## Title
Dispersion of Passive Tracers in the Surfzone



Authors
Fedderson, Falk
Guza, Robert T.

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# Dispersion of passive tracers in the surfzone

Feddersen and Guza
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## Introduction

In Southern California, terrestrial runoff pollution often drains directly onto the beach, degrading water quality and leading to increased beach closures each year. Beaches are a significant piston in California's economic engine and beach closures can have significant economic impact on local communities. Runoff pollution can be localized, as from a storm drain, or can be more diffuse with many smaller, distributed sources. In either case, upon entering ocean waters, the pollution is first mixed, dispersed, and advected within the surfzone (the region of breaking waves). However, behavior of polluted waters upon entering the surfzone is not understood, and advancing this understanding is crucial to improved beach water quality.

The dispersion of passive tracers, such as pollutants, in the surfzone was be examined using both drifter observations and nearshore wave/circulation models with the goal of understanding the mechanisms of dispersion and to develop formulations for predicting dispersion.

## Surfzone Drifter Deployments

GPS-tracked surfzone drifters were deployed at Torrey Pines Beach in San Diego on Nov. 3, 2004. This day was chosen because of both the small tidal excursions (about 0.2 m) and good GPS satellite coverage. Also deployed were three Sontek Triton Acoustic Doppler Velocimeters (ADV), sampling at 2 Hz, on a cross-shore transect with sensing volumes 0.8 m above the bed. The freely floating, impact resistant, GPS-tracked surfzone drifters are 0.5-m tall cylinders with most of their volume below the water line. A horizontal disc at the bottom of the body tube dampens vertical motions in the waves, allowing broken waves to pass over the drifter without pushing or "surfing" it ashore. Drifter GPS positions are internally recorded at 1 Hz with absolute position error of about $\pm 4$ m. Post-processing using carrier phase information reduces the absolute error to $\pm 1$ m. There were 9 separate releases of 9 drifters on a cross-shore transect. Two drifters were released side-by-side at each of 4 cross-shore locations, and a single drifter was released at a 5th location for a total of 77, approximately 1000 s long, drifter trajectories.

## Observational Analysis

Observed surfzone dispersion was quantified using one- and two-particle statistics derived from Lagrangian drifter data acquired on two days with contrasting waves and currents. On day 1, approximately normally incident waves were relatively small ($H_s \approx 0.5$ m) and currents were weak

($|\bar{v}| < 0.1\ \mathrm{m\,s^{-1}}$). On day 2, waves were obliquely incident and larger ($H_s \approx 1.4$ m) driving a current which reached $|\bar{v}| \approx 0.7\ \mathrm{m\,s^{-1}}$ in the surfzone.

Larger waves and stronger alongshore currents correspond to larger diffusivities. On day 2, diffusivities (both one- and two- particle) were about twice those on day 1. On both days, the one-particle diffusivities are time dependent. Initially, the strongest diffusion is in the cross-shore ($x$) direction, however, after many wave periods the one-particle diffusivity in the alongshore ($y$) direction was about twice that in $x$. Thus, at long times an ensemble-averaged surfzone tracer spreads more quickly in $y$ than in $x$. The asymptotic values of the diffusivity are $\kappa_{xx}^{\infty} = 0.7$ (1.5) $\mathrm{m^2 s^{-1}}$ and $\kappa_{yy}^{\infty} = 2$ (4.5) $\mathrm{m^2 s^{-1}}$ on day 1 (2). The asymptotic values of the one-particle diffusivity (both $\kappa_{xx}$ and $\kappa_{yy}$) are similar within and seaward of the surfzone, however, asymptotic values are reached faster within the surfzone.

Surfzone two-particle statistics suggest the presence of inertial subrange-like turbulence. The form of the two-particle normalized separation probability density functions at all times are nearly identical to those found in 2D inertial subrange turbulence. Thus even at the largest times ($\sim 200$ s) and separations ($\sim 60$ m), pairs of drifters do not move independently. Two-particle dispersion grows like $D^2 \sim t^{3/2}$ with scale-dependent relative diffusivity $\mu \sim l^{2/3}$. Both scalings differ from classical inertial subrange turbulence ($D^2 \sim t^3$ and $\mu \sim l^{4/3}$). Two-particle statistics in the surfzone are consistent with a diffusion equation for the particle separation pdf in which the diffusivity is both time and separation dependent, in contrast to inertial subrange turbulence, where the diffusivity depends only on separation.

Mechanisms of dispersion were investigated. The theoretical asymptotic diffusivity from the Stokes drift of unbroken irrotational surface gravity (sea-swell and infragravity) waves is much smaller than observed, suggesting rotational motions are important to surfzone dispersion. The sheared mean alongshore current observed on day 2 was used in a simple model of shear dispersion. The model overpredicts the one-particle asymptotic diffusivity $\kappa_{yy}^{\infty}$ and the time to reach this value. The model does, however, predict the slope of the observed $t$ growth of $\kappa_{yy}$ for intermediate times. Although possibly important on day 2, shear dispersion cannot explain day 1 results when $\bar{v}$ is small. We speculate that a modified two-dimensional turbulent eddy field governs surfzone dispersion, and the source of this vorticity (at $O(5-50)$ m) is alongshore gradients in breaking wave height associated with finite crest lengths.

This work has led to the following presentations and publications

- Spydell, Feddersen, Guza, Schmidt, Observing Surfzone Drifter Dispersion, 2006 AGU Ocean Sciences Meeting

- Spydell, M., F. Feddersen, R. T. Guza, W. Schmidt, Observing surfzone dispersion with drifters, *J. Phys. Oceangr.*, in press, 2007 (see http://iod.ucsd.edu/~falk/papers.html)

## Numerical Modeling

A time-dependent Boussinesq wave model which resolves individual waves and parameterizes wave breaking is used to numerically simulate velocities and sea surface height in the surfzone. The model extent is 700 m in the cross-shore ($\Delta x = 1$ m) and 2000 m ($\Delta y = 2$ m) in the alongshore. The alongshore is periodic and uniform with the bathymetry equal to the alongshore mean of that at Torrey Pines. The model is forced by oscillating the sea surface so that the modeled spectrum matches the observed. Wave energy is absorbed in sponge layers at the cross-shore edges of the domain. After the model reached a statistically steady state (1000 s into the model run), 2000 model surfzone drifters were released and advected by the model's horizontal velocity released. Modeled drifters are advected with the Boussinesq model horizontal velocities. and were tracked for approximately 2000 s.

Lagrangian statistics of drifter trajectories in surfzone circulation models are examined and compared to single-particle and two-particle dispersions statistics observed on a natural beach for waves that are normally incident. Modeled Eulerian and Lagrangian statistics are similar to those observed. In particular, for the Eulerian statistics, the model reproduces the observed cross-shore variation in significant wave height, wave direction, and wave spread. For the Lagrangian statistics, modeled time-dependent dispersion and scale-dependent diffusivity is consistent with the observed. It is further shown that wave spread and breaking create low-frequency (time-scales longer than the peak period) surfzone vortical flow which in turn causes the dispersion. The effect of wave conditions (significant wave height, peak period, and directional spread) which govern the magnitude of the vortical flow, and therefore the dispersion, is determined.

This aspect of the project, has led to the following presentations and publications

- Spydell and Feddersen, Guza, Schmidt, Observing Surfzone Drifter Dispersion, 2006 AGU Fall Meeting, San Fransisco, 2006.
- Spydell, Lagrangian Dispersion in the Surfzone, PORD Seminar, Scripps Inst. of Oceanography, May 30, 2007.
- Spydell, M., and F. Feddersen, Lagrangian Dispersion in the Surfzone 1: Directionally Spread Random Waves, in preparation, 2007.