ACOUSTIC MONITORING OF NEARSHORE HARD BOTTOM: APPLICATIONS IN MORPHOLOGIC INVESTIGATIONS AND NUMERICAL MODELING

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Abstract: Acoustic data collected on the 8 km segment of beach south of Sebastian Inlet, FL in water depths ranging from -1.5 to -6 m were analyzed along with high resolution bathymetric data to relate temporal and spatial variability in the morphologic changes to reef/hard bottom coverage. Decadal bathymetric changes showed scour (-1.5 m) on the upper shoreface of the beach fill zone along with shoreline retreat (-15 m). Sand deposition (+1 m) and shoreline advancement were concentrated in the zone directly within inlet influence and south of the beach fill zone, which is characterized by complex reef morphology. Model simulations showed that under waves approaching from the north east, the sand transport magnitude increased at about 5 km south of the inlet. The model was successful in reproducing morphology changes from July 2009 to January 2010 including scour on the upper shoreface and deposition south of the beach fill zone.

Introduction

Non-erodible (hard) bottom is a widespread coastal feature with many oceanographic and engineering issues. Hard bottom may occur in several forms such as limestone or other sedimentary rock, coral reef, and even submarine structures like breakwaters. The Coquina/limestone outcrops from the Anastasia formation (Pleistocene) are a common feature off the beaches south of Sebastian inlet, FL in Indian River County. Nearshore reefs are also of great environmental value as a benthic habitat and considered as protected areas. They have to be considered during beach fill activities and overall local sand management. The hard bottom coverage and therefore, reef morphology is believed to play a major role in sedimentation patterns within the Indian River County beaches south of Sebastian Inlet, in addition to natural sand bypassing.

Nearshore hard bottom can be identified using a variety of field and remote sensing techniques. Field mapping techniques include underwater transects surveys using scuba divers and a variety of acoustic systems which provide increased spatial resolution and even bottom characterization algorithms. However, field monitoring is often challenging because of the reef occurrence in shallow waters and breaking waves, which create hazardous survey conditions

under fair weather. These conditions are also a limiting factor in remote sensing mapping techniques since water clarity is affected. Hard bottom coverage constitutes valuable data when integrated with repeated high resolution bottom topography measurements, therefore providing a great way to increase our understanding of the spatial variability in the bathymetric and shoreline changes with respect to reef morphology, and to improve management of beach fill projects. The representation of non-erodible substrate is of great importance to numerical modeling studies, since it constitutes a constraint on sediment transport and the induced bathymetric change. In some cases, hard substrates may be covered by a thin layer of sand, providing sediment supply for transport. Hard bottom was recently implemented into coastal morphology models (Buttolph et al., 2006).

This study integrates acoustic data collected on the 8 km segment of beach in Indian River County, FL in water depths ranging from -1.5 to -6 m. The main objectives were: 1. to identify nearshore reef outcrops and relate to the bathymetric and shoreline changes derived from survey data (over several time scales); 2. to integrate the hard bottom coverage for use in the Coastal Modeling System (CMS, Buttolph et al., 2006); and 3. to reproduce sand transport and morphology change patterns in a 6 month model run to understand interactions with reef outcrops and assess the model performance.

Study area

The study area consists of the section of beach located directly south of Sebastian Inlet in Indian River County, FL between R monuments R1 and R30 (Figure 1). These benchmarks used for beach profile monitoring, were placed by Florida Department of Environmental protection (DEP) every 1,000 ft (300 m) and increase for north to south in every county. The system is microtidal, having a moderate wave climate with mean annual wave height of 0.6 m and a tidal range of approximately 1 m (Zarillo and Brehin, 2009). The barrier island system consists of Holocene and modern sediments overlying the limestone/coquina rock of the Pleistocene Anastasia Formation (Zarillo and Brehin, 2009). The central Florida barrier system is a perched barrier chain consisting of a veneer of modern beach and littoral sands over the Anastasia. Outcrops and ridges of this coquina rock are common around the low tide mark and develop into a series of shore parallel reefs, especially to the south of Sebastian Inlet. Nearshore reef in Indian River County were already identified using underwater transects (Harris, 2003). Results have shown a great spatial variability in the distribution and determined two segments within the study area: the first one from R1 to R10 and the second one from R10 to R30.

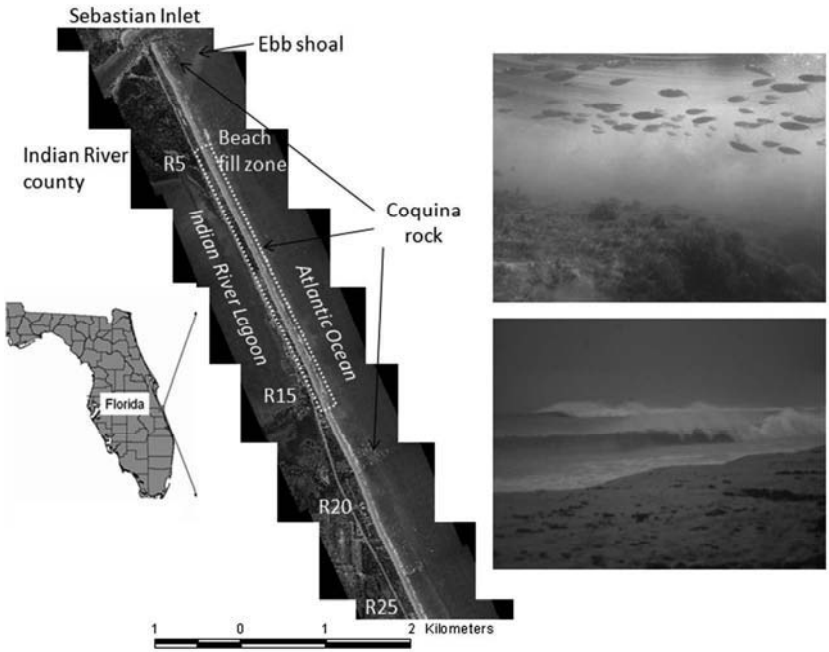

Figure 1. Study area: geographic setting (left); underwater view of reef near R10 (top right); waves breaking on the outer reef near R16 during Hurricane Bill in Aug. 2009 (bottom right).

The Sebastian Inlet District (SID) was formed in 1919 by the State of Florida to maintain its navigability as a tidal inlet, and manage the sand resources within the inlet and adjacent beaches. In 1948, the inlet was artificially cut into the limestone and stabilized by offset jetties to prevent from sand deposition in the channel and shoaling by increasing tidal current velocities. Present configuration was achieved in the early 1970s. As a result of changed hydrodynamics and the interruption of sand transport by jetties, an important shoal system developed along with a downdrift offset and subsequent sand starvation on the south beaches. Engineering activities for combating erosion have consisted of dredging from the interior sand trap at the westward edge of the channel first excavated in 1962, and subsequent mechanical bypassing to the beaches on the downdrift side of the inlet from R5 to R16. Over the past 10 years more than 1 million cubic meters of sand have been placed on the beaches. The SID has undertaken intensive monitoring effort including aerial images and bathymetric data measurements to follow beach fill performance and inlet morphologic evolution (Zarillo and Brehin, 2009).

Methods

Measured morphologic changes

Hydrographic surveys of the inlet system and surrounding beaches were conducted on a semi-annual basis by the SID since the winter of 1991. Offshore elevation data are gathered by conventional boat/fathometer surveying methods from -1 m to -16 m. The domain includes shoreline distances of 10 km both north and south of the inlet, with extensive coverage of the flood-shoal and back barrier (Figure 2, left). The spatial resolution in the south region was increased since the summer 2009 survey with the use of multi beam sonar. Bottom topography data are converted to xyz format and imported into a geographic information system (GIS) to calculate bathymetric, cross-section and shoreline changes that describe the evolution of sand reservoirs over time.

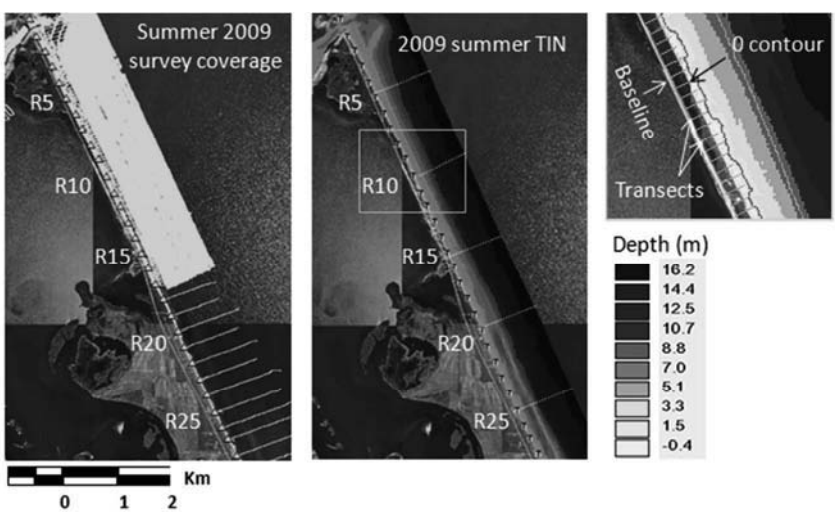

Figure 2. Methodology for TIN's/3D surface generation, cross-section extraction and shoreline change calculations.

All analyses were performed according to the Triangulated Irregular Network surfaces (TIN) method, in which surfaces, or masks (representing the inlet or the surrounding beach sand reservoirs), are generated for each survey period (Figure 2, middle). Bathymetry change calculations were performed using a combination of the 3D-Analyst© and the Image Analyst© extensions of ArcGIS© to describe the evolution over time. Cross-sections at three R markers were extracted using the Profile extractor PE© tool. Analysis of the shoreline position from survey data was based on digitizing the zero contour, which

represents the mean water high water line (MHWL) for the NGVD29 datum. To determine the change in shoreline position among surveys, a common baseline with NAD27 projection was created manually using BeachTools© (Zarillo and Brehin, 2009) running along the SRA1A. Perpendicular transects from this baseline to the digitized shoreline were created every 300 m apart for a total number of 60 transects. The bathymetry and shoreline change maps were overlaid with the shapefile representing the reef coverage discussed below. More information concerning the methodology and calculations can be found in Zarillo and Brehin, 2009.

Hard bottom/reef identification

Acoustic data were collected during the summer of 2009 by the Biological Oceanography Laboratory at Florida Tech on the 8 km segment of beach from the R2 to approximately R30 in water depths ranging from -1.5 to -6 m using a single beam sonar system. The configuration consisted of the RoxAnn Groundmaster GD-X manufactured by Sonavision Limited with a Furuno dual frequency echo sounder (50 kHz and 200 kHz). The system was interfaced with a laptop and GPS unit. Signatures of acoustic returns were collected and logged with RoxMap Scientific Software Version 3.1.0.4. The process of seafloor classification was determined by the software using the two echo returns referred to as E1 and E2. A pulse is sent from the transducer to the seafloor and reflected back to the surface as the primary echo (E1). The echo is then reflected off the underside of the sea surface, travels back to the seafloor and returns as the secondary echo (E2). The groundtruthing was done by marking the GPS location of each signal group with a buoy and having a group of scuba divers visually assess and take grab samples of the bottom type. The collected samples were classified using a variety of methods (taxonomic identification and geological characterization of sediments using standard dry sieving technique). The point theme data was then incorporated in the GIS analysis system to generate a shapefile of the hard bottom/reef coverage. The coverage is used to overlay the calculated bathymetric changes and input into the modeling study.

Model analysis of sand transport patterns and morphological change

The Coastal Modeling System (CMS) is a robust and computationally efficient set of numerical models developed by the U.S. Army Engineer Research and Development Center (ERDC) Coastal Hydraulics Lab (CHL). The CMS-FLOW model is a time dependent, 2-D finite volume circulation and transport model that calculates water surface elevations, two components of the current, and sediment transport on a rectilinear grid (Buttolph et al. et al., 2006). CMS-FLOW can be fully-coupled with Wave-Action Balance Equation Diffraction

model (CMS-WAVE) through user specified intervals (Buttolph et al., 2006). This process, called steering, allows interval outputs from each model to be transferred to the other model updating the inputs prior to continuation of the next interval run. The details of CMS-WAVE are given in Demirbilek (2007). Previous CMS model runs have already highlighted model capabilities in simulating inlet morphologic changes under the Lund sand transport Formula (Zarillo and Brehin, 2007). For this particular study, sediment transport calculations were performed under the NET Lund formula The mean sediment grain size was set to 0.3mm on the first column of cells (depth from 0 to -1m). On the second and third column of cells (depth from -1 to -2m and -2 to -3m approximately), the mean grain size was decreased to 0.25 and 0.2 mm. For model calculations, the sediment transport time step was set to 10 seconds and morphology time step set to 1 hour. The interior model domain extends north-south along the Indian River Lagoon and into the Atlantic Ocean to a depth of about 16 m (Figure 3). The bottom topography dataset consisted of a combination of the high resolution beach profiles/hydrographic survey data of the inlet system and surrounding beaches collected in July 2009 (SID), and offshore data from the Coastal Relief Model. For the circulation/sediment transport model, the grid cell sizes range from 30 to 100m, whereas the wave model uses a uniform grid cell size of 50m. Morphological constraints were applied by tagging the non-erodable cells, using shapefiles of hard bottom discussed in the above setion.

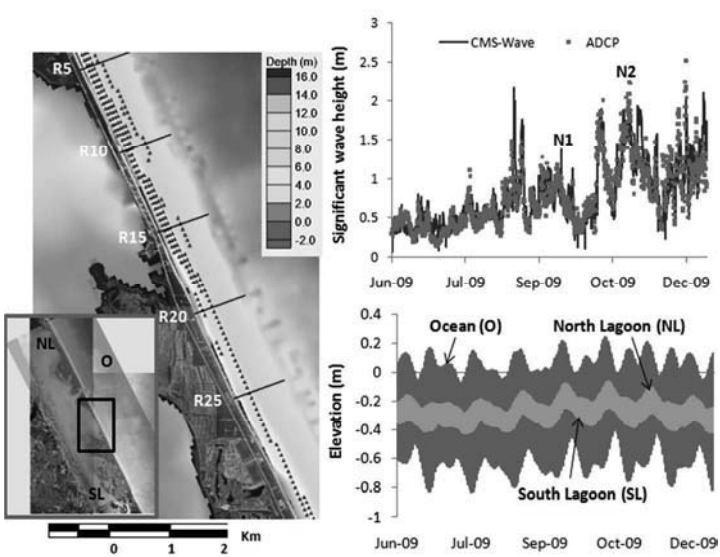

Figure 3. CMS model grid (left), and wave and water level input (boundary conditions).

Model runs consisted of the hydrodynamic/sediment transport model (CMS-FLOW) at hourly output and coupled with the wave model (CMS-WAVE), having wave updates every 3 hours. Model was run over a six-month period, from June to December 2009. The circulation model was driven by time series of water surface elevations (WSE) based on a prediction from tidal constituents derived from measured data. Time series were inserted at the three boundaries of the model domain consisting of North Lagoon (NL), South Lagoon (SL), and Ocean (O) (Figure 3, bottom right). Wind data consisted of time series of hourly wind speed and direction, collected at the meteorological station located on the north jetty of Sebastian Inlet. Wind data were used as input to both circulation and wave models inserted uniformely at the offshore boundary. The wave model used time series of wave height, period and direction, as well as spreading parameters, which were derived from hindcast data. There was a good match between the predicted and the measured wave heights extracted in the nearshore north of the inlet in a water depth of 6m (Figure 3, top right). The nearshore wave gage maintained by the Florida Tech Coastal Engineering Laboratory consists of four wave gages deployed for 1 to 3 months at a time. Variables recorded include significant wave height (H_s), dominant wave period (T_p) and direction (D_p), current velocity and direction, and water level.

Results

Measured morphologic changes

Net bathymetric and shoreline changes calculated from the survey data between R1 and R30 in Indian River County are presented in the following section with shapefiles of the reef coverage. Calculations were performed over two time periods: July 2009 to January 2010 (Figure 4) and July 2000 to July 2010 (Figure 5). The color code for net bathymetric change is that blue colors represent erosion whereas red colors indicate deposition. Net bathymetric changes from July 2009 to January 2010 (Figure 4) indicate scour (-1m) on the upper shoreface between the south jetty (R1) and southern edge of the bypass bar (R3) and to a lesser extent (-0.5 m) on the upper shoreface between R13 and R18. Deposition (+0.4 m) occurred on the upper and lower shorefaces between R5 and R14. Large patches of deposition (up to +1.2 m) were located on the upper shoreface between R20 and R23. Shoreline changes were characterized by a retreat from R1 to R5 (-20 m), followed by advancement from R5 to R10 (+20 m). Shoreline changes were relatively small from R10 to R20 with advancement peaking near R16 (+15 m) before retreating again from R20 to R25 (-10 to -30 m). Overall shoreline changes were in agreement with spatial variations in bathymetric changes and zones experiencing shoreline advancement were located within depositional zones.

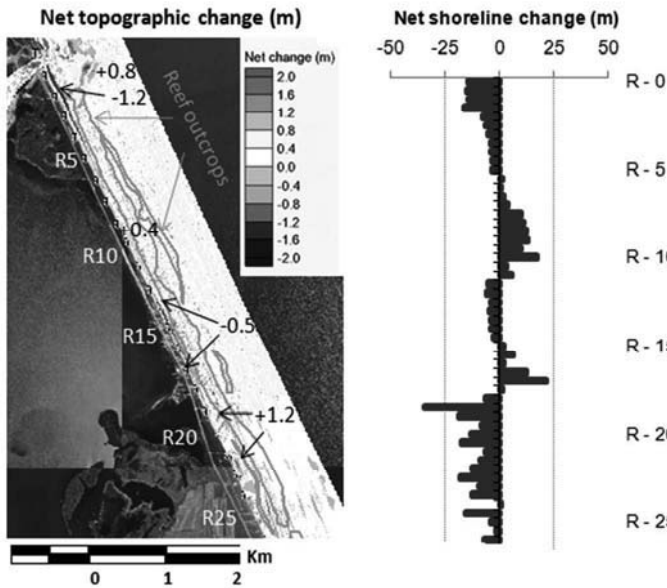

Figure 4. Seasonal morphologic changes from July 2009 to January 2010.

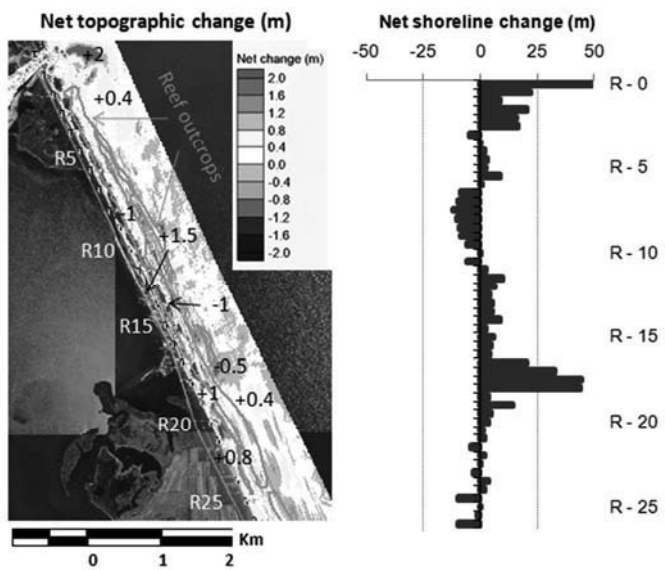

Figure 5. Decadal morphologic changes from July 2000 to July 2010.

Net bathymetric changes from July 2000 to January 2010 (Figure 5) show scour from R2 to R17 ranging from -0.3 to -1.2 m (upper shoreface) and from -0.2 to -1 m (lower shoreface). This corresponds to the beach fill zone which undergoes shoreline retreat (-15 m).The erosional pattern on the upper shoreface (landward of the reef outcrops) was reversed near R17 with significant sand deposition (+1 m) dominating the section from R17 to R30. Sand deposition (+0.5 to +1m) occurred on the beach face from the south jetty (R1) to R5 and from R10 to R17. This zone experienced shoreline advancement (+10 to +20 m from R1 to R5 and +5 to +10 m from R11 to R22). The lower shoreface from R17 to R30 experienced overall erosion (-0.5 m) but large patches of deposition (+0.5m) (approximately 1km long) were observed off R18 and R25. Largest shoreline advancement occurred within this zone peaking near R16-R18 (+40 m). Morphologic changes over the long term highlighted several geomorphic zones within the south domain: first zone controlled by inlet; second zone controlled by a combination of beach fill and reef; third zone dominated by reef. Spatial variability in reef morphology was evidenced in Figure 6, which presents cross-sections extracted from the 2009 summer bathymetric data.

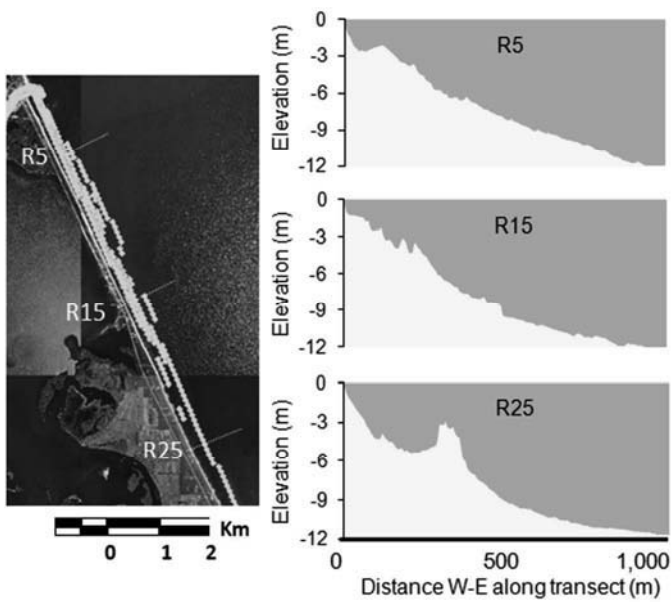

Figure 6. Location of reef outcrops based on acoustic monitoring (left); profile extracted from the July 2009 high resolution data (right).

Model analysis of sand transport and morphology change

Model outputs of sand transport and morphology change from June to December 2009 are presented in the following section. Morphology change calculations (net bathymetry and cross-section) were performed by subtracting the final model grid minus the initial model grid. Results were analyzed along with the measured changes discussed in the previous section. Sand transport patterns for two wave events approaching from the northeast but of different magnitude (low and high energy events, N1 and N2, respectively) are presented in Figure 7. For both events, sand transport was south-directed. Under low energetic conditions (N1), sand transport magnitude was greatly reduced by Sebastian Inlet and picked up south of R15 (0.0001m^3/s). The width of the transport zone increased south of R15. Under high energetic conditions the sand flow was continuous and much more important (0.001m^3/s). Overall sand transport was constrained shoreward of the edge of the reef outcrops, with the exception of the southernmost zone near R25.

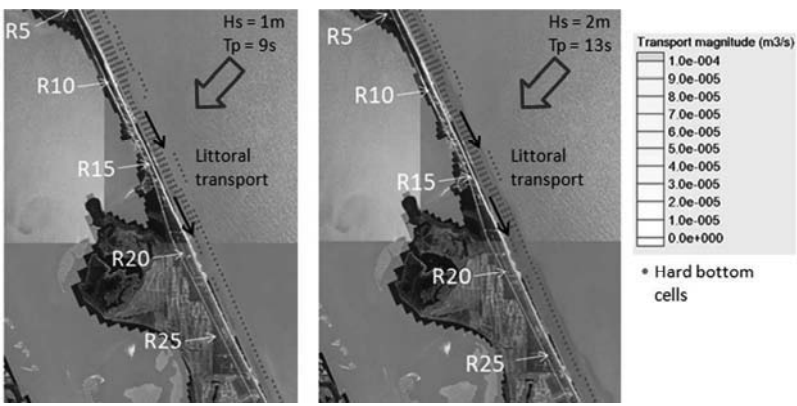

Figure 7. Snapshot of sand transport patterns from CMS run for a low energy event (left) and a high energy event (right) under northerly approaching waves.

Model predictions of morphology change from June to December 2009 are presented in Figure 8 for two cases (hard bottom and no hard bottom). The model simulation under the hard bottom case (Figure 8 left) predicted scour up to -1 m on the upper shoreface from R1 to R3, and from R10 to R15. The plot showed increased patches of deposition (up to +1 m) south of R17, which was in agreement with the measured changes discussed earlier and further suggested that large sand bodies moved alongshore and became trapped landward of the reef outcrops in this zone of complex reef morphology. This reinforced the idea of a “reef controlled” sedimentation south of the beach fill zone with natural sand trapping by those reef. The influence of the hard bottom routine was further

exemplified by the net change from the same run but without the hard bottom cells (Figure 8 right). Tagging the hard bottom cells and therefore accounting for reef outcrops reduced significantly the scour on the upper shoreface and led to more deposition on the shoreface, especially in the R20-R30 area.

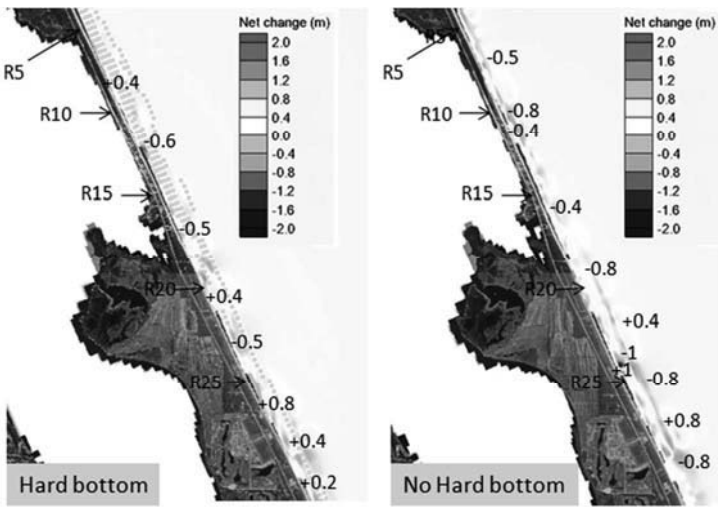

Figure 8. CMS model output of net morphology change (m) for 6-month run (June 2009 to December 2009)

The morphology change outputs (final/last time step) were used to extract profiles at R5, R15, and R25. They are presented along with the measured profiles (SID data) of summer 2009 (initial model) and January 2010 in Figure 9, left. The figure illustrates the spatial variability in profile and reef morphology and in particular the unique half pipe profile shape at R25. The net elevation change (Figure 9, right) was calculated by subtracting the July 2009 to January 2010 measured profile data (dotted line) and for the model, by subtracting the final profile minus the initial profile (summer 2009 bathymetry). Measured profile change at R5 over the 6 month period showed changes oscillating between -0.2 m to +0.6 m. Measured profile changes at R15 were negative (-0.5 m) across the upper shoreface and followed by an oscillation between negative and positive changes (-0.2 to +0.6 m) on the reef zone and across the lower shoreface. Measured changes at R25 showed positive values up to +0.6 m in the nearshore zone (0 to +250m seaward of the MHWL) whereas negative values (scour) are found just landward of the reef edge. The largest profile changes occurred within the landward zone of the reef at R25 while they were more widespread over the entire profile at R5 and R15. This further

suggests reef morphology control on profile evolution. Modeled elevations as indicated by red markers matched the measured profile changes for all 3 profiles. Differences included model underestimation of the net profile change at R5 and R15 and overestimation at R25.

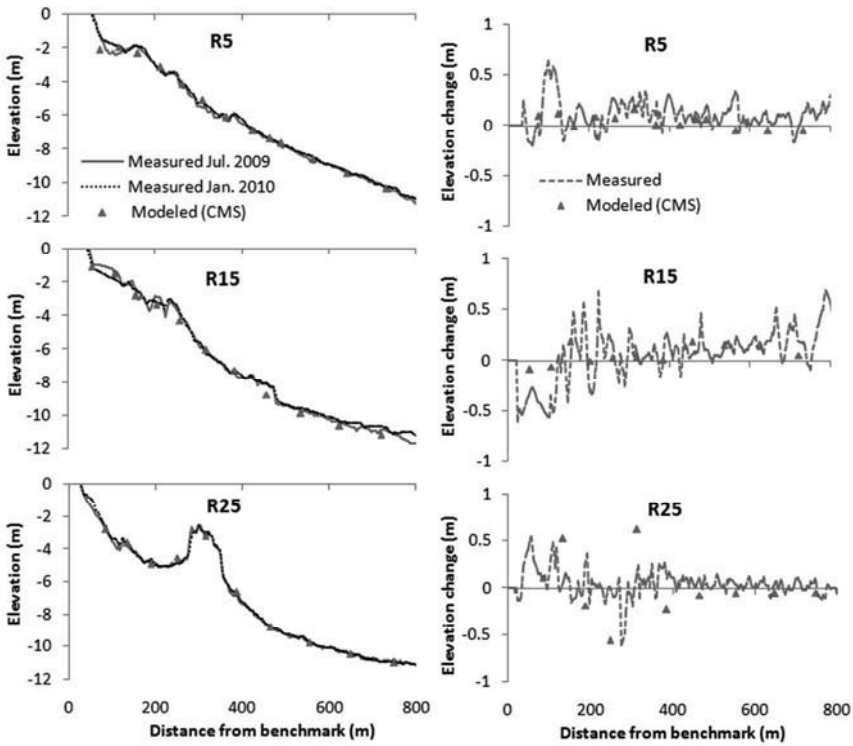

Figure 9. Profiles extracted at R5, R15 and R25 (left), Elevation change from July 2009 to January 2010 for measured vs. model data (right).

Summary and conclusions

Acoustic data collected on the 8 km segment of beach in Indian River Country from R2 to approximately R30 in water depths ranging from -1.5 to -6 m were analyzed along with high resolution bathymetric data (SID). The morphologic analysis highlighted several geomorphic zones within the analysis domain, characterized by different sedimentation control mechanisms. The first zone extends from R1 to R5 (south jetty to south of the attachment bar) and is located directly within Sebastian Inlet influence. The natural bypassing mechanisms control the sedimentation processes, with decadal changes characterized by

important sand impoundment and shoreline advancement. The second zone extends approximately from R5 to R16, and corresponds to the beach fill zone. The decadal changes showed this section was experiencing scour on both upper and lower shorefaces with shoreline retreat (-15 m) in the northern part from R6 to R11. Results further highlighted the necessity for beach fill operations on this R4-R16 section. The third zone extends from R16 to R30 which is a zone of complex reef morphology. The U shape morphology was evidenced by cross-section analysis at R25. Reef morphology acts as a natural sediment trap for retaining large features moving alongshore and being transported from the above beach fill zone. Decadal changes showed deposition on that zone and shoreline advancement peaking near R16-R18.

Model simulations showed that under waves approaching from the northeast sand transport was constrained/funneled landward of the offshore reef edge with increased magnitude and width near R16 while transport was reduced by the inlet in the upper north zone. The model was successful in reproducing net morphology changes from July 2009 to January 2010 and in particular the scour on the upper shoreface and deposition patches south of R20 resulting from the large sand bodies that moved alongshore in between the reef outcrops and were trapped in the upper shoreface zone where reef morphology changed. The presence of nearshore reef rock in the model simulation greatly controlled the scour on the upper shoreface while increasing deposition on the southern part of the domain. The measured trends in cross-sectional changes along 3 profiles (R5, R15, and R25) were successfully reproduced by the model simulation, including the positive profile changes observed landward of the reef outcrops across R25.

Ongoing work includes profile extraction at every R marker from R1 to R30 and a thorough characterization of reef outcrops using various parameters (distance from MHWL, width, etc.). The analysis is being performed over the past decade or so and combined with a data based model of the south beaches using a statistical approach to determine the empirical modes of change as a function of reef location.

Acknowledgements

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References

Buttolph. A.M., Reed, C.W., Kraus, N.C., Ono, N., Larson, M., Camenen, B., Hanson, H., Wamsley, T., and Zundel, A.K. (2006). Two-dimensional depth- averaged circulation model CMS-M2D: Version 3, Report 2, Sediment transport and morphology change. *ERDC/CHL TR-06-09,* U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Demirbilek, Z., Lin, L., and Zundel, A. (2007). WABED Model in the SMS: Part 2. Graphical Interface. *Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-I-74*. , U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Harris, L.E., 2003. Correlation between nearshore reef structure and shoreline change in Indian River County, FL. *Proceedings of Coastal Sediments '0,* CD- ROM Published by East Meets West Productions, Corpus Christi, TX ISBN- 981-238-422-7, 14 p.

Zarillo, G. A., Brehin F. G. A., 2009, STATE OF SEBASTIAN INLET REPORT: An Assessment of Inlet Morphologic Processes, Historical Shoreline Changes, and Regional Sediment Budget, *Technical Report 2009-1*, Sebastian Inlet Tax District, FL

Zarillo, G. A., Brehin F. G. A. 2007. Hydrodynamic and Morphologic Modeling at Sebastian Inlet, FL. *Proceedings of Coastal Sediments '07*, New Orleans, LA, ASCE Press, 1297-1311.