

Evaluating tidal and wave corrections on shoreline extraction from satellite imagery in Mediterranean micro-tidal beaches

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1. Introduction

Coastal areas are essential for biodiversity, economic activity, and cultural heritage, supporting diverse habitats and protecting inland regions from storm surges and erosion. However, they face increasing threats from erosion intensified by climate change, sea-level rise, and human activities like construction and land reclamation. Accurate monitoring of coastal changes is crucial for effective management to prevent further degradation. The 'instantaneous' shoreline position, defined as the water-land boundary line visible in the image (Boak and Turner, 2005), is the most commonly used indicator for coastal monitoring. Satellite imagery offers wide spatial coverage and frequent revisit times. Sentinel-2 (S2), with a medium spatial resolution (10 m) and a five-day revisit cycle, has been widely used in coastal studies for detecting shoreline changes and mapping coastal features (Cabezas-Rabadán et al., 2019). PlanetScope (PS) provides even higher temporal resolution with daily imagery, beneficial for monitoring dynamic coastal environments where rapid changes occur (Abdelhady et al., 2022). Natural phenomena like tides and wave action affect the accuracy of shoreline extraction, causing temporal variations in shoreline positions. Incorporating these effects is fundamental to ensure that extracted shorelines reflect the true position. This work aims to (i) evaluate the impact of tidal and wave corrections on the accuracy of shoreline extraction using the automated tool presented in (Angelini et al., 2024), and (ii) provide additional evidence of the methodology's effectiveness by extending validation to a larger temporal dataset of the same tideless Mediterranean beaches.

2. Material and method

Coastal monitoring was conducted on three sandy, micro-tidal Mediterranean beach: Castelldefels (CDF) in Spain, and Feniglia (FNG) and Marina di Grosseto (MRN) in Italy (Fig. 1). The dataset comprises three S2 and three PS images, one for each site. S2 level-2A products and PS images, both orthorectified and georeferenced, were selected as close as possible to the dates of the reference orthomosaics (maximum 4 days). Auxiliary data such as Digital Surface Models (DSMs) with 1 m of spatial resolution and sea-level data were used. As validation data, three high-resolution orthomosaics (25 cm) were used to manually digitize the reference shorelines. Local authority WMS services for each site were consulted to download both auxiliary and validation data. The methodology extends the shoreline extraction technique from (Angelini et al., 2024) by including planimetric corrections for tidal and wave run-up contributions using Stockdon's formula (Stockdon et al., 2006). The process involves preprocessing satellite imagery to calculate spectral indices and applying unsupervised classifica-

tions (Gaussian Mixture Model and K-means) to binarize rasters into water and land. To extract the contours the Marching square algorithm coupled with a Laplacian smoothing algorithm was applied. Finally, accuracy was assessed by comparing S2 and PS-derived shorelines with reference shorelines from high-resolution orthomosaics using the "baseline and transect" method. The same transects, spaced 10m apart, were used to provide two versions of the shorelines: corrected with displacement due to tide and waves (transl) and uncorrected (raw)².

3. Result and discussion

The calculation of the total displacement, accounting for both tidal and run-up contributions, showed that in four out of six cases, the values exceeded one meter (Table 1). In Table 2, the Mean Absolute Deviation (MAD), Bias, and Root Mean Square (RMS) of the shoreline position error for each case study were reported. The best combination of method and index is also shown for both the uncorrected (raw) and corrected (transl) shorelines. The obtained results are consistent with previous studies (Angelini et al., 2024), showing the best performance at the CDF and FNG beaches and the worst at MRN, which requires differentiated strategies due to its complex environment. For PS data, the best performance was achieved in two out of three sites using the same index-method combination (NIR-K-means). For S2 data, no single index-method combination fits all beaches, indicating that a universal approach is not feasible, aligning with previous conclusions (Pucino et al., 2022). Similar considerations apply to accuracy (Vos et al., 2023). Tidal and wave corrections altered error statistics at the decimeter level, often leading to slight error reductions, consistent with other studies (Vos et al., 2023). This underscores the need to analyze other site-specific error sources related to morphological characteristics or satellite image coregistration.

4. Conclusion

This study demonstrates that incorporating tidal and wave corrections in satellite-derived shorelines increases their reliability, removing a potential source of error. Future research will explore the integration of various data sources and correction techniques to further refine shoreline extraction methods. Applying these methodologies to diverse coastal environments will help validate their generalizability and effectiveness, contributing to global efforts in coastal preservation and management. Further improvements will focus on validating the results using multi-temporal high-resolution orthomosaics and extracted shorelines to verify correlations through linear regression rates, allowing for quantification of the improvements achieved through the correction methods.

References

- Abdelhady, H. U., Troy, C. D., Habib, A., Manish, R., 2022. A simple, fully automated shoreline detection algorithm for high-resolution multi-spectral imagery. *Remote Sensing*, 14(3), 557.
- Angelini, R., Angelats, E., Luzi, G., Ribas, F., Masiero, A., 2024. Shoreline Extraction Methods from Sentinel-2 and PlanetScope Images. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-1-2024, 1–6.
- Boak, E. H., Turner, I. L., 2005. Shoreline definition and detection: a review. *Journal of coastal research*, 21(4), 688–703.
- Cabezas-Rabadán, C., Pardo-Pascual, J. E., Palomar-Vázquez, J., Fernández-Sarría, A., 2019. Characterizing beach changes using high-frequency Sentinel-2 derived shorelines on the Valencian coast (Spanish Mediterranean). *Science of the Total Environment*, 691, 216–231.
- Pucino, N., Kennedy, D. M., Young, M., Ierodiconou, D., 2022. Assessing the accuracy of Sentinel-2 instantaneous sub-pixel shorelines using synchronous UAV ground truth surveys. *Remote Sensing of Environment*, 282, 113293.
- Stockdon, H. F., Holman, R. A., Howd, P. A., Sallenger, A. H., 2006. Empirical parameterization of setup, swash, and runup. *Coastal Engineering*, 53(7), 573–588.
- Vos, K., Splinter, K., Palomar-Vázquez, J., Pardo-Pascual, J., Almonacid-Caballer, J., Cabezas-Rabadán, C., Kras, E., Luijendijk, A., Calkoen, F., Almeida, L. et al., 2023. Benchmarking satellite-derived shoreline mapping algorithms. *Communications Earth & Environment*, 4(1), 345.

Table 1. Date of reference orthomosaics and total displacement between S2 and PS data and reference shoreline.

Site	Reference Date	Total distance (m) S2 - Reference	Total distance (m) PS - Reference
CDF	25/05/2017	0.4	1.4
FNG	05/04/2023	1.5	1.3
MRN	20/07/2019	0.3	1.5

Table 2. Statistical characterization of the shoreline position error: results are reported for the best methodologies (index and method) for each date and site, distinguishing original (raw) shorelines and those with tidal and wave corrections (transl).

Site	Type	Index	Method	MAD (m)	Bias (m)	RMS (m)
Sentinel-2						
CDF	raw	NDWI	GMM	1.9	-0.9	2.5
	transl	NDWI	GMM	1.8	-0.5	2.4
FNG	raw	MNDWI	K-means	3.2	0.2	4.2
	transl	MNDWI	K-means	3.5	1.7	4.5
MRN	raw	AWEIsh	K-means	5.1	-1.9	6.1
	transl	AWEIsh	K-means	4.9	-1.4	5.9
PlanetScope						
CDF	raw	NIR	K-means	1.3	-0.7	1.7
	transl	NIR	K-means	1.9	1.5	2.9
FNG	raw	NIR	K-means	2.0	-1.4	2.4
	transl	NIR	K-means	1.7	-0.1	2.0
MRN	raw	NDWI	GMM	2.4	-1.0	2.8
	transl	NDWI	GMM	2.1	0.4	2.4

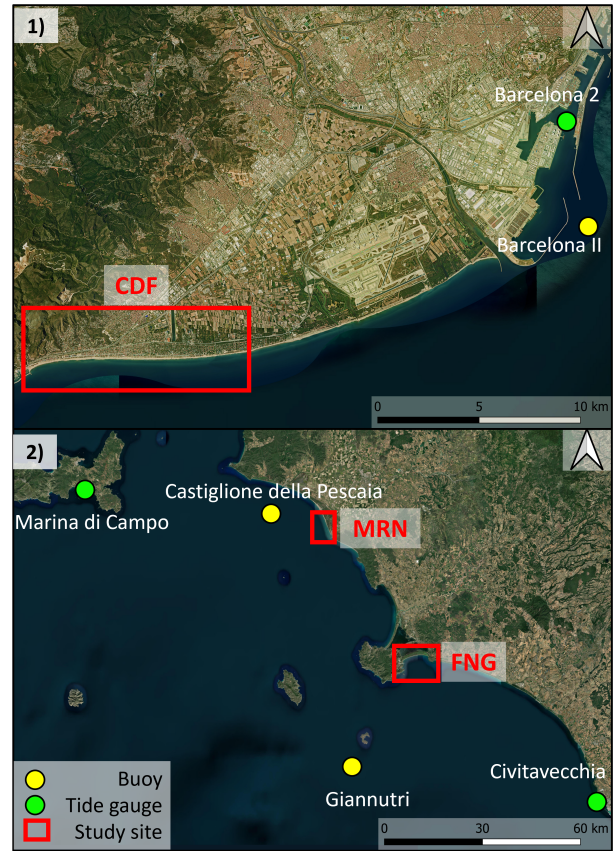


Figure 1. Study areas: a section of Llobregat Delta in front of Castelfelers (CDF) (Spain) in 1), the beaches of Marina di Grosseto (MRN) (Italy) and Feniglia (FNG) (Italy) in 2).

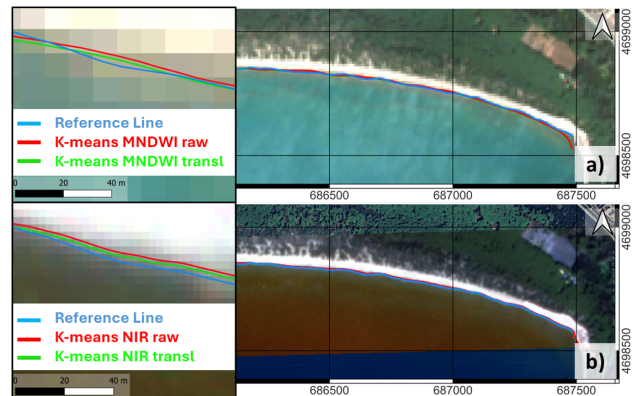


Figure 2. Visually results of FNG beach: a) show a general view and a zoom of the best method-index combination for S2 data, b) show a general view and a zoom of the best method-index combination for PS data.