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High-Resolution Dynamics of Stratified Inlets

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LONG-TERM GOALS

The long-term goal of this research program is to provide accurate environmental assessments of high-energy, stratified river mouth environments through the use of advanced models, remote sensing systems, and autonomous measurement systems.

OBJECTIVES

1) Continue analysis of WHOI measurements from the mouth of the Columbia River (MCR) obtained in RIVET II to quantify and elucidate the hydraulic conditions of the estuary , and apply these findings to the interpretation of remotely sensed frontal features obtained as part of the DARLA MURI project.

2) Use observations and analysis from RIVET II to inform the non-hydrostatic modeling of fronts and related coherent structures that occur at the MCR that is being performed by Tom Hsu's team at U. Delaware.

3) Perform additional field work in conjunction with the testing of the ATLAS sonar system to obtain high-resolution data of frontal structures in the Columbia River and to explore the potential of data fusion with remote and autonomous assets.

WORK COMPLETED

The analysis of the RIVET II data is essentially complete, and papers are being completed or have been submitted that report on those findings. A new set of field data was obtained from the mouth of the Columbia River in September, 2015, which should provide unprecedented, three-dimensional rendering of hydraulic phenomena through the combination of radar, forward-looking sonar, and in situ data.

RESULTS

The discovery of oblique hydraulic jumps by the Honegger and Haller has led to extensive dynamical analysis, combined with fusion of in situ and remote sensing data. This analysis has refined the interpretation of the jump phenomenon, confirming its dynamical basis and providing a predictive framework for the timing and location of oblique jumps. Hydrostatic, finite-amplitude theory yields

the general characteristics of the position and orientation of the fronts. Geyer is working with Honegger and Haller on the final edits of a manuscript to be submitted to the Journal of Geophysical Research that documents the structure and dynamics of the hydraulic jumps based on hydrostatic theory.

Whereas the hydrostatic analysis explains the occurrence, location and orientation of the fronts, the detailed examination of the in situ and remote sensing data demonstrate finescale structures that indicate significant departures from hydrostatic balance in the frontal regions. During the field observations in September, 2015, large-amplitude solitary waves were observed at the hydraulic jump at Jetty A [Figure 1]. Intense convergence of the near-surface velocity (from 1.5 to 0 m/s in less than 50 m) caused strong convergence of wave energy, leading to intense breaking and entrainment of bubbles. The steepened waves provide the signal that is readily detected by the x-band radar (Honegger et al., in prep.), and the bubbles show up in the acoustic backscatter [Figure 1, 3rd panel]. A remarkable and unexpected aspect of these frontal structures is the intense transverse velocity variations occurring within the solitary waves [Figure 2]. These transverse motions illustrate the fundamentally three-dimensional nature of these jumps. The in situ observations of the non-hydrostatic structure of the front provide critical sea-truth for interpretation of the remote sensing imagery as well as for the testing of numerical model representations of these processes.

A more complex three-dimensional structure was revealed at the jump near the North Jetty during the 2015 observations, where the radar backscatter indicated the ribbon-like pattern of transverse features in surface roughness that had been observed during the 2013 observations. The new in situ data showed periodic features of similar scales, in which marked velocity perturbations were observed [Figure 3]. The density structure and acoustic scattering also showed similar periodicity, suggesting large-amplitude upwelling and downwelling pulses associated with the ribbon structures.

Geyer has interacted with Tom Hsu's group at Delaware in the development and application of non-hydrostatic models for examination of the dynamics of strongly forced stratified flows. The model NHWAVE was successfully applied to the plume lift-off problem, using Geyer's observations from the Connecticut River as a test case for evaluating the model's ability to capture the scales and structure of the non-hydrostatic features. The results of this model application were written up in a manuscript submitted to the Journal of Geophysical Research (Yu et al., submitted). Hsu's group is also addressing the more challenging problem of modeling the three-dimensional structure of the ribbon features that occur at the North Jetty. The results of this effort are promising, but some differences between the new (2015) observations in the Columbia River and the model-generated structures need to be examined and explained.

IMPACT/APPLICATIONS

The observations obtained in this study are impacting the interpretation of remote-sensing data of hydrodynamically induced surface features. The insights gained about the generation of surface fronts will lead to new methods of quantifying the depth-varying flow and stratification based on remotely sensed surface features. This will have implications for environmental assessments in denied areas, where only remote-sensing data is available. The environmental measurements and analysis are being used for testing models and will improve the prediction of environmental conditions in areas of Naval interest.

RELATED PROJECTS

ONR is supporting a closely related project to provide in situ ground-truth for the ATLAS sonar system and to explore methods of data fusion between autonomous and remote-sensing systems.

REFERENCES

Yu, X., T.-J. Hsu, F. Shi, W.R. Geyer and J.T. Kirby, submitted. Large eddy simulation of idealized river plumes at high Reynolds number. Submitted to *Journal of Geophysical Research*, August 2015.

Honneger, D.A., M.C. Haller, W.R. Geyer and G Farquharson, in prep. Recurring, oblique internal hydraulic jumps at a stratified estuary mouth. To be submitted to *Journal of Geophysical Research* fall 2015.

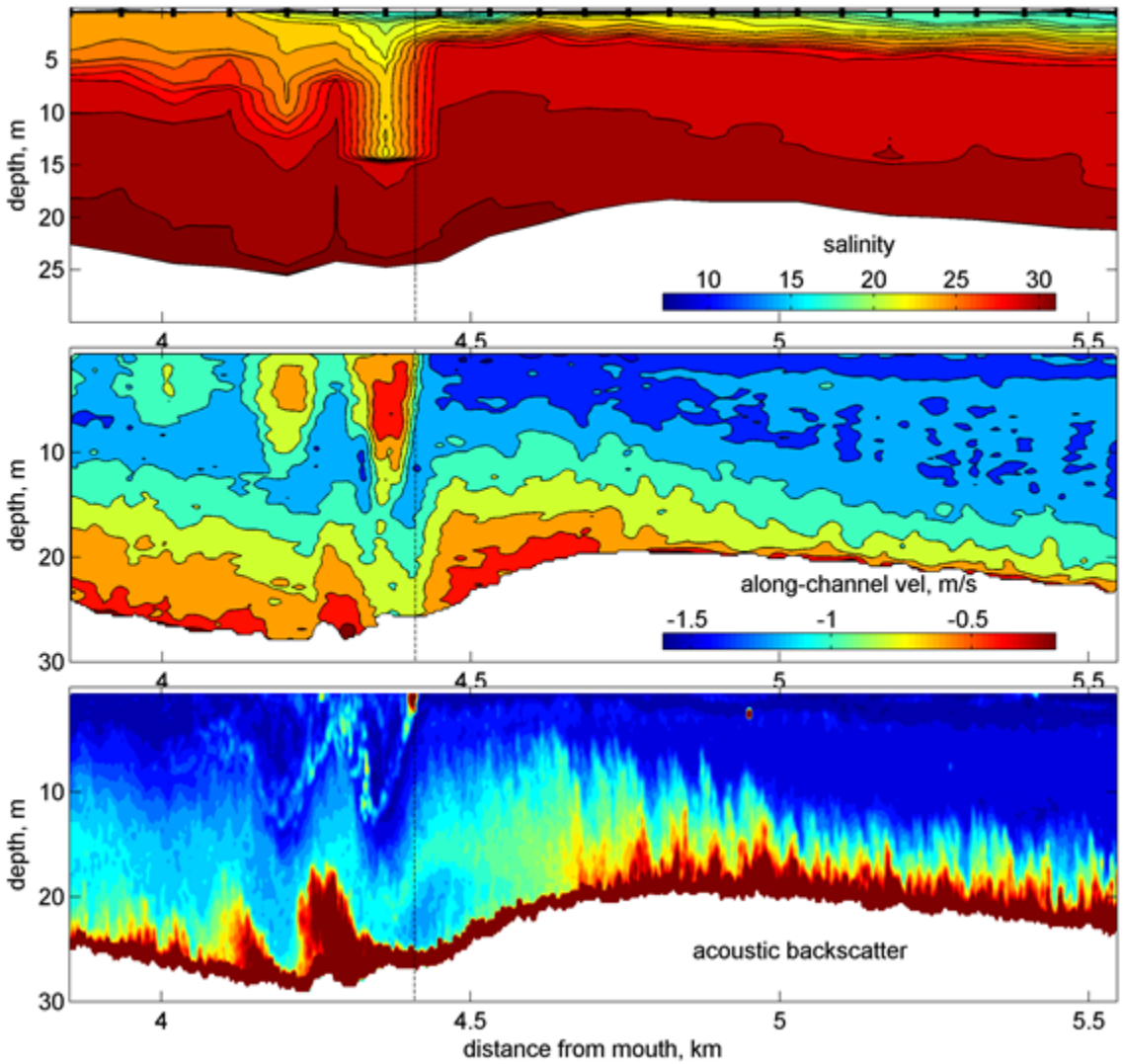

Figure 1. Contour plots of salinity, along-channel velocity and acoustic backscatter across the hydraulic jump during the ebb on 9 September, 2015. The surface expression of the jump (as detected by the x-band radar) is indicated by the vertical line. The velocity data indicate extreme horizontal convergence at the jump location, which results in a local maximum in acoustic backscatter due to accumulation of bubbles from breaking waves at the surface. The non-hydrostatic, undular jump structure is clearly evident.

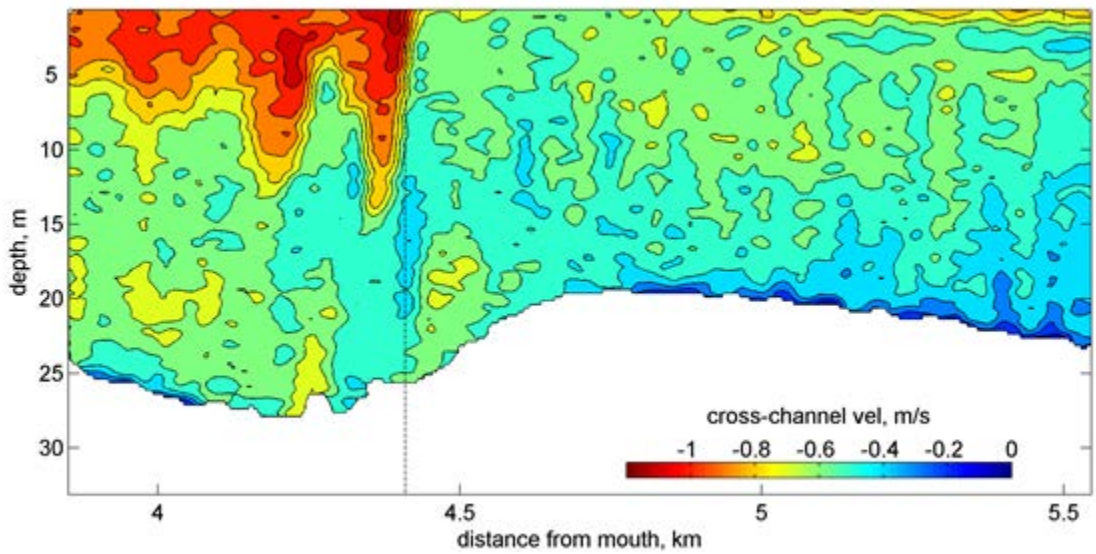

Figure 2. Contours of cross-channel velocity in the vicinity of the hydraulic jump near the A Jetty observed on 9 September, 2015. The jump is associated with southward (cross-channel) velocities of more than 1 m/s. These strong transverse shears illustrate the inherent three-dimensionality of the hydraulic jump structure within the Columbia River estuary.

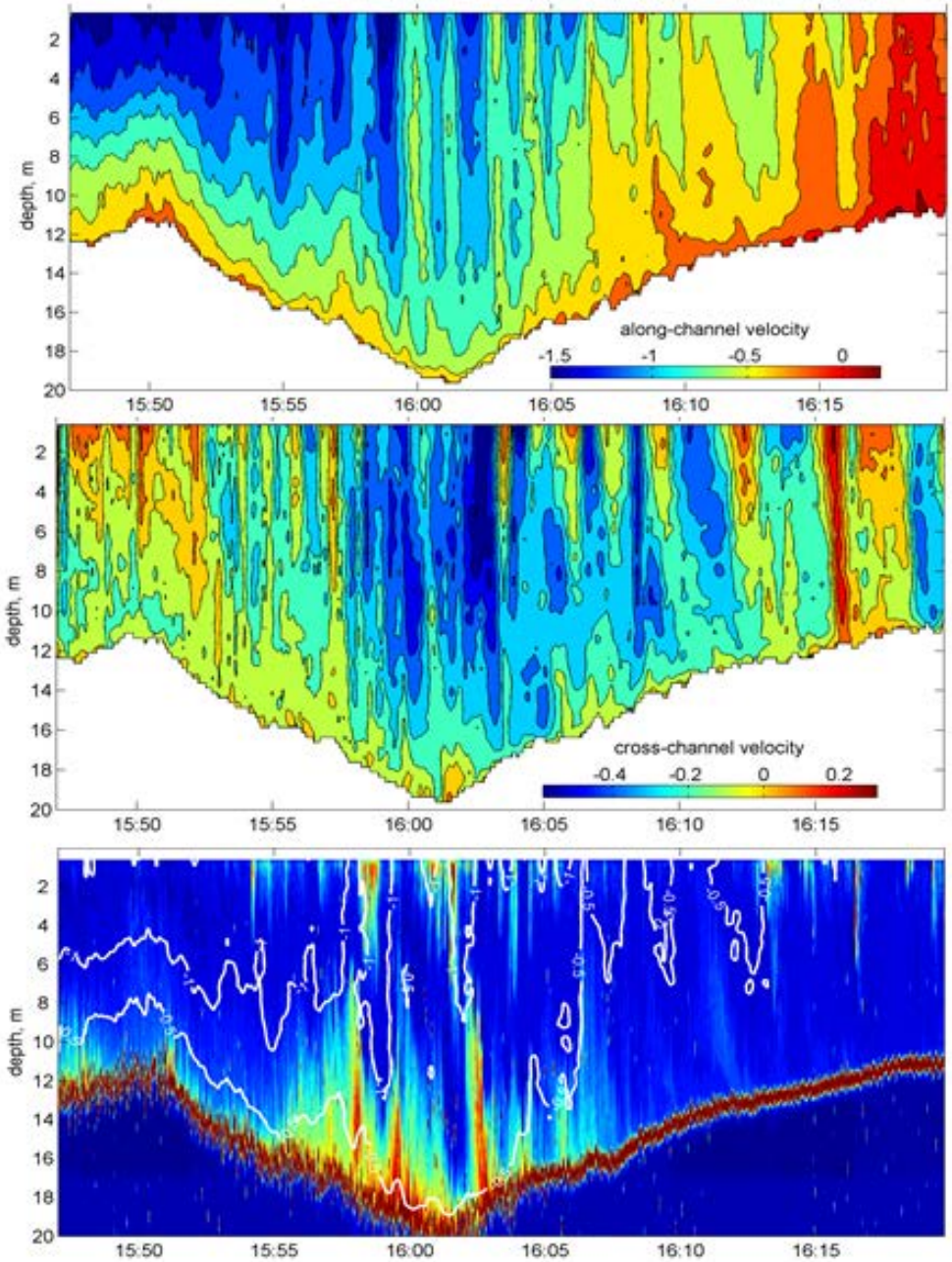

Figure 3. Contour plots of salinity, along-channel velocity and acoustic backscatter along a line parallel to the North Jetty on 9 September, 2015. The x-band radar indicated the ribbon-like pattern of transverse features in surface roughness at this time. These data indicate that the most notable in situ signal is the variation in transverse velocity, which inditcates that these features have large fluctuations in vertical vorticity. The vorticity fluctuations are consistent with the numerical simulations by Hsu's group at the University of Delaware.