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

Interactions of Waves and River Plume and their Effects on Sediment Transport at River Mouth (RIVET I)

Tian-Jian Hsu and Fengyan Shi
Civil and Environmental Engineering
Center for Applied Coastal Research
University of Delaware
Newark, DE 19716, USA
Email: thsu@udel.edu, fyshi@udel.edu. Tel: 302-831-4172

Grant Number: N00014-10-1-0176; N00014-13-1-0120

LONG-TERM GOALS

To develop a robust coastal/nearshore modeling system for inlet hydrodynamics, sediment deposition/resuspension, river plume processes and the resulting morphodynamics in a highly dynamic environment dominated by strong tidal flows and waves.

OBJECTIVES

- To study the interactions of tidal flow, waves and complex bathymetry at New River Inlet, NC using NearCoM-TVD and field data observed during a recent field campaign through close collaboration with other researchers.
- To study how a spatially/temporally varying bottom friction parameterization due to wave-current interactions, seabed dynamics (bedforms; sheet flows) can affect the hydrodynamics, sediment transport and the resulting morphodynamics of a tidal inlet.
- To investigate the relationship/correlations between the flow variables computed from the numerical model results and remotely-sensed signatures.

SIGNIFICANCE

The interaction between the hydrodynamics and complex bathymetry can produce highly heterogeneous and locally energetic flows, e.g., in a tidal inlet dominated by tidal flow and wave-current interaction. Consequently, the morphological evolution around such tidal inlet also becomes very dynamic. These two factors cause concerns over navigation safety especially in areas where routine surveys are not possible. Through significantly improved remote sensing technology, data on the surface flow features and limited information on the bottom bathymetry can be obtained. However, a complete prediction on the detailed hydrodynamics, bottom bathymetry and morphodynamics still relies on numerical modeling. On the other hand, it is also unclear if existing wave-averaged coastal modeling systems are sufficiently robust to provide the critical link (interpolation) between the remote-sensing data and the ground-truth data. The main challenges appear to be due to several key intra-wave and bottom boundary layer processes that are not directly resolved in typical coastal modeling systems. For example, it is well-known that in numerical modeling of inlet hydrodynamics, the results are sensitive to parameterization of bottom friction, which is a complicated function of flow depth, bedform and wave-current interactions.

In the past decade, there have been significant amount of research efforts devoted to improve the wave-current coupling in a wave-averaged coastal modeling system (e.g., Putrevu & Svendsen 1999; Mellor 2005; Kumar et al. 2011). The numerical model, NearCoM, adopted in the proposed study is due to one of such efforts supported by NOPP and Office of Naval Research (Shi et al. 2003, 2011). On the other hand, processes that occur in the bottom boundary layer, such as the enhanced roughness due to waves and bedforms, also play critical roles in determining the bottom friction. Typical coastal modeling systems are not designed to resolve processes occur close to the seabed, such as the centimeter-scale wave boundary layer. Hence, an appropriate bottom friction formulation, which parameterizes the key nearbed and seabed processes, need to be implemented. Recent field experiments at New River Inlet, NC (RIVET I) provide comprehensive data on hydrodynamic, sediment transport and bathymetry change via in-situ and remote-sensing measurements. Results disseminated by many researchers involved in RIVET I efforts allow detailed validation of the existing coastal modeling systems with a longterm goal to bridge the remotely-sensed signatures with water column and seabed processes using numerical models. In this report, we discuss our effort to validate NearCoM-TVD with measured field data. Thanks to the comprehensive observational datasets and environmental parameters provided by RIVET I researchers, our detailed model validation allows us to further evaluate the approproaite parameterization of bottom friction used in the numerical model.

APPROACH

A new version of the Nearshore Community Model System (NearCoM-TVD) is utilized in this study to investigate hydrodynamics, sediment transport and morphological evolution of New River Inlet, NC. NearCoM-TVD integrates the wave model SWAN (Booij et al., 1999) and the quasi-3D nearshore circulation model SHORECIRC (Svendsen et al. 2004). The quasi-3D circulation model incorporates the effect of wave on the vertical structure of current based on the theory of Svendsen & Putrevu (1994). There is very limited freshwater input at New River Inlet and the flow is assumed to be well-mixed in this study. Hence, we adopt the depth-integrated circulation model, which is more computationally efficient to simulate the entire system over the whole duration of the field campaign. It also allows us to carry out diagnostic study using different bottom friction parameterizations.

WORK COMPLETED

In early 2012, we carried out preliminary simulations and made simulation results available to field experimentalists of RIVET I project to evaluate the phase lag between velocity and surface elevation in the inlet (Elgar/Raubenheimer; Geyer/ Traykovski) and the timing of drifter release (Feddersen/Guza). A webpage was established since March 2012 to disseminate model results: http://www.coastal.udel.edu/~jialin/NewRiver.htm

In summer 2012, we carried out detailed model-data comparions during the month of field observation at New River Inlet (NRI), NC. We have collaobrated with Elgar/Raubenheimer's team to validate modeled flow velocity and significant wave height with measured data at about 25 sensors location throughout the inlet channels and nearshore region. We also collaborated with Geyer/Traykovski's team on mode-data comparison on two sensors located in the old and new channels where significant

bedform migration was observed. We also provided detailed model results to Guza/Feddersen's group to carry out drifter prediction and comparison with measured drifter trajectories.

During the NRI meeting in Arlington (VA) on April 23~24, 2013, we presented our modeling study and exhanged research ideas with many other participating researchers in this DRI. Afterward, we received additional bathymetry survery data from MacMahan/Reiner's team, who carried out more extensive re-survey near the bay side of the inelt. Dr. Lippmann also provided us with his ADCP data so that we can further evaluation the vertical structure of flow velocity through the inlet. This most updated bathymetry is used for the simulation presented in this report. The earlier version of NearCoM incorporates parameterization of wave-current interaction in the bottom friction based on Putrevu & Svendsen (1990). However, this formulation is based on the monochromatic wave parameteration (old version NearCoM uses the monochromatic wave model REF/DIF). When SWAN is coupled in the current version of NearCoM-TVD, the formulation needs to be evaluated. Therefore, we recently implemented the boundary layer wave-current interaction formulation of Soulsby et al. (1993) (see also Soulsby 1997), which does not require wave phase information. As we will discuss in the next Section, model prediction is improved when more complete wave-current interaction is incorporated.

Recently, we also incorporated two sediment transport parameterizations into NearCoM-TVD, both involve the capability to model wave-driven onshore sediment transport due to wave skewness/asymmetry (Kobayashi et al. 2008; van Rijn et al. 2011). The new model is validated with Duck94 onshore/offshore sandbar migration events (Gallagher et al. 1998). The new NearCOM-TVD with full sediment transport capability will be made publicably available soon. Since this summer, we have been preparing a complete user manual and a journal paper reporting the new model capability on tidal inlet, complex nearshore bathymetry and sediment transport. We are currently also preparing a journal manuscript regarding model validation at NRI and the effect of wave-current interaction on tidal jet. In fact, with such detailed model-data comparison, we are able to critically evaluate model's capability for different region of the nearshore-inlet-bay system and the effect of bottom friction parameterization. To further model the bedform dynamic, we included two bedform predictors in NearCOM-TVD and results will be compared with field observation. Since bottom drag coefficeint is known to affect the model results, we are also interested in using a bedform-dependent drag coefficent in the model in the near future.

RESULTS

For the model simulation results presented here, we utilized bathymetry provided by Dr. McNinch (USACE) surveyed on May 1~2, 2012 and more recent supplement survey provided by MacMahan/Reniers' group. The entire model domain extends from the edge of the continental shelf to the estuary. A closeup view near the inlet is shown in Figure 1. A deeper channel (5~10 meter in depth) located in the lower side of the inlet can be clearly seen while the depth in the upper side of the inlet is shallow. A curvilinear mesh is adopted with coarse resolution offshore and fine resolution in the nearshore region and around the mouth of the inlet (minimum mesh size is 10 m).

Model results shown here are for May 1st~30th. The tidal boundary condition is implemented via surface elevation data from the tidal database of large-scale circulation model ADCIRC (see Figure 2a). The offshore boundary condition in SWAN is given as a JONSWAP distribution using measured significant wave height and wave angle from direction Waverider ID 190 (Figure 2b and 2c). In this report, we like to focus on the effect of different bottom friction parameterization on the simulated flow field. To illustrate this, we present detailed flow field on May 2, which is of moderate tide and moderate wave energy (see shadowed area in Figure 2).

Previously, we have been using bottom friction parameterization of Putrevu & Svendsen (1990). As we presented in the NRI meeting, model results using bottom friction parameterization of Putrevu & Svendsen (1990) generally show good agreements with the measured data in the surf zone and channels. However, the intensity of the ebb tidal jet is somewhat over-predicted. The over-prediction is specifically noticeable near the outer surf zone where the intensity of the jet diminishes. For instance, figure 3a shows the simulated instantaneous flow velocity field during maximum ebb on May 2 and the strong ebb tidal jet extends all the way to sensor #09 and #28. However, when the bottom friction with full wave-current interaction of Soulsby (1997) is used, the simulated ebb tidal jet is significantly weaker (see Figure 3b). Weaker ebb tidal jet is consistent with measured data. In Figure 4 and 5, we can observe that model results using Putrevu & Svendsen (1990) parameterization clearly show over-prediction of flow speed (compare blue curves with red-dots), which is consistent with the snapshots shown in Figure 3. On the other hand, model results using Soulsby (1997) parameterization agree better with measured data in both sensor #09 and #28 because the predicted current speed is weaker. It appears that with the comprehensive model-data comparison, our research effort can be used to diagnose physical processes involved in the bottom friction parameterization. Our next step is to investigate bottom friction parameterizations that involve bedforms.

IMPACT/APPLICATIONS

Our coastal modeling effort using NearCoM-TVD at New River Inlet compliment other modeling efforts in this DRI utilizing Delft3D and wave-resolving Boussinesq wave models. Model results also help other researchers, who focus on in-situ measurements and remote sensing, to better interpret the wave-current hydrodynamics and surface features. Through this DRI, the development of NearCoM-TVD is significantly enhanced with abundant data measured by other researchers through detailed model-data comparison.

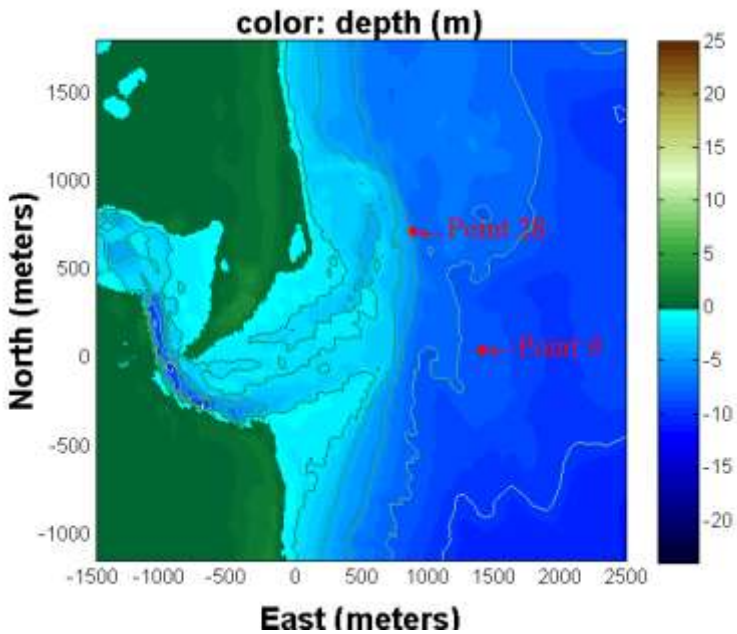


Figure 1: Bathymetry of New River Inlet with two sensor locations (#09, #28) discussed in this report. Bathymetry data is provided by Dr. McNinch (USACE).

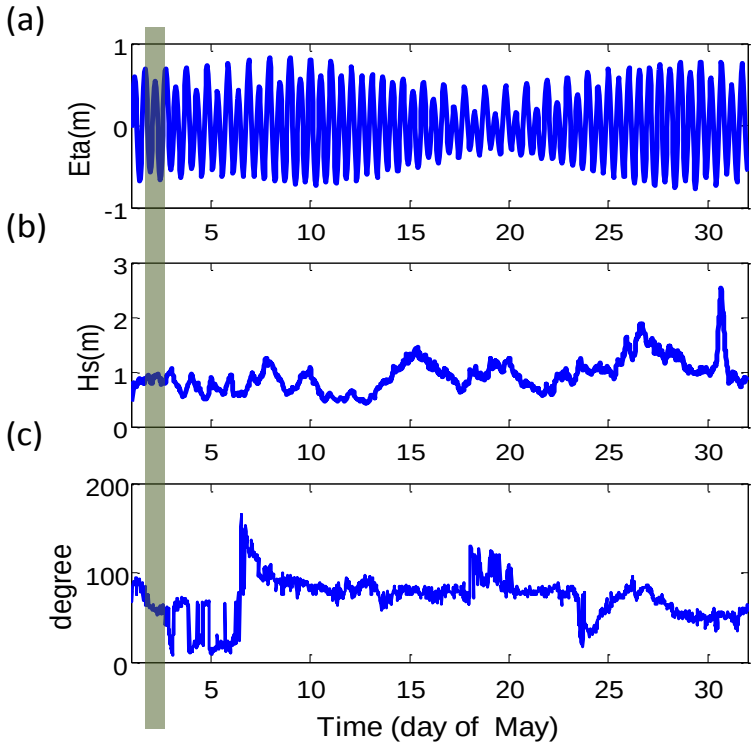
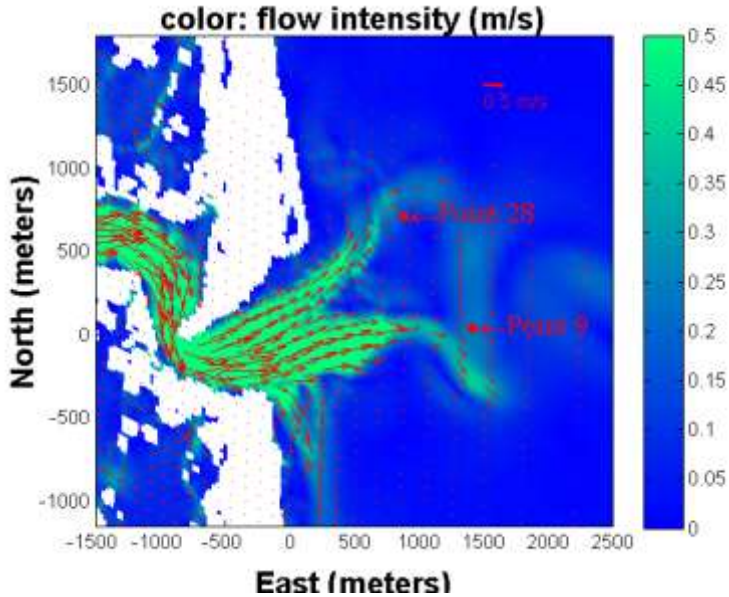


Figure 2: (a) Surface (tidal) elevation specified at the offshore boundary using the tidal data base provided by ADCIRC (http://adcirc.org); (b) significant wave height and (c) wave direction during May 1st to 31st from directional Waverider ID190 (see http://www.frf.usace.army.mil/waverdr190/realtime.shtml)

(a)



(b)

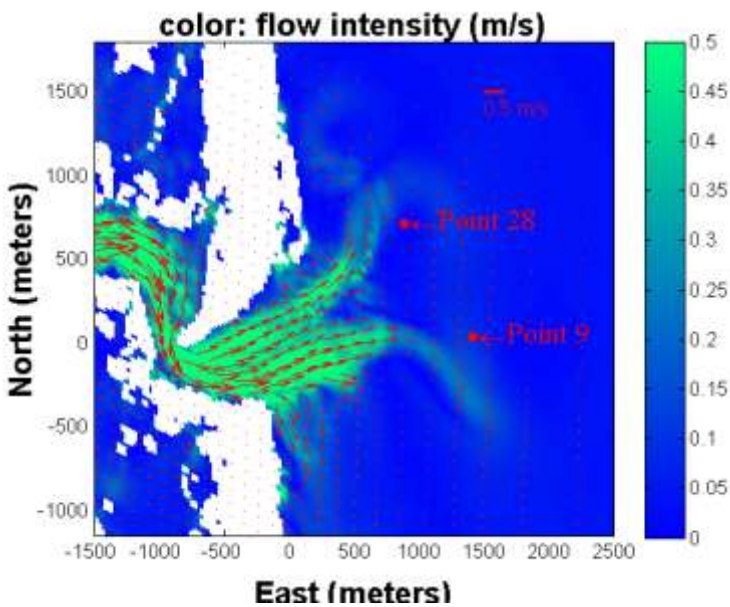


Figure 3: Instantaneous flow velocity during maximum ebb on May 2nd 00:00. (a) Simulation results using Putrevu & Svendsen (1990) where wave-current interaction is not fully incorporated in bottom friction due to coupling wih SWAN. (b) Simulation results using Soulsby (1997) where wave-current interaction is fully parameterized in the bottom friction. Peak ebbing flow in the channel can exceed 1 m/s but lower range of color bar is used to better illustrate the extend of the tidal jet.

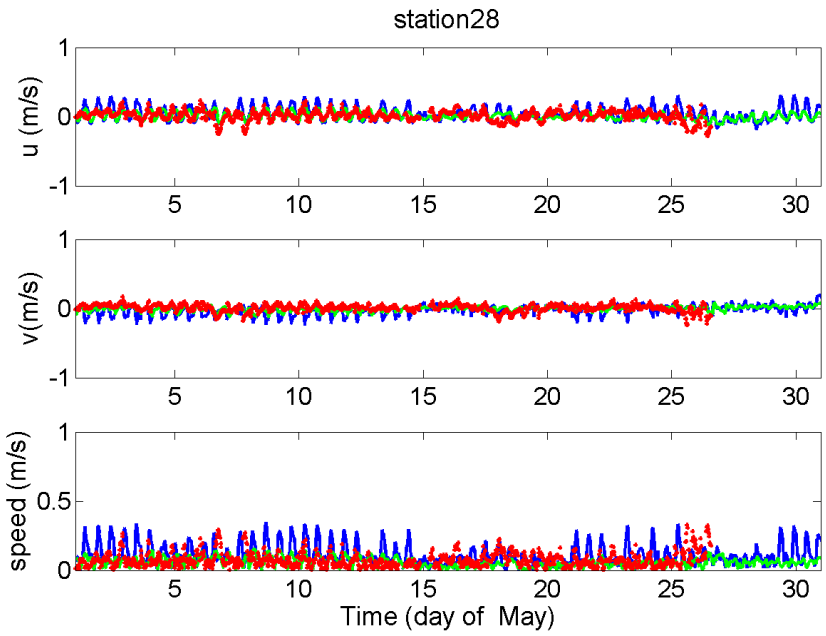


Figure 4: Comparions of time series of flow velocity in the east-west (a), north-south (b) directions and total speed between the measured data (red dots), model results using Soulsby (1997) bottom friction (green curves) and model results using Putrevu & Svendsen (1990) (blue curves) at Sensor #28. Field data is provided in collaboration with B. Raubenheimer and S. Elgar (WHOI).

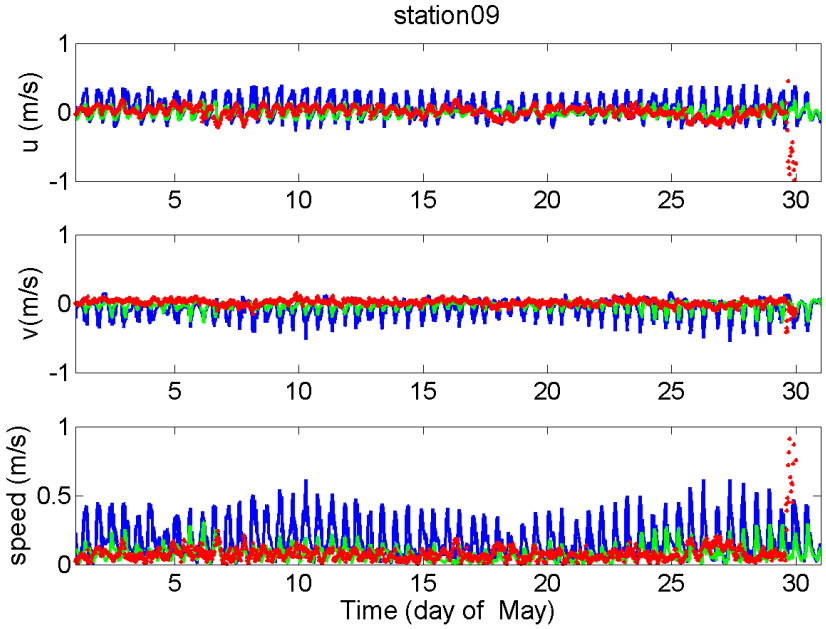


Figure 5: Comparions of time series of flow velocity in the east-west (a), north-south (b) directions and total speed between the measured data (red dots), model results using Soulsby (1997) bottom friction (green curves) and model results using Putrevu & Svendsen (1990) (blue curves) at Sensor #09. Field data is provided in collaboration with B. Raubenheimer and S. Elgar (WHOI).

REFERENCES

Booij, N., Ris, R. C. and Holthuijsen, L. H. (1999), A third-generation wave model for coastal regions, Part I: Model description and validation, J. Geophys. Res. Vol. 104, C4, pp.7649-7666.

Chen, J., Hsu, T., and Shi, F. (2012) Numerical modeling of hydrodynamics and sediment transport of New River Inlet (NC) using NearCoM-TVD, 2012 Ocean Science Meeting, Session #29 (Nearshore Processes), B0822.

Kobayashi, N., Payo, A., and Schmied, L., 2008, Cross-shore suspended sand and bedload transport on beaches, J. Geophys. Res., 113, C07001, doi:10.1029/2007JC004203

Kumar, N., Voulgaris, G., Warner, J. C. (2011) Implementation and modification of a three-dimensional radiation stress formulation for surf zone and rip-current applications, Coastal Eng., 58, 1097-1117.

Mellor, G.L., (2005). Some consequences of the three-dimensional currents and surface wave equations. Journal of Physical Oceanography 35, 2291–2298.

Putrevu, U., and Svendsen, I. A. (1999), Three-dimensional dispersion of momentum in wave-induced nearshore currents, Eur. J. Mech. B/Fluids, 18, 409–427, doi:10.1016/S0997-7546(99)80038-7.

Shi,F.,Svendsen,I.A., Kirby, J.T., and Smith, J. M., (2003), A curvilinear version of a Quasi-3D nearshore circulation model, Coastal Engineering, 49 (1-2), 99-124

Shi,F., Hanes D.M., Kirby J.T., Erikson L., Barnard P., and Eshleman J., (2011),Pressure gradient driven nearshore circulation on a beach influenced by a large inlet-tidal shoal system, J. Geophysical Res.,VOL. 116, C04020, doi:10.1029/2010JC006788.

Soulsby, R.L., Hamm, L., Klopman, G., Myrhaug, D , Simons, R.R., and Thomas, G.P., 1993, Wave-Current Interaction within and outside the bottom boundary layer. Coastal Engineering, 21, 41-69.

Soulsby, R. L., 1997, Dynamics of marine sands, Thomas Telford, London.

Svendsen, I. A., and Putrevu, U., 1990, “Nearshore circulation with 3-D profiles”, Proc 22th Int. Conf. Coastal Engrg., ASCE, 241-254.

Svendsen, I. A., and Putrevu U. (1994), Nearshore mixing and dispersion, Proc. R. Soc. London A, 445, 561–576.

Svendsen, I. A., Haas, K., and Zhao, Q., (2004) Quasi-3D Nearshore Circulation Model SHORECIRC: Version 2.0, Research Report, Center for Applied Coastal Research, University of Delaware.

van Rijn, L. C., P.K. Tonnon, D.J.R. Walstra, (2011) Numerical modelling of erosion and accretion of plane sloping beaches at different scales, Coastal Eng., 58, 637-655.

PUBLICATIONS

1. P. J. Snyder, and T.-J. Hsu (2011) A numerical investigation of convective sedimentation, *J. Geophys. Res.*, 116, C09024, doi:10.1029/2010JC006792. [PUBLISHED, REFEREED]
2. Yu, X., Hsu, T.-J., Jenkins, J. T., Liu, P. L.-F., (2012) Predictions of vertical sediment flux in oscillatory flows using a two-phase, sheet flow model. *Advances in Water Res.*, 48, 2-17. [PUBLISHED, REFEREED]
3. Yu, X., T.-J. Hsu, S. Balachandar, Convective instability in sedimentation-Linear stability analysis, *J. Geophys. Res*. 118(1), 256-272. [PUBLISHED, REFEREED]
4. Shi, F., Ma, G., Kirby, J., & Hsu, T.-J. (2012). Applications of a TVD solver in a suite of coastal engineering model. *Coastal Engineering Proceedings, 1*(33), currents.31. doi:10.9753/icce.v33.currents.31 [PUBLISHED]
5. Chen, J.-L., Shi, F., Hsu, T.-J., Kirby, J. T., (2013) NearCoM-TVD - a quasi-3D nearshore circulation and sediment transport model. [IN PREPARATION]