USING SPECIFICATION OF OVERBURDEN TO IMPROVE NUMERICAL LONGSHORE SEDIMENT TRANSPORT MODELING

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The Sebastian Inlet Florida Coastal Processes Model computes sediment transport pathways in the nearshore to support sediment management activities. Longshore sediment transport rates are computed by the model and compared with field data. The model is run with two alternative specifications of hard bottom to investigate the impact on computed transport rates. One alternative specifies known hard bottom outcrop locations and the second, a uniform one-meter overburden throughout the model domain. The uniform overburden specification improved longshore sediment transport rate computations throughout the model domain. The goal of this work is to improve upon nearshore sediment transport and morphology by addressing uncertainty in hard bottom locations and ephemeral coverage. This paper documents the modeling effort and the changes necessary to improve model performance in the nearshore.

Keywords: overburden, longshore sediment transport, tidal inlets

INTRODUCTION

The Sebastian Inlet is one of the few connections between Florida's Indian River Lagoon and the Atlantic Ocean. Sediments are routinely dredged from an interior sand trap located approximately 760 m from the inlet throat. A portion of the removed material is manually bypassed to the downdrift beaches on the south side of the inlet. The remained is stockpiled in an onsite dredged material management area (DMMA). The Sebastian Inlet District (District) is charged with managing the inlet resources and has employed the use of numerical models to assist in these management activities. Present work includes interest in refining longshore sediment transport calculations within the model.

Geologic Setting

High percentages of coarse carbonate material are present throughout the model domain and concentrated near areas of highest wave energy such as the ebb shoal crest. Percentages of this material can range from 7% to 96% averaging about 34% (Watts and Zarillo, 2015). The source of this material is primarily weathering of the Anastasia Formation coquina, which is exposed throughout the study area as rock outcrops. These rock outcrops are incorporated in the model as hard bottom (non-erodible areas). The grain size distribution can be bimodal. These sediment characteristics were developed from an intensive sediment sampling effort collecting and processing over 500 samples from winter and summer conditions. This large-scale sampling effort supported domain wide specification of sediments.

Geomorphology

The Sebastian Inlet is characterized by a large, well developed ebb shoal along with a downdrift attachment bar. From prior work, the sediment reservoirs in the system routinely hold and release material (Zarillo et al., 2018). The flood shoal volume has decreased by approximately 200,000 cubic yards over three years after dredging and expansion of the sand trap.

METHODS

Numerical Model

This section will briefly present the numerical model approach. For a more thorough description, see Watts, 2019, Zarillo et al., 2018, Zarillo et al., 2016 and Zarillo et al., 2014. The Coastal Modeling System (CMS) has been applied to this tidal inlet since 2007 and continues to be an effective tool to guide management activities at the inlet. The CMS is developed and maintained by the USACE Coastal Inlets Research Program (CIRP) and is documented in Sanchez et al., 2014a and Sanchez et al., 2014b. The annual modeling effort is supported by ongoing and comprehensive field monitoring that includes nearshore directional waves, currents, bottom water temperature, vertically referenced water surface elevation and standard meteorological observations including sea surface temperature. Bi-annual bottom topography surveys include beach profiles capturing the dune line to the -14 m

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contour using a combination of ATV, instrumented personal watercraft, single beam and multibeam methods. Full description of monitoring activities and real time field data is available in Zarillo, 2018.

This CMS consists of wave and flow models run implicitly and coupled. The wave model is run at a regional scale using Wave Watch III (Tolman, 2009) input to bring offshore waves to the local model boundary. The regional grid uses a traditional cartesian grid configuration with uniform refinement throughout. Regional grid consists of approximately 70,000 computational cells having an alongshore distance of 18 km and a cross shore span of 40 km extending to water depths of 40 meters. The local model domain spans approximately 18 km alongshore and 10.5 km offshore extending to a water depth of 17 km. This local domain encompasses the Indian River Lagoon as well as the Sebastian Inlet which is situated near the alongshore center. This local grid uses a quadtree telescoping approach that optimizes computational time while supporting high levels of resolution in nearshore and inlet areas. The flow grid contains nearly 300,000 computational cells ranging from 5 m by 5 m around the inlet area to a maximum of 160 m by 160 m in the offshore portions. Additional refinement was added to the nearshore areas to maintain uniform resolution alongshore to the approximate depth of closure. This uniform nearshore refinement increased model stability and resolved longshore sediment transport computations. Figure 1 shows the grid configuration and domain extents with quadtree telescoping refinement. Previous work (Watts and Zarillo, 2015; Zarillo et al., 2014) has indicated that a uniform alongshore refinement is most effective for simulating cross shore and alongshore processes.

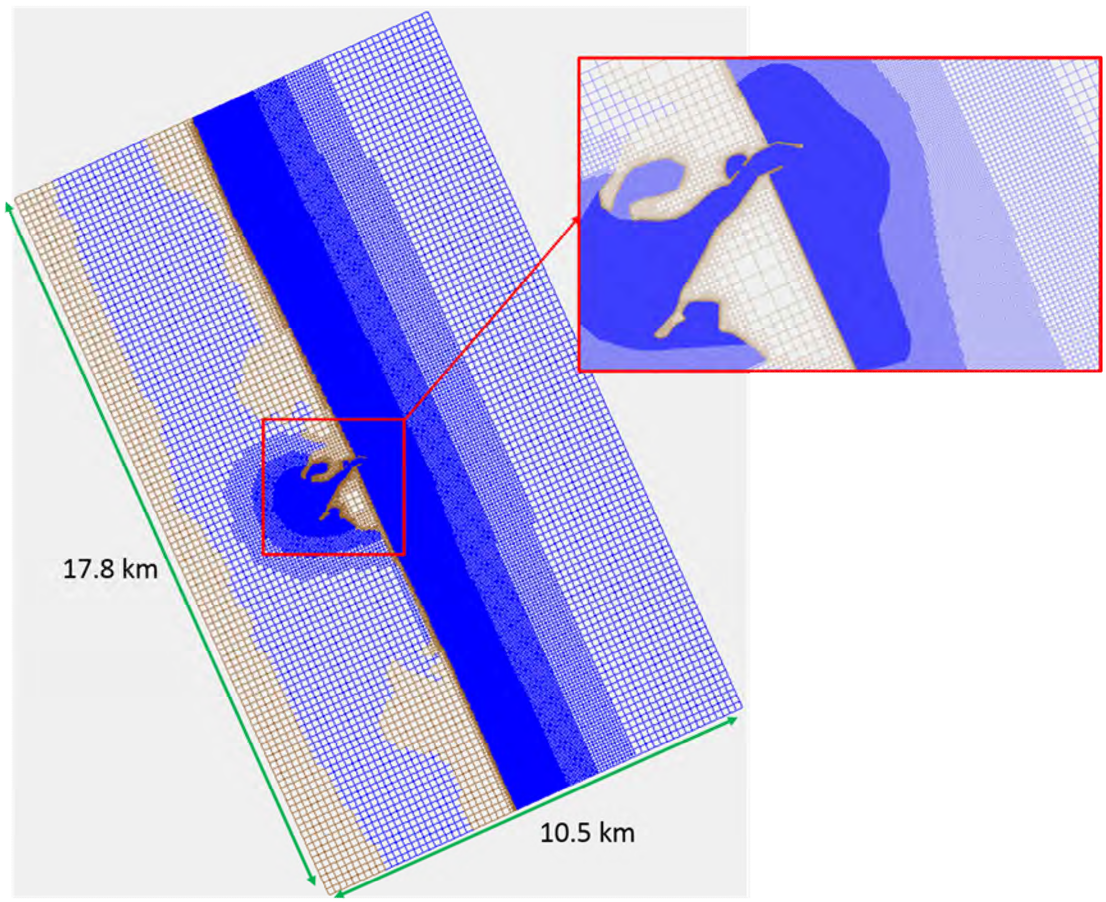

Figure 1. CMS local flow grid refinement.

Model temporal set up was determined by the bottom topography survey dates performed in summer and winter. The model run times are summarized in Table 1 and span between the seasonal survey events.

Table 1. Model temporal set up.

Model Run	Start	End	Months
Winter 2014 - 2015	6/1/2014	1/31/2015	8
Spring 2015	1/1/2015	7/31/2015	7

The sediments in the model are represented as single spatially varying modal grain size. Sediment characterization supported the development of winter and summer sediment delineations. Work documented in Watts and Zarillo (2015) indicated that modal grain size in contrast to the traditional D50 is more representative of this sedimentary environment.

The presence and specification of hard bottom is important in this model application. Reef and rock outcrops are present to the south of the inlet and their locations known and incorporated in the model. Rock outcrops to the south were acoustically mapped and subject to ground truthing via Scuba survey (Brehin, 2014). Additional field work via Scuba diving in the north portion of the domain indicated the presence of rock outcrops that were not previously mapped. Previous model runs indicated an overestimation of both longshore sediment transport (LST) and morphologic change. To examine the behavior of the model with respect to specification of overburden, two model runs were performed. One, including the mapped hard bottom outcrops to the south specified and a second, including hard bottom specified throughout the model domain to the depth of closure along with a 1 m overburden. These alternatives will be referred to as Model 1 and Model 2, respectively.

Longshore Sediment Transport Calculation Methodology

This section describes the methods for determining longshore sediment transport (LST) from the model and field data.

Model Results Analysis

The CMS uses a combined bed load and suspended approach to predict sediment transport referred to as the non-equilibrium total load (NET). The NET model for sediment transport uses a non-equilibrium approach to the suspended load and assumes a local equilibrium for the bed load. Sixty alongshore transects were constructed within the model domain as observational coverages to facilitate sediment transport rate determination from the primary model solution file. These cross shore transects correspond to the annual surveys that are based on the Florida Department of Environmental Protection Coastal Range Monument Locations (FDEP, 2017) and generally span 300 m between each profiles. It is known from previous work and examination of the ebb shoal and downdrift attachment point, that the net movement of sediments is from North to South. Directional convention for this analysis is towards the south for positive sediment transport and negative to the north. The average offshore water depth of these transects is 12.3 m, which is beyond the range of depth of closure computed at 7.4 m to 10.0 m (Brutsché et al. 2016). Sediment transport fluxes are calculated along each profile for the entire model run using the procedure documented in Sanchez et al., 2014a. The net total load sediment transport rate statistic was used for this work and is a temporal integration using the following relationship (Sanchez et al., 2014a).

$$\bar{Q}_t = \oint_L \frac{1}{T} \int_t (\vec{q}_t \cdot \vec{n})\, dt\, dL \qquad (1)$$

Where $\vec{q}_t$ is the total-load sediment transport rate vector, t is time, L is the length of the observational arc, and $\vec{n}$ is the unit vector normal to the observational arc. This methodology was used to compute the LST rate for each model run alternative.

Model Skill

Hydrodynamic model skill is evaluated using field measurements via bottom mounted Acoustic Doppler Current Profiler (ADCP) located north of the North Jetty at the 8 m depth contour. This unit provides directional waves, current magnitude and direction through the water column, water surface elevation and water temperature. The data from this gauge is used to quantitatively evaluate model skill for the hydrodynamics. Table 2 provides a summary of goodness of fit statistics developed for wave height at this location.

Table 2. Model skill winter 2014 simulation.

Parameter	Correlation Coefficient (R2)
Wave Height	0.72

For this work, the following guidance is used to evaluate the strength and direction of the correlation coefficient (R2). Table 3 summarizes these qualifications and are adapted from Sanchez, 2014a.

Table 3. Correlation coefficient qualifications.	
$0.7 < R^2 < 1$	Strong
$0.4 < R^2 < 0.7$	Medium
$0.2 < R^2 < 0.4$	Small
$R^2 < 0.2$	None

The calculated wave height indicates a strong relationship to the measured values at this location in the model domain. This paper focuses on evaluating the performance of LST throughout the model as compared to measurements. Model skill for morphology and sediment transport are addressed in the next section.

Measured LST

A digital elevation model (DEM) is generated using field data and interpolated onto the model grid using nearest neighbor. Field data included multibeam and single beam surveys conducted annually as part of the ongoing monitoring work. These data combined with bathy topo Light Detection and Ranging (LIDAR) data available through NOAA Digital Coast to create individual DEMs for spring and winter conditions. Measured cross shore profiles were extracted from the two seasonal DEMs using the observational arcs.

This method supports a 1-to-1 comparison to facilitate uniformity in comparison between measured and calculated datasets. Difference between summer (initial) and winter (final) profiles are calculated, and volume change is approximated by using trapezoidal integration within a MATLAB script. The trapezoidal integration is performed over the length of the profile with uniform point spacing. This volume change is then assumed to be uniform between observational arcs. The same observational arcs used in the LST rate calculations from the numerical model are used for the measured data to support analysis continuity.

RESULTS

Figure 2 plots the measured and computed LST rates alongshore for each observation arc. Alongshore distance is on the vertical axis and transport rate is on the horizontal. LST rates are provided in m3 over the 8-month observation period. A solid black line represents measured values. The dashed line with solid marker indicates model alternative 1 including rock outcrops only and the dotted line represents model 2 alternative that includes the global 1-meter overburden. The north end of the domain is at the top of the plot and south is represented at the base. The location of the inlet is approximately 8,600 meters from the north. The most northern portion of the domain is set as the origin.

Examining the trends alongshore for the study area, the incorporation of domain wide specification of hard bottom reduced the computed LST rates domain wide. This reduction in LST is nearly uniform alongshore. Maxima and minima of LST rates between the two model alternatives are maintained. Both models overpredict LST but follow trends of measured LST with isolated deviations.

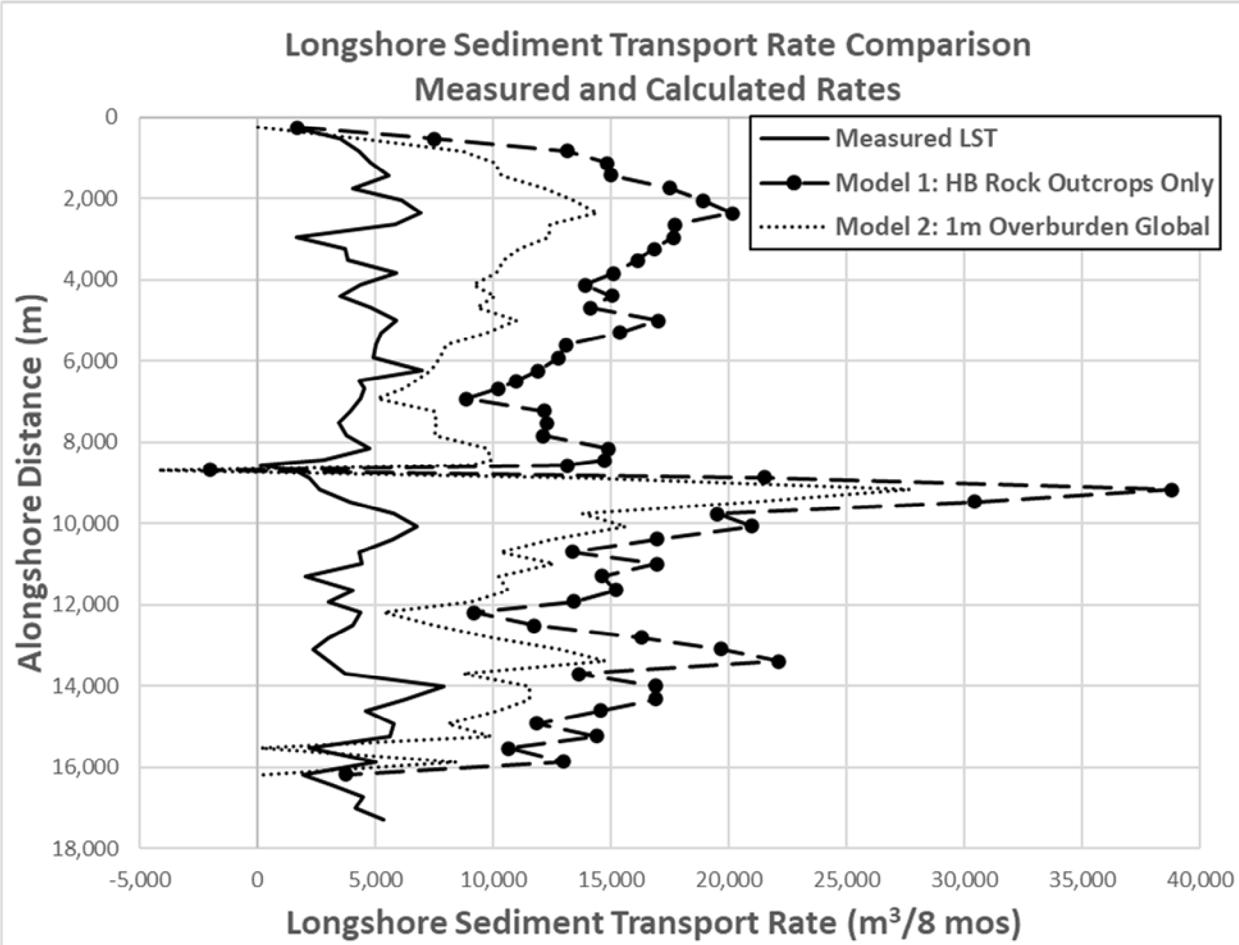

Figure 2. Longshore sediment transport rate comparison.

Table 4 provides a comparison between measured LST rates during the 8-month interval and both model alternatives along with the deviation from measured for both alternatives. Alongshore distance is referenced from the northern boundary of the model domain. The inlet is located approximately 8.5 km from the north boundary. Values are rounded to the nearest 100. For brevity, a selection of transects are provided in the north and southern portions of the model domain.

Table 4. Longshore sediment transport measured and modeled summary

Location	Alongshore Distance (m)	Measured (m^3 per 8 month)	Model 1: HB Reef Rock Outcrops only	Difference (Model 1 – Measured, m^3)	Model 2: Vertical Control 1 m HB	Difference (Model 2 - Measured, m^3)	Difference between Models (m)
North	2,000	6,100	18,900	12,700	13,400	7,200	5,500
	4,100	4,300	13,900	9,500	9,100	4,800	4,700
	6,500	4,300	11,000	6,700	6,700	2,400	4,700
	8,200	4,800	14,900	10,100	9,700	5,000	5,100
Inlet							
South	8,900	2,200	21,500	19,300	13,900	11,700	7,600
	9,800	5,800	19,500	13,700	13,800	8,000	5,700
	11,300	2,000	14,600	12,600	10,300	8,200	4,400
	14,000	8,000	16,900	9,000	11,600	3,600	5,400

The tidal inlet is an alongshore discontinuity and processes acting south of the inlet are not necessarily the same as the north. The mean error is presented in Table 5 by shoreline segment and by model alternative. Mean error was computed as the mean of the difference between measured and calculated values. Positive values indicate an overprediction of the model for sediment transport.

Table 5. LST mean error (m^3).

Model Alternative	North of Inlet	South of Inlet
1	9,500	9,700
2	4,700	5,000

The error is reduced by 50% in the north and 48% in the south with the incorporation of domain wide overburden. The model error increases to the south for both model alternatives. This is likely due to the inlet influence and the need for better representation of the flow through the inlet throat.

DISCUSSION

Uniform Reduction in LST Alongshore

Examining the system, the incorporation of the domain wide overburden above a non-erodible hard bottom, reduces sediment transport rates globally and brings computed LST rates closer to the measured values. This may indicate that the LST reduction may be independent of processes involved in sediment transport but more closely related to sediment volume availability in the model.

Performance of LST Computations Alongshore of a Tidal Inlet

This section evaluates the performance of the model at specific areas within the domain that are subject to different processes. Comparing the performance of the model north of the inlet to the performance south of the inlet, deviation from the measured values is larger moving southward away from the inlet. Error from measured values was largest at observational arcs located closest and south of the inlet.

Arc 31 is approximately 60 m south of the inlet and closest to the south jetty of Sebastian Inlet. This arc is approximately 8,700 m from the north boundary of the model domain. This location is likely in the recirculatory cell that forms immediately downdrift of the inlet. This arc predicted LST rates in the opposite direction to measured. The model for both alternatives predicted sediment erosion rather than sediment accretion as indicated by observations. This is also the only location where Model 2 alternative caused a larger bias from measured values rather than an improvement. This is one of the areas of maximum rock exposure and minimal overburden.

Arcs 32 through 36 (8,900 – 10,000 m alongshore from the north boundary) had the largest departure from measured values. This region includes the downdrift attachment bar and continues approximately 600 m southward. This area is in direct influence from the inlet and waves refracting and breaking over the ebb shoal and downdrift attachment point. These complex processes lead to a challenging environment to simulate.

Considering the shoreline north of the inlet, the model consistently overpredicts LST and this bias increases for Arcs 25-30, which span approximately 1.5 km north of the inlet. This behavior indicates the model is overpredicting movement of material relative to measured observations. Arcs 29 and 30 are closest to the north jetty and indicate a reduction in sediment movement during this time period rather than an increase indicated by measured values. The dominant wave direction is from the north east and net LST is directed southward. However, episodic reversals have been observed in bottom mounted ADCP data. The north jetty was constructed with rubble mound rocks in the late 1940s and extended in 1972. In 2003, a fishing pier was constructed on top with support pilings. The fishing pier and support pilings make surveying the rubble mound jetty difficult and the condition of the rubble mound structure is unknown.

The rubble mound height specification within the model is set from LIDAR data performed before the fishing pier was constructed. A small shoal routinely forms immediately south of the jetty within the inlet throat which is likely from material passing through the jetty.

This model application benefits from recent advancements in the CMS for incorporation of structures and a more recent survey of the structure using advanced LIDAR techniques to resolve the jetty and support pilings would be beneficial. Additional 3D structure modeling or a tracer study would need to be applied to investigate the impact the pilings have on the flow conditions and the porosity of the underlying jetty structure.

The greater bias for larger LST rates south of the inlet may in part be due to poor representation of the ebb jet. There is a lack of field data for currents through the inlet and the seaward extent of the ebb jet beyond what can be seen in aerial imagery. Therefore, the model has not undergone rigorous calibration for currents through the inlet, which may not be well represented in the model. The channel throat is hard bottom and was constructed by excavating into the Anastasia Formation primarily composed of coquina. From a qualitative standpoint, ephemeral shoals as channel linear marginal bars are predicted in the model and compare well with field observations. However, the model would benefit from direct field measurements of currents.

CONCLUSIONS AND FUTURE WORK

Complete and correct representation of the environment being modeled is paramount for accurately calculating any coastal process. Calculated LST has been improved by incorporating a representation of bedrock or overburden. Future field work will include sub-bottom mapping of the location of bedrock for computation of overburden for entire model domain. The model computations for LST are reasonable but have potential for improvement with incorporation of additional refinements to the representation of sediment overburden and texture. Further adjustments to rock outcrops and overburden in areas immediately south of the inlet is recommended.

This work determines LST from successive bottom topography surveys that are compared to LST values calculated by a process-based model. This method could be improved and better calibrated by additional comparisons between LST values and field values. Future work will involve suspended sediment sampling to calibrate bottom mounted ADCP backscatter measurements.

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REFERENCES

Brehin, F.G. 2014. Management at Sebastian Inlet, Florida. (Doctorate of Philosophy in Oceanography Dissertation), Florida Institute of Technology, Melbourne, FL.

Brutsché, K. E., Rosati III, J., Pollock, C. E., & McFall, B. C. 2016. Calculating Depth of Closure Using WIS Hindcast Data (CHETN-IV-45). Retrieved from Vicksburg, MS.:

FDEP. 2017. Coastal Range Monument Locations. Retrieved from: http://geodata.dep.state.fl.us/datasets/coastal-range-monument-locations

Sanchez, A., Lin, L., Demirbilek, Z., Beck, T., Brown, M., Li, H., Zundel, A. 2014a. Coastal Modeling System User Manual. Vicksburg, MS: Coastal and Hydraulics Laboratory.

Sanchez, A., Wu, W., Li, H., Brown, M., Reed, C., Rosati, J. D., & Demirbilek, Z. 2014b. Coastal Modeling System: Mathmatical Formulations and Numeric Methods. Vicksburg, MS.

Tolman, H. L., 2009: User manual and system documentation of WAVEWATCH III version 3.14. NOAA / NWS / NCEP / MMAB Technical Note 276, 194 pp.+ Appendices.

Watts, I. M. 2019. Advancing Numerical Calculation of Mixed Sized Sediment Transport and Morphology Change (Doctoral dissertation).

Watts, I. M., Zarillo, G. A. 2015. Numerical Modeling of Mixed Size Sediments in Mixed Energy Environments. Paper presented at the Proceedings of the Coastal Sediments 2015, San Diego, CA.

Zarillo, G. 2018. Coastal Processes Research Group. Retrieved from https://research.fit.edu/wave-data/

Zarillo, G., Watts, I. M., Erickson, L., Hall, K., & Ramos, S. 2018. State of Sebastian Inlet Report: 2018 An Assessment of Inlet Morphologic Processes, Shoreline Changes, Local Sediment Budget and Beach Fill. Florida Institute of Technology, Melbourne, FL.

Zarillo, G. A., Watts, I. M., Erickson, L., Hall, K., & Enfinger, J. 2016. State of Sebastian Inlet Report 2016. Florida Institute of Technology, Melbourne, FL.

Zarillo, G. A., Watts, I. M., Erickson, L., Brehin, F. G., Hall, K., & Chauhan, S. N. 2014. State of Sebastian Inlet Report 2014: An Assessment of Inlet Morpholoigc Processes, Shoreline Changes, Sediment Budget and Beach Fill Performance. Florida Institute of Technology, Melbourne, FL.