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Oceanography at coastal scales: Introduction to the special issue on results from the EU FP7 FIELD_AC project

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ABSTRACT

The high-resolution and coupled forecasting of wind, waves and currents, in restricted coastal domains, offer a number of important challenges; these limit the quality of predictions, in the present state-of-the-art. This paper presents the main results obtained for such coastal domains, with reference to a variety of modelling suites and observing networks for: a) Liverpool Bay; b) German Bight; c) Gulf of Venice; and d) the Catalan coast. All of these areas are restricted domains, where boundary effects play a significant role in the resulting inner dynamics. This contribution addresses also the themes of the other papers in this Special Issue, ranging from observations to simulations. Emphasis is placed upon the physics controlling such restricted areas. The text deals also with the transfer to end-users and other interested parties, since the requirements on resolution, accuracy and robustness must be linked to their applications. Finally, some remarks are included on the way forward for coastal oceanography and the synergetic combination of *in-situ* and remote measurements, with high-resolution 3D simulations.

1. Introduction

High-resolution meteo-oceanographic modelling is required to solve coastal scale oceanographic processes, where the local scale variability in orography and bathymetry (wind jets, diffraction, etc.) produces spatial gradients, not always well captured by these models; this results in errors well in excess of those found for open sea conditions. The FIELD_AC project (Fluxes, Interactions and Environment at the Land–Ocean Boundary. Downscaling, Assimilation and Coupling), funded by the European Union FP7 Space Programme (2010–2012), aimed to provide and improve operational services for coastal areas and to generate added value for shelf and regional scale predictions, from GMES Marine Core Services. The Catalan coast in the North Western Mediterranean, the German Bight in the North Sea, Liverpool Bay in the Irish sea and the Gulf of Venice in the North Adriatic Sea have been used as case studies of coastal zones, with different physical processes and user needs.

Each of these coastal areas had an array of instrumentation deployed for several years and some enhancement of the previously-existing systems, carried out during the project. Nested modelling suites for the four contrasting environments were developed and compared, looking for: generic advances, such as the benefits of structured versus unstructured grids; and the added value of local data assimilation. The physical conditions range from micro- to macro-tidal and from being subjected to small to large storm surges. Wave conditions range from mild to severe and the degree of coastal irregularity show also wide variability. In all the cases considered in FIELD_AC, the oceanographic domain can be considered as being semi-enclosed. Hence, the focus is upon the improvement of coastal predictions, through model down-scaling and more sophisticated model coupling, including land–ocean and atmospheric–ocean boundaries.

The coupling and nesting can be considered, in general, for: wind with waves; wind with currents; waves with currents or for a combination of wind, waves and currents. The waves have been noted to enhance the currents through the wave-induced mass fluxes and the excess momentum fluxes; through the gradients of radiation stresses, also modify modify the mean water level. In contrast, the waves reduce the currents through increased bed shear stresses and may have an effect on air–sea momentum transfer.

Following, opposing or shear currents may spread out or focus the wave energy fluxes, resulting in modifications to wave height, period and direction. These wave–current interactions have been at the core of the Project, for macro-tidal conditions, where such an interaction is expected and, similarly for micro-tidal conditions,

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where some current intensification events occur, for example off the Catalan coast. Some velocities of the order of 1 ms^{-1}, the order of magnitude larger than the conventionally accepted currents, have been identified as significantly modifying the wave features.

The analysis has continued with the quest for the best strategy to include the continental discharge as a part of the land boundary condition. Likewise, how the frequency and accuracy of the offshore boundary condition, from regional operational models (within the MyOcean project), may affect the quality of the results obtained. Coastal domains, where the effect of this land boundary condition plays a key role, can be schematized in 2DH, 2DV or 3D approaches. Because of saltier water intrusion in near-bed layers and freshwater stratification near the surface layer, which is controlled also by wind, there is a requirement for 3D simulations and analyses. This need can be illustrated also by the intermittent stratification of the water column that has been observed in measurements and simulations, as a function of the freshwater discharge (on a short time-scale of hours to days) or solar radiation (on a medium-term time-scale, of days to months). We have observed also the difficulties in measuring salinity in turbid coastal environments and in determining sharp gradients, induced typically by coastal zone boundaries and transitions.

Such observations have led to the "ultimate" question of how best to combine models and local observations for robust coastal predictions, at the same time developing an insight into the underlying coastal oceanographic processes. This is the main hypothesis addressed by this Special Issue and summarised in this introductory paper. Towards this objective we have analysed different measurement networks and a number of numerical (wind/wave/current) models, with diverse coupling and nesting strategies. The modelling skill has been assessed in terms of bulk parameters; also, in terms of more local, physically-defined parameters, including metrics for displacement phase and amplitude of the various signals considered. Such an assessment has included also local assimilation since in coastal domains the large variety of time and space scales involved (particularly the shorter ones) requires supplementing satellite images with *in-situ* observations. Satellite images can provide only a limited improvement, due to the rapid variability and sharp gradients mentioned above. Pointwise or *in-situ* measurements can contribute only locally to the improvement of results; this is due to the short time interval between observed information and information travel time, through the computational domain. As a consequence, observations will only have a transient effect in the simulations.

Following the above concepts, this introductory paper reviews the modelling tools and observational systems for the (4) case studies considered in the Project (Section 2). How the results obtained address users requirements is considered in Section 3. Finally, the performance limits of simulations and observations are considered, in terms of physical processes and the needs of coastal stake holders (Section 4). The text ends with some discussion on the future of coastal oceanography, acknowledging that "errors" grow as we get closer to the shore and this requires a combination of improved physical models – incorporating the non-linear processes typical of the near shore, such as those associated to wave breaking –/ high-resolution *in-situ* observations /– capable of resolving the important gradients found near the coast due, e.g., to topo-bathymetric features – and remote images commensurate with the time/space scales present near the land–sea border.

2. Models and observing systems for the study areas

The four study sites, in which the methodology of the FIELD_AC project was applied, are Liverpool Bay, the German Bight, the Gulf of Venice and the Catalan coast. The first two locations are on the North-West European continental shelf, with moderate to large tides; the latter two are in the Mediterranean Sea, with low tidal ranges. Each site is in a coastal area affected by freshwater run-off, but experiencing different coastal management problems. The locations are shown in Fig. 1. A brief overview of their characteristics, together with the models and observing systems applied to each, are presented below. All the local models were embedded in the MyOcean regional forecast/analysis systems, for the North-West European Shelf and the Mediterranean.

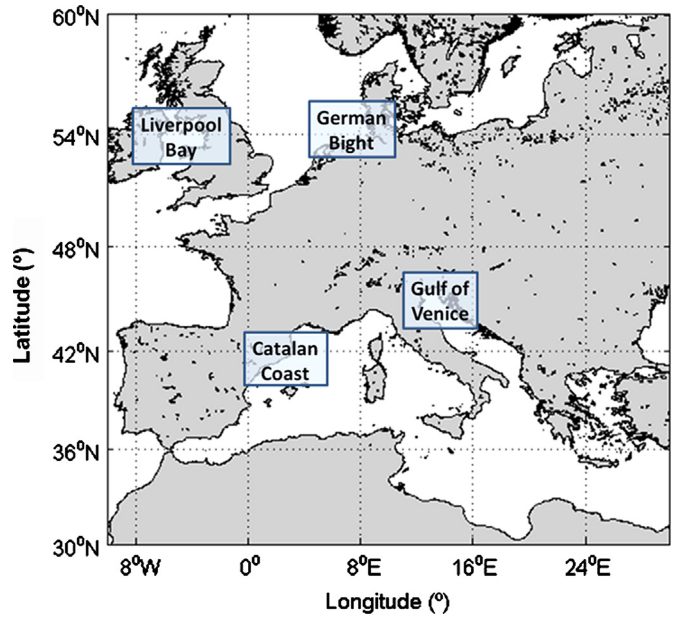

Fig. 1. Overview map of the four study site locations considered in the FIELD_AC project.

Combining data with models, using data assimilation, enables an objective analysis of the environmental state which allows decisions based on "objectively" simulated (numerical) results supported by observations; this pre-supposes an improvement with respect to more qualitative environmental assessments where assumptions sometimes lack the basis of an objective evaluation; this is due, among other reasons, to the limited resolution of coastal "details" in conventional oceanographic simulation.

2.1. Liverpool Bay

Liverpool Bay is a semi-enclosed shallow sea area (< 40 m deep) with a macro-tidal range (up to 10 m) situated in the eastern Irish Sea, with extensive intertidal areas. It is a Region Of Freshwater Influence (ROFI), in which the runoff from the Rivers Mersey, Dee, Ribble and Conwy has a strong influence. It is somewhat sheltered from the prevailing south-westerly winds, but can be affected by winter storms. North-westerly winds generate fetch-limited waves, of up to 5 m in height. Coastal management issues include coastal flooding, erosion and water quality, as well as navigation for the Port of Liverpool.

The Liverpool Bay Coastal Observatory (2002–2012) was used to provide much of the observational data used in the project; these were supplemented by some additional observations made specifically for the FIELD_AC project. The Proudman Oceanographic Laboratory Coastal Ocean Modelling System, coupled with a wave model and the European Regional Seas Ecosystem Model (POLCOMS-WAM-ERSEM), were used; these were in addition to the FVCOM (Finite Volume Coastal Ocean Model) unstructured model for the hydrodynamics, waves and ecosystem modelling. A nested model system was used, downscaling from a 12 km