

“Dynamics of Sandwaves under Combined Wave - Current Forcing and Mine Burial Processes”, and “RIVET I and Mine Burial Analysis”

Peter A. Traykovski¹ and W. Rockwell Geyer²

Woods Hole Oceanographic Institution

Woods Hole, MA 02543

phone: (508) 289-2638¹ or 2868² fax: (508) 457-2194

email: ptraykovski@whoi.edu , rgeyer@whoi.edu

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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 understanding bedform characteristics (ripple to sandwave and sandbar scale) in relation to wave- and current-forced mean and turbulent flow.

OBJECTIVES

1. Measure the currents, hydrodynamic boundary layer processes, sediment-transport processes and bedform evolution in energetic ebb-tidal shoal environments, where nonlinear interactions between waves and tidal currents are critically important to the sediment transport and the morphological response to changing forcing conditions.
2. Determine the mechanism responsible for the burial of mine-like objects in regions of active bedforms.
3. Develop instrumentation to make essential measurements for the above objectives. This includes autonomous and manned survey vessels with a carrier phase GPS and Doppler profilers for resolution of near bed turbulence and flow.

APPROACH

In order to measure the processes responsible for inlet morphologic change we conducted repeat bathymetric and hydrographic surveys along with in-situ time series measurements of water velocity (waves and currents), sediment transport (both suspended load and bedload via bedforms migration) and bed elevation. In 2012, we focused on measurements in New River Inlet, NC as part of the first phase of the rivers and inlets (RIVET) DRI. Our approach to this project consisted of combined spatial shipboard and AUV surveys with in-situ measurements from seafloor mounted frames (quadpods). The spatial surveys were conducted with a small boat with an ADCP, and motorized kayak with sidescan, echosounder and post-processing kinetic (PPK) GPS system and a REMUS-100 AUV with an ADCP, sidescan and PPK-GPS system. Grab samples and CTDs were also collected from the small boat. The goal of the combination of these survey vessels was to document the spatial variability of bedform geometry, bed grain size, and flow velocity on time scales that resolved tidal variability. The

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vessel/AUV survey data provide a larger scale context with which to interpret the high-resolution quad-pod measurements.

The in-situ quadpod measurements were optimized to measure sediment transport processes and forcing hydrodynamics. A particular focus was the temporal evolution of the bedform geometry and migration combined with the wave and current hydrodynamic forcing for these changes. The quadpod measurements also included profiles of turbulence, as turbulence is both modulated by the bedforms and forces the sediment transport processes controlling bedform evolution. Both bedload suspended load sediment transport processes were resolved, with bedform migration serving as a proxy for bedload and acoustic backscatter profiles were used for suspended load. In 2013, our work focused on analysis of the data collected in 2012.

Once formulations for sediment transport processes and bedform evolution have been developed, these formulations can be used in models to understand the relative roles of the processes in morphodynamic evolution of the inlet system. Models can also be tested using both the quadpod and the spatial survey velocity measurements.

In terms of mine burial, our approach is to examine the coupled bedform mine system as burial and scour processes are often closely coupled to bedform dynamics.

WORK COMPLETED

The observations at New River Inlet consist of time-series measurements from quad-pods at two locations from May 2 to 24, high-resolution bathymetric/bedform/velocity surveys, and large-scale vessel/AUV measurements of velocity. Repeated side-scan surveys across the inlet (Figure 1) indicate significant spatial gradients in bedform amplitude (η), wavelength (λ), orientation and migration rate that depend on the local intensity of flow, wave orbital amplitude, and the overall flow geometry. Fifteen grab samples were collected along a cross-inlet transect aligned with the quad-pods to examine the relation between the spatially variable flow and bedforms. Fieldwork completed for the mine burial project has been documented in previous annual reports. Preparation of new side-looking multibeam bedform imaging sonars and mine-like targets with motion sensors has also been completed in preparation for a fall mine burial deployment at Wasque Shoals.

Instrument Development

In New River inlet The REMUS-100 with the PPK-GPS surface piercing antenna prototype was completed and tested for stability in variety of conditions. The system proved stable in mild conditions, but struggled to both keep the antenna from becoming submerged in highly energetic conditions. The maximum vehicle speed of 3 m/s and GPS dropouts when submerged also hampered performance in energetic conditions. In order to rectify this in 2012 we developed a motorized kayak shipboard bathymetry and sidescan system to document the spatial variability of the bedform field. This system produced excellent data (Figure 1) as stability was not an issue, and the operator could adapt the survey plan to changing conditions such the presence of absence of breaking waves. Based on the success of the motorized kayak, in 2013, in collaboration with Hanu Singh we developed an autonomous version of the motorized Kayak (Figure 2). This vessel has an endurance of ~ 10 hrs, navigation precision of 2 m of a track in up to 2 m/s current and maximum speeds of 5 m/s. In summer of 2013, we collected several high quality ADCP and bathymetry surveys with this system,

RESULTS

The rotary sidescan sonar and 2-axis rotary pencil beam sonar measurements from the quad-pods as well as the bathymetric/bedform surveys indicate that the large-scale bedform geometry changes significantly through the observation period, and variations of small-scale bedforms are observed on timescales of hours. For example, the rotary sidescan images in Figure 3 shows sheet-flow conditions over large dunes ($\lambda = 4$ m, $\eta = 40$ cm) during maximum ebb, but 3 hours later the entire field of dunes is covered with large ripples ($\lambda = 50$ cm). The adjustment timescale of the large dunes appears to be about 1-2 tidal cycles, and their structure and evolution appear to depend both on the tidal current amplitude and wave conditions (movies are available at <https://vimeo.com/ptraykovski>). The conditions at the end of the deployment with weaker tidal flows show the absence of large-scale bedforms apparently due to the reduction of tidal forcing. With the same local forcing, water depth, and grain size, as the SW channel site, the NE Channel has much smaller and less steep bedforms (Figure 4 and Figure 5). This indicates the proximity of our SW measurement site to the deep channel with faster flows supports larger bedforms, and that the bedforms at that site are not in equilibrium with local conditions. Compared to models and empirical formulas ([Fredsøe and Deigaard, 1992]) for tidal bedform dimensions, the bedforms in the SW channel are shorter wavelength, ($\lambda = 5$ m observed vs. $\lambda = 10$ predicted) and steeper than predicted ($\eta/\lambda = .1$ observed vs. 0.05 predicted). The bedforms in NE channel are much smaller than predicted.

Image to image cross correlations from the pod in the SW channel reveal migration rates of the large bedforms at rates up to $U_{bedform} = 2$ m/hr during strong spring tide ebb flows (Figure 3). The ripple migration data was used to estimate bedload sediment transport rates as $Q_{bedform} = (1 - \epsilon)0.5 \eta U_{bedform}$, where η is the measured ripple height, and the scaling factor 0.5 assumes an approximately zero skewness ripple geometry, and the porosity was assumed to be 0.5 also. The bedload transport can be compared to predicted bedload transport calculated using the semi-empirical Meyer-Peter Muller (MPM) formula (Figure 6), [Meyer-Peter and Muller, 1948]. While this formula is well established for unidirectional flows, it has not been tested with tidally reversing bedforms that are often found in inlets. To fit the observed bedload transport rate the MPM formula was used with a quadratic stress estimate with the coefficient of drag adjusted to 0.0014. This C_d is consistent with log layer grain roughness scaling:

$$C_{D,skin\ friction} = \left[\frac{\kappa}{\log(30z_r/2.5d_{50})} \right]^2 = 0.0015 \quad (1)$$

This result has important implications for bedload transport modeling as it suggests that traditional approaches should be successful to first order. The data does show an approximately factor of 2 variability about the predictions, with flood tide bedform migration flux under predicted, and neap tide migration flux over predicted. Further analysis will examine this.

The pulse-coherent Doppler velocity profiler (PC-ADP) provides turbulent velocity data at 1-cm resolution across the bottom boundary layer, allowing the influence of the bedforms on the boundary layer turbulence to be examined and quantified. Turbulent Reynold's stresses were also quantified using the difference in velocities from two ADV's mounted with sampling volumes located 75 cmab. Surprisingly, the results show little difference at the two sites given the large differences in bedform steepness at the two sites. One model ([McLean et al., 1999]) for from drag suggests a drag coefficient of:

$$C_{d,form\ drag} = 0.5C_{dune}\eta / \lambda \quad (2)$$

With a dune drag coefficient of 0.2 this results in a large $C_{d,form\ drag}$ of 0.01 for the SW site, and a smaller value of 0.002 for NE site. The ratio of these two estimates based on bedform steepness is 5 in contrast to the observed Reynolds stress ratio of ~ 1.2 . An alternate model for $C_{d,form\ drag}$ is the log law with the bedform height used the roughness scale. In this estimate, the ratio of drag coefficients would scale as the log squared of the ratio of the bedform heights, which has a value of 2, closer to the observed. This conceptual model of bedform roughness is based on overlapping wakes as opposed to the steepness scaling which is consistent with individual roughness elements with non-overlapping wakes. These results were presented at the fall 2012 AGU meeting.

IMPACT/APPLICATIONS

Analysis of this data set will lead an increased understanding of sediment transport processes in tidal inlets and bedform evolution and will allow better prediction of the morphodynamic response of the system to variations in forcing parameters. Quantifying the relations between bedform geometry and frictional drag will also aid in an increased ability to model the flow field in environments such as this. The instrument and technique development will useful in a variety of future projects.

RELATED PROJECTS

Three grant numbers are included in this report as N00014-13-1-0767 (“Instrumentation for Plume, Sediment and Bed Dynamics in Energetic Coastal Environments: A Multibeam Sidescan Sonar and Portable Turbulence Profiler”) is a DURIP to develop equipment for the science projects: N00014-11-1-0291 (“Dynamics of Sandwaves under Combined Wave - Current Forcing and Mine Burial Processes”) and N00014-13-1-0368 (“RIVET I and Mine Burial Analysis”), which are highly related.

This project is also closely related to several other ONR efforts including our Columbia River Mouth Experiment, the OASIS project with John Trowbridge to measure wave boundary layer stresses in support of optical measurements of particle dynamics (Environmental Optics), and integrating the pcADPs on Geyer's MAST (Physical Oceanography). The DURIP was also used to develop equipment for those projects.

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- Meyer-Peter, E., and R. Muller (1948), Formulas for bed-load transport, paper presented at Paper presented at 3rd Meeting. IAHR, Int. Assoc. Hydraul. Res, Stockholm.

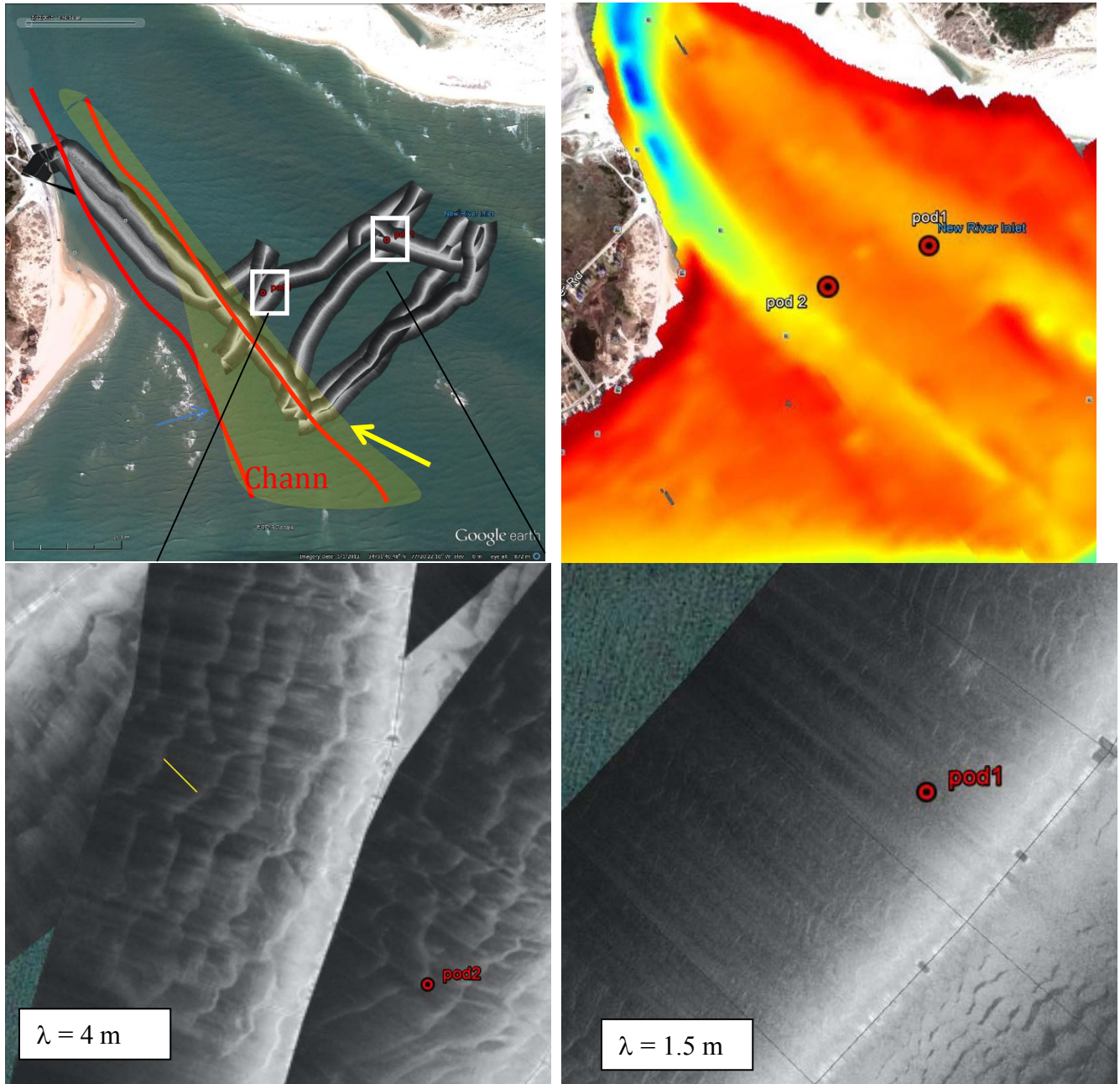


Figure 1. *Upper Left: Sidescan sonar survey of New River Inlet showing the location of our two quadpods in the NE and SW channels. Upper Right: Bathymetry data from USACE. The surveys consistently show 3-4 m wavelength bedforms on flanks of the dredged SW channel (Lower Left) during spring tides and smaller bedforms on the shoals and the NE channel (Lower Right).*



Figure 2. Motorized manned catamaran kayak (Catyak) in New River Inlet (left) and autonomous jet drive kayak (Jetyak ASV) with through hull mounted ADCP, echosounder and sidescan (right).

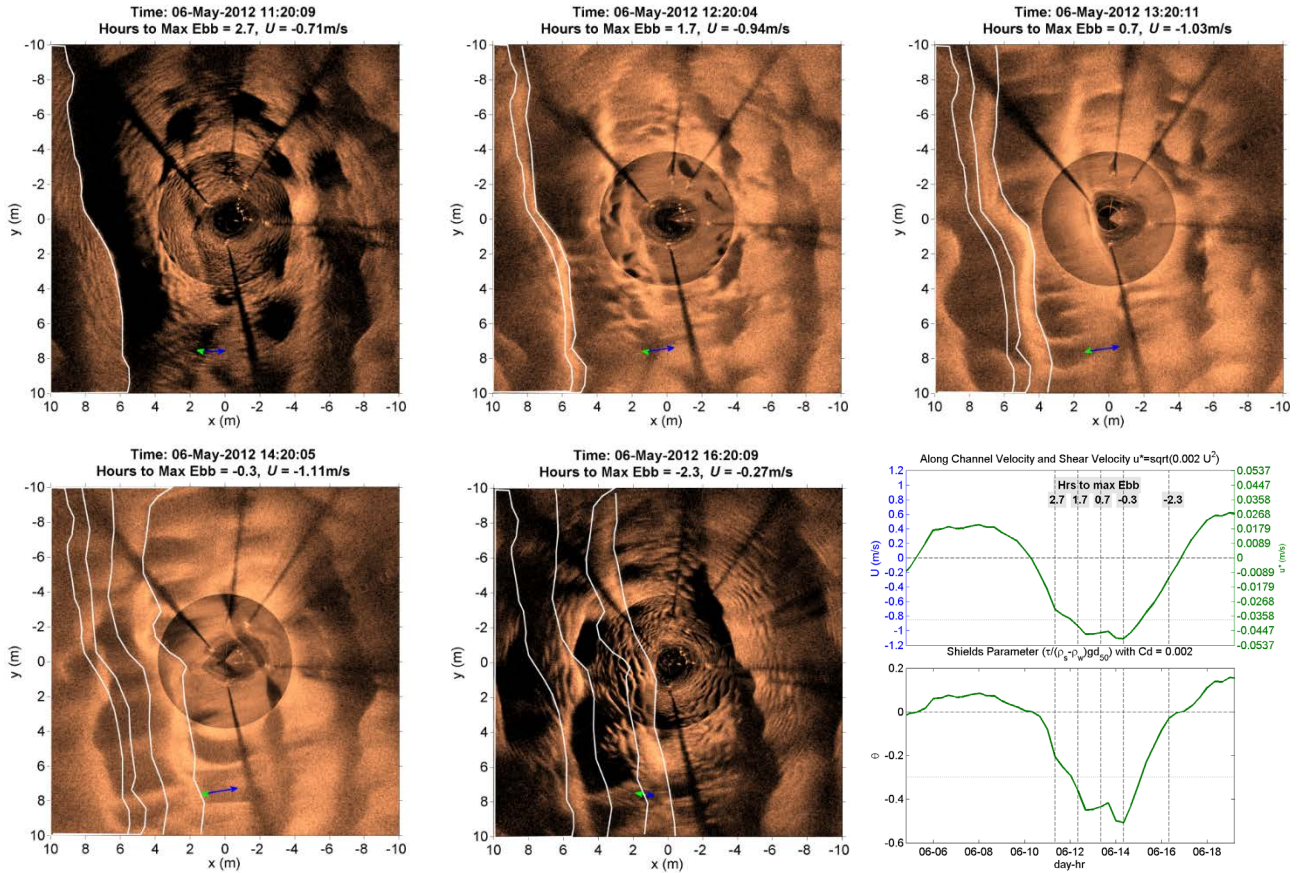


Figure 3. Time series of bedform imagery in the dredged channel (SW) channel of New River Inlet during spring ebb tide. The white lines superimposed on the imagery show crests from the previous images and indicate a migration rates up to 2 m/hr. While the large scale features retain their shape and height during migration, the smaller wavelength ripples (50 cm to 1 m) become washed out at flow rates over 0.8 m/s (Shields Parameter = 0.5).

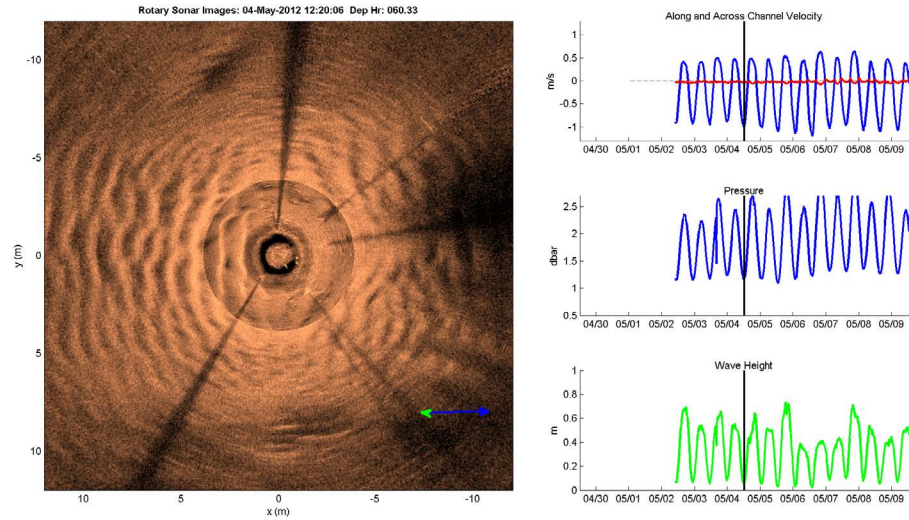


Figure 4. Bedform imagery from the NE channel of New River Inlet during spring ebb tide showing 1.5 m wavelength bedforms.

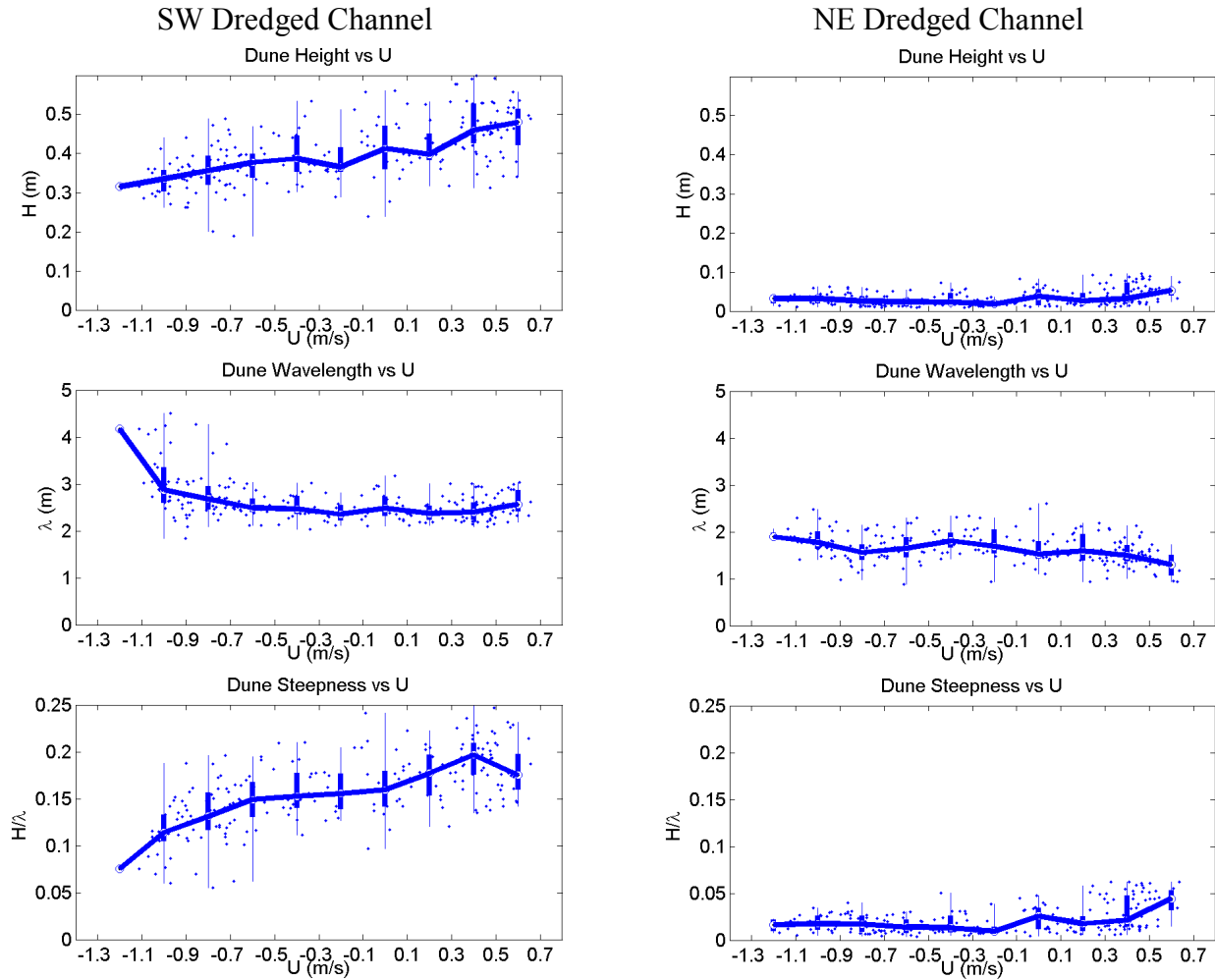


Figure 5. Bedform Height (upper), Wavelength (middle) and Steepness (lower) vs. water velocity for the SW (left) and NE (channels)

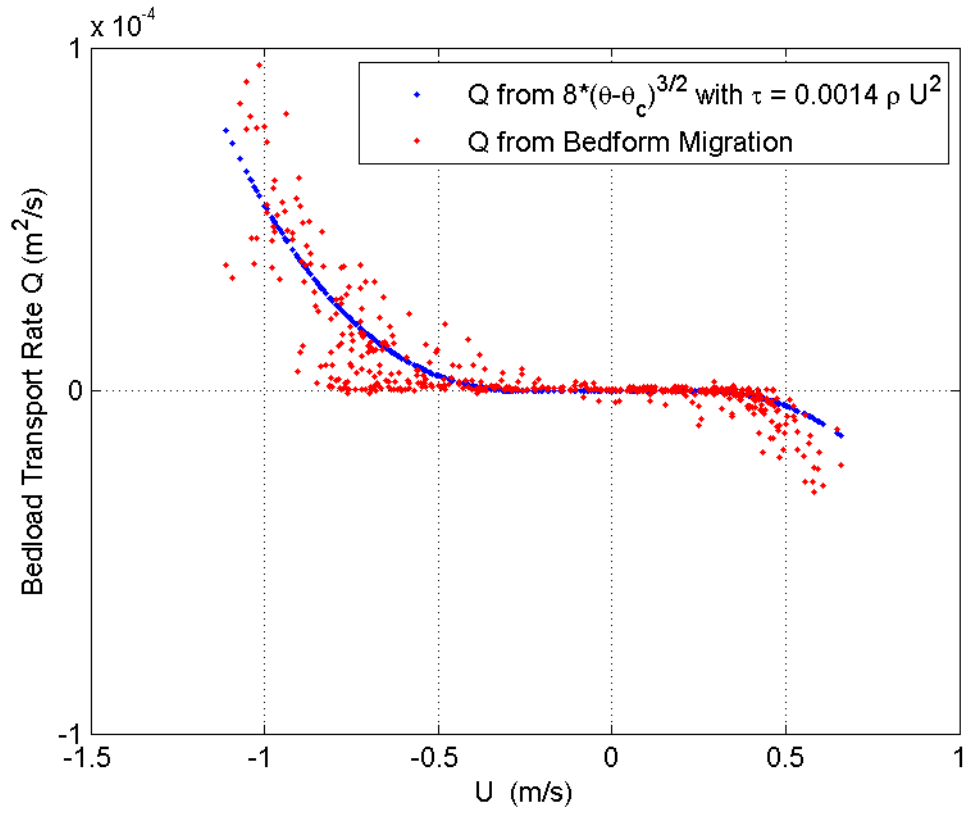


Figure 6. Meyer-Peter Muller bedload predicted and measured ripple migration bedload transport rate.

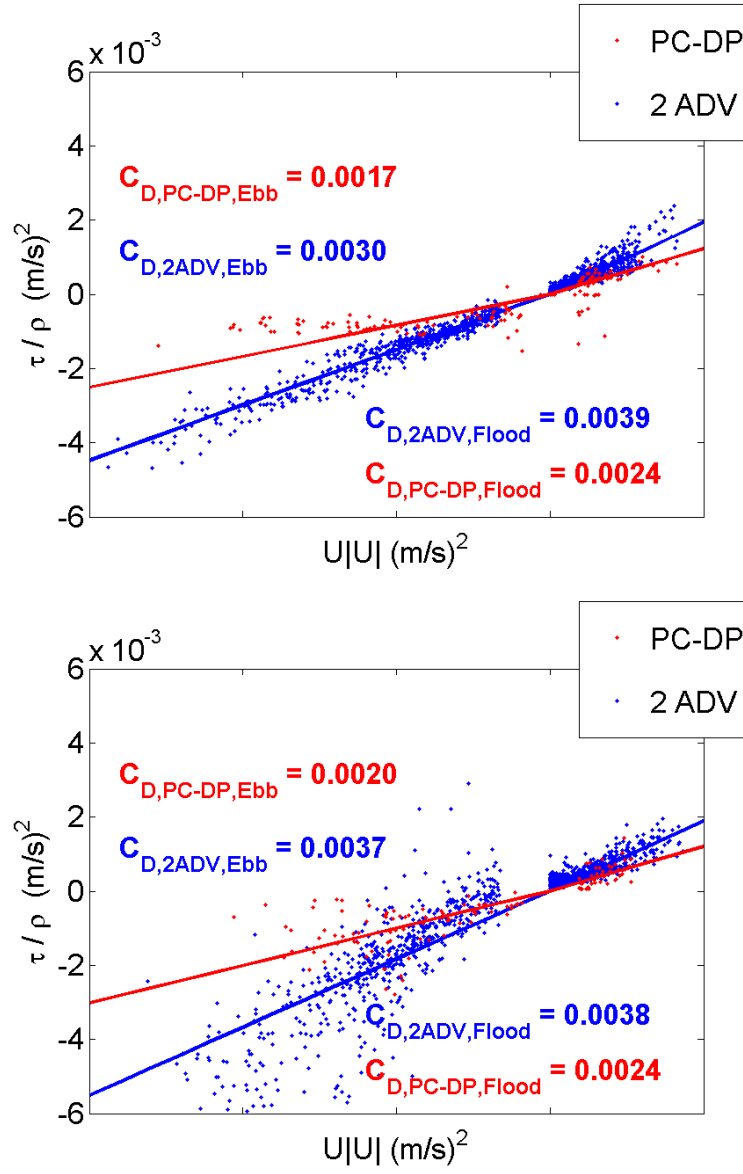


Figure 7. Dual ADV and pulse coherent Doppler profiler Reynolds stress and drag coefficient estimates from the SW channel (upper panel) and NE channel (lower panel). The results are surprisingly similar given the large difference in bedforms at the two sites.