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Short communication

Tide-induced flow signature in rip currents on a meso-macrotidal beach

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ABSTRACT

On rip-channelled beaches, intense rip currents are driven by waves due to alongshore variations in breaking-induced wave energy dissipation. This study addresses for the first time the potential development of tidal currents superimposed onto the wave-driven circulation. This phenomenon is observed on a rip-channelled meso-macrotidal beach (Biscarrosse, SW France). Field measurements show 20 to 45% stronger mean rip velocities during ebb than during flood. Numerical experiments reveal that this asymmetry is the signature of tidal currents developing over the rip channel morphology. This asymmetry is found to increase roughly linearly with increasing tidal range. These results are significant to beach safety and lifeguarding and stimulate further numerical exercises.

1. Introduction

Surfzone sandbars are ubiquitous patterns in the sand along wave-exposed coasts. Sandbars often display remarkable alongshore periodic undulations in both their depth and cross-shore position referred to as crescentic sandbars or bar and rip systems. On these rip-channelled beaches, rip currents (narrow seaward-flowing jets) are driven by alongshore variations in bathymetrically-controlled wave breaking (Bonneton et al., 2010), with rip velocity fluctuating on timescales of the order of 1 min (infragravity motions, MacMahan et al., 2004a) and 10 min (Very Low Frequency motions, VLFs, MacMahan et al., 2004b). These topographically-controlled rip currents are one of the most deadly coastal hazards (Scott et al., 2011) and have a significant impact on transport and dispersion of pollutants, nutrients and tracers (Reniers et al., 2009, 2010; Shanks et al., 2010) and thus to the overall coastal ecosystem.

Over the last decades, scientists have been working to improve our understanding of topographically-controlled rip currents through a variety of techniques including field (e.g., Brander, 1999; MacMahan et al., 2004a; Bruneau et al., 2009; Austin et al., 2010) and laboratory (e.g., Haller and Dalrymple, 2001; Kennedy and Thomas, 2004; Castelle et al., 2010) experiments, video imaging systems (e.g., Holman et al., 2006; Turner et al., 2007) and mathematical and numerical modelling (e.g., Reniers et al., 2009; Castelle et al., 2006; Bruneau et al., 2011). In the field, for low- to moderate-energy wave conditions, tidal elevation is found to dictate occurrence of rip current activity. In most studies, increasing rip current activity occurs with decreasing tidal elevation resulting in maximum rip current intensity near low tide (e.g., Brander, 1999; MacMahan et al., 2006). Other studies noticed maximum rip current intensity between low and mid tide for low- to moderate-energy wave conditions (e.g., Brander and Short, 2000; Castelle et al., 2006; Bruneau et al., 2009; Austin et al., 2010, 2013) and rip current likely not flowing at high tide. In addition, on the SW coast of France, Castelle et al. (2006) and Bruneau et al. (2009) observed that the occurrence of maximum rip current intensity moves closer to high tide with increasing incident wave energy. Recently, Austin et al. (2013) observed the presence of net tidal currents in the alongshore direction on a macro-tidal beach. These authors noted maximum tide currents occurring around mid tide, when the maximum rip currents occur on the side of the low tide. Overall, the common perception of rip currents in tidal environments is that tide acts mainly as a change in water level. This means that, for a given wave condition and tidal elevation, rip current intensity is the same during ebb and flood. Yet, a more detailed examination of the rip current data in Bruneau et al. (2009) suggests that this is not exactly the case as substantially larger rip current intensities were measured during ebb than during flood. This corroborates qualitative lifeguard observations on this stretch of the French coast which suggest that, during low-energy wave conditions, rip

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currents are more efficient in pulling swimmers away during ebb than during flood. Accordingly, it is worth testing the hypothesis that tide-induced currents on wave-exposed rip-channelled beaches are significant.

In Section 2, the study area and the field experiments as well as the modelling strategy are described. Section 3 presents field evidence of the tidal signature in rip current velocity data at Biscarrosse Beach (Bruneau et al., 2009) and model application to investigate the influence of the hydrodynamic forcing (tides and wave conditions) on rip current flow asymmetry. A discussion on the impact of this flood/ebb asymmetry in rip currents is presented in Section 4.

2. Data and method

2.1. Study site and data collection

The Aquitanian coast is a wave-dominated, high-energy, meso- to macrotidal environment exhibiting a strongly alongshore non-uniform and dynamic double sandbar system (Castelle et al., 2007). The outer and inner bars exhibit most of the time crescentic patterns and a transverse bar and rip morphology, respectively. Biscarrosse Beach is located at about 10 km southward of the Arcachon Lagoon Inlet (Fig. 1a) and is exposed to high-energy swells generated in the North Atlantic Ocean that are characterised by an annual mean significant wave height (H_s) of about 1.36 m and a mean period (T_m) of the order of 6.5 s (Butel et al., 2002). Tides range from 1.5 m to 4.8 m with an average of about 3.2 m.

During the Biscarrosse field experiment carried out in June 2007 (Bruneau et al., 2009), the beach exhibited a relatively alongshore-uniform subtidal outer bar and a well-developed inner bar-and-rip morphology with a wide range of wavelengths (Fig. 1b). A well-developed bar and rip system (narrow and deep rip channel, Fig. 1b) was intensively instrumented to investigate the time evolution of wave-driven circulation. Persistent shore-normal waves were measured during the experiment with offshore significant wave heights ranging from 0.6 to 3 m and peak periods ranging from 8 to 11 s. A detailed description of the field site and measured wave-driven circulation during the experiment is given in Bruneau et al. (2009). The authors emphasised the strong tidal modulation of the rip currents for low-energy conditions ($H_s < 1$ m) with a maximum rip flow magnitude between low and mid tides, and reasonably large mean rip current flows (>0.5 m/s). This behaviour differs from the one during energetic conditions when intense undertow dominates the overall rip current circulation throughout the whole tide cycle.

2.2. Numerical model strategy, set-up and application

Our modelling system couples the spectral wave model SWAN (Booij et al., 1999) with the non-linear shallow water circulation model MARS (Lazure and Dumas, 2008) using the depth-averaged (2DH) mode. Recently, wave-related processes were integrated (Bruneau et al., 2008, 2011) to compute wave-driven circulation according to Smith (2006). Defining $\vec{U}$, the horizontal velocity and ζ, the free surface elevation, mass and momentum conservation equations can be derived as follows:

$$\partial_t\bar{\zeta} + \partial_i\bar{h}U_i = -\partial_i\tilde{Q}_i \quad (1)$$

$$\partial_t U_i + U_j\partial_j U_i + g\partial_i\bar{\zeta} = -\partial_i\tilde{J} + \frac{D^r k_i}{\sigma_r\rho\bar{h}} + \frac{\tilde{Q}_j}{\bar{h}}(\partial_i U_j - \partial_j U_i) + \frac{H_i}{\rho\bar{h}} + \frac{\bar{\tau}_i^S - \bar{\tau}_i^B}{\rho\bar{h}} \quad (2)$$

where subscript i refers to the two horizontal coordinates. X and Y represent the alongshore and cross-shore directions, respectively. t is the time, ρ is the water density, g is the gravitational acceleration, $\bar{h}$ is the mean water depth, H_i is the lateral turbulent shear stress, D_r

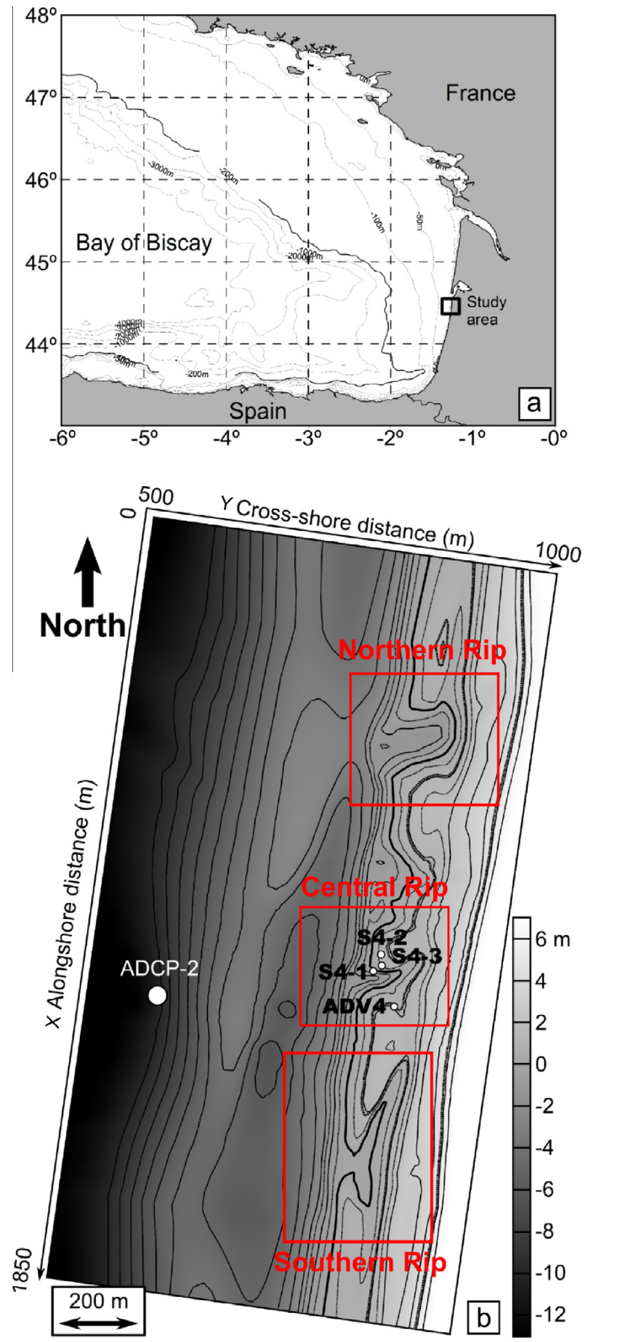

Fig. 1. (a) Atlantic front of the French Coast and continental shelf in the Bay of Biscay. The black box shows the Biscarrosse Beach location; (b) The Biscarrosse double-barred Beach during the field experiment (June 2007) with the deployment positions of the ADCP-2, S4 and the ADV4 sensors. Red squares indicate the three bar/rip morphologies used in the present study. The 0 level refers to the lowest astronomical tide. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

is the roller energy dissipation and, τ_i^S and τ_i^B are the surface and bottom shear stresses, respectively. The wave mass transport is written as:

$$\tilde{Q}_i = (E^w + E^r)\frac{k_i}{\rho ck} \quad (3)$$

where k_i is the wave number, E^w and E^r are the energy induced by the wave-organised motions and the roller contribution, respectively. c_p is the wave phase celerity and σ_r is the relative frequency.