# An interactive WebGIS observatory platform for enhanced support of integrated coastal management

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**A. Oliveira†, G. Jesus†, J.L. Gomes†, J. Rogeiro†, A. Azevedo, M. Rodrigues†, A.B. Fortunato†, J.M. Dias‡, L.M. Tomas‡, L. Vaz‡, E.R. Oliveira∞, F.L. Alves∞, S. den Boer†**

†National Civil Engineering Laboratory
Av. do Brasil, 101
1700-066 Lisbon, Portugal
aoliveira@lnec.pt

‡ CESAM, Department of Physics
University of Aveiro
Campus Universitário de Santiago
3810-193 Aveiro, Portugal

∞ CESAM,
Environment and Planning Department
University of Aveiro
Campus Universitário de Santiago
3810-193, Aveiro, Portugal

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**ABSTRACT**

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A new WebGIS observatory platform is presented, tailored for risk assessment and emergency preparation and response in coastal areas. The tool combines a sophisticated forecast modeling system for multi-scale analysis of water bodies, including waves, hydrodynamics and oil spills prediction, with real-time monitoring networks for forcing and continuous validation purposes. Tailor-made visualization and analysis products, conceptualized for multiple uses through a service-oriented framework, provide an easy and interactive access to both data and predictions. The system was customized for oil spills risk assessment and the rapid response to an oil spill emergency, and applied to the Aveiro lagoon. The tool addresses oil spill problems in two complementary ways: 1) a detailed risk assessment through georeferenced hazard and vulnerability maps and GIS layers of information to support the definition of contingency plans; and 2) the visualization of georeferenced oil spill predictions produced by a real-time oil spill forecasting system. Improvements relative to existing risk systems are 1) the possibility of selecting quick-access predictions for fast emergency response or high-quality, georeferenced GIS prediction products, 2) the flexibility in accessing products to evaluate local impacts of oil spills both in the water column and in the intertidal areas, and 3) the enhanced hazard and risk analysis through a combination of a multi-scenarios approach with the historical database of spill predictions, forced by daily hydrodynamic forecasts. Dependability of information, for both model results and monitoring data, is being implemented through innovative ways, targeting the robustness and quality control of the WebGIS platform.

**ADDITIONAL INDEX WORDS:** *WebGIS, risk management, oil spill, real-time monitoring, forecast systems.*

## INTRODUCTION

The timely prediction and monitoring of environmental conditions as well as the anticipation of hazardous events are essential parts of integrated coastal and harbor management, providing the necessary information for safe navigation and harbor operation, and the protection of valuable natural assets.

Coastal observatories have been under development for over a decade in the USA and in Europe (Baptista, 2006, Daniel et al., 2004), addressing many problems and spanning several disciplines, through the monitoring and prediction of several variables, such as wind, waves, sea surface elevation and some geochemical quantities (Gonzalez *et al*., 2008; Rodrigues *et al*., 2013). These observatories encapsulate our ability to characterize the behavior of water bodies, by integrating numerical models, monitoring networks and information technology systems, to provide real-time predictions of the main drivers in coastal zones. With the recent emergence of reliable and cost-effective automatic data acquisition systems and highly efficient and reliable numerical water quality models, the most important constraints for the operational use of real-time forecasting and monitoring systems have been minimized (David *et al*., 2013; Rodrigues *et al*., 2013).

Herein, an interactive and flexible computational GIS-based platform is presented. Named RDFS-PT, this platform takes advantage of novel technologies to provide on-line, intuitive and geographically-referenced access to real-time data and model predictions, and to produce on-demand services in support of routine management of coastal resources and harbor operations. This platform is intended for the daily use of harbor authorities and coastal management entities and is available at each deployment site to the relevant end-users.

The enhanced interface is based on a previous deployment using Drupal, a PHP-based Content Management System (CMS) used to access model metadata, status and products. To allow for geospatial placement of monitoring and forecast products, as well as model output query capabilities, map server support (Geoserver) providing Web Map Services (WMS) have been added to the RDFS-PT. A WebGIS was developed in Flex, using the OpenScales library to handle geospatial information. This

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WebGIS is being built in a modular and generic way, to allow future inclusions of new models, sensor networks and services required by coastal authorities and emergency agents. The requirements analysis of this platform was developed in close cooperation with several harbor and coastal management authorities, to promote its usefulness for management purposes.

The WebGIS platform is demonstrated in the recent deployment for the oil spill risk management in the Aveiro coastal lagoon, developed in the scope of the Portuguese Science and Technology Foundation (FCT) research project PAC: MAN and INTERREG project SPRES (spres.ihcantabria.com). Particular attention is given to the reliability of the real-time monitoring network and the automatic validation of model results, supported by dependable concepts applied to sensors and models.

The paper is organized in three sections, besides this introduction. The conceptualization of the generic nowcast forecast system, including technological choices presented in the next section. This is followed by the implementation of the generic technological system to the oil risk management in the Aveiro lagoon. The Aveiro lagoon is a large coastal system in Portugal, which is presented here to demonstrate the flexibility, service-provision and usefulness of the system. The paper closes with the major conclusions and the identification of the research directions ahead. .

## RDFS-PT: A MULTI-PURPOSE NOWCAST-FORECAST INFORMATION SYSTEM

### Conceptual vision and building blocks

The ability to simulate and forecast the dynamics of estuarine and coastal zones is essential to assess the social, ecological and economic impacts of human interventions and climate variability and changes, and to support the sustainable management of these regions. A growing pressure on coastal management, fuelled in Europe by multiple legislation (Water Framework Directive - http://ec.europa.eu/environment/water/water-framework/, OSPAR Convention - http://www.ospar.org/, Marine Strategy Framework Directive - http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive), has fostered the development of computational nowcast-forecast systems (NFS) that provide predictions of several quantities at short time scales, by integrating numerical models and field data.

The reliability of the predictions of NFS depends on the accuracy of the models behind them and on the availability of real-time field data for the automatic validation of the predictions. However, the hydrodynamic and water quality simulation of water bodies poses a number of challenges: 1) on the adequate temporal and spatial scales for all relevant processes; 2) on the computational requirements for its use within a forecast system; and 3) on the methodology to quantify and reduce error propagation within the chain of cascade modelling. These difficulties, often combined with a lack of real-time data for the validation of model predictions, have prevented the development of nowcast-forecast systems that account for all relevant processes and interactions.

Integrated modelling approaches, combining both cross-scale, unstructured grids hydrodynamic and water quality models, are thus required to cover the full range of the relevant spatial and temporal scales of the processes in coastal systems. Usage of high-performance computational resources and optimized models also play major role in providing the necessary accuracy at computational times compatible with forecasting uses (Costa *et al.*, 2009).

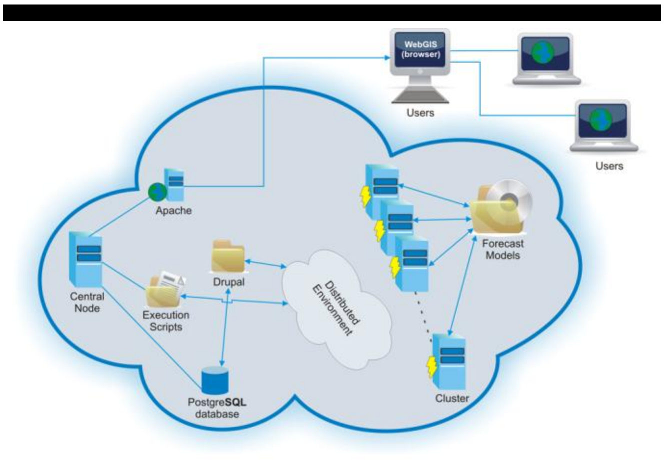


Figure 1. Physical architecture of the RDFS. Adapted from Jesus *et al.*, 2012.

The nowcast-forecast information system proposed herein, RDFS-PT, is based on the deployment of a generic forecasting platform, adaptable to any geographical location, and customizable for coastal applications, which was originally developed at CMOP (Center for Coastal Margin Observation & Prediction, U.S.A. – Baptista, 2006) and was adapted and extended by LNEC (Jesus *et al.*, 2012; 2013). The system integrates a set of numerical models that run in parallel automatically in a high-performance environment. The RDFS-PT platform is capable of coupling waves, tides, storm surges, river flows, precipitation and winds, providing forecasts of water levels, currents, water temperatures, salinity and waves for a target area. It was recently extended for water quality (fecal contamination in sewer systems and estuarine water bodies, and oil spills in coastal regions, Rodrigues *et al.*, 2013).

The usefulness of NFS and other decision-support systems for coastal management problems is also often hampered by the difficulties in the communication of the results. A broad spectrum of users, with different needs (e.g., water body managers, water utilities, general public) using different platforms (desktops, mobiles, tablets) should be reached.

A new intelligent platform for coastal management was developed, based on the integration of waves, hydrodynamics and water quality RDFS-PT forecasting and on real-time on-line monitoring networks, and the automatic comparison between data and predictions. The platform is devoted to the surveillance and real-time decision support, in particular to support the issues of early-warning during contamination events and the reliability analysis of data, through a combination of information from predictive models and sensors.

The platform is conceived in a user's service-oriented architecture, providing on-line access to both real-time model predictions and data-derived products, at different levels of detail and complexity. Real-time model predictions are generally stored in two distinct servers (a main server and a redundant one). In both cases data are stored in the file system via NETCDF standard format, allowing future use in other models. Regarding the mentioned user-oriented services, a set of webservices is provided at the RDFS-PT website, either through a geographic user-interface (geo-referenced imaging data by WMS services) or through an alpha-numeric webservice to scope timeseries from the data outputs in user-specific points of the model grid.

The platform is built in a modular and generic way, including both quick access products and a Web Geographic Information

System (WebGIS). This WebGIS allows the visualization of the existing network monitoring information, and can easily be extended in the future for new data sources, either publicly available or provided by the coastal authorities and other end-users. Services are automatically provided in the platform for comparison between model predictions and these data, granting robustness and long-term evaluation to the whole system to the end-users.

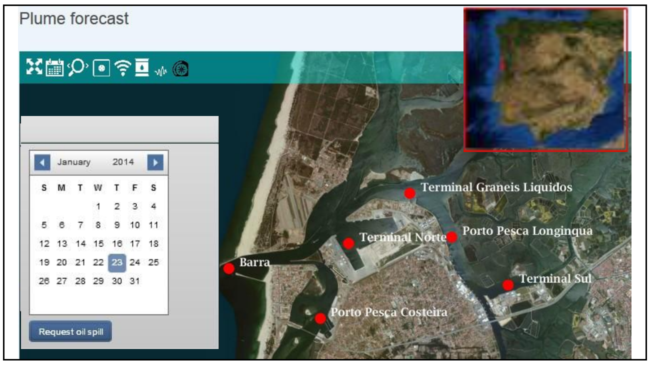


Figure 2. Location of oil spill hotspots in the Port jurisdiction area. The location of the Aveiro lagoon within the Iberian peninsula is shown in the inset

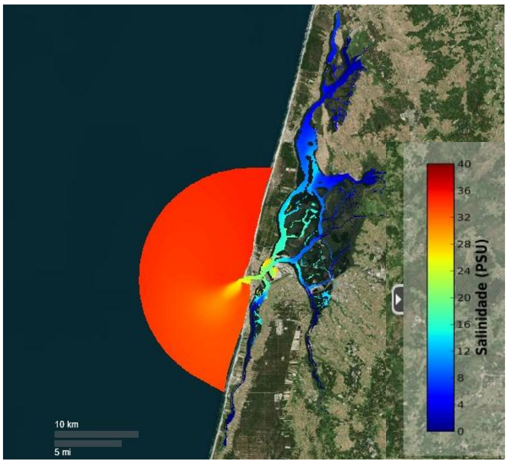


Figure 3. Example of forecast product for salinity.

## Architecture and technological approach

RDFS's physical architecture includes several computer servers and a shared file server. This central file server provides archival storage for model outputs, access to model results, and tools for managing the forecasts. Every day, each computer server runs one or more forecasts (depending on its capacity). The components of RDFS-PT and their interactions are illustrated in Figure 1.

The RDFS-PT forecasting process runs on Linux operating systems and, at its core, is composed of a set of Perl scripts scheduled on crontab. Running on a daily basis, these scripts prepare and launch the simulations for each model producing forecasting results, among others. The scripts start by gathering all the necessary input data, mostly from a PostgreSQL database, to force the models and then launch the simulation. At the end of the simulation, all relevant output results are made available to the central node. Simulation requirements include the results of the previous run (and/or other forecast models simulation results), forecasts from regional circulation models and atmospheric models, and data from field sensors.

A cascade modeling approach is used, forced by external regional models. Each model is fed by the outputs of the previous model, customized for each model format.

Model output results are then processed in the forecast engine, using visualization tools such as VisTrails or the matplotlib library, to generate automatically model forecast products and data/model comparisons, to be included in the WebGIS platform.

The RDFS-PT platform is a customized deploy of Drupal, a PHP-based Content Management System (CMS), which is used to access model metadata, status and products. Web Map Services (WMS) and Geoserver map server provide GIS support for the generated products and a more interactive and intuitive user interface, allowing geospatial placement of products, as well as model output query capabilities. The WebGIS was developed in Flex, using the OpenScales library to handle geospatial information. This WebGIS was built in a modular and generic way, allowing the visualization of RDFS-PT data and the flexible integration of spatial data from other sources.

## Forecasting modeling system and model components

RDFS-PT includes models for circulation, wave generation and propagation, oil spill fate, ecosystem dynamics and fecal contamination, among others. Herein, the models used in the application of the platform to the oil spills in the Aveiro lagoon are briefly described.

Circulation is simulated with the community model SELFE (Zhang and Baptista, 2008). SELFE solves the 3D baroclinic shallow water equations for elevations, velocities, salinity and water temperature. The domain is discrete with finite elements in the horizontal and mixed S-Z coordinates in the vertical. A semi-implicit time stepping algorithm combined with an Eulerian-Lagrangian treatment of the advective terms in the momentum equations provides a robust and spurious-free solution, free of Courant number restrictions. SELFE is fully parallelized. In the Aveiro lagoon, SELFE is forced by water elevations, temperatures and salinities from a regional model (www.myocean.org) at the ocean boundary, quasi-real time river flows (www.snirh.pt) and atmospheric forcings (www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs; climetua.fis.ua.pt/).

Oil transport and weathering is computed with the 2D version of VOILS (Azevedo *et al*., 2009; 2014). VOILS contains the most relevant processes for the transport and rheological changes of the oil, such as advection, evaporation, scattering at the surface, emulsification, dispersion and dissolution in the water column, and shoreline retention and reposition. It is particularly suited for the representation of complex coastlines and coastal studies, as it is based on unstructured meshes to simulate physical processes on a multi-scale approach. VOILS solves a transport-type equation for the thickness of the oil at the surface. The equations are solved with a combination of finite volumes and Eulerian-Lagrangian methods, which provide efficiency and mass conservation.

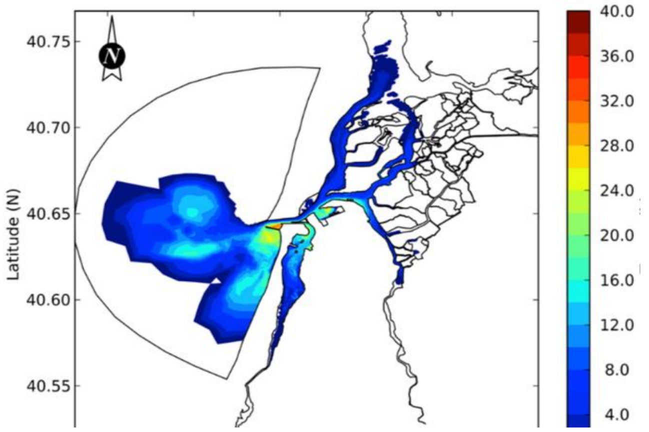


Figure 4. Oil exposure indicator (hours), which shows the time that a particular node of the simulation grid has been affected by the presence of oil during an oil spill model simulation.

## Real-time monitoring networks

Constraints for reliable, large-scale, operational use of hydraulic models in real-time forecasting have been minimized with the recent appearance of low cost and reliable automatic data acquisition and transmission systems, as well as with the usage of highly efficient and reliable numerical models.

An advanced, new monitoring framework, within the broad-range RDFS-PT system, was developed to provide dependable real-time monitored data. These data are essential to validate model predictions, issue alerts or to support decisions on mitigation measures to be performed in the areas at risk.

A wireless sensor network was built, where each node gathers and transfers data into a web-database system, setting up a real-time web-based management system. Two possible data transmission procedures are possible. In the first one, the data transmission process is triggered through a central server located at the National Civil Engineering Laboratory (LNEC). This server connects to the sensor via the GSM modem and requests the measurements stored in the data logger. Alternatively the sensor itself uploads the measurements data to an FTP server, hosted at LNEC, triggering the communication process. This flexible approach allows for different types of sensor deployments and data acquisition rates and simplifies future sensor node integration.

Sensor measurements often contain faulty values and outliers whose detection may be of major importance in a dependable monitoring network supporting risk management. Alerts may be configured for all parameters, triggering the dispatch of emails or mobile messages whenever the defined limits are reached.

## Dependable requirements for risk management information systems

A cascade of uncertainties present in each part of a risk management system affects the reliability of the forecasts. The timeliness and quality of monitoring data gathered and used subsequently in forecasting models, is affected by external disturbances (e.g., biofouling, corrosion). Moreover, in a distributed computing system, where multiple scripts are running simultaneously and large quantities of data are being processed from different sources, an innocuous fault in one process may affect the outcome of a forecast and cause a system breakdown. Also, in RDFS-PT input, data from both forecast models and other sources are largely heterogeneous, due to their different origins and sensors. This heterogeneity makes it difficult to ensure the full reliability in the system, as complex scenarios arise from the specific effects of each technology.

New solutions to automatically adjust the sensors measurements are under development, taking into consideration all critical aspects of the sensor networks in the aquatic monitoring process. There is a strong need for reliable data collection in harsh coastal and marine environments, making dependable techniques important to improve the robustness of the sensors measurements.

Regarding software failures, the solution implemented was based on failure models mainly regarding the input and output of the forecast models. Redundancy and bypass methods were the preferred tactics to tackle problems originating from sources outside the forecasting system. If a data source is unavailable, similar sources are adopted or most likely information is used. In case of incomplete or unsuccessful forecasts, the use of redundant forecasts (ran on a different workstation) is the first option, or else a rerun is always tried. When all automated solutions fail, a maintenance team is alerted (automatically) on unsolvable

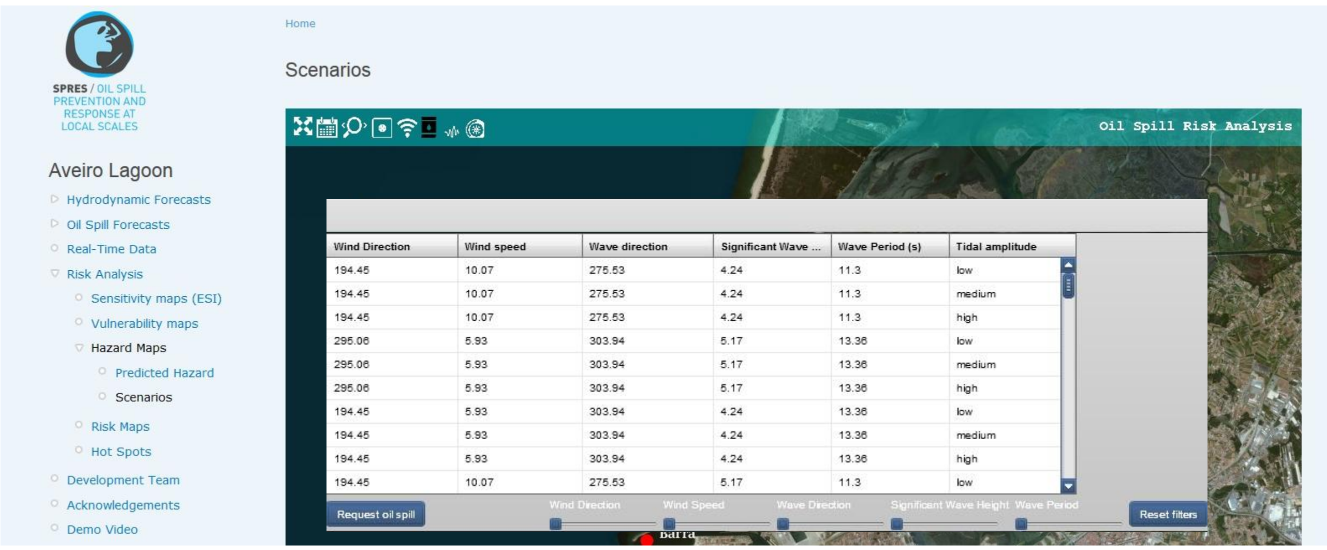


Figure 5. Filtering interface for quick search of oil hazard maps for specific scenarios.

situations, with resort to checklist mechanisms in the master scripts, so that human intervention may correct faulty processes. A fully reliable RDFS-PT is a future goal, but many failure causes remain to be identified and solved.

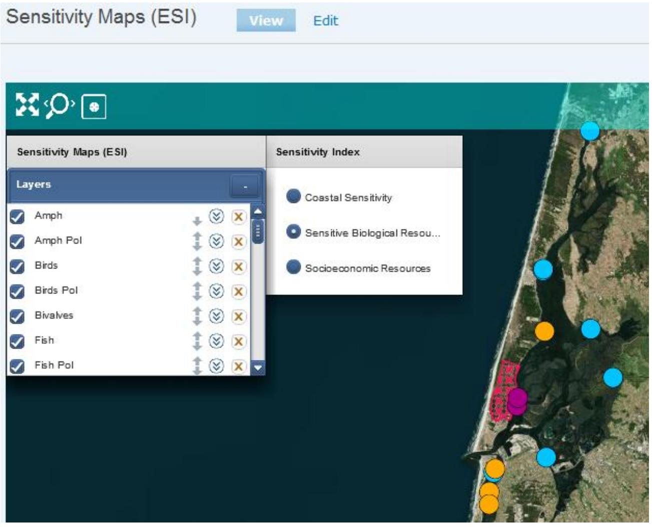


Figure 6. Partial view: choice of layers in Sensitivity Maps view.

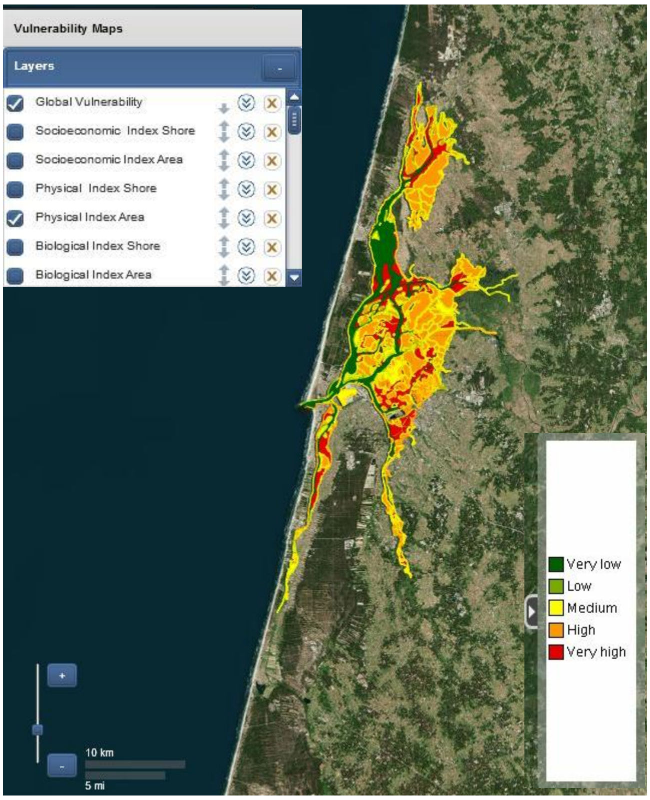


Figure 7. Global Vulnerability and Physical Index Area map.

## RDFS-SPRES: A WEBGIS OBSERVATORY PLATFORM FOR OIL SPILL RISK MANAGEMENT IN THE AVEIRO LAGOON

### Concept and general methodology

Natural and anthropogenic disasters worldwide, like oil spills, can lead to severe environmental and economic losses (Dietrich et al. 2012). Even for the accidents whose timing and location are unpredictable, many prevention and mitigation actions can be done to reduce the severity of the disaster. This issue motivated the development of a high-accuracy coastal oil spill nowcast-forecast system to assist emergency agents, taking into account the various forcing mechanisms and relevant processes of oil spill evolution and pathways in coastal environments. These advanced tools constitute an effective asset for coastal managers and emergency agents, as they can significantly improve local contingency plans and contribute to effective emergency management.

The advanced risk management tool presented herein addresses oil spill risks in two ways: 1) an enhanced risk assessment portal combining hazard maps, provided by high-resolution simulations based on a multi-scenario approach, and georeferenced vulnerability information, organized along physical, ecological and socioeconomic views (Oliveira *et al*., 2014); and 2) georeferenced oil spill predictions produced by the real-time oil spill forecasting system. Both functionalities are available within the same WebGIS platform, as a "one-stop-shop" for all relevant information for coastal managers and emergency agents.

The adaptation of RDFS-PT for oils spill was done through the integration of the model VOILS (Azevedo *et al*., 2009, 2014). Forced by daily hydrodynamic predictions, the oil model runs automatically also on a daily basis, for pre-specified locations. Given the time requirements for the availability of predictions and the need to provide a quick answer in the event of a spill, the 2D mode of VOILS is used, simulating the oil slick thickness at the surface, accounting for oil retention and reposition at the land margins, as well as all processes at the water surface.

Herein, the RDFS-PT platform is applied to the Aveiro lagoon, a coastal ecosystem located in the Northwest coast of Portugal, valuable both at ecological and economical levels. The lagoon holds several habitats and relevant anthropic activities (e.g. recreational activities, port activities, fisheries/bivalve harvesting). The application to the Aveiro lagoon is supported by a previous pilot deployment of the RDFS-PT (http://ariel.lnec.pt/, Rodrigues *et al.*, 2013) for the hydrodynamic prediction in the Aveiro lagoon. This deployment was improved through an update of bathymetry, integration of ocean boundary water elevations from MyOcean and by the integration of a real-time monitoring network at two key locations (Gomes *et al*., 2012). This network provides automatic validation of the modeling system predictions besides the possibility of environmental analyses based on historical records of the water characteristics in the lagoon.

### Innovative emergency and risk management system

The Aveiro lagoon oil risk RDFS-PT platform was conceptualized for emergency management through pre-defined hot spots for oil spills (Figure 2), where a plume of 10 tons of RFO/HFO N.6 oil is released, all defined with the collaboration of the Port Authority. Oil spill predictions for all spots and all scenarios (Figure 3) are run in parallel processors, to provide the fastest availability of results. These results are then processed into indicators for oil impact analysis, such as the time of exposure to oil at every node of the domain (Figure 4), for each oil spill model simulation. From the analysis of Figure 4 one can evaluate the areas affected by the oil for a particular simulation. Information on the surface slick and on the beached oil can be processed and visualized as different GIS layers, allowing for the quick specification of the most adequate response or mitigation action.

A detailed risk assessment, based on georeferenced hazard and vulnerability maps, can also be visualized in the interface. A multi-scenario approach, based on the most likely environmental scenarios for accident-prone conditions (wind, waves and tides) was used to generate hazard maps. To facilitate the oil pathways analysis, the platform provides a filtering service for each forcing factor and for the probability of the combination of factors, allowing a quick access to specific simulations (Figure 5).

The oil spill emergency component is closely linked to the formal risk management tool. While oil forecast runs are ongoing, a preliminary estimate of the potential oil pathways can be inferred, as the platform automatically selects and highlights the pre-run scenario closest to the forecasted environmental conditions. Likewise, the oil spill forecasts also contribute to progressively enrich the database of scenarios. Every day, each new set of oil runs is integrated in the risk analysis database and made available at the filtering menu. This closed loop will continuously increase the completeness of the platform and consequently its usefulness for real accidents.

The flexible and generic nature of the platform will enable at a later stage the possibility to combine, in a single screen, different layers of sensitivity, vulnerability and hazard maps, as well as relevant oil indicators at selected locations – receptor points. Receptor point information will be readily available as data time series for visualization, analysis and download. For the same points, the platform will provide the mitigation and response action fact sheets under development in the SPRES project.

## CONCLUDING REMARKS AND OUTLOOK

Herein, an interactive and flexible computational GIS-based platform is presented, which takes advantage of novel technologies to provide on-line, intuitive and geographically-referenced access to real-time data and model predictions, and to produce on-demand services in support of coastal resources and harbor operations management as well as emergency procedures. The forecasting engine behind the platform is supported by multi-scale, high-accuracy numerical models for both hydrodynamics and oil transport and weathering, which handle all relevant processes both in the water column and intertidal areas.

The platform, generally denoted as RDFS-PT, was customized for oil spill risk management and successfully applied to the risk of an oil spill within the Port of Aveiro jurisdiction area.

Future development efforts will include:

- the inclusion of additional oil indicators in support of local risk evaluation and emergency resources allocation;
- an on-demand oil spill simulator, in addition to the real-time forecast of the evolution of pre-defined plumes;
- the customization of the interface for the general public, with specific products for recreational purposes;
- the adaptation of the spatial data infrastructure developed for the River Basin Management Plans, compliant with the Inspire Directive, to the oil spill management system

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