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Low-Energy Rip Currents Associated With Small Bathymetric Variations

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ABSTRACT

We show for the first time that low-energy waves can induce a rip current system over subtle alongshore bathymetric variations. Comprehensive field measurements across a rip current that morphologically migrated (~ 12 m/day) through a coherent cross- and alongshore array of co-located pressure and velocity sensors were obtained. The rip current is associated with a small bathymetric surfzone non-uniformity (1 in 300 alongshore variation). The circulation was kinematically non-uniform for ~5% of the time over the course of the 20 day experiment and was present at low tides associated with increases in rip current activity. The presence of the rip current and mild-sloped rip channel induce statistically significant alongshore variations in H_{rms}, wave direction, directional spreading, infragravity waves, and very low frequency motions. Changes in the directional spreading are correlated with the presence of very low frequency motions influenced by the presence of the rip current.

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1. Introduction

Rip currents are strong, jet-like, seaward-directed flows that originate within the surf zone owing to alongshore gradients in wave-induced radiation stresses and pressure (Bowen, 1969; Dalrymple, 1978; Haller et al., 2002). Long and Okzan-Haller (2005) showed that refraction of waves travelling across offshore submarine canyons can create variations in wave height alongshore that induce rip currents in the absence of local surfzone bathymetric non-uniformity. In contrast, most field observations of rip currents to date have been coupled to variations in the surfzone alongshore bathymetry, which induce alongshore differences in the wave forcing (Shepard et al., 1941; Shepard and Inman, 1950; Sonu, 1972; Aagaard et al., 1997; Brander and Short, 2001, MacMahan et al., 2005), but the development of the bathymetric non-uniformity remains unclear. Furthermore, the degree to which surfzone bathymetric non-uniformities induce a hydrodynamic response, in particular a rip current, is unknown. We show for the first time that low-energy waves can induce a rip current system with subtle alongshore bathymetric variations.

Within the last decade, more quantitative field and laboratory observations of rip currents have become available (Aagaard et al., 1997; Brander, 1999; Brander and Short, 2000, 2001; Haller and Dalrymple, 2001; Haas and Svendsen, 2002; Haller et al., 2002; Callaghan et al., 2004; MacMahan et al., 2005, MacMahan et al., submitted for publication). Most of these rip current field experiments have explored rip currents on beaches that support persistent, energetic rip currents. However, there have been few comprehensive field observations of rip current hydrodynamics owing to the difficulty of deploying instruments in a rip channel, and in part because of the tendency for the rip channels to migrate alongshore. During the Nearshore Canyon Experiment (NCEX) in fall 2003 at Torrey Pines, California, a morphologically controlled rip current fortuitously migrated slowly through an extensive cross- and alongshore array of co-located electromagnetic current meters and pressure sensors over ~10 days. The kinematics of this low-energy rip current system and the corresponding subtle rip morphology are described.

2. Field site

2.1. In situ observations

Field observations were obtained during NCEX (October 29 to November 18, 2003; yeardays 302–322). The beach is characterized as near planar with a surfzone slope of 1:70 between $50 \geq x \geq -75$ and an offshore slope of 1:50 between $-75 \geq x \geq -200$, where the cross-shore distance is positive onshore (see Fig. 1). Two primary arrays were deployed: 1) an alongshore array of 6 pressure and bi-directional digital electromagnetic current meters, dems, spanning approximately 500 m, and 2) a cross-shore array of 6 pressure and dems ranging from the shoreline to a depth of 3.5 m. Incorporated into the cross-shore array were 8 paroscientific pressure sensors (paros), 6 of which were co-located with the 6 cross-shore dems. Pressure and dem

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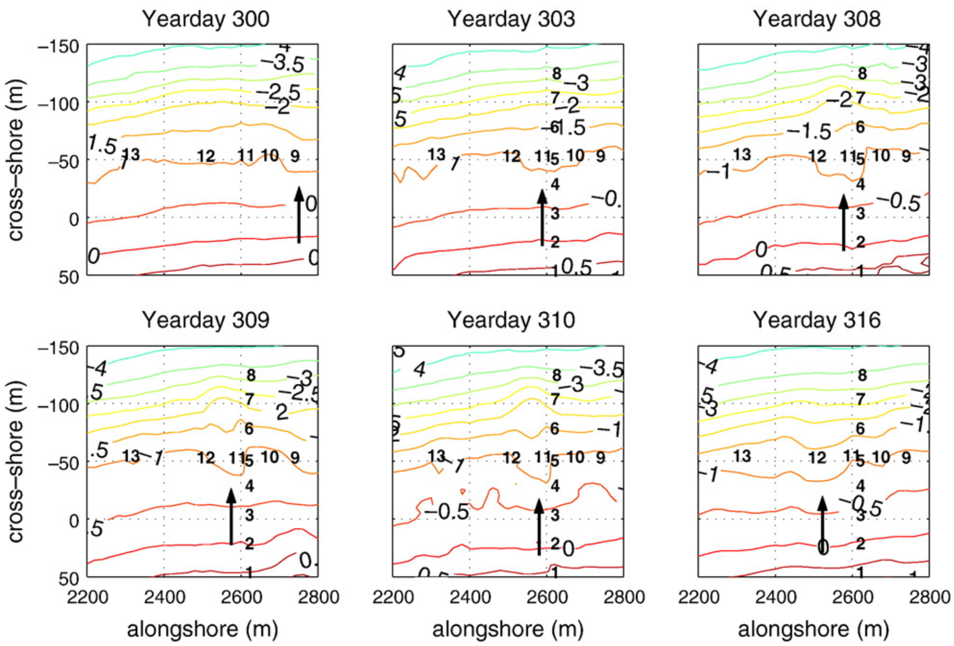

Fig. 1. Bathymetry referenced to mean sea level (MSL) for yeardays 300, 303, 308, 309, 310, and 316. Bold numbers represent co-located pressure and velocity instruments. Arrows represent rip channel locations, which are referred to in the text.

sensors were sampled continuously and synchronously at 15 Hz, while the paros were sampled at 1 Hz. The dems were approximately 35 cm off the sea bed, except PUV8, which was 1 m off the sea bed.

Directional wave spectra were measured with an upward-looking, broad-band, acoustic Doppler current profiler located in approximately 6 m water depth ($x = -246$ m) in line with the cross-shore array. During the measurement period, the significant wave height (H_{mo}) ranged 50–125 cm, the mean wave period ranged 3.5–12 s, and the mean wave direction ranged −12° to +12° (Fig. 2). Only a few moderate storm events occurred during the experiment, near the onset and at the end of the measurement period (yeardays 304, 320, and 322). Hourly mean alongshore currents averaged over the alongshore array ranged between −75 cm/s to +25 cm/s. Rip current activity occurred for yeardays 303, and 306–315, during which time H_{mo} was approximately

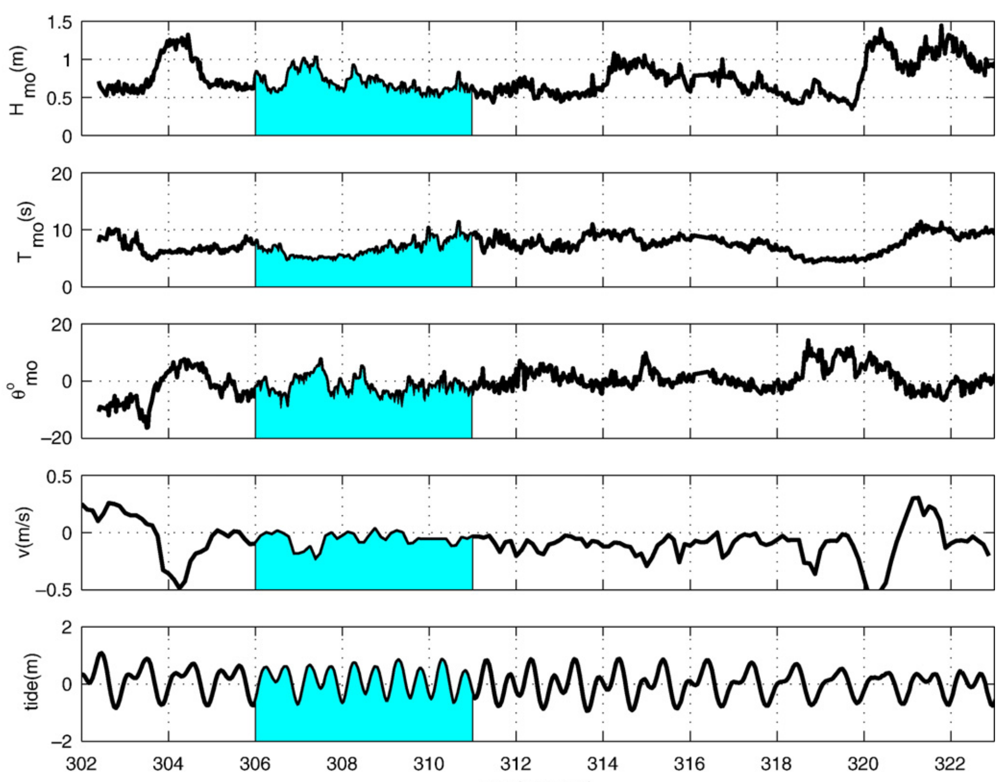

Fig. 2. Wave climate measured by directional ADCP in 6 m water depth, approximately 250 m offshore: significant wave height, H_{mo} (top), mean wave period (second), peak wave direction (third), alongshore-averaged mean alongshore velocity (fourth), and tidal elevation (bottom). Shaded region represents period of rip current activity.