Blue carbon attenuation of future coastal risks related to extreme stream- and sea-water levels: the high-resolution 2D simulation as a management tool

Pierre Lochin, Antoine Collin, Dorothée James, Yves Pastol, Stéphane Costa

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Lochin, Pierre[1]; Collin, Antoine[1,2]; James, Dorothée[1]; Pastol, Yves[3] and Costa, Stéphane[4]

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Introduction

Anthropogenic pressure on the world's coastal areas is accelerating given the rising population density, resulting in severe deterioration of coastal ecosystems (Neumann et al. 2015). This impact in turn exacerbates the vulnerability of coastal populations, threatening many human lives. Vulnerability to seaside flooding is becoming a significant concern because of the rising sea level (Vitousek et al. 2017). In addition, increasing precipitation anomalies also create a risk of recurrent landside flooding. The concomitance between these two types of hazards is increasingly prevalent, leading to a greater vulnerability of populations (Zellou and Rahali 2019). Our original study aims to model the cumulative effect of extreme events, such as a massive tide, stormy wave (Collin et al. 2020), and heavy precipitation in the context of rising sea level by 2100. We are also assessing the positive impact of barrier ecosystems in mitigating the risks associated with these phenomena. The blue carbon ecosystems help to reduce the vulnerability of coastal dwellings (Sutton-Grier, Wowk, and Bamford 2015; Temmerman et al. 2013). To do this, we model these events on the northern coast of Brittany (France), which hosts densely populated areas behind barrier ecosystems and within coastal valleys composed of urban and rural areas. To achieve this, we use the TUFLOW hydrodynamic model to simulate our models with high-resolution data (>10 m). The results generated through the development of this hydrodynamic model are expected to (1) highlight the importance of natural adaptations, the so-called blue carbon ecosystems, in mitigating coastal risks, and (2) to furthermore promote the resilience of coastal dwellings through implementing measures to protect and restore these ecosystems, which are often neglected in coastal defence developments (Naylor et al. 2012).

[1] *EPHE-PSL Research University, CNRS LETG 6554, 15 boulevard de la mer, 35800 Dinard*
[2] *Labex CORAIL, Papetoai, French Polynesia*
[3] *SHOM, 13 rue de Châtellier, 29200 Brest*
[4] *Caen-Normandie University, CNRS LETG, Esplanade de la Paix, 14000 Caen*
E-mail contact: pierre.lchn@gmail.com

Materials and methods

Our study site focuses on the Bay of Beaussais and its associated watershed, which are located on the northwest coast of France in Brittany (Figure 1). This region is characterized by a temperate climate under a significant oceanic influence occasionally leading to severe storms, especially in winter. The main specificity of this area is its exceptional tidal range, which can reach up to 13 meters.

Figure 1. Location of water height measurement sites on the Bay of Beaussais

To build our model, we had to implement several steps. First, we established a topo-bathymetric model using photogrammetric methods with a pair of stereo-Pleiades images and different sources of terrain elevation data (Almeida et al. 2019). From this topo-bathymetric model, we can build our hydro-dynamic model. This one requires many input data and the addition of specific climatic and hydrological events. In our case, we have simulated a significant storm generating waves of significant height, a major tide representing a tidal range of about 13 meters, a precipitation phenomenon of 50-year type, and finally a sea-level rise of 1 m by 2100 (Shen et al. 2018). Realistically, we have re-created the swell of the Ciara storm of February 11, 2020, via the CGWAVE model (1.8 m), coupled with the tide of April 9, 2020 (13.20m), associated with the rainstorm of May 25, 2010 (108 mm in 7 hours).

These first parameters allowed us to run our first models and adjust the hydraulic and physical parameters of the different surfaces of the watershed. Figure 1 shows the difference between the uncalibrated model, based on values from the literature (Rawls, Brakensiek, et Miller 1983; Silva et al. 2007), and the calibrated model. Table 1 shows the last values used for the different land-use land-cover classes of our watershed after calibration. The TUFLOW model is extremely sensitive to variations of surface roughness values, that we present in Table 1.

Once our model was calibrated, we generated different land-use land-cover models: (1) a classical model based on current land-use land-cover ; (2) a green model, taking into account a watershed that is very slightly anthropized and mostly composed of natural adaptations; and (3) a grey model containing a highly anthropized and artificial land-use land-cover with very few blue carbon ecosystems. Finally, on these different land-use land-cover models, we conducted several runs with our hydrodynamic model. From the results obtained, we examined the water heights of four (fig.2) strategically located points (1: Industrial Area; 2: Salt marsh; 3: Polder; 4: Camping) observed during the 24 hours of simulations.

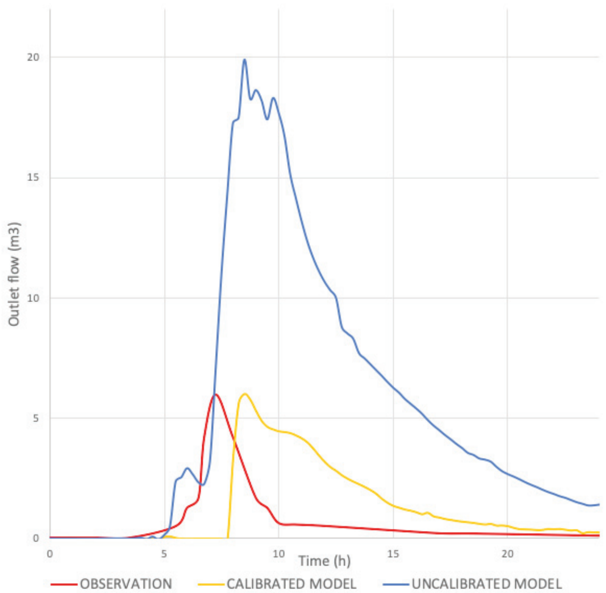

Figure 2. Comparison between calibrated and uncalibrated models in relation to observations on Floubalay

Table 1. Land-use land-cover roughness values after calibration

Land-use	Wooded areas	Urban areas	Crops	Grasslands	Heathland	Reedbed	Beaches	Seagrass beds
Roughness	0.2	0.013	0.035	0.045	0.07	0.18	0.025	0.12

Results and discussion

Figure 3 presents a comparison of green and grey simulations, to assess the effects of natural adaptations, when considering the current sea-level and the sea-level rise by 2100. Two different trends have emerged. The first can be seen in points 1, 3 and 4. The difference between the grey and the green simulation in terms of water level is hardly visible. The green simulation shows a tendency to flatten floods through slightly lower peak floods and slower receding water levels. There is one main reason for this small difference between the two simulations, which are different in terms of land-use land-cover. These 3 points are located in direct proximity to the coastline and at a very low altitude.

The land-use land-cover, even if it differs significantly, has little impact on runoffs. These points are also slightly influenced by the runoffs of terrestrial origin given the important flood peak after 8 hours of simulation, which is perfectly correlated with the tidal peak. This trend can also be observed in the simulation in 2020 on points 1 and 3. About the point 4, there is a noticeable difference in 2020. Indeed, the green simulation shows much lower flood peaks compared to the grey simulation. The difference between the flood peak of the grey simulation and the green simulation is about 1 m, i.e. about 1/3 less between the two simulations in terms of water height.

This difference might be attributable to the fact that the rise in sea level results in much greater marine submersion, limiting the effects of natural adaptations on runoff attenuation. The second tendency observable on these results is visible on the graph of point 3. A real difference in water level between the peak flood of the green simulation and the grey one is visible here. This difference may be attributed mainly to the fact that this point is more distant from the shoreline and slightly higher in the low-lying coastal zone. This point is also located close to a coastal river, so overland flows can highly influence it. However, natural adaptations have a more beneficial influence on the attenuation of land flows than marine submersions.

These two distinct trends provide valuable insights into the capacity of natural adaptations and blue carbon ecosystems to mitigate floods. In the areas situated furthest from the coastline, in the low-lying area, the contribution of natural adaptations is very interesting, as it significantly mitigates the flood peaks. However, even in a fully resilient watershed without human influence, the areas closest to the coastline will still be heavily impacted by the sea. It is therefore essential to avoid all anthropogenic settlements in these areas, which are highly exposed to numerous hazards.

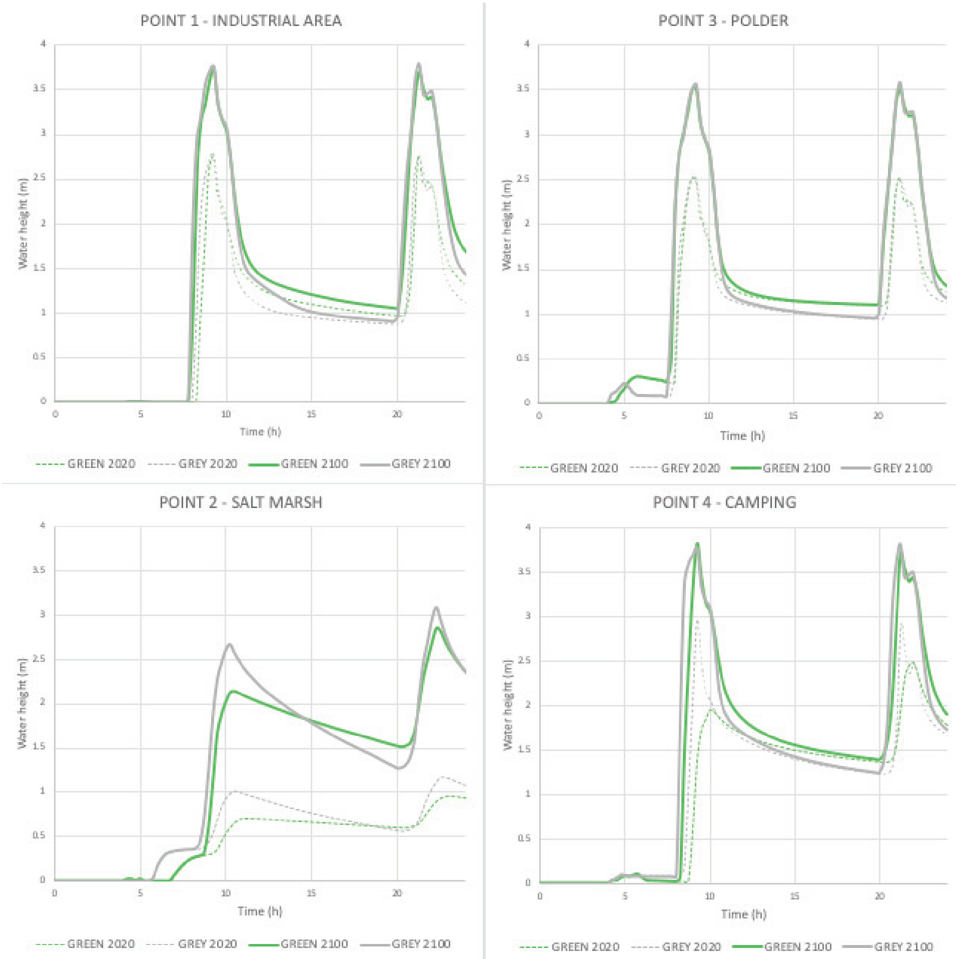

Figure 3. Water heights measured at 4 different locations according to 2 different simulations by 2100 compared to 2 different simulations by 2020.

Conclusions

The TUFLOW hydrodynamic model allows the simultaneous simulation of climatic and maritime coastal hazards which usually occur independently. This model, therefore, makes it possible to analyse the combined impact of events occurring in environments already highly exposed. We have been able to highlight the benefits of natural adaptations in the protection of coastlines against flooding. These blue carbon ecosystems can help to smooth and mitigate floods and thus reduce the impact on coastal populations. These natural adaptations play a non-negligible role by reducing water levels at specific points by more than 1/3 for the same events. However, their effect is much more limited in areas directly exposed to the phenomenon of marine submersion. Nevertheless, such ecosystems enhance the resilience of coastal areas and mitigate the impact of extreme events. It is therefore essential to promote actions to protect and restore these blue carbon ecosystems, which provide numerous ecosystem services, including coastal protection.

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