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Short-Crested Breaking Waves and Vorticity

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LONG-TERM GOALS

The long-term goal is to determine the contribution of short-crested breaking waves to vorticity (and thus mixing) in nearshore regions and near strong flows from inlets or river mouths.

OBJECTIVES

The objectives of our research were to:

- Investigate the magnitude of vorticity generated by individual short-crested breaking waves
- Develop simplified models for vorticity generation by breaking waves
- Investigate the relationship between vorticity generation and the low frequency eddies that drive surfzone tracer dispersion

APPROACH

Our approach is to develop new field methods and instrumentation to enable measurements of the processes affecting vorticity, and to assess the importance of those physical processes to numerical models of the nearshore region.

WORK COMPLETED

Surfzone vorticity, wave, current, and optical image data was collected durring the 2011 VORTEX pilot study aimed at measuring vorticity and eddies generated by short-crested breaking waves. The findings were published in the article "Vorticity generation by short-crested breaking waves", in Geophysical Research Letters, and it was featured on the December 2012 cover (Figure 1). The data from the 2011 VORTEX pilot study was further analyzed for connections between vorticity generated by short-crested breaking waves and the low frequency horizontal eddies thought to mediate tracer dispersion (Figure 2). Analytic models for short-crested vorticity were developed and had good agreement with data in the mid-surfzone, but had poor agreement in the outer surfzone. Current work is focused on evaluating the model over a wider range of conditions. This type of model may provide parameterizations for adding short-crested breaking effects to wave averaged models.

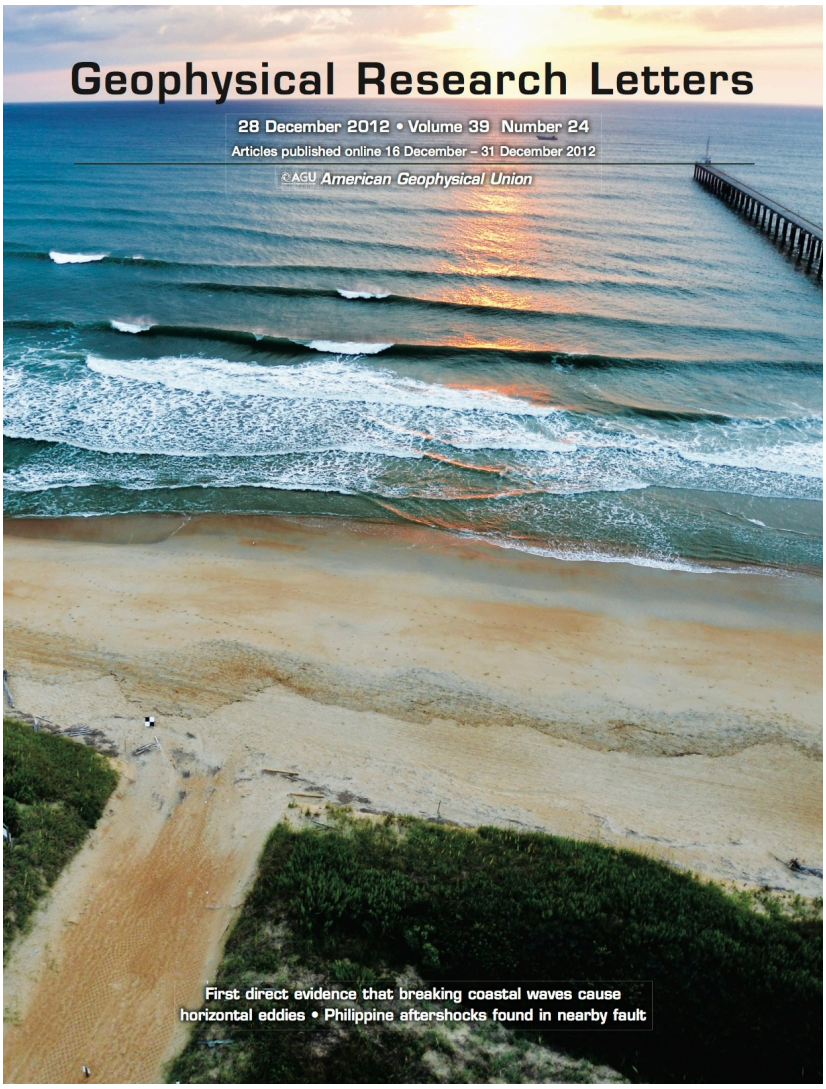

Figure 1. The cover of Geophysical Research Letters featuring short crested waves breaking at Duck, NC.

Dispersion and mixing near a tidal inlet was investigated with fluorescent dye during the Rivers and Inlets DRI (RIVET), where increased wave directional spread on the ebb shoal was expected to increase the number of short crested breaking events (thus vorticity and mixing). New methods were developed for measuring fluorescent dye concentration in nearshore regions using airborne multi- and hyperspectral imaging, and the results were published in the June 2014 issue of the Journal of Atmospheric and Oceanic Technology.

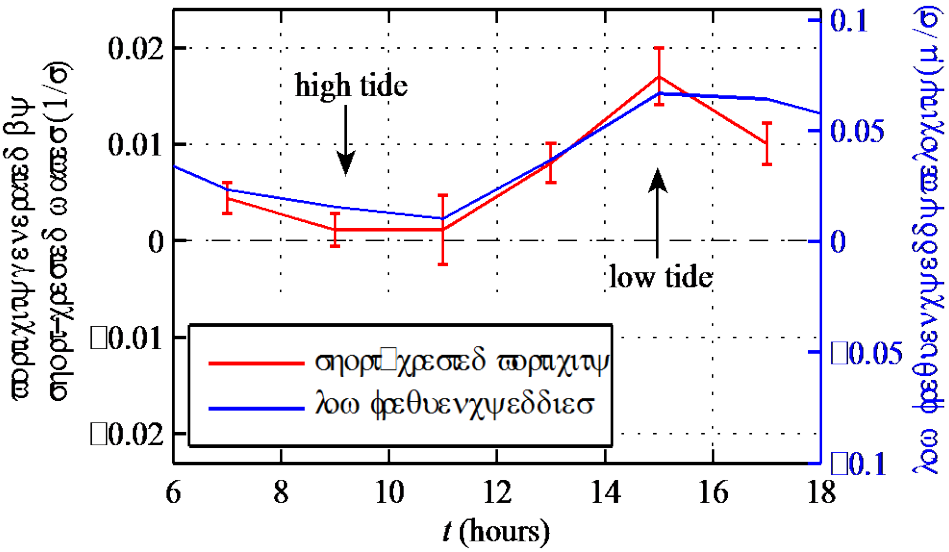

Figure 2. Vorticity generated by individual short-crested breaking waves within the surfzone (red curve), shown as 2-hour binned means ± the error in the mean, and the rms low frequency eddy velocity (blue curve) versus time t. The generated vorticity varies with the tidal water depth, with low vorticity at high tide (near t = 9 hours) and high vorticity at low tide (near t = 15 hours). The strength of low frequency eddies is highly correlated with the magnitude of wave generated vorticity (r = 0.94), and suggests that short-crested breaking waves are a primary forcing mechanism for surfzone eddies and tracer dispersion. The transfer of energy from small scale O(10 m) eddies generated by breaking waves to low-frequency large-scale O(100 m) eddies is expected for the quasi 2D flows found at those scales in the surfzone.

RESULTS

Low frequency eddies are thought to be the primary process that disperses tracers in the surfzone and nearshore, but the mechanisms that generate these eddies are not understood. We found that high frequency short-crested breaking events transferred energy to low frequency eddies. The high correlation between the magnitude of vorticity generated by short crested breaking waves and the strength of low frequency eddies (Figure 2) suggests that short-crested breaking is a controlling factor for nearshore tracer dispersion and eddy viscosities. The effects of short-crested breaking should be included in wave-averaged models when accurate predictions of current structure or tracer dispersion are required.

The newly developed remote sensing methods for measuring fluorescent dye concentration using airborne multi- and hyperspectral imaging has increased spatial coverage by several orders of magnitude over previous jet ski based observations (Figure 3), and dye plumes longer than 6 km were measured in a single aerial pass. Using a new three-band method, the aerial dye measurement corrects for suspended sediment and has mean errors of 2 parts per billion (including spatial errors).

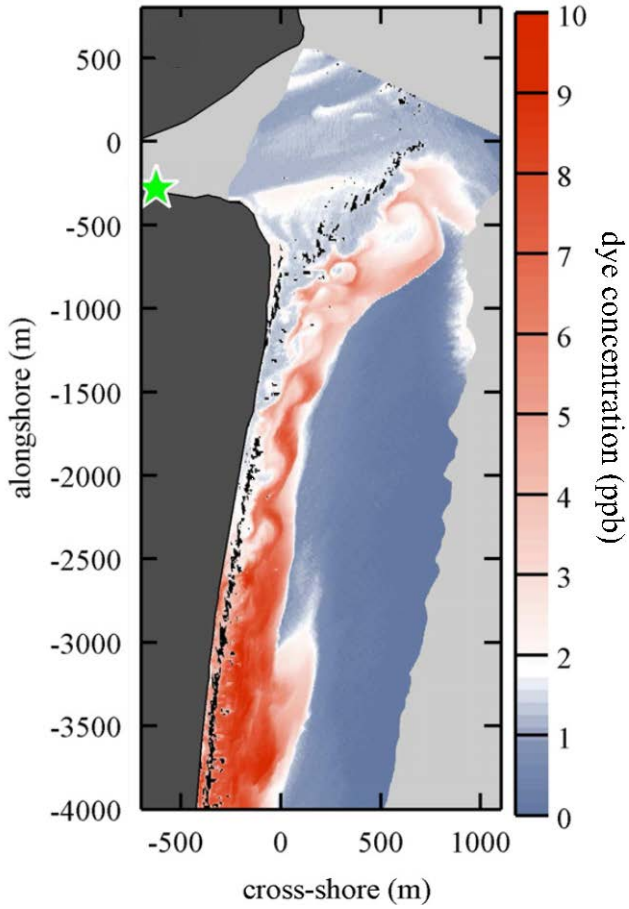

Figure 3. Hyperspectral dye concentration measurements (ppb, see legend) on 7 May 2012 during the RIVET DRI. Dye was released continuously just inside the inlet (green star symbol), and this image was taken 90 min after the dye release ended. Dark gray regions indicate land, light gray regions indicate water outside the imaged area, and black regions indicate foam from breaking waves. The rapid transport within the surfzone bought clear water into the region along the shoreline just south of the inlet while dye remains farther offshore. At the seaward edge of the surfzone the dye field shows evidence of shear instabilities, with dye being transported from offshore back into the surfzone.

IMPACT/APPLICATIONS

The vorticity project made the first measurements of surfzone vorticity about a vertical axis (i.e., horizontal eddies), and the first measurements of vertical voritcity generated by short crested breaking waves. Short-crested breaking is found to be a significant source of surfzone vorticity, and high correlations with low frequency eddies suggest short-crested breaking is a controlling factor on surfzone tracer dispersion. Our study indicates that the effects of short crested breaking waves should be included in numerical models of the surfzone. The vorticity study changes the way the surfzone eddy field is viewed, and puts a strong emphasis on individual breaking waves. It is clear that averaging over the wave field removes important physics from surfzone and nearshore models.

The development of new low-cost methods for measuring fluorescent dye tracers from aerial platforms opens a wide array of dispersion process studies. In particular these methods map coherent structures (Figure 3) that were unresolved in previous measurements made on cross- and alongshore transects. Coherent structures, such as rip currents and eddies, are thought to be important mechanisms for exchanging fluid and suspended material between the shoreline and the inner continental shelf.

RELATED PROJECTS

An ongoing surfzone vorticity project funded by NSF complements the pilot project analysis funded by this ONR project. A new vorticity sensor was developed and deployed along with extensive cross- and alongshore velocity and pressure arrays during a month-long experiment at Duck, NC. The time series of surfzone vorticity is being used to explore the variation in wave-generated vorticity over a range of wave conditions, and the additional arrays will be used to study vorticity input from sheared currents and wave groups.

PUBLICATIONS

Clark, D.B., S. Elgar, and B. Raubenheimer (2012), (COVER) Vorticity generation by short-crested breaking waves, *Geophysical Research Letters,* 39, L24604, doi:10.1029/2012GL054034, [published, refereed]

This article is available at:
http://www.whoi.edu/science/AOPE/people/dclark/pubs/Clark_etal_GRL_2012.pdf

Clark, D.B., L. Lenain, F. Feddersen, E. Boss. R.T. Guza (2014), Aerial Imaging of Fluorescent Dye in the Nearshore, *Journal of Atmospheric and Oceanic Technology*, 31, 1410–142, doi: 10.1175/JTECH-D-13-00230.1 [published, refereed]

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