CHAPTER 27

Operational Oceanography at the Service of the Ports

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The Spanish ports demand operational oceanography products for their operation. In recent years, this demand has been fulfilled by SAMOA project. SAMOA (Sistema de Apoyo Meteorológico y Oceanográfico a las Autoridades portuarias - System of Meteorological and Oceanographic Support for Port Authorities) is revolutionary in the way solutions are provided to the operational oceanography needs of port authorities. An integrated system, ultimately based on Copernicus Marine Environment Monitoring Service (CMEMS) data, has been developed. A total of 10 new high-resolution atmospheric models (1 km resolution, based on Harmonie), 10 wave models (5 m, mild slope), and nine circulation models (70 m, ROMS) have been developed and operationally implemented. In terms of instrumentation, SAMOA has improved the preexisting large network of Puertos del Estado by means of 13 new meteorological stations and three global navigation satellite systems associated with the tide gauges. Twenty-five ports from 18 port authorities will benefit from these new modeling and monitoring advances.

Introduction

Approximately 85% of total imports and 60% of Spanish exports are channeled through ports, a fact that speaks for itself of the vital role they play in Spain's national economy.

The ports suffer the extreme events of essential physical variables, especially wind, waves, and sea level. This affects the installations during all phases of the harbor life, from design to operation. To respond to these complex needs, the SAMOA initiative (Sistema de Apoyo Meteorológico y Oceanográfico a las Autoridades portuarias - System of Meteorological and Oceanographic Support for Port Authorities) was born, co-financed by Puertos del Estado and the Port Authorities.

All previously existing (models at the regional scale and measuring networks: buoys, tide gauges, and high-frequency radars) and new products (the models and instrumentation described in this paper) have been fully integrated in a specific SAMOA visualization tool that is being managed by administrators in the harbors. In addition, there is a new alert system via e-mail and SMS (short

Alvarez Fanjul, E., et al., 2018: Operational oceanography at the service of the ports. In "*New Frontiers in Operational Oceanography*", E. Chassignet, A. Pascual, J. Tintoré, and J. Verron, Eds., GODAE OceanView, 729-736, doi:10.17125/gov2018.ch27.

message service), that is fully configurable by the users in the port community. Finally, an extended set of applications, including oil spill models and air pollution monitoring tools, have been fully integrated into the system.

Uses of the system, among others, include: (1) provision of information for knowledge-based operation of infrastructures (i.e., to forecast port closings due to extreme events); (2) aid for pilot operations; (3) safer and more efficient port operations (i.e., crane operations affected by winds, planning of roll-on/roll-off operations); (4) fighting against oil spills in the interior of the harbours, and (5) control of water and air quality.

SAMOA is based on activities of the SAMPA project (Sistema Autónomo de Monitorización y Previsión en Algeciras – Algeciras autonomous monitoring and forecasting System), developed with the Algeciras Port Authority, which in the present framework functioned as a laboratory for the Spanish Port System. SAMOA has been co-financed by the Spanish Ports (75%) and by Puertos del Estado (25%).

The Monitoring Component

SAMOA relies heavily on previously existing Puertos del Estado monitoring networks (25 buoys, eight high-frequency radars, and 40 tide gauges). As such, SAMOA has been used to fill detected knowledge gaps, improving the coverage of meteorological stations on the ports (13 new stations) and the control of the tide gauges by means of continuous global navigation satellite systems (three new stations).

The Atmospheric Component

SAMOA's meteorological component provides a high-resolution forecast for surface weather variables, especially winds, over harbour influence areas. This is done using a new configuration and integration of the HARMONIE-AROME model running semi-operationally at 1 km resolution over the ports of Almería, Avilés, Baleares, Barcelona, Gijón, Las Palmas, Málaga, Melilla, Tenerife, and Tarragona.

HARMONIE (Hirlam-Aladin Research on Mesoscale Operational NWP in Europe) is a spectral bi-Fourier limited area numerical weather prediction (NWP) model. The main features of the model's deterministic system are thorough data assimilation (Brousseau et al., 2011) and surface treatment, a non-hydrostatic dynamics core with semi-Lagrangian semi-implicit discretization over the horizontal grid, and hybrid coordinate on the vertical. The AROME implementation (Seity et al., 2011) is designed for high resolution, 2.5 km by default, including new parametrizations like convection or solar radiation, but it can be forced to reach higher horizontal resolutions providing even better results. Running HARMONIE-AROME at the very high resolution of 1.0 km includes several challenges. Numerical time step is adjusted to 30 seconds to keep a continuous air flow without overloading computational resources. Topography is based on Global Multi-resolution Terrain Elevation Data (GMTED2010; Danielson and Gesch, 2011), a global digital elevation model with 250 m resolution, appropriate for generating a smooth and realistic field through upscaling without introducing orographic noise. The boundary conditions are obtained from the 0.1 degree resolution integrated forecasting system model from the European Centre for Medium-Range Weather Forecasts, as testing proved (not shown) that it provides better results than using an intermediate Agencia Estatal de Meteorología (AEMET; the Spanish meteorological agency) HARMONIE-AROME model.

The model runs twice per day on the European Centre for Medium-Range Weather Forecasts' supercomputer, at 00 UTC and 12 UTC, with a forecast length of 48 hours over the areas of interest. The results obtained reveal much richer dynamics than the AEMET official 2.5 km forecast (Fig. 27.1), capturing smaller eddies and more local behaviors. The quantitative verification, performed with the MONITOR tool developed by HIRLAM, shows an improvement of the statistical scores for the highest resolution model wind forecast both for deep convection episodes and long-term periods over the four main areas. However, several issues remain unresolved for very high-resolution mesoscale models, such as the use of a more suitable verification method, adequate data assimilation, or the continuous improvement of forecast accuracy through model improvements.

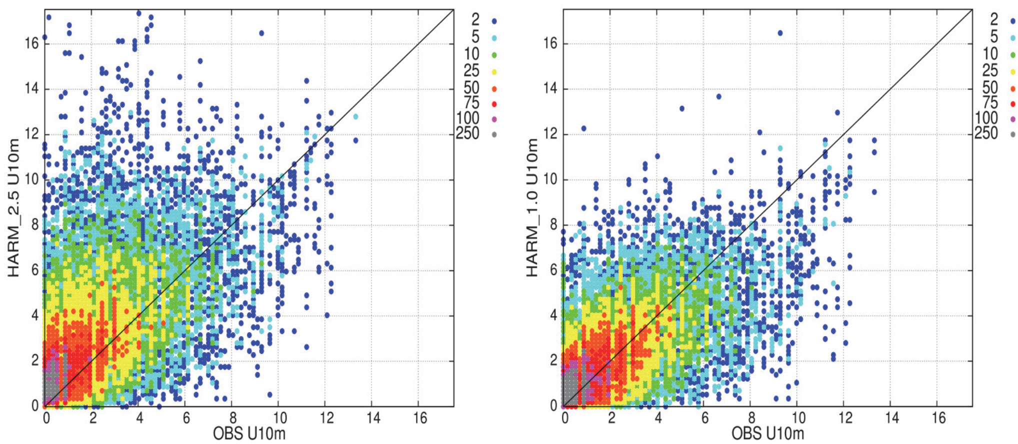

Figure 27.1. Validation over the Gulf of Biscay area during March 2017. Left: Scatter plot of 10 m wind observations against operational 2.5 km HARMONIE-AROME; Right: Against new 1.0 km HARMONIE-AROME. The different point colours indicate the range of cases that occurred.

The Circulation Component

The SAMOA circulation component produces, on a daily basis, a short-term (three-day) forecast of three-dimensional currents and other oceanographic variables, such as temperature, salinity, and sea level for nine Spanish ports in the Mediterranean (Barcelona, Tarragona, Almería), the Iberian Atlantic (Bilbao, Ferrol), and the Canary Islands (Las Palmas, Tenerife, La Gomera, and Santa Cruz de la Palma).

The three-dimensional hydrodynamic model used in the SAMOA circulation systems is the Regional Ocean Modeling System (ROMS; Shchepetkin and McWilliams, 2005).

The SAMOA model applications consist of two nested regular grids with spatial resolutions of ~350 m and ~70 m for the coastal and harbour domains, respectively. The chosen vertical discretization consists of 20 sigma levels for the coastal domains (except for the Canary Island implementations where, due to the deepest bathymetry, 30 levels are used) and 15 levels for the port domains. Bathymetry of the SAMOA coastal systems is built using a combination of bathymetric data from the General Bathymetric Chart of the Oceans (GEBCO; Becker et al., 2009) and from specific local high-resolution sources provided by local port authorities.

At the surface, models are forced by daily updated high frequency (hourly) winds and heat and water fluxes from AEMET forecast services. The SAMOA forecast systems are Copernicus Marine Environment Monitoring Service (CMEMS) downstream services, being the coastal models nested into the regional CMEMS Iberia Biscay Irish forecast solution. In those ports where river freshwater discharges may be relevant (Ferrol, Bilbao, Barcelona, and Tarragona) it is included in terms of climatological data, but developments are underway to include a hydrological model.

Prior to the operational launch of the SAMOA systems, the quality of a one-year of SAMOA coastal and port products was assessed by comparingn model solutions with observations, both from in situ moorings and remotely-sensed products. A validation tool has been implemented to evaluate the downscaled SAMOA local solutions, using available operational observational sources (both remotely-sensed, including high-frequency radar and in situ). Apart from validating the local solution, the objective of this tool is to evaluate the effectiveness of the dynamical downscaling performed, providing an objective measure of potential value-added with respect to the regional Copernicus solutions (in which local models are nested). An example of this potential value-added evaluation is shown in Fig. 27.2.

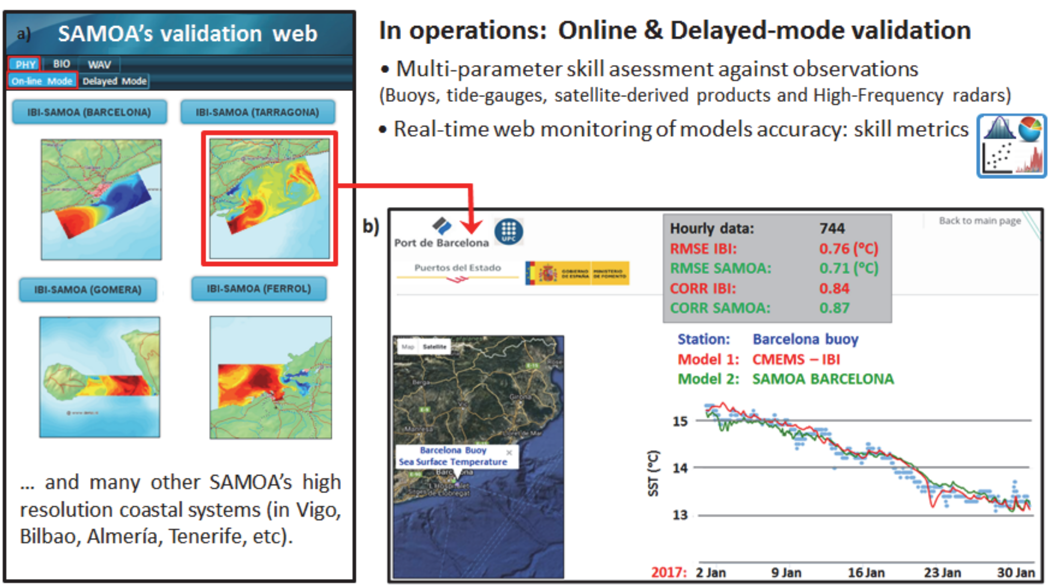

Figure 27.2. Snapshot of the multi-parametric ocean model skill assessment tool, implemented by Puertos del Estado to validate operationally SAMOA downscaled local solutions and to compare them with the "parent" regional solution in which they are nested (the CMEMS IBI MFC forecast product).

The Wave Component

The SAMOA wave component has been designed to provide a three-day forecast of agitation (significant wave height in the interior of the port) inside 10 Spanish ports of special interest: Almería (two ports), Gijón, Las Palmas (three ports), Málaga and Santa Cruz de Tenerife (three ports). Prior to SAMOA, Puertos del Estado was running an operational wave forecast able to provide, using the SWAN model, wave forecasts at the harbours mouth. Thanks to the SAMOA developments, this forecast has now been downscaled to the interior of the ports at extremely high resolution (2 m).

The new system is based on the spectral reconstruction technique of sea states, using a monochromatic wave catalogue previously computed in advance by means of a model based on the elliptical approximation of the mild slope equation. The process includes some ad hoc innovative improvements:

- Updated numerical solver to speed up the simulations (reaching 10x times faster than similar models), which has enabled changes in the meshing tool to reach the above-mentioned resolution.
- Introduction of the reflection response algorithm in the numerical contours as a function of the incident wave period and based on the functional response of each type of pier and breakwaters analysed.

Results of the system have been validated and calibrated using agitation data measured by the Puertos del Estado tide gauges (Fig. 27.3), which are able to measure sea level at a 2 Hz sampling rate and, therefore, are capable of measuring this variable. The model output is validated on a daily basis with this instrumentation.

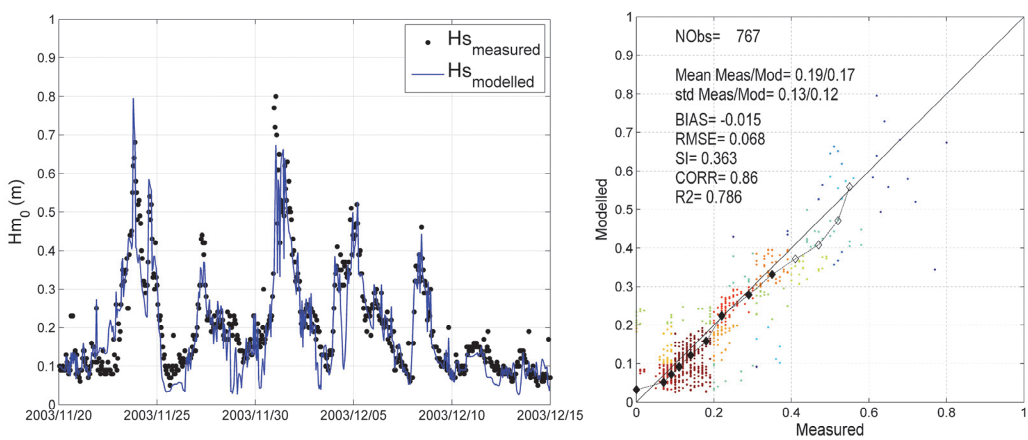

Figure 27.3. Example of validation of the operational predictions in the ports of Barcelona, using agitation data provided by the tide gauge. Measured and simulated time series comparison (left). Scatter plot of modelled and measured time series (right).

Integration and Downstream Tools

The SAMOA model outputs are freely accessible through the Puertos del Estado's THREDDS catalogue (the THREDDS data server is a web server that provides metadata and data access for scientific datasets using a variety of remote data access protocols.). Likewise, free access to some products is granted via the Puertos del Estado's Portus web interface (http://portus.puertos.es). Additionally, a specific tool for the port authorities—the CMA (Cuadro de Mando Ambiental - see Fig. 27.4)—has been developed to properly exploit all SAMOA products, and has been implemented in 25 ports, to date. The CMA is based on a web interface (http://cma.puertos.es) and provides easy access to all information generated by the SAMOA systems, both in real time and in forecast mode. Users can define thresholds for all spatial points inside the application (model points and measuring stations) that are used to trigger alerts. The CMA is also capable of creating customised PDF reports for each forecast point.

Additionally, a user-friendly oil spill model and an atmospheric dispersion model have been developed and incorportated into the CMA.

Port managers granted the access to the tool can define the level of permission that users have. For example, some users can get permission for visualization, but might not have access to the oil spill model. Algeciras harbour is a very good example of how the CMA tool should be used, wherein a community of 250 port users utilize the CMA tool (including the companies located at the facilities).

The CMA is also is utilized to configure personalised alert systems, defining the points and the alerts to be triggered, as well as the reception method (e-mail or SMS). The alerts can be defined as a combination of parameters, conditions, and/or thresholds as complex as desired by the user.

Future Plans

Building on the success of SAMOA, a SAMOA 2 project is being launched. This second phase will include new components, such as a wave overtopping forecast and extremely high-resolution wind prediction (2 m). In 2020, by the end of SAMOA 2, the system will have the following components: 44 CMA implementations in different ports (of a total of 46 ports in the national system), 20 1 km resolution atmospheric forecasts, 21 agitation systems, 31 circulation systems, 19 new meteorological stations, eight global navigation satellite systems, 15 very high wind forecast systems, plus other additional modules. There are plans to use the new models to explore, for example, the wave current interactions.

With the new system in place, the most important challenge for the Spanish Port System will be to implement the methodologies necessary to make proper use of all the new available tools. While some ports are very active and are already making good use of the new information, other are still not able to fully exploit it. Several initiatives will be launched to reduce this gap. Making operational oceanography a core part of the port management business is probably the most significant result of SAMOA.

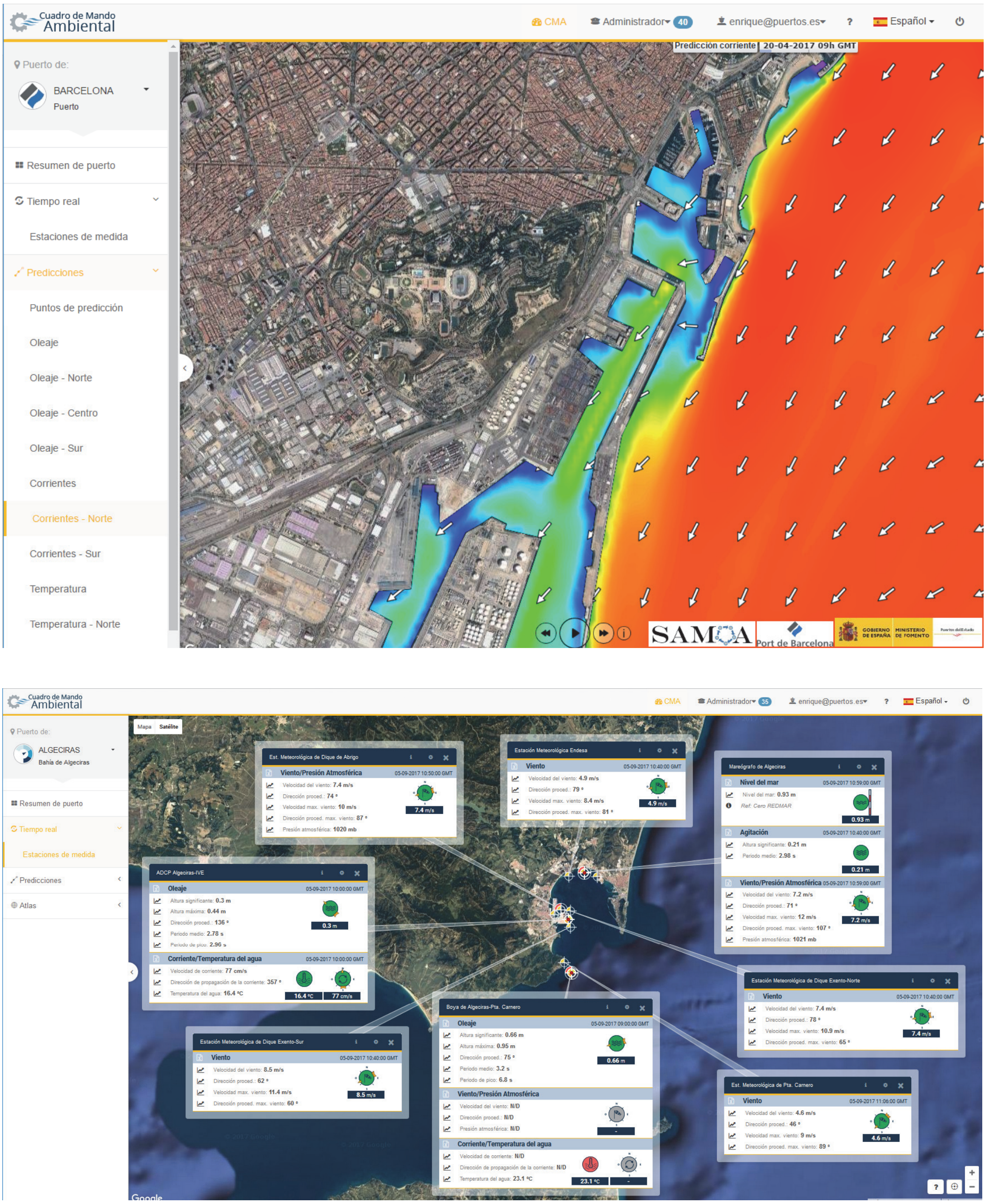

Figure 27.4. The SAMOA visualization tool, showing the circulation at Barcelona Port (upper panel) and the real-time measurements at Algeciras Harbour (lower panel).

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