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Tidal influence on the littoral drift of a beach with complex bathymetry: example of the Vougot beach, Guissény (France)

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Abstract:
Rocky coastal zones, including beaches constrained by rocky headlands, represent approximately 80% of the world's coastline. In such coastal environments, with complex topo-bathymetry, the offshore wave conditions can be very different compared to the conditions at the wave breaking point due to refraction and diffraction processes that play an important role in nearshore wave transformation. The obliquity of waves at the breaking point controls the direction and intensity of the longshore drift and the induced sediment transport. In addition, on macrotidal beaches, tides induce water level variations that strongly impact nearshore current circulation. The present study analyses longshore currents in the surf zone of a sandy beach in a complex coastal macrotidal environment: Vougot beach (France). Wave refraction is shown to invert the predicted longshore current (wave direction changed by almost 90°). In the surf zone, the current is first driven by the tidal current. The wave climate influences the magnitude: the westward longshore current reaches 0.6 m/s during an energetic event and is proportional to the significant wave height. Commonly used formula to predict wave-generated longshore currents failed to reproduce observations. Numerical modelling is in progress to test the influence of tides and waves on surf zone currents.

Keywords:
Longshore drift, Tidal current, Complex bathymetry, Wave refraction.

1. Introduction

Rocky coastal zones, including beaches constrained by rocky headlands, represent approximately 80% of the world's coastline (TRENHAILE, 1987). Rocky headlands are known to influence coastal currents (GEORGE *et al.*, 2018). They can serve as wave convergence points, obstructions, or focal points for currents. The shape of the coastline, and the presence of sandbars or shoals exerts a significant influence on the distribution of the longshore current along the coast (KUMAR *et al.*, 2000). In such coastal environments, with complex topo-bathymetry, the offshore wave conditions can be very different from those at the wave breaking point due to the refraction and diffraction processes that play an important role. The obliquity of waves at the breaking point controls the direction and intensity of the longshore drift and the induced sediment transport. In addition, on shallow macrotidal beaches, tides induce water level variations that strongly impact nearshore current circulation (SEDRATI & ANTHONY, 2007).
The aim of this study is to improve the understanding of hydro-morphodynamic processes in complex coastal environments, in order to understand better the observed morphodynamics. This understanding is necessary to improve models of coastline evolution that reproduce the observed changes and predict future change scenarios, in particular in response to climate change (DISSANAYAKE *et al.,* 2021). The experimental site is the beach of Vougot in Brittany (France, Figure 1), at which topo-morphological monitoring (monthly beach profiles including the intertidal zone and the dune) has been carried out for more than 17 years. The multi-year evolution (since 2004) shows a long-term erosion trend on the eastern part of the beach, while the western part is accreting (SUANEZ *et al.,* 2010; SUANEZ *et al.,* 2012; SUANEZ *et al.,* 2015). These morphosedimentary changes suggest longshore sediment transport linked to the littoral drift, oriented from east to west (e.g. CHATAIGNER *et al.,* 2019; CHATAIGNER *et al.,* 2020; DISSANAYAKE *et al.,* 2021). To test this hypothesis, in situ measurements of nearshore wave height and direction, as well as currents (cross-shore and longshore), in the intertidal zone as well as offshore of the beach (up to 35 m depth), were made with current meters, pressure sensors and imagery acquired by a drone.

2. Study site and field experiment

A field experiment was conducted from February to April 2022 at Vougot beach, which is located on the northern coast of the Finistère department (North Brittany, France) (figure 1a). Vougot beach is mainly a sandy beach, with fine to medium sand, with a median sand grain size D50 of 0.25-0.32mm in the intertidal zone, and finer sands on the dune (D50=0.2mm). At the eastern end of the beach, pebbles and cobbles may be exposed following erosive winter storms, and periglacial deposits may also be uncovered at some altitudes in the intertidal zone (SUANEZ *et al*., 2012). The beach/dune system faces a 3 to 6 km wide platform in the coastal zone with reefs and islets (figure 1b).

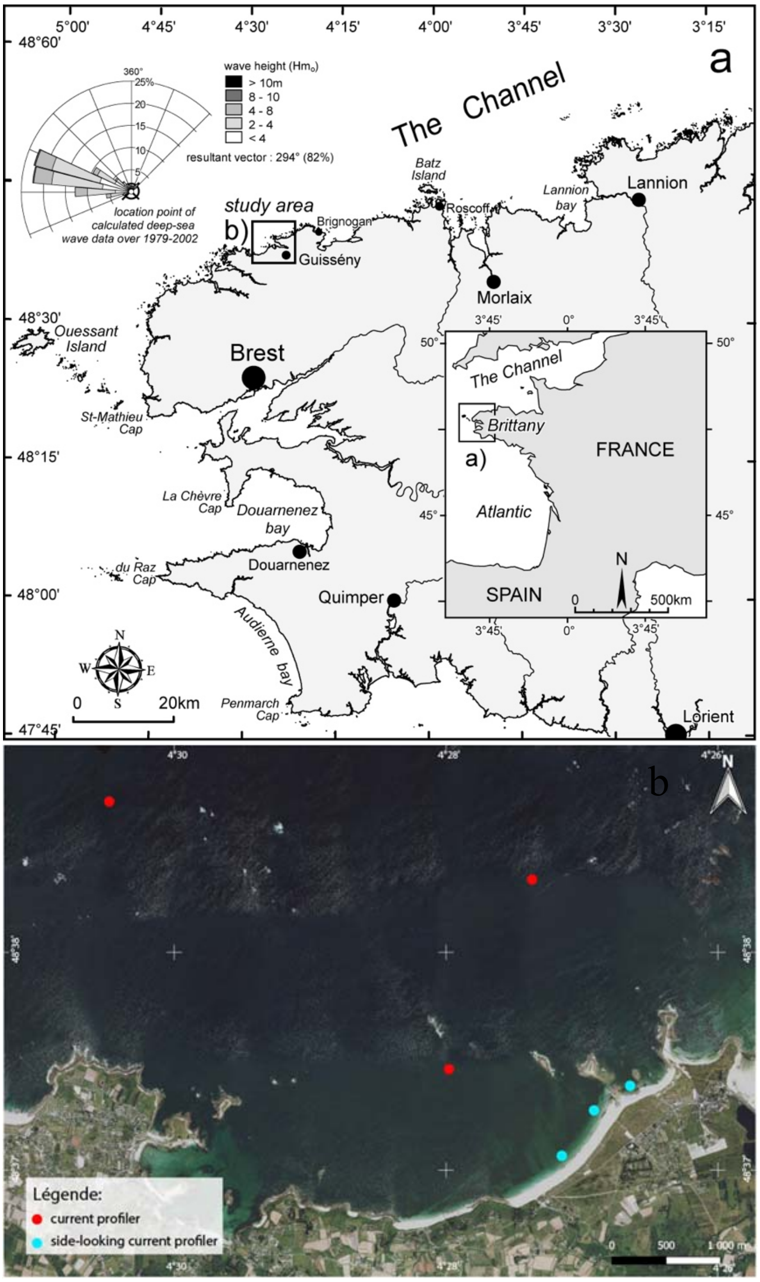

Figure 1. Location maps. a) Regional scale, with the wave climate 1979-2002 giving a mean wave direction of 294°; b) local scale: Study site of Vougot beach (Guissény, France) indicating the location of the six Acoustic Doppler Current Profilers (red dots : 600 and 1200 kHz ; blue dots : side-looking 1 and 2 MHz).

These features create complex nearshore topo-bathymetry that strongly influences the local hydrodynamics (i.e., wave and currents) (SUANEZ *et al*., 2012; DISSANAYAKE *et al.,* 2021). The macrotidal range reaches 8.4 m for astronomic tides, and the intertidal beach surface can extend over 400 m at low tide. The offshore energetic waves come

from the west-north-west direction (figure 1a). The mean offshore significant wave height is about 3 m, with a peak period about 10 s. The coastline is facing NNW (about 330°).
In order to understand the hydrodynamic functioning of the beach in relation to the morphological changes observed over the last several years, this study is based on two approaches: the wave propagation from the offshore to the nearshore from aerial pictures and numerical outputs (WaveWatchIII from Homere database, BOUDIERE *et al*., 2013), the tidal current and the longshore current due to incident breaking waves from current-meters data located in 9 m-depth (red dot close to the beach, Figure 1b), and in the surf zone in the middle of the intertidal zone (blue dots, figure 1b). The offshore current-meters (by 35 m-depth NW and by 20 m-depth NE, red dots in figure 1b) are used to validate/calibrate the numerical hindcasts. The side-looking current-meters are 1 and 2 MHz Aquapro Nortek© instruments, programmed with 0.4 and 0.2 m of blanking, respectively, with 0.25 and 0.20 m vertical cells, measuring hourly waves over 1024 data at 2 Hz from the velocity spectrum and currents over 5 min at 1 Hz. The compasses were previously calibrated, and the data were converted to longshore/cross-shore direction by defining the longshore direction as parallel to the isobath contours from available bathymetry data (Litto3D®), resulting in (from West to East) cross-shore directions of 328°, 294° and 342°. To limit the uncertainties in the calculation, the current-meters were placed aligned with the longshore direction on the beach, and the data have been recovered in the mooring referential XYZ (with X Eastward and Y offshore). The nearshore measurements have been performed over two periods: from 22nd to 24th of February and from 1st to 4th of March, 2022.

3. Results

3.1 <u>Wave propagation from deep-sea to nearshore</u>

From aerial and satellite data, and numerical outputs from the numerical model WWIII (HOMERE database), wave refraction is investigated. Figure 2 shows an example from 26 October 2010: whereas the offshore waves propagate toward the coast from WNW, the nearshore waves arrive almost from the North. The offshore significant wave height was about 3 m. The coastline faces on average NNW (about 330°). Given this offshore wave direction, the longshore drift would have been predicted to be directed to the East. However, given that wave refraction caused the waves to approach the nearshore zone from the North, the envisioned longshore drift is toward the West.

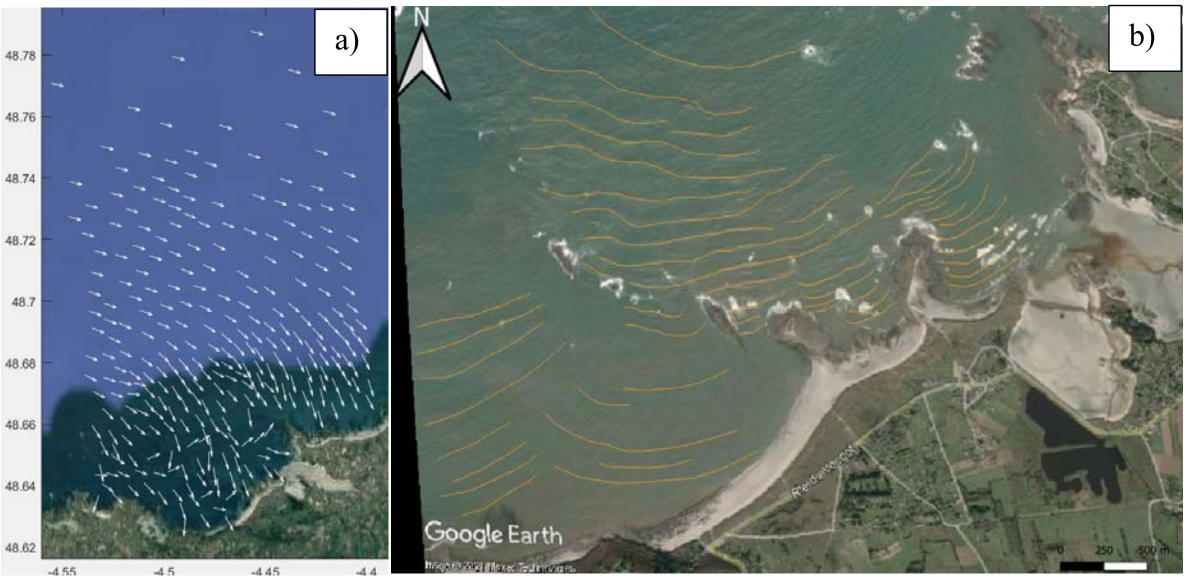

Figure 2. Wave direction from offshore to nearshore 26 October 2010. The offshore significant wave height was about 3 m. a) WWIII wave direction from the HOMERE database in front of Vougot beach, demonstrating strong wave refraction ; b) Aerial picture from Google Earth©, the wave crests have been highlighted.

3.2 Nearshore waves and currents

Figure 3 shows the data from the 9 m-depth current meter (most southern red dot, Figure 1b) in black, and the two side-looking profilers on the western part of the Vougot Beach, P5 in blue and P6 in red (middle and west blue dots respectively, Figure 1b) corresponding to the cross-shore transects investigated in previous studies (SUANEZ *et al*., 2015; CHATAIGNER *et al*., 2020). The first period was during neap tide (tidal range about 5 m, figure 3d1) and the second during spring tide (tidal range reaching 8 m, figure 3d2). The wave incidence at P5 and P6 (in the surf zone) is always positive leading to a predicted longshore drift westward. The wave incidence in front of P6 in 9-m depth seems modulated by the tide, with negative incidence during a couple of hours (~1-3 hours) at low tide.

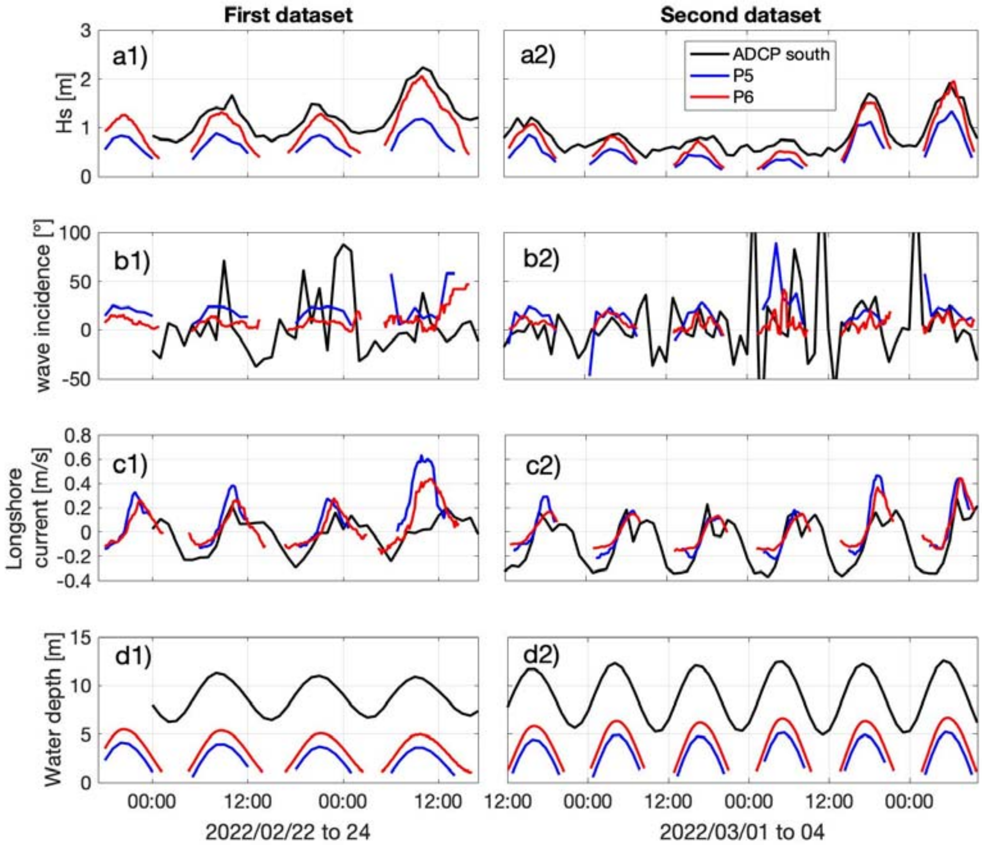

Figure 3. Hydrodynamic data from the 9 m-depth current meter (most southern red dot, Figure 1b) in black, and the two side-looking profilers on the western part of the Vougot Beach, with P5 in blue and P6 in red (middle and west blue dots respectively, Figure 1b). The left column corresponds to the first period of measurements (2022/02/22 to 24) and the second column to the second period (2022/03/01 to 04). a) Significant wave height Hs; b) wave incidence considering the orientation of the coast for P5 and P6 and using the P6 orientation for the ADCP south; c) the vertically-averaged longshore current positive to the West and d) the water depth.

Five tides exhibit high-tide Hs of about 1.5-2 m (energetic periods) and three tides have high-tide Hs lower than 1 m (calm periods). The current in 9 m-depth (black, figure 3c) alternates in phase with the tide, and is slightly asymmetric: about 0.35 m/s Eastward during the flow, and about 0.2 m/s (with two peaks) westward during the ebb phase of the spring tide (0.2 m/s during the flow and 0.1 m/s during the ebb phase of the neap tide). Considering the surf-zone current, the westward maximum is in phase with the first ebb velocity peak. During calm periods, the westward maximum velocity is similar in the surf-zone and in 9 m-depth, suggesting that the tidal current is also present in the surf-zone. During energetic periods, the westward longshore current in the surf zone is stronger than the 9 m-depth current (reaching 0.6 m/s during energetic event) and is proportional to Hs (by a factor of 0.56 and 0.32, and $R^2 = 0.97$ and 0.97, for P5 and P6, respectively) suggesting the generation of a westward longshore drift. During the flow phase, the surf-zone current is eastward and is about 0.1-0.2 m/s weaker than the 9 m-depth, independent of the wave climate.

4. Discussion and conclusion

The presented results suggest that the tidal current and the longshore drift are superposed in the surf zone and that both need to be considered in order to evaluate the longshore sediment transport on beaches in macrotidal environments. However, the sum of the 9 m-depth current and a longshore current predicted by commonly used empirical formula for wave-generated longshore currents (e.g. GALVIN, 1967; LONGUET-HIGGINS, 1970; THORNTON & GUZA, 1986) does not allow reproducing the variability or the sign of the measured currents. These formulas are based on a linear relationship with the angle of wave incidence. The measured current does not seem to be linked to the wave incidence measured in the surf zone or in 9 m-depth. The uncertainty on the mean wave direction measured by the acoustic current meter can be large (about 10°). This could explain the poor relationship with the wave incidence and thus the poor predictions of the longshore current in the surf zone. Finally, since the wave incidence angle is modulated by the tide, the prediction of the wave-generated longshore current is not trivial from commonly used empirical formulae. Deltf3D numerical simulations are in progress to test the influence of waves and tides on the nearshore current (DISSANAYAKE *et al.,* 2021).

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