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IMPROVING STORM SURGE AND WAVE FORECASTS FROM REGIONAL TO NEARSHORE SCALES

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Abstract

Submersion risks assessment requires different tools and methods from regional to coastal scales. The SHOM's strategy relies on numerical modelling and observational systems applied in a challenging multi-scale context.

At regional scales, storm surge and wave models Hycom and Wavewatch III, bathymetric digital terrain models (DTMs) and observational tide/buoy networks used within the operational national storm surge service (Homonim project with M et eo-France) are presented, as well as their applications in climatological 40-year hindcasts. At coastal scales, coupling between models at decametric resolutions is required for better forecasting of coastal processes (currents/levels and wave interactions). The aim is to improve knowledge of marine hazards locally, and to develop infra-departmental warning systems based on real time flooding forecasts or statistical risk management tools. The development of such tools requires fine scale topo-bathymetric DTMs and dedicated oceanographic campaigns for model validation.

To combine regional to coastal scales and improve numerical performance, the modelling strategy will soon be based on a new numerical model from the TOLOSA library (TOols Library for unstructured Ocean models and Surge Applications). This state-of-the-art numerical code, that handles many types of numerical schemes, physical formalisms and meshes, should lead to ultra-high resolution forecasting capacities, allowing for finer processes studies and forecasts (wave setup, port oscillations, infragravity waves, estuarine dynamics, overflows).

Keywords: waves, storm surge, forecasting, measurement, risks

1. Introduction

Improving knowledge of the marine flooding risk requires a precise assessment of the physical characteristics of the coastal zone (bathymetry, topography, metocean conditions) through observation monitoring and numerical modelling. Operational monitoring of the relevant metocean variables such as water level, current and waves is important but must be supplemented by extensive oceanographic campaigns to characterize all the processes in detail. Numerical modelling is a way to predict submersion hazards at different spatio-temporal scales, but also allows for a better understanding of the measured processes. At regional scales, a forecasting system based on separated atmospheric storm surge and offshore waves models may allow a coarse prediction of coastal flood risks at low computational costs. It is thus particularly suited for operational flooding risk assessment and studies requiring several decades of hindcasts. At these spatial scales however, waves-current interactions and waves dissipation processes, such as wave set-up/set-down that affect the surface elevation (Dodet *et al.*, 2019), remain poorly represented. Modeling these processes requires coupling between atmospheric storm surge and wave models at decametric resolutions (Bertin *et al.*, 2012).

The methods to improve our knowledge of submersion, based on observations, modelling and statistical analysis are described here, then some modelling results of our regional Atlantic and inner-shelf scales configurations are presented. Finally, limitations and perspectives of our works are given.

2. Methods

2.1 Bathymetry and oceanographic observations

Bathymetric data mainly originate from the SHOM's bathymetric database. Survey depth measurements were collected with different sounding methods (lead-lines, single beam and multibeam echosounders, airborne LIDAR). DTMs combining these datasets and topography are built on the French Atlantic coast (Biscara *et al.*, 2016) and locally, in Pertuis-Charentais Sea and Saint-Malo Bay (Seyfried *et al.* 2021). The REFMAR and CANDHIS operational networks give, respectively, observed sea surface height (and deduced surge from calculated tides predictions) in harbours, and offshore to inner shelf sea states characteristics between 100 m and 10 m depth (see Figure 1 for datasets longer than 5 years).

2.2 Models and configurations

Tide and storm surge modelling relies on a barotropic version of Hycom (Bleck, 2002, Baraille and Filatoff, 1995) using curvilinear grids, and on the wave stochastic model Wavewatch III® (WW3, Tolman 2019) on unstructured grids.

French Atlantic regional configurations (HR systems) were developed and calibrated as part of the HOMONIM research project (Jourdan *et al.*, 2020) to meet the requirements of the operational numerical forecast capacity for the French storm surge warning system (e.g. forced by Météo-France atmospheric and wave models, HR-MF). They allow a sub-kilometric (500 m to 1 km) representation of atmospheric storm surge and wave parameters. A 40-year surge/current/waves hindcast (forced by hourly, 30km resolution ERA5 atmospheric reanalysis, HR-ERA5 in the following) ran with these configurations is also presented here.

At inner shelf scales, higher resolutions are reached by coupling Hycom and WW3 using the OASIS coupler (Michaud *et al.*, 2015) and allow the representation of nearshore processes such as the wave set-up. The physical performance of this system is discussed here through the results of two ~30m resolution configurations on the Pertuis-Charentais (THR-Charentes) and Saint-Malo (THR-Malo) areas.

2.3 Extremes values analysis

An extreme value analysis is performed to evaluate the ability of the model to represent the extreme events. The extreme events are identified by applying the Peak Over Threshold (POT) method. The exceedance events were modelled according to the Generalized Pareto Distribution (Coles 2001). Return levels are calculated from this analysis, which is performed on both modelled and observed skew surge (difference between maximum sea level and tide for each tide cycle), as well as significant wave heights (Hs).

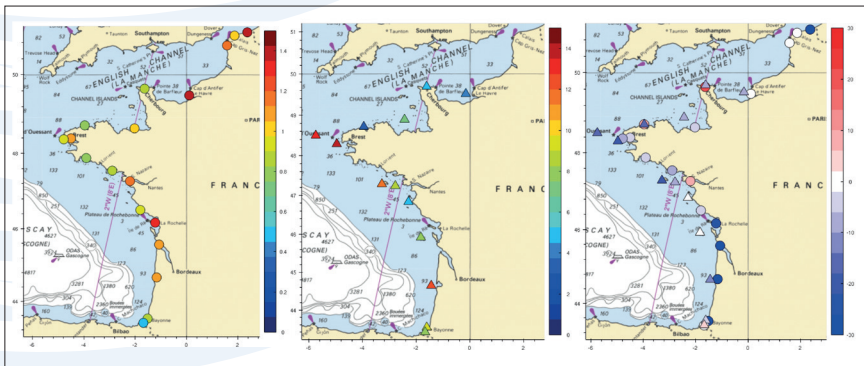


Fig. 1. 100-year return levels for Skew Surge observations (left), 100-year return levels for Hs observations (center) and 100-year return level errors for Skew Surge and Hs (right).

3. Results

3.1 Regional modelling

The HR-ERA5 configurations are able to well represent the extreme values of skew surge and Hs (Figure 1). The highest return levels of skew surges and Hs are observed, respectively, in the eastern part of the English Channel and at La Rochelle, (up to 1.4 m) and in front of Brest (les Pierres Noires buoy, 15 m). The largest model errors occur along Nouvelle Aquitaine coasts (from La Rochelle to Bayonne) for skew surge and at Belle-Ile for Hs.

Those errors (mainly underestimation) can partly be attributed to ERA5 forcings, and could be reduced using more accurate atmospheric and boundary forcings, such as Météo-France atmospheric and wave models. As an example, for Xynthia and Eleanor storms that have induced coastal floodings in Pertuis Charentes Sea (Bertin *et al.*, 2012) and Saint-Malo Bay, it significantly improves the amplitudes of waves and storm surge (Figure 2, HR-MF compared to HR-ERA5 results), although a slight over estimation of storm surge can be observed for Xynthia storm.

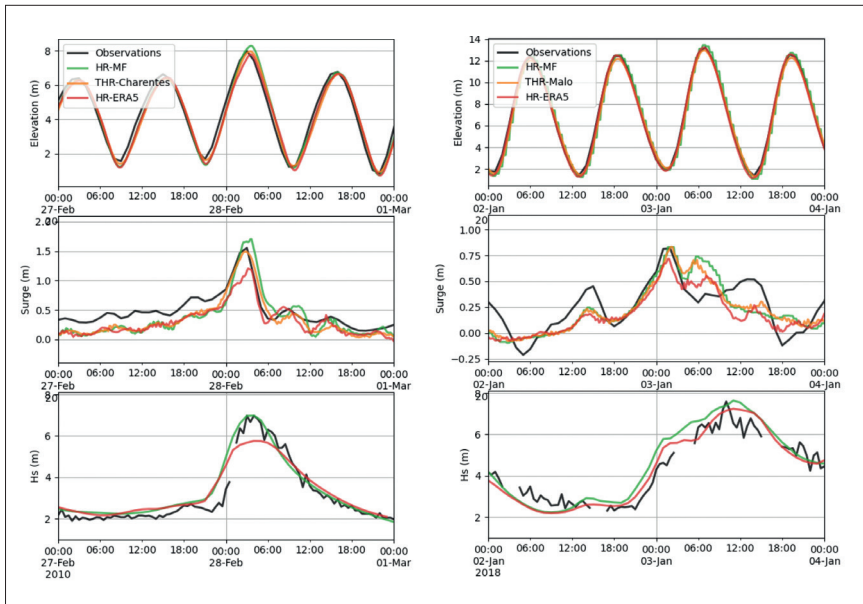


Fig. 2. Time Series for Xynthia storm in La Rochelle (left) et Eleanor storm at Saint-Malo (right). Simulations HR-ERA5, HR-MF and THR configurations are compared to tide gauge measurements at La Rochelle (left) and Saint Malo (right), and to buoys measurements at Oleron buoy (buoy #01703, west of La Rochelle, left) and Bréhat (buoy #02204, north of Saint Malo, right).

3.2 Inner shelf scales modelling

Additional precision of prediction can still be achieved using the decametric coupled modelling system in these two coastal areas. Several improvements resulting from the coupling effect on the enhanced representation of dynamical processes, as well as the finer resolution of the coastline itself, are obtained considering storm surge levels (Figure 2).

In the Pertuis Charentais area during Xynthia, currents and water levels on foreshore or shallow depths stations such as La Cotinière are more accurate (not shown), which allows for finer, more precise tide and surge levels prediction. Wave effects on the water level (Figure 3) can locally reach 20 cm on wave-exposed coasts (Ré and Oleron islands) to lower at -10 cm before the waves breaking zone.

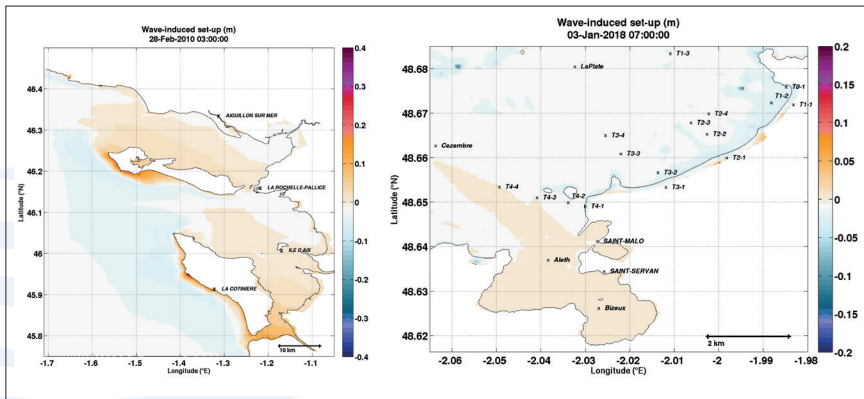


Fig. 3. Map of wave set-up (in meter) on Pertuis Charentais (left) during Xynthia storm (28 February 2010 at 3 a.m.) and Saint-Malo bay (right) during Eleanor storm (3 January 2018 at 7 a.m.). Tidal operational stations are reported in capital letters. Moorings deployed during PAPI Saint-Malo oceanographic campaigns are represented (right).

As expected as this could be regarding theory and literature (Bertin et al, 2012), but these results need to be compared to measurements to really estimate the contribution of very high resolution coupling. Apart from La Rochelle tide gauge, where the wave setup is negligible due to the sheltered location, acquired measurements during Xynthia are too scarce.

In macrotidal regions such as Saint-Malo (tidal range can reach 14 m) wave-currents effects on the water level may significantly depend on tide amplitudes. During Eleanor storm (Figure 3), it hardly reaches 5 cm during high tides. When arriving at Saint-Malo dike during high tides, waves are still well formed and have not yet broken, so only a set-down is generated. Numerous photos and videos of these events show wave breaking on the dike and overtopping. These processes cannot be modeled by decametric phase-averaged coupled systems.

4. Conclusions and perspectives

The wave and surge modelling system at regional and inner-shelf scales are presented. Improving the atmospheric forcing, resolution and the physics by coupling waves and levels models, allow a better representation of the processes near the coastline. The lack of operational tidal and wave observations limits the validation process. To raise this obstacle, dedicated extensive oceanographic campaigns were conducted in Saint-Malo bay in winter 2018 – 2019 (Seyfried *et al.*, 2021, see Figure 3 for the location of some of the 38 instruments) and Ré Island in winter 2020-2021 (in progress). This will provide datasets to further evaluate the capacity of numerical models to represent flooding processes at decametric, and then even finer, metric scales.

Increasing the model resolution is no longer the only bottleneck when modeling highly nonlinear coastal processes. Spectral wave models are not the dedicated tools to represent wave transformation nearshore. The coupling system between wave and surge models offers only a simplified parameterization of the real interactions. To take up the challenge of the accurate assessment of flooding, the unstructured surge model Tolosa-sw (Couderc *et al.*, 2017) which is destined to replace Hycom for operational forecasts, will thus be completed nearshore by a non-hydrostatic module (Richard, 2020; Durand *et al.*, 2020).

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