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BRIEF NOTE

Effects of the winter storms of 2017 on the Atlantic coast of Rabat: A preliminary evaluation

Effets des tempêtes hivernales de 2017 sur la côte Atlantique de Rabat : Evaluation préliminaire

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Abstract. This paper considers the preliminary results of storms effects on the Rabat coast that occurred on 28 February and 1st March, 2017 in Morocco, in order to identify and manage risk coastal areas in the future. Indeed, the beaches were strongly eroded, the rock fills were destabilized and the constructions have been flooded and devastated.

Keywords: Storm, Erosion, Coast, Rabat.

Résumé. Cet article présente les résultats préliminaires des effets de tempêtes sur la côte de Rabat au Maroc, surgies entre le 28 février et le 1er mars 2017, pour but d'identification et de gestion des zones côtières à risque dans le futur. En effet, les plages ont été fortement érodées, les enrochements ont été déstabilisés et les constructions ont été submergées et détruites.

Mots-clés: Tempête, Erosion, Côte, Rabat.

INTRODUCTION

The geographical situation of the Moroccan coastal cities makes them vulnerable to natural hazards and extreme events such as storms, tsunamis, floods and erosion ... In general, statistical data on the storms that affected the Moroccan coast during the last century are rare, although some references were quoted by Simonet & Tanguy (1962), Cherfaoui & Doghmi (2002), Minoubi *et al.* (2013) and El Messaoudi *et al.* (2016) about storm events that were generated during the winter, and caused damage to infrastructures, property and personal injury.

The storms of 28 February and 1st March, 2017 generated waves with 6 to 7 m of significative height that reached the Moroccan coast between Kenitra and Tarfaya (National Meteorological Department, unpublished data). The objective of this short report is to describe some effects of this storm on buildings and coastal infrastructure along the coast of Rabat (34°N; 6°W).

STUDY AREA

The coast of Rabat is located in the north-west of Morocco, is oriented NE-SW and is mostly composed of lithified sand dunes parallel to the coastline, separated by longitudinal cliffs and depressions (locally called Oulja), transversally cut by the Bouregreg estuary that separates Rabat from Salé city.

Morphologically, the barrier beach of Rabat is characterized by lithified high dunes (probably ancient spits) eroded frontally by sea cliff. The southern part of the coast is made in general by small sandy beaches (Casino, Sables d'Or, Skhirat…) separated by rocky cliffs and limestone pavement platforms (South of Temara, Miramar, Guéville). (Gigout 1957, Akil 1980, Saaidi 1988, Chabli *et al.* 2003, Akil *et al.* 2008, Chahid, 2017).

MARINE WEATHER

According to the Moroccan National Meteorological Department, the storms that affected the Moroccan coast between Kenitra and Tarfaya on 28 February and 1st March 2017, and engendered swells, winds and windwaves from the north-west was due to a depression located in the North Atlantic Ocean combined with strong winds (100 km/h) and elevated tide amplitude (Fig. 1). The maximum significant height recorded in SIMAR point 1052036 by Puertos del Estado (http://www.puertos.es/en-us/oceanografia/Pages/portus.aspx) was about 3.68 m

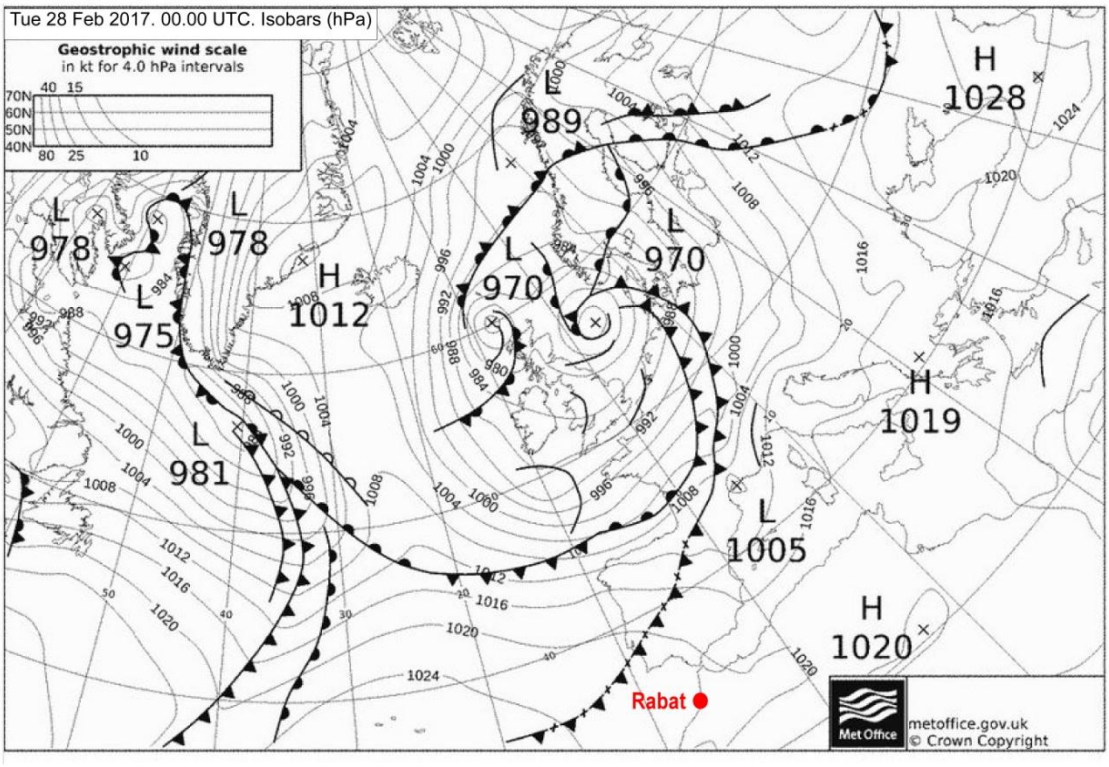

Figure 1. weather chart of 28 February 2017 at 00.00 UTC. Isobars in hPa. Altitude information is referenced to mean sea level. http://www.wetterzentrale.de/reanalysis.php?map=1&model=bra&var=45&jaar=2017&maand=2&dag=28&uur=0000&h=1&nmaps=24

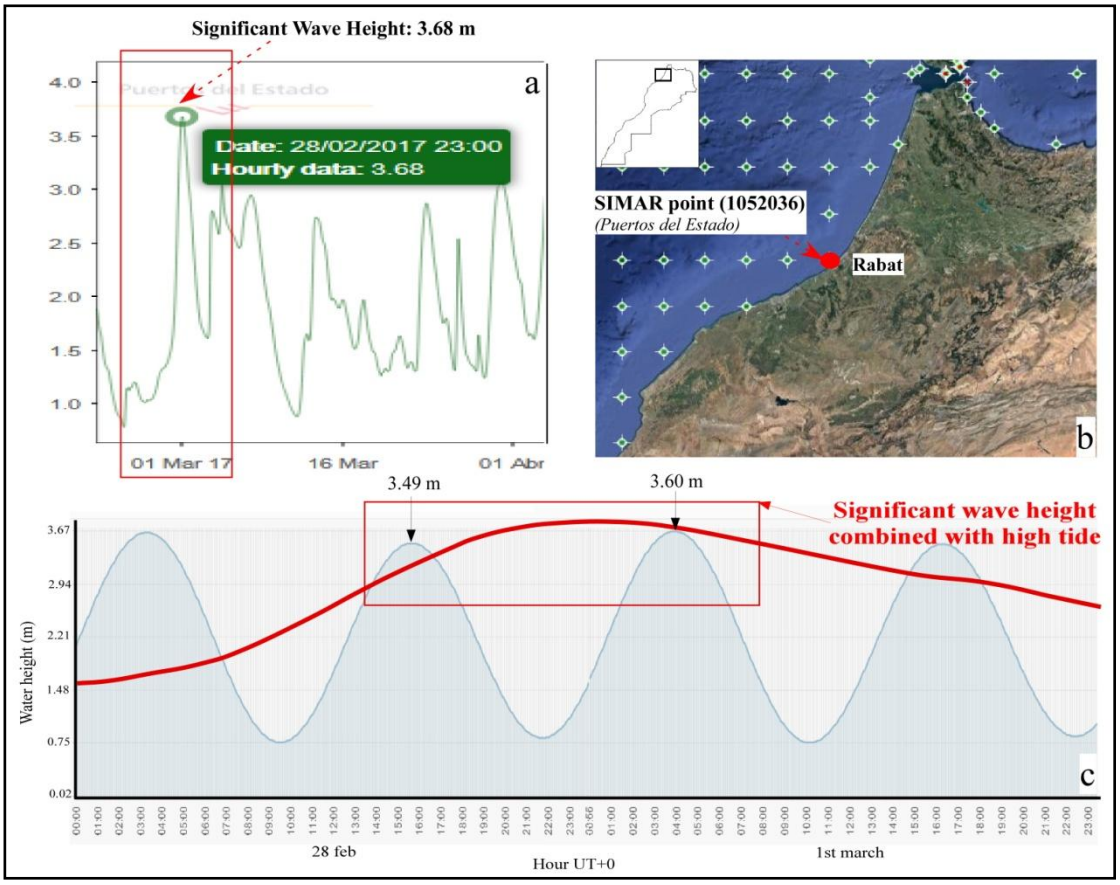

Figure 2. Significant height (a) recorded in SIMAR point 1052036 by Puertos del Estado (b) superimposed with high tide (c). http://www.puertos.es/en-us/oceanografia/Pages/portus.aspx; http://maree.shom.fr/harbor/RABAT/hlt/0?date=2017-02-28&utc=0

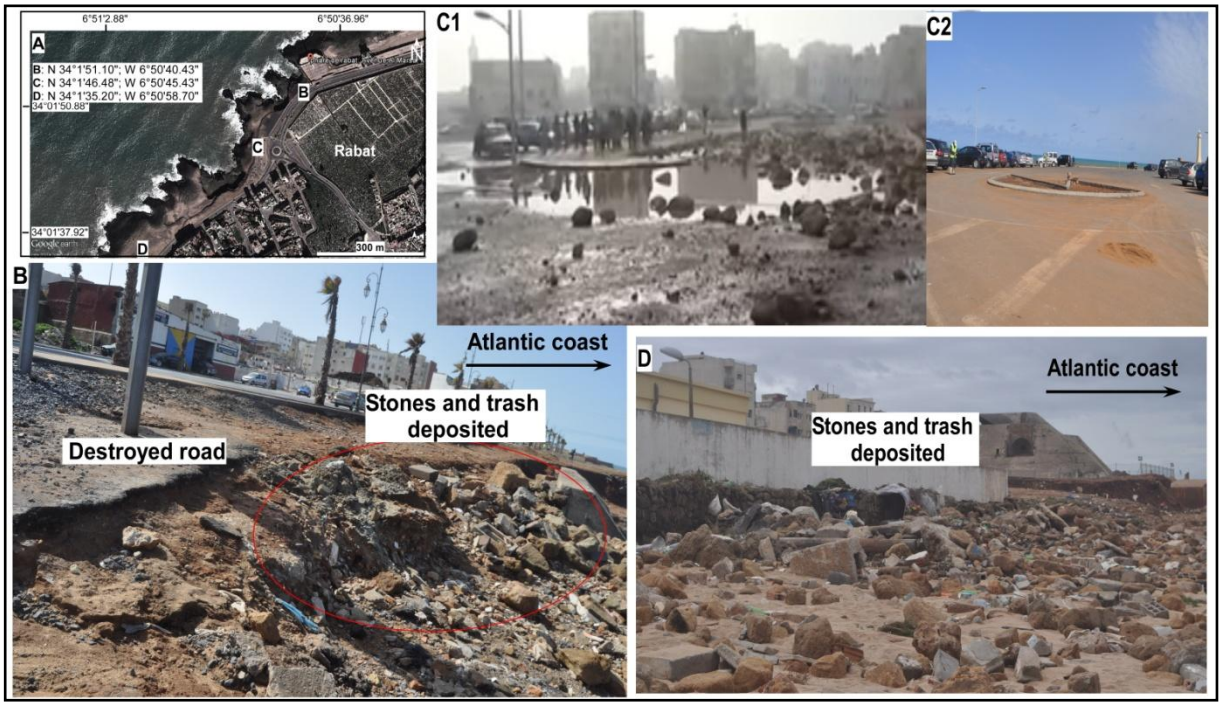

Figure 3. Damage caused by the storm surge on the Coast of Rabat. A: Location of the observation sites; B: Destroyed road, stones and trash deposited in the road; C1: Stones dragged away in parking; C2: Parking cleaned after the storm surge; D: Stones and trash deposited.

Figure 4. Damage caused by the storm surge on Temara. A: Location of the observation sites; B: Destroyed and displaced wall, displaced boulder (1.4 x 0.8 x 0.5 m); C: inundation marked by sand deposited (~150m); D: Sidewalk and wall destroyed.

while the high tide was about 3.49 m on 28 February at 15h37 and 3.60 m on 1st March at 3h54 (http://maree.shom.fr/harbor/RABAT/hlt/0?date=2017-02-28&utc=0) (Fig. 2).

EFFECTS OF THE STORMS OF 2017

The observed effects of both storms are mainly illustrated in figures 3 and 4.

Effects on the rocky cliff of Rabat

On the coast of Rabat, the waves reached buildings at a distance of 170 m from the shoreline. (Fig. 3-C) (N 34°1'46.48"; W 6°50'45.43"). Inundation damaged parts of the rocky cliff, the road and some coastal infrastructures, displaced boulders, washed away and deposited sand and trash on the 12 m high road (Fig. 3-C,D). By 7 March, although sand and stones had been cleared from the road and parking (Fig. 3-C2) by the Municipality, damage was still visible (Fig. 3-B).

Effects on the sandy coast of Harhoura-Temara

Damage caused to the sandy coast of Harhoura and Skhirat was spectacular as coastal structures were severely affected since they were close to the beach and marine hydrodynamic energy was strongest. Flooding was observed along the coastal road and especially in the areas where the coastline was closest to infrastructures. The inundation reach was about 150 m (Fig. 4-C). The wave currents were strong enough to destroy the 6 m high sidewalk (N 33°55'49.59"; W 6°57'26.40"), break and then displace stairs (N 33°55'45.41"; W 6°57'31.5") and wash away sand and boulders carved from the cliff (N 33°55'48.15"; W 6°57'23.99"). The largest boulder found at 30 m from coastline, attained a volume of ~0.6 m^3 (1.4 × 0.8 × 0.5 m) and 1.2 tons assuming a volumetric weight of 2000 kg/m^3 (Fig. 4). In addition, 6 persons were caught by the huge waves in Val d'Or beach; some were able to escape while a woman died in the hospital.

DISCUSSION AND CONCLUSION

The effects of the winter storm of 2017 on the Atlantic coast of Rabat were briefly described in this note based on field observations, and showed that waves completely flooded the inland and caused several damages on coastal buildings and infrastructures.

This extreme phenomenon was referred to using various terminologies; it could be a storm surge since it was induced by a summation of the effects of the depression off the North Atlantic Ocean, the strong winds and the high tide (Galli & Hontarrède 2001). It can also be due to superimposed waves as the study area is far from the depression center. Based on scientific literature, the flooding may also correspond to a "meteotsunami" or "meteorological tsunami" because it was characterized by long period waves causing comparable behaviour to the tsunami (Defant 1961; Rabinovich & Monserrat 1996 and 1998, Bryant 2014, González *et al.* 2001). The meteo-tsunami phenomenon has much in common with storm surges (Levin & Nosov 2009), and the only formal difference between a storm surge and a meteo-tsunami consists in the difference between their maximum periods. The maximum period for a meteotsunami does not exceed several hours, while storm surges may last several days (O'Brien *et al.* 2013).

The same phenomenon occurred three years ago in January 2014, during a North Atlantic low pressure system called "*Hercules* that affected the Atlantic coast in Portugal, England, Spain, Morocco… and caused several damages (Mallet *et al.* 2014, Ministère de l'équipement du transport et de la logistique 2014). Therefore, it is important to understand the physical processes of erosion, flood and coastal development to sustainably manage the coastal zone.

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