Interactions of Waves, Tidal Currents and Riverine Outflow and their Effects on Sediment Transport (RIVET I)

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LONG-TERM GOALS

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

OBJECTIVES

- To validate the quasi-3D nearshore hydrodynamic model, NearCoM-TVD, using observed wave and circulation data at New River Inlet (NRI), NC during RIVET I field campaign.
- To investigate the interactions of tidal flow, waves and complex bathymetry and the resulting sharp transition of flow patterns near the ebb tidal deltas of NRI.
- To investigate the effect of wave-current-bathymetry interaction on tidally-averaged residual flow pattern, sediment transport pattern and the resulting morphological evolution.

INTRODUCTION

In a tidal inlet characterized by complex bathymetry, the interaction between tidal flows and surface waves can produce spots of intense flow with high spatial and temporal variability (e.g., Shi et al. 2011; Olabarrieta et al. 2011; Orescanin et al. 2014). Therefore, the morphological evolution in such tidal inlets also becomes very dynamic. 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 also requires numerical modeling. On the other hand, it is also unclear if the existing wave-averaged coastal modeling systems are sufficiently robust to provide the critical link between the remote-sensing data and the ground-truth data. For example, it is well-known that in numerical modeling of inlet hydrodynamics, the results are sensitive to parameterization of wave-current interaction and bottom friction.

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 this study is due to one of such
efforts supported by NOPP and Office of Naval Research (Shi et al. 2003, 2011). Field experiments at New River Inlet, NC (RIVET I) carried out during the month of May 2012 provided comprehensive data on hydrodynamic, sediment transport and bathymetry change via in-situ and remote-sensing measurements (e.g., Wargula et al. 2014). Results disseminated by many researchers involved in RIVET I efforts allow comprehensive validations of the existing coastal modeling systems. In this modeling study, a newly improved version of NearCoM, called NearCoM-TVD (Chen et al. 2014a) is used in this integrated observational and modeling study. The model is validated with observed waves and circulation at 30 locations, including in a recently dredged navigation channel and a shallower channel, and on the ebb tidal deltas, for a range of flow and offshore wave conditions during May, 2012 (Chen et al. 2014b). Near the ebb tidal deltas, the model reproduces the rapid onshore (offshore) decay of wave heights (current velocities) observed in the measured data. Model results reveal that this sharp transition zone coincides with the location of the breaker zone over the ebb tidal deltas, which is modulated by semi-diurnal tides and by wave intensity. The modeled tidally averaged residual flow patterns show that waves play an important role in generating vortices and landward-directed currents near the inlet entrance. Numerical experiments further suggest that these flow patterns are associated with the channel-shoal bathymetry near the inlet, similar to the generation of rip currents (e.g., MacMahan et al. 2010). Model results also show that wave intensity and direction play a crucial role in controlling the morphological evolution of the ebb tidal deltas. Highlights of these findings are summarized in this report.

**APPRAOCH**

A new version of the Nearshore Community Model System (NearCoM-TVD) has been developed and utilized in this study to investigate hydrodynamics, sediment transport and morphological evolution of New River Inlet, NC (Chen et al. 2014a). 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 waves on the vertical structure of current based on the theory of Svendsen & Putrevu (1994). After a series of model validations with field observed waves and circulations, the numerical model is used as a diagnostic tool to understand the interplay between tidal current, wave and bathymetry.

**WORK COMPLETED**

The development of NearCoM-TVD and the preliminary model-data comparison were completed before 2013. In this supplement data analysis grant, we focused on refined model validation with field data observed in 30 different sensors in the channels and ebb tidal deltas (data obtained in collaboration with Raubenheimer/Elgar team (WHOI)) and an diagnostic study using model experiments in order to understand the dominant mechanisms causing the resulting complex flow pattern and sediment transport. A manuscript summarizing the numerical model development and model validation on nearshore sandbar migration was published in early 2014 (Chen et al. 2014a). Another manuscript focused on detailed model validation with field data measured at NRI and the diagnostic study was recently submitted for publication (Chen et al. 2014b). Detailed numerical simulation results are also made available to several other participating groups for drifter modeling (Spydell et al. 2014) and for comparison with Autonomous Underwater Vehicle (AUV) measurement (Rogowski et al. 2014), etc.
RESULTS

For the model results presented here, we utilized bathymetry provided by Dr. McNinch (USACE) surveyed on May 1–2, 2012 and supplement survey provided by Drs. Reniers and MacMahan. The entire model domain extends from the edge of the continental shelf to the estuary (see Figure 1a). The tidal boundary condition is implemented via surface elevation data obtained from the tidal database of large-scale circulation model ADCIRC. 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. A close-up view near the inlet is shown in Figure 1b. Our numerical simulations focus on the interaction between tidal current and waves in the two channels and nearby ebb tidal deltas. A curvilinear mesh is adopted with coarse resolution offshore and fine resolution near the inlet (minimum mesh size is 10 m). Model results shown here are for May 1st–30th, 2012. More detailed numerical implementation and model results are reported in a manuscript recently submitted for publication (Chen et al. 2014b). Several highlights of the numerical investigation are summarized as follow.

The numerical model is validated with observations from 30 co-located wave and current sensors during a one-month long field experiment that included spring and neap tides and a range of wave conditions. The numerical model reproduces the waves and circulation observed throughout the nearshore and the inlet, including two channels and ebb tidal deltas. For example, at sensor 5 (see Figure 1b for location), east-west flows are predicted well, and although north-south flows are slightly under-predicted (Figure 2a,b). The tidal flows and water depth changes modulate the wave heights, consistent with the observations (Figure 2c). The overall model skills for flow velocities and significant wave height are around 0.9. The observations and simulations both show a narrow (few hundred meters) transition between the current-dominated and wave-dominated processes over the ebb tidal deltas. In particular, wave heights vary over multi-day periods at sensor 78 located at the 5-m depth of the southwest ebb tidal delta (see Figure 3a) in response to offshore winds. However, only a few hundred meters landward, wave heights are relatively small and tidally modulated (sensors 76 and 77, Figure 3b,c). Flow speeds are small at sensor 78, but become large and tidally modulated at sensor 77 and 76 (Figure 3d,e,f). These features are capture by the numerical model although the overall model skill here is lower (range around 0.5–0.85) than that in the channels. Model results suggest that this transition region occurs over the narrow breaker zone, which is modulated by tidal water depth fluctuations.

The validated model is used to study the complex hydrodynamic patterns of the inlet-bay-beach system through tidally-averaged residual flow. Figure 4a shows the tidally-averaged residual flow field for a spring tide-stormy wave condition (similar to May 27, 2012 but only representative M2 tide is used to drive the model). The modeled residual flow velocity exceeds 0.5 m/s in the southwestern channel just offshore of the entrance between the two ebb tidal deltas. The residual flow velocity over the ebb tidal deltas is about 0.3 m/s. On the southwestern ebb tidal delta, a clockwise circulation pattern can be seen (see III in Figure 4a), which feeds (or is adjacent to) a strong southwestward-directed alongshore current driven by the oblique incident waves. Another clockwise circulation pattern appears off the northeastern shore (see I in Figure 4a). Moreover, over the central ebb tidal delta, the residual flow is landward-directed with a magnitude exceeding 0.25 m/s (see II in Figure 4a), although seaward-directed flow prevails in the two channels. Comparing simulations with tidal-flow-forcing only (see Figure 4b), these circulation patterns no longer exist. Clearly, waves play an important role in generating the circulation patterns near the inlet entrance, enhancing offshore-directed flow in the channels and driving landward-directed currents over the ebb tidal deltas. Further simulations and
analysis suggest that it is the interaction between waves and bathymetry causes these residual flow patterns and the mechanisms are similar to those in rip-current systems (e.g., MacMahan et al. 2010).

Tidally-averaged residual sediment fluxes are estimated by coupling NearCoM-TVD with a total load sediment transport mode (Soulsby 1997). Modeled sediment fluxes and patterns of accretion and erosion when waves are included differ from those when waves effects are removed from the simulation. Figure 5a shows modeled tidally-averaged sediment flux during the spring-tide stormy-wave condition with waves incident from the southeast while Figure 5b is the corresponding sediment flux with wave effect excluded. Comparing to the sediment flux simulated without waves, sediment flux in the southwestern (deeper) channel is enhanced seaward of the ebb tidal shoal (extending beyond the 6-m bathymetric contour). Waves also induces significant sediment fluxes over the ebb tidal deltas and adjacent shore. Numerical experiments further suggest that when waves are incident from the southwest, the enhanced transport in adjacent ebb tidal deltas is less significant (not shown). Divergences and convergences of the tidal- and wave-driven transport result in spatially variable sediment accretion and erosion. Figure 6a shows the corresponding seabed change over one-tidal cycle during the spring-tide stormy-wave condition with waves incident from the southeast, while Figure 6b is the corresponding seabed change without waves. Consistent with the sediment flux results shown in Figure 5, there is very minimum seabed change over the ebb tidal deltas when waves are excluded in the simulation. In summary, model study suggested that tidal amplitude, wave intensity, and wave direction all influence the morphodynamics of New River Inlet. Particularly, waves plays an important role in controlling the morphodynamics of ebb tidal deltas.

**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: (a) Location of New River Inlet, NC. The dashed box is the computational domain and the cross symbols are NOAA buoys. The tidal constituents provided by the ADCIRC [Luettich et al., 1992] database are applied at the southwestern, southeastern, and northeastern open boundaries of the numerical model. (b) An expanded view of the inlet entrance with colocated pressure gauges and current meters (circles). The bathymetry are (color contours, scale on the right) superposed on a Google Earth image.
Figure 2: Modeled (blue curves) and measured (red dots) (a) east-west (u) velocity, (b) north-south (v) velocity, and (c) significant wave height (Hs) at sensor 05 in the southwestern channel (Figure 1b) versus time. The model skill for u, v, and Hs are, 0.96, 0.95 and 0.87, respectively.
Figure 3: Modeled (blue curves) and measured (red dots) (a, b, and c) significant wave height and (d, e, and f) current speed at sensors 78, 77, and 76 versus time. See Figure 1b for sensor location.
Figure 4: (a) Tidally-averaged residual flow field of a spring tide-stormy wave condition. Box (I) indicates a clockwise circulation on the northeastern shore. Box (II) signifies an onshore residual flow observed on the central ebb tidal delta. Box (III) shows a meandering residual flow pattern on the deeper channel and southwestern ebb tidal delta. (b) The residual flow field driven only by tidal forcing (no waves).
Figure 5: (a) Tidally-averaged residual sediment fluxes for a spring tide-large wave condition with waves incident from the east-southeast. (b) Tidally-averaged residual sediment fluxes for the same spring tide but without waves. The solid curves are bathymetric contours (0, 2, 4, 6, and 8 m depth relative to NAVD88).
Figure 6: (a) Colormap (scale on the right) of seabed change after one tidal cycle for a spring tide-large wave condition with waves incident from the east-southeast. (b) Colormap of seabed change after one tidal cycle for the same spring tide condition without waves. The solid curves are bathymetric contours (0, 2, 4, 6, and 8 m depth relative to NAVD88).

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