HIGH FREQUENCY SHORELINE AND WAVE RUN-UP DETECTIONS THROUGH OPTICAL VIDEO IMAGERY. EXAMPLE FROM KAMARI BEACH, SANTORINI

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Abstract

Shoreline and wave run-up positions and their changes form fundamental morphological parameters of coastal zone dynamics. In this study, the winter 2-D shoreline and wave run-up/swash maxima positions are detected/monitored in geo-rectified coastal imagery of high spatio-temporal resolution obtained from a Beach Optical Monitoring System (BOMS) installed in a highly touristic beach (Kamari, Santorini). The variability of the shoreline and wave run-up positions is linked with concurrent high-frequency wind and wave records. During the 106-day monitoring period, it was found that shoreline displacement was ranging between 6-19 m and wave run-up position changes were ranging between 21-40 m. Correlation of beach morphodynamics with the wave forcing has shown that energetic wave events can trigger changes in the beach spatio-temporal dynamics. The study results suggest that the BOMS could provide a fast, powerful and efficient beach monitoring tool. It is noted that the shoreline and wave run-up maxima are also important for beach management, as the latter plays the most significant role in the definition of the landward boundary of the Public Maritime Domain (i.e. the “aigialos” line) according to the legislation in many European (and in Greece).

Keywords: beach morphodynamics, shoreline detection, wave run-up, coastal video monitoring, image processing.

1. Introduction

Beaches form one the most dynamic environments in earth. Their morphological changes can be very frequent, being dependent on beach exposure to the hydrodynamic action and the sediment supply. Beaches are also important coastal ecosystems, providing flood protection to other significant coastal ecosystems (e.g., wetlands and lagoons) and the very substantial and increasing infrastructure/assets (e.g., coastal roads, airports, industrial/urban development) they front/support/host. Moreover, they have a high aesthetic/hedonic and socio-economic value, being the focus of the 3S (Sun-Sea-Sand) tourism, a most significant sector of the touristic industry. Therefore, studying of beach morphodynamics is of paramount environmental and socio-economic significance, especially when concerning that most beaches worldwide are under an increasing erosion risk, which is projected to exacerbate in the future (Monioudi *et al.,* 2017).

Shoreline and wave run-up positions are fundamental parameters of the swash zone dynamics and are crucial factors for coastal planners, engineers, and local authorities, as they are typically used for effective coastal planning and the design of coastal protection works (Vousdoukas, 2014). In addition, they form important regulatory boundaries. Shoreline position defines the extent of the dry beach, and thus has impact on the carrying capacity (i.e., the number of beach visitors that can be hosted simultaneously), whereas the maximum position of the wave run-up forms a reference line (defined as the “aigialos line” in Greek) beyond which a ‘setback’ zone of no further development/constructions are allowed according to the national (Greek Law 2971/2001) and European legislation (e.g., the ICZM Protocol to the Barcelona Convention [Art. 8(2) and the EU Directive 2014/52/EU].

Estimation of wave run-up and shoreline positions is a complicated task, as nearshore hydro-morphological changes (or coastal morphodynamics) are based on complex processes-response mechanisms driving the swash zone, operating at various spatio-temporal scales (Suanez *et al.,* 2015). The traditional mapping techniques are not able to cope with the issue satisfactory, as they are not able to provide accurate records of high spatio-temporal coverage. High-resolution satellite images, which are commonly used for the extraction of such morphological parameters in large scale, are not only characterized by high cost, but also from low temporal coverage, while in many cases images cannot be recorded due to physical restrictions (e.g. cloudiness occurring during extreme storminess). On the other hand, repeated topographic records through classic leveling/positioning methods, require dedicated human efforts especially during extreme storm events. Over the recent years, emphasis has been given to the development of image processing algorithms/techniques, capable to record/monitor with high accuracy specific coastal features of interest on specialized optical datasets deriving from coastal video monitoring systems (e.g., Vousdoukas, 2014; Velegrakis *et al.,* 2016).

2. Material and Methods

An autonomous Beach Optical Monitoring System (BOMS) was installed at the southernmost part of Kamari beach at an elevation of 17 m, close to St. Nicholas church, set to monitor a beach stretch of about 680 m long at the southern part of Kamari beach (Fig. 1). The BOMS comprises of a station PC and 2 video cameras set to obtain beach imagery of high resolution (3gp videos, 1920 × 1080 pixels) with a sampling rate of 5 frames per second (fps) in burst mode (for 10 minutes at the beginning of each day-light hour). Images are pre-processed by the station PC. Initially, they are corrected for lens distortion, geo-rectified and projected on real-world (UTM) coordinates using standard photogrammetric methods and Ground Control Points (GCPs), collected with a Differential GPS (Topcon HiPer RTK-DGPS). The geo-rectified and UTM-projected images of each hourly 10-minute burst (3,000 snapshots/frames) are then furthermore processed in order to generate high resolution (always less than 0.25 m) time-stack images expressing the time-average (TIMEX images) and the time-maxima (IMMAX images) foaming positions, amongst other coastal optical products (see also Velegrakis *et al.,* 2016). Separate software tools have been developed/used in order to i) generate a single mosaic that combines the mosaics generated for each of the 2 cameras; and ii) rotate the generated mosaics by setting as reference point (x = 0, y = 0) the position of the optical system (Fig. 1). For the purpose of this study, TIMEX and IMMAX datasets for a highly energetic period (in terms of wave activity) have been extracted, covering 106 days (16/12/2016 - 29/03/2017). However, due to video system downtime, optical data were not available for 14 days (21-24/01/2017 and 06-15/02/2017).

In order to facilitate the shoreline and wave run-up detection monitoring procedure, two automated coastal feature detectors have been developed/used. The detectors are based on a localised kernel that progressively 'walks' along the feature of interest on the georectified TIMEX or IMMAX imagery, automatically following the high intensity zone along the shoreline. The site-specific configuration parameters of the detectors are: i) the preferable, in terms of shoreline/wave run-up following, general direction of kernel movement along the imagery (left to right in this case); and ii) a corresponding user-defined "root" cross-shore transect at the edge of the image which spans across the feature of interest (i.e. the shoreline or/and the wave run-up).

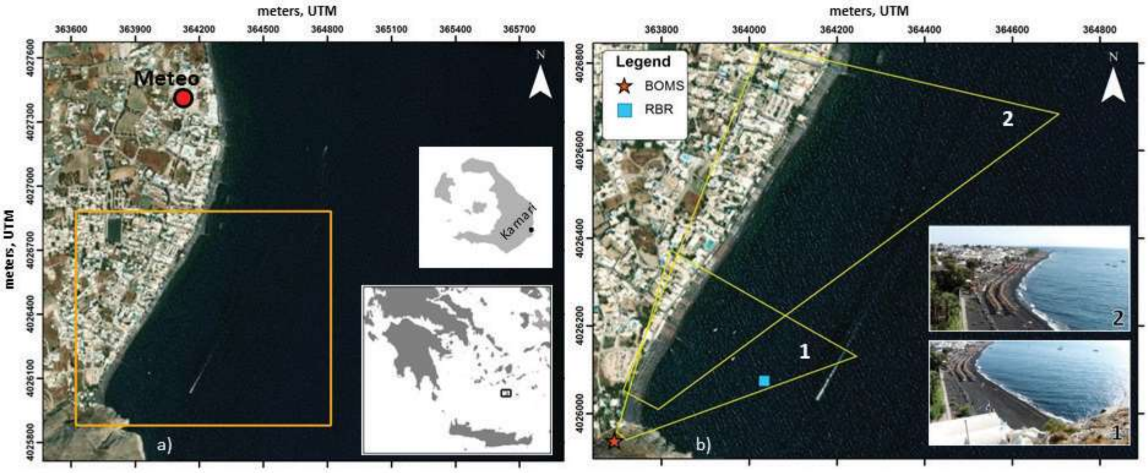

Fig. 1: a) Kamari beach, Santorini; the orange box shows the area studied, whereas the position of the deployed meteorological station is also shown. b) The study area (southern part of the beach), showing the field of vision of the 2 video cameras and 2 corresponding frames; the location of the RBR wave logger is also shown (*satellite image source: Google Earth*).

In addition to the BOMS, a wave logger (RBRvirtuoso D|) was deployed 220 m offshore the beach at 9.2 m water depth (Fig. 1b) and provided high frequency (6 Hz) wave data during 10-minute hourly bursts, concurrent to the optical records, during the period of 17/12/2016 - 29/03/2017. Using these data, hourly values of the wave climate (zero-moment wave height - Hm0 and peak wave period - Tp) were estimated. In addition, a meteorological station was installed at the roof of a hotel (*Alexandra beach*), located close to the deployment area at about 150 m from the BOMS deployment site - Fig. 1a) for a longer period (20/11/2016 - 26/06/2017) providing wind velocity and direction data. Furthermore, wind velocities over 6 Beaufort deriving from the sector where Kamari beach is exposed (between 35°-180° N) were selected and the criterion of Sanchez-Arcilla *et al.,* (2008) according to which: "*the minimum time to consider a storm event as a storm surge is 6 hours and the maximum gap between the observations 18 hours*" was used in order to isolate the storm events that affected the beach.

3. Results

During the 106-day monitoring period, cross-shore shoreline and wave run-up positions showed significant variability. At any shoreline section 0.25 m long, the differences between the minimum and maximum y-point was ranging between 6-19 m (Fig. 2a), whereas wave run-up changes along the shoreline were found to range between 21 - 40 m (Fig. 2b). Areas of increased shoreline variability are associated mainly with areas of the southern (at about x between 50 - 225 m) and central (at about x between 475 - 550 m) parts of the beach (Fig. 2c). By comparison, two sections of the beach showed standard deviations lower than 2 m and seem to be quite stabilized (at about x between 250 - 300 m and 575 - 650 m). The maximum recorded wave run-up variability is concentrated at the central sector of the monitored beach (at about x between 125 - 525 m) with wave run-up variability ranging between 30 - 40 m in most cases, whereas the edge parts of the monitored beach show lower values (Fig. 2d).

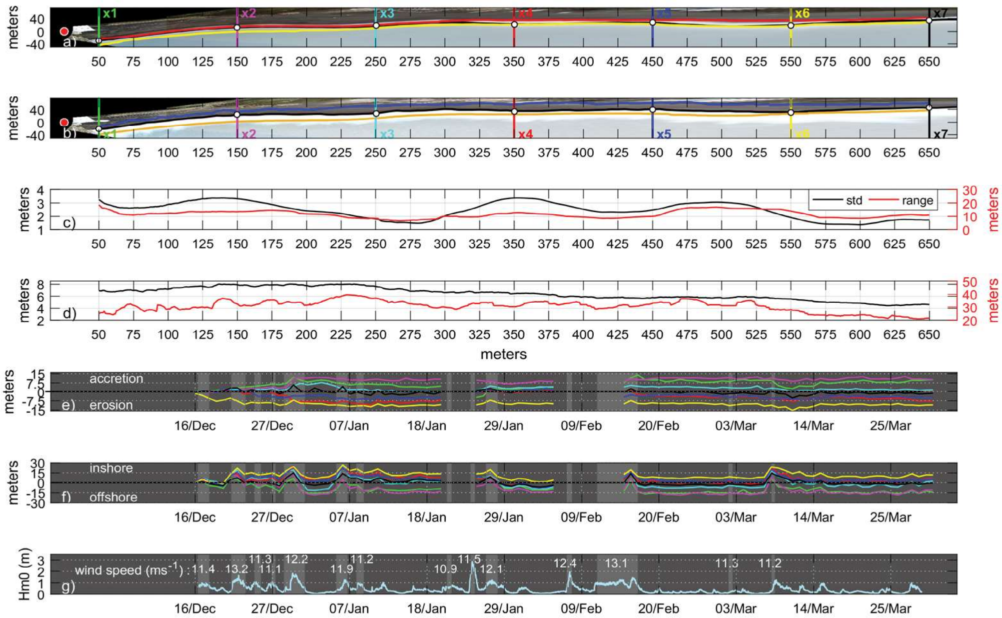

Fig. 2: a)-b) Georectified TIMEX and IMMAX mosaics at the beginning of the monitoring period from the southern part of Kamari beach showing also the locations of the 7 selected/representative profiles, the BOMS (red circle) and the range between the minimum and maximum recorded positions. c)-d) Spatial distributions of the standard deviation (std) of cross-shore shoreline position and range and wave run-up position and range, respectively, detected during the monitoring period. e)-f) Temporal changes in cross-shore beach accretion/erosion and wave run-up, respectively, at the 7 locations shown in panel a; changes are relative to the shoreline and wave run-up position recorded at 16/12/2016 09:00. g) Wave heights recorded from the RBR logger during the monitoring period; light gray stripes indicate the timing, duration and speeds of energetic wind events (winds from the southern sector with speeds > 10.8 ms^{-1} and duration > 6 hours).

Morphodynamics becomes clearer when examining the temporal changes of the 7 selected/representative equally distanced profiles (Fig. 2e and 2f). The cross-shore profiles located at the southern part of the monitored beach sector (x1 and x2) showed accretion behavior (of about 10 m) compared to the starting day of the monitored period. On the contrary, for the same period, cross-shore profiles x4, x5 and x6 showed beach erosion of similar magnitude (10 m), whereas cross-shore profile x7 located at the northernmost part of the monitored beach area didn't show significant changes. Beach response is found to be very energetic to the events detected/recorded during the monitored period (Fig. 2g). Shoreline positions in all of the examined cross-shore sections are found to respond to detected storm events with wave heights greater than 1 m approaching from directions where the beach is exposed (e.g. at the events of 27/01 14/02 and 09/03), whereas wave run-up changes follow a similar trend. It is evident that during events of increased wave energy approaching the beach, wave run-up responds in all cases by excursion to the inshore. In general, higher values of wave run-up are recorded for the central section of the beach, compared to the southern and the northernmost sectors, which may be attributed to milder slopes.

4. Discussion / Conclusions

Beach morphology of the southern part of Kamari beach was found to be highly variable during the monitoring period. Maximum changes in shoreline position are recorded for the southernmost sector of the beach, whereas wave run-up variability for the same sector was found to be close to the lowest recorded value (of about 25 m). In addition, the minimum changes in shoreline position are found at the same location, with the highest recorded wave run-up values (at x about 200 - 250 m). Areas of common high shoreline and wave run-up variability are found at the central part of the examined beach area. The shoreline was more variable (over time) at the southern and central sectors of the beach. Most of the recorded energetic wave events of the monitored period were found to approach the beach from the NE, E and SE sectors (Fig. 2g).

The automated approach developed to extract shoreline and wave run-up positions from TIMEX and IMMAX images showed to be an efficient tool in resolving beach variability in fine spatio-temporal scales. Both positions are of high importance for coastal planners and engineers, as they form fundamental parameters of the swash zone dynamics. At the same time, these morphological parameters form regulatory boundaries. The shoreline position defines the beach carrying capacity (i.e. the number of visitors/ tourists that can be hosted simultaneously in a beach), whereas the swash maxima (i.e. the maximum recorded wave run-up) of a beach forms a reference line (defined as the "aigialos line" in Greek) beyond which a 'set-back' zone of no further development/constructions are allowed according to the national (Greek Law 2971/2001), European (e.g., the Floods Directive 2007/60/EEC and the amended EIA Directive 2014/52/EU) and international legislation [e.g., the ICZM Protocol to the Barcelona Convention (Art. 8(2)]. A significant result of the present work is the development of an objective and cost-effective methodology to define such coastal regulatory boundaries. It has to be noted that detections are focused at (proximal) beach sections for both beaches, due to the increased pixel footprint in these areas; thus, the results are characterized by extremely high accuracy. However, in the case of defining set-back zones (see above), detections of lower accuracy could be also used, and thus, longer beach sections can be monitored.

5. Acknowledgements

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