# MULTIDECADAL SHORELINE VARIABILITY LINKED WITH ESTUARINE SANDBANK WELDING: THE NORTH MEDOC COAST, SOUTHWEST FRANCE

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**Abstract**: Sandy coasts at the edge of inlet or estuary mouth often show the largest shoreline variability. However, previous work primarily addressed small-scale tidal inlets as time- and space-scales of morphological change make the system much easier to monitor. The aim of this study is to understand and quantify the controlling factors affecting shoreline change along the North Medoc Coast adjacent to the Gironde estuary mouth, SW France. Bathymetric surveys (1909-2021) and shoreline data from various sources (1940-2021) show that a massive estuarine sandbank welded to the shore in the early XX$^{th}$ century. Since then, the bulge of sand has been diffusing alongshore, causing the shoreline to erode by up to ~400 m over the last 80 years. This study suggests that it is critical to monitor bathymetric changes in such environment, to understand chronic erosion impacts on coastal infrastructures, to better anticipate future shoreline change and guide coastal management strategies.

## Introduction

Estuary mouths and their adjacent sandy coasts are often focal points for coastal development and human recreation. However, these coastal sectors also often show the largest shoreline changes, with rapid erosion and accretion periods alternating on the period of years to decades (e.g., Castelle et al., 2018, 2022). Such shoreline variability is complex and enforced by an interplay between external (e.g., waves) and internal (e.g. ebb tidal delta cycles) factors (e.g. Fitzgerald, 1984), which make their evolution poorly predictable. In addition, so far studies addressing the evolution of such coastal systems mostly focused on reasonably small systems (e.g. Gaudiano and Kana, 2001), which are characterized by a shoreline variability occurring on shorter time and space scales (Ridderinkhof et al., 2016) and are thus easier to monitor.

The North Medoc coast, southwest France, is adjacent to the Gironde estuary (Figure 1a) and is exposed to energetic waves generated in the North Atlantic

Ocean, with mean offshore significant wave height and peak period of approximately 1.8 m and 11.5s, respectively. Offshore, spring tidal currents show complex patterns and can exceed 1 m/s. Over the last centuries, the 15-km long shoreline sector to the south of the estuary mouth, including the coastal municipality of Soulac-sur-Mer, has suffered periods of severe erosion, threatening coastal infrastructures. Since the mid-19th century, a large range of coastal defences has been progressively constructed to preserve the northern sector from shoreline erosion. Then riprap seawalls and groins have been used to protect the more exposed urban areas. Since 2019, localized beach nourishments (~$60.10^3$ $m^3$/yr) have been performed during every spring along the most vulnerable areas to buffer incident wave energy. Despite all these measures, some urbanized (Figure 1c) and state forest sectors (Figure 1b) are still threatened by erosion.

In order to propose and develop an optimal coastal management strategy it is critical to document and understand the past multidecadal shoreline changes along this 15-km coast. Such improved understanding is also expected to guide the development of numerical and conceptual models.

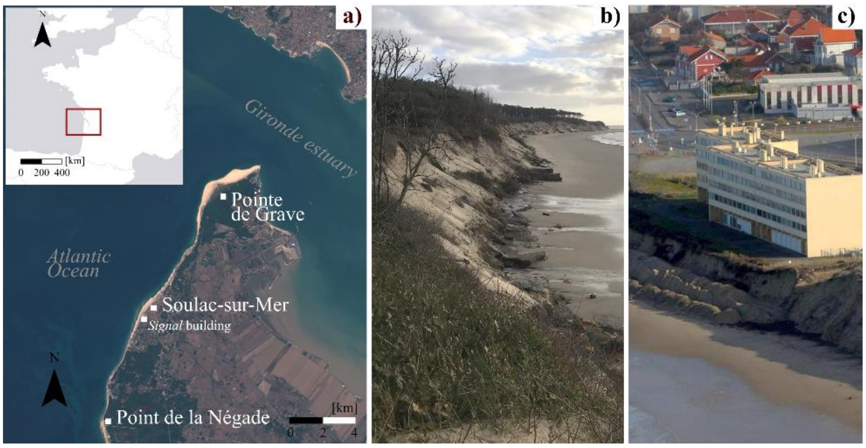


Fig. 1. (a) Location map of the study area; (b) photograph of Pointe de la Négade where severe chronic erosion depleted the coastal dune system and left the coastal forest directly exposed to marine erosion and and (c) photograph at the end of the 2013-14 winter of the « Signal » building (Soulac-sur-mer) erected in the 60-70s when the shoreline was located hundreds of meters further offshore.

**Methods**

Times series of shoreline position (Figure 3) were addressed combining four different data sources: (1) 39 geo-referenced orthomosaics photos between 1940 to 2014 from which shoreline position was manually retrieved using the dune foot as proxy ; (2) the CoastSat toolkit (Vos et al., 2019) was used to extract over 300 waterlines (interface between water and sand) from Google Earth Engine satellite database (1987-2022); (3) 14 topographic surveys, including 100m spaced beach transects and LIDAR of the dune front profile, were performed between 2013-2021 by the company Casagec Ingenierie in the southern part of the study area, from which the dune foot position was extracted (GNSS1) ; (4) 13 in situ shoreline surveys (GNSS2, 2014-2021) acquired along the entire study area at the dune foot, using an all-terrain vehicle (ATV) equipped with a 2-m accuracy GPS.

The links between shoreline change and estuary mouth dynamics were addressed using 11 large-scale bathymetric charts produced between 1909 and 2021. The 9 bathymetric data prior 2000 were obtained from digitized individual sounding points (c. 4000 points per survey, Figure 2d). The two last datasets were collected from single beam echo sounder surveys in 2019 and 2021. The bathymetric Digital Elevation Models (DEMs) were generated using spatial interpolation methods with anisotropy (Figures 2a, b and c).

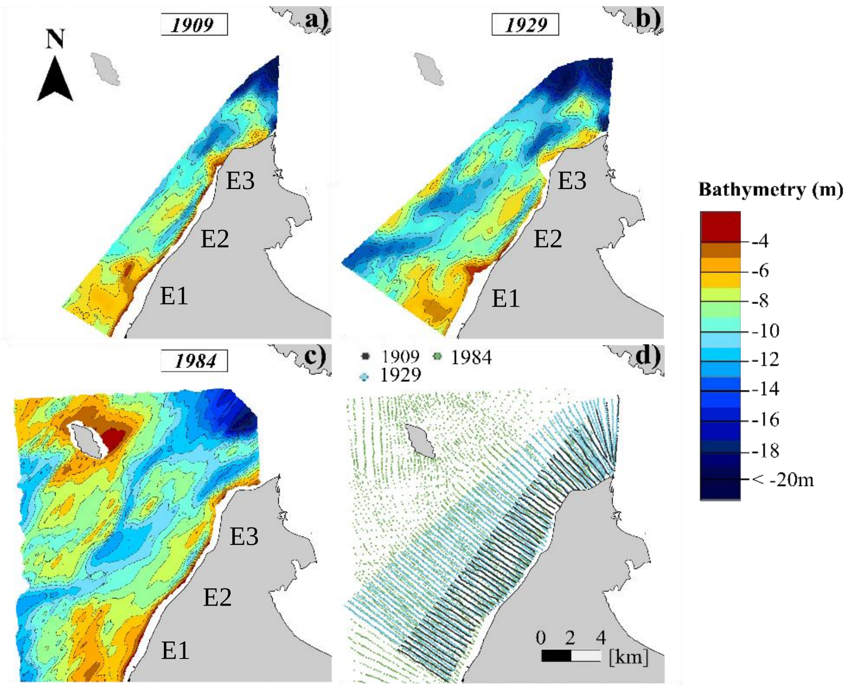


Fig. 2. Bathymetric maps of (a) 1909, (b) 1929 and (c) 1984, in French official altimetry reference NGF/IGN69, obtained by interpolation of bathymetric measurements with sounding locations showed in (d)

## Results

Figures 2a, 2b and 2c show the interpolated bathymetries surveyed in 1909, 1929 and 1984. Two large sandbanks can be observed in these maps. The largest one (E1 in Figure 2), in the South of Soulac-sur-Mer, migrated landwards and attached to the coast between 1909 to 1929. The alongshore sandbank « E2 » widened from 1909 to 1929 and drifted northwards to E3. In the bathymetric maps of 1959 and 1970 (not shown), this alongshore sandbank attached to the coast close to Pointe de Grave. This shoal is showed welding on the 1984 chart (Figure 2c).

Figure 3 shows the time series of shoreline position over the period 1940-2022 at two different locations (see blue lines in Figure 3c) highlighting contrasting and complex behaviors. In the south of Soulac-sur-Mer (Figure 3b), the shoreline has been eroding for 80 years at a nearly steady rate of -4.3 m/yr. In contrast, further north, at Pointe de Grave (Figure 3c), accretion reaches +3.9 m/yr, with large interannual variability. Interestingly, the space- and time-averaged rate (-0.01 m/yr) indicates that on this stretch of coast welding events and diffusion nearly balance. However, as shown in Figure 3, this mean shoreline change rate masks a large spatial and temporal variability, with eroding / stable / accreting periods alternating over both time and space.

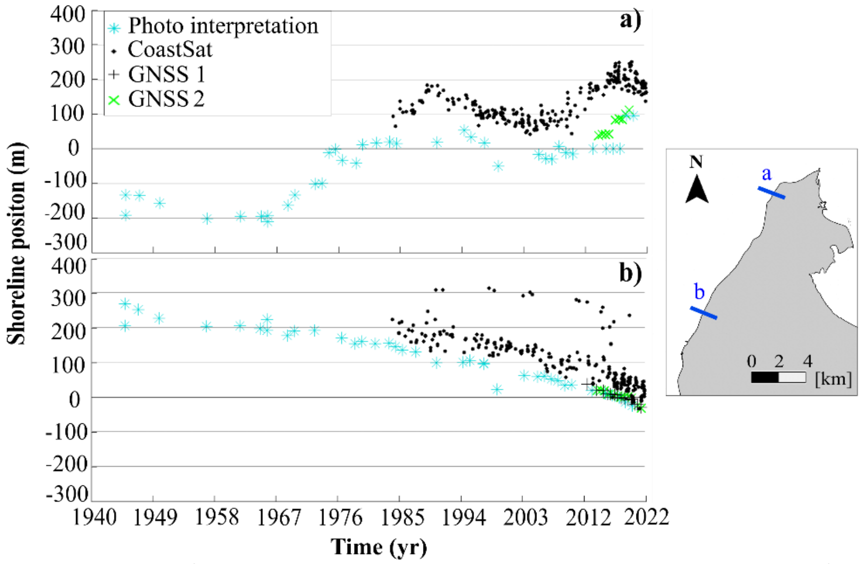


Fig. 3. Times series of shoreline position at a) Pointe de Grave and b) Soulac-sur-mer. c) Map of the study site showing the location of the two profils a) and b).

## Discussion and conclusions

In this study, two large welding events were described in the 30s and the 70s (Figures 3a and 3b). As indicated by local archives (e.g. historical photographs, not shown here), the major sandbar welding (E1) in the south of Soulac-sur-Mer coincided by a rapid and large widening and rising of the beaches around Soulac-sur-Mer.

Since the shoal attached, this section of coastline has been chronically eroding owing to the alongshore diffusion of the bulge of sand. The second welding event (E2) drove the large shoreline accretion observed in the 60s and 70s (Figure 3b).

Since more than a century, the shoreline in the North Medoc shows dramatic changes in both time and space, which are largely controlled by the welding of estuarine sandbanks (Fitzgerald, 1984; Lenstra et al., 2019; Burvingt et al., 2022). The previous "natural" welding events captured in our multidecadal analysis and the subsequent shoreline bulge diffusion characteristics may serve to guide and size future large-scale beach "artificial" nourishments (e.g. de Schipper et al., 2016) in the area, which is hypothesized by some to be the only sustainable strategy to mitigate chronic erosion in the southern part of the study area.

## Acknowledgements

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