OPERATIONAL MARITIME WEATHER FORECAST FOR PORT ACCESS AND OPERATIONS USING THE AQUASAFE PLATFORM

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ABSTRACT

Operational weather forecast systems, based on the AQUASAFE platform, have been set up for several ports in Europe and South America, to support the need to increase productivity and maintain safety. This platform can be used to downscale waves and currents' forecasts to a resolution of the order of 10 to 100 m and disseminate modelled and measured data in real time. AQUASAFE is also being used to support the evaluation of the water depth in navigation channels. These data are displayed in real time in control rooms' screens, in mobile Apps and automatic reports disseminated via email. One of the desktop clients that connects to the forecast server is the Oil Spill Simulator, used in emergency situations (to support oil spill or search and rescue operations).

The first sections of the present paper are dedicated to describe the main features of operational weather forecast systems like downscaling, validation and reliability, based on the implementation and maintenance experience of the authors. The latter sections describe the AQUASAFE software and its various components.

CONTEXT

The present economic context of rapid growth in the movement of goods in a lot of ports, and the predicted increase in world seaborne trade in the next decade, is key to justify the need for operational systems. Ports need to increase productivity as they need to cope with growing demand (increase in trade), different demand (growing size of vessels) and the capital and time constraints in growing port infrastructures.

Daily work in port management is made of decisions on ship manoeuvring, docking/undocking and loading/unloading operations. These operations are almost always restricted by weather conditions. Therefore, real time sensor data and forecast information help reduce significantly the risk involved in each decision. The emergence of high resolution operational models to forecast metocean parameters, at the scale of port infrastructures, also enables better adequacy of weather forecast for each site.

Additionally, it is possible to share the basis on which decisions are taken among the parties involved in port operations.

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Operations become more efficient (and probably more profitable) as a better match is made between tight schedules of container ships, or tight security of LNG carriers, and the operational weather limits of each Terminal. Thus, the impacts in the logistic chain where ports are included are extremely positive.

In this context, PIANC's MarCom Working Group 54 produced a set of recommendations "on the use of hydro/meteo information for navigational channel and port basin operations, including the determination of operational limits" (PIANC, 2012). The work described here, and already being used in some ports, follows closely those recommendations.

OPERATIONAL MODELLING

Hydrodynamics and wave propagation modelling methodology used in the operational systems described here is based on downscaling global scale models to local scale, in order to forecast correctly parameters like sea level, currents or waves. Meteorological forecast also has a similar approach but institutes or companies specialized in meteorology are usually used as data suppliers (e.g. MeteoGalicia).

This downscaling methodology is also embedded in the concepts behind some modelling systems like WRF (atmospheric model) or SWAN (waves nearshore).

For hydrodynamic prediction, there are also many systems using this approach such as ROMS, Delft3D and MOHID. The latter has been used by Hidromod in several operational systems in Portugal (Silva et al., 2013, Leitão et al., 2013) and abroad (Bartolomeu et al., 2014, Leitão et al., 2015). Other references can also be found for the operational use of MOHID for marine and coastal areas of France (Delpey et al., 2014), Spain (Carracedo et al., 2006), South Korea (Lee et al., 2009, Cho et al., 2013, Cho et al., 2014 and Park et al., 2015) and Argentina/Uruguay (Santoro et al., 2011). This hydrodynamic model is particularly important due to its relevance to forecast access windows for channels subject to tidal restrictions, which is one of the highlighted subjects of the MarCom Working Group 54 report (PIANC, 2012).

The downscaling methodology followed with the MOHID model (Leitao et al., 2005) has proven to be an efficient solution to integrate large scale oceanic processes with local scale coastal, estuary and river related processes.

VALIDATION

Short range

Validation of a local scale forecasting system is based on: tide gauges, wave buoys and weather stations. Online validation is achieved by comparing what is being measured, for a recent period of time like the last 24h, with model forecast. Figure 1 shows one the weather forecast information output at the Port of Sines where several models are predicting waves, sea level and atmospheric conditions, and measured values are continuously compared with model values.

The real time validation is very useful to interpret short range forecast (less than 24h). It is also very useful to interpret real time data, when there are malfunctions in the measuring equipment, or to detect systematic errors in models.

Figure 1: Example of one AQUASAFE interface used in the Port of Sines (Portugal) where data from a wave buoy, a tide gauge and a weather station is compared with forecasts in real time

Weekly validation

A weekly report sent by the Port of Sines AQUASAFE server enables the analysis of the quality of the forecast for the previous week. The kind of results shown in Figure 2 and Figure 3 for different parameters allow the users of the system to see how forecast is aligned with measures. For instance, in can be seen that the peak on wave height that occurred on the 8 of May was well predicted 4 days earlier. Increase and decrease in wave height forecast is quite similar for results produced 1 to 4 days ahead of the occurrence.

Figure 3 shows a sharp drop in correlation coefficient for forecast time ranges larger than 5 days, for the analysed period. Also an increase in the RMSE can be seen in Figure 3, for similar time ranges.

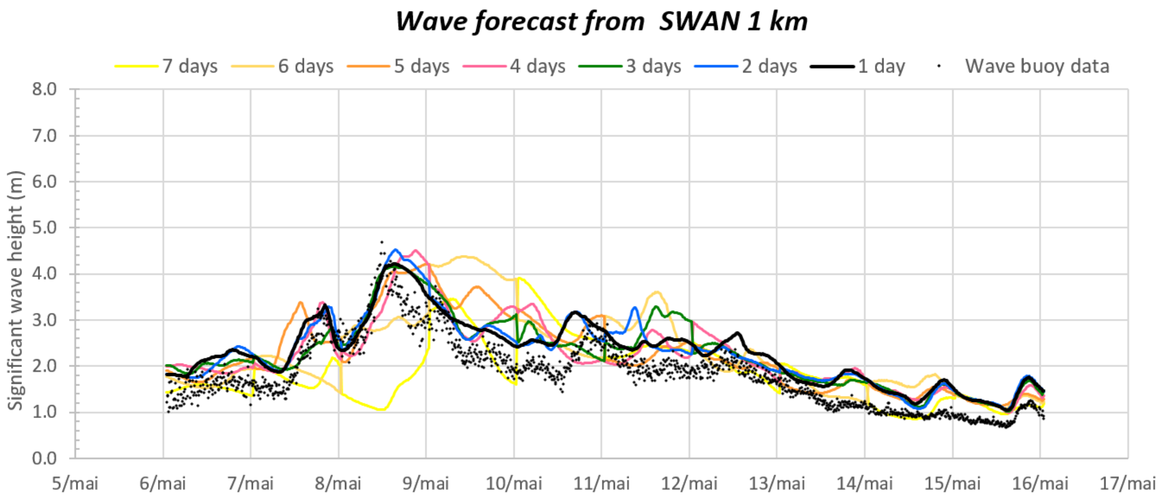

Figure 2: Significant wave height forecast for the area of Sines (Portugal) and comparison with the wave buoy data. Forecast is made operationally with a SWAN model (1km resolution) and results are taken 1 to 7 days prior to measured values.

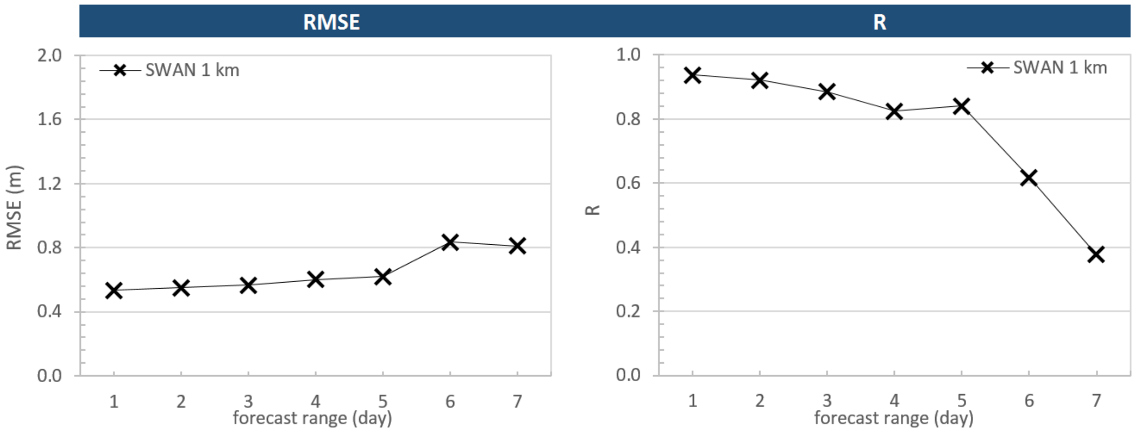

Figure 3: Significant wave height forecast for the Port of Sines (Portugal). On the left: Root mean square error of significant wave height for increasing forecast time range. On the right: Correlation coefficient of significant wave height for increasing forecast time range. Period analysed: 6/5/2016 to 16/5/2016

Another available validation tool is the comparison of sea surface temperature (SST) from hydrodynamic models with SST products based on remote sensing and in-situ observations. The satellite products accessible via an AQUASAFE system for Portuguese waters corresponds to the following solutions provided by Marine Copernicus: Global Ocean OSTIA L4 sense, European Ocean-Sea L4 multi-sensor and the Global Ocean IFREMER CERSAT Global Blended Mean Wind Fields. With this type of product it is possible to validate the spatial variability of forecasts (Figure 4).

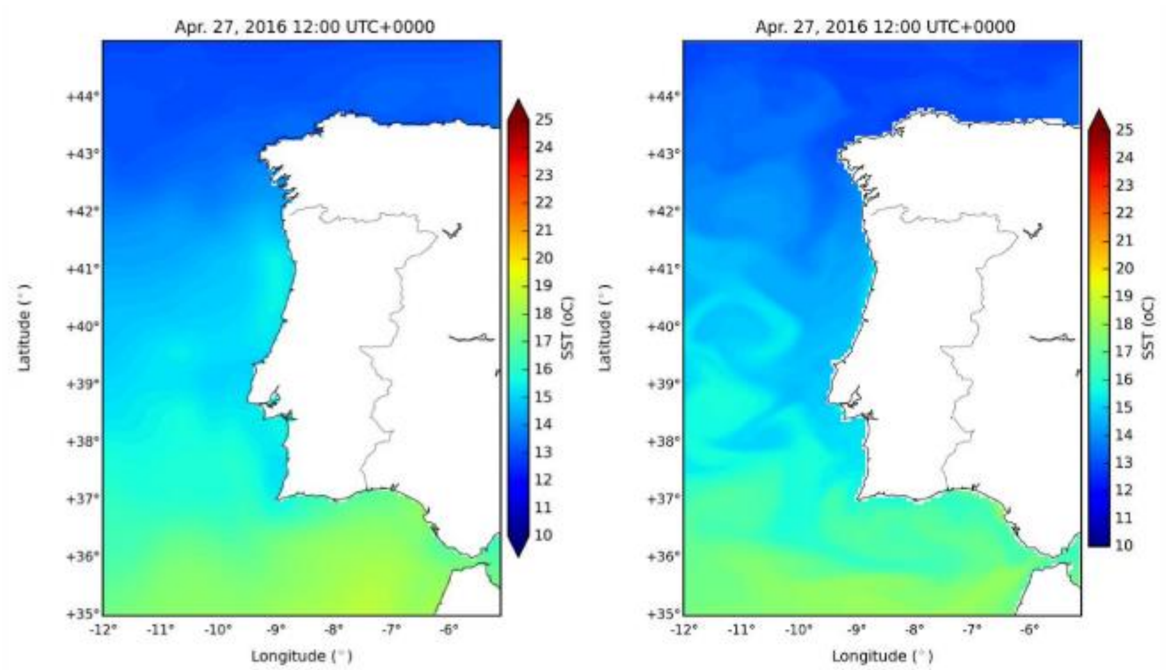

Figure 4: Sea surface temperature for 27/4/2016, at 12:00 UTC: OSTIA product on the left versus MOHID model on the right

Seasonal validation

Another kind of validation is done about every 6 months, when these operational systems are audited and detailed error statistics are calculated. An example of such statistics for the AQUASAFE system of the Port of Leixões (Portugal) is given on Table 1. The results show that a good forecast is available and how it is degraded with the time range of the forecast. For example, for significant wave height (Hs) a 24 h forecast with the SWAN model (1 km resolution) has a correlation coefficient (R) of 0.93 and a Normalized root mean square error (NRMSE) of 10.9%. As would be expected, forecasting the same Hs with a 96h time range decreases the correlation to 0.88 and increases the NRMSE to 12.9%. It can also be seen that WW3 wave propagation models have similar errors for the same time range forecast.

The same type of considerations can be made about wind velocity and sea level, both presented also in Table 1. Regarding sea level, a major difference is obtained between the level of the tide table and the forecast available through modelling. In a large number of situations, the forecast system is used to adapt tidal access windows.

Table 1: Statistical parameters of the comparison between measurements and forecast for different models and different forecast time range for a 6 month period (1/11/2015 to 1/5/2016) and for the area of the Port of Leixões (Portugal)

Parameter	Model	Resolution	Source	Forecast time range	Correlation coefficient	Normalized root mean square error (%)
Significant wave height	SWAN	1 km	Hidromod	24 h	0.93	16.3
	SWAN	1 km	Hidromod	48 h	0.92	16.5
	SWAN	1 km	Hidromod	72 h	0.91	16.7
	SWAN	1 km	Hidromod	96 h	0.88	17.0
	WW3	5 km	Hidromod	24 h	0.93	13.1
	WW3	5 km	Meteogalicia	24 h	0.94	15.2
Average wave period	SWAN	1 km	Hidromod	24 h	0.86	17.2
	SWAN	1 km	Hidromod	48 h	0.83	18.5
	SWAN	1 km	Hidromod	72 h	0.81	19.2
	SWAN	1 km	Hidromod	96 h	0.79	19.9
	WW3	5 km	Hidromod	24 h	0.78	35.3
	WW3	5 km	Meteogalicia	24 h	0.81	35.7
Wind velocity	WRF	4 km	Meteogalicia	24 h	0.81	20.5
	WRF	4 km	Meteogalicia	72 h	0.75	21.9
	WRF	4 km	Meteogalicia	96 h	0.67	23.1
	WRF	12 km	Meteogalicia	24 h	0.79	22.1
	GFS	50 km	NOAA	24 h	0.76	20.3
Sea level	MOHID 2D	25 m	Hidromod	24 h	0.995	2.6
	MOHID 3D	25 m	Hidromod	24 h	0.995	2.6
	Tide table	N/A	Instituto Hidrográfico	N/A	0.986	7.0

RELIABILITY

Marine weather forecast reliability is measured with several indicators. Those indicators usually address the server, the local client, mobile phone App connection, data sources and reporting. The values must be high enough so that the system is dependable.

As an example, the availability indicators from a recent audit to a system deployed for the Portuguese Port Administration of Sines are shown below (audit period: 1/1/2016 to 1/7/2016):

- **i)** Server accessibility: the uptime of the platform was 99.5% of the time.
- **ii)** Desktop client: accessibility to the server and application functionality 99.5% of time;
- **iii)** Mobile App: mobile application was available 90.1% of the time;

iv) Sources of operational information: internal models had a run-efficiency level above 86.8% and external models above 85.7% (Table 2). The availability of real-time measurements for the audited period ranged between 97.3% and 99.1%;

v) Forecast reports: the forecast reports were sent daily during the audited period. Due to failures in some model forecast, some reports were generated also with failures. Nevertheless, the forecast time range of one day was always guaranteed during the audited period, with the exception of forecasts of sea level on 12/06 and 13 / 06.

Table 2: Information sources efficiency

Data sources	Description	Success (%)
Internal models	Hydrodynamic model (MOHID)	92.3
	Harmonic tide model (FES 2012)	97.8
	Wave propagation model (SWAN)	86.8
External models	Hydrodynamic model (MyOcean)	95.1
	Wave propagation models (SWAN and WW3)	85.7 to 95.6
	Atmospheric models (GFS and WRF)	97.3 to 97.8
Real time data acquisition	Tidal gauge	97.3
	Wave buoy	99.1
	Weather station	97.9

AQUASAFE PLATFORM

The AQUASAFE platform aims to increase efficiency in operations management, providing real time information and its integration with forecast and diagnostics tools.

Measured data (sensors, remote detection, etc.) and modelled data (meteorology, hydrodynamics, waves, etc.) are integrated in a platform which synchronizes it all in time, space and units in order to provide easy and robust access to real time and forecast information. The global architecture of the Platform is presented in Figure 5.

The system was developed using a service oriented architecture. This allows a large flexibility as port authority can choose between the pre-developed interfaces (desktop, web or mobile) or have its own customized interfaces.

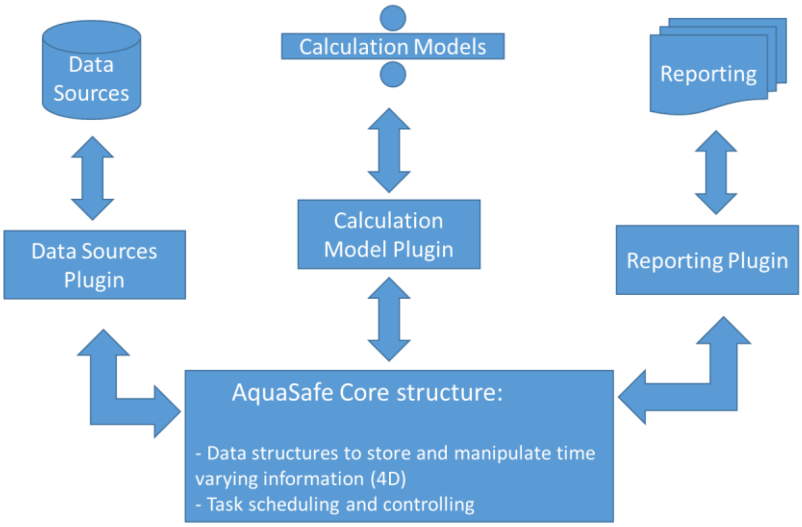

Figure 5: Architecture of the AQUASAFE Platform

Components

The platform is divided into server and clients. The server is a collection of cloud services to manage environmental data. The main client is a desktop application where users can configure and consume those services.

Figure 6 describes the general actions of the platform. Most actions are performed without human interaction by the "Automated Server" at regular intervals. These actions can also be triggered by users with sufficient privileges. Simple users can only configure how to consume information.

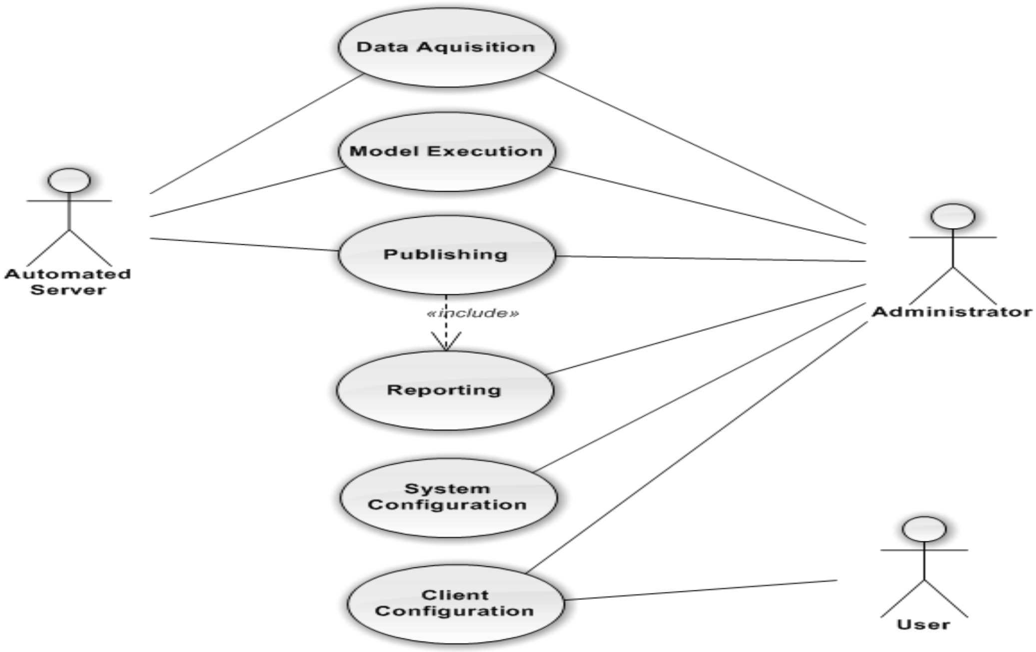

Figure 6: AQUASAFE platform use case

Server

The Server is divided into 5 main modules:

- Data Storage and indexing
- Data Acquisition
- Model Execution
- Reporting
- Publishing

The server needs to store or index data produced either by the Data Acquisition components or by Model Executions. Two main types of data are stored:

- Time series: data in a single point for a single property along time. For example data from a temperature sensor on a weather station
- Grid data: data on a structure or unstructured grid (1D, 2D or 3D) that varies in time. For example data from radar images or model results.
- Images: Images can be generated form Grid Data internally by the platform or from external sources

Time Series are stored in a database. Metadata on Grid and Images is stored in the database and data files on disk. Data is only stored for a limited interval in time according to pre-defined and automated backups/purges.

Data acquisition

Data is available in multiple formats (*eg*: asccii, xls, etc.. for time series or HDF5, NETCDF, GRIB for grid data). Multiple protocols can serve data, *eg*: FTP, http, OPEN DAP, Sensor Observation Service (SOS). Some types of data are downloaded by the platform while others are only indexed.

The data acquisition module is responsible for:

- Downloading or rebuilding indexes to known data sources;
- Transform between known formats and the AQUASAFE platform uses for storage.
- Indexing the new information in the AQUASAFE platform data store.

All these processes occur in pre-defined intervals or on-demand.

Model execution

The AQUASAFE platform is able to execute mathematical models on user demand or pre-defined intervals. The work cycle for a model execution is assumed as:

- Data Preparation or input
    - Boundary conditions
    - Initial conditions
- Model Executions
- Data extraction

The data preparation step creates the necessary boundary and initial condition files. Boundary conditions force the model execution throughout the duration of the model run (eg: rainfall for a watershed model or wind for a hydrodynamic model). Initial conditions set the start values for model properties (eg: water level for a hydrodynamic model or initial soil water content for a watershed model). Sometimes initial conditions are obtained from the results of previous executions. This is referred as “Hotstart”, as opposed to “Coldstart”, when initial conditions are set from other sources or default values.

Reporting & Publishing

Reports created by the AQUASAFE platform can contain Time Series and images. Images can be created from grid files or Time Series indexed in the database, creating charts or maps. Reports can also contain raw Time Series values in the form of tables.

Reports can be created in office compatible formats (Open XML), pdf, xml or simple ASCII. Other formats can be incorporated since the design general base structure is flexibly based on interfaces.

Publishing is used to disseminate reports or alerts to a list of users. Publishing can occur by: E-mail, SMS, Http, FTP or local file share.

Administration

Through the client interface it is possible to control most of the features of the system like creation/edition/deletion of users, manage workspaces, define monitoring stations, start/stop any task, manage maintenance tasks and define/publish reports. Doing these tasks over an interface means that administration of the operational system can be made either by the final user or by the service provider.

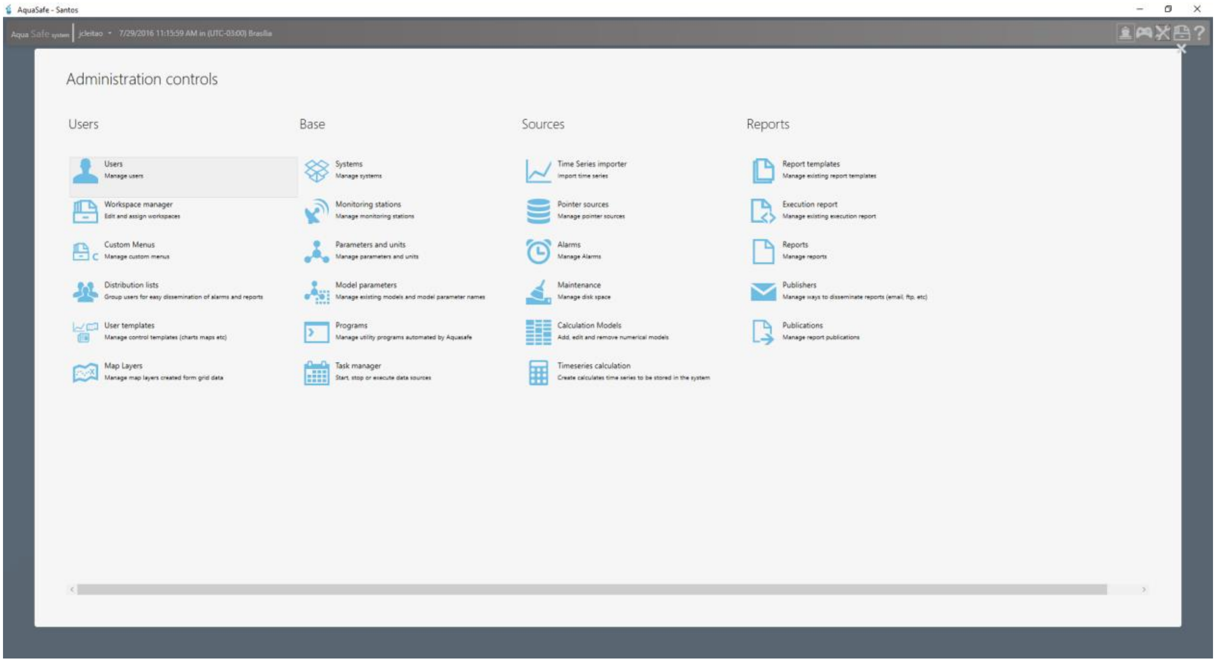

Figure 7: Administration controls of the one AQUASAFE deployment

Oil spill Simulator

Oil Spill Simulator (OSS) is a client of the AQUASAFE Server and allows the user to run oil spill scenarios using metocean data available in servers. As this tool automatically downloads metocean data from the AQUASAFE Server, the reliability and robustness of this solution is much higher if the same information is being used daily for port operations and access.

The user can define several oil spill scenarios for the time frame over which metocean solutions are available locally. When defining an oil spill the user needs to provide the following inputs: spatial location, time instant of the discharge, volume, oil type and metocean conditions (e.g. constant or forecasts variable in time and space, stokes drift, wind effect). The spatial location can be defined by a point or by a polygon in the GIS window.

Input/output

One of the important features for this kind of tools, which is available in the AQUASAFE OSS implemented in several Ports, is the ability to share information with other software platforms, either input or output. As input, remote oil observation upload via local file or via a standard web service connected to a geoserver data base are available.

For output, the user of this tool is able to visualize in a GIS environment the metocean solution and the oil spill results (Figure 8). The oil slick can be represented by a cloud of particles or by a polygon. In the case of cloud view, the colour represents the slick thickness. The polygon representing the slick limits can be published in shapefile and kml formats. The user can also represent the slick center of mass trajectory.

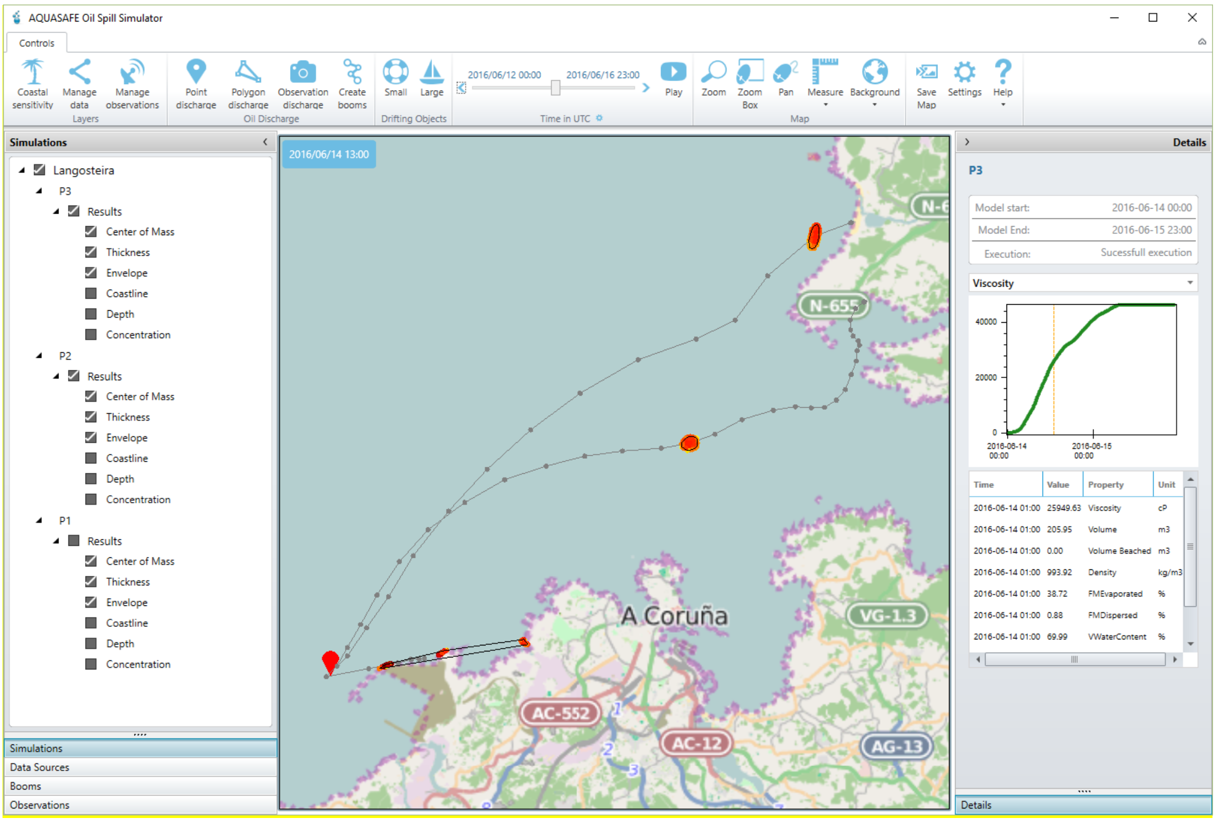

Figure 8: Example of the AQUASAFE OSS implemented for the Port Authority of A Coruña (Spain)

CONCLUSION

High resolution operational weather forecasting is making its way into the operation rooms of Port Authorities, but also to cell phones and web pages.

The need to keep improving efficiency and safety in maritime transport is presently an important driving force for the development of operational weather forecast services like the ones presented here. This will surely help having “cost-effective, reliable and sustainable infrastructures to facilitate the growth of waterborne transport” (PIANC´s general objectives).

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