STATE OF SEBASTIAN INLET REPORT: 2023

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

by

Gary A. Zarillo, Ahsan Habib,
Jo-Ann Rosario-Llantín

Department of Ocean Engineering and Marine Sciences

Florida Institute of Technology

Melbourne Florida

May 2023

Executive Summary

The 2022 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 2022. 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 2022 revealed two important processes. First, it 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 three time scales, including a longer time scales of 15 and 10 years and a time scale of 2 to 3 years to demonstrate the ability of the coastal sand reservoir to respond to rapid and abrupt sea level fluctuations.
Over the time period of 2006 to 2022, 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 abrupt and short periods of rising and falling sea level are apparent in short terms sediment budgets calculated for the 2010-2012 period of rising sea level and the 2015-2018 falling sea level period.

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 2022, 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. Deep learning methods (DLM) also known as machine learning are applied to the Sebastian area model as method to provide model boundary conditions when measured or other model data are temporarily or permanently unavailable.

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 2021 report through the late summer months and fall of 2022. Since the original analysis documented in the 2007 report, sand volume changes, sand budget, and morphological changes have been updated through 2022. Shoreline changes between 1958 and 2007 were documented in the 2007 using aerial images and between 1990 and 2007 using field survey data. The 2013 State-of-the-Inlet Report, was expanded to provide an historical update of Sebastian Inlet and included a series of appendices updating the original 2007 analysis, as well as a description of ongoing numerical modeling experiments explaining the hydro- and sediment dynamics of Sebastian Inlet. The 2013 report documents present a longer term view of Sebastian Inlet's evolution and associated management strategies that have been applied over the years. The more recent reports from 2016 thought 2021 reports emphasize the sand volume calculations and sediments budgets of the Sebastian inlet area. In the present report emphasis is on describing sand volume changes and related sediment budget calculations. A more detailed sediment budget template is developed consisting of beach and upper shoreface sediment budget cells and lower shoreface to inner continual shelf cells. The morphological analysis, sand budget analysis and the shoreline analysis are updated to 2022 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. In this section of the 2022 Inlet report, details of sand volume exchanges around the inlet are provided in more detail quantify sand budget calculations

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 and beaches.

A review of the sand volume changes within Sebastian Inlet shoals and sand budget cells over a 16-year period is used to annualize the sand budget in the inlet region. Sand budgets are presented as annualized terms but calculated over intermediate to longer term time periods. A new aspect in this report is calculations of shorter term sediment budgets within the longer term calculations to document the response of rapid coastal to sea level fluctuations that are a feature of the Florida coast (Zarillo, 2023).

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 District (SID) 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 1 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 1000 ft. Since 2011, survey methods have included multi-beam swath bathymetry 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 and fall of 2022.

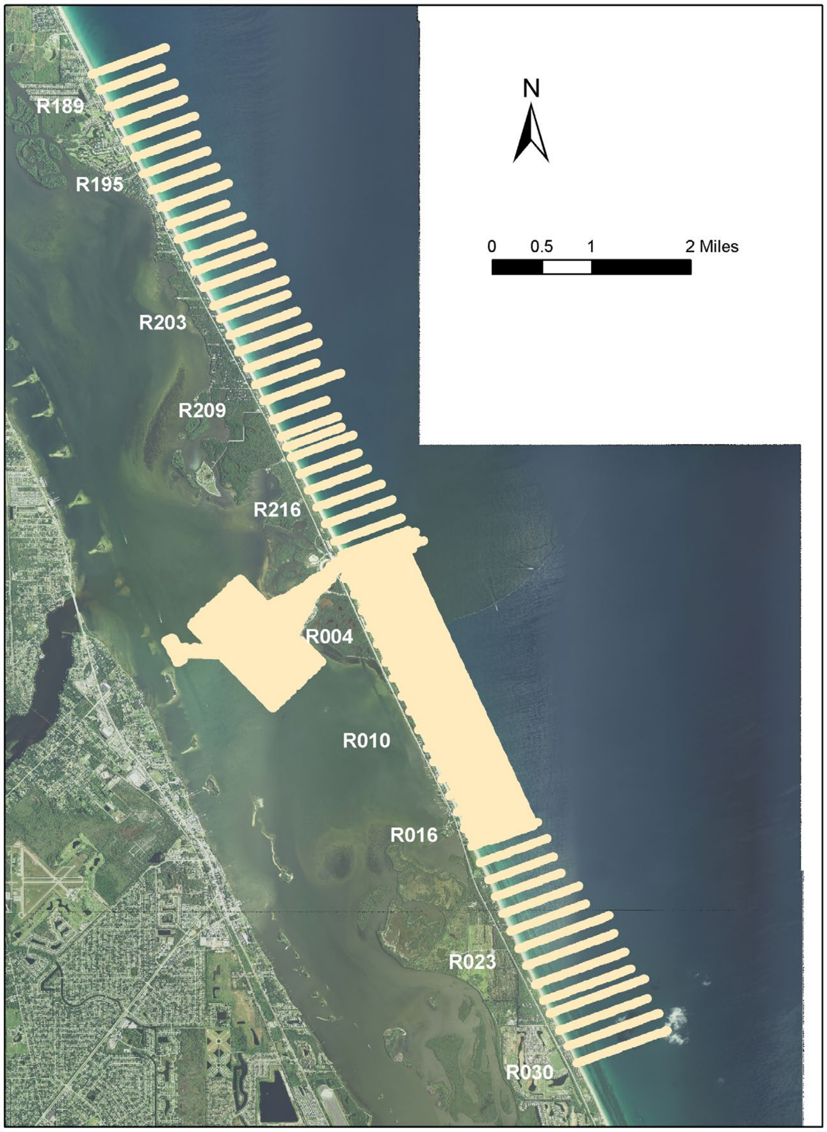


Figure 1. Typical Extent of hydrographic survey (2019 winter).

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
Winter 2022*	x	x	x	x	x	30,000	30,000
Summer-Fall 22*	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 2 shows the sand budget cells used to calculate the changes in sediment volume associated with alongshore littoral transport and cross-shore sediment exchanges between the upper and lower shoreface. 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 -40 feet, NAVD88

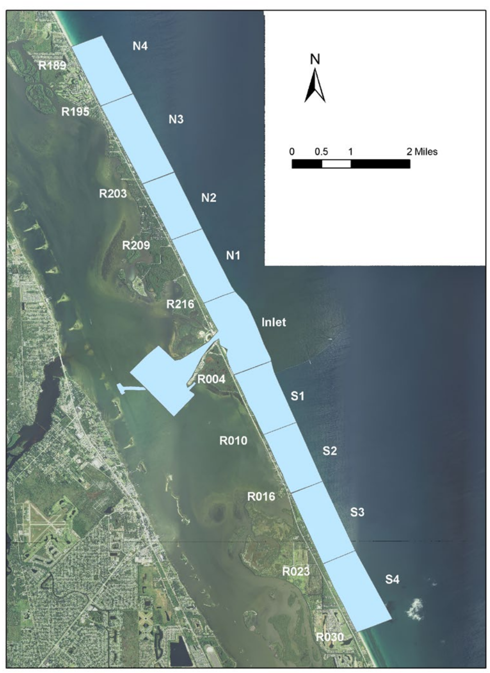


Figure 2. Sand budget cells.

As of this report further subdivisions are included within the budget cells shown in Figure 2 to consider sediment exchanges between the beach and upper shoreface and the lower shoreface and inner continental shelf. These subdivisions and shown in Figure 3 along with labels identifying the cell designation and the location of the Sebastian Inlet sand trap

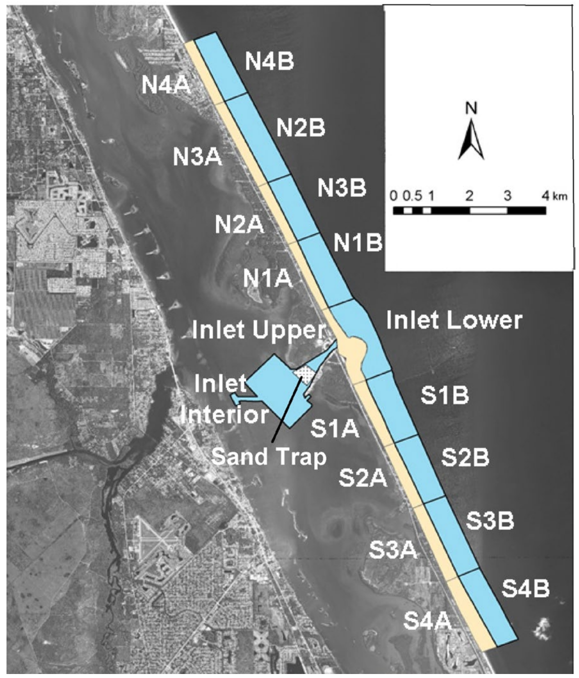


Figure 3. Upper and lower divisions of the sediment budget cells.

Within the immediate area of Sebastian Inlet further subdivisions are made to characterize sand reservoirs that exchange sand under a combination of strong tidal currents and wave action. 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 166,220 cubic yards of material was dredged from the sand trap of which 113, 500 cubic yards were placed and graded on the beaches to the south of inlet between Indian River County R-Markers R10 and R17.   Approximately 52,700 cubic yards of additional dredged material, balance of the sand trap and navigation channel volumes, were placed in the

Sebastian Inlet dredge material management area (DMMA). In 2021, approximately 60,000 cubic yards of sand was trucked from the DMMA and placed on the beach between R-9 and R-17.   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.

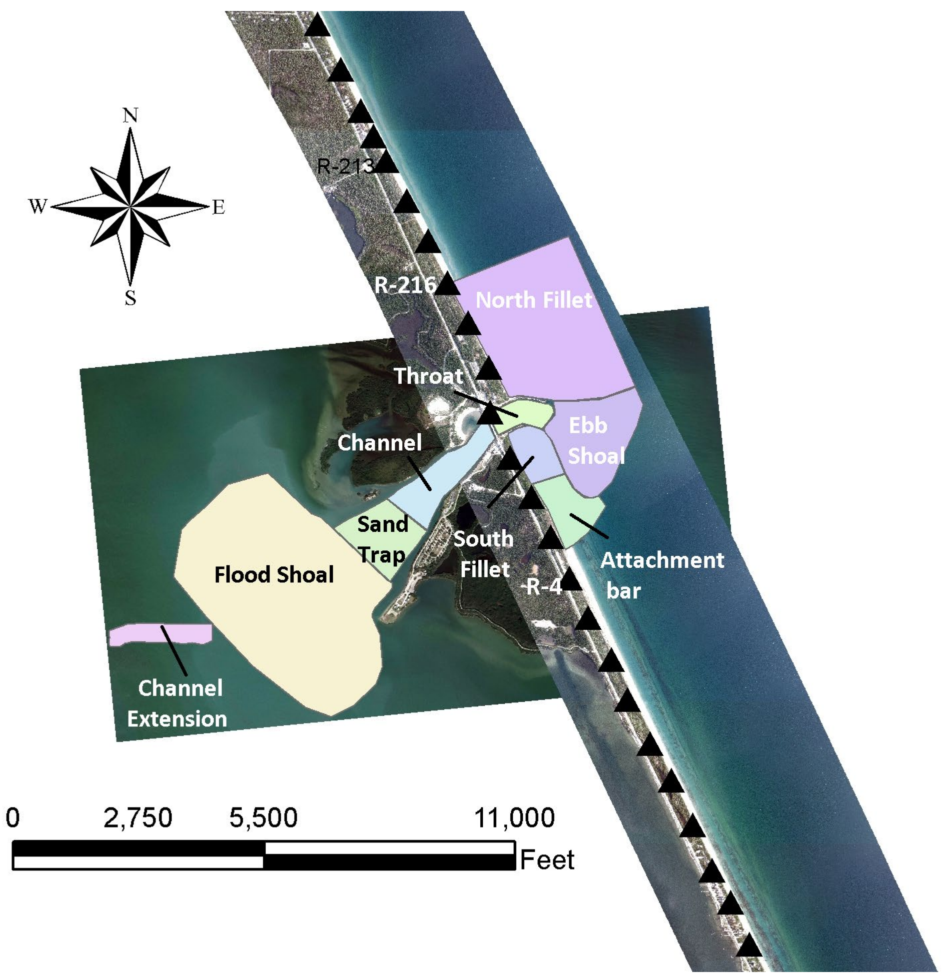


Figure 4. Morphologic features forming the inlet sand reservoirs.

2.2 Sebastian Inlet sand reservoir volume analysis

The sand reservoirs are contained within the inlet sand budget cell (Figure 2 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 consolidated inlet littoral cells, which are then sub-divided into upper and lower shoreface cells (Figure 3) 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 2022 is illustrated in Figure 5. Integrated seasonal volume changes over time provide a net volume change and visualization of trends. Seasonal 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 summer and fall survey of 2022. Over this period the ebb shoal volume varied over a range of about 50,000 cubic yards. As seen 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. A comparison of the cumulative sand volume changes in the ebb and flood shoal is shown in Figure 6. Volume changes are not highly correlated between these two sand reservoirs, but the longer term volume trends are opposite. The ebb shoal volume has increased in 2005, punctuated by shorter variations of up to 50,000 cubic yards. In contrast the total volume of the flood shoal has declined by about 125,000 cubic yards since 2007, but subject to shorter term variations of 100,000 cubic yards or more. Larger variations in ebb shoal volume are directly linked to dredging of the Sebastian Inlet sand trap. Each sand trap excavation temporarily disrupts of the sediment balance within the interior of the inlet resulting in a temporary sharp decline in flood shoal volume. 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.

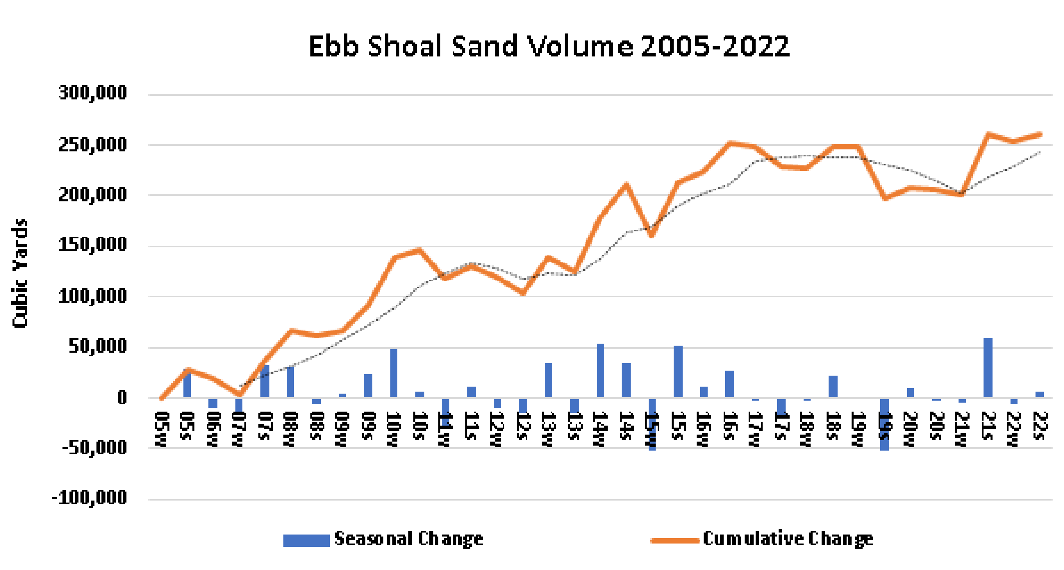


Figure 5. Volumetric evolution of the ebb shoal from summer 2005 to summer 2022.

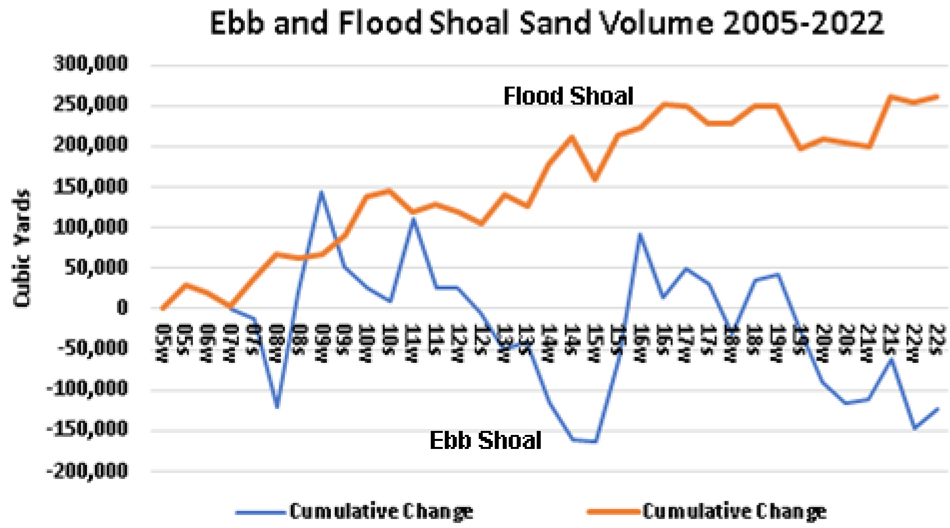


Figure 6. Cumulative sand volume changes of the Sebastian Inlet ebb shoal and flood shoal

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 7, 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.

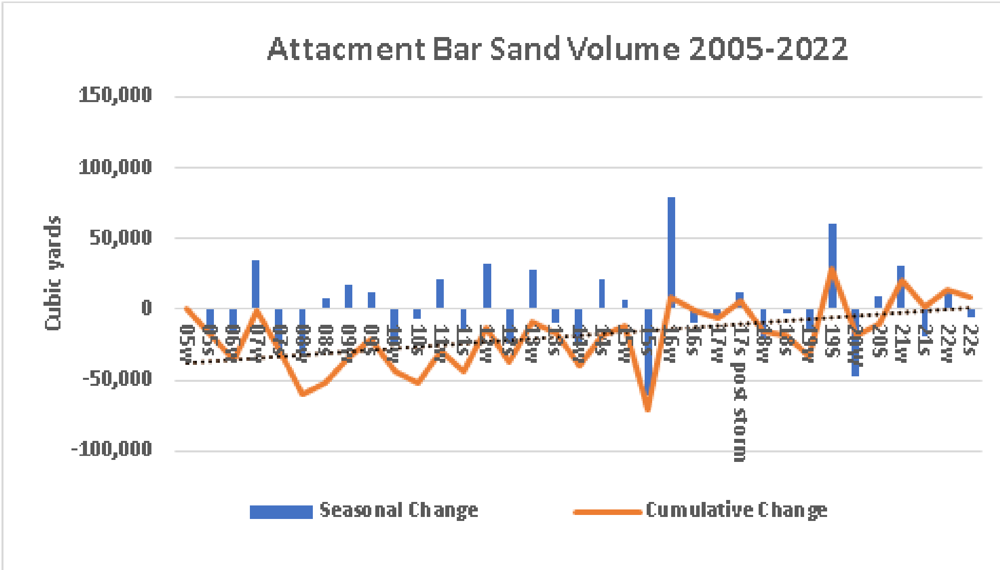


Figure 7. Volumetric evolution of the attachment bar from summer 2005 to winter 2022.

The volumetric evolution of the sand trap is presented in Figure 8. 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 8 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 63,000 cubic yards of new sediment most of which was deposited between summer of 2020 and winter survey of 2021 (Figure 8.)

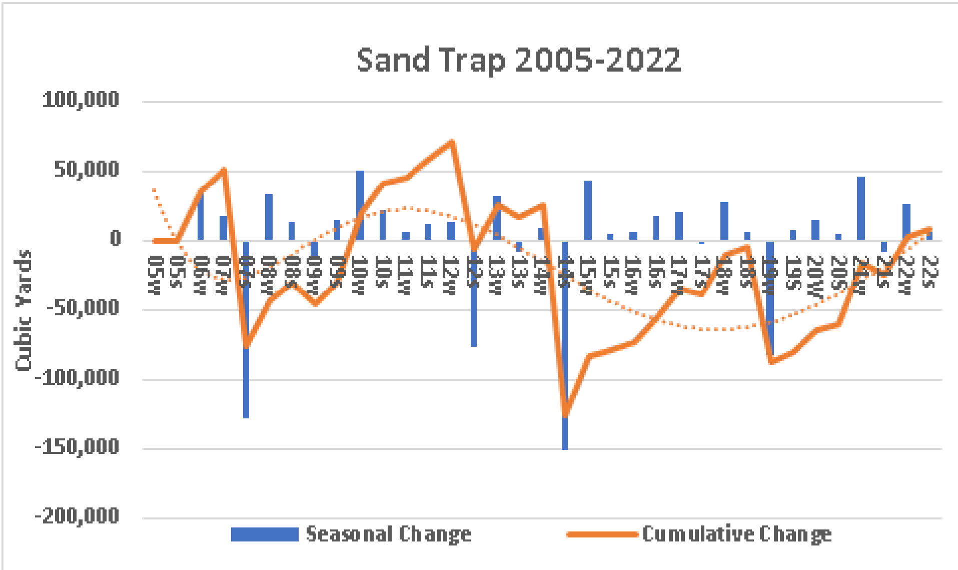


Figure 8. Volumetric evolution of the sand trap from winter 2005 to winter 2022.

Changes in flood shoal volume (Figure 9) 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 9. 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 losses exceeding 100,000 cubic yards through the summer of 2021   The sand volume loss beginning in 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

As of the summer/fall survey of 2022 the flood shoal volume reached a minimum and recovered about 10,000 cubic (Figure 9). Net volume change of the flood shoal in the 16-year period since 2006 is an approximate a loss of up to 150,000 cubic yards. Intra-annual sand volume fluctuations of 50,000 to 100,000 cubic yards can occur in any year.

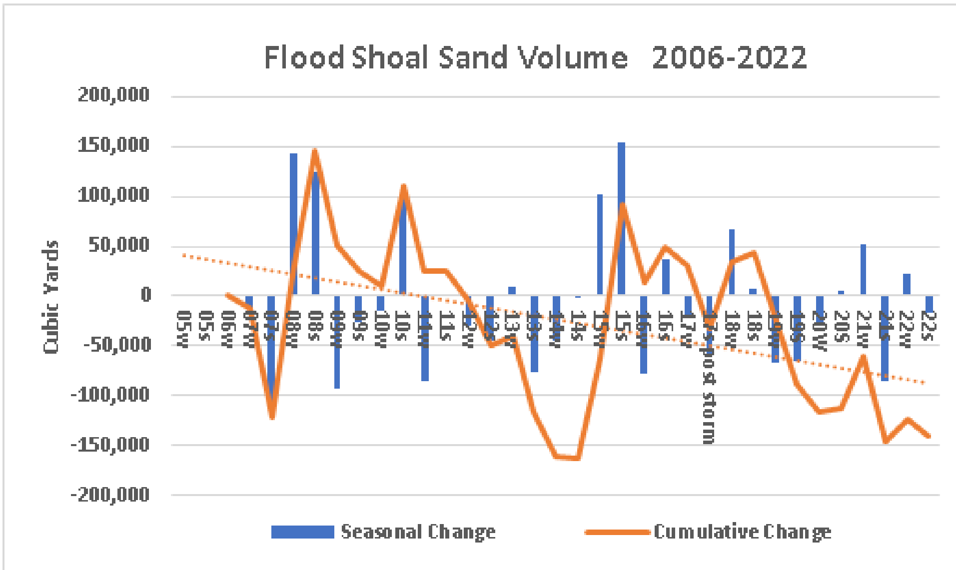


Figure 9. Volumetric evolution of the flood shoal from winter 2006 to winter 2022.

The record of changes in sand volume in the channel extension to the Intracoastal Waterway is shown in Figure 10. 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. Like 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 summer 2019 is linked to dredging of the channel extension during the 2019 sand trap bypass project. Between summer 2019 and summer 2021, the channel extension had a net gained about 13,000 cubic yards of sediment (Figure 10). Since 2021 the sediment volume in the channel extension has decline by about 10,000 cubic yards. This period of sediment volume decline is like that of the flood shoal and inverse of the ebb shoal volume pattern.

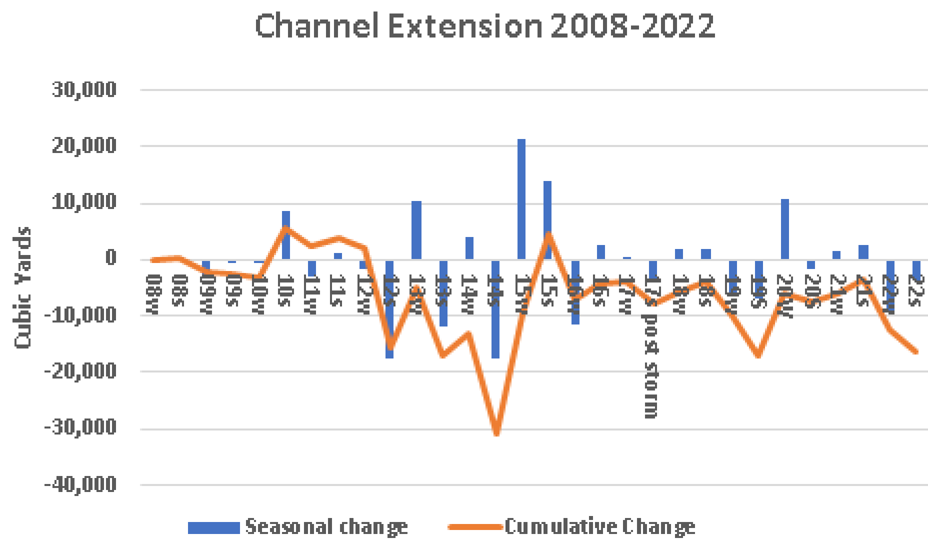


Figure 10. Volumetric evolution of the channel from winter 2008 to winter 2022.

2.3 Sand budget cells

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 2 and 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. This cell is further subdivided into upper and lower inlet components and an interior inlet component as shown in Figure 3. The interior cell also includes the Sebastian Inlet sand trap (Figure 3). Annualized volume changes (ΔV) for each cell are calculated over different time periods and 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 including upper beach/shoreface and lower shoreface components (Figure 3) are shown in Figure 11 through Figure 18, ranging from the northernmost to the southernmost cells. Under Section 3 of this report volume changes in the upper beach/shoreface and lower shoreface components of these cells are used to calculated sediment budgets over a different time periods.

Volume changes in the N4 cell (R189 and R195, Figure 11) indicate a net sand volume loss of about -340,000 cubic yards from 2006 to 2022, most of which is accounted for by volumes losses since the summer of 2017 after Hurricane Irma impacted Florida. A 100,000 cubic yard rebound occurred between summer 2021 and winter 2022, followed by 150,000 cubic yard loss in late 2022 possibly due to Hurricanes Ian and Nicole that 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.

Volume changes in the N3 cell, (R195 - R203, Figure 2), are shown in Figure 12. Like 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 dominated in both the N4 and N3 cells except for a 200,000 cubic yard gain observed between the winter and summer surveys of 201. Between the summer survey of 2018 and winter survey of 2021 sand volume declined by about 250,000 cubic yards in N3 in a pattern like that of N4. Net sand volume losses in N3 since 2006 are about 230,000 cubic yards

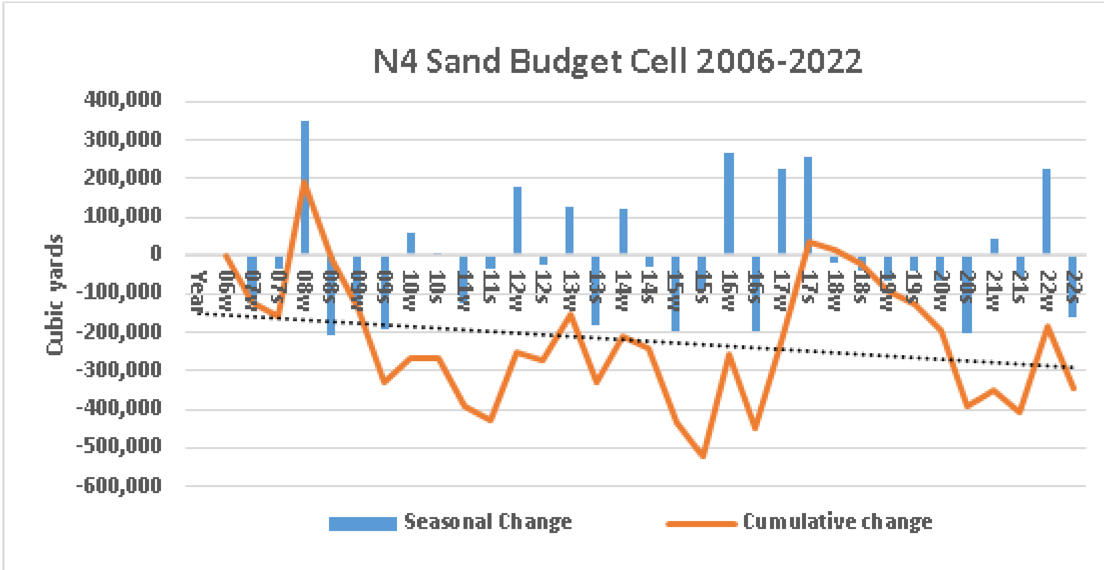


Figure 11. Volumetric evolution of the N4 sand budget cell 2006-2022

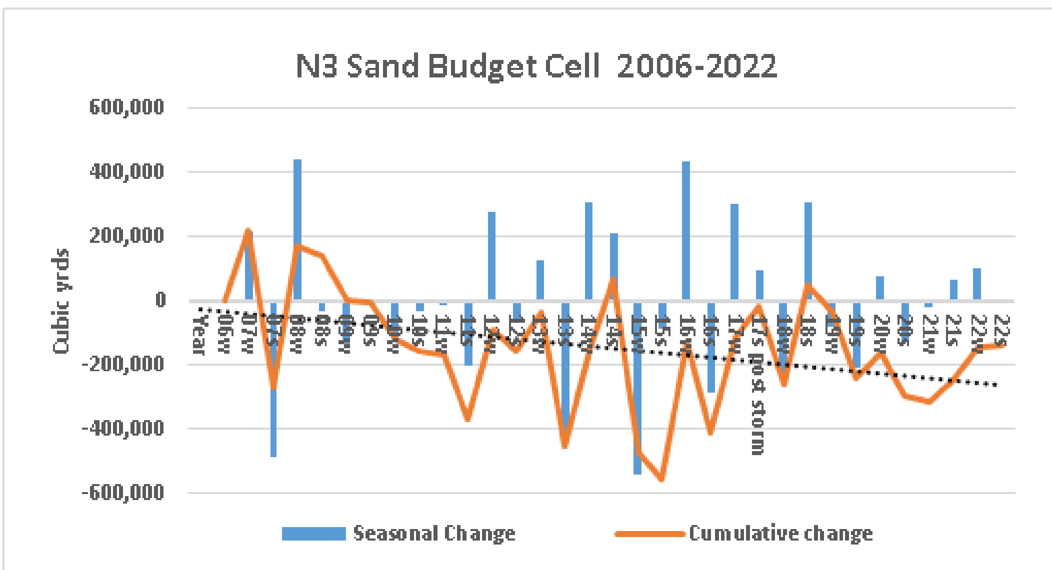


Figure 12.Volumetric evolution of the N3 sand budget cell 2006-2022.

Seasonal volume changes found in the N2 sand budget cell (Figure 13) 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 winter survey of 2022. A gain of nearly 200,000 cubic yards occurred between winter and the summer/fall survey of 2022. This gain resulted in a 16-year net volume change of near zero.

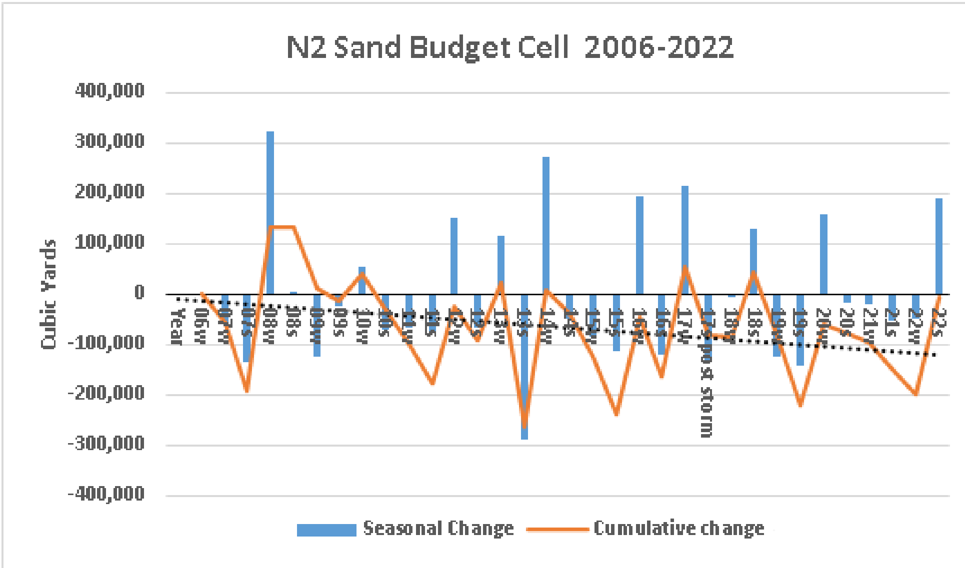


Figure 13. Volumetric evolution of the N2 sand budget cell 2006-2022.

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. Like the N2 budget cell to the north, net volume change in the N1 cell consisted of a small loss of about 180,000 cubic yards between 2006 to 2022.

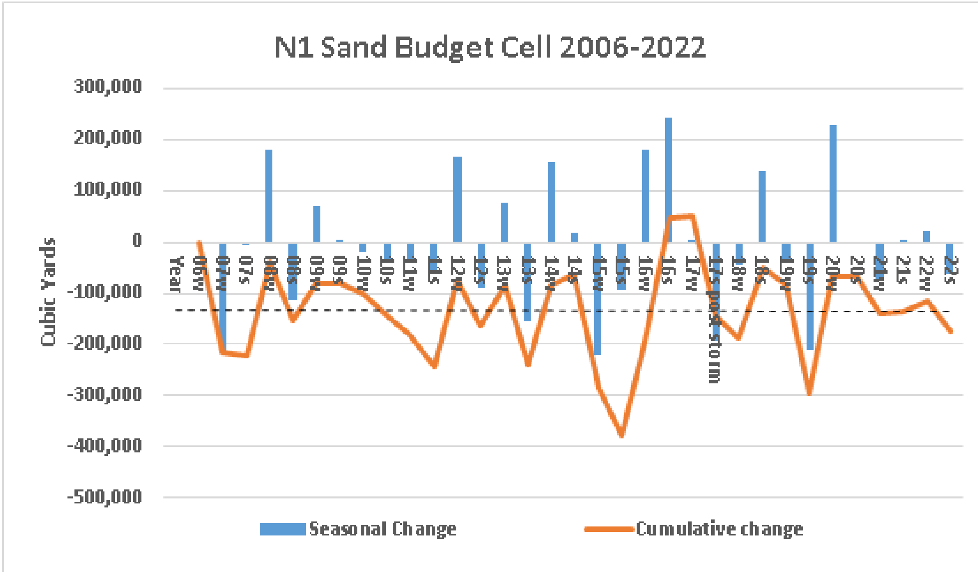


Figure 14. Volumetric evolution of the N1 sand budget cell 2006-2022.

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 11 to Figure 14, increase to the north with distance from Sebastian inlet

Volume changes for the inlet sand budget cell (Figure 2, Figure 15) are a combination of volume changes in the ebb and flood shoals, as well as the sand trap and main inlet channel (conveyance channel). 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 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 independent of the sand trap excavation, but linked to accumulations of sand volume from the south directed littoral drift.

Over the past 16 years, net change in sand volume in this cell is a gain of about 400,000 cubic yards and has been as large as nearly 600,000 cubic yards as recorded in the summer survey of 2018 (Figure 15). However, since 2018 the sand volume in the flood shoal has decreased by about 200,000 cubic yards balancing some of sand volume accumulations of about 400,000 cubic yards between 2013 and 2018. The interaction among the various sand reservoir components included in the overall inlet sand budget cells is further explained under Section 3 of this report dealing with sediment budget calculations. Sediment budget calculations consider the balance among the interior, upper inlet and lower inlet sand budget cells as shown in Figure 3

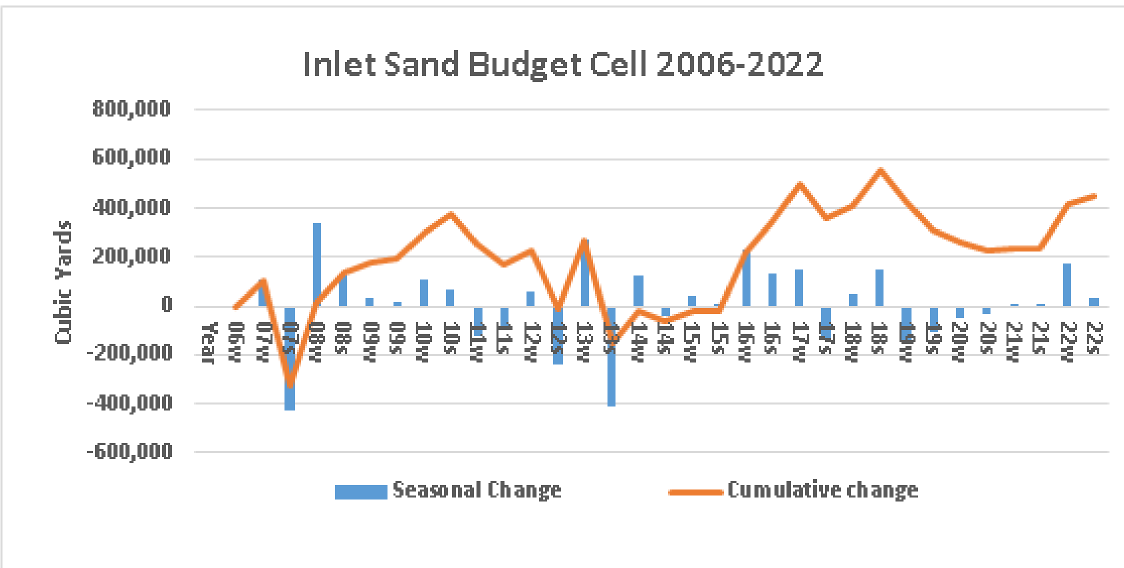


Figure 15. Volumetric evolution of the inlet sand budget cell 2006-2022.

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 continues volume loss in the flood 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 since 2018 as seen in Figure 16.

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

The volumetric evolution of the S1 cell, situated between R4 and R10 immediately south of the inlet cell, is shown in Figure 16. 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. A portion of this pattern is due to sand placement from the sand trap. 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 19. Losses during this period from S2 and S3 also were passed to the S4 cell (Figure 17 and Figure 18). 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 13 and Figure 14) and to some extend in the S2 and S3 cells to the south (Figure 17 and Figure 18). Seasonal sand volume changes in S1 since the winter survey of 2020 have been less than 100,000 cubic yards until the summer/fall survey of 2022 in which a sand volume gain of about 190,000 cubic yards was recorded. The source of this volume is likely a combination of bypassing across Sebastian Inlet of sand eroded from the N1 cell (Figure 14), volume loss from the flood shoal (Figure 9) and potentially onshore movement of sand from the effects of log period, but low waves along the east coast of Florida produced by Hurricane Ian. After the 2022 sand volume gain net volume change in the S1 cell from 2006 to 2022 is about 200,000 cubic yards as seen in Figure 16.

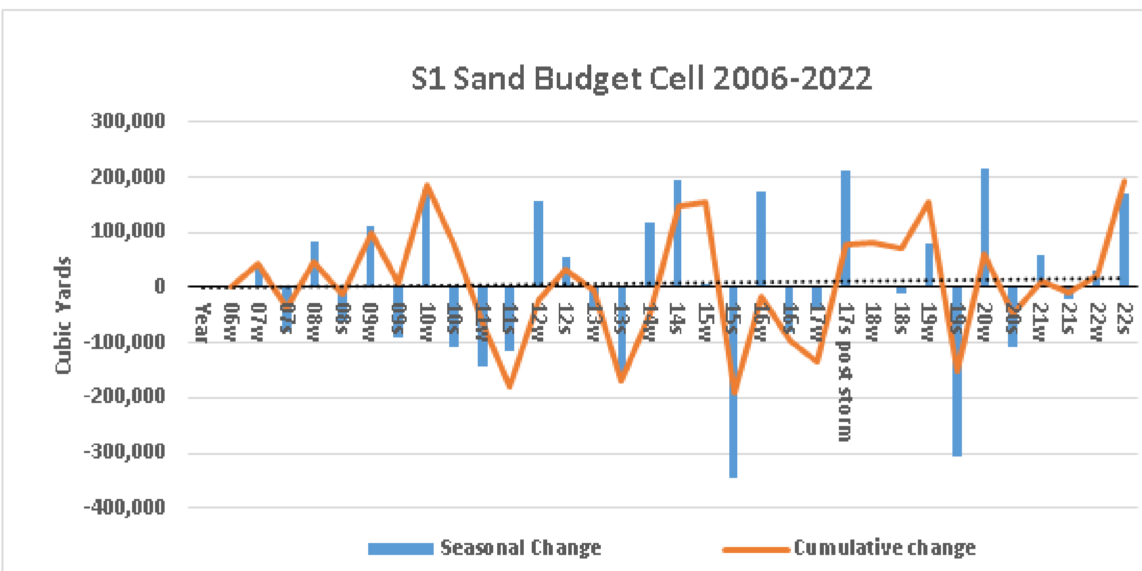


Figure 16. Volumetric evolution of the S1 sand budget cell 2006-2022

Sand volume changes in the S2 cell (Figure 17, R-10 – R16) are a combination of regional and littoral drift gains and sand placement by SID and Indian River County (IRC). . 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 380,000 cubic 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 100,000 cubic yards occurred included a seasonal losses of about 50,000 to 100,00 cubic yards and smaller gains of about 20,000 cubic yards. Over the 16-year period between 2006 and 2022, the volume change in the S2 cell was a net loss of about 230,000 cubic yards.

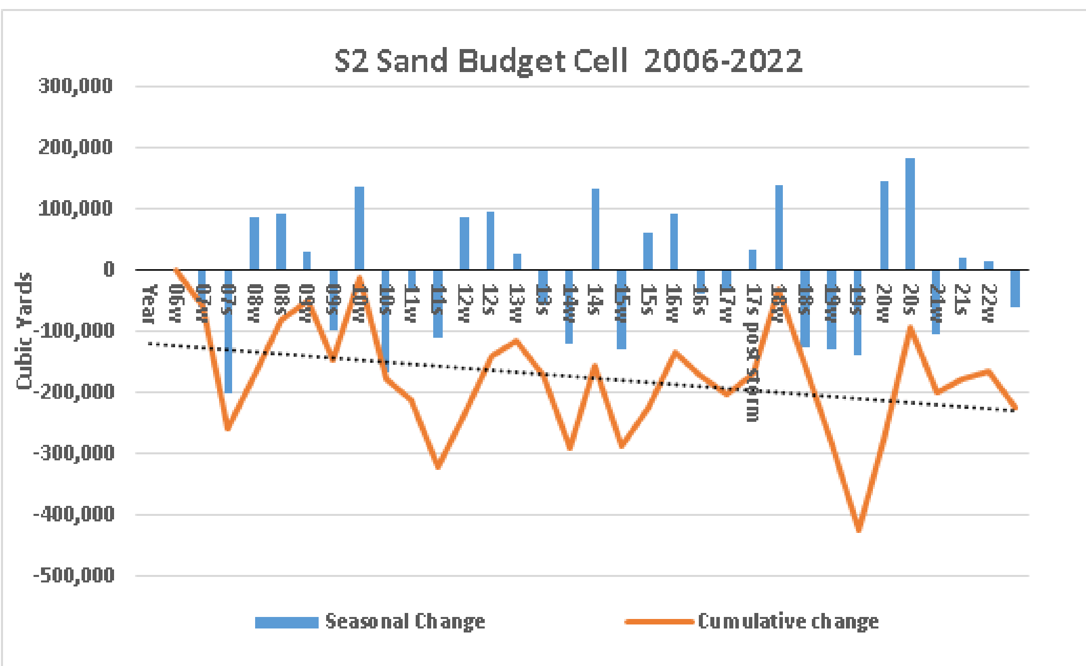


Figure 17. Volumetric evolution of the S2 sand budget cell 2006-2022.

Sand volume changes in the S3 cell (Figure 18) 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 and 2020 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 winter 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. 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 the winter 2020 survey. As suggested for 2020 volume gains in the S2 cell, 2020 gains in S3 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/fall 2022 surveys included a net decline of about 150,000 cubic yards including balancing seasonal fluctuations of more than 200,000 cubic yards. Net volume change in this cell between 2006 and 2022 is approximately a loss of 430,000 cubic yards.

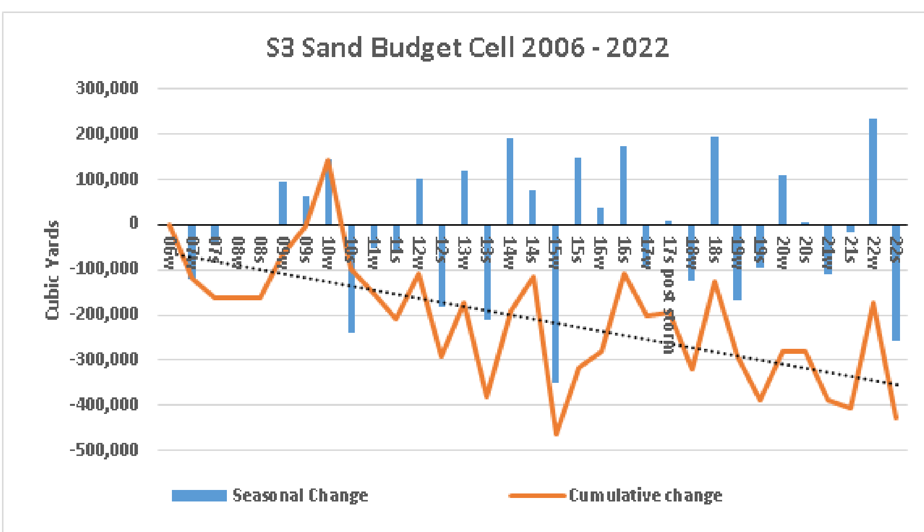


Figure 18. Volumetric evolution of the S3 sand budget cell 2006-2022.

The S4 sand budget cell (Figure 17, located between R23 and R30 (Figure 2) like S3, has an imbalance between seasonal gains and losses that add up to a net cumulative volume loss of about 556.00 cubic yards between 2006 and 2022. 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, 2016, 2018 in some cases 2020 are not apparent S4. Seasonal offsets between S4 and sand budget cells to the north indicate the role of sand movement in the littoral drift system.

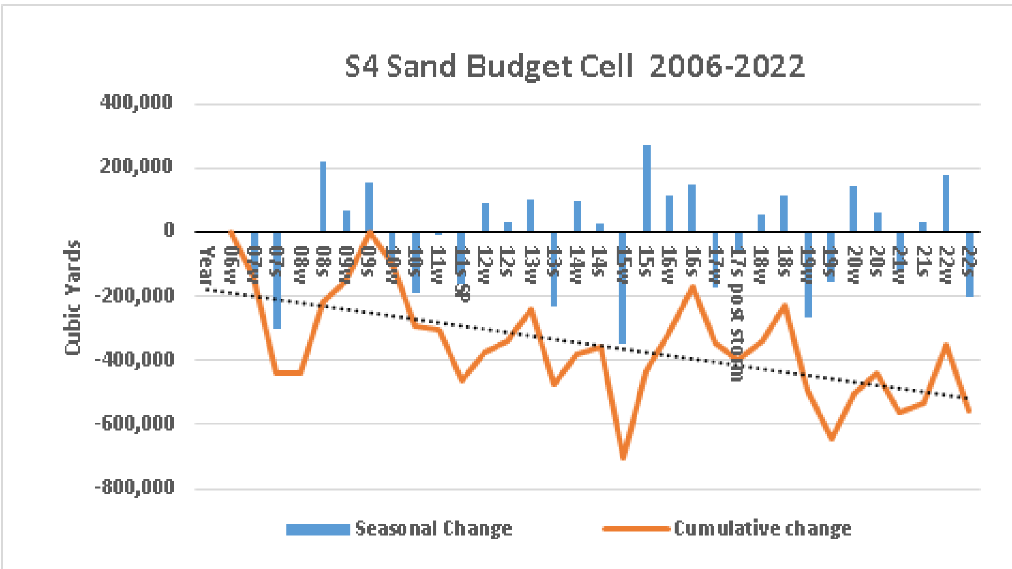


Figure 19. Volumetric evolution of the S4 sand budget cell 2006-2022.

2.4 Analysis of Sand volume changes, 2006 – 2022

To view trends among of the sediment budget cells Figure 20 compares sand volume changes in sediment budget cells on the north side of Sebastian Inlet (N4 – N1) along with the inlet sediment budget cell. 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 11 though Figure 14. This amounts to a moving average over an 18-month period though the 2006 to 2022 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 20). In sand the N4 through N2 sand budget cells the sand volume declines reverse to volume gains though summer 2019 followed by sand volume declines in 2020 through the winter survey of 2021 . 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 2020. This trends reverse in the winter 2021 survey followed by continued volume declines into 2022. However, as seen in Figure 14 the linear trend of sand volume change between 2006 and 2022 is flat and net sand loses are lower compared to N4 to N2 cells

Figure 21 compares sand volume changes among sand budget cells on the south side of Sebastian Inlet (S1 – S4). Trend patterns on the south side of Sebastian 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 net volume losses are more than 300,000 cubic yards over the 16-year period of record. In sand budget cell S2, where much of the sand trap material 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 bypassing from the sand trap.

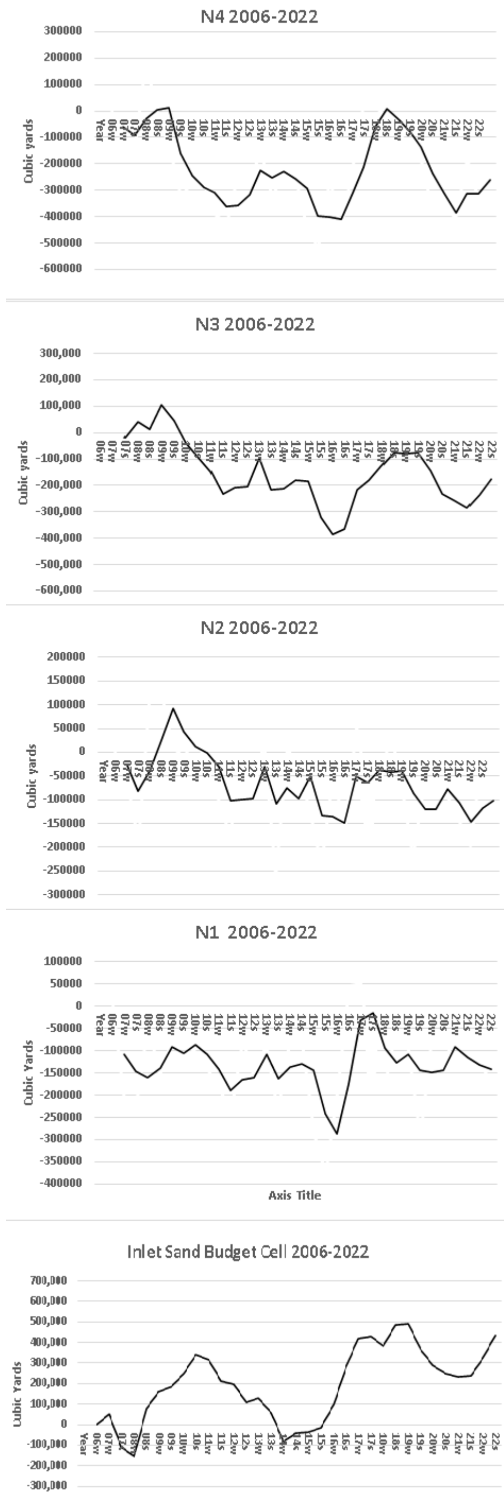


Figure 20. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells N4 to N1 and in the inlet budget cell from 2006 to 2022.

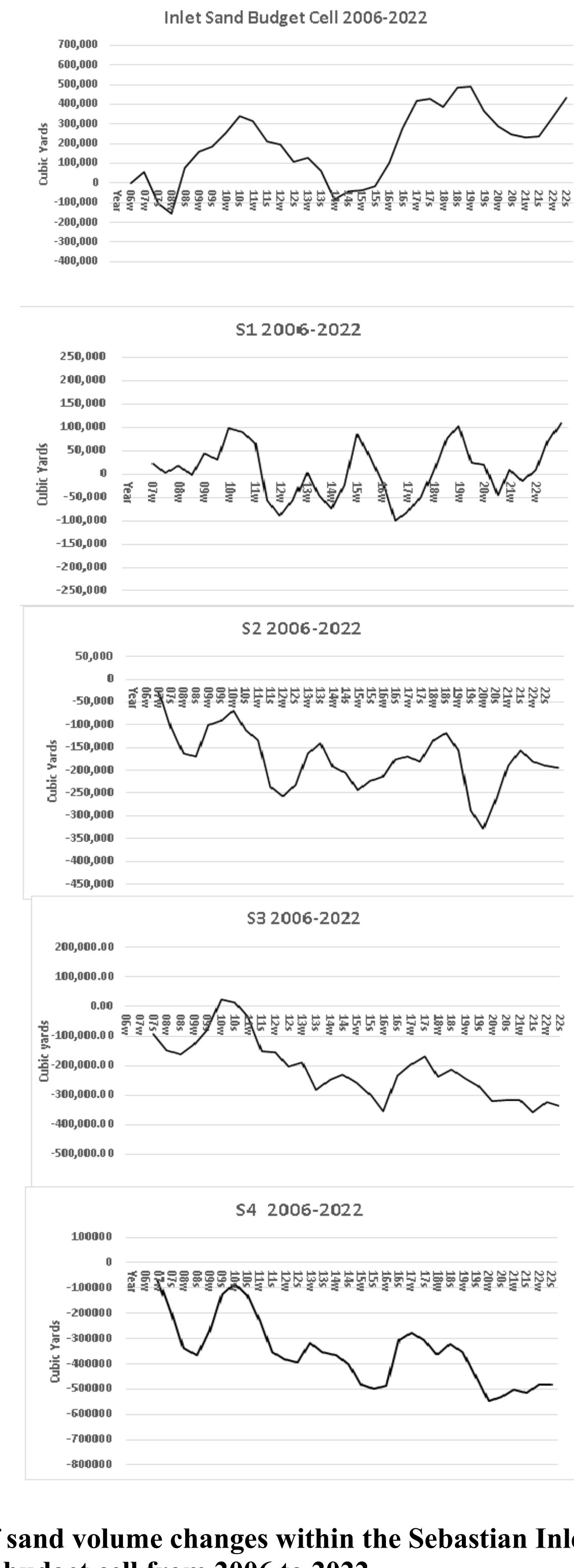


Figure 21. Comparison of sand volume changes within the Sebastian Inlet sediment budget cells S1 to S4 along with the inlet budget cell from 2006 to 2022.

As stated in the 2021 State of the Sebastian Inlet report (Zarillo et al, 2020) there is correlation between interannual sea level trends and changes in shoreface sand volumes. As an example Figure 22 compares the 2006 to 2022 sea level record filtered to emphasize interannual trends and compared with the sand volume records from the S3 budget cell. 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 lag time between sea-level changes and shoreface sediment volume response.

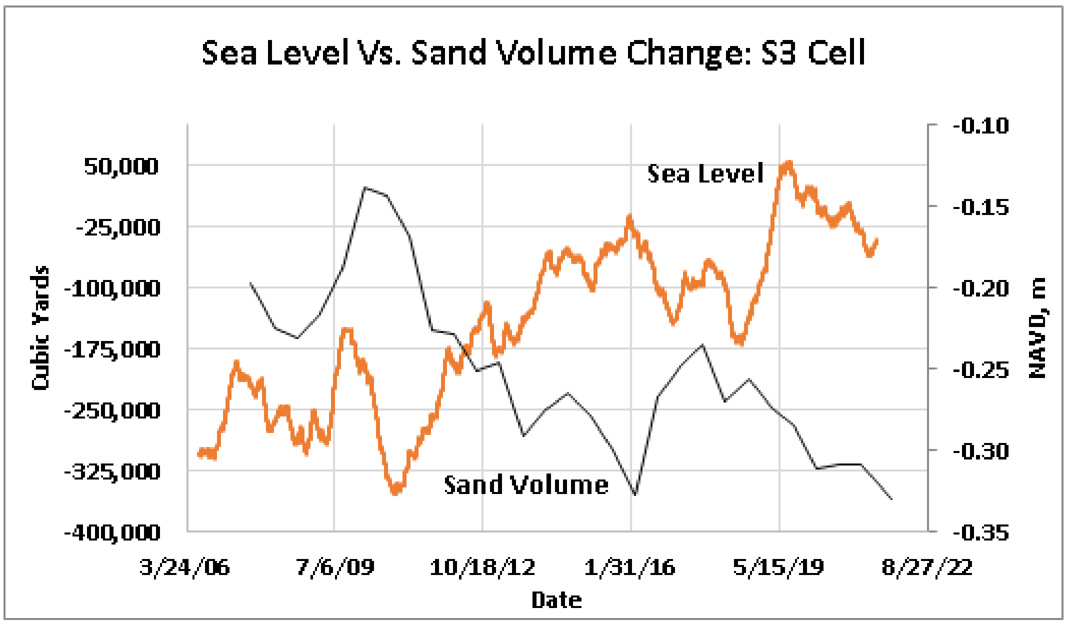


Figure 22. Comparison of fileted the 2006 to 2022 filtered sea level record with the filtered sand volume change record of the S3 budget cell.

The example shown in Figure 22 indicates that sea level change is 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 2022 with measured cumulative volume changes in each sand budget over the same period. Sand volume versus sea level change is shown in pairs of sand budget cells beginning with cells N1 and S1 and progressively with distance from Sebastian Inlet. Overall, the relationship is like 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.

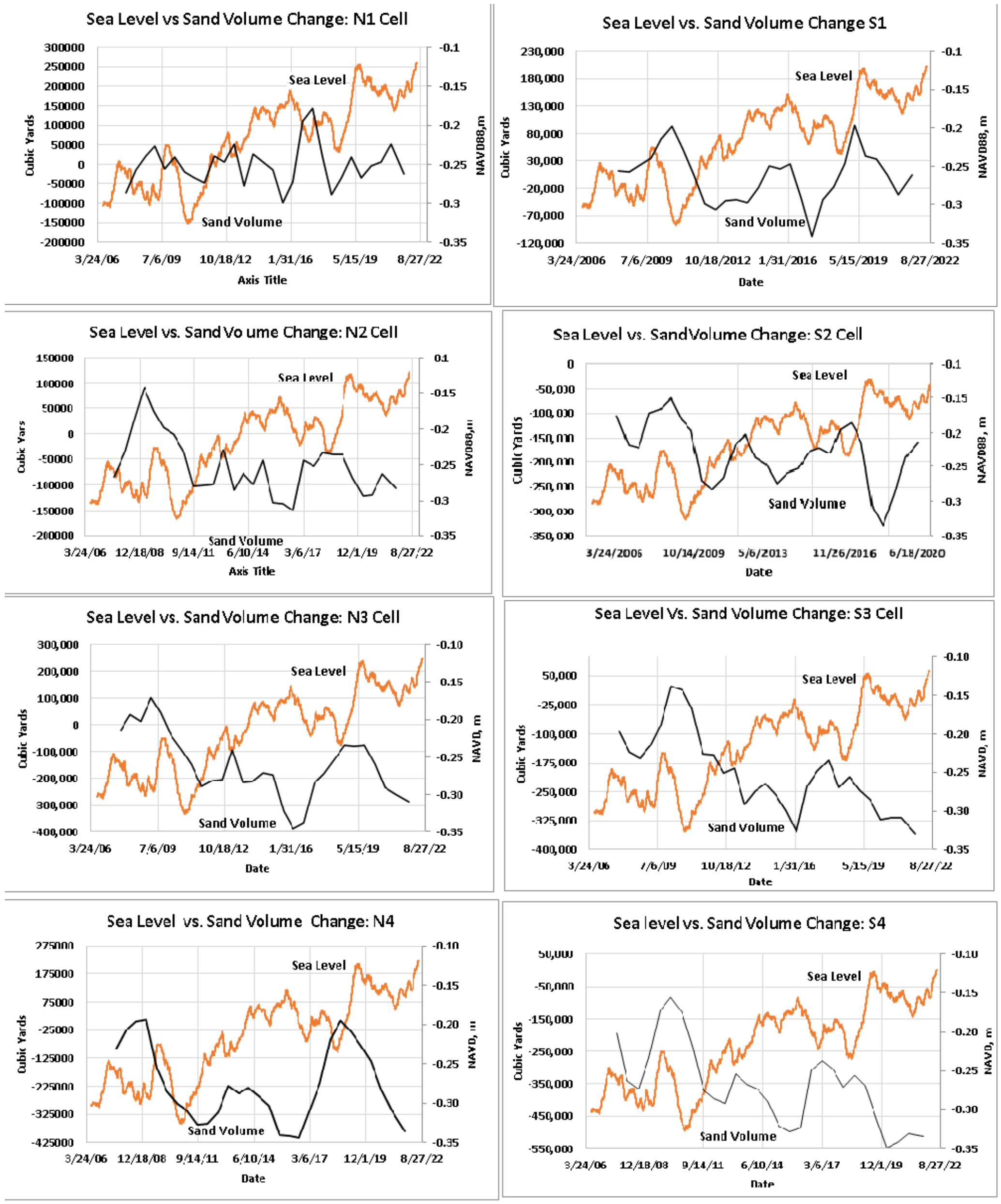


Figure 23. Comparison of sea level changes cumulative sand volume changes within the sand budget cells to the north and south of Sebastian Inlet

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.

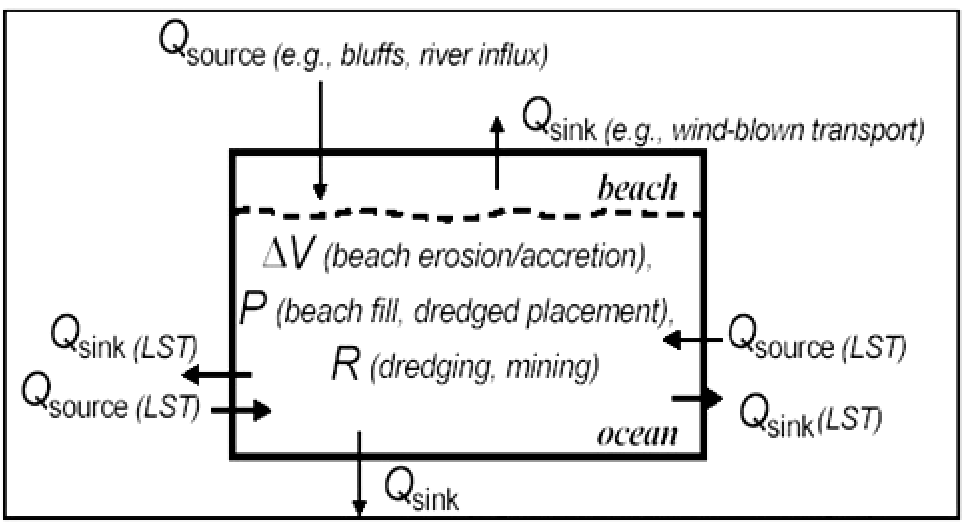


Figure 24. Schematics of a littoral sediment budget analysis (from Rosati, 2005).

Determination of net volume change for the local sediment budgets for Sebastian Inlet was based on volumetric analysis masks presented in section 2. Of this report. 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 two to fifteen years between 2007 and 2022. The computational cells (masks) that were used to establish the local sediment budget are shown in the Figure 3. As describes In Section 2 and shown in Figure 3 the consolidated sediment cells are divided into beach/shoreface and lower shoreface components. Accordingly 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 U.S. Army Corps of Engineers Coastal Inlet Research Program. Details of these procedures can be found in the technical report by Rosati et al. 2001. Based on super regional sediment budget calculations described in Zarillo et al, 2007, an initial input value (Qsource) of 150,000 yd3/yr. was specified. 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 (R)	S1	S2	S3	S4
2007-22	Winter	2,179P	2,397P	1522P	1015P	36,873R	24,380P	25664P	13971P	16599P
2007-22	Summer	2,179P	2,397P	1522P	1015P	36,873R	24,380P	25664P	13971P	16599P
2011–21	Winter	3,269P	3,727P	2,283P	1,522P	46,810R	12,808P	10,478P	22,899P	26,659P
2011–21	Summer	3,269P	3,727P	2,283P	1,522P	46,810R	12,808P	10,478P	22,899P	26,659P
2010 –12	Winter	0	0	0	0	0	21,800	32,700R	19,827P	40,469P
2015–18	Summer	3,144P	4,140P	2,987P	2,044P	0	10,485P	15,727P	2,621P	11,166P

3.2 Sand budget results

The sand budget is presented on four distinct time scales ranging from a longer-term budget for the past 15-year and 10-year periods to short term budgets that examine volume changes and sand flux over 3 and 2 -year periods. The budget uses calculated annualized volume change per cell as inputs (see Figure 2). Annualized beach fill material is accounted for in the N4 to N1 cell on the north side of Sebastian Inlet, the inlet cell, and the S1 to S4 cells a shown in Figure 2. The 2 and 3-yaer sand budget calculations correspond with periods of either rising or falling sea level within an overall period of rising sea level at rate of 10mm (1 cm) per year as documented in the Annual Sebastian Inlet monitoring report (Zarillo and Llantin, 2023)

Interpretation of the fluxes, especially those leaving the southernmost cell (S4, R16-R30) must consider that the sand budget assumes a fixed input rate of either +150,000 or +200,000 cubic yards per year entering the first north cell (N4). Sand transport was assumed to flow north to south.

Figure 25 Illustrates results of the 14-year sand budget analysis bounded by the winter surveys of 2007 and 2021. All but one of the upper beach/shoreface sand budget cells registered annualized sand volume loss, 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, cross shore sand transport cells are applied to balance the lower shore face cells along with transport beyond seaward boundary of some budget cells. Lower shoreface sand budget cells near Sebastian Inlet registered net volume gains and are balance by cross-shore transport from the upper beach/shoreface cells or upper inlet cell to the lower shoreface. An additional source for deposition on the lower shoreface surrounding the inlet could be sediments from the multiple sand bypass projects from the sand trap conducted between 2007 and 2022. The texture of these lower shoreface sands is in the fine to very fine sand range compatible with lower shoreface energy environment and with the fine sand textures of the sand trap material. The overall sand volume loss from the beach/upper shoreface cells, which extend to a depth of about -20 feet NAVD88 is attributed to a long period of rapidly rising sea level in combination with tropical storms in this period, which facilitate episodes of erosion.

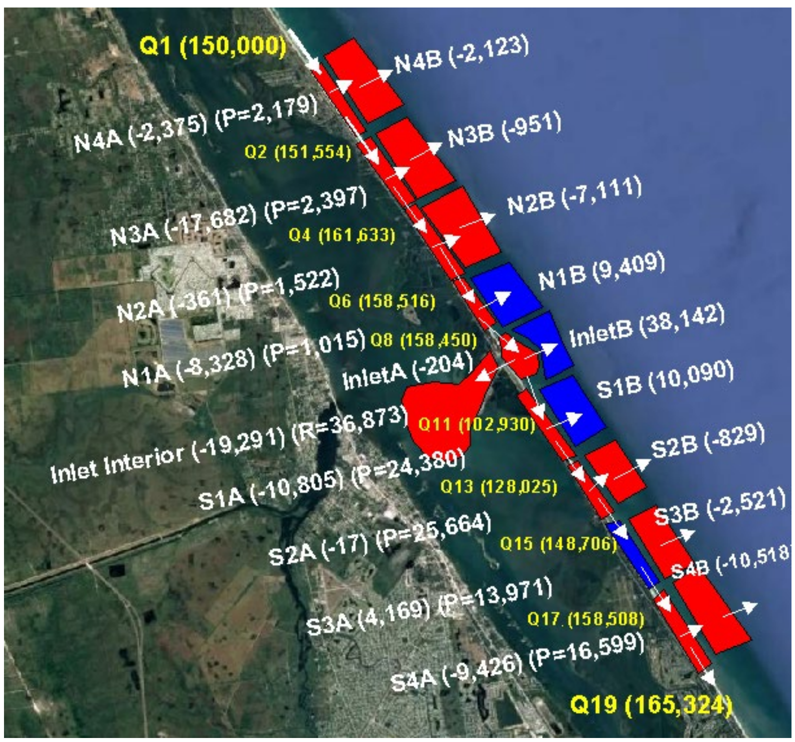


Figure 25. Annualized 15-year sediment budget for the winter 2007 to winter 2022. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

The sand retention rate over the 15-year period can be computed by adding annualized and volume changes across the lower, upper, and interior inlet sediment budget cells and adding the annualized sand volume removed from the sand trap. In the winter to winder 2011 to 2021 sediment budget the retention rate is 55,520 cubic yards per year.

Figure 26 presents the details of the summer to summer sand budget between 2007 and 2022. In this calculation offshore sand transport is required to maintain a balanced annualized littoral sand budget. Lower shoreface cells more distal to the north and south of from Sebastian Inlet registered and volume losses. Like the 2007 to 2022 winter to winter sediment budget lower shoreface sand budget cells surrounding Sebastian Inlet registered a net volume gain. Volume gained also occurred over inlet cells including the interior cell, upper inlet cell and lower inlet cell, which can be considered a lower shoreface cell. Some of the volume gain may be related to repeated sand bypass projects over the 15-year period, including offshore transport of the fine sand that is typical of the Sebastian Inlet sand trap. In this summer oriented budget, benefit of sand placement by Brevard County in the north cells and by the Sebastian Inlet District in the S1 and S2 budgets cells can be seen. Sand budget cells S3 and S4 have losses from both the beach/upper shoreface and lower shoreface cells. Sand release to the inner continental shelf is typically required to balance the sand budget in these cells.

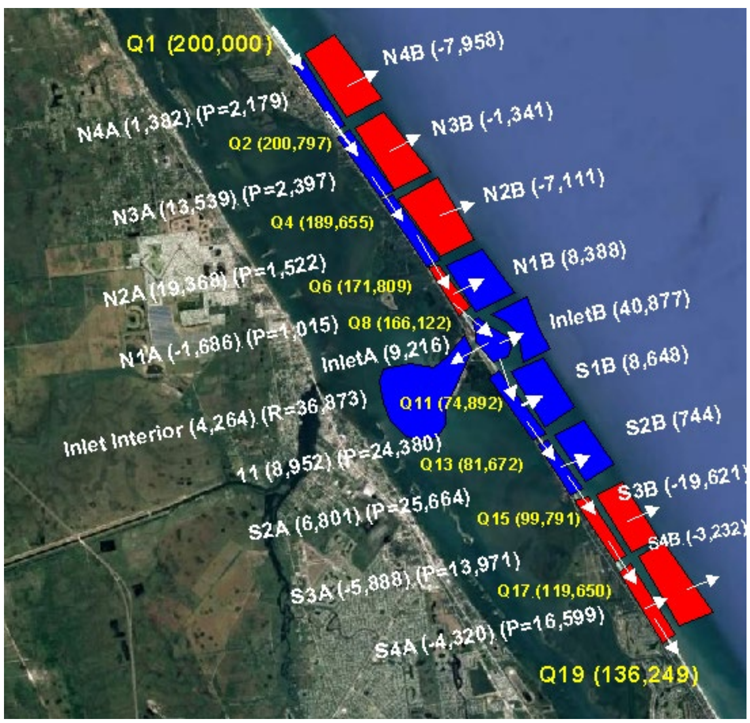


Figure 26. Annualized 15-year sediment budget for the summer 2007 to summer 2022 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

The summer to summer sand 2011 to 2021 sand retention rate computed by adding volume changes across the inlet sediment budget cells and adding the annualized sand volume removed from the sand trap is 92,230 cubic yards per year

The winter to winter 10-year sand budget between 2011and 2021 (Figure 27) is a mix of annualized sand volume gains and losses (Figure 27). Like the 15-year sand budget shown in Figure 26, the more distal segments of the sediment budget to the north and south of Sebastian Inlet lost sand volume at high rates. The rate of sand volume loss from the lower shoreface cell of N4, N3 and S3 and S4 was high, averaging more than 20,000 cubic yards per year and required offshore transport to the inner continental shelf to balance each budget cell. The lower shoreface cells from N1 to S2 were subject to annal volume gains, the largest rate of gain being within the lower shoreface inlet cell B (Figure 27). Some of the volume gain in these cell may be from sand retained from bypass projects back passed and transported offshore. The annual retention rate of sand volume within the Sebastian Inlet shoal system was 51,475 cubic yards per year

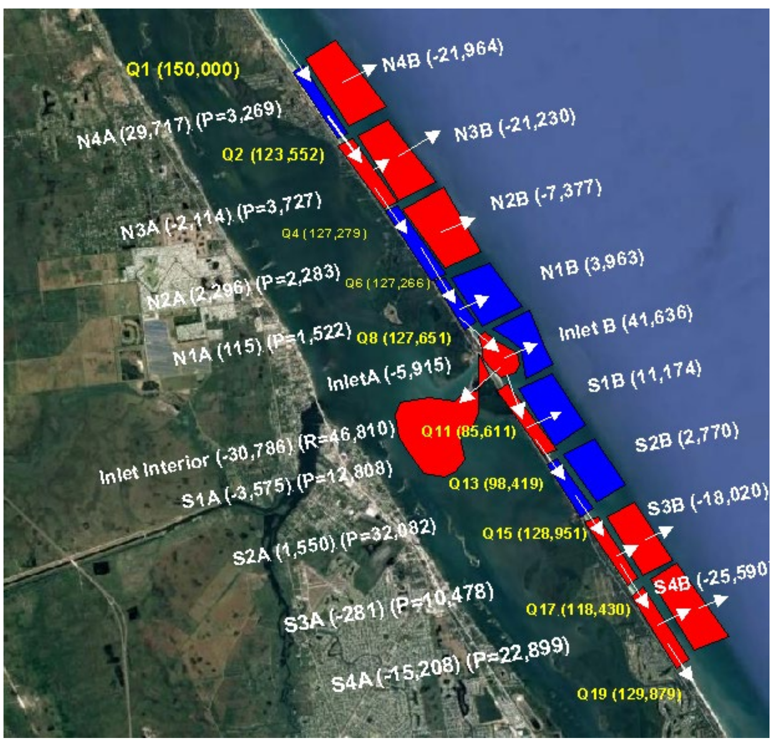


Figure 27. Annualized 10-year sediment budget for the winter 2011 to winter 2021 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicate calculated sand flux rate in cubic yards per year. P= annualized placement quantities and

R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

The analysis results for a 10-year sand budget based over the summer to summer period between 2011 and 2021 were applied in a recent reformulation of the Sebastian Inlet Management Plan to estimate annualized sand bypassing target volumes Figure 28 illustrates the summer to summer 10-year (2011 to 2021) sand budget.   Like the 2011-2021 winter sediment budget the lower shoreface cells surrounding Sebastian Inlet registered sand volume gains. Compared to the winter budget lower surface sediment budget cells N2B and N3B turned to positive volume gains. Lower shoreface cells S3B and S3B continued to register sand volume losses, but at an annualized rate notably smaller compared to the winter budget. This is consistent with a summer sand budget, which may include seasonal sand volume gains and losses due to milder wave energy conditions. The annual retention rate of sand volume within the Sebastian Inlet shoal system was 61,207 cubic yards per year.

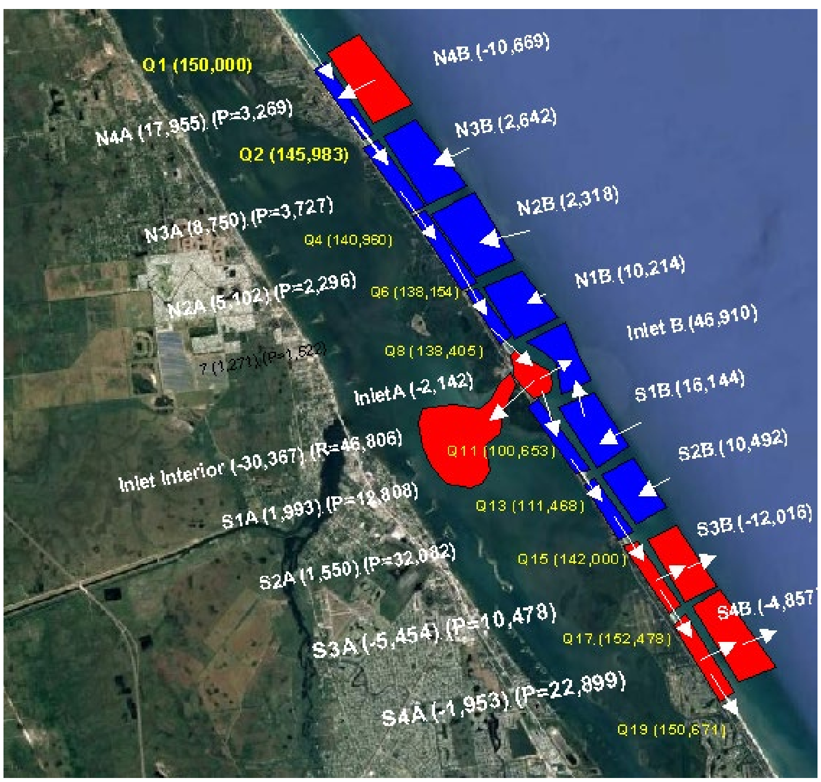


Figure 28. Annualized 10-year sediment budget for the summer 2011 to summer 2021 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and

R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss. 61,207

3.3 Short-Term Sand budgets

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 transport beyond the budget cell S4 and the south end of the calculations. It is likely that both the hurricanes and rising sea level contributed to offshore sand volume losses.

The influence of sea level changes at time scales shorter than a decade on the coastal sand volume can be seen in sand budgets calculated during intra-decadal periods of both rising and falling sea level. Figure 29 compares changes in sand volume cell S2 with the 2006 to 2021 sea level record. Sediment budgets are calculated for 2010-2012 and 2015-2018 noted in Figure 29. The 2010 to 2012 decline in sand volume corresponds to a period of rising sea level, whereas as the 2015 to 2018 increase in sand volume in the S2 cell corresponds to a period of falling sea level. The correspondence can have a lag period of to 6 months or more

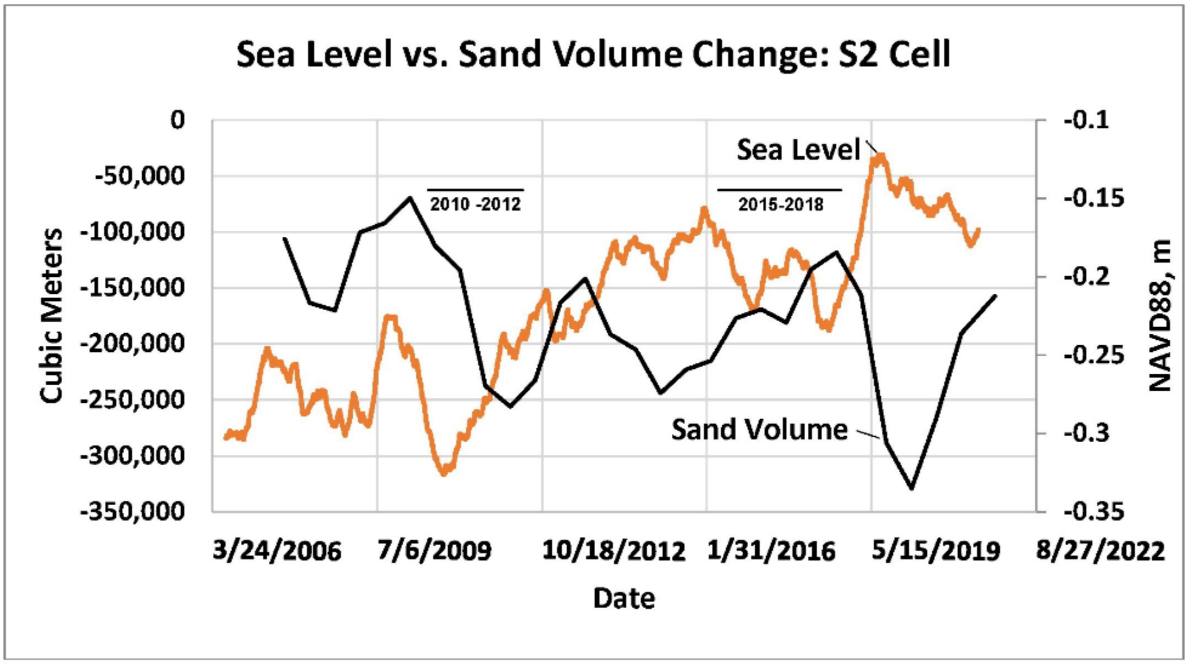


Figure 29. Comparison of sand volume changes and sea level within the S2 sediment budget cell. The 2010 – 2012 and 2015-2018 intra-decadal sand budget calculations periods are also indicated.

The sand budget calculated over the 2010-2012 rising sea level interval is dominated by sand volume losses on the upper shoreface and beach (A cells). Lower shoreface cells (B cells) north of Sebastian inlet are depositional and balanced by sand volume losses from the beach and upper shoreface. As calculated, the inlet interior cell is balanced by adding the observed annualized sand volume gain as a net transport vector from the upper shoreface cell Inlet A (Figure 11). South of the Sebastian inlet, all sediment budget cells have annualized sand volume loss. The lower shoreface cells are balanced by releasing sand volume to the inner continental shelf as indicated by vectors pointed offshore.

The sand budget 2015-2018 shown in Figure 31corresponds to a period of net sea level drop of about 8cm over a 3-year period. This time period also included the impacts of two hurricanes on the central Florida Coast (Mathew, 2016 and Irma, 2018), which produced large wave heights, but only moderate storm surge elevations. Despite these storms, the overall character of the 2015 to 2018 sand budget is depositional. All sand budget cells have sand volume gains except for S1A and S2A to the south of Sebastian Inlet. In order to balance the beach/upper shoreface cells, sand volume contributions are required from lower shoreface cells as indicated by the onshore transport vectors in Figure 31 Assuming net south directed littoral drift, the starting annualized transport rate at the north boundary of the sand budget area is assumed to be 200,000

CY/yr. Previous work in this area has shown that shorter term sand budgets often require higher transport rates to accommodate the large seasonal fluctuations in sand volume that have been observed on shorter time scales. Longer term budget exemplified by the 15-year budget shown in Figure 25Figure 29 are more likely to be characterized by smaller volume changes and lower net transport rates as the shorter term variability is reduced by averaging to produce annualized sediment budgets.

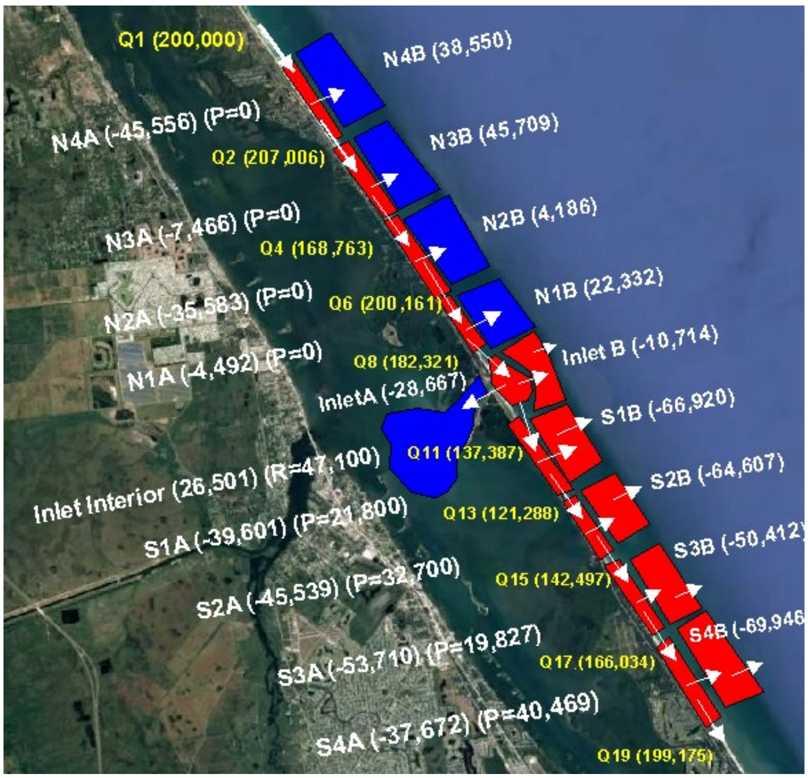


Figure 30. Annualized 2-year sediment budget for the winter 2010 to winter 2012 time period. Values shown to the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

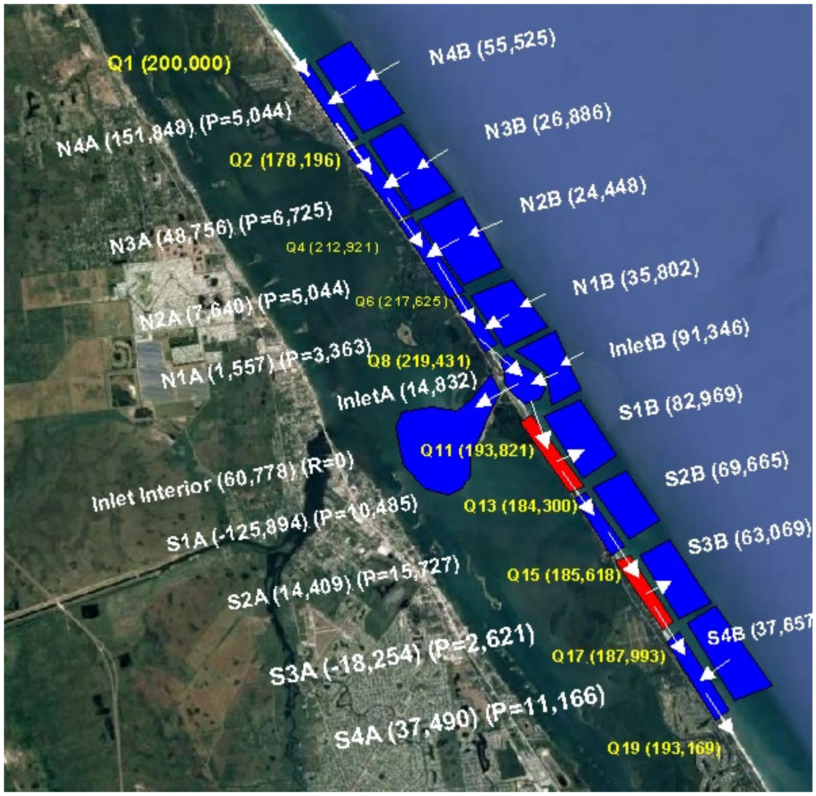


Figure 31. Annualized 3-year sediment budget for the summer 2015 to summer 2018 time period. Values on the west of the barrier island indicate sand volume changes and values on the east indicates calculated sand flux rate in cubic yards per year. P= annualized placement quantities and R = annualized value of sand removed from the sand trap. Blue cells indicate sand volume increase whereas red cells indicate sand volume loss.

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

4.2 Topographic Change 2006 to 2022

A perspective view of the regional topography is shown in based on the 2022 topographic survey. On the north side of Sebastian Inlet the slope of the shoreface is steeper compared to the shoreface configuration to the south side of Sebastian Inlet. The width of the active shoreface profile to the south of Sebastian Inlet is strongly influenced by an elevated rock terrace composed of lithified late Pleistocene carbonate- rich coastal sediments. The position Sebastian inlet is located at the elevation change and the history of its position before being stabilized by the present jetties may have been controlled by the step-up in the elevation of the rock terrace.

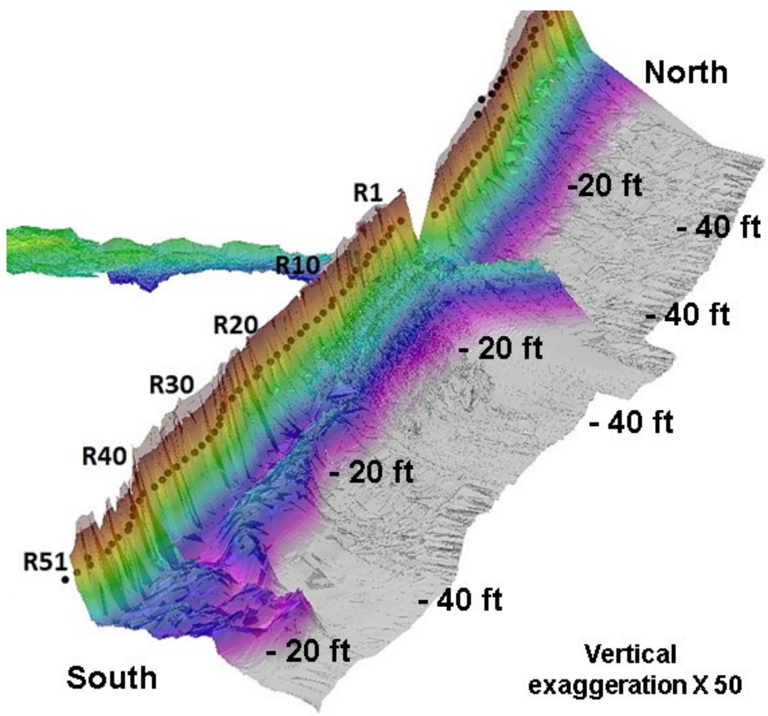


Figure 32.

Calculated Net topographic changes between 2006 and 2022 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 are largely due to erosion from the beach and shoreface rather than sand volume losses at depths greater than 20 feet. Sand volume gains in the winter to winter 15-year 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 resulting in sand deposition and an increase to 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.

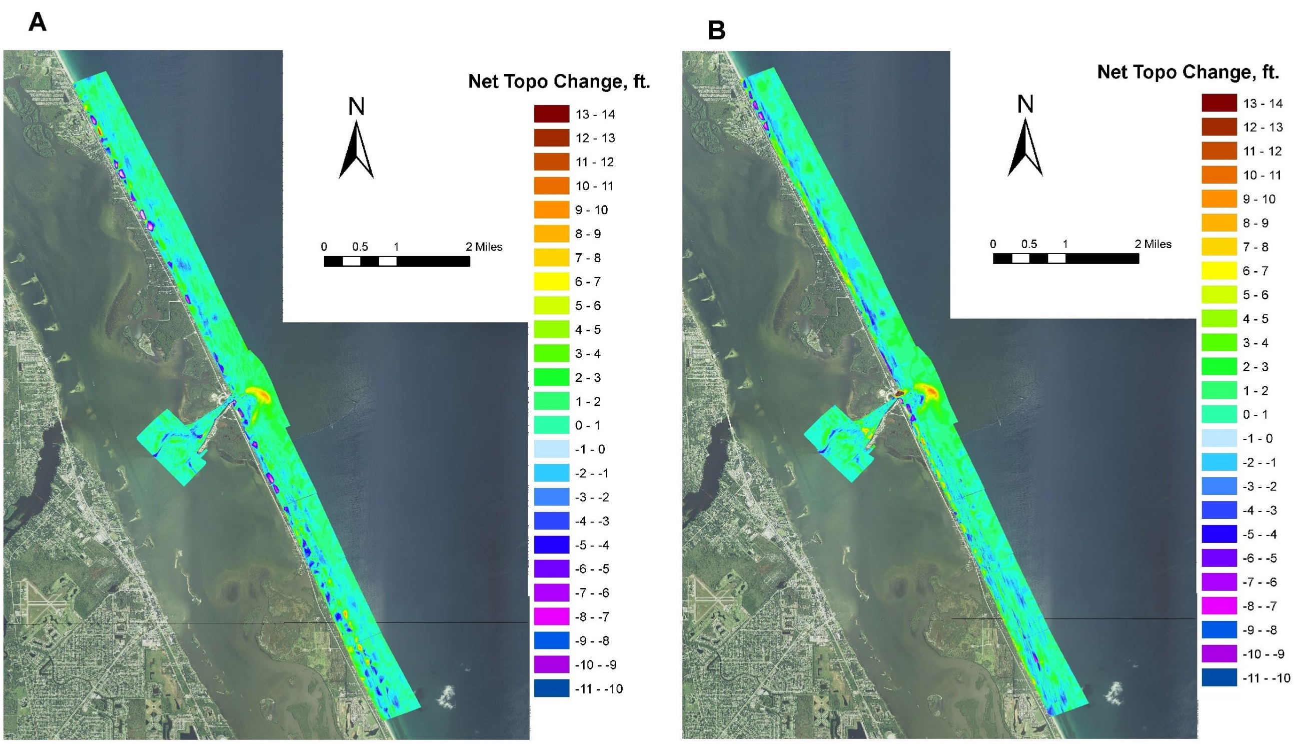


Figure 33. Net topographic (elevation) changes between 2007 winter to 2022 winter (panel A) and 2007 summer to 2022 summer (panel B) associated with the 15-year sediment budget calculation

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 27 and Figure 28. Annualized sand volume loss within the inlet budget cell is due to a combination of sand trap dredging and erosion 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 is on the ebb shoal and in the attachment bar areas indicating sand bypassing across Sebastian Inlet.

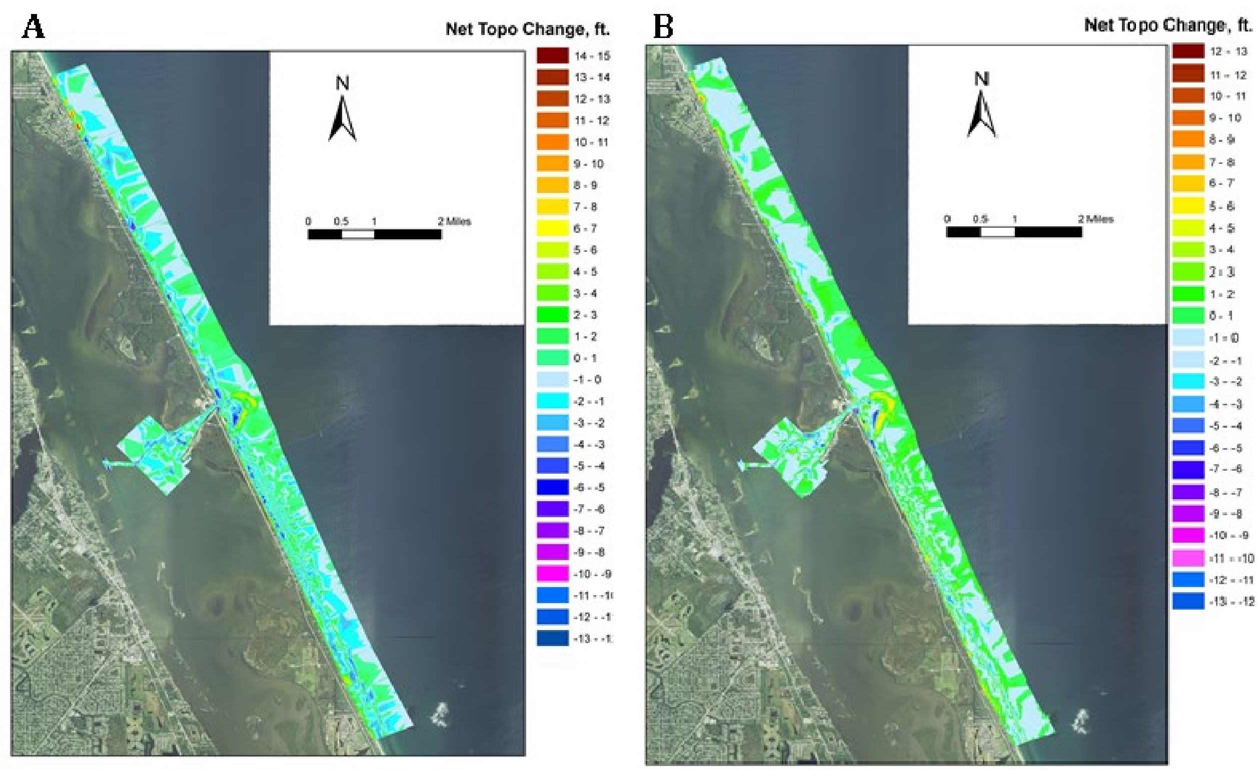


Figure 34. Net topographic (elevation) changes associated with the 2011winter to 2021 winter (panel A) and 2011 summer to 2021 summer (panel B) associated with the 10-year sediment budget calculation

The 2-year sand budget topographic changes under the 2010-2012 rising sea level period are depicted in Figure 35. The associated sand budget calculation is shown in Figure 30. Sand volume losses in NB1, N2B, N3B and N4 are focused on the upper shoreface and beach. Sand volume losses on the beach and upper shoreface are in part due to transport to the lower shoreface and inner continental shelf as shown in Figure 30.

South of the inlet in sand budget cells S1S2, S3 and S4 sand volume losses occur on the beach, shoreface, and inner continental shelf as indicated by abundance of blue spectrum colors. As indicated in the sand budget components shown in Figure 30 sand volume losses are partly due to offshore transport during this period of rising sea level.

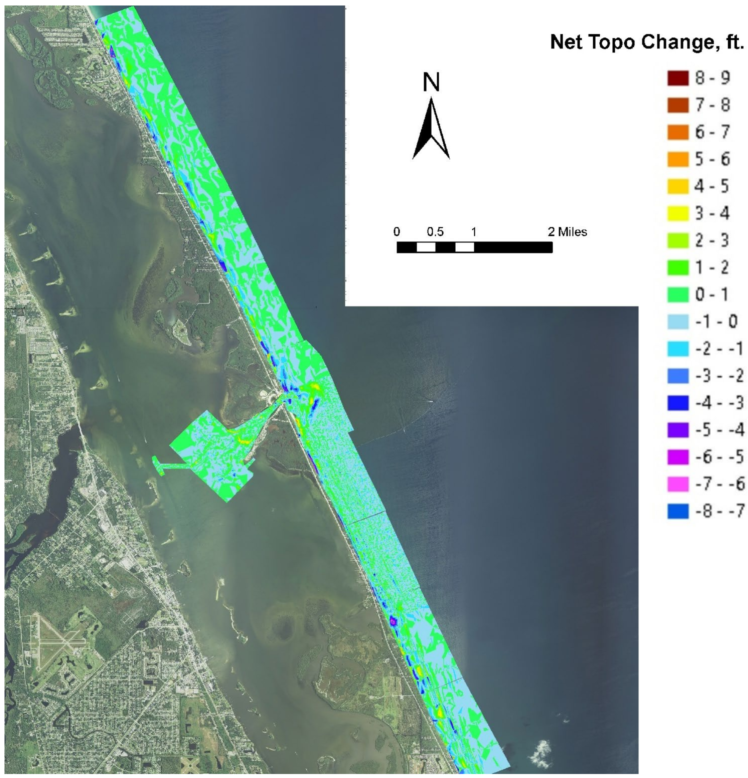


Figure 35. Net topographic (elevation) changes associated with the winter to winter (panel A) and summer to summer (panel B) associated with the 5-year sediment budget calculation

Sand volume and associated topographic gains during the 2015-2018 period of falling sea level are shown in Figure 36. The nearly continuous yellow-red spectrum colors indicate net sediment deposition over 2015-2018 period. The sediment budget calculation for this period demands some onshore sand transport from the inner continual shelf and cross-shore transport of sand from the lower to upper beach/shoreface to balance the and budget cells (see Figure 31).

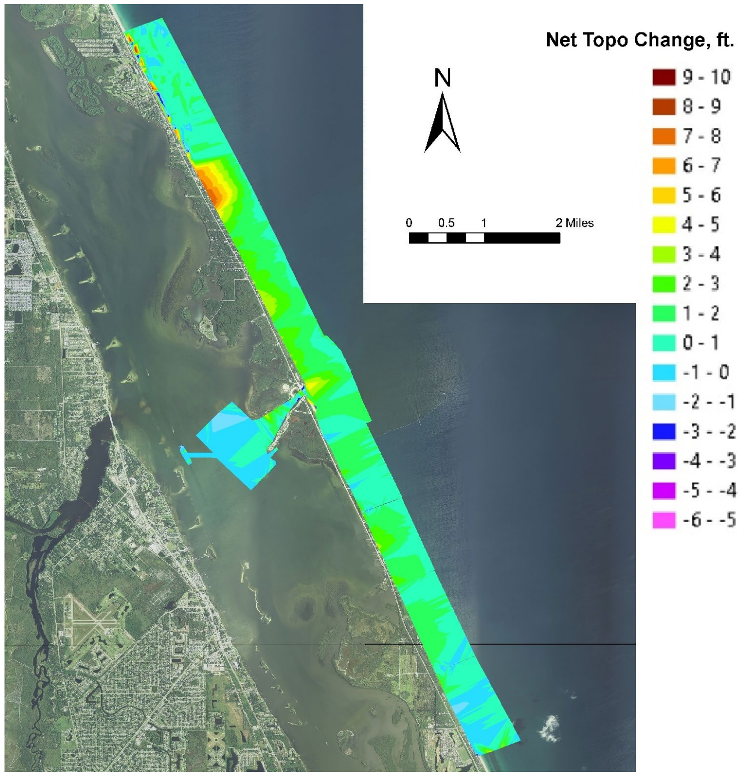


Figure 36. Net topographic (elevation) changes summer 2015 to summer 2018.

5.0 Image Based Shoreline Change

This section of the report provides an update of the shoreline change analysis from aerial imagery taken in 2022. 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 somewhat parallel to Florida State Road A1A (SR-A1A) to the wet/dry line (low-tide terrace). 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.

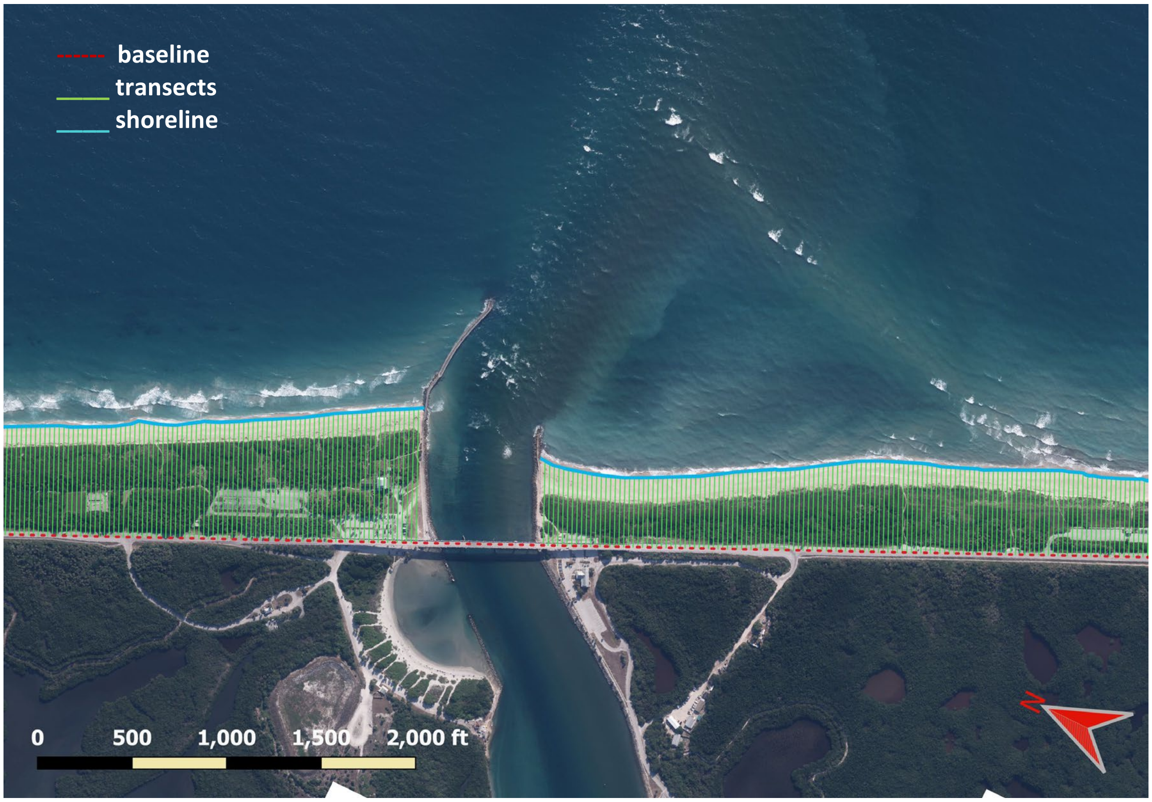


Figure 37. Baseline (dotted-red line), Transects (green lines) and blue line is the image-based 2022 shoreline immediate to Sebastian Inlet.

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 2022 is compared directly with 1958, 2012, 2017, 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 5 shows the extent of coverage of the full study domain and of the assigned sub-zones (e.g. NZ1, NZ2, etc.) used in the shoreline analysis. The rates of change have been updated for an historical time period of sixty-three years (1958-2022), an intermediate period of ten years (2012-2022), and short-term analyses that account for recent changes from 2017-2022 (five years), as well as those occurring most recently from 2021 to 2022 (annual).

Table 3. 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**	**N Zone 3**	180.5 - 203	0 - 1480	4.2
		N Zone 2	203 - 216	880 - 1364	2.3
		N Zone 1	216 - 219	1364 - 1480	0.6
		Inlet	BC216 - IRC4	1365 - 1645	1.3
South	**1508 *to* 2974**	**S Zone 1**	0 - 3.5	1508 - 1627	0.6
		S Zone2	3.5 - 16	1627 - 2120	2.3
		S Zone 3	16 - 37.5	2120 - 2974	4.0

Historical Period (1958-2022)

The shoreline changes between the period of 1958 to 2022 (Figure 38) show shifts ranging from -95 feet (near R-marker 12) to +163 feet (south of R-marker 220). 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.

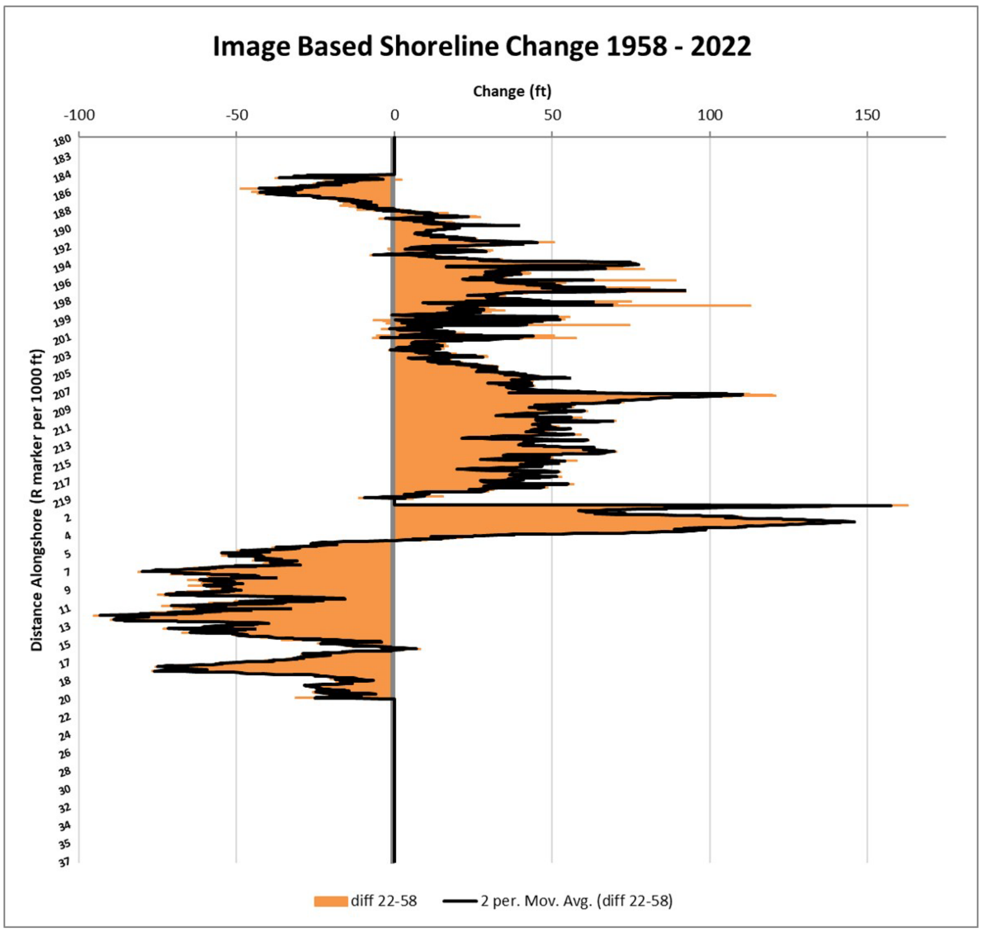


Figure 38. Change (ft) in shoreline position from 1958-2022

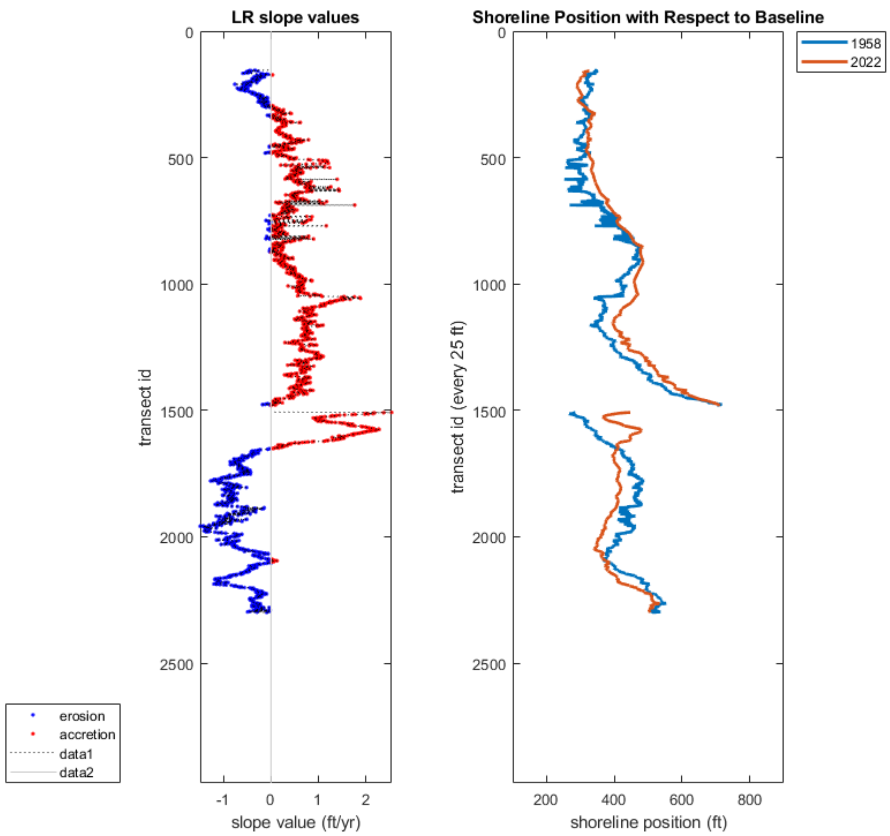
In segment N3, the northernmost area denoting landward migration is close to -48 feet and is centered around R-186, within the same N3 segment the first section denoting seaward migration shows a maximum value of close to +113 feet is centered around R-marker 198. The second area of shoreline advancement is found along segments NZ2 and NZ1, where the maximum seaward migration can be seen around R-208 with a value of close to +120 feet. Approaching the north side of Sebastian Inlet, a small section of shoreline retreat is noticeable with a value of close to -11 feet at R-219. Immediately south of Sebastian Inlet, the area of shoreline showing maximum advancement shows values reaching +162 feet while the widest contiguous section of landward migration (receding shoreline) of up to -95 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 6. Overall, the entire extent (North to South) for the 1958-2022 period presents mostly accretion (43.73%). The North segment shows four sections where erosion occurs however this account to only 12.02%, otherwise accretion areas cover 77.52% of the North extent with an average rate of change of +0.3829 ft/yr. The South extent is where the maximum accretion rate occurs (+2.5442 ft/yr) dominating segment SZ1. Segment SZ2 is where the maximum erosion rate is found -1.4909 ft/yr and erosion dominates 93.12% of this area. Sections SZ1, Nz1, and NZ2 have undergone 95%, 98%, and 100% accretion (respectively).

Table 4. Summary shoreline changes for the historical period (1958-2022)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-1.4909 to 2.5442	0.1148	27.46	43.73
North	-0.7620 to 1.8877	0.3829	12.02	77.52
NZ 3	-0.7620 to 1.7653	0.1966	19.64	62.77
NZ 2	0.0697 to 1.8877	0.6985	0.21	100
NZ 1	-0.1764 to 0.8873	0.4758	4.27	95.73
Inlet	-0.1764 to 2.5442	0.9801	1.78	88.61
SZ 1	0.0000 to 2.5442	1.5463	0.82	98.36
SZ 2	-1.4909 to 0.6564	-0.657	93.12	6.88
SZ 3	-1.2005 to 0.0000	-0.1079	21.05	0.12
South	-1.4909 to 2.5442	-0.1555	43.5	10.42

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 +0.5 ft/yr, this agrees with the central value of accretion rates (red dots) dominating the North. The secondary grouping centered around -0.8 ft/yr in the histogram corresponds for the most part to the erosion trends dominating SZ2 and SZ3, while the spread in values seen over +1.5 ft/yr can be attributed for the most part to segment SZ1.



(a) (b)

Figure 39. Period of 1958-2022 (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).

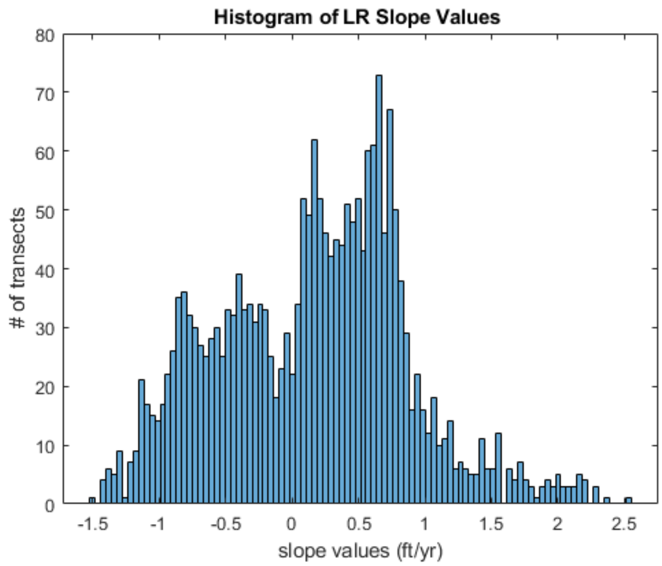


Figure 40. Frequency of rate of change (slope value in ft/yr) for entire domain (1958-2022).

<u>Intermediate Period (2012-2022)</u>

The changes in shoreline position from 2012 to 2022 (Figure 41) show overall seaward migration (advancement) throughout the entire domain centered around +12 feet with a maximum seaward migration of +86 feet near R-202. Several segments of shoreline retreat are interspersed throughout the entire domain.

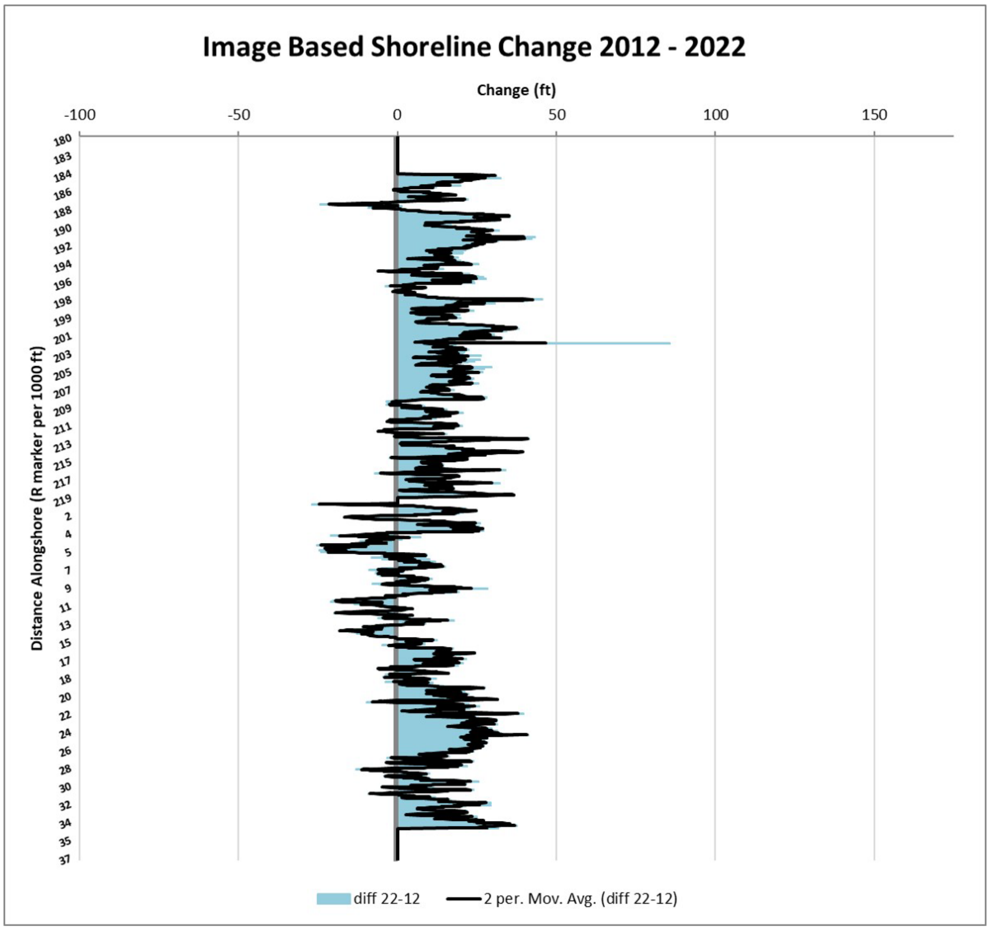


Figure 41. Change (ft) in shoreline position from 2012-2022.

The full extent from North to South show 57.51% accretion and 13.68% erosion with an average rate of change of +0.7405 ft/yr (Table 7). Similarly, most segments show accretion ranging from 18.25% (S3) to 96.58% (N1). Segment NZ1 has an average rate of change of +1.4421 ft/yr. In general, the average rate of change is centered around a value of close to +1.3 ft/yr (Figure 42 and Figure 43(a)) for the North and around 0.16 ft/yr for the South, being the

SZ3 and NZ3 segments the ones driving the average of the accretion rate (in ft/yr) with 0.2039 and 1.2831 values respectively. Maximum values of accretion (red dots) occur at NZ3 (+8.5690 ft/yr.

Table 5. Summary of short-term changes for the recent period (2012-2022)

Extent	Range (ft/yr) *Max Erosion to* *Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-2.6820 to 8.5690	0.7405	13.68	57.51
North	-2.4360 to 8.5690	1.3109	6.48	83.05
NZ3	-2.4360 to 8.5690	1.2831	5.22	77.19
NZ2	-0.6220 to 4.1460	1.3278	9.48	90.52
NZ1	-0.7050 to 3.6760	1.4421	3.42	96.58
Inlet	-2.6820 to 3.6760	1.0561	16.73	73.67
SZ1	-2.6820 to 2.7100	0.9711	21.31	77.05
SZ2	-2.5400 to 2.8400	-0.0988	53.04	46.96
SZ3	-0.6470 to 2.7510	0.2039	2.81	18.25
South	-2.6820 to 2.8400	0.1649	21.17	32.74

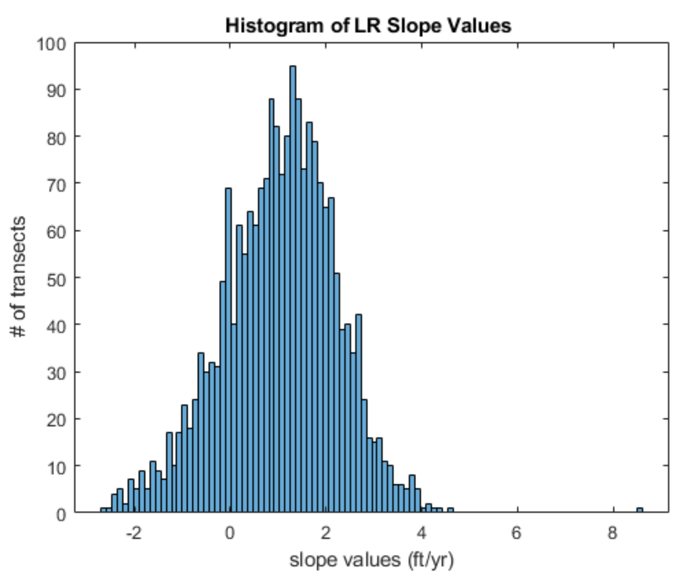


Figure 42. Histogram indicating number of transects per slope value (ft/yr) for 2012-2022.

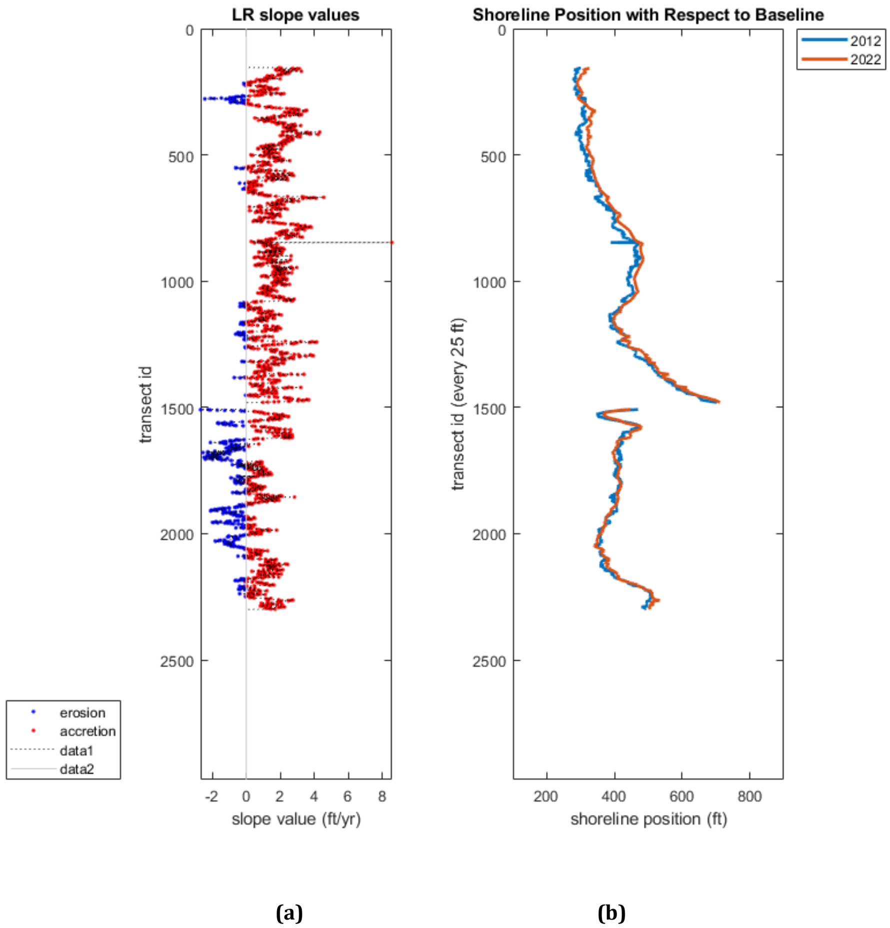


Figure 43. Period of 2012-2022. (a) Shoreline change rate in ft/yr (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

Recent Changes (2017-2022)

Shoreline changes from 2017 to 2022 (Figure 44) experienced mostly landward migration (recession) throughout the entire domain. A maximum change of +21.6 feet (near R-219) is found immediately north of the inlet in NZ1, however landward shoreline migration (recession) dominates the segment. The range of shoreline change in segment S1 is from -12.06 ft/yr to +2.9460 ft/yr (Table 8). Several small areas in all segments show advancement in the shoreline but only segment S3 show a wider section indicating advancement (seaward migration) with values up to +20 feet (R-25). The maximum shoreline retreat is found in SZ1 with a value of -60.3 ft/yr (R-220).

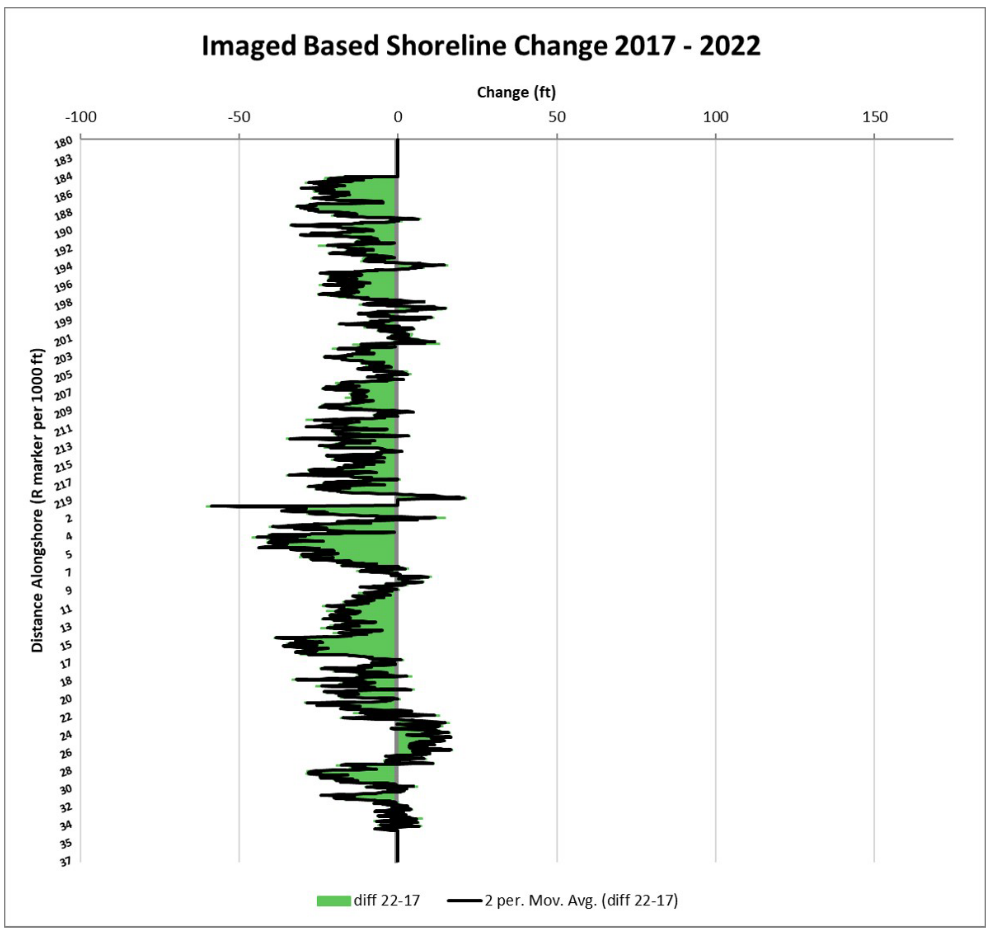


Figure 44. Change (ft) in shoreline position from 2017-2022.

Table 6. Summary of short-term changes for the latest update (2017-2022)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-12.0600 to 4.3220	-1.9356	63.76	7.43
North	-7.0320 to 4.3220	-2.0662	78.33	11.21
NZ3	-6.8020 to 3.1020	-1.808	69.01	13.39
NZ2	-7.0320 to 0.9880	-2.4802	94.64	5.36
NZ1	-7.0140 to 4.3220	-2.3233	81.2	18.8
Inlet	-12.0600 to 4.3220	-3.5998	79.36	11.03
SZ1	-12.0600 to 2.9460	-4.2575	90.98	7.38
SZ2	-9.1840 to 2.0740	-3.4888	92.11	7.89
SZ3	-6.6520 to 1.0120	-0.4876	20.23	0.82
South	-12.0600 to 2.9460	-1.8025	50.17	3.74

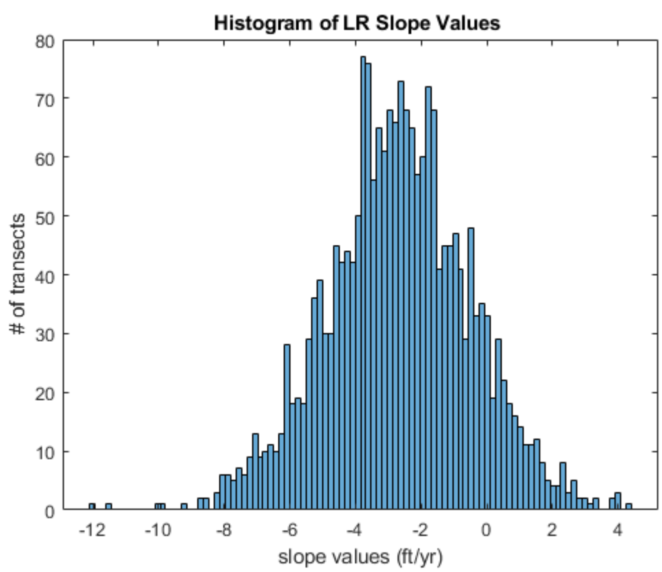
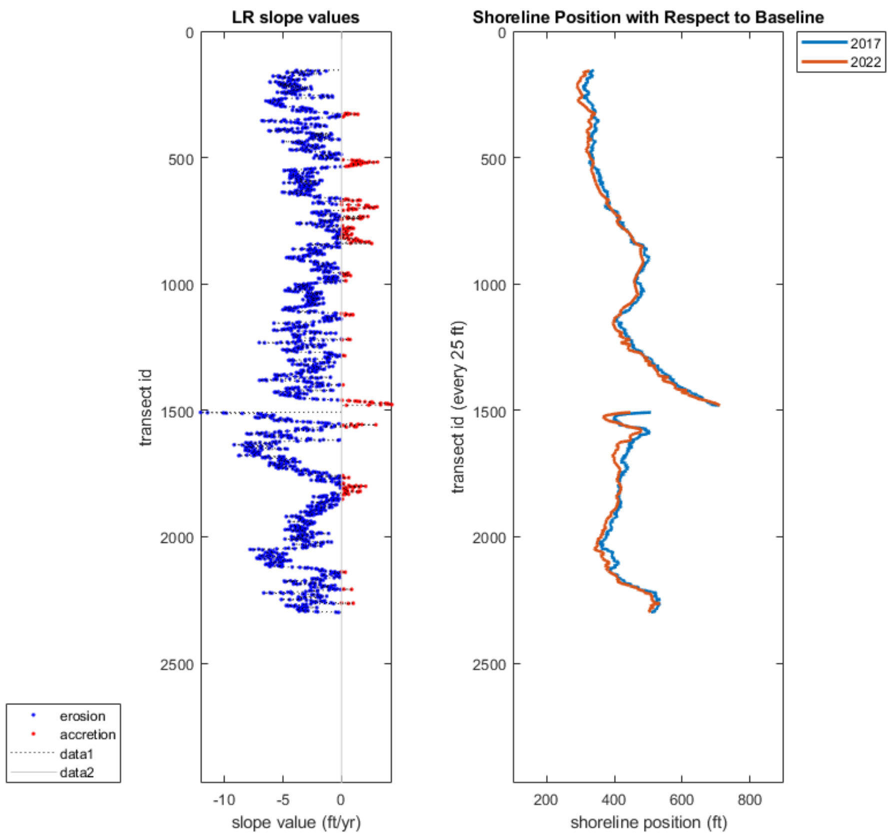


Figure 45. Histogram indicating number of transects per slope value (ft/yr) for 2017-2022.

The full extent from North to South show 63.76% erosion and 7.43% accretion with an average rate of change of -1.9356 ft/yr (Table 8). Similarly, most segments show erosion ranging from 20.23% (S3) to 94.64% (N2). In general, the average rate of change is centered around a value close to -2 ft/yr (Figure 42 and Figure 43(a)) for the entire domain, being the North segments (NZ3, NZ2, and NZ1) the ones driving the average of the erosion rate (in ft/yr) with -

1.808, -2.4802, and -2.3233 values respectively. Maximum values of accretion (red dots) occur at N1 (+1.0120 ft/yr) and maximum values of erosion (blue dots) occur at S1 (-12.0600 ft/yr).



(a) (b)

Figure 46. Period of 2017-2022. (a) Shoreline change rate in ft/yr (according to LR method calculated for each transect); (b) Shoreline position in feet (from baseline to wet/dry line).

Annual Update (2021-2022)

The shoreline changes occurring between 2021 and 2022 (Figure 47) show shifts ranging from -78 feet to +45 feet (seen immediately south and north of the Inlet). Although seaward and landward migration of the shoreline are seen to alternate throughout the domain, most of the shoreline show advancement. Segment NZ2 shows 71.34% accretion at an average rate of +4.1669 ft/yr. The rest of the segments experience shoreline seaward migration, except for N1 and S1 where erosion dominates at 62.39% and 83.60% respectively.

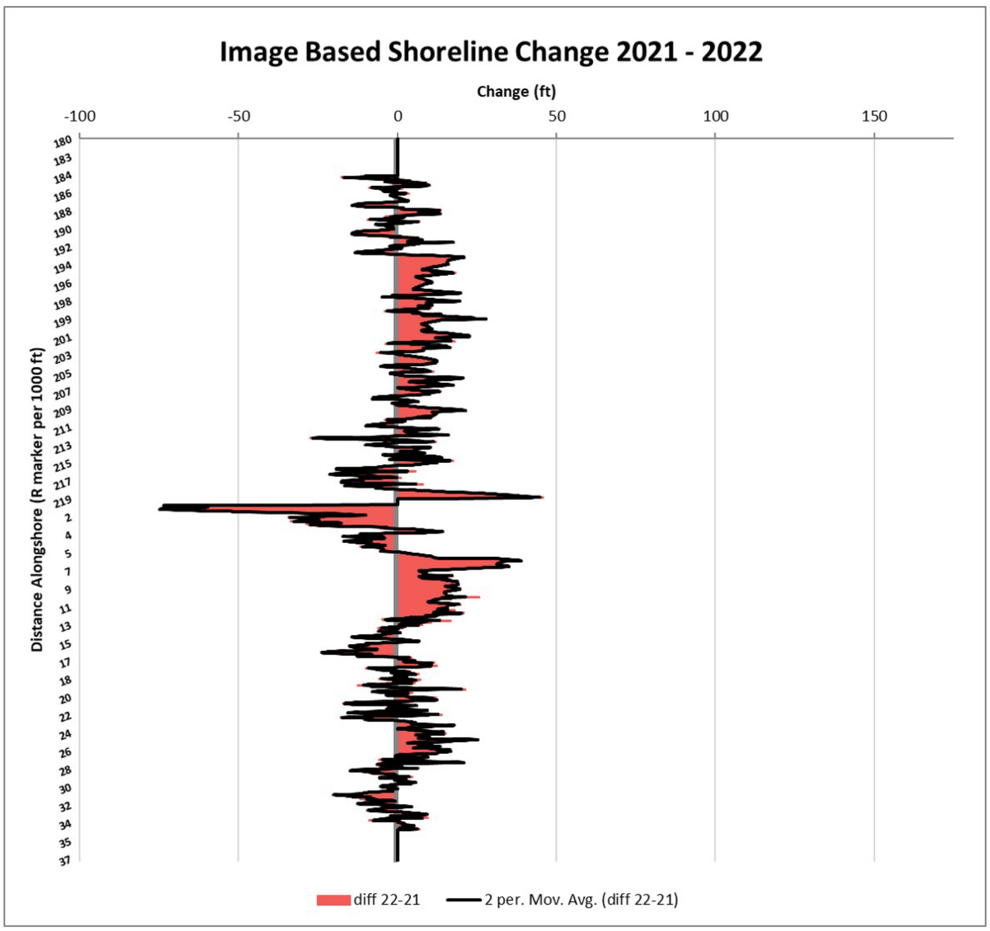


Figure 47. Change (ft) in shoreline position from 2021-2022.

The majority of the spread and peak frequencies occur around +4 ft/yr more easily noticeable in Figure 48. Values above +20 ft/yr are found in most segments except SZ1, while.

values below -20 ft/yr are clustered predominantly in SZ1 where the rate of shoreline change ranges from -74.9900 ft/yr to +14.5800 ft/yr.

Table 7. Summary of short-term changes for the recent period (2021-2022)

Extent	Range (ft/yr) *Max Erosion to Max Accretion*	Rate of Change (ft/yr)	Erosion %	Accretion %
North to South	-74.9900 to 45.8300	2.0931	25.85	45.34
North	-27.5600 to 45.8300	4.2095	27.68	61.85
NZ3	-17.7100 to 27.9800	4.5459	22.7	59.7
NZ2	-27.5600 to 21.7500	4.1669	28.66	71.34
NZ1	-21.6300 to 45.8300	1.6298	62.39	37.61
Inlet	-74.9900 to 45.8300	-12.7306	68.33	22.06
SZ1	-74.9900 to 14.5800	-27.0263	83.61	14.75
SZ2	-23.9300 to 38.8800	6.3896	35.83	64.17
SZ3	-12.9100 to 21.4200	0.0649	9.59	11.46
South	-74.9900 to 38.8800	-0.0421	24.44	29.48

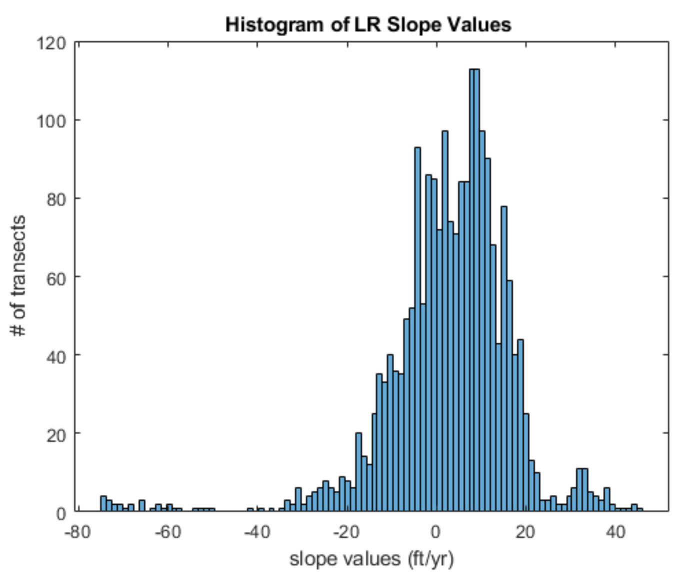
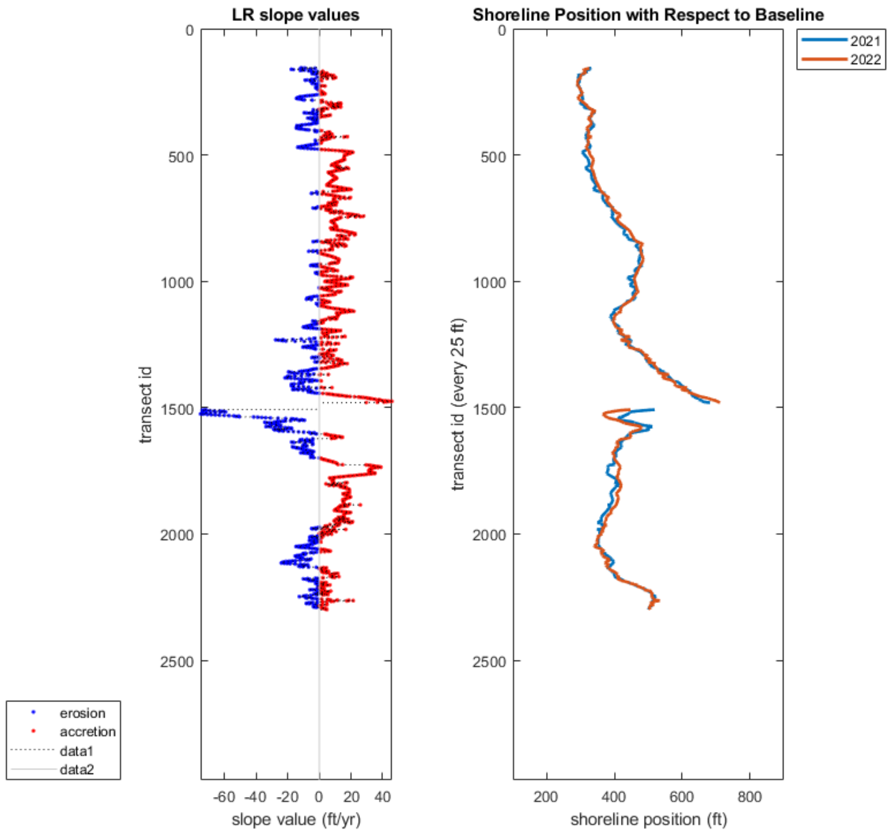


Figure 48. Histogram indicating number of transects per slope value (ft/yr) for 2021-2022.



(a) **(b)**

Figure 49. Period of 2021-2022. (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).

7.0 Survey Based Shoreline Change

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 ArcGIS©. Once the XYZ data files from hydrographic surveys were contoured, the extension was also used to highlight the zero-contour so that this one interval could be digitized to represent the position of the shoreline. Once highlighted, the zero-contour was extracted by hand-tracing the contour using shoreline-generating tool in BeachTools© (Hoeke et al. 2001). To determine the change in shoreline position, a common baseline with a NAD83 projection running along the SRA1A was created manually using BeachTools©. This extension was also used to generate perpendicular transects from this baseline to the digitized shoreline every 25 ft, to match the transect interval used in the image-based analysis. For detailed methodology on the shoreline change calculations, the reader is referred to previous reports (Zarillo et al., 2007, 2009, 2010).

Similarly, as with the image-based analysis, changes to the survey-based shoreline position were determined by subtracting the distances along each transect between time-series of interest. The results presented and discussed in this section will focus on the on seasonal changes in the survey-based shoreline. The rates of change have been obtained comparing winter to winter and summer to summer seasons for various time periods. Winter surveys were analyzed for time periods corresponding to: long-term of fifteen years (2007-2022); intermediate term of ten years (2012-2022); recent-term of five years (2017-2022); and annual (2021-2022). At the time of this report the 2022 Summer survey was not available, thus comparison is performed using the last year available which is 2021. Summer surveys were analyzed for time periods corresponding to: long-term of fourteen years (2007-2021); intermediate term of nine years (2012-2021); recent-term of four years (2017-2021); and annual (2020-2021).

Winter Surveys (2007, 2012, 2017, 2021 and 2022)

Changes between **Winter 2007 and Winter 2022** show large excursions in the shoreline, alternating between advancement and retreat along the entire domain (Figure 50, orange line). A large area of landward migration can be identified centered around R-11 with a maximum value of +81 ft. A seaward migration wide can be seen around R11 in S3 with a value of -214 ft. The overall trend during this period is towards landward migration indicating 52.07% erosion interspersed with areas of accretion that account for 25.55% of the full extent (Table 10 and Figure 51-a) ranging from -17.5293 ft/yr to +2.4440 ft/yr. Due to the distribution of the rate of change values, 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 -1.8128 ft/yr.

Table 8. 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 07-22	-17.5293 to 2.4440	-1.8128	52.07	25.55
Winter 12-22	-9.6590 to 4.3350	-1.4718	59.8	17.82
Winter 17-22	-22.9940 to 9.4140	-3.0564	69.98	7.63
Winter 21-22	-32.5700 to 26.5300	-4.4179	59.09	18.52

The results for **Winter 2012-2022** analysis are in part similar to those of Winter 2007-2022. Figure 50 (blue line) show large excursions in the shoreline that alternate from advancement and retreat. The north section is dominated by receding a shoreline with a maximum value of -92.48 ft at R-216 (N2 segment). The south section alternates from seaward migration immediately south of the Inlet (on S1 segment) to landward migration on S2, and a noticeable area showing reversal between advancement and retreat in S3. Ultimately, the entire south extent tends towards shoreline retreat with an overall 59.8% erosion and 17.82% accretion, where the average rate of shoreline change is -1.4718 ft/yr and a range of -9.6590 ft/yr to +4.3350 ft/yr (Table 10 and Figure 51-b).

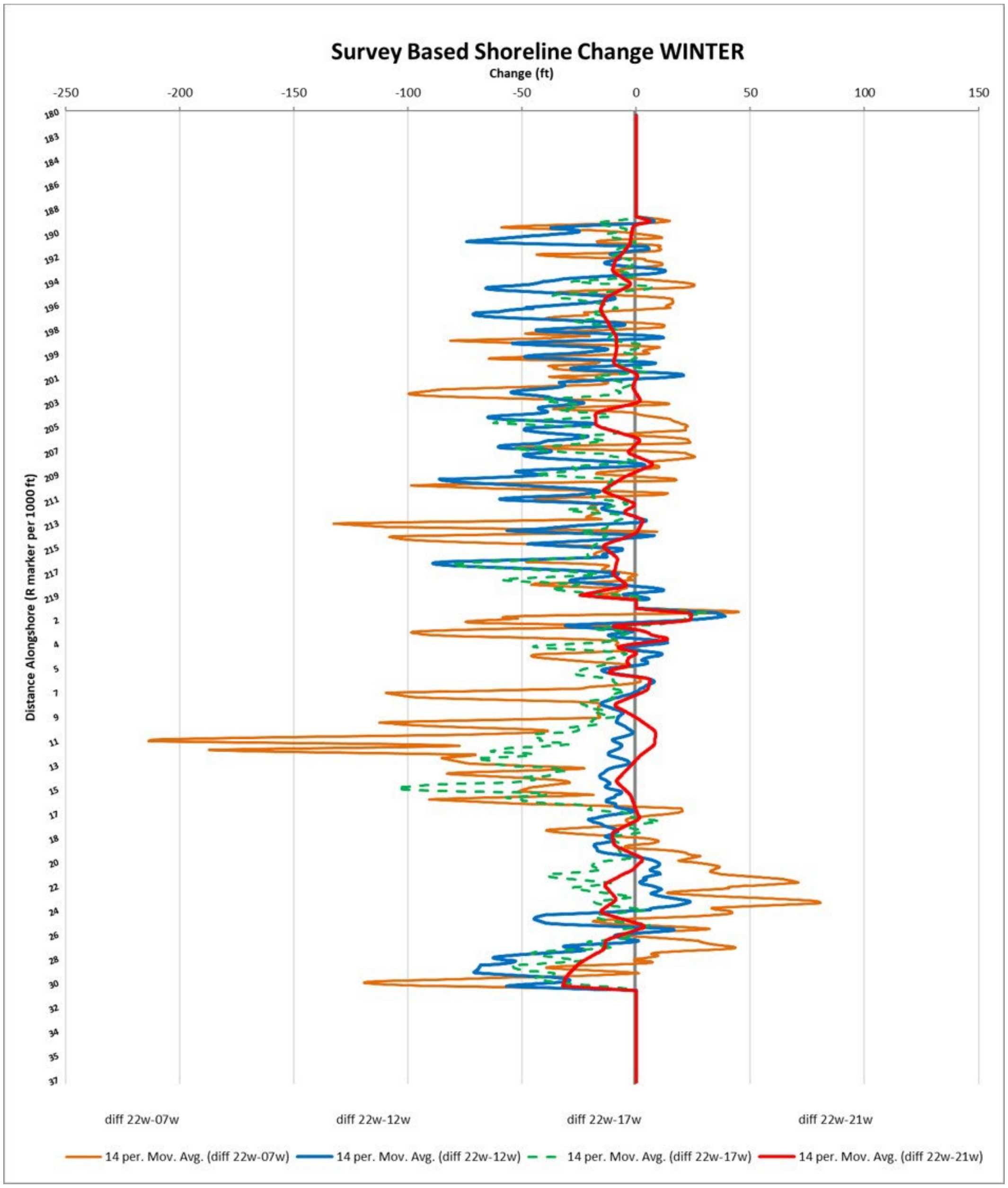


Figure 50. Survey-based change in shoreline position for 07w-22w (orange line), 12w-22w (blue line), 17w-22w (dashed-green line), and 21w-22w (red line).

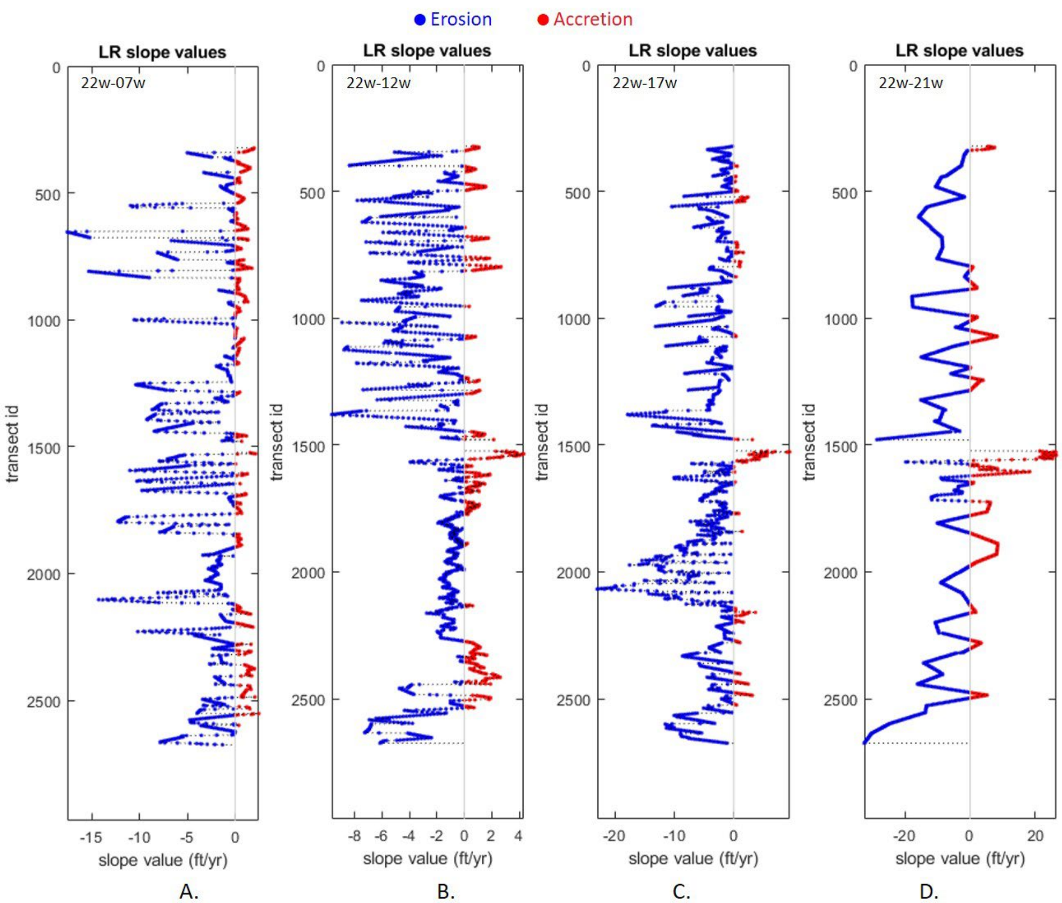


Figure 51. Shoreline rate of change (in ft/yr) for entire domain WINTER surveys: (a) 07w-22w, (b) 12w-22w, (c) 17w-22w, and (d) 21w-22w.

Winter 2017 and Winter 2022 shoreline changes (see Figure 50 (dashed green 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 close to +30 ft. The 17w-22w shoreline retreat have maximum value of -52 ft near R-29. The rate of change observed for the full domain has an average of -3.0564 ft/yr and has a range of -22.9940 ft/yr to +9.4140 ft/yr (Table 10 and Figure 51-c). This period is the only one in the Winter analysis with marked overall erosion of 69.98%.

The most recent **Winter period of 2021w and 2022w** (Figure 50, solid red line) show that landward migration dominated the domain from north to south with one area in the S1 segment where shoreline advancement is observed just south of the inlet. The small section in S1 shows a maximum change of close to +20 ft. Table 10 and Figure 51-d show that 20w-21w is dominated by erosion (42.69%) and has an average shoreline rate of change of -1.3958 ft/yr.

<u>Summer Surveys (2007, 2012, 2017, 2020 and 2021)</u>

Shoreline changes for Summer surveys are shown in Figure 52 and are seeing to follow a similar trend across all periods along the entire domain. The north area shows excursions that are mainly around -50 ft to +30 ft while in the south area the differences between the various periods are more noticeable and a wider offset from each other can be observed.

The period of **Summer 2007-2021** (dashed orange line) shows shoreline advancement in most of the north segment with large extreme switchbacks mostly observed in the south and immediately next to the inlet where a value of +47 is seen at R219 and a value of -143 at R2 (Figure 52). This is the only period in the Summer analysis that show accretion of 43.29% (Table 11 and Figure 53-a).

Table 9. 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 07-21	-10.2314 to 3.7829	-0.0469	34.32	43.29
Summer 12-21	-18.8667 to 6.5256	-2.2643	61.82	15.8
Summer 17-21	-22.5650 to 15.2375	-2.2785	52.54	25.08
Summer 20-21	-34.7900 to 50.5700	-1.3958	42.69	34.92

The results for **Summer 2012-2021** indicate that most of the shoreline has retreated (Figure 52, blue line) and erosion dominates this period. The maximum value of shoreline retreat is -166.4 ft at R-marker 15. There is a 61.82% of the area undergoing erosion and only 15.8%

experiencing accretion (Table 11 and Figure 53-b). The average shoreline rate of change is that of -2.2643 ft/yr and the range of the rate of change is from -18.8667 ft/yr to +6.5256 ft/yr.

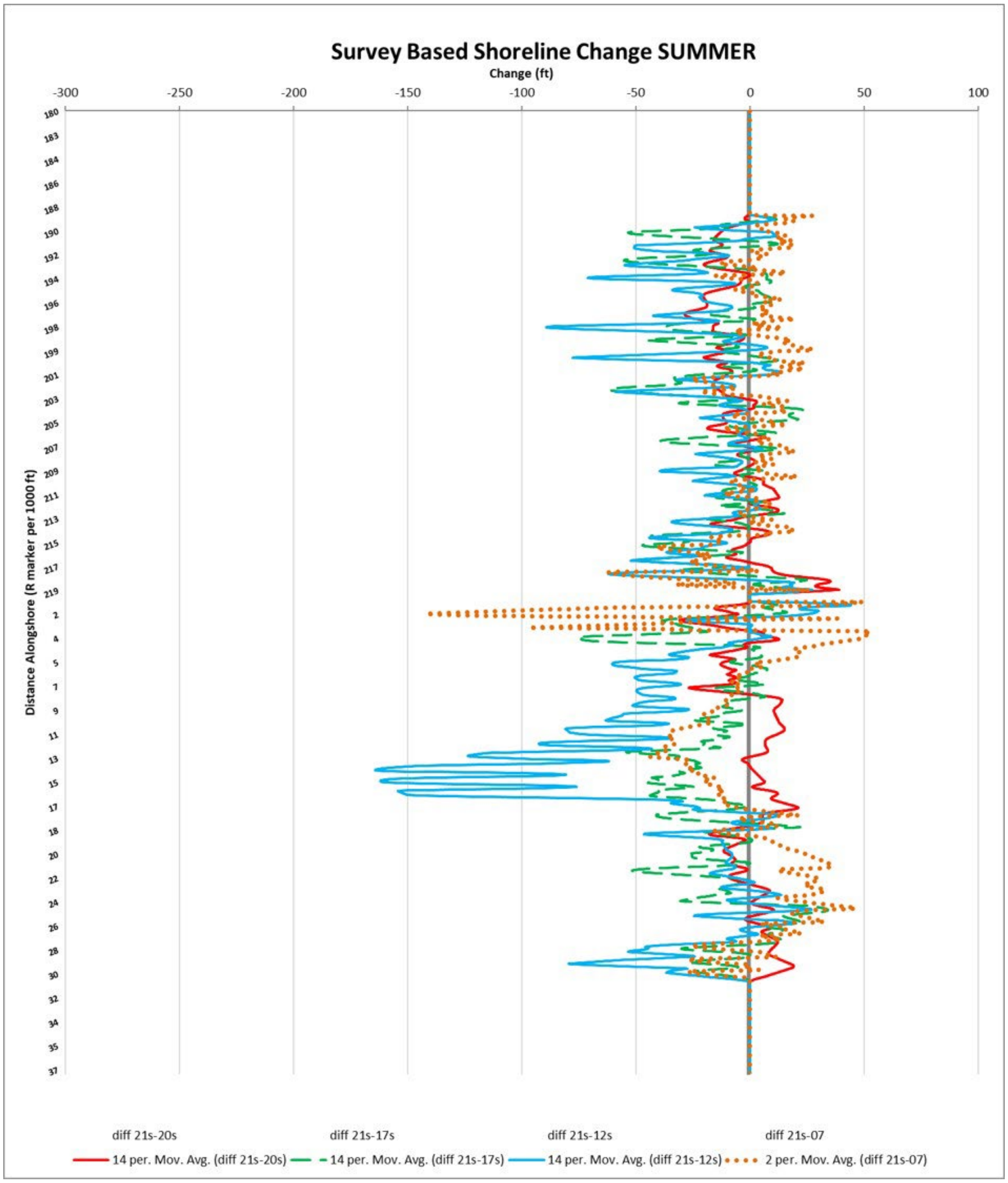


Figure 52. Survey-based change (ft) in shoreline position for 22s-21s (red line), 17s-21s (dashed-green line), 12s-21s (blue line), and 07s-21s (dotted-orange line).

The Summer period of **2017s-2021s** (Figure 52, green dashed line) show landward shoreline excursions consistently throughout the domain. The maximum value of shoreline retreat is -81.23 ft found near R-marker 4. In general, this period shows 52.54% erosion and

25.08% accretion (Figure 53-c and Table 11). The average rate at which the shoreline is changing is -2.2785 ft/yr with a range of the rate of change reaching values from -22.5650 ft/yr to +15.2375 ft/yr.

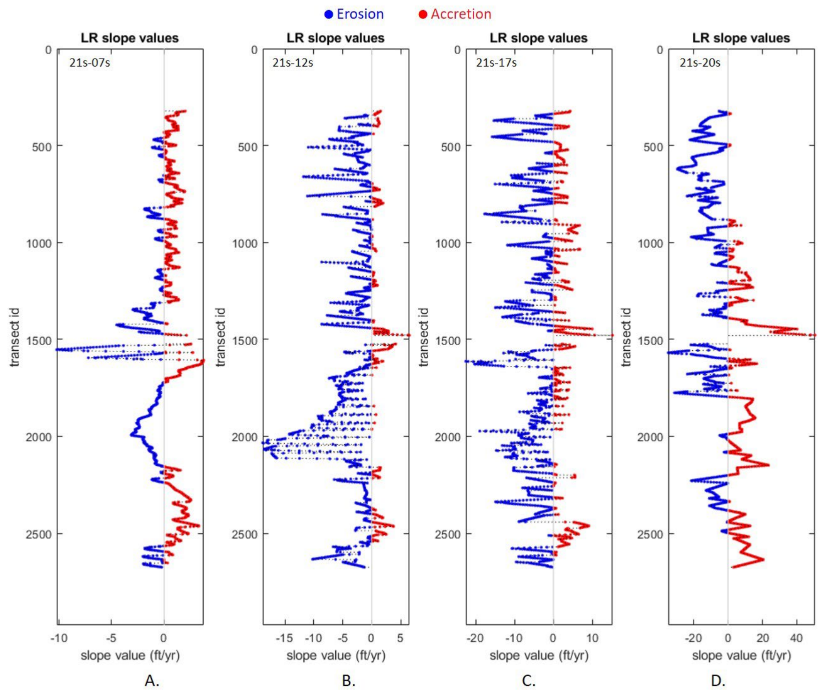


Figure 53. Shoreline rate of change (in ft/yr) for entire domain SUMMER surveys: (a) 07s-21s, (b) 12s-21s, (c) 17s-21s, and (d) 20s-21s.

The results for **Summer 2020-2021** analysis show several excursions in the shoreline that alternate from advancement and retreat (Figure 52, red line); however, the most dominant pattern throughout the domain tends towards landward migration (recession). The receding shoreline accounts for 42.69% erosion (Figure 53-d and Table 11). Overall, this period has an average rate of shoreline change of -1.3958 ft/yr and a range of -34.79 ft/yr to +50.57 ft/yr.

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 in Figure 54 for 2022 image (black line), 2022 winter (blue line), and 2021 summer (red line). 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 and years.

Results indicated that both survey-based shorelines (22w and 21s) are predominantly positioned seaward from the 2022 image-based shoreline (22i) with several reversals from this trend found along the entire domain and most noticeably in segments N2 and S3.

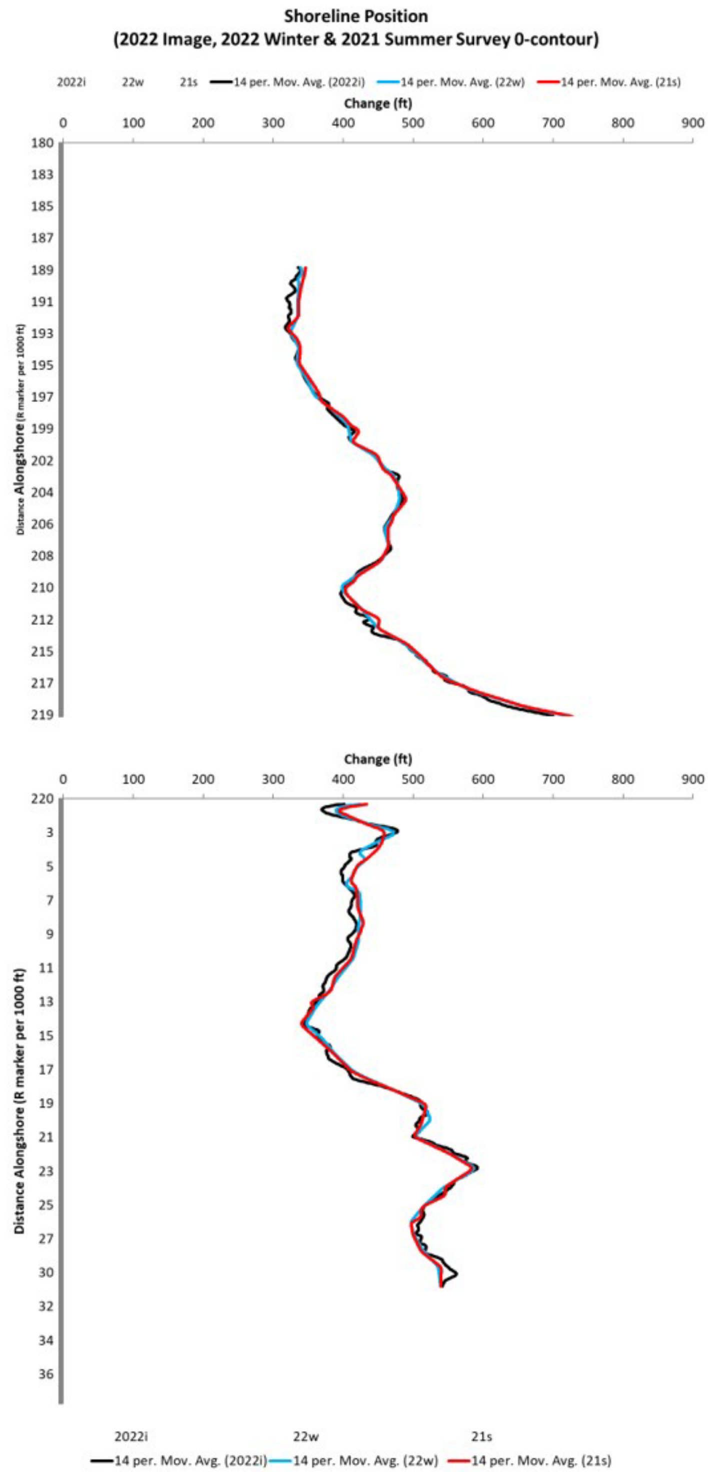


Figure 54. Shoreline positions for image-based and survey-based. Black line is 2022 Aerial image; Blue line is 2022 Winter survey; and red line is 2021 Summer survey.

8.0 Real- Time and Forecast Model of Sebastian Inlet: Update

A coastal processes model application 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.

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.

Model setup and calibration procedures have been described in previous State of the Inlet Reports. 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). In this report we briefly describe the application of machine learning or deep learning methods (DLM) applied to the Sebastian Inlet model that can be used if measured or other model data are not available. The DLM methods can also referred to as artificial intelligence methods. In practice, this would allow the model to continue to produce predictions even if data sources for model boundary conditions or temporarily or permanently unavailable. Details of DLM methods can be found in Bolton and Zanna, 2019

8.1 Deep Learning Model Performance

Flow boundary conditions were created by using data predicted by DLM. The predicted salinity, temperature and water level data were added with corresponding hindcast data in accordance with the datetime. Two different simulations were run separately – one with deep learning forecast data and another with original HYCOM data in a similar setup. Model outputs were compared at Sebastian Inlet and LOBO station inside the Indian River Lagoon. Timeseries of model results for water level, salinity, temperature, u, and v components of velocity were compared.

Water level

Water level timeseries were compared (Figure 55) at three stations – inside Sebastian Inlet, North jetty located north of the inlet in coastal ocean and the LOBO station inside the IRL estuary. Water level (blue line) output from the model run with deep learning prediction matches quite well with output from the model with HYCOM forecast data (red line). However, the deviation increases as prediction goes further in future timesteps. The heat map of water level difference between original forecast and deep learning predicted forecast in Sebastian Inlet (Figure 56) shows water level difference is ~0 inside estuary and coastal area but there is difference of 0.02m near open ocean boundaries.

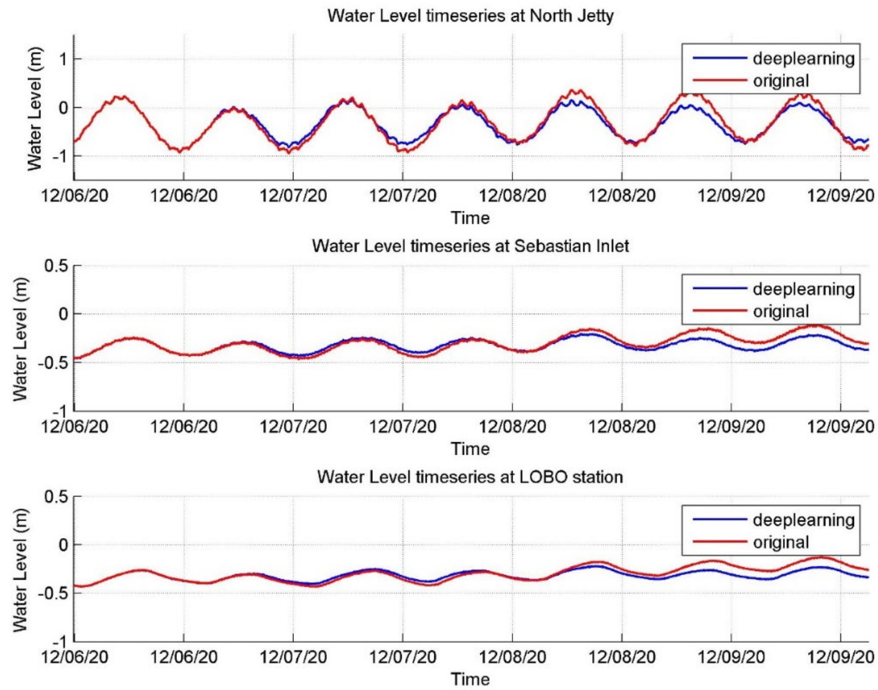


Figure 55. Water level timeseries of simulation outputs with deep learning forecast data (blue line) and HYCOM forecast data (red line) at North Jetty (top panel), Sebastian Inlet (middle panel) and LOBO station (bottom panel).

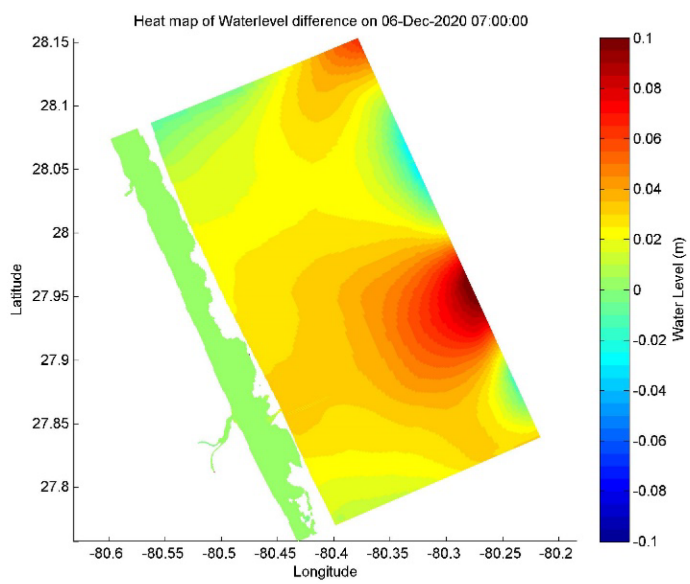


Figure 56. Heat map for water level difference between original and deep learning forecast in Sebastian Inlet region.

Salinity and Temperature

Salinity and temperature outputs from both simulations were compared at two stations including LOBO (Figure 57) and Sebastian Inlet (Figure 58). At both stations salinity and temperature comparison showed similar patterns, near perfect match for first 2 days but on third (last) day a small difference emerged. The difference is also insignificant in absolute value which indicates a very good match between original and deep learning prediction data. Thus, it is concluded that the deep learning model successfully predicted salinity and temperature data.

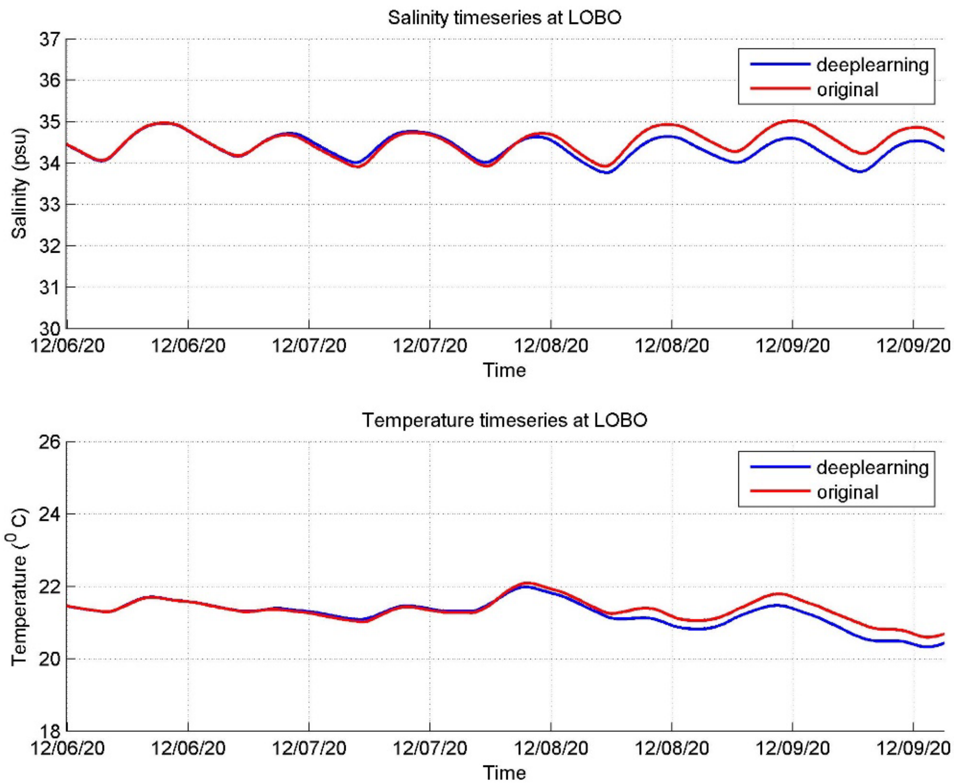


Figure 57. Top panel: Salinity timeseries of simulation results with deep learning forecast data (blue line) and original forecast data (red line) at LOBO station. Bottom panel: Similar plot for temperature.

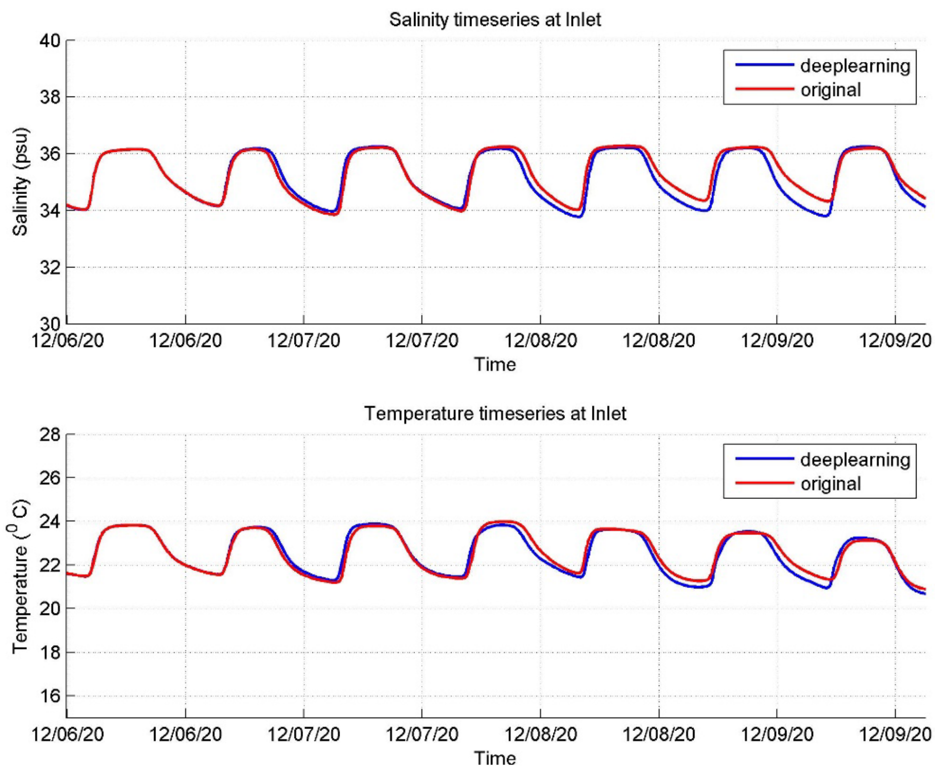


Figure 58. Top panel: Salinity timeseries of simulation results with deep learning forecast data (blue line) and original forecast data (red line) at Sebastian Inlet. Bottom panel: Similar plot for temperature.

The heat map plot (Figure 59) for salinity difference between original forecast and deep learning predicted forecast in Sebastian Inlet shows that deep learning predicted forecast is close to the original forecast over the model domain except for a 0.01 psu difference which is quite small. Figure 59 also presents a temperature difference heat map between deep learning and original forecast in Sebastian Inlet region, which shows deep learning predicted forecast model matched well with original forecast model throughout model domain except near ocean boundaries where temperature difference is 0.2^0C. Noticeable differences near open ocean boundaries at a few those locations could be due to complex mesh grid associated with these area and significantly higher ocean depth.

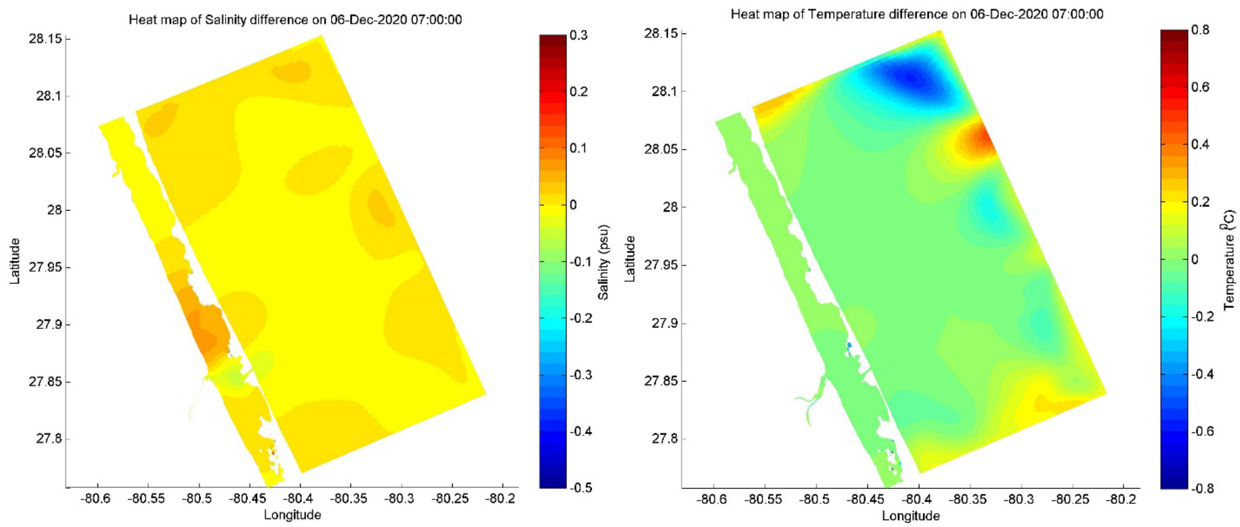


Figure 59. Left: Heat map for salinity difference between original and deep learning forecast models in Sebastian Inlet region. Right: Similar plot for temperature.

E-W and N-S velocity component

E-W and N-S velocity components were also compared at the LOBO station (Figure 60) and Sebastian Inlet (Figure 61). At LOBO station, u and v component of velocity predicted from deep learning matched well with observed data except for some difference at the end. DLM prediction at Sebastian Inlet showed bit more deviation than that of LOBO on last day of the prediction. Figure 62 presents E-W and N-S velocity component differences in a heat map difference between deep learning and original forecast in Sebastian Inlet region. The difference is near 0 over most of the model domain except near and at open ocean boundaries where the difference is 0.5 m/s.

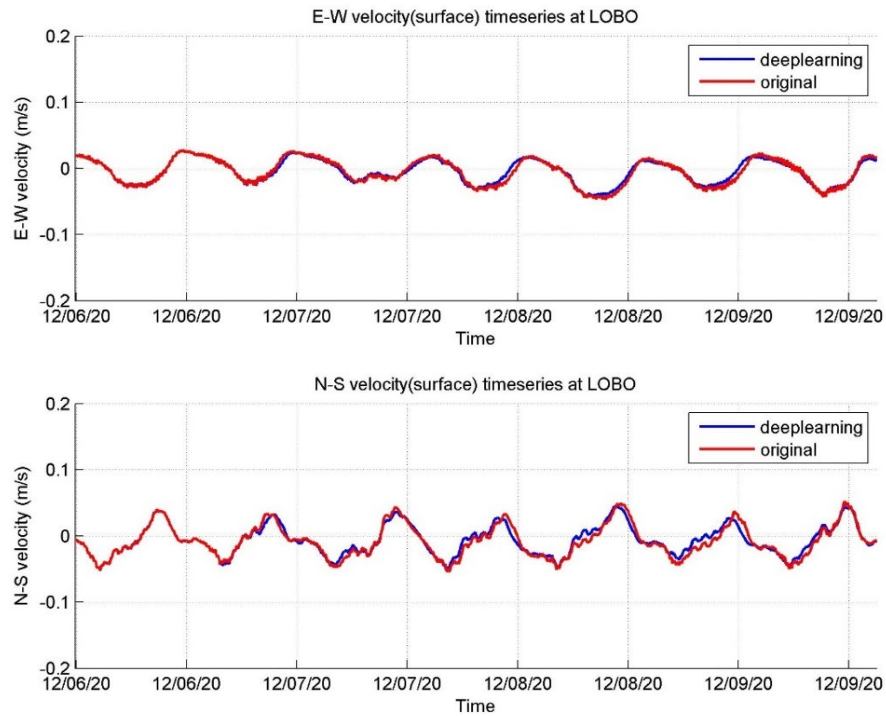


Figure 60. Top panel: E-W velocity timeseries of simulation results with deep learning forecast data (blue line) and original forecast data (red line) at LOBO station. Bottom panel: Similar plot for N-S velocity component.

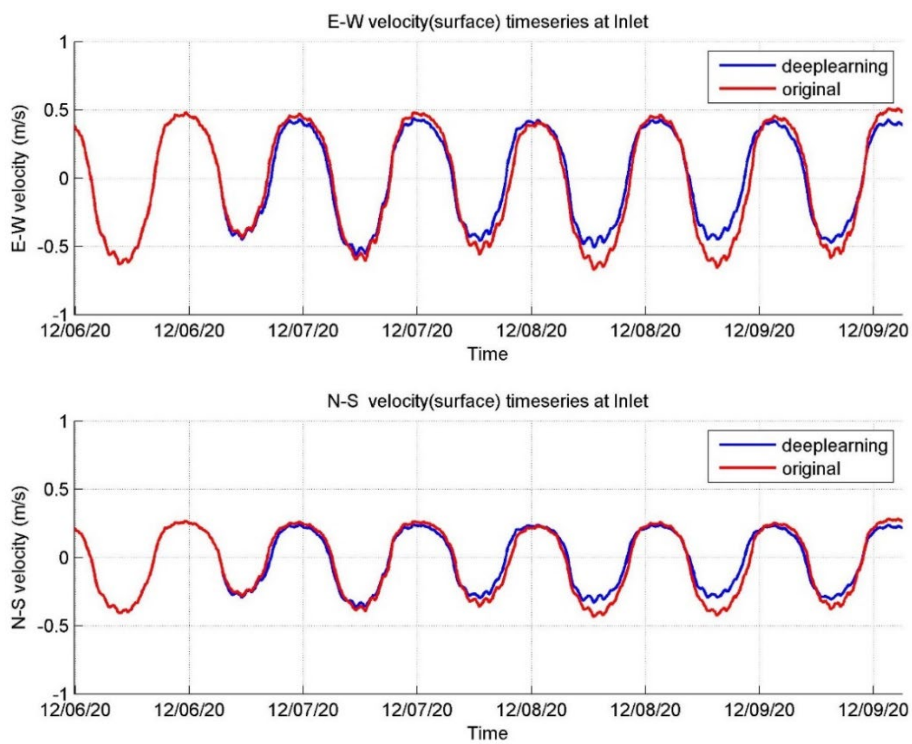


Figure 61. Top panel: E-W velocity timeseries of simulation results with deep learning forecast data (blue line) and original forecast data (red line) at Sebastian Inlet. Bottom panel: Similar plot for N-S velocity component.

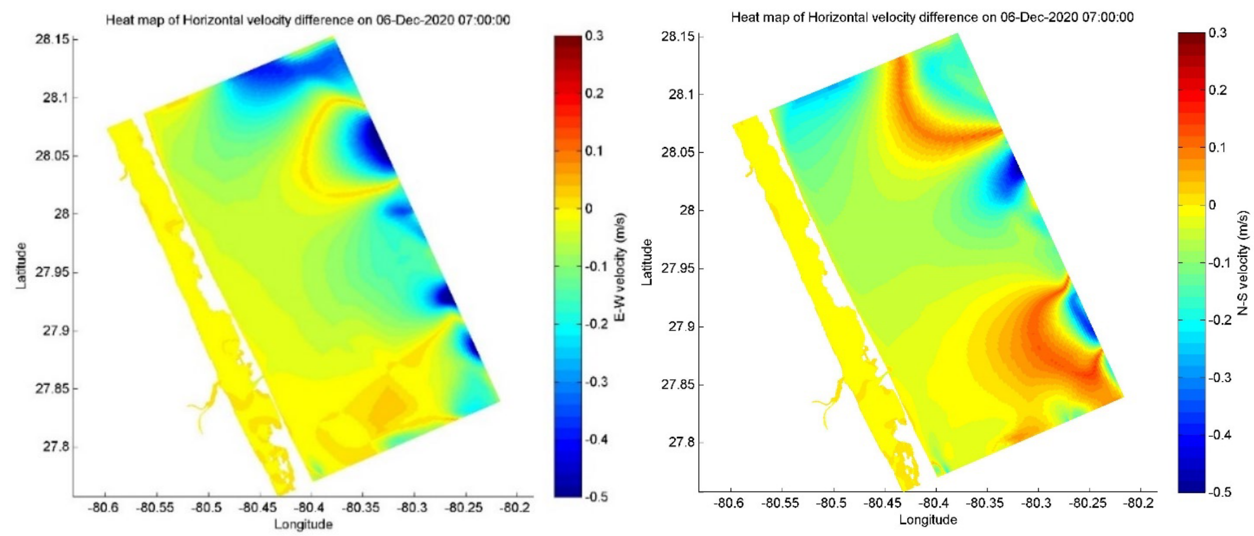


Figure 62. Left: Heat map for E-W velocity component difference between original and DLM models in Sebastian Inlet region. Right: Similar plot for N-S velocity component.

The deep learning model as applied to the Sebastian Inlet areas displayed high accuracy in predicting salinity, temperature, and water level data. Forecast run with DLM showed strong correlation with original simulations. However, the accuracy decreases with increased timescale, which could be due to propagation errors associated with recursive methods. A hybrid method, combination of direct and recursive strategy, could be another alternative to multi-day forecasts. However, this approach would be computationally expensive due to the need for developing multiple models at the same time. DLM developed here using recursive strategy performed quite well to accomplish desired goal of getting 3 days of forecast, therefore a computationally expensive approach was not adopted here. The deep learning model presented here is applicable to the Sebastian Inlet area. To apply this deep learning model for other locations, the model will need to be retrained using site-specific data with similar techniques as applied here.

The DLM developed in this study could resolve the issue of lack of forecast data in developing coastal and estuarine models, especially for several days of forecast. This study documents concept, detailed methods, development, performance, and application of deep learning model and nested model approach in estuarine and coastal modeling. This work could serve as framework for future use, development, and implementation of a real time forecast modeling system for estuary and coastal area where forecast data are unavailable. Future research would greatly benefit from similar data driven approaches supplemented to numerical modeling.

Overall, deep learning model predicted results correlated satisfactorily with the original simulation, thus machine learning model could help resolve the issue of inadequate data in developing coastal and ocean model.

9.0 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) an update of the real-time and forecast coastal processes numerical model described the application of deep learning methods (DLM) to deal with gaps or absence of data at model boundaries.

- 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 2022 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 15-year period between 2006 and 2022, it can be demonstrated that periods of increasing cumulative sand volume losses correspond to periods of rising sea level

- Shorter interannual periods of either falling or rising sea level correspond to periods of cumulative sand volume gains or losses respectively as exemplified by a period of falling sea level from 2015-2018 and the 2010-2012 period of rising sea level
- The dynamic equilibrium and trends of sand volume changes within the inlet sand reservoirs associated with Sebastian Inlet are summarized in sediment budget calculations.
- The sand budget for the Sebastian Inlet region is reported at three-time scales, including a longer time scales of 15 and 10 years, a time scale of 2 to 3 years to demonstrate the ability of the coastal sand reservoir to respond to rapid and abrupt sea level fluctuations.
- Over the time period of 2007-2022, 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 continued use of beach/upper shoreface and lower shoreface inner continental shelf sediment budget cell subdivisions 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.
- Deep learning methods (DLM) as applied to the coastal processes model can be applied when/if model boundary data, either measured from other models is interrupted or unavailable.
- 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.

Acknowledgments:

The project team acknowledges the Sebastian Inlet District Commissioners, the District Executive Director James Gray for their support.

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