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# Rip current system over strong alongshore non-uniformities: on the use of HADCP for model validation

**B. Castelle, P. Bretel, S. Morisset, P. Bonneton, N. Bonneton, M. Tissier, C. Sotin, A. Nahon, N. Bruneau, J.-P. Parisot, S. Capo, S. Bujan, V. Marieu**

CNRS, UMR EPOC-5805
Univserité de Bordeaux
33405 Talence Cedex, France
b.castelle@epoc.u-bordeaux1.fr

**ABSTRACT**

CASTELLE, B., BRETEL, P., MORISSET, S., BONNETON, P., BONNETON, N., TISSIER, M., SOTIN, C., NAHON, A., BRUNEAU, N., PARISOT, J.-P., CAPO, S., BUJAN, S., MARIEU, V., 2009. Rip current over strong alongshore non-uniformities: on the use of HADCP for model validation. Journal of Coastal Research, SI 56 (Proceedings of the 10th International Coastal Symposium), pg – pg. Lisbon, Portugal, ISBN

Modeling and understanding topographically-controlled rip currents remains a challenging task. One of the reasons is the lack of intensive, high-spatial resolution, flow field measurements in the rip channel vicinity. During the ECORS (DGA-SHOM) intensive field measurements, an intertidal inner-bar rip channel was instrumented with fixed eulerian current meters. In addition, for the first time in such a system, a Horizontal ADCP (HADCP) was implemented in the vicinity of the rip current, on the sandbar edge, for horizontally profiling wave induced-currents. Results show that the HADCP provides unique information on the shear in the vicinity of the rip neck, which is particularly useful for model calibration. The HADCP data was compared with local flow measurements for various tide and wave conditions, showing a very good agreement at a 5 m range. Restrictions and recommendations for HADCP implementation in the field are pointed out. The use of HADCP for horizontally profiling rip current circulations would benefit from being deployed outside of the breakers to measure the cross section of the rip head where sediment plumes and bubbles are essentially surface dominated. In this rip current system area, which would suffer from acoustic opacity only during high energy conditions, the rip current jet is strongly unstable owing to the current shear. HADCP would provide unique information on the rip current instabilities and vortex shedding in this poorly understood area of the rip current system.

**ADITIONAL INDEX WORDS:** *Mean Currents, Shear, deployment strategy*

## INTRODUCTION

Rip currents are approximately shore-normal, seaward flowing, intense jets that originate within the surf zone and broaden outside the breaking zone (MACMAHAN *et al*., 2006). In recent years, there has been significant interest in rip currents systems, as they are important for beach safety and localized dune erosion during storms (THORNTON *et al*., 2007). Rip current circulations are driven by longshore variations of wave-induced radiation stress (LONGUET-HIGGINS and STEWART, 1964). These gradients can be due to spatial variability of the incident wave field in the presence of wave groups (DALRYMPLE, 1975), wave-current interactions (DALRYMPLE and LOZANO, 1978), wave field interaction with lower-frequency waves such as edge waves (SYMONDS and RANASINGHE, 2000) or local topographic variations (BOWEN, 1969). The latter is called 'topographically-controlled rip current', while the three others refer to 'transient rip currents' (JOHNSON and PATTIARATCHI, 2004).

Surprisingly, and even if topographically-controlled rip current systems are the easiest rip current type to capture in the field, intensive and high spatial resolution measurements in the rip channel vicinity is lacking. Eulerian measurements and, more recently, lagrangian techniques have been used to investigate rip current systems. The latter, when a sufficient number of drifters (~ 30) is released during a sufficient duration (~ 3 hours), can be transformed into a horizontal mean circulation field (MACMAHAN *et al*., in press). However, this requires small tidal ranges, a substantial post-processing effort, and a large number of investigators on the field devoted to this task (MACMAHAN *et al*., in press). Measurements of the vertical structure of rip current flows have been attempted in the field, despite limited. A vertical array of current meters can be used for this purpose (see for instance MACMAHAN *et al*., 2005). Acoustic Doppler Current Profilers (ADCP) have been deployed to provide higher-resolution data on the vertical structure of rip currents. While results showed that flows were essentially depth uniform except in the rip head vicinity where maximum velocities were measured near the surface, accurate measurements in the surf zone are difficult to obtain. Intense wave breaking, and particularly plunging breakers, can inject significant amounts of air bubbles into the water column, making the area acoustically opaque and limiting ADCP measurements in the surf zone (SMITH and LARGIER, 1995; VAGLE *et al*., 2001). A substantial number of laboratory experiments (HAMM, 1992; HALLER and DALRYMPLE, 2001; KENNEDY and THOMAS, 2004; among others) have been undertaken to grasp rip current circulation information more easily than on natural beaches. However, other techniques for capturing high-spatial resolution horizontal circulations in the surf zone are required on

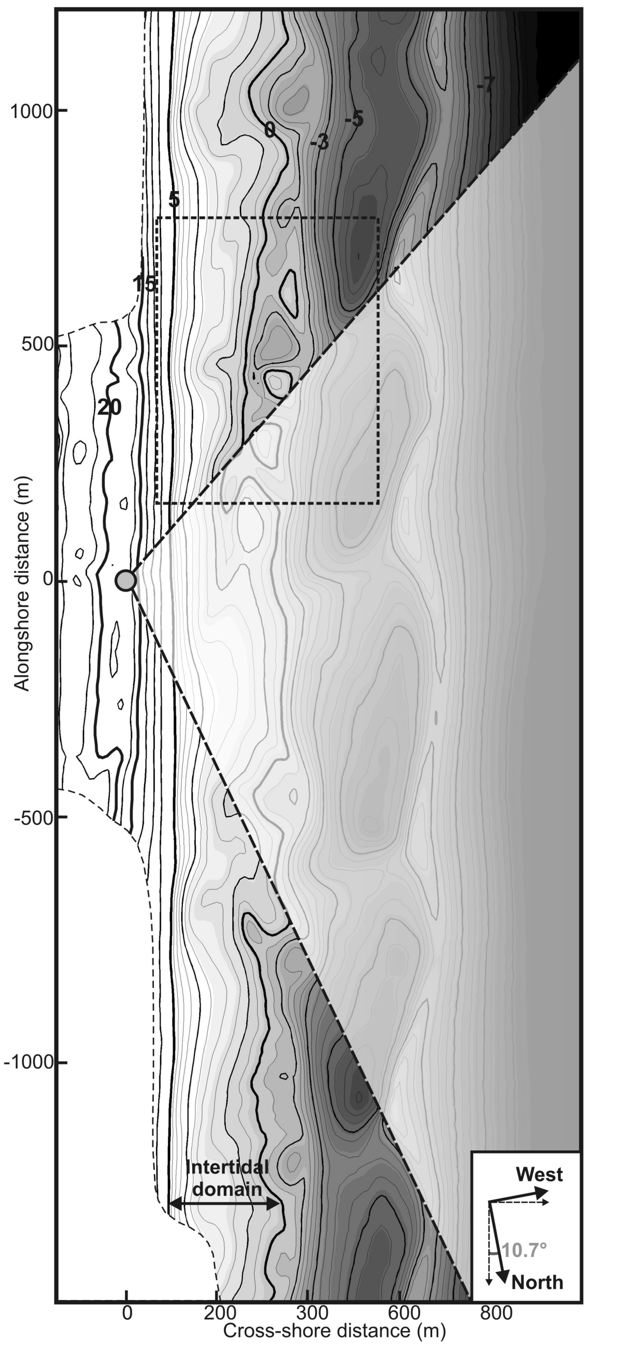


Figure 1. Bathymetry (dune, intertidal and subtidal zones) of TVB on the 6th of April 2008 during the ECORS field measurements (with the shaded zone delimiting the video imagery area facing the main instrumented zone). The dashed box indicates the computational grid used in this study to compute horizontal wave-induced circulations over strong alongshore non-uniformities.

the field. This is particularly true for wave-induced horizontal circulation model validation issues.

Truc Vert Beach (TVB), SW France, is a double-barred wave-dominated beach that has been intensively investigated over the past decade (see CASTELLE *et al*., 2007 for a review). In particular, rip current investigations over the strongly alongshore non-uniform intertidal inner bar were recently attempted using field data (CASTELLE *et al*., 2006; BONNETON *et al*., 2006; BRUNEAU *et al*., in revision) and/or a modeling approach (CASTELLE and BONNETON, 2006; BRUNEAU *et al*., in this issue). Despite these studies substantially improved our overall understanding of the high-energy rips that persistently occur along this meso-macrotidal coast (flow velocities, tidal modulation, very low frequency pulsations, etc), accurate information on flow velocities in the main body of the rip current system is lacking, and the degree of ability of the model to accurately reproduce the rip current circulations needs further investigations. Here we describe another technique, potentially complementary to the more commonly used eulerian and lagrangian techniques, suitable for wave-driven horizontal circulation model validation.

The 6-week ECORS (SHOM-DGA) international intensive field campaign took place in early 2008 at Truc Vert Beach during a wide range of offshore conditions. Here we focus on a 5-day period when a strongly alongshore non-uniform rip channel was instrumented with two VECTORS and one ADCP to provide wave and flow measurements in both the rip feeder and the rip throat. In addition, a Horizontal ADCP (HADCP) was implemented in the vicinity of the rip current for horizontally profiling wave-induced current circulation. While the previous HADCP deployments were undertaken in river, harbors and in the nearshore region far offshore of the breakers (see for instance MARMORINO *et al*., 1999), here we performed the first attempt to measure wave-driven circulations with this instrument.

The paper presents the input of the HADCP to provide information of the shear in the rip channel, which is usually difficult to grasp from traditional measurement techniques and which is important for mixing calibration in depth-averaged flow models. The accuracy of the HADCP measurements is tested and recommendations for future HADCP deployments in wave-dominated environments are provided.

## METHODS

### Field site description and data collection

The 6-week ECORS (SHOM-DGA) field campaign took place at TVB. During the experiment, the study area was exposed to high-energy conditions, with persistent high wave angle with respect to shore-normal (NW direction). During the five first weeks of the experiment, this wave forcing together with a surprisingly most of the time significantly alongshore-uniform inner-bar morphology, resulted in quasi-persistent sinuous southerly longshore current rather than horizontal circulation patterns. In addition, the only available complete bathymetry of the area coinciding with the deployed sensor period was collected during the last week of the experiment. Therefore, this period was chosen for comparing results from a numerical model with flow measurements gathered from an array of VECTORS, an ADCP and the HADCP. Figure 1 shows the TVB bathymetry during the studied period. The intertidal morphology was highly variable in the alongshore direction. A wide and strongly alongshore-uniform inner bar was observed in the main instrumented area, where the video imagery station was implemented and a large array of additional sensors was deployed. Therefore, the chosen instrumented area for the present study was translated about 500 m to the South of the main study area, where strong alongshore non-uniformities and rip current circulations were observed. The HADCP was located in the northern feeder of the rip channel with an array of VECTORS and an ADCP, all located in the rip channel vicinity (Figure 2).

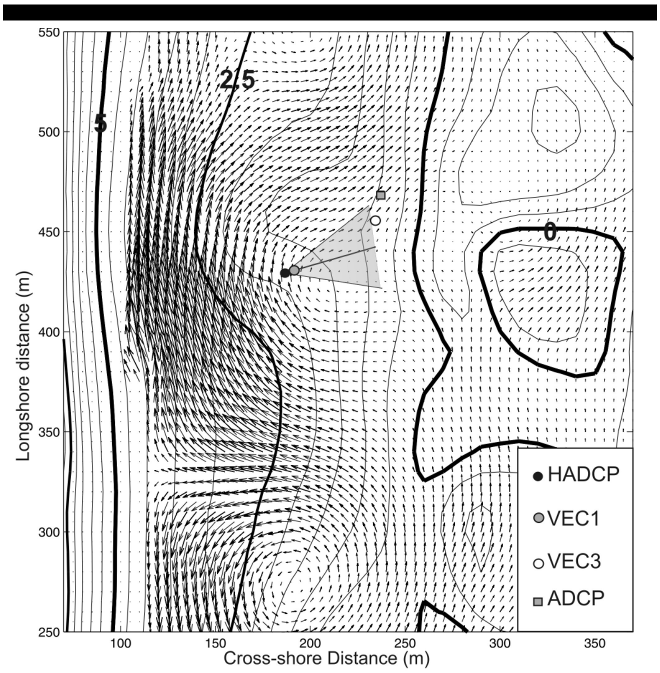


Figure 2. Zoom on the area of interest of a simulation of wave-induced currents (April 4, 4h00, $Hs$ = 1.1 m, $Tp$ = 11.34 s, $\theta$ = 15.54°, tide level of 4.13 m close to high tide), with location of the HADCP, the VECTORS (VEC1 and VEC3) and the ADCP.

## HADCP measurements

HADCP measurements consist in velocity characterization by Doppler Effect along three beams on a horizontal plan. Angles between beams are 25°, with the central beam oriented offshore in the direction of the rip channel (Figure 2). The acoustic Broadband technology of the system produces high accuracy measurements at a frequency of 2 Hz, with cell size of one meter. A range up to 50 m can be expected for the most favorable hydrodynamic conditions. The velocity resolution with our instrument (HADCP Teledyne RDI 600 KHz) and with the set up we used (2Hz, cell size 1 m) was +/- 5.6 cm/s. Each component of the measured Doppler Effect measured along a single beam was recombined to compute the current vector for each cell of the profiler (MORISSET and BRETEL, 2008). A specific frame was designed for these purposes. The instrument was previously tested in May 2006 at TVB over an alongshore-uniform stretch of intertidal domain. First comparisons with a single point current-meter provided good results for low energy conditions (BRETEL and BONNETON. 2007), which motivated the HADCP deployment during the ECORS field campaign. In this study we define the mean currents by the 30-minute averaged flow velocities measured by this instrument.

## Model set-up

A numerical model was implemented on the study area to provide preliminary information on the use of HADCP measurements for depth-averaged wave-induced current models. The model used herein is detailed in CASTELLE *et al.* (2006). The SWAN wave model (BOOIJ *et al.*, 1999) is coupled to a time- and depth-averaged flow model. We ran the model every 30 minutes on the domain shown in Figure 1, with 5 x 5 m grid cells. The bathymetry was extended of about 100 m to provide periodic lateral boundary conditions. Wave boundary conditions (directional wave spectrum) were provided by the DATAWELL wave buoy located in 20 m depth seaward of the studied area.

## RESULTS

During the 5-day period investigated herein, wave angle with respect to shore normal $\theta$ was large (15° < $\theta$ < 50°), with associated low energy waves (0.5 cm < $Hs$ < 1.5 m). Wave conditions were typically the result of the superimposition of a very low energy shore-normal swell and a persistent N-NW wind sea. Simulations and measurements showed the presence of a sinuous longshore current over the alongshore non-uniformities during higher tides and higher wave angles, while circulation cells associated with a rip current was observed during lower tides due to strong alongshore variations in wave breaking across the strongly three-dimensional geometry of the inner-bar system. Maximum mean currents measured by VEC1 and VEC3 were on the order of 0.5 m/s, and the ADCP also revealed higher flows close to the sea surface, in agreement with the observations of BRUNEAU et al. (in revision) during similar wind/wave conditions.

The ability of the model to simulate wave heights and mean currents has been tested. Results (not presented herein) show a fair agreement at both the VEC1 and VEC3 locations. Then, the HADCP measurements have been carefully compared with the VEC1 data, facing the HADCP central beam at a distance of about 5 m. This comparison was done for a wide range of offshore wave conditions and tide levels (MORISSET and BRETEL, 2008). Figure 3 shows an example of time series comparing the flow velocities measured by the HADCP and the VEC1. Results show a good agreement for the time series. A summary of the undertaken comparisons is given in Table 1. While the standard deviation of the error between the HADCP measurements and the VEC1 data is on the order of 0.1 m/s, the error decreases to values on the order of 0.001 m/s when computing mean flow velocities (Tab. 1), which gives confidence for using the mean horizontal profiles of currents measured by the HADCP. Therefore, were assumed the HADCP mean flow measurements to be of good quality for larger ranges, as shown in Figure 4. It is to be noted that the small difference between the VEC1 and HADCP data may be partly caused by the slightly different depth levels at which the data was

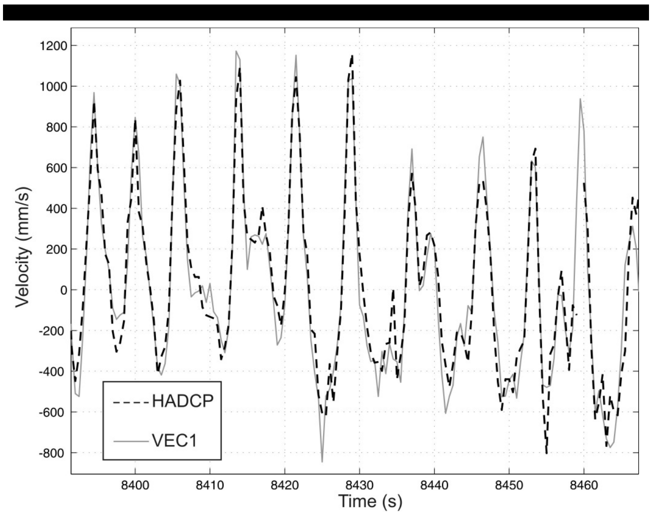


Figure 3. Example of time series showing the comparison of the ADCP flow measurements with the VEC1 located at about 5 m facing the HADCP. A summary of the comparison for different tide cycles is given in Table 1.

Table 1: Computed HADCP measurements accuracy by comparison with the VEC1 measurements (MORISSET and BRETEL, 2008).

| Date | Part A | Part B: | Part C: |
|---|---|---|---|
| Hs(m) | 0.48 | 1.13 | 1.41 |
| Mean Error (mm/s) | 1.55 | 1.81 | 3.97 |
| Error standard deviation (mm/s) | 111.99 | 105.16 | 110.3 |
| Signal to noise ratio | 5.26 | 8.14 | 14.09 |

obtained. Figure 5 shows the HADCP measurements on the 4th, 6th and 7th of April for different tide levels and offshore wave conditions. HADCP flow measurements reveal the strong shear of mean currents, and also how this shear is strongly tidally modulated.

## DISCUSSION AND CONCLUSIONS

When the HADCP was located outside of the breakers, the agreement with the 30-minute averaged currents measured by the ADV was very good, with a mean error on the order of a few mm/s. According to the HADCP measurements presented in this paper, and the other attempts undertaken for more energetic conditions during the ECORS campaign (not presented herein), collecting high quality horizontal profiles of wave-induced currents in the surf zone is a challenging task. The three main difficulties are the requirement for deploying a stable frame with very fine adjustment (pitch, height above sand, etc), the absorption of acoustic echo by bubbles on profiler range when intense wave-breaking occurs, and the effect of shallow water which reduces the range because of beam interception with water surface or moving sandy bottom.

Therefore, recommendations can be made for further deployment of such a system to capture wave-induced horizontal circulations. Turbulence due to wave-breaking, particularly for high-energy wave conditions, appears to be the main limitation of the HADCP deployment, as it strongly limits the horizontal extent of the validity of the profiling range, as previously pointed out by several authors for the use of ADCP (SMITH and LARGIER, 1995; VAGLE *et al.*, 2001). Therefore, the use of a HADCP for horizontally profiling surf zone circulations would certainly benefit from being deployed seaward of the sandbar system, that is, further offshore than the deployment strategy presented here. This would be particularly useful for profiling currents across the rip head (horizontal profiling in the alongshore direction). The visual markers of the rip head such as sediment plumes and bubbles outside of the surf zone are surface dominated (MACMAHAN *et al.*, 2006) and, therefore, bottom mounted HADCP measurements would not suffer from acoustic opacity for low to moderate energy conditions (for high energy waves the surf zone would be saturated and would start far offshore of the sandbar system). In this rip current system area, the rip current jet is strongly unstable owing to the current shear. HADCP would provide unique information on the rip current instabilities and vortex shedding in this poorly understood area of the rip current system. This data would also be of high value for non-stationary wave-induced current models. During the ECORS campaign, unfortunately, wave conditions did not allow a safe HADCP deployment in this area.

Although this constitutes a strong limitation for investigating mean currents and the shear in the surf zone, optimistic results were also obtained when investigating bore merging and wave celerity (not presented in this paper), and other potential applications remain. To conclude, HADCP deployment is challenging and appears to be complementary to the more commonly used eulerian and lagrangian techniques to capture wave-driven circulations in the nearshore.

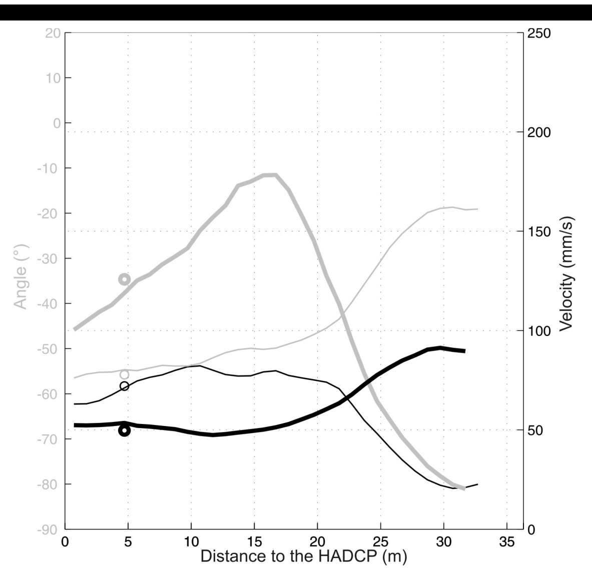


Figure 4. Example of comparison of HADCP measurements (lines) with the VEC1 (circles) facing the HADCP rig, on the 7th of April 2008 at 4h (thin) and 5h30 (thick).

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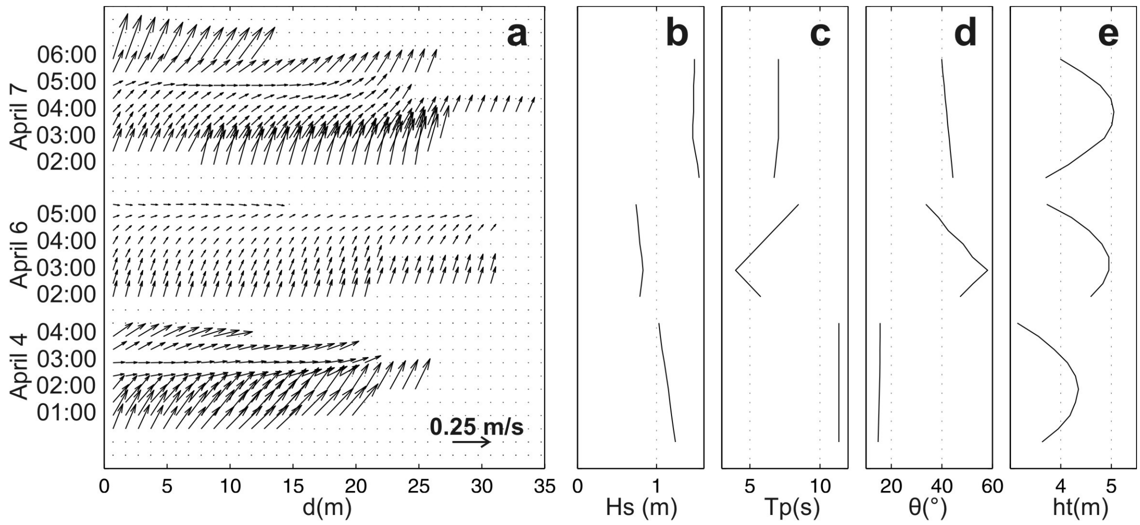


Figure 5. Example of HADCP measurements collected during the experiment. Mean wave–induced current vectors (a) as a function of *d* the distance to the HADCP and averaged every 30 minutes for different offshore wave conditions with (b) the significant wave height *Hs*, (c) the peak wave period *Tp*, (d) the wave angle *θ* with respect to shore-normal and (e) the tidal elevation *ht*.

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