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Coastal Dynamics in the Black Sea Observed from Optical and SAR Satellite Images

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Abstract. This paper presents an overview of the approach developed to detect coastal dynamics by combining Synthetic Aperture Rader (SAR) and optical images. The method was developed with Sentinel-1 SAR and Sentinel-2 MSI images with a spatial resolution of 20 m, to detect the coastline changes in the Black Sea between 2016 and 2023. When compared with *in situ* measurements, the results showed that our approach provides reliable results with the rate of coastline change having a root mean square error of 1.73 m/year. In the Black Sea, around half the coastline changes are a result of natural process, and around 35% associated with coastal engineering. Natural coastline changes were mainly observed in deltaic areas, such as the Danube Delta. 91% of the artificial changes were found in the southern Black Sea coast on the Turkish coastline, and are a result of airport and harbour construction, and land reclamation activity. The results of this study can provide information on interventions that support the sustainable coastal zone management.

Keywords: coastal dynamics · shoreline · Earth observation · Black Sea

1 Introduction

Coastal zones are among one of the most productive environments, and provide essential ecosystem services to society (Turner et al., 2015). Coastal zones in the Black Sea are impacted by multiple pressures including sea level rise, increasing intensity of storms, changing wind and wave conditions, and also relevant anthropogenic disturbances (Vespremeanu & Golumbeanu, 2017). Monitoring and understanding coastal

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dynamics are crucial to identifying effective interventions that sustainably maintain the integrity of the coastal zone and the ecosystem services they provide.

The exploitation of satellite-based Earth observation provides an efficient way to monitor coastline changes due mainly to its characteristics of large spatial coverage and short revisit period, and the ability to reconstruct past previously unmonitored events (Luijendijk et al., 2018). Two types of remote sensing data can be used to monitor coastline changes: (i) optical imaging platforms; and (ii) synthetic-aperture radar (SAR) platforms (Apostolopoulos & Nikolakopoulos, 2021). The advantage of optical image is it can clearly distinguish land and water due to the contrast in the reflectance characteristics of bright land surfaces compared to darker water (Xu, 2006). However, optical images are impacted by clouds, shadows cast by cliff lines, and very high suspended sediment concentrations in the water. Whilst not being impacted by cloud, SAR images can be used to detect small morphological changes (Tsokas et al., 2022), but can suffer from noise introduced by waves, and vegetation change and boat traffic. Thus, a combined approach builds on the strengths of each sensor type.

This study aimed to: i) develop a method for monitoring coastline changes using the combination of optical and SAR satellite images; and ii) detect the coastline changes in the Black Sea between 2016 and 2023, whist focusing on the region of most significant changes, i.e., the Turkish Coastline.

2 Methodology

2.1 *In Situ* Data Collection

In situ coastline data were collected from the Romanian and Georgian coasts in the Black Sea between 2016 and 2023. The *in situ* coastline data were used to validate the accuracy of the satellite-extracted coastline, along with the satellite-detected coastline change rate and areas.

2.2 Satellite Data Processing

Sentinel-1 VH SAR images and Sentinel-2 MSI optical images with a spatial resolution of 20 m in July and August between 2016 and 2023 were downloaded from Google Earth Engine (GEE). For SAR images, we selected a reference image in 2016 and 2023, and subtract the reference from all images in other years to characterize the change taking place, then the average was calculated from the first step to establish the difference intensity. Accretion and erosion were identified from pixels where the difference intensity values were higher than 95% and smaller than 5% respectively.

For optical images, we firstly calculated the normalized difference water index (NDWI, Xu, 2006) using the following equation:

$$NDWI = (B3 - B11)/(B3 + B11) \quad (1)$$

where B3 is the green band and B11 is the near-infrared band from sentinel-2 MSI images. Coastlines from each year were then extracted from the NDWI images using a threshold determined from Otsu's method (Otsu, 1975). The coastline in 2023 was converted to points with a 100 m interval, and it served as the reference. For each point, the shortest distance to the coastlines in all other years were calculated. Finally, linear regression analysis was carried out for between years and the calculated shortest distances, and coastline change rates were determined from the regression slope.

The detected changes from SAR images and optical images were compared, and only the locations where both SAR images and optical images showed the same change direction (i.e., erosion or accretion) were treated as real coastline changes and kept for further analysis.

3 Results

We compared the extracted coastline from optical images with *in situ* measured coastlines in Romanian and Georgian coasts, they showed a very good agreement, and the detected coastline change rate from optical images agreed well with the value calculated from *in situ* data with a root mean square error (RMSE) of 1.7 m/year. The detected coastal change areas from SAR images also in line with the changes detected from *in situ*-measured coastlines (Jiang et al., 2025).

Applying the proposed method to the whole Black Sea coast revealed that there were totally 35.1 km^2 changes between 2016 and 2023, 50.2% of the changes are in the Danube Delta region (coast from Sasyk Lagoon in Ukraine to Cape Midia in Romania), which were mainly natural changes because of the interactions between Danube River and the Black Sea. 43.3% (15.2 km^2) of the changes occurred in the Turkish coast, and 72.5% of these changes are artificial changes associated with coast engineering, which accounts to 91% of all the artificial changes in the Black Sea coast. On the contrary, natural changes only accounts to 20.0% of the coastline changes in the Turkish coast, which is 15.9% of all the natural changes in the Black Sea coast (Table 1).

Table 1. Coastline changes in the Turkish coast between 2016 and 2023.

Type of change	Direction of change	Area of change (km^2)	Percentage of change in the Turkish coast (%)	Percentage of change in the Black Sea coast (%)
Natural change	Accretion	1.5	10.0	4.3
	Erosion	1.5	10.0	4.3
Artificial change	Advance	10.5	69.2	30.0
	Retreat	0.5	3.3	1.4
Other change	all	1.1	7.5	3.2

Natural changes appeared mainly where rivers, deltas, estuaries, barrier beaches, pocket beaches and sandy coasts occur. For example, the Danube Delta in the west, the Kızılırmak-Yeşilırmak deltas in the south, the Chorokhi-Rioni-Kodori River mouths in the east of the Black Sea (Jiang et al., 2025). Artificial changes mainly occurred in the Turkish coast because of constructions of airport, harbours, ports and so on.

At the Turkish coast, large artificial change areas are associated with the construction of the Rize-Artvin Airport, the Filyos Port, and the Istanbul Airport (Fig. 1b, and Jiang et al., 2025). In addition, the construction of İyidere Port (Fig. 2a-2c) provides another engineering induced example of coastline advance in the eastern Turkish coast. Land reclamation provides another driver of coastline advance along the Turkish coast, including reclamation on the Kirazlık (Fig. 2d-2f) and Türkeli coastlines (Fig. 2g-2i).

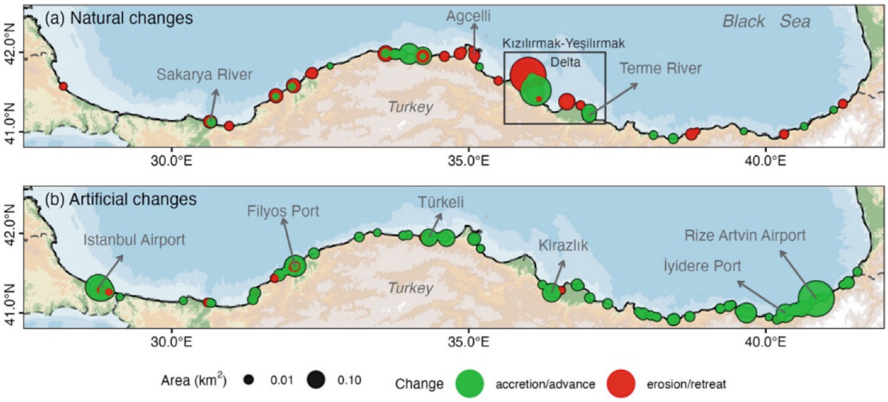

Fig. 1. Natural and artificial changes in the Turkish coast detected from optical and SAR images between 2016 and 2023. Size of the circle represents the change area. Green and red represent accretion (advance) and erosion (retreat), respectively.

The most substantive natural changes along the Turkish coastline occurred in the Kızılırmak-Yeşilırmak deltas, which are the two main rivers flowing from Turkey into the Black Sea (Fig. 1a, and Jiang et al., 2025). Other natural changes on the Turkish coastline, tend to occur close to river mouths, but tend to be less significant than those in the Kızılırmak-Yeşilırmak deltas. For example, accretion was observed in the southern flank of the Terme River mouth (Fig. 3a-3c), accretion and erosions were observed in the Sakarya River mouth (Fig. 3g-3i). Examples also exist where erosion is associated with currents of the Black Sea, such as along the Agcelli coast (Fig. 3d-3f).

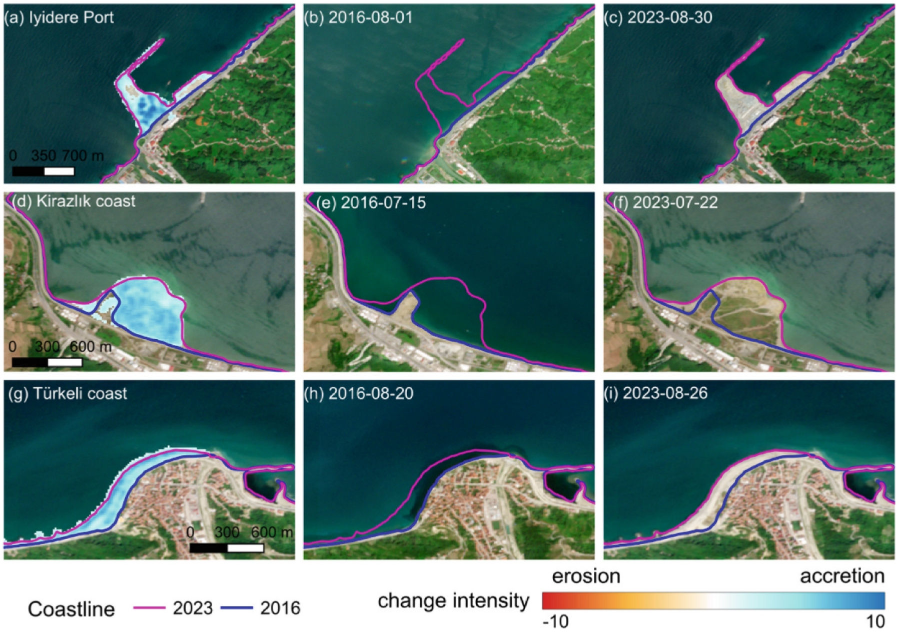

Fig. 2. Examples of artificial changes in the Turkish coast from 2016 to 2023. (a)-(c) İyidere Port, (d)-(f) Kirazlık coast, (g)-(i) Türkeli coast. Pixel colour scale represents the difference intensity (DI) from SAR images, dark blue and pink lines represent the coastlines in 2016 and 2023 respectively. Background images are from Sentinel-2 MSI true colour imagery.

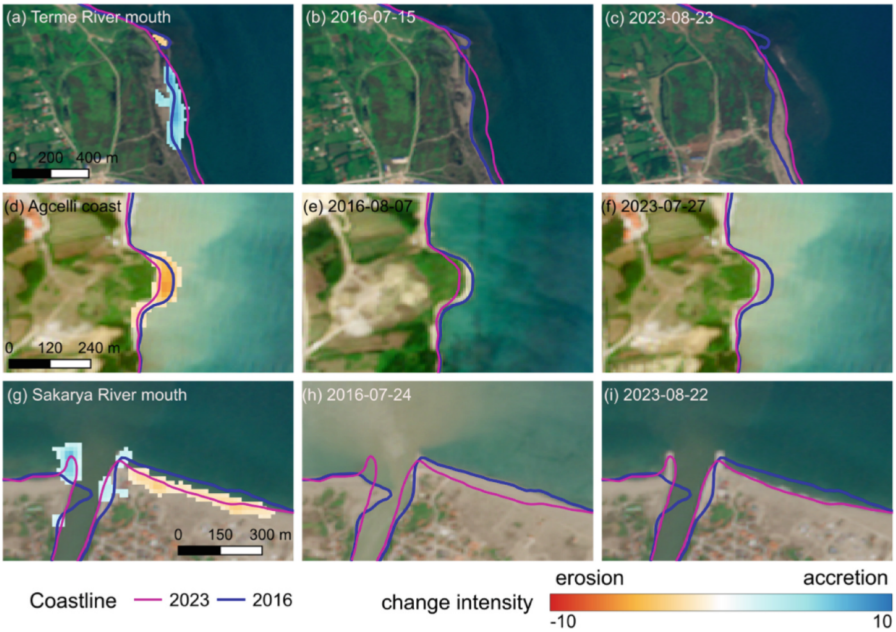

Fig. 3. Examples of natural changes in the Turkish coast from 2016 to 2023. (a)-(c) accretion in the Terme River mouth, (d)-(f) erosions in the Agcelli coast, (g)-(i) accretion and erosion in the Sakarya River mouth. Pixel colour scale represents the difference intensity (DI) from SAR images, dark blue and pink lines represent the coastlines in 2016 and 2023 respectively. Background images are from Sentinel-2 MSI true colour imagery.

4 Discussion and Conclusions

The method proposed in this study provides an efficient and accurate way for coastal dynamic monitoring, which is very useful in large area monitoring and in areas where *in situ* data are not available. The use of optical and SAR data provides not only the rate of coastline change, but also the change in surface extent. In addition, the matching procedure of the detection results from the two types of images used in this method serves as a cross validation, which demonstrates the reliability of the approach. Nevertheless, some limitations in the proposed method remain: (i) the method is not able to detect small changes (e.g., groynes), limited only by the spatial resolution of the satellite data, in this case 20 m; (ii) the method has only been validated in the Black Sea coast, which has a negligible tidal range and has not be tested in coastlines impacted by large tidal ranges; and (iii). Vegetation changes on the land adjacent to the coast can influence and lead to overestimation of the change estimated from SAR imagery. Further studies are still required to refine the approach.

Nevertheless, the results demonstrate a good agreement with previous studies of the Black Sea coast. Natural erosion and accretion in the Danube Delta were reported by Cherkez et al. (2020), occurring mainly in river mouth area. Coastal erosion in the Yeşilırmak Delta were reported by Kuleli et al. (2011) and Kale et al. (2019), and associated with the change of sediments supply because of dam construction in the river catchment. However, we didn't observe significant coastline changes in the northern Bulgarian coast as reported by Stanchev et al. (2018). This is likely, because they used very high spatial resolution data from field survey and orthophoto images.

Comparing our results with the shoreline types reported by Tătui et al. (2019), we found that natural changes we identified in this study are mainly located in the coast areas characterised by sand and pebbles. We also found that 91% artificial changes are located in the Turkish coast, indicating significant human activities in the study period. The observable activities from satellite images include the new constructions of airport, harbours, ports, and some land reclamations in the Turkish coast. Those activities may have posed impacts to the coastal habitats and aquatic ecosystem in the Black Sea. In addition, this study demonstrates the level of influence of human activities in the coastal zones. Besides reducing river sediment supply sources by damming and embankment, the direct interventions in the coastal zones and extensive constructions play a major role in some areas of the Black Sea (e.g., the Turkish coastline) on the same order of magnitude with the natural changes.

Despite some limitations, the methodology developed provides a systematic synoptic approach to assessing coastal dynamics and an approach that could help target sustainable interventions to sustain the integrity of the vulnerable coastal areas and the ecosystem services they support.

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Sensing Short-Term Adaptive Cycles in Mesotidal Energetic Beaches from Satellite Imagery

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Abstract. The rapid development of approaches to automatically detect and extract shorelines from satellite imagery is revolutionizing the way we study coastal systems, offering deeper insights into their dynamic responses and adaptive capacities. This study evaluates the performance of the CoastSat toolkit in detecting shoreline retreat and recovery at Praia de Faro beach, South Portugal, following storm Emma in March 2018. The mesotidal, low-tide-terrace beach experienced significant erosion, with an average retreat of 20 m. PlanetScope imagery is used to assess shoreline detection accuracy, due to its higher temporal coverage compared to other open-access satellite constellations. This includes understanding the correspondence between the detected waterline and two water levels: the tide level and the instantaneous water level (combined effect of wave runup and tide). Linear water level corrections are applied to horizontally translate the detected water levels to a reference elevation that enables temporal comparisons. Results suggest that beach morphology strongly influences optimal correction approaches due to the type of beach response to storms, such as profile rotation. Under non-storm conditions, detected waterlines generally represent astronomic tide levels. While tide-level-based corrections improve accuracy during storms, runup-based corrections consistently outperform under non-storm conditions. Consequently, applying corrections that account for slope changes, runup levels during non-storm conditions, and tide level under storms enables the detection of storm impacts and recovery with an accuracy of approximately 6 m in Praia de Faro. These findings highlight the importance of tailoring detection methodologies to the morphological state of the beach as it evolves over time.

Keywords: Shoreline detection · Storms · Morphological state

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1 Introduction

There is growing consensus on the understanding that resilient coasts are not necessarily stable, but dynamic and adaptive systems changing in response to external disturbances [1]. Especially under increasing future uncertainty and changing conditions, system resilience needs to be assessed by approaches centered on evolution and adaptation [1]. The increasing availability, resolution and spatial coverage of satellite imagery opens new means of deriving reliable, continuous and long-term data in the coastal zone, enabling the reconstruction of adaptive cycles at temporal scales ranging from months to decades. Yet, the application of these data depends on their accuracy and temporal frequency. Accuracy limitations are usually linked to the definition of the shoreline and the ability to identify the desired transition [2], and to the correction of the extracted shorelines, especially as tidal range increases [3]. Strategies to improve the accuracy of results include not only tidal corrections but also, but also, and depending on the beach state [4], runup, swash or surge levels [4, 5].

Here, we explore automated shoreline detection from satellite imagery, focusing on its performance under the impact of storms. This exercise is intended to assess short-term beach profile adaption cycles at the mesotidal, energetic coast of South Portugal, namely at the (intermediate) low-tide-terrace (LTT) beach of Praia de Faro. Shoreline retreat induced by storm Emma reached values around 20 m while recovery profiles recovered up to 91.7% of the eroded volume after two months [6]. The magnitude of the observed retreat and the rapid recovery, offer a challenging example in terms of beach morphodynamics to test the accuracy and sensing ability of satellite-derived shorelines.

2 Approach

The present work applies the open-source python-based CoastSat toolkit [7, 8] for the detection of satellite-derived shorelines (SDS), to explore shoreline changes associated with the impact of the Emma storm (28 February to 5 March 2018) in Praia de Faro (Fig. 1). The lower revisit period of PlanetScope (PS), compared to Landsat 7 and 8 and Sentinel-2, leads to higher availability of imagery with low to none cloud coverage (41 versus 5, 4 and 12, respectively) around the storm. Due to the high temporal coverage of PS, the analysis uses PS imagery obtained between 3 February and 28 April.

First, we evaluate the effect that extraction parameters related to the thresholding techniques have on the extracted satellite derived waterlines (SDWLs), by evaluating the correspondence between the SDWL and two water levels: (1) the tide water level, accounting for surge and astronomic tides, and (2) the instantaneous water level, accounting for wave runup. The first was obtained from the Huelva tidal gauge (Redmar network, Puertos del Estado) and the second was calculated [9] using wave time-series from Faro buoy (Fig. 1). The transition or threshold value that separates water and sand is computed applying the weighted peaks (WP) thresholding approach [8]. The sensitivity of the shoreline detection to the constant parameter (peak fraction) is evaluated by extracting five datasets using peak fraction (pk) values ranging between 0.6 and 0.8.

Then, we examine the possible influence of the beach morphology to the horizontal correction of extracted SDWL to a common elevation contour to enable temporal comparison of SDS. For the case of Praia de Faro, this level corresponds to the top of the beach berm, which is around 3 m above mean sea level (MSL). Three beach profiles from RTK-DGPS surveys before and after the storm are used to assess the accuracy of the SDS (profile PW, PC and PE; location Fig. 1). One of the profiles (PE) is backed by a foredune while the other two have rip rap seawalls (PC and PW).

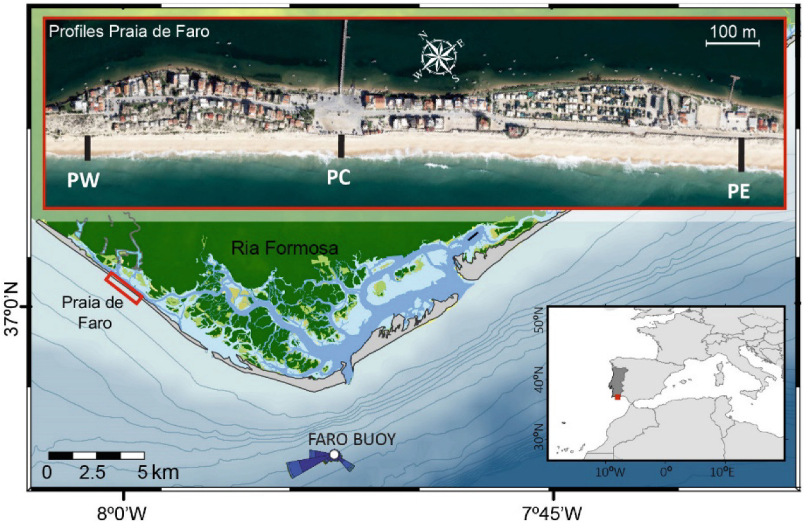

Fig. 1. Location of the study area and in situ measured profiles.

3 Results

3.1 Satellite Derived Waterlines and Water Levels

Five sets of SDWL were extracted from PS imagery using a range of pk values (0.6 to 0.8 with a step of 0.05). The greater the pk value, the landward the position of the SDWL. This difference increases during low tide and storm conditions, reaching values of 20 m between the two extreme values. Examining the position of these lines with the corresponding images, one can observe that the indicator detected is the transition between the wet and the dry sand or the water if the image coincides with the upwards excursions of the swash. The wet sand seems associated with water saturation when the tide is low and the LTT is exposed or with the latest swash/runup excursion across the beachface. Therefore, the landward-most line appears to better represent the wet/dry transition, especially when tides are low. The elevation in the measured profiles, corresponding to the horizontal position of the SDWL, was extracted in order to compare with tide and runup levels. The results do not show a clear correspondence between the water levels and the projected elevations, with the latter systematically corresponding to levels greater than the tides and lower than the estimated runup. The estimated RMSE values are approximately 1 m for both tide and runup levels (Table 1). Errors decrease for tide levels as pk values are reduced (e.g., pk = 0.6, RMSE = 0.68 m) but increase for runup levels, reaching 1.37 m. Bias values are also around 1 m, with the tide consistently showing a negative bias and the runup showing a positive one. These results suggest that the level captured by the SDWL may correspond to the tide level, which is more accurately represented when pk = 0.6.

Table 1. Accuracy results (meters) for the extraction and correction of shorelines. Comparison between the elevations of the SDWL in the profiles and the tide and runup levels in the first row.

		pk = 0.6 tide	pk = 0.6 runup	pk = 0.8 tide	pk = 0.8 runup
SDWL height & WL	RMSE (Bias) All profiles	0.7 (−0.3)	1.4 (1.2)	1.1 (−0.9)	1.1 (0.7)
Constant slope	RMSE (Bias) All profiles	18.1 (−9.3)	24.0 (−19.5)	16.18 (2.3)	20.5 (13.7)
Variable slope	RMSE (Bias) All profiles	7.9 (0.9)	16.6 (−13.7)	9.2 (−7.7)	12.9 (7.4)
Constant slope	RMSE (Bias) Non-storm	10.5 (−3.3)	15.2 (−12.5)	8.3 (−4.8)	7.1 (4.9)
Variable slope	RMSE (Bias) Non-storm	8.3 (−0.1)	11.6 (−8.5)	9.7 (−8.3)	4.7 (2.2)

3.2 Satellite Derived Shorelines

Corrected shorelines were obtained by projecting the SDWL to the 3 m contour above MSL, which reflects volumetric changes across the profile for the study area. RMSE values indicate poor performance when the correction assumes a constant beachface slope (Table 1) and slight improvements for pk = 0.8. Accuracy significantly improves when observed beachface slope variations are incorporated, reducing errors to below 10 m for the tide level corrections. Notably, better fits are achieved for non-storm conditions, highlighting the challenges of correcting for storm conditions. Excluding storm conditions reduces RMSE to approximately 5 m when applying pk = 0.8, variable slope and runup-based corrections.

A final analysis suggests that greater accuracy is achieved when corrections are tailored for each profile. For profile PE, tide-based corrections with pk = 0.8 provide the best fit before and during the storm, whereas runup-based corrections perform better immediately after the storm passage. For profiles PC and PW, runup-based corrections yield better results, except during the storm. Incorporating these specific adjustments can improve the overall RMSE to 4.6 m (pk = 0.8). While this demonstrates the potential for increased accuracy, applying such tailored corrections to long-term datasets may not be practical due to uncertainties beyond the validation data. Consequently, we found that using runup levels to correct shoreline positions under non-storm conditions and tide levels during storm conditions across all profiles slightly reduces accuracy but provides an acceptable result, with an RMSE of 5.7 m. Applying the correction criteria to the three-month SDWL dataset yields promising results, effectively capturing the storm-induced retreat and recovery, with relatively stable SDS observed before and after the storm passage (Fig. 2). Still, the profiles backed by hard structures (PC and PW) show higher error with in-situ measurements than the natural profile (PE).

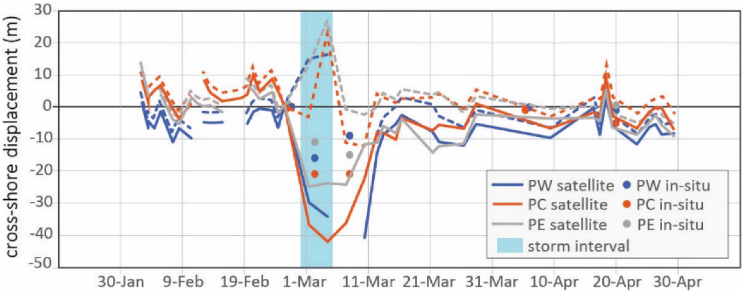

Fig. 2. Time-series of cross-shore changes. Dashed lines show the results for constant slope.

4 Discussion

This work evaluated the potential of different satellite platforms to capture storm erosion and recovery at a mesotidal intermediate LTT beach in southern Portugal. The greater temporal frequency of PS compared to Landsat 7 and 8 and Sentinel-2 made it a highly reliable source of data for the storm impact evaluation in the area. The application of different thresholds to separate water from sand during SDWL extraction from Coastsat [8] helped to identify the best solution for the study area. The results indicate that the detected SDWLs represent the tide level, improving with thresholds that push the lines towards the water (i.e., low peak fraction). However, when shoreline position corrections are applied under non-storm conditions, runup-based correction and thresholds shifting the lines landward, retrieve better accuracies. Alternatively, tide-based corrections perform better during storm conditions. One question arising from these results is the discrepancy between the water level identified by the satellite and the level that performs better for horizontal correction. This becomes more pronounced during low tides when the LTT is exposed, suggesting that uncertainties may stem from the average slopes used for correction, which do not represent the profile complexity. However, testing this hypothesis is not possible with the available data, as the profiles do not extend to the entire LTT morphology. In general, we find that accuracies improve if the changes in slope are considered and that uncertainties might be derived from the complex LTT beach morphology, where two contrasting slopes define the upper and lower intertidal zone of the profile. The observed storm-induced erosion in the study area flattened the profile, inducing profile rotation and pushing the detection lines seaward because of the storm impact. Thus, if the slope is not considered, the results give the opposite response with enlargement of the beach under storm impact and the transfer of sand to the lower part of the profile. Previous works found that alternative water level definitions for horizontal correction of shorelines might be required, depending on the beach morphologic state [4]. The authors found that tidal elevation led to substantial accuracy at reflective beaches, while accounting for wave-induced water fluctuations performed better in dissipative sites. Other works found that accounting for the changes in slope did not improve accuracies [10]. The discrepancy between this statement and our findings can most likely be attributed to the two distinct types of beach response of flattening and retreat [11]. Flattening requires approaches that incorporate slope changes to account for profile rotation, whereas under retreat quasi-stable slope can be assumed.

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Risk Communication by Coastal Geoscientists

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Abstract. Storms often harm coastal communities, a situation expected to worsen due to climate change and urban development. Effectively communicating with diverse audiences is thus critical for adapting to and attenuating increased coastal risks. This research focuses on risk communication by Coastal Geoscientists and Engineers, aiming to assess their perspectives and practices. The method used was an online questionnaire, with data collected in 2022–2023. The sample (n = 133) average age was 45, with slightly more men and mostly from Europe. About 95% of participants reported engaging in public communication, and most do coastal risk communication. Direct interaction with audiences such as public talks (74%) is preferred over indirect communication, and 79% had at least one annual contact with a journalist. Participants believe decision-makers should be more informed about risk location, frequency of occurrence, and how to engage citizens with coastal risk. However, this does not align with their top communication subject (coastal physical processes). Some significant differences were found in how gender, professional roles, and scientific backgrounds influence perceptions and priorities in coastal risk communication.

Keywords: Science Communication · Geoscience outreach · Coastal Risk · Engagement with society

1 Introduction

Storms on coastal areas often damage urban shorelines, placing coastal communities at immediate risk. In 2020, 2.15 billion people lived in the near-coastal zone and 898 million in the low-elevation coastal zone globally [1]. Consequently, significant areas, infrastructures and people are at risk from coastal hazards including storm surges, inundations, waves, and coastal erosion. Furthermore, the coastal risk is likely to increase in the future due to climate change and ongoing coastal development [1, 2]. Hence, scientific and management organizations bear ethical obligations to provide useful information about the risks people face when benefiting from being in coastal areas.

Communicating with diverse audiences is critical for adaptation to, and mitigation of increasing coastal risks and developing plans for integrated coastal management [3]. Though studies have been addressing the complexity and putting forward best practices in risk communication (e.g., [4]), there is still a lack of tailored science communication

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strategies efficient at engaging citizens in coastal risk and thus augmenting the success of the coastal adaptation processes [5].

Communication of coastal risks, as with all other scientific areas, relies on the joint efforts of several professional groups (including scientists, science communicators, journalists, policy-community mediators, and decision-makers). The current research is focused on an informal scientific field - Coastal Geoscience and Engineering (CGE). CGE, defined by [6], encompasses professionals working on coastal processes, integrating expertise across physics, geomorphology, engineering, and management. CGE has many topics suitable for public engagement with science, such as the impact of storms, tidal currents, coastal management, coastal evolution, sea-level rise, ecosystem services, and climate change.

The main objectives of this research were to have an international depiction of science communication done by CGE, identify their perspectives for communication, and assess what they think and how they do risk communication.

2 Methods and Sample

The method to collect data was a self-administered online questionnaire with 25 closed questions, taking an average of 10 min to complete. A comprehensive description of data collection and analysis can be found in [7]. Experts' names were extracted from three major international conferences: Coastal Sediments 2019, Coastal Engineering 2020, and Coastal Dynamics 2021. Data was collected between September 2022 and March 2023. Of the 975 contacts extracted from the proceedings, 133 responses were obtained (14% response rate).

Most respondents were male (n = 71, 53.4%), with a mean age of 45.4 (SD = 11.2). The sample average age was 45 and closely balanced between Natural Sciences (51%) and Engineering. Main participants' career status were researchers (n = 57, 42.9%), Assistant/Associate Professors (n = 22, 16.5%) and Full Professors (n = 19, 14.3%). Most participants were from the European continent (n = 95, 71.4%), even though North America and Oceania had over 10 replies in each case.

Experts' perceptions and attitudes towards science communication, reported practices and opinions about coastal risk communication were assessed using descriptive statistics. Mann-Whitney U tests were conducted to find potential differences according to sociodemographic characteristics (gender, professional category, and scientific background). In the case of gender, the analyses exclusively focused on male and female participants due to the limited representation (3.8%, n = 5) of other genders (e.g., non-binary).

3 Results and Discussion

3.1 Perspectives and Practices of Science Communication

Only 5% of respondents to the survey said they do not communicate with a lay audience. In other studies, the percentage of researchers who do not communicate is higher, as reported by [8] regarding geoscientists (24%); [9] regarding Portuguese geoscientists

(11.5%); [10] concerning USA climate scientists (27%); and [11] on UK scientists (26%). Most CGE participants (79%) consider science communication as part of their job. Nevertheless, they identified barriers to these activities, the most frequent was the lack of time due to other obligations (as recorded by [9, 11]). Direct interaction with audiences is preferred (e.g., lectures, talks, 74%), over indirect ways of communication (media and social media). The public sector (e.g., municipalities, 55%) and school students (43%) were the main audiences. About 79% had at least one contact per year with a journalist, a value comparable to results obtained by other studies [10, 12]. For most aspects of science communication, differences in opinion according to gender, age, and professional category were not significant. However, it was found that more women perceived the lack of communication training as an obstacle, and had a greater tendency towards hands-on activities. The interaction with journalists was significantly more frequent among men, professors, and older individuals.

3.2 Risk Communication

The majority (82%) of participants engaged in coastal risk communication, focusing on the type of coastal hazards (59%), such as severe storms and sea-level rise (Fig. 1).

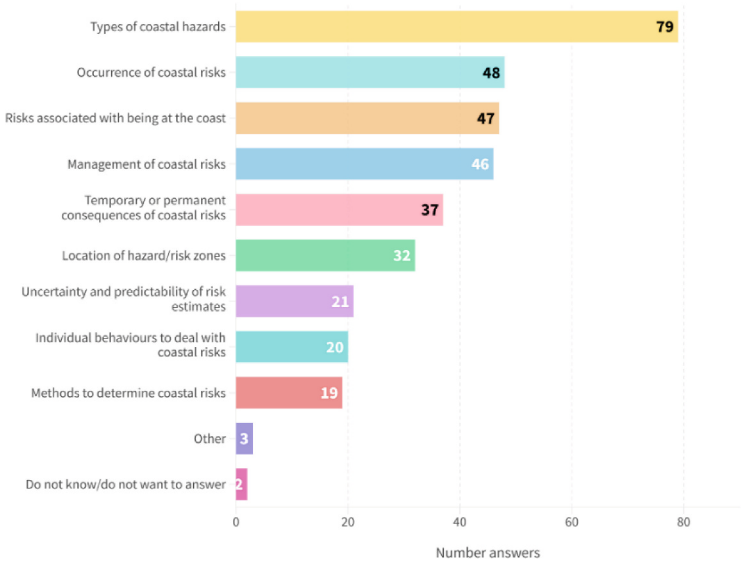

Fig. 1. Prevalence of participants' responses regarding coastal risk topics for communication. Note that multiple answers were allowed, therefore the sum is greater than 100%.

The least relevant topic was the methods to determine coastal risks (48%). Notably, 30% considered that individual behaviours in dealing with coastal risks are a less relevant topic for communication (Fig. 1). Men and women generally share similar perceptions and attitudes toward coastal risk communication, however, women more frequently signed the importance of communicating individual behaviours to deal with coastal risks.

Professors were marginally more likely to prioritise the description of 'Types of coastal hazards', as a primary topic for communication. On the other hand, researchers more frequently identified the risks associated with being at the coast, as a primary focus, a difference that reached statistical significance. Experts with an engineering background showed a greater emphasis on technical aspects of coastal risks. For example, they more frequently identified the 'Occurrence of coastal risks' as a main topic, with a marginally significant difference. Furthermore, 'Methods to determine coastal risks' were prioritised significantly more often by engineering experts. These findings suggest that scientific background significantly influences experts' priorities and attitudes toward coastal risk communication.

Participants think decision-makers should be more informed about risk location, the frequency of occurrence, and how to engage citizens with risk (Fig. 2). However, this does not align with the participants' top communication subject to decision-makers, which were the physical processes of coastal risks.

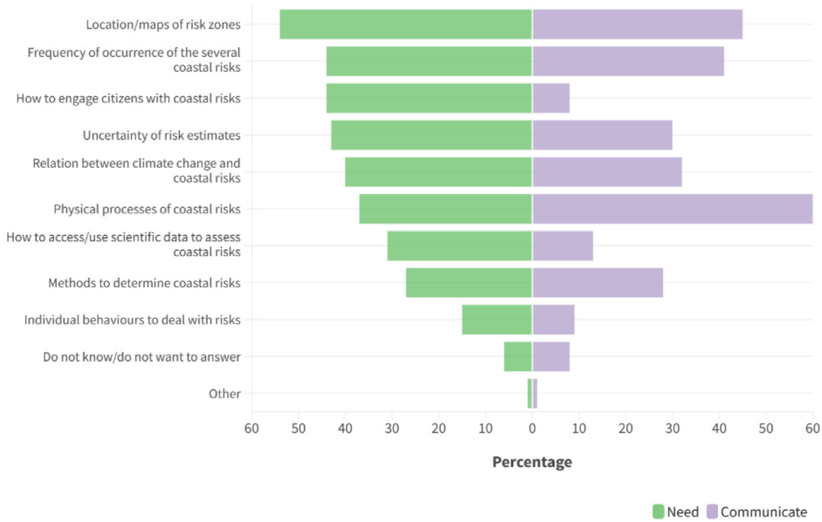

Fig. 2. Topics of coastal risk that researchers think decision-makers should know more about (left-hand side, green) and that researchers have communicated (right-hand side, violet).

The analysis of gender in experts' perceptions revealed no statistically significant differences. Notable differences emerged between researchers and professors in their perceptions of decision-makers' informational needs. Researchers prioritised 'Location/maps of risk zones', while professors 'Uncertainty of risk estimates'. Regarding communicated topics with decision-makers, professors were more likely to have addressed 'Methods to determine coastal risks' and the 'Relation between climate change and coastal risks'. These findings suggest that professors focus on methodological and contextual aspects of coastal risks, while researchers highlight spatial and participatory elements, reflecting a local approach. Experts from the natural sciences were more likely to prioritise 'Location/maps of risk zones' as a critical need for decision-makers, though this difference was marginally significant. Conversely, engineers reported more frequent communication about the ‘Uncertainty of risk estimates’. This significant discrepancy indicates that engineering experts place greater emphasis on addressing uncertainties in risk assessments, while natural sciences experts prioritise spatial information.

4 Conclusions

This study shows that 73% of the inquired researchers on coastal geoscience and engineering have been active in science communication for at least 1/year. Even considering that more productive researchers may communicate more [10] and that the sample is biased towards the more productive researchers, it is reasonable to conclude that CGE researchers are considerably active in science communication. Topics that are communicated, including risk assessment and impacts of climate change, are mainly tangible issues rather than more abstract science concepts. The findings suggest that the scientists involved in coastal risk are open and willing to communicate, and intend to engage with society and help citizens make informed decisions.

Overall, some significant differences were found in how gender, professional roles, and scientific backgrounds influence perceptions and priorities in coastal risk communication. Understanding these differences is essential for developing interdisciplinary and effective coastal risk communication strategies.

The study may have limitations concerning the sample size and representativeness of the community of coastal geoscientists and engineers. The number of participants was lower than desired and it is possible that the sample is not representative of the community.

The insights stress the importance of considering diverse perspectives in developing tailored and effective communication strategies for coastal risk management. Since there is little previous information about the public communication of coastal geoscientists and engineers, further studies should be done, if possible with a higher number of respondents, to enhance knowledge about this important and increasingly relevant area of science communication.

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