Near-shore circulation

Waves and rip currents

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Introduction

Definition: rip currents are fast seaward-directed, narrow currents that originate in the surf zone.

Origin: rip currents are generated by alongshore modulations in wave-related forcing within the surf zone.

Relevance: rip currents redistribute phytoplankton, nutrients, sediment, pollutants, and humans across the surf zone and inner-shelf.
Linear bar-trough

Structure interaction

Swash rips

Transverse bars

Mega rip

Shear instabilities

Transient rips

Dalrymple et al., 2010
Let’s measure this!

Volunteers can sign up tomorrow!
Observations

Wave height variation
Tidal modulation of mean rip current circulation
VLF-motions with $O(10)$ minute time scale
Infragravity waves
Incident waves

Ripex, 2002, MacMahan et al., 2004
Model predictions

Delft3dD model calculations

Observations (RIPEX)

Too sparse

Good or bad match?

Reniers et al., 2007
Novel approach: Surfzone Drifters

- hand-held GPS = $150
- $250 per drifter, total
- absolute horizontal position accuracy < 0.40m
- velocity error < 0.01m/s

RCEX, 2007, MacMahan et al., 2009
Design similar to Schmidt et al., 2003
Drifter Deployments

• 5 to 8 deployments per experiment
• 2-3 hours in duration
• 14-26 drifters deployed
• drifters released in clusters of 4-15
• soft boundary limits defined
Dye too!

MacMahan!

Vicious shore break

students

modelers
Drifter Vectors

- 10m by 10m bins
- 5+ independent observations per bin
Rip Current Observations

**symmetric** rip current circulation - 1 occurrence

2 counter-rotating cells

**asymmetric** rip current circulation - 7 occurrences

each cell rotating in a dominant direction
Human Drifter

starting position

first revolution (~7 min)

second revolution (~6 min)

ending position
Laboratory observations

Courtesy of Bruno Castelle et al., 2009
Consequences for Rip Escape

1) Stay afloat within the breakers
2) Swim parallel if outside of the breakers
**Model verification**

**Objectives**

1. Evaluate Delft3D modeling capability in predicting 3D nearshore rip current circulation

2. Subsequently assess the importance of the Stokes drift and VLFs in surf zone retention on a rip channeled beach

**Approach**

Combine unique field observations of rip circulation with numerical modeling. Use virtual drifters to assess surf zone retention.

**Relevance**

Human health, visibility, swimmer safety, ecology, etc
RCEX conditions

- Drifter deployments
- Offshore ADCP at 12.8 m depth
RCEX observations

GPS-Drifter inferred mean velocity field yrd124. **Onshore flow over shallow shoals** and **offshore flows in rip channels**.

GPS-drifters provide a **Lagrangian** measurement!

**ADCPs provide an Eulerian measurement** of the subsurface flow velocity.
Modeling approach

Wave groups

Bound and free long waves

Offshore flow bc

No flux

Wave and flow model

Offshore wave bc

No flux

Periods of 25 s and longer.
Bound long waves
Leaky and trapped waves
VLFs
Mean currents
Offshore boundary

**JONSWAP,** \( D(\theta) \sim \cos^s(\theta) \)

\[
E_w(x, y, t) = \frac{1}{2} \rho g \left| A_{low}(x, y, t) \right|^2
\]

**Hilbert Transform and low-pass filter**

\[
\eta(x, y, t) = \sum_{j=1}^{N} \hat{\eta}_j e^{i(\sigma_j t - k_{x,j} x - k_{y,j} y + \phi_j)} + *
\]
Model description

Delft3D wave and flow model (Lesser et al., 2004) solves for non-linear shallow water velocities in a GLM framework (Walstra, Roelvink, Groeneweg, 2000)

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} + f v = -g \frac{\partial \xi}{\partial x} + F^x + H_x + \frac{\partial}{\partial z}\left( u_z \frac{\partial u^E}{\partial z} \right) \]

GLM velocities are given by:

\[u = u^E + u^S\]

And the Stokes drift is calculated from (Phillips, 1977):

\[u^S = \frac{ka^2 \cosh(2k(h+z))}{2 \sinh^2(kh)} k\]
Wave and flow modeling

Model resolves the wave energy at the wave group time scale (25 s and longer).
Low-frequency motions I

Intersecting wave trains

\( f_1 = 0.101 \text{ Hz} \)
\( f_2 = 0.990 \text{ Hz} \)
\( \theta_1 = -12.25^\circ \)
\( \theta_2 = 12.5^\circ \)

(Fowler and Dalrymple, 1990)

Vorticity:

\[ Q = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \]
Low-frequency motions II

Alongshore separated wave groups

Two distinct wave groups (Ryrie, 1983)

Note that the time scale is determined by friction.
Surf Zone Eddies (VLFs)
Surface flows

Small differences between Eulerian and GLM flow

Good match with drifter inferred velocities.

Devil in the details!
Forcing

Body force

Shear stress
Outer surfzone
Outside surfzone
VLF velocity

Vortical motions with O(10) minute time scale

MacMahan et al., 2004, Reniers et al., 2007, 2009

Low-pass filtered, $f < 0.004$ Hz, de-trended signal
summary

Surface flow velocity pattern  ++
Subsurface velocity
  • Inner surfzone (adcp4)  +
  • Outer surfzone (adcp6)  +--
VLF-velocities (adcp5)  ++

Next: use surface velocities to examine surf zone retention
Drifter tracking

\[ x_i(t) = x_i(t_0) + \int_{t_0}^{t_0+t} u^E(x_i, t) dt \]

**Eulerian tracks**

\[ x_i(t) = x_i(t_0) + \int_{t_0}^{t_0+t} u(x_i, t) dt \]

**GLM tracks**
Surfzone retention

\[ E = \frac{X_s}{HT} \]

\[ P = \frac{\sum d_i(x_i > x_s)}{\sum d_i} \cdot 100\% \]

\( X_s \) corresponds to the outer edge of the surf zone
Lagrangian Coherent Structures

Transport barriers
Explain patches and streaks

Detaching VLF eddy

Reniers et al., 2010
Cross-shore exchange

Patch-like distributions within the surf zone and streak-like distributions outside the surf zone!

Photo by Ed Thornton
conclusions

rip current circulations are mostly contained within the surf zone
~20% surf zone exits per hour on an open coast beach via a rip currents
Significant more retention than anticipated
Stokes related retention is important
VLFs are dominant mechanism for exchange
LCS explain patchy distributions in surf and streaks outside