UNDERSTANDING COASTAL CHANGE FROM NOISY SATELLITE-DERIVED SHORELINE DATASETS: INFLUENCE OF TIDE AND RUNUP CORRECTION AND SPATIAL AVERAGING

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Abstract: Free-of-charge publicly available optical satellite imagery can now be used to provide short-term to multi-decadal shoreline satellite-derived shoreline (SDS) data, with errors typically under 10 m on microtidal beaches. However, SDS accuracy dramatically worsens at high-energy and/or meso to macrotidal low-gradient beaches, which challenges a robust assessment of shoreline variability and trends. In this contribution we demonstrate that, on such beaches, water level (tide + runup) correction and/or an adapted space-averaging of uncorrected (noisy) SDS dataset can substantially reduce uncertainties and thus allow addressing the time- and space variability of shoreline change and their primary drivers.

Introduction

Shoreline change occurs across a wide range of time scales, including e.g. short-term storm erosion, interannual shoreline variability enforced by large-scale climate patterns of atmospheric variability, and multi-decadal change driven by various processes such as sea-level rise and coastal sediment supply. A core issue to improve our understanding and ability to predict shoreline change is therefore to monitor shoreline change at the highest possible frequency and the longest possible time scale on a large range of sandy environments representative of the natural variability. Free-of-charge publicly available optical satellite imagery can now be used to provide short-term to multi-decadal shoreline data from the local to the global scale using a variety of techniques (Toure et al., 2019; Sanchez-García et al., 2020; Bishop-Taylor et al., 2021). On microtidal beaches, satellite-derived shoreline (SDS) errors are typically under 10 m (e.g. Vos et al., 2019), but accuracy can dramatically worsen at high-energy and/or meso to macrotidal low-gradient beaches due to the action of breaking waves affecting the total water level at the coast and blurring the dry sand / water limit (Castelle et al., 2021; Konstantinou et al., 2022). Such large uncertainties challenge the assessment of long-term trends, interannual shoreline variability and their physical drivers.

In this contribution, we explore if tide and/or runup correction and/or spatial averaging of (noisy) SDS datasets can allow addressing the time and space variability of shoreline change and their drivers. This analysis is performed along the high-energy meso-macrotidal sandy coast of southwest France showing large shoreline variability in both time and space. More detail can be found in Castelle et al. (2021, 2022).

Methods

The southwest coast of France is made of high-energy meso-macrotidal sandy beaches, of which 269 km are addressed here (Fig. 1a). This section of coastline has been eroding over the last decades, on average, although erosion and accretion can alternate in both time and space particularly near large-scale tidal inlets and estuary mouths (Bernon et al., 2016; Castelle et al., 2018). However, such patterns and time scales are still poorly understood due to the low time resolution of the available datasets.

We used the CoastSat toolkit developed by Vos et al. (2019), which allows extracting waterlines from publicly available optical satellite data through Google Earth Engine. The southwest coast of France was subdivided into 126 boxes to which satellite images were cropped and processed with CoastSat. Each box contains eight 250-m spaced central transects used for analysis, the other transects overlapping those in the two neighboring boxes (Fig. 1b,c). Overall, 269 km of sandy shoreline (538 transects) were analyzed with 104,444 individual shoreline positions between April 12, 1984 and December 31, 2020.

We used wave data from a regional wave hindcast to extract wave conditions at the unstructured grid point the closest to the box in nearly 50-m depth (cyan dots in Figure 1a). Wave conditions were transformed into wave conditions at breaking using an empirical formula to force a bulk longshore transport formula and further compute time-averaged longshore gradients. A coastal model hindcast of water level was used to estimate the water level at the coast at Truc Vert which, together with empirical estimation of runup from breaking wave conditions allowed estimating the total water level at the coast at this location. Tide and/or runup corrections of the SDS were performed using a constant beach slope of 0.05.

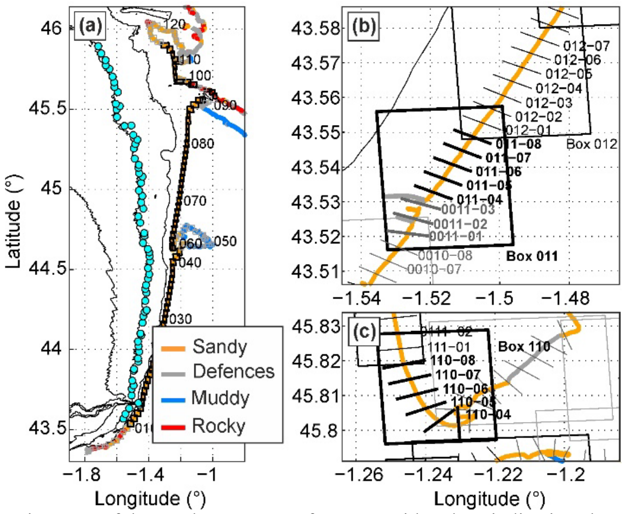

Fig. 1. (a) Location map of the southwest coast of France, with colour indicating shoreline type, and with the bathymetry contoured. The boxes (numbered) indicate Coastsat image extraction zones along the entire coast with the cyan dots indicating the corresponding wave hindcast grid points in approximately 50-m depth where wave time series were extracted. The thick black boxes show the boxes used in the present analysis. Middle and right-hand panels show a zoom onto boxes 011 and 110 and examples of corresponding satellite image. (b,c) Each box consists of eight 500-m spaced cross-shore transects, with in each thick black box the greyish transects disregarded from the analysis (e.g. outside of the domain, located in a sheltered area).

Results

Over 1984-2020 and based on the non-corrected SDS dataset, the shoreline eroded by 0.55 m/yr with maximum erosion (accretion) reaching 15.61 m/yr (6.94 m/yr), with the largest changes observed along coasts adjacent to the inlet and estuary mouths (Fig. 2). We found that, away from the presence of ebb-tide deltas and swash bars affecting offshore wave transformation and nearshore circulation, the long-term shoreline trend is well explained by the gradients in longshore drift (not shown). By averaging the yearly SDS along the entire coastline, we find that interannual shoreline variability is well correlated with the winter West Europe Pressure Anomaly (WEPA) (Fig. 3), which outscores the other conventional teleconnection pattern indices. WEPA even explains more than 80% of the space-averaged shoreline variability over the recent period 2014-2020 when more and higher quality satellite images are available. A more local assessment of the links between climate indices and shoreline response shows that correlation with all climate indices dramatically drops downdrift of the large-scale estuary mouths and inlets.

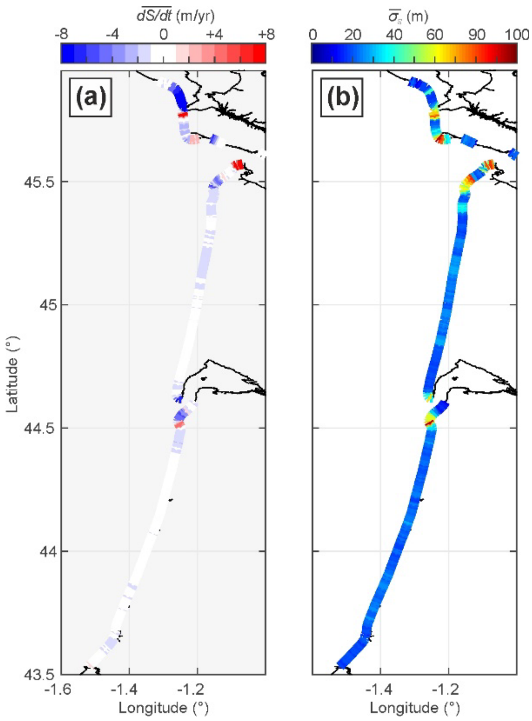

Fig. 2. 1984-2020 SDS statistics: (a) 2500-m moving averaged shoreline change trend; (b) 2500-m moving averaged shoreline standard deviation around the trend.

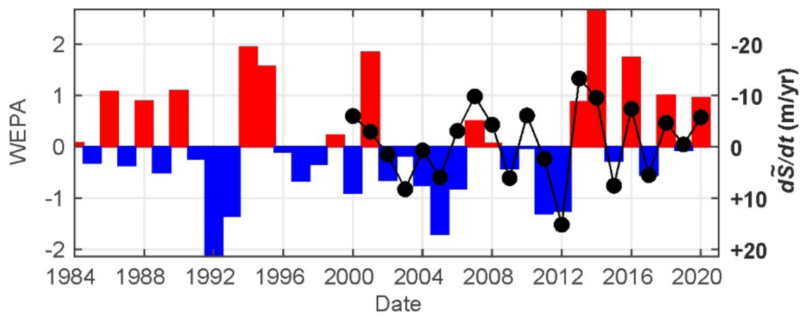

Fig. 3. Time series of winter WEPA climate index (coloured bars) and superimposed yearly shoreline change in (black dots) averaged over the 269 km of sandy coast since 1999 (years with spatial coverage >90%). Note that shoreline change axis is flipped, with positive WEPA generally driving shoreline erosion.

We also show that, locally at Truc Vert beach, the corrected satellite-derived shoreline trends and interannual variability are in much better agreement with field measurements than without any correction (and without time- and space-averaging). Including non-tidal water level residuals (e.g. wind-driven surge) and accounting for time- and elevation-varying beach slope for horizontal correction did not improve satellite-derived shoreline position. A new total water level threshold is proposed to maximize the number of usable images while minimizing errors (0.2-m vertical dashed line in Fig. 4b). Accounting for wave runup and the new water level threshold at Truc Vert, the number of usable satellite images is doubled and shoreline position errors are at least halved compared to previous work at this site. Using the 1984-2019 reconstructed shoreline, we also show that the satellite-derived shoreline trends and interannual variability are in better agreement with field measurements (not shown).

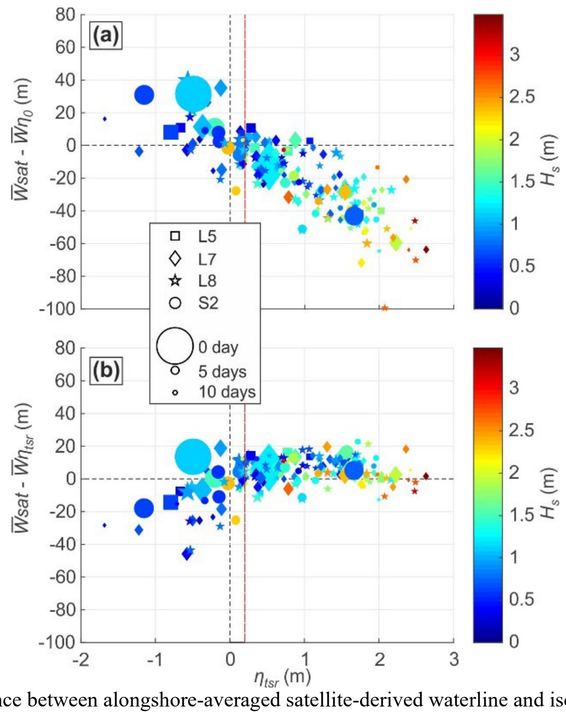

Fig. 4. Difference between alongshore-averaged satellite-derived waterline and iso-contour cross-shore waterline position computed from in situ topographic surveys (a) without corrections and (b) with tide and runup correction, positive meaning more landward satellite-derived waterline. In all panels, significant wave height Hs is coloured, symbol indicates the satellite and symbol size is proportional to the duration between the satellite image and the closest Truc Vert beach topographic survey used to compute iso-contours.

Conclusions

This work (Castelle et al., 2021, 2022) demonstrates that an adapted space averaging of uncorrected (noisy) SDS dataset can allow addressing the time and space variability of shoreline change and their primary drivers including large-scale climate patterns of atmospheric variability. It suggests that such SDS analysis can be performed along any coastline in the world in order to guide future model development and application. Given that tide, and particularly runup, corrections at this coast dramatically decrease SDS errors, we hypothesize that such correction could allow narrowing the moving average window and thus provide higher spatial resolution information on shoreline response at high-energy and/or meso to macrotidal low-gradient beaches.

Acknowledgements

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