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Erosion and sediment transport processes along Eresos coastal zone (Lesvos, Greece)

Andreadis O., Hasiotis T., Psarros F., Chatzipavlis A., Velegrakis A.

Department of Marine Sciences, University of the Aegean, University Hill, Mytilene, Greece

*corresponding author: T. Hasiotis

e-mail: hasiotis@marine.aegean.gr

Abstract: This paper demonstrates the results of a 5 year monitoring program for the study of coastal erosion in the highly touristic beach of Eresos in Lesvos island. The beach is exposed mainly to S and SW winds. Frequent topographic (RTK-GPS), bathymetric (single-beam echo-sounder), morphological (side scan sonar) and sedimentological studies in shallow waters (<11.0 m) in conjunction with scuba diving observations, meteorological information and a hydrodynamic experiment, evidence an extremely energetic across and longshore transport of the sandy seafloor sediments. Two longshore bar / trough systems at ~0.5 and ~3.0 m depth are found to move substantially during storms, whereas the sonar mosaics show ripples and ribbon-like bedforms, the latter distributed at the west half part of the inshore area deeper than the 5.0 m water depth and oriented perpendicular to the shoreline. High frequency wave/current measurements show near-bed flows up to 35 cm/s, directed SSW that matches with the direction of the ribbon-shape features. The abovementioned findings verify the active sediment transport and the spatio-temporal complexity of the micro-morphology in the Eresos coastal area.

Keywords: beach erosion, morphodynamics, spatio-temporal changes, hydrodynamics, Eresos beach

1. Introduction – Study area

Island pocket beaches are currently under erosion (Monioudi *et al*., 2017) due to Climate Variability and Change (CV & C) as well as anthropogenic influences (Seneviratne *et al*., 2012). At the same time these environments are important economic resources as they form important touristic destinations (http://www2.unwto.org/en).

There are various reasons causing beach erosion, especially to island beaches (Peduzzi *et al*., 2013), the most significant being: (i) changes in the wave regime due to climate change (i.e. frequent and longer lasting extreme wind events, (ii) limited material supply/input to the coastal sedimentary budget (e.g. dammed hydrological basins, sand extraction for building purposes etc.), (iii) poorly designed/studied coastal structures (seawalls, local fishing ports etc) that disturb the shore morphodynamic processes and seasonal equilibrium.

The study area, Eresos beach in Lesvos Island (NE Aegean Sea) (Fig. 1), is a ~2 km long pocket beach, being one of the major tourist destinations on the island. An intermittent stream, Halandras R., discharging at the central part of the beach has been dammed since 1999, thus diminishing sediment supply to the beach. The coast consists of medium-coarse sands with occasional gravels. The beach is open to the waves from the southern sector and it is characterized by a very low tidal regime, not exceeding 15 cm on spring tides. A small islet exists at the eastern side at a close distance to the beach.

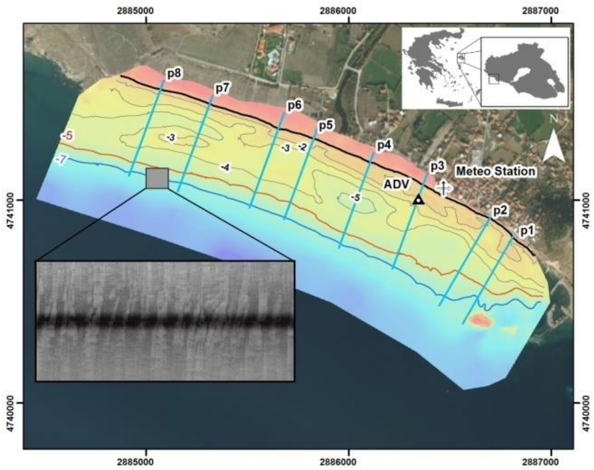

Figure 1. The coastal area of Eresos, in Lesvos Island. The inset at the top right shows the location of the study area. Sonograph (down left) showing ribbon-like bedforms on the seafloor, forming across isobaths contours.

The beach has experienced significant development during the last 50 years, which is mainly based on seasonal (summer) tourism. During that period a fishing port has been constructed at its eastern margin, whereas the easternmost part of the beach is backed by promenades and seawalls. In recent decades the beach suffered severe erosion, particularly along its eastern part (Velegrakis *et al*., 2008).

The objective of the present study is to identify patterns of sediment transport and the resulting changes in the beach sediment reservoir due to hydrodynamic forcing along Eresos coastal zone.

2. Methods

During the 5-year monitoring period of the beach processes (2011-2016, almost one data-set per year) topographic, bathymetric, morphological, sedimentological, meteorological and hydrodynamic information was collected. An RTK DGPS (TopCon Hipper II) was used to record backshore beach profiles and also supported bathymetry that was carried out repeatedly with a single beam hydrographic echo-sounder (Hi-Target H370) in a dense grid of survey lines. Landmarks at the start of every beach profile where constructed with respect to the maximum wave set up and the local landscape (Fig 1). The datasets were corrected with respect to the tidal level at the day of recording relative to the coastline position. Morphological mapping was conducted using a high resolution, low-cost side-scan sonar (Tritech StarFish 450F) and SonarWiz Map software for post processing and mosaicing. 18 sediment samples were collected from several points along the inshore and backshore zones and they were analyzed by dry sieving. Grain-size parameters were calculated with Gradistat. A meteorological station (Davis Vantage) was installed at the beach front to collect wind data, which were processed with respect to high intensity events (>6Bf – stormy weather) and they were consequently correlated with the morphodynamic observations of the coastal zone. The wave regime was hindcasted from the wind data using the Jonswap methodology. Additionally, an Acoustic Doppler Velocimeter (ADV - Nortek Vector 3D) was employed at 1.8 m water depth along profile 3 in order to collect simultaneous wave and current information during a storm event. Matlab and ArcGIS were used for metocean data analysis and mapping purposes. The geomorphological results were occasionally ground-truthed by scuba diving.

3. Results

The inshore part of the beach is characterized by two intermittent longshore bar and trough systems, at ~0.5 and ~3.0 m water depth, which were found to modify/shift considerably during storms. Topographic (onshore) and bathymetric (inshore) combined profile time-series (Fig. 2) reveal that the deeper and most prominent longshore bar is temporally shifted more than 100 m, demonstrating the highly variable environment of Eresos coastal area.

Comparison between succssive bathymetric datasets shows the spatial distribution of depth variability, indicative of the high sediment mobility (Fig. 3). For example, assessment of the differences between the April 2014 and February 2015 datasets (~ 10 months period) displays a significant longshore bar shift towards deeper waters, reaching 75 m, whilst elevation differences locally exceed 1.5 m. A standard deviation plot between all the available bathymetric datasets (Fig. 3) demonstrates the spatial distribution of depth variability during the entire monitoring period. It is evident that elevation changes exceeds 1.5 m distributed shallower than 7 m but being more prominent in less than 5 m water depth and almost up to the shoreline (~350 m in horizontal distance).

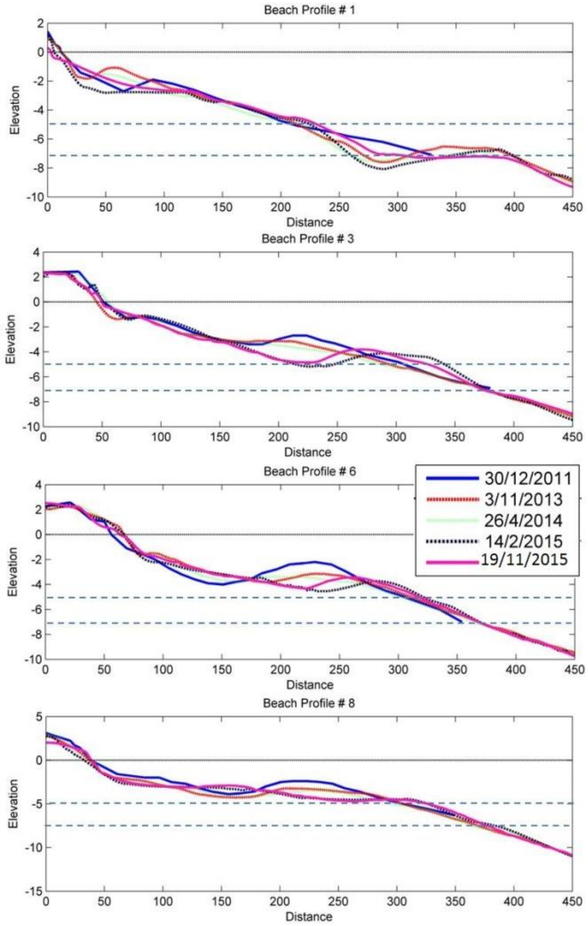

Figure 2. Selected topografic/bathymetric profiles (1, 3, 6, 8, see Figure 1 for locations) for five survey periods, showing significant temporal and elevation variability. Intermitent lines represent closure depths at 5 and 7 m.

The weather data which were collected during the 5-year study period were sorted and analyzed in order to identify storm events (≥ 6Bf) with respect to homogenous U10 windspeed, time of start and duration as well as wind direction (Table 1). The rose diagram (Fig. 4) has been constructed only for the southern sector winds that are responsible for the main geomorphological changes in the study area. It is clear that SSE and SW winds are the most intense, attaining speeds up to 14-16 m/s. Next, the Jonswap methodology was used for the estimation of the significant wave height and peak wave period, which were found to be 1.8 m and 6 sec, respectively. The closure depth (CD - Hallermeier, 1981) was calculated for all the storm events, found to be ~5 m, and ~7 m for the biggest storm of the dataset (storm 16 - Table 1). These results coincide with the observed morphological changes along the topo/bathymetric profiles (Fig. 2) and the standard deviation plot for all the available bathymetric data sets (Fig. 3) that seem to take place shallower than the 7 m isobath suggesting that sediments are re-distributed within these depths but they do not escape deeper than the closure depth.

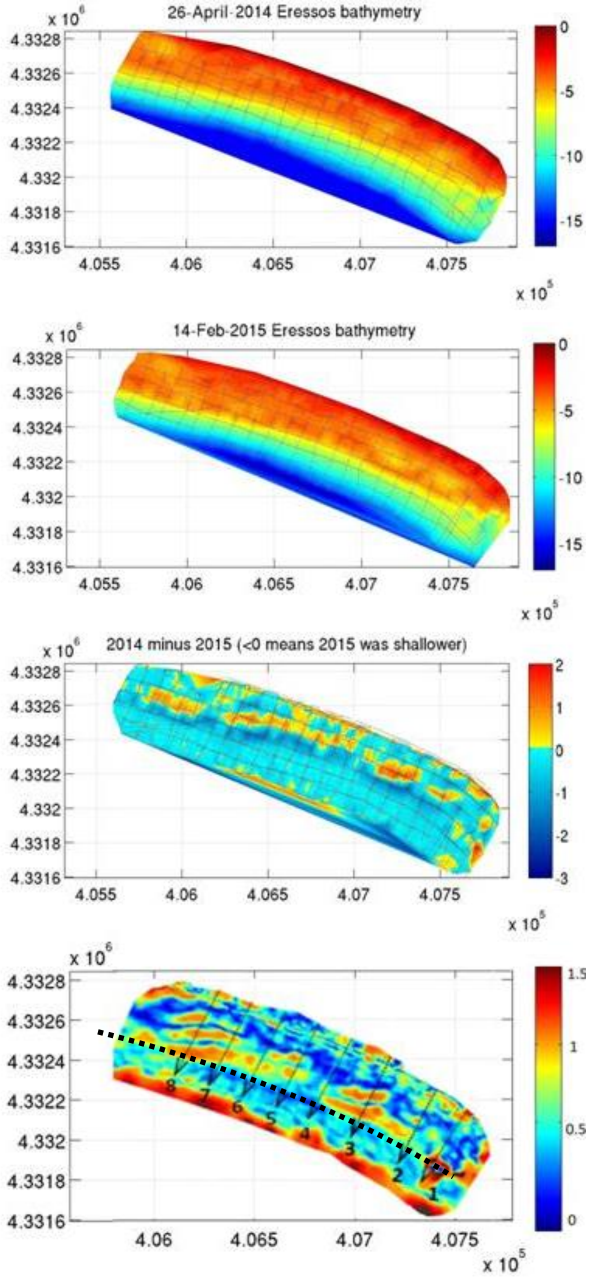

Figure 3. Spatial distribution of seabed elevation changes between April 2014 and February 2015 datasets (3 upper plots) and standard deviation (lower plot) of all the available bathymetric datasets. Dashed line represents the closure depth of 7 m.

Table 1. Storm grouping for the 5-year (2011-2016) monitoring period. Major storms are in bold and main survey periods in yellow colour.

Storm ID	Start	End	U10	Duration	Direction	
1	22/1/2011 21:53	23/1/2011 7:23	11,1	9,5	166	SSE
2	13/4/2011 20:52	14/4/2011 9:22	12,5	12,5	158	
3	17/12/2011 8:49	18/12/2011 4:19	12,1	19,5	177	S
Survey	**30/12/2011**					
4	***5/1/2012 22:48***	***7/1/2012 6:18***	***13,2***	***31,5***	***176***	*S*
5	23/5/2013 10:30	23/5/2013 19:30	11,3	9,0	195	SSW
Survey	**3/11/2013**					
6	24/11/2013 19:00	25/11/2013 5:00	11,4	10,0	222	SW
7	18/1/2014 11:00	18/1/2014 15:00	10,9	4,0	203	
8	***8/2/2014 9:30***	***10/2/2014 4:00***	***11,8***	***42,5***	***213***	SSW
9	1/3/2014 10:00	1/3/2014 17:00	11,0	7,0	223	
10	2/3/2014 18:00	3/3/2014 1:30	11,0	7,5	212	
Survey	**26/4/2014**					
11	29/5/2014 18:00	30/5/2014 3:45	10,9	9,8	232	SW
12	23/10/2014 5:45	23/10/2014 18:00	11,8	12,2	184	S
13	***28/12/2014 20:00***	***29/12/2014 16:00***	***14,1***	***20,0***	***232***	
14	11/1/2015 20:15	12/1/2015 15:00	12,5	18,8	230	
15	24/1/2015 7:30	24/1/2015 18:00	11,1	10,5	225	SW
16	***30/1/2015 8:30***	***2/2/2015 9:45***	***13,1***	***73,3***	***217***	
17	4/2/2015 17:15	5/2/2015 0:30	10,9	7,3	225	
Survey	**14/2/2015**					
18	6/3/2015 11:00	6/3/2015 21:30	11,3	10,5	180	S
19	6/4/2015 13:45	6/4/2015 22:15	11,3	8,5	196	SSW
Survey	**19/11/2015**					
20	***21/11/2015 0:45***	***22/11/2015 11:15***	***12,1***	***34,5***	***213***	SSW
21	25/11/2015 18:45	26/11/2015 6:15	11,6	11,5	213	

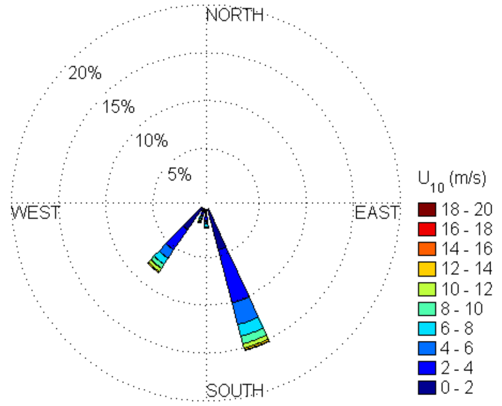

Figure 4. Wind rose diagram showing data (speed / direction) distribution only for the southern sector.

Successive side scan sonar surveys have shown the distribution and spatio-temporal variability of varius reflectivity types, related to (i) diverse textural characteristics (finer and coarser sandy sediments), (ii) low-relief hard-grounds occurence and (iii) low-relief bedforms (ripples and ribbon-like features), which have been all attributed to the local hydrodynamic regime (Nasras *et al*., 2015; Andreadis *et al*., 2016). However, the most interesting features are the ribbon-like bedforms that develop deeper than the 5 m isobath, mainly at the western half of the inshore area, and appear as repeated irregular bedforms developing perpendicular to the coastline, and having a special pattern of high and low reflective strips. The highly reflective strips usually host ripples forming across the ribbon direction. This pattern correspond to slight relief and textural changes suggesting strong near-bed flows transversely to the slightly sloping seabed. Scuba diving verified the side scan sonar interpretation, since it became evident that very low relief troughs occupied by sand ripples alternate with bands of finer sands, all developing perpendicular to the isobaths (Fig. 5).

Groun-truthing was concluded by grain-size analysis that revelaed sandy sediments of a mean size ranging between -0.08 and 2.08 Ø.

Figure 5. Low-relief ribbon-like band at 8-11m depth, hosting sand ripples and neighbored by finer sandy sediments.

The ADV experiment took place during a high-energy event of SSW blowing winds (storm no. 20 - see Table 1). The instrument recorded significant wave heights > 0.7 m (up to 1.0 m) and peak periods up to 7.5 sec until the end of the record (Fig. 6). Bed current velocities reached 0.35 m/sec with a direction of about 190-220º (perpendicular to the coastline) (Fig. 6).

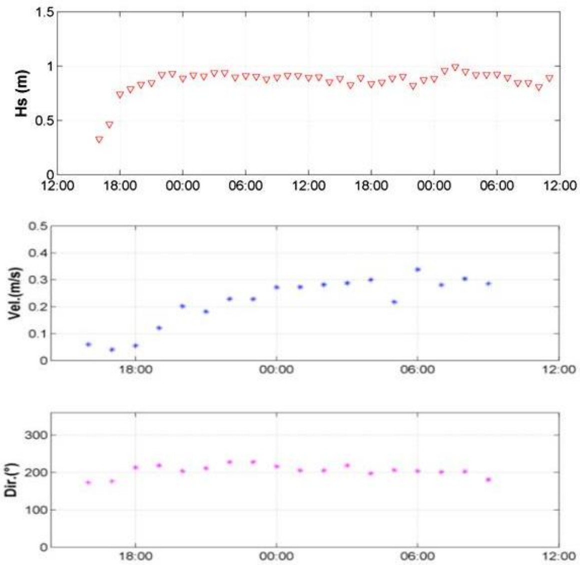

Figure 6. High frequency hydrodynamic information showing significant wave heights, current velocoties and directions during a high energy event.

4. Discussion – Conclusions

The information obtained from this study has shown that the morphodynamic processes in Eresos coastal area display a spatio-temporal variability and they are probably influenced by the local landscape and human intervention (islet, fishing port, seawall/promenade). The existence of the small fishing port and of an islet close to the shoreline at the east end of the beach causes wave diffraction, affecting the hydrodynamic regime and sediment transport. Data from the topo/bathymetric profiles and the standard deviation plots (Figs. 1 to 3) verify elevation changes that have resulted in considerable sediment loss from the eastern part of the beach and accumulation close to the islet. Profiles 1 to 3, along the seawall, clearly show severe onshore erosion, whereas profiles 4 to 8 reveal a better-balanced coastal system with seasonal erosion / accretion processes and onshore / inshore berm / bar formation, down to a water depth of ~2 m.

The wind record during the monitoring period (Fig. 4, Table 1) displays that the prevailing southerly winds come mainly from SSE directions but most of the storms seem to occur mainly from SSW-SW. Eresos beach has an almost NW-SE orientation, hence facing cross-shore SSW-SW storms that increase surge, wave set up and formation of rip currents. Storm events affect dramatically the geomorphology of the inshore area as deduced from the topo/bathymetric profiles at well as from the spatial distribution of elevation change plots, where the cumulative longshore bar/trough migration reach 100 m towards an offshore direction. Severe storm events happen almost once a year, they are able to affect the deeper sand bar causing spatio-temporal migration beyond CD5 and even CD7 (Fig. 3 – standard deviation plot) thus accounting for the permanent loss of inshore sediments that cannot re-supply the beach. These processes together with the reduced material supply from the surrounding hydrological basin, due to retention in the Halandras dam upstream, limit beach sediment renewal and disturb the coastal sediment balance.

The intense cross-shore sediment transport is not reflected only by the apparent movement of the deeper (mainly) longshore bar/trough system, but also by the existence of the observed ribbon-like bedforms in the side scan sonar records. It appears that there is an offshore undertow sediment transport mechanism that is driven by storm events, taking place through particular and spatially determined pathways as shown by the ribbon-like features, which are distributed mainly in the western part of the Eresos inshore area. The hypothesis is reinforced by the currents direction as recorded during the ADV experiment that suggest a strong sediment transport trend that is probably able not only to migrate and re-shape the longshore bars but also to induce movement beyond the CD. The fact that for more severe storms the CD shifts to 7 m, support cross-shore sediment movement possibly through the ribbon-like bedforms, which are mainly located deeper than the 5 m isobath and eventually sediment loss from the beach sediment budget.

Conclusively, our results (i) show energetic nearshore sediment transport and offshore sediment transfer via particular cross-shore corridors, (ii) signify the value/need of repeated inshore mapping for the monitoring of morphological changes and for sheding light in the prevailing coastal processes and (iii) can better drive advanced hydrodynamic models for the design of coastal protection measures in Eresos coastal area.

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