

Dispersion in the Surfzone: Tracer Dispersion Studies

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Award Number: N000140610330

LONG-TERM GOALS

Terrestrial runoff and river input dominates urban pollutant loading rates. Often draining directly into the surfzone, this pollution degrades surfzone water quality, leading to beach closures (*e.g.*, Boehm *et al.*, 2002), increases health risks (*e.g.*, diarrhea and upper respiratory illness) (Haile *et al.*, 1999), and contains both human viruses (Jiang and Chu, 2004) and elevated levels of fecal indicator bacteria (Reeves *et al.*, 2004). Surfzone mixing processes disperse and dilute such (and other types of) pollution. On smaller length-scales (smaller than the water depth), breaking-waves and bed-generated turbulence mix tracer. However, field surfzone observations of turbulence previously have been extremely scarce, and much about surfzone small-scale turbulence is not known. On larger scales (10–100 m), horizontal dispersion is driven by surfzone eddies and meanders associated with shear waves (Oltman-Shay *et al.*, 1989) or finite breaking crest length (Peregrine, 1998). Understanding the small and large length-scale mixing processes important to predicting the fate (transport, dispersal, and dilution) of surfzone tracers whether pollution, bacteria, larvae, or nutrients.

OBJECTIVES

The scientific objective is to improve understanding and modeling of dispersion of tracers (pollution, fecal indicator bacteria, fine sediments) within the nearshore (a few 100 m of the shoreline) and especially within the surfzone where breaking waves intensify mixing processes and drive strong mean currents. We have focused on two components of analysis of the HB06 experiment performed in Fall of 2006. The first is studying the small-scale turbulence in the surfzone due to breaking waves and the second, is larger scale surfzone Lagrangian drifter dispersion. Other efforts include analysis of dye tracer mixing and phytoplankton patchiness at HB06.

APPROACH

Surfzone Turbulent Dissipation Rate:

The vertical structure of turbulence in the surfzone is of interest. Both breaking waves and near-sea-bed shear are possible sources of turbulence. Here a key turbulence statistic, the

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1. REPORT DATE 2008		2. REPORT TYPE		3. DATES COVERED 00-00-2008 to 00-00-2008	
4. TITLE AND SUBTITLE Dispersion in the Surfzone: Tracer Dispersion Studies				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Scripps Institutions of Oceanography, 9500 Gilman Drive, La Jolla, CA, 92093-0209				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

turbulent dissipation rate ϵ is estimated from Acoustic Doppler Velocimeters observations following

HB06 Drifter Dispersion

Two types of dispersion can be estimated from Lagrangian drifter data: absolute and relative. Absolute diffusivities characterize tracer dispersion averaged over many releases in a coordinate frame fixed to the common release point. Relative diffusivities describe the spreading of the average patch in a coordinate frame fixed to the center of mass of each individual patch. Dispersion is generally calculated by examining the “spreading” of Lagrangian data (dye or drifters). The separation rate of Lagrangian particles (*e.g.*, surfzone drifters) is fundamentally related to the spreading of a tracer patch. As they disperse differently in the surfzone, drifters and dye provide complimentary insights into surfzone dispersion dynamics.

WORK COMPLETED

- Spydell et al. (2008) is now in press.
- Omand et al. (2008) has been revised to *Limnology and Oceanography: Methods*.
- A manuscript intended for *J. Atmospheric and Oceanic Tech.* (Feddersen) is almost ready for submission. This manuscript deals with the methods of analyzing Acoustic Doppler Velocimeter data for estimating the turbulent dissipation rate.
- A manuscript describing the HB06 surfzone turbulence results (see below) is being prepared for publication.
- A manuscript intended for *J. Geophysical Res.* (Spydell, Feddersen, Guza) is also almost ready for submission. This manuscript looks at surfzone drifter dispersion from Huntington Beach.

RESULTS

HB06 Experiment

Observations were collected from 15 September to 17 October 2006 (800 hours) at Huntington Beach CA, a site with chronic water quality problems. A cross-shore transect of co-located pressure sensors and acoustic Doppler Velocimeters was deployed spanning 160 m out to 4 m mean water depth (Fig. 1). The tide range was nominally ± 1 m. The data was sampled at 8 Hz. The ADVs sampled between 0.5-1.0 m above the bed. The cross- and alongshore coordinate are x and y , respectively. The mean water depth is given by h and the vertical coordinate is z with $z = 0$ m at the sea-bed. The distance below the mean sea surface is $z' = h - z$. At each of the frames, hourly estimates of significant wave height H_{sig} , cross-shore energy flux $F = Ec_g$, mean alongshore current \bar{v}_m , and turbulent dissipation rate ϵ were estimated.

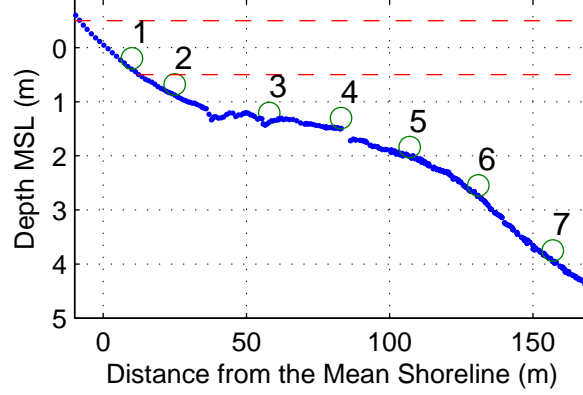


Figure 1: HB06 cross-shore instrument transect. The circled numbers indicate instrumented frames with acoustic Doppler Velocimeters (ADV) and pressure sensors. The horizontal red dashed lines indicate the typical tide range.

Surfzone turbulence studies

The turbulent dissipation rate ϵ was significantly larger (by a factor of 10) inside the surfzone (blue curve first 400 hrs) versus seaward of the surfzone (red curve in Fig. 2), indicating the importance of wave breaking to turbulence in the surfzone. The surfzone ϵ is related to the incoming H_{sig} (lower panel Fig. 2) with larger waves leading to larger ϵ . Furthermore, there is significant tidal modulation of surfzone ϵ . At lower tides when the ADV is closer to the surface (and the source of breaking wave turbulence), ϵ is stronger. In addition, at later times (hours 500-700), frame 3 is alternately within and seaward of the surfzone as the tide goes up and down. The frame 3 ϵ varies strongly as wave breaking is turned on and off (see strong oscillations in blue curve in Fig. 2).

We seek a non-dimensional scaling for the dissipation rate ϵ in the surfzone. Following Terray et al. (1996), who developed a scaling for open-ocean whitecapping breaking waves, the dissipation is non-dimensionalized as

$$\tilde{\epsilon} = \frac{H_{\text{sig}}\epsilon}{dF/dx} \quad (1)$$

where $dF/dx = d(Ec_g)/dx$ is the cross-shore gradient of the the incoming wave energy flux (Ec_g) which is estimated from the frames. The non-dimensional ϵ has a consistent relationship with the non-dimensional distance below the mean surface z'/H_{sig} at each frame (Fig. 3). This relationship can be modeled as a power law relationship as

$$\frac{H_{\text{sig}}\epsilon}{dF/dx} = C \left(\frac{z'}{H_{\text{sig}}} \right)^\gamma \quad (2)$$

where C and γ are fit at each frame.

At the 3 surfzone frames, the fit γ vary between -1.5 and -2 with fit skill varying between 0.4 and 0.6 (Fig. 3). This best-fit γ is consistent with results from open-ocean wave breaking which has

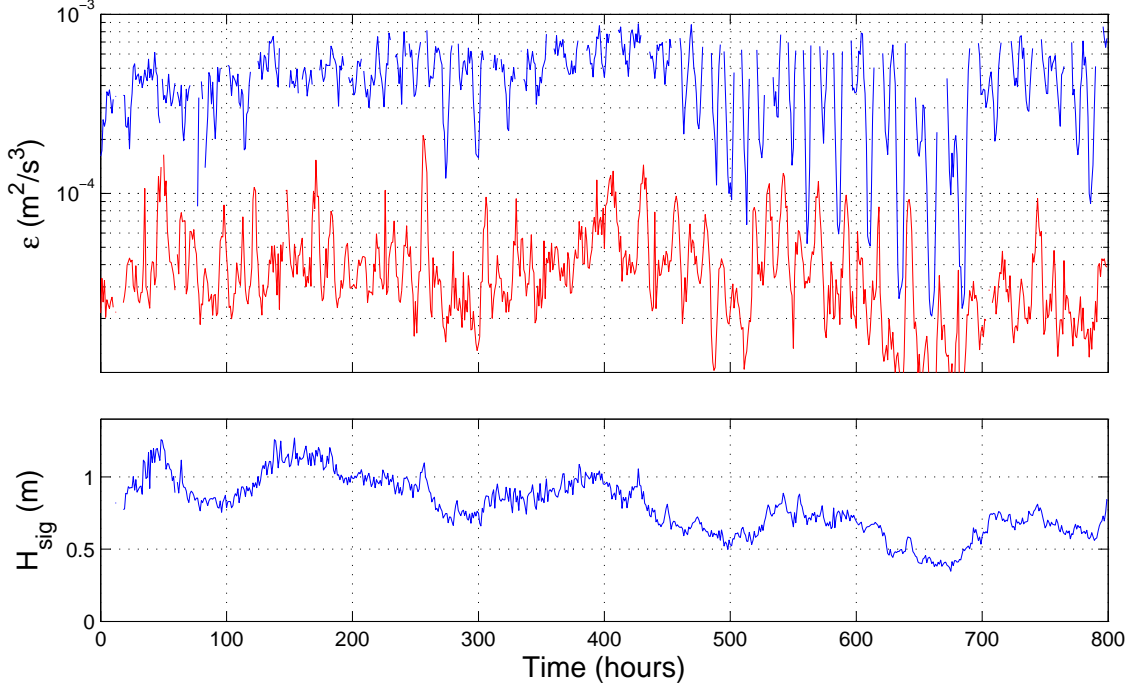


Figure 2: HB06 time series of (top) turbulent dissipation rate ϵ at frames 3 (blue) and 6, and (bottom) incident significant wave height H_{sig} at frame 7.

$\gamma = -1.9$ (Terray et al., 1996). This implies that the mechanisms by which turbulence diffuses down in the surfzone are similar to those in the open-ocean. However, one open question is why the constant C varies so much between the frames. This is being investigated further.

HB06 Surfzone Drifter Diffusivity Parameterization

Five days, Sep. 17, Oct. 2,3,14, and Oct. 15, 2006, of GPS-tracked drifter data was collected at Huntington Beach, CA during the HB06 experiment. The drifter data consists of along- and cross-shore positions as a function of time, sampled at 1 Hz. There was a total of 20.2, 26.7, 16, 20.5, and 20 hours on drifter data on each day. Position errors are approximately ± 2 m and are correlated in time. For a complete description of the drifters and data quality see *Schmidt et al.* (2003) and a thorough description of the data processing and diffusivity estimation appears in *Spydell et al.* (2007). The cross- and alongshore coordinates are $x = 0$ and y , respectively.

A preliminary attempt to parameterize the effect of varying Eulerian surfzone conditions on surfzone mixing during HB06 is made by examining the effect of surf conditions on the asymptotic diffusivity for each of the five days of Lagrangian data collected at Huntington Beach. A parameterization linking the cross-shore diffusivity to the significant wave-height H_{sig} and mean period \bar{T} is given in *Inman et al.* (1971) with

$$\kappa_{xx}^{\infty} \simeq \alpha H_{\text{sig}}^2 / \bar{T} \quad (3)$$

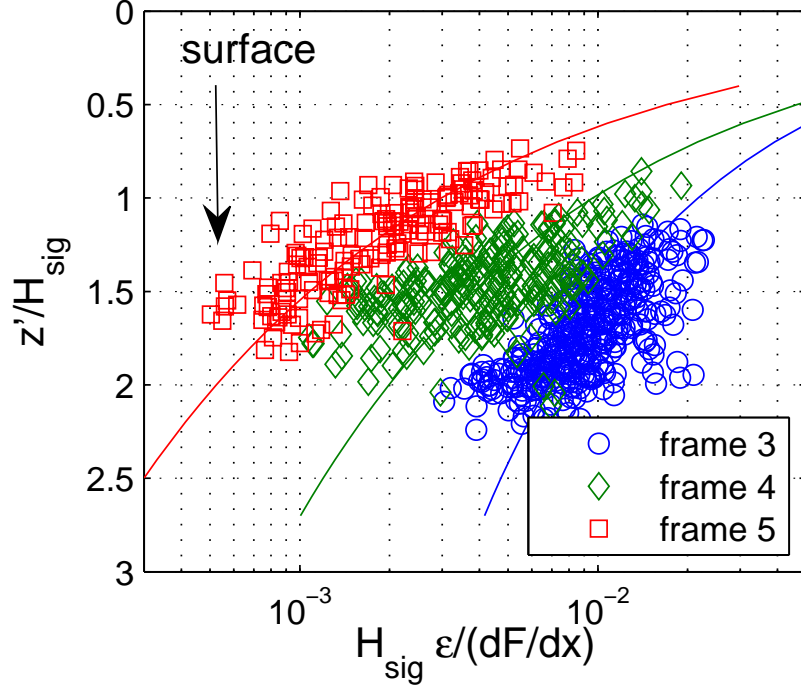


Figure 3: Nondimensional dissipation rate $H_{\text{sig}}\epsilon/(dF/dx)$ against non-dimensional distance below the mean sea-surface z'/H_{sig} at frames 3, 4, and 5 (see legend) when in the surfzone. The solid lines are the best fit to a power law relationship $H_{\text{sig}}\epsilon/(dF/dx) = \alpha(z'/H_{\text{sig}})^\gamma$ where $\gamma \approx -1.9$ at all the frames.

for the mixing of a passive tracer due to broken wave bores in the surfzone. Recently, this relationship was obtained for a simple model of surfzone cross-shore tracer diffusion by bores (Feddersen, 2007). Specifically, Feddersen (2007) showed that κ_{xx} in (3) is the average cross-shore tracer diffusivity resulting from bores of height H_s and period \bar{T} . As this relationship parameterizes the effect of broken wave bores entraining and mixing tracers, there is no reason to expect this relationship to hold for Lagrangian drifters which (by design) are not entrained in bores. Thus, it is expected that a “cloud” of tracer would grow much more than an equally sized “cloud” of drifters after the passing of a single bore. Moreover, the mixing due to bores occurs on wave period time-scales, much shorter than the low-frequency vortical motions which disperse drifters (Spydell and Feddersen, 2008).

Using the wave statistics from the most offshore sensor, the asymptotic cross-shore diffusivity κ_{xx}^∞ is well fit by this relationship (see Fig 4-left). In particular, fitting the data to (3) results in $\alpha = 20.9 \pm 5$ with a skill of 0.90. Although not used in the fit, the day at Torrey Pines (TP04) with small waves $H_s = 0.5$ m (Spydell et al., 2007), is also reasonably fit by this relationship

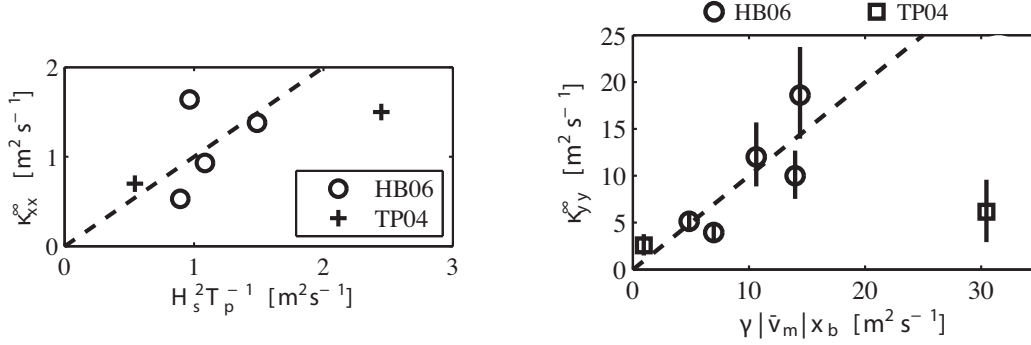


Figure 4: (LEFT) The HB06 asymptotic cross-shore diffusivity κ_{xx}^{∞} (circles) $\propto H_s^2/\bar{T}$ with best-fit $\alpha = 20.9 \pm 5$. Wave height H_s and mean period \bar{T} are estimated seaward of the surfzone (≈ 160 m from the shoreline). The linear best-fit constrained to go through the origin (dashed line) has a skill of 0.90. Also shown (but not included in the fit) are TP04 (Spydell *et al.*, 2007) data points. (RIGHT) The HB06 asymptotic alongshore diffusivity κ_{yy}^{∞} (circles) versus (a) $\gamma \bar{v}_m x_b$ where \bar{v}_m is the maximum alongshore current and x_b is the surfzone width. The best-fit (dashed lines) results in $\gamma = 0.52 \pm 0.08$ with skill= 0.93. Error-bars (approximately 68% confidence limits) are indicated by vertical lines. Also shown (but not included in the fit) are TP04 (Spydell *et al.*, 2007) data points. This figure is from Spydell *et al.* (2008) in preparation.

whereas the second day with the much larger $H_s = 1.35$ m is poorly fit (pluses in Fig. 4-LEFT).

As previously mentioned, this relationship is meant to parameterize the effect of bores on tracers while the effect of bores on drifters is considerably different. Thus, this fit of the HB06 data to (3) is surprisingly good and suggests that H_s and \bar{T} are somehow involved in controlling the low frequency vortical cross-shore surfzone motions responsible for dispersion (Spydell and Feddersen, 2008), although the exact mechanisms are unknown.

In the alongshore, shear wave induced turbulence may effect the dispersing with the alongshore diffusivity related to the magnitude of the alongshore current. The following scaling is investigated

$$\kappa_{yy}^{\infty} = \gamma |\bar{v}_m| x_b \quad (4)$$

where \bar{v}_m is the maximum of the alongshore current measured by the current meters, x_b is the break point (surfzone width) as determined by energy flux, and γ is a nondimensional constant found via a least-squares fit. This scaling is motivated by mixing length theory which has a characteristic velocity scale (maximum alongshore current) multiplied by a length-scale (the surfzone width).

The data is well fit by (4) with $\gamma = 0.52 \pm 0.08$ and a skill of 0.93 (Fig. 4-right). Fitting κ_{yy}^{∞} to a constant length scale L_x , rather than using the scaled variable surfzone width γx_b in (4), also results in a good fit as the surfzone width was nearly the same on all days except one. Thus, the asymptotic alongshore diffusivity is proportional to the maximum alongshore current.

IMPACT/APPLICATIONS

Potential impacts include improving surfzone and nearshore mixing parameterizations based upon bulk factors such as wave height, wave period, bathymetry, and currents.

RELATED PROJECTS

There are no active related projects.

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PUBLICATIONS

These publications acknowledging ONR support during this support period can be downloaded at <http://iod.ucsd.edu/~falk/papers.html>.

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