Morphodynamic responses of sandy and gravel beaches to hydrodynamic conditions

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Introduction

Nearly 50% of the world's population currently lives in coastal areas (Cohen et al., 1997), which represents a population density three times higher than the global average (Small and Nicholls, 2003), which projections predict will significantly increase in the 21st century (Nicholls et al., 2008; Neumann et al., 2015; Merkens et al., 2016). Populations, activities and ecosystems are thus exposed to the many natural risks associated with these types of environments, including storms, marine submersions, tsunamis and coastal erosion. An increase in frequency and intensity of these risks is also expected in the ongoing context of climate change (Shongwe et al., 2008, Gastineau and Soden, 2009, Cai et al., 2014, Cai et al., 2015). For these reasons, it is **crucial** to have a detailed **understanding of coastal systems' functioning mechanisms** and the **ability to predict their evolution** in order to adapt our societies to the consequences of climate change and to protect humans and environmental interests on the coasts.

Among the different types of coasts (rocky, sandy, with cliffs, etc.), **beaches** are loose and deformable sedimentary deposits composed of mobile materials (mud, sand, gravel) that may or may not be cohesive, and whose **morphology significantly influences the impact of extreme events on the coast**. Previous studies have made it possible to develop **models** for predicting the **response of sandy beaches** under different hydrodynamic conditions in **microtidal contexts**, notably through the development of **memory effect** and **recovery time** concepts.

With its **macrotidal** environment and **pebble beaches**, the evolution of the **Normandy coastline** is challenging to predict because this type of beach has barely been studied thus far. This poster is presenting the thesis conducted by Antoine Soloy at M2C laboratory (Continental and Coastal Morphodynamics) of the University of Rouen Normandy, under the direction of Imen Turki and Nicolas Lecoq. Its objective is to better understand the processes involved in the hydromorphological dynamics of the Normandy coast in order to develop new tools and concepts adapted to the modeling of such environments.

1 – Beach : Definition, processes and classification

According to Short (1999), a beach is a **wave-accumulated** sediment deposit that extends from the base of the modal wave height zone - the maximum depth over which waves can move sediment - to the upper limit of the swash zone - beyond which the waves have no influence on the sediment (Fig. 1). Between these two limits, we find a subaerial zone with the presence of one or more berms, followed by a shallow depth surf zone, where waves break, and finally an area of shoaling further offshore, where the slope increases.

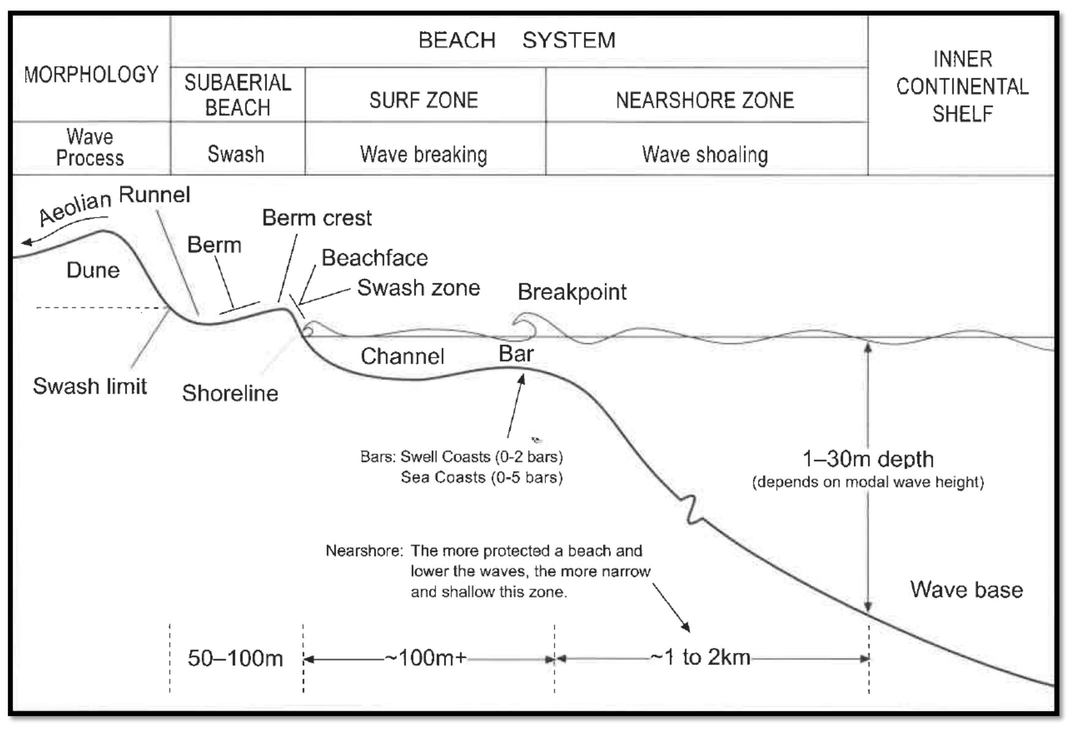

Fig. 1 – Definition sketch of a high-energy beach system, including the zone of wave shoaling across the nearshore zone, wave breaking across the surf zone and final wave dissipation in the swash zone. Low-energy beaches are smaller in scale and have a small to non-existent surf zone. (Short, 1999)

On a global scale, beaches can be found on any coast that is exposed to waves and whose sediment is sufficiently abundant and mobile. While no other parameters are essential for their presence, beach morphology is **significantly influenced** by different environmental conditions, including **tidal range**, **wind**, **sediment quality** (size, shape, composition), **area size** and **shape**, presence of **vegetation** and **water temperature** and **chemistry** (Short, 1999).

Thus, a beach's morphology is the result of the **interaction** between **numerous physical factors** whose relative influences **continuously change over time**, varying the **cross-shore** and **long-shore transports** that cause morphological changes. Wright and Short (1984) classified beaches according to their morphology, showing that it depends on each beach's ability to **dissipate** or **reflect** wave energy (Fig. 2). This classification has since been expanded to take into account the influence of the tidal range, and is generally adapted to the regions studied (Scott et al., 2011).

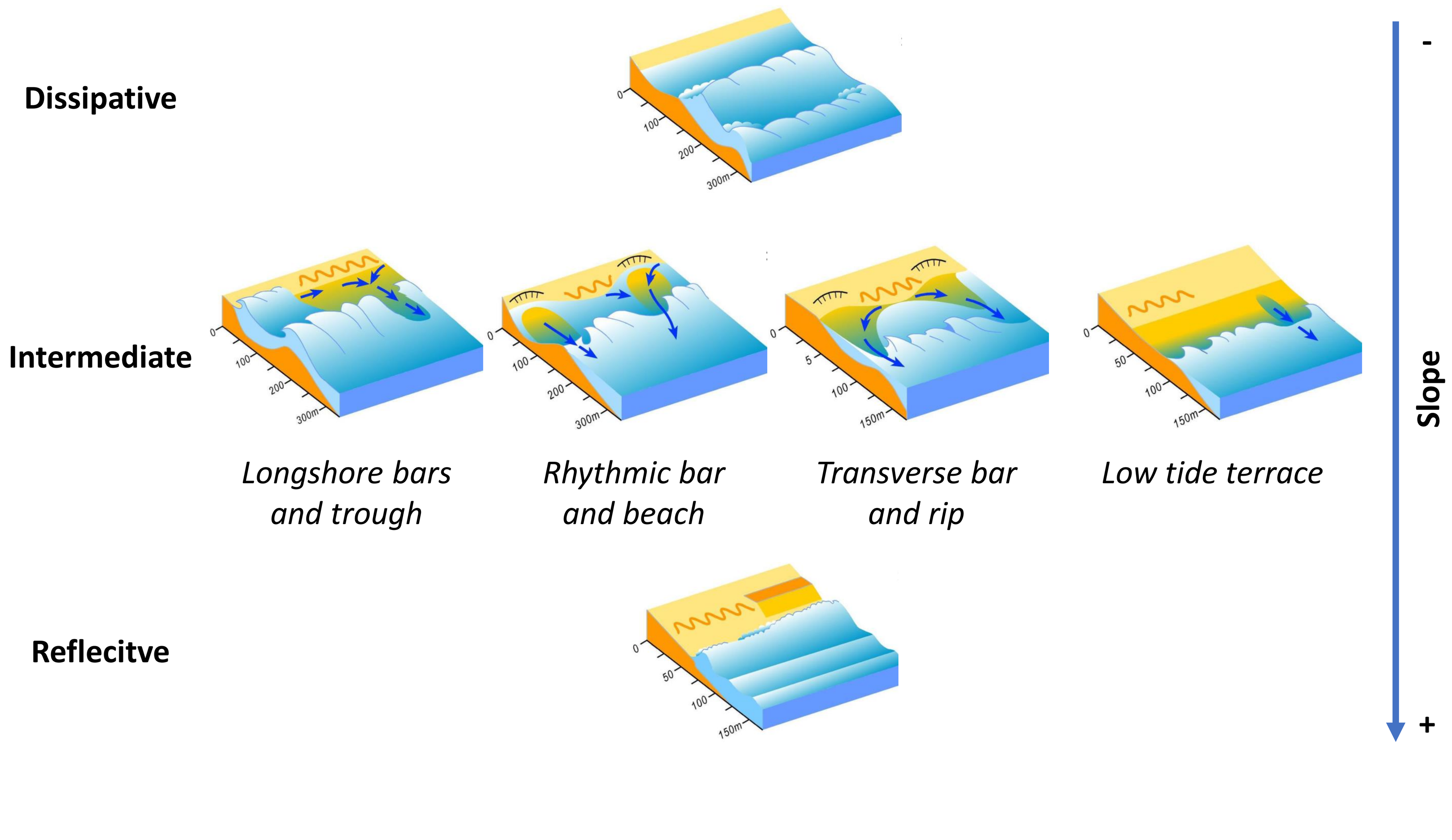

Fig. 2 – Beach classification of Wright and Short (1984), modified from NIWA (National Institute of Water and Atmospheric Research) of New Zealand.

2 – Concepts for modeling beach dynamics : Recovery time – beach memory effect

Modeling is a key step in the coastal management process, as it makes it possible to predict the consequences of voluntary or involuntary changes in the conditions of an environment like a beach. To this end, numerous studies have been carried out to develop different concepts related to the evolution of beaches, two examples of which are displayed in the following.

The **recovery time** corresponds to the time required by a beach to a state of equilibrium after the occurrence of a natural or anthropogenic disturbance (storm, nourishment...). For example, it was implemented by Turki et al (2015) to model the rotation and translation of the coastline in Barcelona, Spain, highlighting its evolution over time. They observed that at each event, the parameter studied significantly deviates from its equilibrium state and then gradually tends to return to it (fig. 3).

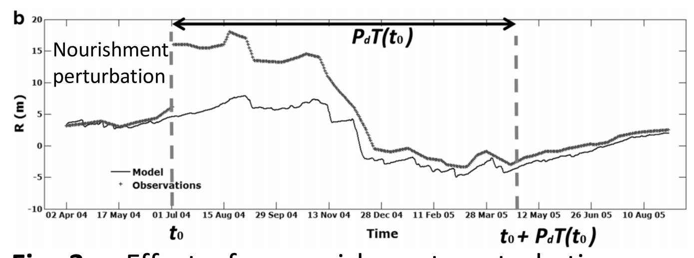

Fig. 3 – Effect of a nourishment perturbation on a beach rotation time serie (Turki et al., 2015)

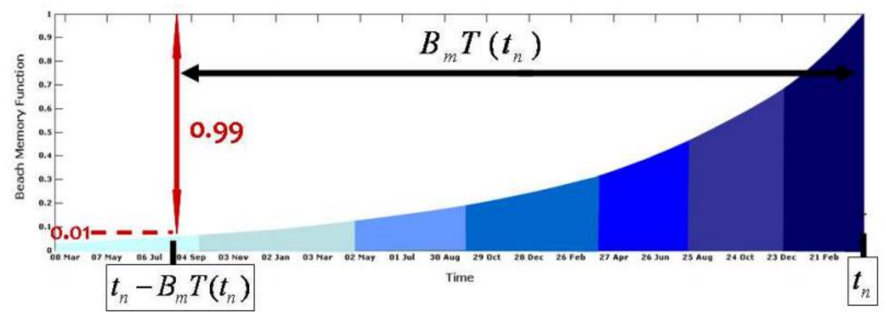

Fig. 4 – Beach memory function exponentially increasing while getting closer to the present time (Turki et al., 2012)

The concept of **memory effect** developed by Turki et al (2012) highlights the impact of disturbances on the beach morphology at a given time. The authors thus show that the instantaneous beach profile depends on the integral of events energy that preceded it, weighted by an exponential factor (fig. 4 ; eq. 1).

$$B_mF(t_n,k) = e^{-\int_{t_n-k}^{t_n} P(t).dt} \quad \text{(eq. 1)}$$

3 – Applications to the Normandy coasts

Famous for its chalk cliffs, the **Normandy coast** is dotted with **pebble and sandy beaches** that are subject to the **semi-diurnal macrotidal tides** of the English Channel. As such conditions have been studied very little in terms of the morphological evolution of the coastline under the influence of storms, it is essential to focus on it in order to better understand the mechanisms that take place and to develop effective prediction capabilities, particularly in the context of climate change.

To this end, with the participation of local authorities, **Pourville sur Mer** Beach, an **intermediate pebble** beach located near Dieppe, has been equipped with a system of video cameras capable of continuously recording the beach conditions (fig. 5). The geometry of the images captured is corrected to enable the extracting of morphological (foreshore topography) and hydrodynamic (height, period, wave velocity) information. Eventually, the data will be used as parameters in a model for predicting the morphological evolution of beaches, using concepts such as the **relaxation time** and **beach memory**, especially during **storm events**, which are expected to increase in intensity and frequency as consequences of **climate change**.

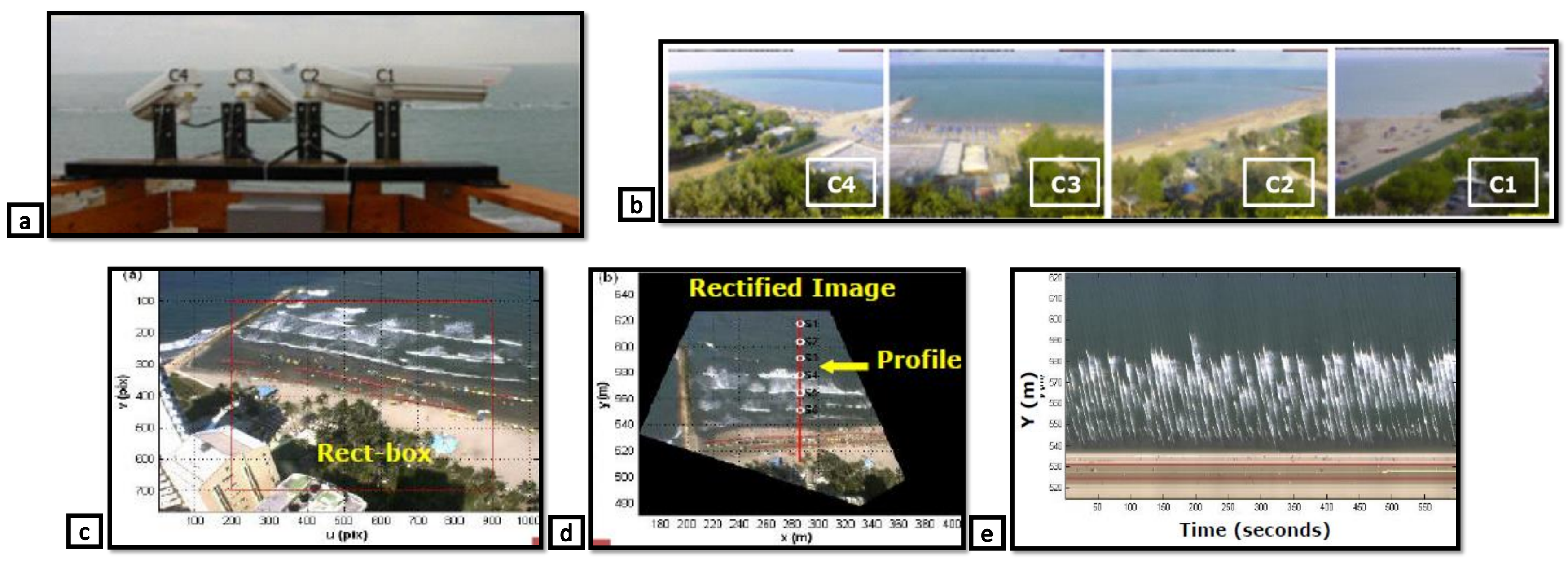

Fig. 5 – a: Example of a video monitoring installation in Spain. b: Panoramique view as captured by cameras. c: Region of Interest (red box). d: geometry correction and profile definition (red line). e: time stack of pixel colors along the defined profile.

In the future, several other camera installations will be set up, notably in **Villers sur Mer**, where the beach is **dissipative and sandy with macrotidal tides**.

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