CURRENT, WAVE AND TIDAL OBSERVATIONS FROM A HORIZONTAL ACOUSTIC DOPPLER PROFILER INSTALLED ON SCRIPPS PIER IN LA JOLLA, CALIFORNIA, USA

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Horizontal (side-looking) acoustic Doppler current profilers are emerging as an attractive alternative to bottom-mounted profilers in direct monitoring of currents, waves and tides in the nearshore region. This study evaluates the feasibility of a single side-looking Doppler current profiler in mapping the currents in a shallow, non-channelized flow field (the open nearshore region). We discuss the limitations, considerations, and capabilities of one such system. Wave and tide data collected by the system are also presented. Operational concepts of flow homogeneity, installation aspect ratio and side lobe interference are addressed. The feasibility of the system to monitor events such as rip currents is also discussed.

INTRODUCTION

Motivation

Direct monitoring of currents, waves and tides is an important practice throughout the lifespan of any coastal structure that is in direct contact with the water. Today, these measurements are typically done by deploying current profilers within the vicinity of the structure or its proposed location. Over the last 20 years, bottom-mounted, vertically-profiling acoustic Doppler instruments have been the instrument of choice for measurements in these nearshore regions, with multiple units generally required for the desired spatial coverage. Although this approach has been successfully used in a wide variety of settings over the years, it has some significant restrictions: multiple instruments are required for full spatial coverage; placement of bottom-mounted systems is impractical or impossible in areas of high vessel traffic, dredging, etc.; deployment of bottom-mounted instruments are complex and laborious; instrumentation costs are considerable; and desirable wave measurement packages are usually additional options that increase an instrument's operational complexity and cost.

More recently, however, side-looking Doppler profilers are emerging as an attractive alternative to bottom-mounted profilers (Earwaker et al., 2002). A single horizontally-mounted profiler affords a relatively large spatial coverage (at times >100 m); allows for the use of existing structures such as piers, pilings or bridges to be used as deployment platforms; and greatly simplifies instrument deployment. Furthermore, side-looking profilers are typically more affordable than similar bottom-mounted instrumentation due to simpler design and can offer embedded pressure-based wave data without considerably increasing the system's complexity or cost.

However, side-looking Doppler current profilers were primarily designed for shallow (usually < 10 m) confined-channel applications, such as volumetric discharge in rivers or other canals. As such they have limitations in meeting the

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basic Doppler assumption of flow homogeneity between acoustic beams as well as being more susceptible to interference from nearby boundaries, given the shallow depths where they are typically installed.

In this paper we describe near-surface, nearshore currents, tides and wave height data from a single side-looking acoustic Doppler profiler in order to address its feasibility in shallow, non-channelized flow conditions. The instrument used is relatively low-cost and extremely low power and is installed on the Scripps Institution of Oceanography's pier, located in La Jolla, California. Current patterns at the site are primarily alongshore (both northward and southward depending on the tidal cycle), but do span the entire range of directions, including onshore and offshore. Such mixed flow direction and the site's shallow depth pose special challenges to horizontally-mounted profilers which are addressed in this paper. We also address the feasibility in the system's use for monitoring rip currents.

Location and Deployment Setup

As part of an ongoing instrument study, a SonTek SL500 side-looking acoustic Doppler profiling system was installed at the end of the Scripps Institution of Oceanography's pier, Fig 1.

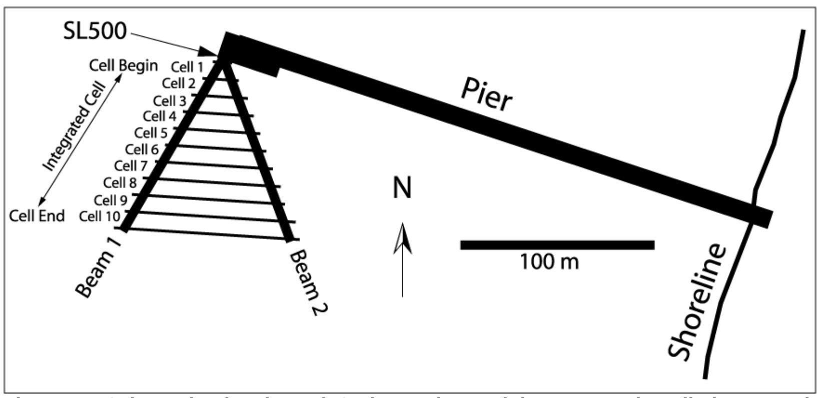

Figure 1. Schematic drawing of Scripps Pier and instrument installation. Both SL500's horizontal acoustic beam paths are shown, drawn to their maximum acoustically-feasible extent. Each individual range cell is shown as well as extent of the single integrated cell. North is 0° direction.

The pier is approximately 300 m long, and perpendicular to the shoreline at La Jolla Shores beach. The pier has an azimuth of 289°, therefore it approximates an East-West line offset northward by 19°. At the seaward end of the pier the water depth is around 7 m and the pier's deck is around 10 m above MLLW (CDIP, 2007). Several instrumentation sheds are present at the seaward end of the pier, allowing of easy access to power, cabling and computer setup.

The SL500 used in this study was mounted facing primarily south, on the pier's second-to-last piling. The instrument was mounted ~3.5 m above the bottom, approximately in the middle of the water column. The required 12vdc power was supplied to it via a cable fed through an instrumentation shed on the pier's deck. Data was collected in the SL500's internal memory and downloaded periodically. Although the system has been in operation since March 2006, five data subsets are presented here:

Table 1. Data summary	
18 April to 6 June, 2006	Data collected using 20-minute averaging intervals once an hour for currents, tides and waves
14 July to 29 July, 2006 August 28 to September 18, 2006 September 20 to October 11, 2006 17 November to 8 December, 2006	Data collected using 1-minute averaging intervals continuously for currents only

Horizontal current profile data was collected throughout the range of the two side-looking beams. Data was screened for low returned signal strength (Signal-to-Noise ratio, SNR) and all data less than or equal to 3 dB was removed. The profile comprised of 10 horizontal cells of 11 m each with a blanking distance of 2 m (Fig. 1). The system's ping rate was 1 Hz and data was averaged for 20 minutes or 1 minute intervals according to the schedule in Table 1. Ancillary data (temperature and pressure) were also collected at 1 Hz and averaged for the same period as the velocity data.

Water pressure data was collected at the sensor by the unit's built-in piezoresistive (strain-gauge) pressure sensor (0.1% accuracy). The pressure sensor was sampled at 1 Hz during the user-defined averaging interval. When wave data were collected (20 minute sampling schedule), raw 1 Hz data were recorded to the SL500's internal memory; when wave data were not collected (1-minute averaging interval), the 1 Hz data were averaged together and the mean of the 60 samples (60 seconds at 1 Hz) were recorded. Wave data was computed internally by the instrument's CPU and recorded in near-realtime (that is, once an hour at the end of each 20 minute burst). A total of 1024 pressure samples collected at 1 Hz were used to compute the basic non-directional wave statistics parameters of H_{m0} and T_p.

Current And Wave Conditions

Fig. 2 shows the integrated range cell's data (full acoustic range) for the 18 April to 6 June data set. As seen from the water speed and direction data, the local currents are tidally influenced, with the semi-diurnal character being only lightly observed in the currents (see pressure data as well). The overall current speeds are low, in the order of 10-20 cm/s. However, periodic storm events can increase currents speed and almost completely mask the tide's influence over the currents' direction, as can be seen during the 27 May storm.

Response from the 27 May storm can also be seen in the wave data, altering the significant wave height characteristics typical off of the Southern California coast. At the onset of the storm, shorter period (higher frequency) waves dominate, likely generated by the storm front winds. Their energy is then slowly passed onto longer period (lower frequency) waves at the peak of the storm, where the highest waves and steadier current direction are also observed.

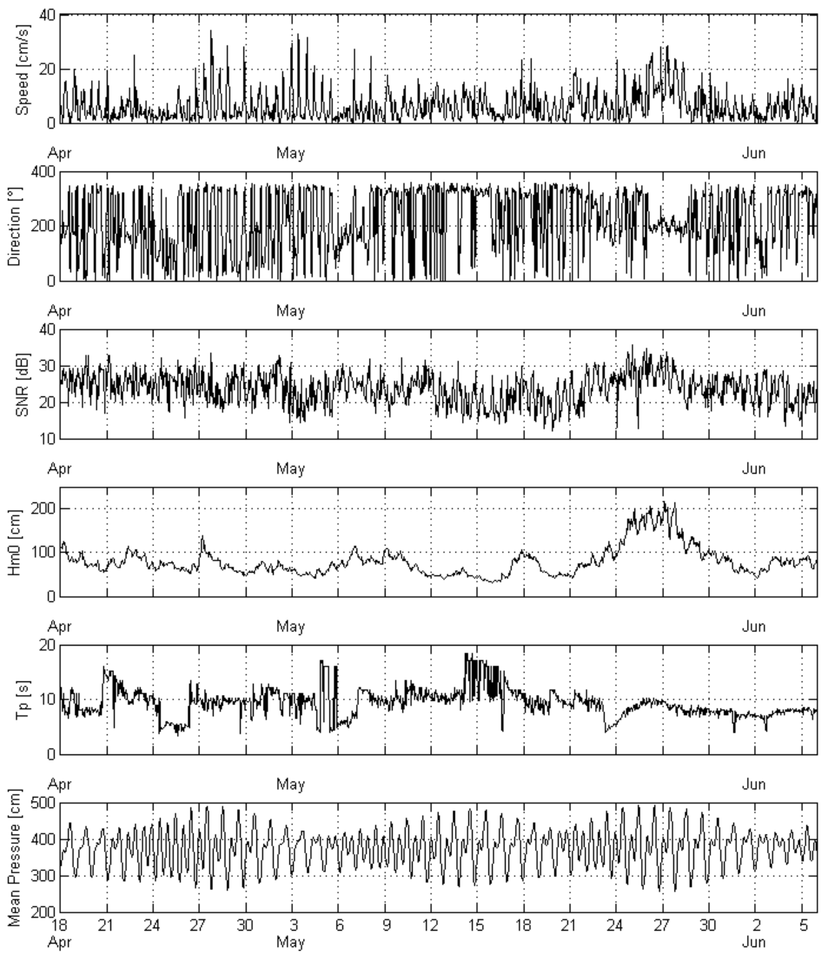

Figure 2. Time-series of water speed, direction and returned signal strength (signal-to-noise ratio, SNR) data from the 18 April to 6 June data set for the single integrated cell. Significant wave height, peak period and mean water pressure data is also shown for the same time period.

As a comparison, significant wave height data from the Scripps Institution of Oceanography's Coastal Data Information Program (CDIP) station 073—located just a few meters away (CDIP, 2007)—agrees well with the SL500's data (Fig. 3).

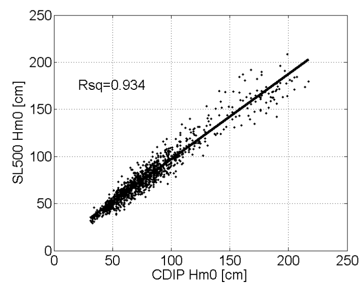

Figure 3. Linear regression comparison between CDIP station 073 H_{m0} and the SL500's internally-computed H_{m0} showing how well they agree (R^2 0.934). Comparison is for 18 April to 6 June data set.

DISCUSSION

Side Lobe Interference

One of the main complications in using side-looking Doppler profilers in shallow depths, as in this study, is side lobe interference. Although acoustic transducers used in Doppler profilers are highly directional, the acoustic energy they produce spills outside of their main beam path (referred to as a main lobe) and into secondary (or side) lobes that, although containing less acoustic energy than the main lobe, have wider beam widths. As such, an important practical characteristic of Doppler profiler operation in side-looking profiling applications is the installation's aspect ratio, defined as the ratio of the maximum effective horizontal distance to the vertical distance from system to the closest boundary (Polonichko and Romeo, 2007; SonTek, 2007). This is illustrated in Fig. 4.

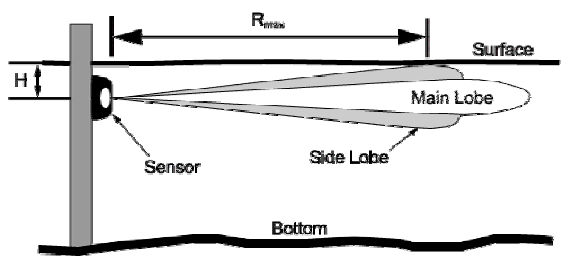

Figure 4. Conceptual diagram of an acoustic Doppler profiler installation, showing the main lobe and a side lobe. The main lobe describes the maximum acoustically-feasible range for the sensor, but the maximum effective range is the intersection of the side lobe with the surface—data beyond this range is likely to be affected. Thus the system's aspect ratio (R_{max}/H) is of critical importance for side-looking applications. Modified from Polonichko and Romeo (2007).

Traditionally the main (central) lobe has been used in horizontal Doppler applications to define the maximum profiling range of a particular system, but as Polonichko and Romeo (2007) have demonstrated, side lobes are the dominant source of boundary interference given their wider beam width. In practical terms, increased side lobe interference from the water surface and/or the bottom can result in biased (typically low) velocities, decreased profiling range, or can even completely dominate the reflected signal, invalidating the measurement.

As with all SonTek Doppler instruments, the SL500 system used in this study has transducers built with a proprietary side lobe suppression technique (commonly called "shading") that increases the practical aspect ratio of the installation by as much as 80% when compared to ordinary transducers at this same deployment depth. Comparable increases in range have also been reported by Earwaker et al. (2002) for deeper depths. As Fig. 5 illustrates, because of the increased side lobe interference of ordinary transducers, the first three side lobes must be considered in the aspect ratio, despite their generally narrower main lobe On the other hand, in a shaded transducer only the first side lobe can effectively produce interference even though its main lobe is slightly wider than ordinary transducers. Side-looking profiling systems that have one off-plane transducer (tilted up to derive three dimensional currents) are even more subject to limited installation aspect ratios and must be deployed at considerable depth in order to clear nearby obstructions from the water surface and/or bottom.

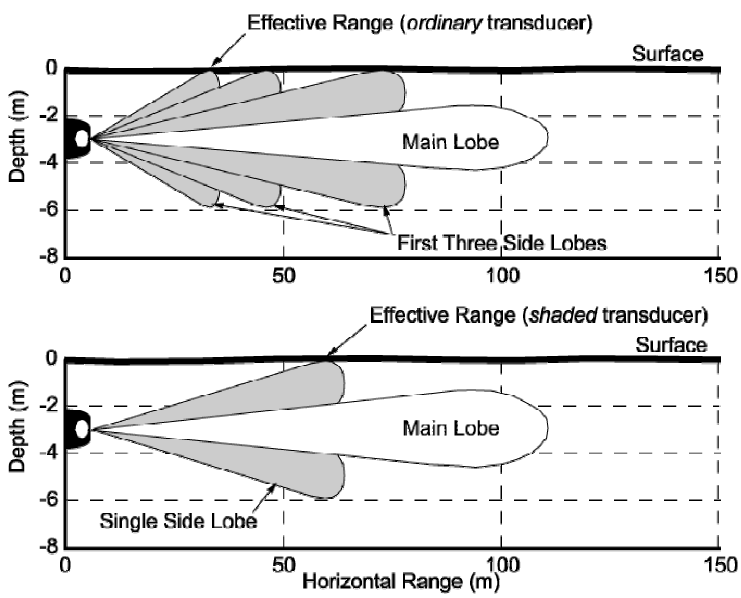

Figure 5. Effects of transducer side lobe suppression ("shading") on the effective range of a horizontal acoustic Doppler profiler. For the 3 m installation depth of this study, an ordinary transducer's effective range (top panel) would be limited to about 33 m due to side lobe interference. But the SL500's shaded transducer (bottom panel) has an effective range of about 61 m—an increase of over 80%. The side lobe suppression technique has a critical impact on the system's aspect ratio. Modified from Polonichko and Romeo (2007).

Due to side lobe interference, it is critical that the beams' path and system's tilt be carefully monitored at the time of installation and during the installation's lifetime. This is commonly done with the help of an on-board tilt sensor. With horizontal Doppler profilers today having acoustically feasible ranges of > 100 m, even a couple degrees of tilt can reduce the effective range and so every effort must be made to insure a level installation.

Non-Channelized Flow

In side-looking profiling applications it is desirable to have all acoustic beams profile along a single plane in order to minimize potential disturbances from nearby boundaries (e.g. the surface and/or bottom) and, as such, allow the unit to be installed in relatively shallow water. And because such systems are typically installed on existing structures such as piers and docks, it is also desirable that they profile long distances so that their sampling volume is not affected by flow disturbances created by the nearby structures but rather are representative of the current to be measured.

However, all Doppler profiling applications rely on the fundamental assumption that the flow field is uniform across the area covered by all of the system's acoustic beams. That is, the water across one of the beams has the same speed and direction as the water across all other beams (SonTek, 2001). The SL500's maximum profiling range is 120 m, and with its 25° beam slant angle the distance between the two beams at their maximum extent is over 110 m. This large spatial coverage, although desirable in channelized flow conditions, may not be optimal for measurement in shallow, non-channelized flows where currents can come from multiple directions depending on tidal fluctuation, wave action and storm activity. Therefore, one cannot match cell-to-cell as is traditionally done because the Doppler shift observed in one range cell along one beam often differs from that observed in the same cell along the other beam, hence generating inconsistent readings as illustrated in Fig. 6.

One method this study applied in dealing with this lack of flow homogeneity and break down of the basic Doppler assumption is to treat all cells together as one single range cell. This is automatically done by the SL500 where a single integrated cell, defined by two user-selectable parameters ("Cell Begin" and "Cell End"; Fig. 1), can be placed anywhere along the range of the acoustic beams. Typically this cell is programmed to extend the largest range possible, and hence due to this larger spatial averaging, can deliver data with less noise than those collected by smaller cells.

Another method applied to deal with the basic Doppler assumption breakdown is to match overlapping cells. Overlapping must be done on cells which are parallel to a desired flow direction, thus creating a "virtual channel" within which the velocity is measured. To check for proper overlap, only cells where >80% of their range on one beam overlapped with a range cell on the other beam were used. One practical use of this technique is described on the next section.

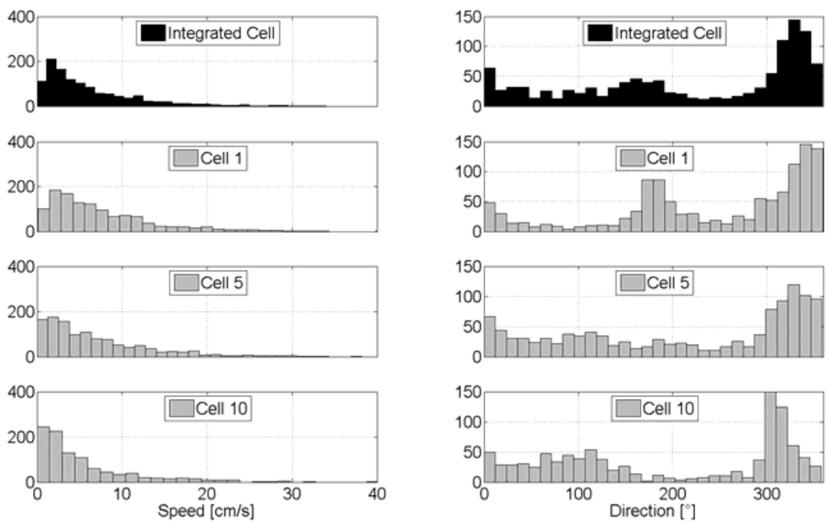

Figure 6. Histograms of water speed and direction data from the 18 April to 6 June data set for the single integrated cell and cells 1, 5 and 10 (reference Fig. 1). As the distance from the instrument increases, the distance between the acoustic beams also increases, therefore making it increasingly difficult to match up a cell on one beam with the same cell on the other beam. Note difference in water speed and direction with increasing distance from instrument. The apparent bias in the water speed might also be caused by side lobe interference discussed previously.

Rip Currents

One of the goals of this study was to determine the feasibility of side-looking profilers such as the SL500 in monitoring rip currents. Rip currents are channelized (jet-like) flows perpendicular to the shoreline that originate within the surf zone and move offshore past he breakers at speeds up to 1 m/s (MacMahan et al., 2005). In addition to posing a hazard to swimmers (Lascody, 1998), rip currents can transport sediment and shape the shoreline (Cooke, 1970; Kamphuis, 2000).

Because rip currents are channelized flows in a non-channelized volume (the open nearshore region), it should be possible to use a two dimensional horizontal profiler to measure such currents. However, due to the break down of the basic Doppler assumption discussed earlier, in order to be able to measure such currents, the Doppler profiler must be mounted perpendicular to the current. But, as was the case in this study, it is not always possible to mount these systems perpendicular to the current (the SL500's central axis was directed slightly offshore; Fig. 1), especially when the current's direction is variable. Therefore, we cannot make the assumption that, if a rip current is captured by a given range cell on the shoreward beam (beam 2) that it will show up on the same range cell on the seaward beam (beam 1). Also, because rip currents are relatively narrow jet-like flows, the SL500's single integrated cell's spatial coverage is too large for proper identification of such events.

Applying the range cell overlapping technique, data from shore-perpendicular overlapping range cells were combined and represented as a single range cell. The result was cells 5-6 on the shoreward beam (beam 2) were matched with cells 4-5 on the seaward beam (beam 1), as illustrated (Fig. 7).

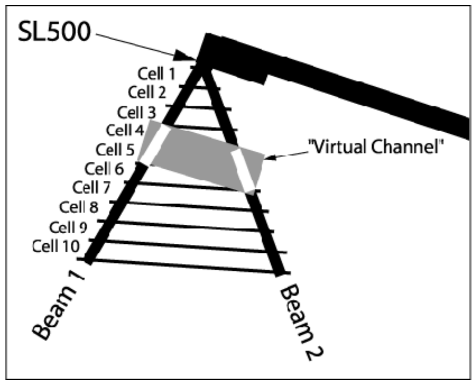

Figure 7. Close-up of Fig. 1, showing SL500's range cell locations and "virtual cell" created by the overlap of cells 4-5 on beam 1 and cells 5-6 on beam 2.

Following this, a simplistic definition of a rip current was adopted to facilitate identification of rip currents within this "virtual channel" and to differentiate them from the background current flow. An individual rip current had to: a) reach a speed of at least 50 cm/s; b) flow ± 30° perpendicular to the shoreline; and c) last at least 5 minutes. The data was then scanned for time periods where the definition could be met. A total of 13 episodes met at least two of the conditions and a representative subset of the results are shown on Fig. 8.

The biggest limitation in this analysis was the time threshold used. All offshore flow spikes that reached at least 50 cm/s failed to last the predetermined 5 minutes used to differentiate them from the background currents. However, the velocities do show a significant increase from, and return to, their background values, thus suggesting a jet-like flow as expected of a rip current. Note that there is approximately 40 m (horizontally) between beam 1 and beam 2 at the center of the virtual channel, thus at 50 cm/s, it takes approximately 80 seconds for a rip current to go from beam 2 to beam 1 and so the 5 minute limit used might be excessive.

Although the analysis of this data set for rip current identification shows only limited results, it is possible that if the rip current regime of this area approximated the more channelized conditions described by MacMahan et al. (2005) we would have observed improved results. Further investigation with multiple instrumentation (such as video imagery) is required to validate the feasibility of horizontal Doppler current profilers in identifying episodic events such as rip currents.

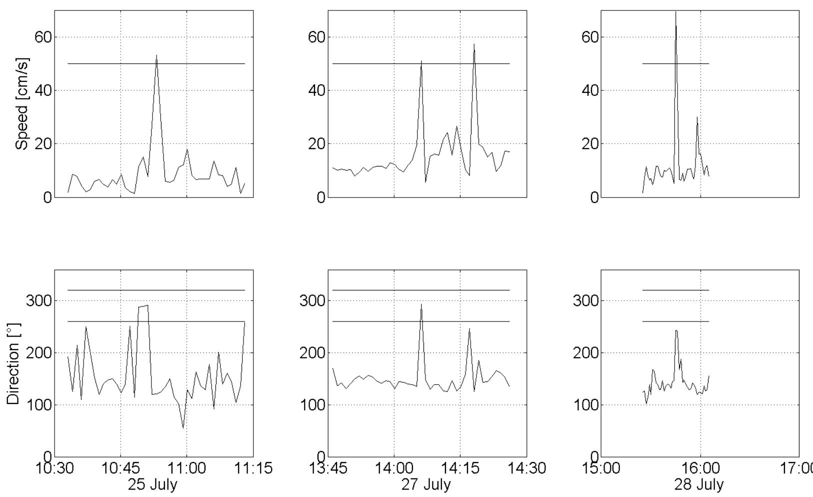

Figure 8. Computed water speed and direction for 25, 27 and 28 July, processed according to the rip current definition used in this study, inside the "virtual channel". The horizontal line in the top panels indicates the 50 cm/s threshold used. The horizontal lines in the bottom channel indicate the 260-320° threshold for "offshore" flow direction.

CONCLUSIONS

With the emergence of long-range side-looking acoustic Doppler current profilers as a tool for mapping the nearshore flow field, several considerations must be taken into account in order to assure data quality. Of primary concern is interference generated by acoustic side lobes that can limit the system's effective range. Consequently, the installation's aspect ratio must also be carefully considered in order to minimize the impact of nearby boundaries, such as the water surface and/or bottom.

Because the basic Doppler assumption of flow uniformity between acoustic beams can break down in non-channelized flows (such as the open nearshore region), special consideration must be taken when analyzing flow data from horizontal Doppler profilers in these conditions. In particular, flow direction can often be negatively affected by the large spatial coverage of such systems.

This study has also addressed some of the implications of using side-looking Doppler profilers in the monitoring of episodic events such as rip currents. It was shown that such systems have a promising potential, but further investigation is necessary in order to properly quantify and validate this potential.

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Abstract 112

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