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ORIGINAL ARTICLE

Long-term vs short-term subsite erosion rates on microtidal shore platforms (Southern Mallorca, Balearic Islands, Western Mediterranean)

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Abstract

We address changes in microtopography of a supratidal rocky surface on calcareous rocks in the shore platform of s'Alavern (S de Mallorca) by means of a TMEM monitoring device. TMEM site was installed in 2004 and subsequent microtopographies were obtained in 2005, 2008 and 2021; as well as a bi-hourly monitoring in 2005. When comparing subsite short-term erosion rates against long-term erosion rates, the results indicate that the erosion rates obtained during time intervals of less than 5 years show higher erosion rates (0.45 vs. 0.22 mm year^{-1}) and with greater variance than those obtained for monitoring intervals greater than a decade. When comparing the variability of the value of the microtopographical altitude in hourly intervals with the behaviour of those same points on a long-time scale, it is evident that, in the short term, those points that experience negative displacements show higher long-term erosion rates than those that experience positive shifts on an hourly scale. However, this pattern is not statistically significant, which suggests that the magnitude and trend of the microtopography change is reflecting the role of different processes and agents that are operating at different temporal scales.

Keywords Rock coasts · Shore platforms · TMEM · Temporal scales · Erosion rates

Introduction

Shore platforms are erosional rock coast landforms defined as near-horizontal or gently slope rock surfaces at the shoreline (Trenhaile 1980; Stephenson 2000). Different agents and processes participate in shore platforms erosion and dismantling. Rock surfaces are lowered by the detachment of joint blocks and other rock fragments forced by wave quarrying, by the abrasion of particulate material transported by waves across the platform, or by rock decay agents, such as wetting and drying, salt weathering or biological grazing and boring (Trenhaile and Porter 2018). The contribution or preponderance of the physical erosion or of the rock decay is close related to the rock type, as well as to the climate and to the geographical setting (vid. Kennedy et al. 2014). There are numerous attempts to quantify shore platform surface lowering and unravel the contribution of physical processes or rock decay by means of the micro-erosion meter (MEM) (High and Hanna 1970) or the traversing micro-erosion meter (TMEM) (Trudgill et al. 1981; Stephenson 1997). Nowadays, both techniques are a common place among the rock coast research community (Stephenson and Finlayson 2009; Yuan et al. 2022). MEM or TMEM studies, very often, measure shore platform downwearing over periods of about 3 years (the life of a research project), because, in cases of relatively high denudation rates, the results are useable and relevant despite the technique error and other methodological constrains (e.g.,Trudgill 1976; Spencer 1981; Gill and Lang 1983; Viles and Trudgill 1984; Swantesson et al. 2006; Stephenson and Kirk 1998). Recently a number of studies has extended these records to multidecadal scale and have contributed to unravel the processes efficacy and agents on shore platforms (Stephenson et al. 2010, 2019; Trenhaile and Porter 2018; Yuan et al. 2020). Other authors have shortened the temporal scale over which MEM and TMEM have been used seasonally, to a few days or hours (e.g.,Stephenson et al. 2004; Gómez-Pujol et al. 2007a; Hemmingsen et al. 2007; Mayaud et al. 2014; Yuan et al. 2018).

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As studies progress in the characterization of shore platform erosion using TMEM devices, and because we benefit from larger TMEM erosion time series or wider spatial sampling networks, new possibilities of analysis open up. This is especially true when regarding to the meaning and contribution of different dimensions in rock surface dismantling, such as the spatial scale or the temporal scale, in and between TMEM sites, as well as at TMEM subsite level. For instance, Viles (2001) had pointed up that few rock decay studies address if the scales of process observation are the same as the scales of process operation, or if one process results in morphological imprint at different spatial scales. On the other hand, Goudie and Viles (1999), in a seminal work on frequency and magnitude in rock decay studies, recognized that processes operating very often on a surface, not necessarily can remove large amounts of material, whereas unusual but energetic events can mobilize large amount of material. Moreover, in the conceptual model of the factors affecting the erosion rock coasts reviewed and updated by Naylor et al. (2012) it is also evident that different processes and agents can operate over the same surface, and this fact implies that different spatial (from cm to mm) and temporal (seconds to years) scales, related to each particular process, participate in rock surface dismantling. Against this background, when changes in the microtopography of a rocky surface are characterized by means of TMEM, the next questions arise: the erosion rates obtained at different time scales (hourly, daily, seasonal, annual, decadal or larger intervals) are the results of the same process or of different processes and agents? Moreover, is it possible that the rates of erosion produced by a process or agent on a short-term time scale, are attenuated over time? Or vice versa, can long-term, less-frequent, but highest in magnitude events mask the continuous, but less effective action of the more frequent processes?

To contribute to this methodological debate on the use of TMEM in rocky coast surfaces, the goal of this paper is to explore the erosion rates changes at subsite level across different TMEM survey time intervals on the same rock surface. In doing so we analyse the changes in a limestone supratidal shore platform surface, where a TMEM site was installed in 2004 and subsequent microtopographies were obtained in 2005, 2008 and 2021; as well as a bi-hourly monitoring in 2005.

Study site

The study was conducted at the Southern coast of Mallorca (Balearic Islands, Western Mediterranean) along a cliffy coast sector known as s'Alavern or cala s'Esglesieta (Fig. 1). The area consists of a slightly crenulated coast, where vertical cliffs generally more than 15 m in high rest on near horizontal shore platforms (slope < 1.5°), that range from 3 to 15 m in width. Shore platform ends with a vertical seaward edge

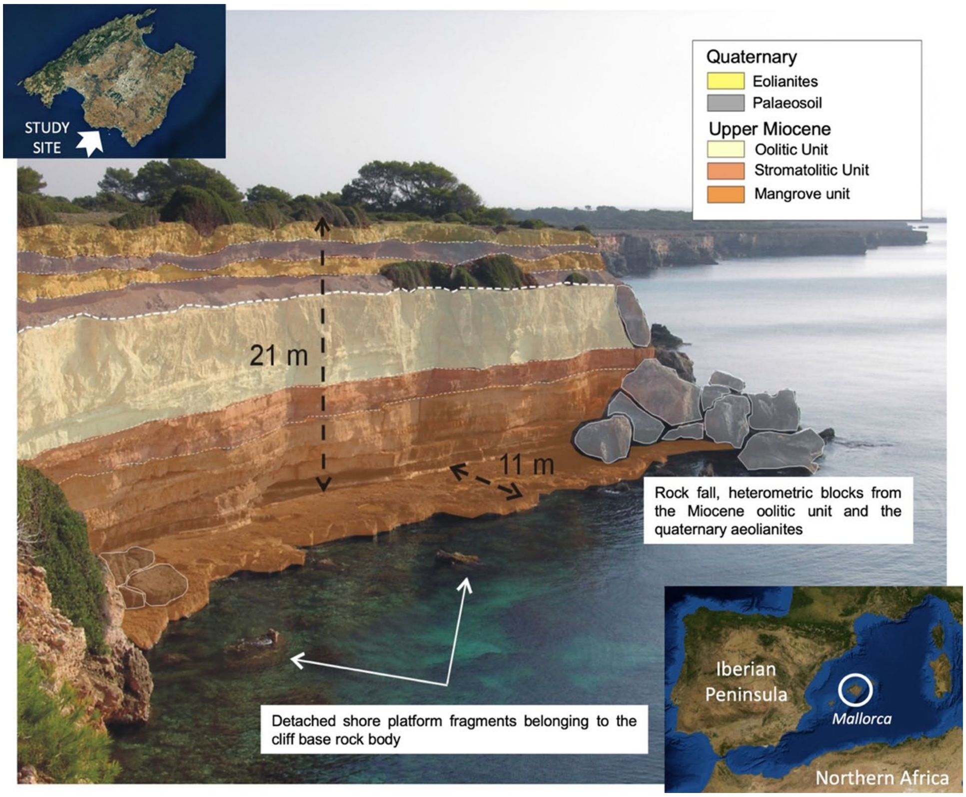

Fig. 1 Location map of the study site along the southern coast of Mallorca (Balearic Islands, Western Mediterranean)

that drops vertically 0.4 m above mean sea level. Shore platform remains most of the time emerged, nevertheless when at deep water depths waves reach 1 m in significant height, then they can splash and sweep the platform surface (Fig. 2). According to Gómez-Pujol et al. (2019) Southern coast of Mallorca is exposed to moderate winds that produce short-period waves at the shore, significant wave height ranges from 0.1 to 1 m with periods between 3 and 6 s. Storms are highly probable between December and February. Balearic sea is a microtidal environment. Tides are dominantly semi-diurnal, being the mean range of 0.2 m and the maximum water-level displacement forced by barometric high pressure close to 1 m. Time-series from Puertos del Estado (2023) show that monthly mean significant wave height have been progressively increasing from 2008 to 2021 (Fig. 3a) moving from mean values in winter larger than to 0.4 m to values larger than 0.8 m. The time series for monthly maximum significant wave height (Fig. 3b) also shows a similar trend, until 2008 maximums did not attend extreme values larger than 4 m, and from this year, there are many events at yearly basis that reach this significant wave height (Fig. 3b). From May 2004 to May 2021, the monthly maximum significant wave height just did not reached 1 m in 30 months, most of them corresponding to summer conditions (May–August), a 14.6% of the months. This mean that in the 85.4% of the cases, at least once each month, waves arrived to 1m in height, and therefore, waves sweep the shore platform.

Fig. 2 Traversing-micro-erosion meter used in this study and the supratidal bolt site characterized at s'Alavern shore platform

Shore platform surface is intensively colonized by cyanobacteria, fungi and lichen, resulting in dark coloration. Overlaying the near horizontal morphology, there is a conspicuous secondary relief along the platform surface, where basin pools and micropits, as well as joint or fracture widening forms, are not unusual (Gómez-Pujol et al. 2006a). The cliff and the shore platform are made of Upper Miocene interbedded calcareous sandstones and calcisiltites that belong to the Reef Unit, the Santanyí Limestones Unit (Fornós et al. 2002) and to Pliocene coastal calcarenites known as the Sant Jordi Calcarenite Unit (Mas 2015). The top of the cliff is covered by alternating reddish paleosoils and Pleistocene carbonate aeolianites (Mas 2015). Shore platform development is benefited from the differences in rock texture and resistance between the Reefal Unit calcarenites, and lower mudstone level of the Santanyí Limestones. The shore platform rock body consists of a carbonate bioclastic calcarenite, very rich in foraminifers, but quite micritized. Carbonate content of the rock is up to 98.1%, rock density is 1.6 g cm^{-3}, and porosity is high (24.7%). The N-type Schmidt Hammer rebound number is of 41 and corresponds to moderate resistant rocks (Gómez-Pujol et al. 2007b). The study site experiences a Mediterranean temperate climate with an average rainfall of 700 mm a^{-1} and average minimum temperatures of 7.4 °C in winter and average maximum temperatures of 30.2 °C in summer.

Materials and methods

At s'Alavern shore platform, the surface microtopography and rates of erosion have been surveyed by means of a Traversing Micro-Erosion Meter (TMEM) (Fig. 2). The TMEM is a modified version of the Micro-Erosion Meter (MEM) that was first described by High and Hanna (1970). The MEM consists of an equilateral triangular base, with legs in each corner and an engineering dial gauge placed on a pillar that rests on the centre of the plate. Each leg rests on a bolt permanently fixed into rock. The end of each leg is machined in a different way: one has a conical depression, one has a horizontal plane, and finally one has a V-shape grooving. In this way each leg opposes the movement to different directions and the exact relocation of the plate is achieved through the Kelvin Clamp principle. Therefore, the triangular base can be understood as a relative datum, and high precision relative heights (µm) can be obtained by means of the engineering dial gauge. Successive relative height readings of the same position can be used to calculate rock surface rates. If the dial gauge is placed in the centre of the triangular base just one reading for bolt site can be obtained. If the

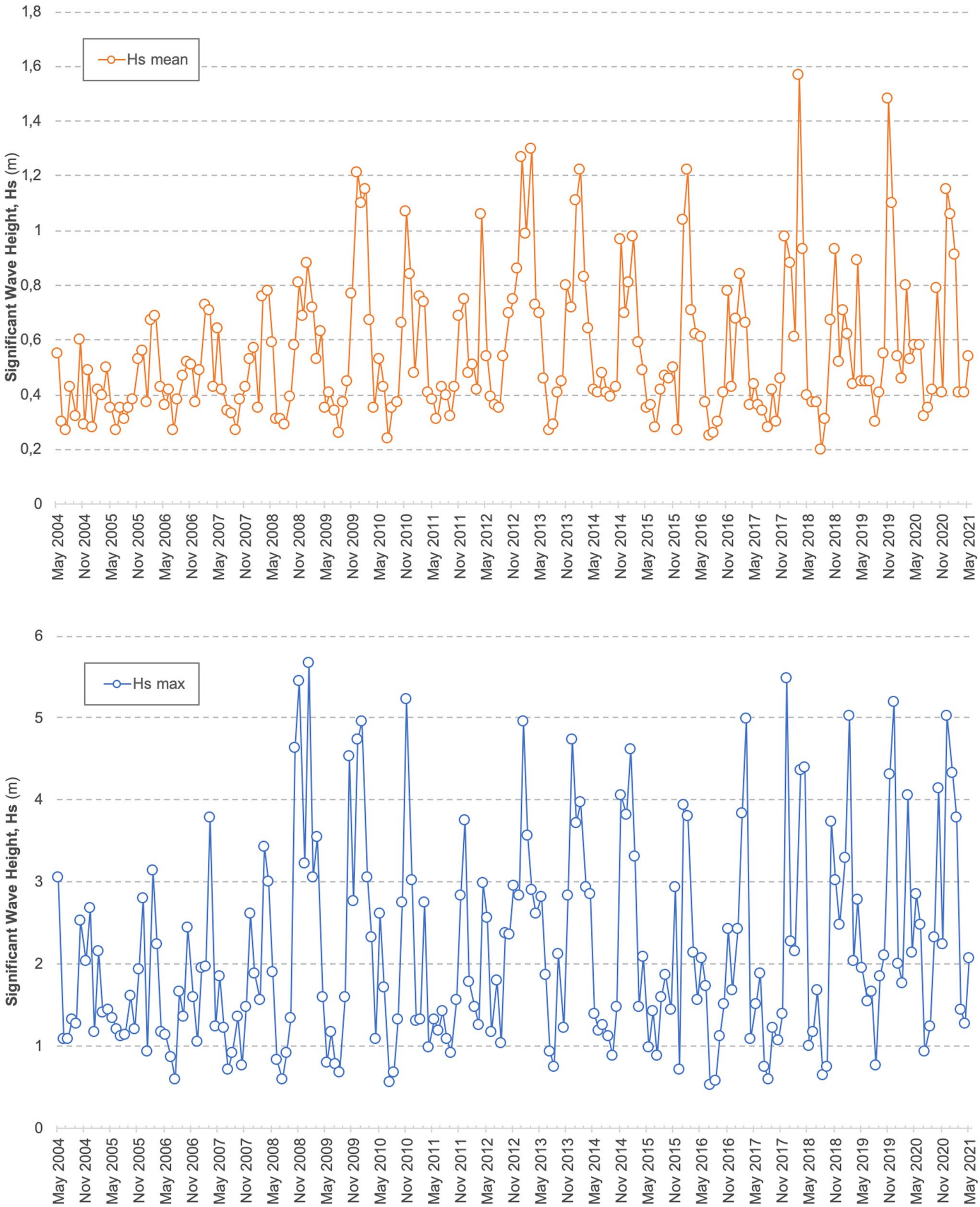

Fig. 3 Monthly mean (**a**, upper panel) and maximum (**b**, lower panel) significant wave height at the nearest marine climate reanalysis node to s'Alavern (Puertos del Estado, 2003; SIMAR 2119112)

dial gauge is slightly displaced from the centre of the plate, then three relative height readings can be taken rotating the instrument 120°. Trudgill et al. (1981) modified the MEM, mounting the dial gauge on a block with three arms separated 120° that was independent of the triangular base. In this new version the base plate is cut resulting in a triangular frame with legs. Along the sides of the frame, a number of ball bearing are fixed. The space between ball bearings holds the dial gauge block arms, and a precise location is obtained each time the instrument is placed on a bolt site. The number of relative heights obtained using the TMEM device depends on the size of the base and the number of ball bearings fixed along each side of the base. Additional information on the technique constrains and development can be consulted in Stephenson (1997), Stephenson and Finlayson (2009) and Yuan et al. (2022).

The TMEM device used in this study, manufactured by Mechanical Engineers of the University of Sussex (UK), allows to obtain a maximum of 148 individual measurements in a 135 cm^2 frame surface: with one relative height reading each cm^2 of the rock surface. According to Stephenson (1997) we used a digital engineering dial gauge (Mitutuoyo ID-C1025) connected via a USB cable to a laptop and assisted by a communication software (Winley V.14.5) that registers automatically the measurements in a spreadsheet. Previously to the fieldwork engineering dial gauge was calibrated. In doing so, in laboratory conditions with constant temperature and on a stainless-steel surface, where bolts were previously fixed, we selected randomly 20 individual positions of measurements and we took at least 10 times the relative height at each position. From this procedure we concluded that the average instrument error was of ± 0.002 mm.

TMEM bolt site used in this study was installed in May 2004, at supratidal zone of the shore platform, 1.5 m from the cliff toe, at 0.75 m above mean sea level and 12.7 m from shore platform edge or seaward drop. Subsequent rock surface microtopographies were obtained in 2005, 2008 and 2021; as well as a bi-hourly monitoring in 2005 (vid. Gómez-Pujol 2006; Gómez-Pujol et al. 2007b).

Differences in microtopography and erosion rates across time (2004, 2005, 2008 and 2021) were assessed by means of two separate univariate analysis of variances (ANOVA) of repeated measures (Grafen and Hails 2002) using SPPS software. When comparing the relation between microtopography behaviour during bi-hourly surveying against large-term erosion rates, we conducted a univariate inter-treatments ANOVA. In both cases data was checked for homogeneity of variance using a Cochran's test and Levene's test on equality of error variances, and data transformed appropriately to satisfy the assumptions of ANOVA.

Results

Summary of TMEM site microtopography values are presented in Table 1 and Fig. 4. In this table, there are the mean relative height of the surface, the standard deviation, the 25th and 75th percentiles of the microrelief values, as well as the minimum and maximum relative height values for 2004, 2005, 2008 and 2021 surveys. There is a large range of relative heights, from close to 0–8.5 mm, being the mean of the microrelief or the average relative height of 4 mm. Nevertheless, this mean relative height decreased along time (Fig. 4) passing from 4.31 mm in 2004 to 3.91 mm in 2021. A univariate ANOVA test of repeated measures was conducted to evaluate if there was a significant change on microtopography, since the gross of the values included between the 25th and the 75th moved, respectively, from 3.16 to 2.90 mm, and from 5.56 to 5.08 mm. For this reason each temporal survey (2004, 2005, 2008, 2021) was introduced as a factor, and then the exact 143 positions of relative heights were compared. Differences in relative height values between surveys of May 2004, August 2005, June 2008 and February 2021 were significant (ANOVA $p < 0.000$; Table 2) and we can conclude that rock surface experience significant changes on microtopography across time. Complementary within-subject contrast tests reveal that TMEM readings, which are equivalent to time, explain 55.5% of the changes in microtography by themselves. Figure 5 presents the estimated marginal means of each factor in the ANOVA analysis, this figure shows that there is a general trend in TMEM site microtopography that takes the form in a general reduction of the relative height, and generalized erosion process. However, this erosive pattern is more intense and evident in 2008 and 2021 than between 2005 and 2004. The pairwise comparison of the ANOVA analysis, show that the

Table 1 Descriptive statistics of TMEM site microrelief (absolute height value respect the TMEM frame in mm) values for 2004, 2005, 2008 and 2021 surveys at s'Alavern shore platform supratidal TMEM bolt site

TMEM survey	2004	2005	2008	2021
N	143	143	143	143
Mean	4.31	4.31	4.14	3.91
Median	4.28	4.36	4.09	3.78
Variance	2.84	2.86	2.92	2.52
Minimum	0.62	0.59	0.00	0.00
Maximum	8.16	8.27	8.47	8.01
Percentiles				
25	3.16	3.16	2.96	2.90
50	4.28	4.28	4.09	3.78
75	5.56	5.56	5.37	5.08
100	8.16	8.16	8.47	8.01

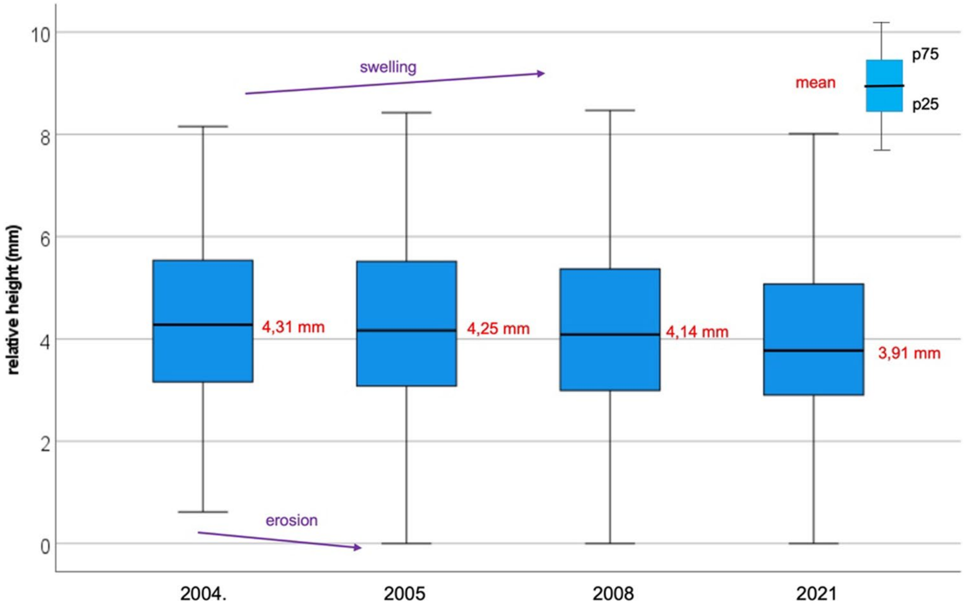

Fig. 4 Box-plots of relative height values at subsite level at s'Alavern shore platform supratidal bolt site across time (2004, 2005, 2008 and 2021)

Table 2 ANOVA for the changes of microrelief across time at s'Alavern shore platform supratidal TMEM bolt site

Source	Type II sum of squares	*df*	Mean square	*F*	Sig	Partial eta squared	Noncent. parameter	Observed power[a]
Test of between-subject effects								
Intercept	9870.49	1	9870.49	887.07	0.000	0.862	887.068	1.000
Error	1580.05	142	11.13					
Test of within-subjects contrasts								
Year (linear)	12.61	1	12.61	176.84	0.000	0.56	176.84	1.000
Error	10.13	142	0.71					

Test of between-subject effects (upper) and test of within-subjects contrasts (lower)

[a] Computed using alpha = 0.05

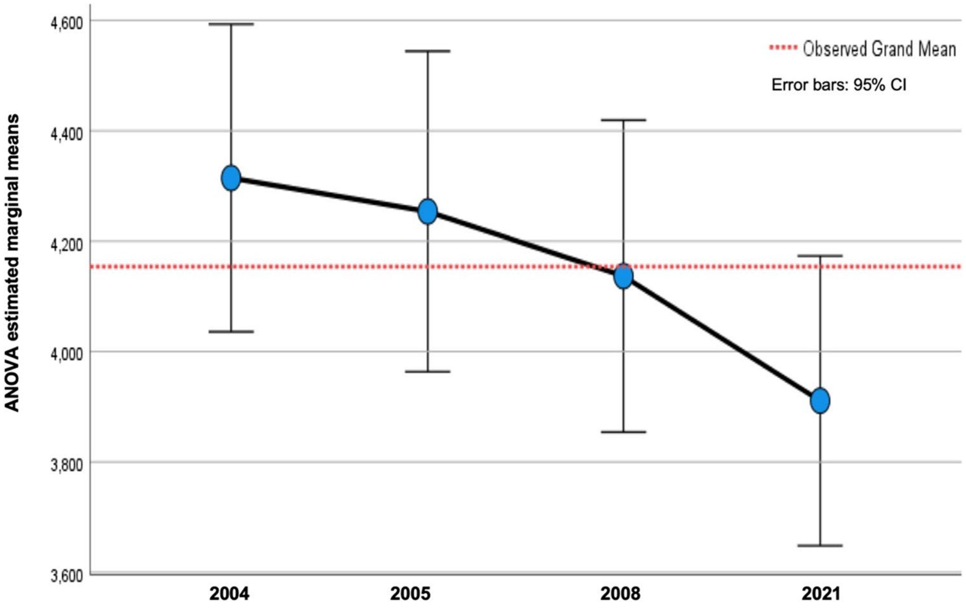

Fig. 5 Estimated marginal means of each factor in the ANOVA analysis for changes in relative height values along time

differences between populations are significant ($p < 0.001$) except for those surveys separated 1 year that exhibit similar relative height values (2004 vs 2004, $p < 0.435$; Table 3). Nevertheless as Fig. 4 shows, despite the generalised and significant negative change in microtopography, it should be noticed that in respect of the initial 2004 microtopography, there are TMEM reading positions that have experienced an increase or rise in their relative height, as well as others that have experienced larger erosion than those that the engineering dial gauge can measure. For this reason, since 2005, there are TMEM reading positions that reached values of 0 mm in relative height, whereas in 2004, the minimum relative height was of 0.62 mm. In summary, mean relative height decreased from 2004 to 2021. Differences in relative height between surveys separated 1 or 3 years were low, although some points experimented both large swelling or erosion events (Fig. 4). On the other hand, when the differences between TMEM surveys is larger than 5 years, then differences in microtopography show global changes affecting both highest and lowest reading positions.

Once we know that there are significant changes in microtopography, it is also interesting to explore if these changes exhibit similar rock surface change rates (erosion/swelling rates). In doing so, we contrast rates obtained from the comparison of the different surveys microtopographies (2004 vs 2005, 2004 vs 2021, 2005 vs 2008, 2005 vs 2021 and 2008 vs 2005). Three main groups of erosion rates data sets can be separated according to the elapsed time: 1-year erosion rates, 3-year erosion rates and decadal erosion rates. Figure 6 shows that rock surface change rates tend to reduce their absolute value and variance as the time between TMEM readings increase. In addition, all the reading intervals exhibit positive and negative erosion rates, indicating that a different time scales rising events also can be identified. Erosion rates based on time intervals lower than 10 years are twice (ca. -0.45 mm year^{-1}) than those based on time intervals larger than 10 years (ca. -0.20 mm year^{-1}), erosion rates variance also decreases as the between TMEM readings increase (Table 4). Rock surface change rates obtained from survey intervals larger than 3 years show rate variances close to 10 times than those based on 1-year survey interval (Table 4). As time between readings is larger than 10 years the variances are equated. Otherwise 3- and 4-year time lapses are roughly similar (0.013 vs 0.009). If we focus on the surface trend, positive or negative rock surface changes, at short-time scale maximum erosion attends between -0.85 yo -0.32 mm year^{-1}, at large-time scale (> 10 years) ranges from -0.13 to 0.17 mm year^{-1}. Swelling rates are of 0.26 to 0.88 mm year^{-1}and ca. 0.34 mm year^{-1}, respectively (Table 4).

Once a difference in the magnitude and variability of the rates obtained on an annual and decadal scale at the subsite level has been noted, as well as the existence in both of erosive and swelling records, there is the possibility of exploring if there is a relationship between the points that experience ‘rise’ and ‘descent’ trends of microtopography on short temporal scales, with those on long temporal scales. Gómez-Pujol (2006) surveyed the same TMEM bolt site on 24 August 2005, every 2 h from 07:00 to 22.00 h. Following Gómez-Pujol et al. (2007b) differences from successive readings for the same TMEM position were classified into ‘rising points’ when the differences were positive and greater than 0.010 mm, or into ‘falling points’ when the differences were negative and greater than 0.010mm. Those successive readings that show differences of less than 0.010 mm, in either, positive or negative directions, were classified as ‘no change’. Finally, each one of the 142 TMEM positions were classified in one of the three categorical groups (rising point, failing point and no change point) according

Table 3 Pairwise comparison of the ANOVA analysis results between microrelief surveys at s’Alavern shore platform supratidal TMEM bolt site. Bold numbers correspond to significant changes in microtopography

TMEM survey (I)	TMEM surcvey (J)	Mean difference (*I–J*)	Std. error	Sig.	95% confidence interval for difference	
					Lower bound	Upper bound
2004	2005	0.061	0.034	0.435	−0.029	0.150
	2008	0.178	0.039	**0.000**	0.072	0.283
	2021	0.404	0.030	**0.000**	0.322	0.485
2005	2004	−0.061	0.034	0.435	−0.150	0.029
	2008	0.117	0.022	**0.000**	0.059	0.176
	2021	0.343	0.036	**0.000**	0.246	0.439
2008	2004	−0.178	0.039	**0.000**	−0.283	−0.072
	2005	−0.117	0.022	**0.000**	−0.176	−0.059
	2021	0.226	0.037	**0.000**	0.127	0.324
2021	2004	−0.404	0.030	**0.000**	−0.485	−0.322
	2005	−0.343	0.036	**0.000**	−0.439	−0.246
	2008	−0.226	0.037	**0.000**	−0.324	−0.127

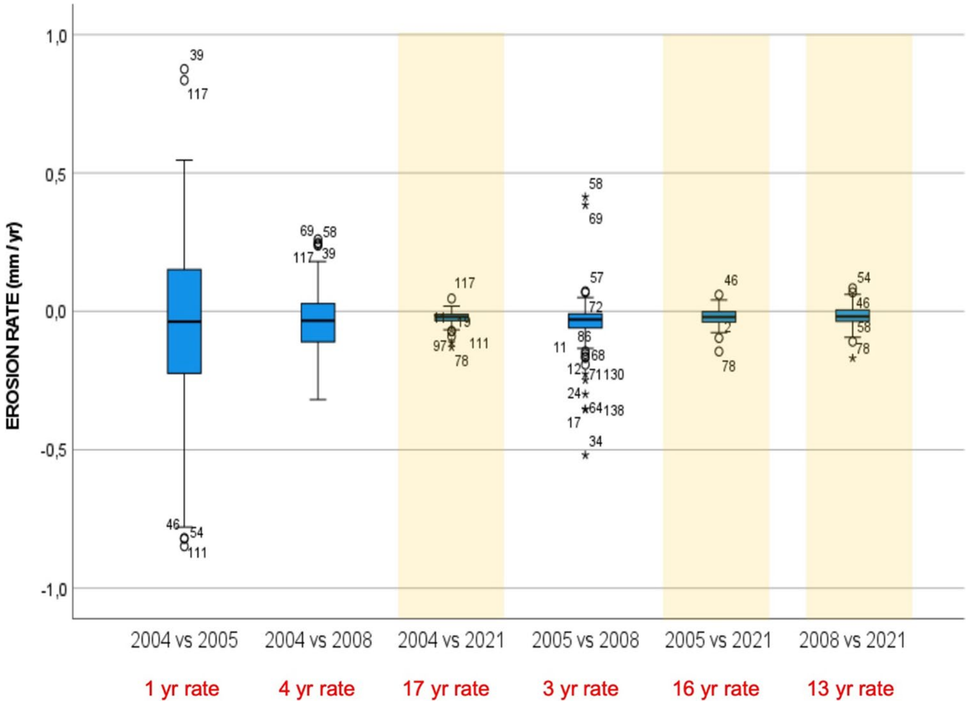

Fig. 6 Box-plots of microrelief change rates for different survey time periods

Table 4 Descriptive statistics of TMEM erosion rates (in mm) from different time intervals at s'Alavern shore platform supratidal TMEM bolt site

	2004–2005 1-year rate	2004–2008 4-year rate	2004–2021 17-year rate	2005–2008 3-year rate	2005–2021 16-year rate	2008–2021 13-year rate
N	143	143	143	143	143	143
Mean	−0.048	−0.043	−0.024	−0.041	−0.022	−0.018
Median	−0.379	−0.034	−0.197	−0.294	−0.020	−0.019
Std. dev.	0.315	0.115	0.022	0.925	0.028	0.034
Variance	0.100	0.013	0.000	0.009	0.001	0.001
Minimum	−0.848	−0.378	−0.130	−0.519	−0.145	−0.169
Maximum	0.875	0.261	0.046	0.414	0.061	0.083
Percentiles						
25	−0.230	−0.112	−0.035	−0.061	−0.039	−0.036
50	−0.378	−0.334	−0.197	−0.029	−0.206	−0.019
75	0.151	0.028	−0.103	−0.009	− 0.001	0.005
100	0.875	0.261	0.046	0.414	0.060	0.083

Negative values correspond to erosion rates, and positive one to swelling rates

to their modal surface change pattern during the whole short-term survey. This three categorical groups of surface behaviour at short temporal survey were used to evaluate if these same points experienced different erosion rates at long term scale (2004 vs 2021). Figure 6 shows that all the categorical groups at long term include both positive and negatives rock surface change rates. Those points that, during 24-h monitoring, have a model behaviour in which the rock surface tends to descend, at large time scale experience higher erosion rates than those points that, during 24-h monitoring, have modal behaviours classified as stable or as rise. The average erosion rate at large time scale was of 0.026 mm year^{-1} for those point classified as modal failing points at 24 h-surveys, 0.024 mm year^{-1} for rising point and 0.021 mm year^{-1} for stable or no moving points (Table 4). Nevertheless, and being the error variance equal across groups and existing an apparent pattern on the estimated marginal means of long-term erosion for each categorial group (Fig. 7), the univariate inter-treatments ANOVA analysis, shows that the differences between populations are not significant ($p > 0.005$) (Table 5). This means that the rock surface change patterns at short-term scale do not predispose in a conclusive way a surface behaviour at long-term scale.

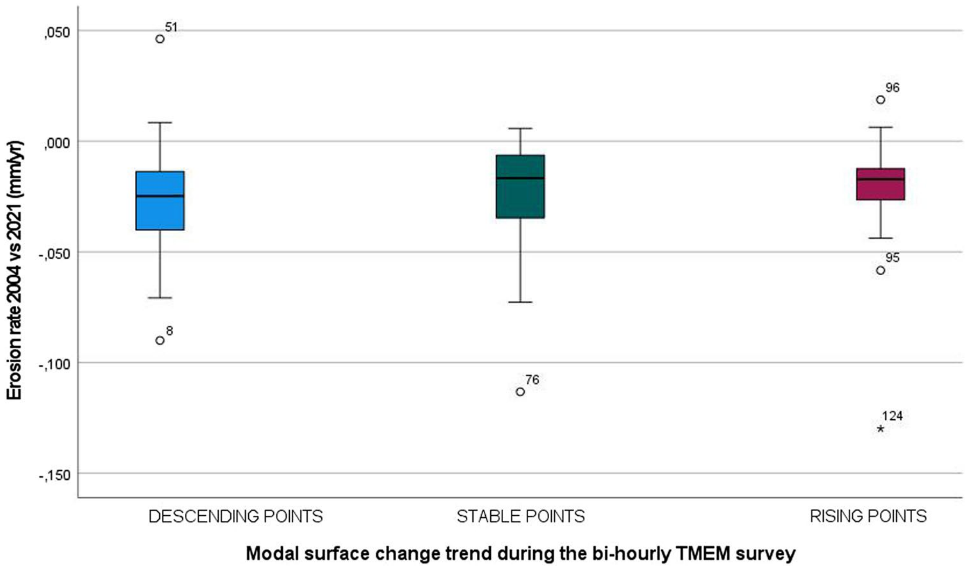

Fig. 7 Microrelief change rate at large-time scale (decadal) against modal trend of TMEM reading points at short-time scale (bi-hourly)

Table 5 Univariate ANOVA (inter treatments) for large term the erosion rates at s'Alavern shore platform supratidal TMEM bolt site grouped according their modal surface trend (ascending, descending, no change) in short-term surface change survey

Source	Type II sum of squares	*df*	Mean square	*F*	Sig	Partial eta squared	Noncent. parameter	Observed power[b]
Test of between-subject effects								
Corrected model	0.001[a]	2	0.000	0.694	**0.502**	0.010	1.387	0.165
Intercept	0.079	1	0.079	166.548	0.000	0.545	166.548	1.000
Modal trend	0.001	2	0.000	0.694	0.502	0.010	1.387	0.165
Error	0.066	139	0.000					
Total	0.148	142						
Corrected total	0.67	141						

[a] *R* squared = 0.010 (adjusted *R* squared = − 0.004)

[b] Computed using alpha = 0.05

Discussion

Results show that supratidal limestone rock surface at s'Alavern shore platform have experienced a significative change in microrelief from 2004 to 2021, resulting in an average relative height decrease from 4.31 mm to 3.91 mm. One of the critical findings from this supratidal rock surface monitoring programme is that the rock surface change rate tends to reduce their magnitude and variance as time interval between TMEM readings increase. In other words, erosion rates obtained from comparing the same TMEM positions separated by 17-, 16- or 13-year survey, shown erosion rates which are half that the rates obtained in samplings separated by 4 years or less. This pattern does not match results from other authors who have published studies with long-term TMEM. For example, Stephenson et al. (2019) presented a database, where there are different TMEM bolt sites in different profiles along the Kaikoura Peninsula (New Zealand). In this study there are cases, such as KM3B or KM3H, or KM1A itself (Table 1, p. 7) in which it is possible appreciate how the rate of erosion decreases along time. For instance, at most supratidal zone is of 1.078 mm year^{-1} calculated from a 2-year survey, 0.832 mm year^{-1} for a 10-year survey and 0.656 mm year^{-1} for a 20-year survey. Although this attenuation pattern is not as significant as in the case we are dealing with in the present paper, and that on the contrary there are other bolt sites that increase their erosion rate over time. Something similar can be seen in the results of Trenhaile and Porter (2018), although in a very different context to the environment of the New Zealand platforms and with a more important role of cold-related processes. For instance, on the coastal platforms of Mont Louis, at Québec (Canada) the most supratidal bolt sites (e.g., TMEM 6 at Line 3; Table 1, p. 95) show erosion rates of 1.02 mm year^{-1} for 6-year surveys but the rates are reduced to 0.45 mm year^{-1} for 10-year survey. Although it is also true that many other bolt sites in this study remain constant or increase their rate of erosion along time. Stephenson et al. (2010) showed that erosion rates calculated over longer time periods are reduced compared to short-term rates. At some point they attributed this behaviour to a technical disturbance, as the results of faster eroding bolt sites, where lost and these points were removed from the data set they used. Despite of this, when they compared the erosion rates means between short and long time periods, they did not find significant differences between the data sets. However, the results of the cited works, show the erosion rates as the average of all the TMEM readings of the same bolt site; while in the present work, we addressed the 143 erosion rates values at subsite scale. This point is important, because not only we compare the behaviour of microtopography at short time intervals (i.e., annual rates), but we can also explore how microtopography changes on a daily or hourly scale relate to behaviour at long time scales.

Gómez-Pujol et al. (2007b) showed that bi-hourly microtopography changes at s’Alavern supratidal shore platform responded to a biological forcing of the rock surface, since maximum ‘swelling’ or the number of TMEM ‘rising points’ accounted during periods of the increase of humidity (30–70%), whereas the maximum number of TMEM ‘falling points’ accounted when temperature increased and the maximum number of TMEM ‘no moving’ points where registered during maximum insolation hours (21–34°C). Because the surface microtopography pattern was opposed to the thermal expansion and contraction, and because SEM exploration revealed an intense biofilm colonization below the rock surface, it was concluded that those changes of 0.03 mm ascending or descending points were triggered by the biolfim’s hyphae wetting and drying. This pattern has also been identified in other locations worldwide by Gómez-Pujol et al. (2007a), Yuan et al. (2018) and also in laboratory conditions by Yuan et al. (2019). It is interesting to note that the changes in the hourly scale detected in s'Alavern have an order of magnitude similar to that of the annual rates. If the averages of the erosion rates obtained in intervals of 1 or 3 years, are around 0.41–0.47 mm year^{-1}, with maximum decreases between 0.32 and 0.84 mm year^{-1}and maximum ascents of 0.24 and 0.88 mm year^{-1} (Table 4), the fluctuations on a bi-hourly scale are -0.30 to 0.35 mm (Gómez-Pujol et al. 2007a). This could imply that biogeomorphological processes by themselves could explain or be responsible for microtopography changes on short time scales (hourly, seasonal, annual). It would be logical to think that those positions of the TMEM that experience more changes in the microtopography during the short time cycles, due to an increase in the fatigue of the rock, would result in a TMEM position with larger downwearing rates on the long-time scale. However, the results obtained on the coastal platform of s'Alavern (Fig. 6) and the ANOVA indicate that there are no significant differences regarding the erosion rate on a decadal scale with respect to the modal behaviour of the microtopography to fluctuations on an hourly/daily scale. What this result suggests is that the biological forcing that has been identified in the short term loses prominence as the time between TMEM surveys increases. It is clear from Fig. 5 that when the time between readings is larger than 10 years, at subsite level, the rock surface evolves more homogenously, erosion rates are lower and variance among the 143 TMEM readings is significantly reduced. Trying to answer the question of why the magnitude of microtopography changes at short temporal scales are not maintained over time; or what is the same, why the biogeomorphological driver loses power on a decadal scale, leads us back to the classic debate between the role of waves and weathering in the shaping of shore platforms. Although it cannot be forgotten, as Viles (2013) notes, the importance of the interconnection between different erosion mechanisms, empirical data from south-eastern Australia points up that in those sectors of the shore platforms, where the action of the waves dominates over the weathering processes, erosion rates tend to present values more homogeneous at both, the spatial and temporal level (Yuan et al. 2020). Very close to the coastal platform that is the subject of this study, Gómez-Pujol et al. (2006b) quantified the roughness of the rock surface at the millimetre scale on different rock surfaces, some in the intertidal, the others in the supratidal. One of the conclusions of this study was that the roughness of the intertidal zones subject to the most frequent action of the waves was smaller and more homogeneous than the microroughness of the supratidal zones, where weathering processes attacked the rock more punctually and less homogeneously in spatial terms. If we extrapolate these results to the patterns we have detected in the evolution of rock surface microtopography as the time between TMEM readings increases, and if we consider that the longer the time between samples, the more likely storm waves wash the surface of the shore platform is also greater, then we can conclude that this action of the waves on the surface of the rock at the subsite level would be more homogeneous, and the erosion rates would present similar values both on spatial and temporal scale. Data from Fig. 3 shows how wave energy sweeping s’Alavern shore platform until 2008 was less energetic, that the waves that have been washing the platform surface from 2008 to 2011. During this last period, each month there was at least once sea storm event with enough significant wave height for sweeping the platform surface and reach the TMEM station.

These facts have a methodological implication regarding the use of TMEM and sampling times when working in environments with erosion rates that are not excessively high or with a relatively resistant rock. Stephenson and Finlayson (2009), Stephenson et al. (2019), Yuan et al. (2020) or Gauci et al. (2022) conclude that 3 years of sampling are sufficient to extrapolate erosion rates from the TMEM and that the rates obtained, although they tend to decrease as the sampling time increases, in terms of average are not significantly different. In this study, however, in a microtidal context, and according to the location of the most supratidal TMEM bolt sites, the results indicate that it is possible to obtain erosion rates, but some caution must be exercised in interpreting their meaning. Thus, at the subsite level, rates obtained with intervals of less than 4 years reflect the role of agents or processes more closely linked to weathering, among which biological ones play a prominent role. Biofilms do not colonize the rock homogeneously and tend to concentrate or accumulate more biomass in one context (depending on the porosity or characteristics of the grains, the type of contact between them, humidity, etc.) than in others. Therefore, within the subsite, and in addition to registering more important microtopography changes than those obtained on a decadal scale, there is a greater spatial variability of the response of the rock surface. In that sense, some caution must be exercised when extrapolating erosion rates to longer time frames, because it has been verified that the fluctuations caused in this case by agents, such as biofilms, are in terms of magnitude greater than those they register on a decadal scale and when other agents, such as the mechanical action of the wave, can play a more relevant role in the configuration of the microrelief. Which in our case translates into lower and more homogeneous erosion rates at the subsite level. Microtopographic changes forced at short-time scale, not necessarily result in similar erosion rates at larger temporal scale. In other words, the short-term rates overestimate, in the context studied, the erosion of the coastal platform. In poor-energetic marine environments and with rocks like the ones we are dealing with, at least 10 years of sampling is needed to be able to have conclusive values in relation to the shore platform downwearing. After all, the values of erosive rates obtained with the TMEM technique cannot be separated from the considerations of frequency and magnitude or of the action at different spatial and temporal scales, in the sense that they are considered for rock studies weathering both by Goudie and Viles (1999) and Viles (2001).

Concluding remarks

Surface lowering on microtidal limestone shore platform have been recorded over daily, 1, 3, 4, 13, 16 and 17 years using a TMEM. Erosion rates based on time intervals lower than 10 years are twice (ca. -0.45 mm year^{-1}) than those based on time intervals larger than 10 years (ca. -0.20 mm year^{-1}), erosion rates variance also decreases as the between TMEM readings increase. The comparison of short-time scale microtopography changes with large-scale changes highlight that agents or processes more closely linked to weathering, among which biological ones play a prominent role at short-time surface change, and waves at large-time surface change. The magnitude of short-time surface change not necessarily is equivalent or representative of the magnitude and values of the surface change at large scale. Therefore, despite in similar settings as we are dealing with, TMEM studies shorter than 3 years are useful for unravelling o characterizing the action of different weathering processes, this data should be managed with caution, since it is not useful for depicting or understanding the landform evolution. For this purpose, to capture efficiently the role of waves and marine physical effect on shore platforms, at least decadal TMEM surveys are needed.

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Data availability TMEM readings raw data used in this paper is available under request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

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