Fluxes, Interactions and Environment at the Land-Ocean Boundary. Downscaling, Assimilation and Coupling.

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DISCLAIMER

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NOTE: Completed and submitted to EC through SESAM application.

B FINAL REPORT

Final Publishable Summary report

Executive Summary

The FIELD_AC project (FP7-Space call of European Union Research) has shown the possibility to achieve reliable predictions of wind/wave/current/water quality/sediment transport in the coastal zone with a high level of detail. This means having advance information on the state of the sea and the resulting coastal zone status for decisions such as closing beaches after a storm (due to polluted water quality) or for actions directed to reduce risk levels under a storm (due to combined waves and rain). The improved and more efficient (cheaper) predictions have also served to establish the safe time interval to transport concrete “caissons” to a harbour construction site or to enrich the coastal wiki with knowledge for present and future generations.

The EU research project FIELD_AC (Space Call of the 7th Framework Programme) has dealt with the improvement of the reliability of such coastal zone predictions based on the best available modelling tools, the offshore boundary conditions provided by the “core” services (such as MyOcean) and the satellite plus in situ data available in four characteristic field sites.

These field sites, because of their permanent monitoring, can serve as a bench mark test case for other European Union coastal zones. They are: i) The Catalan coastal zone, ii) The gulf of Venice, iii) The German Bight, iv) The Liverpool bay.

The obtained advances in knowledge and modelling of coastal regions have allowed a more reliable and efficient (cheaper) set of predictions in the coastal zone for physical parameters such as wind, waves, currents or mean sea level. The improvement also extends to ecological parameters (such as the onset of the spring blooms illustrated in figure 1), water quality parameters (such as dispersion of sewage outfalls illustrated in figure 2) or morphodynamic parameters (such as suspended sediment transport under a storm, see figure 3). These advances stem from a careful coupling of high resolution models that has shown how the use of high resolution, fully coupled wave and hydrodynamic models leads to significantly different wave fields (see figure 4), which in situ measurements proved to be more accurate.

The necessity to increase spatial resolution and, at the same time, emphasizing the coupling mechanisms among different numerical models, has allowed FIELD_AC to prove that current-wave interactions is very often a necessity for coastal areas, even in the North Western Mediterranean where it was previously disregarded.

The issue of mutual interactions between “parent” and “child” numerical domains, or between meteorological and oceanographic processes, has been the core of the FIELD_AC research and it is likely that it will represent a cutting-edge science aspect for the next decade of research in this field. Benefits resulting from FIELD_AC achievements may be expected at operational forecasting (order of days) and climatic analysis scales (order of one decade), and therefore illustrate a wide range of potential applications of the obtained results.

The application of these advances to the modelling tools has supported the establishment of a new private company and to reinforce the technology of another, already existing, high-tech company. They have used our results in commercial applications in Europe (e.g. Spain and Norway), America (e.g. Brasil) and Australia. Finally our results are also being considered (e.g. new formulation for friction on the sea-bed) for improving state of the art models in other European Union institutions.

Summary description of project context and objectives

The coastal zone is exposed to increasing levels of population, activities and, as a consequence, assets at risk. This requires, as clearly identified at the beginning of the project a higher accuracy and reliability of meteo-oceanographic predictions that encompass a wider range of physical and ecological variables than what was previously available. As an illustration the discharge from the continent (via rivers or distributed land discharge) into the coastal sea is a "must" if we want to predict the water quality status near coastal cities, tourist beaches or rich aquaculture or fishery areas.

FIELD_AC (Fluxes, Interactions and Environment at the Land-Ocean Boundary. Downscaling, Assimilation and Coupling) has addressed this problem that generates growing social concern by:

1) Implementing a sequence of coupled and nested meteo-oceanographic models that simulate the atmospheric and hydrodynamic fields (wind, atmospheric pressure, waves, current and associated transport). This allows a robust high resolution simulation provided that the coastal scale parameterizations are updated and incorporate the new processes that appear near the coastal zone (e.g. the surf zone circulatory system).
2) Structuring the data and metadata from in situ observations in the coastal zone for the four studied coastal sites.
3) Structuring the remote observations (data and metadata as well) that, combined with the in situ data has provided a level of information for the four studied coastal domains not available before and which has also served for an efficient validation of numerical models and, eventually for an assessment of the quality of remote images near the land-sea boundary.
4) Establishing a common bench mark case, the Catalan coast, where the various modelling sequences have been run using the same meteorological driving field (provided by one of the partners) to test the performance limits of advanced European computational tools against those coming from other countries (notably the US) and in terms of the validation performed with in situ and remote observations.
5) Performing a comparison of the nested modelling approaches by the various partners with emphasis on commercial codes (such as e.g. those used by DHI or SIMO) with "traditional" models that much less user friendly have however benefited from a longer period of validation (e.g. associated to the research track of the participating institutions which cover more than three decades). This has served to establish the pros and cons of commercial versus research tools and establishing their particular limitations.
6) Preparing and testing the methodology to assimilate coastal scale, even local observations into a modelling sequence. The added value of combining point wise and spatially distributed observations into a coupled and nested modelling suite has also been assessed.
7) Analysing the effect of boundary conditions both from the offshore and from the land site into the obtained model results. This has served to revisit the concept of coastal zone width which for the water part (equally for the land part) is a dynamic definition depending on the prevailing processes and their energy level. This has also informed the quality and robustness of results in our

studied coastal domains where most of the computational grid points are affected by information provided through the boundaries.

8) Paying particular emphasis to the accessibility and quality of MyOcean products as a boundary condition for the offshore part of our domains since our simulations have been considered from the beginning a downstreaming activity of the MyOcean products offered by the marine core services.

9) Preparing and testing a transfer protocol for our data and simulations to all interested end users and stake holders. The emphasis has been on both elements, since the observations and the simulations have proved to be two sides of the same coin, in the sense that some of our end users could only be “convinced” of the value of high resolution simulations after seeing the same features in the observations (e.g. the intensification of current velocities near the Barcelona harbour entrance which, although a long standing complain of the harbour pilots had never been accepted by the authorities until first our simulations and then our measurements showed it).

10) Promoting the long term exploitation of project results by storing them into the expertise of the participating Universities and research centres (where they have been used to launch continuation research projects) and into the two participating private companies (where they have been used for further commercial applications). In this respect special mention deserves the project spin-off SIMO which has gained visibility and a market niche thanks to the FIELD_AC project.

To raise social awareness and to build up social confidence on the performed simulations we have selected four case studies that cover Northern Europe (Liverpol Bay and German Bight) and Southern Europe (Catalan coast and Venice gulf). Our selection of case studies encompasses a wide range of geographical settings, from open sea (Catalan coast) to estuary (Liverpool Bay) or lagoon (Venice Gulf) conditions. It also covers from micro to macro tidal conditions (from the Catalan coast to Liverpool Bay) incorporating also two cases of meso tidal conditions (German Bight and Venice Gulf). The studied cases also encompass from continuous continental discharge (Northern Europe cases) to flash flood torrential type of meteo-patterns (Mediterranean cases). The wave conditions go also from mild to energetic and the social and economic pressures represent a wide variety, representative of the European coast.

Regarding the generation of user driven results we have started the project with the organization of four workshops (all of them in 2010, from July to November) in the four studied sites. The invited users or receivers of project results have covered the various socio-economic sectors that converge in the coastal zone and they can be illustrated by coastal and river authorities, harbour authorities, fishermen, aquaculture companies, water quality agencies, construction firms, consultancy firms, environmental groups, etc. All the participants in the workshop received a questionnaire and were interviewed at various stages during the project development to achieve a two way interaction where the project researchers conveyed results and got in exchange ideas and practical criteria for enhancing the usefulness of our simulations. This has been particularly triggered by the presence of two private companies (DHI and SIMO) within the partnership and has resulted in an efficient transmission to society of the advances in technology and scientific aspects obtained within the project.

SIMO in particular has been created within FIELD_AC and is still, three years after its starting date, operating with a consolidated staff of six and with a fan of activities that go from visualization tools to the use of meteo-oceanographic predictions for supporting navigation routes, coastal construction activities or the impact prevention for accidental oil spills.

In this transfer of project production the DHI partner has supported tremendously the transfer of advances to the world wide market that they have. Moreover the linkage between a well-established company from Northern Europe and a recently created University spin-off in Southern Europe, has proved an interesting experience and a natural transfer of know-how.

The dissemination to the general public has included a variety of communication means such as TV, newspapers and the wiki. These have served to reflect on the project advances and to distil the socially more relevant elements for public dissemination.

The international context has been represented by our International Advisory Board (IAB) and project presentations in specially organized sessions at international conferences such as EGU (European Geosciences Union). In the IAB we have counted with representatives from the US, one of the clearer competitors of European technology in the field of coastal oceanography. We have had IAB representatives from the government (USGS - United States Geological Survey) and private groups (such as ASA- Applied Science Associates, Inc.). The exchanges have crystalized in two visits (from both sites), participation in the IAB meetings and stages of researchers at USGS. The fact that one of UPC old students is part of the US private company has also served to consolidate the links. This has allowed a much better informed use of the ROMS code (a world reference where FIELD_AC has contributed and gained a name in the international arena for high resolution simulations). It has also served to steer our production of results towards a more practical setting, a clear US component that must be acknowledged. This has contributed to making explicit the uncertainty intervals of our simulations and combining physical predictions with statistical descriptors.

We have also presented the results of our research to a wider group of researchers and countries, via the international conference presentations and the invited members from third countries Universities and Government (covering from China to Bulgaria and Romania for instance) where the main findings from FIELD_AC have been presented and discussed, together with their applicability to other environments not studied in the project (for instance applications of the ROMS simulations to the Black Sea).

The European Union and international research dimension of the project have been also presented in structured conference sessions notably at EGU 2012 and 2013. The emphasis here has been on the concept of a "coastal operational framework" where a virtual or physical linkage of codes, measurements and simulated results has been presented in a consistent manner. Because of that the title of the session organized at EGU-2012 (to be repeated in 2013 in the wake of Field_AC) was "Oceanography at coastal scales. Modelling, coupling and observations". This summarizes the concept of the project in the sense that an efficient transfer of results to interested social parts can only be achieved by a smart combination of these three elements. That was the rationale for selecting the Field_AC partners (expertise on processes and models by combining Universities and research centres together with commercial companies) the four studied sites (including four of the European Union coastal observatories with a better and longer set of data) and end users (encompassing the large variety of economic sectors with presence or interests in the coastal zone).

Description of the main S & T results/foregrounds

Integrated Assessment

In the FIELD project, right from the beginning, we have produced results related to i) the scientific (such as equations, terms, etc) elements contained in the project, ii) the technological aspects associated to the science (such as assimilation, statistics, analysis from observations, etc) and iii) the applications resulting from the former to components (covering the fields of waves, currents, sediment transport, nutrient dynamics, etc).

In the first year and regarding the scientific aspects, we have contributed a new type of source functions for inclusion in wave modelling under restricted generation conditions (Ardhuin *et al*, 2010). We have also analysed the effect of transient driving terms and short duration events (Alomar *et al,* 2010). Finally we have dealt whith the probabilistic description of wave breaking in wave generation models and how that affects the resulting bulk parameter prediction (Filipot *et al*, 2010).

From the technology stand point we have studied the assimilation techniques for coastal domains to optimize the boundary conditions for tidal components, based on remote observations from High Frequency radars (Barth *et al*, 2010). We have also carried out a statistical assessment of the observational networks and their role in supporting model validation, assimilation and eventual decision making (Schulz-Stellenfleth and Stanev, 2010).

From the application stand point we have considered the consequences of storminess, based on the advances gained with our nested modelling sequences (Rozynsky *et al*, 2010) and the application of these modelling sequences to harbour quay design (Sánchez-Arcilla *et al*, 2010).

The second project year, i.e.2011, FIELD_AC has produced results in the general areas of i) scientific development, including equations, their coupling an interactions and the effect produced by boundary conditions (now making reference to site specific analysis), ii) technological elements going from assimilation to statistical characterization of the obtained results or data analysis and interoperability and iii) applications, covering the same grounds as in the previous year but with more depth and a wider scope as will be described in what follows.

In the scientific area we have proposed a new set of wave-current interaction equations as a function of depth (Bennis and Ardhuin, 2011). We have also proposed a set of equations for diffusion and double diffusion near the free surface and how to introduce that in circulation models (Kantha *et al*, 2011). We have equally considered the 3D framework for wave current interaction from a theoretical perspective (Bennis *et al*, 2011) and how to integrate wave, current and sediment transport model in this case supported by video recordings (Carniel *et al*, 2011).

The partnership has studied the coupling of tidal and wind driving terms under sharp bathymetric variations and with the support of high frequency radar observations (Port *et al*, 2011). In the same manner we have analysed the wave current coupling at the free surface and at the bed boundary layer (Bricheno *et al*, 2011) and the wind–wave–current coupling and model performance under the same conditions (Bricheno *et al*, 2011). In this manner we have also analysed the domain of influence of the free surface and bed boundary layers in the resulting hydrodynamic field (Bricheno *et al*, 2011).

We have also employed our coupled modelling suits for the wave-current-sediment coupling in the Venice lagoon (Carniel *et al*, 2011) and for the Catalan coast (Pallares *et al*, 2011). This has allowed establishing the limits of coastal scale operational models and based on the studied cases but with a more general view so as to distil some generic consequences for operational oceanography (Sánchez-Arcilla *et al*, 2011).

Finally we have dedicated some attention to the effects of the bed boundary layer in the evolving wave and current fields, particularly for beds with cohesive sediments (fluid muds) and high concentration sediment layers (Toorman and Bi, 2011).

In the technology area we have considered the use of primary productivity to assess the skill of a physical oceanography model (Kantha *et al*, 2011). We have also classified our wave forecasts using advanced geo-estatistical techniques, including the Aitchison (Tolosana *et al*, 2011) distribution.

The project has addressed wave assimilation at local scales using non stationary kriging (Tolosana *et al*, 2011). In the same manner it was necessary to analyse data interoperability and the Thredds data server (Bergamasco *et al*, 2011) to facilitate the exchange of information from the four coastal observatories in FIELD_AC. We have also studied the combination of *in situ* measurements, remote images and simulated fields (Schulz-Stellenfleth *et al*, 2011) for the circulation in the German Bight.

In the application area we have used the high resolution models for hind casting and performing the corresponding improved statistical analysis (Sclavo *et al*, 2011). In this same manner we have analysed the wave climate combining high resolution model simulations with observations (Wolf *et al*, 2011). The project has also applied our suite of hydrodynamic models to determine shoreline evolution after a beach nourishment operation, with emphasis on the rapid initial stages for which our high resolution set of models is particularly appropriate (Archetti *et al*, 2011). We have also combined high resolution models with remote images for the hydrodynamic analysis of detailed features in the Venice Gulf (Benetazzo *et al*, 2011).

The partnership has employed the developed models to characterize wave extremes in the Adriatic (Carniel *et al*, 2011). Another application was the extension of the modelling suits to determine the dynamics of the coast in the Northern Adriatic (Carniel *et al*, 2011). We have also combined high resolution models with ferry box data to assess the limits of such an approach for the German Bight (Grayek *et al*, 2011).

The partners have extended the operational high resolution current predictions to a number of applications in the Northern Spanish coast, with emphasis on the Vigo and Coruña harbours (Cerralbo *et al*, 2011). The same approach has been employed for water circulation in Mediterranean harbours such as Barcelona (Grifoll *et al*, 2011) where the small magnitude of the resulting velocities offered a tough challenge for models and measurements alike (Grifoll *et al*, 2011).

We have considered the hazards under present and future climate conditions with our high resolution models (Tolosana *et al*, 2011) and analysed the constraints imposed by the end user requirements upon our oceanographic predictions (Fernandez *et al*, 2011). The team has also employed a smart combination of observations and models to improve the wave climate characterization in restricted domains such as Liverpool Bay (Wolf *et al*, 2011) and with this enlarge the applications of the Liverpool Bay coastal observatory (Howarth *et al*, 2011).

In the year 2012 FIELD_AC has contributed to the areas of i) science, dealing with the integration of downscaled/coupled models together with the analysis of the underlying variability, ii) technology, addressing data set combinations and the more practically oriented aspects of the modelling suites and iii) application and dissemination, including in this last year the four studied sites plus the Catalan coast intensive study period, corresponding to the field campaign that was performed in the previous year.

In addition to the more specific papers that will be summarized in what follows special attention was paid in this last year to the collection of combined papers for a FIELD_AC special issue, to be sent in February 2013 and therefore reported with the date 2013 in what follows. The same regarding the state of the art position paper that we denote the White Paper of Field_AC.

Regarding the special issue we have considered a number of Journals out of which we have finally left the selection between Continental Shelf Research, with an impact factor of 2.088 and Ocean Dynamics, with an impact factor of 1.774. The FIELD_AC partners decided to go for Continental Shelf Research because of its higher impact factor. Now we have the approval of the Journal in the sense that they have accepted the list of proposed papers and contents and have requested an additional introductory paper showing the theme of the project and the special issue.

Regarding the White Paper we have initially selected the Progress in Oceanography Journal because it is one of the few ones, well considered in the literature, with a high impact factor (3.142) and accepting papers of around 100 pages. However in the preparation process we have also received offers to publish such a state of the art review in Geofizika (with an impact factor of 0.789), Oceanology (with an impact factor of 1.242) and the scientific publishing company Aracne. We have decided to go, as initially scheduled for the Progress in Oceanography presentation, starting from the White Paper report delivered at this time which will be next subject to internal (within the project) and external reviewing in the sense that we want to incorporate other remarks from researchers in the partner institutions but who have not participated in FIELD_AC and also from top level researchers outside the project institutions. With this we shall send the improved report to the Journal.

In the science area we have integrated the river, tide and meteorological forcing for semi enclosed domains such as Liverpool Bay (Bolaños *et al*, 2012) and have also analysed the resulting patterns for more open but coastal domains such as the Catalan coastal shelf (Grifoll *et al*, 2012).

The partners have studied the multi scale coupled modelling of waves and currents (Grifoll *et al*, 2012) and the variability of the momentum balance equations and resulting implications for the modelling results for shelf circulation in restricted domains (Grifoll *et al*, 2012). This has led to the development of a multi scale coupling framework (Grifoll *et al*, 2012).

The high resolution modelling sequence has been analysed in terms of the impacts due to the downscaling process in the simulation of key processes in semi enclosed domains (Bricheno *et al*, 2013) (Polton *et al* 2012). As an illustration we have considered the effect of density gradients in high resolution simulations for areas such as Liverpool Bay has also been analysed (Howarth *et al*, 2013).

The partners have included in the analysis the water/sediment exchanges and wave/current variability at the inner shelf under micro tidal conditions subject to sharp variability in time (short duration storm events) and space (wind jets associated to coastal topography irregularities) (Pallares *et al*, 2013) (Alomar et al, 2013).

In the technology area we have improved the use of large data sets and have illustrated the possibilities of such large volumes of informati+on for deriving improved knowledge on physical oceanographic processes (Bergamasco *et al*, 2012). We have also established the performance of circulation models with and without assimilation from high frequency radar currents in 3D codes (Schulz-Stellenfleth *et al*, 2012).

In the area of applications we have considered the role of rogue or freak waves in navigation accidents, such as the case of the Louise Majesty accident (Cavaleri *et al*, 2012). We have simulated the future wave scenarios under different climatic conditions in the Mediterranean (Benetazo *et al*, 2012) or the sediment dispersion under present conditions after a flash flood event (Fernandez *et al*, 2012).

The partners have studied with our sequence of tools, the long term morphodynamic evolution and the relation with the North Atlantic winter oscillation (Rozynski *et al*, 2012) and the circulation around a groin field, including the performance of a “deteriorated groin system” (Rozynski *et al*, 2012). The partnership has also produced a paper on the prediction of beach evolution in the Baltic Sea with high resolution modelling (Pruszak *et al*, 2012).

Another category of applications has been obtained by using the sequence of high resolution models for the evolution of stratification in the Northern Adriatic (Bolaños *et al*, 2013). In this same manner we have treated the dispersion of fresh water under impulsive flood events for two river types (Liste *et al*, 2013), (Falcieri et al, 2013).

As a final contribution wrapping up the scientific contents of the project with some “elements” of the technical and application aspects (intended to be of use for future modelling, observational and application apects) is the “White Paper”.

In this White Paper, produced during 2012 but presented during 2013, we have seven main chapters. The first chapter, dedicated to the **Introduction**, includes a short description of the state of the art on physical oceanographic modelling, on the performance and results of various applications for single models (meteorological, waves, currents) and a discussion on the interactions considered in the present state of the art. The emphasis is on coastal domains, where the predictions became more difficult due to the high resolution and the new processes that appear, notably the enhancement of interactions and coupling. Here we also describe the main aim of the paper which is the modelling and application of physical oceanography in coastal and shallow areas, pointing out the present limitations, the present accuracy limits and the main uncertainties and knowledge gaps. We also explain how we look towards the future so as to provide steering for future developments.

Chapter 2 is dedicated to **Modelling**. It starts with some general comments about the modelling tools and the main types of problems commonly encountered in advanced modelling exercises under the present state of art when moving to coastal and shallow waters. Chapter 2 has the following subchapters:

2.a. Meteorological Modelling. This section deals with coastal scale meteorology, starting from the boundary conditions provided by large scale runs and with emphasis on performance and reliability. We specifically address the problems when dealing with land-sea boundaries, the influence of orography and the spatial and temporal scales involved. We give a very short description of the performance of the models used in the project, which represent the state of the art, and dedicate some attention to a coastal validation with measured data.

2.b. Wave Modelling. This section presents the generation wave models, with a brief overview of the evolution from older ones. The emphasis is on the performance for coastal and shallow waters and the new processes that appear in this area. We discuss the difficulties of solving these processes (e.g. diffraction) and link them to the main time and spatial scales where they are needed. We consider nested modelling and structured versus unstructured grids, showing the implications for the physics and the numerics. We provide some examples of different situations and the relevance of the single processes.

2.c. Current Modelling. Here we review the performance of 2D and mainly 3D models for coastal scales. We discuss the characteristics of the most advanced models in the present state of the art, showing the new problems and processes that appear when we move toward shallower water. We discuss resolution input data, time and space scales, discretization of the vertical coordinate and accuracy limits. We also present some examples of application and the nested and coupled modelling suites employed using both structured and unstructured grids.

2.d. Transport and water quality model. Here we considered the transport and water quality models employed in the project (state of the art) with emphasis on shallow water processes such as re-suspension. We discuss the data required, the modelling limits and the eventual extension to other (active) substances (pollutants, nutrients, etc). Next we examine the main processes considered in the models and the time and spatial scales involved. We present an accuracy analysis and some examples of application.

In chapter 3 we describe how the various models interact and the corresponding physics of the interactions between dominant processes. The emphasis is on the physics, the numerics and the resulting accuracy and limitations for predictions. The first section (3.a.) discusses the interactions between wind and waves, presenting the physics of the problem the available semi-empirical formulations and the resulting *momentum* exchanges. We discuss the implications for coastal scales, when compared to large scale analyse. The section ends with a summary of the present state of the art limitations for restricted area models and the way to circumvent them.

In the second section (3.b.) we discuss the coupling between waves and currents, with emphasis on the physics and the processes involved and how the available mathematic formulations are able to reproduce them. We consider the relevant space and time scales and how they affect the numerical modelling sequences. We also address the accuracy that can be provided by present modelling tools and the implications for practical applications. In the next section (wind and currents) we follow a similar approach, with emphasis on the steps from theory to practical applications.

This chapter ends with a section on the coupling between wind, waves and currents. We discuss the additional elements that appear when combining the three elements together and the limitations of the present state of the art, since this ternary analysis although in theory the final point of the methodology, is still far from solved and seldom use in numerical simulations.

In chapter 4 we deal with **Coastal data and assimilation**. The first section deals with existing data, the instruments available and the rest of information and meta information stored in the coastal observatories corresponding to the four studied sites. We discuss the accuracy, frequency of data, time scales resolved and even touch briefly upon the cost and management of such data sets. We also review briefly the remote images and how they can be applied to solve coastal zone problems, including radar and satellite images.

This chapter finally also discusses the validation (eventually assimilation) of our oceanographic modelling tools using the data available, starting from the calibration with recorded data (past), continuing with the comparison of present forecasting with on-going measurements (present) and the improvement in future predictions with past and present observations (assimilation for the future).

In chaprer 5, **Applications for the study areas**, we analyse the four areas considered in the project, in terms of their different characteristics and to show the applicability and performance limits of the various models to each geometry and combination of drivings. The first section presents a brief description of each of the areas with geometry characteristics and relevant processes. This is the basis to present some of the main results obtained for the Catalan coast, the Liverpool Bay, the German Bight and the Venice Gulf which is the second section of this chapter. We discuss separately the wind fields, the wave fields, the current fields and for some applications the resulting sediment transport patterns. We present uncoupled and coupled model runs and we compare them with measured data, discussing the dependence of local scale results on the large scale fields and the role of boundary conditions.

Chapter 6 presents an **Inter comparison for the Catalan Coast**. The purpose is to inter compare the performance of various modelling suites, including both commercial and scientific type of codes, for the same area (the Catalan coast) and using the same data input (meteo fields from the Barcelona Supercomputing Center, partner in the project), and the same data for validation (corresponding to the intensive field campaign during the FIELD_AC project). The chapter starts presenting the reasons for selecting the Catalan coast site as a bench mark test case and the rationale behind the selected period for the campaigns and from the subsequent comparison here presented. We have discussed the data available and a general description of the period in terms of meteorology, wave conditions and circulation patterns.

The second section of this chapter presents the meteorological modelling for the Catalan coast campaign period, showing the WRF model configuration employed for the simulations, the model set-up and the specific problems of the area. We discuss the performance for the different meteo-conditions and show some examples of the output fields compared with measured data, discussing the accuracy and the limitations.

The second section presents the results for the Catalan coast in terms of waves and currents. Regarding waves we compare observations with simulations provided by the different models. The comparison is carried out in terms of objective analysis parameters, with focus on the differences between the models and the discrepancies between models and measured data. We try to explain, to the best possible limit, the reason for these differences and analyse them. While trying to minimize the discrepancies due to different inputs, physics and numerics, a certain level of differences has appeared as inevitable during the simulations, although at a much smaller level than previously performed inter comparisons in other research exercises. Here we also include an analysis of the influence of the coupling and the sensitivity of the results to the input information. For the current part we follow a similar approach, inter comparing the models among themselves and with the measurements. The comparison is done with objective analysis parameters, focusing on the differences between models and the discrepancies with the observations. We also try to provide explanations for these discrepancies and look at the errors due to the different inputs, physics or numerics. The influence of the coupling and the sensitivity to the input information is also here included. Finally we complete this section with some remarks on the accuracy required in the input to achieve a given target level of accuracy in the results.

The final chapter of the paper is the **Discussion Section**, where we critically review the advances, discuss where we are in the present state of the art and delineate the main steering lines for future research.

1) First Field_AC year

The work in the first Field_AC year can be summarized by the following points:

1 – Setting up and implementing a sequence of nested models for wind, wave, current and transport fields, that allow a robust high resolution and coupled prediction, such as was the main aim of the project. This includes state-of-art coastal-scale parameterizations and also the new parameterizations proposed by project partners and published in the corresponding scientific journals.

2 – Preparing the data and related information (metadata) for all the in situ observations available in the four studied coastal sites. This applies, in particular, to the Catalan coast case, which is going to be the common benchmark test for the project. The aim, in here, is to have readily available the required in situ information for an efficient model validation.

3 – Preparing the remote observations (data and if appropriate metadata), that will be combined with the in situ data, in the four studied coastal domains. This serves another project general objective, which is to combine local and remote information for a more reliable and efficient validation of models at coastal scales.

4 – Planning the multidimensional Field Campaign in the Catalan coast case, specifying dates, types of sensor, processing protocols and the way to implement this data set into the normal project development.

5 – Intercomparing modeling approaches among the different partners, with particular emphasis on: a) Nesting strategies b) Coupling Strategies, so that expertise is shared within the partnership.

6 – Preparing a methodology to assimilate in situ and remote coastal data into the modeling sequence. The added value of considering, jointly, point-wise and spatially-distributed observations, as already mentioned in the project description, remains one of the important aims of the project.

7 – Analyzing how the boundary conditions control the model results and what is the region influenced by boundary information in the output. This is critical for small-sized coastal domains, where most of the computational grid can be affected by the information provided through boundary conditions.

8 – Testing the accessibility (eventually quality) of My Ocean products as boundary conditions for the off-shore boundaries in our simulations. This will also provide a feedback to the My Ocean products.

9 – Building a linkage and transfer protocol for disseminating our coastal data and predictions to all interested end-users and stakeholders. The aim here is to contribute to a future certifying process of GMES products, which needs to be done at coastal scales since it is in the coastal zone where most of the “conflicts” and therefore “needs” for reliable forecasting arise.

The work in WP1 started with the end-user identification and establishing the corresponding contact via the site specific work shops. The same agenda was followed during the four workshops, although it was considered that a flexible approach could be followed so as to enhance end-user open communication. A specific questionnaire was created addressing the oceanographic products the different end-users may already have and their target oceanographic product. The same questionnaire was used in the four different workshops. End-users were encouraged to fill-up the questionnaire during the workshop, and some time was allocated to that purpose in the workshop agenda. Also, questionnaires were sent to end-users unable to attend their specific workshop so that they could explain their oceanographic needs. The number of answers was close to 70%.

In the 1st year, we also disseminated project results by means of specialist magazines (see figure 1 as an example of a divulgation summary) and by means or conventional scientific publications (11 papers with impact factor and 7 communications at well recognized conferences or forums).


Prediccions fiables i precises

"El 60 % de les platges estudiades estan en una situació dolenta"

DEBATE

El cambio climático

El mal 'uso' de la costa

Nuestras infraestructuras costeras son inevitablemente 'estáticas', cuando el estado natural de la costa es dinámico

Figure 1: Example of news about FIELD_AC

The work of WP2 in this first year was related to the high resolution meteorological modelling and the high resolution wave/current/transport modelling. It consisted in identifying the main processes at oceanographic coastal scale and selecting the most suitable model suites for showing the added value of down streaming services, i.e. forecasting at very local scales based on regional scale data. The modelling comprises wind, wave, current and transport/dispersion codes.

We have been setting up a number of wave models for the four studied sites. We have established a preoperational WAM code for the North sea (5x5km2) and German Bight (1x1km2), driven by wind fields of the German Meteorological service and providing bidimensional spectra every 12h and bulk parameters every 3h. For the Irish Sea and Liverpool bay we have implemented WAM for the Irish sea and SWAN for the Liverpool bay. For the Northern Adriatic and German Bight DHI has implemented the high resolution spectral model MIKE21_SW and a Bousinesq MIKE21_BW for wave propagation in one of the inlets of the Venice lagoon. For the Norhtern Adriatic ISMAR has also implemented SWAN for a curvilinear computational grid of 10km for the outer domain, 3km in the intermediate domain near Venice and then a nested grid of 500 metres. UPC has implemented SWAN for the same 3 grids as the meteo model, i.e. 9x9km2 (Mediterranean sea), 3x3km2 (Balearic sea), 1x1km2 (Catalan Coast domain).

These circulation and transport computations, at very local scales (mesh sizes between 200 and 500m) have been compared with satellite images, such as for instance MERIS with 300m resolution (ENVISAT from ESA). The model results and the observations, with comparable resolution which was not available before, show consistency and, for instance, for the case of the German Bight, the oscillatory behaviour of the sediment pools and the outflow of suspended particles into the North Sea (tidally driven) are very similar. The emphasis has been on defining the same grids and bathymetry for the wind/wave/current/transport models. The work in WP3 dealt with the boundary conditions at the Sea-Land border, the offshore boundary condition, the free surface boundary conditions and the sea bed boundary condition.

We have evaluated the relative merits of various boundary and closure, with important challenges to improve models, programming the selected one and introducing it as an operational boundary condition into the sequence of oceanographic models to improve the model performance for extreme rain events (flash floods) and for fluid mud beds.

Regarding open boundary fluxes, we are using boundary conditions from MyOcean whenever posible. For the Liverpool bay finistera we are using data from the Atlantic margin model run by NOC, with a resolution of 12km. For the German case we are already using the MyOcean North-Western European shelf model with 6km horizontal resolution and 3 vertical layers. We are also starting to use Topex/Poseidon data (sea surface elevation from tides, particularly for the German case).

In WP4 we focused, during this first year, on (atmosphere – ocean coupling) and task (open sea – coastal sea coupling), according to the original planning in the description of work. However, we have soon realized that it was preferable to widen the coupling approach right from the beginning, and because of that we also started to consider in the first year the coupling to the land discharge and the wave current interactions.

In WP5 we have worked to establish a link to MyOcean products, mainly as an offshore boundary condition for our domains. In this respect we have established a Service Level Agreement with MyOcean and we have updated continuously the relationship, by compiling all the information from the local networks in the 4 field sites.

More specifically, we signed a SLA with MyOcean which has been giving us access to the MyOcean set of products, which, in turn, have been used by the partners regularly for the predictions. As an illustration, we are using the MyOcean North Western European shelf modelling system, with an hourly output at 6km horizontal resolution and 3 vertical layers as boundary information for the German Bight case.

The quality of a data set was assured in near real time and including physical, sedimentary, geochemical and biological parameters, both of time series type and as gridded data fields (for satellite, HF radar and preoperational model data). The time series are stored in an Oracle data base while the satellite and radar images are stored in NetCDF format with climate forecasting conventions. Depending on the data type a web mapping service or a chart plot is also offered.

We have also worked on the remote sensing products available and required for FIELD_AC. They have been bed for i) the analysis of dynamics in coastal seas, ii) local data assimilation (against point wise conditioning) and iii) preoperational services. We have made use of advanced algorithms for obtaining high resolution information (HZG algorithms to retrieve wind from SAR (WiSAR) on board satellites ERS1, ERS2, RADARSAT1, ENVISAT). In this case the wind directions were derived from visible linear features in the image, while wind speeds were obtained from normalized radar cross sections. The main sensors considered are the advanced synthetic aperture radar (ASAR, operating at C-band) which is a micro wave radar that ensures continuity with the image mode and wave mode of ERS1 and ERS2 (SAR). We have equally considered the MERIS (medium resolution image spectrometer) operating in the solar reflective spectral range by ESA at ENVISAT, with a coverage of 2 out of 3 days. These images have 15 spectral bands that allow to determine concentrations of chlorophyll, suspended matter and similar. The retrieval algorithm has also being derived by one of the FIELD_AC partners (HZG).

Regarding the field covering 2 characteristics periods for the Catalan Coastal Sea domain, and initially planned for the spring of 2011 and the winter of 2012 it was advanced and started the campaign 10 months before what was initially scheduled. The Catalan Coast field campaign began on 11th November 2010 and went on until 18th January 2011.

This year we also started to work on data assimilation at local scales, which has been a rather controversial topic in the state-of-art. However due to the fact that coastal domains need a higher time and space resolution than open sea domains, while not offering enough time horizon for a quick validation procedure (information ”propagation” time within coastal domains) we have decided to perform an initial analysis based on our 4 field cases. This will also allow to consider the anisotropy always present in coastal domains and which is not normally included in open sea analysis (e.g. figure 2).

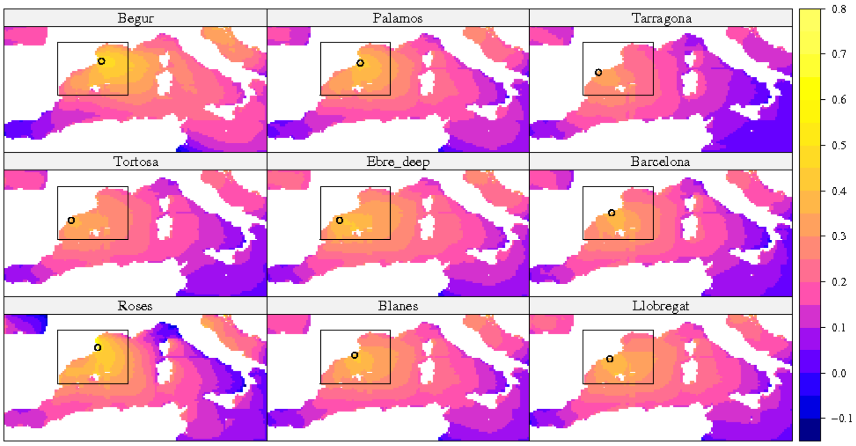

Figure 2: The initial covariance matrix for Hs data assimilation in the Catalan Coast domain. The 9 points correspond to the 9 buoy positions and the plots indicate the area of influence (white/yellow higher influence) of each data point.

2) Second Field_AC year

The work in WP1 has been related, during this second year, to the dissemination of project activities and the results we have obtained. In general terms, it has consisted in assessing the local scale forecasting services in terms of quality and usefulness for the coastal society, plus a continuation of all on-going work related to the preparation of material for the operational dissemination and transfer of project results. In parallel we have structured a multidisciplinary data base and kept on with the dissemination of project results.

We have concluded that a number of sizable markets exists, but despite a growing market and the anticipation of value added demonstration products, the service industry needs to further professionalize its services in terms of adopting common validation protocols, certification and end-user integration. The scientific community on the other hand must continually improve the skill, usability and flexibility of the modelling tool boxes and share the advances both in open source and commercial software in order to broadly address the end-users and the expected future SME's venturing into this market.

Based on selected user driven high resolution ocean forecasting services, the value of certification and qualification has been discussed in depth including input from the end-users. Figure 3 visualizes some key elements for sustainable operational services in coastal seas. For decision making the users require information which they consider reliable and they can trust. This means that they have "enough" knowledge or have experience with the error bars in general and that the proposed error bars are small enough for the information to add valuable advice.

Hence the two boxes 'Qualification and certification' and 'Forecast Service' are considered equally important. 'Qualification and certification' should be interpreted broadly not only relating to quantitative prediction skill of the provided physical parameters, but also including the effectivity with which these are transformed into information or advice that the end user can easily adapt to in the daily working routines and the degree to which the end-user is ready to rely on the information in decision making.

Figure 3: Key elements for sustainable operational services in coastal seas

This second year we have continued disseminating our results to other end users (Universities, schools, civil associations, etc...), and other countries such as China, U.S. and Bulgaria. This dissemination has also included MCS providers (MyOcean) and data agencies. We have also continued our contribution to raise societal awareness by showing the project and its results in press, TV and radio and we have also established new operational services or agreements with new clients (illustrated here by a SIMO SLA, see figure 4).

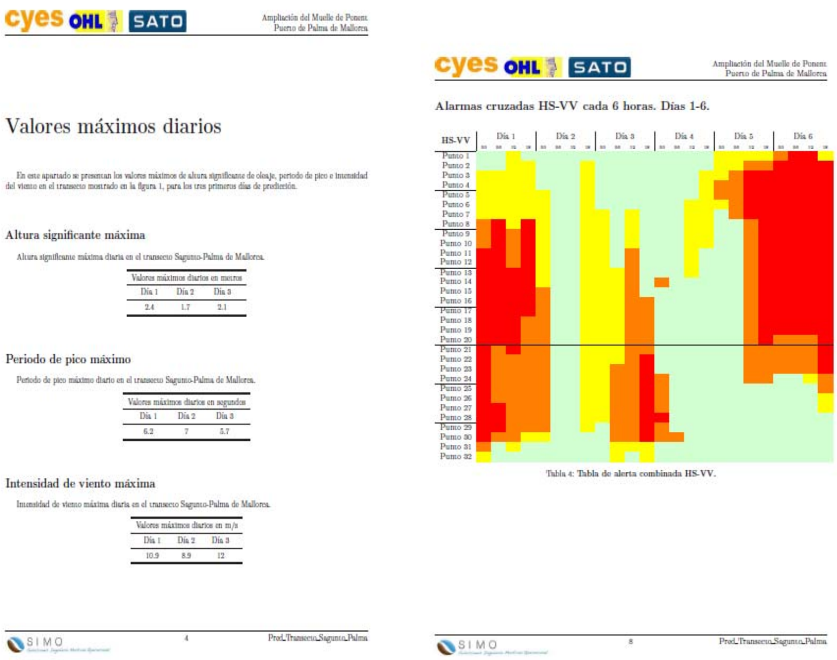

Figure 4: Example of Operational Service report.

The work of WP2 in this second year has consisted in the implementation of high resolution models for the FIELD_AC study sites. Complementary work on meteorological models and wave models has been carried out despite these tasks having been finished during the first year of project duration, in order to perform additional tests for validating the models and to improve the coupling between them.

When coupling waves and currents two different aspects have been considered: the effect of waves on the current field, and the effect of currents on the wave field. Only a slight modification of the simulated results can be appreciated when adding the current fields. In the locations closer to the coast is where the effect of currents is more important, although the current field contained discrepancies with respect to field data. For deeper locations, where the effect of currents is almost negligible, a really good current field is needed to improve the predictions, and if it is not available it is better not to include the current effects in the wave simulations.

We have also investigated the effects of Asymmetric Strained Stratification on flow, turbulence and sediment transport, during a spring-neap cycle and within a tidal oscillation. We have used a combination of high frequency 3-D fine resolution numerical model (POLCOMS) and moored data to study the turbulence and hydrodynamics of this ROFI. The observations show that, contrary to previous studies, stratification happens near high water when turbulence dissipation is maximum, suggesting that the Asymmetric Strained Stratification processes are happening near the bottom, similar to a salt wedge estuary. Results from 3-D modelling show that the dynamics in the ROFI are 3-dimensional, thus any previous depth-averaged simplifications cannot be applied.

We have also worked on the near-shore circulation models in order to implement a nested model system to solve the near-shore circulation for instance from the Catalan Coast. The model used is ROMS and the system starts from MyOcean products where the information of currents, sea level and tracers is obtained at 6.5 km resolution. The atmospheric fluxes are also obtained from MyOcean, which corresponds to ECMWF products. The downscaling scheme consists of three increasing resolution models (see Figure 5). The first model (SHECAT) covers approximately the Catalan Shelf, the slope and the bottom basin of the Catalan Sea with a resolution of 1 km. The Coastal model has a resolution of 250 m and covers basically the potential Llobregat and Besos river plumes. Finally the local domain, with 40 m of resolution, covers the area where the field campaigns were carried out.

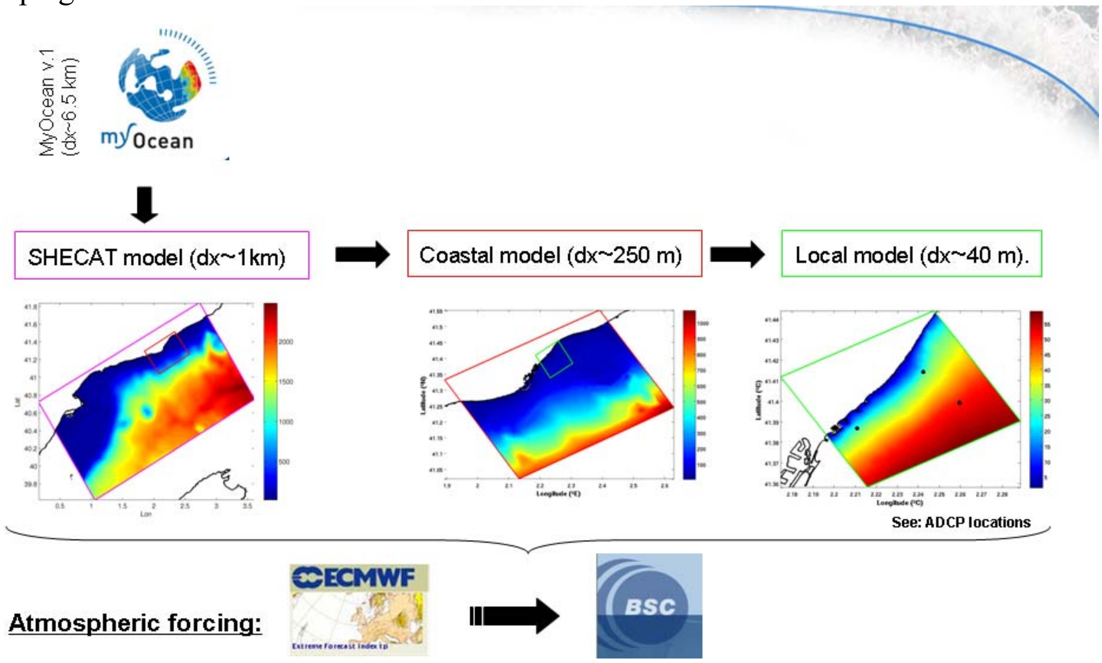

Figure 5: Implementation scheme of the modelling system to solve the near-shore circulation in the Catalan sea.

To apply these hydrodynamics results to sediment transport and to the cycles of production we have run specific codes such as SDM or ERSEM. The SPM model has been tested for instance in the Irish Sea. Bed stresses combining the effects of waves and currents have been introduced to force the model – leading to increased sediment resuspension, and transport. Remaining the difficulty of quantifying coastal sediment sources. The ERSEM model has been equally implemented and tested in the Irish Sea for a single annual cycle. The spring bloom has been qualitatively well predicted, anticipating its onset as it happens in Nature. A similar exercise has been carried out for the German Bight. The results capture how the Po River plume dynamics affect the coast and evolve in the N. Adriatic (figure 6). At the same time, the southern regions, with relatively high sediment concentrations, reflect the contribution from the Apennine rivers. It is interesting to note that in spite of their small freshwater discharge, the Apennine Rivers with a steep gradient, are able to provide a strong sedimentary input into the Adriatic Sea.

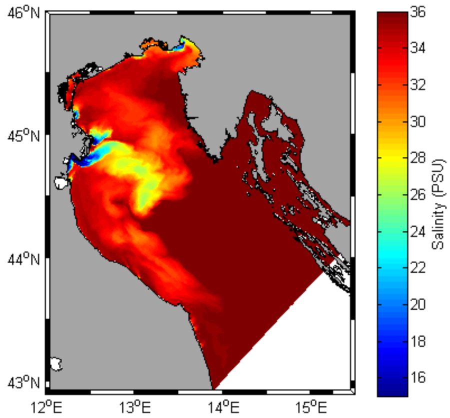

Figure 6: Salinity field in the Gulf of Venice (COAWST snapshot at November 9, 2010, 12:00 UTC). While the influence of Po river plume is rather evident, it is also possible to disseminate the local effects that other rivers produce on the western Adriatic coast and in the northern-eastern Gulf of Venice region.

In WP3 we have considered the boundary control on the studied domains, that can become important or critical in coastal areas. Because of that we are looking at the land, ocean, surface and bottom boundary conditions simultaneosly and with the required detail and within a general methodology to introduce the 3D boundary conditions for river discharges and for urban run-off into coastal circulation models applying the approach to the 4 study sites.

The assimilation of sea surface temperature (SST) from MyOcean has been implemented in our similations. The input variables of the meteorological models are the temperature, pressure, momentum and humidity. Over the ocean surface and coastal areas, SST is an important variable. The default configuration of the system uses the NCEP analysis of SST at 0.5º of cell grid spacing. The increase of horizontal spatial resolution of SST (SST from MyOcean at 0.05º) should allow to better reproduce local complex mesoscale structures that appears over coastal areas, in particular in the 4 domains studied in FIELD_AC.

This second year considerable advances were made dealing with benthic high-concentrated layers and fluid mud in cohesive sediment transport modelling. With progress in modeling transport of sandy sediments with an admixture of fine grains. Different options for bottom friction models have been explored, not surprisingly showing the largest differences in the near shore zone. The bulk empirical JONSWAP formulation with a suitable friction coefficient showed quite robust results in spite of its empirical nature. But also bed roughness has been modeled as a function of sediment characteristics and waves and current conditions. This formulation has been incorporated to wave dissipation by bottom friction in a source term included in a new version of the WAVEWATCH 4.04 model where it has shown considerable impact.

In WP3 we have also studied this second year the open boundary conditions. Our model implementations now use MyOcean boundary conditions as an input. We have been setting either a series of nested models and, as an alternative, an unstructured model that can provide the necessary resolution. Unstructured grids show many advantages, but finite difference nested grids models can still be faster and less complex and have a large user community. There remains a need to further assess the quality of the open boundary conditions against in situ-and remote sensing data (for a wider number of conditions) in order to understand the impact of the open boundary condition on the results obtained for the near coast study sites.

Following our research results, the need for regional wave modelling, as an operational product, has been identified leading to the initiation of the EU MyWave project, complementing the MyOcean project and where some FIELD_AC partners participate. Finally, the question of error transmission in the chain of models, spurious information (added or subtracted) at internal bounderies and control of boundary and initial conditions was part of the work using the already assembled modelling suites and framing performance limits of what we have called the Coastal Operational Framework.

As an illustration for the Catalan Coast, the coupled versions of ROMS-SWAN have been implemented in a coastal and local domain, with 250 m and 40 m grids respectively. Model output for selected events have been compared to satellite data from MyOcean, to data from dedicated campaigns during the Field_AC project and to data from operational buoys. For wave-current interactions and coupling, a set of benchmark cases had to be setup for testing each of the formulations considered. In Figure 7, a sample output of some preliminary simulations is shown. The coupling formulation used is based on the Vortex Force formalism which considers the influence of wave effects on currents in an Eulerian framework as the sum of two-components: the gradient of a Bernoulli head and a vortex force. The Bernoulli head represents an adjustment to the pressure in accommodating the incompressibility requirement and the vortex force is a function of the interaction between the vorticity of the flow and the Stokes drift.

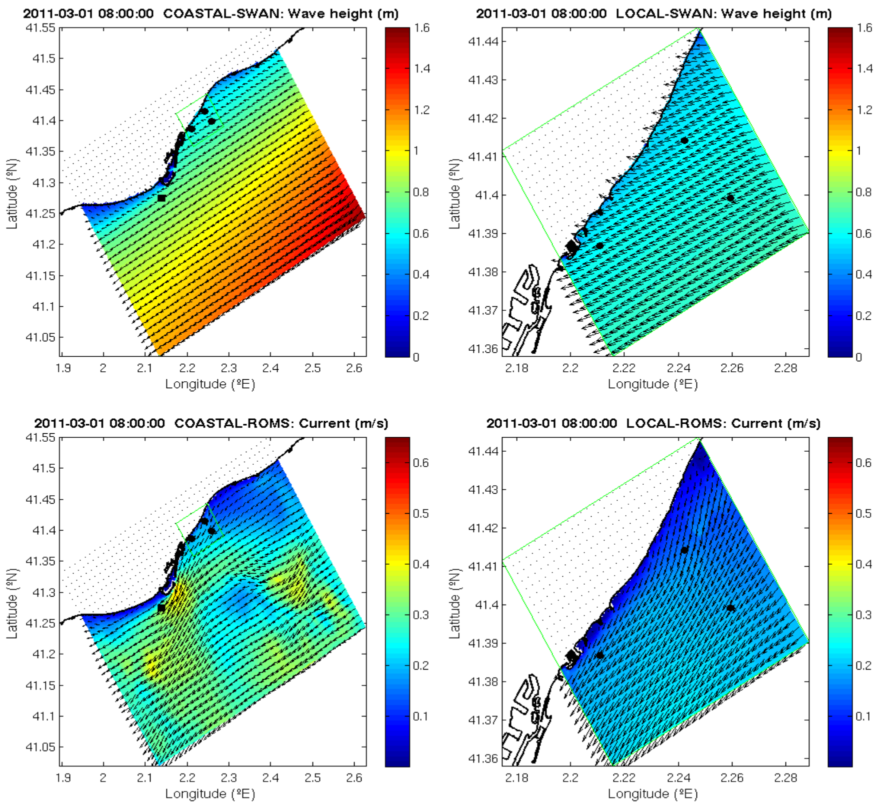

Figure 7: Snapshot of the nested coupled-model system based on ROMS-SWAN applied to the Catalan coast case. The ADCPs deployed during the field campaign of the project are marked with a black circle.

Coupling and interactions with an unstructured mesh have been also assessed using the spectral wave model WAVEWATCH III and the 3D circulation model HYCOM. Different test cases have been selected to validate all the terms implemented in the circulation and wave models. A field campaign was planned and executed for november 2012 in the Iroise sea. We have been working on the coupling of a 3D current within each component (wave length) of the wave spectrum model in order to accurately reproduce the wave propagation on a sheared current in deep water. Performed tests have been done in a well mixed area (Iroise sea), by comparing a wave model forced by a tidal current velocity and a baroclinic sea surface induced velocity that suggest how sensitive is the wave propagation to a small difference in the amplitude and vertical distribution of the velocity input for the spectral wave model.

In WP5 we have continued working in the link to MyOcean products mainly as an offshore boundary condition for our domains downloading regularly the information. The practical exploitation of the existing coastal observatories in the four field sites has continued providing access to the partners. Moreover, for some observatories there were additional 3 observational campaigns (e.g. Liverpool Bay during 2011). The purpose of these campaigns was to extend the capabilities of Observatory, focusing on the effects of the biogeochemistry entering from the rivers into the coastal sea. We have also compiled the remote sensing database and linked it to the remote observations from other sources, distinguishing what is available from what would be desirable in the coming future. The data are stored in a spatially distributed database, which also contains in-situ multi-sensor observations. They have been freely accessible via the COSYNA data portal.

Regarding the first Field_AC field campaign (as an illustration) it started on November 11, 2010 and ended on January 18, 2011. During this campaign the following equipment was deployed: 2 AWACs (points A1 and A2 in Figure 8) at 24 m depth (measuring waves and current profiles) with 1 OBS coupled to each one, 1 RDI (recording only current profiles) and 1 directional buoy (measuring directional waves). The RDI and the buoy were located at 50 m depth (point A3). Moreover, 2 CTD campaigns were planned, one before and one after a rain event. They were carried out on November 19th and December 2nd, with 35 CTD profiles each one.

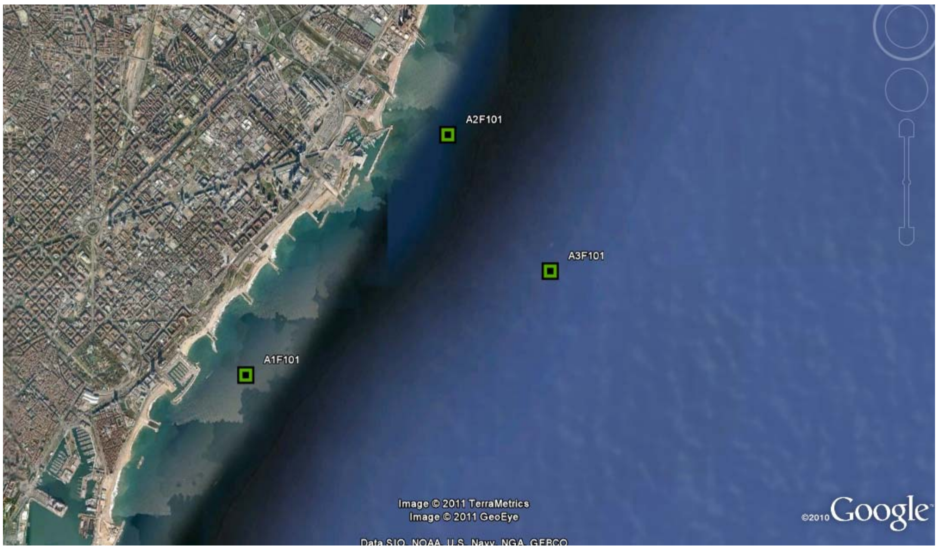

Figure 8: Location of the measuring stations in the Field_AC campaigns.

Regarding assimilation, in parallel to the work on FerryBox data the investigations concerning the exploitation of HF radar were continued. Three HF radar stations have been in operation in the German Bight providing surface current observations on a pre-operational basis. A methodology has been developed to combine these measurements with numerical model data in order to optimize state estimates. The results have been assessed in a pre-operational framework. The availability of longer time series has also allowed statistical analysis, e.g., identification of tidal constituents, as well as case studies. e.g. storm events.

3) Third Field_AC year

In the 3rd year of Field_AC we have continued in WP1 building demos and establishing contracts detailed in other parts of this report. We have developed a web-GIS application where all the numerical modelling results from several partners and the data collected during the field campaign could be easily analysed. The architecture of this whole system is primarily based on the previously noted SOS (and PostgreSQL) server for observed data and THREDDS data server for numerical data. Using different open-source JavaScript libraries, such as OpenLayers, GeoExt, Ext.js or JQuery these two different data sources were combined in a GIS based platform easily accessible through any web browser. One of the main potentials of this platform is the possibility of comparing collected and simulated data in order to help in the different calibrations and validations of the implemented numerical models.

In WP2 we have run for scientific and application purposes the pre-operational modeling suite of the 4 studied sites. For instance NOC set up three nested models for the Irish Sea/Liverpool Bay at 12, 4, and 1.3 km resolution. The model system was run for a storm event over the Irish Sea and the sea level pressure and wind outputs were used to force the coupled hydrodynamic and wave model POLCOMS-WAM; the effect of the variable WRF resolution on the wind, storm surge and wave hindcast was assessed. An improvement was observed in WRF model pressure and wind speed when moving from 12 km to 4 km resolution with errors in wind speed decreasing more than 10% on average. When moving from 4 km to 1.3 km no significant further improvement was observed. The atmospheric model results at 12 km and 4 km were then applied to the ocean model.

Moreover, the precipitation has been used in the KUL hyrological model to provide hourly river outflow data. By including these hourly outflows into the Liverpool Bay model, we gained a better understanding of how the land derived freshwater flux enters the ocean. Liverpool Bay's high tidal range and large intertidal areas mean that fresh water entering in a low water tidal channel as opposed to that flowing in at high water will have a very different impact.

An intercomparison of the different model suites has been carried out for the common case of the Catalan cost, modelling the same study area and using similar inputs and boundary conditions and comparable spatial resolution. Table 1 shows the models and the institutes that participated in the intercomparison exercise.

Wave model	Letter	Institution
WAM cycle 4.5.3	A	HZG
SWAN	B	UPC
WAM	C	NOC
Wavewatch III (4.04)	D	SHOM
MIKE 21	E	DHI
WAM cycle 4.5.3	F	ISMAR
NETTUNO	F'	ISMAR

Table 1: Wave models, corresponding institutions and the letters used to refer to them.

In WP3, an executable program has been developed by the KU Leuven that can predict the discharges based on the forecasted rainfall for both the Llobregat river, the Besos river and four CSO locations. It has been shown that using conceptual models to predict the freshwater input into oceanographic models is a good approach as reasonably accurate results can be obtained with very short calculation times, an important prerequisite for an operational model. The hydrological model developed by KUL has been set up for Liverpool Bay and validated for the period 2004-2010. This model uses precipitation from the WRF model run by BSC and by NOC shelf model run at BSC. The model has been locally modified at NOC.

These complex routines that we have developed to simulate BBL processes in the presence of waves and mobile sediment. The short (order-10 s) oscillatory shear of wave-induced motions in a thin wave-boundary layer produces turbulence and generates large instantaneous shear stress. In Figure 9, the current, wave and current+wave are shown in function of the wave height. The figure show how the wave dominates in a region close to the shoreline. In opposite, the current-stress prevails in the river discharge region and offshore.

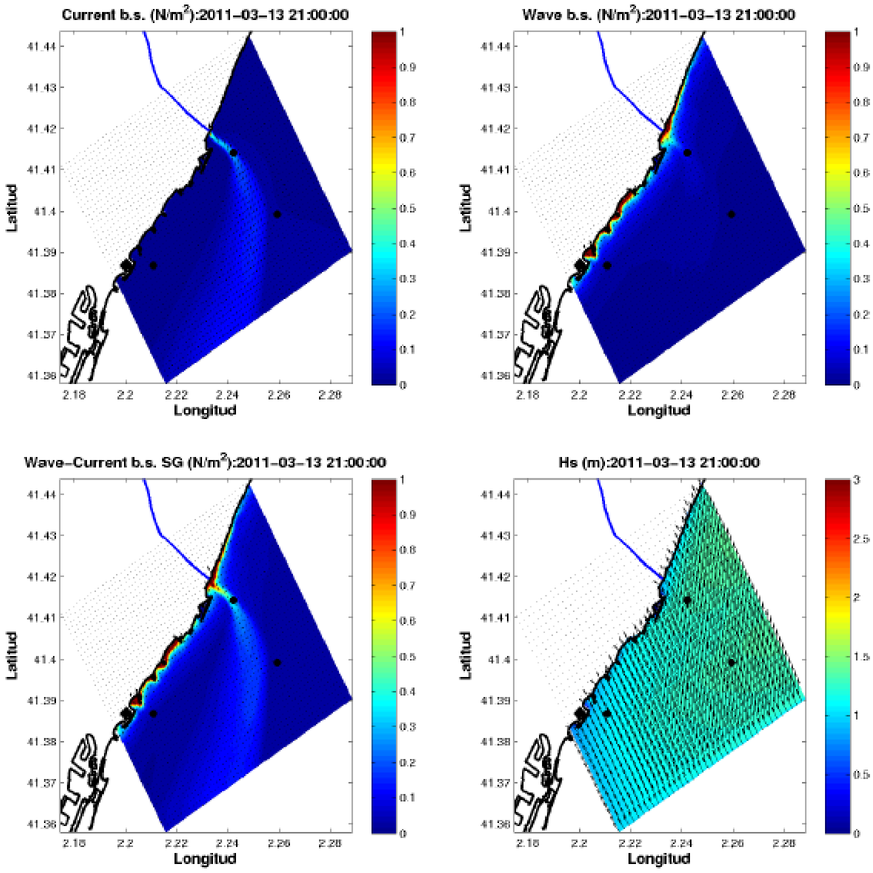

Figure 9: Snapshot of current-stresses, wave-stresses, wave+current stresses and wave height for a high water discharge from the Besòs river.

The resolution of boundary forcing in both time and space is also very important, as shown by the example of high resolution winds. In an experiment for downscaling and coastal forecasting, it was apparent that the model using more frequently available boundary conditions outperformed the model performance using the currently available MyOcean boundary conditions. This experiment illustrated that improvements to the standard MyOcean products could be made. The over predictions in the offshore significant wave height for uncoupled and coupled models (Figure 10) may be accounted for by the overestimation in the wind speed, however in the nearshore the significant wave height is under-predicted. This implies that the balance between energy input and loss in the activated model source terms becomes less accurate in shallow water. The need to reduce the energy loss may explain the need for a reduced bottom friction coefficient in shallow water.

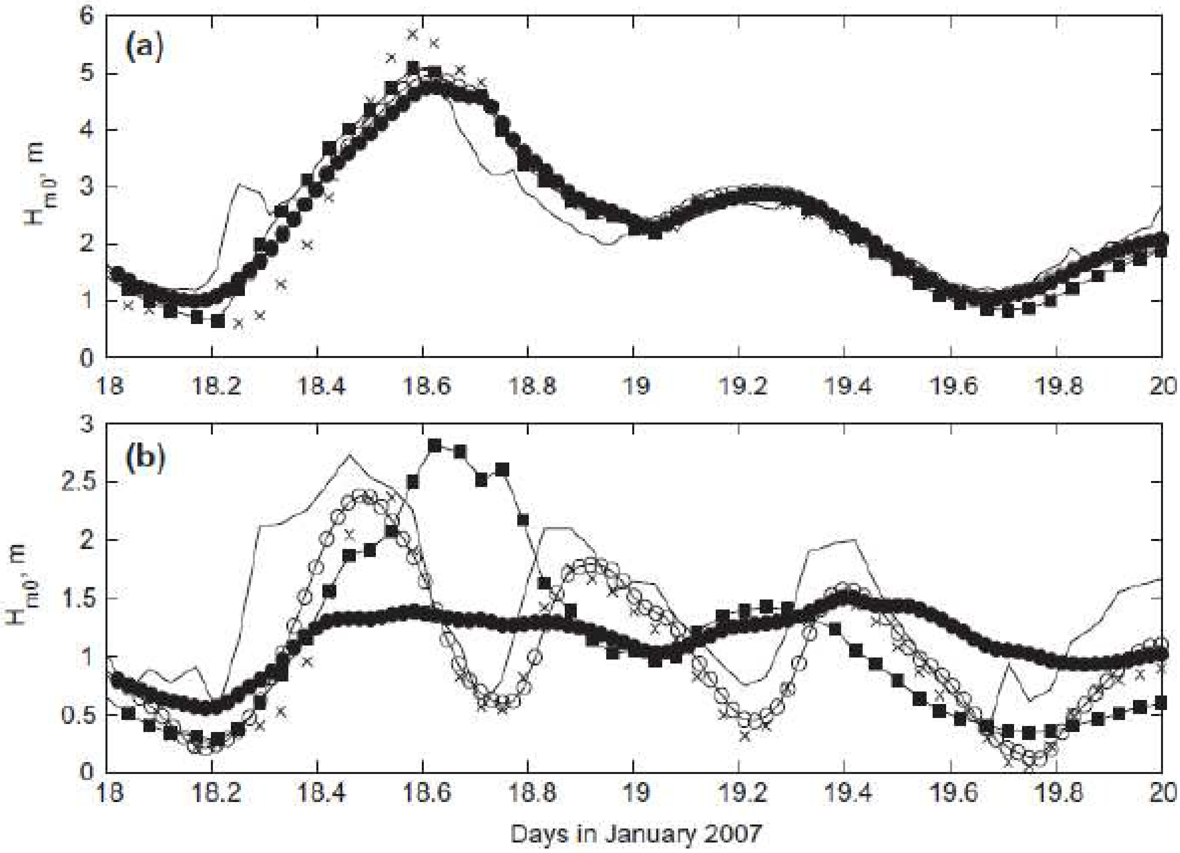

Figure 10: The offshore (a) and nearshore (b) significant wave height, Hm0, observations (solid line) compared with the 1-way coupled POLCOMS–ProWAM with relaxed limiter hindcast and reduced JONSWAP bottom friction (crosses), the 1- way coupled POLCOMS–SWAN hindcast with reduced JONSWAP bottom friction (line with unfilled circle symbols), the uncoupled ProWAM hindcast with Madsen wave-alone bottom friction (line with filled square symbols) and the uncoupled SWAN hindcast with reduced JONSWAP bottom friction (line with filled circle symbols).

In WP4 we have dealt with coupling and downscaling issues. For instance two different COAWST model setups (grid sizes of 2 Km and 500 m) were implemented by ISMAR covering the full Adriatic Sea and the Gulf of Venice. A 2-km grid is not always an eddy resolving grid, and the downscaling to 0.5 km is necessary to capture almost completely the internal dynamics of ocean circulation. In this line, during 2012, DHI has dealt with consolidating and validating a repeatable methodology for downscaling baroclinic oceanographic flow models.

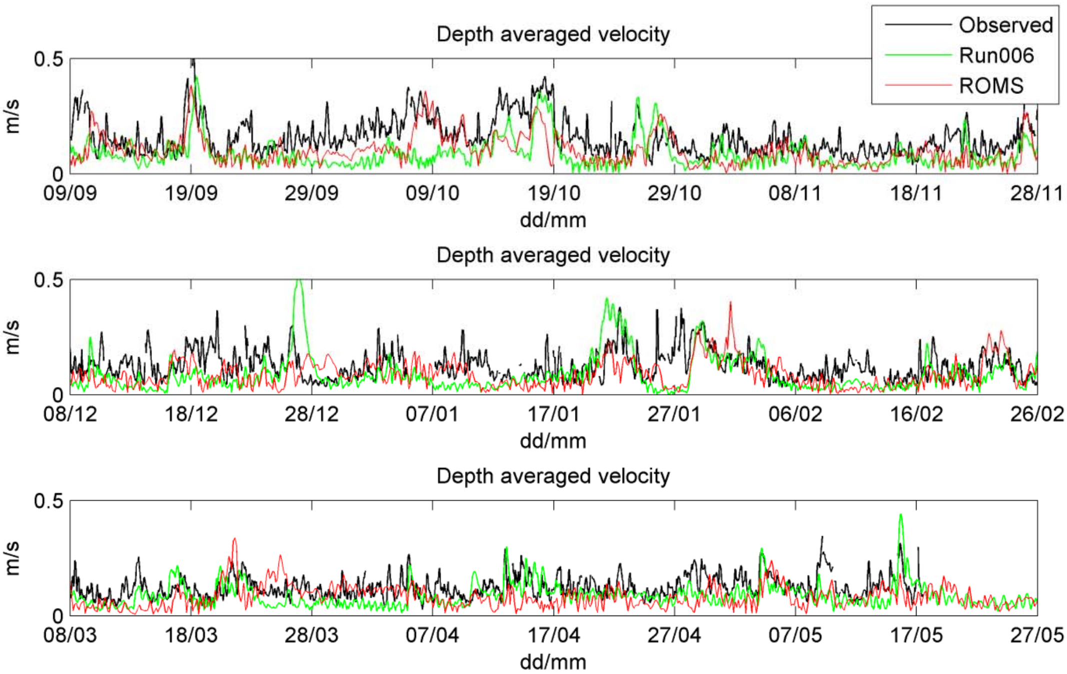

Figure 11: Depth averaged current speed in the Northern Adriatic for a 8½ months period.

Following the repeatable MyOcean based downscaling methodology, using the MIKE 21/3 model complex provides reliable results. Figure 12 shows results from the Northern Adriatic ROMS model run at ISMAR and MIKE 3 FM model run at DHI (named Run006 in the plot) validated against observations. This shows the efficiency of the collaborative FIELD_AC downscaling methodology. While ROMS is statistically slightly best, the validation study demonstrates complementarity of the models. With comparable computational efforts, the unstructured mesh model has coarser resolution at the offshore position used in the validation but is efficient for downscaling the signals with higher resolution than the structured mesh model when needed for an engineering application for a coast or a structure at sea. On the other hand, the structured mesh is more efficient in model applications where a uniform model resolution is required.

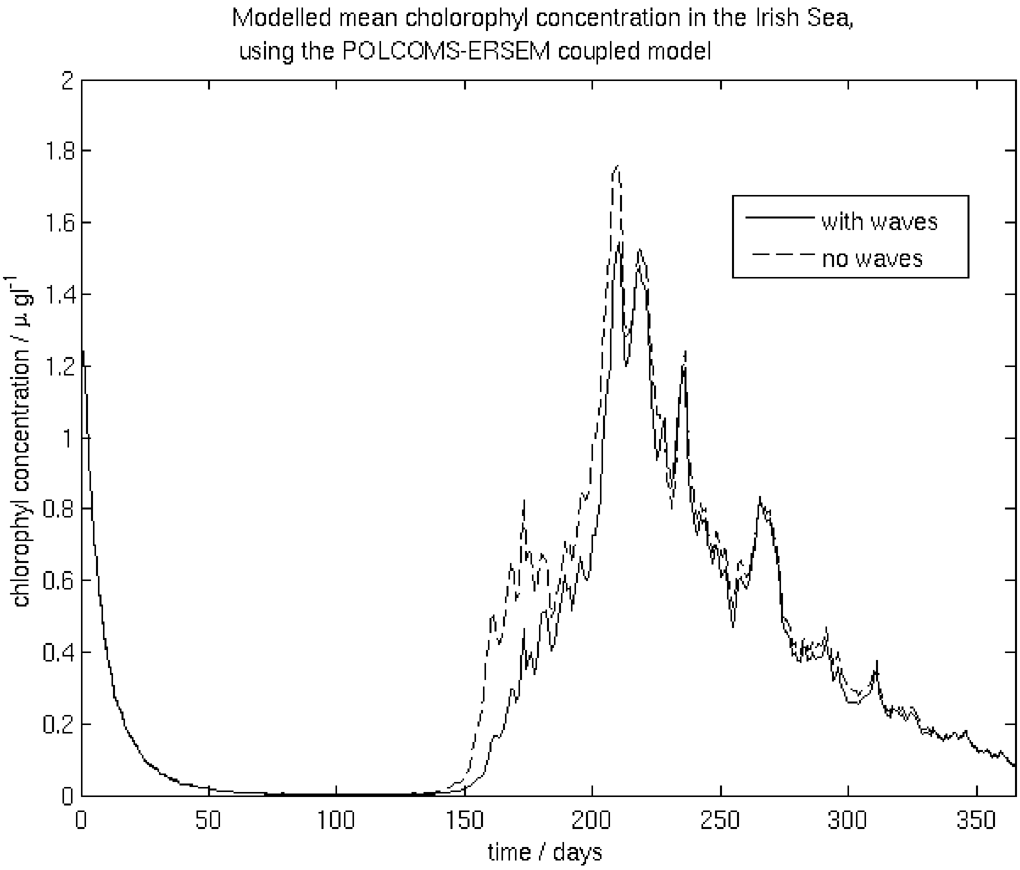

Figure 12: Time series of modelled chlorophyll in the Irish Sea POLCOMS-ERSEM model, with and without coupling.

A similar set-up has been run for the Irish Sea by NOC, with and without the wave model WAM. The European Regional Seas Ecosystem Model (ERSEM) has been run together with the coupled wave-current POLCOMS-WAM model. When POLCOMS-ERSEM is run with and without waves, an impact on the timing of the spring bloom was observed (figure 12). Though there is no direct coupling between the wave and ecosystem models, there is an indirect coupling through the hydrodynamic model.

In WP5 new technologies, such as active and passive samplers, automated sensors and new quality control procedures have been integrated into the coastal observations networks. Most of the acquired data were of great value for e.g. the validation of hydrodynamic modelling and for the study of biogeochemical processes.

As an example, in the beginning of 2012 a one year HF-radar dataset from three stations were available at HZG for the first time. Figure 15 shows the tidal ellipses for 2011 in the area of the German Bight where at least two radar overlap. The complex structures of the ellipses are caused mostly by the bathymetry: strong gradients in the bathymetry result in flattened ellipses. In the south-east the direction of rotation changes from counter-clockwise (in red) to clockwise (in blue) caused by the freshwater entry of the rivers Weser and Elbe. In Figure 13 the corresponding residual currents are shown. They are caused by wind, Stokes drift and predominantly the coastline.

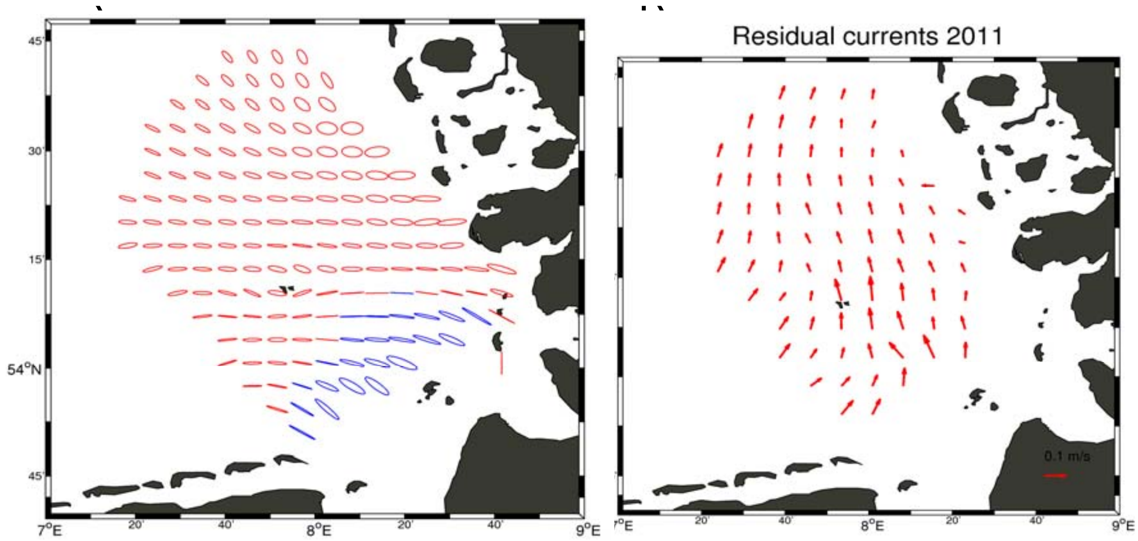

Figure 13: Tidal ellipses (a) and residual currents (b) for 2011 in the German Bight derived from HF-radar data.

Numerical simulations were compared with in situ data and satellite images for the common Catalan cost case. The comparison was between the total suspended matter plume shape from MODIS images and surface salinity shape from ROMS results. Figure 14a shows the contour of the plume shape from MODIS image (total suspended matter, TSM). The surface salinity surface salinity (ROMS results) is shown in Figure 14b and Figure 14c shows the total suspended matter from MODIS overlay into the surface salinity form ROMS results on March 17th 2011. The shape of the plume from MODIS is very similar to the shape of the surface salinity from ROMS results. It means that there are qualitative similarities between both plumes.

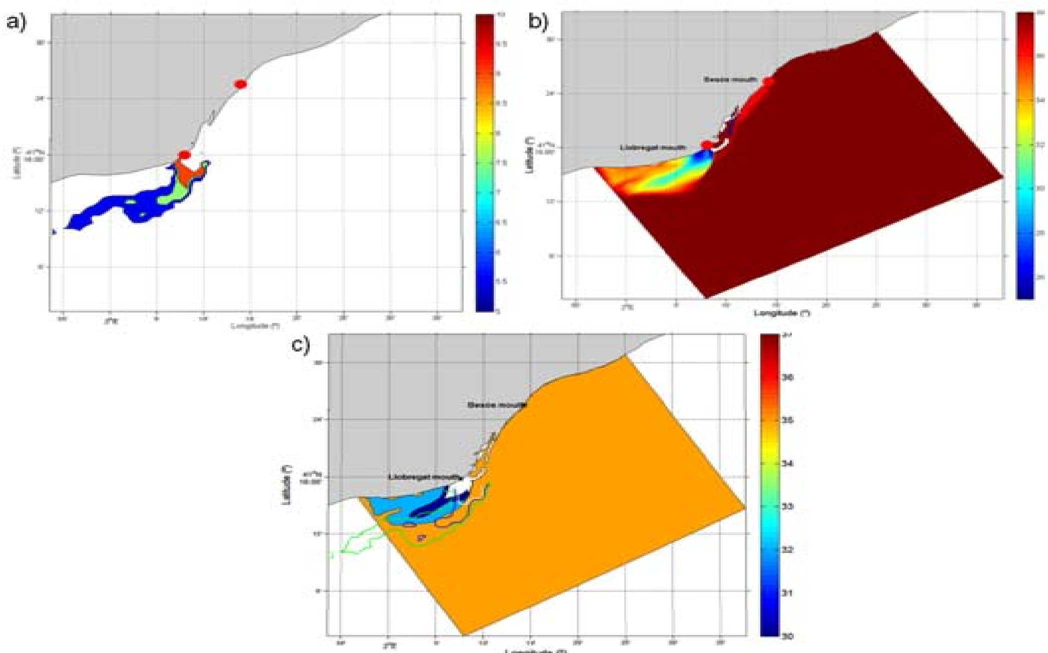

Figure 14: Total Suspended Matter (MODIS) (a. left) and surface salinity (ROMS results) (b right). c) shows the total suspended matter from MODIS overlay into the surface salinity from ROMS results on March 17th 2011.

Potential impact and the main dissemination activities and the exploitation of results

Impact of FIELD_AC

The project impact started during the first year of project development and then gained progressively *momentum* reaching a summit by the end of the project. It has encompassed five main dimensions: 1) Visualization of results, 2) Application of results to the initially targeted sectors, 3) Applications of results to new sectors, 4) Low cost, high-reliability operational oceanography and 5) Transfer to education, science and general public training and awareness

1. Visualization of results

Soon after the project started it became apparent the need to improve the post processing tools to offer results in a flexible manner and presenting the variables together with their acceptable ranges in a way that was easy to understand by our end users. This requires the development of visualization tools which was mainly done by SIMO with the support of DHI (figures 15a and 15b).

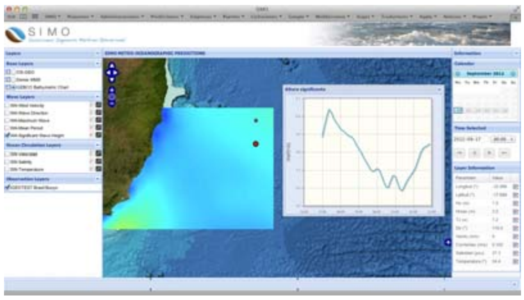

Figure 15a

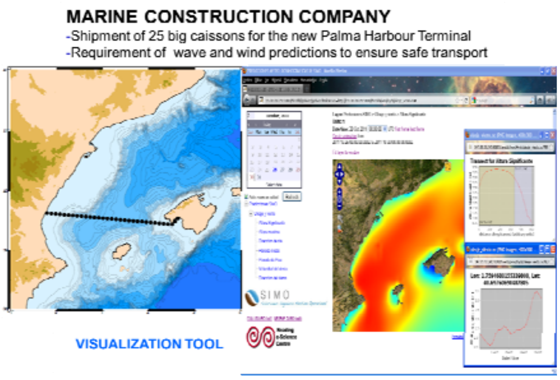

Figure 15b

Figures 15a and 15b: Sample illustration of the visualization of results based on the wave visual tool developed by SIMO for the coast of Brazil (15a) and the coast of Spain (15b).

This has served to structure the presentation of our project results and also has enhanced the marketing opportunities since it has led to applications in the coasts of America, Africa and Asia. For America the coast of Brazil has benefited from the work of SIMO. For Africa, Takoradi harbour in Ghana has also been the object of a contract.

These visual tools have also resulted beneficial for the coasts of Europe where several applications have been done for Denmark, Italy and Spain. The visual tool has also been used for application elsewhere, inspiring parallel developments in Germany and the UK.
One of the main direct beneficiaries have been navigation companies and coastal authorities in the sense that risks have been more easily identified and the coastal water quality status has been characterized in a much more objective and quantitative manner.

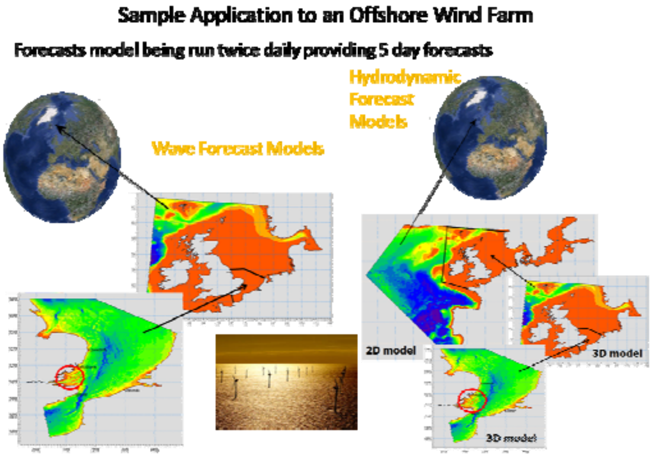

Figure 16: Schematization of one of the applications of HR coastal oceanography to renewable (wind) marine energy

2. Application of results to the initially targeted sectors

The application of results to the initially targeted sectors has covered construction companies and activities, all along the initially selected users starting from the four case studies. Because of that there have been applications in Spain, Germany, Italy and the UK. Additional illustrations can be mentioned in the Danish coast or the harbour of Mallorca. An alternative application has been the analysis of navigation conditions during trajectories where some accident took place. This can be illustrated by the accident to a ship off the Catalan coast performed, in this case, by the Italian partners. This has served to include the concept of freak waves into our oceanographic predictions, to assess the corresponding risks and to show the insurance companies the benefit of operational oceanography, since for the case of this particular ship there was a large discussion about whether the conditions could be considered "normal" or had to be declared as exceptional, with the subsequent implications for the insurance companies.

The impact of the project has reached SMEs (fish farm, companies dealing with fish farming, satellite oceanography, water quality and the Government Water Agency). We have also reached academic attendees and from decision making public bodies (at Municipal, Regional and National levels). The influence of high resolution modelling was illustrated in very practical terms, starting from the effect of the bottom discretization (see figure 17) or by the fate of suspended sediment concentration plumes as a function of the sediment sizes and the prevailing meteorological conditions (see figure 18).

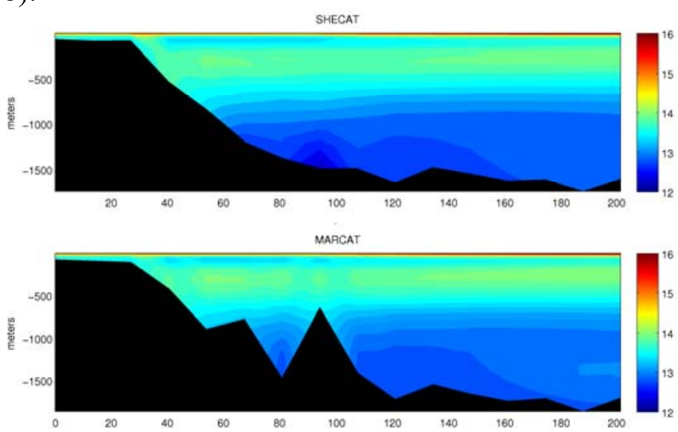

Figure 17: Temperature plots for the Catalan Coast domain at 2 scales, showing the mesh size influence (3km versus 1km) on the "perceived" bottom shape.

The applications to other coasts in the planet have included harbours in the coast of Africa, beaches in the coast of America and Australia, etc. In all cases the application of operational oceanography products has enhanced the combination of the resistant design with the functional design, in the sense of assessing the structures and their impact from the survival point of view and also from the operational point of view. This has benefited a more integrated approach to the holistic design of coastal or harbour structures which we have shown needs high resolution operational products such as the ones we have prepared in FIELD_AC.

Finally our results have also contributed to the implementation of European Union directives such as the Water Framework Directive or the Marine Strategy Framework Directive. These directives have implied the development of contingency plans for harbour and beach authorities. For this purpose we have shown how our operational oceanography products and the collection of cases, in the way of an atlas, could be used for the considered studied areas, namely Gulf of Venice, Liverpool Bay, German Bight or Catalan coast.

3. Applications of results to new sectors

The situation of economic crisis that has been affecting several European Union countries, notably those of the South, during the project development has affected our initial target of sectors for exploitation of operational oceanography products. Because of that we have been forced to move from our initial targets (related to water quality, tourism, fisheries and aquaculture) to more traditional sectors which have been affected to a lesser degree by the economic situation. This has meant enlarging the fan of users and including transport (activities and supporting structures), renewable energy and insurance.

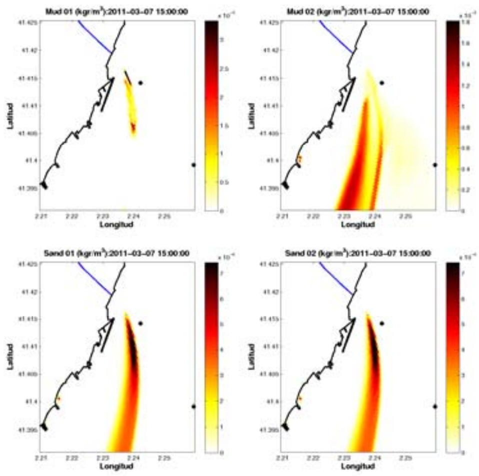

Figure 18: Suspended Sediment Concentration (Kg/m3) at the sea surface during a storm in Besòs river (Catalan Sea pilot site). Four classes of sediment were considered in the analysis.

Our obtained applications can be illustrated by construction companies in maintenance operations where accurate predictions are essential because the scale of the construction turns out to be much smaller than that of a new e.g. harbour structure from scratch. This means that the construction means are more sensitive to operational predictions and that the thresholds must be determined with a much higher level of accuracy. This has supposed an increased challenge for our operational oceanography products, both in terms of resolution and accuracy.

The improved exploitation of existing structures, beach, harbour or coastal, has also required more accurate operational predictions. For instance a by-product of FIELD_AC is the incorporation of current predictions into harbour operation and exploitation, a pending subject in Europe and in general in worldwide Ports. The optimization of touristic beaches in terms of water quality and safety has also become one of our target sectors, because of the higher competition between Mediterranean beaches but also because of the increasing competition between Northern and Southern European Union countries. Beach quality has been served by improved transport and dispersion predictions while beach safety has been supported by predictions of wave conditions and the near shore circulatory system.

The renewable energy sector, still not deeply affected by the economic situation, has proved to be another important market for high resolution coastal oceanography. In this respect we have been involved in operational assessments (figure 16) of the safety and maintenance of *offshore* wind turbines. We have also participated in the evaluation of the renewable marine energy (essentially wind, waves and currents) at a variety of locations in the British, Danish and Spanish waters. As a result of that we have got involved in several KICK-INNOENERGY projects with the aim of showing the value of operational oceanography for renewable energy.

From the stand point of optimization we have also approached the market of navigation routes, both in terms of costs and comfort which are related to the wave conditions along the route. For this the high resolution coastal oceanographic predictions we offered have improved the conditions (time, cost, etc) of the trips. They have also allowed to reduce the probability of dangerous accidents. This has been extended to the risk of accidental oil spills.

Figure 19: Sample application of iBeach for Smartphone

In this latter field we have used our high resolution predictions for contingency plans and assessing risk from a variety of pollution sources, mainly related to oil. The same tools have been used to predict sediment plume evolution, as a function of grain sizes (figure 18). The zoning included in the visualization tool has proved to be useful as requested for instance by the Comcat plan, the emergency plan for the pollution of marine waters of the Catalan government. We have also shown how our high resolution predictions could be of use for a number of harbour authorities which are now considering the possibility to incorporate our products into their operation routines.

Finally the last two application sectors considered have been the climatic field and the construction activities. Regarding climate we have shown how our operational oceanography products could be of use to run with a higher reliability past storm events and therefore contribute to an improved probabilistic assessment of wave conditions from hind casting. This has been applied to a number of Mediterranean cases notably the Gulf of Venice as shown by the FIELD_AC publications. From the standpoint of construction activities we have shown how our operational oceanography products, because of the higher reliability, could be used to support construction decisions since at the time of construction harbour or coastal engineering works are more exposed to unexpected storm events and therefore the damages and associated risks can be higher.

4. Low cost, high-reliability operational oceanography

The FIELD_AC project has contributed to develop and demonstrate end-to-end engineering application of downscaling techniques for waves and currents to local coastal scales. This basically has two components: 1) development of model engines as well as validation and demonstration of downscaling techniques and 2) making application of the downscaling techniques operational in real engineering application. FIELD_AC developed the components of 1), while concurrent independent commercial projects have largely provided the real impact in 2).

Our software packages (notably codes like MIKE by DHI) are used in daily operations by universities, research institutions, consultants and entrepreneurs all over Europe and hence an efficient gateway for bringing the impact of FIELD_AC to real design and decision making processes. The close collaboration between public and private partners in FIELD_AC has contributed to a general development of oceanographic flow, spectral wave models and associated transport codes. In particular, the implementation of the combined prescribed baroclinic velocities and flather barotropic boundary conditions in combination with tool development for transforming the MyOcean regional scale model results to boundary conditions in the flow models, has proven successful and is already being applied in a number of projects on-going. Further wave generation models like MIKE 21 SW have implemented white-capping source alternative formulations from the research partners and now support formulations developed by SHOM and the WAM modelling groups in FIELD_AC. These developments are all well summarized in the FIELD_AC publications.

The applications could theoretically also have used e.g. model boundaries based on e.g. US Navy or other products similar to MyOcean. FIELD_AC is the key reason that the downscaling tools, demonstrations and applications are now based on MyOcean products. The developed techniques have presently been applied to a number of projects.

Because of the economic situation we have explored alternative routes to transfer our high resolution operational oceanography products, mainly for variables related to wind, waves or water quality. For that purpose we have developed a web based application and a smartphone based application. This later one, called *ibeach* (figure 19) has been applied for a number of cases. For the Danish coast we have developed a system based on indicators and for the international company Agbar where we have developed a number of forecasts that constitute a simplified demo illustrating the commercial capabilities of the tool.

Other alternatives explored with initial promising results are the commercialization of operational oceanography for small craft and eventually also for small craft harbours. These products, at a low cost if generated within the existing operational platforms, can also be transferred at a limited cost using smartphone applications. Because of that and in the context of economic stagnation that many European Union countries are now, we are expecting a future commercialization based on these advances. They also could support the optimization of trajectories for water sports or even commercial trajectories (by way of illustration see figure 20 which represents the optimization from the comfort and speed point of view between Amsterdam and New York). The combination of tools and dissemination platforms have allowed to reach new market sectors not initially targeted.

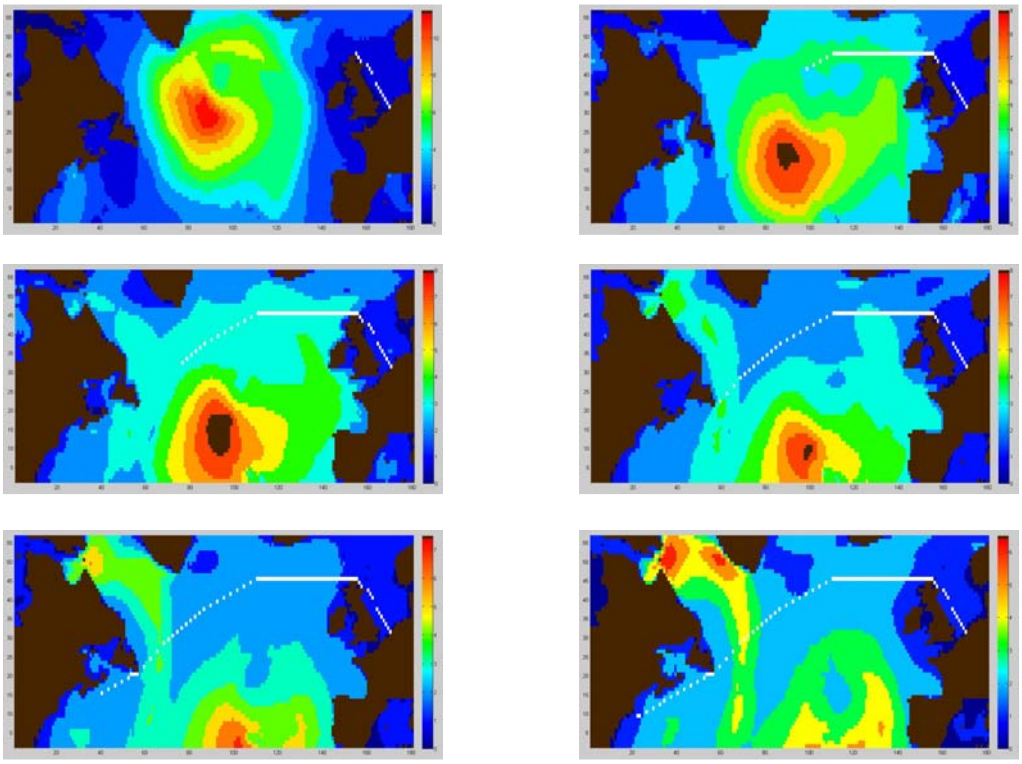

Figure 20: Illustration of a confort-optimized marine route between Rotterdam and New York

5. Transfer to education, social and general public training and awareness

Our operational oceanography products have also contributed to raise awareness for the general coastal society about the possibilities and limitations of operational oceanography at coastal scales. We have presented in newspapers, TV and radio programs the recent advances in operational oceanography, both related to FIELD_AC but also related to the MyOcean core service. The emphasis has always been on the applications for beach management, coastal water safety and risks, etc (figure 21). Our advances have also benefited some contributions to the wiki and to the development of technical protocols for construction companies, design companies or environmental companies. The FIELD_AC results have also been introduced in a number of master courses run by the participating groups. In this respect they have benefited national level master courses where the researchers from the public centres contribute. From an European point of view our advances have been used in the Erasmus mundus Comem master program where one of the partners runs oceanography courses for students from the European Union and worldwide

One of the transferable products of FIELD_AC is the set of novel observations (simultaneous observations to characterize storm events over land and sea) to provide a bench mark for calibration of high resolution simulations of meteo-oceanographic fields with an unprecedented level of accuracy for coastal applications. There are two types of results that deserve special attention from the impact perspective. They are the structured data bases and the demos corresponding to a number of selected applications.

The data bases that have been developed within FIELD_AC correspond to a) the four coastal observatories included in the project and b) the specific intensive field campaign carried out at the Catalan coast. For the first element the structure developed for the field data base has benefited the ordering and accessibility of the data from the four coastal observatories. Moreover it has also introduced the novelty of storing not only observations but also the simulations which makes the data bases more comprehensive and of wider applicability for the interested sectors.

Regarding the field campaign for the Catalan coast the data base will ensure efficient access to the obtained data and the corresponding bench mark case for coupling land to ocean for the coming years, since all the registered data and metadata have been stored according to international conventions and after been subject to online and offline quality control checks. This supposes a significant step ahead with respect to conventional research projects where further use of the obtained observations require always some sort of personal contact with the scientist in charge.

The second element are the demos that have been developed for a number of application cases. Here we shall only present demos for particular events and not for the standard case studies corresponding to the four field sites. The first demo belongs to the simulations carried out for the London array *offshore* wind farm. The simulations are based on a 3D set of models, using both finite differences and finite elements and running the analysis at a number of resolutions and supported by a number of boundary conditions (figure 16).

An alternative case is the Northern North Sea where a set of 3D models have been run and validated at three depths (figure 22). As a complementary case we have also run the Adriatic Sea, including the flood in Venice from November 2012, very close to the end of the project. Here we have compared a number of models (figure 21) including also a 3D finite element code and encompassing the various sources for this flood, namely the astronomic tide, the general circulation component and the effects of wind and atmospheric pressure.

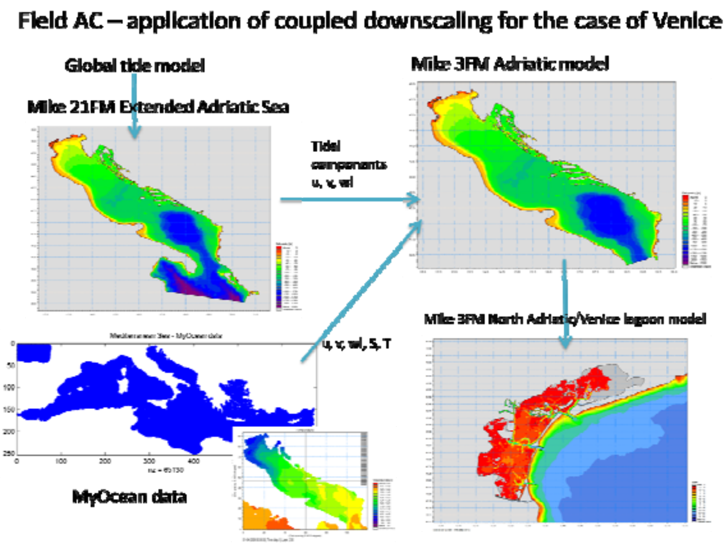

Figure 21: Illustration of the application of a nested and coupled modelling suites to the always challenging case of Venice (within one of our FIELD_AC study sites).

The final demo corresponds to the Dee estuary where the significant wave height, the storm surge and the meteo parameters where registered (figure 23). The resulting wave current fields, including interactions, have been analysed and compared with observations and with previously available estimates. Finally, as a last check for one of the most sensitive parameters (the residual current field), the resulting vertical profile has been compared with detailed observations. The difficulty arises from the various factors contributing to this residual current field and the fact that it is a difference between "large" numbers that may induce correspondingly big errors. As a final application the bed shear stress for various tidal stages has been also calculated to represent the hydrodynamic effect on biota, which is an on-going part of the research.

In summary, Field_AC has had an impact in i) science development for (physical) coastal oceanography, ii) operational applications (for wind, waves and current at coastal scales), iii) transfer from research centres to private companies (notably the SME SIMO), iv) dissemination at EU and international levels (e.g. EGU sessions, Advisory Board, etc), v) support to coastal decision making (harbour and coastal authorities and water agencies).

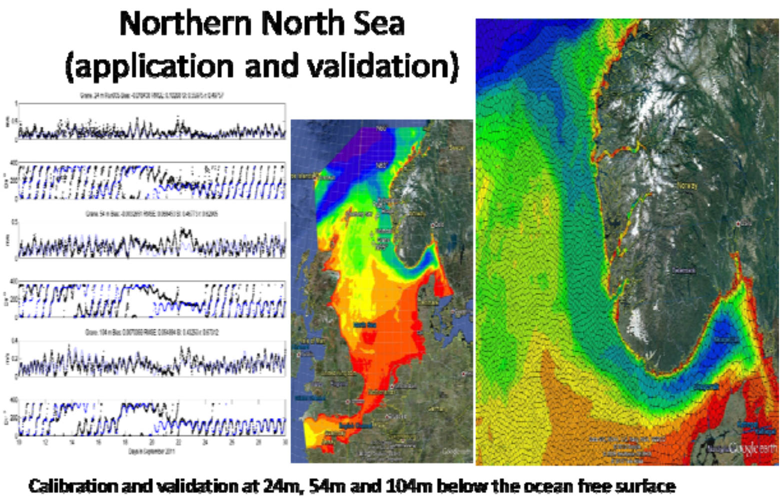

Figure 22: Variable grid modelling of circulation in the North Sea, with calibration at 3 depths representative of the *water column.*

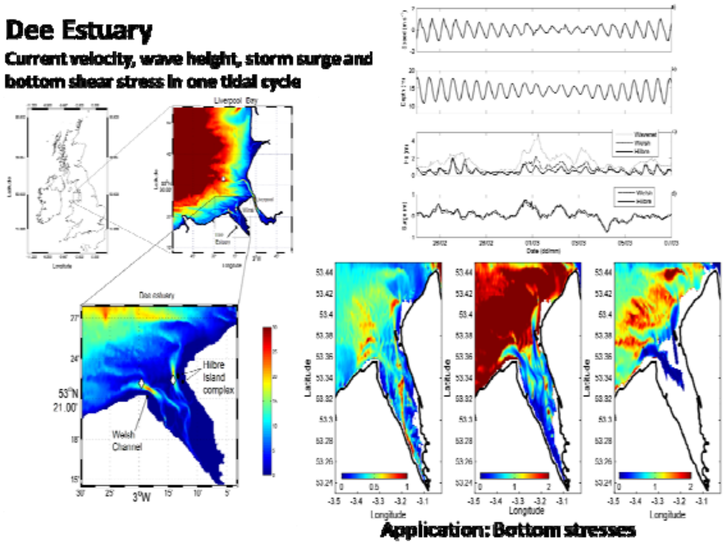

Figure 23: Numerical simulations of waves, surges and currents ofr the Dee estuary. As an applied product the bed shear stresses along the tidal cycle have been also calculated.

Address of project public website and relevant contact details

The FIELD_AC website is the following: http://www.fieldac.eu

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C. Use and dissemination of foreground

NOTE: Completed and submitted to EC through SESAM application.

D. Report on societal implications

NOTE: Completed and submitted to EC through SESAM application.