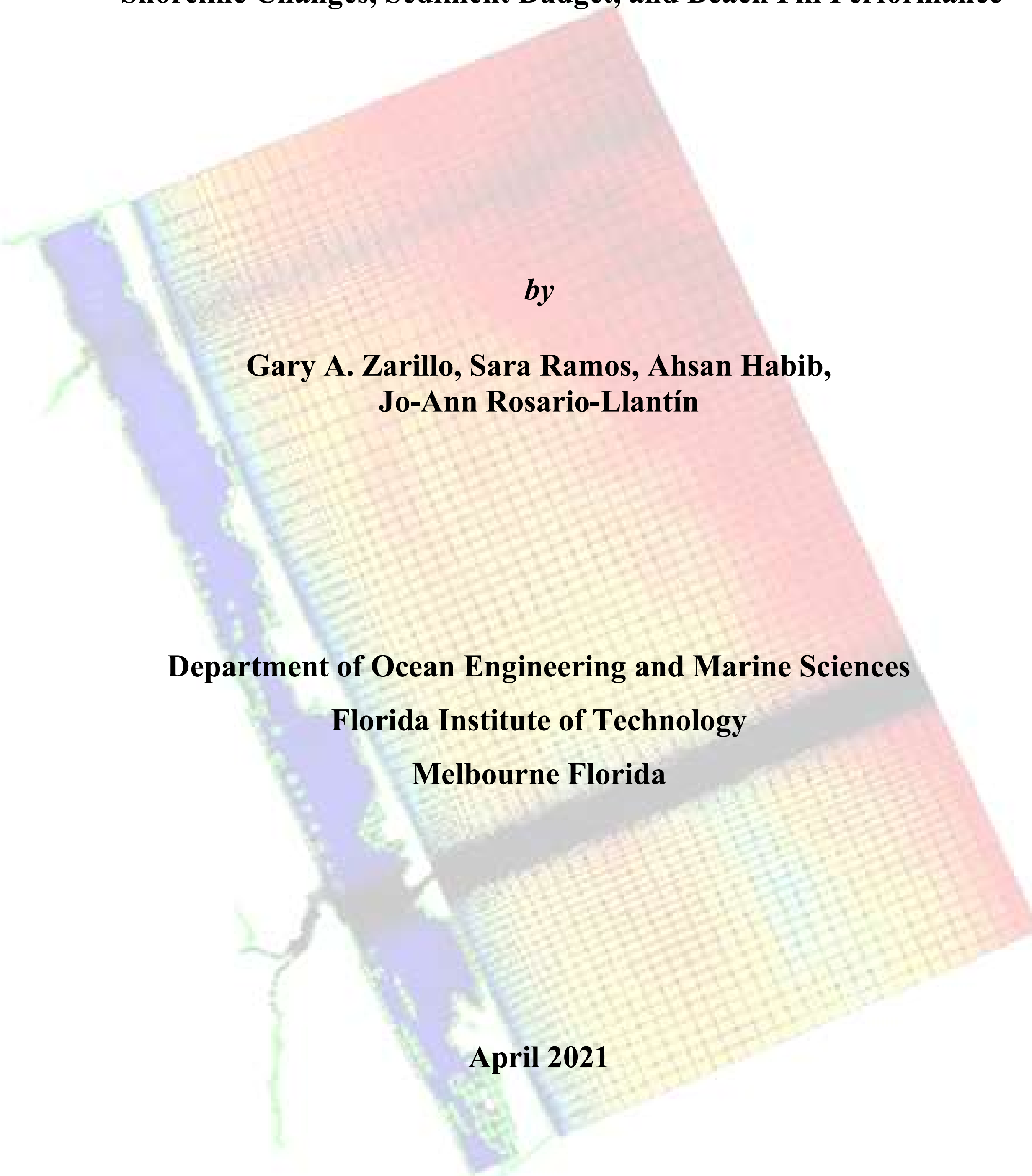
STATE OF SEBASTIAN INLET REPORT: 2020

An Assessment of Inlet Morphologic Processes, Shoreline Changes, Sediment Budget, and Beach Fill Performance



by

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Executive Summary

The annual update of the State of Sebastian Inlet includes five major areas of work; 1) an update of the analysis of volume contained in the sand reservoirs of the inlet system, 2) analysis of morphologic changes within the inlet system, 3) calculation of the sand budget based on the results of the sand volume analysis, 4) an update of the shoreline change analysis, and 5) development of a real time and forecast hydrodynamic model of Sebastian inlet and vicinity.

The sand volumetric analysis includes the major sand reservoirs within the immediate inlet system and sand volumes within the sand budget cells to the north and south of Sebastian Inlet. The volume analysis for each inlet sand reservoir extends from 2006 to 2020. Similar to the volumetric analysis described in previous state of the inlet reports, most inlet sand reservoirs are in a long-term dynamic equilibrium characterized by occasional large seasonal changes in volume superimposed on longer term interannual trends. An examination of coastal sea level changes and sand volume changes between 2006 and 2020 revealed two important processes. First, is can be demonstrated that the Sebastian Inlet sand reservoirs and the beach and shoreface areas both to the north and to the south of the inlet undergo periods of regional volume losses and periods of volume gains. These gains and losses cover the entire region rather than being inversely linked to gains or losses in adjacent subsections

When sea level records measured at Sebastian Inlet are examined over the 14-year period between 2006 and 2020, it can be demonstrated that periods of cumulative sand volume losses or correspond to periods of rising sea level. Conversely, periods of falling sea level correspond to periods of increasing sand volume. Regional sand volume changes occur at a lag period of about one year with respect to sea level changes. Further, the sea level record for late 2019 and the first eight months of 2020 indicates that another period of falling is underway. This suggests a potential for an upcoming period of sand volume gains may occur if the trend continues.

The dynamic equilibrium and trends of sand volume change within the inlet sand reservoirs associated with Sebastian Inlet are also reflected in sediment budget calculations. In this report the sand budget for the Sebastian Inlet region is calculated at three time scales, including a longer time scales of 10 years , a time scale of 5 years, and a shorter time scale of 3 years. The most useful time scale is considered to be 10 years since it integrates over seasonal sand volume changes that can mask longer term trends. Over the time period of 2006 to 2020, the benefits of sand by-passing from the sand trap and beach fill placement to the south of the inlet can be shown to mitigate sand volume losses on the south side of Sebastian Inlet even when other areas are losing sand volume. The impacts of rising and falling sea level are more apparent in the 10-year and 5-year sand budget. Shorter term budgets cannot account for the lag-time over which shoreface and beach sand volumes adjust to interannual sea level changes.

Similar to the sand volume analysis, the results of shoreline mapping from survey data and aerial imagery vary considerably by time scale and by data sets from which they are derived. Differences between shoreline position bases on aerial imagery are compared with shoreline

extracted from survey data. Over the 10-year time scale from 2010 to 2020, shoreline changes south of the inlet reflect the position of beach fill placement in 2011, 2012 and 2014 and 2019. These projects provided sections of advancing or stable shoreline. Guidance is provided for interpreting shoreline position versus sand volume analysis in terms of evaluating the stability of the beach and shoreface.

A new real time and forecast three-dimensional coastal processes model of Sebastian Inlet is described in this report. The model is based on the Deltares Delft3D numerical model code designed for shallow marine and estuarine environments. The model operates on a high resolution computation grid that is nested in much larger basin scale ocean and atmospheric models. A summary of the model setup and performance is presented in this report. A detailed technical document on this ongoing model effort is available from the Coastal Processes Research Group at Florida Tech.

Based on this analysis recommendations are made for management of sand resources by the Sebastian Inlet District

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1.0 Introduction and Previous Work

This report extends the analysis of the State of Sebastian Inlet from the publication of the 2019 report through the late summer months of 2020 . In the original 2007 report, sand volume changes, sand budget, and morphological changes between 1989 and 2007 were examined (Zarillo et al. 2007). In addition, shoreline changes were documented between 1958 and 2007 using aerial images and between 1990 and 2007 using field survey data. In the 2013 report, much of the long-term analysis presented in the 2007 report was summarized in the main body of the text and re-stated in a series of appendices. This effort was to present a long-term analysis of inlet evolution and associated management strategies that have been applied over the years. The 2016 ,2017 and 2019 reports emphasized the sand volume calculation within the sand reservoirs and sand budget cells of the Sebastian inlet area. At this time the major sand budget cells and sand reservoirs were more or less stable in terms of longer term trends outside of seasonal fluctuations. In the present report, the morphological analysis, sand budget analysis and the shoreline analysis are updated to 2020. The movement and exchange of material between the sediment reservoirs during and after the storm are be examined as well as the hydrodynamic conditions during the storm. In addition, the new real time three-dimensional Deltf3D circulation model of Sebastian Inlet and adjacent coastal and estuarine waters is introduced.

2.0 Sand Volume Analysis and Sediment Budget

This section of the report provides an update of the sand budget around the inlet based on semiannual surveys of topography and changes in the sand volume contained in the various shoals associated with Sebastian Inlet. Much of the information in this report can be found in a series of annual "State of the Inlet" reports issued since 2007. The body and appendices of these reports provides detailed analyses of morphological and physical processes that control the dynamic equilibrium of the Sebastian Inlet system. In this section of the 2020 Inlet report details of sand volume and sediment budget exchanges around the inlet are provided to verify and update the Sebastian Inlet Sand Budget

The sandy shoals and veneers of sand within the Sebastian Inlet system are considered sand volume reservoirs that can gain, retain, and export sand throughout the system. A conceptual model of inlet sand reservoirs is given in a paper by Kraus and Zarillo, (2003). The concepts presented in this paper are the conceptual basis of littoral sand budgets in the vicinity of tidal inlets. Figure 1 shows the concepts of exchanges among tidal inlet sand reservoirs, including bypassing of sand across the inlet entrance to nourish adjoining shoreface and beaches. The visual concepts included in Figure 1 are the basis of terms used in sediment budget calculations (Rosati et al 1999).

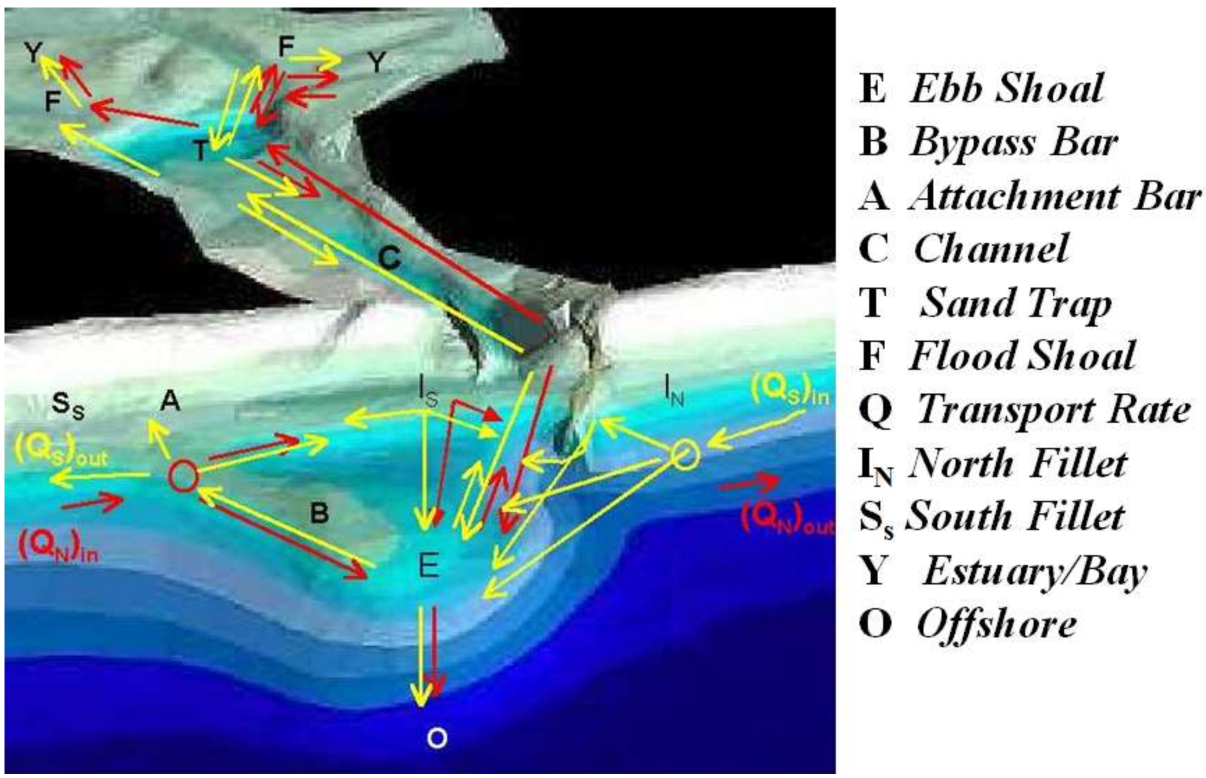

Figure 1. Schematic vector diagram of sediment transport pathways among sand reservoirs at Sebastian Inlet (From Kraus and Zarillo, 2003).

After a review of the sand volume changes within Sebastian Inlet shoals and sand budget cells over a 10-year period, the annualized sand budget in the inlet region is quantified. Sand budgets are presented as annualized terms but calculated over intermediate to longer term time periods. It will be noted in the summary and conclusions that the magnitude of the budget terms, including sand volume retained or exported by the inlet can change according to time scale (Zarillo, 2010). Time scales of 5 years and longer, provide fewer variable terms and more consistency for management.

2.1 Sand volume analysis methods

Certified hydrographic surveys of the inlet system and the surrounding shoreface and beaches have been conducted for the by Sebastian Inlet Tax District (SITD) since the summer of 1989. Table 1 lists the surveys completed in since 2006. Starting in winter 1991, surveys have been performed on a semiannual basis. Offshore elevation data are gathered by a combination of conventional boat/fathometer methods and multibeam acoustic surveying methods from -4 ft. to -40 ft.NAVD88 in accordance with the Engineering Manual for Hydrographic Surveys (USACE, 1994). Multibeam data are collected on the south side of Sebastian Inlet from FDEP Range Maker R1 through R17 in Indian River County, FL.

Figure 2 shows the survey area including the entire inlet system (ebb shoal, throat, sand trap and flood shoal, etc.), and the adjacent barrier island system as well. The survey area extends approximately 30,000 ft. north (Brevard County) and 30,000 ft. south (Indian River County) of the inlet. Beach profiles taken about every 500 ft. Since 2011, survey methods have included multi-beam swath on the south side of the inlet entrance. The multibeam data provides high spatial resolution in areas where reef rock outcrops occur. The dredged channel extension between the inlet and the Intercoastal Waterway (ICW) to the west has been surveyed semi-annually since it was constructed in 2007.

This comprehensive dataset provides excellent support for volumetric calculations of inlet shoal and morphologic features, as well as for the analysis of changes in shoreline position through a “zero contour” extraction technique. Datasets used for this report are complete though the summer of 2020.

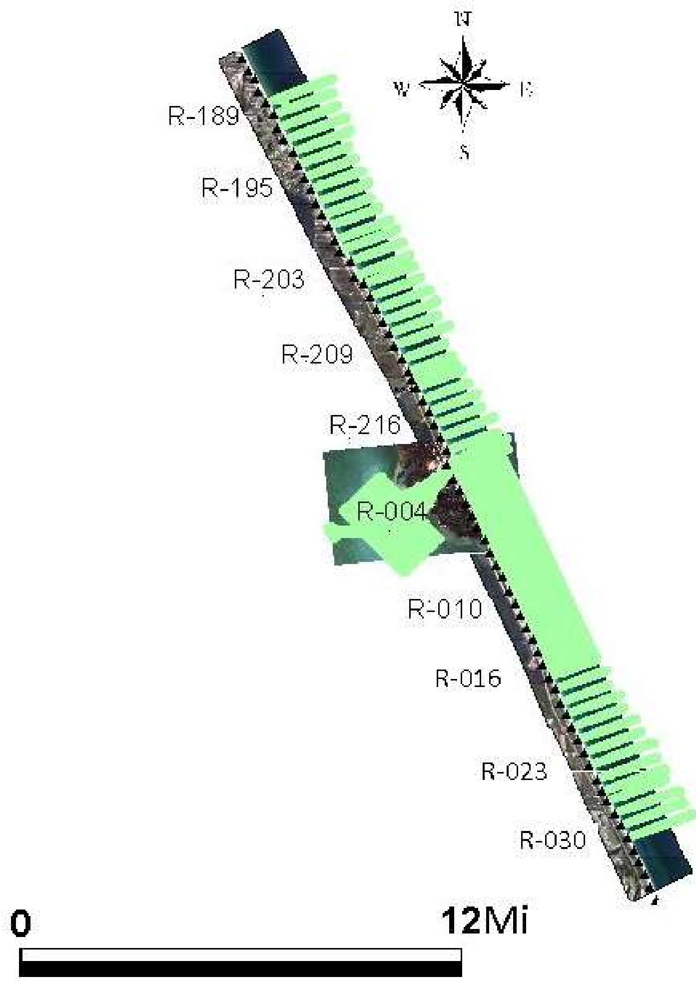

Figure 2. Extent of hydrographic survey (2019 winter).

Table 1. Summary of Hydrographic Surveys completed since 2006

Survey Date	Ebb shoal	Channel	Sand trap	Channel Extension	Flood shoal	North beach (ft)	South beach (ft)
2006-2007	x	x	x			30,000	30,000
Jan-08	x	x	x		x	30,000	20,000
Jul-08	x	x	x	x	x	30,000	30,000
Jan-09	x	x	x	x	x	30,000	30,000
Jul-09 *	x	x	x	x	x	30,000	30,000
Jan-10 *	x	x	x	x	x	30,000	30,000
Jul-10 *	x	x	x	x	x	30,000	30,000
Jan-11 *	x	x	x	x	x	30,000	30,000
Jul-11 *	x	x	x	x	x	30,000	30,000
Jan-12 *	x	x	x	x	x	30,000	30,000
Jul-12 *	x	x	x	x	x	30,000	30,000
Jan-13 *	x	x	x	x	x	30,000	30,000
Jul-13 *	x	x	x	x	x	30,000	30,000
Jan-14 *	x	x	x	x	x	30,000	30,000
Jul-14 *	x	x	x	x	x	30,000	30,000
Jan-15 *	x	x	x	x	x	30,000	30,000
Jul-15*	x	x	x	x	x	30,000	30,000
Winter 2016*	x	x	x	x	x	30,000	30,000
Summer 2016*	x	x	x	x	x	30,000	30,000
winter 2017*	x	x	x	x	x	30,000	30,000
Summer 2017*	x	x	x	x	x	30,000	30,000
Winter 2018*	x	x	x	x	x	30,000	30,000
Summer 2018*	x	x	x	x	x	30,000	30,000
Winter 2019*	x	x	x	x	x	30,000	30,000
Summer 2019	x	x	x	x	x	30,000	30,000
Winter 2020*	x	x	x	x	x	30,000	30,000
Summer 2020	x	x	x	x	x	30,000	30,000

* Multibeam data

Once each hydrographic survey is complete, volumetric data are added to the series of volume changes and volume changes from one survey to another are calculated. For consistent comparison from survey to survey, the Sebastian Inlet region is divided into subsections representing either a sand budget cell or sand reservoir. Figure 3 shows the sand budget cells used to calculate the changes in sediment volume associated with littoral transport rates over time. The N4 and N3 cells are north of the inlet entrance. N4 is bounded by FDEP R-Markers R189 and R195 in south Brevard County whereas the N3 sand budget cell is bounded between R195 and R203. The N2 and N 3 cells are placed between R203 and R-216. The inlet cell includes all of the sand reservoirs shown in Figure 4 and are bounded to the north by R-216 and to the south in Indian River County by R-4. On the south side of Sebastian Inlet sand budget cells are designated as S1, S2, S3 and S4. The S1 cell begins at R-4 and is bounded to the south by R-10 followed by the S2 cell bounded between R-10 and R16. Sand budget cell S3 extend from R-16 to R-23 followed by cell S4, which terminates at R30. All of the cells extend seaward to an approximate depth of -25 feet, NAVD88, which is considered beyond the depth of closure for changes in topography.

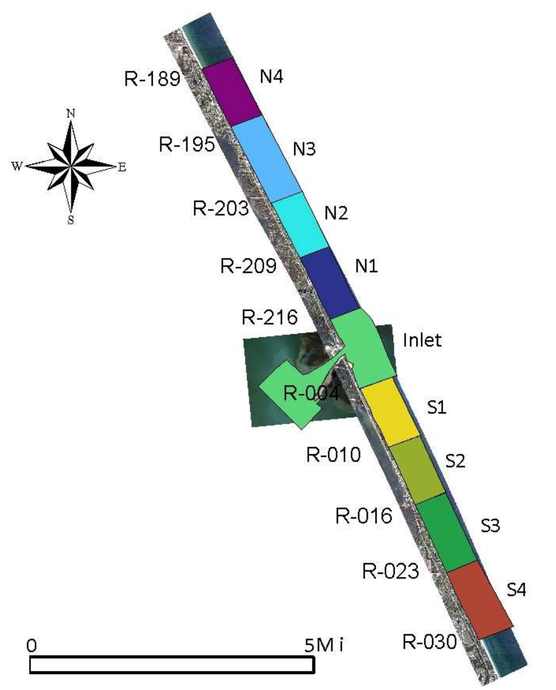

Figure 3. Sand budget cells.

Within the Inlet sand budget cell (Figure 3), further subdivisions are made to characterize sand reservoirs that exchange sand under the influence of strong tidal currents and waves. These subdivisions are shown and identified in Figure 4. Two of the sand reservoirs, the flood shoal and the ebb shoal are volumetrically large and control the magnitude of the topographic changes and sand bypassing within the Sebastian Inlet. The major reservoirs include the ebb shoal, flood shoal, and the sand trap. The sand trap, first excavated in 1962, re-established in 1972, and expanded in 2014 also influences the volume of the sand budget when it is periodically dredged. The most recent excavation of the sand trap was complete in June 2019. Approximately 124,000 cubic yards of material was dredged from the sand trap of which 113, 500 cubic yards were placed on the beaches to the south of inlet between Indian River County R-Markers R10 and R17. Approximately 52,700 cubic yards of material were placed in the Sebastian Inlet dredge material management area (DMMA). Other sand reservoirs contain lower sand volume relative to the ebb and flood shoals and the sand trap, but may exert influence over sand transfer as exchange locations as shown in Figure 4. The attachment bar on the south side of the inlet serves this role.

The raw survey data in Easting, Northing, and elevations are imported into the ArcGIS software platform. Using 3D analysis and spatial analysis capabilities of GIS, the total volume of sediment in each cell or reservoir is calculated relative to a base elevation. These volumes are then compared between survey dates.

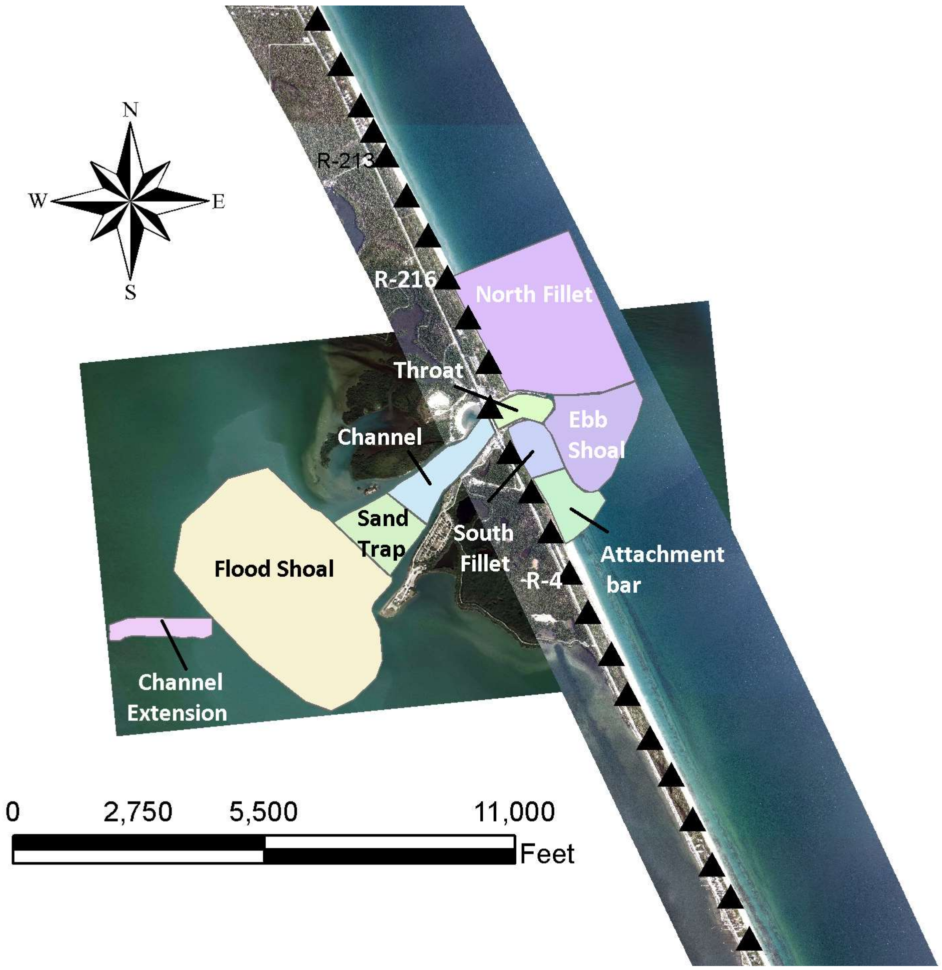

Figure 4. Morphologic features forming the inlet sand reservoirs.

2.2 Sand reservoir volume analysis

The sand reservoirs are contained within the inlet sand budget cell (Figure 3 and Figure 4). In order to fully understand the sand budget process, it is important to examine volume adjustments of each sand reservoir over time and in terms of variability and volume magnitude. Along with the sand reservoirs within the inlet, it is also useful to examine sand volume changes in sand budget cells contained within the barrier island system to the north and south of Sebastian Inlet. By considering the volume and variability of budget terms over shorter and longer time periods, the sand budget analysis can be more effectively applied to managing the regional sand resources. Thus, before presenting the sand budget for the Sebastian Inlet region, the volume evolution is reviewed for the major inlet sand reservoirs and for the cells within the sand budget calculation.

Results presented in the volumetric analysis are divided into two subsections. Section 3.1 presents the volumetric evolution of the largest sand reservoirs within the inlet sand budget cell (Figure 4) with plots of net seasonal and cumulative volume change over time. Section 3.2 presents the volumetric evolution of the inlet littoral cells used for the sand budget computation. The calculated net seasonal volume changes (ΔV) serve as inputs to the sand fluxes (ΔQ) for the budget calculations discussed in Section 4. When reviewing the time series plots of volume changes in sand reservoirs and sand budget cells, the range of the vertical scale should be noted for each. Smaller sand bodies having less total volume have a much smaller range in volumetric changes compared to large sand bodies such as the flood shoal.

The volumetric evolution of the ebb shoal from 2005 to 2020 is illustrated in Figure 5. Volume gains and losses that integrate over time to provide net volume change occur on short time scales that are usually on the order of 6 to 12 months. Volume gains or losses are most often followed by counter balancing volume losses or gains. For instance, 12 months of sand volume gains totaling about 89,000 cubic yards on the ebb shoal from July 2013 to July 2014 were followed by about a 50,000 cubic yard sand volume loss from July 2014 to winter 2015. This was followed by about 85,000 cubic yards of column gain though the summer months of 2016 (Figure 5). Little net change occurred from the summer of 2016 to the survey completed in summer of 2018. Since the 2018 the ebb shoal has lost about 50,000 cubic yards of its volume.as of the summer of 2020. Although seasonal and annual changes on the ebb shoal can reach and exceed 50,000 cubic yards it is important to recognize trends of volume change that occur over longer segments of time and can contributed to the overall sand budget of Sebastian Inlet. In Figure 5 a trend of increasing ebb shoal sand volume occurred over an approximate 5 year period between 2005 and 2010 that totaled about 150,000 cubic yards. This was followed by a 3-year period of stability between 2010 and 2013 that bounded a small net loss of 20,000 cubic yards of sand. Between the winter 2013 and winter 2018 survey the ebb shoal gained approximately 100,000 cubic yards. The recent trend of rising sea level and associated sediment processes may have contributed to the loss of ebb shoal volume since 2018. The ebb shoal volume along with volume changes in the flood shoal and sand excavations from the sand trap dominate the sand budget changes linked the inlet. These interactions are discussed under Section 4 of the report.

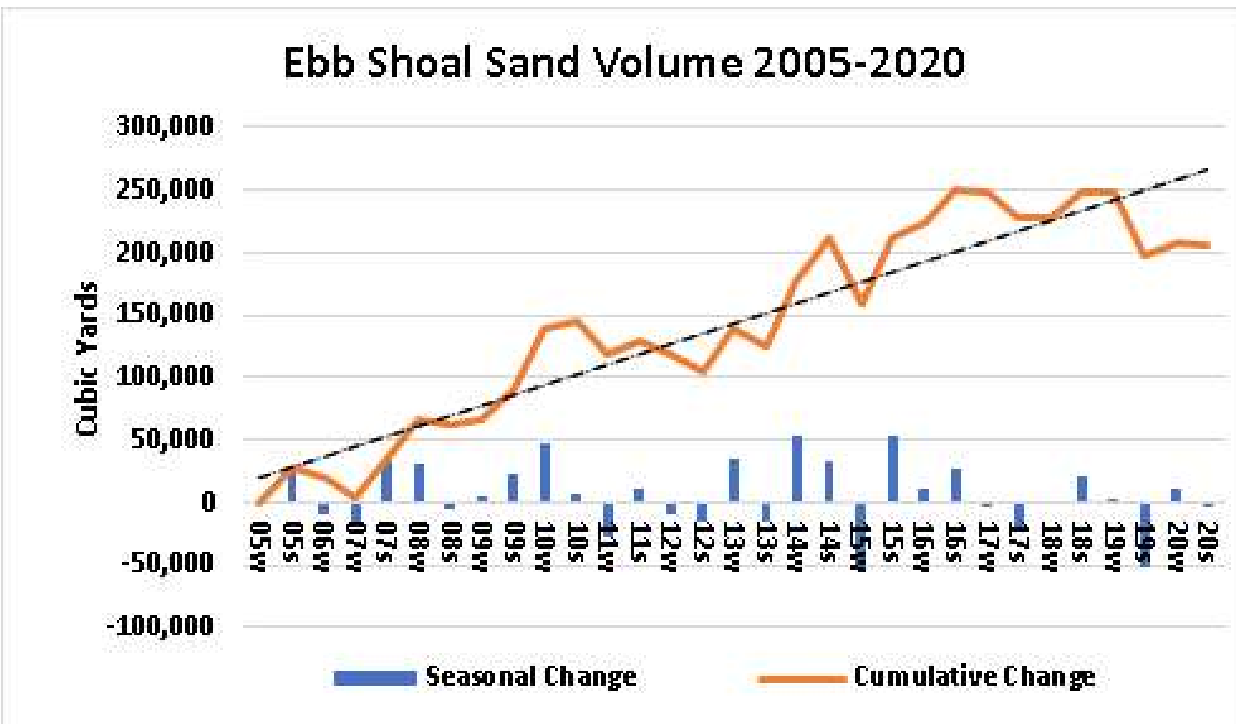

Figure 5. Volumetric evolution of the ebb shoal from summer 2005 to summer 2020.

The sand volume changes of the attachment bar are small due to its role as a sediment redistribution zone rather than an accumulation or storage zone (Zarillo et al., 2007). As seen in

Figure 6, volume changes alternate between positive and negative on a seasonal basis. Increases in sand volume usually occur during the winter season of higher wave energy, whereas volume losses from the attachment bar usually occur during the summer season. It is likely that the winter sand volume increases are due to sand bypassing around the inlet entrance by higher energy winter wave conditions. Losses in the summer months are likely due to the movement of sand further south or back to the inlet entrance during the lower energy conditions of the summer season and north directed littoral sand transport by wave energy from the southeast in the summer. Most recently an increase in bar volume of about 70,000 cubic yards seen in the summer 2019 survey may be related to partial back passing of sand placed between R10 and R17 from the sand trap in the winter of 2019. This was partially balanced by a volume loss of about 40,000 cubic yards by winter of 2020. Sand volume in the attachment bar has increased by about 35,000 cubic yards since 2005.

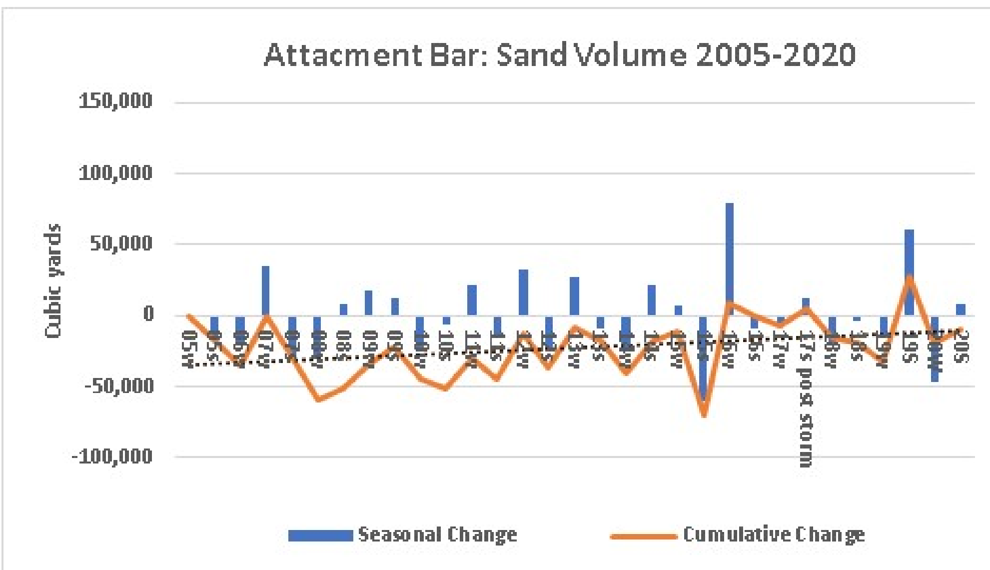

Figure 6. Volumetric evolution of the attachment bar from summer 2005 to winter 2020.

The volumetric evolution of the sand trap is presented in Figure 7. The trends and patterns of volume change are dominated by excavation from the sand trap in 2007, 2012, 2014, and 2019. Post dredge annual sand volume gains are on the order of 30,000 to 40,000 cubic yards averaging 15,000 to 20,000 cubic yards every 6 months. The pattern in Figure 7 shows that the highest rate of sand volume gains occurs in the first 6 months after dredging followed by smaller gains or small loss of volume thereafter until the next dredging cycle. The record from January, 2012 to July, 2014 clearly marks the recent dredging projects to bypass and expand the sand trap in 2014. Figure 7 illustrates the mechanical bypassing of spring 2012 with the removal of approximately 122,000 cubic yards of sand from the sand trap. In the winter to spring of 2014, approximately 160,000 cubic yards of material were removed as the trap was expanded. About 120,000 cubic yards of this material was placed to the south of Sebastian Inlet between R4 and R10. Since the 2014 sand trap expansion sand volume gains totaled about 121,000 cubic yards through the summer of 2018. The gains include about 43,000 cubic yards in the first six months after dredging followed by smaller gains of less than about 6,000 cubic yards per year through the winter of 2016. Analysis of surveys in summer 2016 and winter 2017 indicate a total gain of about 37,000 cubic yards of sand. Sand volume gains in the second half of 2017 were minimal but followed by a gain of about 28,000 cubic yards by the winter survey of 2018. The winter survey of 2019 showed a sand volume loss of about 90,000 cubic yards related to the ongoing dredging of the sand trap. The final as built survey indicates 124,000 cubic yards of sediment was removed from the sand trap. Since the 2019 by pass project the sand trap has gained approximately 40,000 cubic yards of new sediment (Figure 7.

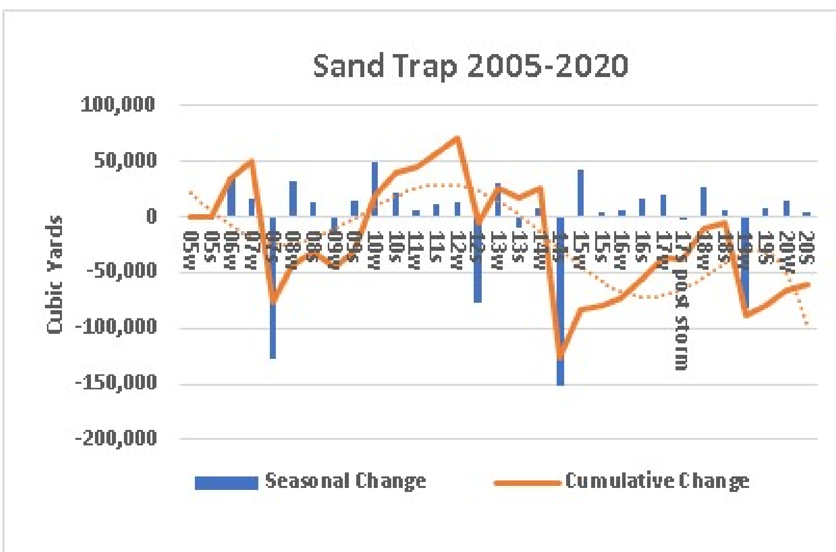

Figure 7. Volumetric evolution of the sand trap from winter 2005 to winter 2020.

Volumetric changes for the flood shoal (Figure 8) can be more than 100,000 cubic yards on a seasonal basis.   Temporary losses of sand volume of more than 50,000 cubic yards from the flood shoal are associated with sand trap dredging, which temporarily limits the supply of sand reaching the shoal. The pattern of recovery can be seen after the sand trap excavation in 2007 when the flood shoal recovered and increased its volume by summer of 2008. A period of continuing relatively large sand volume loss began in January, 2011 and continuing through 2014 when the sand trap was expanded. Initial losses may have been due to loss of sea grass coverage beginning in 2011, which helps to stabilize the flood shoal. After expansion of the sand trap in 2014, the flood shoal entered a period of recovery and expansion, which continued through the summer of 2015 as seen in Figure 8. Seasonal variations in the ebb shoal volume were on the order of 25,000 to 50,000 cubic yards through 2018, followed by a sand volume loss of about 100,000 cubic yards. The sand volume loss recorded by the winter 2019 survey is linked to dredging of the Sebastian Inlet Sand Trap as described in this, and previous State of the Inlet Reports. It is likely that the flood shoal volume will increase over time as the sand trap re-fills and sand is passed to the flood shoal. As of the summer survey of 2020 the flood shoal volume has reached a minimum and has begun to rebound as the sand trap (Figure 7) is filling with new material and sand can be transported past the trap into the flood shoal.

Net volume change of the flood shoal in the 14-year period since 2006 is an approximate a loss of only about 115,000 cubic yards, although intra-annual sand volume fluctuations of more than 200,000 cubic yards can occur in any year. The net volume loss within the flood shoal is expected to be reduced by the next survey in winter 2021.

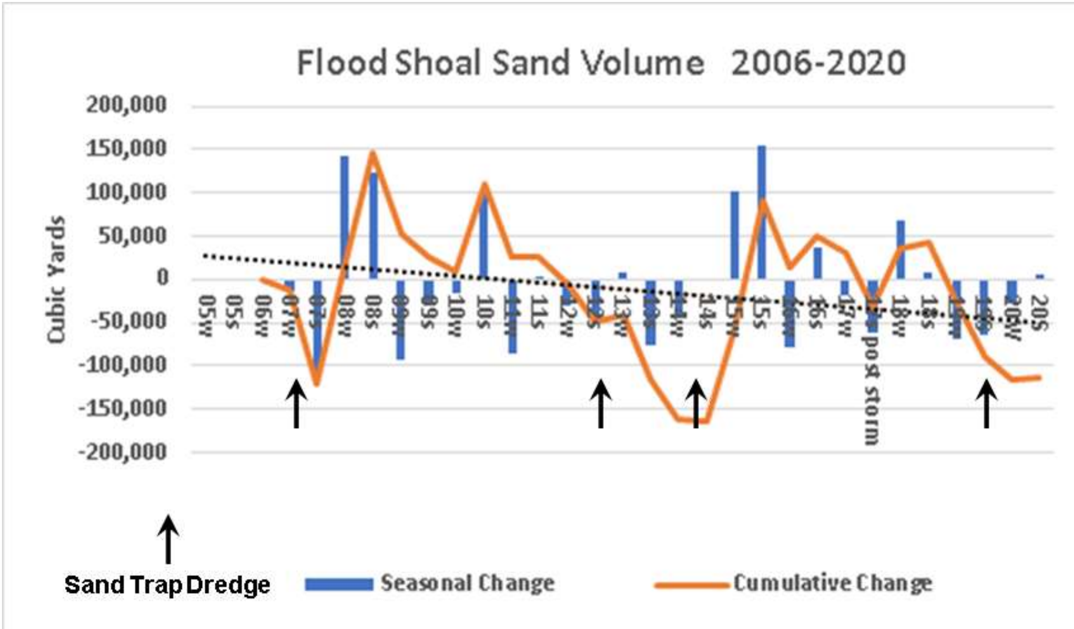

Figure 8. Volumetric evolution of the flood shoal from winter 2006 to winter 2020.

The record of changes in sand volume in the channel extension to the Intracoastal Waterway is shown in Figure 9. This area, first dredged for navigation in 2008 is dynamically linked to the sand trap and flood shoal sand exchanges. Sharp declines in sand volume occurred in 2012 and 2014 as the channel extension areas was dredged along with the sand trap. These declines may have also been influenced by sand volume losses in the adjacent flood shoal area and lined to losses of sea grasses. Similar to the flood shoal, sand volume sharply increased within the channel in 2015 followed by a loss of about 10,000 cubic yards in the 2016. A sand volume decline of about 13,000 cubic yards between summer 2018 and winter 2019 is linked to dredging of the channel extension during the 2019 the sand trap bypass project. Since 2019 the channel extension has a net gained about 9,000 cubic yards of sediment (Figure 9).

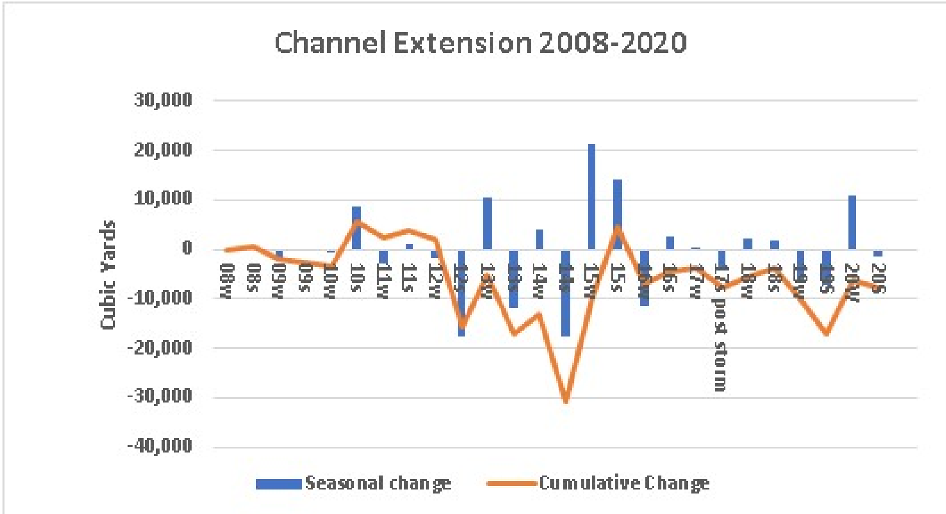

Figure 9. Volumetric evolution of the channel from winter 2008 to winter 2020.

2.3 Sand budget cells

The sediment budget calculations discussed in this report depend on the analysis of individual sand budget cells. The sand budget computational cells are shown in Figure 3. The inlet sand budget cell encompassing the nearshore zone from R216 in Brevard County to R4 in Indian River County, includes the ebb shoal, flood shoal, attachment bar and all other reservoirs shown in Figure 4. Annualized volume changes (ΔV) for each cell, calculated over different time periods, were added to the sand budget equation to calculate the annual net littoral sand transport in and out of each cell. Annualized placement and removal volume data are also included to account for dredging/mechanical bypassing and beach fill activities in the cells concerned. Time series of volumetric change since 2006 for the nine littoral sand budget cells (Figure 4) are shown in Figure 10 through Figure 18, ranging from the northernmost to the southernmost cells.

Volume changes in the N4 cell, the section between R189 and R195, are presented in Figure 10. Results indicate net change in volume of about -400,000 cubic yards from 2006 to 2020, most of which is accounted for by volumes losses since the summer of 2017 after Hurricane Irma impacted Florida. Large fluctuations in sand volume have occurred on a seasonal basis and sometimes exceed 200,000 cubic yards of either gains or loses. Particularly large variations occurred 2007 to 2008 and then again in the 2016-2017 period. Gains of sand volume from the summer of 2016 to the post storm period of 2017 recovered about 400,000 cubic yards and have offset accumulated losses since the winter of 2013. Since the summer survey of 2017 the N4 sand volume has declined in by about 400,000 cubic yards

Volume changes in the N3 cell, (R195 - R203, Figure 3), are presented in Figure 11. Similar to the N4 cell, large volume changes in N3 are usually seasonal; characterized by gains in the winter months and volume losses in the summer months. This cycle is related to the stronger south directed littoral drift under winter conditions sending more sand into the N4 and N3 cells from the beach and shoreface to the north in Brevard County. This usual pattern of seasonal volume shifts has changed since summer of 2017 survey, which was characterized by a gain in sand volume in the N3 cell corresponding with a large gain in the N4 cell to the north. Conversely, large sand volume losses were recorded in the N2 and N1 cell to the south of N3. This was likely due to the impact of Hurricane Irma in September of 2017 that were recorded in the post-storm survey completed in late September. Storm waves approach from the southeast may have caused event scale erosion in the N2 and N1 cells transporting sand into the N3 and N4 cells to the north. Wave heights of up to 17 feet at periods of 12 or more were measured by the Sebastian Inlet wave gage. Since this event seasonal sand volume losses have been the observed in both the N4 and N3 cells except for a large sand volume gained recorded in N3 in the Summer 2018 survey data.

Seasonal volume changes found in the N2 sand budget cell (Figure 12) are similar in magnitude and pattern to those recorded in the N3 cell. In the post Hurricane Irma period, a large volume gain was recorded in the Summer 2018 survey along with similar gains in the N3 cell to the north and N1 cell to the south. After 2018 sand volume losses were recorded though the end of 2019 after which the seasonal volume change pattern seems to be re-establishing and marked by large winter and volume gains followed by summer volume losses. The 14-year net volume change in N2 is about loss of about 70,000 cubic yards.

Net sand volume change in the N1 Cell (R209-R216) followed the pattern of the N2 budget cell marked by sand losses possibly related to Hurricane Irma, followed by a return to a more normal pattern beginning with the summer survey data of 2019. Similar to the N2 budget cell to the north, net volume change in the N1 cell consisted of a small loss of about -60,000 cubic yards between 2006 to 2020.

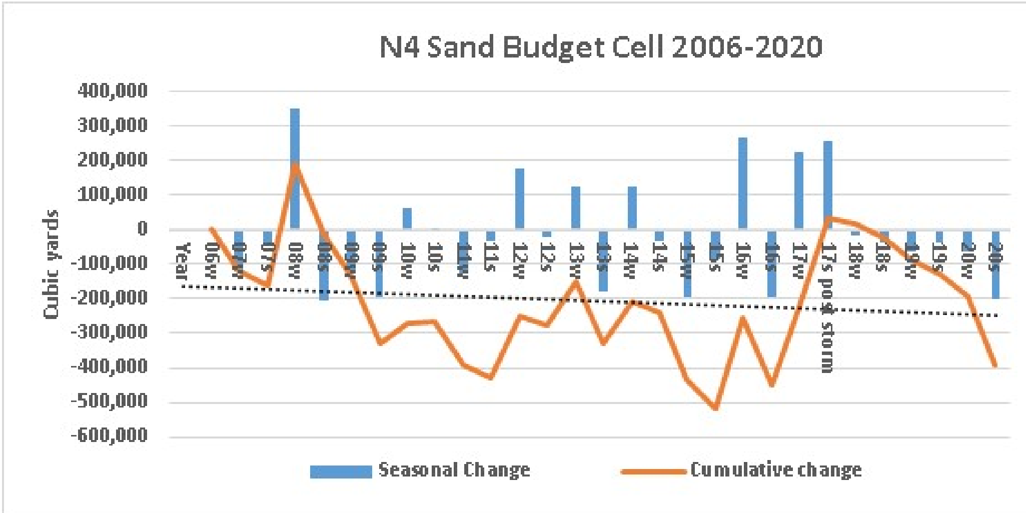

Figure 10. Volumetric evolution of the N4 sand budget cell 2006-2020

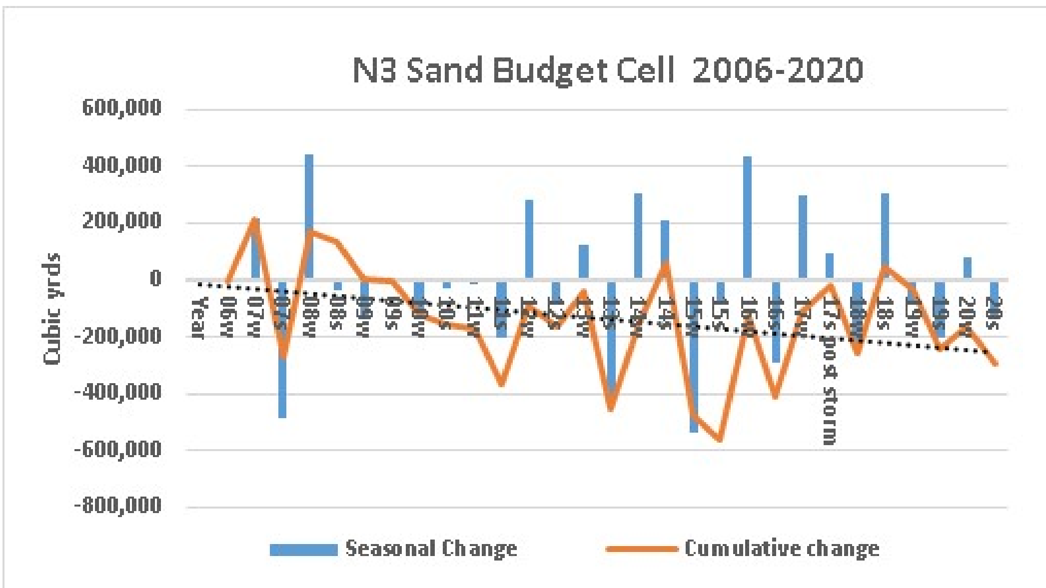

Figure 11.Volumetric evolution of the N3 sand budget cell 2006-2020.

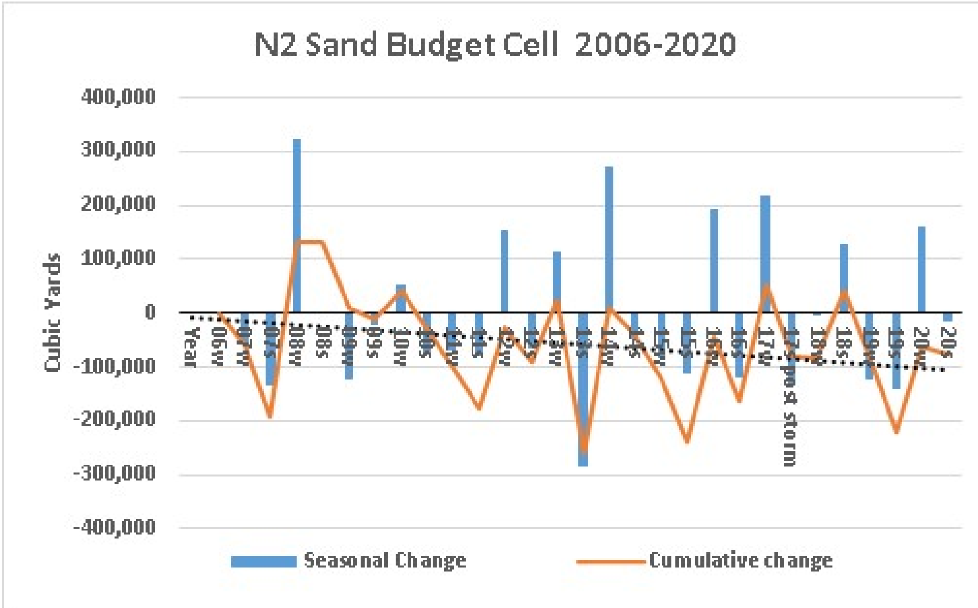

Figure 12. Volumetric evolution of the N2 sand budget cell 2006-2020.

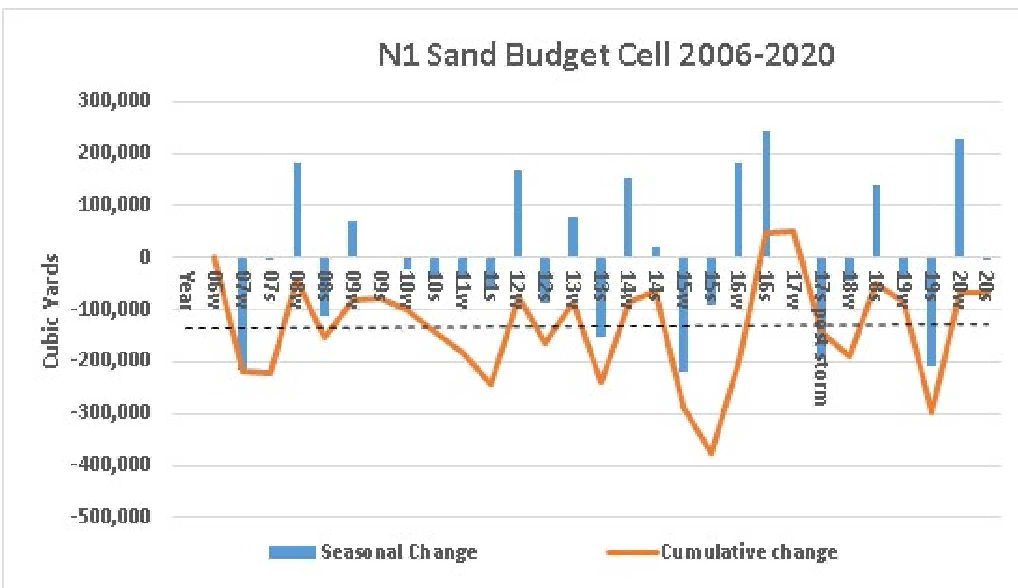

Figure 13. Volumetric evolution of the N1 sand budget cell 2006-2020.

Volume changes for the inlet sand budget cell (Figure 3) are shown in Figure 14. Sand volume in this budget cell is the combination of the ebb and flood shoals, as well as the sand trap and main inlet channel (conveyance channel). Thus, variations and trends of volume change in the ebb and flood shoal are reflected in the sand volume patterns of the inlet budget cell. Sand is also stored in the channel and the fillet areas within about 4,000 feet of beach and shoreface to the north and south of the inlet entrance (Figure 4).

Sand volume seasonally fluctuates showing moderate gains in the higher energy winter months and moderate losses in the lower energy summer months. Divergence from this pattern occurs in association with major storms or in response to bypassing from the sand trap as can be seen in 2007, 2012, 2014 and 2019. This the cycle of abrupt sand loss followed by period of sand volume gain is due to a combination of sand removal by dredging the sand trap and responding losses from the flood shoal followed by recovery of sand volume in the trap and rebound of the flood shoal. The influence of the ebb shoal sand volume within the inlet budget cell is considered to be independent of the sand trap excavation, but linked to accumulations of sand volume from the south directed littoral drift.

Over the past 14 years, net change in sand volume in this cell is a gain of about 200,000 cubic yards and has been as large as nearly 600,000 cubic yards as recorded in the summer survey of 2018 (Figure 14). However, since 2018 the sand volume in the ebb shoals has decreased by about 400,000 cubic yards offsetting the sand volume accumulations of about 400,000 cubic yards between 2013 and 2018.

Inspecting the volume changes in the sand trap, flood shoal, and ebb shoal, as well as volume losses in the N1 cell just to the north of the inlet cell, shows that the post sand bypass volume gains in the inlet are due to a combination of sand trap infilling, flood shoal rebound, and sand releases from the N1 cell to the inlet. The cycle of sand losses and gains within the inlet budget cell beginning with each sand bypass from the sand trap are beginning to repeated as inlet system again responds to the 2019 sand bypass dredging event. Based on previous experience, the inlet budget cell volume gains since 2014 are now reversed due to volume loss in the flood shoal and ebb shoal. Sand released from the inlet budget cell is also likely to provide a benefit of increasing sand volume in the S1 to S4 budget cells to the south of the inlet as exemplified by volume gains in the S1 budget cell between 2008 and 2010 as seen in Figure 15.

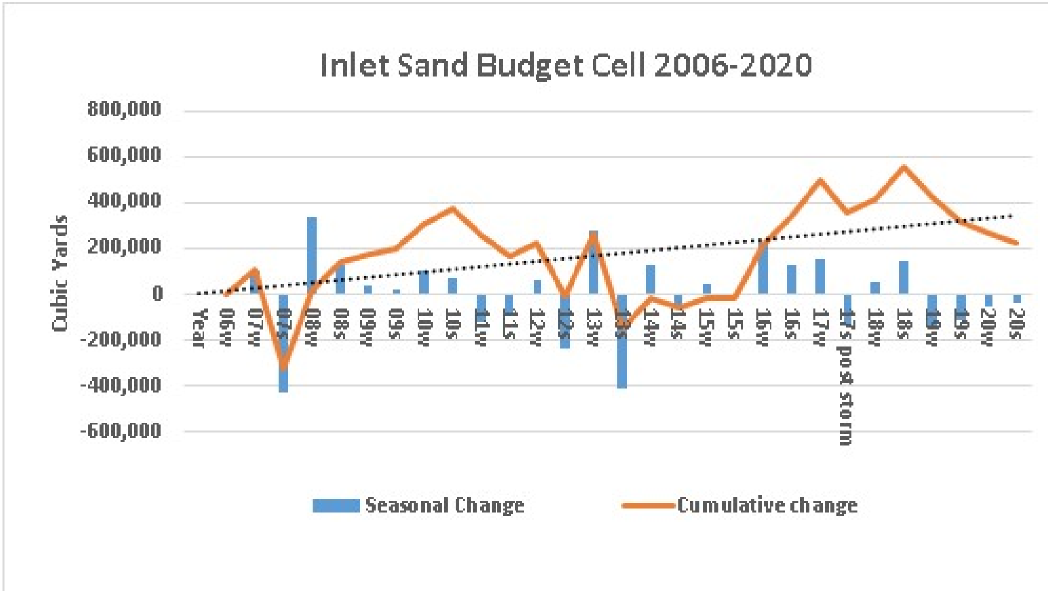

Figure 14. Volumetric evolution of the inlet sand budget cell 2006-2020.

In addition to the link with excavation of the Sebastian Inlet sand trap, interannual variations in sand volume within the inlet budget cell may be influenced by interannual sea level fluctuations . Periods of decreasing sand volume correspond to periods of rising sea level, whereas period of sand volume increase correspond to periods of falling sea level along the Florida coast. Interannual variations in sea level driven by ocean basin scale processes such a Gulf Stream flow variability should not be conflated with longer term trends of rising sea level

The volumetric evolution of the S1 cell, situated between R4 and R10 immediately south of the inlet cell, is shown in Figure 15. The normal volume change pattern in this cell is a seasonal variation marked by volume gains in the winter and volume loss in the summer as seen between July, 2007 and winter, 2010. Seasonal losses of about 100,000 cubic yards occurred in this cell though the summer of 2011 followed by a gain of about 150,000 cubic yards recorded in the winter survey of 2012 and another gain of about 50,000 cubic yards by the summer of 2012. These gains are, in part due to 122,000 cubic yards of sand placed within the budget cell from the Sebastian Inlet sand trap. The volume gains of 2013 then dissipated by the summer of 2013 followed by a large volume gain in 2014 in the cell, again in part, due to sand bypass from the inlet sand trap. Large sand volume gains in all sand budget cells observed in the winter survey of 2014 indicate that there was a regional depositional event in this period that may be caused by onshore movement of sand from the lower shoreface. Sand volume gains of 2014 in the S1 cell were then passed to the S4 cell by the summer of 2015 as shown in Figure 18. Losses during this period from S2 and S3 also were passed to the S4 cell (Figure 16 and Figure 17). The S1 cell regained about 380,000 cubic yards of sand by the winter of 2018 due to large volume increases recorded by the winter 2016 survey and the post Irma survey of 2017, which served as the summer survey. Similar to 2014, there was a regional depositional event during this period as seen in the records of all sand budget cells from N4 to S4. A gain recorded in the 2019 winter survey captures some of the fill material bypassed form the sand trap. Although the official placement location for the fill was between R10 and R17, some of this material may have spread into the S1 cell as indicated by sand volume losses recorded in the S2 sand budget cell located between R10 and R17. A sand volume gain of about 81,500 cubic yards was measured between the late summer survey of 2018 and the late winter survey of 2019. The winter 2019 sand trap bypass project was followed by a very large seasonal fluctuation in sand volume consisting of an approximate volume loss of 300,000 cubic yards recorded in the summer 2019 survey and a volume gain of more than 200,000 cubic yards recorded in the winter 2020 survey. The summer 2020 survey indicated a sand volume loss of about 105,000 cubic yards in the S1 budget cell. . Net volume change in the S1 cell from 2006 to 2020 was a small loss of about 30,000 cubic yards.

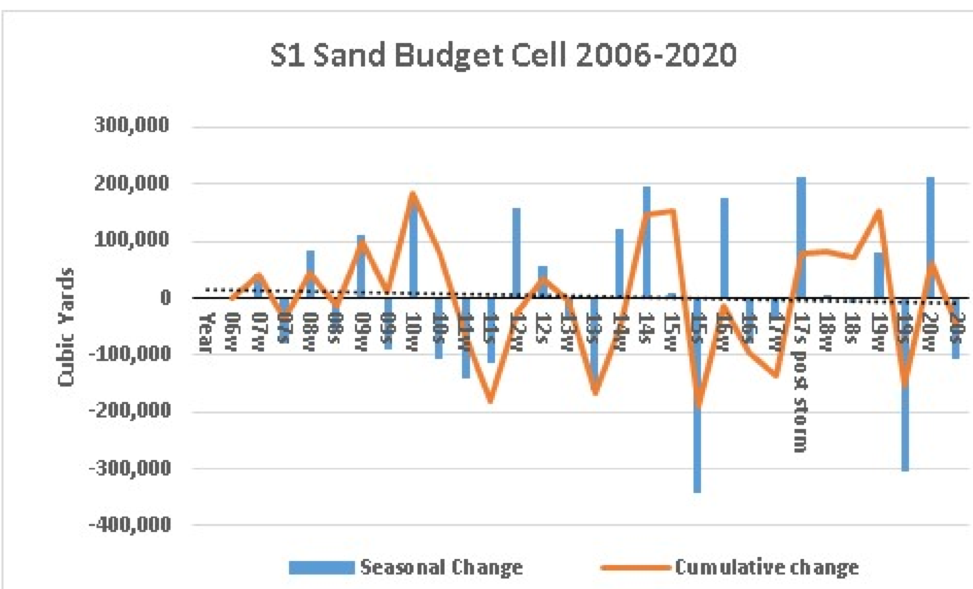

Figure 15. Volumetric evolution of the S1 sand budget cell 2006-2020

Sand volume changes in the S2 cell (Figure 16, R-10 – R16) are a combination of regional and littoral drift gains followed by sand volume losses that are usually shifter shifted to the S3 and S4 cells. Gains the in 2010, 2014 and in 2016 are part of regional depositional events followed by sand volume losses over the following year. Sand volume losses sequentially recorded by three surveys between the summer of 2018 and summer 2019 totaling about 380,000cubic yards were balanced by sand volume gains totaling about 330,000 cubic yards in the 2020 surveys. The 2019 sand bypass project placed approximately 113,500 cubic yards of sand excavated from the sand trap was placed in the S2 budget cell. Apparently, a large portion of this volume was back passed to the S1 cell where a gain of approximately 80,000 cubic yards was recorded in the winter 2019 survey. The afore mentioned 2020 sand volume gains in the S2 cell may indicate that much off the sand trap material eventually returned to the S2 cell. Over the 14-year period between 2006 and 2020 the net volume change in the S2 cell was a net loss of about 90,000 cubic yards.

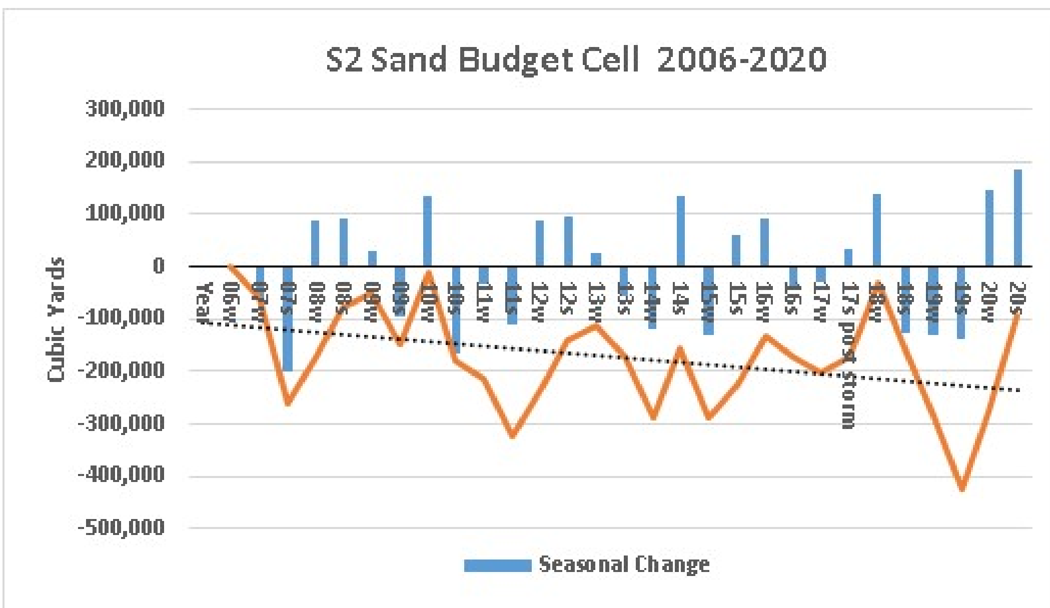

Figure 16. Volumetric evolution of the S2 sand budget cell 2006-2020.

Sand volume changes in the S3 cell (Figure 17) located between R16 and R23 have a more consistent seasonal pattern of gains followed by losses compared to S2 sand budget cells. However, gains are not always in the winter and losses in the summer. The regional sand volume gains of 2010, 2014, and 2016 are noted in the S3 record. Some of the gains in the S3 cell are offset by one season from a sand gain-loss cycle in cells father to the north indicating transfer of sand to the south by littoral drift. A net sand volume loss of about 318,000 cubic yards between 2006 and 2018 is attributed to a series of seasonal losses not completely balanced by sand volume gains in the following season. This was partially offset by a large seasonal gain of about 194,00 cubic yards between the winter and summer surveys of 2018. However, this was followed by a sand volume loss of about 168,000 cubic yards as recorded in the winter 2019 topographic survey data. One of the larger seasonal losses of sand volume occurred in the winter of 2015 of about 350,000 cubic yards. This event was also seen in most of the other sand budget cells. Sand volume losses totaling about 270,000 cubic yards was partially balanced by sand volume gains in S2 of about 110,000 cubic yards recorded in a combination of the winter and summer 2020 surveys. As suggested for 2020 volume gains in the S2 cell, 2020 gains in S2 may be the result of sand drifting south that included beach fill from the 2019 sand trap project.

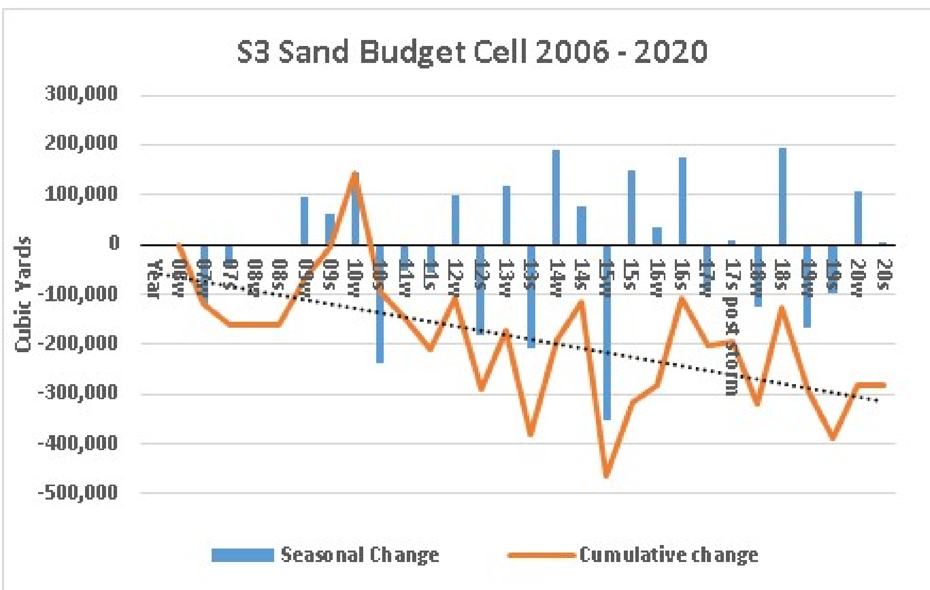

Figure 17. Volumetric evolution of the S3 sand budget cell 2006-2020.

The S4 sand budget cell (Figure 16, located between R23 and R30 (Figure 3) like S3 has an imbalance between seasonal gains and losses that add up to a net volume loss of about 450,000 cubic yards between 2006 and 2020. The seasonal pattern of sequential gains and losses is not as consistent as seen in the S2 and S3 cell. The regional sand volume gains of 2010, 2014, and 2016 persist in S4. Seasonal offsets between S4 and sand budget cells to the north indicate the role of sand movement in the littoral drift system. The interrelation of seasonal sand volume changes among the budget cells is examined in Section 3.3 of this report followed by the sand budget calculation in Section 3.4

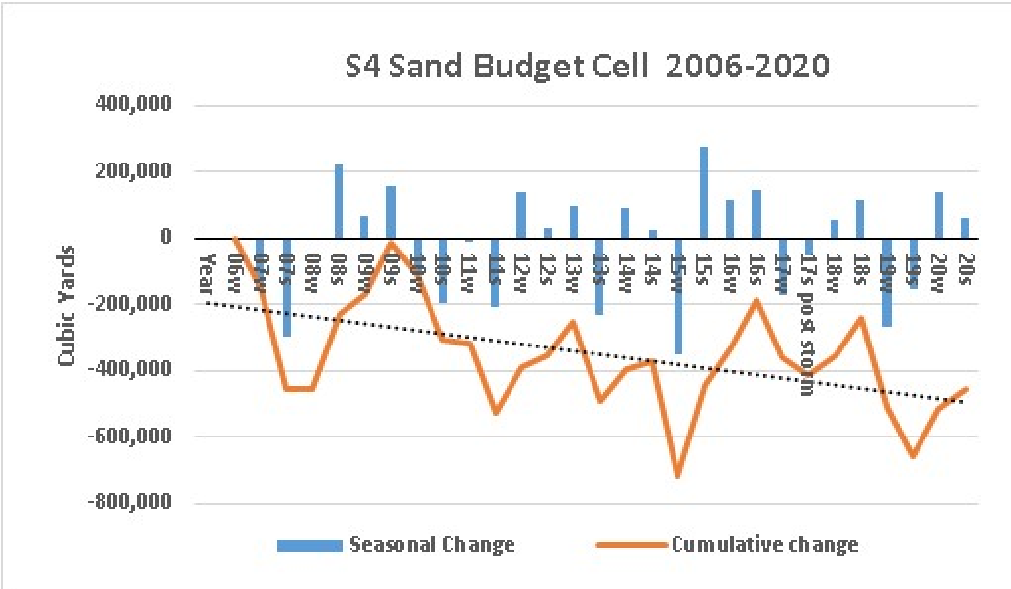

Figure 18. Volumetric evolution of the S4 sand budget cell 2006-2020.

2.4 Analysis of Sand volume changes, 2005 – 2020

Individual sand reservoirs and sand budget cells show short term changes that when integrated over time yield a net sediment budget when placed in an annualized format. Further, short-term changes can be spatially tracked though the barrier island-inlet system to observe how sand is moved from one compartment to another. Thus, in order to formulate a regional sand budget based on these data, it is important to consider temporal interrelation among the sand volume components of the Sebastian Inlet system. The time scale of a sediment budget should consider the dynamics of sand volume adjustments. Establishing a sediment budget on a very short time scale could reflect only abrupt changes from seasonal storms and not account for ongoing trends.

To view trends among of the sediment budget cells Figures 19 compares sand volume changes in sediment budget cells on the north side of Sebastian Inlet(N4 – N1). To emphasize this and compare trends among the sand budget cells a 3-point moving average has been applied to the cumulative sand volume change data shown Figure 10 though Figure 13. Thus, amounts to a moving average over an 18-month period though the 2006 to 2020 sand volume data . The overall pattern of trends is the same for all four sand budget cells on the north side if Sebastian inlet and includes declining sand volume from winter 2009 through summer 2016 (Figure 19). In sand the N4 through N3 sand budget cells the sand volume declines reverses to volume gains though summer 2019 followed by sand volume declines in 2020. In the N1 cell just north of the Inlet sand budget cell the sand volume gains end with the summer 2017 survey followed by a net loss of sand volume though the summer of 2019. In the 2020 survey data sand volume in the N1 cell seems to have stabilized although not fully resolved by the 18-month moving average.

Figure 20 compares sand volume changes among sand budget cells on the south side of Sebastian Inlet(S1 – S4. Trend patterns on the south side of Sebastián inlet in each of the sand budget cells are similar to those in budget cells on the north side of the Inlet. Sand volume trends are most apparent in budget cells S3 and S4 where a trend of sand volume decline is very apparent between the winter survey of 2010 and the winter survey of 2016. In sand budget cell S2 where much of the sand trap materials was placed in 2012, and 2014 a trend of declining sand volume is seen between winter 2012 and winter 2015, but at a lower magnitude. Trends are weaker in sand budget cell S1 adjacent to the Inlet budget cell. In this cell large variations of sand volume are apparent and overwhelm the trends even within the applied 18-month moving average. This cell benefits from natural sand bypassing around Sebastian Inlet along with the benefits of by passing project from the sand trap.

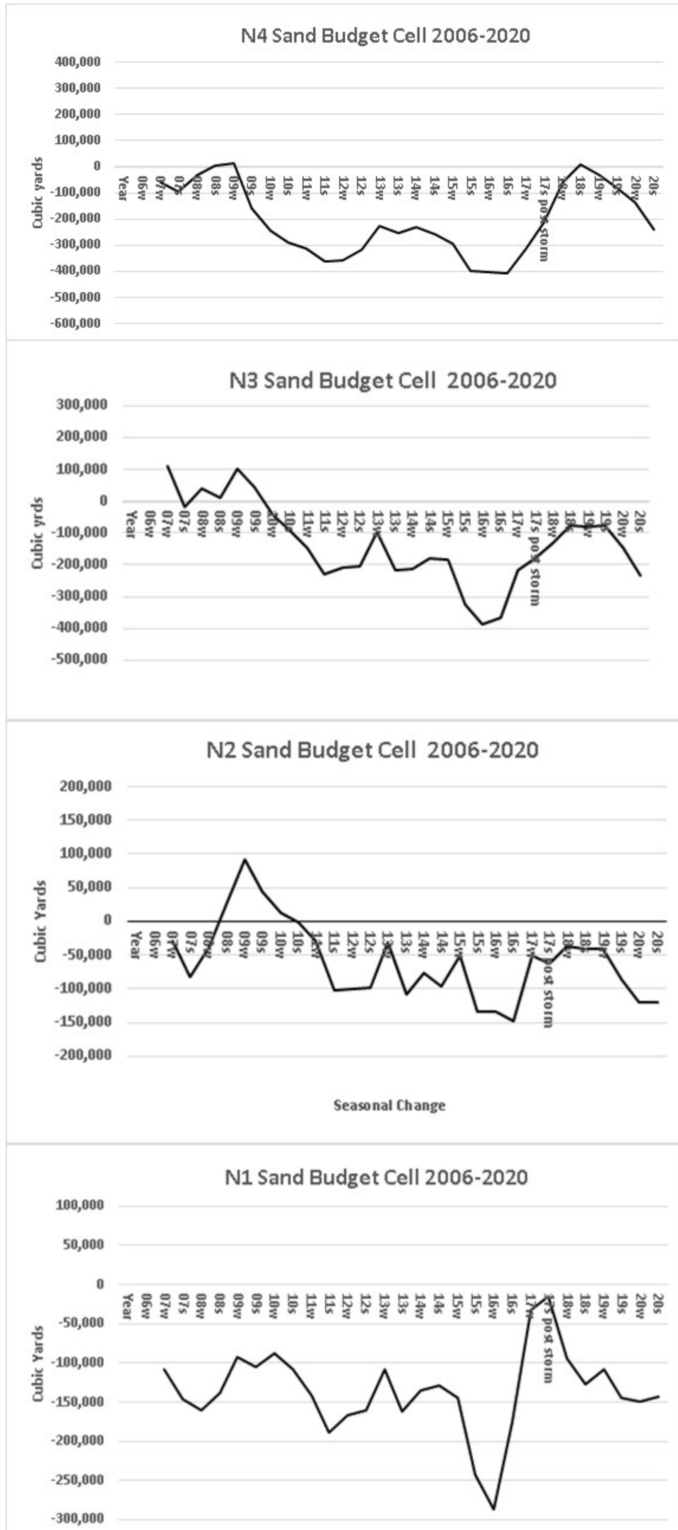

Figure 19. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells N4 to N1 from 2006 to 2020.

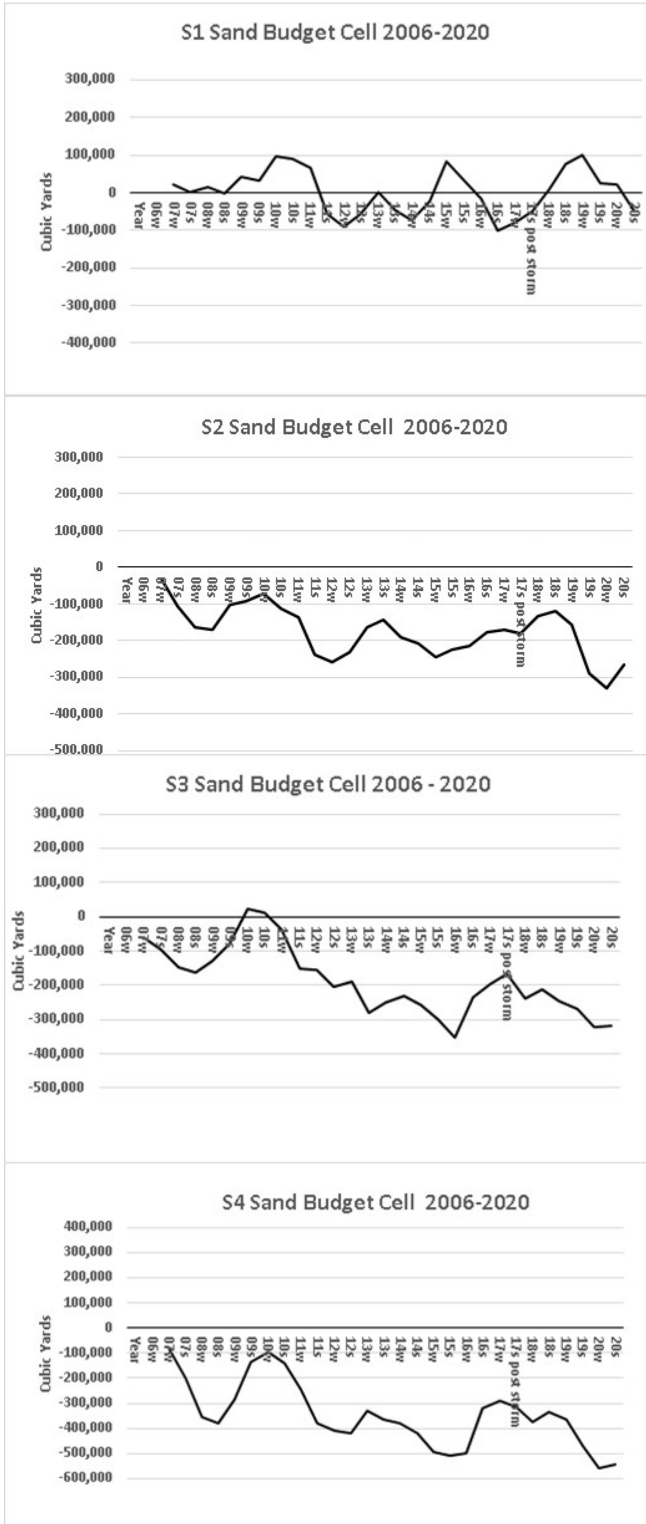

Figure 20. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells S1 to S4 from 2006 to 2020.

Figure 21 is a similar moving average presentation of cumulative and volume changes within the Inlet sand budget cell. The pattern of sand volume change within the Inlet budget cell is very similar to the trends seen in the budget cells to the north (Figure 19) and to the south (Figure 20) of Sebastian Inlet. A period of sand volume increase reached a peak in 2010 and 2011 followed by a multi-year decline in sand volume through 2014-15. From 2016 to 2019 sand volume increased and then reversed to a decline according to the 2020 survey data.

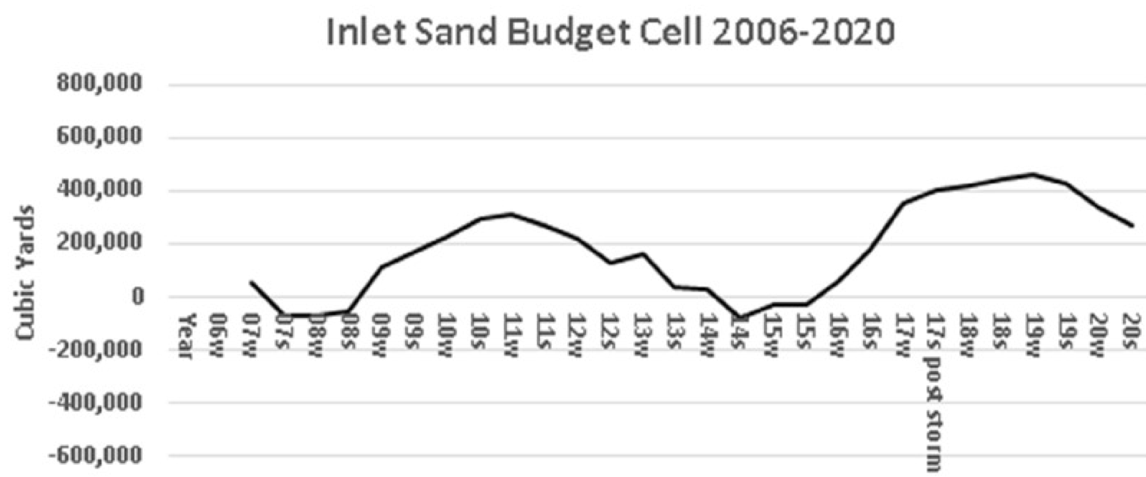

Figure 21. Sand volume ternds within the Inlet Sand budget cells presents on the basisn of an approximate 18-monnth moving avage over the 2006 to 2020 period of record.

The similarity of sand volume trends over the 14- year records requires some thought about controlling factors. As stated in the 2019 State of the Sebastian Inlet report (Zarillo et al, 2019) there is correspondence between interannual sea level trends and changes in shoreface sand volumes. Figure 22 compares the 2006 to 2020 sea level record filtered to emphasize interannual trends and compare with the sand volume records from the S3 budget cell It can be seen that there is an inverse relationship between sand volume and sea level. Higher sea levels correspond to lower sand volume contained within the S3 cell. Likewise, lower sea levels correspond with intervals of higher sand volume. The interannual trends of rising sea level from 2010 to 2016 corresponds to a 6-year trend of declining sand volume in the S3 budget cell. The correspondence in time is not exact and can be offset by a season due to the filter methods and possible lag time between seal changes and shoreface sediment volume response.

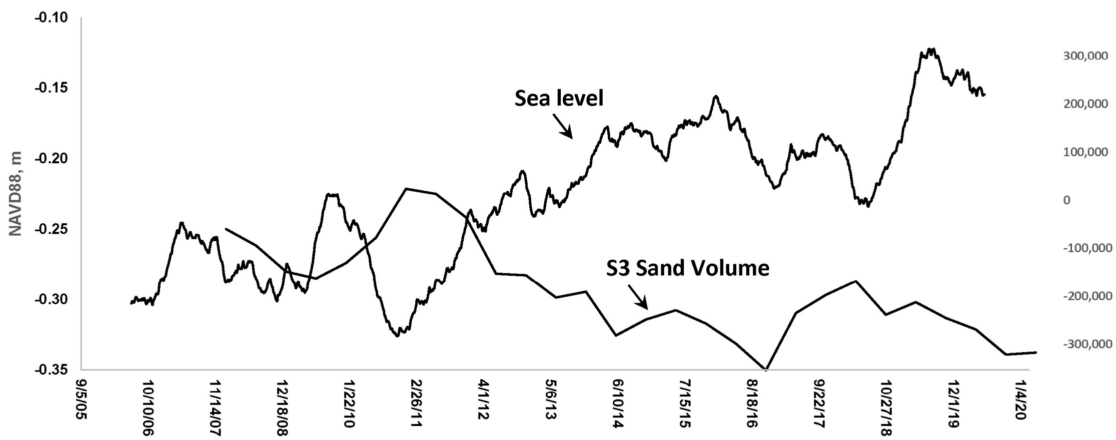

Figure 22. Comparison of fileted the 2006 to 2020 filtered sea level record with the filtered sand volume record of the S3 budget cell.

Figure 23 combines the unfiltered cumulative sand volume records from the inlet budget cell and the sand budget cells south of the inlet cell as a series of bar graph plots and makes a comparison with the 2006 to 2020 sea level record. Overall, the relationship is similar to that shown in Figure 22. Sand volume increase in sand budget cells correspond to lower sea levels, whereas periods of sea level rise correspond to trends of sand volume loss.

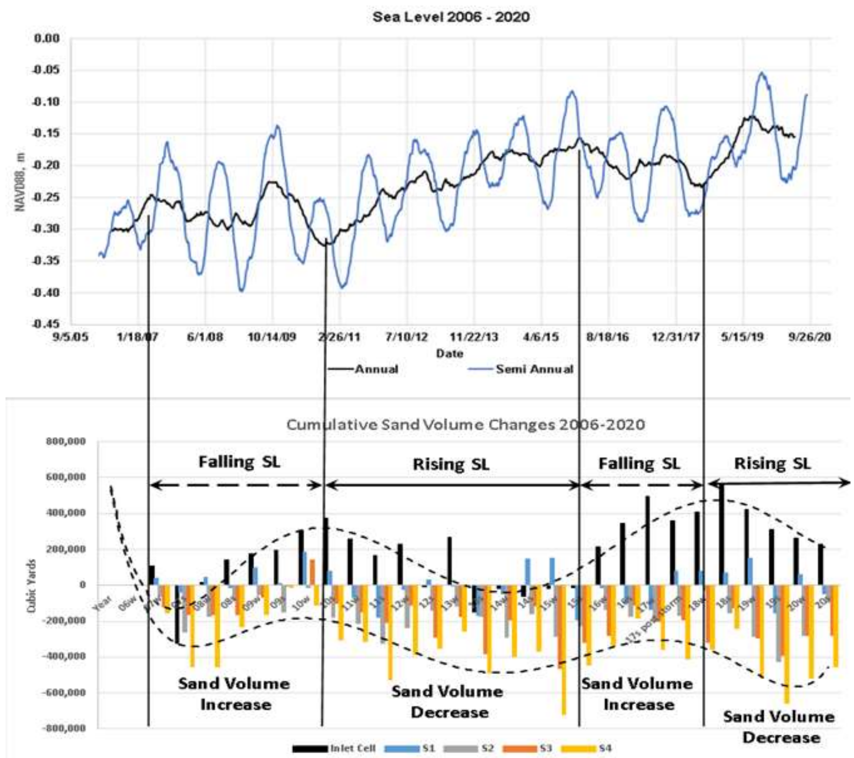

Figure 23. Comparison of cumulative sand volume changes within the Inlet cell and sediment budget cells south of Sebastian Inlet with sea level trends.

3.0 Sand Budget: Sebastian Inlet and Surrounding Barrier Segments

3.1 Methods

A sediment budget uses the conservation of mass to quantify sediment sources, sinks, and pathways in a littoral cell environment. It is used to quantify the effects of a changing sediment supply on the coastal system and to understand the large-scale morphological responses of the coastal system. The sediment budget equation is expressed as:

$$\sum Q_{source} - \sum Q_{\sin k} - \Delta V + P - R = residual \qquad \text{Equation 1}$$

The sources (Qsource) and sinks (Qsink) in the sediment budget together with net volume change within the cell (ΔV) and the amounts of material placed in (P) and removed from (R) the cell are calculated to determine the residual volume. For a completely balanced cell the residual would equal zero (Rosati and Kraus, 1999). Figure 24schematically shows how calculations are made within each cell of the sediment budget model.

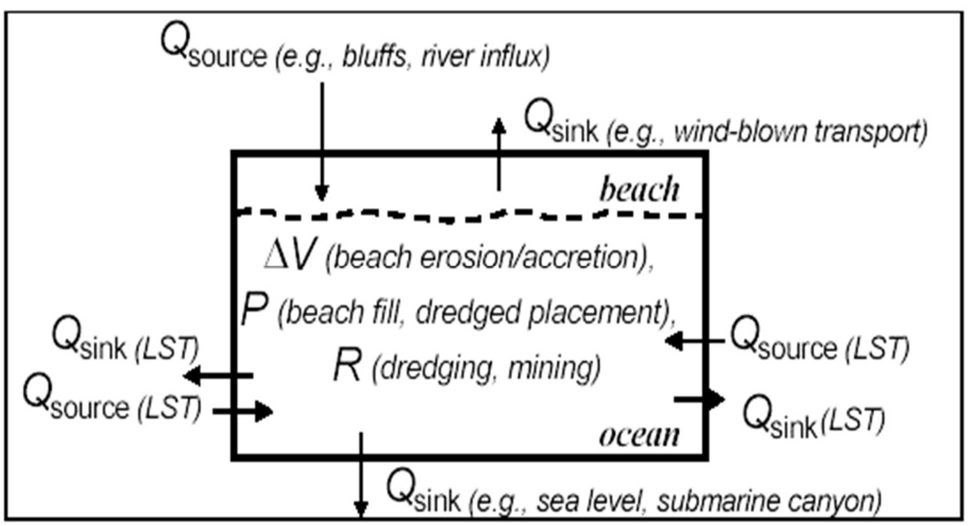

Figure 24. Schematics of a littoral sediment budget analysis (from Rosati and Kraus, 1999).

Determination of net volume change for the local sediment budgets for Sebastian Inlet was based on volumetric analysis masks presented in section 3.0. The sediment budget encompasses the area between monuments R189 in Brevard County to monument R30 in Indian River County.

Since variability of the seasonal sand volume changes can be larger than the average range of values in the sediment budget, the temporal scale of the calculations is based on several time periods ranging from three to ten years between 2010 and 2020. The computational cells (masks) that were used to establish the local sediment budget are schematically shown in the volumetric section (see Figure 3). Volume changes for each mask were determined according to the methods described above in the net topographic changes section and input into the Sediment Budget Analysis System (S.B.A.S) program, provided by the Coastal Inlet Research Program. Details of these procedures can be found in the technical report by Rosati et al. 2001. Based on super regional sediment budget calculations described in Zarillo et al, 2007, an initial input value (Qsource) of 150,000 yd3/yr. was specified. However, for some time periods the initial input value was increased to 200,000 yd3/yr. to accommodate periods of larger transport rates bounded by winter seasons and increased storm activity. The placement values (P) correspond to the beach fill projects that were included in the calculations. Most of this placement is to the south of Sebastian inlet in the S2 and S3 sand budget cell from either the Sebastian Inlet sand trap or from upland sources accessed by Indian River County. However, beginning in 2016, placement in the N4 and N3 cells are associated with post-hurricane repair of beaches in south Brevard County. Removal of sand (R) through mechanical bypassing was included to account for the 2012, 2014, and the 2019 dredging projects within the sand trap. However, removal of sand (R) through offshore losses was assumed to be zero for all cells since the boundaries of the masks extend beyond the depth of closure. This assumption is usually applied for the longer-term 10-year sand budgets. In the shorter term it may be necessary to assume either import of sand from offshore sources or import of sand to balance short-term sand budgets at time scales of 3 to 5 years. Placement and removal values are annualized and presented in Table 2.

Table 2. Annualized placement and removal volumes for sand budget calculations. Units are in cubic yards per year

Time Period	Season	N4	N3	N2	N1	Inlet	S1	S2	S3	S4
2010–20	Winter	1572	2070	1493	1022	-44883	24080	19296	6831	13205
2010–20	Summer	1572	2070	1493	1022	-44883	24080	9470	5210	13205
2015 –20	Winter	3144	4140	2987	2044	-65366	22240	64516	5982	6600
2015–20	Summer	3144	4140	2987	2044	-32108	22240	5280	2740	6600
2017-20	Winter	5240	6899	4978	3406	-48667	0	41220	6870	0
2017-20	Summer	5240	6899	4978	3406	0	0	8800	1467	0

3.2 Sand budget results

The sand budget is presented on three distinct time scales ranging from a longer-term budget for the past 10-years to short term budgets that examine volume changes and sand flux over 5 and 3-year year periods. The budget uses calculated annualized volume change per cell as inputs (see Figure 3). Annualized beach fill material is accounted for in the N4 to N21 cell on the north side of Sebastian Inlet, the inlet cell, and the S1 to S4 cells a shown in Figure 3.

Interpretation of the fluxes, especially those leaving the southernmost cell (S2, R16-R30) must consider that the sand budget assumes a fixed input of either +150,000 or 200,000 cy/yd. entering the first north cell (N4). Sand transport was assumed to flow north to south. The components of the long-term sand budget are listed in Table 3and covers the period from 2010 through 2010. A comparison is made between winter and summer-based budgets.

Table 3. Ten-year sand budget of annualized volume changes per cell and flux (2010 – 2020).

Time Period	Winter 2010 – Winter 2020 Qin=200,000 cy/yr.		Summer 2010 - Summer 2020 Qin=150,000 cy/yr.	
Sediment Budget Cell	**DV (cy/yr.)**	**Q (cy/yr.)**	**D(cy/yr.)**	**Q (cy/yr.)**
North 4	7,709	193,863	-12,559	164,131
North 3	-4,090	180,023	-13,992	180,193
North 2	-10,189	171,705	-4,482	186,168
North 1	3,490	169,237	7,492	179,698
Inlet	***4,113***	***145,096***	***-14,658***	***166,102***
South 1	-12,353	152,529	-12,403	177,585
South 2	-22,606	169,431	-11,551	183,432
South 3	-42,287	193,549	-18,273	183,536
South 4	-40,636	222,390	-14,994	186,735

Figure 25 is a visual representation of the data listed in Table 3and covers the period from 2010 through 2010. A comparison is made between winter and summer-based budgets.

. Shown are the locations of the sand budget cells and the annualized volume changes, and sand fluxes calculated from the survey data. Refer to Figure 10 through Figure 18 for plots of sand volume changes in each of the sand budget cells. For each of these records the volume changes are annualized over the sand budget period and listed in Table 3.

The analysis results for the 10-year sand budget based on a winter to winter period show that all but three cells lost sand volume between 2010 and 2020.   Sand budget cells N4 and N1 to the north of Sebastian Inlet, registered annualized volume gains over this period. The remaining budget cells registered sand volume losses. The annualized sand volume losses were relatively small due to the placement from the sand trap and other sources and large littoral drift rates moving sand from north to south. The inlet cell gained an annual average of about 4,100 cubic yards of sand per year. The other annualized increases in sand volume north of Sebastian inlet were on the average less than 8,000 cubic meter per year. When 2012, 2014, and 2019 sand trap excavations are combined, the annualized rate of sand removal from the inlet cell is about 44,900 cubic yards per year. On the south size of Sebastian inlet sand volume losses in budget cells 1 and 2 were moderate and on the order of 10,000 to 20,000 cubic meters per year. These cells directly benefited from sand trap bypass project over the 2010 to 2020 sand budget period.

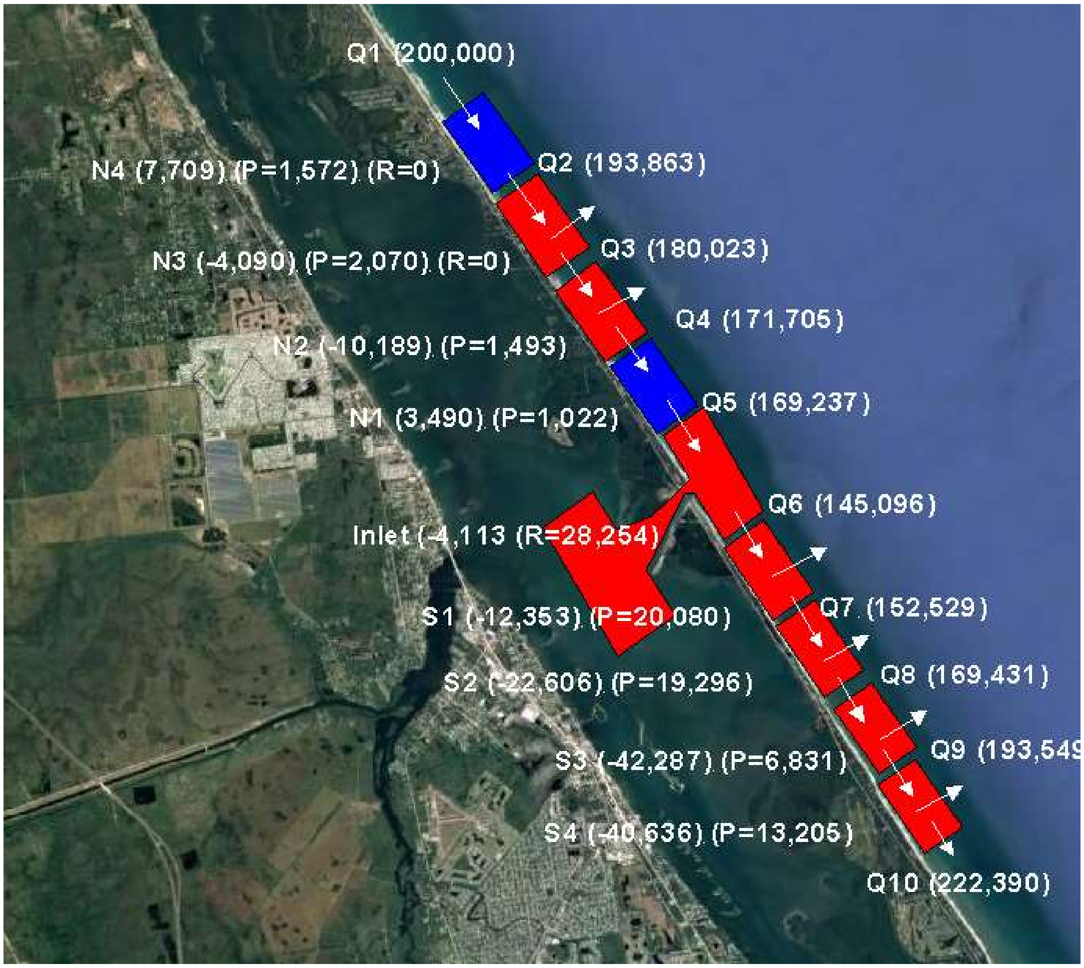

Figure 25. Annualized 10-year sediment budget for the winter 2010 to winter 2020 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

Figure 26 is the visualization of the summer to summer 10-year (2010 to 2020) sand budget. All budget cells registered moderate annualized losses of sand volume except for budget cell N1 adjacent to the inlet cell. The inlet sand budget cell registered an annualize loss of about 14,658 cubic yards, similar in magnitude to the other cells having losses. The magnitude of the annualized sand volume changes was smaller than the winter to winter changes and on the order of about 4,000 to 18,000 cubic yards. Sand volume in the S1 to S4 cells were again aided by sand placement from the Sebastian Inlet sand trap and from upland sources used by Indian River County. The small annualized volumes of sand placement budget terms (P) in the N4 to N2 cells are derived from placement of about 30,000 cubic yards of sand on the beaches by Brevard County in the post storm period of 2017. Over the 10-year period between 2008 and 2018 a total of 520,670 cubic yards of sand was placed in these cells for an annual average of about 52,060 cubic yards.

Figure 26. Annualized 10-year sediment budget for the summer 2010 to summer 2020 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

The 10-year sand budget period was influenced by three passing hurricanes as well as a trend of rising sea level between 2010 and 2016 as seen in Figure 22 and Figure 23. Both sand budgets calculated for this period required the assumption of net offshore transport to produce reasonable rates of annualized longshore sand transport between the budget cell as well as beyond the budget cell S4 and the south end of the calculations. It is likely that both the hurricanes and rising sea level contributed to offshore sand volume losses. The offshore annualized offshore sand volume losses were set at between 10,000 and 25,000 cubic yards per year in selected budget cells as indicated by the arrows directed offshore in Figure 25 and Figure 26.

A 5-year sand budget was calculated to compliment the longer term 10-year calculation. Table 4 lists the results for the winter 2015 to winter 2020 and summer 2015 to summer 2020 five-year calculations. The winter sand budget begins with an annualized input of 200,000 cubic yards at the north sand budget cell N4. Most of the sand budget cells registered annualized volume gains in the 2015 to 2020 period except for an annualized volume loses of about 18,000 cubic yards in sand budget cell S1 just to the south of the inlet budget cell (Figure 27). Annualized sand volume gains in most of the sand budget cells creates a deficit of sand volume available for littoral transport to the south. This requires, an extreme sand volume input value at the north end of the sand budget calculation, onshore transport of sand, or a reversal of the littoral transport directions. Another way to balance the sand budget would be simply assume no net littoral drift when the transport calculation becomes zero and the sand is added to budget cells. When viewed on a gross sand transport basis one can also make a judgment that the net transport is tending towards zero and the sand volume is moving north and south adding up to a net transport of near zero. This demonstrates the difficulty in calculating shorter term sand budgets. In this analysis we assume that there is an additional source of sand moving onshore from beyond the depth of the survey coverage. These additional sand sources could also correspond to temporary shifts to a lower sea level in the past two years as illustrated in Figure 21 along with a period of post-storm recovery after Hurricane Irma in September of 2017.

The five-year summer to summer sand budget listed in Table 4 and illustrated in Figure 28 is mostly depositional on an annualized basis. The 2015 to 2020 time period corresponds to a period of sand volume gains across most of sand budget domain. As seen in Figure 28, the summer to summer 5-year sand budget includes a trend declining sand volume loss and increase in sand volume gains in the S1 to S4 cells even as the cumulative sand volume increased within the inlet sand budget cell. This period also corresponds to a period of declining sea level beginning in 2019, but cannot be completely resolved within the filtered data until a longer sea level record is available. In order to balance the sand budget and keep the calculated net littoral drift moving to the south at a rate of above 100,000 cubic yards per year, a net onshore transport of sand is assumed seven of the nine sand budget cells. Thus, the net annulate rate at the north end of the sand budget is assumed to be 200,000 cubic yards per year and the net south directed rate of sand movement calculated at the south end of the budget area is about 218,000 cubic yards per year.   In the 5-year summer to summer sand budget the pattern of sand deposition on the south side of the inlet budget cell is the reverse of the pattern in the winter budget although the magnitude of sand volume changes is similar. In the summer sand budget, the S1 and S2 budget cells have relatively high annualized sand volume increases, whereas the S3 and S4 cells registered a small annualized sand volume gain and sand volume loss, respectively (Table 4).

Table 4. Five-year sand budget annualized volume changes per cell and flux.

Time Period	**winter 2015 – Winter 2020 Qin=200,000 cy/yr.**		**Summer 2015 - Summer 2020 Qin=200,000 cy/yr.**	
Sediment Budget Cell	**DV (cy/yr.)**	**Q (cy/yr.)**	**DV (cy/yr.)**	**Q (cy/yr.)**
North 4	48,388	204,756	25,237	178,007
North 3	62,198	196,698	53,067	179,080
North 2	43,863	237,439	32,229	169,838
North 1	55,748	245,620	61,999	159,883
Inlet	***55,748***	***157,764***	***48,696***	***129,079***
South 1	-18,406	176,170	28,598	150,481
South 2	1,766	215,624	26,339	208,174
South 3	18,336	203,270	3,628	210,528
South 4	20,124	189,746	-1,020	218,148

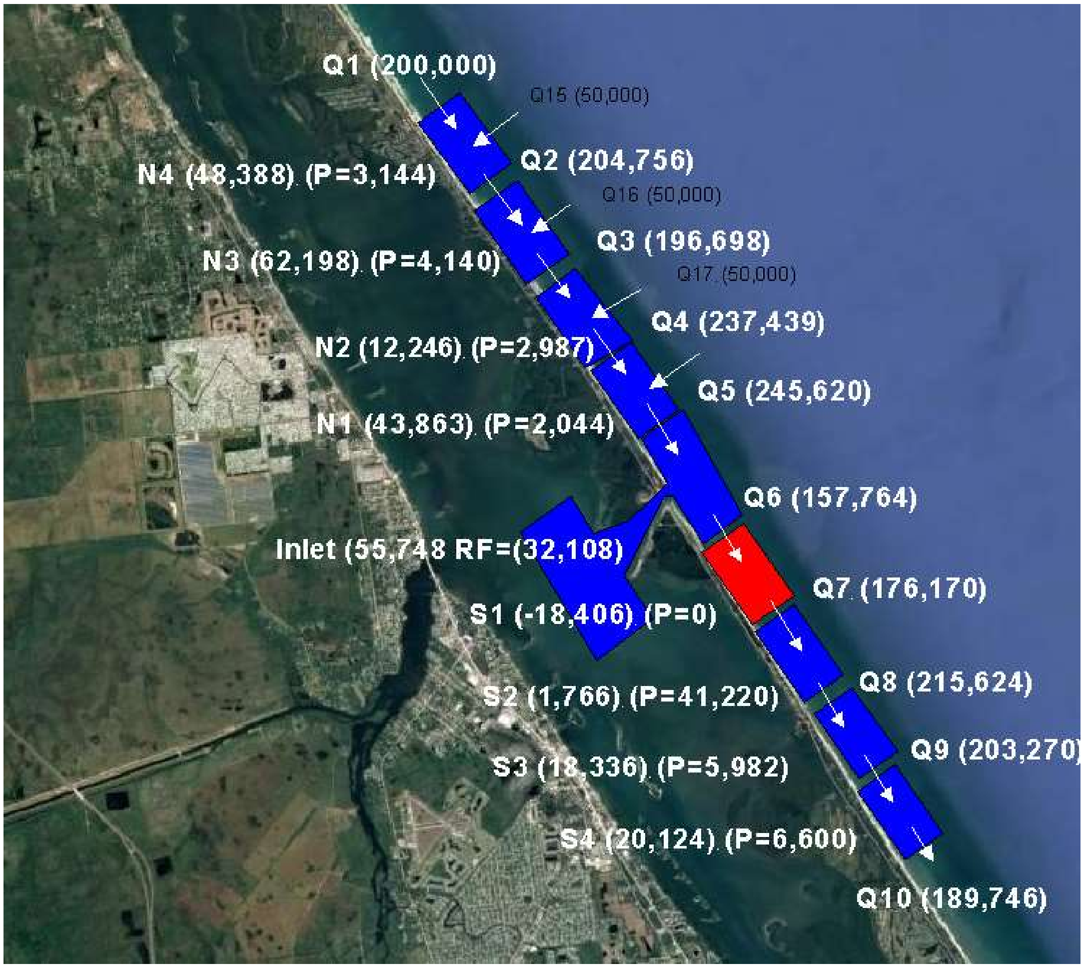

Figure 27. Annualized 5-year sediment budget for the winter 2015 to winter 2020 time period. Values shown to the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

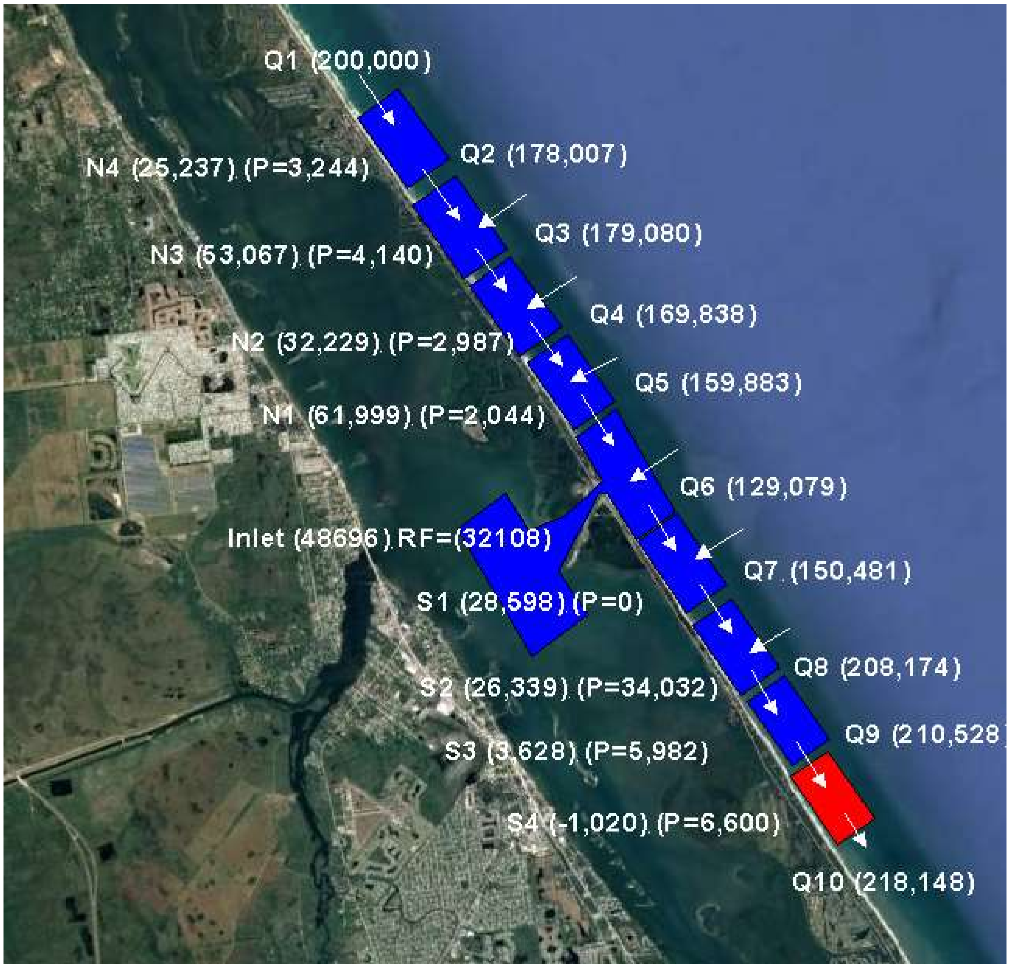

Figure 28. Annualized 5-year sediment budget for the summer 2015 to summer 2020 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

The 3-year winter and summer sand budgets (Table 5) are more difficult to interpret in terms sea level changes due to limited sea level trends over shorter periods of time and complete response of sediment volume adjustments to sea level, which may take a year or longer. As seen in Figure 19 and Figure 20 , the 2017 to 2020 period corresponds to sand volume losses in most budget cells. Exceptions are the S1 cell in the winter to winter 2017 to 2020 budget (Figure 29) and the S2 cell in the summer to summer budget (Figure 30). Sand volume declines began after Hurricane Irma impacted the Florida Coast. The winter 2017 survey was completed before the storm and the summer 2017 survey was completed just after the storm. The most recent trend of sea level drop in sea level data began in 2019, but will not be completely resolved until more recent sea level records can be recorded. The response of beach and shoreface sand volume to sea level changes may take a year or longer to become measurable.

Table 5. Three-year sand budget annualized volume changes per cell and flux.

Time Period	Winter 2017 – Winter 2020 Qin=150,000 cy/yr.		Summer 2017 - Summer 2020 Qin=150,000 cy/yr.	
Sediment Budget Cell	**DV (cy/yr.)**	**Q (cy/yr.)**	**DV (cy/yr.)**	**Q (cy/yr.)**
North 4	10,793	144,447	-142,359	247,599
North 3	-16,243	167,589	-91,773	296,271
North 2	-38,145	190,712	1,391	299,858
North 1	-38,948	233,066	-32,246	285,510
Inlet	***-77,395***	***231,794***	***-43,559***	***230,402***
South 1	65,564	166,230	-41,690	222,092
South 2	-25,366	192,816	25,105	238,207
South 3	-26,18 0	185,866	-18.902	213,979
South 4	-53,435	199,301	-14.488	178,467

Figure 29 displays the results of calculating 3-year sand budgets from winter 2017 to winter 2020 . Most sand budget cells lost volume with the exception of the N1 cell at the north end and the S1 cell just south of the inlet budget cell. A relatively larger annualized lost rate occurred in the inlet budget cell that exceeded 75,000 cubic yards per year over the 3-year period. Part of this sand volume loss can be attributed to the sand trap excavation during the winter of 2019. Sand volume gain in the S1 cell may be in part attributed to placement of sand in the S2 cell that dispersed to the north during the beach fill project. Winter climate may have also produced strong natural sand bypassing around Sebastian Inlet which calculated at an annualized rate of about 232, 000 cubic yards.

The summer to summer 2017 to 2020 sand budget shown in Figure 30. This 3-year sand budget also showed sand volume losses in most budget cells and high littoral transport rates between sand budget cells as a consequence. The S1 cell just south of the inlet cell lost sand volume and the sand volume gain in the S2 budget cell may be attributable to placement from the sand trap. In both, 3-year sand budgets additional sand fluxes directed offshore were required to balance the sand budget and keep annualized longshore transport rates at reasonable levels. This may be attributable to the winter wave climate as well as the impacts of Hurricane Irma. If the trend of falling sea level continues sand volume in many of the sand budget cells may increase over the next few years.

Figure 29. Annualized 3-year sediment budget for the winter 2017 to winter 2020 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss. Offshore transport from each of the cells was required to balance the sand budget.

Figure 30. Annualized 3-year sediment budget for the summer 2017 to summer 2020 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss. Onshore transport from cells N1 to N4 was required to balance the sand budget.

4.0 Morphologic Changes

4.1 Methods

The analysis uses the same datasets and overall methodology as the sand volume analysis and sand budget analysis described under Sections 2, 3 and 4. The morphologic change section is subdivided according to the time period of analysis. The time interval covered in this report includes a longer time period of 2010 to either 2020 and a shorter interval covering approximately 1 year to 18 months. The net morphologic changes over 5-year and 20-year periods are presented in the series of earlier report (Zarillo et al, 2007, 2012, 2013, 2016).

In the color convention for figures depicting topographic change; blue colors erosion, whereas red and orange colors indicate deposition. Topographic changes were combined with results from shoreline changes and sand budget calculations for a better understanding of the sedimentation processes.

4.2 Topographic Changes

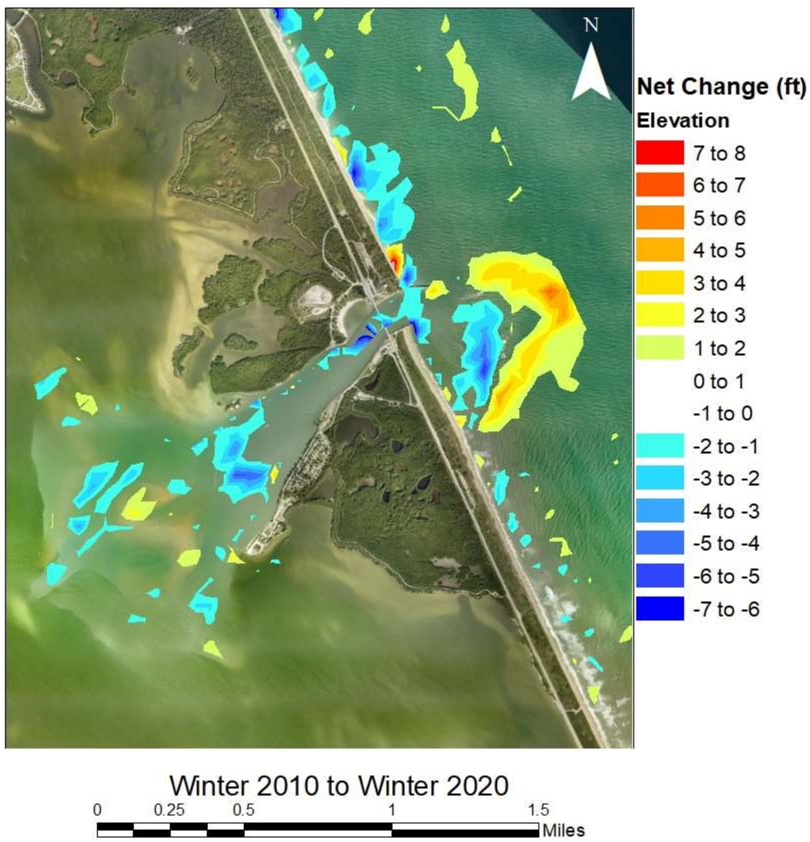

Figure 31 shows net topographic changes in the vicinity of Sebastian Inlet for the longest time period examined based on the winter 2010 and winter 2020 topographic surveys. As seen in Figure 5 and Figure 8 in Section 2 of this report, the net sand volume change within the inlet sand budget cell is dominated by sand volume losses in the sand trap due to dredging and gains in the ebb shoal. Integrated over the 10-year period net sand volume losses in this cell were on the order of 43,000 cubic yards. Consistent with sand volume calculations for the 10-year sand budget, blue colors dominate on the shoreface to the north and south of Sebastian inlet where topographic changes indicate erosion. Net topographic changes mapped from summer to summer between 2010 and 2020 are similar to the winter to winter net changes (Figure 32). Blue colors dominate all areas except the crest of the ebb shoal. Erosional net topography change over the sand trap and flood shoal, which are connected sediment pathways, represents and volume losses due to the three dredging projected (2012,2014, 2019) completed over this period.

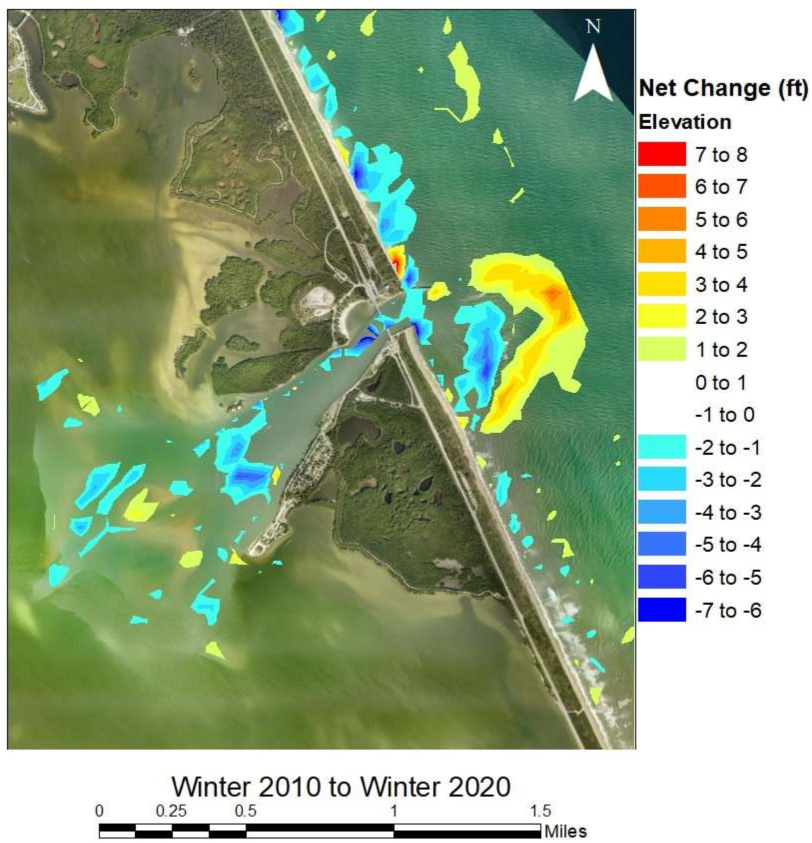

Figure 31. Topographic changes in the vicinity of Sebastian Inlet between the winter 2010 and winter 2020.

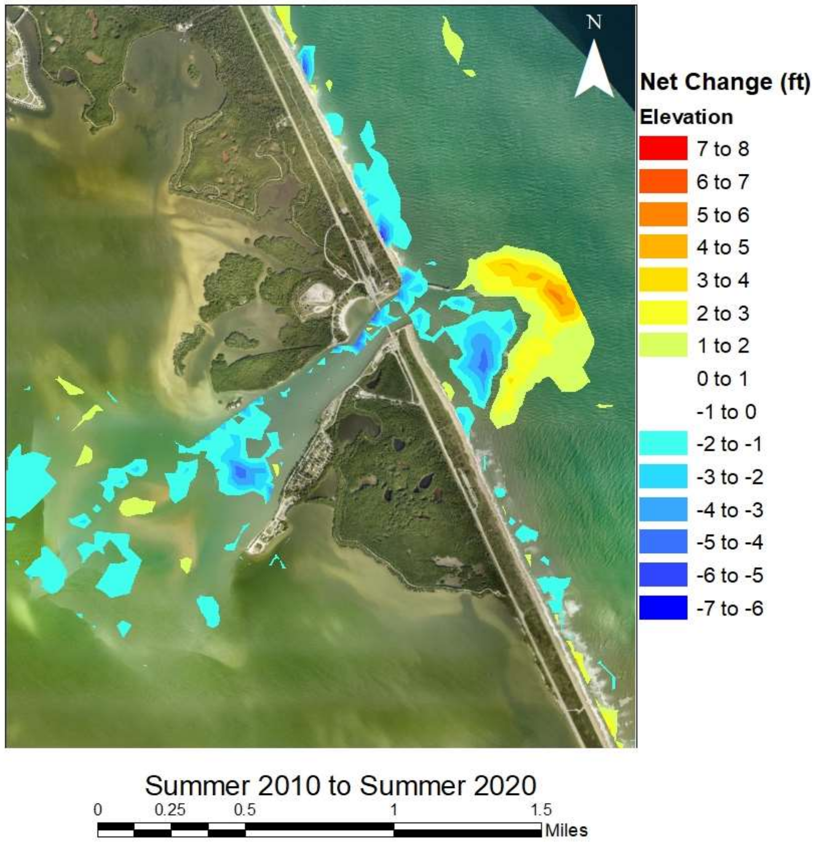

Figure 32. Topographic changes in the vicinity of Sebastian Inlet between the summer 2010 and summer 2020.

Five-year net topographic changes are shown in Figure 33 and Figure 34. Topographic changes depicted in the figures are consistent with the sand volume gains in most sand budget cells during this period (see Figure 27and Figure 28), and especially consistent with the assumption that onshore transport of sand is necessary to provide an approximately balanced sand budget. In the vicinity of the inlet sand budget cell (Figure 27) deposition dominates except along the upper shoreface and beach. Partial infilling of the sand trap is also apparent after the 2019 excavation.

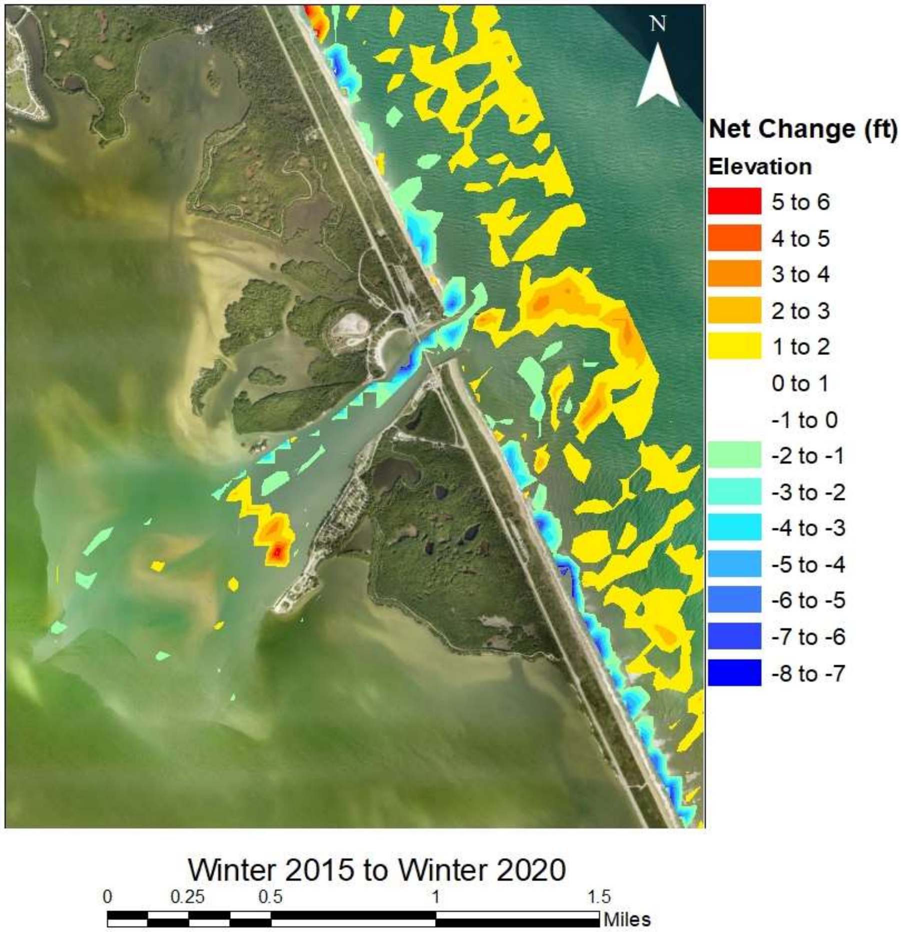

Figure 33. Topographic changes in the vicinity of Sebastian Inlet between winter 2015 and winter 2020.

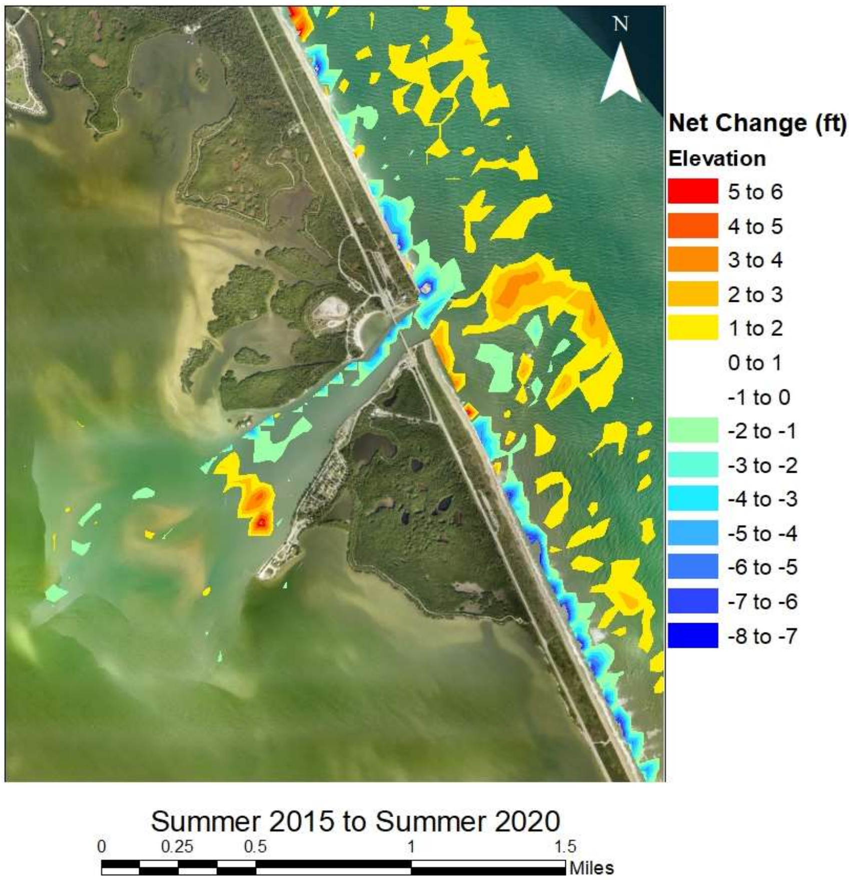

Figure 34. Topographic changes in the vicinity of Sebastian Inlet between summer 2015 and summer 2020.

As indicated by the 3-year sand budgets Topographic changes between 2017 and 2020 indicated more erosion than deposition in most areas. Figure 35 shows topographic changes between the winter 2017 and winter 2020 in the vicinity of the inlet sand budget cell. Whereas topographic increases are seen along the upper shoreface and beach, erosion is indicated over the ebb shoal areas and along the main inlet channel. The pattern of topographic changes in the summer 2017 to summer 2020 comparison (Figure 36), but the magnitude of erosion within the immediate inlet area decreased along with persistent topographic gains just to the north hand south of the inlet entrance.

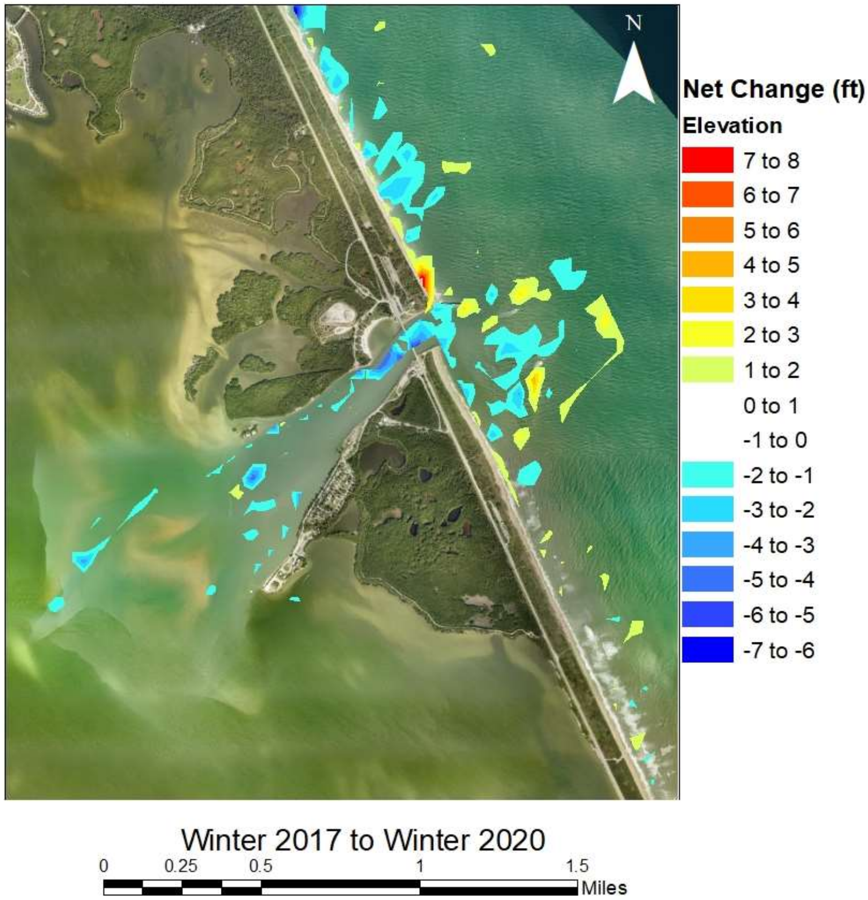

Figure 35. Topographic changes in the vicinity of Sebastian Inlet between winter 2017 and winter 2020.

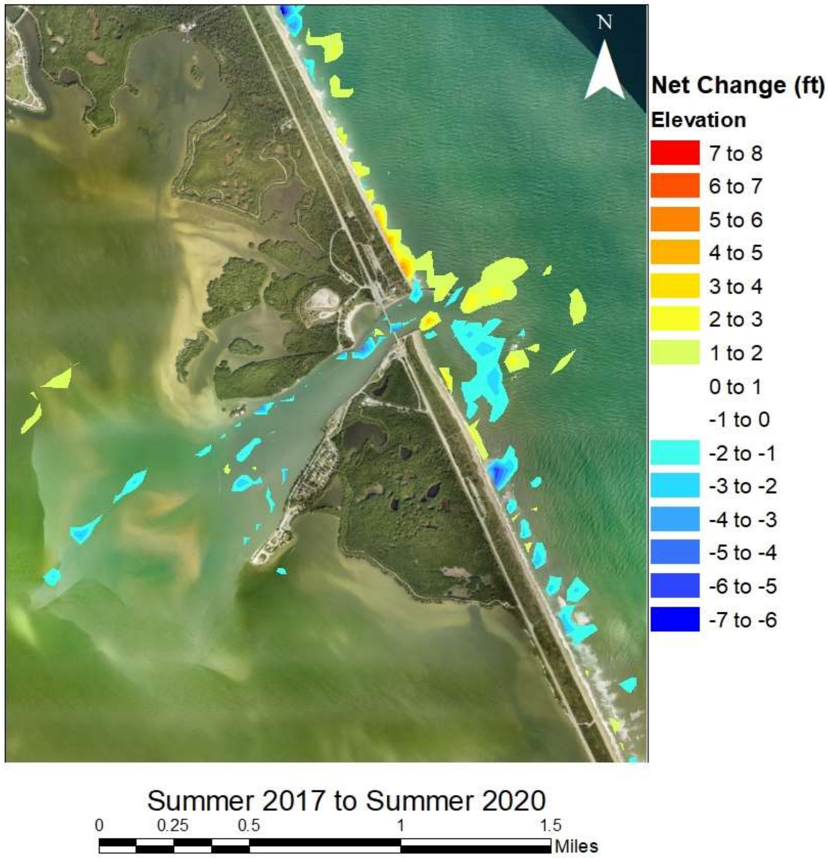

Figure 36. Topographic changes in the vicinity of Sebastian Inlet between summer 2017 and summer 2020.

Topographic changes on an annual to 18-month basis are shown in Figure 37and in Figure 38, respectively. In the winter 2019 to winter 2020 comparison, infilling of the sand trap is apparent along, which also can be seen in Figure 7 showing sand trap volume changes. Over this 12-month time interval there is no accumulation of sand on the lower shoreface although that might be expected due to a short term trend of falling sea level though 2019-2020. Further, as can been seen in Figure 5 sand volume loss occurred in the ebb shoal area over this time period. A longer trend of dropping sea level may leave an imprint on topographic changes.

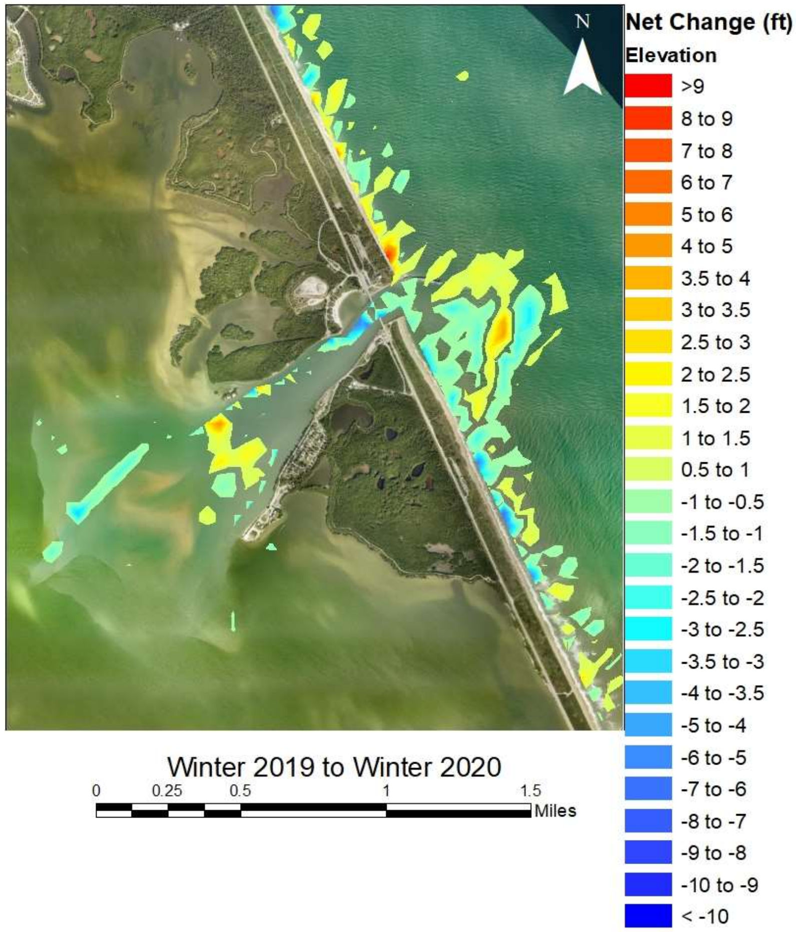

Figure 37. Topographic changes in the vicinity of Sebastian Inlet between winter 2019 and winter 2020.

Figure 38 shows net topographic change over the approximate 18-month period between winter 2019 and summer. Although volume gains are seen in the sand trap area, at this time scale there was overall sand volume loss in the immediate vicinity of Sebastian Inlet as shown in Figure 14. Sand volume losses on the upper shoreface south of Sebastian Inlet are consistent with sand volume loss in the S1 budget cell (Figure 15). Further south, topographic gains are consistent with sand volume gain in the S2 budget cell (Figure 16). North of Sebastian inlet sand volume gains on the upper shoreface and beach match moderate sand volume gains in the N1 budget cell for this time period (Figure 13).

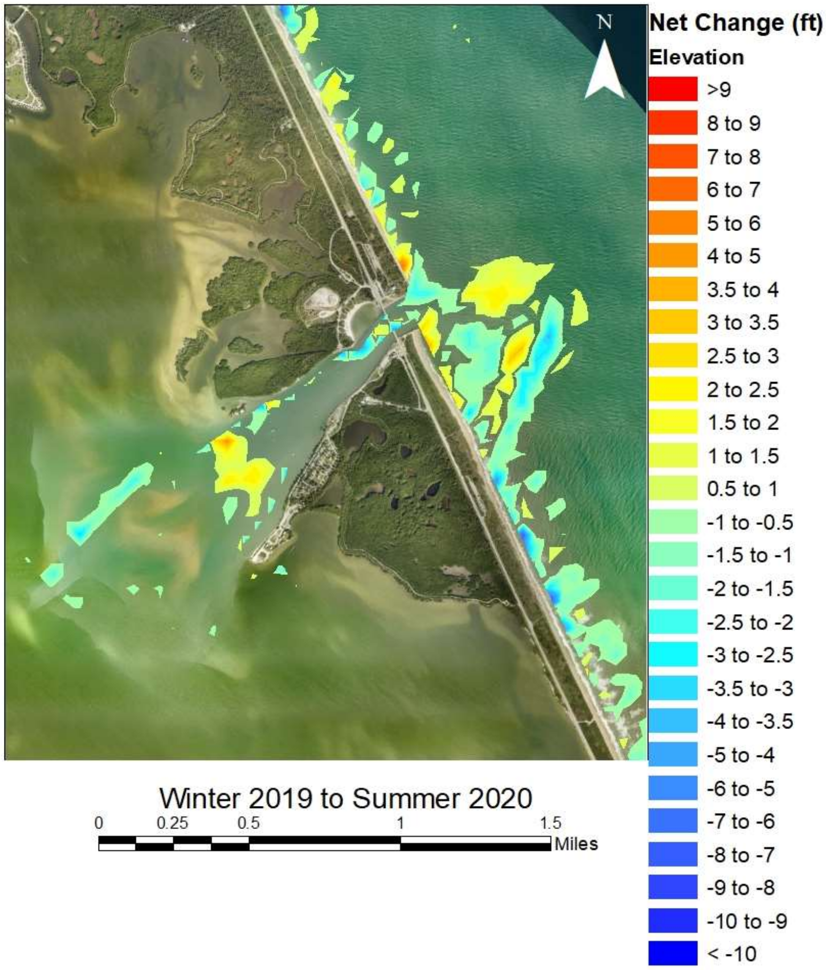

Figure 38. Topographic changes in the vicinity of Sebastian Inlet between winter 2019 and summer 2020.

5.0 Image Based Shoreline Changes

5.1 Methods

Shoreline positions were digitized from the geo-referenced aerial imagery for a domain covering approximately 14 miles from north to south of Sebastian Inlet, FL. Changes to the shoreline position were determined by comparing time series of transects generated every 25 ft along the coast. Transects were generated using the BeachTools© extension for ArcGIS © from a standardized baseline (see Figure 39) that runs somewhat parallel to Florida State Road A1A (SR-A1A) to the wet/dry line (low-tide terrace).

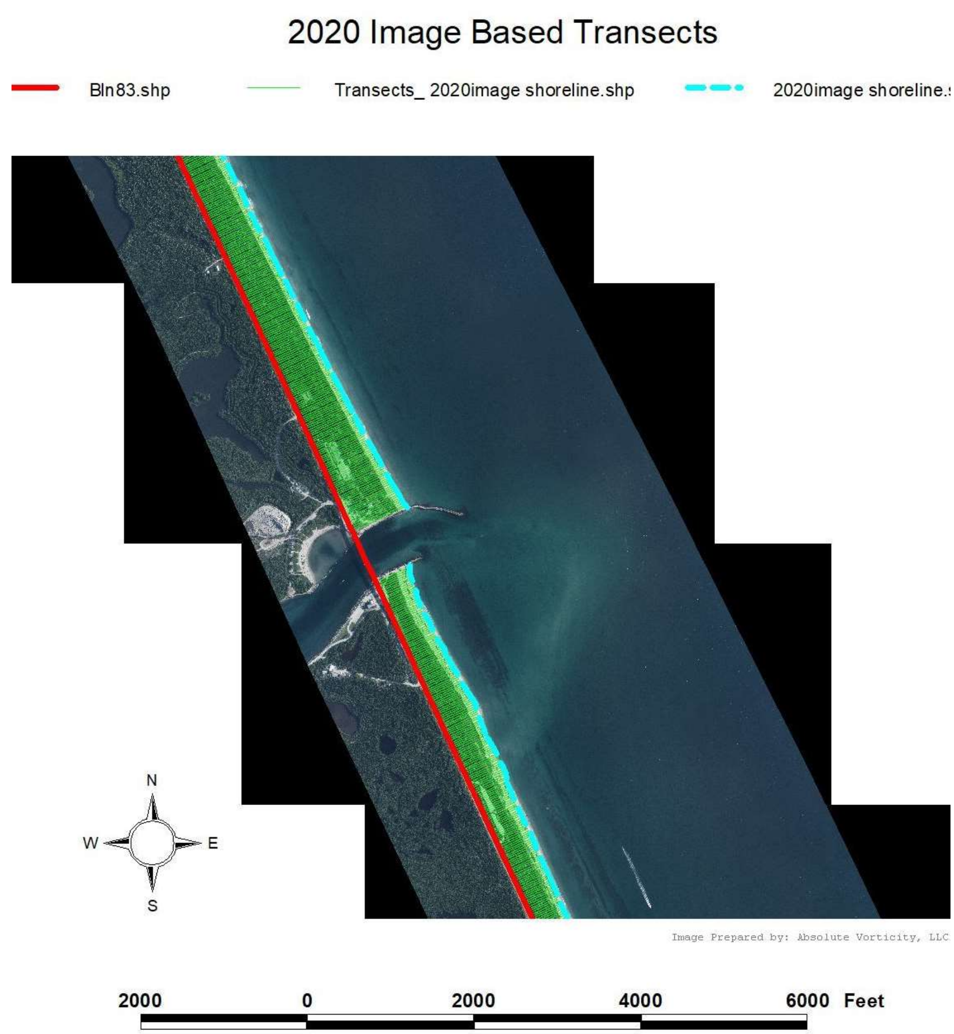

Figure 39. Baseline (red line), Transects (green lines) and light blue line is the image-based 2020 shoreline around Sebastian Inlet.

The change in shoreline position was determined by subtracting the distances along each transect between time-series of interest. Shoreline change analysis included the use of the End Point Rate (EPR) and the Linear Regression (LR) methods (Crowell et al., 1993; Morton et al., 2002). In this report, the shoreline change values were calculated from the direct comparison of the two years of interest. In other words, the most recent year which is 2020 is compared directly with 1958, 2010, 2015, and 2019 respectively. Thus, the results from the EPR and LR methods yielded almost identical values and even though the EPR method would have suffice to explain the change in the shoreline position, it is the value of the slope of the line calculated from the LR method which allowed to explain the rate at which the shoreline is changing. For details on the EPR and LR methodologies the reader is referred to State of Sebastian Inlet Technical Report 2007-1.

5.2 Shoreline change analysis results

The results presented and discussed in this section focus on the on image-based shoreline change. Table 6 shows the extent of coverage of the full study domain and of the assigned sub-cells (e.g., N1, S2, North) used in the shoreline analysis. The rates of change have been updated for an historical time period of sixty-two years (1958-2020), an intermediate period of ten years (2010-2020), and short-term analyses that account for recent changes from 2015-2020 (five years), as well as those occurring most recently from 2019 to 2020 (annual).

Table 6. Summary of transect coverage to extract shoreline data from aerial imagery

Domain	Transect ID	Sub-Domains	R Marker	Transect ID	Extent Coverage in Miles
North	0 *to* 1480	N3	180.5 - 203	0 - 1480	4.2
		N2	203 - 216	880 - 1364	2.3
		N1	216 - 219	1364 - 1480	0.6
		Inlet	BC216 - IRC4	1365 - 1645	1.3
South	1508 *to* 2974	S1	0 - 3.5	1508 - 1627	0.6
		S2	3.5 - 16	1627 - 2120	2.3
		S3	16 - 37.5	2120 - 2974	4.0

Historical Period (1958-2020)

The shoreline changes between the period of 1958 to 2020 (Figure 40) show shifts ranging from -102 feet (near R-marker 12) to +159 feet (near R-marker 219). Two major sections of shoreline recession are seen flanking three main areas of shoreline advancement. In segment N3, the first section denoting landward migration (recession) close to -55 feet is centered around R-186, within the same N3 segment the first section denoting seaward migration (advancement) close to +60 feet is centered around R-marker 194. The second area of shoreline advancement is found along segments N2 and N1, where the maximum seaward migration can be seen around R-207.5 with a value of close to +116 feet. Immediately south of Sebastian Inlet, an area of shoreline advancement is centered around R-219 with values of close to +160 feet while the widest contiguous section of landward migration (receding shoreline) of up to -102 feet at R-12 dominates most of S2 and the part of S3 that has data available for this analysis.

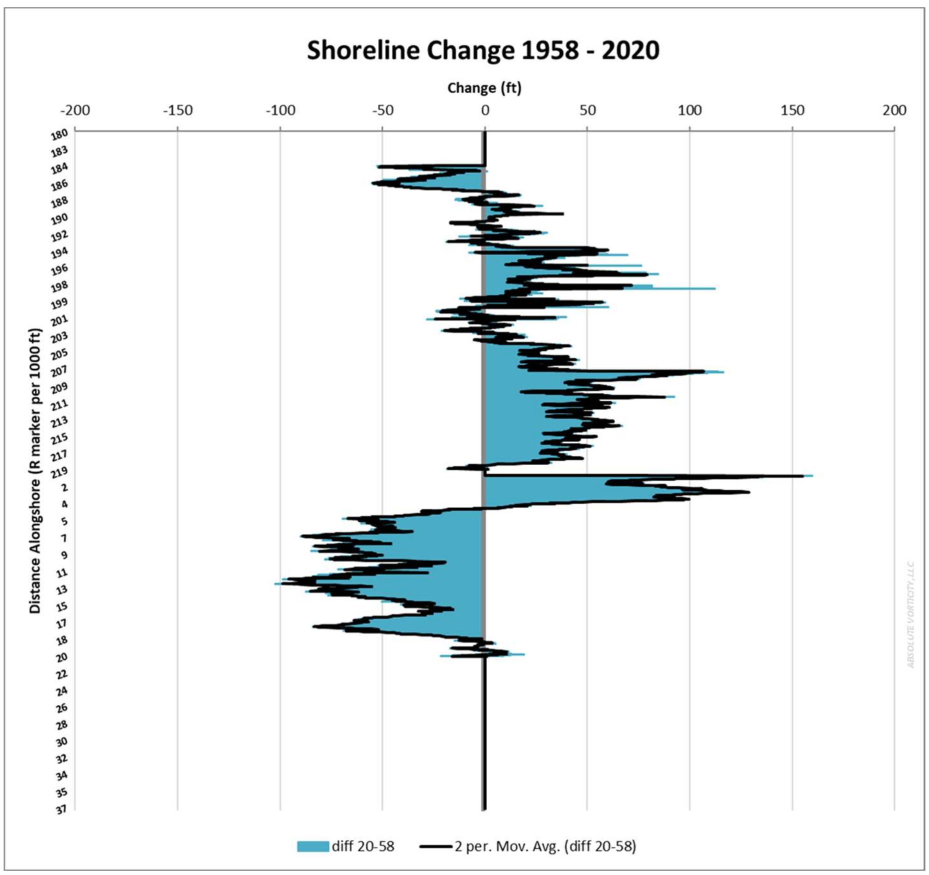

Figure 40. Change (ft) in shoreline position from 1958-2020

The range of the shoreline change rates, the average shoreline change rate for a segment or extent, and the percentage of the shoreline undergoing erosion or accretion within each segment are summarized in Table 7. Overall, the entire extent (North to South) for the 1958-2020 period presents mostly accretion (40.57%). The North segment shows three main sections where erosion occurs (19.85%), otherwise accretion areas cover 69.95% of the North extent with an average rate of change of +0.31 ft/yr. The South extent is where the maximum accretion rate occurs (+2.6 ft/yr.) dominating segments N3, N2, N1 and S1. Segment S2 is where the maximum erosion rate is found -1.65 ft/yr. and erosion dominates 94.94% of this area. The area immediately south of the Inlet (S1) have undergone 100% accretion, closely followed by N2 (97.53%) and N1 (87.18%) also dominated by accretion.

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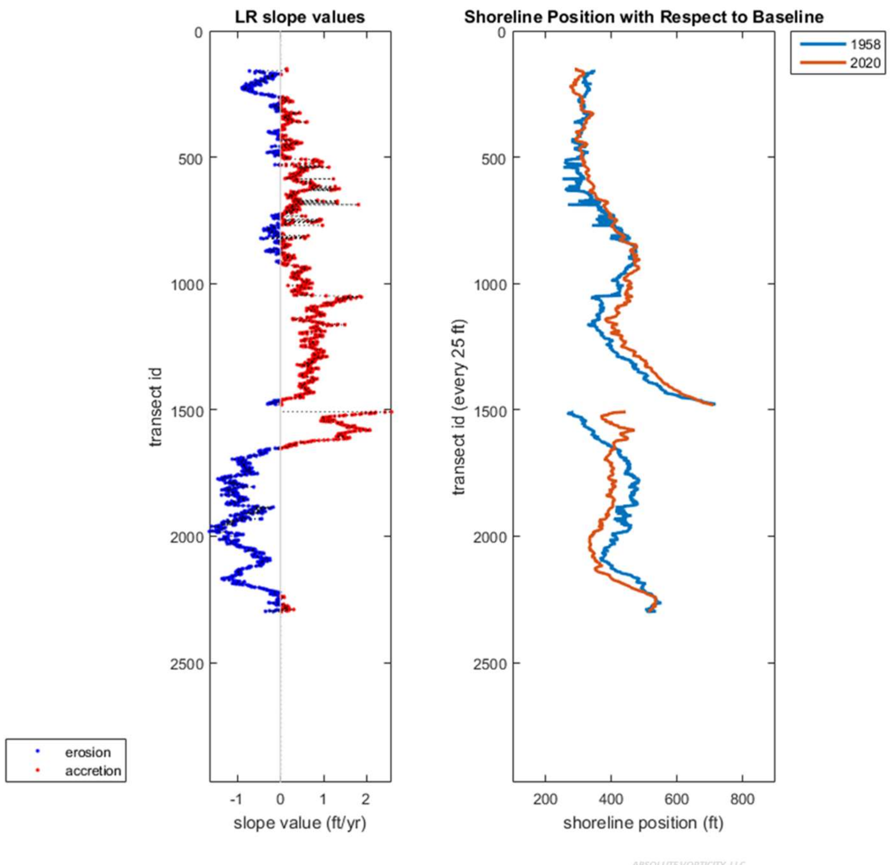
Table 7. Summary shoreline changes for the historical period (1958-2020)

Extent	Range (ft/yr.) *Max Erosion to Max Accretion*	Rate of Change (ft/yr.)	Erosion %	Accretion %
North to South	-1.6510 to +2.5776	0.0460	30.76	40.57
North	-0.8927 to +1.8784	0.3076	19.85	69.95
N3	-0.8927 to +1.8097	0.0912	30.42	52.44
N2	-0.0950 to +1.8784	0.6681	2.47	97.53
N1	-0.2997 to +0.8511	0.4417	12.82	87.18
Inlet	-0.2997 to +2.5776	0.9563	5.34	85.05
S1	+0.6253 to +2.5776	1.4535	0	100
S2	-1.6510 to +0.6253	-0.8237	94.94	5.06
S3	-1.3563 to +0.3077	-1.1029	17.89	3.16
South	-1.6510 to +2.5776	-0.2184	42.33	11.66

Another way to visualize the results presented in Figure 40 (a) is with a histogram plot (Figure 42) which shows the frequency at which a particular value of the rate of change occurs throughout the study domain for the particular time period considered. The majority of the spread and peak frequencies occur around +0.12 ft/yr., this agrees with the central value of accretion rates (red dots) dominating segment N3 which accounts for close to one third of the extent for this period. The secondary grouping centered around -0.8 ft/yr. in the histogram corresponds for the most part to the erosion trends dominating S2, while the spread in values seen over +1 ft/yr. can be attributed for the most part to segment S1.



(a) (b)

Figure 41. Period of 1958-2020. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

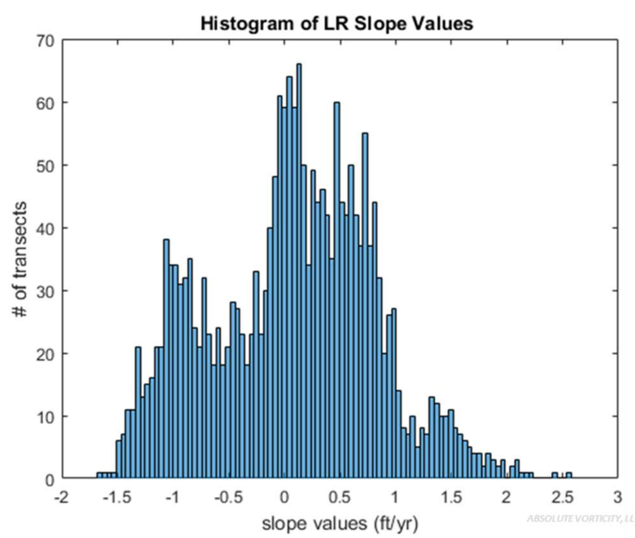


Figure 42. Frequency of rate of change (slope value in ft/yr.) for entire domain (1958-2020).

Intermediate Period (2010-2020)

The changes in shoreline position from 2010 to 2020 (Figure 43) show overall seaward migration (advancement) throughout the entire domain centered around +22 feet with a maximum of close to +90 feet immediately south of the inlet (near R-1). Only two narrow sections in segments N1 and S2 show changes indicating retreat (landward migration) of -49 feet and -36 feet respectively. The second largest seaward advancement occurs in S3 near R-21 with a value of +76 feet.

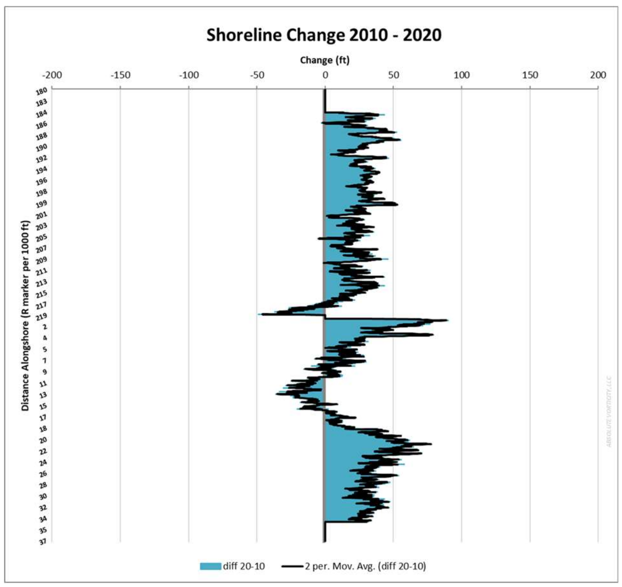


Figure 43. Change (ft) in shoreline position from 2010-2020.

The full extent from North to South show 78.49% accretion and 11.03% erosion with an average rate of change of +2.05 ft/yr. (Table **8**). Similarly, most segments show accretion ranging from 50.20% (S2 segment) to 100% (S1). Segment N1 shows erosion of 60.68%, where the average rate of change -0.77 ft/yr. In general, the average rate of change is centered around a value of +2.01 ft/yr. (Figure 44 and Figure 45(a)) for the entire domain, being segments N3, N2 and S3 the ones driving the average of the accretion rate (in ft/yr.) with +2.29, +2.07, and +2.77 values respectively. Maximum values of erosion (blue dots) occur at N1 (-4.90 ft/yr.) and S2 (-3.61 ft/yr.).

Table 8. Summary of shoreline changes for the period 2010-2020

Extent	Range (ft/yr.) *Max Erosion to Max Accretion*	Rate of Change (ft/yr.)	Erosion %	Accretion %
North to South	-4.9060 to +9.0290	2.0499	11.03	78.49
North	-4.9060 to +5.5480	1.9845	5.54	84.27
N3	-0.2860 to +5.5480	2.2997	0.57	82.29
N2	-0.5720 to +4.5940	2.0727	1.24	98.76
N1	-4.9060 to +2.1810	-0.7685	60.68	39.32
Inlet	-4.9060 to +9.0290	2.5883	25.27	65.12
S1	+2.3980 to +9.0290	5.5839	0	100
S2	-3.6120 to +3.1680	0.0781	49.80	50.20
S3	0 to +7.7730	2.7766	0.12	84.33
South	-3.6120 to +9.0290	2.0992	16.77	74.10

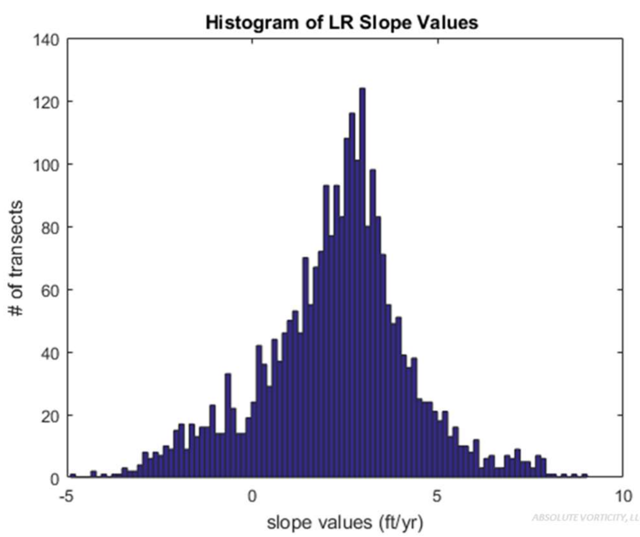
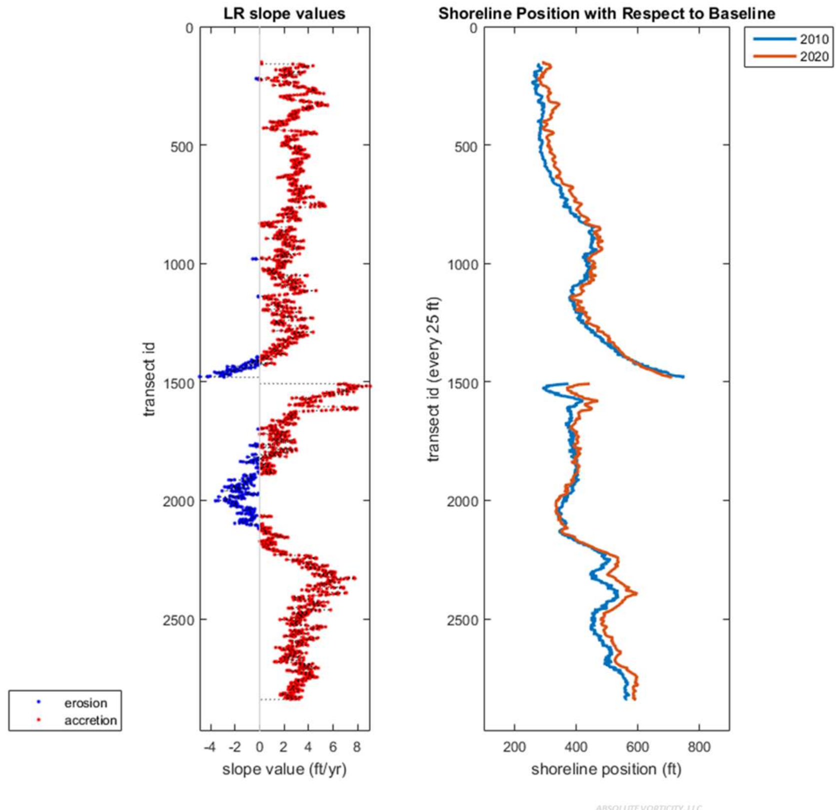


Figure 44. Histogram indicating number of transects per slope value (ft/yr.) for 2010-2020.



(a) (b)

Figure 45. Period of 2010-2020. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

Recent Changes (2015-2020)

Shoreline changes from 2015 to 2020 (Figure 46 and Figure 47) experienced mostly seaward migration (advancement) throughout the entire domain. A maximum change of +128 feet (near R-1) is found immediately south of the inlet in S1 where seaward shoreline migration (advancement) dominates the segment. The range of shoreline change in segment S1 is from +4.09 ft/yr. to +25.71 ft/yr. (Table 9). Several small areas in most segments (except S1) show retreat in the shoreline but only two sections in segments N1 and S2 show considerable changes indicating retreat (landward migration) of close to -50 feet. It is in these two segments where the maxima of the range of erosion rates are found, -9.55 ft/yr. and -9.51 ft/yr. (segments S2 and N1 respectively). In the vicinity of the inlet, segment N1 shows an average rate of change of -3.18 feet per year while S1 has an average accretion rate of +13.82 ft/yr. Sixty-six percent of the domain undergoes accretion, predominantly occurring in segments N3, N2, S1 and S3 centered at an average rate of change of +2.95 ft/yr. for the full extent. The two segments that show erosion around 71% are N1 and S2.

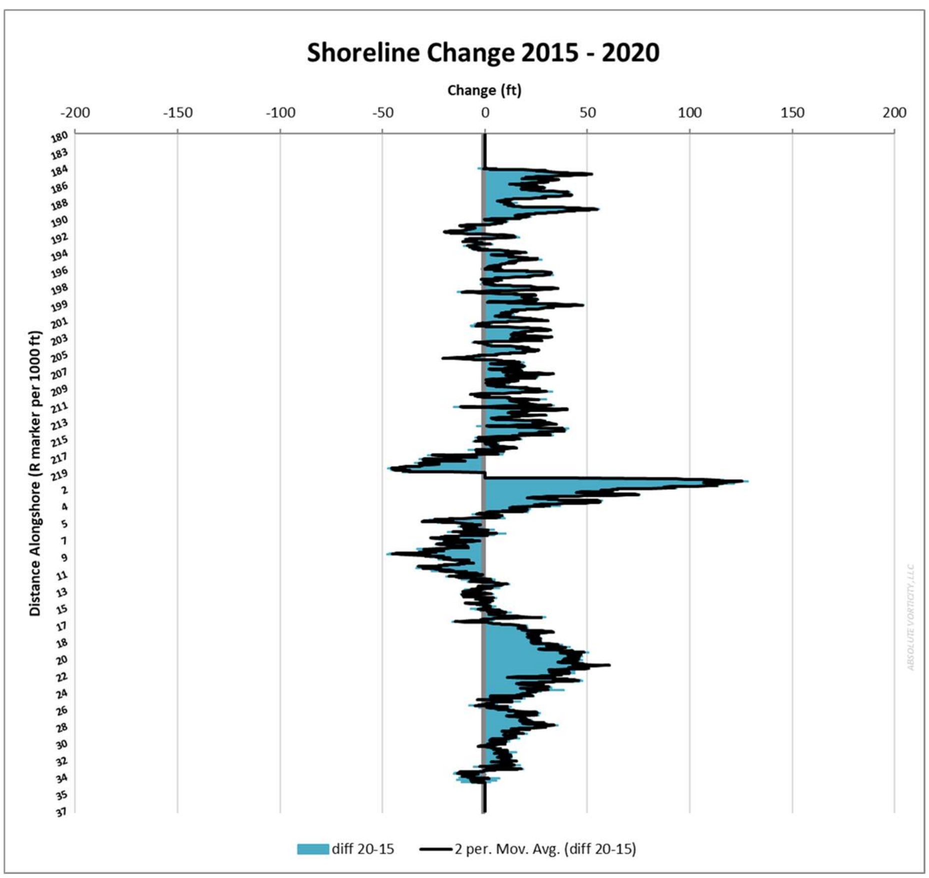
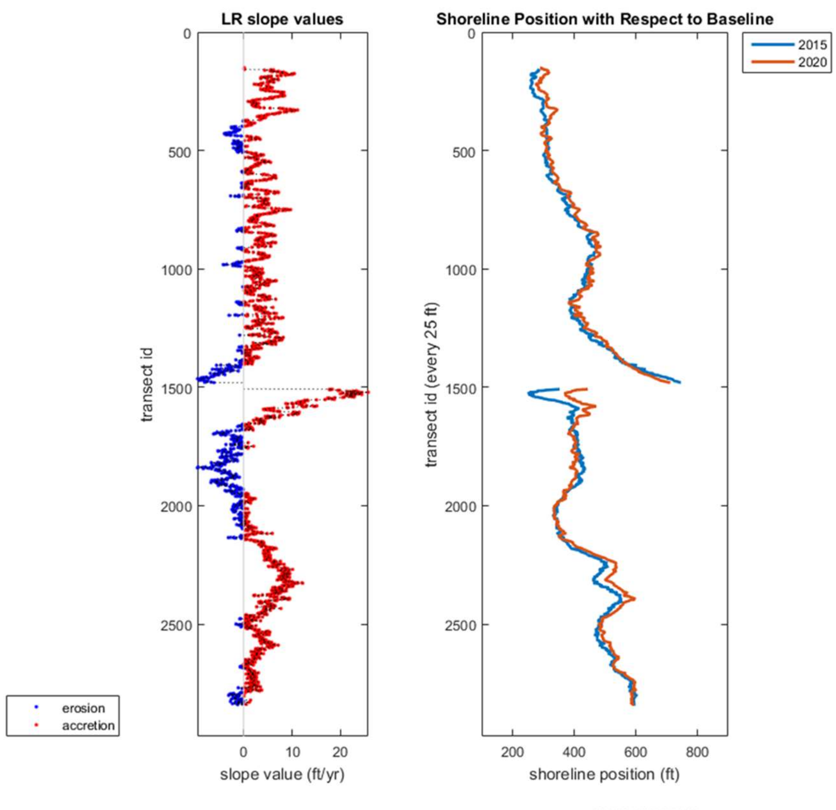


Figure 46. Change (ft) in shoreline position from 2015-2020.

Table 9. Summary of shoreline changes for the period 2015-2020.

Extent	Range (ft/yr.) *Max Erosion to Max Accretion*	Rate of Change (ft/yr.)	Erosion %	Accretion %
North to South	-9.5520 to +25.7080	2.3207	23.16	66.35
North	-9.5080 to +11.1300	2.1590	17.56	72.25
N3	-3.9940 to +11.1300	2.5077	13.39	69.47
N2	-4.2060 to +8.2020	2.8109	11.96	88.04
N1	-9.5080 to +3.1300	-3.1834	71.79	28.21
Inlet	-9.5080 to +25.7080	5.3291	29.89	60.50
S1	+4.0940 to +25.7080	13.8260	0	100
S2	-9.5520 to +7.3640	-1.3662	71.66	28.34
S3	-3.1700 to +12.1880	3.0886	8.77	75.56
South	-9.5520 to +25.7080	2.4649	29.24	61.62



(a) **(b)**

Figure 47. Period of 2015-2020. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

Annual Update (2019-2020)

The shoreline changes occurring between 2019 and 2020 (Figures 48-50) indicate shifts ranging from -49 feet to +39 feet. Although seaward and landward migration of the shoreline is seen to alternate throughout the domain, 65.18% of the shorelines show retreat. Segment (S2) show 98.79% of shoreline retreated at an average rate of -19.0 ft/yr. (Table 10). The rest of the segments also experience shoreline retreat but at lower rates from -4.13 ft/yr. to -0.95 ft/yr. Only few narrow sections of shoreline show prominent seaward progression, in particular, near R-3 in S1 and near R-189 in N3 with values respective values of +38.43ft and +32.86 ft.

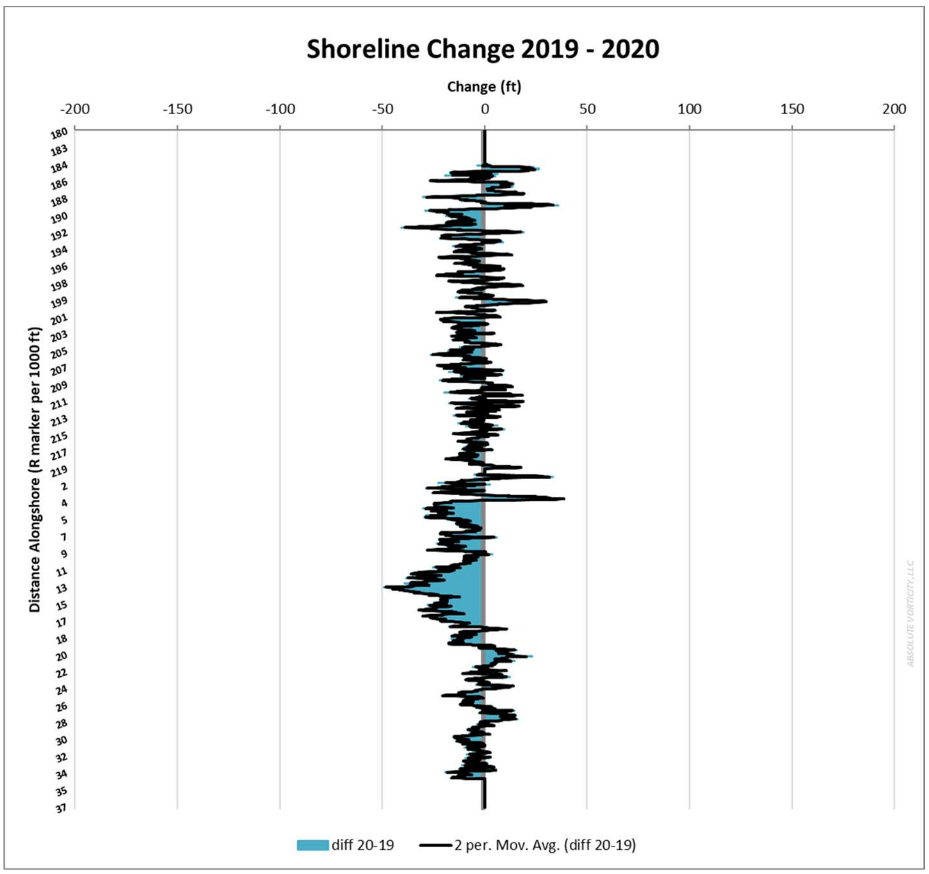


Figure 48. Change (ft) in shoreline position from 2019-2020.

The majority of the spread and peak frequencies occur around -5.6 ft/yr. more easily noticeable in Figure 49. Values beyond -20 ft/yr. are clustered predominantly in S2 where the range of shoreline change values go from -49.4 ft/yr. to +6.2 ft/yr. Meanwhile, values over +20 ft/yr. are found in S1 and N3, where the rate of shoreline change is -0.95 ft/yr. and -2.9 ft/yr. correspondingly.

Table 10. Summary of shoreline changes for the period 2019-2020.

Extent	Range (ft/yr.) *Max Erosion to Max Accretion*	Rate of Change (ft/yr.)	Erosion %	Accretion %
North to South	-49.3700 to +39.1000	-5.7153	65.18	24.34
North	-40.6100 to +36.0000	-3.3778	61.31	28.49
N3	-40.6100 to +36.0000	-2.9026	54.60	28.26
N2	-26.3300 to +18.8700	-4.1369	69.28	30.72
N1	-19.0000 to +17.8500	-3.9105	79.49	20.51
Inlet	-28.9200 to +39.1000	-4.0026	66.90	23.49
S1	+28.9200 to +39.1000	-0.9582	65.00	35.00
S2	-49.3700 to +6.2000	-19.0268	98.79	1.21
S3	-30.2300 to +23.4000	-2.6921	54.62	29.71
South	-49.3700 to +39.1000	-8.0283	70.28	20.59

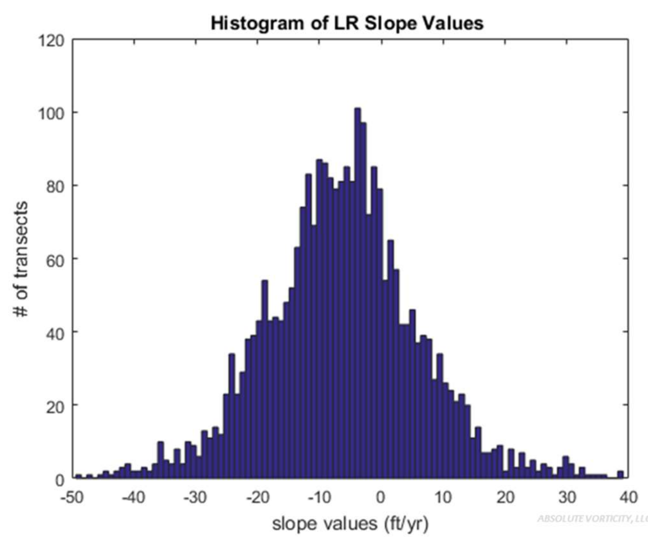
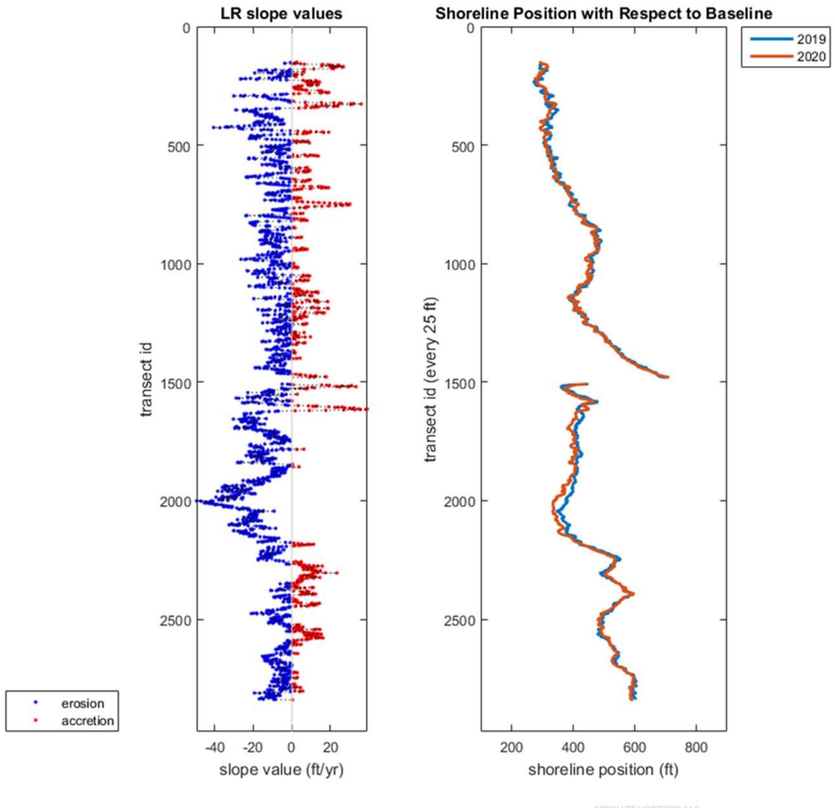


Figure 49. Histogram indicating number of transects per slope value (ft/yr.) for 2019-2020.



(a) (b)

Figure 50. Period of 2019-2020. (a) Shoreline change rate in ft/yr. (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

6.0 Survey Based Shoreline Change

6.1 Methods

Analysis of the shoreline position derived from hydrographic surveys was based on digitizing the zero-contour to represent the shoreline. The zero-contour represents the same elevation as the mean water line (MHW) for the NAVD88 vertical datum used during the ground surveys. The advantage for using surveys to determine the shoreline position was the improved temporal resolution since hydrographic surveys are typically performed on a seasonal basis at Sebastian Inlet. However, there is a trade-off for spatial resolution because transects were typically spaced 500 ft to 1,000 ft apart. Generating a survey-based shoreline began with generating contour plots using the ImageAnalyst© extension in Arcview3.2©. Once the XYZ data files from hydrographic surveys were contoured, the extension was also used to highlight the zero-contour so that this one interval could be digitized to represent the position of the shoreline. Once highlighted, the zero-contour was extracted by hand-tracing the contour using shoreline-generating tool in BeachTools© (Hoeke et al. 2001). To determine the change in shoreline position, a common baseline with a NAD83 projection running along the SRA1A was created manually using BeachTools©. This extension was also used to generate perpendicular transects from this baseline to the digitized shoreline every 25 ft, to match the transect interval used in the image-based analysis. For detailed methodology on the shoreline change calculations, the reader is referred to previous reports (Zarillo et al., 2007, 2009, 2010).

Similarly, as with the image-based analysis, changes to the survey-based shoreline position were determined by subtracting the distances along each transect between time-series of interest. The results presented and discussed in this section will focus on the on seasonal changes in the survey-based shoreline. The rates of change have been obtained comparing winter to winter and summer to summer seasons for various time periods. Winter surveys were analyzed for time periods corresponding to: long-term of fifteen years (2005-2020); intermediate term of ten years (2010-2020); recent-term of five years (2015-2020); and annual (2019-2020). At the time of this report the 2020 Summer survey was not available, thus comparison is performed using the last year available which is 2019. Summer surveys were analyzed for time periods corresponding to: long-term of fourteen years (2005-2019); intermediate term of nine years (2010-2019); and recent-term of four years (2015-2019).

6.2 Winter Surveys (2005, 2010, 2015, 2019 and 2020)

Changes between Winter 2005 and Winter 2020 show large excursions in the shoreline, alternating between advancement and retreat along the entire domain (Figure 51), red dashed line). Three larger areas of seaward migration can be identified (two on the north and one on the south) while one large area grouping mostly landward migration can be seen on the south segment. It is on the south section where the maxima of shoreline retreat and advancement values are located (-230.71 ft at R-11 and +100.99 ft at R-21.5). At first glance, it is difficult to determine if the overall trend is towards seaward or landward migration, however from a more detailed analysis it was determined that the changes in the winter shoreline from 2005 and 2020 point towards accretion (Table 11 and **Figure** 52-a). The full extent from North to South show 41.75% accretion and 36.47% erosion and ranging from -15.3807 ft/yr. to +6.8160 ft/yr. Due to the distribution of the rate of change values, that is, the majority of the accretion values fall closer to zero while the erosion rate values are farther from zero, the average rate of change (mean slope) results in a negative value centered around zero (-0.2843 ft/yr.).

Table 11. Summary of shoreline change rates for the 0-contour Winter survey line along the North to South Extent.

Temporal Range of Survey	Range of Rate of Change (ft/yr.) *Max Erosion to Max Accretion*	Mean Rate of Change (ft/yr.)	Erosion %	Accretion %
Winter 05-20	-15.3807 to +6.8160	-0.2843	36.47	41.75
Winter 10-20	-14.5310 to +7.9020	-0.3576	41.88	36.37
Winter 15-20	-39.4000 to +13.7940	-4.3782	52.17	25.85
Winter 19-20	-44.3700 to +81.4100	+9.0006	23.43	54.45

The results for Winter 2010-2020 analysis are somewhat similar to those of Winter 2005-2020. Figure 51 (green solid line) show large excursions in the shoreline that alternate from advancement and retreat, there are three areas of seaward migration (two on the north and one on the south), and one distinctive area with mostly landward migration on the south segment. Unlike the 05w-20w period, the 10w-20w retreating section on the south is easily identified because the values are "clustered" without alternating with advancing values. In those marked areas of seaward and landward migration, the maxima of shoreline retreat and advancement values are identified as: +55.57 ft at R-194, +74.39 ft at R-212, -48.12 ft at R-11.6, and +65.08 ft at R-20. The majority of the rate of shoreline change values fall close to zero with an average of -0.3576 ft/yr. and a range of -14.5310 ft/yr. to +7.9020 ft/yr. (Table 10 and Figure 50-b). Overall, this period results in 41.88% erosion and 36.37% accretion.

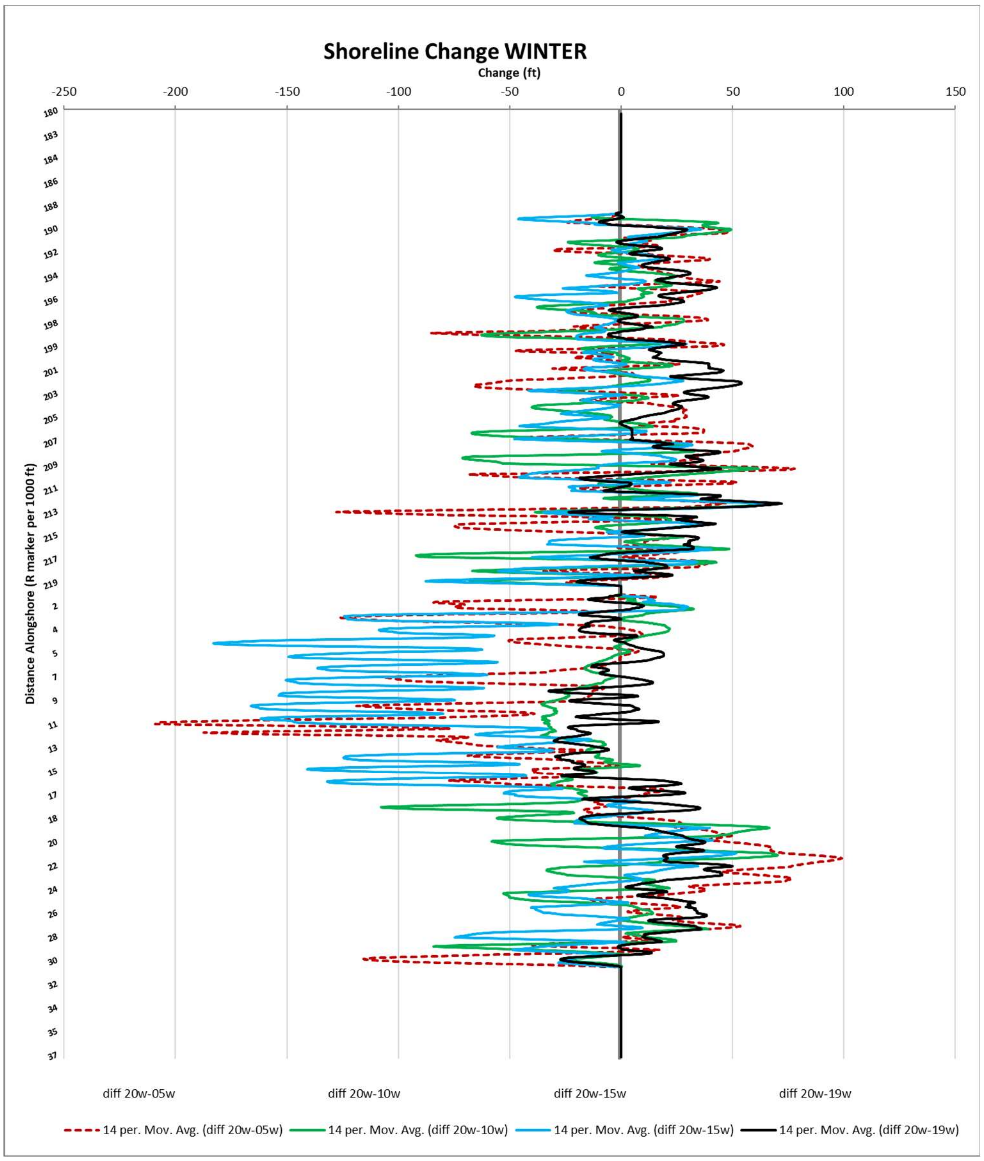


Figure 51. Survey-based change (ft) in shoreline position for 2005w, 2010w, 2015w, 2019w and 2020w.

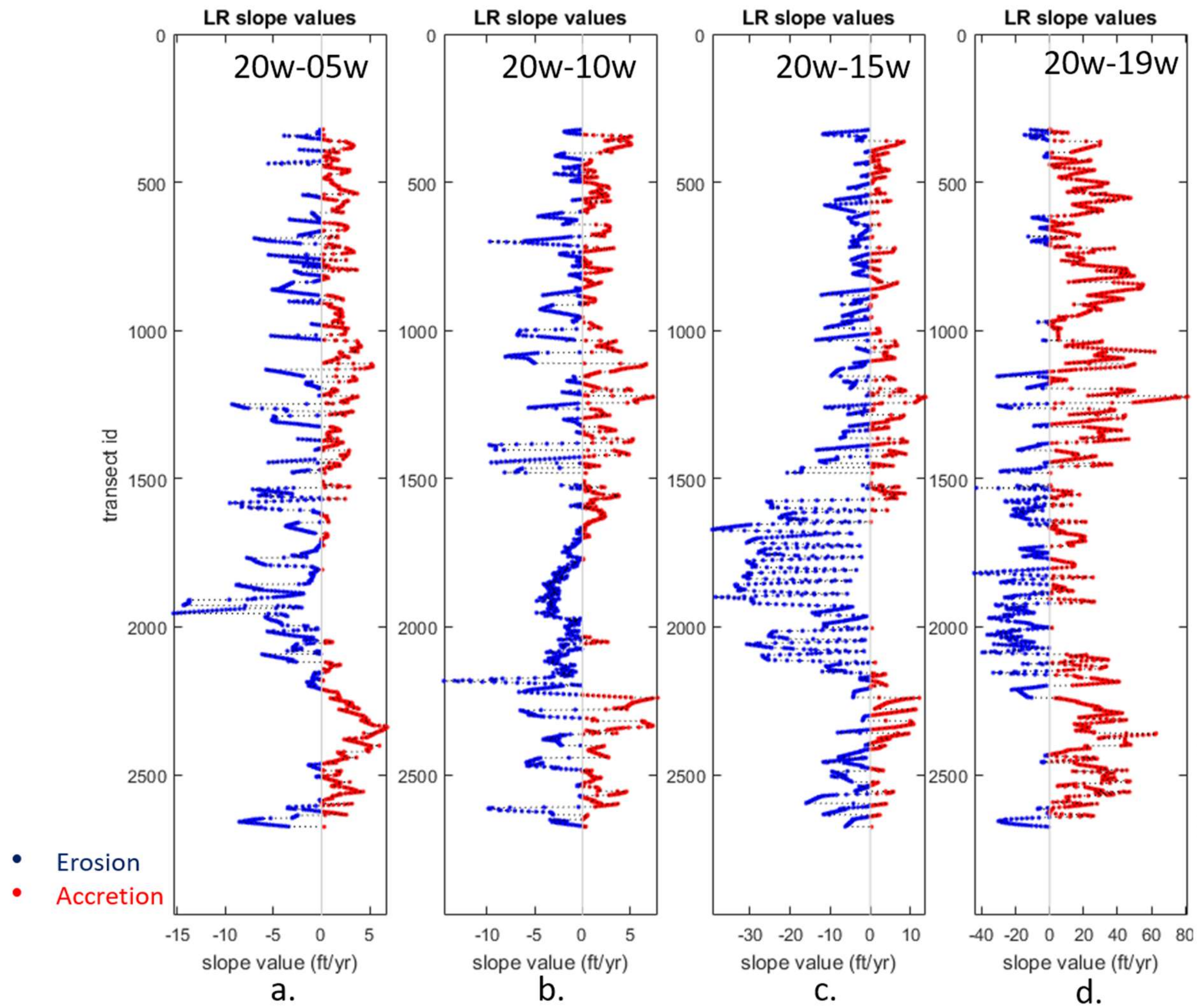


Figure 52. Shoreline rate of change (in ft/yr.) for entire domain WINTER surveys: (a) 05w-20w, (b) 10w-20w, (c) 15w-20w, and (d) 19w-20w.

Winter 2015 and Winter 2020 shoreline changes (see Figure 51 (solid blue line)) continue to show values alternating from advancement and retreat, however two areas of seaward migration, one north and one on south of the inlet can be discerned, and one segment of pronounced landward migration can be found on the south segment. The 15w-20w retreating section on the south is easily identified by the large negative values contained in the area. The maxima of values in those aforementioned areas are: +68.97 ft at R-212, -195.35 ft at R-4.6, and +53.78 ft at R-21. The majority of the rate of shoreline change values fall close to zero with an average of -0.36 ft/yr. and a range of -14.53 ft/yr. to +7.90 ft/yr. (Table 11and Figure 52-c). This period is the only one in the Winter analysis with marked overall erosion (52.17% erosion and 25.85% accretion) and an average rate of change of -4.38 ft/yr.

The most recent Winter period of 2019w and 2020w (Figure 51, solid black line) show two areas of seaward migration (one on the north and one on the south) and one area where landward migration is observed. The advancing area on the north has a maximum value of over +80 ft of shoreline change near R-212 and the area on the south near R-22 has a maximum value of +62.64 ft. The area in the south showing landward migration has values of -35.65 ft/yr. at R-12. Table 11 and Figure 52-d show that 19w-20w is dominated by accretion (54.45%) and has an average shoreline rate of change of +9 ft/yr.

6.3 Summer Surveys (2005, 2010, 2015, and 2019)

At first glance, Summer survey changes from the different periods (Figure 54) follow a similar pattern. The North segment values centered at about -11 ft, one area in the South with noticeable shoreline retreat in the vicinity of R-16, followed by a last segment in the South with values around -20 ft. The changes observed between 2019s and 2005s range from -20.56 ft/yr. to +4.61 ft/yr. (Table 12) and an average rate of shoreline change of -1.23 ft/yr. This period shows overall erosion (55.13%) and with the majority of accretion areas found along the North segment and immediately South of the Inlet (Figure 54a).

Table 12. Summary of shoreline change rates for the 0-contour Summer survey line along the North to South Extent.

Temporal Range of Survey	Range of Rate of Change (ft/yr.) *Max Erosion to Max Accretion*	Mean Rate of Change (ft/yr.)	Erosion %	Accretion %
Summer 05-19	-20.5571 to +4.6136	-1.2323	55.13	22.89
Summer 10-19	-13.5167 to +5.7267	-1.9486	62.89	15.13
Summer 15-19	-50.1200 to +19.3875	-8.7196	71.09	6.92

The results for Summer 2010-2019 analysis indicate that most of the shoreline has retreated and erosion dominates this period. There is a 62.89% of the area undergoing erosion and only 15.13% experiencing accretion (and Figure 54b). The range of the rate of change if from -13.52 ft/yr. to +5.73 ft/yr. The average shoreline rate of change is -1.95 ft/yr.

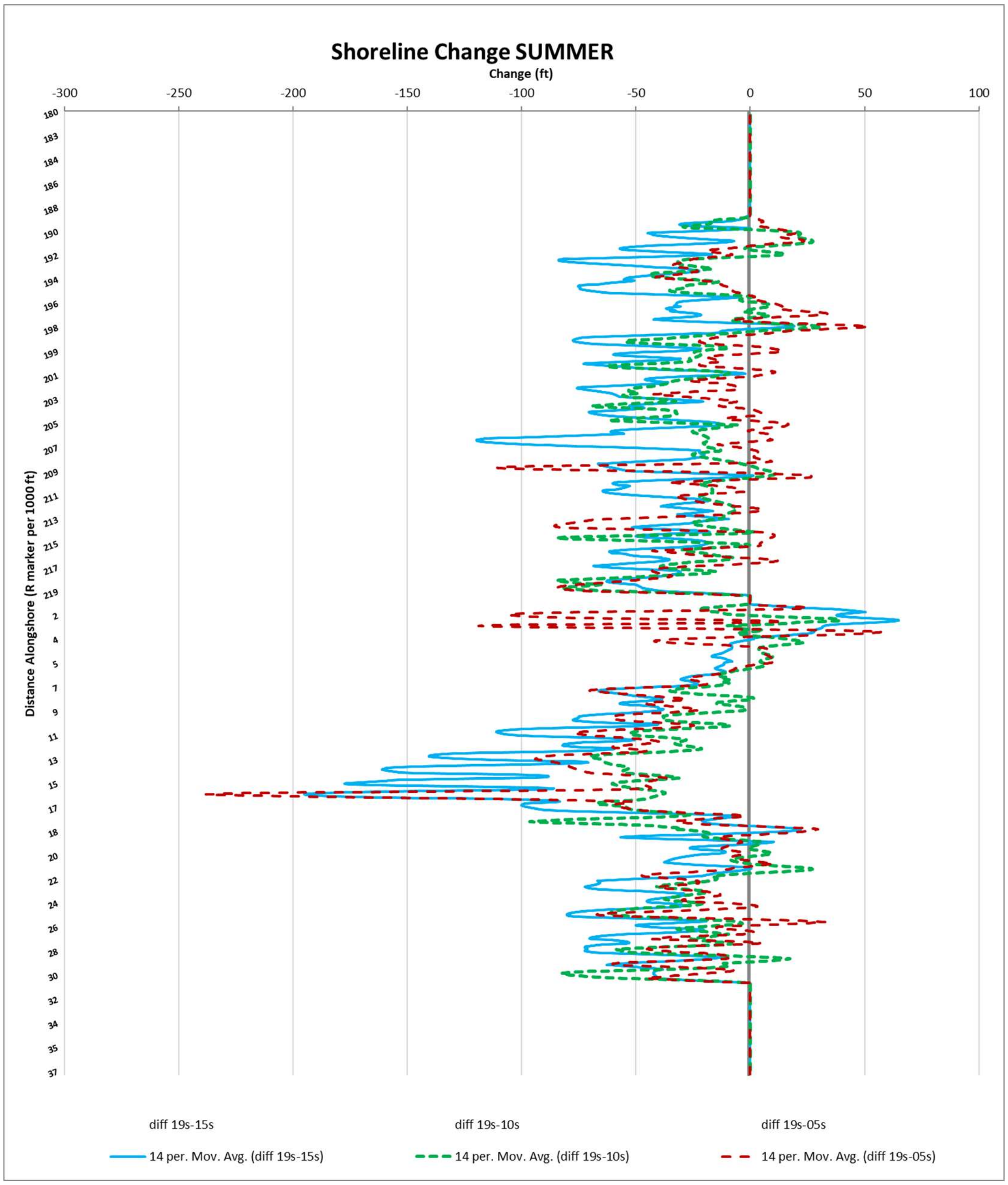


Figure 53. Survey-based change (ft) in shoreline position for 2005s, 2010s, 2015s, and 2019s.

The most recent Summer period studied is 2019s and 2015s (Figure 53, solid blue line). The variability in the shoreline change values is more drastic, and consistently throughout the domain larger values are found. Maximum shoreline retreat of close to -200 ft is found near R-marker 17. In general, this period shows 71% erosion and only 6.9% accretion concentrated immediately south of the inlet (Figure 54-c and Table 11). The average rate at which the shoreline is changing is -8.72 ft/yr. with a range of the rate of change reaching values from -50.12 ft/yr. to +19.39 ft/yr.

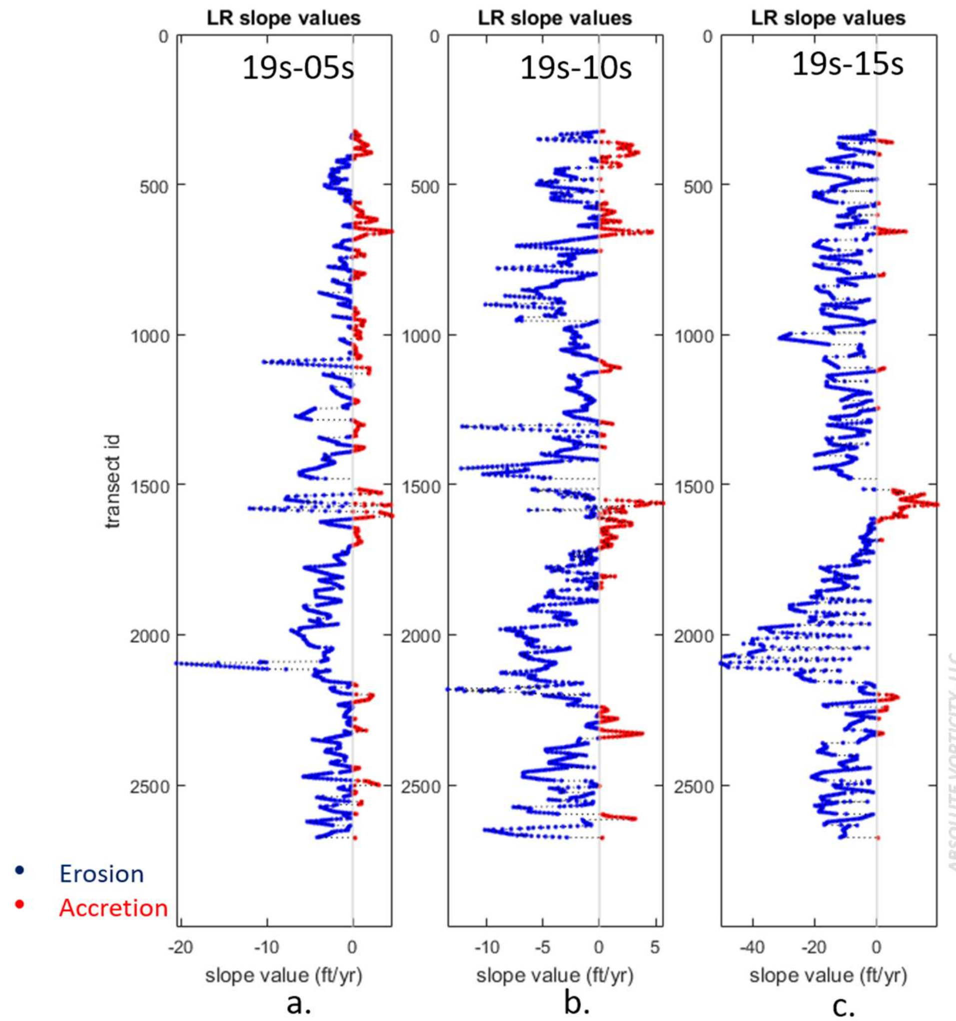


Figure 54. Shoreline rate of change (in ft/yr.) for entire domain SUMMER surveys: (a) 05s-19s, (b) 10s-19s, and (c) 15s-19s.

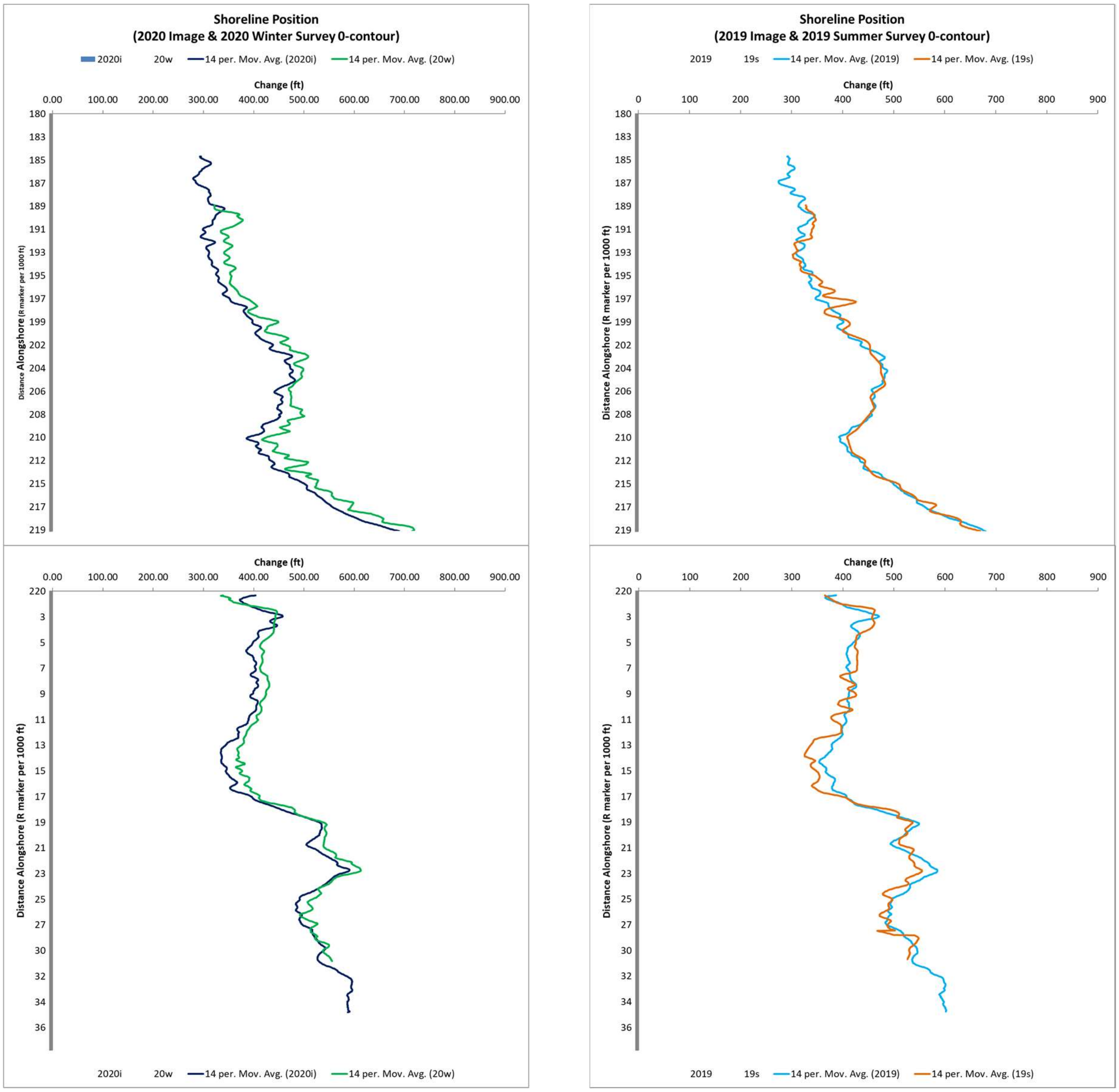
6.3 Survey vs. Image Based

The 0-contour survey lines on which the shoreline is based are usually measured profiles spaced every 500 to 1000 ft, whereas the raw shoreline data are captured every 25 ft in the aerial images. Even though the survey-based and the image-based shorelines are digitized and re-sampled at a 25 feet interval, due to a much lower spatial resolution of the raw survey data when compared to the image-based shoreline, the survey-based shoreline pattern is spatially more variable.

The comparison between survey-based and image-based shoreline position is presented for 2020 (winter) and 2019 (summer) in Figure 55 (a) and (b), respectively. Whereas, variability exists in the shoreline profile and some reversals occur along the domain, the main patterns of the shoreline position are analogous in both methods

Results indicated that overall, the 2020 winter survey shoreline (or 20w) is positioned approximately +25 feet seaward from the 2020 image-based shoreline (20i) with minimal areas showing reversals from this trend (Figure 55a). When looking at the North and the South segments separately, this seaward positioning of the 0-contour line relative to the aerial image shoreline persists. On average, 20w is +32.45ft seaward from 20i on the north section, while 20w is +17.48 ft seaward from 20i on the south domain.

Results from the comparison of 2019 summer and 2019 image shorelines indicate that in general the 2019 summer survey shoreline (or 19s) is positioned -1.25 feet landward from the 2019 image-based shoreline (19i) and with relatively more areas showing reversals from this trend (Figure 53b). Separately, the North segment shows seaward positioning of the 0-contour line (19s) of +4.64ft relative to the aerial image shoreline (19i), while on average on the South the 19s shoreline is -7.11ft (landward) from 19i.



a. b.

Figure 55. Shoreline positions for image-based and survey-based. (a) is 2020 Aerial image and 2020 Winter survey; (b) is 2019 Aerial image and 2019 Summer survey.

6.4 Guidance for interpreting shoreline position versus sand volume budgets

It is noted that among the aerial image shoreline, survey shoreline, and sand budget trends over time can diverge or converge in terms of indicating either erosion or deposition along the coast. It should be considered that the shoreline positions whether established by survey or aerial image, do not necessary represent the volume of sand contained in the shoreface within the depth of average wave base. Work by Wright and Short (1984) shows that the beach and shoreface oscillate among a number of “beach states” that reflect recent wave and storm activity. Beach state and the condition of the adjoining shoreface can range from fully accreted state in which nearshore sand resources are concentrated on the upper shoreface to a fully dissipative state under which beach sands have been eroded by higher energy waves and concentrated into a nearshore bar and spread to the lower shoreface. Thus, a fully accreted , wide beach including a distinct berm and foreshore, may indicate a lower volume of sand contained in the submerged shoreface. Conversely, a narrow beach above the water that has has receded could represent a submerged shoreface containing a large volume of sand recently eroded from beach and moved offshore.

In this study it was found that at the time scale of about 10 years, the average negative rate of change in the 0- contour shoreline agreed in sign with net sand volume loss applied to the 10-year sand budget (see Table 3 and Table 11). Conversely at the 5-year time scale, the shoreline change rates base on aerial image analysis and the sand volume changes applied to the sand budget analysis are in agreement indicating shoreline accretion non the average and net sand volume gains (see Table 4 and Table 9).

A shoreline position captured from an aerial image or survey data over a short period of time provides a snapshot view of the beach condition at a particular time. Sand budget analysis involving a three-dimensional survey of sand volumes provide more space and time integrated view the beach and shoreface compared to a one dimensional shoreline

7.0 Real- Time and Forecast Model of Sebastian Inlet

A coastal processes model application is being developed that provides real time and forecast predictions of water levels current, wave height and direction, salinity and water temperature around Sebastian Inlet. The real time simulation is based on the Deltares, Inc. Delft3D modeling system that has been widely applied in the US and Europe. Eventually this model will include predictions of sand transport, and morphological change. The following sections describe model setup and testing. These include development of the model grid or mesh and examples of model calibration for water level at Sebastian Inlet. Details of the model formulation can be found in Roelving and Banning,(1995).

Major model features that make Delft3D appliable to the Sebastian Inlet area is modular structure including hydrodynamics (Delft3D-Flow), surface waves (Delft3D-Wave), morphology (Delft3D-Mor), and water quality (Delft3D-WAQ). The Delft3D-Flow module solves the unsteady shallow water equations including the horizontal equations of motion, the continuity equation, and the transport equations for conservative constituents. The model can be used to simulate both two-dimensional and three-dimensional non-steady flow and transport phenomena driven by river discharges, tidal and meteorological forcing. The model grid must be orthogonal and can be boundary fitted, on either curvilinear or spherical coordinate systems. The flow model can be used to predict the flow in shallow coastal areas, estuaries, lagoons, rivers, and lakes. The presently operational model forecast can be viewed at https://realtimefl.githsub.io/Sebastian_Inlet.

7.1 Overview of the Delft3D model setup

The model covers Sebastian Inlet and sections of the coastal ocean and interior of the Indian River Lagoon. A curvilinear orthogonal grid was created having computations cells ranging in size from 14 m within inlet to 475 m in the coastal area and with 5 sigma layers. The grid represents coastal zone from Wabasso Beach to Indialantic Beach (Figure 56).

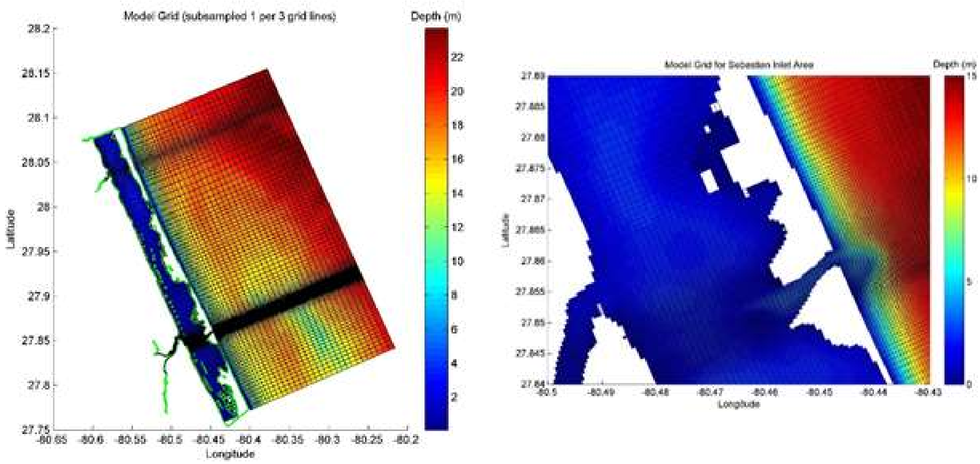


Figure 56. Left: Regional view of the Delft3D model grid. Right: Model detail in the vicinity of Sebastian Inlet.

The regional bathymetric data to populate the model computational grid shown in Figure 56was downloaded from NOAA coastal digital elevation model and blended with local bathymetric data sets acquired from the Sebastian Inlet District topographic survey program. The model is driven by water elevation time series that includes tides and lower frequency sea level oscillations, and meteorological forcing. The temperature, salinity and sea surface elevation along north, south and east open boundaries were derived from basin scale ocean models consisting of the HYCOM and NCODA Gulf of Mexico 1/25° Analysis (http://www.hycom.org/data/goml0pt04). The meteorological forcing (relative humidity, air temperature, wind, heat flux and precipitation) was derived from the North American Mesoscale (NAM) Forecast system (http://www.ncdc.noaa.gov/data-access/model-data/model-datasets/north-american-mesoscale-forecast-system-nam).
Freshwater r inflows comes the Sebastian River and Turkey Creek. River discharges data were derived from South Florida Water Management District (https://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu).

The required meteorological forcing (relative humidity, air temperature and total radiation) was derived from the hourly output of the NCEP North American Regional Analysis (NARR) (https://www.esrl.noaa.gov/psd/data/gridded/data.narr.html), which has a 5-km spatial resolution. After several trials total solar radiation model was adopted, in which the incoming (short wave) solar radiation is prescribed but the net atmospheric (long wave) radiation and the heat losses due to evaporation, outgoing radiation and convection are computed.

The wave model is based on using the SWAN (Simulating Waves Nearshore, Booij,1999) model suite integrated into Delft3D. Same flow grid and bathymetry were used for wave model setup. Boundary conditions were assigned by creating attribute files compatible with SWAN. Wave simulation can be conducted in two modes- wave standalone or wave-flow coupling. In wave standalone mode, hydrodynamics are assigned using a communication file which stored hydrodynamics data from flow simulation. In coupling mode both wave and flow were run simultaneously where results from flow run are fed into wave simulation in real time. Open boundary conditions for wave model have been derived from global wave model WavewatchIII (https://polar.ncep.noaa.gov/waves/ensemble/download.shtml).

7.2 Model calibration and numerical experiments

A Three-year (2018-2020) simulation has been carried out in support of model verification. In order to calibrate the Delft3D model, several steps were taken, 1) bottom friction parameter, which is critical to correctly simulation bottom friction in shallow water systems, was tested, 2) spatially variable surface wind was experimented, and 3) effects of vertical resolution of the model were also examined

Bottom roughness experiments

A series of numerical experiments have been performed to test effects of bottom friction, vertical resolution, and spatial variability of surface winds. In the CONTROL experiment, the model specified 5 vertical layers along with Chezy (bottom) friction parameter of 65 and was forced with 2-D winds. Three experiments were run by, 1) changing bottom friction parameter to 50, and 80, 2) changing the number to total vertical layers to 10, and 3) using 0-D winds, i.e., spatially uniform winds, from a chosen location (near Sebastian Inlet outside of harbor). Other parameters remained unchanged. Results from these experiments were compared to those from the CONTROL experiment, focusing on Sebastian Inlet. In following details, figures represent shorter time-periods of data (1 month or several) for better visualization.

Several roughness formulae (Chezy, Manning and White-Colebrook) have been tested with model. Chezy roughness formula produces the better outcome, in which uniform Chezy along N-S and W-E direction, respectively, is used. Bottom roughness effects have been tested with various Chezy roughness value (50, 65 and 80) for model runs. The model output was then compared statistically in terms of correlation coefficients, root mean square error and bias (Figure 57 and Figure 58). Model responded to the change in bottom roughness value. A comparison of model output with observed data for various Chezy parameter showed that the point-to-point correlation coefficient between model and observed water level improved when Chezy parameter value increased from 50 but the correlation started deteriorating when the parameter was too high (more than 70, Figure 57). It was found that the optimal value for Chezy parameter to be 65, for which the model output gave the highest model-data correlation coefficients. From now on, all the model experiments presented below having Chezy=65.

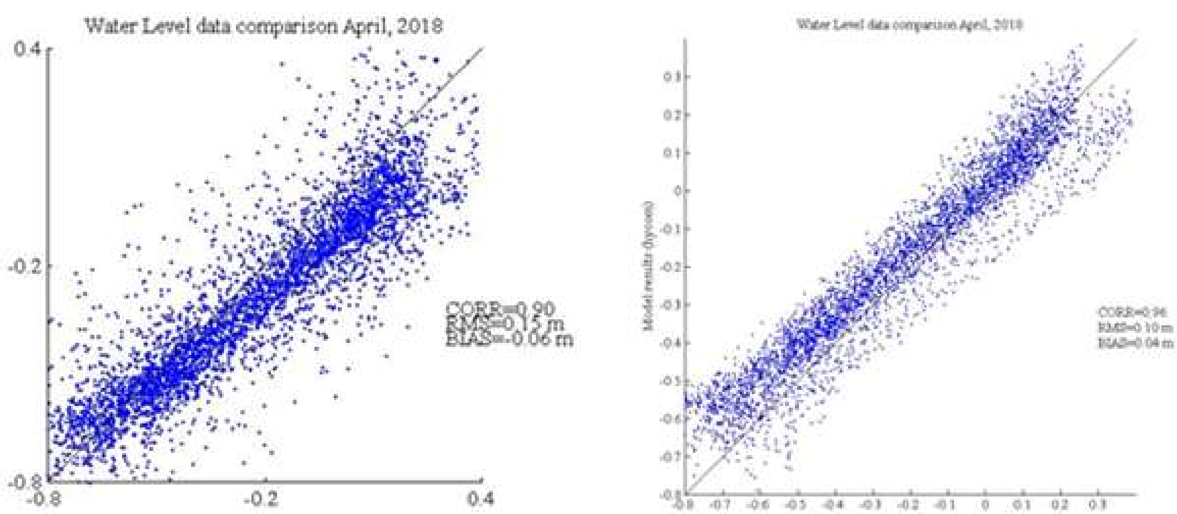


Figure 57. Left: Scattered plot of the model and observed water level with Chezy=80 at Sebastian Inlet in April 2018. Right: Similar plot for Chezy=65.

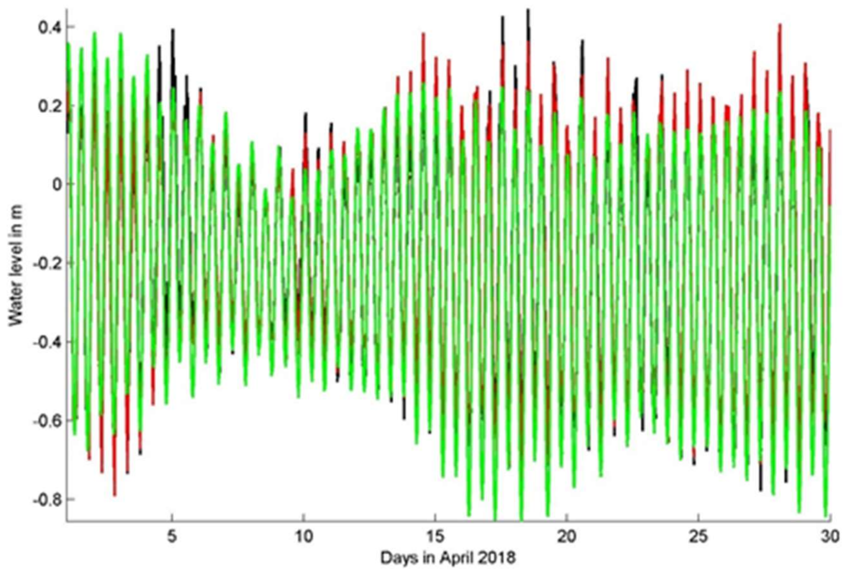


Figure 58. Time series of water level of the model run with Chezy parameter of 65 (redline), 80 (black line) and observed (green line) at the Sebastian Inlet station in April 2018.

Five- vs ten-layer simulations

Modeled water level predictions from the 10-layer and CONTROL (5-layer) experiments are compared in There is little difference for water level between the two experiments (Figure 6.3 and 6.4). Comparison can be quantified in terms of correlation coefficients, root mean square error, and bias between the model and the observed data. For example, the correlation coefficient between modeled and observed water level at Sebastian Inlet does not change significantly from 0.94 in 5-layer model to 0.94 in 10-layer model (Figure 59 and Figure 60). Since changing vertical resolution does not improve performance of the model at significant level, 5-layer model has been chosen for future simulations as 5-layer model is computationally less expensive than 10-layer.

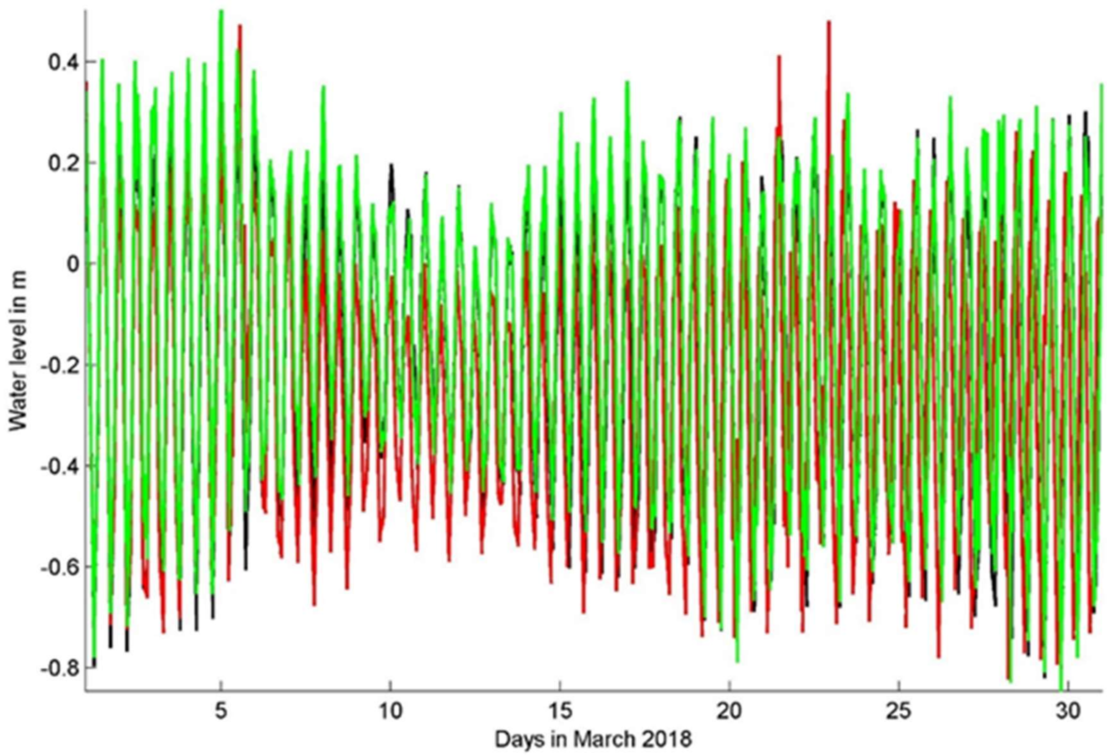


Figure 59. Time series of water level of the 5-layer modeled (red line), 10-layer modeled (black line), and the observed data (green line) at the Sebastian Inlet station in March 2018.

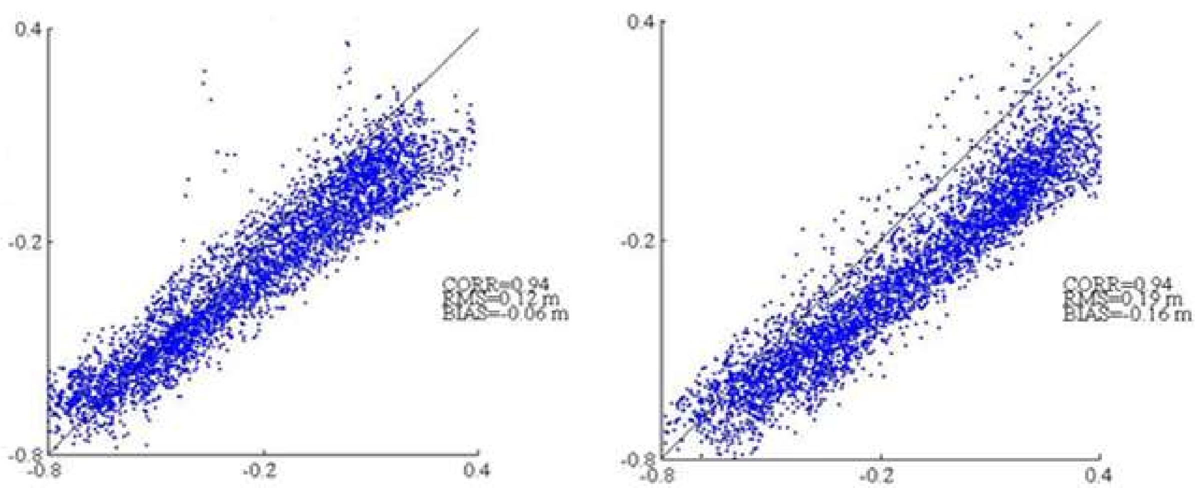


Figure 60. Left: Scattered plot of model and observed water levels at Sebastian Inlet for 5-layer model in February 2019. Right: Similar plot but for 10-layer model.

Uniform (1-D) vs 2-D winds

Similarly, here we compare the model results between the 1-D wind and CONTROL (2-D) experiments. There are some differences between the results from the two experiments.

Modeled water level results from the 2-D experiments correlates slightly better with observed data than that from the 0-D wind (Figure 61). This is likely due to better representation of spatial pressure gradient driven by surface winds in 2-D experiments.

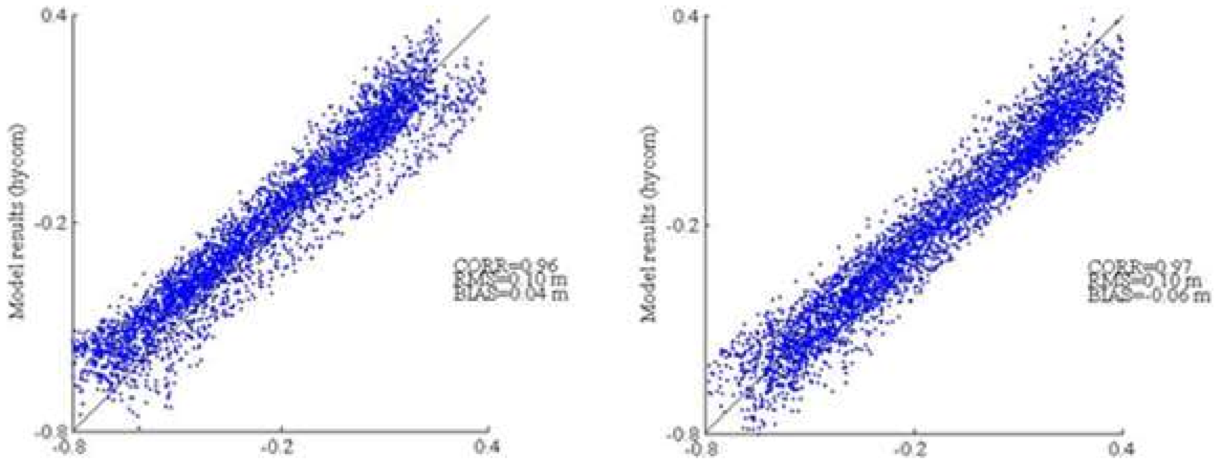


Figure 61. Left: Scatter plot of model and observed water levels with 1-D wind at Sebastian Inlet station in April 2019. Right: Similar plotting of the model with 2-D wind

7.3 Scripting for running the real time and forecast model

For real time forecast, calibrated model's boundary conditions need to be updated with new data from HYCOM and NAM. We used python scripts for web scraping, process of extracting data from a website with automation, to check whether new data is available from this model. Whenever new data is available, the new data will be downloaded for our model domain. Downloaded data is then converted into chosen format (grib2 format to netcdf format) and processed (using Python and MATLAB scripts) to create boundary conditions. A new simulation of our calibrated model is then run with the new boundary condition files. When the simulation run is complete, output will be processed to create time-series plot at our observation stations and coastal area. Each time the new simulation is run with hot start file from the previous run. These plots are uploaded in our website (https://realtimefl.github.io/Sebastian_Inlet/). These scripts are automated and synchronized such a way that it will keep checking for new data at 10 minutes time interval. If new data for boundary conditions are available data will be downloaded and processed, and after simulation output will be processed and uploaded on webpage. If new data is not available, it will sit idly for 10 minutes and check again, creating an endless loop (see following flowcharts in).

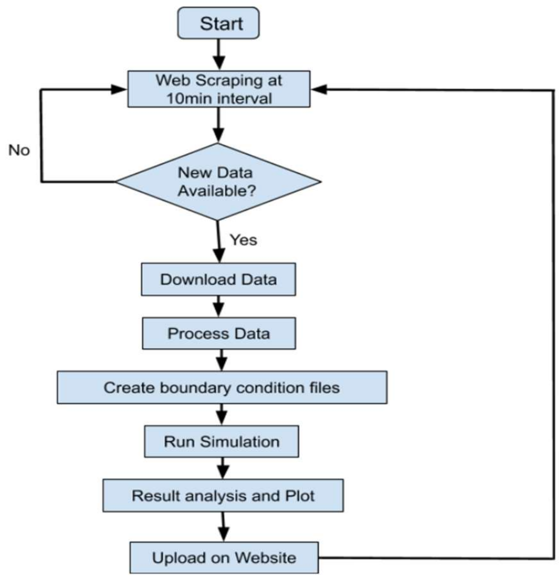


Figure 62. Flow chart of the algorithm for automation.

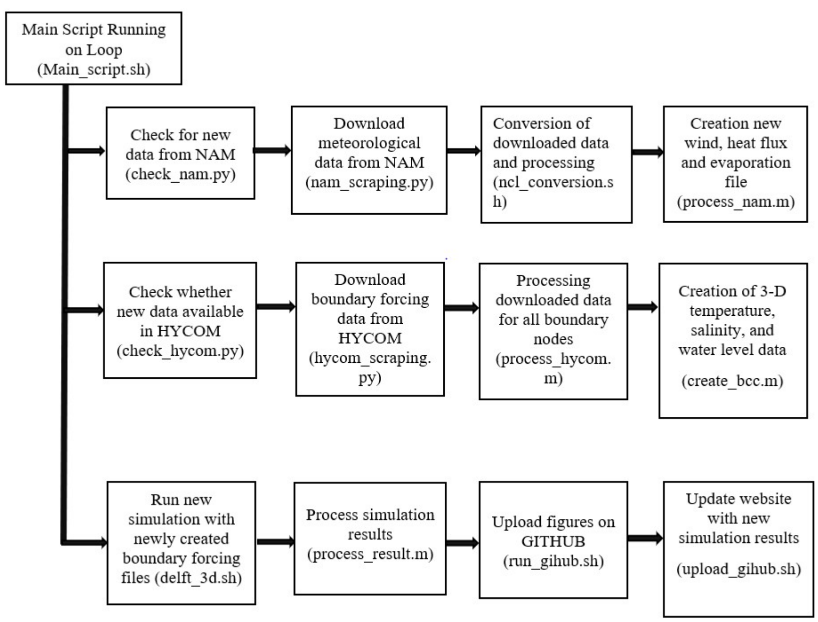


Figure 63. Flow chart of automation scripting processes

7.4 Web hosting of Sebastian Inlet Delft3D model forecasts

A real time website was created and hosted in GitHub (https://realtimefl.github.io/Sebastian_Inlet/). A brief discussion of model domain, model setup and model validation are posted on webpage. We selected 3 stations in our model domain- Lobo station (HBOI lobo station), North Jetty station (Florida Tech station) and Sebastian Inlet station (NOAA station). In real time 3 days of forecast data are posted and updated for these 3 stations. An animation of water elevation map along with currents is also presented in the webpage (Figure 64). The web process is automated with Linux, python and MATLAB scripts.

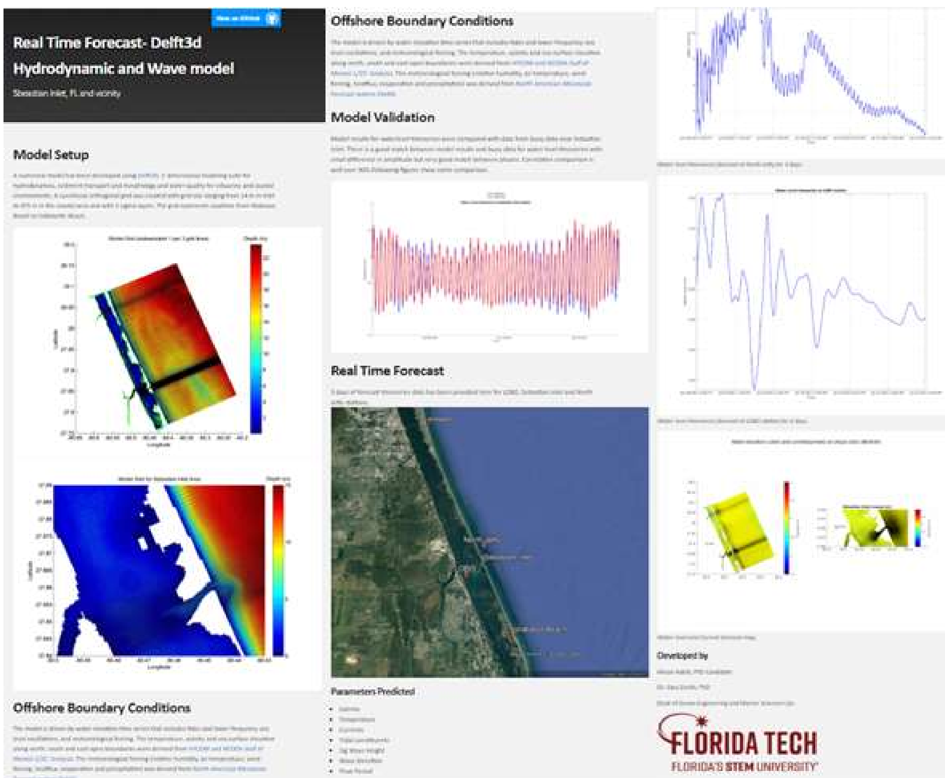


Figure 64. Snapshots of the Delft3D forecast model webpage.

8.0 Conclusions and Recommendations

The annual update of the State of Sebastian Inlet includes five major areas of work; 1) an update of the analysis of volume contained in the sand reservoirs of the inlet system, 2) analysis of the sand budget based on the results of the sand volume analysis, 3) analysis of morphologic changes within the inlet system, 4) an update of the shoreline change analysis, and 5) a description of the real-time and forecast coastal processes numerical model that includes Sebastian Inlet

- The Sebastian Inlet sand reservoirs are in a long-term dynamic equilibrium characterized by occasional large seasonal changes in volume superimposed on longer term trends of a lower order of magnitude.
- Examination of coastal sea level changes and sand volume between 2006 and 2020 revealed two important processes.
    - It can be demonstrated that the Sebastian Inlet sand reservoirs and the beach and shoreface areas both to the north and to the south of the inlet undergo extended periods of regional sand volume losses and periods of and volume gains upon which large seasonal and year to year volume changes are superimposed
    - Large sand volume gains and losses occur over the entire region rather than being inversely linked to gains or losses in adjacent subsections of the coast.
    - Examples of regional changes include sand volume losses on the shoreface of extending from 2010 through 2015 that corresponded to a multiyear trend of rapidly rising sea level along the central Florida coast.
- When the sea level record measured at Sebastian Inlet is examined over the 14-year period between 2005 and 2029, it can be demonstrated that periods of increasing cumulative sand volume losses correspond to periods of rising sea level
- Periods of falling sea level correspond to periods of cumulative sand volume gains and lower cumulative sand volume losses.
- The sea level record for late 2019 through mid 2020 indicates a period of falling sea level is beginning. This indicates a potential for an upcoming period of sand volume gains if this trend continues over several years
- The dynamic equilibrium and trends of sand volume changes within the inlet sand reservoirs associated with Sebastian Inlet are summarized in sediment budget calculations.

- The sand budget for the Sebastian Inlet region is reported at three-time scales, including a longer time scale of 10 years, a time scale of 5 years, and a shorter time scale of 3 years.
- The most useful time scale is considered to be 10 years since it integrates over seasonal sand volume changes that mask longer term trends.
- Over the time period of 2010-2020, the benefits of sand by-passing from the sand trap and beach fill placement projects to the south of the inlet can be shown to locally mitigate sand volume losses that extend over the region
- Similar to the sand volume analysis, the results of shoreline mapping from survey data and aerial imagery vary considerably by time scale.
- Shorelines mapped at any point in time may be more indicative of recent impacts of wave energy and storm activity and not necessarily indicate the overall stability of the coast over longer time periods.
- Sand volume changes included in sand budget calculations provide a more spatially and temporally integrated measure of coastal stability compared to shoreline position
- The ongoing coastal processes numerical model provides a data to day forecast and forecasts over 72 hours (three days) of energy conditions of the central Florida coast including the inner coastal ocean , within Sebastian Inlet , and in the Indian River Lagoon.
- It is recommended that the Sebastian District plan for time scales of 10 years and beyond when sea level is projected to continue rising at higher rates and more extreme interannual variations in sea level amplify the impact of rising seas along the coast
- Based on the correlation between interannual sea level shifts and sand volume on the shoreface it is recommended that the Sebastian Inlet District develop additional resources for beach quality sand to mitigate sea level driven coastal erosion.

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