DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Rivers and Inlets DRI: Plume, Sediment and Bed Dynamics at the Columbia River Bar

W. Rockwell Geyer[1] and Peter A. Traykovski[2]
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2868[1] or 2638[2] fax: (508) 457-2194
email: rgeyer@whoi.edu, ptraykovski@whoi.edu

Award Number: N00014-13-1-0364

LONG-TERM GOALS

Our long terms goals are to understand sediment transport processes, the relevant physical forcing processes and the resulting morphologic evolution of river mouths and tidal inlets and shoals. Specific goals include understading the interactions between frontal dynamics, turbulence, sediment transport and bedform evolution under extreme current- and wave-forcing conditions.

OBJECTIVES

1. Quantify the time-varying hydrodynamic structure of the "lift off" zone of the Columbia River as the plume detaches from the seafloor in the vicinity of the bar during varying tidal and outflow conditions.
2. Measure sediment transport magnitude and direction in the vicinity of the "lift-off" region, and relate the transport to turbulence and small and large scale bed topography.
3. Measure small to medium scale (up to 30 m wavelength) bedform topography and migration rates using a tripod-mounted rotary multibeam sidescan sonar.

WORK COMPLETED

The field work was completed in Fiscal Year 2013. This included deployment and recovery of 2 tripods and adjacent surface moorings, and two sets of high resolution shipboard measurements across the frontal zone during the peak flow and peak tidal conditions of 2013. These measurements provided unique and unprecedented measurements of the hydrodynamic and sediment-transport processes over the Columbia River bar during extreme tidal and river-discharge forcing conditions. The activities over the last year have included processing and analysis of the field data and collaboration with several related analysis and modeling efforts with other members of the DARLA and RIVET II research teams. One of the most productive threads of analysis has been a collaboration with Haller's team at Oregon State University and Faraquharson at APL UW in examining the dynamics of fronts that are clearly resolved by X-band marine radar and airborne synthetic aperture sonar (Fig. 1). The WHOI team used the in situ data to provide estimates of the hydraulic conditions in the estuary during the times of the observations of fronts, to test and verify the theory for supercritical front propagation. We also provided input in a manuscript that was submitted to GRL on this topic. We also contributed data

and analysis in support of investigations by Thomson at UW APL on the influence of waves on mixing within the surface plume. We contributed to a manuscript on this topic which was also submitted to GRL. Meanwhile we are continuing our own analyses of the dynamics and sediment transport processes. Geyer is focusing on two scientific themes—frontal dynamics as revealed by the shipboard measurements, and mixing processes due to the combined influence of frontal-zone shear and boundary-layer processes. Traykovski is continuing his analysis of the sediment-transport processes associated with the combined influence of waves and currents on the Columbia River bar. He has used the acoustic measurements of bedform migration to quantify the rate of bedload transport, and then combined these with stress estimates to test parameterizations of bedform migration rates.

RESULTS

An exciting result of the combined analysis of the DARLA and RIVET II teams is the identification of oblique hydraulic jumps that occur over the Columbia River bar. Honegger and Haller first identified these features with their shore-based, X-band radar (Fig. 1), and we used the combination of the ground-based and aircraft radar data in combination with WHOI's in situ data (Fig. 2) to confirm that these frontal features are indeed oblique hydraulic jumps. This is a unique finding—although such features have been identified in single-layer hydraulics (e.g., Akers and Bokhove 2008), this is the first such observation in context with stratified hydraulics. The discovery is important in its own right for advancing our understanding of stratified flows, but the successful use of remote-sensing techniques to identify sub-surface phenomena is of particular importance in the Navy's interest in remote sensing of subsurface processes in critical coastal environments.

The WHOI team also contributed to analysis of the influence of breaking waves on plume mixing, mainly the work of Thomson at UW APL. Our main contribution to this effort was guidance in the use of the Lagrangian salt balance equation to infer the rate of vertical mixing. The WHOI measurements of the structure of the river plume were also used to inform this analysis. The result that waves have an important role in plume mixing is somewhat controversial, and the work is leading to a lively and productive scientific discourse that will improve our understanding of wave-induced mixing as well as stratified mixing in river outflow zones.

One of the key findings of the analysis of the shipboard data is a confirmation of the Armi-Farmer (1986) theory of hydraulic control of fronts at the Columbia River bar (Fig. 3). Although this result has been demonstrated previously in estuarine environments, this study documents the interaction of stratified mixing processes and frontal dynamics in a strongly time-dependent tidal environment. The front forms during the latter part of the ebb tide, but its strength and location of the front depend critically on the mixing that occurred during the peak ebb. Only during extreme spring tides and maximum river outflow conditions is there enough mixing to produce frontal conditions at the river-mouth bar. Under neap tide conditions and weaker river flow, the front is weaker and it forms within the estuary.

The high-energy conditions of the estuary also provide an ideal setting to examine the mechanics of stratified mixing. We are particularly interested in the relative importance of mixing "hot-spots" due to enhanced shears at constrictions and other topographic features relative to more spatially distributed boundary-generated turbulence. Preliminary results indicate that distributed, boundary-layer mixing is more important in the Columbia than localized "hot-spots", and we are working on a parameterization to provide prediction of the heterogeneity of mixing that would be applicable across estuarine regimes.

This type of basic research is contributes to a better understanding and better models of estuaries and coastal environments, leading to better predictions of conditions in areas of Naval interest.

Traykovski has analyzed he acoustic imagery from the tripod near the mouth of the Columbia in order to obtain bedform migration rates, which are converted into bedload transport rates. These indicate seaward-oriented bedload transport during the spring tides, and flood-dominant transport during neaps, consistent with the spring-neap variations of peak stresses (Fig. 4) . The accompanying stress measurements indicate that bedform migration and bedload transport rate vary as stress to the 3/2 power, and that the Meyer-Peter Muller bedload model successfully predicts dune migration bedload with grain roughness shear stress (Fig. 5). However his analysis indicates that tidal time dependence is key to dune geometry, and that the shapes of the dunes are poorly predicted by steady-flow dune models.

IMPACT/APPLICATIONS

The observations obtained in this study have already had an important impact on 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 hydrodynamic and morphodynamic models and will improve the prediction of environmental conditions in areas of Naval interest.

RELATED PROJECTS

ONR is supporting a closely related project in which the Columbia River mouth provides a challenging test environment for the operation of the ATLAS sonar system.

REFERENCES

Akers, B., & Bokhove, O. (2008). Hydraulic flow through a channel contraction: Multiple steady states. *Physics of Fluids*, **20**, 056601.

Armi, L., & Farmer, D. M. (1986). Maximal two-layer exchange through a contraction with barotropic net flow. *Journal of Fluid Mechanics*, **164**, 27-51.

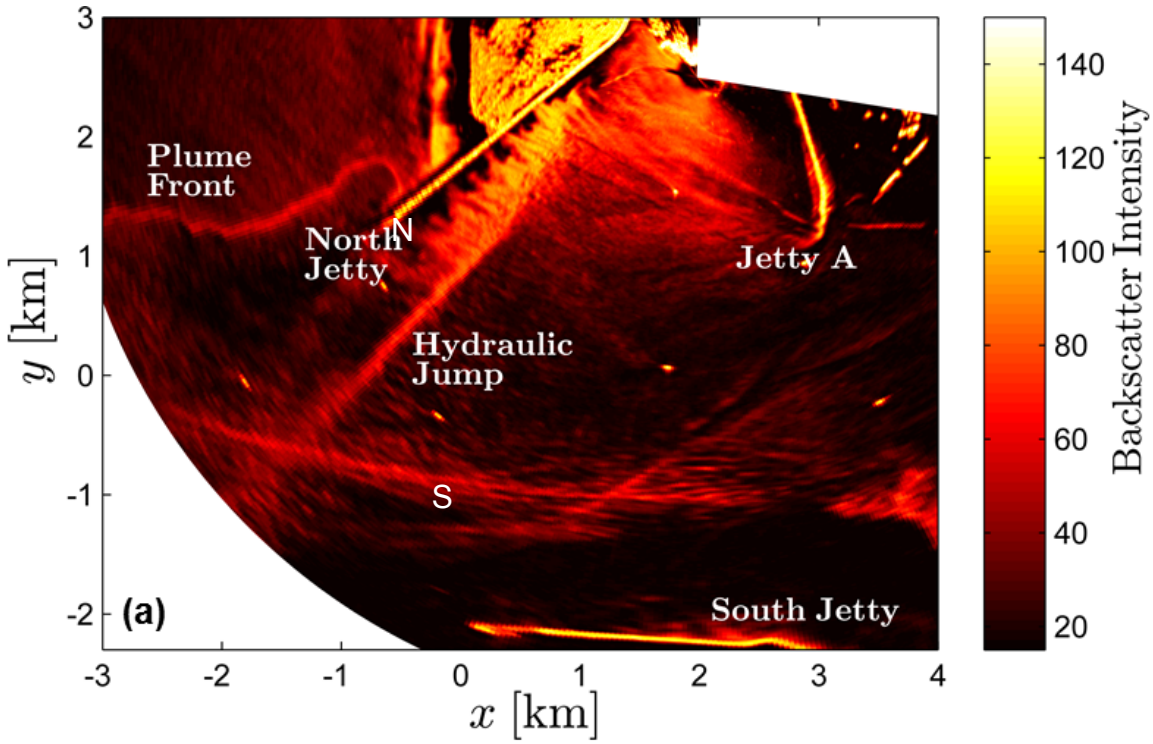

Figure 1. Low-pass filtered marine radar image during supercritical ebb conditions, showing intersecting oblique fronts (from Honegger et al. submitted ms). The angle of these fronts to each other is determined by the magnitude of the internal Froude number, which is a function of the stratification and the outflow velocity. Letters "N" and "S" correspond to positions shown in transect in Fig. 2.

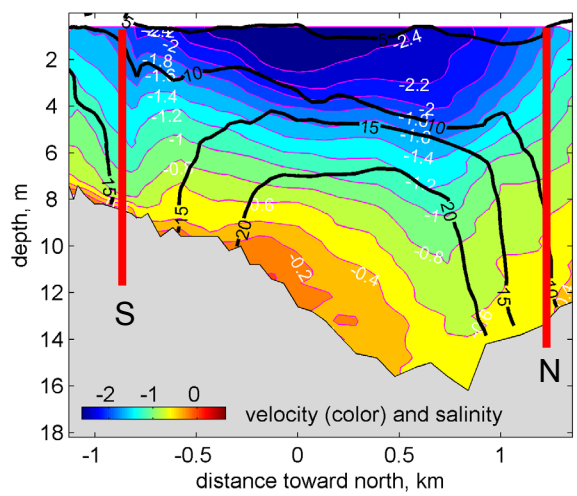

Figure 2. Cross-section of salinity (black contours) and velocity (color contours) across the mouth of the estuary during ebb, during a similar phase of the tide as the radar image of Fig. 1. The locations of the fronts are shown as red lines. Strong convergence of velocity and abrupt deepening of the upper layer occur at the fronts.

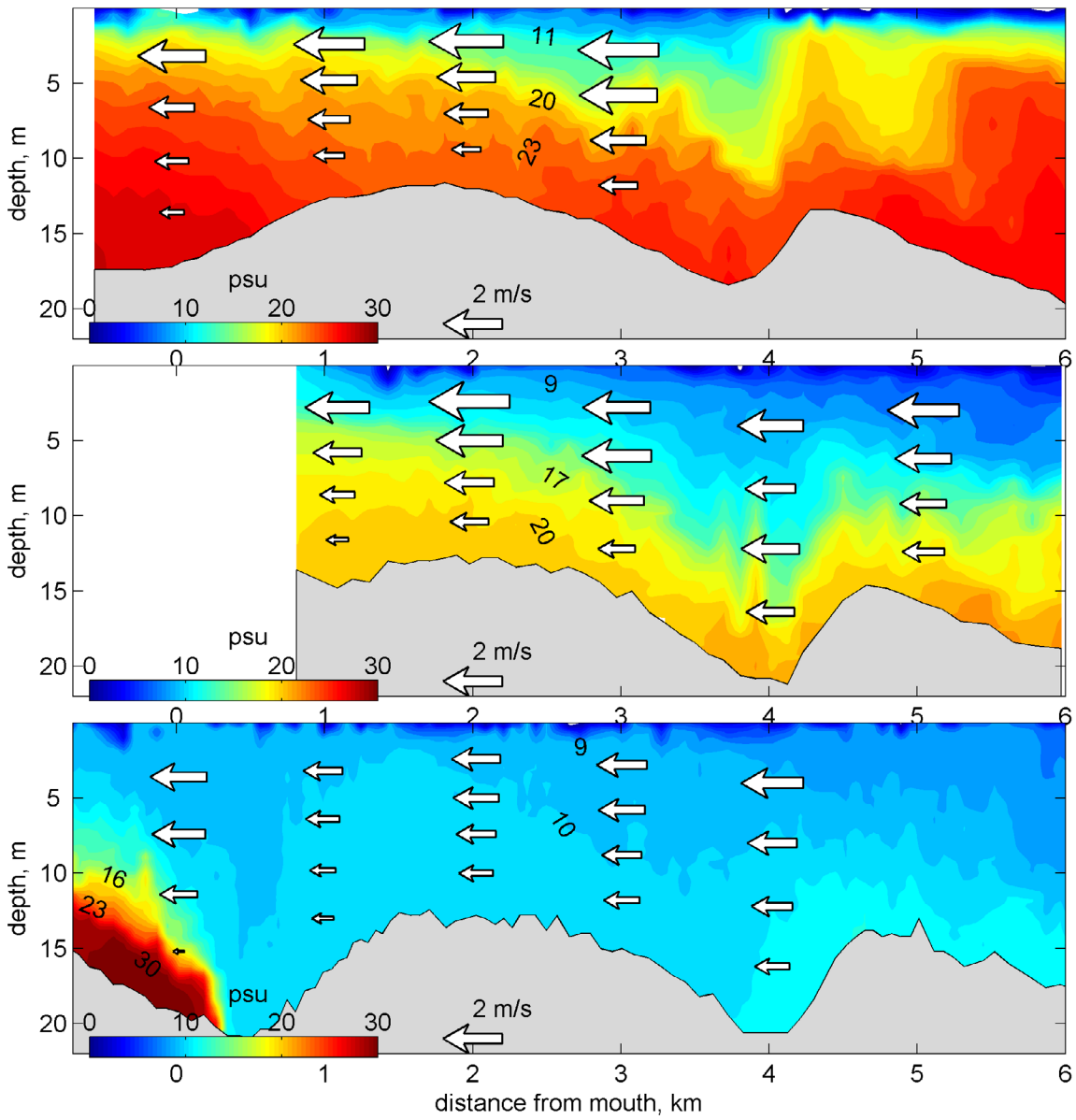

Figure 3. Salinity (color contours) and velocity (white arrows) during maximum ebb for extreme spring-tide conditions, showing the development of the front at the mouth of the Columbia River (0 km). The panels correspond to one hour before, during, and one hour after maximum ebb. The missing data for the 2nd panel is due to extreme sea conditions during maximum ebb. The composite Froude number G=1.03 at the front in the 3rd panel, consistent with the Armi-Farmer (1986) theory.

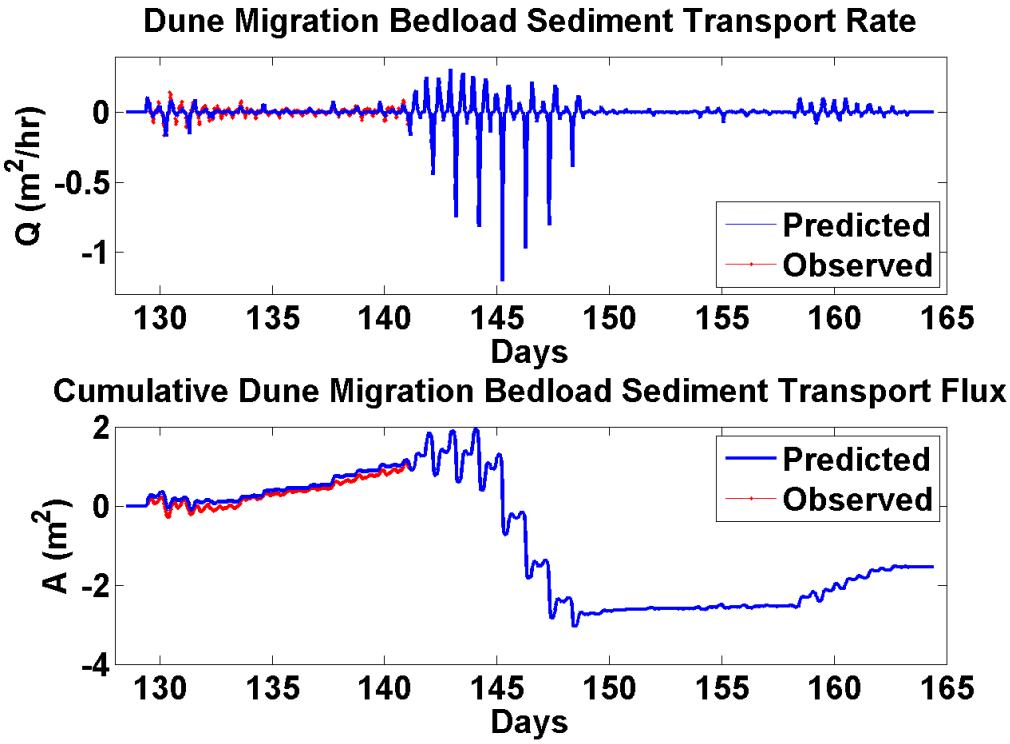

Figure 4. Bedload sediment flux at Tripod 1 near the mouth of the Columbia River, estimated from sidescan sonar measurements of dune migration. The upper panel shows instantaneous migration rate, with large peaks in seaward (negative) transport occurring during the big spring tides. The lower panel shows the integrated flux, with slight landward net transport during neaps and strong seaward flux during springs.

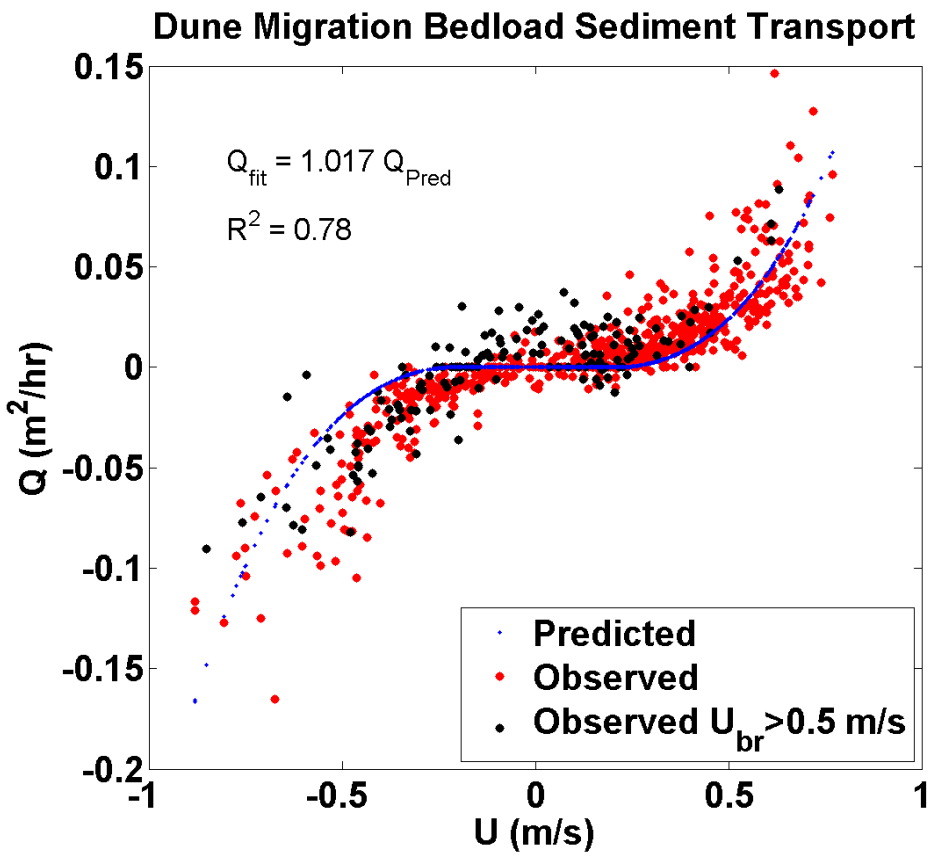

Figure 5. Bedload flux as a function of current velocity, including a comparison with the Meyer-Peter Muller equation for bedload flux to the measurements. U_{br} is the orbital wave velocity, which enhances landward sediment flux during weak tidal flow conditions.