CEST 2023

18th International Conference on Environmental Science and Technology

Athens, Greece, 30 August to 2 September 2023

Morphological changes recorded from an automated beach optical monitoring system in a highly touristic pocket beach, Coral Bay, Pegeia, Cyprus

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Abstract This paper demonstrates preliminary results of a Beach Optical Monitoring System (BOMS) installed in Coral Bay Beach (Pegeia, Cyprus) in the framework of BEACHTECH project. The BOMS is deployed at the southern sector of Coral Bay, a pocket sandy beach of high touristic and economic importance for the region that also faces considerable erosion problems. Shoreline and wave run-up positions are recorded from specialized georectified coastal images following automatic procedures and with fine spatio-temporal resolution. Wind speed and direction data were logged from a meteorological station deployed at the same area and used to access the wind climate. For the examined period, it became evident that beach response to the wind climate is irregular, driven by the hydrodynamic action with different shoreline erosion/accretion and recovery patterns. The research demonstrates that such types of coastal monitoring systems are able to provide a powerful, automatic and efficient tool for coastal engineering, management and planning.

Keywords: Beach Morphodynamics, Shoreline Detection, Wave Run-up, Coastal Video Monitoring, Image Processing

1. Introduction

Beaches are one of the most dynamic environments on earth, constantly evolving due to the interplay of physical processes such as hydrodynamic action and sediment transport. Changes in beach morphology (morphodynamics) encompass a broad spectrum of temporal and spatial scales, ranging from hours to centuries and from small-scale sediment ripples to large-scale coastal features. At the same time, beaches are crucial coastal ecosystems, providing protection from flood to the natural habitats (lagoons and wetlands) and the coastal communities/infrastructure they front. In addition, beaches are the focus of the 3S (Sun-Sea-Sand) touristic model, a most significant sector of the touristic industry, the 3rd largest economic activity worldwide (WTTC, 2022). Therefore, studying beach morphodynamics is of paramount importance, as it can have profound implications for coastal communities and ecosystems, especially when concerning the fact that most of the world's shorelines are already experiencing erosion (Luijendijk et al., 2018), which is projected to exacerbate in the future (IPCC, 2023), threatening infrastructure /property and natural habitats.

Shoreline and wave run-up (i.e., the swash excursion maxima) positions are two fundamental parameters of beach morphodynamics, while at the same time they 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). Furthermore, they are frequently used to form important regulatory boundaries. Shoreline position defines the limits of the dry beach width, and thus has impact in the carrying capacity (i.e., the number of beach visitors that can be hosted simultaneously). 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 coastal development is 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).

Nevertheless, accurate records/monitoring of shoreline and wave run-up positions is not an easy task, as beach morphodynamics are based on complex interactions between land and sea that operate at various spatio-temporal scales. The traditional mapping techniques are not able to provide records of appropriate spatio-temporal coverage, while satellite imagery which is commonly used to extract such morphological parameters in large scales are characterized by (i) high cost and (ii) low temporal coverage due to meteorological restrictions (e.g., cloudiness) and the satellite route. In recent years, coastal scientists tend to use coastal video monitoring systems that are capable to record and monitor coastal features of interest with fine spatio-temporal resolution (i.e., Vousdoukas 2014; Velegrakis et al. 2016).

2. Methodology

An autonomous Beach Optical Monitoring System (BOMS - http://www.vousdoukas.com/index_video.html) was installed in a highly touristic "pocket" sandy beach of SW orientation located in Cyprus (Coral Bay, Pegeia municipality). The BOMS comprises of a station PC, a meteorological station (deployed at an elevation of 7.5 m) and a Vivotek IP8362 video camera (deployed at an elevation of 6.5 m), set to obtain beach imagery (3gp videos, 1920 × 1080 pixels) with a sampling rate of 5 frames per second in burst mode (for 10 minutes at the beginning of each daylight hour). Images 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 Hipper RTK-DGPS). The geo-rectified and UTM-projected images of each hourly 10-min burst (3,000 snapshots/frames) are furthermore processed in order to generate high resolution time-stack images of the cross-shore shoreline and wave run-up position (TIMEX and IMMAX images, respectively - Figure 1a and 2a) amongst other coastal optical products (for details see Velegrakis et al. 2016). Separate software tools have been developed/used in order to rotate the generated TIMEX and IMMAX imagery by setting as reference point (x = 0, y = 0) the position of the camera (Zone 36 S: 442458.2 m N, 3856962.2 m E). For the purpose of this study, a TIMEX and IMMAX dataset has been extracted, covering a 70-day winter period (13/12/2022 – 20/02/2023).

Two automated coastal feature detectors were used in order to extract the shoreline and wave run-up positions on each hourly TIMEX and IMMAX image, respectively. The detector is based on a very fast algorithm that uses 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 (Chatzipavlis et al., 2019). The site-specific configuration parameters of the detector are: i) the preferable general direction of kernel movement along the imagery (right to left in this case); and ii) a corresponding user-defined "root" cross-shore transect (at the leftmost edge of the image in this case) which spans across the feature of interest. In terms of record accuracy, this tends to decrease with the distance from the camera due to the increasing pixel footprint. Concerning the low elevation of the deployed BOMS at Coral Bay resulting to a narrow field of vision, a proximal beach stretch of about 95 m long was considered for the dectections. In this area, the pixel footprint and the accuracy of detections are estimated at about 0.25 m. The shoreline and wave run-up position recorded on 13/12/2022 at 14:00 (at the beginning of the monitoring period) is set as reference line in order to estimate the shoreline and wave run-up variability during the 70-days monitoring period. In this contribution, information is shown for 5 representative and equally spaced (with a 20 m distance between each other) cross-shore profiles (Figure 1a-c).

3. Results

During the 70-day monitoring period (13/12/2022 – 20/02/2023) cross-shore shoreline and wave run-up positions showed significant variability. At any section of the monitored beach, the differences between the minimum and maximum cross-shore shoreline and wave run-up points were ranging between 4 - 14.5 m and 4.0 – 18 m, respectively (Figure 1b and 2b). Areas of increased shoreline and wave run-up variability are associated mainly with areas of the central and southeast of the monitored beach section (at about x between 0 - 65 m), while the southwest part of the monitored beach showed standard deviations lower than 2.5 m and seems to be quite stabilized (at about x between 65 - 98 m). The morphological evolution becomes clearer when examining the temporal changes of the 5 selected/representative equally distanced profiles. The cross-shore profiles located at the central and southeast parts of the monitored beach (x3, x4 and x5) showed in general accretional behavior (of about 4-7 m, Figure 1c) with the corresponding recorded wave run-up positions being diplaced offshore (of about 4-10 m, Figure 2c), compared to the starting day of the monitored period. On the contrary, cross-shore profiles x1 and x2, located at the southwest part, are found to be slightly eroded (by 2-4 m) with the corresponding recorded wave run-up positions being diplaced inshore (of about 2 m), compared to the beginning of the monitoring period.

Two wind events with intensity greater than 4 Beaufort were detected during early February (Figure 1c - gray stripes), after analysis of the wind data derived from the meteorological station. During these events, shoreline response was significant at the southeastern sector of the monitored beach (displacement of about 6 m at cross-shore positions x5 and x4), while minor changes have been recorded at the southwestern sector (cross-shore positions x1 and x2) (Figure 1c). For the same wind events, wave run-up positions follow a similar pattern (Figure 2c). However, the morphological evolution of the monitored beach was found to be triggered during specific dates (on 27/12, 09/01, 14/01, 20/01 and 09/02), for which there were no significant wind records.

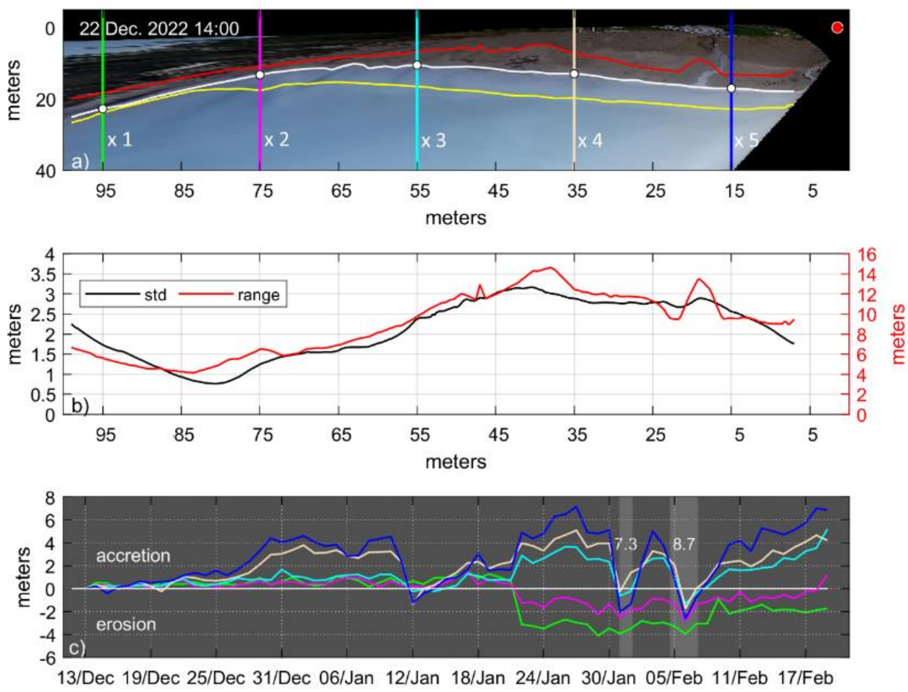

Figure 1. a) Selected georectified TIMEX image from Coral Bay beach showing the locations of the 5 selected profiles, the BOMS (red circle), the shoreline as detected on the selected/shown TIMEX image and the range between the minimum and maximum recorded shoreline position; b) spatial distributions of the standard deviation (std) and range of the cross-shore shoreline position detected during the monitoring period; c) temporal changes in cross-shore beach accretion/erosion at the 5 locations shown in panel a; changes are relative to the shoreline position recorded at 13/12/2022 14:00; light gray stripes indicate the timing, duration and velocity of energetic wind events (winds from the S and SW sectors with speeds > 7.0 ms^{-1} and duration > 6 hours).

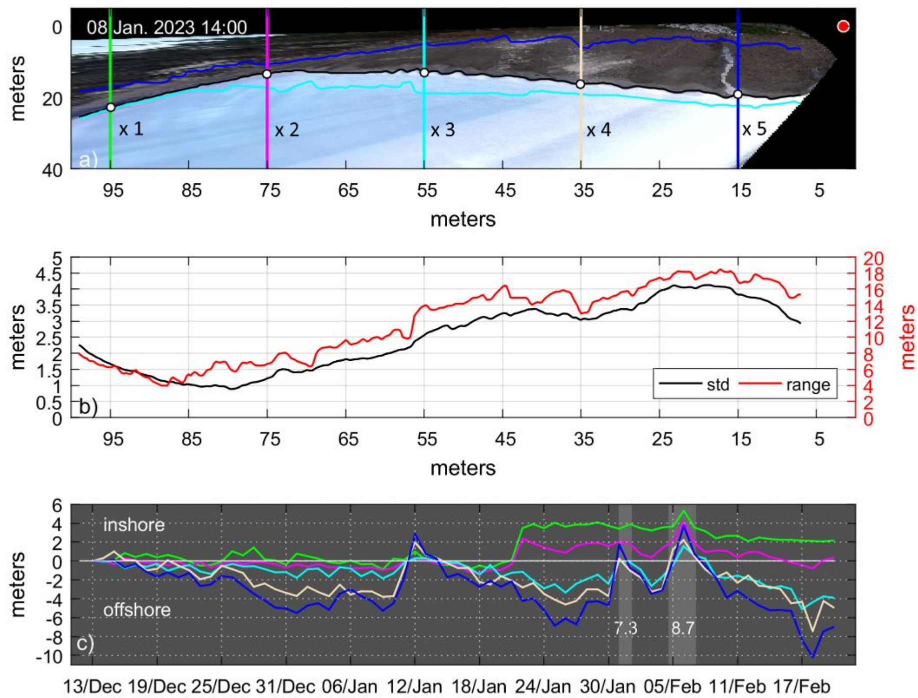

Figure 2. a) Selected georectified IMMAX image from Coral Bay beach showing also the locations of the 5 selected profiles, the BOMS (red circle), the wave run-up as detected on the selected/shown IMMAX image and the range between the minimum and maximum recorded wave run-up position; b) spatial distributions of the standard deviation (std) and range of the cross-shore shoreline position detected during the monitoring period; c) temporal variability in wave run-up position at the 5 locations shown in panel a; changes are relative to the wave run-up position recorded at 13/12/2022 14:00; light gray stripes indicate the timing, duration and velocity of energetic wind events (winds from the S and SW sectors with speeds > 7.0 ms^{-1} and duration > 6 hours)

4. Discussion and Conclusions

Shoreline and wave run-up positions at the monitored area of Coral Bay beach were found to have different behavior at different locations alongshore, during the monitoring period. In general, shoreline and wave run-up variability was detected to be greater at the eastern than the western part of the monitored beach stretch. These differences could be attributed to changes in nearshore slopes which is a crucial factor controling the wave excursion.

Diplacement of the shoreline and the wave run-up positions took place at specific dates, for which no significant wind activity, able to generate sufficient wave action, was recorded from the meteorological station. Such morphological changes could possibly be attributed to the action of swell waves that have been generated elsewhere, considering also the high effective fetch length of Coral Bay beach (nearest opposing coast is located in Egypt, 550 km away).

The developed/tested methodology is considered able to provide an efficient and powerful tool for coastal engineers, planners and the local authorities, since the method was found to provide fast and high-frequency records of shoreline and wave run-up positions. The latter are of extreme importance as they can accurately define (in the long-term) the "aigialos" line, a crucial parameter for coastal planning.

Acknowledgements

This work was supported by the research project BEACHTECH, co-funded by the European Union (ERDF) and national funds of Greece and Cyprus under the Cooperation Program "INTERREG V-A Greece-Cyprus 2014-2020".

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