Monitoring erosion risk in Kamari beach (Santorini)

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Abstract

The objective of the present contribution is to present the results of a study undertaken in the framework of the ERABEACH Project (http://erabeach.aegean.gr/) at Kamari beach (Santorini), one of the most touristic beaches of the Aegean Archipelago. The study combined *state-of-the-art* approaches to monitor beach erosion at different spatio-temporal scales, i.e. (a) analysis and inter-comparison of a 4-year time-series of high resolution summer satellite imagery, (b) collection/analysis of high frequency observations of the shoreline position using a novel optical (video) monitoring system and (c) detailed field topographic/bathymetric, sedimentological and meteorological information collected during repeated ground surveys. Our results suggest that Kamari beach has suffered significant erosion during (at least) the past 4 years. The most vulnerable areas of the beach appear to be its middle and, probably, its northern section. At the same time the beach appears to associated with very significant spatio-temporal variability; differences between the minimum (most inshore) and the maximum (most offshore) shoreline positions varied between 13 and 28 m during the 6-month period of the ground video monitoring. The significant erosion trends observed in the area are likely to be the result of a combination of natural and anthropogenic processes, including potential changes in the nearshore wave characteristics, the construction/presence of a backshore coastal wall/road along the beach that enhances beach erosion during energetic events and diminishing land sediment supply. It appears that technical adaptation measures are urgently required to mitigate erosion, particularly as this is likely to be exacerbated by the projected climatic changes.

Keywords: beach erosion, remote sensing monitoring, Thira, touristic beaches

1. Introduction

The beaches of the Aegean Archipelago comprise a critical local and national economic resource, as they form the basis of the 3S (Sun-Sand-Sea) tourism which is the dominant tourism model in the area. At the same time, the Aegean island beaches are under an increasing erosion risk (Monioudi *et al.*, 2017), due to both natural and anthropogenic forcing, i.e. the projected mean sea level rise and potential changes in the intensity/frequency of extreme weather events and the increasing beachfront development that has negatively affected natural beach resilience, respectively. In order to assess the beach erosion risk, identify its causes and design effective technical adaptation measures, detailed information is required on the erosion trends; this needs monitoring of the beach evolution using approaches capable to record/describe the high spatio-temporal variability associated with the beach morphology. Therefore, the objective of the present contribution is to c cvxc n present the results of a study undertaken at Kamari beach, Santorini (Figure 1), one of the most touristic beaches of the Aegean Archipelago.

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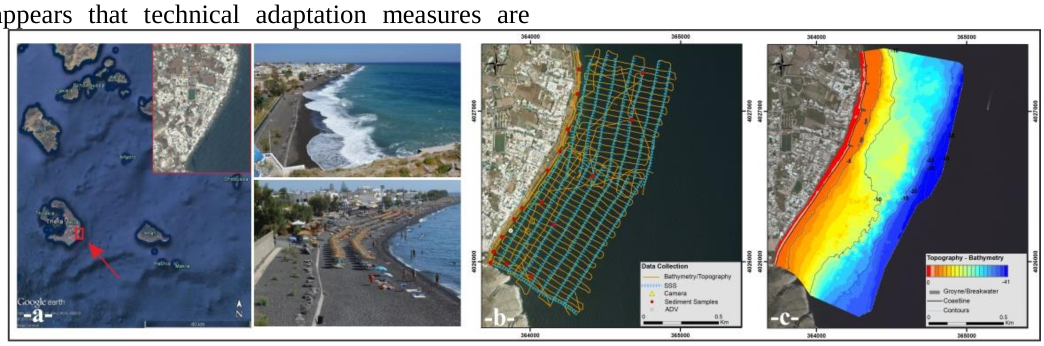

Figure 1. Kamari beach (Santorini): (a) location, the beach and the backing coastal wall/road; (b) survey grid lines, sediment samples, and location of the camera and hydrodynamic observation (ADV) stations, and (c) beach topography/nearshore bathymetry.

The study combined state-of-the-art approaches to monitor beach erosion at different spatio-temporal scales, i.e. (a) time-series of high resolution satellite imagery and (b) a novel optical (video) monitoring system that can provide high frequency information on the shoreline position. Kamari beach is located along the eastern coast of Santorini, an area consisting of volcanic rocks/sediments and isolated metamorphic outcrops. The beach is mainly exposed to ESE winds, having a length of about 1500 m and is bounded to the south by a metamorphic limestone promontory and to the north by a system of small groins and breakwaters; a coastal wall confines the beach and separates it from the highly developed backshore (Figure 1).

2. Methods

In addition to the remote-sensed information, vital field observation regarding the geomorphological, sedimentological and meteorological characteristics of Kamari beach were collected in different periods in 2016 (Figure 1). High precision topographic data were collected for the onshore part of the beach during 3 surveys in April, June and December 2016 using a Topcon Hipper RTK-DGPS, whereas the nearshore bathymetry was recorded using a dense grid of echo-sounding data obtained through a digital Hi-Target HD 370 single beam echo-sounder, deployed from a very shallow draft inflatable boat. The land and marine surveys were designed to overlap in the very shallow waters (at about 0-5-0.8 m water depth) so to 'close' the topographic and /bathymetric surveys. In addition, the nearshore bed morphology/sedimentology was mapped down to water depths of ~25 m, using a high frequency digital side scan sonar for shallow waters (StarFish 450 kHz) and sediment sampling. High-frequency hydrodynamic observations were also collected during the periods 20-22/04/2016 and 13-16/12/2016), using a Nortek Vector ADV deployed at about 2 m water depth. Finally, a weather station (Davis Vantage Pro) was also installed in the area, but the long-term (10-year) wind regime was evaluated using wind information from the Santorini Airport, located some km along the coast to the north. Four types of high resolution satellite images (WorldView-1, WorldView-2, Pleiades and Geoeye-1), obtained between 2013 to 2016 in the summer period (July-August) were made available by the Local Authorities (Geothira) and analyzed to extract historical shoreline positions. For the extraction of the shoreline positions, several models were used; the most appropriate of these models was shown to be that using the normalized difference water index-NDWI to mask the areas covered by water using the Green channel of the imagery. Shorelines were extracted and the net shoreline movements (NSMs) estimated through the Digital Shoreline Analysis System- DSAS (Thieler *et al*. 2009). An autonomous coastal video monitoring system was installed at the beach. The system, which allows automatic, low-cost monitoring of key beach geospatial features, consists of a station PC and two fixed network cameras (center of view elevation of about 22 m above mean sea level), operating at a sampling rate of 5 frames per second and in hourly 10-minute bursts. Images were corrected for lens distortion and georectified/projected on real-world coordinates using standard photogrammetric methods and ground control points (GCPs) collected during dedicated RTK-DGPS surveys. Shoreline detection was performed during post-processing, using an automated coastal feature detector (that records the mean shoreline position over each 10-minute burst (Velegrakis *et al*., 2016).

3. Results and Discussion

The morphological survey revealed sandy sediments of varying grain-size forming ripple fields on the seabed down to the 10 and to 12-15 m water depths along the southern and northern parts of the study area, respectively. Towards deeper water, irregular Posidonia patches occur which gradually develop to uniform meadows. Beachrocks outcrop on the nearshore seabed (at 1 to 4 m water depths) along sections of the shoreline. Beach sediments along the shoreline were found to be coarse-grained (granules/small pebbles), with mean diameters ranging between 2.2 and 9.5 mm and medium/poorly sorted (standard deviation 1.7-3.7 mm). In comparison, the submarine sediments were finer, being medium well to poorly sorted, very coarse to fine-grained sand (mean sizes of 0.17-1.39 mm and standard deviations of 1.5 - 3.4 mm). Kamari beach is exposed to NE, E, SE and S winds, the longer fetch being from SE (Feff = 324 km). Data analysis from the installed meteorological station has shown that, during the monitoring period, the main wind directions were from the: NW (32%), W (28%) and N (20%). In comparison, the long term wind time series (from the Santorini airport) have revealed also occurrence of S and SE winds, which have fetches that can generate considerable waves. During the first hydrodynamic experiment the wave conditions were mild (Hs ~ 0.5 m and Tp ~ 4.5 s) and the currents extremely weak (< 0.025 m/s). During the second experiment (13-16/12/2016), moderate winds were blowing from the NE and an energetic event was recorded, with nearshore waves having Hs of up to 1.5 m and Tp of 4-8 s; however, nearshore mean currents did not exceed the 0.06 m/s.

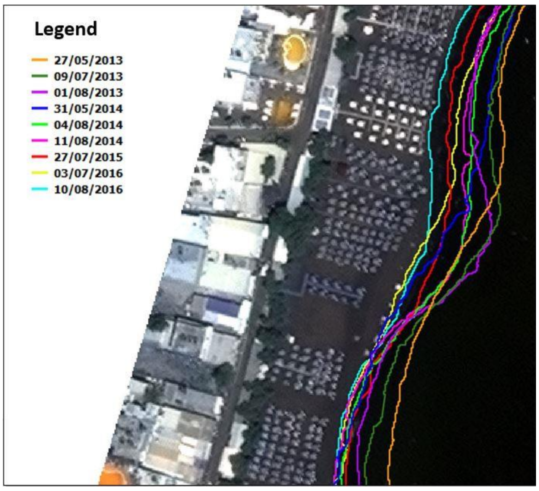

Figure 2. Example from the northern, protected section of Kamari beach, showing historic summer shoreline positions (2013-2016). Note the extensive beach usage.

It should be noted that during this energetic event, considerable wave reflection at the rocky promontory that bounds the beach to the south was observed, which induced non-linear nearshore wave interactions and, possibly the genertaion of standing waves. Extraction of the shorelines from the 2013-2016 summer satellite imagery was carried out using the normalized difference water index-NDWI, and the net shoreline movements (NSMs) were estimated. Within the 3-year period, the shoreline showed considerable landward movement (erosion), especially at the central part of the beach, where position shifts of up to 26 m were recorded. Shoreline advance (accretion) was also locally detected, being about 12 m. The results also indicate high shoreline position variability, which is evident even in the area of the beach associated with coastal protection works (Figure 2); in this area, beach erosion was locally > 20 m. It must be noted that since the satellite images were obtained at the same period (summer) when the beach attains its maximum width, these comparisons are less likely to have been affected by the high seasonal beach shoreline variability (see also below). The topographic surveys showed that the geospatial characteristics of Kamari beach varied considerably within the 8-month monitoring period. Erosion 'hotspots' can be discerned from the shoreline positions and topographic elevations, as well as areas of significant sediment accumulation (Figure 3). Sediment accretion was detected to the north and erosion to the south of the groins. The most intensive erosion was detected to the south of the groins for a distance of about 700 m, where a sediment layer up to 1 m thick appears to have been lost along the entire beach width. In contrast, considerable sediment accumulation is observed along the southern margin of the Kamari beach, which locally may exceed 1.5 m in thickness. These results are consistent with southerly longshore sediment movement, forced by the northerly winds recorded during this period and the absence of S and SE winds (see above). The evolution of the Kamari beach shoreline was also studied in high frequency on the basis of the coastal video system imagery. Due to the system downtime (from vandalism), images are available for two periods: 26/06/2016-06/07/2016 and 16/12/2016-31/12/2016) (Figure 4). The results show contrasting patterns of beach loss or gain along the beach, as well as increased variability; the differences between the minimum (most inshore) and the maximum (most offshore) shoreline positions varied between 13 and 28 m (Figure 4e). Such patterns suggest high spatio-temporal variability of the shoreline, particularly during the more energetic part of the year. The most consistent trend was found to be associated with beach advance at the southern section of the beach, whereas the northern section is characterized mostly by erosion (Figure 4f). It is interesting also to note that the shoreline was characterized by relative stability during the summer observations (Figure 4f). Inter-comparison between the shorelines extracted from contemporaneous coastal video and satellite imagery (3rd July 2016) showed good correlation, particularly when the NDWI index was set to 0.5 (Figure 5); in this case, the RMSE was found to be 0.8 m. These results support the use of the (summer) satellite images to assess longer-term erosion trends at Kamari beach (Figure 2)

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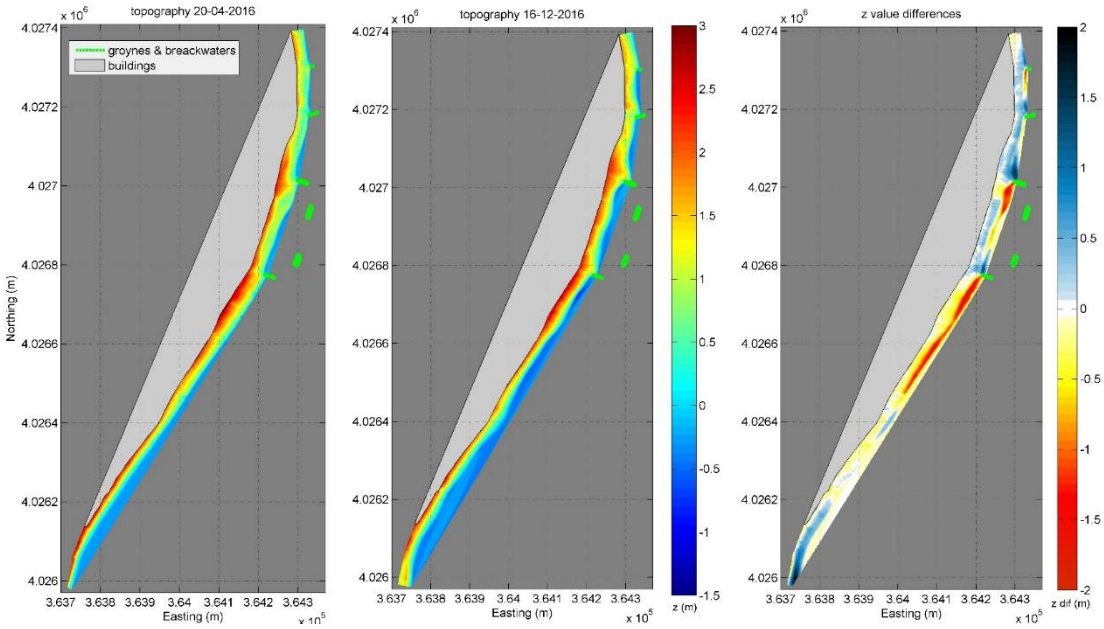

Figure 3. Beach topography in 20-4-2016 (left) and 16-12-2016 (middle). Beach sediment changes (on the basis of the beach topographic surveys) is shown at the right panel.

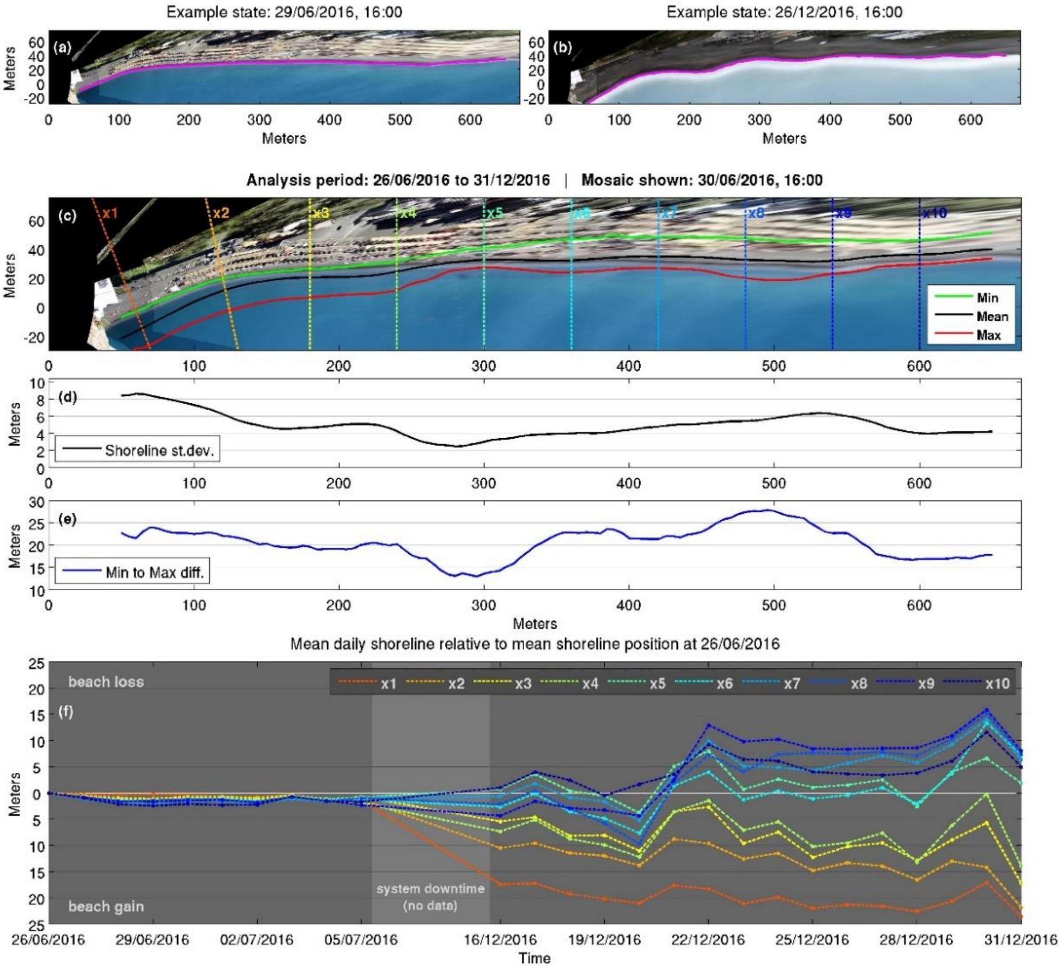

Figure 4. Shoreline analysis based on the coastal video monitoring system (26/06/2016 to 31/12/2016). Examples of georectified mosaics and shoreline positions at (a) 29/06/2016 and (b) 26/12/2016. (c) Mean maximum and minimum shoreline position detections over the entire analysis period. (d) Spatial distribution of the standard deviation of the cross-shore shoreline position. (e) Difference between the Min/Max detections. (f) Temporal evolution of the mean daily shoreline position at 10 selected cross-sections (for location, see panel Fig.4c); changes relative to the shoreline position at the beginning of the monitoring period, 26/06/2016).

Our results suggest an increasing erosion risk for the Kamari beach, particularly along its middle and northern sections. The documented erosion by the ground video optical system appears to have been (mostly) driven by longshore sediment transport towards the southern margin of the beach (Figures 3 and 4). Nevertheless, as there is no long-term record of significant beach accretion at this area, this process may be reversing during energetic wave events forced by S and SE winds. In any case, the shoreline retreat documented by the satellite imagery during a 4-year period, suggests that offshore sediment losses also occur, particularly during energetic events. This process can reduce significantly beach sediment volumes particularly as the supply of beach sediments from the land has been largely diminished due to increased coastal development; the areas of the beachrock outcrops identified along the beach may be acting as significant conduits for such offshore sediment transport (e.g. Vousdoukas *et al*., 2007). The significant erosion trends observed in the area are likely to be the result of a combination of natural and anthropogenic processes. Potential changes in the nearshore wave characteristics, together with the construction of the coastal wall/road at the backshore (Figure 1) that reflects waves and, enhances beach erosion during energetic events (e.g. Andreadis *et al*., 2016) may have been responsible for the severe erosion of Kamari beach in recent years. The results also show that the coastal defence scheme (groins and breakwaters) at the northen margin of the beach is not (anymore) effective, as this area is characterised by erosion during both the 2016 monitoring period (Figures 3 and 4) and in the longer term (at least in the past 4 years - Figure 2). It appears that technical adaptation measures are required urgently to mitigate the erosion of the Kamari beach. The situation is likely to be largely exacerbated by the projected climatic changes and particularly the mean sea level rise (Monioudi *et al*., 2017). In addition, emerging regulation (e.g. the European Directive 2014/52/EE) requires assessments of the impacts of climatic changes on future coastal works as well as assessments of their effectiveness on the basis of cost-efficient monitoring before and after construction. Our results suggest that the approaches employed in the present study can be used to this end, as they have shown that can provide the necessary information with a relatively low cost.

4. Conclusions

Our results suggest that Kamari beach has suffered significant erosion during (at least) the past 4 years. The most vulnerable

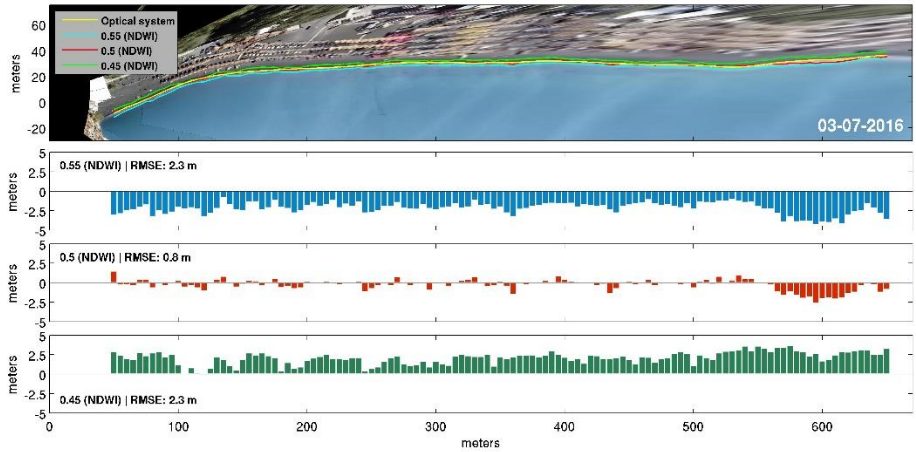

Figure 5. Comparison between shoreline detections from satellite imagery using 3 different values of the normalized difference water index-NDWI (0.45, 0.5, 0.55) with the shoreline detections from the coastal video imagery for the georectified mosaic of 3/7/2016. The smallest RMSE (0.8 m) is found when the MDWI is set at 0.5.

areas of the beach appear to be its middle and, probably, the northern, sections. At the same time the beach appears to associated with very significant spatio-temporal variability; differences between the minimum (most inshore) and the maximum (most offshore) shoreline positions varied between 13 and 28 m during the 6- month period of ground video monitoring. The significant erosion trends observed in the area are likely to be the result of a combination of natural and anthropogenic processes. Potential changes in the nearshore wave characteristics, together with the construction of the coastal wall/road at the backshore may have been responsible for the observed ‘long-term’erosion, which does not seem to have been adequately mitigated by the present coastal defence scheme. It appears that technical adaptation measures are required urgently to mitigate erosion, particularly as this is likely to be exacerbated by the projected climatic changes.

Acknowledgements

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