Near-shore circulation

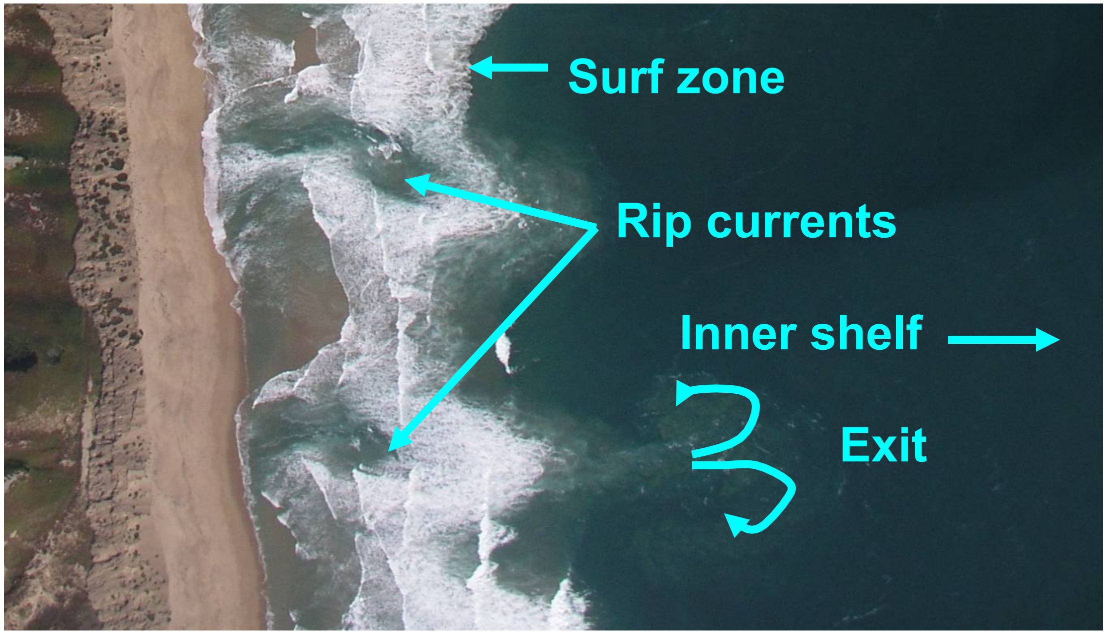
Waves and rip currents

Ad Reniers and Jamie MacMahan

Introduction

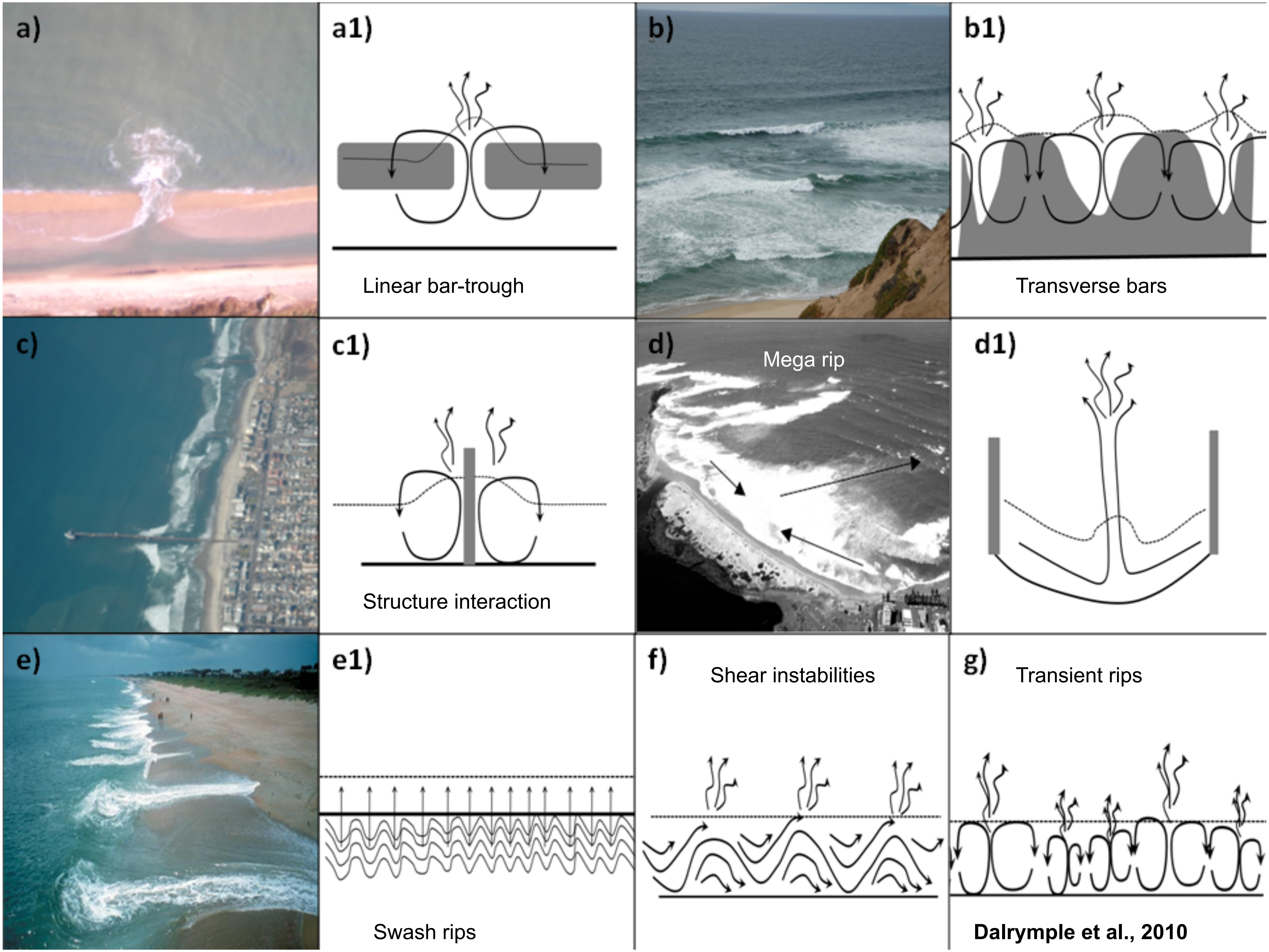
Definition: rip currents are fast seaward-directed, narrow currents that originate in the surf zone

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



Relevance:

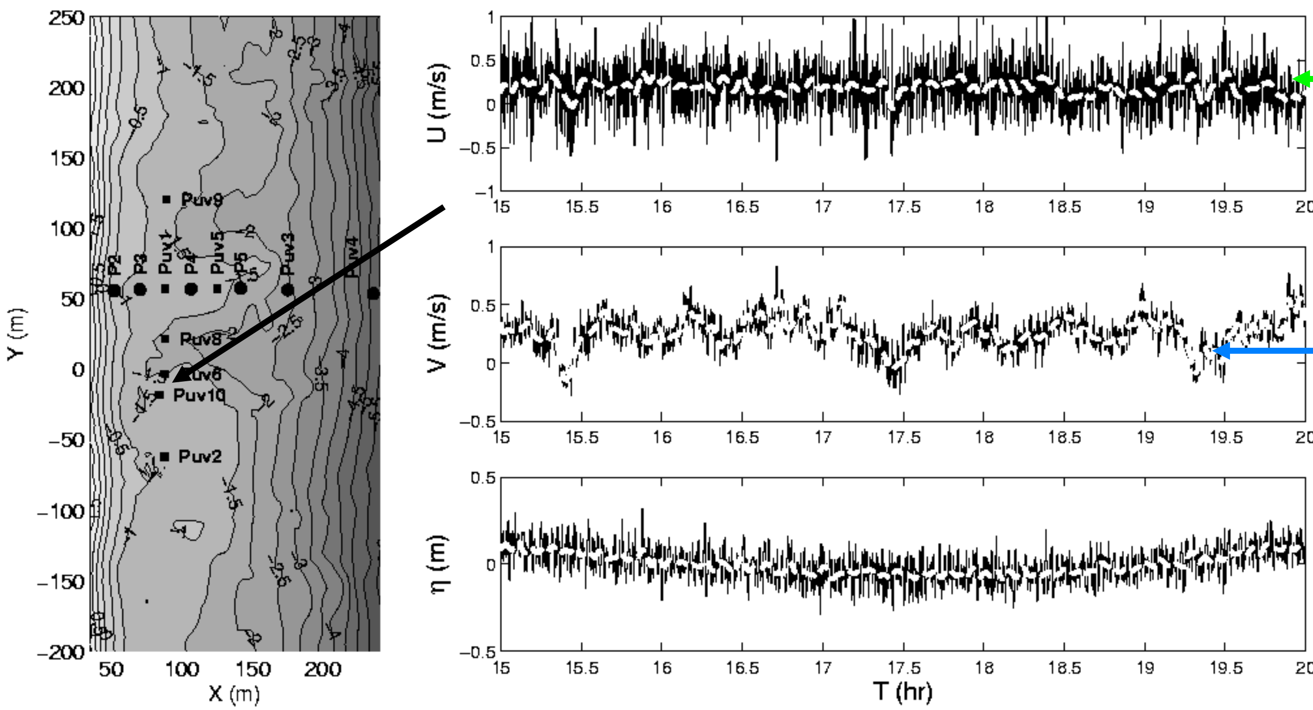
rip currents redistribute phytoplankton, nutrients, sediment, pollutants, and humans across the surf zone and inner-shelf


a)
a1)
Linear bar-trough
b)
b1)
Transverse bars
c)
c1)
Structure interaction
d)
Mega rip
d1)
e)
e1)
Swash rips
f)
Shear instabilities
g)
Transient rips
Dalrymple et al., 2010


Let's measure this!
Volunteers can sign up tomorrow!

Observations

Low-pass filtered time series F<0.04 Hz



Wave height variation

Tidal modulation of mean rip current circulation

VLF-motions with O(10) minute time scale

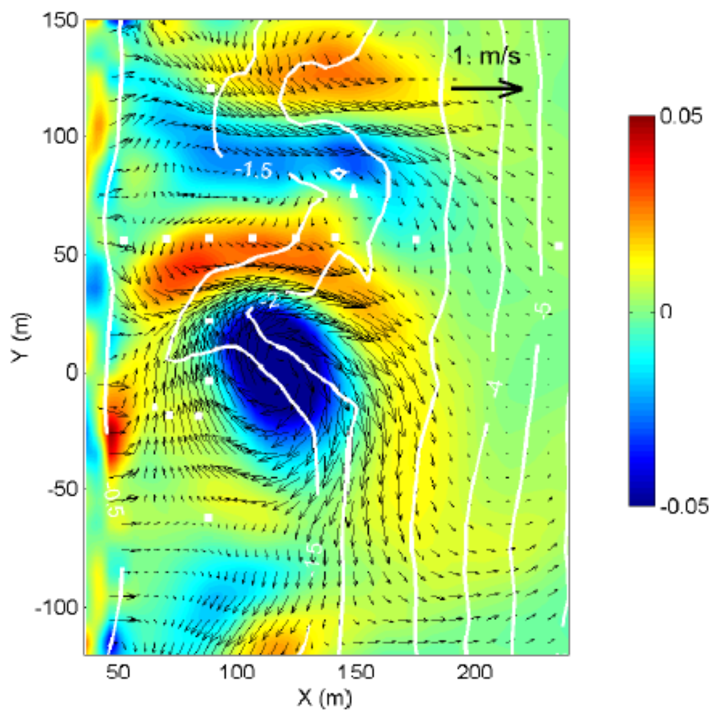
Infragravity waves

Incident waves

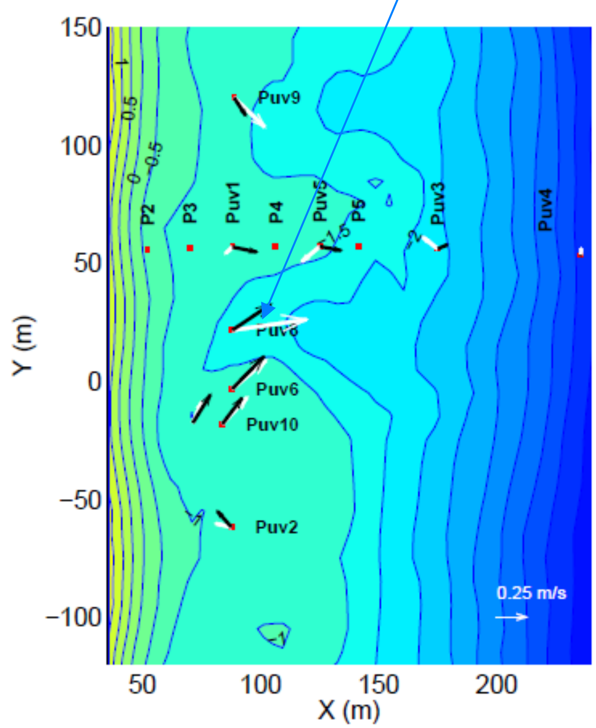
Ripex, 2002, MacMahan et al., 2004

Model predictions

Too sparse



Delft3dD model calculations

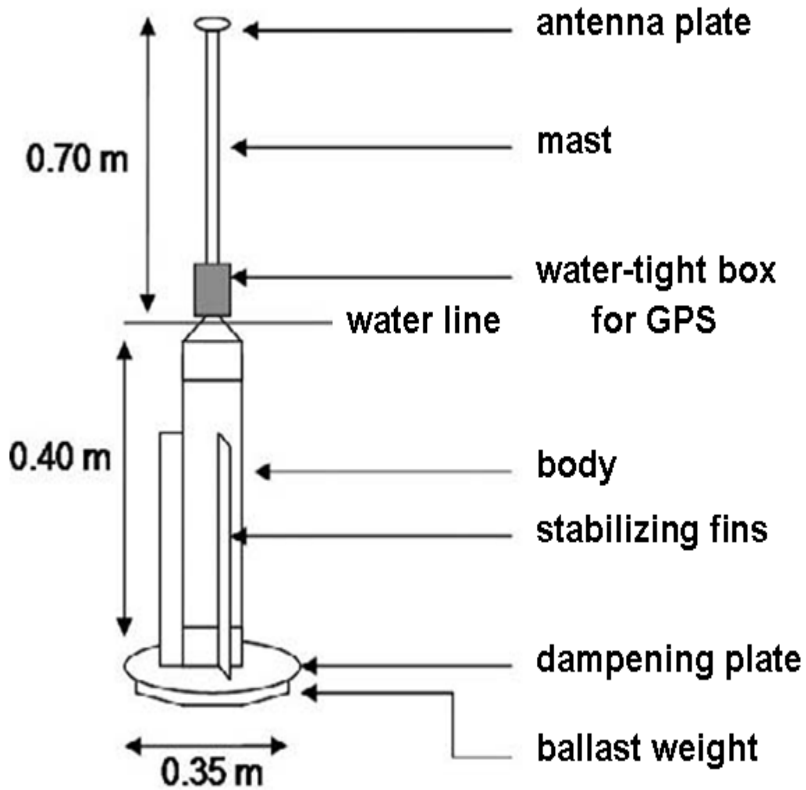


Observations (RIPEX)

Good or bad match?

Reniers et al., 2007

Novel approach: Surfzone Drifters



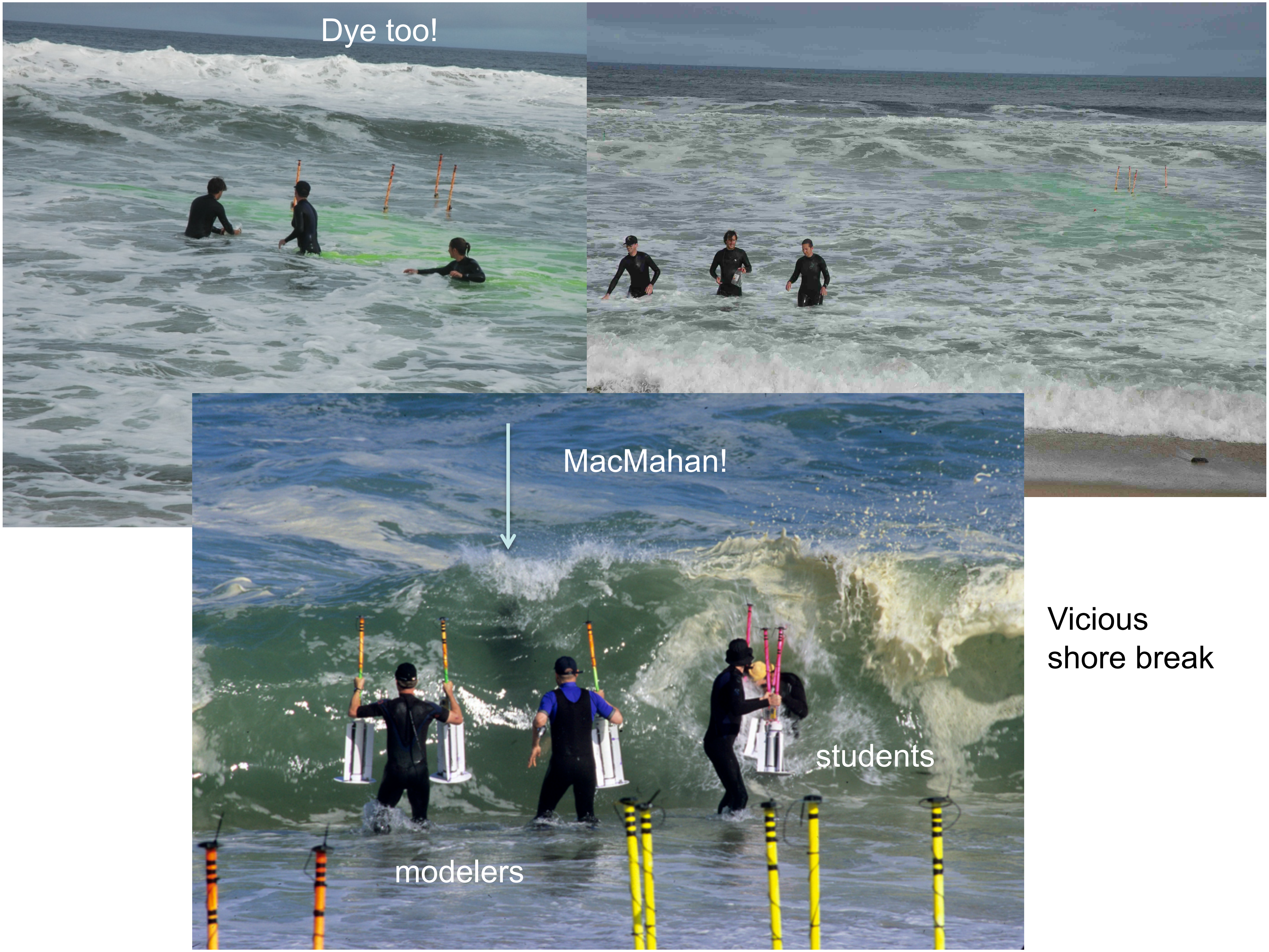
- hand-held GPS = $150
- $250 per drifter, total
- absolute horizontal position accuracy < 0.40m
- velocity error < 0.01m/s

RCEX, 2007, MacMahan et al., 2009

Design similar to Schmidt et al., 2003

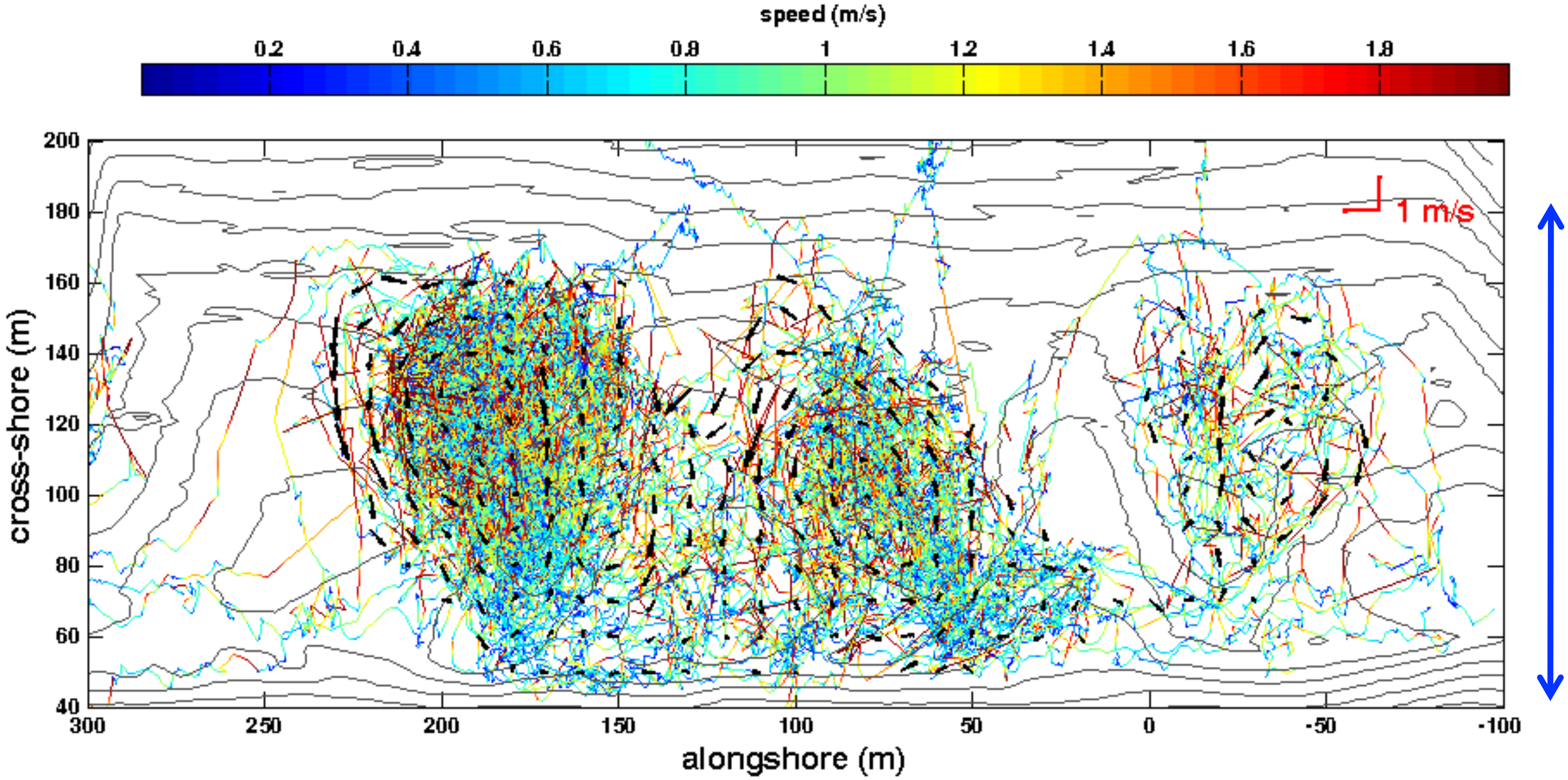
Drifter Deployments

- 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



Vicious
shore break

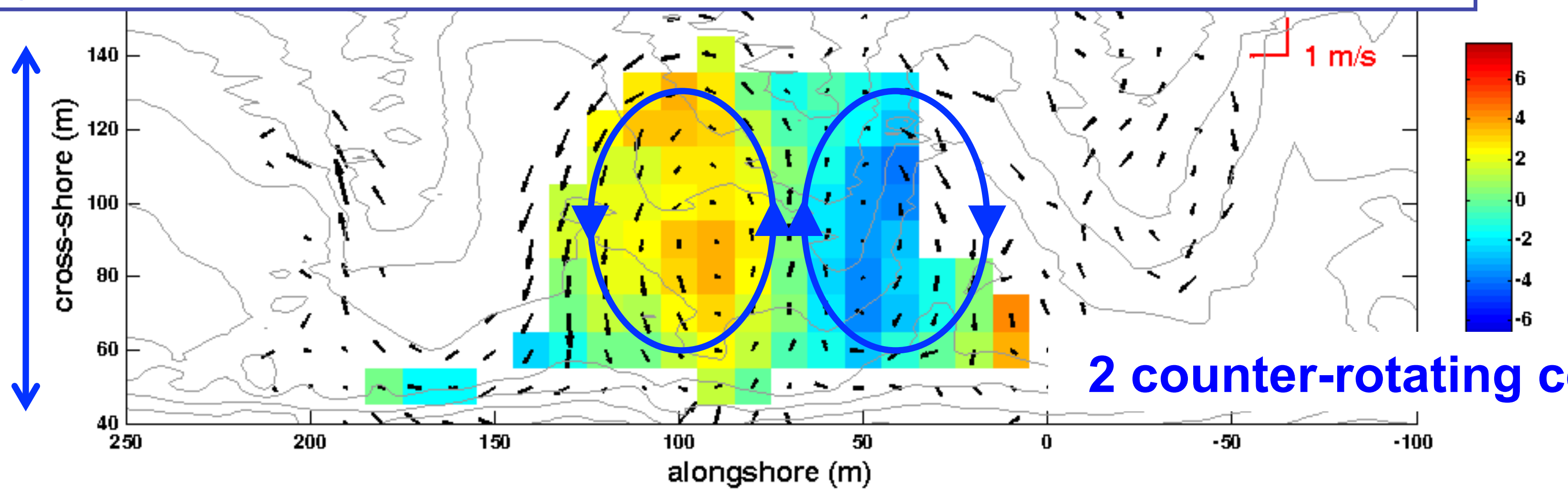
Drifter Vectors



- 10m by 10m bins
- 5+ independent observations per bin

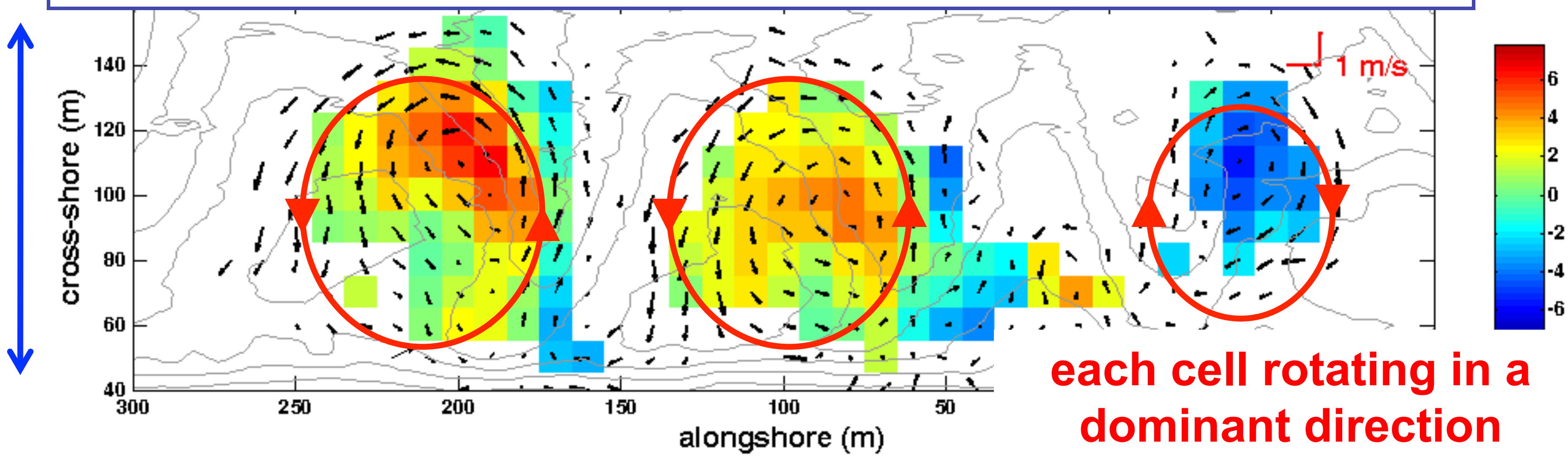
Rip Current Observations

symmetric rip current circulation -1 occurrence



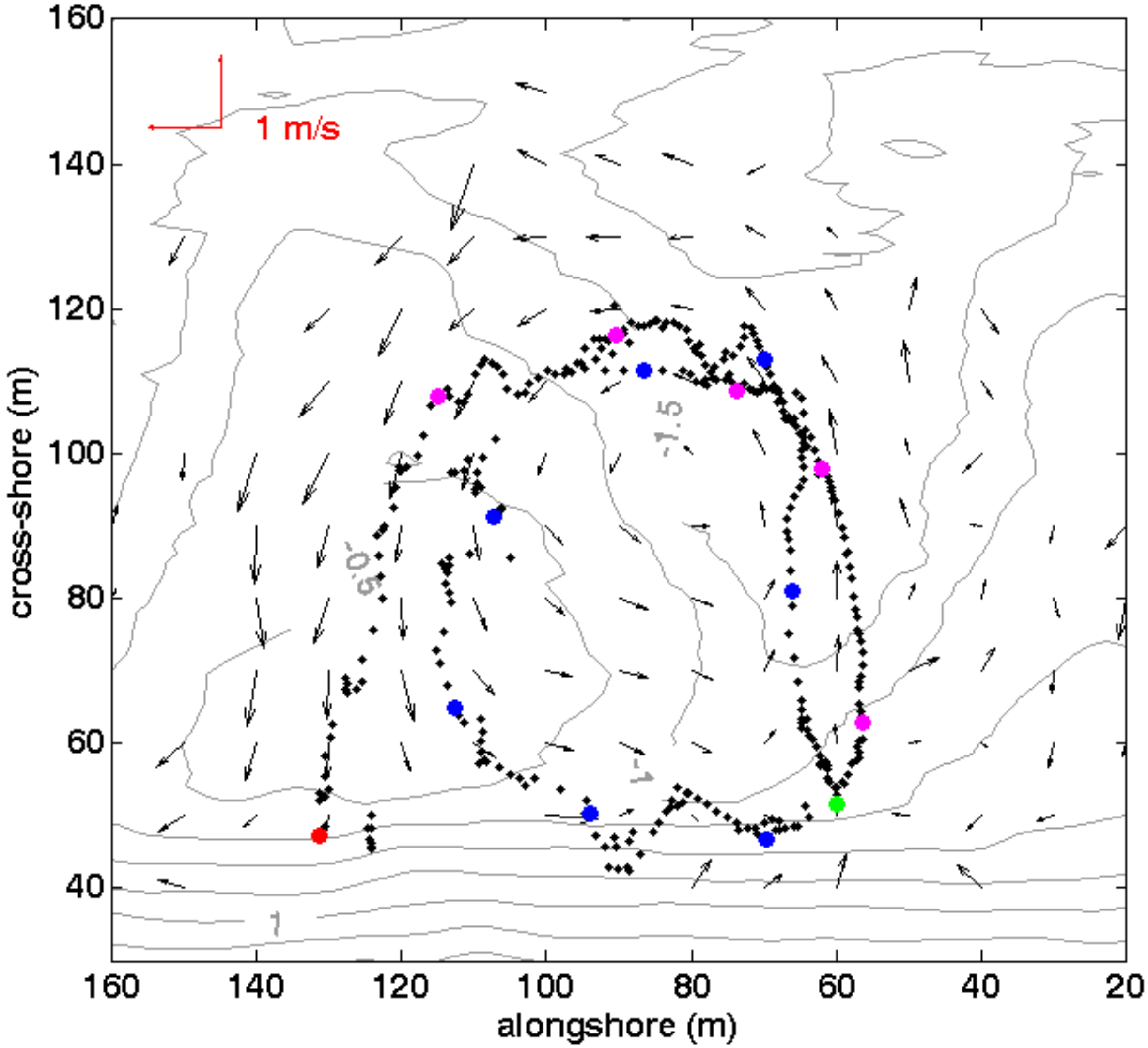
2 counter-rotating cells

asymmetric rip current circulation - 7 occurrences



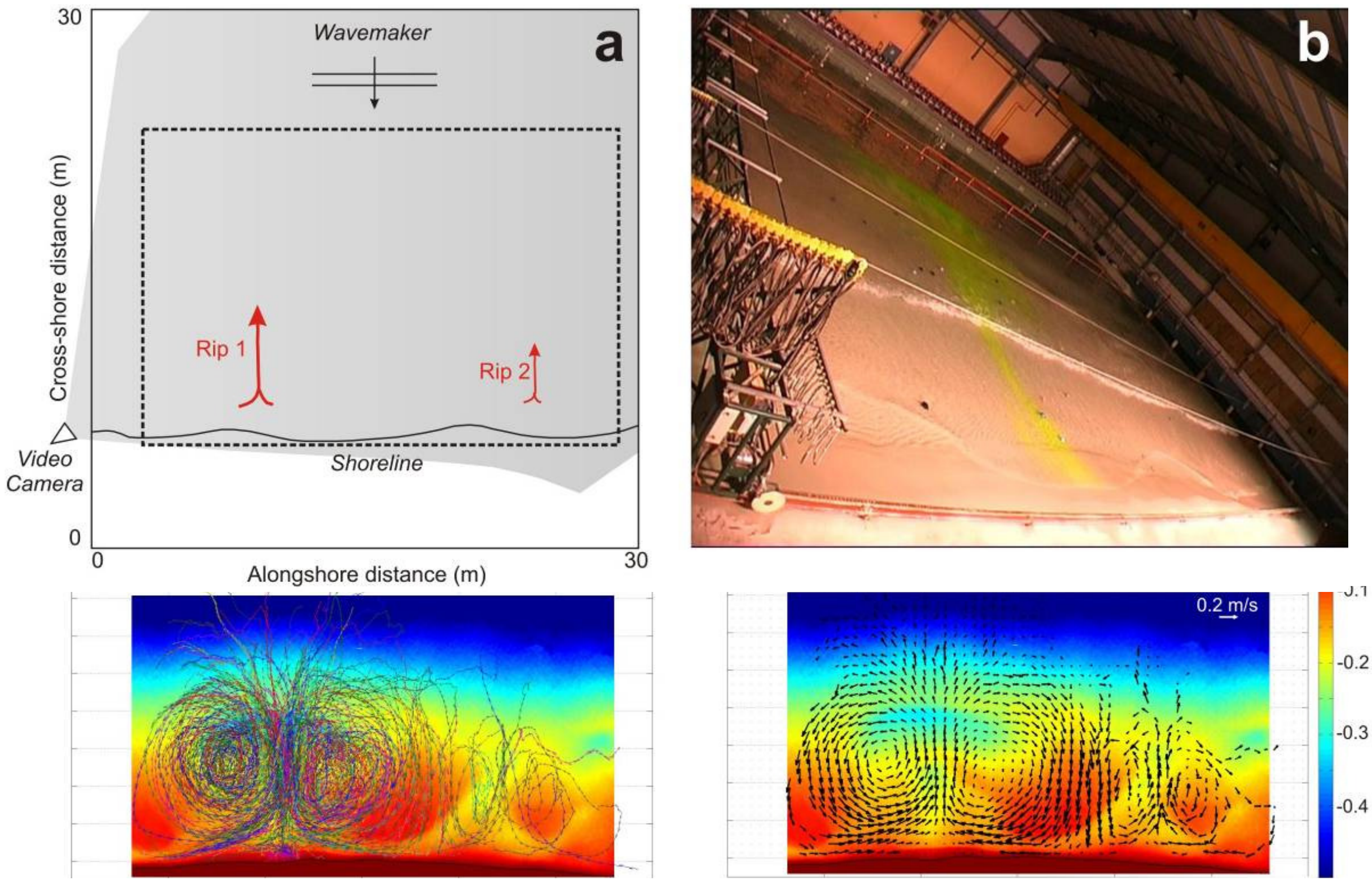
each cell rotating in a dominant direction

Human Drifter



- starting position
- first revolution (~7min)
- 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.

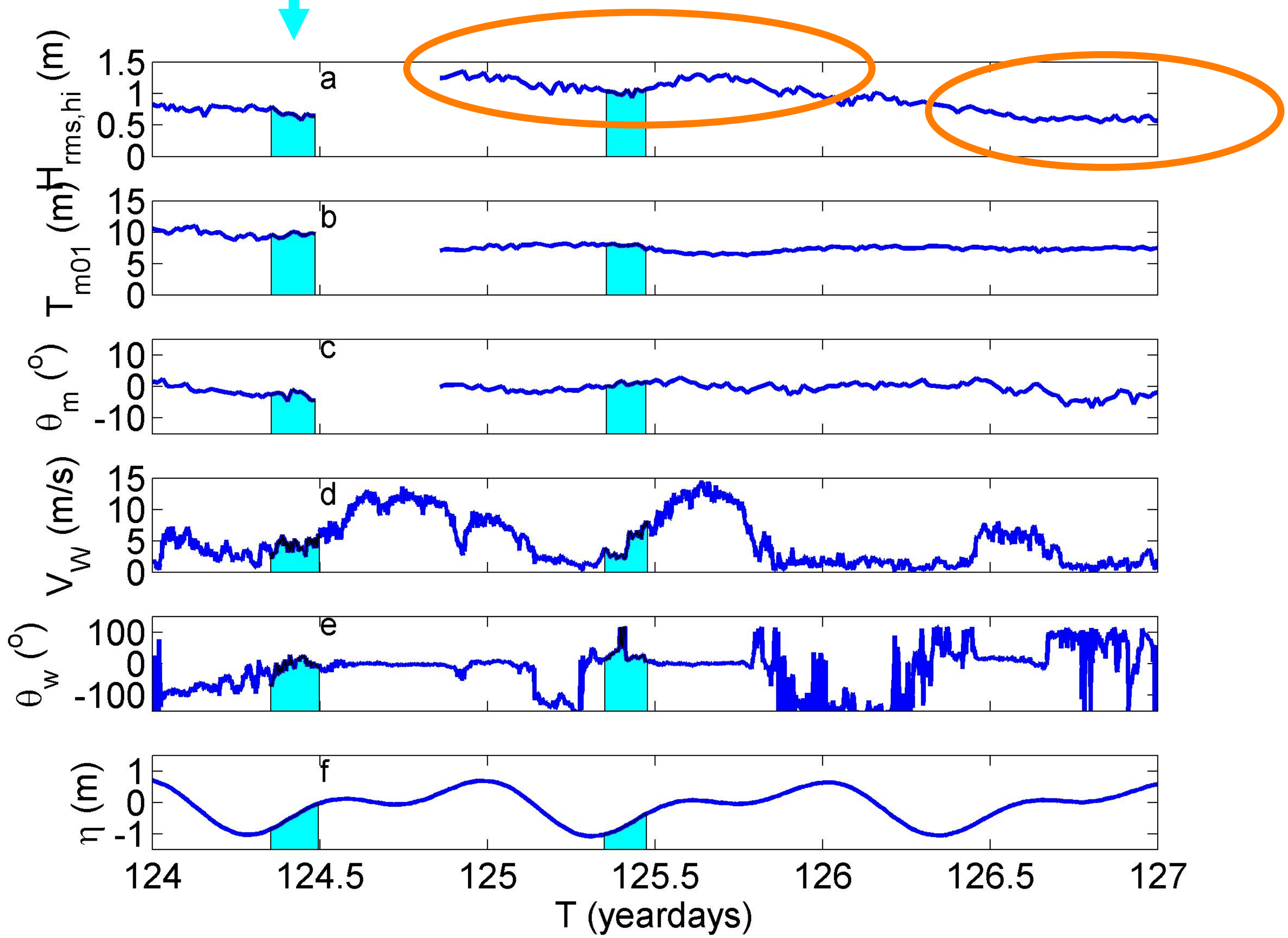
Relevance

Human health, visibility, swimmer safety, ecology, etc

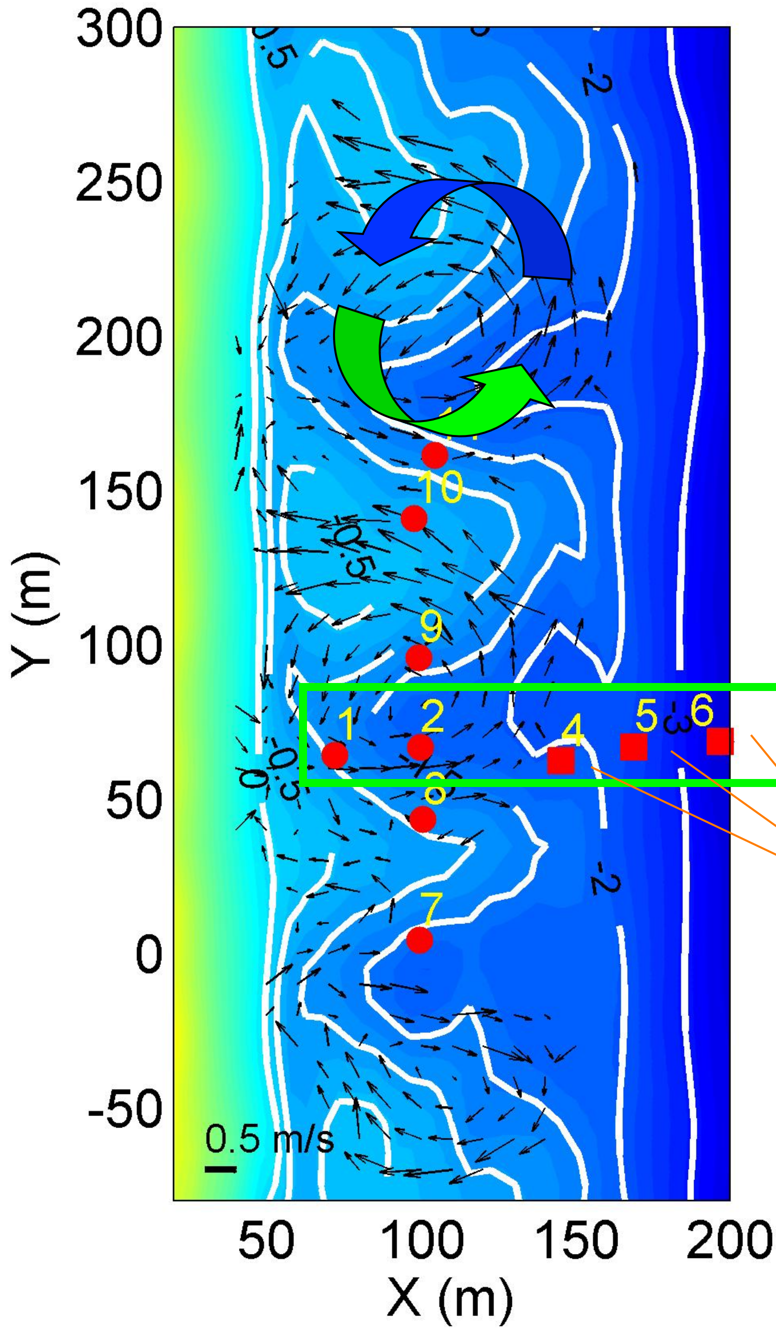
RCEX conditions

: Drifter deployments

Offshore ADCP at 12.8 m depth



RCEX observations



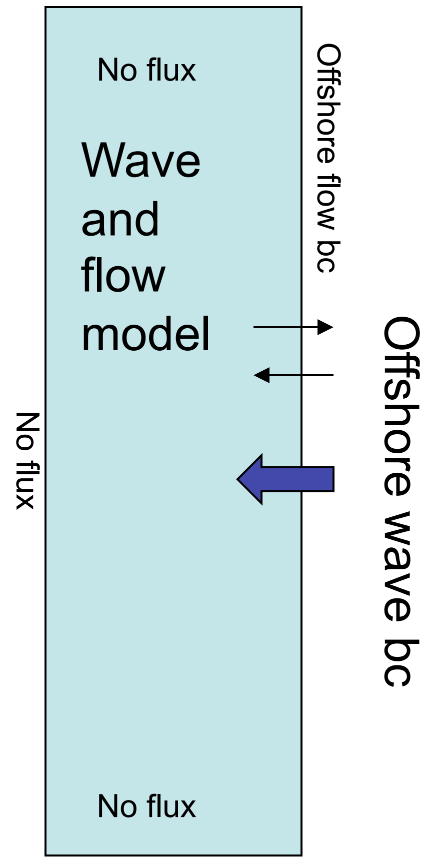
GPS-Drifter inferred mean velocity field yrd124. **Onshore** flow over shallow **shoals** and **offshore** flows in **rip channels**.

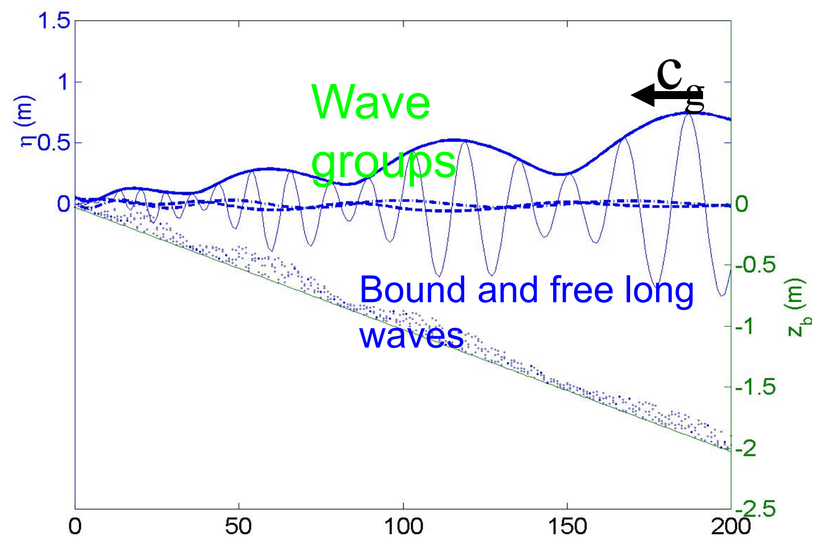
GPS-drifters provide a **Lagrangian** measurement!

Cross-shore array

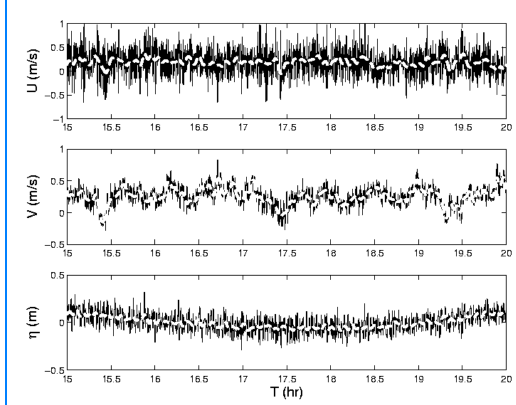
ADCPs provide an **Eulerian** measurement of the subsurface flow velocity

Modeling approach



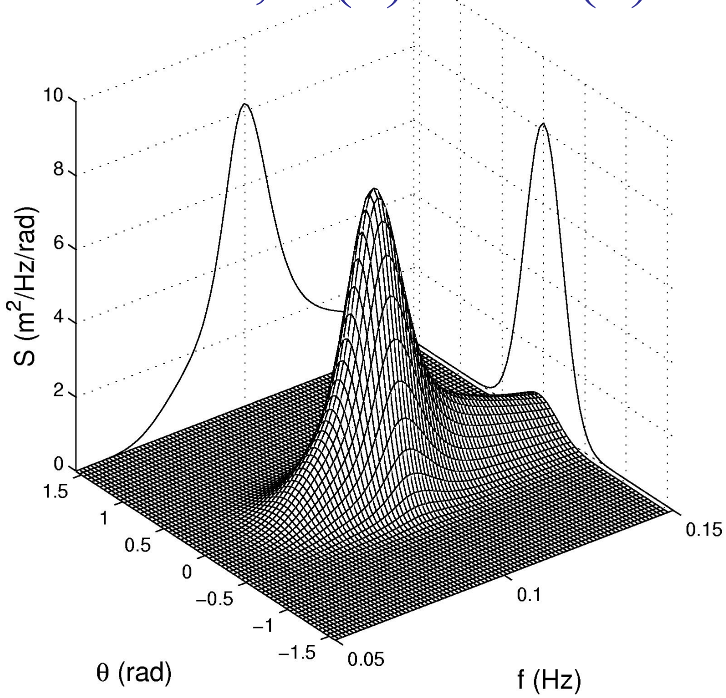


- Periods of 25 s and longer.
- Bound long waves
- Leaky and trapped waves
- VLFs
- Mean currents



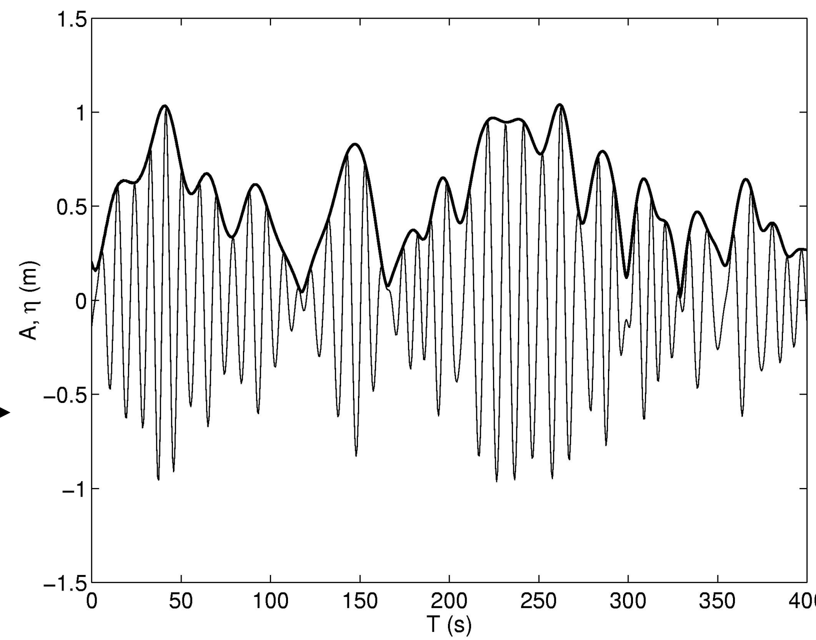
Offshore boundary

JONSWAP, D(θ) ~ $\cos^s(\theta)$



Random phase model

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

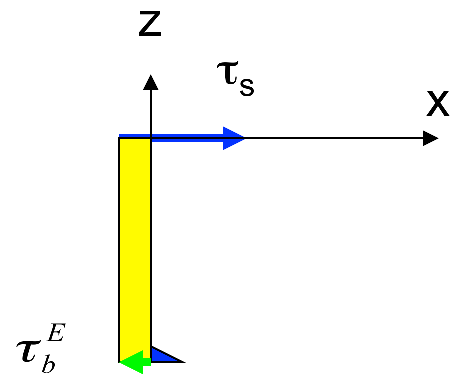


Hilbert Transform and low-pass filter

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

Model description

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



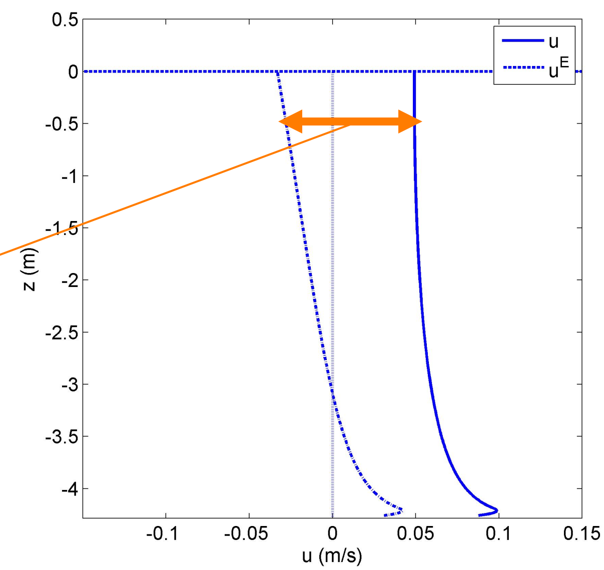
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + fv = -g\frac{\partial \zeta}{\partial x} + F^x + H_x + \frac{\partial}{\partial z}\left(\upsilon_z \frac{\partial u^E}{\partial z}\right)$$

GLM velocities are given by:

$$\mathbf{u} = \mathbf{u}^E + \mathbf{u}^S$$

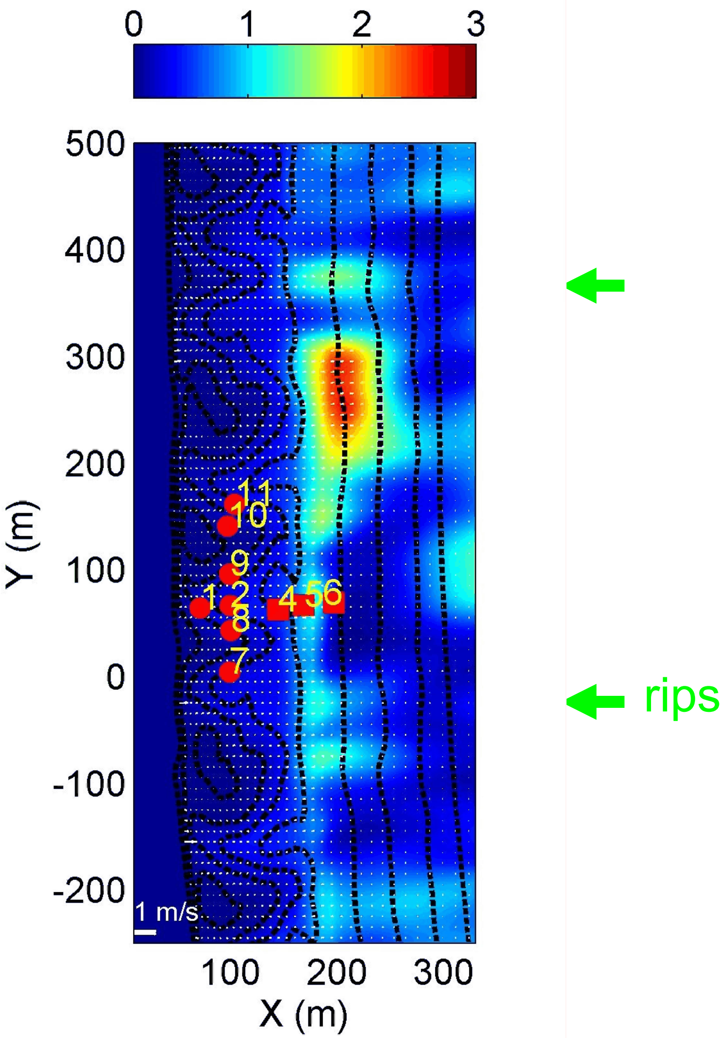
And the Stokes drift is calculated from (Phillips, 1977):

$$\mathbf{u}^S = \frac{ka^2 \cosh(2k(h+z))}{2\sinh^2 kh}\frac{\mathbf{k}}{k}$$

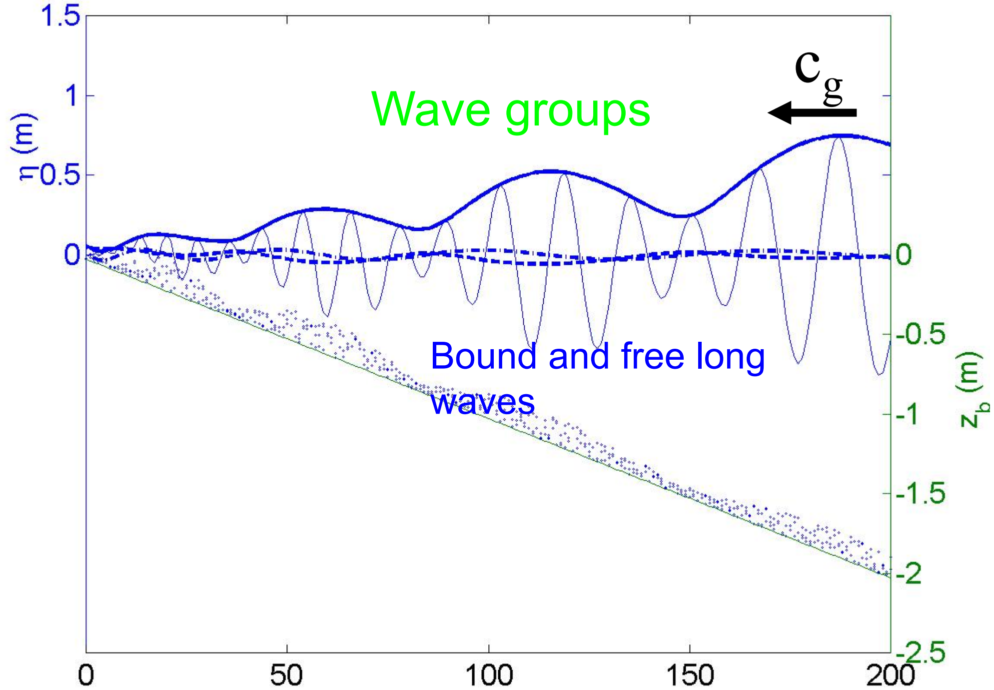


Wave and flow modeling

Animation of wave energy E_w (KJ/m2) and surface flow velocity



Model resolves the wave energy at the wave group time scale (25 s and longer).



Low-frequency motions I

Intersecting wave trains

f1 = 0.101 Hz

f2 = 0.990 Hz

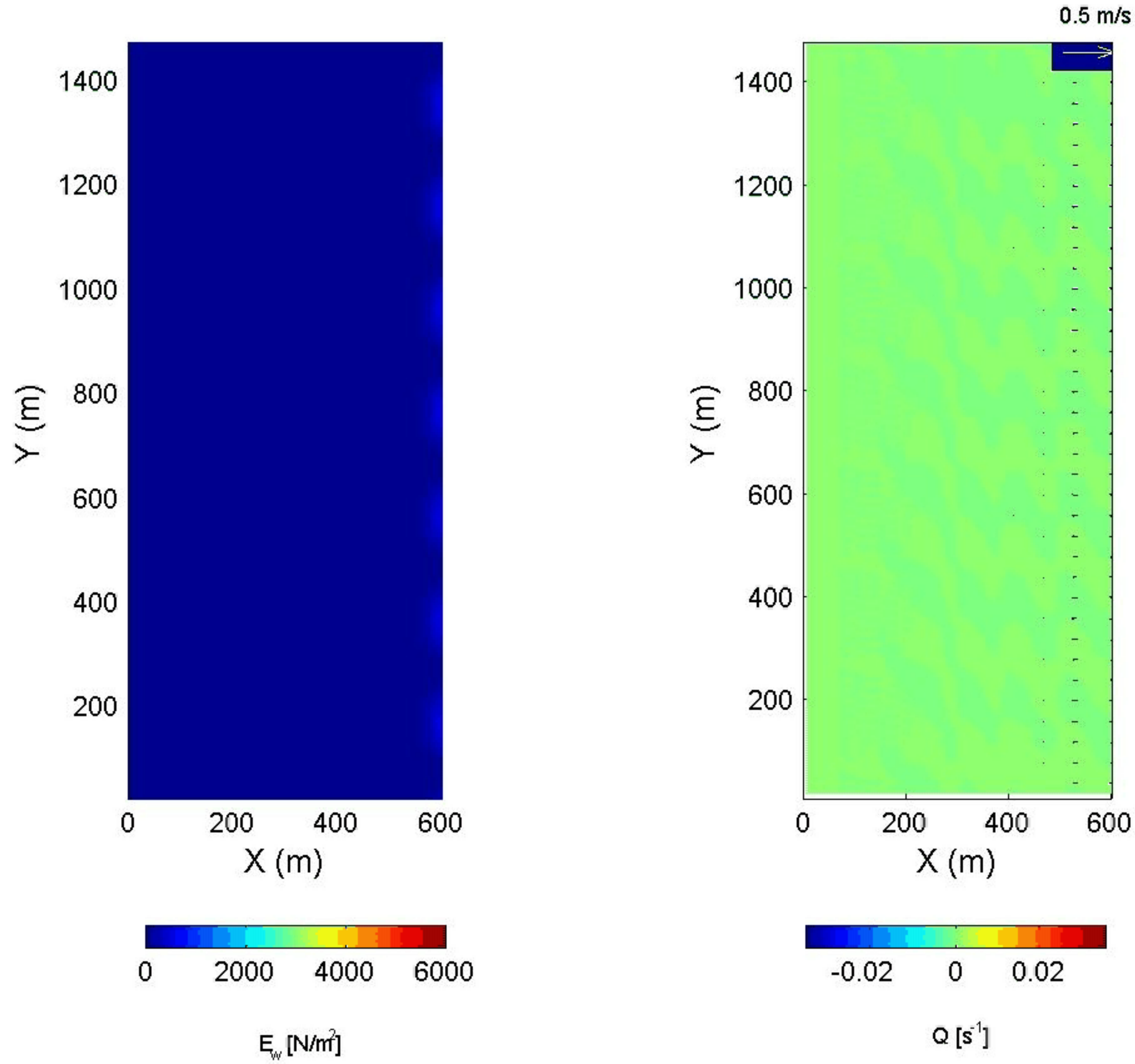
θ1 = -12.25º

θ2 = 12.5º

(Fowler and Dalrymple, 1990)

Vorticity:

$$Q = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

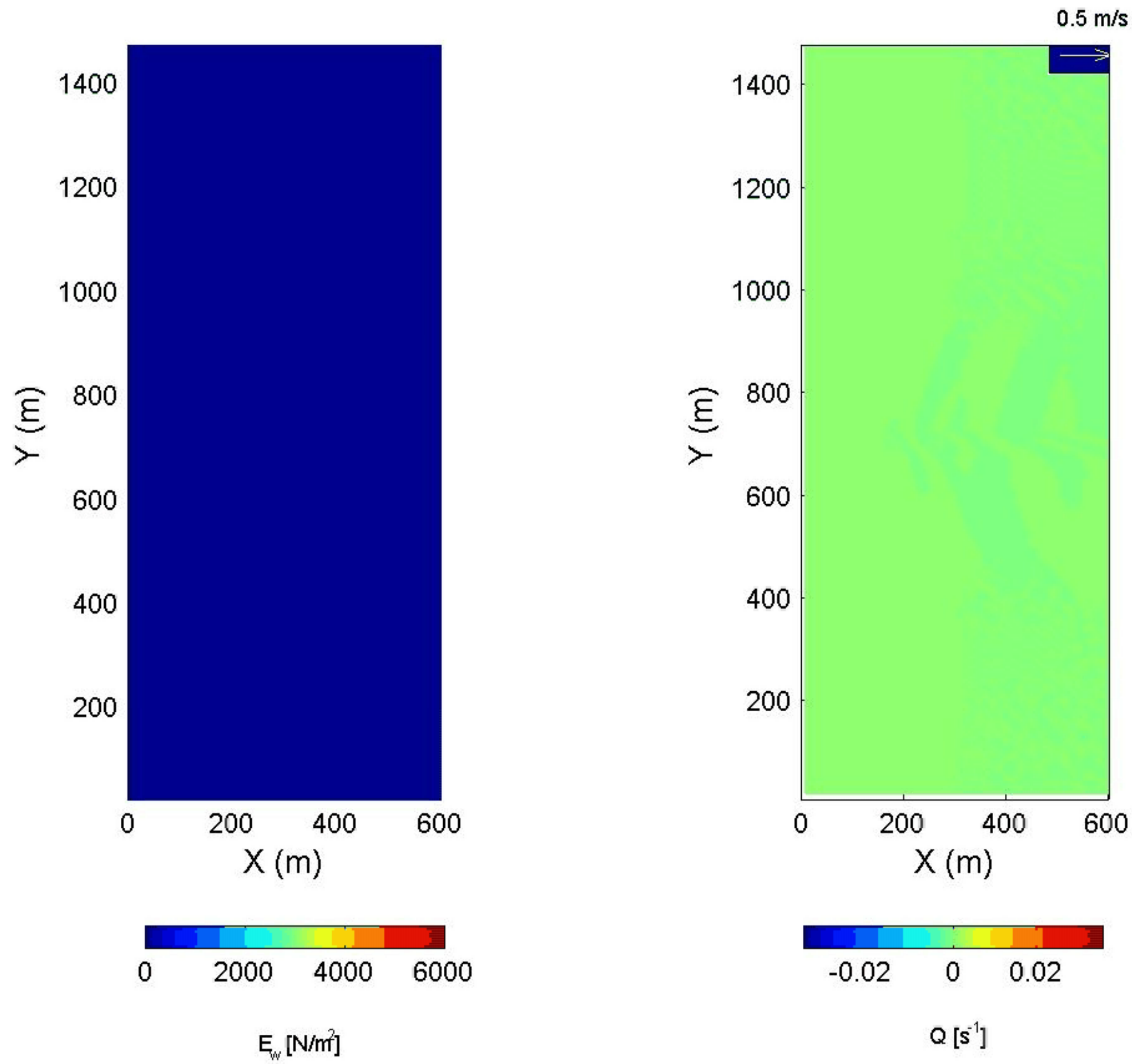


Low-frequency motions II

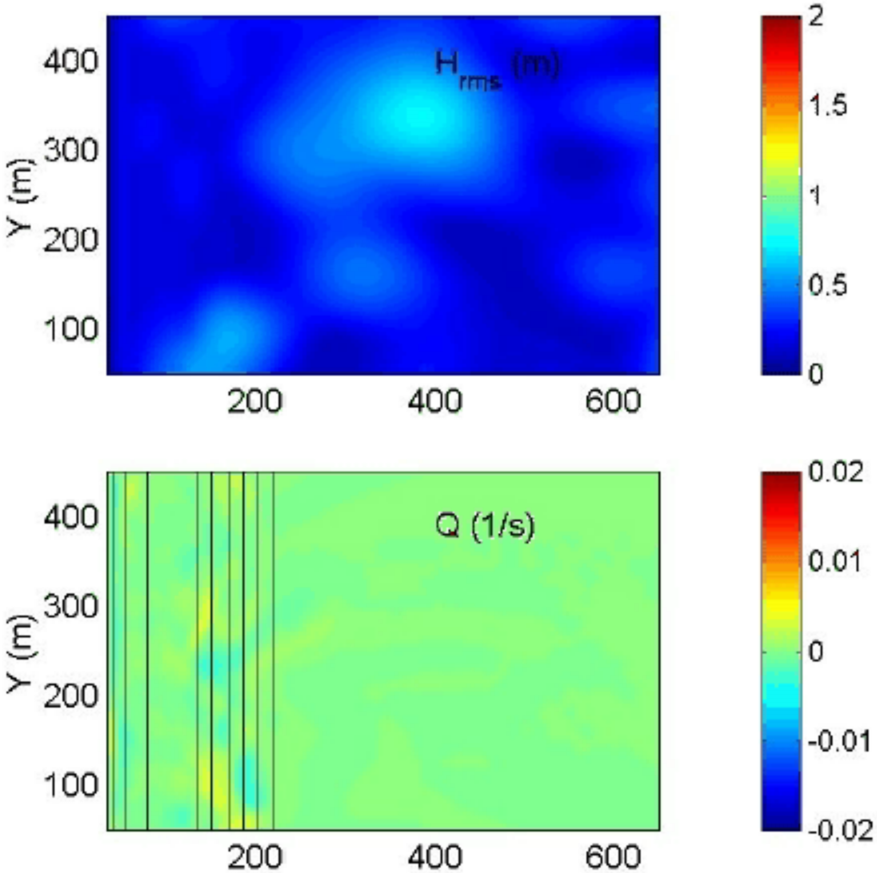
Alongshore separated wave groups

Two distinct wave groups (Ryrie, 1983)

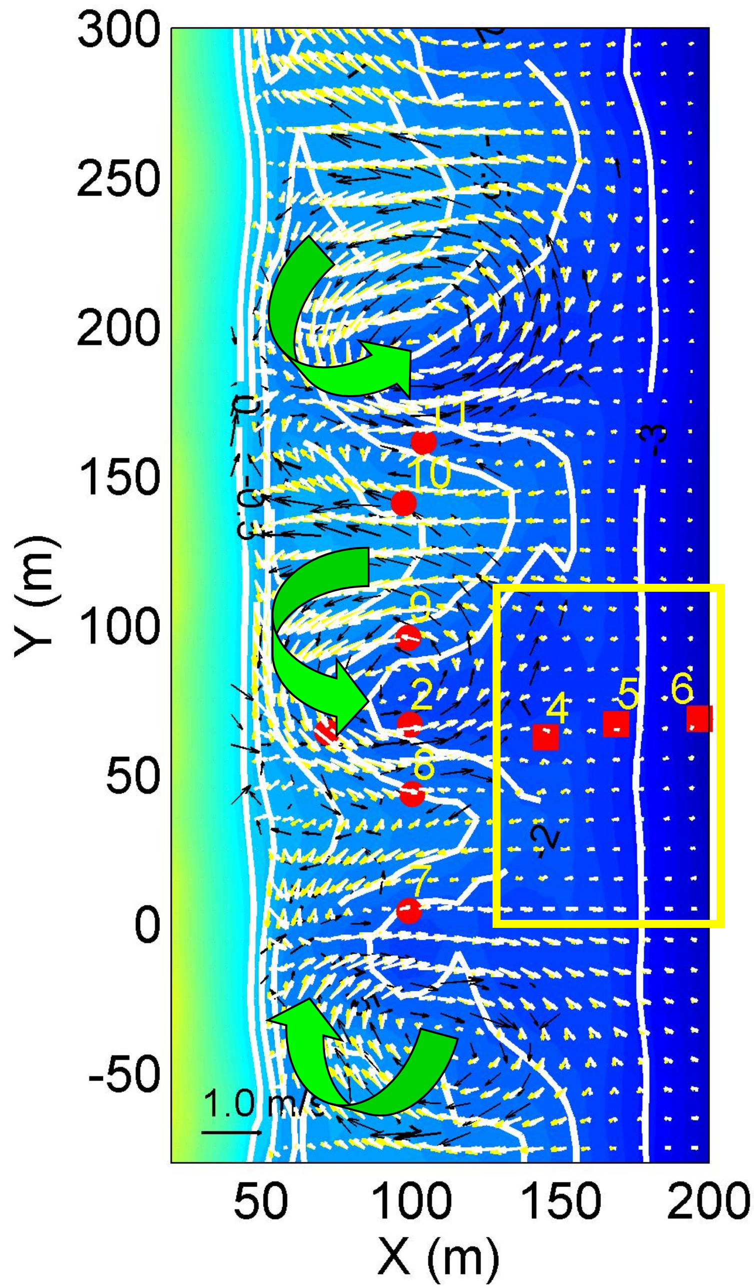
Note that the time scale is determined by friction.



Surf Zone Eddies (VLFs)



Surface flows



GPS-Drifter

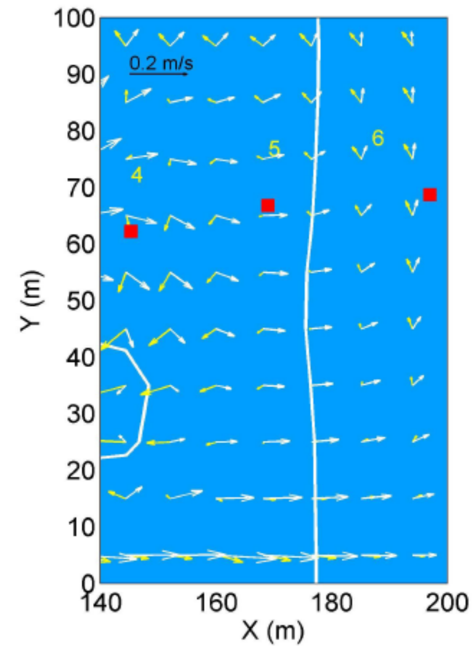
Eulerian

GLM

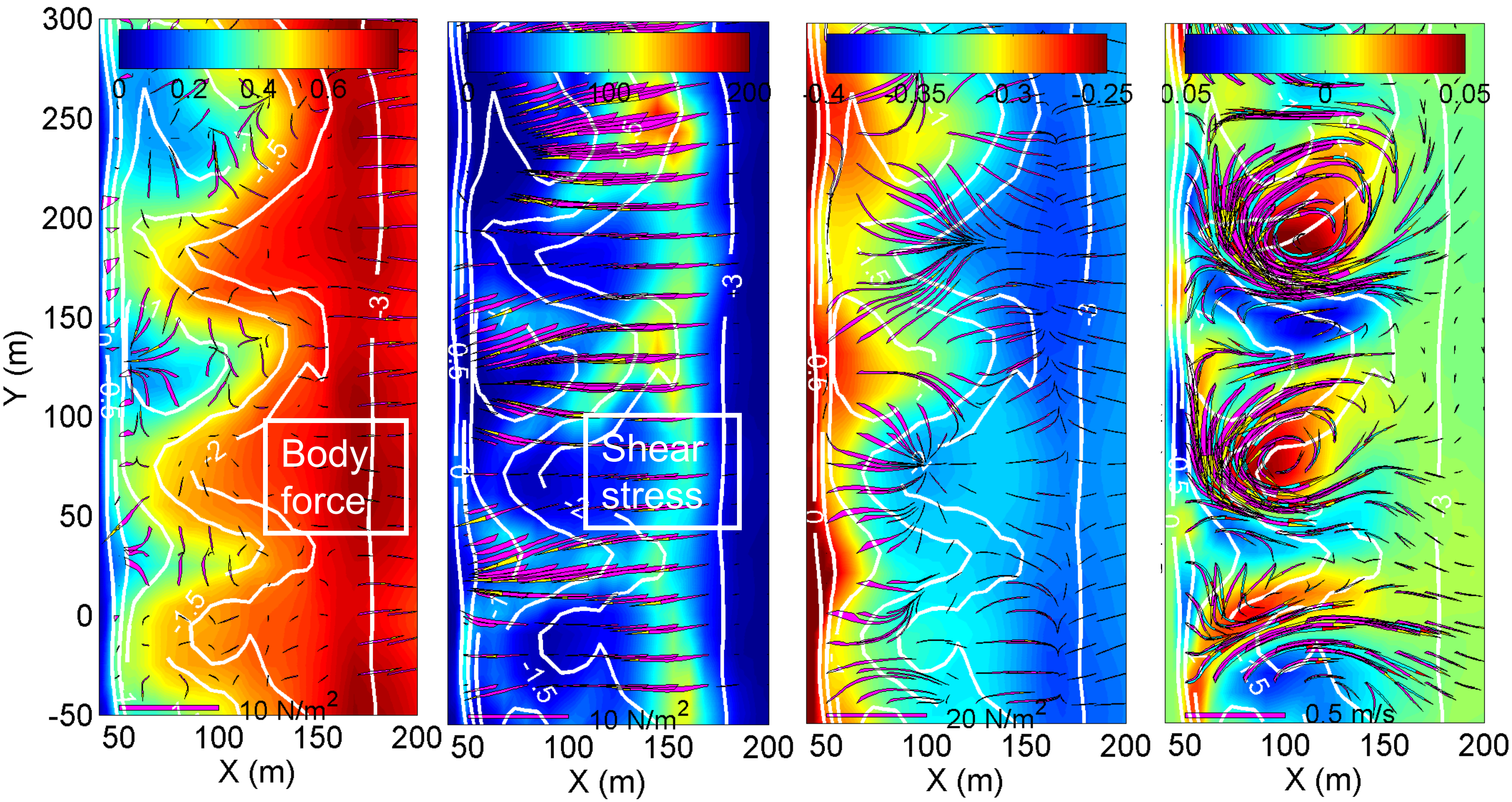
Good match with drifter inferred velocities.

Small differences between Eulerian and GLM flow

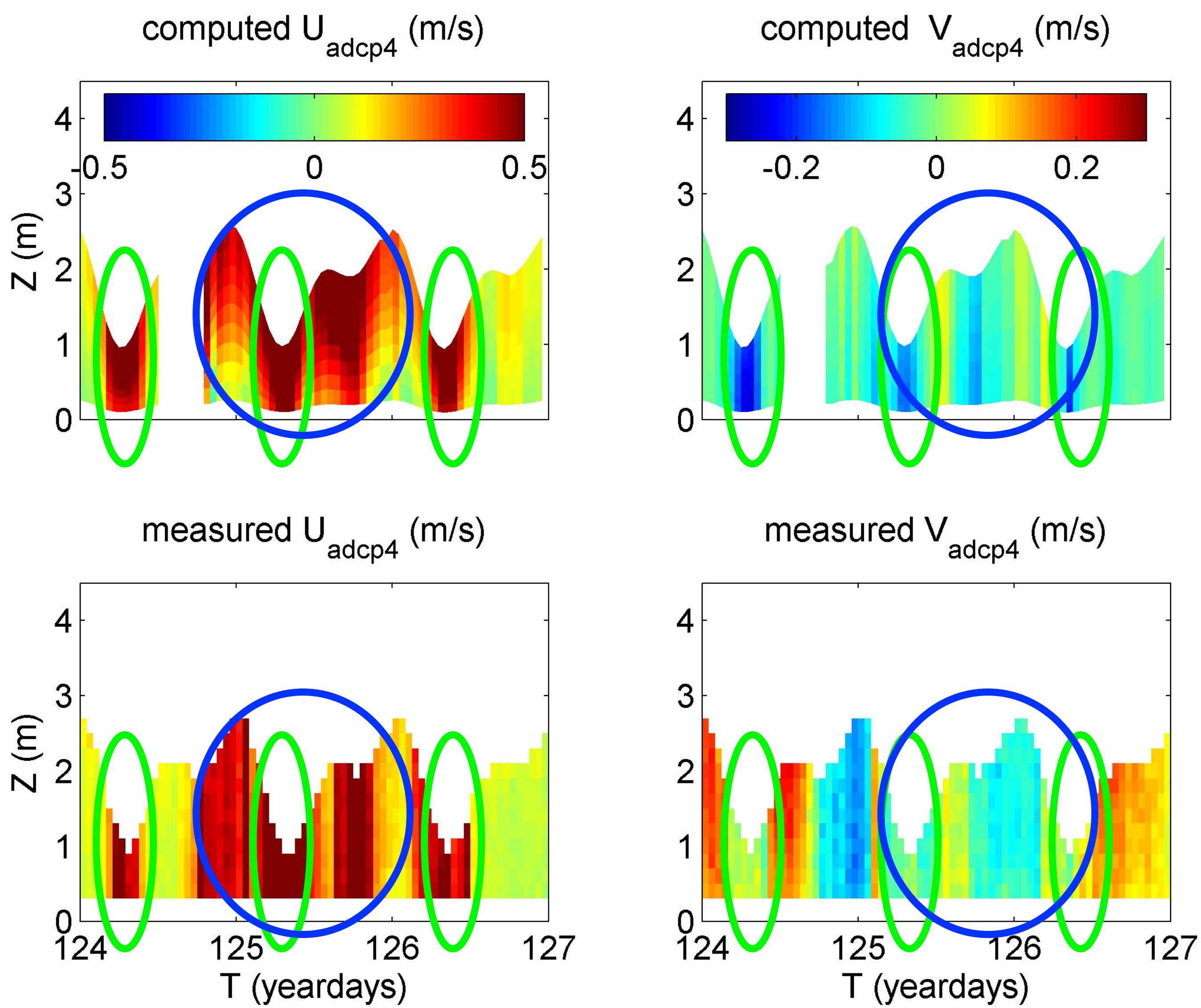
Devil in the details!



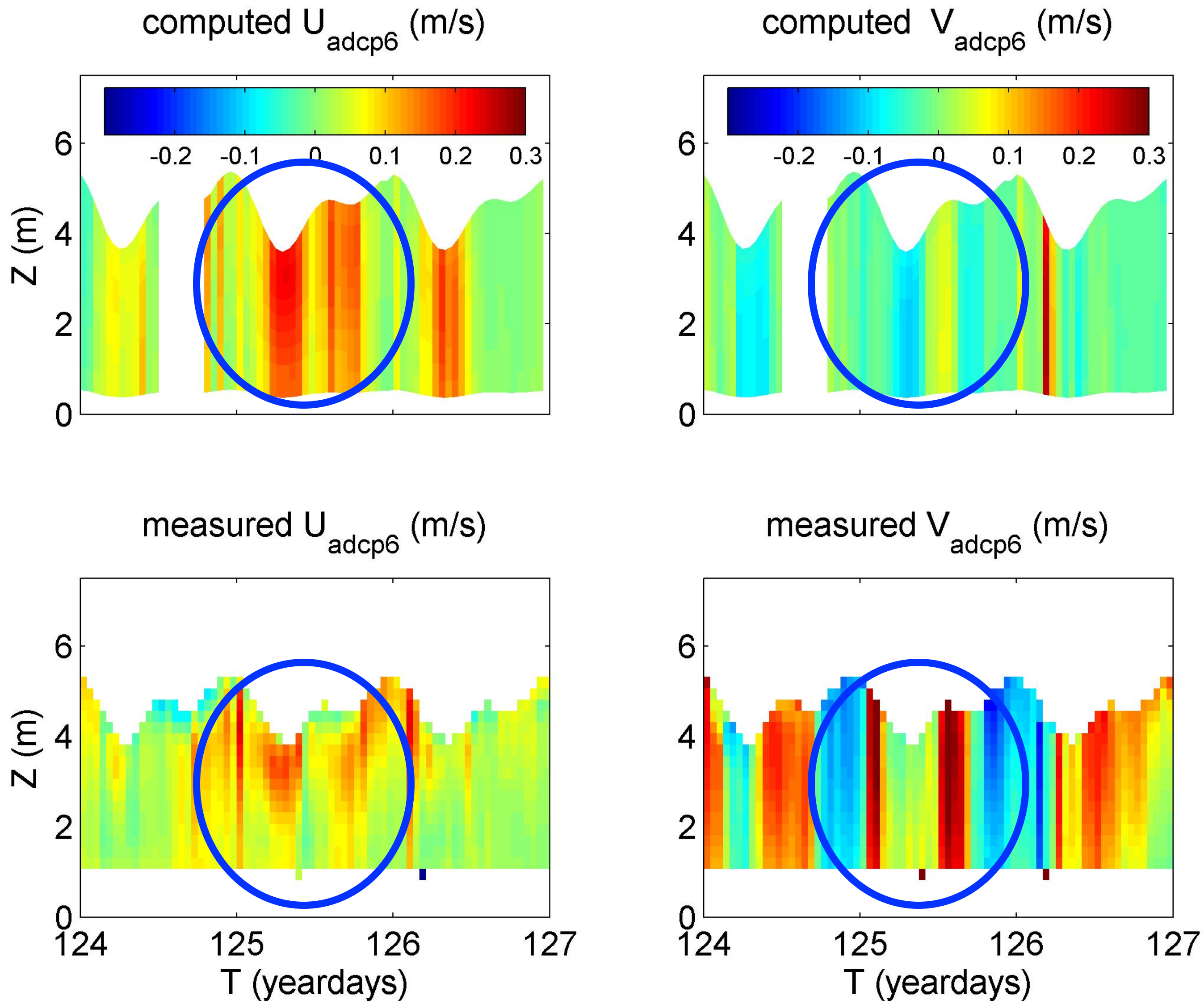
Forcing



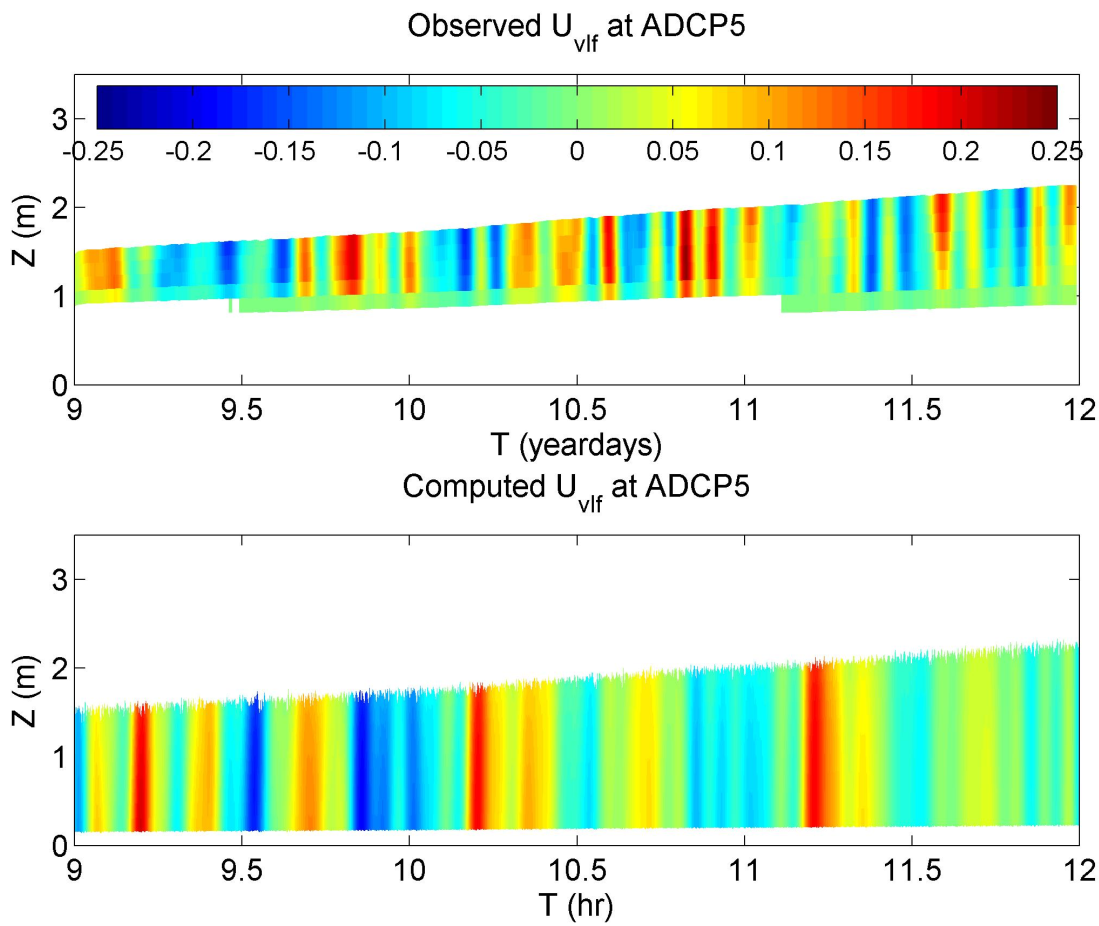
Outer surfzone



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

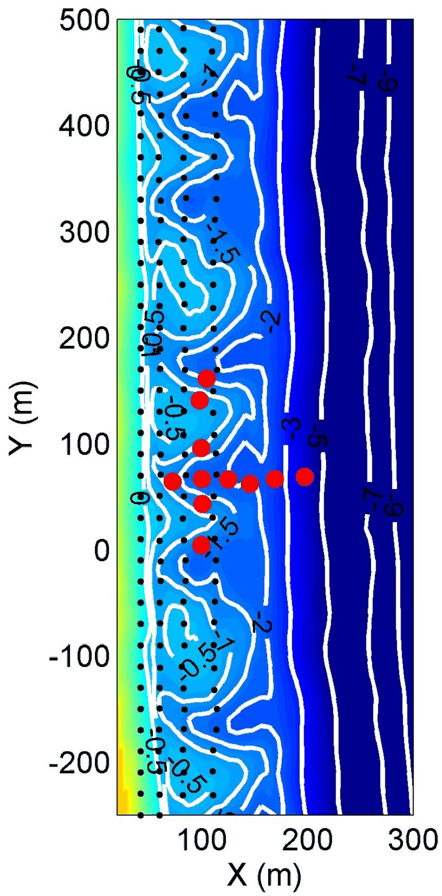
Surface flow velocity pattern	++
Subsurface velocity	
• Inner surfzone (adcp4)	+
• Outer surfzone (adcp6)	+-
VLF-velocities (adcp5)	++

Next: use **surface** velocities to examine surf zone retention

Drifter tracking

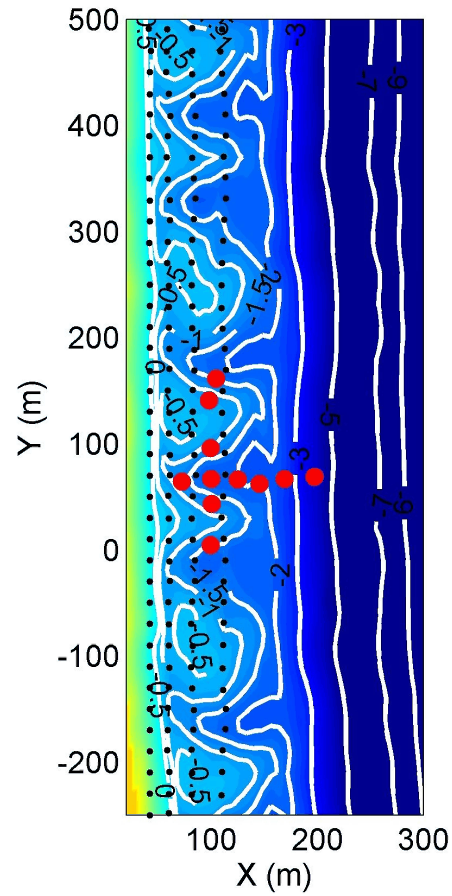
$$\mathbf{x}_i(t) = \mathbf{x}_i(t_0) + \int_{t_0}^{t_0+t} \mathbf{u}^E(\mathbf{x}_i, t)dt$$

Eulerian tracks

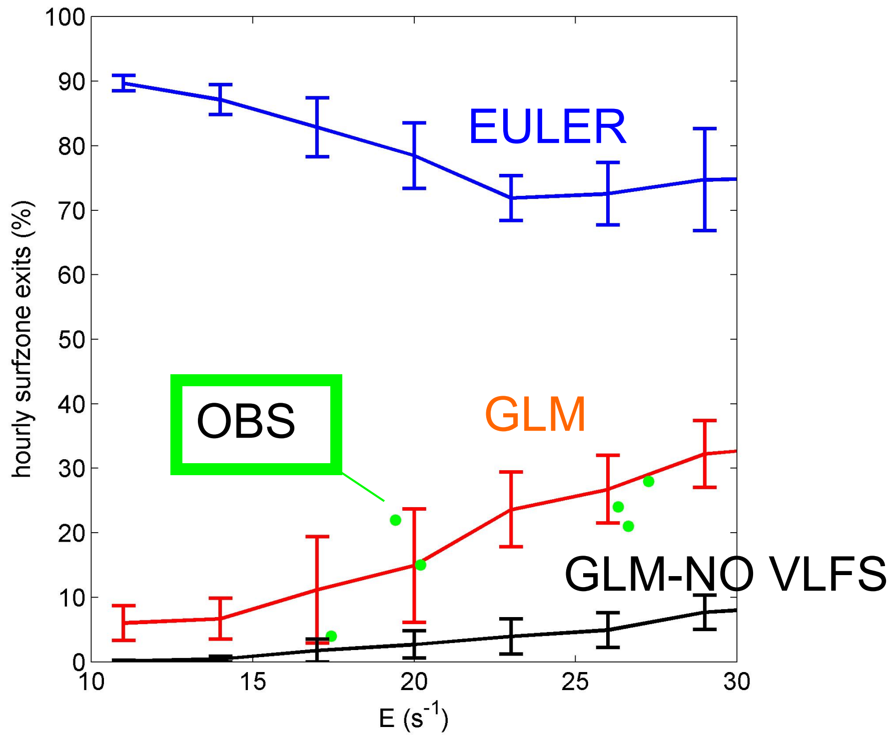


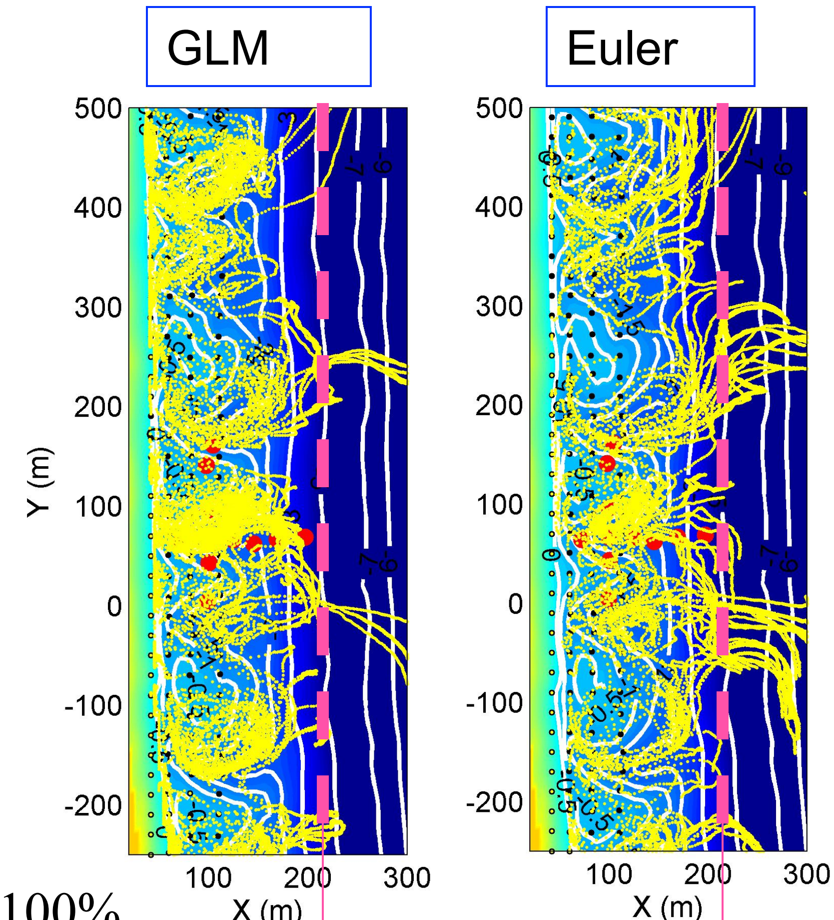
$$\mathbf{x}_i(t) = \mathbf{x}_i(t_0) + \int_{t_0}^{t_0+t} \mathbf{u}(\mathbf{x}_i, t)dt$$

GLM tracks



Surfzone retention





$$E = \frac{X_s}{HT}$$

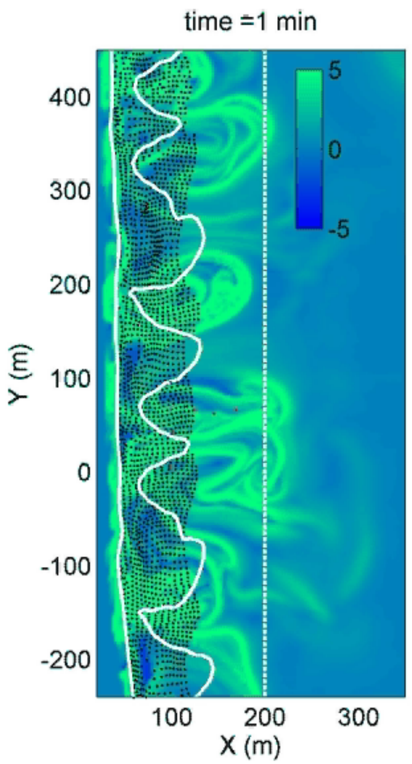
$$P = \frac{\sum d_i(x_i > x_s)}{\sum d_i} \cdot 100\%$$

X_s corresponds to the outer edge of the surf zone

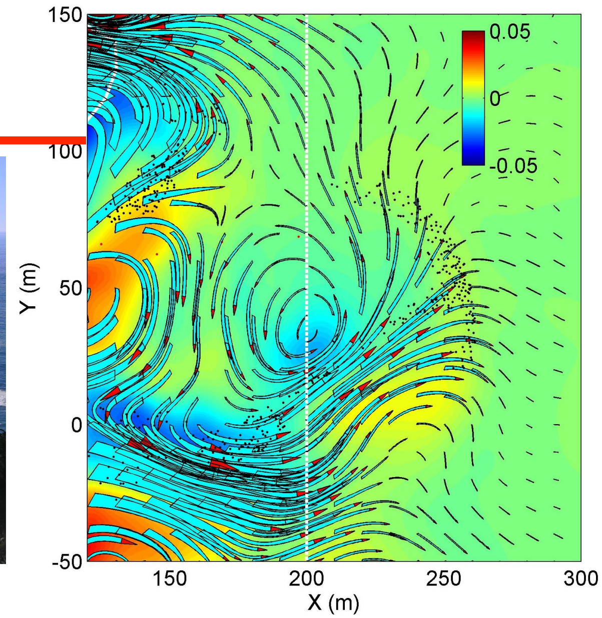
Lagrangian Coherent Structures

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!

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