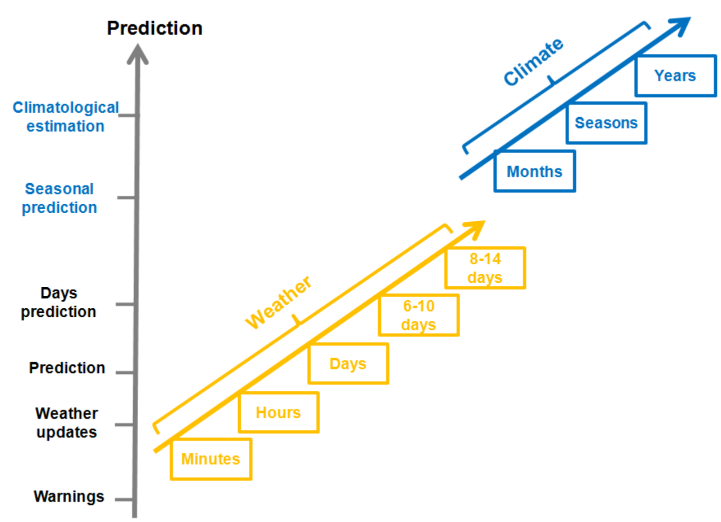

Figure 7.1. Results provided by the wave models for different time interval [47]

7.1 Naval Transport

Nowadays it is estimated that the most economical way of transporting goods over long distances is the maritime transport routes. Using these trails, 80% of the goods are delivered in various parts of the world, these involving a significant number of jobs in ports, shipyards or carriers [48].

Analysing maritime traffic in the Black Sea, it is noted that the western area of the basin is characterized by higher traffic from transport ships because many existing ports in the coastal zone. Romanian area is favoured from this point of view, being situated near two major pan-European routes, namely Corridor VII (Rhine-Main-Danube) and corridor IV (railway route). These corridors connecting main and other transport hubs covering the whole area located between the Black Sea and the North Sea.

Even though the Black Sea is a closed basin, there are situations where wave conditions in the region can reach values close in value to those reported in coastal areas facing the open ocean. [49] Throughout the basin, can develop local energy conditions that far exceed average values. Such a situation occurs at the mouth of the Danube to the Black Sea, where the interaction between coastal currents and waves offshore can develop dangerous waves that can affect the integrity of the ship or crew [50]. By implementing a business model away in this area can easily identify these abnormal phenomena that by switching to a model to estimate the coastal currents, can provide realistic predictions for those passing through.

The Black Sea is also known for developing wind Bora, which usually occurs in the northeast of the basin (Novorossiysk region - Russia). When this phenomenon occurs, wind speed can often present within the interval 15-50 m / s, movement naval movements in the area carried on weight [51, 52].

Accurately estimate the sea state becomes important for ships at sea because marine conditions can change quite quickly, moving quickly from one state to the emergence of a calm sea storms. For military applications, the success of a mission is important to know both the development of wave and wind conditions, and other parameters such as those related to vision or temperature. By avoiding unfavourable conditions, we can ensure the integrity of the vessel and crew, but also may be an important fuel economy by identifying optimal routes of transport. Combining predictions provided by a wave pattern with characteristics ship (and cargo transported) can identify different navigation routes that avoid certain areas that might be dangerous in terms of structural problems.

Also in the development of such predictions it is important to take account of the wind conditions here a special attention to the direction in which propagates. Thus if we consider the low speed wind (less than 10 m / s), which act on the moving ship can increase dramatically speed transmission, while a wind of the vessel will oppose a significant resistance. Taking into account just the wind speed should be noted that a higher wind speed will contribute to the emergence of larger wave heights in contact with the ship's keel will generate frictional forces that reduce the performance of any craft. Also, unwanted situations may arise in which the propeller propelling the ship is not in water, in this case it lost a significant amount of energy [53].

Whatever the activity, those working in marine areas want to have part of a calm sea mention whether leisure or industrial applications. Depending on the characteristics of a ship, in addition to the wave height it is important to know other parameters, such as those related to: the wave length, the slope of the waves or the presence of a confused seas [47].

Waves with a steep slope can cause discomfort to those who are at sea and who are not accustomed to such conditions, with the risk that situations occur flooding the deck of a ship or even sinking it depending on the direction of acting waves relative to the position a craft. By using a wave pattern can cause these effects, elaborating predictions in this regard. For dive enthusiasts, when heavy seas are reported low visibility can be deducted depending on water depth, distance from shore and sea conditions.

Long waves usually have a negative impact on boats, especially those who are at sea. But to oil or other similar vessels for very long, there is a danger that the stern and the bow are supported by the wave crests while amidships is not supported by the waves. In this situation, the ship will be applied fairly strong with the risk of its sinking. Also not to be neglected waves coming into shallow water and can meet their road submerged sand bars, which can significantly increase wave heights.

The Black Sea is a place where sports competitions are conducted frequently, such an event is the Great Sailing Regatta which is becoming more known. At the competition held in 2014 was attended by a large number of 13 yachts had on board around 1200 sailors from various countries such as Russia, the UK and Romania. Usually this competition takes place at the beginning of the winter season (during September-October), implying a route that starts from Constanta (Romania), crossing the Black Sea and reach Novorossiysk (Russia), passing through Sochi (Russia) and ends Varna (Bulgaria) [54].

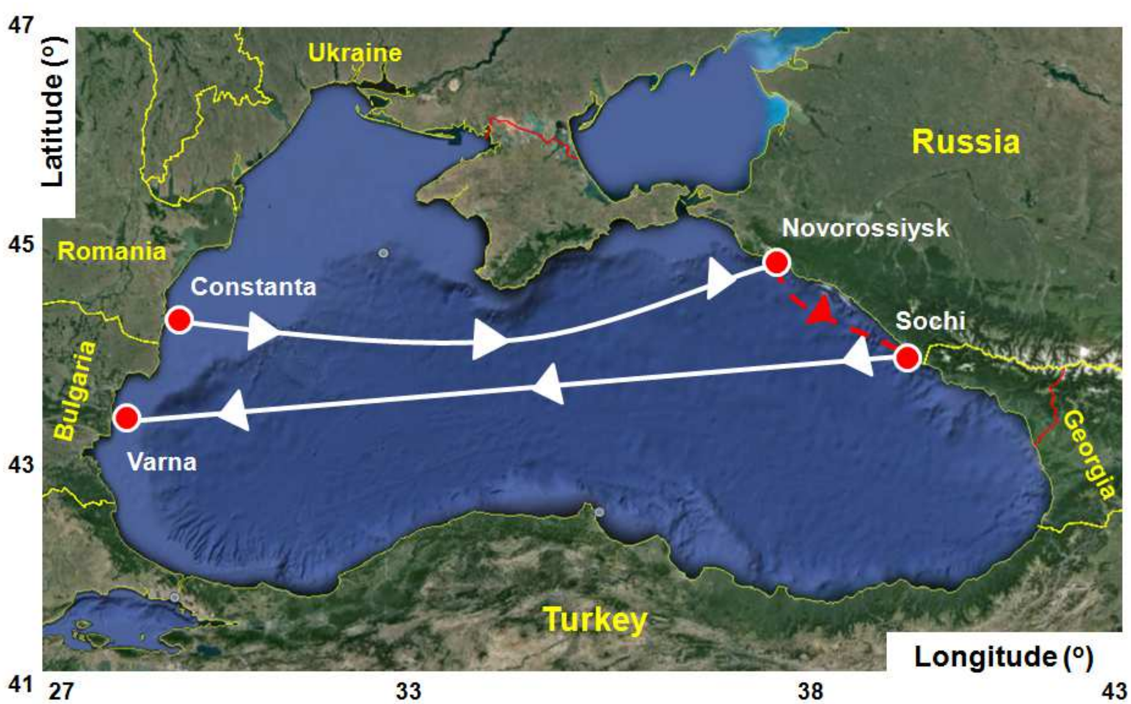

Figure 7.2. Map of the maritime routes considered for the Black Sea tall ships regatta [54]

Usually the Black Sea is known for extreme conditions occurring during the winter season, so that a prediction of waves is based on data assimilation can contribute to an accurate estimate of conditions wave of offshore, elaborating also and predictions coastal customized for specific sectors. Such monitoring done in real time, would contribute to a better knowledge of the conditions of navigation and hence the success of this competition.

7.2 Offshore Industry

Perhaps in this category, the most popular are marine environments whose schedule largely depends on sea conditions, be it the supply of goods or on the transfer of personal and petroleum products. The Black Sea is an area rich in such resources, especially in the western side. Previous studies have revealed that this region is defined by a climate of waves higher energy potential, this being due to air masses acting on the east to the west. From this point of view, the focus of a wave pattern in this area can get detailed information about the impact they have waves on offshore platforms, such as for example in the case of type structures jacket and tower are the most common. The greening component also plays a role, if we consider that this sector is coastal Danube Delta Biosphere was declared a protected area. Therefore, bear in mind that if an accidental release of oil, the impact on the marine ecosystem would be difficult to quantify. By implementing a type SWAN wave model can be identified in an efficient dynamics of oil stain considering certain environmental parameters such as waves, wind currents or coastal developments. By identifying vulnerable areas at risk of being most affected, can take swift action to reduce pollution in these areas, such a prediction with the purpose of reducing efforts logistics and personnel deployed in the event of such an event.

Considering that wave patterns can only simulate waves of wind, they cannot be implemented for the identification of tsunami phenomena. Previous studies [55] revealed the dynamics of these extremes, noting also the catastrophic effects that they had on coastal areas.

Figure 7.3. Gloria drilling platform located in the western part of the Black Sea

Given that the Black Sea is characterized by significant wind conditions is expected in the near future to develop offshore wind farms, particularly in the western part of the sea that seems to be characterized by consistent conditions. A realistic forecast sea state can contribute to the success of such a project by identifying windows of time that can perform specific tasks, such as for example the development of maintenance services. Compared with land areas, this aspect becomes important marine areas because in some cases there are short intervals of time that can carry out such operations, while the transport ships must reach the farm and to return safety. In this regard, we can use the experience gained by Gloria platform operating at a depth of 50 m since 1976. In addition to petroleum products it provides, it is used as a weather station providing important information about conditions offshore marine area that can be used to calibrate and verify the predictions of wave.

Chapter 8

FINAL CONSIDERATIONS

8.1 Considerations on studies performed

The numerical simulations have become a basic tool for any field, among which we can mention applications related to economy, sports or engineering. Even if that is the mathematical basis of these theoretical models is very well developed, there are situations where they can provide erroneous results that are not consistent with reality. This problem can be solved through the use of techniques which can be centered on the correction data assimilation or to use other methods, such as those related to the neural network. For marine environment, which covers an important area of the world, it seems that the best results are obtained using DA techniques, which are already implemented in the major hydro-meteorological centers such as ECMWF and NCEP. The success of these methods is based on extensive experience gained from projects predicting the weather.

Considering the computing power and the development of DA methods, there are currently global database covering decades, providing accurate information about the status of the sea. Given that they only consider certain variables, such information appears to be better suited for areas of ocean or coastal regions. For regional areas there is a tendency for each country to implement its own model, such as for example in the UK (NAE), Australia (AUSWAVE) or Norway (WINCH). By using a specific model can achieve better results in terms of predicting waves of local, because the model will be adjusted to a particular area of computing that is defined by its own characteristics, such as grid bathymetric finer calibration measurements in local situ, a more accurate representation of shoreline, etc. Such a model appears to be suitable for the Black Sea, because the physical processes within this closed basin are totally different from the ocean. The average spectral phase SWAN has been used extensively for this geographical region, especially versatility of this model to be focused on different levels of calculation and areas having different resolutions. This wave pattern has already been implemented and calibrated for the Black Sea, thus there are all prerequisites to develop an operating model to be based on a method of data assimilation (global and local).

In this context, this thesis is a step forward in developing an operational model for the Black Sea wave, the research is focused on the west of the coastal sea and on the Romanian seaside. By evaluating the DA techniques available today, it was aimed at identifying best practices that can be applied to this region and to help to achieve realistic results. Thus, two main methods have been identified, where the global were included in the process of assimilation of the satellite measurements, while local calibration of the results was performed using in situ measurements of the platform Gloria.

The thesis begins with a brief overview of the main DA methods and areas where it can be applied. Here it should be noted that these methods were initially used only in weather prediction centers and are introduced gradually in other areas. The benefits of these methods are that the results can be obtained for any time, this is dictated by studies envisaged. If we relate in the past (hindcast) can restore databases covering decades from just a few information, this data is important in the development of climatological studies. For now (nowcast) can perform simulations that focus on providing environmental warnings or to be used for various applications such as rescue and marine pollution. An assessment of future sea state (forecast) is of interest to those interested in renewable energy sources or activities related to coastal protection.

In Chapter 1, they were presented concrete cases where these methods are used. Regardless of the area analyzed is noted that the time parameter is the most important, more so in the case of extreme conditions such as bioterrorism or floods, which based on a number of variables to be taken decisions in a short amount of time. Other studies focus on the optimization processes, such as in the case of airfoil aerodynamics and improve techniques for casting in the mold. By implementing such systems can significantly reduce expenditure in a particular area, for example in the healthcare sector which can materialize by reducing the number of investigations taking into account the history of a patient.

The next two chapters presents in more detail the theoretical underpinning of the main DA techniques here optimal or variational methods are presented; depending on the type of study they can be 1DVAR, 3DVAR or 4DVAR. They identified the main mechanisms used to minimize the error of an estimate, as defined certain specific parameters such as gain matrix, innovation or cost function. Since the Kalman filter is a benchmark in the field of data assimilation were presented more information about this tool and how it can be applied for solving stochastic processes. Over time this filter has evolved steadily from Discrete Kalman filter, leading to more complex forms such as Extended Kalman filter or filter EnKF.

Chapter 4 is intended to hydro-meteorological prediction centers where operational wave models are implemented. Here they are indicated principles underlying the assimilation of data and theoretical elements that define a wave pattern. Even if the prediction of the waves does not seem at first glance a very important analysis operational models for predicting waves globally observed dynamics of this sector and the interest of some major countries (eg Germany, Canada or Japan) to develop models their focus on various areas of computing. Particular attention is paid to WAM models (Wave Model) or WW3 (WAVEWATCH III) which are used as main models in various hydro-meteorological centers important for the development of global databases.

Even if the Black Sea there is not currently an operational model, researchers from Bulgaria mentioned efforts aimed at the use of the model WAVEWATCH III and satellite measurements for the realization of such a project covering the whole basin. It is presented a case study which, although not the assimilation of data, a simulation was performed using the SWAN model were used wind fields covering a period of 60 years (1949-2010). Based on this information it can be mentioned that the western basin seems to be more important, which seems to focus wave energy naturally. This is due to the wind conditions acting from east to west, here an important role with air masses arising in Russia. It also highlights the latest research in this area, such as those of the DAMWAVE aimed at the implementation of assimilation methods to improve predictions of wave near the Romanian coastal areas.

Chapter 5 presents some of the author's own contributions, which are centered on identifying wind and wave regime in the Black Sea region. The first phase was carried out such an analysis of wind resources near coastal areas, the results were compared with those in the Caspian Sea, which is in the same region and having similar physical characteristics. They were used from the center of ECMWF data that have been processed for a number of 16 reference points distributed along the Black Sea. Because in addition to an assessment Meteorological was pursued and identify theoretical performance of an offshore wind turbines, reported initial data set at a height of 10 m (*U10*) was adjusted by a logarithmic law. In this way, the data were reported at a height of 80 m (*U80*) this represents the lowest height at which such generators operate in marine areas. The analysis of specific parameters (eg power density) was revealed that the western basin seems to present the most energetic characteristics compared Caspian consistent values are observed in the northern part of the basin. Both basins analyzed have in common that areas with good energy potential is located in shallow water regions, this feature represents an asset for the development of offshore parks.

Once identified with good potential energy points, the next step was to compare these conditions with those in areas where the firm operates offhsore North Sea or Baltic Sea respectively. Originally considered for evaluation were a number of 146 projects, but analyzes performed were used only seven projects appear to be close winds value. In general, it was observed that paragraphs chosen from the Black Sea and the Caspian, the level is higher in the first part of the year (January-April), except that the reference point in the Black Sea seems to be defined by values a bit higher. Even if the operating capacity of the turbine indicates values in the range 45-70%, it is important to note that these values for optimum capacity not exceeding 5% throughout the year regardless of the point analyzed, with the exception of December which can record 10%.

Since the routes of navigation in the Black Sea covers lengths quite large, these across the whole basin, in this chapter was aimed at identifying the extreme conditions of wave (*Hs*) and wind (*U10*) that may be encountered by ships go through these routes. These were noted by: Route A (Odessa-Istanbul), route B (Istanbul-Kerch Strait) and Route C (center-Black Sea coastline Georgia). They were considered for analysis of data from ECMWF and project-specific measurements AVISO. At a general analysis may indicate that ECMWF values are a little higher than those of AVISO, there are also important differences between the two monthly databases, especially for wind speed. So based on data from AVISO can say that values are important Airspeed reported in Octobre and November can be reached values of up to 17 m / s, compared with the values provided by ECMWF which can reach values of 21 m / s in November and February. Hs wave heights for both sets of data show February as more important, which are reported values of 5.5 m / s (AVISO) and 7.2 m / s (ECMWF).

Considering that there are certain coastal sectors that can record higher values of marine parameters, was considered useful to provide an overview of the environmental conditions and extreme relative to the Danube Delta region Novorossiysk (Russia).

Chapter 6 is the DA discusses implementation techniques in the Black Sea, is made entirely of the author's own contributions that were disseminated in international scientific meetings. In a first stage, it was monitored using a method involving successive corrections for predicting climate waves in the western Black Sea.

The numerical simulations were conducted using SWAN model, which is focused first on a global scale (Black Sea), after which the results of these simulations were introduced in a local area (western part). For forcing model was used data from wind-CFSR NCEP (National Centers for Environmental United States prediction, Climate Forecast System reanalysis), covering the first six months of 2006. The values obtained from simulations were compared with wave measurements reported by Gloria platform, this data is used as the benchmark to achieve corrections for SWAN simulations. Assimilation involves the transfer of information in spectral space such that for this purpose is used an equivalent JONSWAP spectrum, based on information provided by the wave parameters *Hs* and *Tp*.

The impact of technology YES in geographical space was assessed through two case studies indicated by CS1 (2006/01/19 / H00) and CS2 (2006/01/20 / H00), we observed an improvement in values in SWAN model the conditions in which over-evaluate the actual values in the case of the average energy conditions, while the opposite trend is observed for the most energetic conditions.

For this region was performed and assimilation of satellite measurements for the western area, taking measurements provided by missions ERS, ENVISAT, Jason-1 and GFO respectively. This time the DA method involves using least squares (OLS or) by linear regression parameters are estimated. Although the method provides fairly accurate results, the disadvantage of this approach stems from the fact that it takes at least 10 consecutive pairs of measurements / metrics during simulated driving, otherwise it will not apply any change on the estimates of model. Given that the chosen area is much smaller it is possible that in some cases do not meet this condition because the number of satellites that cross the region in a single day can be quite small. In this chapter proposed a calculation scheme in which the number of parameters wave assimilated (two or four) can get weather current or predictions of waves for more than a few days, underpinned carrying files key (and hot file). These files describe in detail at the end of a stage sea state simulation were used as the basis for further initiation of new simulations and predictions obtained by a method that involves elements DA linear regression. When using several parameters of the wave, it is possible to obtain a more detailed assessment of the state of the sea, estimating and other features, such as for example the direction of the propagating waves. Romanian coastline was also analyzed, considering this time for implementation only parameter *Hs*.

Also in this chapter are proposed several methods that can be applied either globally using the optimal interpolations using a specific correlation length, or a local scale using OLS involves driving a period of 40 days. In addition they applied a method (local) based on the estimation of systematic errors, which are defined separately for normal or storm that demarcated the height Hs of 3 m, which was considered as a reference point .

The final part of the thesis (Chapter 7) are some areas that can be used predictions provided by a wave pattern, except that they are of great use for all those operating in the marine or coastal environment. Usually the most common parameter analyzed is the wave height, but it is important to realize predictions of wave characteristics according to the requirements of potential customers. For example, the slope waves from tourism or fishing is an important parameter than can be used to estimate the state of comfort that we will have those at sea. Given that currently coastal protection in the Romanian seaside area is a major problem and that wind energy and wave in offshore European is increasingly used in this chapter, the author has conducted various case studies that identified impacts that it could have a marine energy farm on coastal waves and currents in this region.

Based on these results, it can be concluded that this thesis is a first attempt to implement the DA techniques in a wave pattern focused on the Black Sea, the results so far are promising. Given that these studies are still in their infancy, it would not be fair to make a comparison with similar results provided by major hydro-meteorological centers that have the resources and tradition in this area. Moreover, the global models are intended to provide general information about the status of the sea areas of the ocean, so it can be questioned the accuracy of databases for isolated areas inland, such as in the case of closed seas and semi- closed. Given that the same methodology (techniques DA + model SWAN) used in this thesis has been successfully implemented in the coastal zone Potugheză, there are all prerequisites to be able to develop a business model centered on the western Black Sea, noting that should be considered closed peculiarities of this increase.

If we had to characterize DA methods used in this thesis, they should be defined by simplicity and effective manner in which transfers spectral corrections and geographical space using computer equipment underperform. Studies conducted may be considered appropriate for the Black Sea, especially considering Romanian coastline of dynamic areas such as shipbuilding, maritime transport and tourism, as well as the extremes that can develop in this region.

8.2 Personal Contributions

In this chapter, the author would emphasize the ability to implement data assimilation techniques both globally and locally, they require a good knowledge of SWAN model and the physical processes that define each area calculation. Also, through this wave pattern, the author has conducted various case studies that have identified the impact of coastal marine energy farms (theoretical) located in the marine environment. The processing of large databases (wind and wave) requires some experience and dexterity in extracting relevant information from the scientific results obtained by the author being appreciated in international events. These achievements are all the more important considering the fact that they were achieved in a relatively small range of time (3 years) allocated to doctoral studies.

Surely the main element of originality is to implement at local methods of data assimilation in the western part of the Black Sea Basin, with special attention being paid to Romanian seaside area. Another novelty is apparent from studies on the impact of a coastal wind farms related to the Danube Delta, the results are interesting given that such a project has an absorption of wave energy low.

The studies presented in this thesis and disseminated work can be grouped several lines of research, mostly focused on obtaining and processing consolidated databases. Mention may be made of the specific activities:

a) Identifying relevant data assimilation theory (literature review)

- a1) Presentation of the main methods used in the DA techniques;
- a2) Evaluation of case studies from various scientific fields that are based DA methods;
- a3) operational analysis of wave patterns and how they are implemented within the framework of international hydro-meteorological centers;

b) Analysis and processing of wind and wave conditions using in situ measurements, reanalysis data and satellite measurements.

- b1) analysis of wind conditions near the Black Sea coastal areas, considering data from ECMWF center reported to range from 2004 to 2013;
- b2) analysis of wind conditions near the coastal Caspian, considering data from ECMWF center reported to range from 2004 to 2013;

b3) analysis of wind conditions near offshore wind farms in Europe (146 projects), based on ECMWF data reported to range from 2011 to 2013;

b4) Analysis of wind and wave conditions along main routes of navigation in the Black Sea AVISO considering measurements reported for the period 2010-2015;

b5) Analysis of wind and wave conditions along main routes of navigation in the Black Sea considering ECMWF data reported for the period 2005-2014;

b6) identification of the wind energy potential of the Romanian seaside area using AVISO measurements reported for the period 2009-2015;

b7) identification of the wind energy potential of the Romanian seaside area using ECMWF data reported for the period 2000-2014;

b8) Assessment of daytime and nighttime wind conditions in the Black Sea using NCEP-CFSR reported data for the period 1999-2008;

b9) analysis of the wave energy potential of offshore wind farms (75 projects) from Germany, Denmark and Britain considering AVISO measurements reported for the period 2010-2015;

b10) Assessment of Conditions in the Mediterranean considering wind measurements AVISO Reported for the period 2010-2014.

c) Implementation of assimilation date Techniques in Black Sea

c1) Making Simulations Using Conditions averaged phase spectral wave model SWAN calculation considering various fields in the Black Sea;

c2) Applying DA methods.Yarmouth on predictions provided by the SWAN model for the western area of the Black Sea. Among the Methods Used CAN BE mentioned: a) optimal interpolation; b) Least Squares;

c3) Implementation Techniques of YES through SWAN model for the Romanian coastline;

c4) Calibrate and validate the model predictions provided by SWAN Using in situ measurements of wave from Gloria platform;

c5) Calibrate and validate the model predictions provided by SWAN Using satellite altimetry measurements from various Missions Such as ERS, ENVISAT, Jason-1 and GFO respectively.

In addition to these contributions, in which the author was directly involved, it would be mentioned two case studies simulated using SWAN model, which was aimed at assessing the impact of coastal marine energy farms. In the first case it was considered a firm theoretical wave (consisting of several links WEC) located close to Mangalia, in this situation is only assessed the impact on local wave field. The second case study was focused on the area near the Danube Delta and involved the use of wind farms whose distance from land was gradually raised in this case is the impact on tidal or wave longitudinal.

It should be noted that a significant percentage of results were included in the project *Data Assimilation Methods for improving the WAVE predictions in the Romanian nearshore of the Black Sea,* ***DAMWAVE*****(PN-II-IDPCE-2012-4-0089)**, http://www.im.ugal.ro/DAMWAVE/index.htm, where the author is part of the research team. Autorul împreună cu coordonatorul echipei de cercetare a proiectului DAMWAVE au participat la seminarul cu tematica *Use of Satellite*

Observations in Numerical Weather Prediction http://www.ecmwf.int/en/seminar-2014-use-satellite-observationsnumerical-weather-prediction organizat în septembrie 2014 de unul din cele mai importante centre de predicție a vremii la nivel global, respectiv European Centre for Medium-Range Weather Forecasts (ECMWF). Au fost purtate discuții privind asimilarea de date în modelele de valuri, atât în acest centru, precum și în alte centre pentru predicția vremii.

The research conducted in this thesis were included in a number of 19 scientific works which are included in the volumes of journals or conferences. Of these, the most important works that may be mentioned are:

a) **Publications in international journals - ISI**, in Advances in Meteorology*, Evaluation of the wind energy potential in the coastal environment of two enclosed seas,* (**I.F: 1.107/2015**) and in Journal of Operational Oceanography, *A multi parameter data assimilation approach for wave predictions in coastal areas*, **(I.F:1.263/2016)**;

b) **Participation in international conferences and publication in conferences' proceedings - ISI**: **MARTECH 2016** (Lisabona, Portugal), **OCEANS'15 MTS/IEEE** (Genova, Italy), **IMAM 2015** (Croatia) și **SGEM 2015** and **2016** (Bulgaria);

c) **The Book** *Asimilarea de date cu aplicaţii la predicţia climatului de val în bazinul Mării Negre*, in Romanian, Ed. Zigotto, 2016, ISBN 978-606-669-182-6.

Based on the results obtained in the first year of doctoral studies, the author was included in the POSDRU 159/1.5/S/132397, *ExcelDOC*, "Excellence in research through doctoral and postdoctoral scholarships" focused on supporting researchers with a high scientific potential.

8.3 Future Research Directions

Given the theme, certainly that future research should consider implementing an operational model focused on both the Black Sea and Romanian seaside. There are domains to be identifie that can apply such predictions results and also implementation into integrated programs that should make possible wave predictions to arrive on time to those who need them. Further there are indicated several research directions and suggestions that may benefit in this respect, as follow:

- Identifying new sources of in situ measurements of the Romanian seaside area which complements the observations provided by Gloria platform;
- Building up a DA algorithm that achieve assimilation and calibration data to be continuous and in real-time;
- Merging SWAN model to a model of currents to estimate the dynamics of coastal currents (both longitudinal and transverse);

- Development of Black Sea databases by running *hindcast* or *forecast* simulations, which can be used for various climatological studies;
- Real-time monitoring of the Romanian coastal erosion through an application that uses information provided by the SWAN model;
- Identify the best solutions in terms of WEC systems that could operate in the Black Sea, considering their energy performance and coastal protection they can provide;
- Develop *seakeeping* studies considering the characteristics of transport ships and the marine environmental conditions that can occur in the Black Sea, including optimal routes navigation planning;
- Implementation of SWAN model (and assimilation techniques) within closed or semi-closed seas and comparisons of the results reported by global models for these regions.

BIBLIOGRAPHY

[1] M. Bocquet. *Introduction to the principles and methods of data assimilation in geosciences*. Lecture notes, Master M2 OACOS & WAPE, Ecole Nationale Superieure des Techniques Avancees Paris Tech. Ecole des Ponts ParisTech. Revision 0.15, pp. 88, 2014.

[2] NK. Nichols. *Mathematical concepts of data assimilation.* In: Lahoz, W., Khattatov, B. and Menard, R. (eds.) Data assimilation: making sense of observations. Springer, pp. 13-40, 2010. ISBN 9783540747024.

[3] M. Nodet. *Introduction to Data Assimilation*. Universite de Grenoble, INRIA, LJK, 2012.

[4] RH. Reichle. Data assimilation methods in the Earth sciences. Advances in Water Resources 31: 1411-1418, 2008.

[5] WMO (World Meteorological Organisation) http://www.wmo.int/pages/index_en.html (Accesat în Decembrie 2015)

[6] F. Bouttier, P. Courtier. *Data assimilation concepts and methods*. Meteorological Training Course Lecture Series, 2002.

[7] Y. Xie, J. Xing, J. Shi, Y. Dou, Y. Lei. *Impacts of radiance data assimilation on the Beijing 7.21 heavy rainfall*. Atmospheric Research 169: 318–330, 2016.

[8] K. Yumimoto, H. Murakami, TY. Tanaka, TT. Sekiyama, A. Ogi, T. Maki. *Forecasting of Asian dust storm that occurred on May 10–13, 2011, using an ensemble-based data assimilation system.* Particuology *in press*, 2015.

[9] DP. Dee. *Bias and data assimilation*. Q. J. R. Meteorol. Soc. 131: 3323–3343, 2005.

[10] M. Ghill, P. Malanotte-Rizzoli. *Data assimilation in meteorology and oceanography*. Advances in Geophysics 33: 141-266, 1991.

[11] SG. Mohinder, PA. Angus. *Kalman Filtering: Theory and Practice using MATLAB*. Second Edition, 2001.

[12] K. Shashank, N. Ravi, M. Rakshith, JV. Alamelu. *Implementation of Kalman Filter to Monitor the Level Fluctuations in a Dam Using FPGA*. Recent Advancements in System Modelling Applications, Lecture Notes in Electrical Engineering, 2013.

[13] PS. Maybeck. *Stochastic models, estimation and control*. Vol. 1. Academic Press, 1979.

[14] AL Pletea, L Popa. *Teoria Probabilităţilor*. Universitatea Tehnică "GH. ASACHI", Iași 1999.

[15] G. Welch, G. Bishop. *An Introduction to the Kalman Filter*. SIGGRAPH 2001, Los Angeles, CA, August 12-17, 2001.

[16] JM. Lefevre, L. Aouf, C. Skandrani, P. Queffeulou. *Contribution of satellite altimetry to wave analysis and forecasting*. 15 years of progress in radar altimetry Symposium, Venice, Italy, 2006.

[17] WAMDI Group. The WAM Model - A Third Generation Ocean Wave Prediction Model. J. Phys. Oceanogr 18: 1775-1810, 1988.

[18] N. Booij, RC. Ris, LH. Holthuijsen. *A third-generation wave model for coastal regions, Part I, Model description and validation.* Journal of Geophysical Research 104, C4: 7649-7666, 1999.

[19] HL. Tolman. *A third-generation model for wind waves on slowly varying unsteady, and inhomogeneous depths and current.* Journal of Physical Oceanography 21:782-797, 1991.

[20] HL. Tolman. *Practical wind wave modeling*. Proc. CBMS Conf. Water Waves: Theory and Experiment, Howard University, Word Scientific Publishers, 2008.

[21] World Meteorological Organization (WMO). *Guide to wave analysis and forecasting*, 1998.

[22] A. Bogathev. *Changes in operational suite of ALADIN-BG*. ALADIN Newsletter No 34, 2008.

[23] M. Dimitrova, A. Kortcheva, V. Galabov. *Validation of the operational wave model WAVEWATCH III against altimetry data from JASON-2 satellite*. Bul. J. Meteo & Hydro 18 (1-2):4-17, 2013.

[24] VS. Arkhipkin, FN. Gippius, KP. Koltermann, GV. Surkova. *Wind waves in the Black Sea: results of a hindcast study*. Nat. Hazards Earth Syst. Sci. 14: 2883-2897, 2014.

[25] A. Kotrikla. *Environmental management aspects for TBT antifouling wastes from shipyards*. Journal of Environmental Management 90: 77-85, 2008.

[26] F. Onea, E. Rusu E. *The expected efficiency and coastal impact of a hybrid energy farm operating in the Portuguese nearshore*. Energy 97: 411-423, 2016.

[27] E. Rusu, C. Ventura Soares, L. Rusu. *Computational strategies and visualization techniques for the wave modelling in the Portuguese nearshore*. Maritime Transportation and Exploitation of Ocean and Coastal Resources 1-2: 1129-1136, 2005.

[28] F. Onea, **A. Raileanu**, E. Rusu. *Evaluation of the wind energy potential in the coastal environment of two enclosed seas*. Advances in Meteorology, Article ID 808617, 2015.

[29] E. Rusu, L. Rusu, C. Guedes Soares. *Prediction of extreme wave conditions in the Black Sea with numerical models*. 9th International Workshop on Wave Hindcasting and Forecasting, Victoria, Canada, September, 2006.

[30] **A. Raileanu**, F. Onea, E. Rusu. *Spatial and seasonal variations of the environmental conditions along the Black Sea shipping routes*. International Multidisciplinary Scientific GeoConferences SGEM, 28 June - 7 July 2016 Albena, Bulgaria.

[31] W. Alpers, A. Ivanov, J. Horstmann. *Observations of Bora events over the Adriatic Sea and Black Sea by space borne synthetic aperture radar*. Mon. Weather Rev 137: 1150-1161, 2009.

[32] AVISO. *SSALTO/DUACS User Handbook: (M)SLA and (M)ADT Near-Real Time and Delayed Time Products*, 2014.

[33] SM. Uppala, PWK. Allberg, AJ. Simmons, U. Andrae, V. Da Costa Bechtold, M. Fiorino, *et al*. *TheERA-40 re-analysis*. Quart J R Meteorol Soc 131: 2961-3012, 2005.

[34] DP. Dee, SM. Uppala, AJ. Simmons, P. Berrisford, P. Poli, S. Kobayashi *et al*. *The ERA-Interim reanalysis: configuration and performance of the data assimilation system*. QJR Meteorol Soc 137 (656): 553-597, 2011.

[35] E. Rusu, **A. Raileanu**. *A multi parameter data assimilation approach for wave predictions in coastal areas*. Journal of Operational Oceanography 2016; *in press*.

[36] O. Makarynskyy, D. Makarynska, E. Rusu, A. Gavrilov. *Filling Gaps in Wave Records With Artificial Neural Networks*. Maritime Transportation and Exploitation of Ocean and Coastal Resources,Guedes Soares, C., Garbatov, Y. and Fonseca, N. (Eds.),Taylor & Francis Group, London, 1085-1091, 2005.

[37] L. Rusu, C. Guedes Soares. *Local data assimilation scheme for wave predictions close to the Portuguese ports*. Journal of Operational Oceanography 7(2): 45-57, 2014.

[38] K. Hasselmann, TP. Barnett, E. Bouws, H. Carlson, DE. Cartwright, K. Enke, JA. Ewing, H. Gienapp, DE. Hasselmann, P. Kruseman. *et al*. *Measurements of wind-Wave growth and swell*

decay during the Joint North Sea Wave Project (JONSWAP). Dtsch. Hydrogr. Z. Suppl, 12, A8, 1973.

[39] WJ. Pierson, L. Moskowitz. *A proposed spectral form for fully developed wind seas based on the similarity theory of S.A. Kitaigorodskii*. J. Geophys. Res. 69 (24): 5181-5190, 1964.

[40] SWAN. *Scientific and technical documentation, SWAN Cycle III version 41.01*. Delft University of Technology, Department of Civil Engineering, the Netherlands, 2015.

[41] AJ. Kuik, GP van Vledder, LH. Holthuijsen. *A method for the routine analysis of pitch and roll buoy wave data*. J. Phys. Oceanogr. 18: 1020-1034, 1988.

[42] DC. Conley, E. Rusu. *Tests of wave shoaling and surf models in a partially enclosed basin*. Maritime Transportation and Exploitation of Ocean and Coastal Resources,Taylor & Francis publications, London, ISBN 13: 978-0-415-39036-1, II:1015-1021, 2005.

[43] E. Rusu, M. Gonçalves, C. Guedes Soares. *Evaluation of the wave transformation in an open bay. Ocean Engineering*; 38(16):1763-1781, 2011.

[44] T. Soukissian, C. Kechris. *About applying linear structural method on ocean data: Adjustment of satellite wave data*. Ocean Engineering 34(3-4): 371-389, 2007.

[45] **A. Raileanu**, L. Rusu, E. Rusu. *Wave modelling with data assimilation in the Romanian nearshore*. In: Proc. of 16th International Congress of the International Maritime Association of the Mediterranean, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September 2015, Croatia, pp.837-843.

[46] L. Rusu. *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 2014, Albena, Bulgaria, Vol. II, 539-545.

[47] COMET. *Understanding Marine Customers*, 2nd Edition; www.meted.ucar.edu (Accesat în Mai 2016)

[48] JS. Fuglestvedt, T. Berntsen, G. Myhre, K. Rypdal, RB. Skeie. *Climate forcing from the transport sectors*. Proceedings of the National Academy of Sciences 105: 454-458, 2008.

[49] E. Rusu. *Wave energy assessments in the Black Sea*. J Mar Sci Tech 14: 359-372, 2009.

[50] E. Rusu. *Modelling of wave-current interactions at the Danube's Mouths*. Journal of Marine Science and Technology 15 (2): 143-159, 2010.

[51] W. Alpers, A. Ivanov, J. Horstmann. *Observations of bora events over the Adriatic Sea and Black Sea by spaceborne synthetic aperture radar*. Monthly Weather Review 137: 1150–1161, 2009.

[52] W. Alpers, AY. Ivanov, KF. Dagestad. *Investigation of coastal wind fields over the Black Sea using Envisat synthetic aperture radar images*. Proceedings of the ESA Living Planet Symposium, held in Bergen, Norway 28 June-2 July 2010, ESA publication SP-686.

[53] Y. Cai, Y. Wen, L. Wu. *Ship route design for avoiding heavy weather and sea conditions*. International Journal on Marine Navigation and Safety of Sea Transportation 8 (4): 551-556, 2014.

[54] STI (Sail Training International). http://www.sailtraininginternational.org/vessels/vessel-database (Accesat în Iunie 2016)

[55] GA. Papadopoulos, G. Diakogianni, A. Fokaefs, B. Ranguelov. *Tsunami hazard in the Black Sea and the Azov Sea: a new tsunami catalogue*. Nat. Hazards Earth Syst. Sci 11: 945-963, 2011.

PUBLICATIONS

A - PUBLICATIONS IN INTERNATIONAL JOURNALS - ISI

1. Rusu E, **Răileanu A.,** 2016. *A multi parameter data assimilation approach for wave predictions in coastal areas*. Journal of Operational Oceanography. http://dx.doi.org/10.1080/1755876X.2016.1192013 (**I.F:1.263/2016)**, main author - correspondent

2. Onea F, **Răileanu A**, Rusu E, 2015. *Evaluation of the wind energy potential in the coastal environment of two enclosed seas*. Advances in Meteorology. Article Number: 808617, 14 pages, doi: 10.1155/2015/808617. http://www.hindawi.com/journals/amete/aip/808617/ **(I.F:1.107/2015)**

B - BOOKS

3. L Rusu, **A Raileanu**, F. Onea, 2016. *Asimilarea de date cu aplicaţii la predicţia climatului de val în bazinul Mării Negre*, in Romanian, Zigotto, 300 p, ISBN 978-606-669-182-6.

C - PARTICIPATION IN INTERNATIONAL CONFERENCES AND PUBLICATION IN CONFERENCES' PROCEEDINGS - ISI

4. **Răileanu A**, Onea F, Rusu E., 2016. *Spatial and seasonal variations of the environmental conditions along the Black Sea shipping routes*. 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena, Bulgaria, www.sgem.org, SGEM2016 Conference Proceedings, ISBN 978-619-7105-62-9 / ISSN 1314-2704, June 28 - July 6, 2016, Book3 Vol. 2, 829-836 pp, DOI: 10.5593/SGEM2016/B32/S15.108.

5. **Răileanu A**, Rusu L., Rusu E., 2016. *Data Assimilation Methods to improve the Wave Predictions in the Romanian Coastal Environment*. 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena, Bulgaria, www.sgem.org, SGEM2016 Conference Proceedings, ISBN 978-619-7105-59-9 / ISSN 1314-2704, June 28 - July 6, 2016, Book2 Vol. 2, 855-862 pp, DOI: 10.5593/SGEM2016/B22/S10.109

6. Onea F, **Răileanu A**, Rusu E., 2016. *Evaluation of the wave energy potential in some locations where European offshore wind farms operate*. MARTECH 2016 - 3rd International Conference on Maritime Technology and Engineering 4 - 6 July 2016 Lisbon, Portugal. In book ISI indexed: Maritime Technology and Engineering 3, Chapter: Evaluation of the wave energy potential in some locations where European offshore wind farms operate, Publisher: Taylor & Francis Group, London, Editors: Guedes Soares & Santos, pp.1119-1124.

7. **Răileanu A**, Onea F, Rusu E, 2015. *Assesment of the wind energy potential in the coastal environment of two enclosed seas.* OCEANS'15 MTS/IEEE GENOVA 18-21 May 2015 Genova, Italy. http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7271248&queryText=onea%20florin&newsearch=true

8. **Răileanu A**, Onea F, Rusu E, 2015. *Evaluation of the offshore wind resources in the European seas based on satellite measurements*. 15th International Multidisciplinary Scientific Geoconference (SGEM) Location: Albena, BULGARIA Date: 18-24 June; 227-234, 2015. http://sgem.org/sgemlib/spip.php?article6134

9. **Răileanu A.**, Rusu L., Rusu E., 2015. *Wave modelling with data assimilation in the Romanian nearshore.* In: Proc. of 16th International Congress of the International Maritime Association of the Mediterranean, IMAM 2015 - Towards Green Marine Technology and Transport, 21-24 September, Croatia, pp. 837-843, http://www.imamhomepage.org/imam2015/

D - PARTICIPATION IN INTERNATIONAL CONFERENCES

10. **A Răileanu**, F Onea, E Rusu, 2015. *Evaluation of the offshore wind energy potential in the Romanian coastal environment at the Black Sea*. Presented at The international symposium Protection of the Black Sea ecosystem and sustainable management of maritime activities - PROMARE 2015, http://www.mareframe-fp7.org/ue_31.html, published in ''Cercetări Marine - Recherches Marines" 46/2016, http://www.rmri.ro/Home/Publications.RecherchesMarines.html **(3rd price for the best oral presentation)**.

11. A. Ivan, **A Răileanu**, F Onea, E Rusu, 2015. *Studies concerning the coastal impact of an offshore wind farm operating in the vicinity of the Danube Delta*. Presented at The international symposium Protection of the Black Sea ecosystem and sustainable management of maritime activities - PROMARE 2015, http://www.mareframe-fp7.org/ue_31.html, published in ''Cercetări Marine - Recherches Marines" 45/2015, **(3rd price for the best poster presentation)** http://www.rmri.ro/Home/Publications.RecherchesMarines.html

12. Onea F, **Răileanu A**, Rusu E. *Evaluation of the general wind conditions in the Black and the Caspian seas*. International Conference Environmental Issues in terms of its Protection and Ecology, 6-7 May 2015, Galaţi, Romania, pp 13-14, ISBN 978-606-696-035-9.

13. Rusu L., **Răileanu A.**, Rusu E., 2015. *An assimilation scheme based on remotely sensed data to improve the results of the numerical wave models in the Black Sea*, International Conference Environmental Issues in terms of its Protection and Ecology, 6-7 May 2015, Galaţi, Romania, pp 11-12, ISBN 978-606-696-035-9

E - PUBLICATIONS IN NATIONAL JOURNALS INDEXED IN INTERNATIONAL DATABASES

14. Onea F, **Răileanu A**, Rusu E, 2016. *Analysis of the extreme wind and wave conditions in the Black Sea as reflected by the altimeter measurements*. Mechanical Testing and Diagnosis, 1, 5-12. http://www.om.ugal.ro/mtd/download/2016-1/1%20MTD_2016_Volume%201_Onea.pdf

15. Zanopol AT, Onea F, **Răileanu A**, 2014. *Coastal impact simulation of a Wave Dragon farm operating in the nearshore of Mangalia*. Constanta Maritime University Annals, 21 (I), 65-70. http://www2.cmu-edu.eu/anale/41-2/

16. Gasparotti, C., **Răileanu, A**. & Rusu E, 2013, New Strategies for the Waste Management in the Black Sea Region, EuroEconomica, 2013, issue 2(32), pages 79-92. http://EconPapers.repec.org/RePEc:dug:journl:y:2013:i:2:p:79-92

F – PARTICIPATION IN NATIONAL CONFERENCES

17. **Răileanu A**, Rusu E, 2014. *Overview on Data Assimilation Methods in the Wave Predictions*, prezentat la 'A doua ediţie a Conferinţei Ştiinţifice a Şcolilor Doctorale din UDJ Galaţi (CSSD-UDJG 2014), 15-16 Mai 2014, Galati, Romania. http://www.cssd-udjg.ugal.ro/2014/resources/Book_of_Abstracts_2014.pdfl.ro/2014/resources/Book_of_Abstracts_2014.pdf

18. **Răileanu A**, Rusu E, *Evaluation of Various Data Assimilation Procedures to Increase the Reliability of the Wave Predictions in the Black Sea*, prezentat la a treia ediţie a Conferinţei Ştiinţifice a Şcolilor Doctorale din UDJ Galaţi (CSSD-UDJG 2015), 4-5 iunie 2015 Galati, Romania. http://www.cssd-udjg.ugal.ro/index.php/2015/abstracts-2015

19. **Răileanu A**, Rusu E, *Advances in increasing the Reliability of the Wave Predictions in the Black Sea by Implementing Data Assimilation Techniques*, prezentat la a patra ediţie a Conferinţei Ştiinţifice a Şcolilor Doctorale din UDJ Galaţi (CSSD-UDJG 2016), 2-3 iunie 2016 Galati, Romania. http://www.cssd-udjg.ugal.ro/index.php/abstracts

G – PARTICIPATION IN RESEARCH AND DEVELOPMENT PROJECTS TEAMS

20. **DAMWAVE** (2013-2015), 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.htm, membru în echipa de proiect.

21. **ExcelDOC** (2014-2015) - proiect POSDRU 159/1.5/S/132397, "Excelenta in cercetare prin burse doctorale si postdoctorale", membru al grupului ţintă.

PERSONAL INFORMATION

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Sex F | Date of birth 07/12/1967 | Nationality Romanian

WORK EXPERIENCE

From 1st of November, 2014

Managing Director of Danubius International Business School

Danubius University from Galati, Bdul. Galati Nr.3, 800654 Galati, Romania

- Coordination of DIBS, analyzing development opportunities, business partnerships management
- Project manager and/or team member in many European projects

Business or sector Education

From 1st of October 2011
To 31st of October 2014

Managing Director of Continuous Learning Centre

Danubius University from Galati, Bdul. Galati Nr.3, 800654 Galati, Romania

- Coordination, analyze opportunities to develop training activities

From 1st of October 2009
To 30th of October 2011

Lecturer in Informatics

Danubius University from Galati, Bdul. Galati Nr.3, 800654 Galati, Romania

From 25th of March 2007
To 30th of September 2009

Research Assistant in Informatics

Danubius University from Galati, Bdul. Galati Nr.3, 800654 Galati, Romania

From 1st of September 2002
To 24th of March 2007

General Manager

Euroserv SRL, Galati

- Project management and consultancy

From 1st of September 1995
To 31st of August 2002

System Engineer

ELIA SA, Galati

- Web applications – research and development

From 6th of June 1994
To 31st of August 1995

Programmer

Credit Bank SA, Galati branch

- Management of banking software applications

From1st of July 1991
To 5th of June 1994

System Administrator

"Dunărea de Jos" University of Galati

- Computer Network administration

EDUCATION AND TRAINING

1st of October 2013 - present

PhD student

EQF-8

"Dunărea de Jos" University of Galati, Romania

Thesis: "Implementarea de metode de asimilare de date pentru îmbunătățirea predicției valurilor cu modele spectrale în bazinul Mării Negre"

2006 - 2010	**Bachelor of Laws** Danubius University from Galati, Romania	EQF-6
1986 - 1991	**Diplomat Engineer - Naval Architecture** "Dunărea de Jos" University of Galati, Romania	EQF-7
October 2011	**Manager** Ttini Smart Ideas SRL, Bucharest, Romania	EQF-6
November 2009	**Project Manager** Dotis Trening SRL, Bucharest, Romania	EQF-6
May 2010	**ECDL Core Certificate 4.0** European Computer Driving Licence Core – RO052199	EQF-6
Februarie 2009	**Quality Insurance Consultant, ISO 9001:2008, ISO 19011:2003** Quality International Consulting SRL, Bucharest, Romania ▪ Third party auditor	EQF-6
April 2008	**Certified Trainer** Social Trade SRL, Galati , Romania	EQF-

PERSONAL SKILLS

Mother tongue(s): Romanian

Other language(s):

	UNDERSTANDING		SPEAKING		WRITING
	Listening	Reading	Spoken interaction	Spoken production	
English	C1	C1	C1	C1	C1
	Replace with name of language certificate. Enter level if known.				
French	B2	B2	B2	B2	B2
	Replace with name of language certificate. Enter level if known.				

Levels: A1/2: Basic user - B1/2: Independent user - C1/2 Proficient user
Common European Framework of Reference for Languages

Communication skills
- Excellent communication skills, team building abilities and strategic management of an international team obtained during the partnership between ELIA SA (the first Internet Service Provider in Galati, Romania), Infobahn International GmbH (Germany) and Cybernet AG (Germany)

Organisational / managerial skills
- leadership (currently responsible for a team of 9 people)
- Project management abilities and practice gained during over 5 years of collaboration with Safe Invest Holding (Austria), since September 2002, as an extraprofessional activity, managing and training over 2.000 sales persons. I also graduated 'Safe Invest Academy' (marketing, management, rhetoric, time management, team building, train the trainers and many others corporate trainings)

Computer skills
- Over 20 years experience in IT (Analysis and maintenance of IT system; Participation in IT research-development activities; Implementation of the e-learning software; National Correspondent for studies on Web Accessibility published on EU e-Agenda)

Driving licence
- B

ANNEXES

Răileanu

- If demanded