Field and Numerical Study of the Columbia River Mouth

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LONG-TERM GOALS

The overall goal is to improve the predictive capability and skill of Delft3D to simulate complex hydrodynamics in an inlet setting in which tides, river discharge, winds, waves, and bottom friction are all important.

OBJECTIVES

The main objectives of our FY15 effort were to:

- Continue analyzing tripod and boat-mounted ADCP data collected during the summer 2013 field campaign at the Mouth of the Columbia River (MCR) and prepare data for publications
- Continue analyzing and compare digital grain size data of bed sediment from 2013 and 2014 field campaigns
- Compare modeled sediment transport rates and bed form metrics to measured bed forms
- Publish SwathPlus bathymetry and backscatter data in USGS data report

- Compare CTD field data (from R. Geyer) to Delft3D model results

APPROACH

In May and June of 2013, USGS scientists (Dr. Guy Gelfenbaum and Andrew Stevens) and staff from the Pacific Coastal and Marine Science Center in Santa Cruz CA teamed with co-PIs Dr. Jamie MacMahan, Naval Postgraduate School and Dr. Ad Reniers, University of Miami (presently at the Technical University of Delft), as well as Dr. Chris Sherwood, USGS Woods Hole to deploy instruments to measure hydrodynamics, map bathymetry, bed forms and seabed grain size, and deploy drifters around the Mouth of the Columbia River (MCR) during the spring freshet (high river discharge) time of year. USGS is also working with Dr. Edwin Elias, Deltares to test Delft3D hydrodynamic and sediment transport model in MCR during high river discharge conditions.

In September 2014, USGS scientists (Gelfenbaum and Stevens) collaborated with Dr. Rocky Geyer of WHOI, Charlie Loeffler of Univsity of Texas, and Jarod Norton of Portland District, U.S. Army Corps of Engineers to collect supplimentry field data at the MCR during low river discharge conditions.

WORK COMPLETED

The observations at the MCR consist of time-series measurements from instrumented tripods at three locations (W, N, S) between May 9 and June 16, 2013 (Figure 1; Table 1). Each tripod was equipped with an upward-looking ADCP, a near-bed ADV, and a pressure sensor to measure hydrodynamics, a CTD and OBS to measure water properties near the bed, and fan- and pencil-beam sonars to measure bed form geometry (Table 2).

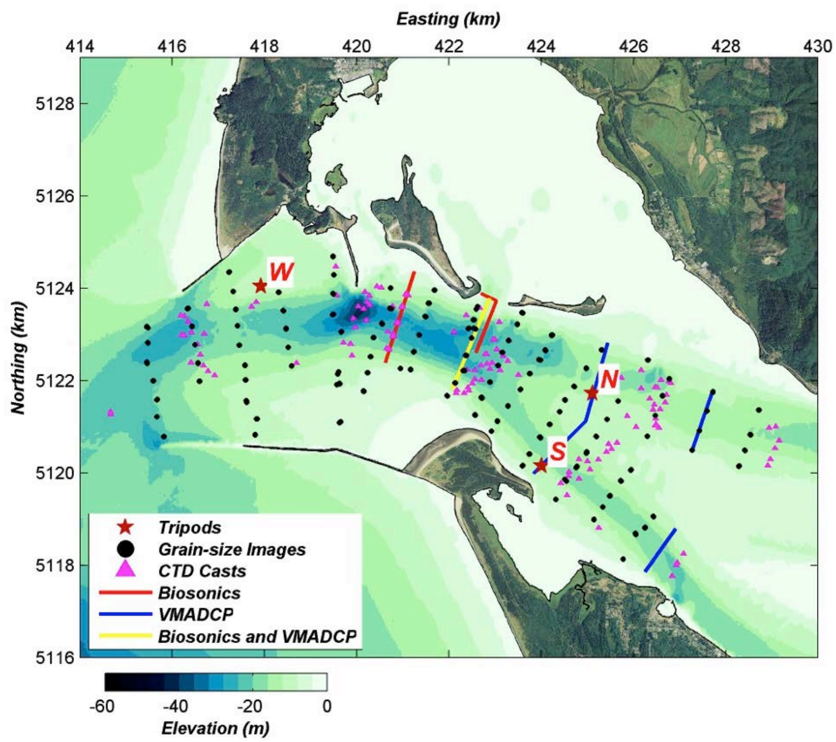

Figure 1. Map showing the locations of 3 instrumented tripods deployed at the MCR between May 9 and Jun 16, 2013, locations of "flying eyeball" seabed grain size images, CTD casts, Biosonics and vessel-mounted ADCP transects.

Bathymetry and co-registered acoustic backscatter were collected throughout the MCR with a SWATHplus-M interferometric sidescan sonar system pole-mounted to the USGS survey vessel R/V *Parke Snavely*. The bathymetry and ancillary data were combined and rendered into a 5-m digital elevation model (Figure 2) and a 1-m DEM for analysis of intermediate sized bed forms (Gelfenbaum et al., 2015).

Digital images of the seabed using the "flying eyeball" (Rubin et al., 2007) from aboard the R\V *Parke Snavely* were collected at 111 locations in June 2013 within the MCR (Figure 1). For each location, between 3 and 5 replicate images were collected and have been analyzed to characterize grain-size distributions (Buscombe, 2008) of surface sediments throughout the MCR (Figure 2). In September 2014, we collected an additional 675 digital grain size images using the "flying eyeball" along a series of transects across the larger bed forms in the estuary (Figure 3).

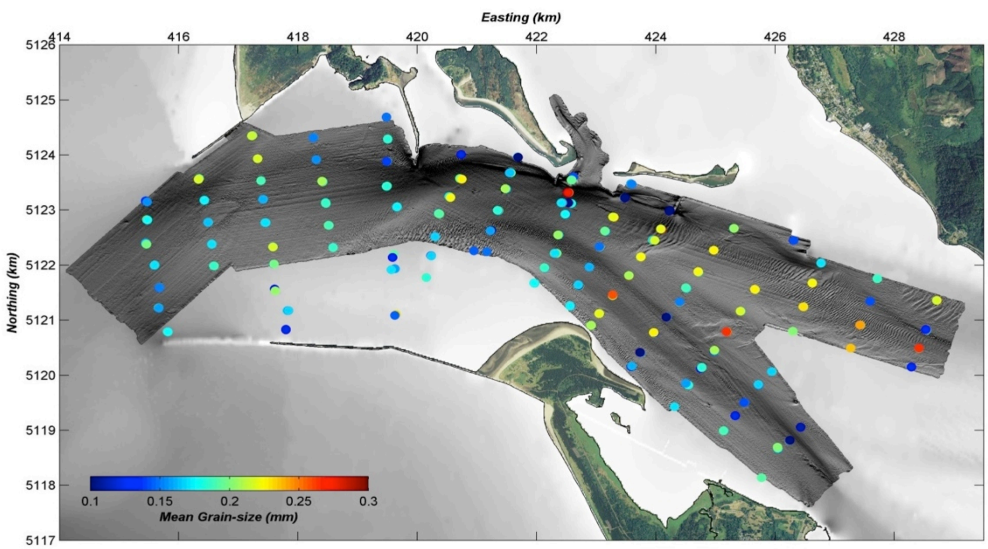

Figure 2. Map of bed sediment mean grain size from digital grain size analysis.

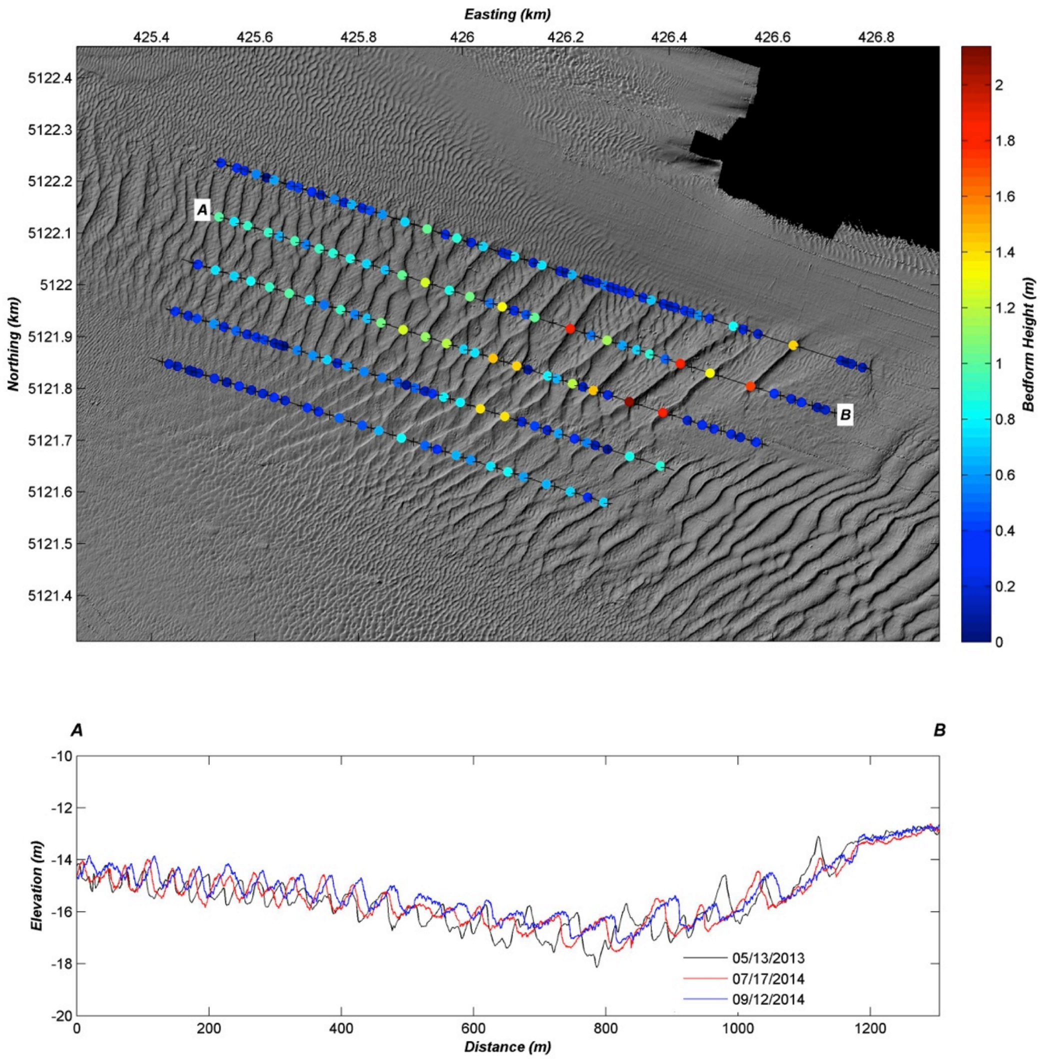

Figure 3. Map of 1-m DEM created from SWATHplus bathymetric data with locations of Biosonics transects from the September 2014 fieldwork. Lower plot shows bed form migration and changes in bed form shape.

RESULTS

The SWATHplus succcessfully mapped bathymetry throughout the MCR characterizing large-scale inlet morphology as well as medium and large-scale bed forms. Important features including a deep hole adjacent to Jetty A, the shallow bar between the main jetties that induces wave shoaling, and a linear ledge along the north side of the channel were mapped in detail (Figure 4). Detailed seafloor mapping also characterized a variety of sand bed forms ranging in size from a few meters in wavelength to nearly one hundred meters (Figure 5).

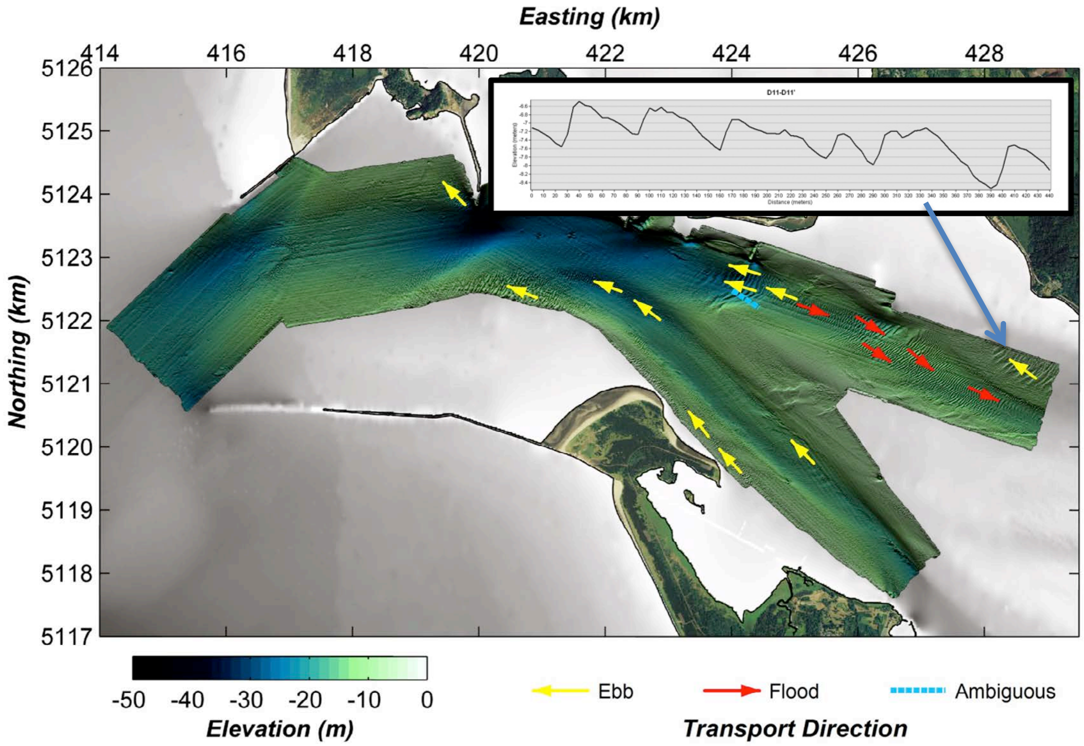

Figure 4. Map of 5-m DEM created from bathymetric data showing multiple bed form fields and the orientation of those bed forms, indicating net sediment transport direction.

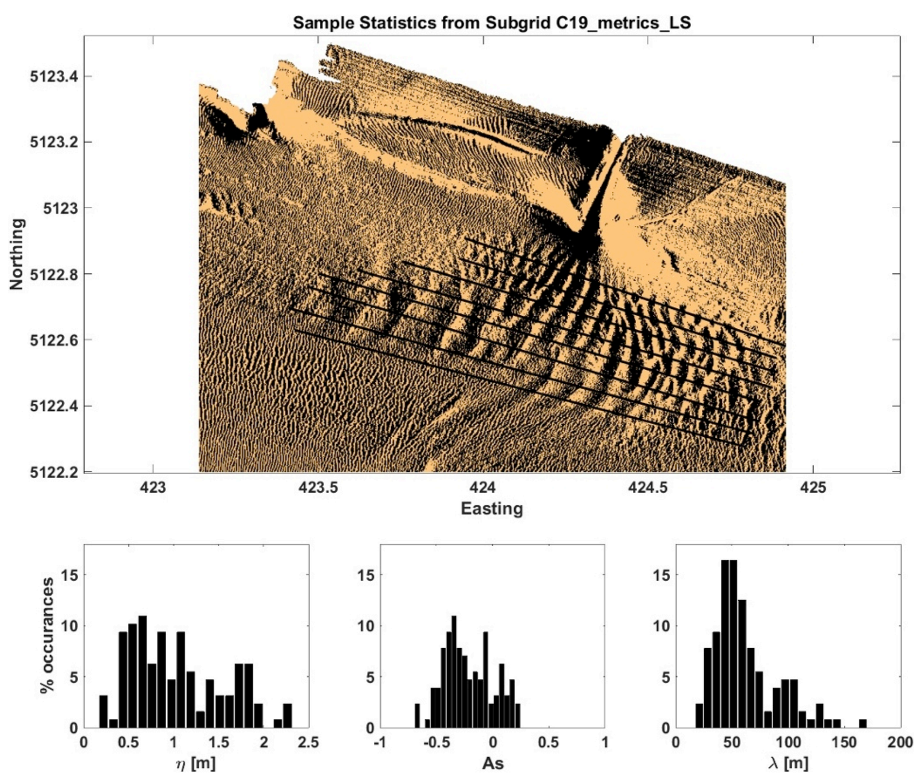

Figure 5. Bed forms of various sizes and shapes in the MCR. H is bed form height in meters and λ is bed form wavelength in meters and As is bed form asymmetry.

Delft3D versus data comparison

Forcing the model with only offshore tidal boundary conditions from TPXO Global Tide model, measured river discharge, and spatially uniform winds from a nearby NDBC buoy, a preliminary comparison between modeled and measured currents shows the model accurately captures the dominant features of the flow. Comparisons between boat-mounted ADCP transects oriented across the main channel reveal the influence of large-scale morphology of the Columbia River estuary on circulation. Large-scale morphologic features in the estuary like Desdemona Sands and Baker Bay have a significant influence on flow patterns in the inlet.

We also compared Delft3D model simulations of salinity to salinity data from CTD profiles collected by Rocky Geyer of WHOI. The CTD data were collected along transects through the estuary entrance during several phases of the tide. During flood tides a salt wedge propagates into the estuary and the model captures the speed and intensity of the salt transport well (Figure 6).

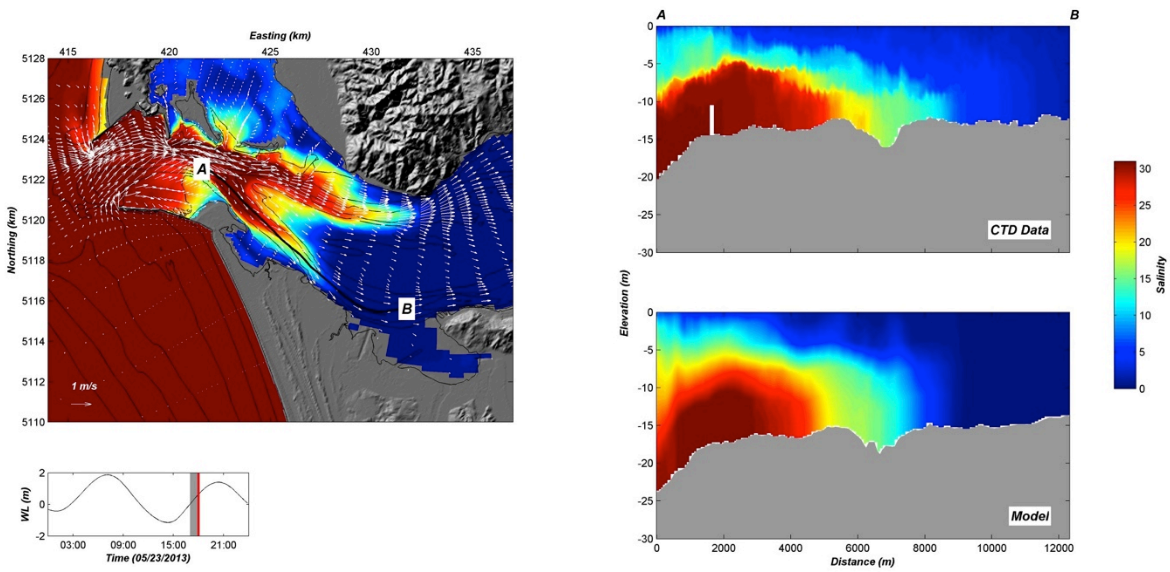

Figure 6. A) Modeled near-bed salinity during a flood tide. Profiles of measured (top right) and modeled (bottom right) salinity along transect A-B through the estuary entrance. CTD data from R. Geyer, WHOI.

During ebb tides the salt wedge is mixed with fresh water and advected seaward. During high river discharge, as during the main experiment, the salt wedge is almost entirely located between the main jetties (Figure 7). The model captures the mixing processes during the ebb tide well and the location and intensity of the salt wedge are well represented. Model simulations of the salt wedge propagation show that the complex morphology of the estuary entrance may induce regions of flow convergence and divergence and can be responsible for the formation of fronts that reach the surface (Figure 8) and are detected by remote sensing from radar and other sensors.

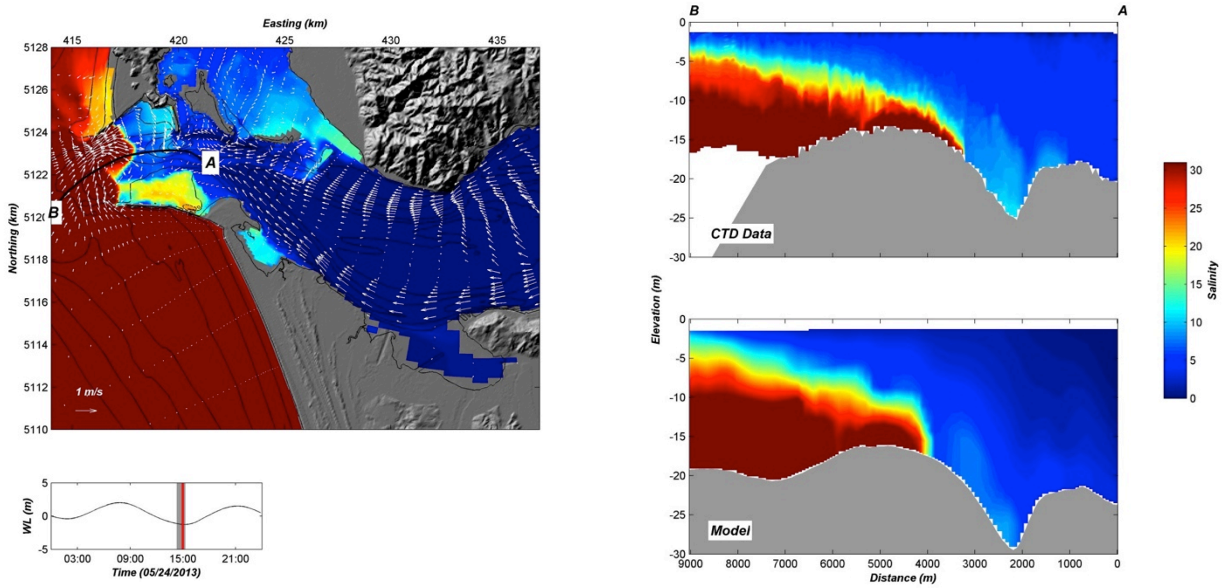

Figure 7. A) Modeled near-bed salinity during an ebb tide. Profiles of measured (top right) and modeled (bottom right) salinity along transect A-B through the estuary entrance. CTD data from R. Geyer, WHOI.

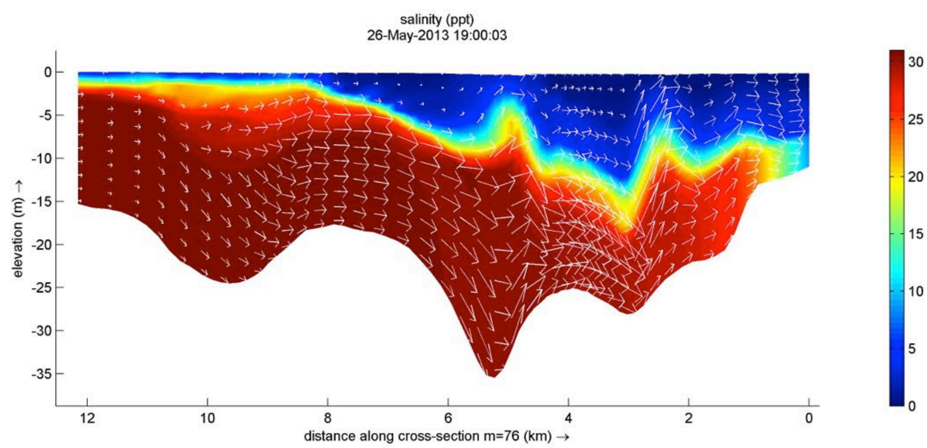

Figure 8. Modeled salinity profile during a flood tide along transect through the estuary entrance. Arrows are velocity vectors. Bathymetric features appear to play a role in inducing flow convergences and upwelling leading to fronts that advect along the surface.

Initial flow simulations assumed a uniform bed roughness in the estuary with Chezy = 65. High-resolution mapping, however, reveals a wide range in bed form sizes throughout the estuary (Figures 4 and 5). Sand waves vary in wavelength from 20 – 90 m, and in height from 0.7 – 2.1 m. Initial analysis of bottom roughness formulations based on sand wave height show that the Chezy roughness could vary by as much as 40% from a minimum of 40 to a maximum of 70. Sand wave heights are predicted from the semi-empirical equation,

$$\frac{\delta}{h} = 0.11\left(\frac{D_{50}}{h}\right)^{0.3}\left(1 - e^{-0.5T}\right)\left(25 - T\right) \tag{1}$$

where δ is the sand wave height, h is the water depth, D_{50} is the median grain size, and T is the excess shear stress (van Rijn, 2005). Equation (1) was developed from flume experiments and a few field measurements and does not accurately predict actual bed form heights measured in the Columbia River. Further research is necessary to better understand and predict sand wave dimensions and their effect on boundary roughness in dynamic estuaries like the Columbia River and San Francisco Bay (Barnard et al., 2013). Our modeling strategy will seek to improve model results using spatially variable roughness maps generated from observed bed form and sediment distributions.

IMPACT/APPLICATIONS

The field measurements collected at the MCR are allowing rigourous testing of the Delft3D hydrodynamic and sediment transport model. The hydrodynamic model was originally successfully validated against low river discharge and small wave conditions during August 2005 by Elias et al. (2012). Conditions during the 2013 experiment were more energetic, with larger waves and higher river discharge. Testing and validating the model during these more energetic conditions are extending the range of applicability of this important model. In addition, the surface drifter deployments (see MacMahan and Reniers annual report) are a new and challenging data set to test the model's capacity to simulate shear and density fronts.

Detailed maps of bed forms observed in the new SWATHplus data will be used to test various bed form models as well as test various bottom roughness schemes in the Delft3D hydrodynamic and sediment transport model.

RELATED PROJECTS

None

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PUBLICATIONS

Gelfenbaum, G., Finlayson, D., Dartnell, P., Carlson, E., Stevens, A., 2015. Bathymetry and backscatter from 2013 Interferometric Swath Bathymetry Systems Survey of Columbia River Mouth, Oregon and Washington. U.S. Geological Survey data set, http://dx.doi.org/10.5066/F7T72FHB

Table 1. Tripod locations, depths, and times of deployment and recovery

Location	Longitude (°E)	Latitude (°N)	Depth (m)	Deployed (GMT)		Recovered (GMT)	
				Date	Time	Date	Time
North Tripod	-123.97139	46.24498	11.2	9-May-13	16:35	15-Jun-13	20:37
West Tripod	-124.06505	46.26505	12.1	9-May-13	18:27	15-Jun-13	22:12
South Tripod	-123.98542	46.23073	13.0	9-May-13	19:51	16-Jun-13	1:47

Table 2. Instruments, sampling scheme, and data products from tripods deployed at the MCR

Instrument Type	Sampling Scheme	Quantity Measured
RDI ADCP	1 Hz Continuous Sampling	Velocity profiles from 2.9 m above bed to surface at 0.5-m resolution
Sontek ADV	22-min burst at 8 Hz every hour	Point measurement of velocity at 0.66 m above bed, range to bed from ADV sensor
OBS	22-min burst at 8 Hz every hour	Point measurement of optical backscatter at 0.67 m above bed
Pressure	22-min burst at 8 Hz every hour	Point measurement of velocity at 1.4 m above bed
RBR CTD	10-sec burst at 6 Hz every 5 min	Point measurement of temperature and salinity at 1.8 m above bed
Imagenex Fan Beam Sonar	1 scan every hour or every 3 hours	Side-scan imagery of bed forms
Imagenex Pencil Beam Sonar	1 scan every hour or every 3 hours	Profiles of bathymetry in vicinity of tripod