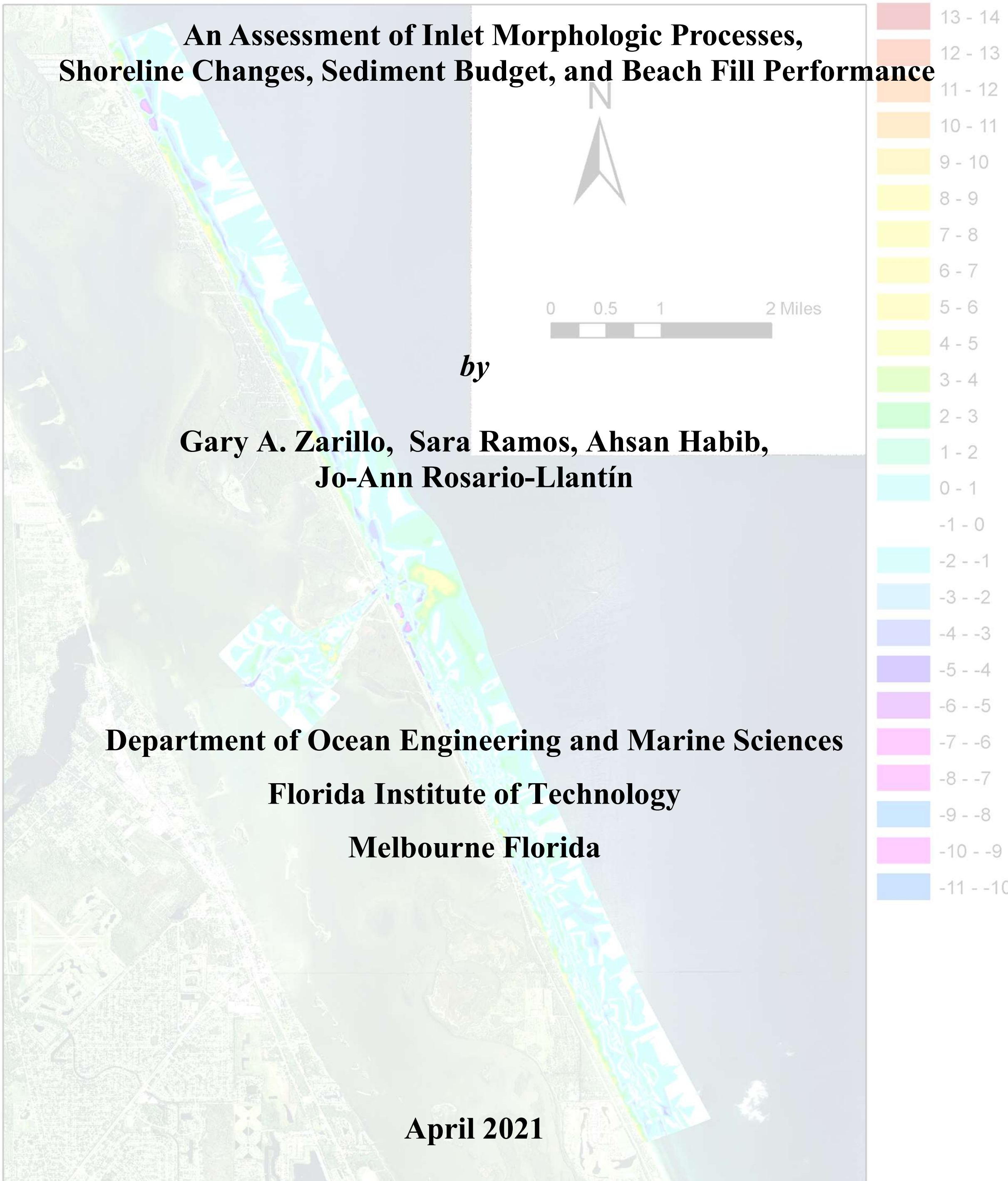
STATE OF SEBASTIAN INLET REPORT: 2021

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) an update of the performance of the real time and forecast hydrodynamic model of Sebastian inlet and vicinity.

The sand volumetric analysis includes the major sand reservoirs within the immediate inlet area 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 2021. 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 2021 revealed two important processes. First, is can be demonstrated that the Sebastian Inlet sand reservoirs and the sand budget cells areas to the north and to the south of the inlet undergo periods of regional volume losses and periods of volume gains. A comparison of interannual shift is sea level with sand volume changes show and inverse relationship in which sand volume decreases with rising sea level and increased during periods of falling sea level. Sand volume gains and losses cover the entire region rather than being inversely linked to gains or losses in adjacent subsections

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 four time scales, including a longer time scale of 14 and 10 years , a time scale of 5 years, and a shorter time scale of 3 years. The most useful time scales is considered to be 14 and 10 years since it integrates over seasonal sand volume changes that can mask longer term trends. Over the time period of 2006 to 2021, 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 2011 to 2021, shoreline changes south of the inlet reflect the position of beach fill placement in 2011, 2012 ,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.

The performance of the 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 recent 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 2021 . 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, and 2020 reports emphasized the sand volume calculation within the sand reservoirs and sand budget cells of the Sebastian inlet area. In the present report it is shown that the trend of sand volumes losses increases with distance both north and south of the entrance of Sebastian inlet. The morphological analysis, sand budget analysis and the shoreline analysis are updated to 2021 and include a discussion of topographic changes within the sand budget cells in addition to the overall budget calculations

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 2021 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 2003).

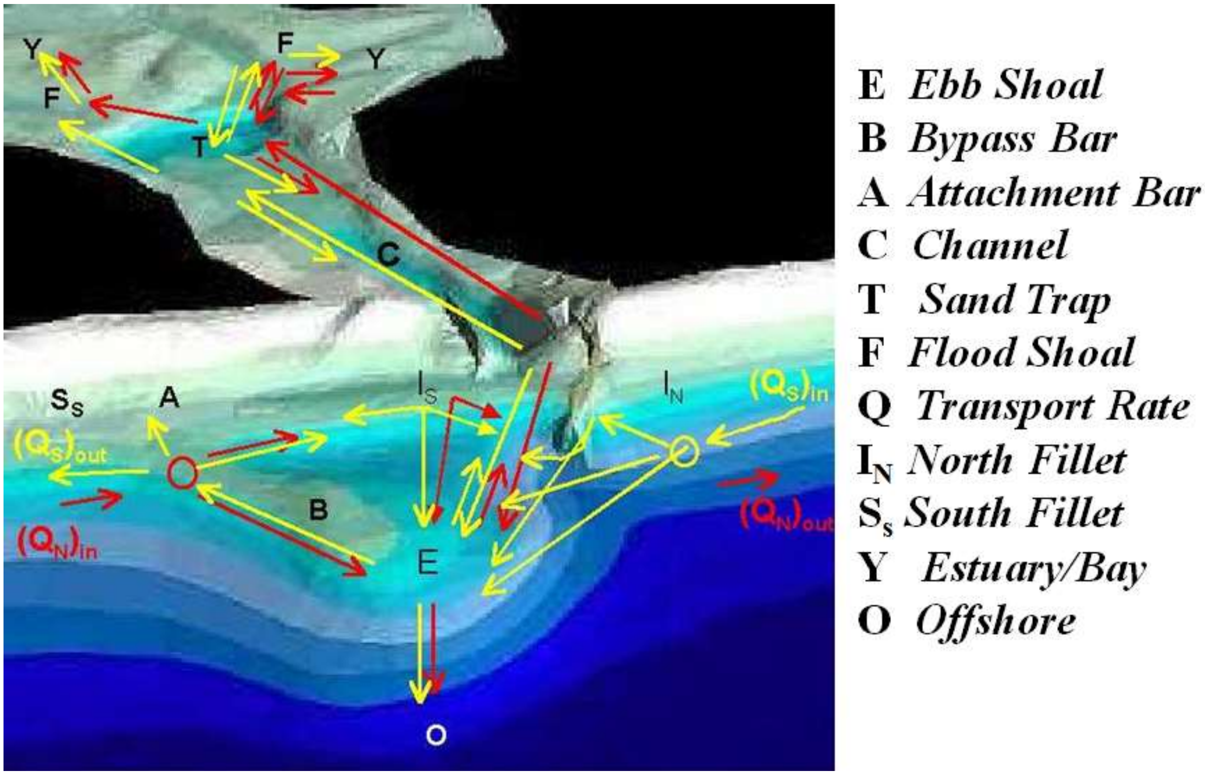


Figure 1. Schematic vector diagram of sediment transport pathways among sand reservoirs at Sebastian Inlet (From Kraus and Zarillo, 2003).

After a review of the sand volume changes within Sebastian Inlet shoals and sand budget cells over a 14-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. 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 are 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 Intracoastal 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 2021.

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)
2006-2008	x	x	x	Begin 2008	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
Winter 2021*	x	x	x	x	x	30,000	30,000
Summer 2021*	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.

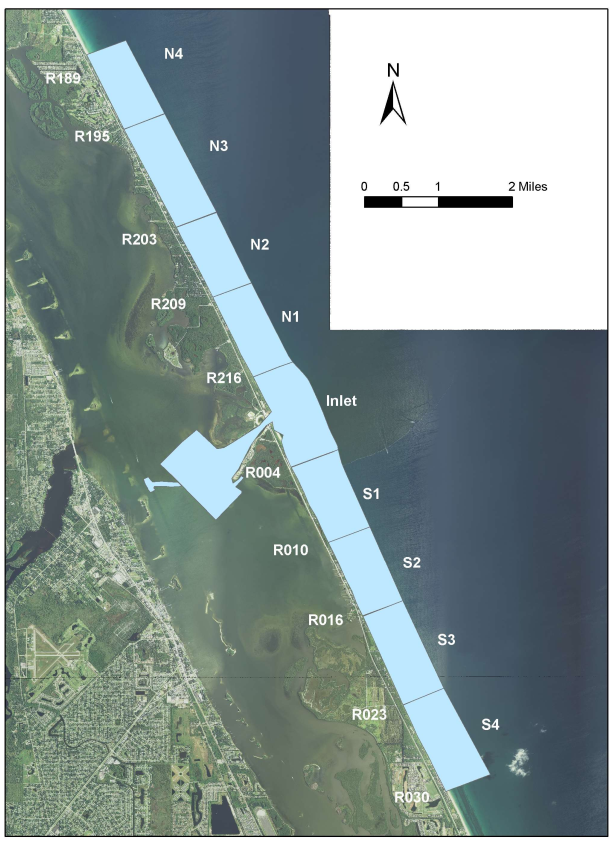


Figure 3. Sand budget cells.

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 georeferenced to the NAVD88 vertical datum and Florida State Plane NAD83 horizontal datum 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.

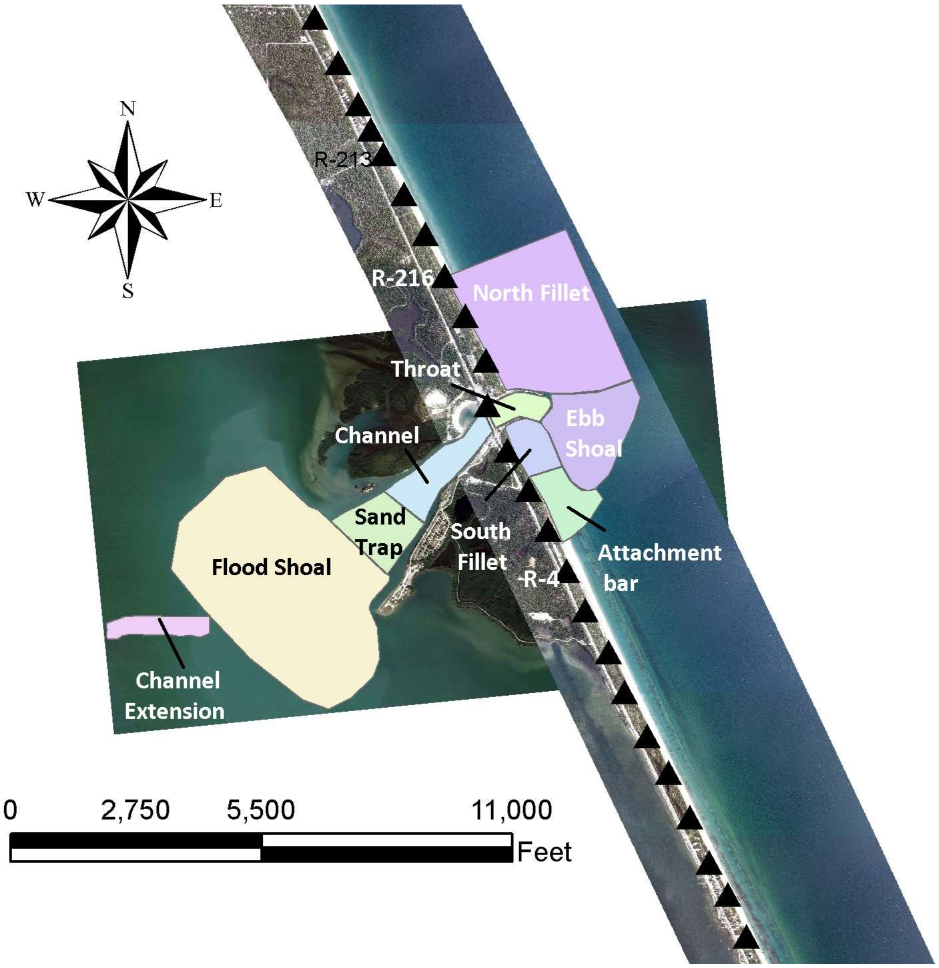


Figure 4. Morphologic features forming the inlet sand reservoirs.

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 2021 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 2021, which was followed by a gain of approximately 50,000 cubic yards recorded in the summer 2021 survey data. This corresponded to an approximate 80,000 cubic yards of sand volume loss on the flood shoal during the same period (see Figure 8). 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. The recent trend of rising sea level and associated sediment processes may have contributed to the loss of ebb shoal volume between 2018.and the winter survey of 2021. 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.

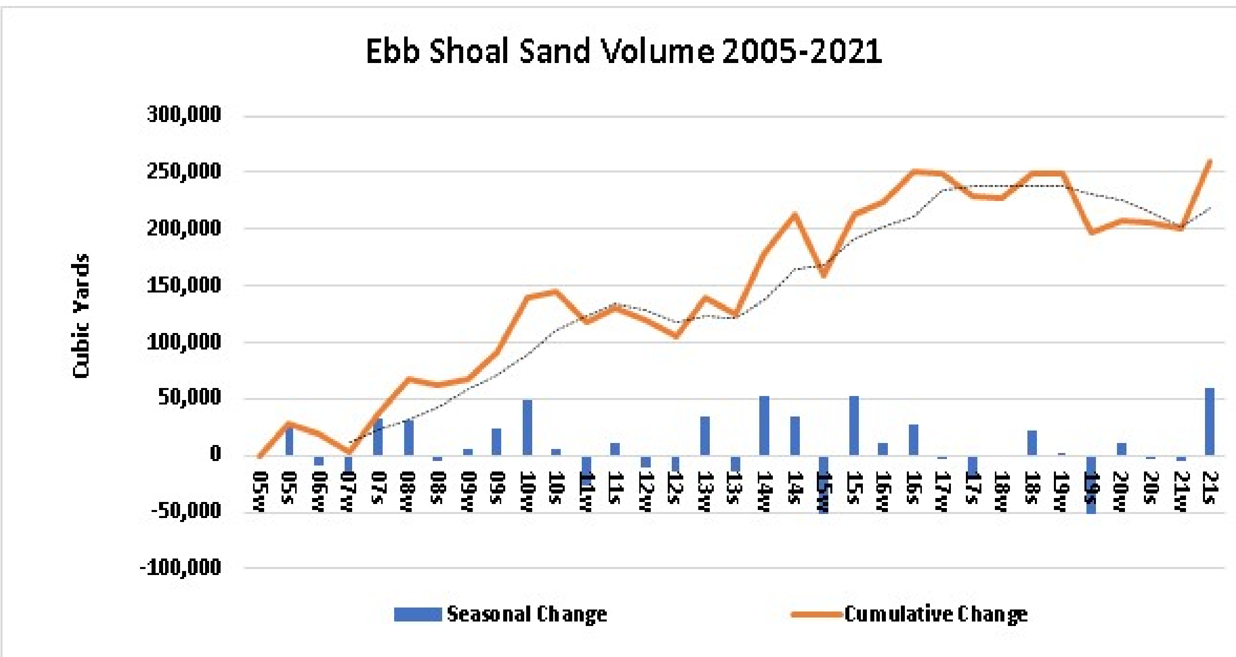


Figure 5. Volumetric evolution of the ebb shoal from summer 2005 to summer 2021.

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. 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 is little changed between the summer of 2020 and 2021 despite seasonal fluctuations. Sand volume in the attachment bar has increased by about 35,000 cubic yards since 2005.

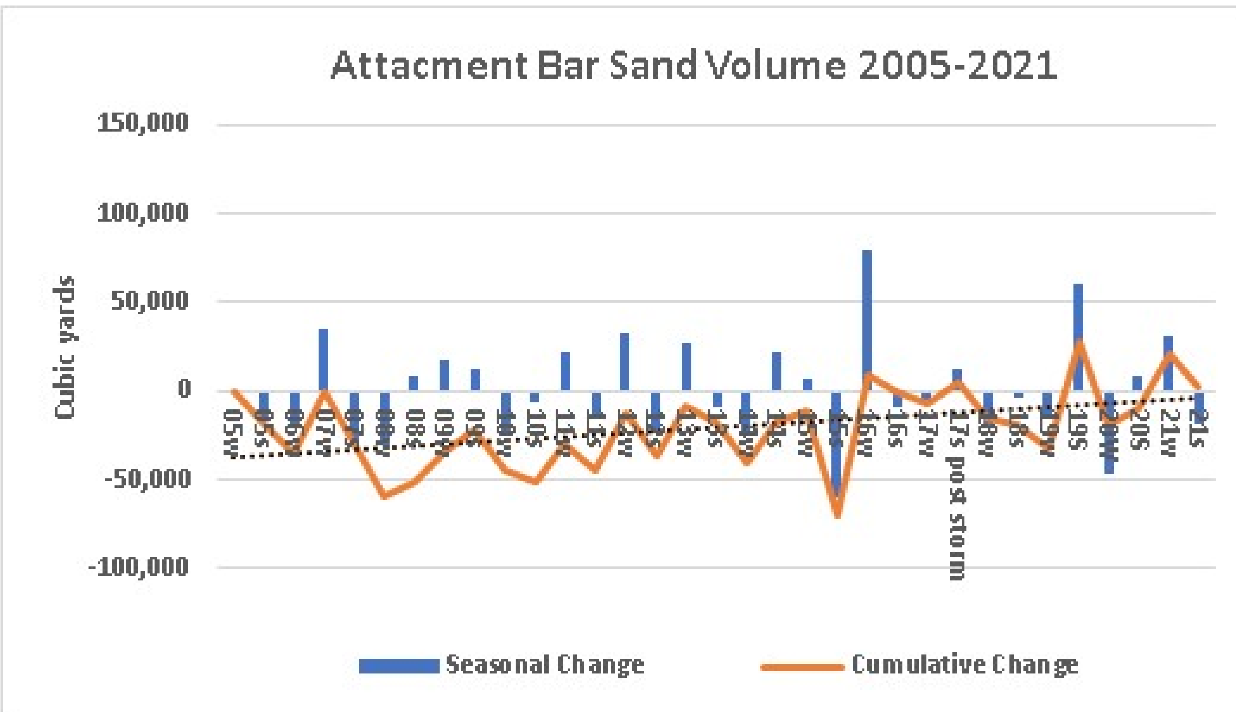


Figure 6. Volumetric evolution of the attachment bar from summer 2005 to winter 2021.

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 usually 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 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 most of which was despotized between summer of 2020 and winter survey of 2021 (Figure 7.)

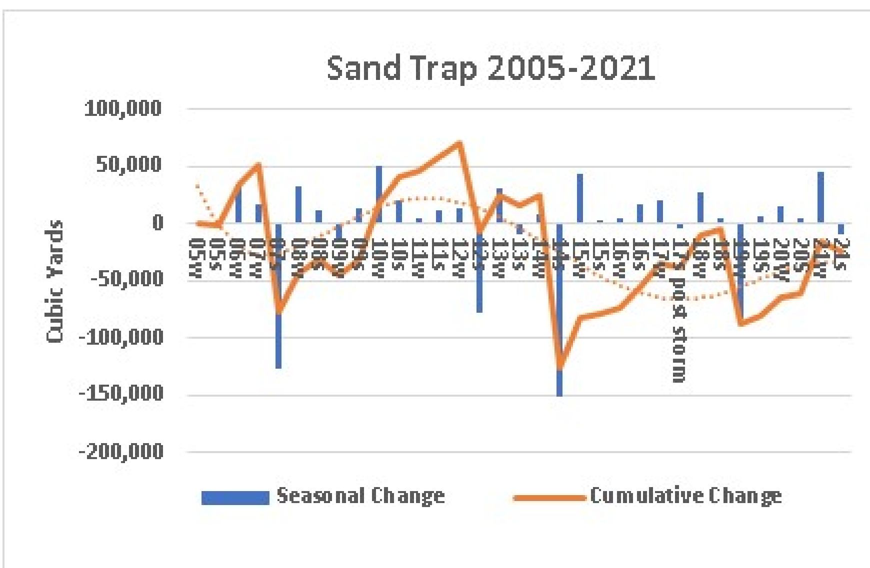


Figure 7. Volumetric evolution of the sand trap from winter 2005 to winter 2021.

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 reached a minimum and recovered about 50,000 cubic yards by the winter 2021 survey.(Figure 7). However, between winter and summer 2021 flood shoal sand volume declined by about 80,000 cubic yards, possibly contributing to sand volume gain on the ebb shoal

Net volume change of the flood shoal in the 14-year period since 2006 is an approximate a loss of only about 150,000 cubic yards, although intra-annual sand volume fluctuations of more than 200,000 cubic yards can occur in any year.

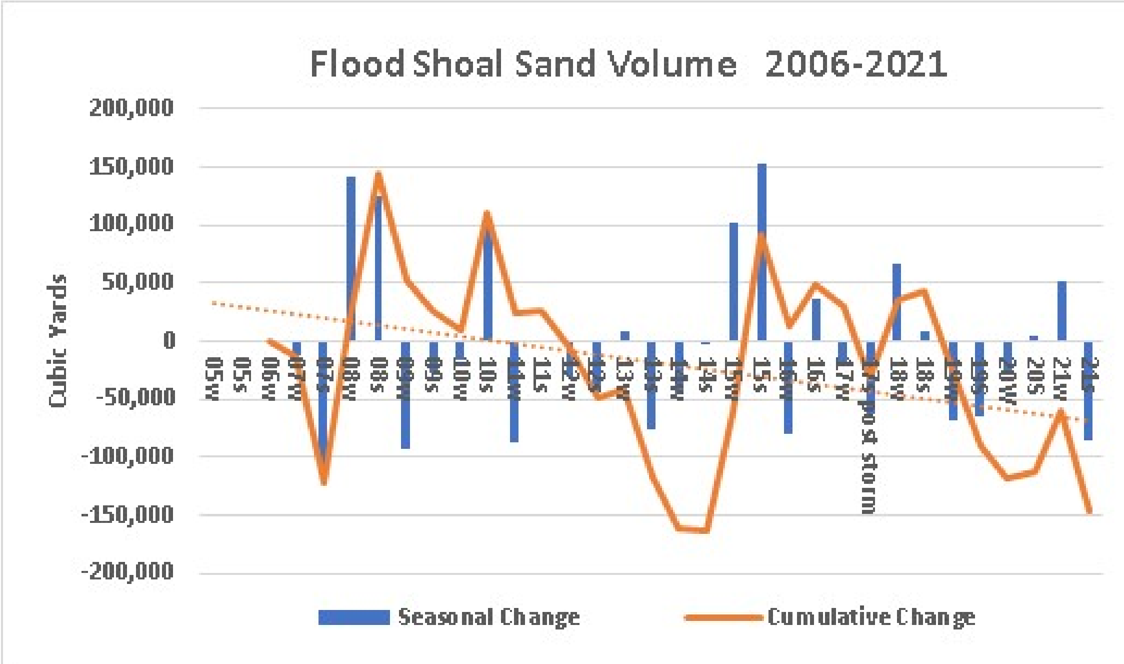


Figure 8. Volumetric evolution of the flood shoal from winter 2006 to winter 2021.

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 about13,000 cubic yards of sediment (Figure 9).

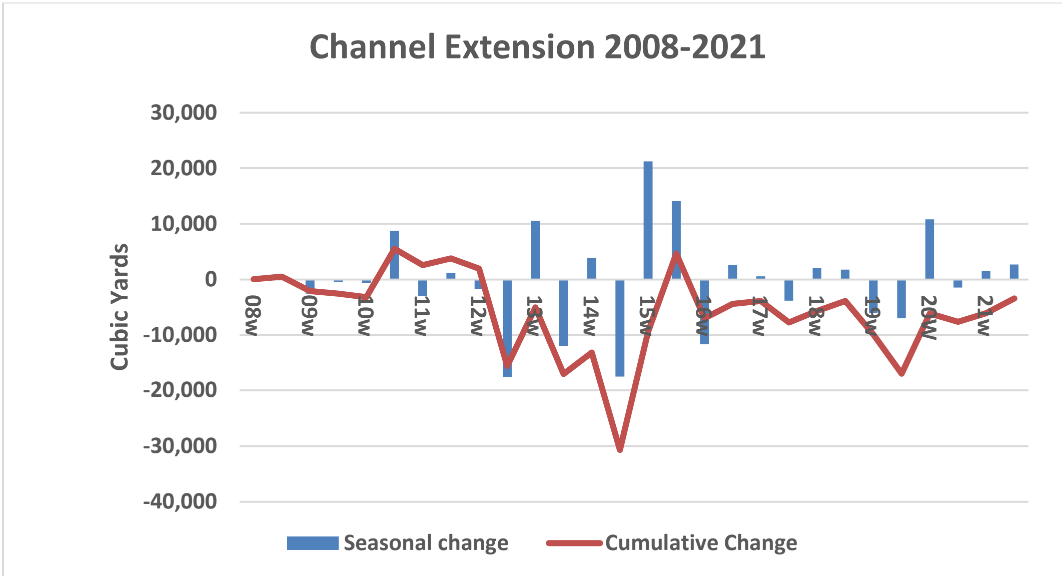


Figure 9. Volumetric evolution of the channel from winter 2008 to winter 2021.

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 2021, 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. Net sand volume losses in N3 since 2006 are about 230,000 cubic yards

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 was reestablishing and marked by a large sand volume gain of about 165,000 cubic yards between summer 2019 and winter 2020. This was followed by followed smaller seasonal losses through the summer survey of 2021. The 15-year net volume change in N2 is about loss of about 150,000 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 150,000 cubic yards between 2006 to 2021.

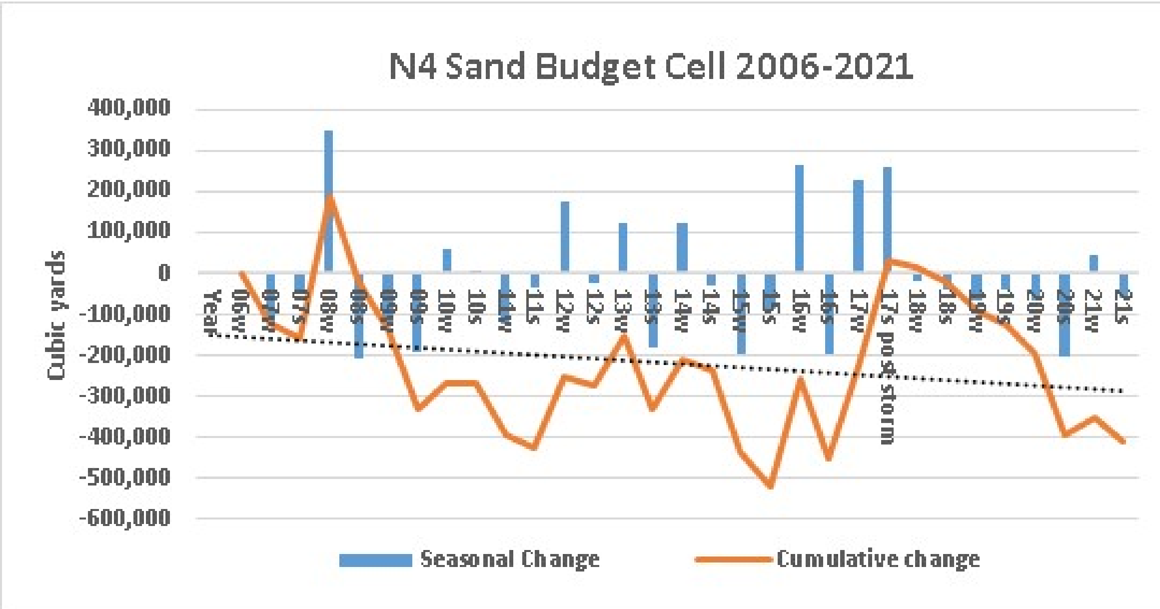


Figure 10. Volumetric evolution of the N4 sand budget cell 2006-2021

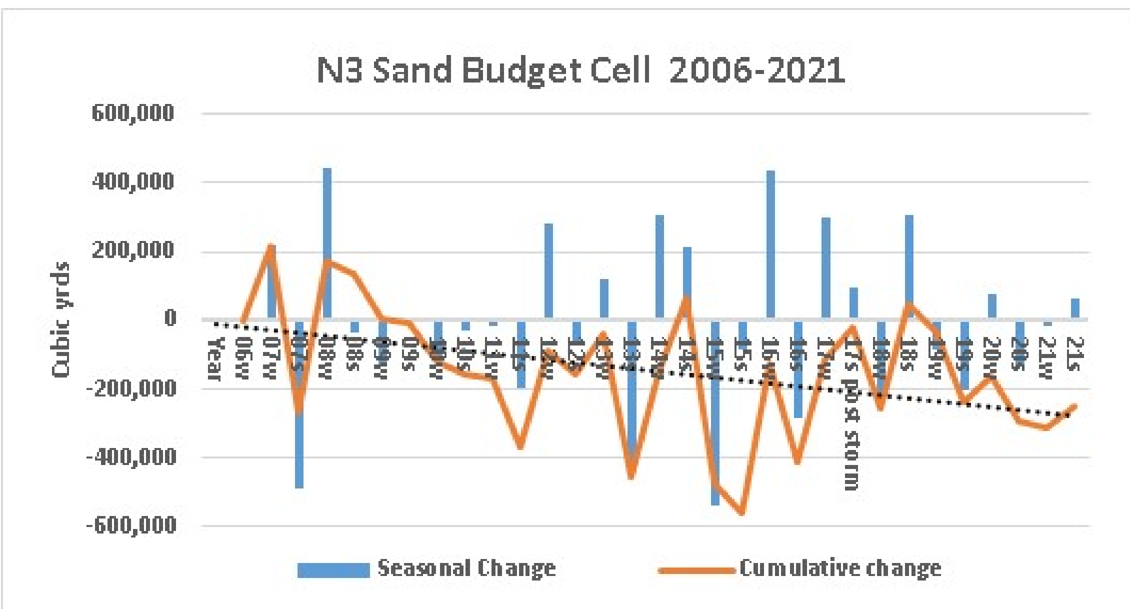


Figure 11.Volumetric evolution of the N3 sand budget cell 2006-2021.

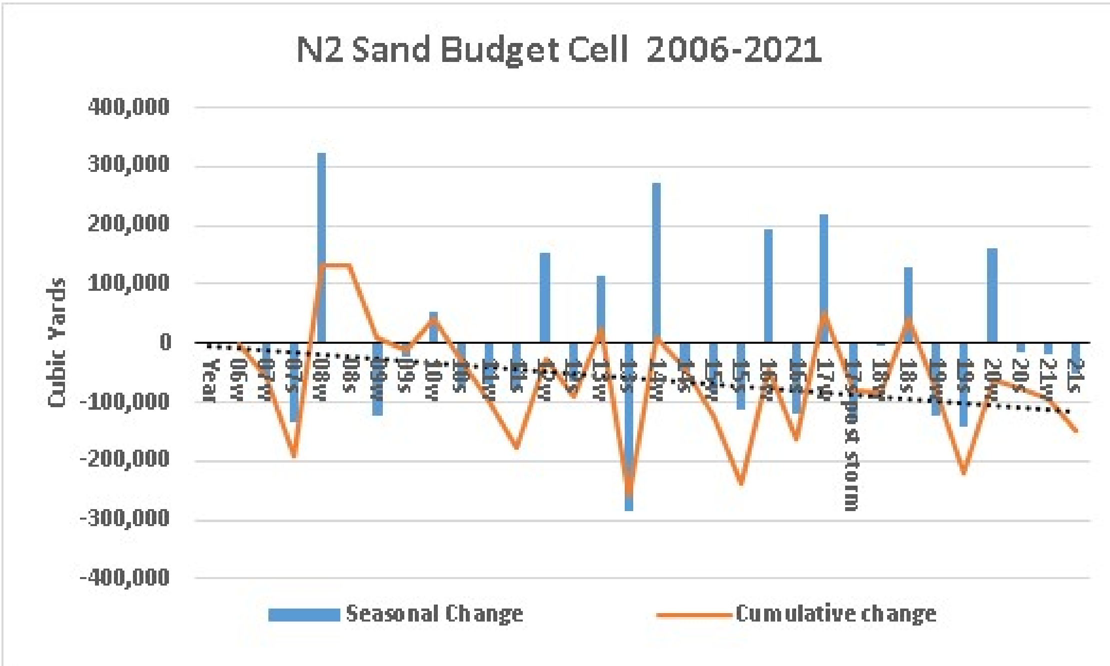


Figure 12. Volumetric evolution of the N2 sand budget cell 2006-2021.

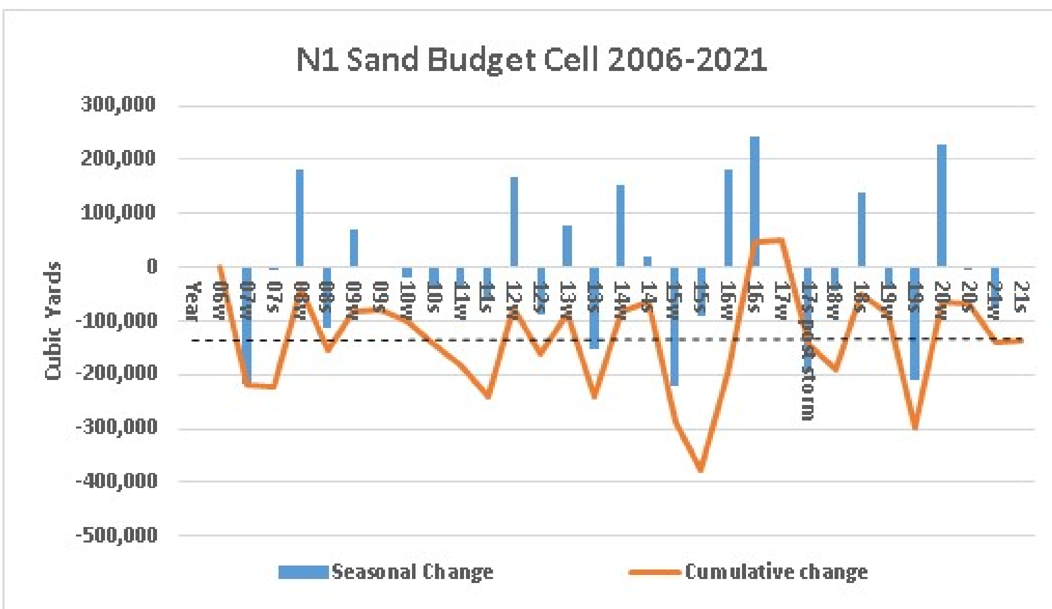


Figure 13. Volumetric evolution of the N1 sand budget cell 2006-2021.

In summary, seasonal changes in all of the sand budget cells to the north of Sebastian Inlet are on the order of, or greater than net longer term net changes. As emphasized by the trend lines shown in volume losses among the N1 to N4 cells north of the inlet Figure 10 to Figure 13, increase to the north.

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 15 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 associated with each sand bypass from the sand trap are beginning to repeated as inlet system again responds to the 2019 sand bypass dredging project. 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.

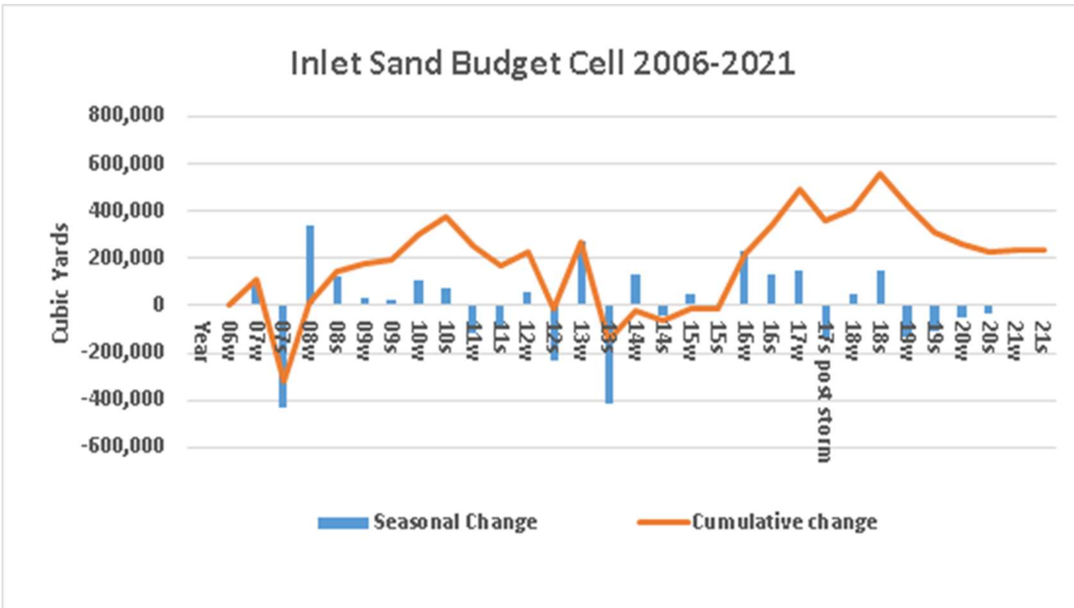


Figure 14. Volumetric evolution of the inlet sand budget cell 2006-2021.

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. A very similar large sand volume fluctuation occurred within the N1 and N2 cells on the north side of Inlet sand budget cell (Figure 12 and Figure 13) and to some extend in the S2 and S3 cells to the south (Figure 16 and Figure 17). Seasonal sand volume changes in S1 since the winter survey of 2020 have been less than 100,000 cubic yards. Net volume change in the S1 cell from 2006 to 2022 is near zero as seen in Figure 15.

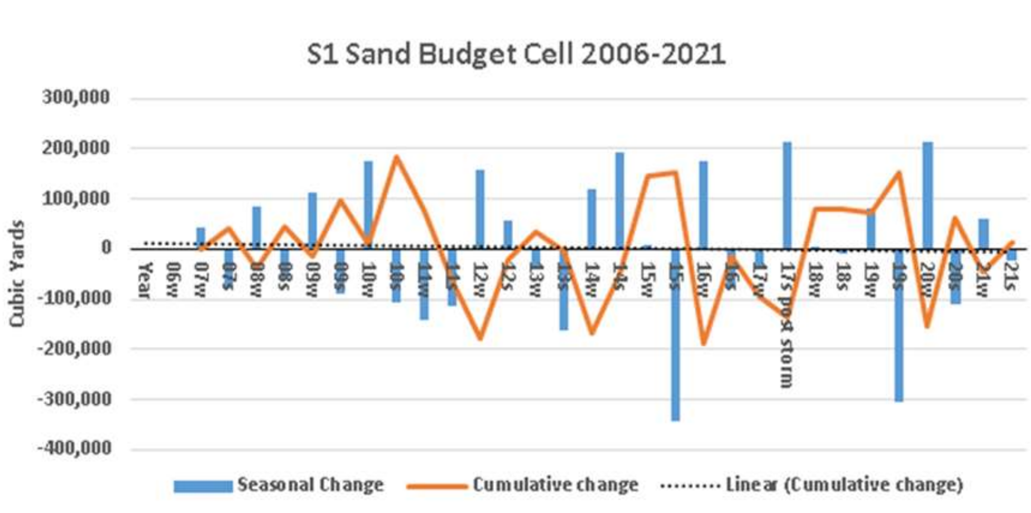


Figure 15. Volumetric evolution of the S1 sand budget cell 2006-2021

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 shifted into 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 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 aforementioned 2020 sand volume gains in the S2 cell may indicate that much off the sand trap material eventually returned to the S2 cell. Since the summer survey of 2020 a sand volume loss of about 80,000 cubic yards occurred included a seasonal loss of about 100,00 cubic yards and gain of about 20,000 cubic yards. Over the 15-year period between 2006 and 2021, the volume change in the S2 cell was a net loss of about 230,000 cubic yards.

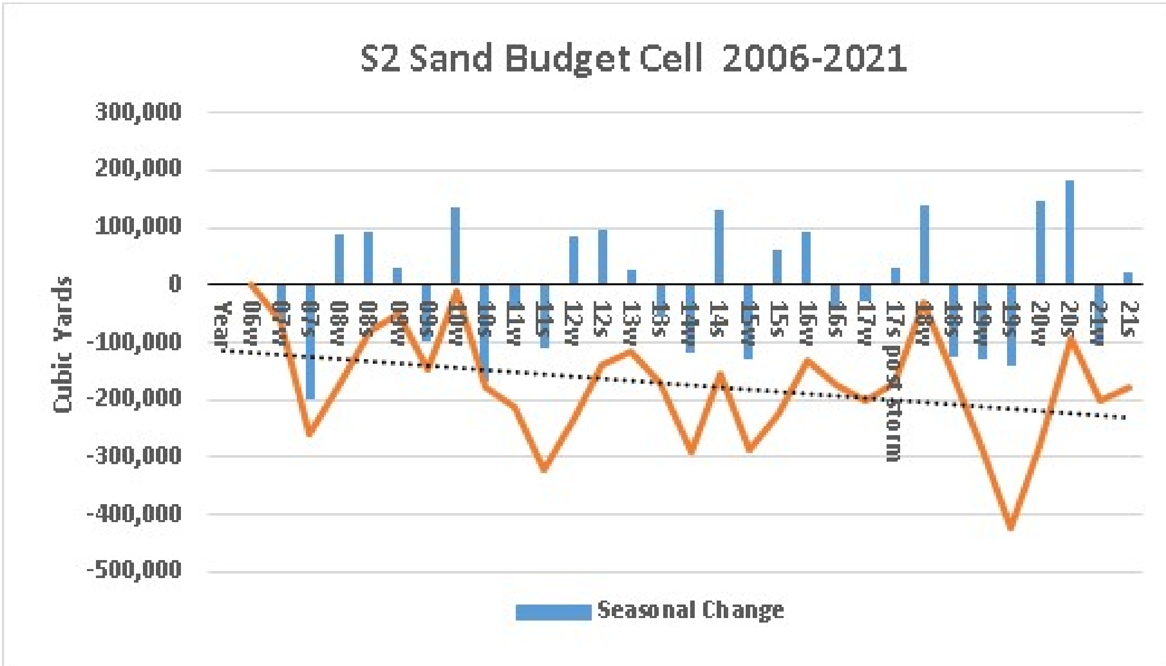


Figure 16. Volumetric evolution of the S2 sand budget cell 2006-2021.

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. Sand volume change between summer of 2020 and summer 2021 included a decline of about 110,000 cubic yards.

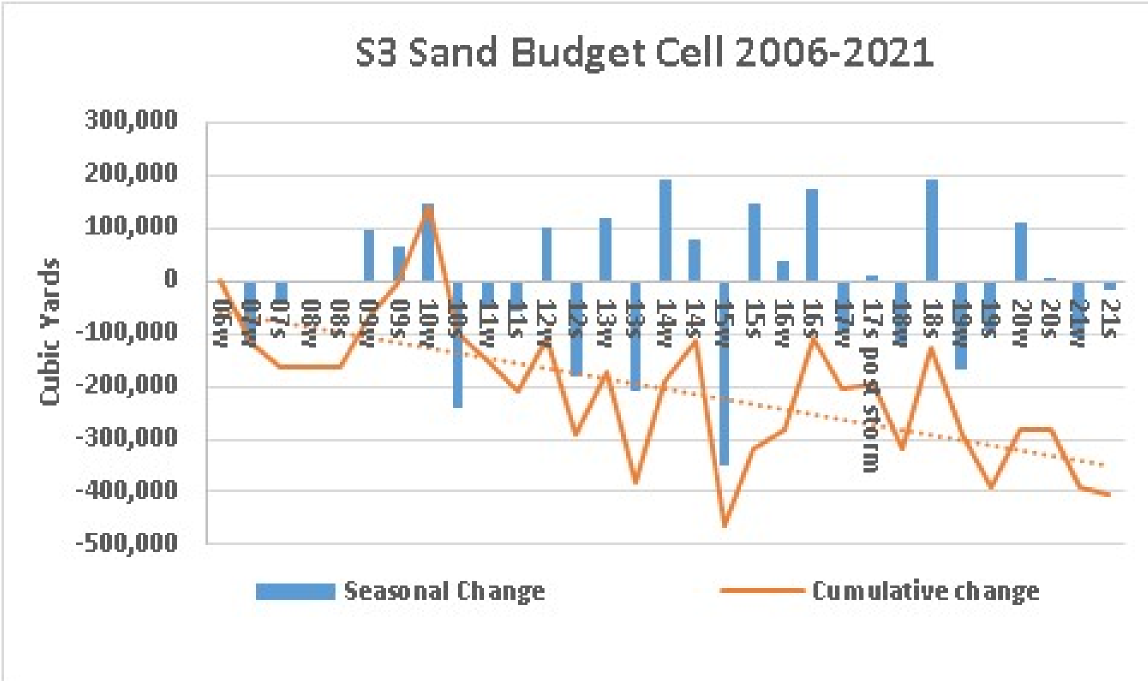


Figure 17. Volumetric evolution of the S3 sand budget cell 2006-2021.

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 600,000 cubic yards between 2006 and 2021. 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 persists 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

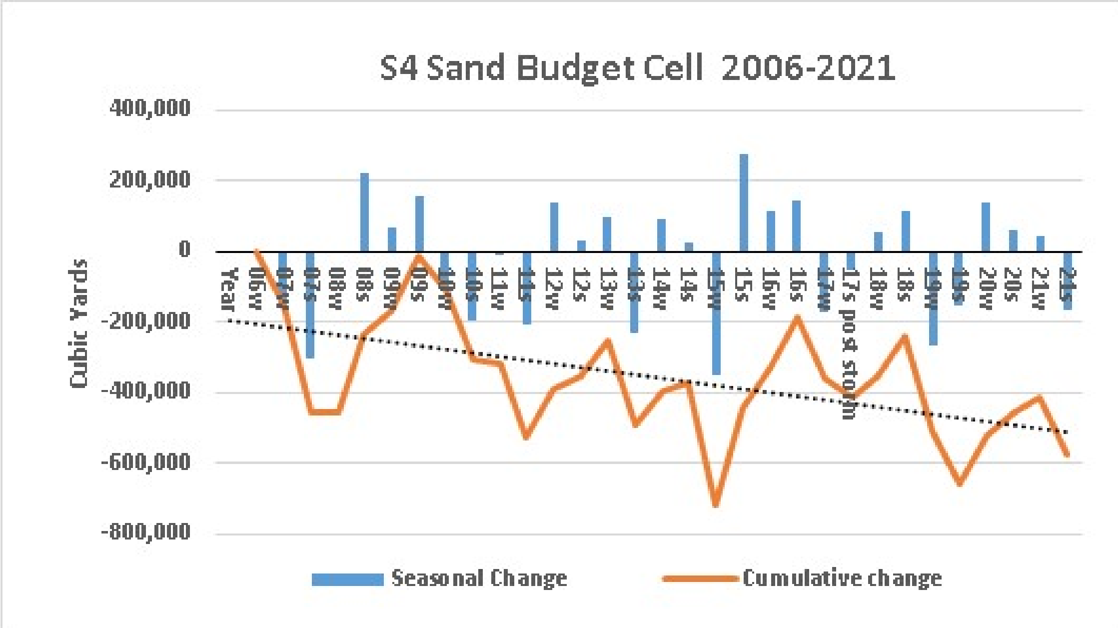


Figure 18. Volumetric evolution of the S4 sand budget cell 2006-2021.

2.4 Analysis of Sand volume changes, 2006 – 2021

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 Figure 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 2021 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 2021. However, as seen in Figure 13 the linear trend of sand volume change between 2006 and 2021 is flat and net sand loses are lower compared to N4 to N2 cells

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.

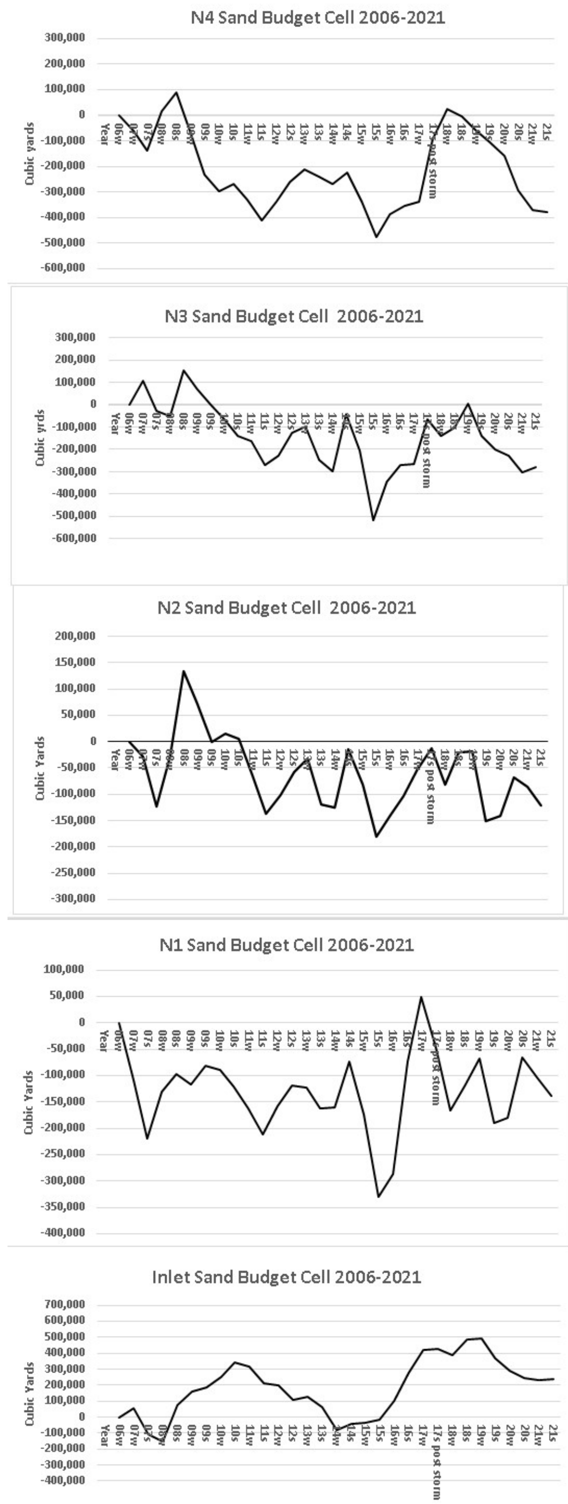


Figure 19. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells N4 to N1 and within the inlet budget cell from 2006 to 2021.

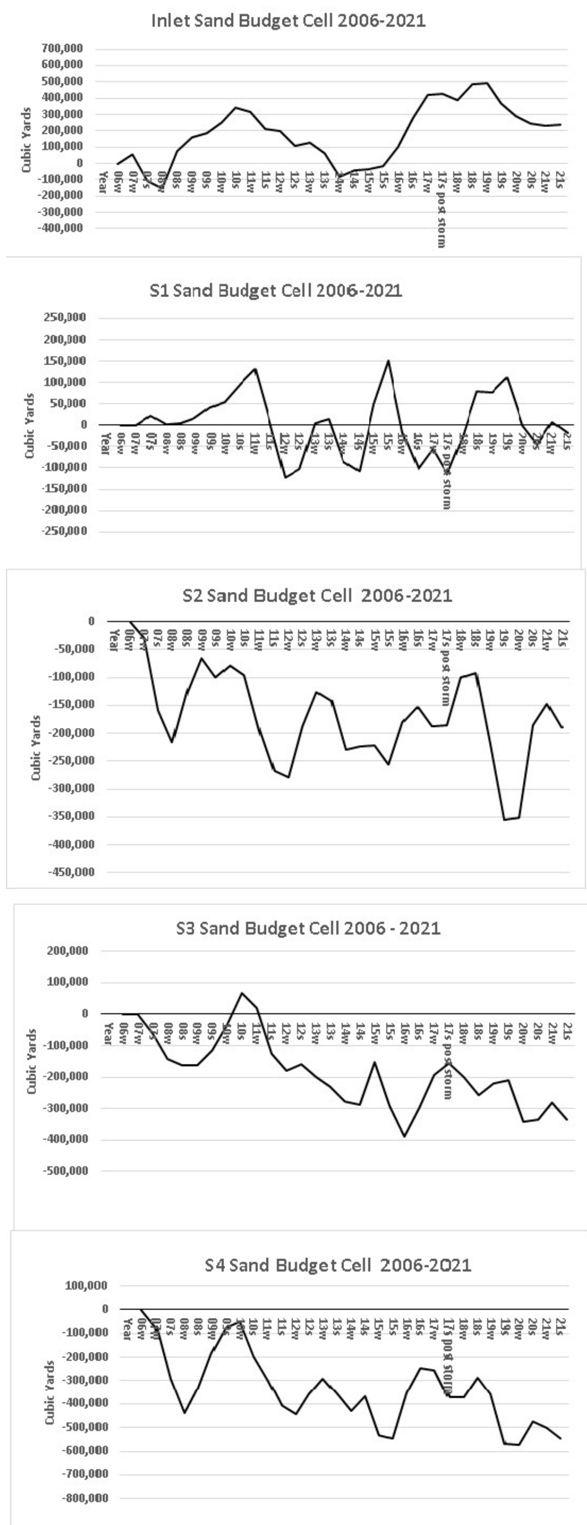


Figure 20. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells S1 to S4 along with the inlet budget cell from 2006 to 2021.

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 declining trend that continued through the summer survey data of 2021

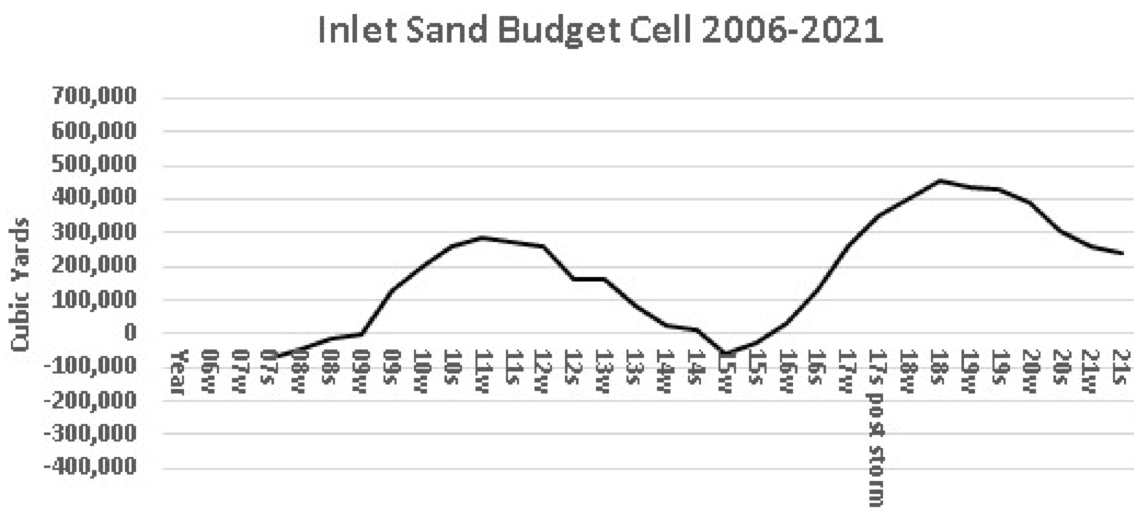


Figure 21. Sand volume trends within the Inlet Sand budget cells presents on the basis of an approximate 18-monnth moving avage over the 2006 to 2021 period of record.

The similarity of sand volume trends over the 14- year records requires some thought about controlling factors. As stated in the 2020 State of the Sebastian Inlet report (Zarillo et al, 2020) there is correspondence between interannual sea level trends and changes in shoreface sand volumes. Figure 22 compares the 2006 to 2021 sea level record filtered to emphasize interannual trends and compared 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 sea-level changes and shoreface sediment volume response.

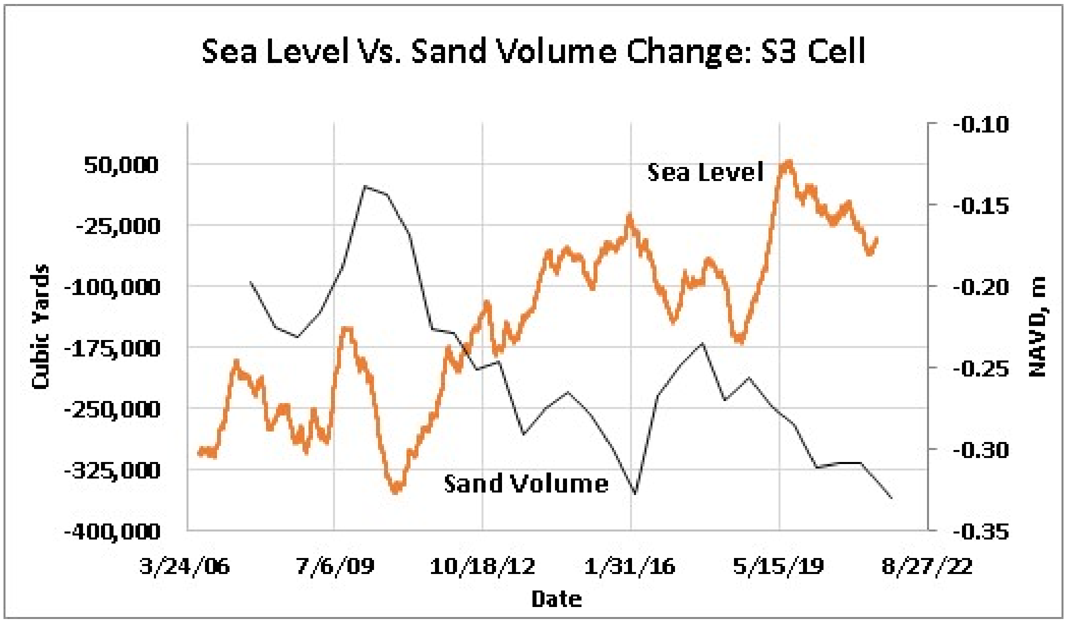


Figure 22. Comparison of fileted the 2006 to 2021 filtered sea level record with the filtered sand volume change record of the S3 budget cell.

The example shown in Figure 21 indicates that sea level change may be a primary control over periods of sand volume increase or decrease within the central Florida coast surrounding Sebastian Inlet . Figure 23 compares the central Florida coast sea level record from 2006 to 2021 with measured cumulative volume changes in each of the sand budget cells over the same period. Sand volume versus sea level change are shown in pairs of sand budget cells beginning with cells N1 and S1 and progressively with distance from Sebastian Inlet. 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.

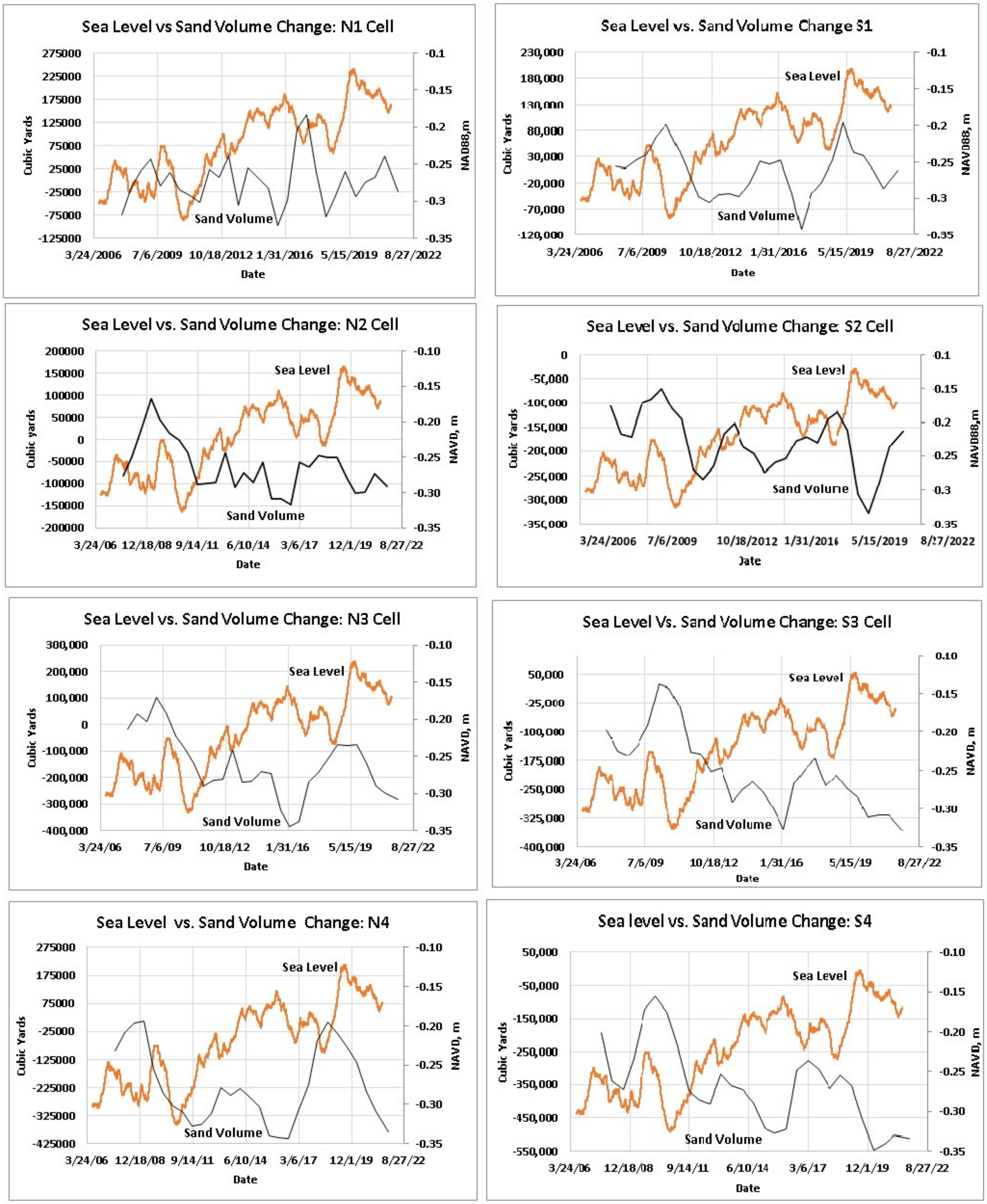


Figure 23. Comparison of sea level changes cumulative sand volume changes within the sand budget cells to the north and south of Sebastian Inlet

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:

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

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 24 schematically shows how calculations are made within each cell of the sediment budget model.

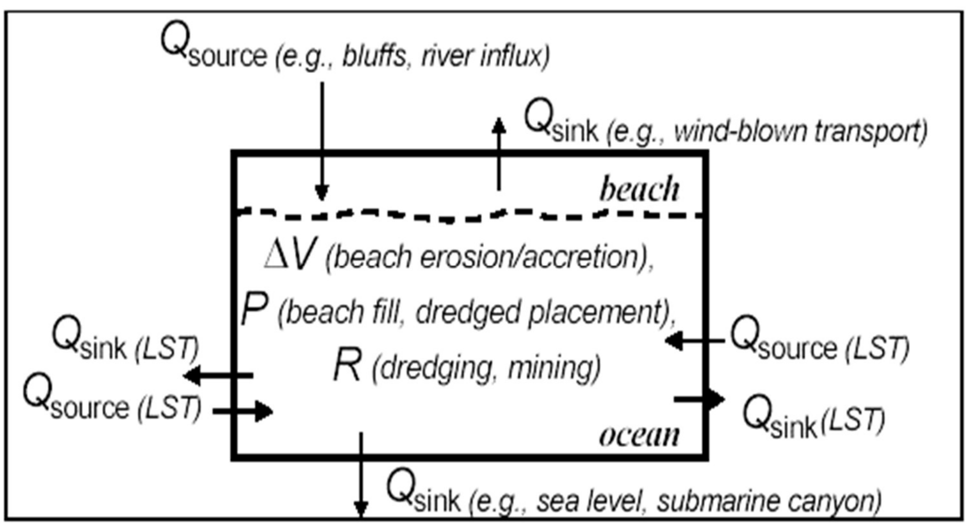


Figure 24. Schematics of a littoral sediment budget analysis (from Rosati, 2005).

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 supe-r regional sediment budget calculations described in Zarillo et al, 2007, an initial input value (Qsource) of 150,000 yd3/yr. was specified. The placement values (P) correspond to the beach fill projects that were included in the calculations. Most of sand placement is to the south of Sebastian inlet in the S2 and S3 sand budget cells 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. Placement and removal values are annualized and presented in Table 2.

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

Time Period	Season	N4	N3	N2	N1	Inlet	S1	S2	S3	S4
2007-21	Winter	1,123P	1478P	1067P	730P	36,681R	21,156P	19,647P	16,821P	19,042P
2007-21	Summer	1,123P	1478P	1067P	730P	36,681R	21,156P	19,647P	16,821P	19,042P
2011–21	Winter	1,572P	1,493P	1,493P	1,022P	11,120R	24,994P	23,808P	21,280P	26,659P
2011–21	Summer	1,572P	1,493P	1,493P	1,022P	11120R	1,572P	1,493P	1,493P	1,022P
2016 –21	Winter	3,144P	4,140P	2,987P	2,044P	29,200R	1,828P	33,756P	33,020P	26,908P
2016–21	Summer	3,144P	4,140P	2,987P	2,044P	29,200R	1,828P	33,756P	33,020P	26,908P
2018-21	Winter	2,540P	3,344P	2,413P	1,755P	48,667R	3,047P	47,460P	53,567P	44,847P
2018-21	Summer	2,540P	3,344P	2,413P	1,755P	48,667R	3,047P	47,460P	53,567P	44,847P

3.2 Sand budget results

The sand budget is presented on four distinct time scales ranging from a longer-term budget for the past 14-year and 10-year periods 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 rate of +150,000 cubic tards per year entering the first north cell (N4). Sand transport was assumed to flow north to south. The components of the 14-year sand budget are listed in Table 3 and covers the period from 2007 through 2021. A comparison is made between winter and summer-based budgets.

Table 3. Fourteen-year sand budget of annualized volume changes per cell and flux (2007 – 2021).

Time Period	Winter 2007 – Winter 2021 Qin=150,000 cy/yr.		Summer 2007 - Summer 2021 Qin=150,000 cy/yr.	
Sediment Budget Cell	DV (cy/yr.)	Q (cy/yr.)	D(cy/yr.)	Q (cy/yr.)
North 4	-16,352	167,475	-17,859	168,982
North 3	-37,818	199,771	1,587	168,873
North 2	-2,766	193,604	3,096	166,844
North 1	5,506	188,828	6,078	161,496
Inlet	9,347	142,800	40,065	84,750
South 1	-2,065	169,021	2,112	106,794
South 2	-9,981	158,649	5,808	120,633
South 3	-19,259	154,729	-17,408	154,862
South 4	*-30,268*	*164,039*	*-6,698*	*180,602*

Figure 25 Illustrates results of the 14-year sand budget analysis bounded by the winter surveys of 2007 and 2021. All but two of the sand budget cells registered annualized sand volume loss, which generally increase with distance north and south of Sebastian Inlet. The N1 and Inlet budget cells register an annualized increase in sand volume. The calculation begins with an input of 150,000 cu/yd per year into cell N4 and assumes net south littoral transport. In order keep the littoral transport rate on the order of 150,000 cu/yd, hypothetical sand losses to the seaward side of some budget cells are applied. At the time of this writing a more spatially detailed sand budget analysis is underway involving partitioning of the sand budget cells into onshore and offshore components to examine cross-shore sand transport contribution to the sand budget. The hypothesis is that sand losses on the topographic shoreface, which extends to depths of about 15 feet are balances by deposition on the inner continental shelf to waters depths of 40 feet. Plots of net topographic change in each of the sand budget calculation periods are provided in Section 4 of this report.

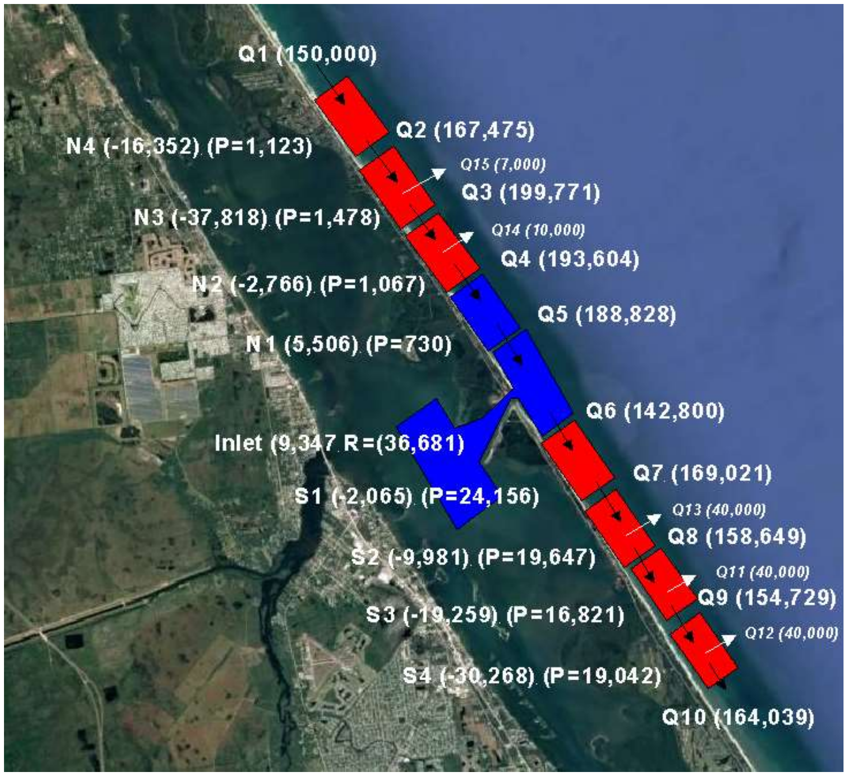


Figure 25. Annualized 14-year sediment budget for the winter 2007 to winter 2021 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

Figure 26 presents the details of the summer to summer sand budget between 2007 and 2021. In this calculation no hypothetical offshore sand transport is required to maintain a balanced annualized littoral transport rate that does not become unreasonably high from north to south. In this budget, 7 of the 9 sand budget cells maintain an annualized sand volume gain over the 14-year period. Cell N4 at the north end of the calculation and cells S3 and S4 at the south end are calculated to have a annualize sand volume loss. This is consistent with the overall trend of increasing sand volume loss and/or smaller annualized sand volume gained with distance from the inlet entrance

In 14-year sand budget calculation the Inlet cell is calculated to have annualize sand volume gains of about 9.400 cy/yd per year in the winter budget and about 40,000 cy/yd per year in the summer budget.

Figure 26. Annualized 14-year sediment budget for the summer 2007 to summer 2021 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.

Table 4 lists the annualized sand volume changes and computed net littoral transport rates (Q-values) for the 10-year sand budgets. Figure 27 is a visual representation of the data listed in Table 4 and cover the 2011 to 2021 time period. 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 4.

Table 4. Ten-year sand budget of annualized volume changes per cell and flux (20011 – 2021).

Time Period	Winter 2011 – Winter 2021 Qin=150,000 cy/yr.		Summer 2011 - Summer 2021 Qin=150,000 cy/yr.	
Sediment Budget Cell	DV (cy/yr.)	Q (cy/yr.)	D(cy/yr.)	Q (cy/yr.)
North 4	4,274	147,298	1,752	149,820
North 3	-14,273	163,064	12,095	139,218
North 2	289	164,268	2,996	137,715
North 1	4,199	161,091	10,448	128,289
Inlet	-1,720	151,691	7,162	132,247
South 1	7,806	168,879	7,806	149,435
South 2	1,308	191,379	14,376	158,867
South 3	-23,875	176,534	-19,740	169,887
South 4	-26,066	169,259	-2,178	148,724

The analysis results for the 10-year sand budget based on a winter to winter period show that there was a mix of annualized sand volume gains and losses inter the winter to winter sand budget. between 2011 and 2021.   The inlet cell registered an annualized loss in sand volume of about 1,700 cubic yards per year, whereas the two sand budget cells to the north and south of the inlet cell registered annualized sand volume gains. Sand budget cells S4 and S4 at the south end were characterized by moderate sand volume losses of about 23,000 and 26,000 cubic yards per year. Net annualized offshore net offshore sand transport was assumed in these sand budget cells in order to maintain a reasonable net Southard littoral transport rate.   Further analysis is underway to provide more details on cross-shore sand transport linked to the sand budget analysis.

Figure 27. Annualized 10-year sediment budget for the winter 2011 to winter 2021 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 28 is the visualization of the summer to summer 10-year (2011 to 2021) sand budget. All budget cells registered moderate annualized gains of sand volume except for budget cells S3 and S4 in which moderate annualized sand volume losses were present. Net offshore transport was assumed in these calls to provide a realistic littoral transport rate.
The Sebastian Inlet budget cell added sand volume at an annual rate of about 7,000 cubic yards.

Figure 28. Annualized 10-year sediment budget for the summer 2011 to summer 2021 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 2011 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.

A 5-year sand budget was calculated to compliment the longer term calculations. Table 5 lists the results for the winter 2016 to winter 2021 and summer 2016 to summer 2021 sand budgets. The winter to winter calculations shows a symmetrical pattern of sand volume changes among the sand budget cell to the north and south of Sebastian inlet. The N1, inlet cell and S1 cells all increased in sand volume as shown in Figure 29. The remaining cell to the north hand south registered moderate annualizes sand volume losses. offshore transport was assumed in several of the sand loss cell to maintain a realistic net littoral transport rates among the sand budget cells.

The five-year summer to summer sand budget listed in Table 5 and illustrated in Figure 30 includes moderate to higher annualized sand volumes loss from the N1 cell, across the inlet cell and south to the S4 sand budget cell. An exception is the S1 cell just to the south of the inlet cell where an annualized gain of about 17.000 cubic yards occurred. Here, sand volume naturally bypassed and removed from the inlet cell directly benefited the S1 sand volume increase. North of the N1 cell, sand budget cells N4, N3 and N2 accumulated sand volume over the 5-year period.

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

Time Period	winter 2016 – Winter 2021 Qin=150,000 cy/yr.		Summer 2016 - Summer 2021 Qin=150,000 cy/yr.	
Sediment Budget Cell	**DV (cy/yr.)**	**Q (cy/yr.)**	**DV (cy/yr.)**	**Q (cy/yr.)**
North 4	-19,093	152,237	8,373	144,771
North 3	-37,310	173,687	32,835	116,076
North 2	-10,298	166,972	3,177	115,886
North 1	11,198	157,818	-36,930	154,860
Inlet	4,645	123,973	-20,991	146,651
South 1	5,696	120,105	17,239	131,240
South 2	-13,300	167,161	-1,014	166,010
South 3	-21,651	161,832	-59,676	158,706
South 4	-48,997	177,737	-72,491	158,105

Figure 29. Annualized 5-year sediment budget for the winter 2016 to winter 2021 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.

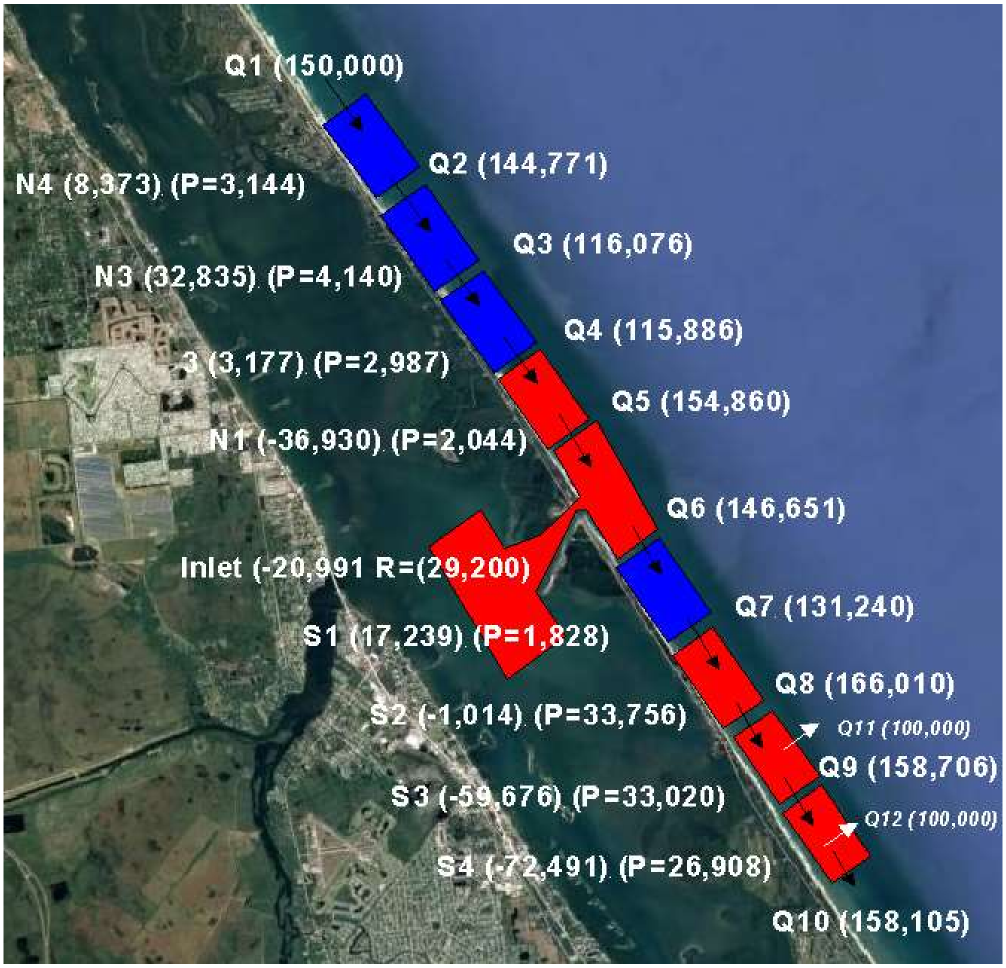


Figure 30. Annualized 5-year sediment budget for the summer 2016 to summer 2021 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized 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 6, Figure 31, Figure 32) 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. Further, over the 3-year sand budget period from 2018 to 2021 sand volume changes are dominated by the seasonally large sand volume shift in response to the seasonal changes in both wave energy and sea levels. The winter to winter and summer to summer sand budget calculations shown in Table 6 were not adjusted by cross-shore sand transport to reduce the large net littoral drift values that arise due to along shore sand volume losses that occurred in most sand budget cells. This the annualized net littoral transport values between the cells and beyond the southernmost cell are unrealistically high. Further refinement of the sand budget cells into onshore shoreface and offshore inner continental shelf components is expected to better resolve cross-shore sand dynamics. Along with sand volume losses to the north hand south of Sebastian Inlet the inlet sand budget cell lost an annualized 50,000 to 70,000 cubic yards of sand volume over the 3-yeaer period.

Table 6. Three-year sand budget annualized volume changes per cell and flux.

Time Period	Winter 2018 – Winter 2021 Qin=150,000 cy/yr.		Summer 2018 - Summer 2021 Qin=150,000 cy/yr.	
Sediment Budget Cell	**DV (cy/yr.)**	**Q (cy/yr.)**	**DV (cy/yr.)**	**Q (cy/yr.)**
North 4	-122,193	274,733	-128,655	281,195
North 3	-18,509	296,586	-98,325	382,864
North 2	-3,555	302,554	-63,625	448,902
North 1	16,148	288,161	-29,653	480,310
Inlet	-57,374	296,868	-71,001	502,644
South 1	-22,527	322,442	-26,680	532,371
South 2	-56,456	426,358	-7,488	587,319
South 3	-23,523	503,448	-93,713	734,599
South 4	-73,850	622,165	-101,922	881,638

Figure 31. Annualized 3-year sediment budget for the winter 2018 to winter 2021 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.

Figure 32. Annualized 3-year sediment budget for the summer 2018 to summer 2021 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

4.0 Morphologic Changes

4.1 Methods

The analysis uses the same datasets and overall methodology applied to the sand volume analysis and sand budget analysis described under Sections 2 and 3 . The morphologic change section is subdivided according to the time periods associated with sediment budget calculations presented in Section 3. Thus, the details of topographic changes and sediment movement can be viewed in each of the sediment budget cells, In the color convention for figures depicting topographic change; blue spectrum colors are assigned to erosion, whereas red and orange colors indicate areas of deposition. Topographic changes were combined with results from shoreline changes and sand budget calculations for a better understanding of the sedimentation processes. The overall conclusion is that those large topographic changes occur on the upper shoreface combined with much smaller changes at depths of 15 to 40 feet NAVD88

Topographic Change 2006 to 2021

Calculated Net topographic changes between 2007 and 2021 are shown in Figure 33. The pattern of topographic changes indicates that the largest topographic changes and most sediment movement takes place on the shoreface at depths shallower than about 15 feet, which is the approximate wave base along the central Florida coast. Sand volume losses in the winter to winter sand within the cells to the north and south of the inlet call are largely due to erosions from the beech and shoreface rather than sand volume losses at depths greater than 20 feet. Sand volume gains in the winter to winter 14-yer budget in the inlet cell are due to sand volume gains in the ebb shoal. Sand volume gains in the budget cell north and south of the inlet cells in the 14-year summer to summer sand budget are due to accumulation on the upper shoreface and beach rather than gains at depth greater than about 15 feet. This implies net onshore transfer of sand to increase the elevation of the beach and shoreface. Inspection of topographic changes within each of the sand budget cells suggests the need to subdivide the exiting cells into upper shoreface and beach components and a separate set of sand budget cells that extends from the base of the shoreface onto the inner continental shelf.

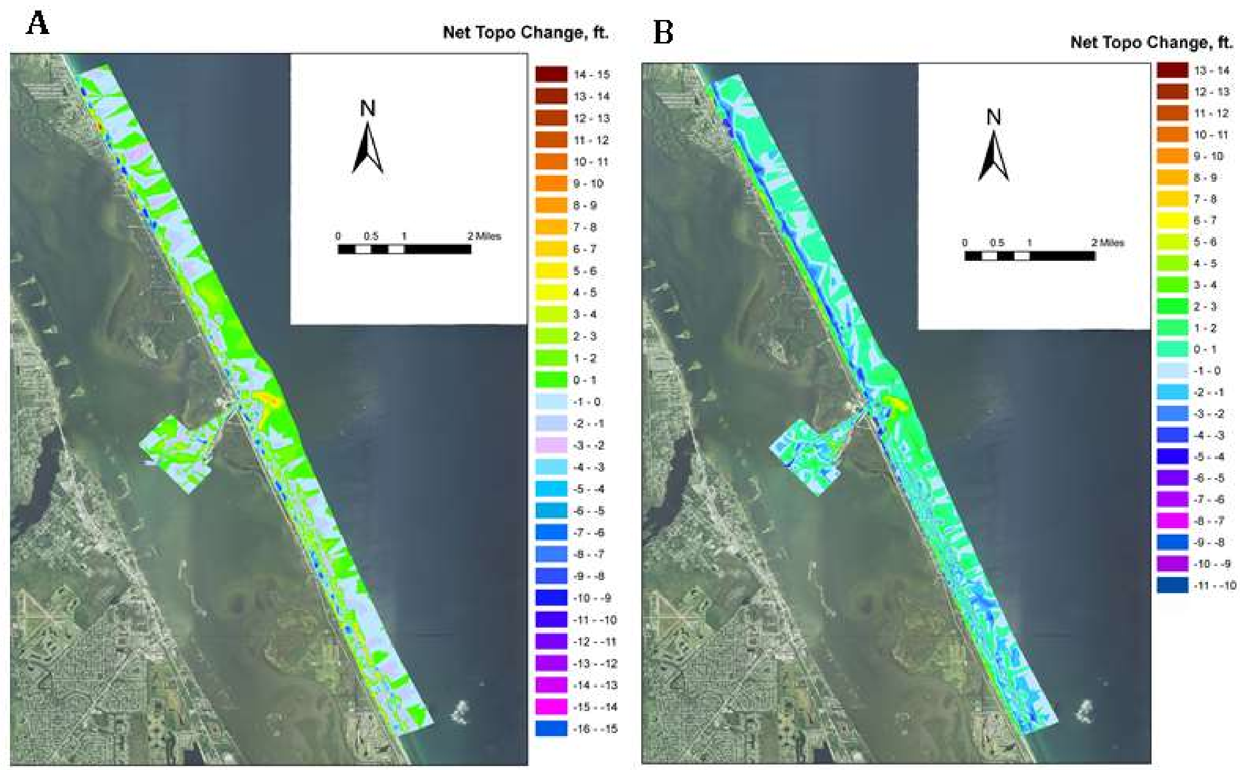


Figure 33. Net topographic (elevation) changes associated with the winter to winter (panel A) and summer to summer (panel B) associated with the 14-year sediment budget calculation

Topographic changes associated with the 10-year sand budget are shown in Figure 34 and consisting of a pattern of alternating upper shoreface pattern of deposition and erosion consist with the budget cell calculations illustrated Figure 27and Figure 28. Annualized sand volume loss within the inlet budget cell is due to a combination of sand trap dredging and erosions on the inner flank of the ebb shoal. Annualized sand volume gained in the N3 ,N3 and S1 and S2 cells are a combination of sand deposition on the upper shoreface and in the case of the S1 and S2 cells, deposition across the inner continental shelf. The upper shoreface and beach along the S1 and S2 cells includes some loss of sand volume to the inner continental shelf. The 10-year summer to summer sand budget (Figure 34 panel B) is largely sand depositional pattern across the shoreface and inner continental shelf. The only noticeable erosion zone are on the ebb shoal and in the attachment bar areas indicating sand bypassing across Sebastian Inlet.

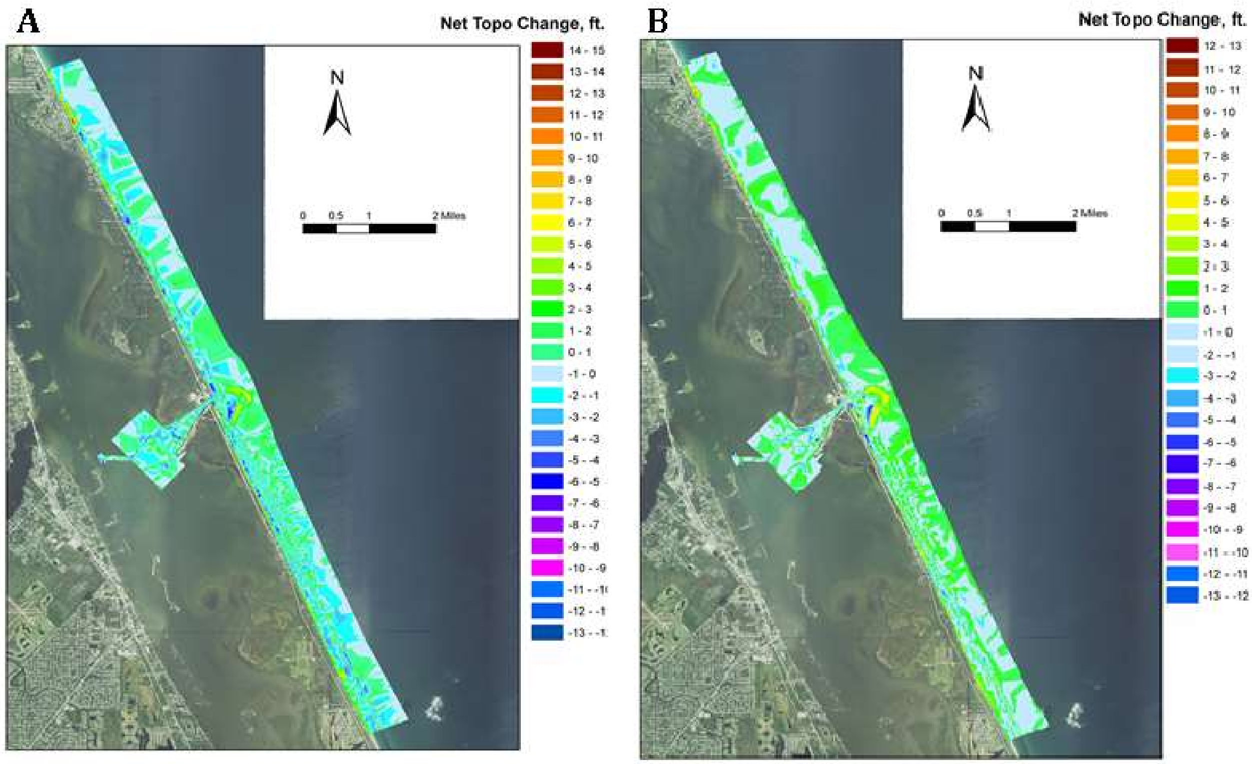


Figure 34. Net topographic (elevation) changes associated with the winter to winter (panel A) and summer to summer (panel B) associated with the 10-year sediment budget calculation

The 5-year sand budget topographic changes are depicted in Figure 35 showing a mix of deposition surrounding Sebastian inlet in the winter to budget (Figure 35, panel A). Sediment volume gains centered on the inlet budget cell are on the lower ebb shoal and in the flood shoal areas, whereas in the N2 cell volume gains are spread across the lower shoreface and inner continental shelf. North of Sebastian Inlet sand volume losses in N1, N2 and N3 are focused on the upper shoreface and beach .South of the inlet in sand budget cells S2, S3 and S4 sand volume losses occur on the shoreface and inner continental shelf as indicated by abundance of blue spectrum colors.

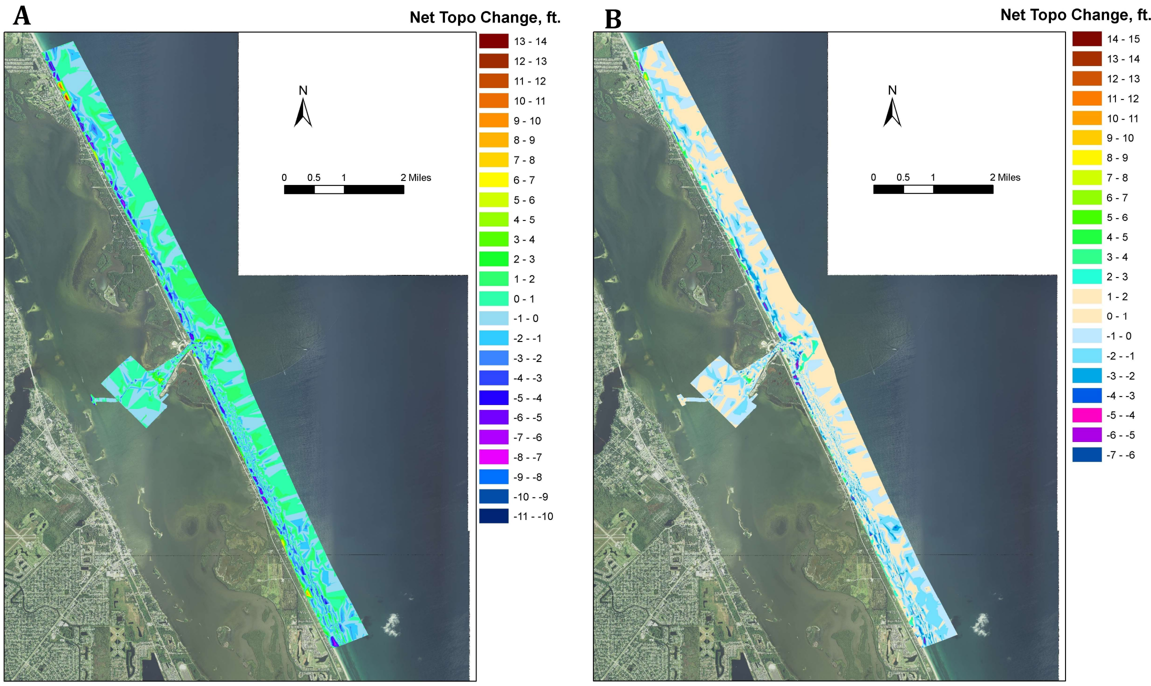


Figure 35. Net topographic (elevation) changes associated with the winter to winter (panel A) and summer to summer (panel B) associated with the 5-year sediment budget calculation

Sand volume losses dominate the topographic changes associated with the winter to winter and summer to summer3-year sand budget calculation (Figure 36) Blue. spectrum colors indicate sand losses across the beach, shoreface and many areas of the inner continental shelf. As stated in Section 3, shorter term sand budget calculation can be dominated by seasonal sand volume changes associated with short term variations in wave energy and sea level in the coastal ocean of Florida. Given the correlation between recent sand volume declines in sand budget cells and sea level rise shown in Figure 23 some of the sand loss could be due to transport seaward beyond the seaward boundary of the sand budget cells. Such removal of sand from the nearshore and shoreface environments could be a permanent.

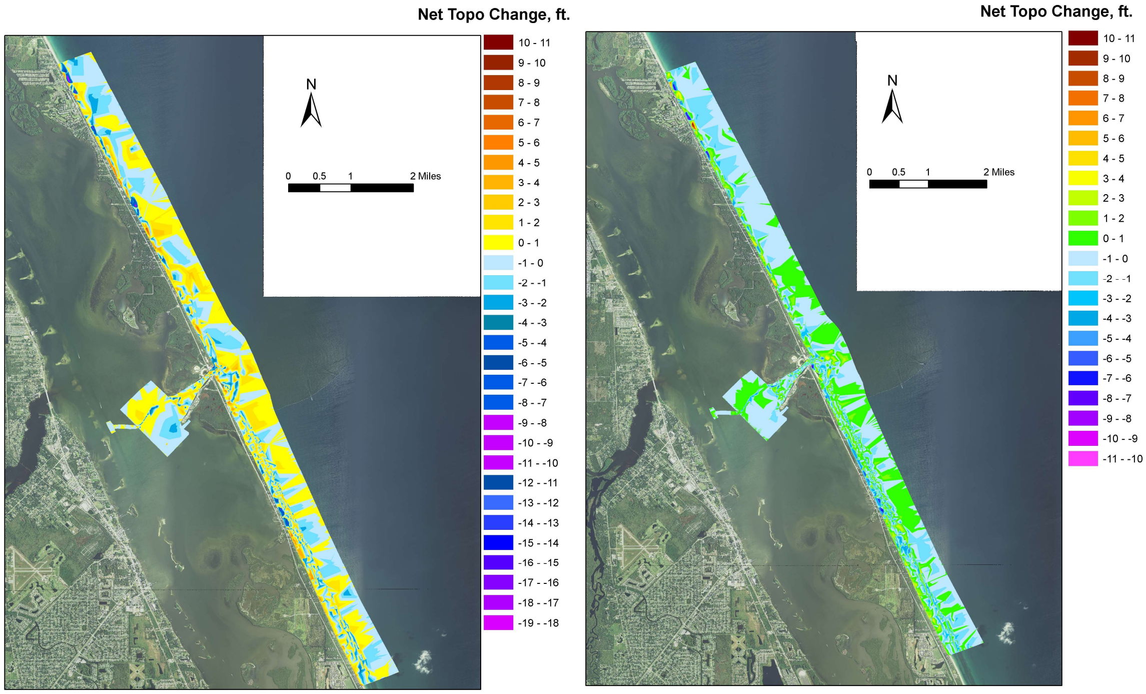


Figure 36. Net topographic (elevation) changes associated with the winter to winter (panel A) and summer to summer (panel B) associated with the 3-year sediment budget calculation.

5.0 Image Based Shoreline Changes

5.1 Methods

This section of the report provides an update of the shoreline change analysis from aerial imagery taken in 2021. More detailed information about the methodology and extent of the sub-domains referenced in this report can be found in a series of annual "State of the Inlet" reports issued since 2007. 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 37) that runs parallel to Florida State Road A1A (SR-A1A) to the wet/dry line (low-tide terrace).

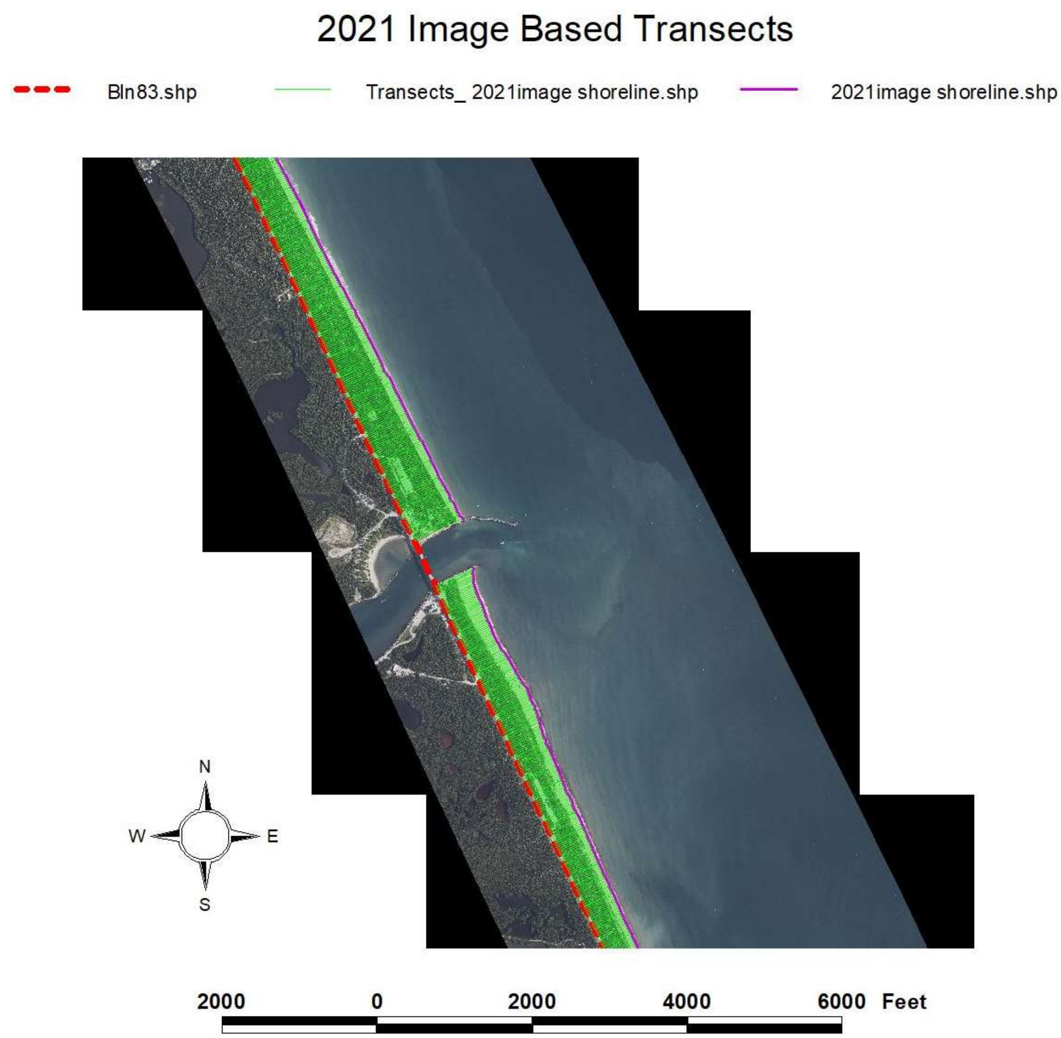


Figure 37. Baseline (red line), Transects (green lines) and purple line is the image-based 2021 shoreline around Sebastian Inlet.

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 2021 is compared directly with 1958, 2011, 2016, and 2021 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.

The results presented and discussed in this section focus on the on image-based shoreline change. Table 7 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-three years (1958-2021), an intermediate period of ten years (2011-2021), and short-term analyses that account for recent changes from 2016-2021 (five years), as well as those occurring most recently from 2020 to 2021 (annual).

Table 7. 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

5.2 Historical Period (1958-2021)

The shoreline changes between the period of 1958 to 2021 (Figure 38) show shifts ranging from -105 feet (near R-marker 12) to +234 feet (south of R-marker 219). Two major sections of shoreline advancement are noticeable along the North to South domain flanked by one noticeable area of shoreline retreat in the north and a major area of recession dominating the southern extent. Interspersed there are smaller areas that alternate between landward and seaward shoreline migration.

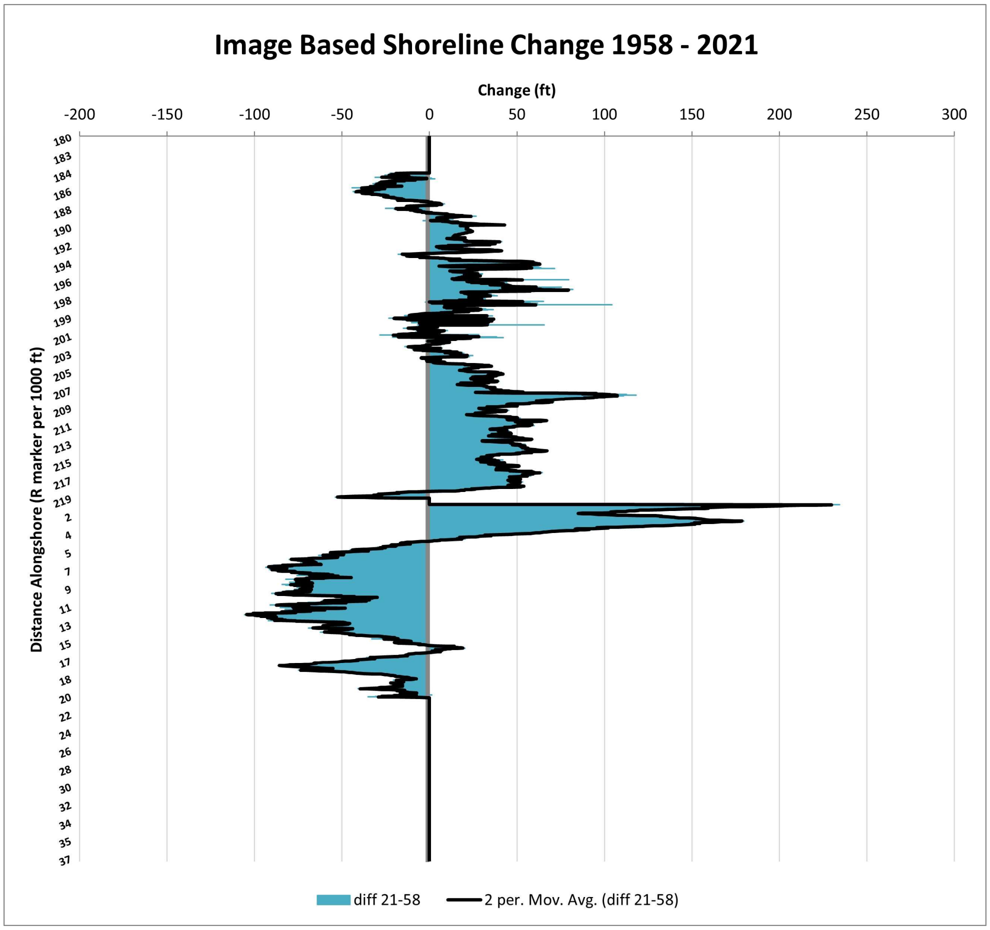


Figure 38. Change (ft) in shoreline position from 1958-2021

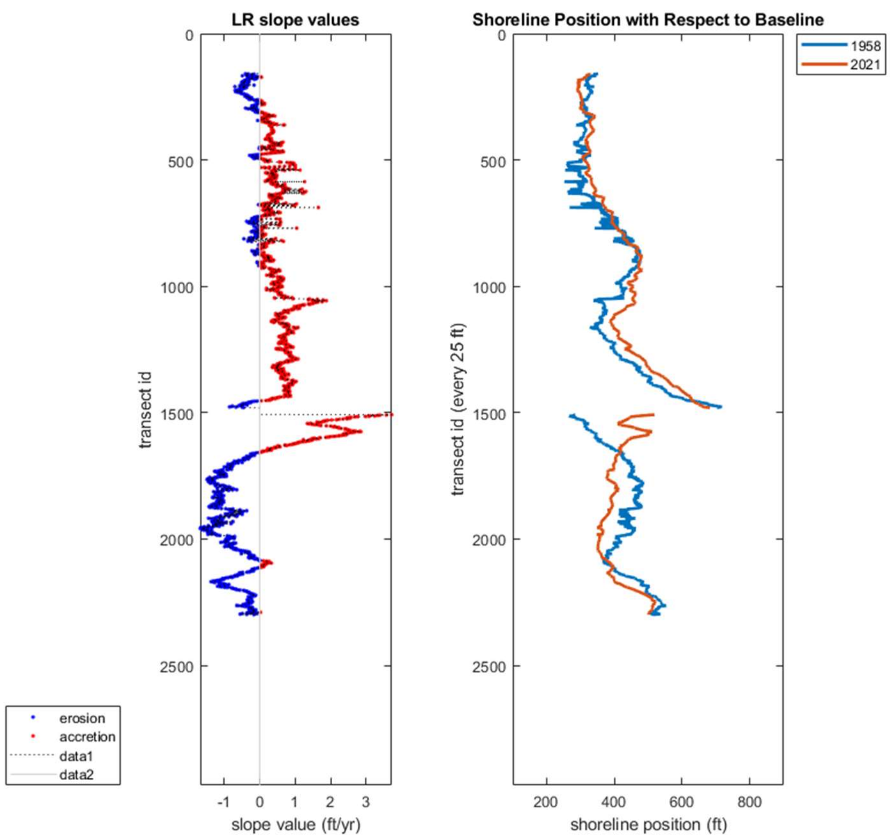
In segment N3, the northernmost area denoting landward migration is close to -44 feet and is centered around R-186, within the same N3 segment the first section denoting seaward migration shows a maximum value of close to +104 feet is centered around R-marker 198. The second area of shoreline advancement is found along segments N2 and N1, where the maximum seaward migration can be seen around R-208 with a value of close to +118 feet. Approaching the north side of Sebastian Inlet, a small section of shoreline retreat is noticeable with a value of close to -54 feet at R-219. Immediately south of Sebastian Inlet, the area of shoreline showing maximum advancement shows values reaching +234 feet while the widest contiguous section of landward migration (receding shoreline) of up to -106 feet at R-12 dominates most of S2 and the part of S3 that has data available for this analysis.

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 8. Overall, the entire extent (North to South) for the 1958-2021 period presents mostly accretion (41.11%). The North segment shows four sections where erosion occurs however this account to only 18.70%, otherwise accretion areas cover 70.56% of the North extent with an average rate of change of +0.3229 ft/yr. The South extent is where the maximum accretion rate occurs (+2.0331 ft/yr) dominating segment S1. Segment S2 is where the maximum erosion rate is found -0.7688 ft/yr and erosion dominates 88.26% of this area. The area immediately south of the Inlet (S1) have undergone 100% accretion, closely followed by N2 (98.14%) and N1 is also dominated by accretion (76.92%).

Table 8. Summary shoreline changes for the historical period (1958-2021)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-1.6795 to 3.7205	0.0839	29.95	41.11
North	-0.8538 to 1.8767	0.3229	18.7	70.56
N3	-0.7024 to 1.6543	0.1288	27.36	54.6
N2	-0.0759 to 1.8767	0.6434	1.86	98.14
N1	-0.8538 to 1.0256	0.4575	23.08	76.92
Inlet	-0.8538 to 3.7205	1.2072	9.61	80.78
S1	0.8498 to 3.7205	2.0331	0	100
S2	-1.6795 to 0.8498	-0.7688	88.26	11.74
S3	-1.3754 to 0.0210	-0.1106	20.94	0.12
South	-1.6795 to 3.7205	-0.1575	41.85	12.13

Another way to visualize the results presented in Figure 39(a) is with a histogram plot (Figure 40) 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 +0.3 ft/yr, which agrees with the central value of accretion rates (red dots) dominating the North. The secondary grouping centered around -0.75 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 39. Period of 1958-2021 (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).

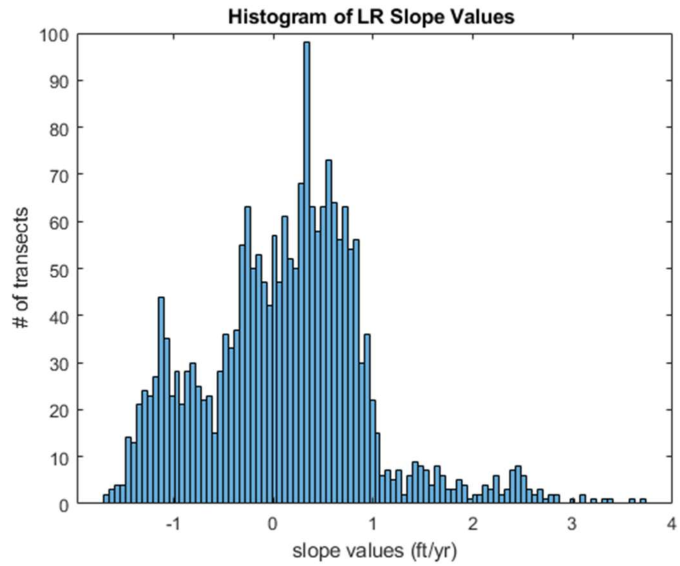


Figure 40. Frequency of rate of change (slope value in ft/yr) for entire domain (1958-2021).

5.3 Intermediate Period (2011-2021)

The changes in shoreline position from 2011 to 2021 (Figure 41) show overall landward migration (recession) throughout the entire domain centered around -20 feet with a maximum landward migration of -67 feet near R-12. Only two narrow sections in segments S1 and S3 show changes indicating advancement (seaward migration) with a maximum of +86 feet immediately south of Sebastian Inlet and of +19.5 feet approaching the center of the S3 section.

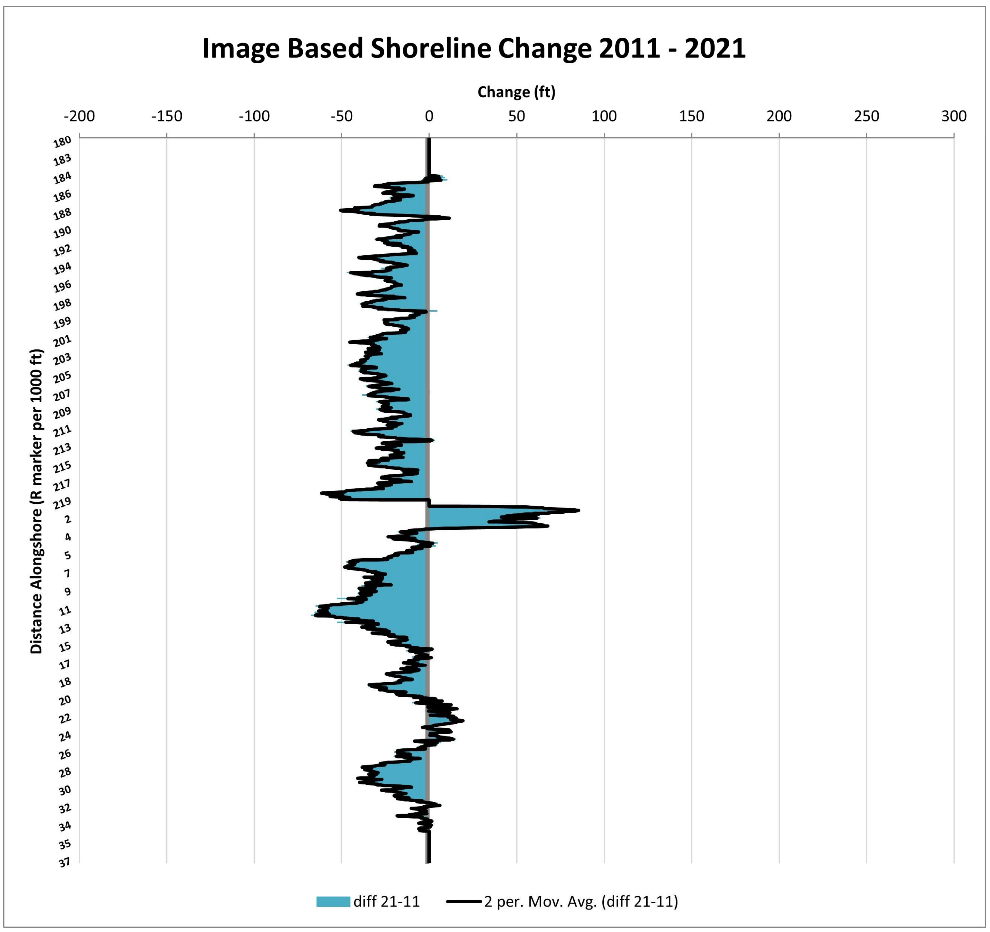


Figure 41. Change (ft) in shoreline position from 2011-2021.

The full extent from North to South show 78.82% erosion and 10.39% accretion with an average rate of change of -1.6654 ft/yr (Table 9). Similarly, most segments show erosion ranging from 57.65% (Inlet sub-section) to 100% (N1). Segment S1 shows accretion of 76.67%, where the average rate of change is +4.0658 ft/yr. In general, the average rate of change is centered around a value of close to -2.6 ft/yr (Figure 42 and Figure 43(a)) for the entire domain, being the

North segment and S2 the ones driving the average of the erosion rate (in ft/yr) with -2.2015 and -2.9431 values respectively. Maximum values of accretion (red dots) occur at S1 (+8.6050 ft/yr) and S3 (+1.9500 ft/yr).

Table 9. Summary of intermediate term changes for the recent period (2011-2021)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-6.7240 to 8.6050	-1.6654	78.82	10.39
North	-6.1560 to 1.2160	-2.2015	87.64	1.62
N3	-5.1170 to 1.2160	-1.8418	79.8	2.16
N2	-4.6370 to 0.3130	-2.6219	98.97	1.03
N1	-6.1560 to -0.3920	-3.1669	100	0
Inlet	-6.1560 to 8.6050	0.3564	57.65	32.74
S1	-1.7690 to 8.6050	4.0658	23.33	76.67
S2	-6.7240 to 0.4560	-2.9431	98.38	1.62
S3	-4.1170 to 1.9500	-0.799	62.57	21.64
South	-6.7240 to 8.6050	-1.123	71.37	19.43

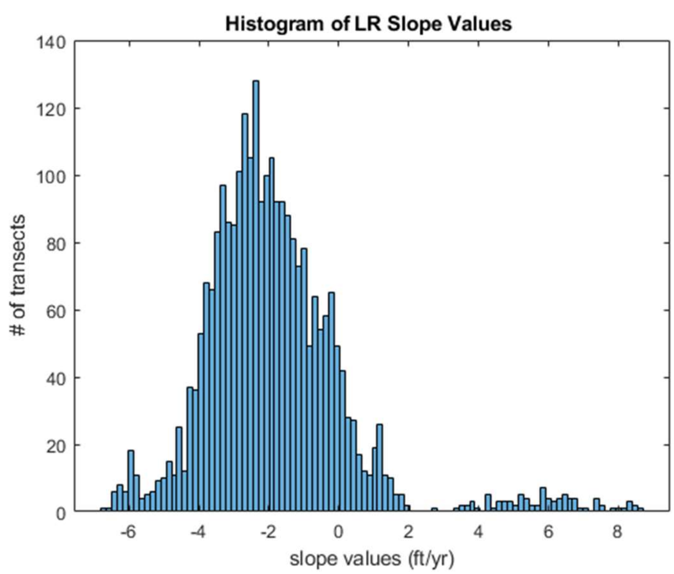
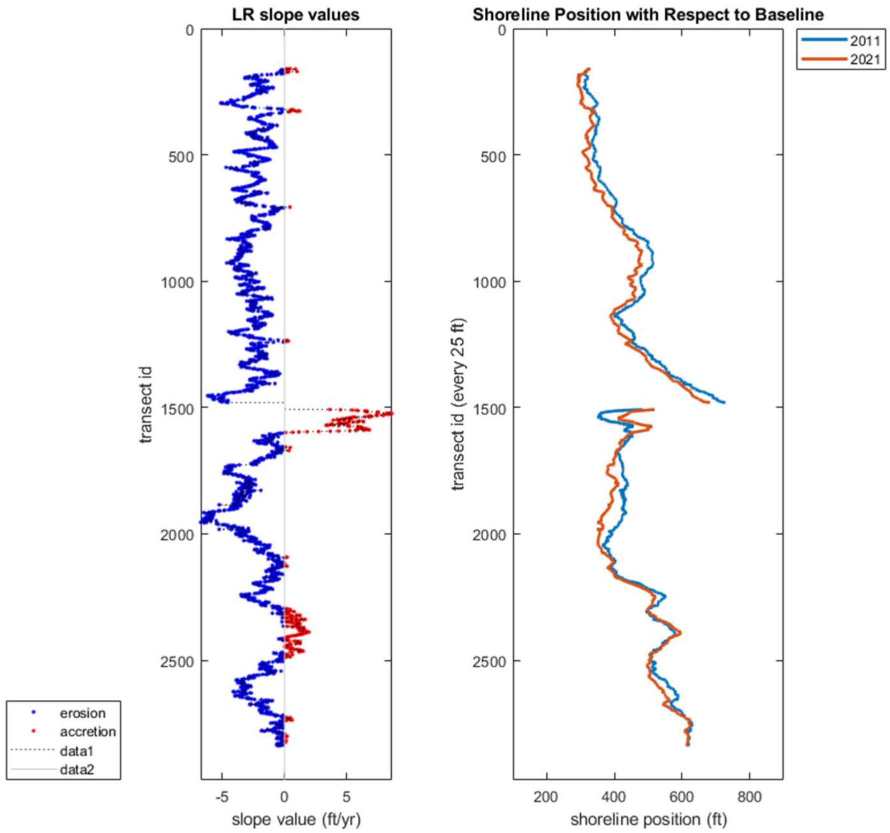


Figure 42. Histogram indicating number of transects per slope value (ft/yr) for 2011-2021.



(a) **(b)**

Figure 43. Period of 2011-2021. (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).

5.4 Recent Changes (2016-2021)

Shoreline changes from 2016 to 2021 (Figure 44) experienced mostly seaward migration (advancement) throughout the entire domain. A maximum change of +98 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 +0.7320 ft/yr to +19.6040 ft/yr (Table 10). Several small areas in the north segments and in S2 show retreat in the shoreline but only two segments S2 show considerable changes indicating retreat (landward migration) of -38.72 feet. Although it is in this segment (S2) where the maximum erosion rate is found with a value of -7.7440 ft/yr, the average rate of change is only -0.5130 ft/yr. In the vicinity of the inlet, segment N1 shows an average rate of change of -3.1834 feet per year while S1 has an average accretion rate of +13.8260 ft/yr. Overall, sixty-nine percent of the North to South domain undergoes accretion, only S2 is dominated by erosion (61.74%).

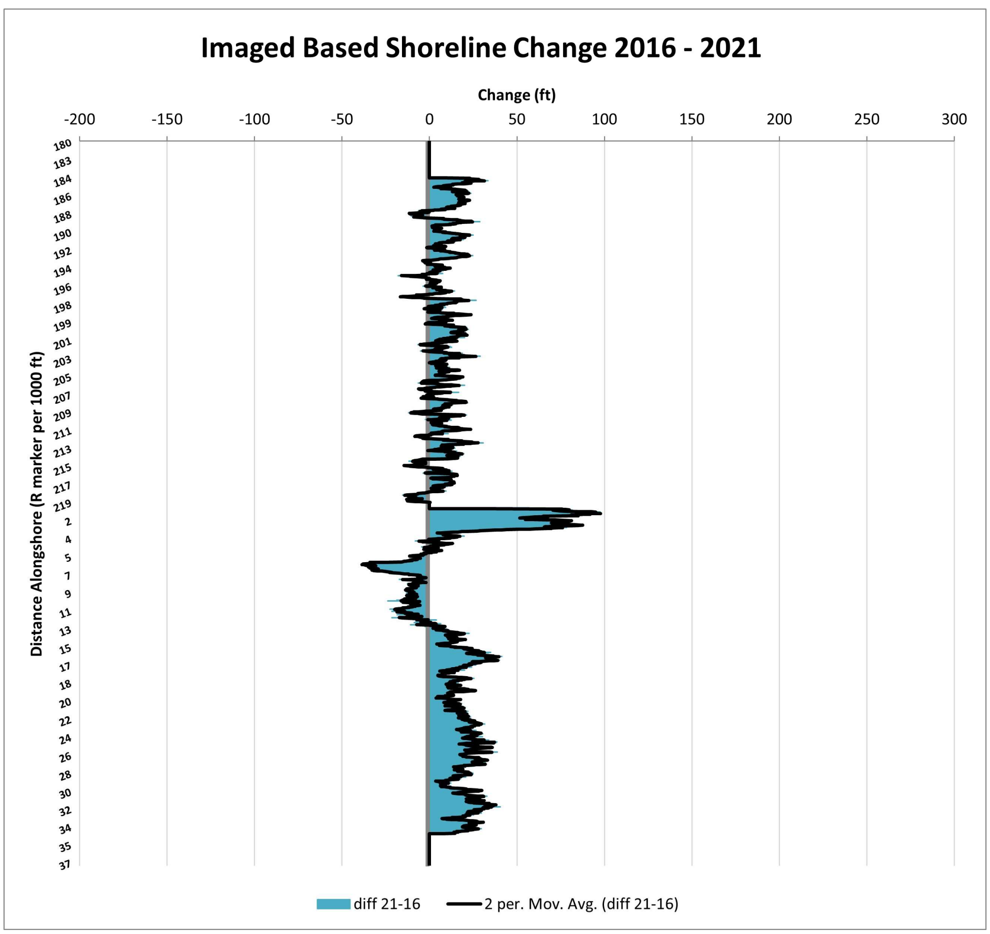


Figure 44. Change (ft) in shoreline position from 2016-2021.

Table 10. Summary of short-term changes for the latest update (2016-2021)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-7.7440 to 19.6040	2.0059	19.53	69.68
North	-3.5880 to 6.7060	1.2754	18.64	70.63
N3	-3.5880 to 6.7060	1.3826	14.07	67.88
N2	-3.0440 to 6.1640	1.2822	22.27	77.73
N1	-3.0940 to 3.2080	0.4863	37.61	62.39
Inlet	-3.0940 to 19.6040	5.6604	18.15	72.24
S1	0.7320 to 19.6040	11.4509	0	100
S2	-7.7440 to 8.2840	-0.513	61.74	38.26
S3	0.0000 to 8.1160	3.4048	0.12	84.21
South	-7.7440 to 19.6040	2.742	20.79	70.01

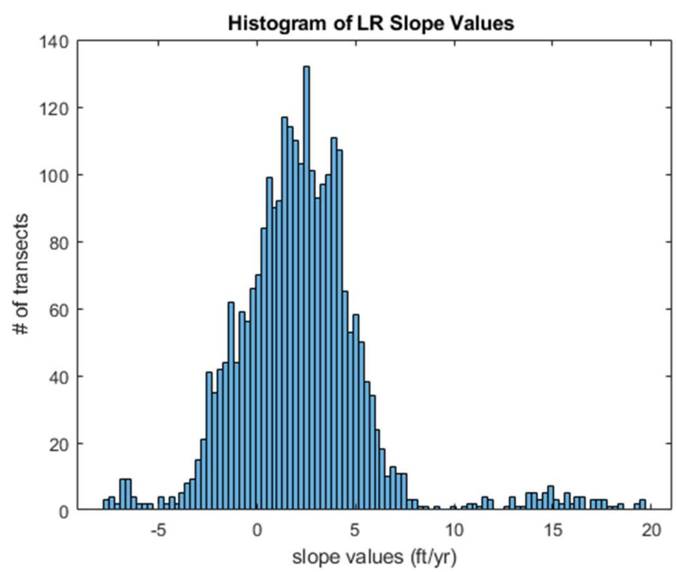
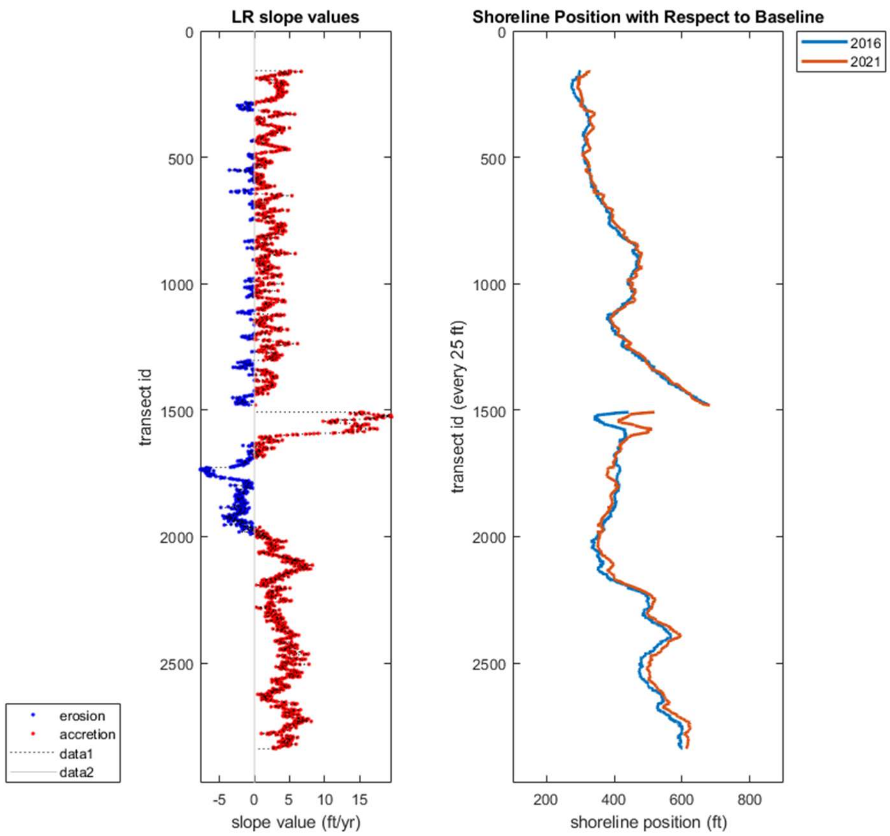


Figure 45. Histogram indicating number of transects per slope value (ft/yr) for 2016-2021.



(a) (b)

Figure 46. Period of 2016-2021. (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).

5.5 Annual Update (2020-2021)

The shoreline changes occurring between 2020 and 2021 (Figure 47) show shifts ranging from -35 feet to +79 feet (seen immediately north and south of the Inlet). Although seaward and landward migration of the shoreline is seen to alternate throughout the domain, 55.16% of the shorelines show advancement (Table 11). Segment S1 show 88.33% of shoreline advanced at an average rate of +37.9685 ft/yr. The rest of the segments also experience shoreline seaward migration at lower average rates from +1.4378 ft/yr (N1) to +8.4762 ft/yr (S3), except for N2 where erosion dominates at 52.99% and has average rate of change of -0.8877 ft/yr. (Table 11).

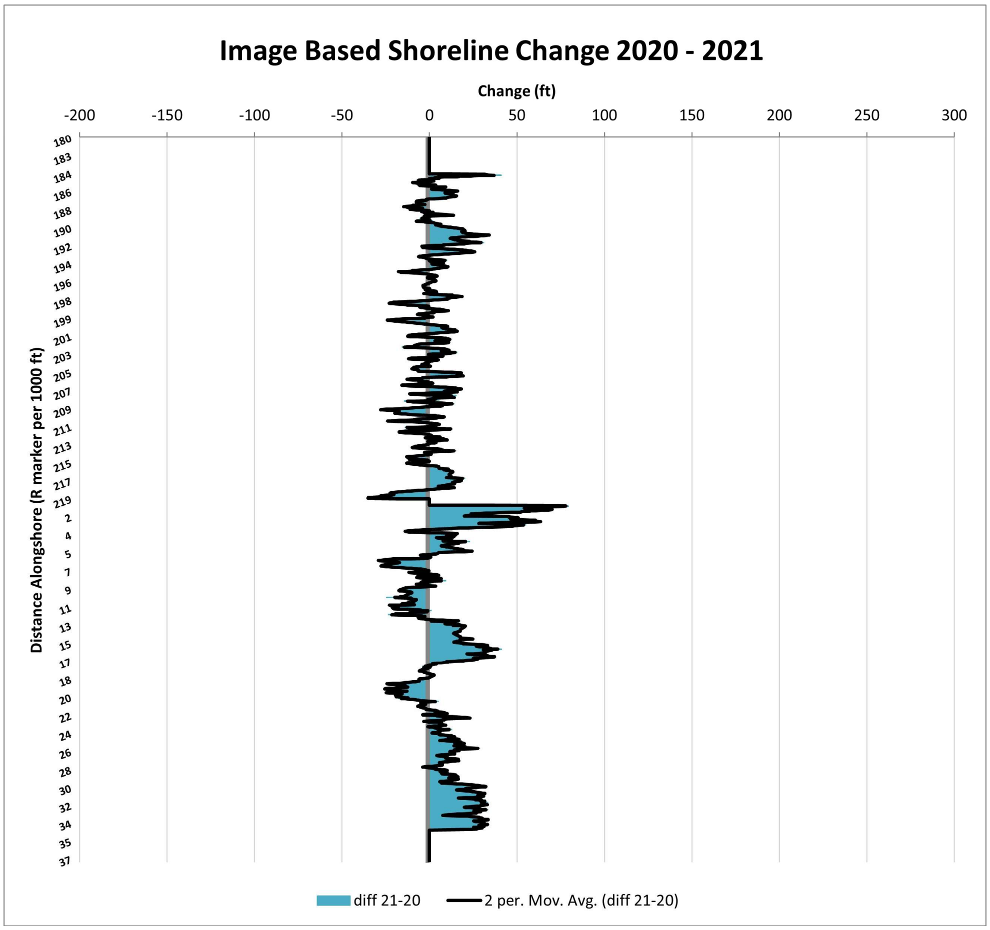


Figure 47. Change (ft) in shoreline position from 2020-2021.

The majority of the spread and peak frequencies occur around +5 ft/yr more easily noticeable in Figure 48. Values beyond -20 ft/yr are clustered predominantly in S1, S2, and S3 where the range of shoreline change values go from -29.8600 ft/yr (S2) to +79.4300 ft/yr (S1). Meanwhile, values below -20 ft/yr are found in found all segments except S1.

Table 11. Summary of short-term changes for the recent period (2020-2021)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-35.3400 to 79.4300	5.0949	34.05	55.16
North	-35.3400 to 34.2500	1.3205	39.64	49.63
N3	-24.6500 to 34.2500	2.5422	33.26	48.69
N2	-28.2700 to 19.3500	-0.8877	52.99	47.01
N1	-35.3400 to 20.1200	1.4378	31.62	68.38
Inlet	-35.3400 to 79.4300	19.344	18.15	72.24
S1	-14.2700 to 79.4300	37.9685	11.67	88.33
S2	-29.8600 to 41.2200	2.6348	47.77	52.23
S3	-25.7300 to 37.3400	8.4762	20.58	63.63
South	-29.8600 to 79.4300	8.9018	29.04	61.76

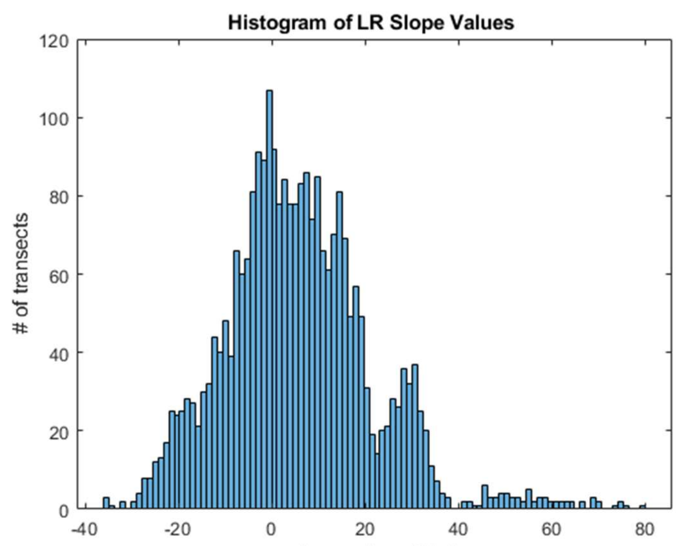
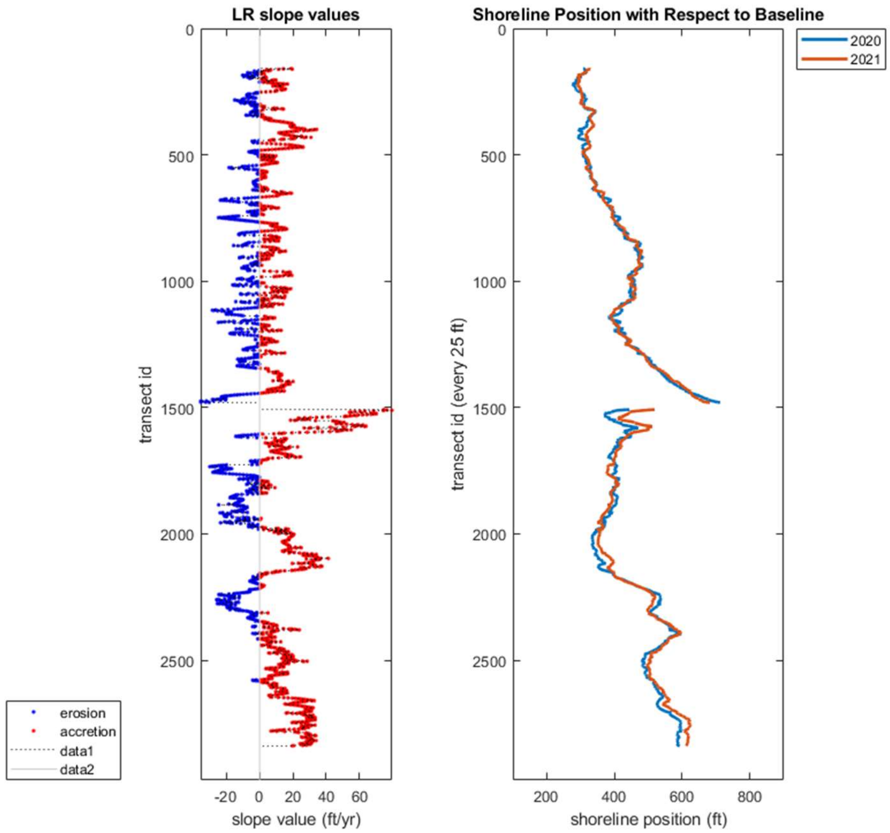


Figure 48. Histogram indicating number of transects per slope value (ft/yr) for 2020-2021.



(a) (b)

Figure 49. Period of 2020-2021. (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 NGVD 1929 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. <u>Winter surveys</u> were analyzed for time periods corresponding to: long-term of fifteen years (2006-2021); intermediate term of ten years (2011-2021); recent-term of five years (2016-2021); and annual (2020-2021). At the time of this report the 2021 Summer survey was not available, thus comparison is performed using the last year available which is 2020. Additionally, Summer 2006 was not available for analysis and thus not included in the comparison. <u>Summer surveys</u> were analyzed for time periods corresponding to: intermediate term of nine years (2011-2020); recent-term of four years (2016-2020); and annual (2019-2020).

6.2 Winter Surveys (2006, 2011, 2016, 2020 and 2021)

Changes between Winter 2006 and Winter 2021 show large excursions in the shoreline, alternating between advancement and retreat along the entire domain (Figure 49, red dashed line). Three larger areas of landward migration can be identified (two on the north and one on the south) while four areas showing seaward migration can be seen on each segment except on S2. It is on the north section where the maximum shoreline retreat is observed (-214.74 ft at R-201). The overall trend during this period is towards landward migration indicating 45.45% erosion, interspersed with areas of accretion that account for 32.2% of the full extent (Table 12 and Figure 50-a) ranging from -14.3160 ft/yr to +3.6040 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 of -0.77 ft/yr.

Table 12. 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 06-21	-14.3160 to 3.6040	-0.7732	45.45	32.2
Winter 11-21	-10.6760 to 4.9310	-0.8054	55.73	21.92
Winter 16-21	-34.0620 to 11.6240	-6.0809	60.4	17.24
Winter 20-21	-69.5800 to 78.6200	-6.5905	53.24	24.4

The results for Winter 2011-2021 analysis are in part similar to those of Winter 2006-2021. (Figure 50,green solid line) show large excursions in the shoreline that alternate from advancement and retreat, however the most dominant of these “switchbacks” are seen in the south part of the domain. Unlike the 06w-21w period, the 11w-21w the retreating section on the north is easily identified because the values are “clustered” throughout N3, N2, and N1 segments with a maximum recession value of -106.76 ft at R-218 (N2 segment). The south section alternates from seaward migration on the S1 segment, landward migration on S2, and seaward migration on S3, but ultimately the entire south extent tends towards shoreline retreat. Overall, this period results in 55.73% erosion and 21.92% accretion, with an average rate of shoreline change of -0.8054 ft/yr and a range of -10.6760 ft/yr to +4.9310 ft/yr (Table 12 and Figure 50).

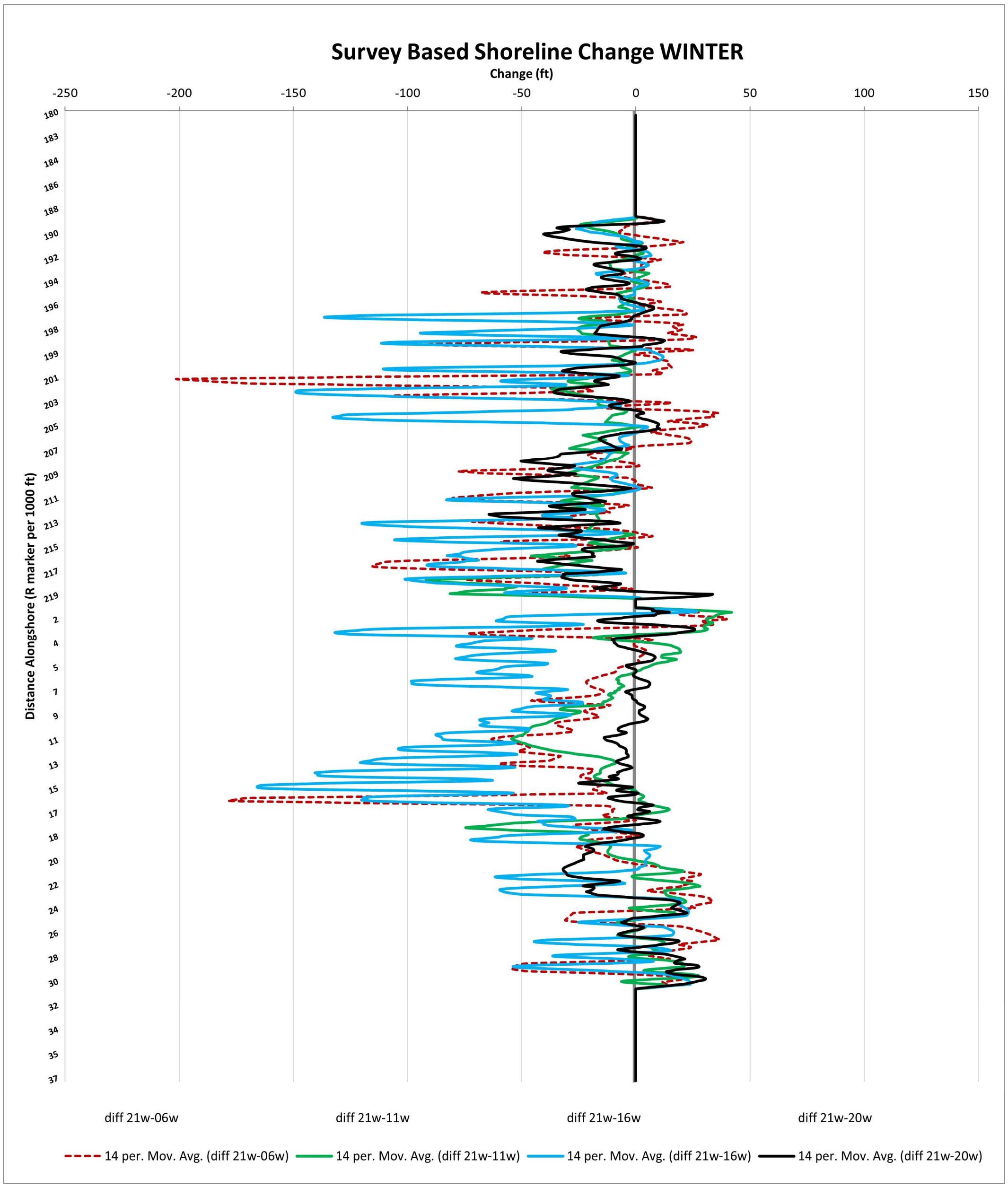


Figure 50. Survey-based change in shoreline position for 2006w, 2011w, 2016w, and 2021w.

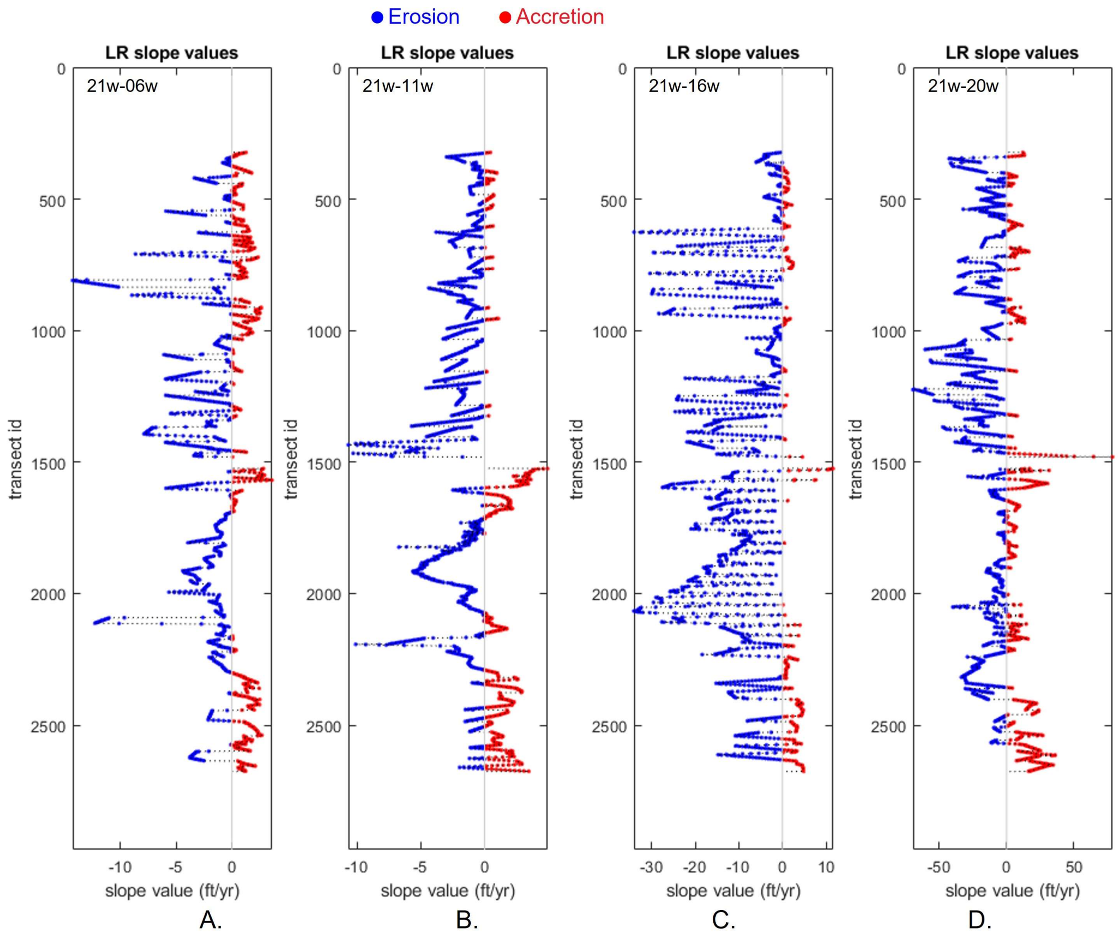


Figure 51. Shoreline rate of change (in ft/yr) for entire domain WINTER surveys: (a) 06w-21w, (b) 11w-21w, (c) 16w-21w, and (d) 20w-21w.

Winter 2016 and Winter 2021 shoreline changes (see Figure 50 solid blue line)) show landward migration as the dominant pattern throughout the entire domain from North to South, however the area immediately south of the Sebastian inlet shows a noticeable change seaward of +58.12 ft, and about half of the shoreline in segment S3 shows advancement up to about +24 ft. The 16w-21w shoreline retreat have maximum value of -170.31 ft at R-15 in S2 and a similar value of -170.15 ft is found at R-197 in N3. The rate of change for the full domain has an average of -6.0809 ft/yr and has a range of -34.0620 ft/yr to +11.6240 ft/yr (and Figure 50-c). This period is the only one in the Winter analysis with marked overall erosion of 60.4%.

The most recent Winter period of 2020w and 2021w (Figure 50, solid black line) show that landward migration dominated the domain from north to south with one area in the S3 segment where shoreline advancement is observed. The retreating area on the north has a maximum value of over +69.58 ft of shoreline change near R-212. A small section in N1, immediately north of Sebastian Inlet shows a maximum change of +78.62 ft. Table 12 and Figure 51-d show that 20w-21w is dominated by erosion (53.24%) and has an average shoreline rate of change of -6.59 ft/yr.

6.2 Summer Surveys (2011, 2016, 2019, and 2020)

Shoreline changes for summer surveys from the periods 20s-16s and 20s-11s shown in Figure 52 (green and red line respectively) follow a similar pattern indicating landward migration throughout the full domain, while period 20s-19s show shoreline advancement predominantly. The results for **Summer 2011-2020** indicate that most of the shoreline has retreated and erosion dominates this period. There is a 61.34% of the area undergoing erosion and only 16.34% experiencing accretion (Table 13 and Figure 53-a). The range of the rate of change is from -10.7733 ft/yr to +6.5900 ft/yr, with an average shoreline rate of change of -1.5777 ft/yr.

Table 13. 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 11-20	-10.7733 to 6.5900	-1.5777	61.34	16.34
Summer 16-20	-39.1075 to 15.7250	-6.1191	64.81	12.87
Summer 19-20	-50.4500 to 64.7800	6.2341	24.17	53.51

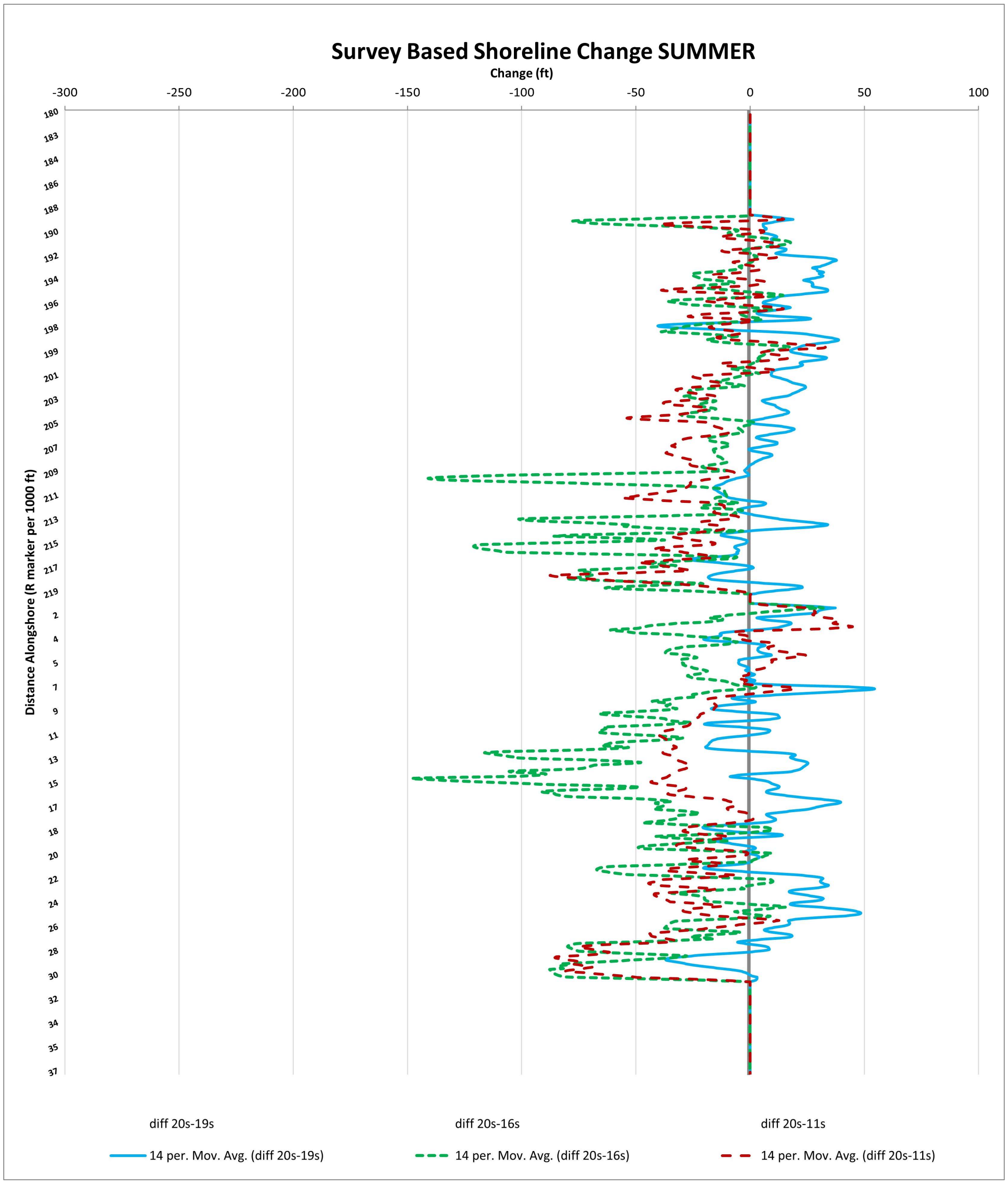


Figure 52. Survey-based change (ft) in shoreline position for 11s-20s, 16s-20s, and 19s-20s.

The Summer period of **2016s-2020s** (Figure 52, green dashed line) show large landward shoreline excursions consistently throughout the domain. The maximum value of shoreline retreat is -156.43 ft found near R-marker 209. In general, this period shows 64.81% erosion and only 12.87% accretion which is seen occurring in N3, S1, and S3 predominantly (Figure 53-b and Table 13). The average rate at which the shoreline is changing is -6.1191 ft/yr with a range of the rate of change reaching values from -39.1075 ft/yr to +15.7250 ft/yr.

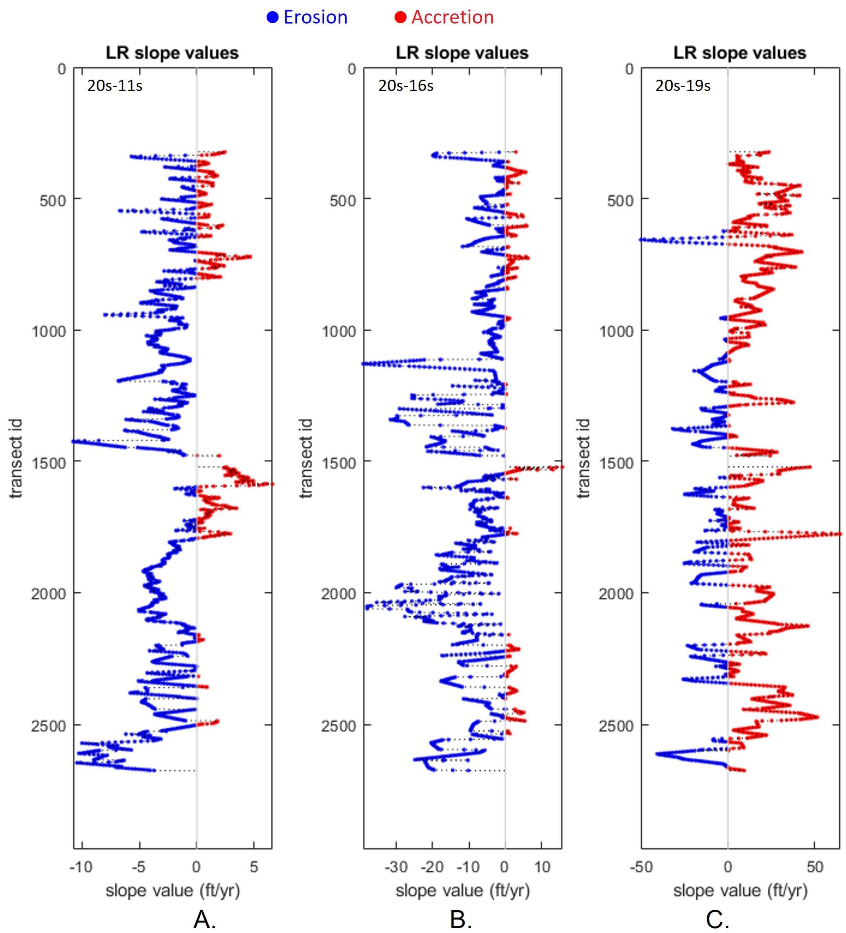


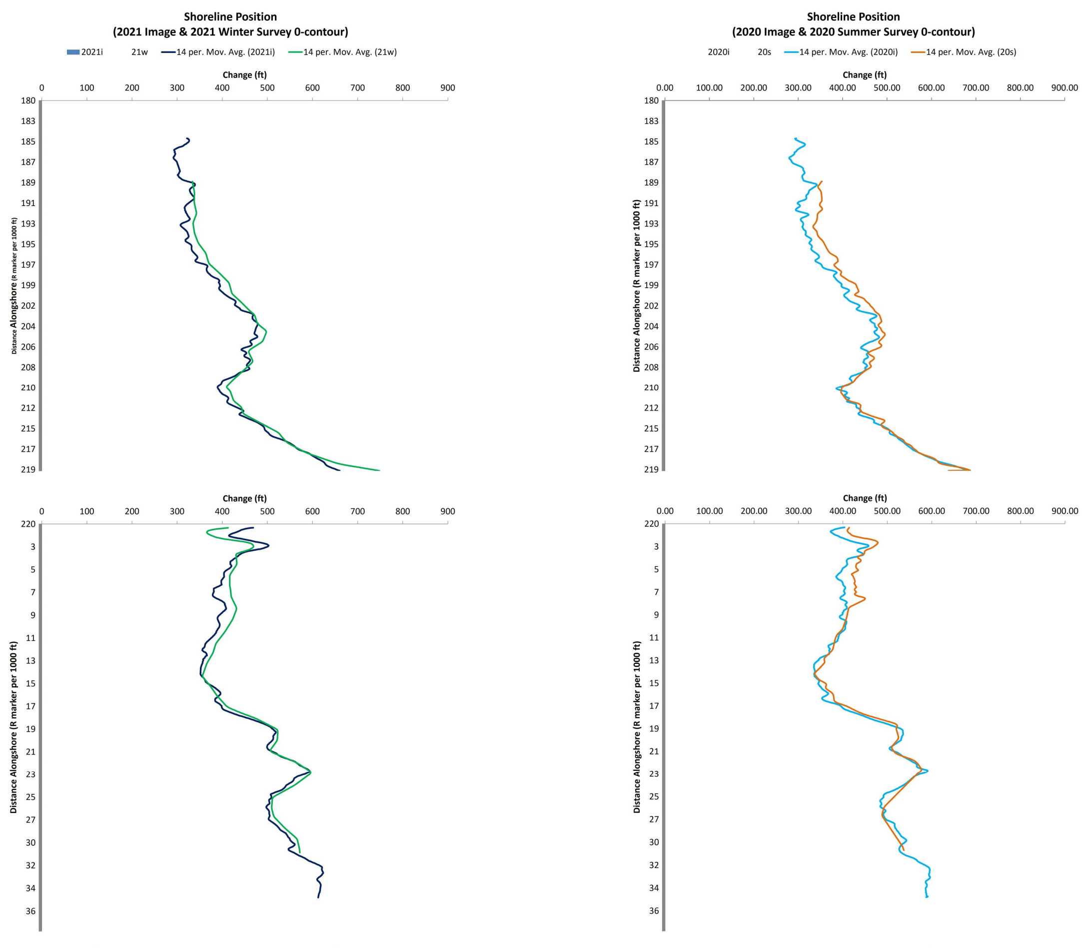
Figure 53. Shoreline rate of change (in ft/yr) for entire domain SUMMER surveys: (a) 11s-20s, (b) 16s-20s, and (c) 19s-20s.

The results for **Summer 2019-2020** analysis show several excursions in the shoreline that alternate from advancement and retreat (Figure 52, blue line); however, the most dominant pattern throughout the domain tends towards seaward migration (advancement). Only the N1 segment shows receding shoreline accounting to 62% erosion in that section, all other segments experience accretion rates (Figure 53-c and Table 13). Overall, this period results in 53.51% accretion and 24.17% erosion, with an average rate of shoreline change of +6.2341 ft/yr and a range of -50.45 ft/yr to +64.78 ft/yr.

6.3 Survey vs. Image Based

The 0-contour survey lines on which the shoreline is based is usually measured every 500 to 1000 ft, while the raw shoreline data is captured every 100 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 image-based shoreline pattern is spatially more variable.

The comparison between survey-based and image-based shoreline position is presented for 2021 (winter) and 2020 (summer) in **Figure 54** (a) and (b), respectively. While spatial variability exists in the shoreline profile and some reversals occur along the domain, the main trend (pattern) of the shoreline position is analogous in both methods.



a. b.

Figure 54. Shoreline positions for image-based and survey-based. (a) is 2021 Aerial image and 2021 Winter survey; (b) is 2020 Aerial image and 2020 Summer survey.

Results indicated that overall, the 2021 winter survey shoreline (or 21w) is positioned approximately +12.5 feet seaward from the 2021 image-based shoreline (21i) with a reversal from this trend found in S1 (south of the inlet Figure 54a). 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, 21w is +15.55ft seaward from 21i on the north section, while 21w is +9.5 ft seaward from 21i on the south domain.

Results from the comparison of 2020 summer and 2020 image shorelines indicate that in general the 2020 summer survey shoreline (or 20s) is positioned +13.8 feet seaward from the 2020 image-based shoreline (20i) and with relatively two areas showing reversals from this trend both found in the S3 segment (Figure 54b). Separately, the North segment shows seaward positioning of the 0-contour line 20s) of +18.3 ft relative to the aerial image shoreline (20i), whereas on average on the South the 20s shoreline is +9.5 ft (seaward) from 20i.

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 55).

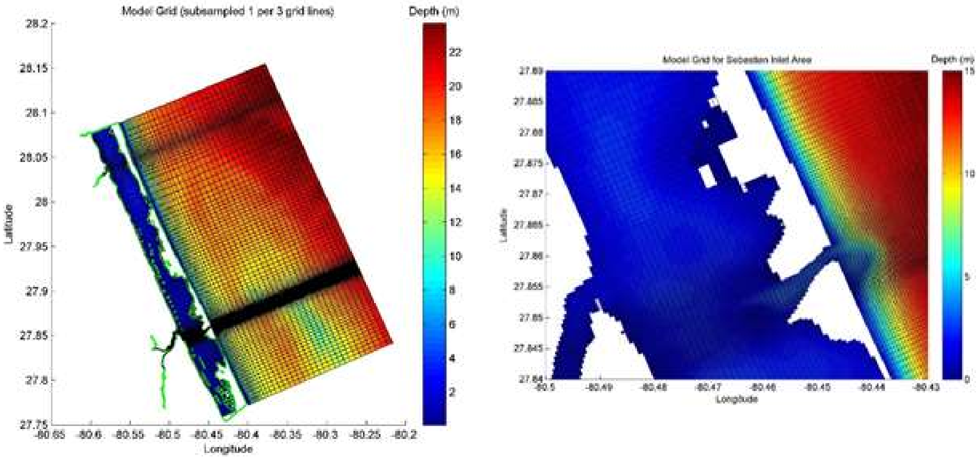


Figure 55. Left: Regional view of the Delft3D model grid. Right: Model detail in the vicinity of Sebastian Inlet.

The regional bathymetric data to populate the model computational grid shown in Figure 55 was 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 56 and Figure 57). 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 56). 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.

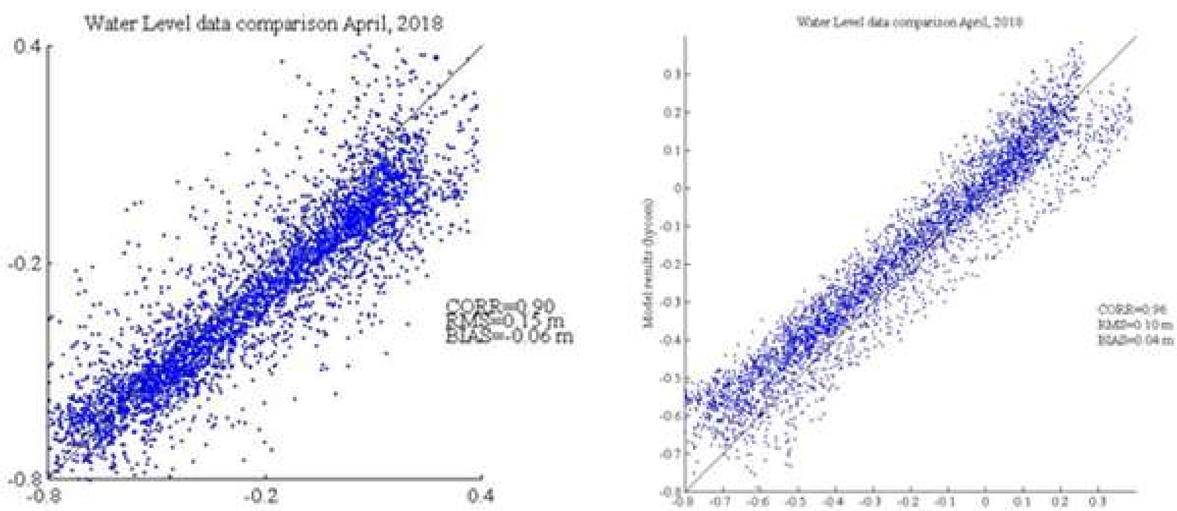


Figure 56. Left: Scattered plot of the model and observed water level with Chezy=80 at Sebastian Inlet in April 2018. Right: Similar plot for Chezy=65.

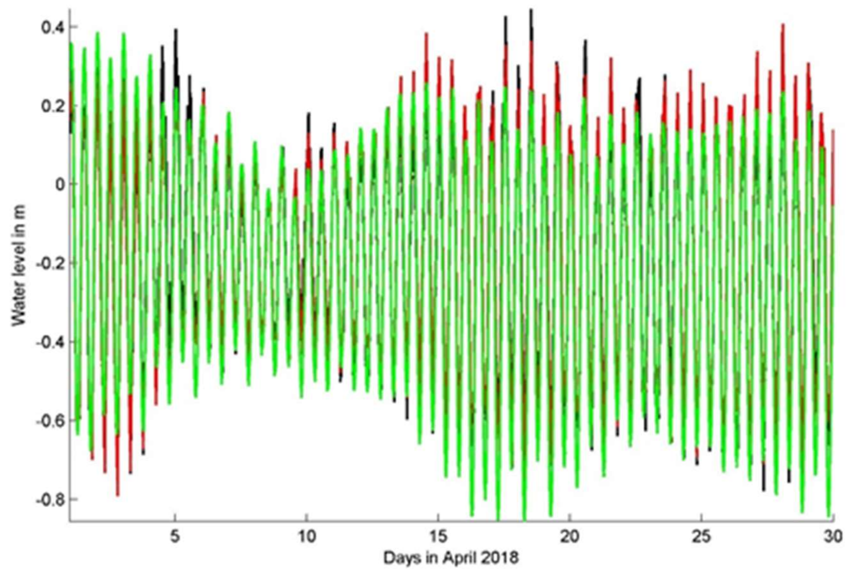


Figure 57. Time series of water level of the model run with Chezy parameter of 65 (redline), 80 (black line) and observed (green line) at the Sebastian Inlet station in April 2018.

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 58 and Figure 59). 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.

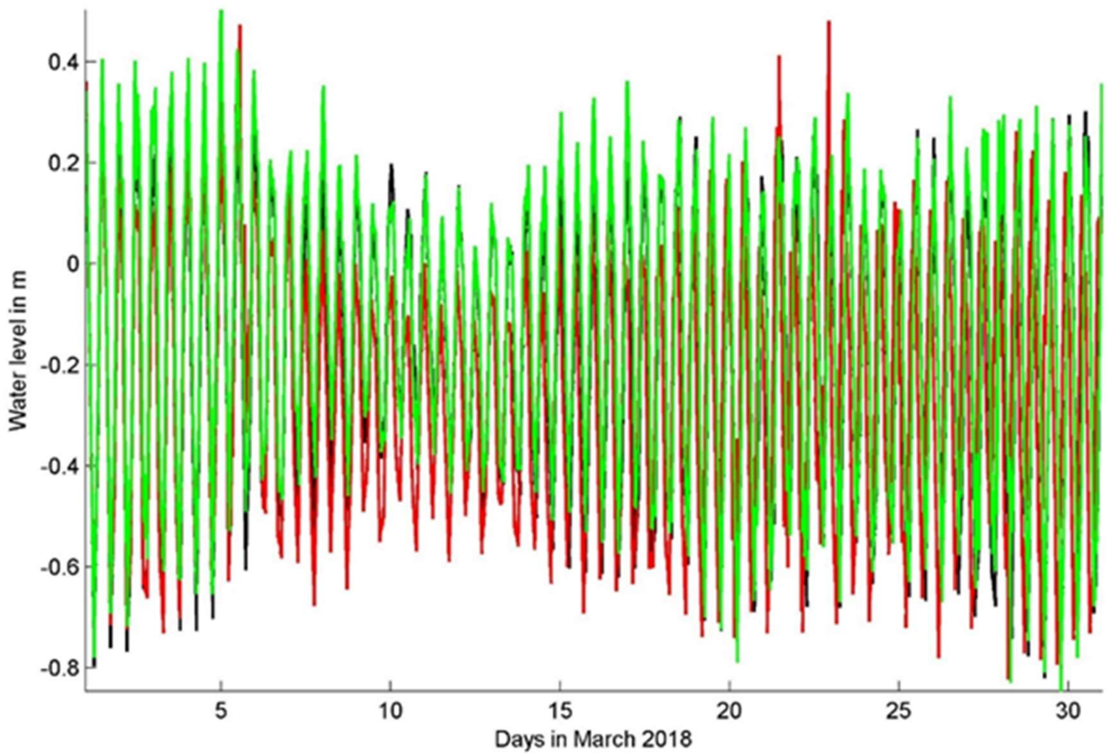


Figure 58. Time series of water level of the 5-layer modeled (red line), 10-layer modeled (black line), and the observed data (green line) at the Sebastian Inlet station in March 2018.

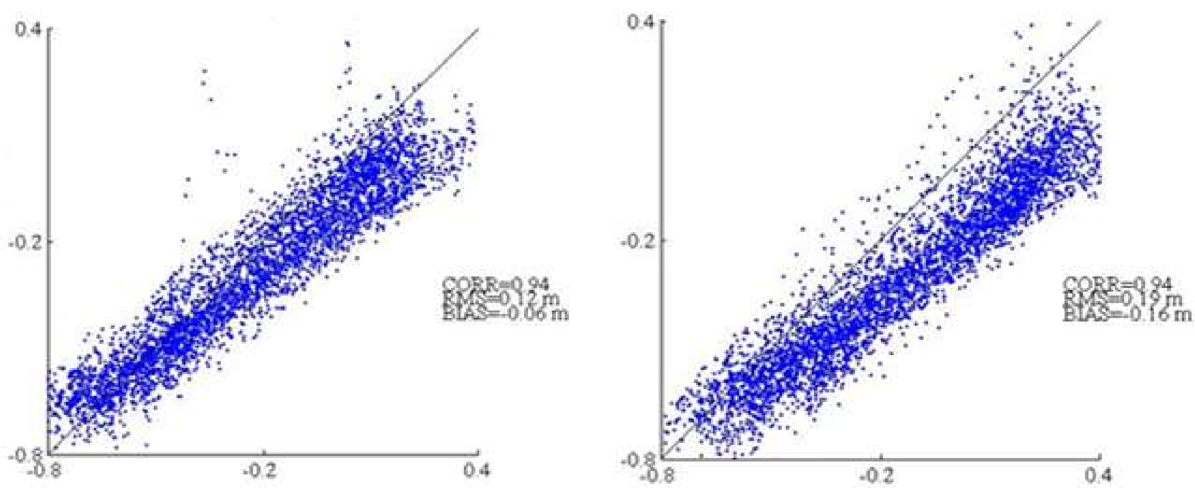


Figure 59. Left: Scattered plot of model and observed water levels at Sebastian Inlet for 5-layer model in February 2019. Right: Similar plot but for 10-layer model.

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 60). This is likely due to better representation of spatial pressure gradient driven by surface winds in 2-D experiments.

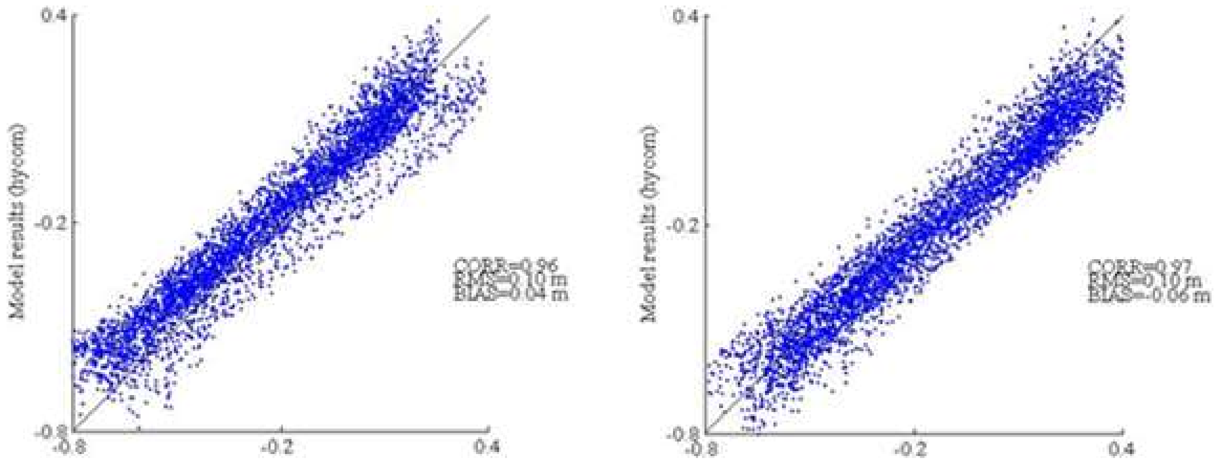


Figure 60. Left: Scatter plot of model and observed water levels with 1-D wind at Sebastian Inlet station in April 2019. Right: Similar plotting of the model with 2-D wind

7.3 Comparison of Model and Observed Significant Wave height

An important capability of the integrated wave and circulation models within the Delft3D model platform is to be able to provide reasonably accurate predictions of wave height. This is especially important at an inlet like Sebastian, which has a narrow and shallow navigation channel subsect to extreme wave-current interaction. Transiting Sebastian Inlet during strong ebbing flow interaction with incoming waves creates a navigation hazard, especially for small vessels. Figure 61 compares observed wave heights from the Sebastian Inlet real-time wave sensor with predicted eave height at the same location within the model computational grid. The model closely follows the trend of increasing and decreasing wave height. For some periods significant wave heights ae slightly over predicted and for other periods model predictions are very close to the measured data.

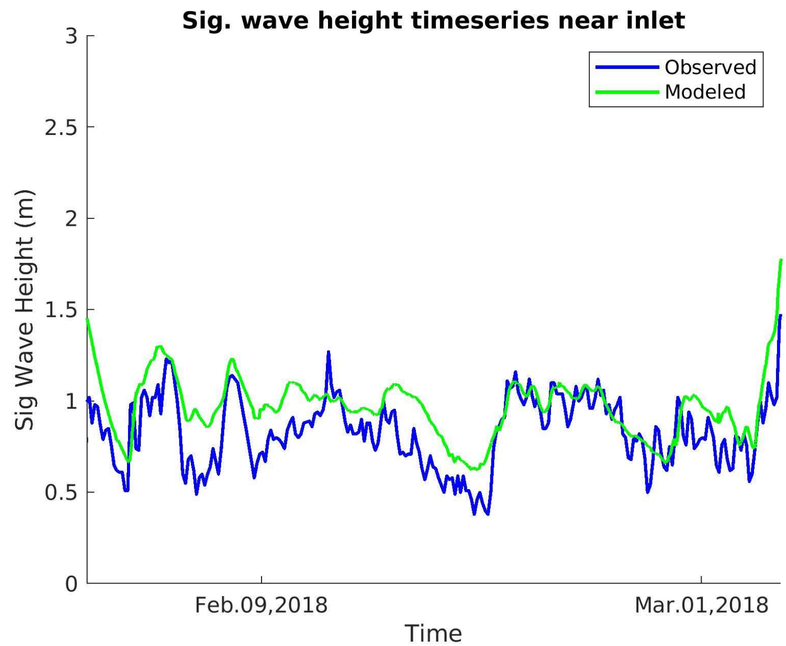


Figure 61. Comparison of model and observed significant wave heights at Sebastian Inlet

7.4 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).

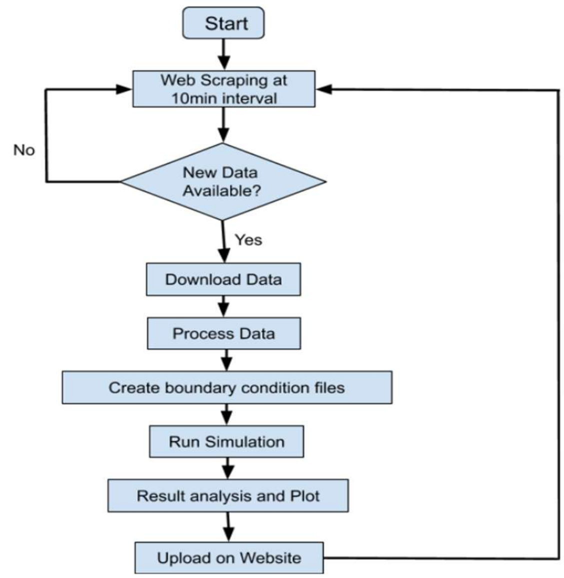


Figure 62. Flow chart of the algorithm for automation.

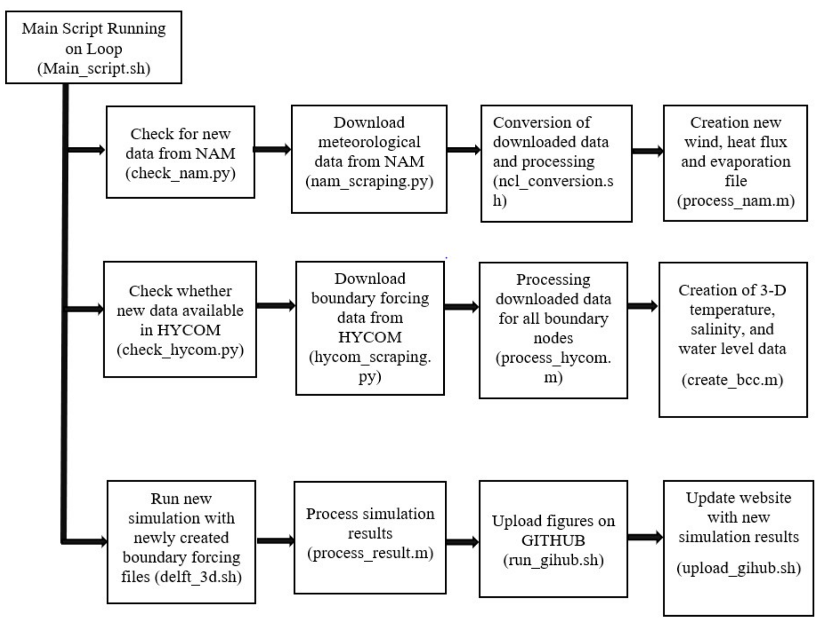


Figure 63. Flow chart of automation scripting processes

7.5 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.

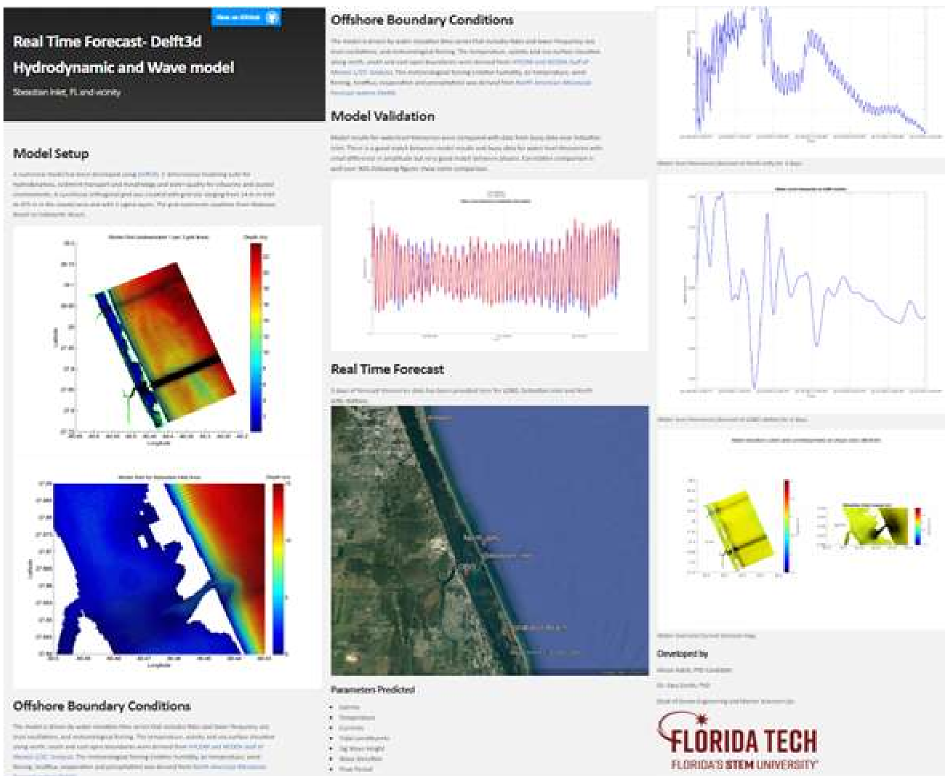


Figure 64. Snapshots of the Delft3D forecast model webpage.

7.6 Examples of Delft3D model simulations at Sebastian Inlet

Figure 65 shows the predicted significant wave height time series at the entrance of Sebastian Inlet over the first 4 days of April 2022. The Delft3D forecast is comparable to the Sebastian Inlet marine forecast from NOAA.

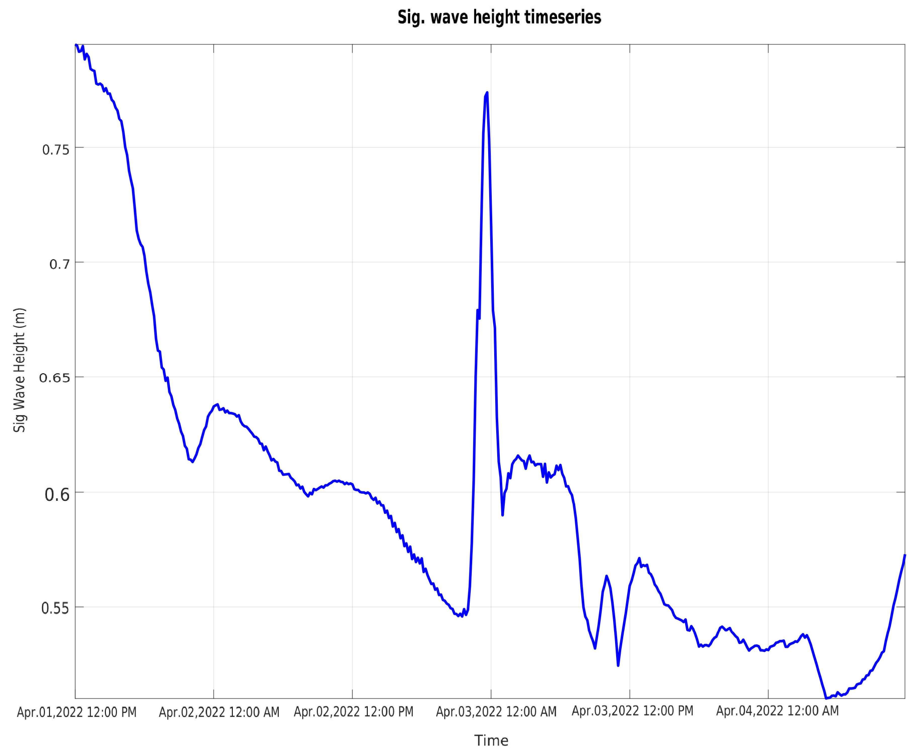


Figure 65. Model wave forecast for April 1 though April 4, 2022

Figure 66 compares predicted inner coastal ocean water levels at the entrance of Sebastian Inlet (A), at Indialantic Beach to the north of Sebastian Inlet (B) and Wabasso Beach south of the inlet (C). The time series cover most of the 2021 period. Panel D of Figure 66 shows the predicted water levels within the Indian River Lagoon adjacent to Sebastian Inlet. The ocean water level time series are dominated by tides, whereas the interior water level time series is displays more of the lower frequency coastal sea level changes that are typical of any year due to seasonal changes in Gulf Stream flow. Much of the tidal amplitude is damped as tidal flows enter the narrow and shallow Sebastian Inlet.

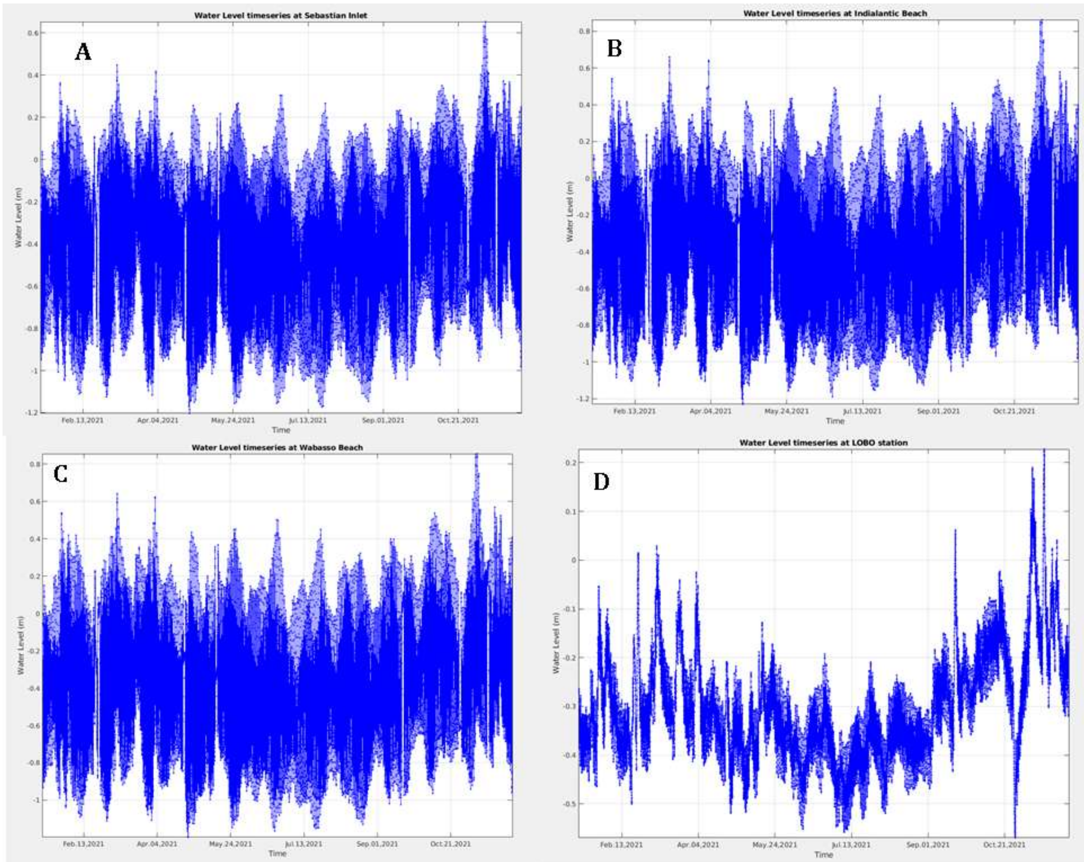


Figure 66. Model forecast of tide dominated coastal ocean water levels at Sebastian Inlet (A), Indialantic beach (B), Wabasso Beach (C), and water levels of limited tidal regime within the Indian River Lagoon adjacent to Sebastian Inlet.

Figure 67 plots predicted water level and flow velocity within the throat section of Sebastian Inlet between April 2 and April 5, 2011. The time series shows that the semidiurnal tidal range is between about 1.0 and 1.2 meters. The corresponding predicted flow velocity reaches as maximum of about 1.5 m/s on the flooding tide to the east represented by positive flow values and a maximum of about 1.0 to 1.3 m/s during the ebbing tide depicted by negative flow values.

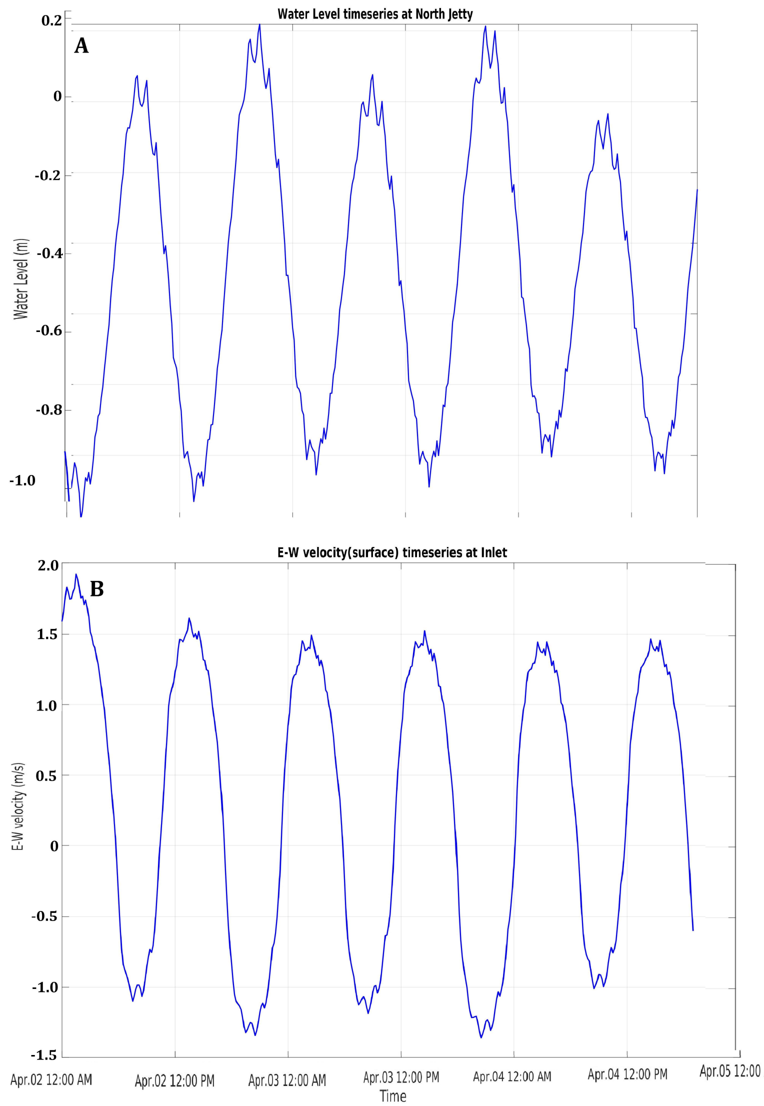


Figure 67. Predicted water levels (A) and predicted surface current velocity at the North jetty of Sebastian Inlet for the April 2 to April5 period.

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 associated with the sand budget analysis, 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 2007 and 2021 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 2011 through 2017 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 2006 and 2021, 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 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 four-time scales, including a longer time scale of 14 and 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 14 and 10 years since it integrates over seasonal sand volume changes that mask longer term trends.

- Over the time period of 2007-2021, 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
- Based on topographic change patterns the Sebastian Inlet Ebb Shoal is serving as a local sand source similar to a river delta-front sand bodies adding sand to adjacent beach and shoreface environments.
- A recommendation to benefit the Sebastian Inlet Management District is to future refine the regional sediment budget into combined beach and shoreface budget cells and offshore shelf sediment budget cells to better resolve cross-shore sand transport and evaluate potential sand losses and gains to and from the inner continental shelf
- 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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