# High Resolution Beach Morphodynamics

A comparison between perched and open beaches

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Antonis Chatzipavlis

PhD Dissertation

εκδοσεις Μιχαλη Σιδερη

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# Chapter 1: Introduction

Beaches are critical coastal environments. They form a substantial fraction of the global coastline (Luijendijk et al., 2018), are important habitats in their own right (Defeo and McLachlan, 2013), have a high hedonic value, and protect their backshore ecosystems, assets, and infrastructure from coastal flooding (Neumann et al., 2015). Tourism, an important economic activity, has been increasingly associated with vacationing wholly, or partially, at coastal locations and beach recreational activities according to the Sun-Sea-Sand (3S) model (UNWTO, 2019). Therefore, beach aesthetics and adequate carrying capacity and infrastructure are crucial for the tourism sector and the economy as a whole (Tzoraki et al., 2018).

At the same time, beaches are very dynamic environments, controlled by complex forcing-response processes that operate at various spatio-temporal scales (Short and Jackson, 2013). They face increasing erosion (Mentaschi et al., 2018; Guisado-Pintado and Jackson, 2019). Beach erosion can be differentiated into: (a) irreversible shoreline retreat due to mean sea level rise and/or negative coastal sedimentary budgets that force beach landward migration and/or drowning (Nicholls and Cazenave, 2010) and (b) short-term erosion caused by storm surges and waves, which may or may not result in permanent shoreline retreats but can, nevertheless, be devastating (Ranasinghe, 2016).

Erosion is particularly alarming for island beaches due to (Monioudi et al., 2017; Andreadis et al., 2021): (i) their (generally) limited dimensions and diminishing sediment supply; (ii) the deterioration of the nearshore ecosystems that provide protection from marine erosion; and (iii) their increasing backshore development, which has increased asset and infrastructure exposure. The projected relative mean sea level rise, combined with potential increases in the intensity/frequency of energetic events (e.g., Vousdoukas et al., 2018), will exacerbate beach erosion with severe impacts on coastal ecosystems, infrastructure/assets and the beach hedonic value and carrying capacity for recreation/tourism (Monioudi et al., 2016; Toimil et al., 2018).

It appears that the improved understanding and prognosis of beach morphodynamics under different hydrodynamic forcings are of high environmental and socio-economic significance (UNFCCC, 2020). The most obvious indicator of beach morphological changes is the shoreline re-alignment. This is controlled by the nearshore hydro- and sediment dynamics and manifested by the swash zone dynamics (e.g., Komar, 1998; Stockdon et al., 2006). Monitoring of the shoreline and wave-run-up positions is essential, i.e. the monitoring of the mean interface between sea and land and of the highest reach of the wave swash, respectively (Vousdoukas et al., 2009b). Assessing the wave run-up heights and/or excursions, in particular, are vital for the effective design of coastal protection works (e.g., Briganti et al., 2005), beach nourishment projects (Dean, 2002), and the planning of efficient coastal management schemes (e.g., Kroon et al., 2007). Moreover, wave run-up excursions under storm conditions have very important legal implications. The highest wave run-up excursion (in a set time frame) is associated with the legal definition/demarcation of the shoreline in international law (e.g., the 2008 Integrated Coastal Zone Management Protocol to the Barcelona Convention) and many national legal systems (e.g., in Spain, France, Italy and Greece), which can have significant and, potentially, contentious implications for both coastal public and private rights and responsibilities (Velegrakis et al., 2021).

In addition to coastal hydrodynamics, beach morphodynamics is subject to various geological controls, including the coastal geo-morphology and the nature, volume, and budget of the beach sediments (Komar, 1998). A defining geological control of the beach morphodynamics is associated with the presence of nearshore structures that significantly alter the beach response to hydrodynamic forcing; thus, beaches can be differentiated into a) open sea beaches and b) "perched" beaches.

Open sea beaches are exposed to the nearshore wave energy from many sectors and show the highest morphodynamics. In comparison, "perched" beaches, which proliferate in many parts of the global coastline, are those beaches that "… are underlain and/or fronted seaward by shallow buried and/or outcropping natural or engineered hard

structures" (Gallop et al., 2012). Natural perched beaches can form on corals, beachrocks or outcropping rock formations (Gallop et al., 2011). Nearshore natural reefs, such as submerged beachrocks and fringing coral reefs, can modify nearshore hydrodynamics by dissipating the incoming wave energy and generating complex nearshore flows (e.g., Peduzzi et al., 2013; Velegrakis et al., 2016). In the case that the reef is backed by a deeper body of water (e.g., a lagoon and/ or a longshore channel), it has been shown that the architecture of the reef/lagoon system can play a major role in the momentum balances across the system and, consequently, to the magnitude of the wave-driven flows and related coastal flushing rates (Gallop et al., 2013). Concerning their morphodynamics, studies have indicated that perched beaches can show significant intra-annual and inter-annual variability (Gallop et al., 2013; 2015). Post-event recovery is also influenced by the presence of nearshore reefs; perched beaches have been observed to recover relatively slowly, with adjacent sections of the shoreline been observed to show contrasting patterns of erosion and accretion (Gallop et al., 2013).

It appears that there is an increased need for monitoring the beach morphological variability in different spatio-temporal scales, to resolve their morphodynamics and assess their erosion risk. As the shoreline and wave run-up positions are features that integrate large part of the information pertaining to beach morphodynamics, information on shoreline retreat (beach loss) and shoreline advance (beach gain) is required with a spatio-temporal resolution that matches that of the shoreline change (Boak and Turner 2005); such information is necessary understand the short- and long-term morphodynamics which, in some cases, can show contrasting trends (e.g. Hapke et al., 2006). As stated above, beach morphodynamics is controlled by complex swash zone interractions, operating at various spatio-temporal scales. Traditionally, projections of beach morphodynamics under different hydrodynamic forcing are provided by morphodynamic modeling techniques which are based on mathematical expressions/algorithms used to parameterize the wave-current interactions and sediment dynamics (e.g. Ranasinghe, 2016) and, thus, are constrained by: a) the high non-linearities involved in shoreline re-alignment due to com-

plex nearshore hydrodynamic, sedimentological and morphological processes that have not yet been completely understood; b) the volume of the required field (topo-bathymetric, granulometric and hydrodynamic) observations; and c) high computational costs. Over recent years modern approaches that utilize Artificial Neural Networks (ANNs) have been proposed as an alternative way of predicting the shoreline position (e.g., Tsekouras et al., 2018; Riazi and Slovinsky 2021); these ANNs require for their training and testing long time series of high frequency, accurate beach geo-spatial information, which can be provided only by beach monitoring optical systems (Vousdoukas et al., 2011; Rigos et al., 2016).

The thesis aims to investigate the beach morphodynamics of both "perched" and open island beaches in high spatio-temporal resolution. Two island beaches were selected for this study: an urban beach fronted by a (submerged) beachrock reef (Ammoudara, N. Crete) and a (touristic) open sea beach (Kamari, Thera). At both beaches, different field observations were collected, including: topo-bathymetric, morphological and sedimentological information, time series of meteorological and hydrodynamic observations, and high spatio-temporal resolution information on the shoreline and wave run-up dynamics using specialized beach optical (video) monitoring/processing systems. In addition, different techniques were used for modeling the beach morphodynamics, including the: a) use of "traditional" morphodynamic models and b) development and testing of specialized, innovative ANNs. The structure of the dissertation is as follows. There are 5 chapters, in addition to the present introductory chapter. Chapter 2 presents the background information related to studied environments/processes, whereas Chapter 3 describes (in detail) the methodological approaches used in the study. Chapters 4 and 5 present the results for the two studied beaches (Ammoudara beach and Kamari beach, respectively), whereas Chapter 6 discusses the findings and presents the major study conclusions.