SATELLITE-DERIVED SHORELINE INTERANNUAL VARIABILITY ALONG THE ATLANTIC COAST OF EUROPE

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INTRODUCTION

Monitoring sandy shoreline evolution from years to decades is critical to understand the past and predict the future of our coasts. Interannual shoreline variability is often primarily enforced by large-scale climate patterns of atmospheric or coupled ocean-atmospheric variability (e.g. El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO)). The seasonal to decadal predictability of these climate patterns recently showed increasing skill (Athanasiadis et al., 2020), which may allow a reduction in shoreline evolution uncertainties in the next decades. Understanding shoreline evolution on interannual to decadal timescales is therefore critical, particularly along the Atlantic coast of Europe, where previous work on a limited number of intensively monitored sites showed a strong control of large-scale climate modes of atmospheric variability on shoreline change (e.g., Dodet et al., 2019, Masselink et al., 2023).

Optical satellite imagery can now infer such datasets locally to globally, but with sometimes large uncertainties and poor spatial resolution leading primarily to regional average analysis. Spatial and temporal averaging of uncertain satellite-derived shoreline (SDS) datasets can be performed to filter out some of the SDS noise and to further provide fair insight into the spatial and temporal modes of shoreline variability (Castelle et al., 2022; Warrick et al., 2023). Although such an approach can work on relatively straight stretches of coast, it is challenging in other environments such as embayed beaches, sandspits or estuary mouths where the time and space patterns of shoreline change can strongly vary alongshore.

In this contribution, we consult an improved state-of-the-art global SDS dataset (Luijendijk et al., 2018) to address the spatial distribution of interannual variability of sandy shores along the Atlantic coast of Europe, and to further identify the primary drivers and coastal settings affecting this spatial variability.

METHODS

In the present work, the ShorelineMonitor (SM) SDS dataset, covering the period 1984-2021, along the western part of Europe was used, from Gibraltar in the South to the northern tip of the Scottish coast. In order to focus on regions which are primarily affected by ocean waves generated in the North Atlantic Ocean, we disregarded the Irish Sea coastline, the English Channel French and UK coastline east of the Cotentin peninsula, and some sheltered and/or east-facing Scottish coastline. This resulted in a total of 34,874 transects, comprising 8,281 sandy transects (~24%), which were analyzed in the present work (Figure 1). The SM SDS dataset was further processed to compute some other shoreline characteristics such as shoreline orientation θ and orthogonal distance D to the closest coast. Because spatial averaging can help to smooth out uncertain and noisy SDS, we also defined a moving average distance L.

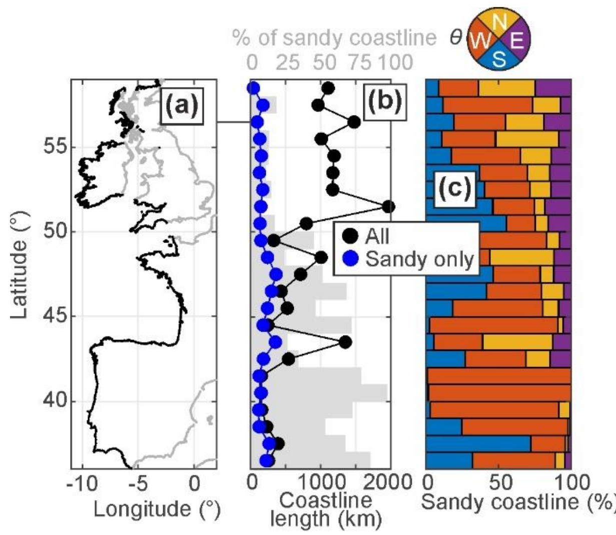

Figure 1 – SM SDS dataset used with (a) coastline of interest (thick black line), and latitudinal distribution (binned at 1° interval) of (b) length and percentage of sandy coastline; (c) sandy coastline orientation θ.

RESULTS

Figure 2 shows the spatial correlation of the winter-mean significant wave height and yearly shoreline change against the primary (December to March) winter-averaged climate indices in the region over the entire time series 1984-2021. Noteworthy, because yearly composites include subsequent spring, summer and early autumn recovery, correlations are expected to be much lower than with post-winter shoreline position (Masselink et al., 2023). The NAO (Hurrell et al., 1995) shows large positive and negative correlation with winter-mean wave height at the most northern and southern latitudes, respectively, with weak correlation in the transition area. In this transition area (approximately between 38°N and 51°N), the West Europe Pressure anomaly (Castelle et al., 2018, WEPA, Figure 2b), and to a lesser extent the East Atlantic pattern (EA, not shown), show a strong positive correlation.

The same analysis was performed for yearly shoreline change dS. In order to reduce shoreline change uncertainties and be able to robustly address complex coastline shapes without introducing errors, dS was averaged using a 5-km moving-average window L and over coastlines with similar orientation θ. Shoreline response shows weaker correlation and more complex patterns than for winter wave conditions (Figure 2). For instance, a consistent positive correlation with WEPA (meaning that a positive WEPA results in increased erosion) is found along the open sandy coast of southwest France, whereas along more complex shorelines positive and negative correlations typically alternate in space and local scale patterns are mostly difficult to pick up.

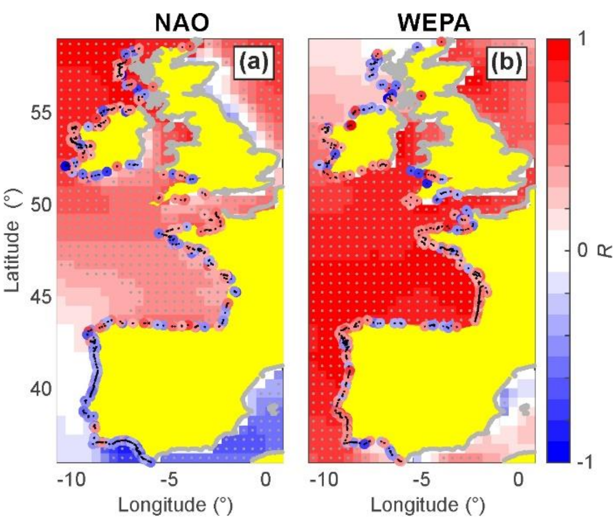

Figure 2 – Spatial correlation of the winter-mean significant wave height and yearly shoreline change *dS* against (December to March) winter-averaged climate indices over 1984-2021: (a) NAO and (b) WEPA. In all panels, for clarity only the shoreline points with a statistically-significant correlation at a 80% confidence level have been plotted, while the grey dots on the wave field show statistically-significant correlations at the 95% confidence level.

DISCUSSION AND CONCLUSIONS

Correlation maps with winter-mean wave height are essentially in line with previous work (e.g. Dodet et al., 2019). However, the details around some sheltered and protected areas, which are typically characterized by multi-directional wave climates, are not reproduced as they require high-resolution wave modelling. We found that, particularly along west-facing coastlines, shoreline response is positively (negatively) correlated against NAO at the highest (lowest) latitudes, meaning that positive (negative) NAO results in increased (decreased) winter erosion. This is in line with local observation in Northern Ireland and south Spain. In between, WEPA and to a lesser extent EA, is positively correlated with shoreline response, which is also in line with a wealth of observations.

The impact of the outstanding winter of 2013/14 is also relatively well captured in the time series of the mean shoreline position (not shown). Only open coast beaches show a consistently statistically significant correlation with some of the climate indices. This is illustrated in Figure 3a for the southwest coast of France, with a positive correlation against WEPA except close to the tidal inlet of Arcachon, and in Figure 3b for the south coast of Spain with a negative correlation against NAO, except once again to inlets and structures. In contrast, along a substantial amount of small coastal embayments, correlations are weak and at some other locations (not shown), the correlation patterns are not in line with previous work based on high-resolution data. The present SDS analysis focused on some of the most energetic environments and with large tide range, thus challenging the SDS accuracy. However, based on a detailed analysis and a spatial averaging approach including coastline orientation and sheltering distance, this work provides new insight into shoreline change from local to regional scale, providing a spatial continuum between previous local-scale studies aiming at linking coastal response with large-scale climate patterns of atmospheric variability.

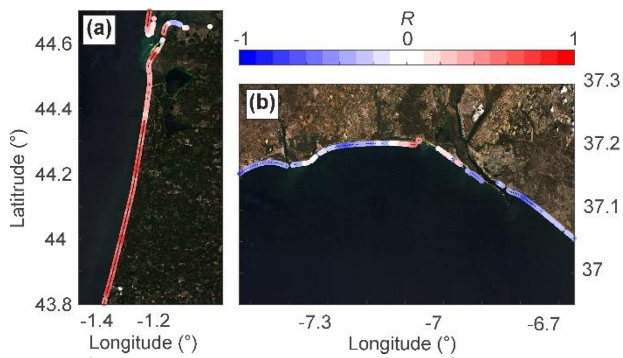

Figure 3 – Zoom onto spatial correlation of yearly shoreline change *dS* against winter climate indices on open coast sectors over 1984-2021: (a) WEPA, Landes coast, southwest France and (b) NAO, southwest Spain and embayed coast sectors:

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