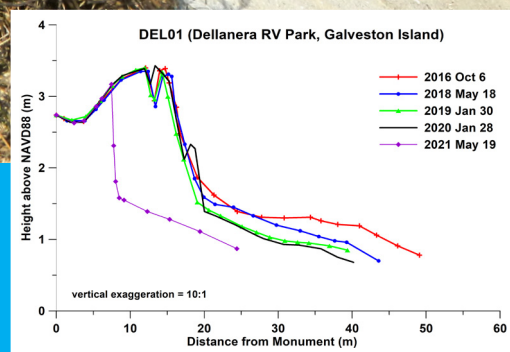
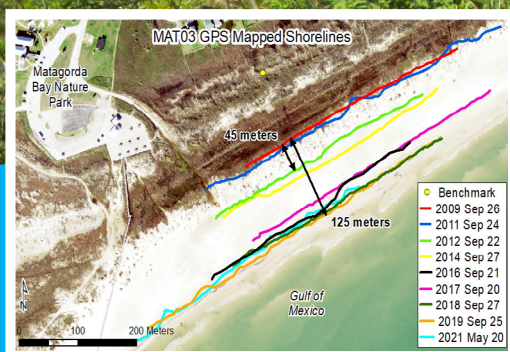
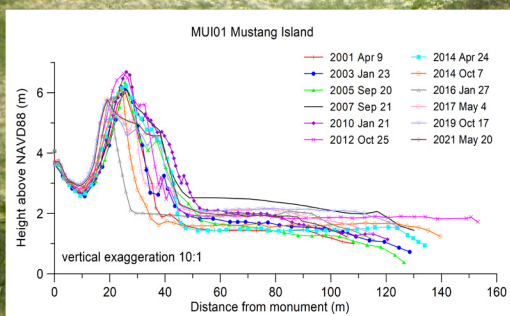
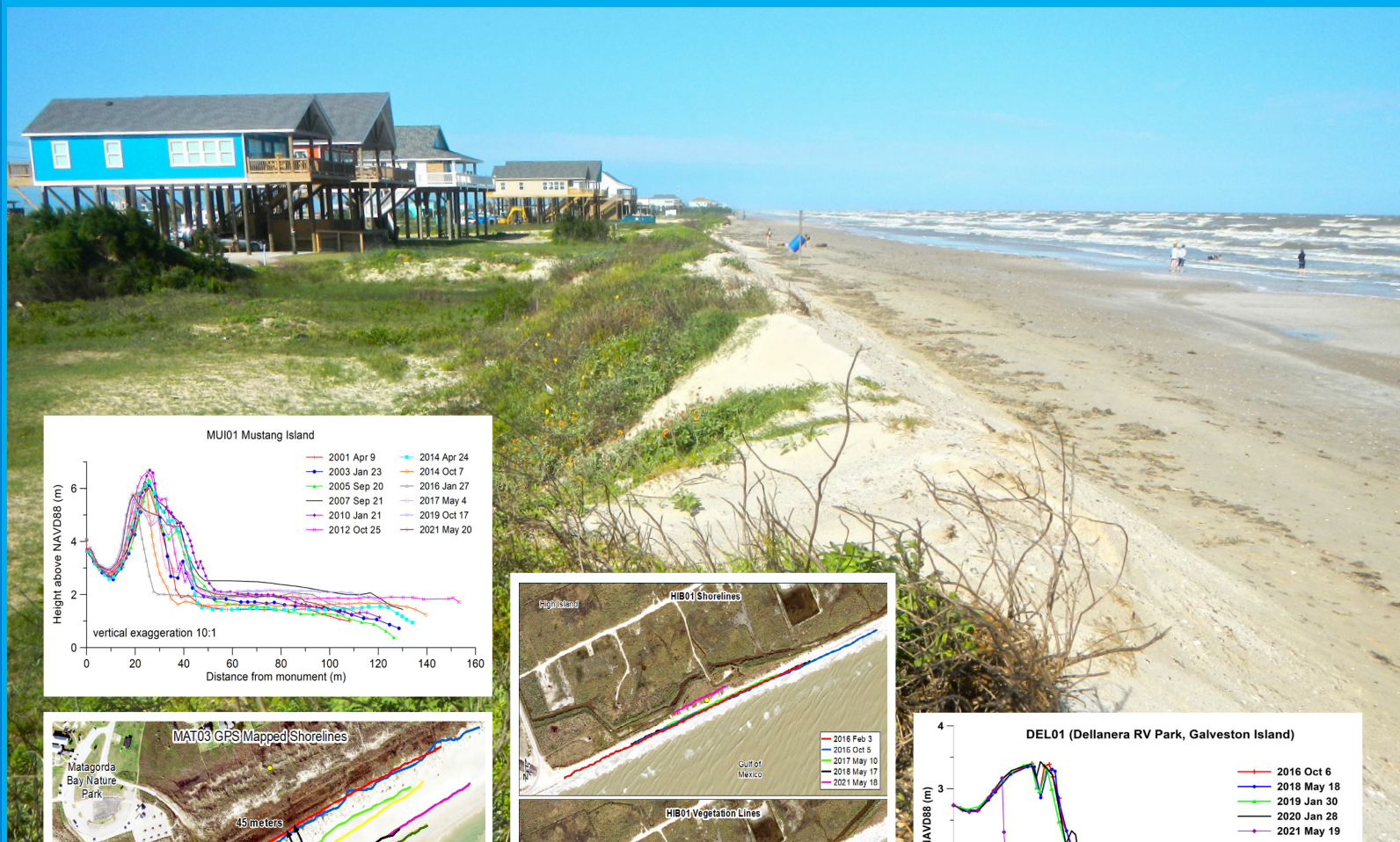


FINAL REPORT

Texas High School Coastal Monitoring Program: 2020–2021

Tiffany L. Caudle



Bureau of Economic Geology

Scott W. Tinker, Director

Jackson School of Geosciences

The University of Texas at Austin, Austin, Texas 78713-8924

September 2021



F I N A L R E P O R T

Texas High School Coastal Monitoring Program: 2020–2021

Tiffany L. Caudle

Report to the Texas Coastal Coordination Council pursuant to
National Oceanic and Atmospheric Administration Award No. NA19NOS4190106

Final report prepared for General Land Office under contract No. 20-039-000-B747

Bureau of Economic Geology
Scott W. Tinker, Director
Jackson School of Geosciences
The University of Texas at Austin, Austin, Texas 78713-8924

September 2021



TABLE OF CONTENTS

Table of Contents.....	i
Tables	ii
Figures	ii
Introduction	1
Program Description	3
Goals.....	3
Methods	4
Data Management, Data Analysis, and Dissemination of Information	7
Student, Teacher, and Scientist Interactions	8
High Island High School	11
Ball High School	12
Brazosport High School.....	13
Matagorda Area Schools	14
Port Aransas High School	15
Cunningham Middle School	16
Port Isabel High School.....	17
Effects on Scientific Research, Coastal Management, and Public Awareness	18
Scientific Results and Texas Coastal Changes: 1997–2021	24
Bolivar Peninsula.....	25
Galveston Island.....	27
Surfside Beach and Quintana Beach	31
Matagorda Peninsula	34
Mustang Island	37
North Padre Island	42

South Padre Island.....	43
3D Coastal model	46
Conclusions	47
Acknowledgments.....	48
References	49
Appendix A: Profile Information	52
Appendix B: Graphs of Volume, Shoreline, and Vegetation Line Change	53
Appendix C: Graphs of Beach Profiles.....	65
Appendix D: Maps of GPS Shoreline and Vegetation Line Positions.....	127

TABLES

Table 1. Schools involved in the THSCMP.....	9
---	---

FIGURES

Figure 1. Location map of participating schools.	2
Figure 2. Students using (A) a sighting level to determine vertical offset between Emery rods and (B) a metric tape to measure horizontal distance.	6
Figure 3. Students mapping (A) the vegetation line and (B) the shoreline (wet/dry line) using handheld GPS units.	6
Figure 4. Students (A) using a sighting compass to measure dune orientation and (B) measuring how far along the shoreline the float (an orange) drifted to determine longshore current.....	7
Figure 5. Location map of High Island High School monitoring sites.	12
Figure 6. Location map of Ball High School monitoring sites.	13
Figure 7. Location map of Brazosport High School monitoring sites.	14
Figure 8. Location map of sites monitored by Matagorda-area schools.	15

Figure 9. Location map of Port Aransas High School monitoring sites.....	16
Figure 10. Location map of Cunningham Middle School monitoring sites.	17
Figure 11. Location map of Port Isabel High School monitoring sites.	18
Figure 12. Lidar topographic-relief image of Galveston Island State Park and Pirates Beach subdivision. Note the difference in beach width between the natural beach and the area in front of the subdivision. From Gibeaut and others (2003).	20
Figure 13. Shoreline position comparison at South Padre Island site SPI08. Shorelines include the wet-beach/dry-beach boundary mapped on September 27, 2011, and September 26, 2012, by THSCMP students using GPS and the shoreline proxy extracted from airborne lidar data acquired in February 2012. Shorelines are superimposed on NAIP imagery acquired on April 23, 2012. From Paine and others (2014).	21
Figure 14. Shoreline position comparison at Surfside Beach site SURF2. Shorelines include the wet-beach/dry-beach boundary mapped on April 24, 2019, by THSCMP students and Bureau staff using ground GPS and the 1 m (3.3 ft) msl shoreline proxy extracted from airborne lidar data acquired in spring 2019, superimposed on 2019 Bureau imagery. From Paine and others (2021).	22
Figure 15. Changes at HIB01 monitored by High Island High School students.	26
Figure 16. Changes to the position of the (A) shoreline and (B) vegetation line at HIB01 between February 2016 and May 2021	27
Figure 17. Profile volume, shoreline, and vegetation-line changes at Galveston Island State Park, September 1994–April 2008.....	28
Figure 18. Beach-profile plots from BEG02 in Galveston Island State Park comparing the post–Hurricane Ike profile with a pre-storm profile from early 2008 and the post–Tropical Storm Frances profile from September 1998. Data from September 2009 (1 year post-storm) is also included.	30
Figure 19. BEG02 datum-reset post–Hurricane Ike profile, plus data collected by Ball High School students. Students are monitoring recovery of the beaches and dunes at this site.....	31
Figure 20. Erosion of the dune at DEL01 in the Dellanera RV Park due to the 2020 hurricane season	32
Figure 21. GPS mapping by Brazosport HS students. A) Shoreline positions at SURF1 from October 2018 through May 2021. B) Vegetation line positions at QUIN1 from April 2019 through May 2021. Both sites have experienced significant erosion during the 2020 hurricane season.....	33

Figure 22. Pre– and post–Hurricane Ike profile data collected by Van Vleck High School students at (A) MAT01 and Palacios High School students at (B) MAT02. Students are monitoring recovery and growth of the foredune at these sites.	35
Figure 23. Shoreline position change at Matagorda Peninsula.	36
Figure 24. Changes in beach and dune volume, shoreline position, and vegetation-line position at MAT03 on Matagorda Peninsula.	37
Figure 25. Foredune expansion at MUI01 on Mustang Island.....	38
Figure 26. Excavated dune profile at MUI01 on Mustang Island.	39
Figure 27. Excavated dune at MUI01 on Mustang Island looking (A) north toward Horace Caldwell Pier and (B) landward.....	39
Figure 28. Mustang Island pre– and post–Hurricane Harvey profile data collected by Port Aransas High School and Texas A&M University–Corpus Christi at (A) MUI01 and (B) MUI03.....	41
Figure 29. Student monitoring at MUI02 documents an increase in volume of the dune system and seaward migration of the vegetation line.	42
Figure 30. Foredune crest changes at NPI08 monitored by Cunningham Middle School students.	43
Figure 31. Changes in sand volume and in shoreline and vegetation-line positions at SPI02 on South Padre Island due to beach nourishment projects and the installation of sand fences.	44
Figure 32. Sand volume and shoreline position changes at SPI08 on South Padre Island due to beach nourishment projects and the installation of sand fences. .	45

INTRODUCTION

The Texas High School Coastal Monitoring Program (THSCMP) is designed to help students and communities living on the Texas coast develop a better understanding of their natural environment. Students, teachers, and scientists work together to gain a better understanding of dune and beach dynamics in their regions. Scientists from The University of Texas at Austin's Bureau of Economic Geology (the Bureau) lead the research and outreach program by providing the tools and training needed for scientific investigation. Students and teachers learn how to measure topography, map vegetation lines and shorelines, and observe weather and wave conditions. Coastal processes, the beach and dune environment, and public access and private property rights provide an ideal setting for teaching middle school and high school students basic and applied science and for illustrating the roles that science and good data-collection practices play in public policy decision-making.

By participating in an actual research project, the students obtain an enhanced science education and provide coastal decision-makers with valuable data about the Texas shoreline. Students monitor changes in beaches, dunes, and vegetation-line position on Bolivar Peninsula, Galveston Island, Follets Island, Matagorda Peninsula, Mustang Island, North Padre Island, and South Padre Island (**Fig. 1**). In support of coastal-management issues, data collected by students are useful in explaining beach cycles and defining short-term versus long-term trends. Defining these trends is important in decision-making regarding coastal development, beach nourishment, and dune restoration projects. The THSCMP observes beaches in several coastal parks: Mustang Island and Galveston Island State Parks, overseen by the Texas Parks & Wildlife Department (TPWD); the Lower Colorado River Authority's Matagorda Bay Nature Park; Cameron County's Isla Blanca Park; Brazoria County's Quintana Beach County Park, and the City of Galveston's Dellanera RV Park. The data collected within these park systems help managers develop a better understanding of their local coastal environments, which allows managers to make wise decisions in long-term management and future park development.

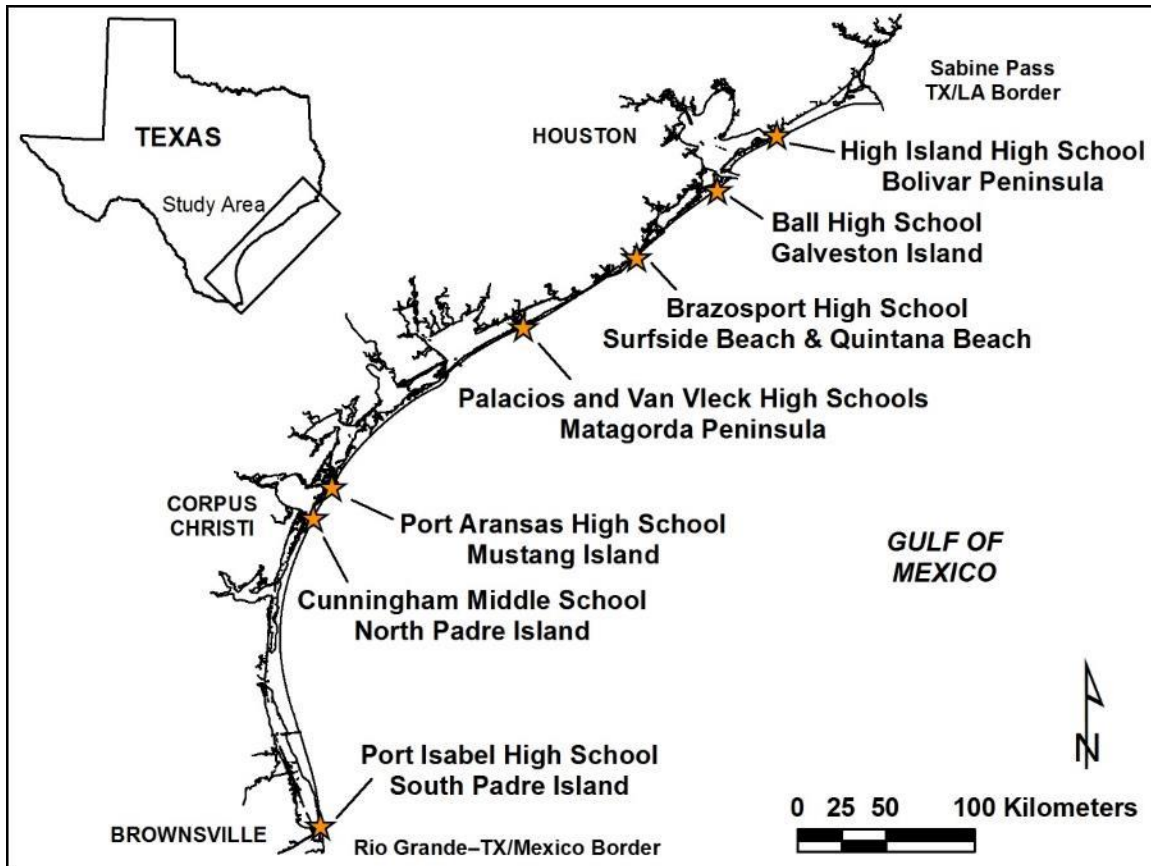


Figure 1. Location map of participating schools.

This report describes the program during the 2020–2021 academic year. During this time, student field trips did not take place due to the ongoing COVID-19 global pandemic. Bureau scientists visited all the THSCMP monitoring sites in order to document and assess the beach and dune system through photographs, map the vegetation line and shoreline with handheld GPS, and conduct beach profiles where feasible. An analysis of data collected and observations made by the scientists is included in this report.

Bureau scientists have created a web-based 3D model for visualizing beach and dune impacts and recovery from Hurricane Ike in 2008 and Hurricane Harvey in 2017. The visualization project includes the following scenes: a general overview of the Gulf of Mexico, overviews of the two hurricanes, and detailed scenes focusing on High Island, Galveston Island State Park, a segment of San Jose Island, and Port

Aransas (<https://www.beg.utexas.edu/visualizations/3d-coastal-model/>). The program is also enhanced by a continuously updated website that includes an interactive data viewer, scientific observations made by each of the participating schools, educational resources including new learning activities, field guides, and recorded lectures about THSCMP and hurricanes (<http://www.beg.utexas.edu/thscmp/>).

PROGRAM DESCRIPTION

Goals

The coastal monitoring program has three major goals:

(1) Provide students with an inquiry-based learning experience. Students make several field trips to their study sites during the school year. Working in teams, they conduct topographic surveys (beach profiles) of the foredune and beach, map the vegetation line and shoreline, collect sediment samples, and observe weather and wave conditions. Back in the classroom, students analyze their data and look for relationships among the observed phenomena. Bureau scientists provide background information and guide inquiries about the data, but students are encouraged to form and test their own hypotheses. Through their collaboration with working scientists on an actual research project, the students gain an enhanced science education.

(2) Increase public awareness and understanding of coastal processes and hazards. All data collected by the students and analyses made by Bureau scientists are publicly available for use by coastal managers, scientists, decision-makers, and the general public. The THSCMP website (<http://www.beg.utexas.edu/thscmp/>) containing the latest data, analysis, photos, and educational resources is central to the project's community outreach aspect. Further aspects of the program conducted to improve public awareness include presentations at conferences by Bureau scientists, student presentations and data-collection demonstrations at community outreach events, the annual report, and scientific journal articles.

(3) Achieve a better understanding of the relationship between coastal processes, beach morphology, and shoreline change, and make data and findings available for solving coastal management problems. The Bureau has conducted a 40-year research program to monitor shorelines and investigate coastal processes. An important part of this program is repeated shoreline mapping and beach profile measuring. Over time, these data are used to determine the rate of shoreline change. A problem we face is the limited temporal resolution of our shoreline data. The beach is a dynamic environment where significant changes in shape and sand volume can occur over periods of days or even hours. Tides, storms, and seasonal wind patterns cause large, periodic or quasiperiodic changes in the shape of the beach. If coastal data are not collected often enough, periodic variations in beach morphology could be misinterpreted as secular changes. The THSCMP helps address this problem by providing scientific data at key locations along the Texas coast. These data are integrated into the ongoing coastal research program at the Bureau and are made available to other researchers and coastal managers.

Methods

The central element of the monitoring program is at least three class field trips during the academic year, weather permitting. During each trip, students visit several locations and apply scientific procedures to measure beach morphology and to make observations on beach, weather, and wave conditions. These procedures were developed during the program's pilot year (1997–1998) and are available on our website, which also includes field forms. A general discussion of the field measurements follows.

Beach profile: Students use a pair of Emery rods, a metric tape, and a hand level to accurately survey a shore-normal beach profile from behind the foredunes to the waterline (**Fig. 2**; Emery, 1961; Krause, 2004; O'Connell, 2001). The students begin the profile at a pre-surveyed datum stake so that they can compare each new profile with earlier profiles. Consistently oriented photographs are taken with a digital

camera. The beach profiles provide detailed data on the volume of sand and the shape of the beach.

Shoreline and vegetation-line mapping: Using handheld Global Positioning System (GPS) units, students walk along the shoreline and vegetation line, mapping these features for display on Geographic Information System (GIS) software (**Fig. 3**). GPS mapping can be used to measure the rates of change to these features. By comparing positions determined through GPS mapping over time, students are able to visualize shoreline and vegetation-line changes.

Beach processes observations: Students measure wind speed and direction, estimate the width of the surf zone, and observe breaker type. They note wave direction, height, and period and they estimate longshore current speed and direction using a float, stopwatch, and tape measure (**Fig. 4**). Students also take readings of shoreline and foredune orientation (**Fig. 4**). From these measurements, they can infer relationships between physical processes and beach changes in time and space. Students also learn to obtain weather and oceanographic data from online resources.

Bureau scientists provide teachers and students with all the training, information, field forms, and equipment needed to conduct the field measurements. During the academic year, Bureau scientists accompany students on at least one field trip. The scientists and students discuss general and theoretical issues regarding scientific research, as well as coastal issues relevant to their community and the State of Texas. These visits also provide scientists with an opportunity to ensure the quality of the data.



Figure 2. Students using (A) a sighting level to determine vertical offset between Emery rods and (B) a metric tape to measure horizontal distance.



Figure 3. Students mapping (A) the vegetation line and (B) the shoreline (wet/dry line) using handheld GPS units.



Figure 4. Students (A) using a sighting compass to measure dune orientation and (B) measuring how far along the shoreline the float (an orange) drifted to determine longshore current.

Data Management, Data Analysis, and Dissemination of Information

All THSCMP data since the inception of the program have been analyzed and archived by Bureau scientists. The THSCMP produces several data products: topographic profiles representing the beach and dune system; GIS shapefiles mapping shorelines and vegetation lines; and photographs of shorelines, vegetation lines, and foredune crests from each data collection site. All scientific data, analyses, and results from the THSCMP are publicly available either through the THSCMP website or by request to Bureau staff.

The THSCMP website (<http://www.beg.utexas.edu/thscmp/>), housed and maintained on a Bureau server, is central to the dissemination of data collected for this program. The website was implemented toward the end of the 1998–1999 academic year. It provides all the information needed to begin a beach-monitoring program and curriculum materials for high school teachers. Each school in the program has a

page on the website dedicated to data, observations, and photos related to their study area. Numerous educational resources are curated on the website that have been developed for use by students and teachers to enhance learning about coastal environments, processes, issues, and hazards. A shoreline movement activity was created this year to help students learn more about the Bureau's Texas Shoreline Change Project and utilizing the interactive shoreline viewer. The website also hosts the 3D coastal visualization model that was developed this year to supplement in-class or at-home learning about coastal change.

STUDENT, TEACHER, AND SCIENTIST INTERACTIONS

During the 2020–2021 academic year, field trips did not take place due to the ongoing COVID-19 global pandemic. Non-essential research travel was prohibited by The University of Texas at Austin through August 31, 2021. The participating school districts were also not allowing field trips during the academic year. The nature of the THSCMP field trips requires middle and high school students to work in close contact with each other to conduct beach profile measurements. Despite being outdoors, it would have been irresponsible of program coordinators to ask students and teachers to conduct these measurements while COVID-19 and its variants were still spreading in communities throughout Texas. The following is a description of the typical student, teacher, and scientist interactions that will resume in the 2021–2022 academic year.

In 1997, Bureau researchers developed a pilot beach-monitoring program with Ball High School on Galveston Island (Caudle and Paine, 2012; Hepner and Gibeaut, 2004). The THSCMP has since expanded several times to now include a total of eight schools (**Fig. 1, Table 1**). Expansion of the program has not only increased the number of schools in the THSCMP but also included middle school students. Students in the program are enrolled in classes such as physics, environmental science, biology, aquatic science, and general science.

Table 1. Schools involved in the THSCMP.

School	Location	Year Started
Ball HS	Galveston Island	1997
Brazosport HS	Surfside & Quintana	2018
Cunningham MS	North Padre Island	2009
High Island HS	Bolivar Peninsula	2016
Palacios HS	Matagorda Peninsula	2006
Port Aransas HS	Mustang Island	1999
Port Isabel HS	South Padre Island	1999
Tidehaven MS	Matagorda Peninsula	2005
Van Vleck HS	Matagorda Peninsula	2005

Bureau researchers work with the same teachers each academic year unless changes occur because of a teacher retirement or a new school joining the program. Researchers communicate directly with teachers to schedule field trips in the fall (September or October), winter (January or February), and spring (April or May). The teacher arranges transportation to the study sites (via bus or SUV, depending on class size) and a substitute teacher to cover their classroom for the day. To encourage school districts to continue participating in the THSCMP, project support provides funding to cover the cost of student transportation and substitute teachers. A stipend is also provided to the participating teachers.

The most heavily used segments of the Texas coast are monitored two or three times a year (**Fig. 1**). Students monitor beaches, dunes, and vegetation lines on the following sandy barrier islands and peninsulas: Bolivar Peninsula, Galveston Island, Follets Island, Quintana Beach, Matagorda Peninsula, Mustang Island, and North and South Padre Islands. Staff from the Lower Colorado River Authority (LCRA) at Matagorda Bay Nature Park help facilitate field trips on Matagorda Peninsula, and

graduate students from the Harte Research Institute, Texas A&M University–Corpus Christi help with the Cunningham Middle School field trips.

A Bureau scientist visits each school at least once, usually coinciding with the first field trip of the academic year. During field trips, scientists discuss coastal issues pertaining to the area that the students are visiting, coastal issues concerning the entire State of Texas, and careers in science. These visits serve not only to enhance scientific instruction but also to give students insight into science as a career and the chance to discuss coastal community concerns.

During field trips, students are divided into two or three teams of five to eight, depending on the size of the class. One team measures the beach profile while the others collect data on weather and waves or conduct a GPS survey of the shoreline and vegetation line. Team members have specific tasks, and after each team completes its tasks at the first location, the teams switch roles so that everyone has an opportunity to collect each type of measurement. Aside from conducting the beach profile and measuring processes and the shoreline, additional tasks can be assigned to the team that finishes first. It is important to assign each student a job to keep them focused and interested, although time for a little fun is also allowed. People normally think of the beach as a place of recreation, and participation in this project should not change that. In fact, it is hoped that program participants will enjoy going to the beach even more because of their newly acquired knowledge and observation skills.

The day of the field trip, students meet in their teacher's classroom to organize equipment and gather additional materials that they may need for the day (coolers with ice and water, lunches, and so on). Throughout the day, data are collected from one to three locations, with sufficient time allotted for lunch. All trips allow ample time for careful data collection while ensuring that students are back at school about 1 hour before the end of the school day. During this hour, equipment is cleaned and stored, and datasheets are copied, and GPS files are transferred to a computer.

Schools participating in the THSCMP face challenges that sometimes hinder the data collection process. Access to sites is sometimes prohibited because of elevated water levels, flooded access roads, beach nourishment activities and equipment, or coastal construction such as dune walkover replacement. Even roadway construction can hinder access to sites. Weather conditions (such as heat, cold, or rain) or wildlife sightings (such as rattlesnakes) can present challenges to the data collection process. All possible attempts are made to overcome challenges, but the safety of students, teachers, and staff is always the highest priority, and sometimes a dataset must be missed.

High Island High School

High Island High School joined the THSCMP during the 2015–2016 academic year. Ms. Caudle works with High Island High School science teacher Maria Skewis. Science students collect data from two Bolivar Peninsula sites that are adjacent to Rollover Pass—BOL02 to the west of the pass and BOL03 to the east (**Fig. 5**). A third site (HIB01), seaward of High Island, is located just past the eastern end of Highway 87 (**Fig. 5**). HIB01 datum point has been lost due to erosion at this site. High Island students will continue to map shoreline and vegetation lines with GPS on High Island beach. Students will also begin collecting shore and vegetation line positions across the mouth of the now closed Rollover Pass. Bureau scientists collected data from the High Island HS sites on May 18, 2021.

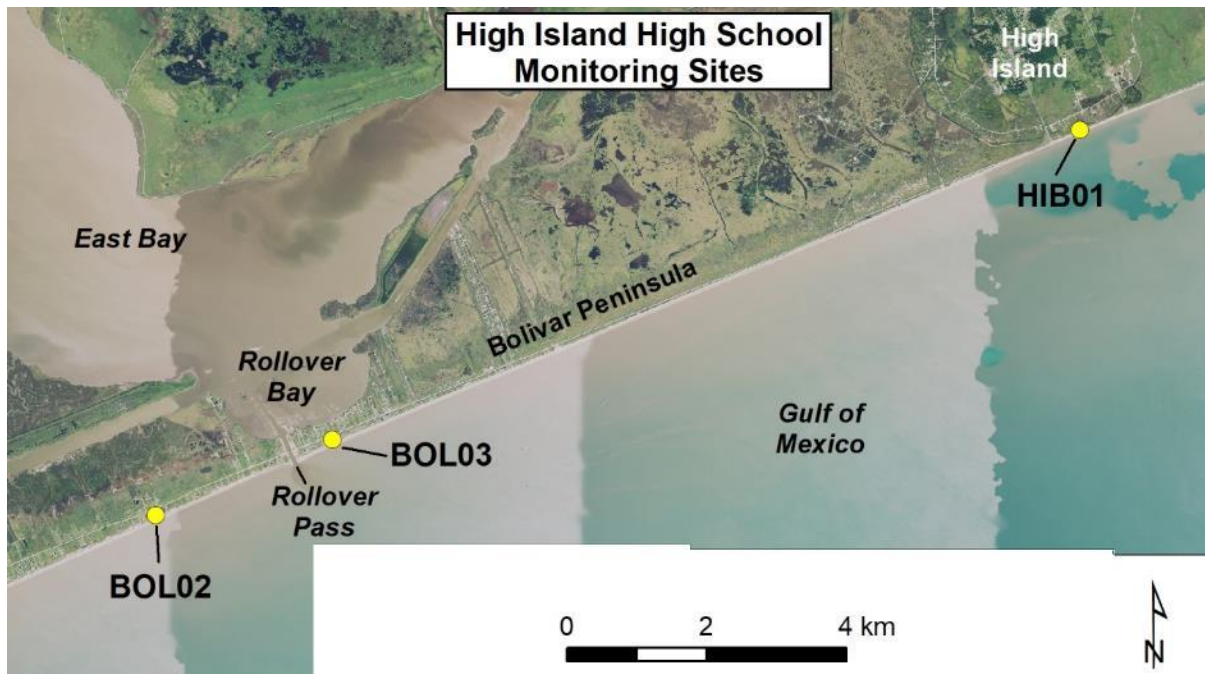


Figure 5. Location map of High Island High School monitoring sites.

Ball High School

Dr. Daniel Hochman's Advanced Placement (AP) Environmental Science classes at Ball High School conduct surveys at site BEG02 in Galveston Island State Park (**Fig. 6**), a profile that the Bureau has been measuring since the 1980's. Ball High School students also collect data at JAM02 in Jamaica Beach and DEL01 in the Dellanera RV Park (**Fig. 6**). Both of these sites monitor beach nourishment and Coastal Erosion Planning and Response Act (CEPRA) beach and dune restoration activities. GPS mapped shoreline positions are collected along the Babe's Beach section of Galveston Island (west of 61st Street) as well. Bureau scientists collected data from the Ball High School sites on May 19, 2021.



Figure 6. Location map of Ball High School monitoring sites.

Brazosport High School

Brazosport High School in Freeport, Texas, joined THSCMP during the 2018–2019 academic year. A new Environmental Science class that participates in the data collection project was added to the Brazosport curriculum. Ms. Caudle works with high school science teacher Kim Summers and senior Environmental Science students to collect data from sites at Surfside Beach and Quintana Beach. Two of the monitoring sites, SURF1 and SURF2, are located in Surfside Beach on southern Follets Island (**Fig. 7**). A third site (QUIN1) was established in Brazoria County's Quintana Beach County Park (**Fig. 7**). Bureau scientists visited the Brazosport HS monitored sites on May 19, 2021. They determined that the datum points at SURF1 and QUIN1 have been lost due to erosion. QUIN1 will be re-established in a more landward position. GPS shore and vegetation lines will continue to be mapped at

SURF1 but a new profile location will be re-established at another site on Follets Island.

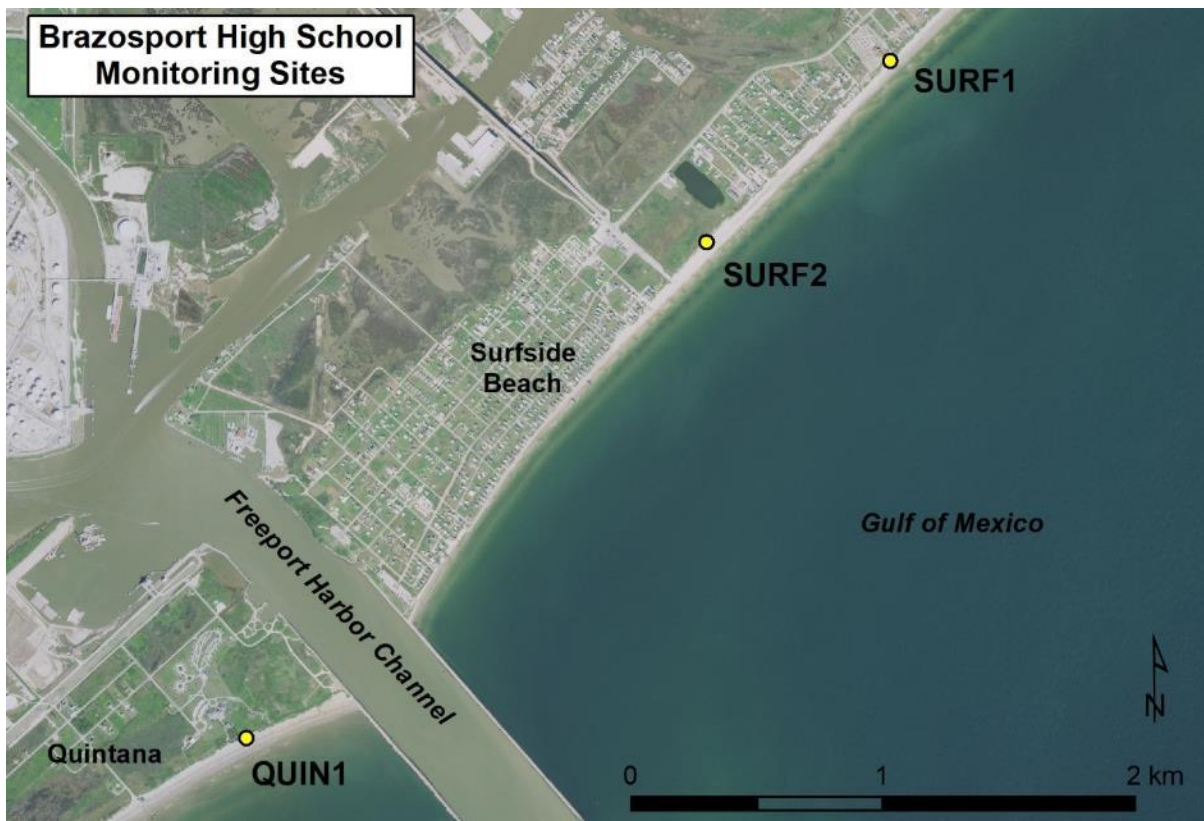


Figure 7. Location map of Brazosport High School monitoring sites.

Matagorda Area Schools

Van Vleck High School from Sherry Martinez’s environmental science class collect data at MAT01 (**Fig. 8**). Science students from Palacios High School collect data at MAT02 (**Fig. 8**). A new teacher will be joining the program for the 2021–2022 academic year. The MAT03 profile location (**Fig. 8**) has seen a significant increase in beach width, including a coppice mound field with intermittent swales that usually contain water, marsh plants, and venomous snakes. It has become dangerous for students, teachers, and staff to collect profile data at this location without the proper protective gear. Though beach profile data is no longer collected at MAT03, Van Vleck and Palacios High Schools continue mapping via GPS of the shoreline and

vegetation line positions at this site. Bureau scientists visited the Matagorda area sites on May 20, 2021.

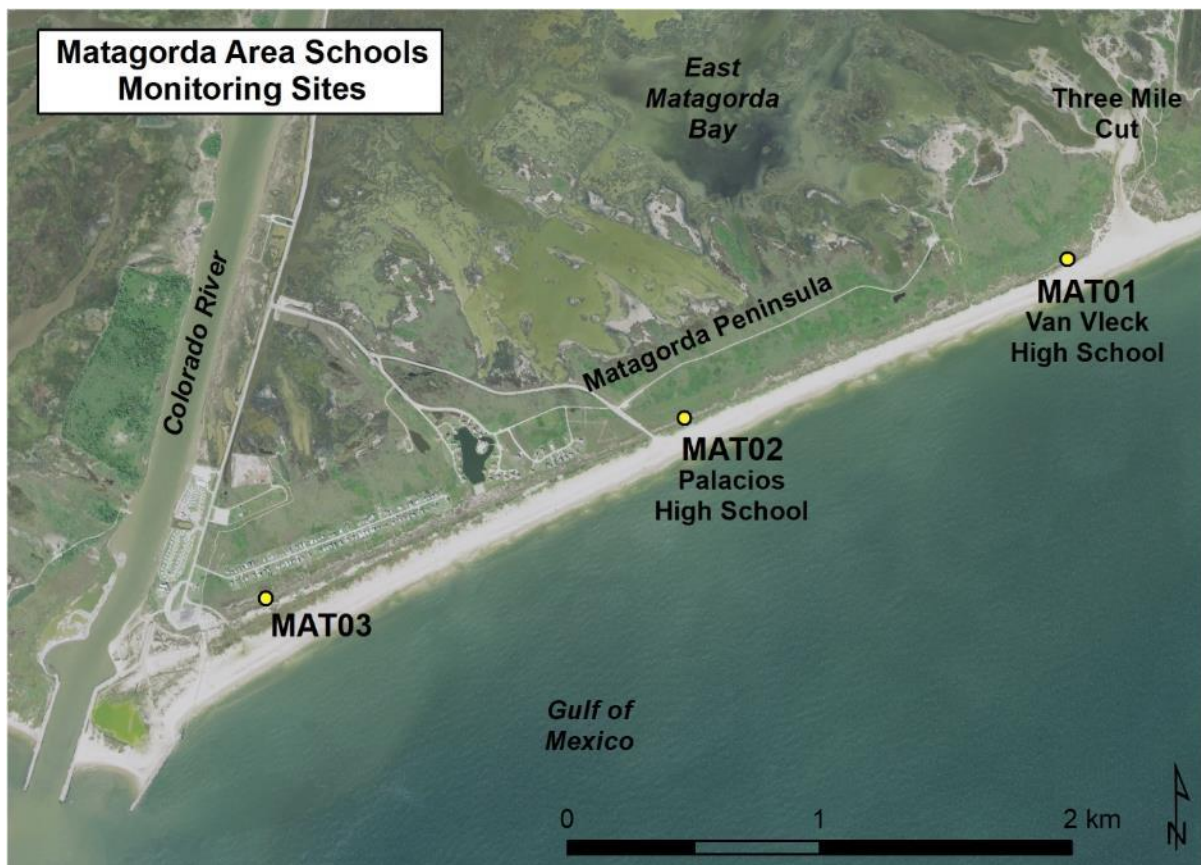


Figure 8. Location map of sites monitored by Matagorda-area schools.

Port Aransas High School

Port Aransas students in Ryan Piwetz's Aquatic Science class collect data at three profile locations on Mustang Island: MUI01 near Horace Caldwell Pier, MUI02 in Mustang Island State Park, and MUI03 at Beach Access Road 1 at the Palmilla Beach Golf Club (**Fig. 9**). Port Aransas High School has been measuring these profiles since 1999. Bureau scientists visited the sites monitored by Port Aransas students on May 20, 2021.



Figure 9. Location map of Port Aransas High School monitoring sites.

Cunningham Middle School

The Bureau collaborates with graduate students and staff at TAMUCC to conduct field trips with students from Cunningham Middle School at South Park (Corpus Christi Independent School District). Teacher Eunice Silva brings 8th grader students to collect data at NPI08 on North Padre Island and NPC06 on the North Padre Island seawall (**Fig. 10**). Both sites monitor the impacts of beach restoration

and maintenance activities. Bureau scientists visited the North Padre Island sites on May 20, 2021.

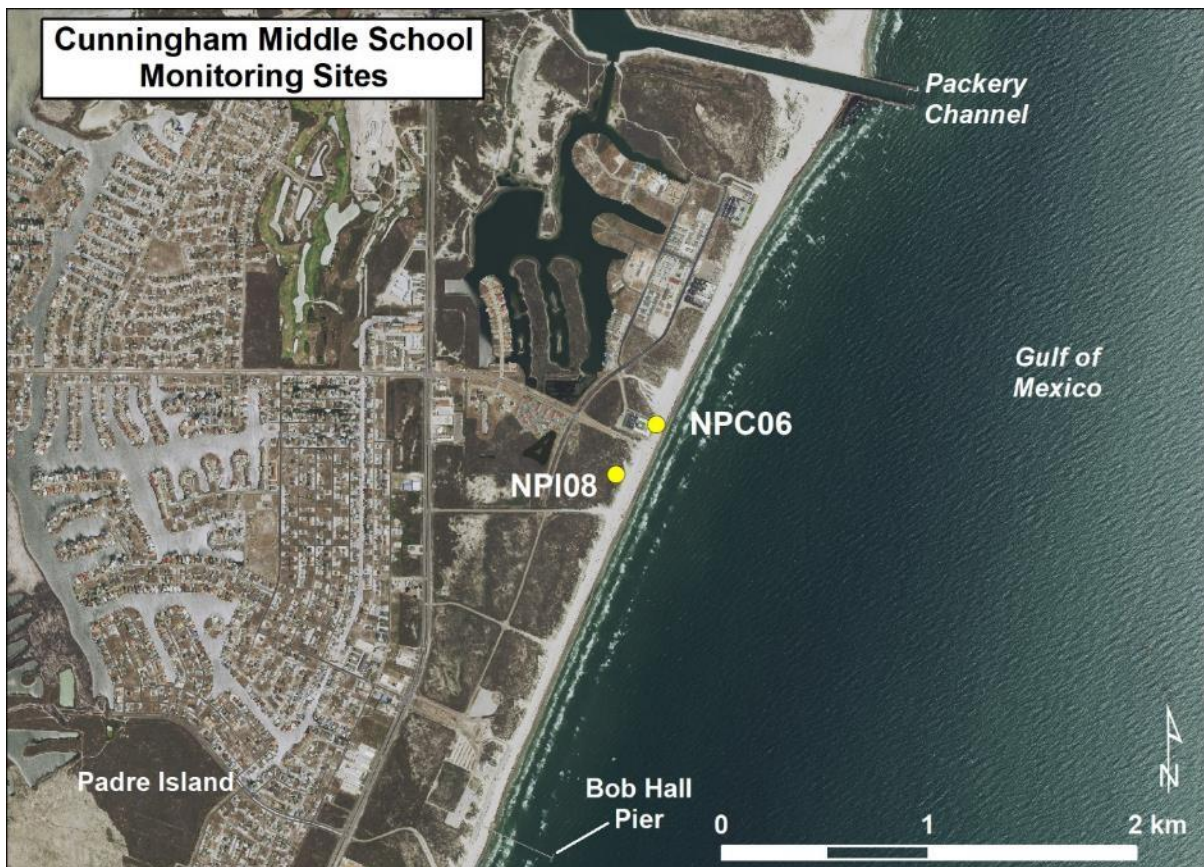


Figure 10. Location map of Cunningham Middle School monitoring sites.

Port Isabel High School

Port Isabel students from Dr. Michelle Zacher's AP Environmental Science class collect data at three profile locations on South Padre Island: SPI01 in Isla Blanca Park, SPI02 at Beach Access #13, and SPI08 at the Tiki Condominiums (E. White Sands Street) (**Fig. 12**). Because of construction of a promenade and new beach pavilion within Isla Blanca Park, the SPI01 datum point was reestablished. Port Isabel High School has been measuring SPI01 and SPI02 since 1999 and SPI08 since 2007. A Bureau scientist collected data from the South Padre Island sites on August 10, 2021.

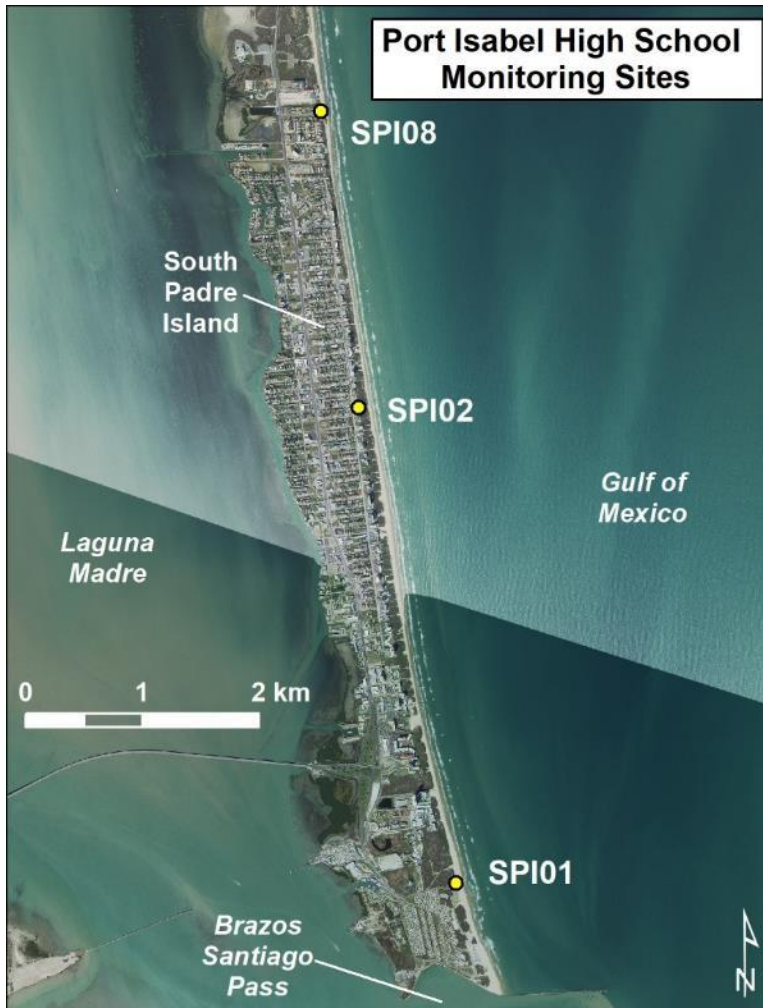


Figure 11. Location map of Port Isabel High School monitoring sites.

EFFECTS ON SCIENTIFIC RESEARCH, COASTAL MANAGEMENT, AND PUBLIC AWARENESS

The first goal of the THSCMP is to provide high school students with an inquiry-based learning experience, which is achieved by involving students in real-world research projects. We emphasize to students that they are collecting critical scientific data that will help scientists address coastal issues affecting their communities. The student-collected beach data can be and have been used by researchers at the Bureau to help respond to several beach-related issues. Data are available for coastal managers, decision-makers, scientists, students, and the public.

Long-term data collection is clearly useful in explaining beach cycles and defining short-term versus long-term trends. Defining these trends is important in decision-making regarding coastal development, beach nourishment, and dune restoration projects. The data collected within city, county, and state parks helps to develop a better understanding of the local coastal environment, which in turn allows managers to make wise decisions regarding long-term management and future park development. Coastal communities and managers throughout Texas—especially our partners at GLO, TPWD, and other coastal parks—benefit from having access to the beach monitoring data collected by this project for use in public-policy and coastal-management decision-making.

THSCMP-collected data has played a large role in important Bureau studies. In one study, site BEG02 has been used by Bureau scientists to investigate the effects of geotextile tubes installed along the upper Texas coast. BEG02, located in Galveston Island State Park (**Fig. 6**), is adjacent to a subdivision where these erosion-control devices have been installed. The study compared beach width (distance from the vegetation line or dune base to the waterline) in front of the geotextile tubes versus at a natural beach area in the adjacent state park. Beach width in the natural beach area was observed to be wider than in the subdivision—45.7 m on average compared to 20.4 m in the subdivision (Gibeaut and others, 2003; **Fig. 12**). The natural area allowed for the landward migration of the dunes as the shoreline retreated, whereas the geotextile tube created a fixed dune line (Caudle and Paine, 2017).

Data collected by THSCMP students are invaluable in verifying shoreline position for updates to Texas' long-term shoreline-change rates, which are widely used by public officials, corporations, and private citizens. These comparisons—in some cases from ground-based GPS data acquired within a few days to weeks of the imagery or lidar survey date—generally show good agreement (within a few meters) between boundaries interpreted from ground-based data and imagery and those extracted from lidar data. Small discrepancies in the position of the lidar-derived shorelines, imagery-derived shorelines, and the wet-beach/dry-beach boundary are likely to

reflect real differences in beach morphology between the dates of the lidar surveys, imagery acquisitions, and ground-based GPS surveys in these dynamic environments.



Figure 12. Lidar topographic-relief image of Galveston Island State Park and Pirates Beach subdivision. Note the difference in beach width between the natural beach and the area in front of the subdivision. From Gibeaut and others (2003).

Beach profiles and GPS-mapped shorelines (wet-beach/dry-beach boundaries) collected by THSCMP students were used to confirm the shoreline position digitized in 2007 aerial photography (Paine and others, 2011, 2012) and the shoreline positions extracted from aerial lidar data collected in 2012 (Paine and others, 2014), 2016 (Paine and Caudle, 2018), and 2019 (Paine and Caudle, 2020). The student-collected data proved vital in validating interpretations of the shoreline positions on Bolivar Peninsula, Galveston Island, Follets Island, Matagorda Peninsula, Mustang Island, and South Padre Island.

For the 2007 shoreline position, georeferencing of the photographs and interpretation of the position of the wet-beach/dry-beach boundary was checked by superimposing GPS-based wet-beach/dry-beach boundary data acquired in 2007 by the THSCMP and the 2007 photo-interpreted wet-beach/dry-beach boundary used for change-rate calculations (Paine and others, 2011, 2012). GPS-mapped shorelines collected by THSCMP students were used to confirm the elevation of the 2012 shoreline position proxy that was used for shoreline change calculations. For example, on South Padre Island (**Fig. 13**; Paine and others, 2014), there is

positional agreement between the 2012 lidar-extracted shoreline; the wet-beach/dry-beach boundary as interpreted using National Agriculture Imagery Program (NAIP) aerial imagery acquired on April 23, 2012; and the wet-beach/dry-beach boundary surveyed via GPS by THSCMP students on September 26, 2012. The 2016 shoreline was determined from 2016 NAIP aerial imagery and a lidar survey conducted by the U.S. Army Corps of Engineers (USACE) between September 9 and October 10, 2016, using the CZMIL airborne lidar system (USACE, 2017). A shoreline positional check, which addressed the relative position of the shoreline proxy and the wet-beach/dry-beach boundary, was accomplished by superimposing the lidar-derived shoreline proxy and GPS-based, wet-beach/dry-beach boundary data acquired in fall 2016 by the THSCMP on georeferenced 2016 NAIP imagery (Paine and Caudle, 2018).



Figure 13. Shoreline position comparison at South Padre Island site SPI08. Shorelines include the wet-beach/dry-beach boundary mapped on September 27, 2011, and September 26, 2012, by THSCMP students using GPS and the shoreline proxy extracted from airborne lidar data acquired in February 2012. Shorelines are superimposed on NAIP imagery acquired on April 23, 2012. From Paine and other (2014).

The long-term rates of Gulf shoreline movement along the Texas coast have been updated through 2019. The shoreline position extracted from 2019 lidar data was verified by visually comparing the shoreline proxy contour elevation with the wet-beach/dry-beach boundary as shown on georeferenced 2016 and 2018 NAIP aerial photographs and imagery acquired during the airborne survey. We used beach profiles and GPS-mapped shorelines acquired by the THSCMP near the dates of the lidar survey to compare the observed wet- and dry-beach positions. The Surfside Beach profile site SURF2 on Follets Island (**Fig. 14**; Paine and others, 2021) is representative of data comparison all along the Texas coast. At this site, there is excellent positional agreement between the 2019 lidar-derived shoreline proxy; the wet-beach/dry-beach boundary mapped on April 24, 2019, by THSCMP participants and Bureau staff; 2018 NAIP imagery, and 2019 aerial imagery.



Figure 14. Shoreline position comparison at Surfside Beach site SURF2. Shorelines include the wet-beach/dry-beach boundary mapped on April 24, 2019, by THSCMP students and Bureau staff using ground GPS and the 1 m (3.3 ft) above mean sea level shoreline proxy extracted from airborne lidar data acquired in spring 2019, superimposed on 2019 Bureau imagery. From Paine and others (2021).

Posters were created from these updated long-term rates (1930s-2019) of shoreline movement along the Texas Gulf of Mexico coast. A poster for the island or shoreline segment studied will be provided to all of the participating schools when field trips resume in the 2021–2022 academic year. Posters will also be provided for the Matagorda Bay Nature Park, Mustang Island State Park, Galveston Island State Park, and the Texas General Land Office.

The THSCMP has increased public awareness of coastal issues through its students and through media reports, presentations at conferences, journal articles, and learning tools. The THSCMP website also continues to be instrumental in extending the reach of the program and increasing public awareness. The program has been featured in the 2006 and 2009 winter issues of *On the Coast*, a coastal-issues newsletter from the Texas General Land Office. In December 2019, the THSCMP was the featured Research Program Profile on the Bureau's website (<http://www.beg.utexas.edu/node/5664>).

Ms. Caudle has presented the THSCMP at the 2013 American Shore and Beach Preservation Association national coastal conference in South Padre Island, at the 2015 Texas Chapter of the American Shore and Beach Preservation Association Symposium in Corpus Christi, in a panel discussion on coastal outreach activities at the 2015 Texas Beach and Dune Forum in Corpus Christi, and at the 2017 Texas Chapter of the American Shore and Beach Preservation Association Symposium in Port Aransas. Ms. Caudle also presented THSCMP to the Bureau of Economic Geology during the Summer Seminar Series on July 30, 2021. The presentation was recorded and can be viewed from the Bureau's YouTube channel: https://www.youtube.com/watch?v=2SLLVBfX_n0.

Port Isabel High School students have presented the THSCMP to coastal visitors at the Winter Outdoor Wildlife Expo (WOWE) at the South Padre Island Birding Center (2017–2020). One student presents an overview of the program to the entire group while the rest of the students demonstrate THSCMP data collection activities in teams. Ms. Caudle, Dr. Zacher, and two Port Isabel High School students were

invited to the annual Coastal States Organization meeting held in South Padre Island in November 2019 to present the THSCMP to meeting attendees.

A paper featuring the program and data collected by the high school students was published in the fall 2004 issue of *Shore & Beach* (vol. 72, no. 4), the journal of the American Shore & Beach Preservation Association (Hepner and Gibeaut, 2004). A paper was written and presented at the 2012 Gulf Coast Association of Geological Societies annual meeting (Caudle and Paine, 2012). A technical communication paper was published in May 2017 in the *Journal of Coastal Research* describing the critical scientific data collected by THSMP students that helps scientists and coastal managers address coastal issues and improve understanding of dune and beach dynamics on the Texas coast (Caudle and Paine, 2017).

SCIENTIFIC RESULTS AND TEXAS COASTAL CHANGES: 1997–2021

Profile data collected by the students are entered into CEDAS v. 4.0 (Coastal Engineering Design and Analysis System)—a system originally developed by the U.S. Army Corp of Engineers and commonly used by coastal engineers and scientists in beach-profile analysis—using the BMAP (Beach Morphology and Analysis Package) module. Beach-volume calculations are then made using BMAP, and shoreline and vegetation-line positions are determined from field notes made by students and scientists. The shoreline is designated by the wet-beach/dry-beach boundary or a berm crest (a prominent break in slope between the forebeach and backbeach) for consistency with historical measurements (Gibeaut and Caudle, 2009). Volume, shoreline, and vegetation-line plots for each monitoring site are found in Appendix B. Profile plots that contain all student-collected data for each monitoring site are found in Appendix C. GPS-mapped shoreline and vegetation-line data for each monitoring site are found in Appendix D.

Since the THSCMP began in 1997, data collected by students have been applied by scientists to investigate beach, dune, and vegetation-line recovery following several tropical cyclones, including Hurricanes Ike in 2008 and Harvey in 2017. Student-collected data are also used to monitor the effects of beach nourishment projects on

South Padre, North Padre, and Galveston Islands; foredune changes on Mustang Island due to beach-maintenance practices; and jetty construction and vehicular traffic on Matagorda Peninsula. Through these real-world examples of scientific observation, students gain a better understanding of environmental issues affecting their communities.

Measurements by the schools involved in the THSCMP show the change through time at each location and highlight the spatial variation found along the Texas coast. The scientific observations documented by THSCMP students help scientists, decision-makers, coastal managers, and the students themselves gain a better understanding of relationships between coastal processes, beach morphology, and shoreline change affecting their local coastal communities. Key research results and coastal issues are presented within this report by region.

Bolivar Peninsula

The beach at HIB01 (**Fig. 5**) has seen significant changes during High Island High School's short monitoring period (**Fig. 15**). On the first field trip, the beach had a steep forebeach, high berm, and a backbeach wide enough for vehicles to travel up and down the beach. Large pieces of pavement that are remnants of Highway 87 were at the upper reach of the swash zone. The October 2017 field trip took place about a month after Hurricane Harvey impacted the Texas Gulf coast. The beach had experienced significant erosion, pavement debris was deposited at the vegetation line, and the elevated berm and backbeach that had once allowed vehicular access to the north was gone. The beach width had recovered by spring 2018.

Since the start of the 2018–19 academic year, HIHS students have been unable to access the site at High Island Beach because of roadway construction at the intersection of Highway 87 and Texas 124. Since that time, the shoreline and vegetation line positions have moved landward, due in part to the impacts of the 2020 hurricane season. The profile site datum has been lost due to erosion of the

beach at High Island. Between May 2018 and May 2021, the shoreline position moved landward 25 meters (just landward of the profile datum location) and the vegetation line moved 45 meters landward (**Fig. 16**).

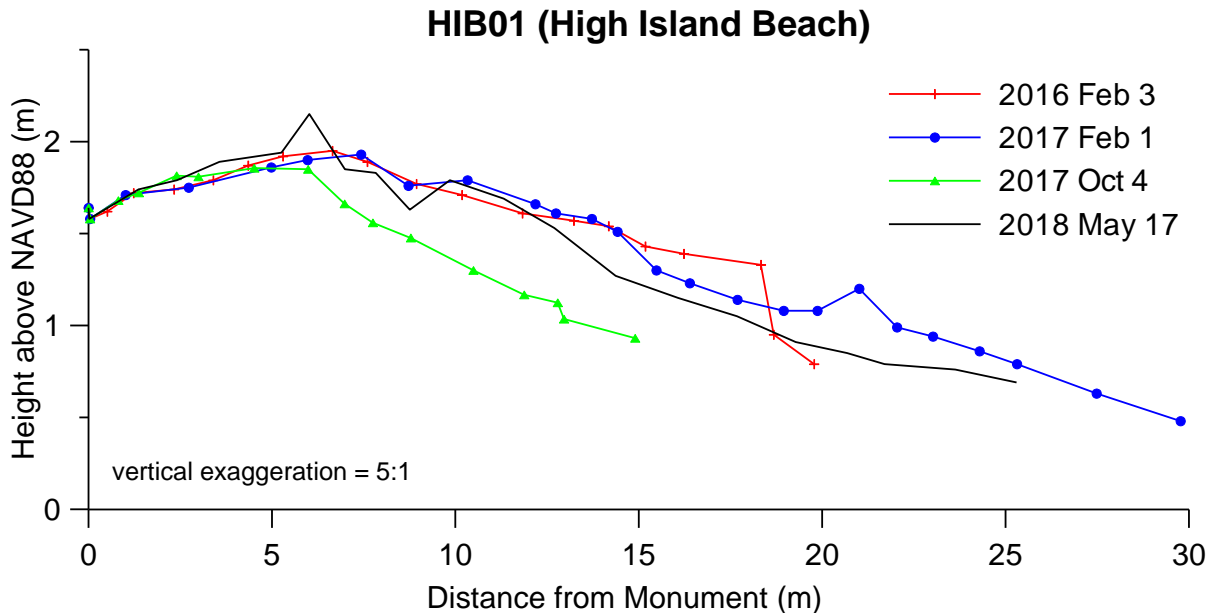


Figure 15. Changes at HIB01 monitored by High Island High School students.

High Island High School students also monitor sites BOL02 and BOL03 adjacent to Rollover Pass (**Fig. 5**). Rollover Pass was cut across Bolivar Peninsula in 1955 with the intention of improving water quality in Rollover Bay and Galveston East Bay. The opening of the pass caused significant erosion to the adjacent beaches and caused sand and sediment to be deposited in the Gulf Intracoastal Waterway (ICW). For years, the U.S. Army Corps of Engineers were required to dredge and remove sediment from the ICW adjacent to Rollover Bay annually at significant cost. Due to the issues caused by Rollover Pass, the Texas Legislature authorized the General Land Office to close the pass. Construction began at the end of September 2019 and was ongoing at the time of High Island High School's second field trip in January 2020. Closure construction was completed in spring 2020. High Island students will be monitoring how the closure of Rollover Pass impacts the beaches adjacent to the site in the future.

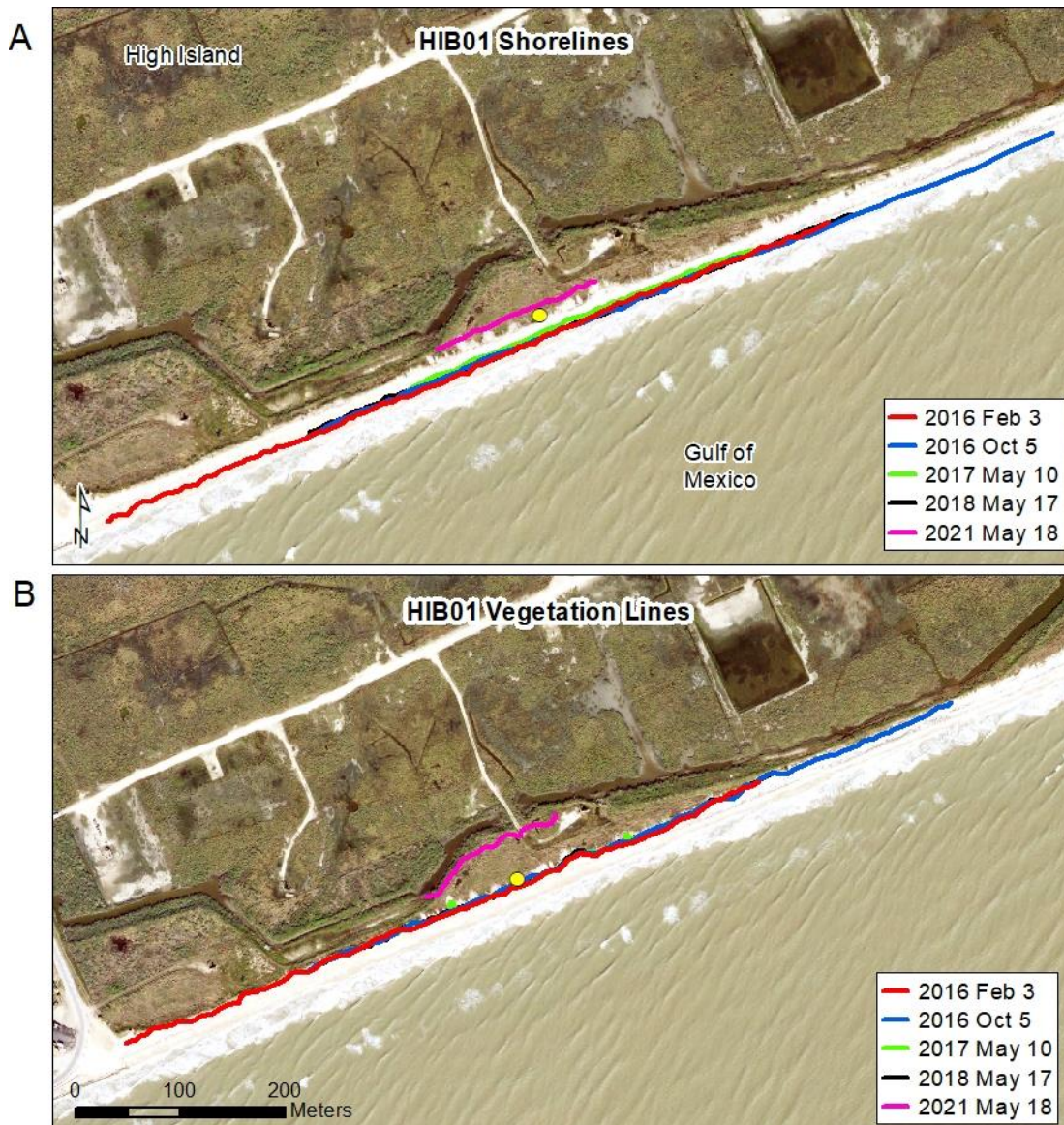


Figure 16. Changes to the position of the (A) shoreline and (B) vegetation line at HIB01 between February 2016 and May 2021.

Galveston Island

Since 1997, Ball High School students participating in the THSCMP have been collecting critical data that is used by scientists at the Bureau to increase understanding of beach and dune recovery stages following major storms. Storm damage to beaches and dunes are indicated by the landward movement of shoreline and vegetation-line positions and a decrease in sediment volume in the beach profile

immediately after storms (**Fig. 17**). The gradual seaward migration of the shore and vegetation lines plus sediment volume increases track beach and dune recovery in the years following storms.

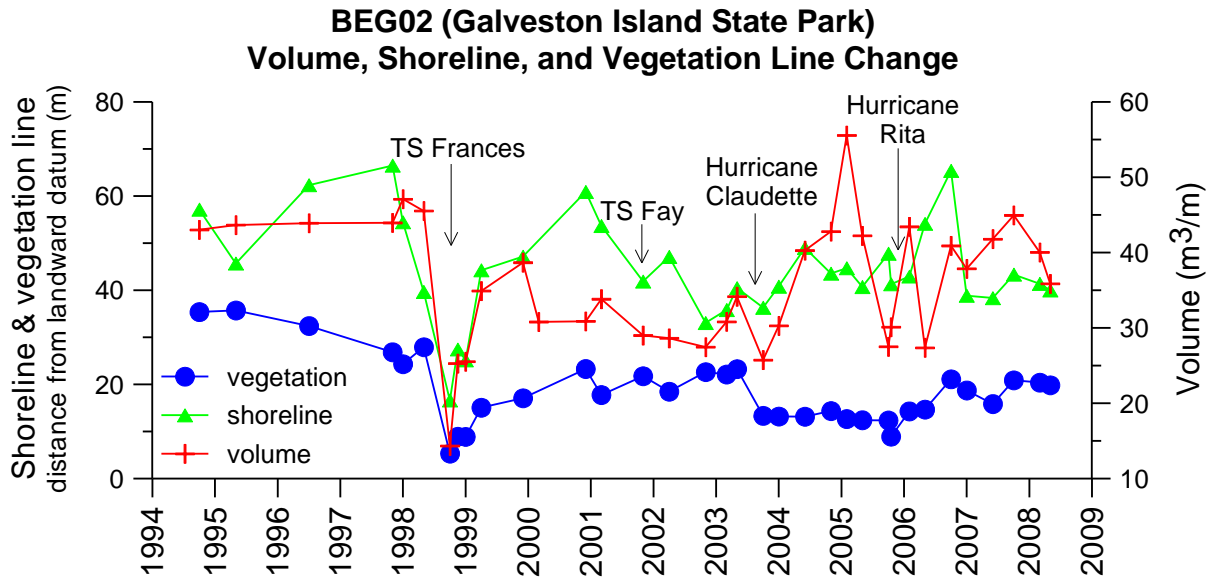


Figure 17. Profile volume, shoreline, and vegetation-line changes at Galveston Island State Park, September 1994–April 2008.

Tropical Storm Frances (September 1998) played a major role in reshaping the beaches on the upper Texas coast. Data collected by Ball High School students on Galveston and Follets Islands documented that Frances caused significant damage to beaches along the southeast coast of Texas. The storm's damage was comparable to damage caused in 1983 by Hurricane Alicia (Gibeaut and others, 2002; Hepner and Gibeaut, 2004; Morton and Paine, 1985), a Category 3 hurricane on the Saffir/Simpson scale (Simpson and Riehl, 1981). Several other severe storms have also impacted the Galveston study area. Tropical Storms Allison (June 2001) and Fay (September 2002) and Hurricanes Claudette (July 2003) and Rita (September 2005) have each caused varying degrees of damage to beaches and dunes along the Texas coast (**Fig. 17**).

The upper Texas coast was severely affected by the landfall of Hurricane Ike in September 2008. Galveston Island experienced significant beach and dune erosion,

as well as extensive damage to property and infrastructure. Ball High School students were unable to participate in the THSCMP during the 2008–2009 academic year because of safety concerns to accessing their monitoring sites. Bureau and TAMUCC scientists visited Galveston Island in early October 2008 to conduct ground surveys—beach profiles, photography, and observations of beach and dune conditions—of the area impacted by the hurricane. During this reconnaissance trip, scientists visited profile location BEG02 in Galveston Island State Park, where they discovered that the datum marker at BEG02 had been destroyed by the storm. Scientists used GPS techniques to navigate to the horizontal location of the datum marker, which post-storm was on the open beach. Before the storm, the marker had been at the corner of a concrete picnic pavilion landward of the foredunes. BEG02 (**Fig. 6**) was reset approximately 60 m landward of the old datum marker along the same azimuth line. The new marker (a buried metal pipe) is landward of a washover feature. Reestablishing the marker allowed students to continue to monitor activities and storm recovery and to compare pre- and post-storm profiles at this location.

Ball High School students from the 2007–2008 academic year provided extremely valuable pre-storm profile data from February 8, 2008, and April 23, 2008. These data have been used to determine how much the beach and dunes changed after Hurricane Ike. **Figure 18** is a profile plot at BEG02 comparing the Ball High School pre-storm profile (April 2008) with the post–Hurricane Ike profile measured on October 7, 2008. The post–Tropical Storm Frances profile from September 16, 1998, is also plotted for comparison. At Galveston Island State Park, the dune system was completely destroyed; the shoreline (wet-beach/dry-beach boundary) moved 53 m landward between April 23, 2008, and October 7, 2008; the vegetation line moved 56 m landward; and the old datum point was 1.14 m above the post-storm surface of the beach (**Fig. 18**; Caudle and Paine, 2017). Data from 1-year post-storm is also included. This profile shows that the elevation of the beach has been restored, the beach width (dunes to waterline) has increased, and incipient dunes are beginning to form (**Fig. 18**).

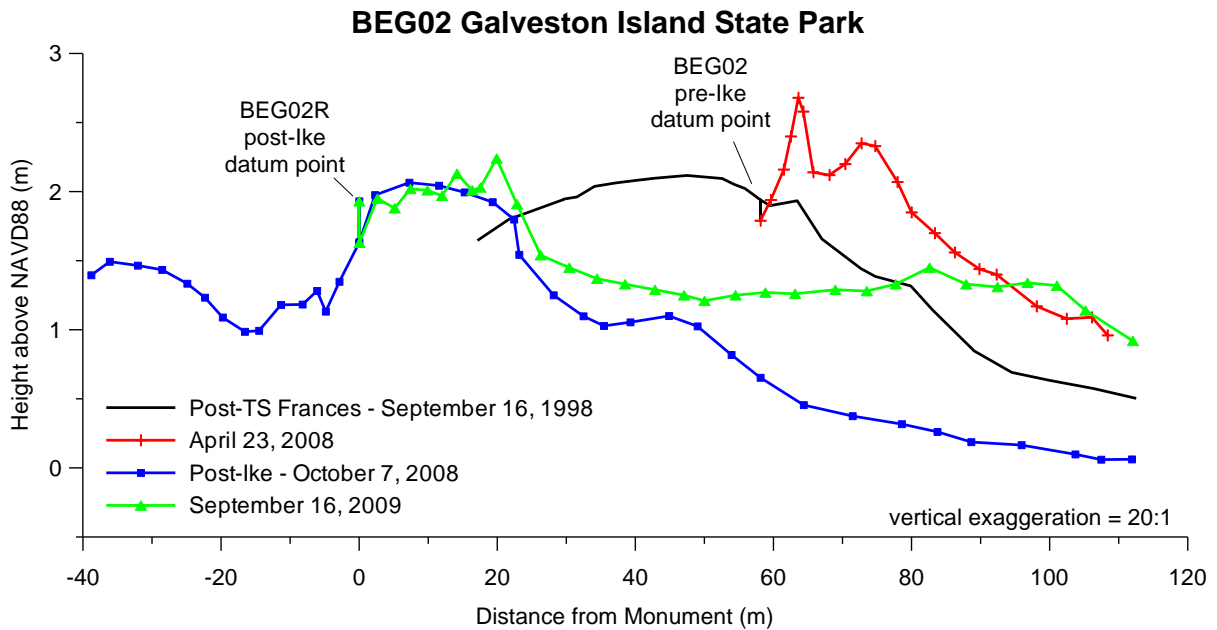


Figure 18. Beach-profile plots from BEG02 in Galveston Island State Park comparing the post-Hurricane Ike profile with a pre-storm profile from early 2008 and the post-Tropical Storm Frances profile from September 1998. Data from September 2009 (1-year post-storm) is also included.

Ball High School students resumed monitoring beaches as part of the THSCMP at the start of the 2009–2010 academic year. Students measured beach profiles at two sites within Galveston Island State Park. At BEG02 (**Fig. 19**), beaches and dunes had continued to recover post-Hurricane Ike. Between September 2009 and January 2011, the foredunes at BEG02 had begun to grow. Whether initial growth of the foredunes is due to natural recovery processes or human intervention is unclear. The foredune ridge has continued to grow in the intervening years. A wide, vegetated zone with expanding coppice dunes has developed between the seaward base of the foredunes and the landward extent of wave run-up (**Fig. 19**).

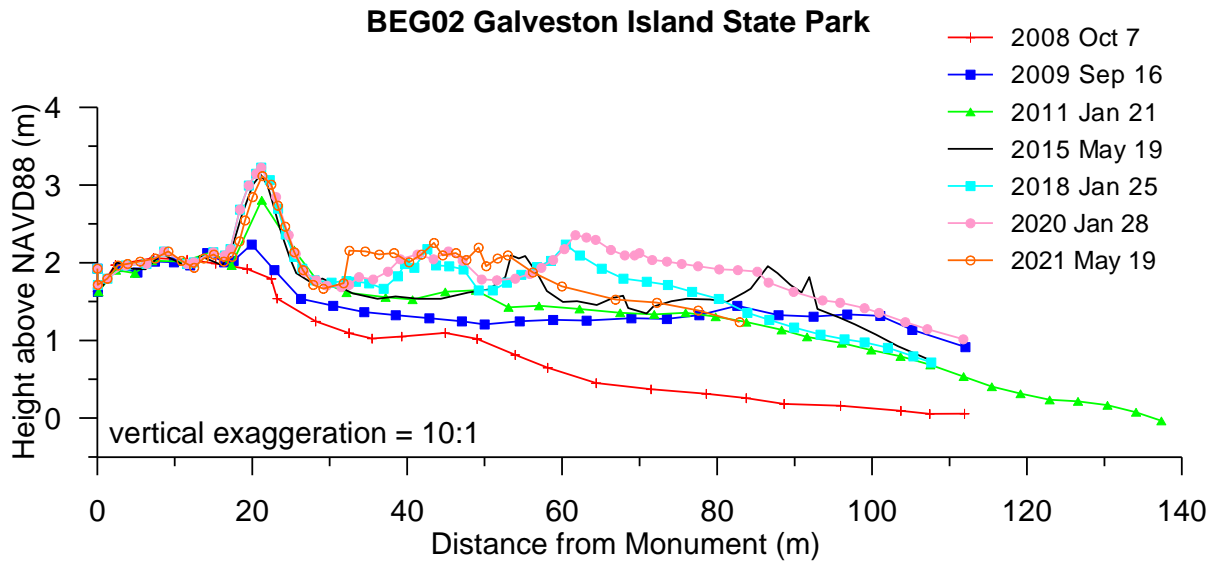


Figure 19. BEG02 datum-reset post-Hurricane Ike profile, plus data collected by Ball High School students. Students are monitoring recovery of the beaches and dunes at this site.

Hurricane Harvey in 2017 had minimal impacts to the beach and dune system on Galveston Island but the 2020 hurricane season did cause beach and dune erosion. At Galveston Island State Park, the beach was eroded landward and overwash was deposited in the coppice dune area (**Fig. 19**). Site DEL01 at the Dellanera RV Park (**Fig. 5**), experienced significant changes to the reconstructed dune (**Fig. 20**).

Surfside Beach and Quintana Beach

Brazosport High School in Freeport, Texas, joined the THSCMP during the 2018–2019 academic year, allowing the program to expand to a section of the developed coast that was previously not monitored. Environmental Science students began collecting data from two sites in Surfside Beach that were established during the first fall 2018 field trip and a site at the Quintana Beach County Park that was established during the spring 2019 field trip (**Fig. 7**). Initial measurements for these new profile locations created a baseline dataset to monitor changes in the beach and dune system into the future.

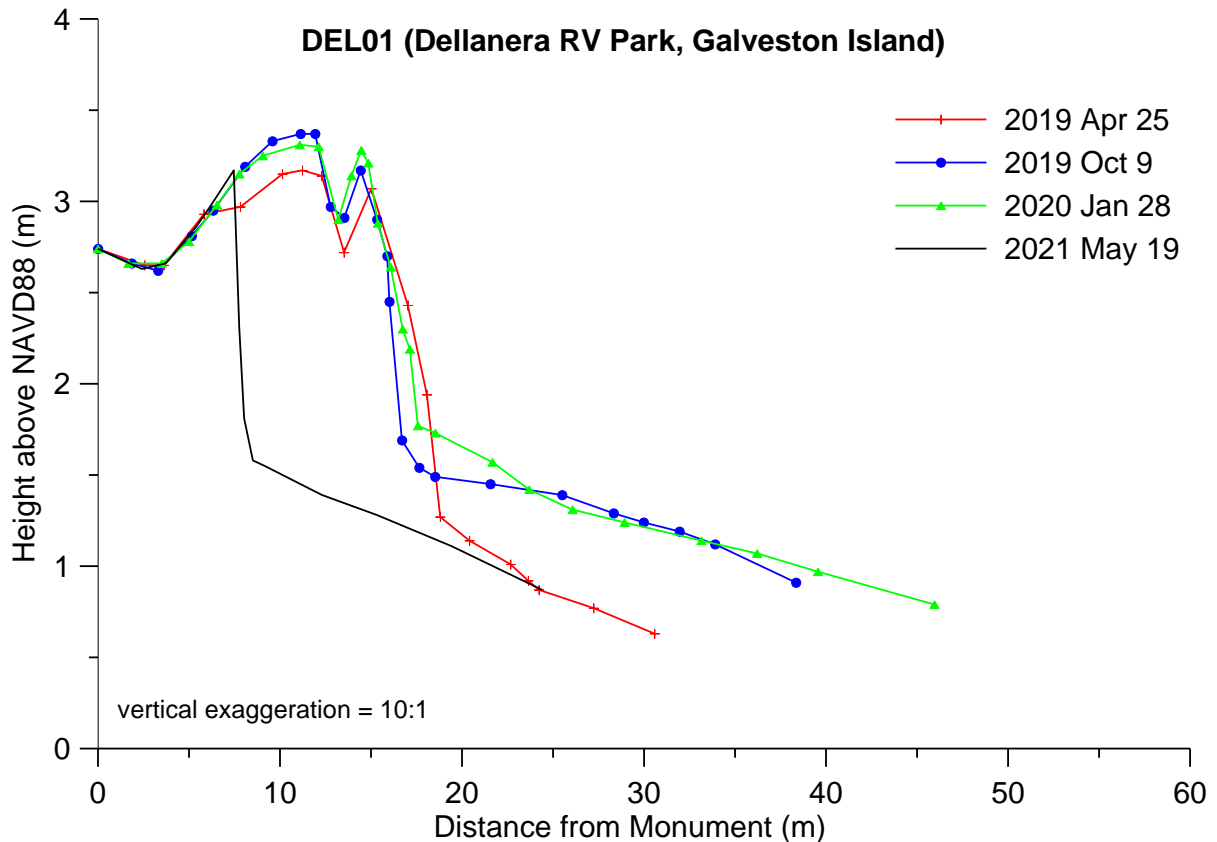


Figure 20. Erosion of the dune at DEL01 in the Dellanera RV Park due to the 2020 hurricane season.

Field visits to the sites on Follets Island and Quintana Beach have shown significant changes to the beach and small dunes that were present on this section of the Texas coast. The dune system at site SURF1 has been completely removed from the beach profile and the shoreline position that was mapped on May 19, 2021 was 15 meters landward from where it was mapped in January 2020 (**Fig. 21A**). At the QUIN1 monitoring location, the small foredune that was present was destroyed and the vegetation line moved 15 meters landward between January 2020 and May 2021 (**Fig. 21B**). The QUIN1 datum will be reestablished in a more landward position. We will continue to collect shoreline and vegetation line positions at SURF1 but will establish a new beach profile location further east on Follets Island.

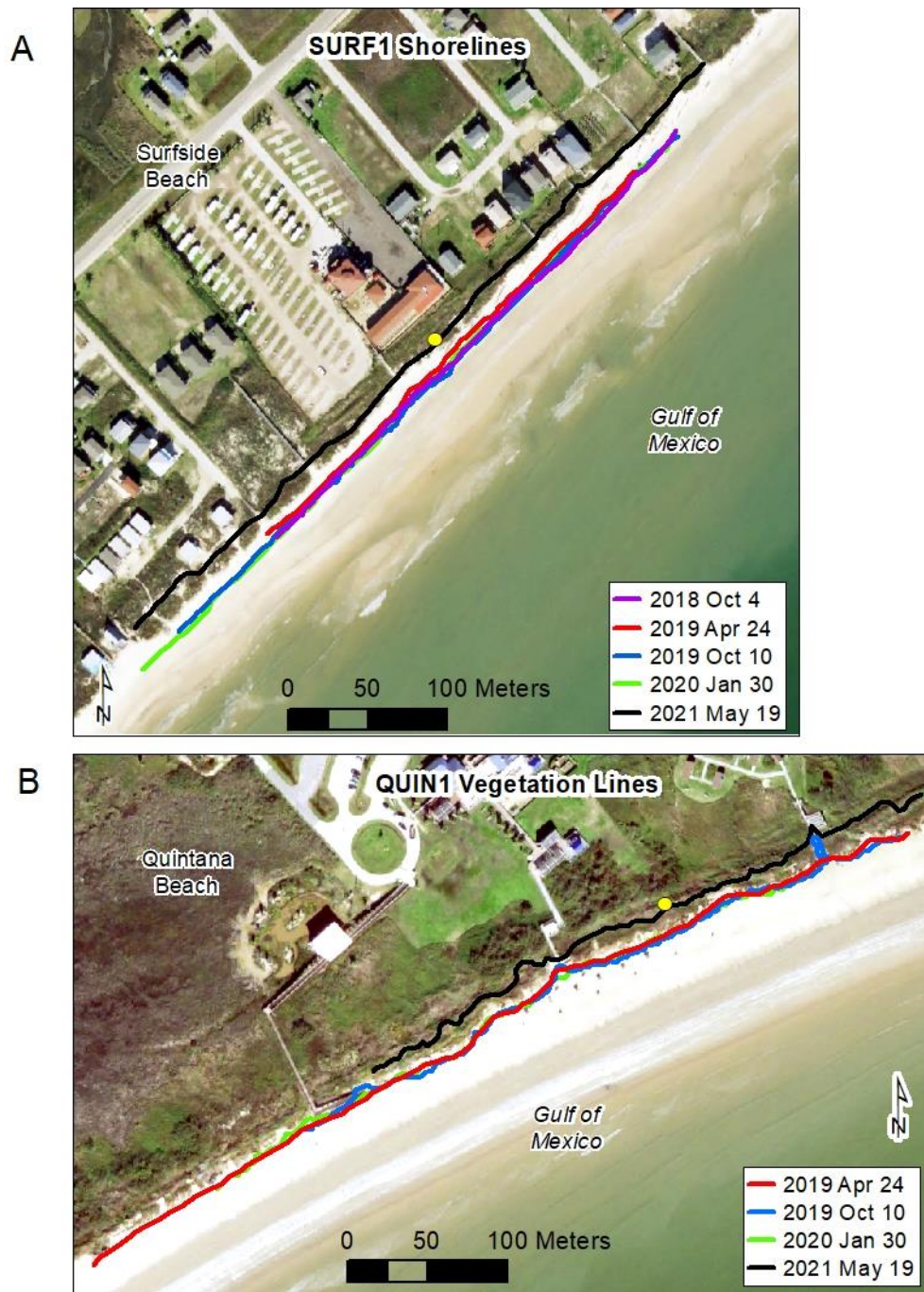


Figure 21. GPS mapping by Brazosport HS students. A) Shoreline positions at SURF1 from October 2018 through May 2021. B) Vegetation line positions at QUIN1 from April 2019 through May 2021. Both sites have experienced significant erosion during the 2020 hurricane season.

Matagorda Peninsula

Van Vleck High School students collect data at MAT01, which is adjacent to a washover channel—Three Mile Cut—that will occasionally open with the passage or landfall of a tropical storm or hurricane (**Fig. 8**). Students from Palacios High School collect data at MAT02, which is northeast of the vehicular beach access point on Matagorda Peninsula (**Fig. 8**). Hurricane Ike made landfall on Galveston Island on September 13, 2008, as a Category 2 hurricane. Owing to the size of the storm, impacts from this hurricane were seen along the entire Texas coast, including on Matagorda Peninsula. The storm surge from Hurricane Ike briefly opened Three Mile Cut and caused vegetation line retreat and dune erosion at MAT01 and MAT02. Over the decade since Ike's landfall, students from Van Vleck and Palacios High Schools have been monitoring the recovery and growth of the dunes (**Fig. 22**) and the seaward movement of the vegetation line (Appendix B) post-Hurricane Ike on Matagorda Peninsula.

Palacios and Van Vleck students measure beaches adjacent to Matagorda Bay Nature Park, which have two special circumstances that make this monitoring especially informative and important: (1) the sites are on the updrift side of the jetty at the mouth of the Colorado River and (2) these sites allow students to compare a beach/dune system where vehicular traffic on the beach is limited (MAT03) with an adjacent area where vehicular traffic is unrestricted (MAT01 and MAT02). Information on impacts of coastal structures (jetties) is critical to coastal management, and impacts of vehicles on Texas' beaches are not well documented. Vehicular traffic was permitted on the beach adjacent to the Nature Park until 2007. Vehicular traffic was restricted in the section closest to the park for several years. Currently, vehicles are able to access this section of beach, but traffic is very limited because of difficult driving conditions.

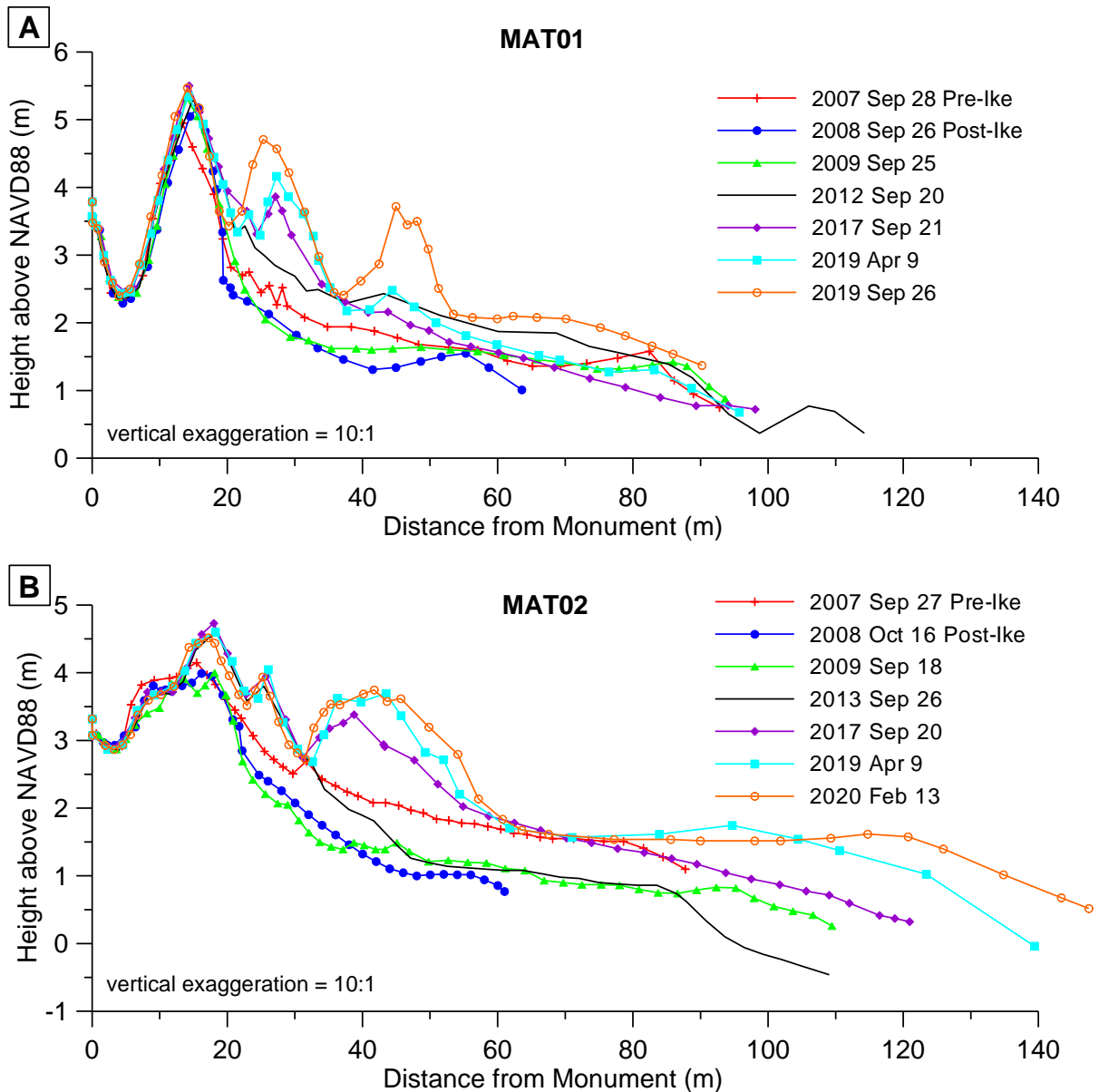


Figure 22. Pre– and post–Hurricane Ike profile data collected by Van Vleck High School students at (A) MAT01 and Palacios High School students at (B) MAT02. Students are monitoring recovery and growth of the foredune at these sites.

In 2009, the U.S. Army Corps of Engineers constructed a new east jetty at the mouth of the Colorado River. GPS-mapped shorelines from September 2009 and September 2012 show a 45-m seaward movement of the shoreline position at MAT03 updrift of the new jetty (**Fig. 23** and Appendix D). Data at MAT03 has shown that the new jetty on east Matagorda Peninsula has caused the shoreline to move

seaward at an average rate of 12.8 m per year between September 2009 and September 2018. GPS mapping has shown that the shoreline position has stabilized between 2018 and 2021 (**Fig. 23**).

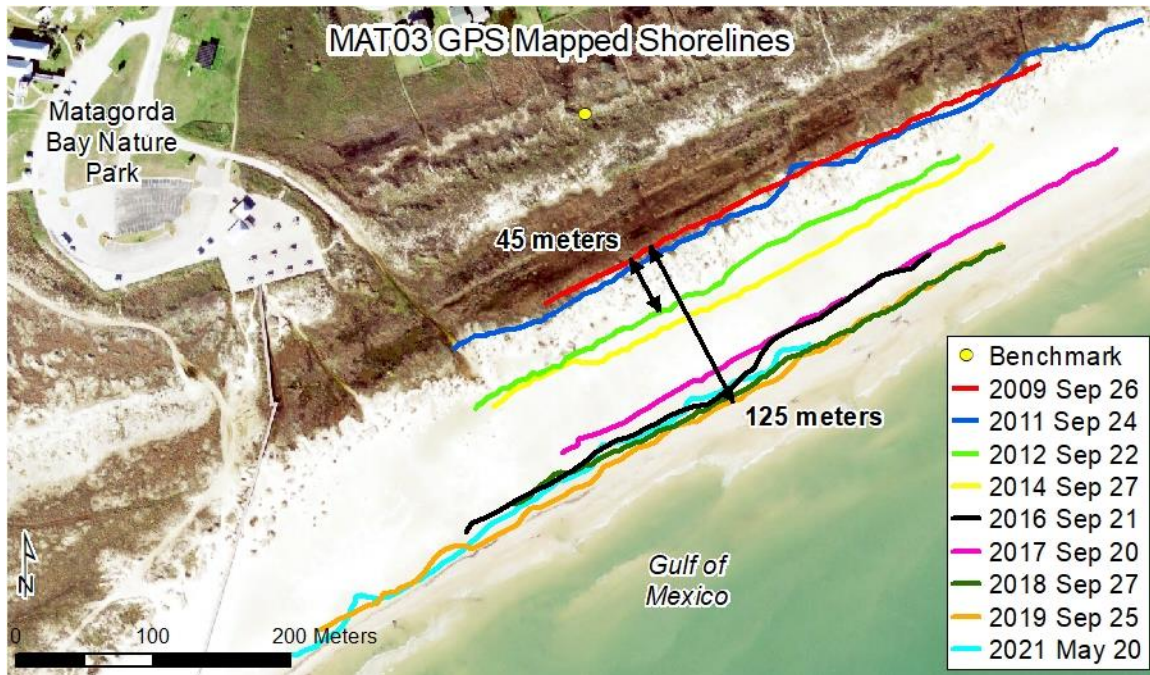


Figure 23. Shoreline position change at Matagorda Peninsula.

Throughout the study period, the shoreline and vegetation-line positions at this site have been continuously moving seaward, and volume has been increasing (**Fig. 24**). The combination of the new jetty impounding sand on the updrift side and the decreased vehicle access at MAT03 has allowed for coppice dune formation to occur on the expanded backbeach area and for new vegetation to develop without being disturbed. On the field trips during the 2015–2016 and 2016–2017 academic years, it was documented that salt marsh plants have become established on the widened backbeach area in the swales between the coppice dunes. Due to the increased width of the backbeach, the salt marsh environment in the swales, and the numerous venomous snakes in the area, profile data will no longer be collected by students at this site. Students from Van Vleck and Palacios High Schools continue to monitor the shoreline and vegetation-line positions.

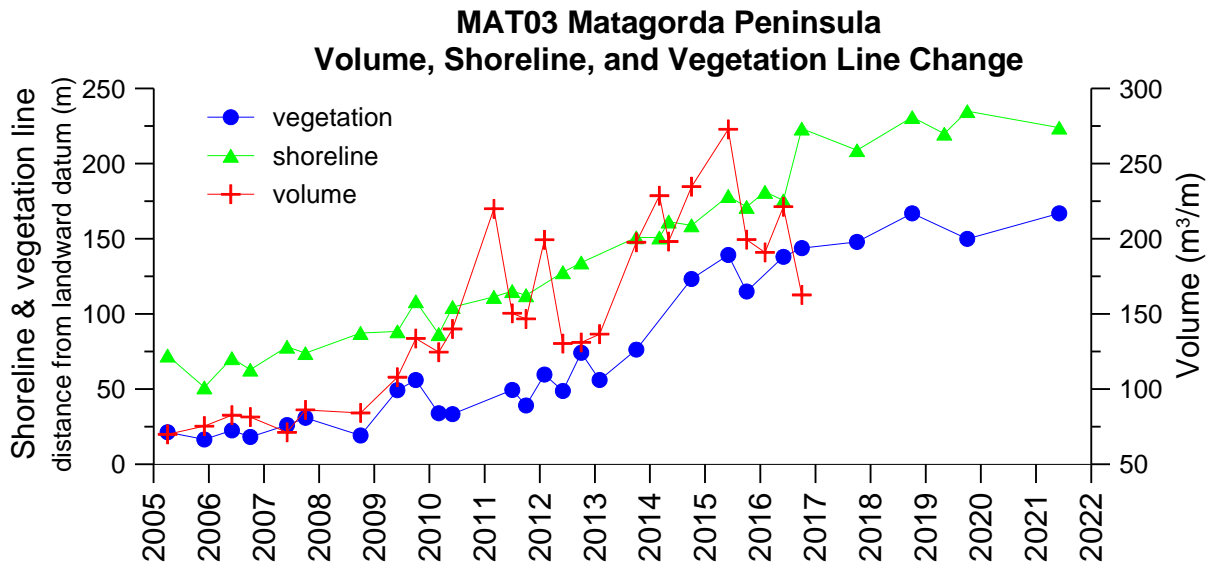


Figure 24. Changes in beach and dune volume, shoreline position, and vegetation-line position at MAT03 on Matagorda Peninsula.

Mustang Island

The beach-monitoring activities of Port Aransas High School students have provided beneficial information about the beach and dune system on Mustang Island (**Fig. 9**). The dune system on Mustang Island is healthy, with tall (> 3 m), wide foredunes along most of the island. The only breaks in the foredune system are at beach-access points and washover features. Beach maintenance practices vary along the island and have changed over time, which the students have documented through their data. Several beaches on Mustang Island, particularly within the City of Port Aransas boundaries, are regularly scraped to remove seaweed (*Sargassum*) from the forebeach. Since the beginning of the coastal monitoring program, Port Aransas students have been monitoring the growth of the foredune system at their profiling sites. **Figure 25** is an example of foredune expansion at MUI01 near Horace Caldwell Pier in Port Aransas. Note that the width of the dunes increased between 2001 and early 2012, although the shoreline remained relatively stable.

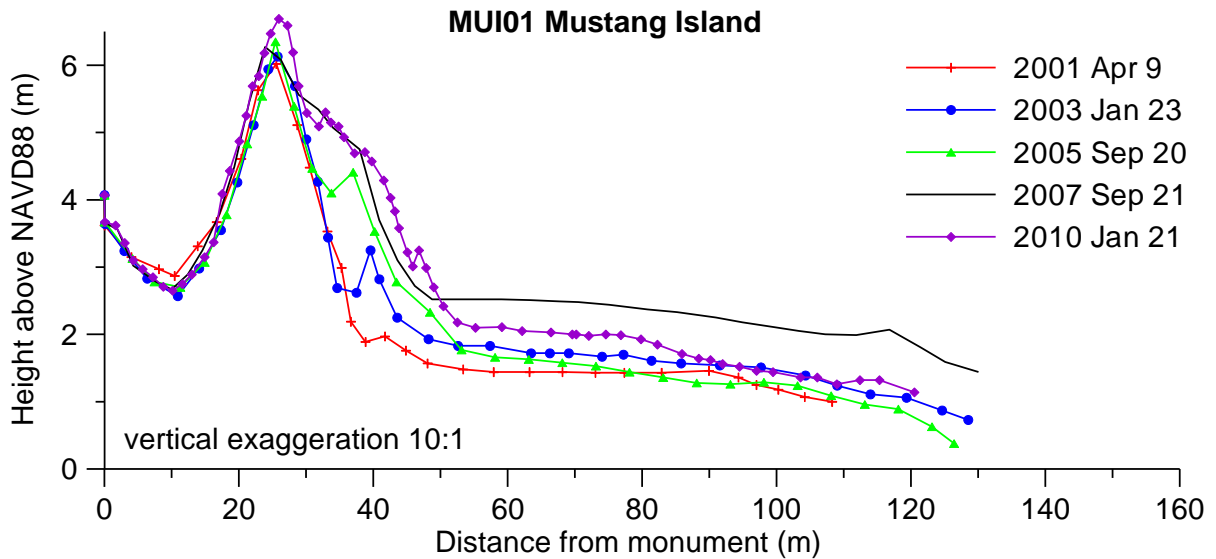


Figure 25. Foredune expansion at MUI01 on Mustang Island.

When Port Aransas students arrived to collect profile data in October 2012, a large part of the dune face had been excavated for a beach-maintenance practice called dune notching (**Figs. 26 and 27**). Students documented that sand was replaced in the foredune by May 2013 and that the vegetation line has been reestablished at the toe of the dune. The dune was notched again during the 2014–2015 academic year. The current width of the foredune is still narrower, and the volume of sand in the profile is less than when the THSCMP began monitoring in 1999 (see change plot in Appendix B). Also, the crest of the foredune is lower in elevation because the dune crest was not stabilized by vegetation for a period of time, resulting in sand being carried away by the wind. The excavated area was slowly filled in between 2016 and 2018 (**Fig. 26**). By the end of the 2018–19 academic year, the foredune was revegetated and stabilized.

The MUI01 location also has shore-parallel bollards that have been installed on the backbeach to confine vehicles to the upper portion of the backbeach. The placement of these bollards has restricted further seaward advancement of the foredune complex and the vegetation line by maintaining a fixed location of the Mustang Island beach road starting at the toe of the dune. Beach maintenance practices such as beach grading and dune notching and the impacts of the fixed position of the

Mustang Island beach road will continue to be monitored by Port Aransas students at MUI01 and compared with the natural processes that occur at MUI02 in Mustang Island State Park.

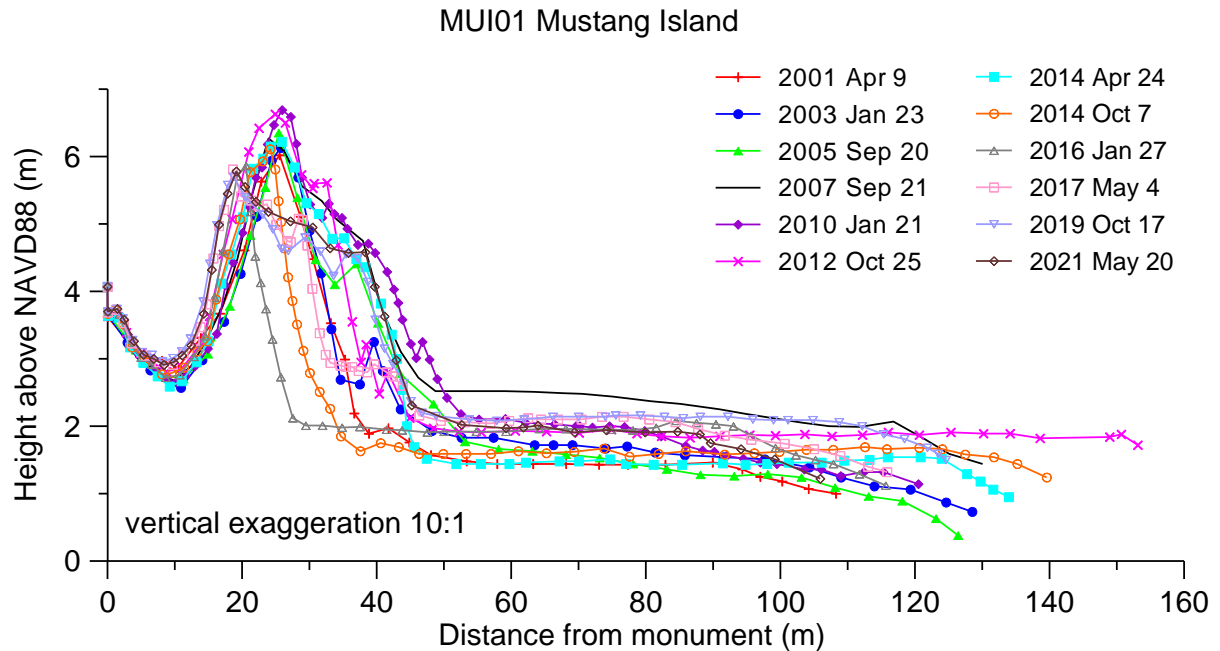


Figure 26. Excavated dune profile at MUI01 on Mustang Island.

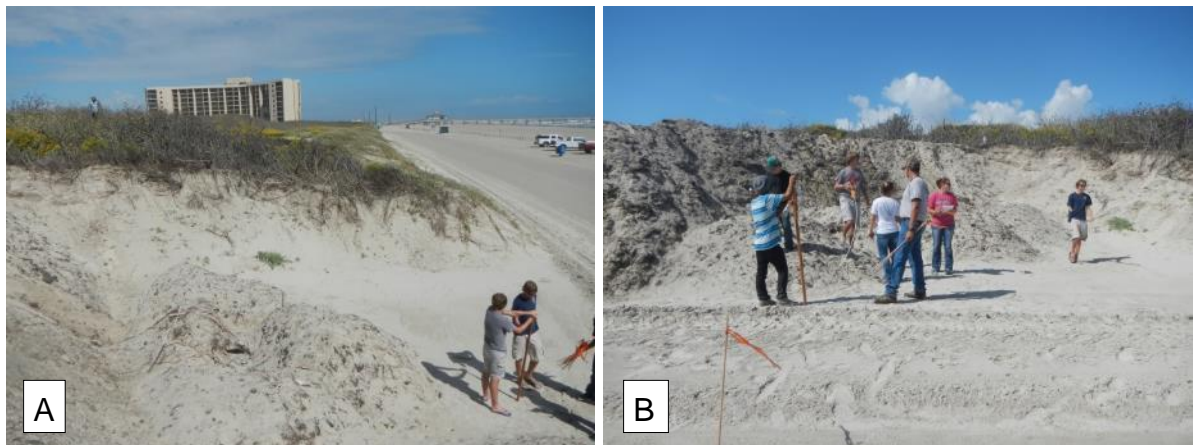


Figure 27. Excavated dune at MUI01 on Mustang Island looking (A) north toward Horace Caldwell Pier and (B) landward.

Hurricane Harvey made landfall on San Jose Island (northeast of Mustang Island) on August 25, 2017, as a Category 4 storm. The City of Port Aransas was devastated

by impacts from a storm surge from the bay and Aransas Pass and from wind and rain damage. Port Aransas High School remained closed for several weeks. Students and staff from the Harte Research Institute at Texas A&M University–Corpus Christi collected post-storm profiles on September 5, 2017, which were compared to pre-storm profiles collected by Port Aransas High School students on May 4, 2017. Despite their proximity to the landfall of a major hurricane, the beach and dune systems monitored by the THSCMP suffered minor impacts. The Mustang Island beaches were planed (lowered), but there was no evidence of scarping on the dunes (**Fig. 28**). The greatest impact to the Mustang Island beach was documented at MUI01, the profile closest to the south jetty at Aransas Pass and the center of the hurricane (**Fig. 28A**). The beach recovered to pre-storm conditions at all three profile locations by January 2018, and the profile remained stable throughout the 2018–2019 academic year. Beach erosion and dune breeches are present on San Jose Island where Harvey made landfall, but this area is not monitored by THSCMP students.

The MUI02 monitoring site is located within Mustang Island State Park, just to the south of Fish Pass. This site has seen significant changes since student monitoring began in 2000. Port Aransas students have documented several lines of coppice dunes forming and coalescing into continuous dune ridges (**Fig. 29**). The dune system and vegetation-line position have expanded seaward, and total profile volume has increased at this location (Appendix B). The shoreline position has remained stable throughout the monitoring program. The increased dune width and stable shoreline position have caused the beach width (distance between vegetation line and shoreline) to decrease. Minimal beach maintenance is performed within the state park boundaries, mainly to keep the beach access points open.

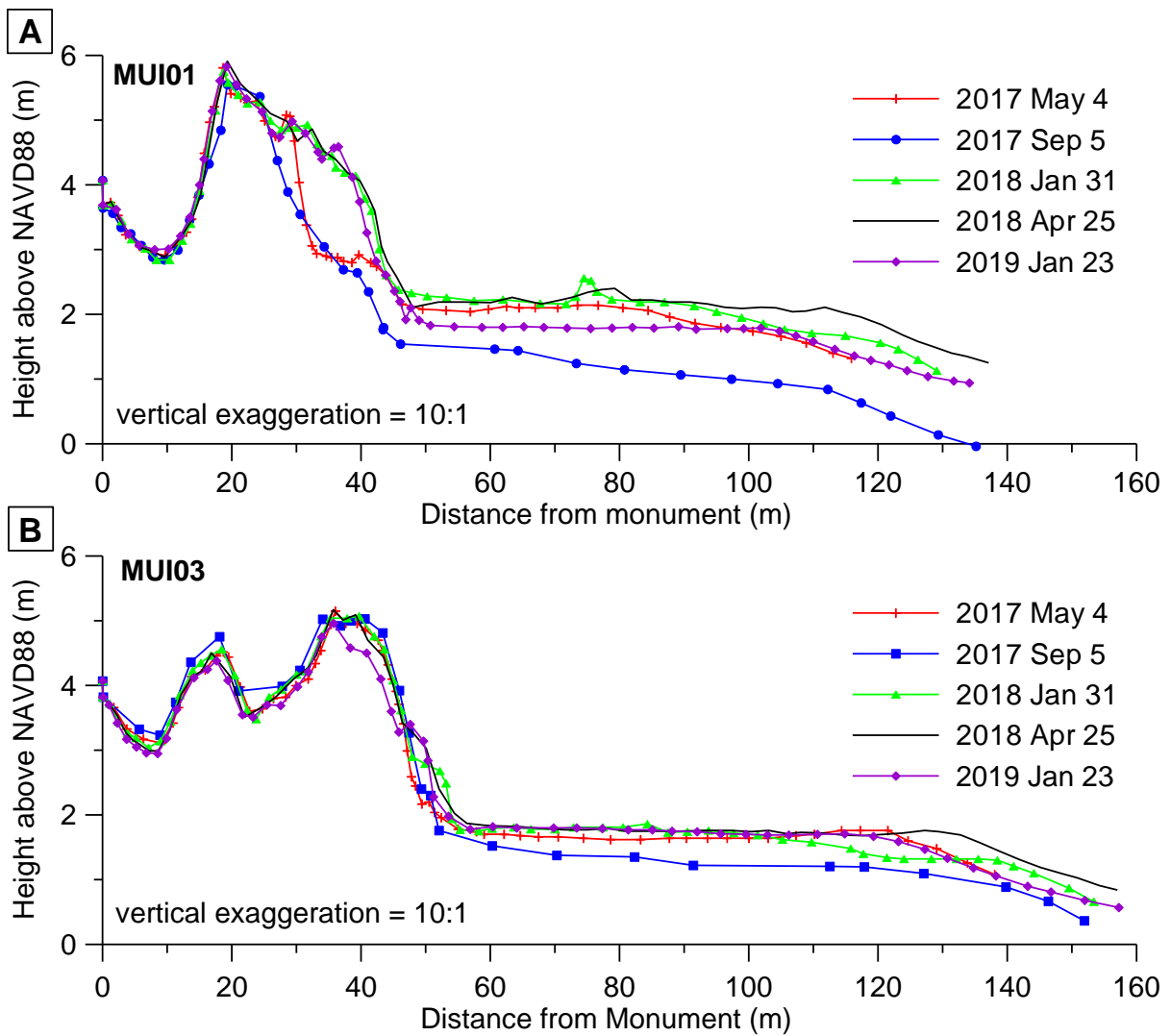


Figure 28. Mustang Island pre- and post-Hurricane Harvey profile data collected by Port Aransas High School and Texas A&M University–Corpus Christi at (A) MUI01 and (B) MUI03.

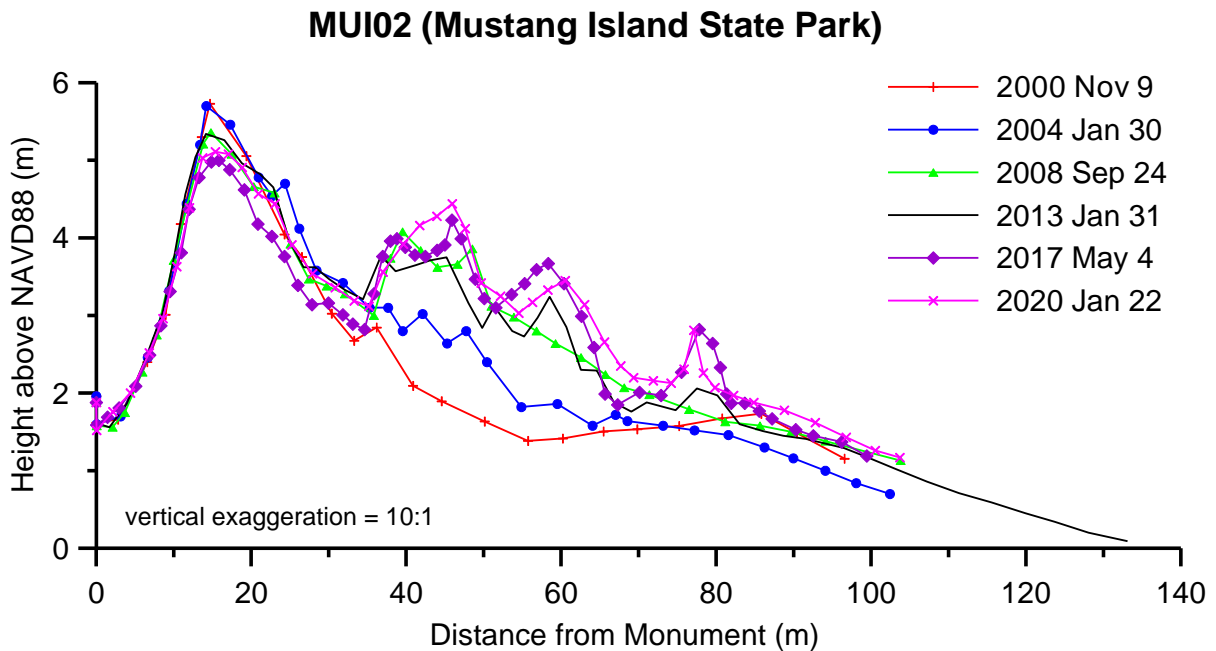


Figure 29. Student monitoring at MUI02 documents an increase in volume of the dune system and seaward migration of the vegetation line.

North Padre Island

Cunningham Middle School at South Park students have documented changes in the dune crest elevation at their profile location. When the program began in 2009, a new profile marker was established along the profile azimuth directly behind the foredune at NPI08 to shorten the profile for the middle school students (**Fig. 10**). Due to the sparse vegetation on the foredune, the sand is constantly being rearranged by prevailing winds. Sand was transported from the top of the foredune down the back slope of the dune so that the landward toe of the dune buried the new datum pipe. This North Padre Island site has added a highly dynamic foredune location to the THSCMP system (**Fig. 30**) that is interesting to monitor and compare with the well-vegetated foredunes on Mustang Island to the north. NPI08 and NPC06 (on the North Padre Island seawall) are also monitored to track the effects of beach nourishment projects using beneficial-use material dredged from Packery Channel and of beach maintenance activities.

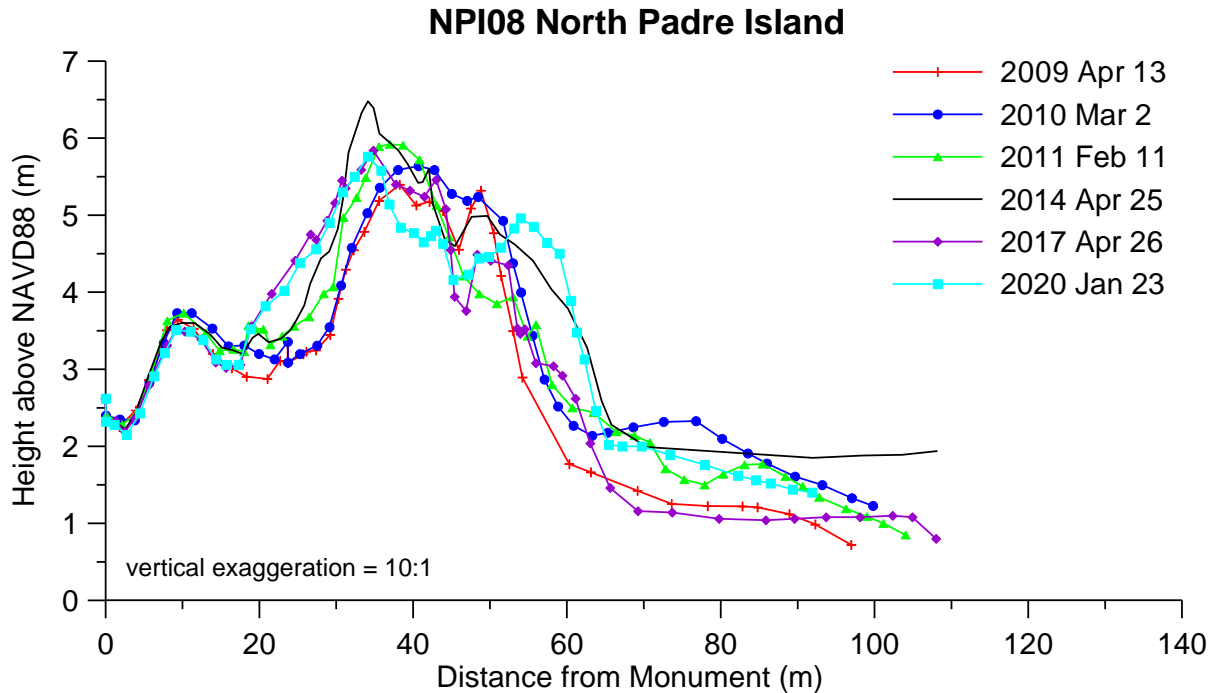


Figure 30. Foredune crest changes at NPI08 monitored by Cunningham Middle School students.

South Padre Island

Brazos Santiago Pass, the southern border of South Padre Island, serves as the southern Gulf of Mexico access to the Gulf Intracoastal Waterway and the Port of Brownsville. Sediment is dredged from the pass biannually and used to nourish the beaches of South Padre Island. The use of sediment dredged from the pass for beach nourishment or other restoration project is called beneficial use of dredged material or BUDM. The three sites monitored by Port Isabel High School students are typically within or adjacent to these nourishment areas.

The SPI02 (**Fig. 11**) monitoring site has been used by students and scientists to monitor the growth of dunes (sand volume) and shoreline movement. When SPI02 was established in August 2000, there were no dunes between the retaining wall and waterline at this location. Since that time, student-collected data has been quantifying the effects of sand fence installations, vegetation planting, and numerous nourishment projects (**Fig. 31**). Port Isabel student collected data, have documented

an overall trend of shoreline advancement and sediment-volume increase throughout the study period (Caudle and others, 2014, 2019). A new dune crossover was constructed at this site in 2017. We were concerned the new crossover would interfere with the profile line. Fortunately, the line runs a few feet to the north of the crossover and the only documented impact to the site was a slight flattening of the profile in the dunes and loss of vegetation, which quickly recovered.

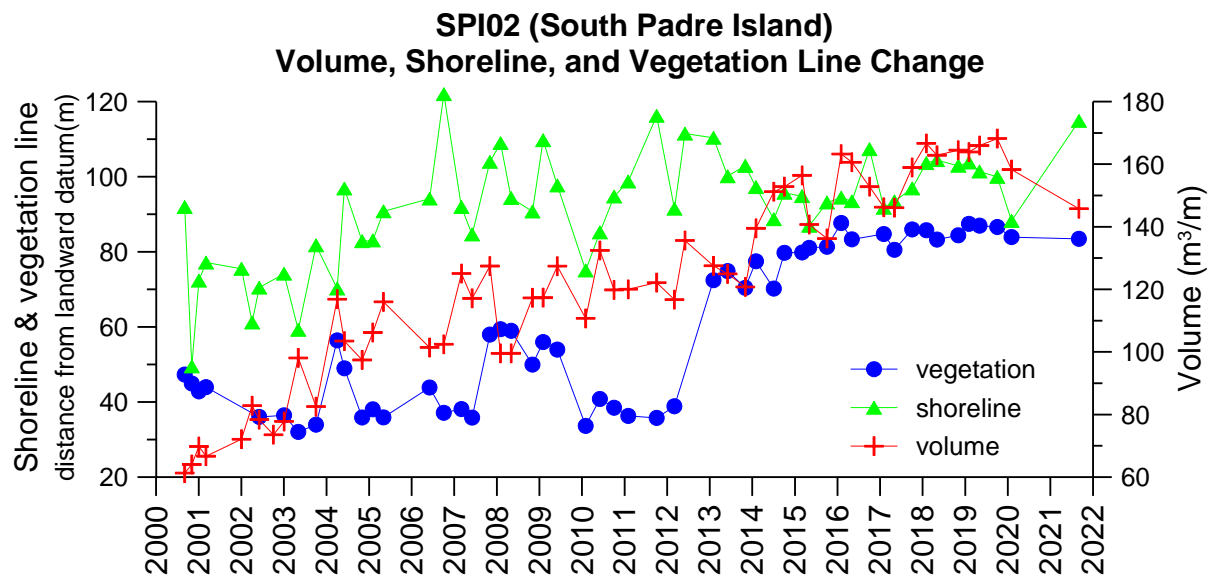
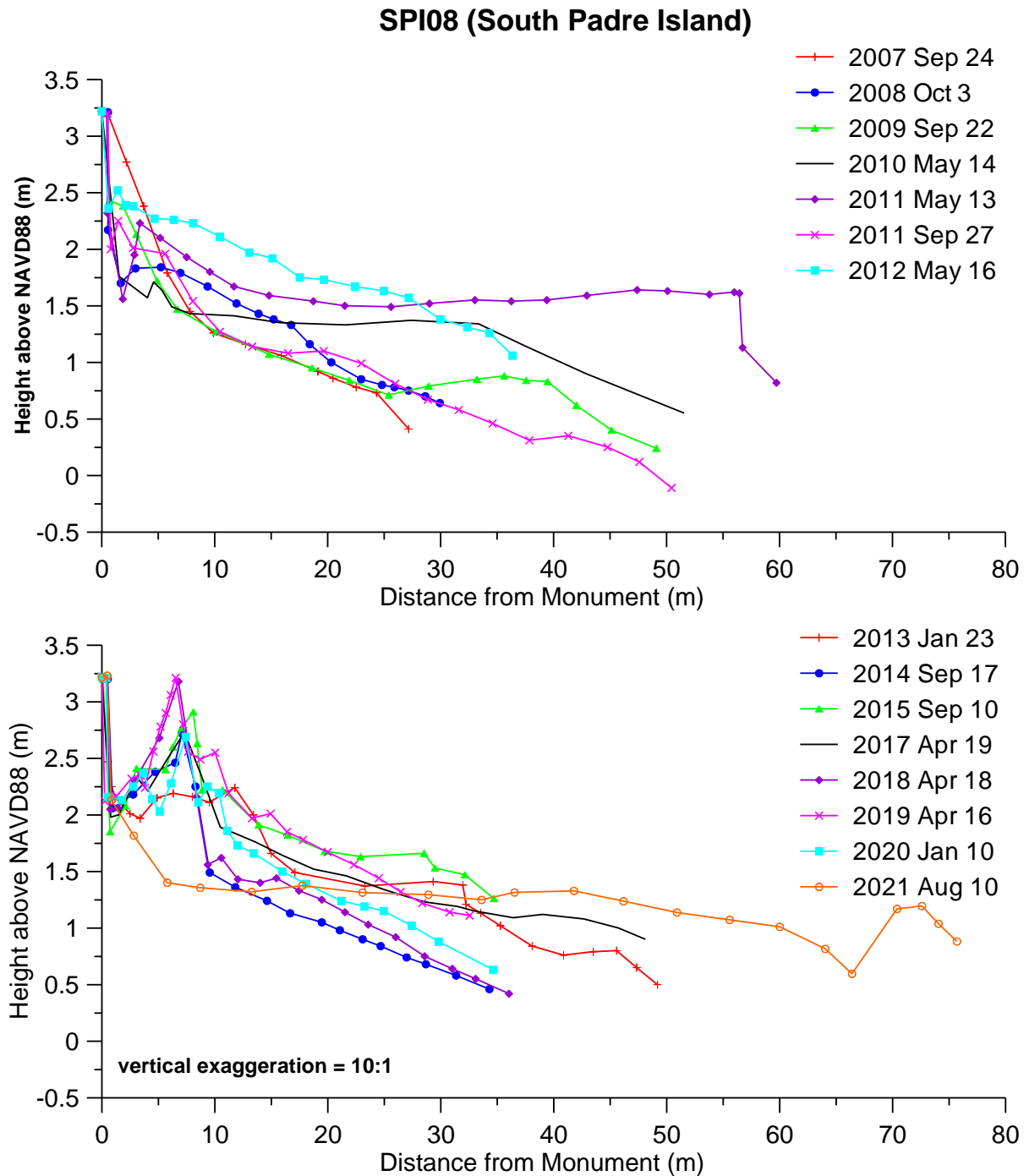


Figure 31. Changes in sand volume and in shoreline and vegetation-line positions at SPI02 on South Padre Island due to beach nourishment projects and the installation of sand fences.

SPI08 is a chronically eroding location in front of the Tiki Condominiums near the north end of the City of South Padre Island (**Fig. 11**). This site has a narrow beach backed by a retaining wall and regularly receives nourishment sand from road maintenance north of the City and from the dredging of Brazos Santiago Pass. The students from Port Isabel have been documenting cycles between beach nourishment, dune creation by beach maintenance practices, and the long-term shoreline erosion trend at this site (**Fig. 32**). The most recent nourishment took place between January 2020 and August 2021. The beach was much wider than had been previously documented but dune restoration or planting was not been part of this

project. Port Isabel students will continue to monitor this rapidly changing and chronically eroding location.



3D COASTAL MODEL

The Bureau developed a web-based 3D model for visualizing beach and dune impacts and recovery from Hurricane Ike in 2008 and Hurricane Harvey 2017. The creation of the model incorporated numerous steps including the implementation of programs written in-house to generate products with desired visualization properties. For example, programs were written to convert from native spatial data formats—such as digital elevation models (DEMs), ArcGIS shapefiles, and aerial photography—into 3D visualization formats. Methodologies for importing these files into the visualization platform were also developed. Another aspect of developing the 3D interactive visualization is developing widgets (buttons, slide bars, menus, pop-up information panels, etc.) and methods for interacting with the data which are all written in javascript. Buttons and sliders were developed to: toggle layers on/off, toggle between pre-defined viewpoints, switch scenes displayed in the primary viewport, adjust the vertical exaggeration of displayed data, and toggle between normal- and full-screen viewing. Building the foundation of the model also included writing scripts to incorporate text and surface-aligned vector data.

This visualization project focuses on the geomorphological impacts of Hurricanes Ike and Harvey on their respective regions of the Texas Gulf Coast. The completed scenes of the model include: general overview of the Gulf of Mexico, Hurricanes Ike and Harvey overviews, and two detailed looks each at the beach and dune impacts produced by both storms. The Hurricane Ike focused scenes are located at High Island and Galveston Island State Park. The Hurricane Harvey scenes are focused on Port Aransas and a segment of San Jose Island. The 3D coastal model can be accessed from the front page of the Texas High School Coastal Monitoring Program website <https://www.beg.utexas.edu/thscmp/> or the direct website <https://www.beg.utexas.edu/visualizations/3d-coastal-model/>.

With the foundation of the 3D coastal model in place, Bureau researchers will be able to build additional scenes or incorporate supplemental datasets and content, for example land use maps or wetland habitats. A Follets Island scene that introduces

the user to the different barrier island environments and how the sea level rise might impact the island will be the next scene to be incorporated into the model.

CONCLUSIONS

The purpose of the Texas High School Coastal Monitoring Program is to provide middle and high school students with a real-world learning experience outside the everyday classroom. The program provides not only hands-on education for students but also valuable data for coastal researchers and decision-makers. During the 2020–2021 academic year, Ball, Brazosport, High Island, Palacios, Port Aransas, Port Isabel and Van Vleck High Schools and Cunningham Middle School were not able to participate in data collection activities at their sites because of the COVID-19 pandemic. Bureau researchers visited the THSCMP monitoring sites to document changes that occurred during the academic year.

In the 24 years since the inception of the program, work by students participating in the THSCMP has been beneficial to Bureau researchers and coastal managers in several research projects. Analysis of the data has been used to investigate storm effects and monitor recovery; to measure impacts to the beach and dune system from beach nourishment, construction of jetties, and beach maintenance practices; and to verify shoreline positions for calculating change rates. Through this successful student research program, scientists, students, and the public continue to gain a better understanding of processes and shoreline change along the Texas coast.

Future measurements by the eight schools involved in the THSCMP will show not only change through time at each location, but also highlights the geomorphic differences found along the Texas coast. Data collected from Bolivar Peninsula, Galveston Island, Follets Island, Quintana Beach, Matagorda Peninsula, Mustang Island, and North and South Padre Islands will help scientists better understand the relationships between coastal processes, beach morphology, and shoreline change at these locations. Coastal communities and managers—especially our partners at the Texas General Land Office, Texas Parks and Wildlife Department, and other

coastal parks—benefit from having access to the beach monitoring data and analysis for use in public-policy and coastal-management decision-making.

The THSCMP website ((<http://www.beg.utexas.edu/thscmp/>) provides direct access to data, analysis of coastal changes organized by school, field trip photos, and educational resources such as the 3D model, field guides, and learning activities.

Due to being unable to conduct field trips this academic year, the focus of the project shifted more toward providing materials for in-class and at-home learning. The 3D model, new learning activities utilizing the 3D model and the Bureau's shoreline movement viewer, shoreline movement posters, and recorded lectures help accomplish those goals.

ACKNOWLEDGMENTS

This project was supported by grant number 20-039-000-B747 from the Texas General Land Office to the Bureau of Economic Geology, The University of Texas at Austin. Tiffany Caudle served as the Principal Investigator. The project was funded under a Coastal Management Program (Cycle 24) grant made available to the State of Texas by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, pursuant to the Federal Coastal Zone Management Act of 1972, NOAA Award Number NA19NOS4190106. Additional funds to support the project came from the Trull Foundation and The Jackson School of Geosciences. Field trip support was provided by staff at Matagorda Bay Nature Park, Lower Colorado River Authority, and by graduate students from the Coastal & Marine Geospatial Sciences Lab at the Harte Research Institute, Texas A&M University–Corpus Christi.

REFERENCES

- Caudle, T. L., and Paine, J. G., 2012, Pre-college student involvement in Texas coastal research: Gulf Coast Association of Geological Societies Transactions, v. 62, p. 27–38.
- Caudle, T. L., and Paine, J. G., 2017, Applications of Coastal Data Collected in the Texas High School Coastal Monitoring Program (THSCMP): Journal of Coastal Research, v. 33, no. 3, p. 738–746.
- Caudle, T.L., Paine, J.G., Andrews, J.R., and Saylam, K., 2019, Beach, Dune, and Nearshore Analysis of Southern Texas Gulf Coast Using Chiroptera LIDAR and Imaging System: Journal of Coastal Research, v. 35, no. 2, p. 251–268.
- Caudle, T.L., Tremblay, T.A., Paine, J.G., Andrews, J.R., and Saylam, K., 2014, Beach and Dune Analysis using Chiroptera Imaging System, South Padre and Brazos Islands, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 13-030-000-6895, 68 p.
- Emery, K. O., 1961, A simple method of measuring beach profiles: Limnology and Oceanography, v. 6, no. 1, p. 90–93.
- Gibeaut, J. C., and Caudle, T. L., 2009, Defining and Mapping Foredunes, the Line of Vegetation, and Shorelines along the Texas Gulf Coast. The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 07-005-22, 14 p.
- Gibeaut, J. C., Gutiérrez, R, and Hepner, T., 2002, Threshold conditions for episodic beach erosion along the southeast Texas coast. Gulf Coast Association of Geological Societies Transactions, v. 52, p. 323–335.
- Gibeaut, J. C., Hepner, T., Andrews, J., Gutierrez, R., and Smyth, R., 2008, Hurricane Rita impacts on the Texas shoreline: a summary report: The

University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 02-267 C, 26 p.

Gibeaut, J. C., Hepner, T. L., Waldinger, R. L., Andrews, J. R., Smyth, R. C., and Gutiérrez, R., 2003, Geotextile tubes along the Upper Texas Gulf coast: May 2000 to March 2003: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA07OZ0134, under GLO contract number 02-493 R, 37 p. plus appendices.

Hepner, T. L., and Gibeaut, J. C., 2004, Tracking post-storm beach recovery using data collected by Texas high school students: *Shore & Beach*, v. 72, no. 4, p. 5–9.

Krause, G., 2004, The “Emery-Method” Revisited: Performance of an Inexpensive Method of Measuring Beach Profiles and Modifications: *Journal of Coastal Research*, v. 20, no. 1, p. 340–346.

Morton, R.A. and Paine, J.G., 1985, Beach and Vegetation-Line Changes at Galveston Island, Texas: Erosion, Deposition, and Recovery from Hurricane Alicia. Austin, Texas: The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 85-5, 66 p.

O’Connell, J., 2001, Beach and Dune Profiles: An Educational Tool for Observing and Comparing Dynamic Coastal Environments: *Marine Extension Bulletin*, Woods Hole Oceanographic Institution Sea Grant Program, Massachusetts, 6 p.

Paine, J.G., and Caudle, T. L., 2018, Shoreline movement along the Texas Gulf Coast, 1930s to 2016: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 16-201-000, 59 p.

- Paine, J. G., Caudle, T., and Andrews, J., 2014, Shoreline movement along the Texas Gulf Coast, 1930's to 2012: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 09-074-000, 52 p.
- Paine, J.G., Caudle, T., and Andrews, J.R., 2021, Shoreline Movement and Beach and Dune Volumetrics along the Texas Gulf Coast, 1930s to 2019: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 16-201-000, 101 p.
- Paine, J. G., Mathew, S., and Caudle, T., 2011, Gulf shoreline change rates through 2007: The University of Texas at Austin, Bureau of Economic Geology, report prepared for the Texas General Land Office under GLO contract number 10-041-000-3737, 38 p.
- Paine, J. G., Mathew, S., and Caudle, T., 2012, Historical Shoreline Change Through 2007, Texas Gulf Coast: Rates, Contributing Causes, and Holocene Context, Gulf Coast Association of Geological Societies Journal, v. 1, p. 13–26.
- Simpson, R. H., and Riehl, H., 1981, The hurricane and its impact: Baton Rouge, Louisiana State University Press, 398 p.
- U.S. Army Corps of Engineers, 2017, 2016 USACE NCMP topobathy lidar DEM: Gulf Coast (TX), Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), Charleston, SC.

APPENDIX A: PROFILE INFORMATION

All profile coordinates are in NAD83. Heights above the GRS80 Ellipsoid were converted to North American Vertical Datum 88 (NAVD88) using the Geoid12B Ellipsoid Model. Profile sites are listed in the order they appear along the Texas coast starting from the northeastern most site closest to the Texas-Louisiana border and traveling south.

Profile	Latitude (deg min)	Longitude (deg min)	Easting (m)	Northing (m)	HAE (m)	NAVD88 (m)	Azimuth (M)
HIB01	29 33.08	94 23.04	365917.69	3269868.01	-25.18	1.64	150
BOL03	29 30.60	94 29.64	355196.55	3265428.50	-23.26	3.54	150
BOL02	29 30.00	94 31.20	352663.65	3264343.08	-23.62	3.17	150
DEL01	29 14.44	94 52.38	317984.46	3236109.93	-23.84	2.74	150
BEG02¹	29 11.64	94 57.09	310255.20	3231059.16	-24.75	1.79	139
BEG02R	29 11.67	94 57.11	310228.82	3231110.58	-24.61	1.93	139
GLO06²	29 11.12	94 58.05	308696.85	3230117.35	-24.32	2.20	138
JAM02	29 10.87	94 58.39	308128.50	3229670.91	-24.29	2.24	140
BEG08³	29 3.22	95 8.90	290838.52	3215830.51	-24.21	2.16	145
SURF1	28 57.47	95 16.59	278154.49	3205457.56	-24.47	1.84	130
SURF2	28 57.08	95 17.03	277426.68	3204737.87	-22.00	4.30	130
QUIN1	28 55.99	95 18.13	275599.85	3202771.80	-24.47	1.82	150
MAT01	28 36.67	95 56.55	212269.73	3168453.74	-22.77	3.79	148
MAT02	28 36.31	95 57.47	210751.39	3167825.80	-23.25	3.32	148
MAT03	28 35.91	95 58.48	209090.26	3167112.23	-21.81	4.78	148
MUI01	27 49.53	97 03.40	691396.24	3079393.46	-22.29	4.07	123
MUI03	27 47.66	97 05.08	688697.42	3075882.34	-22.24	4.07	125
MUI02	27 40.42	97 10.19	680502.6	3062387.97	-24.22	1.88	120
NPC06	27 35.99	97 12.66	676557.71	3054150.56	-21.76	4.19	110
NPI08	27 35.86	97 12.78	676359.73	3053901.89	-23.32	2.62	110
SPI08	26 8.17	97 10.10	683116.29	2892056.38	-18.32	3.22	75
SPI02	26 6.79	97 9.93	683438.99	2889509.24	-18.11	3.39	78
SPI01⁴	26 4.57	97 9.46	684274.71	2885422.83	-18.48	2.97	70
SPI01R	26 4.58	97 9.46	684271.26	2885435.80	-14.94	6.48	70

¹BEG02 reset in October 2008 after Hurricane Ike.

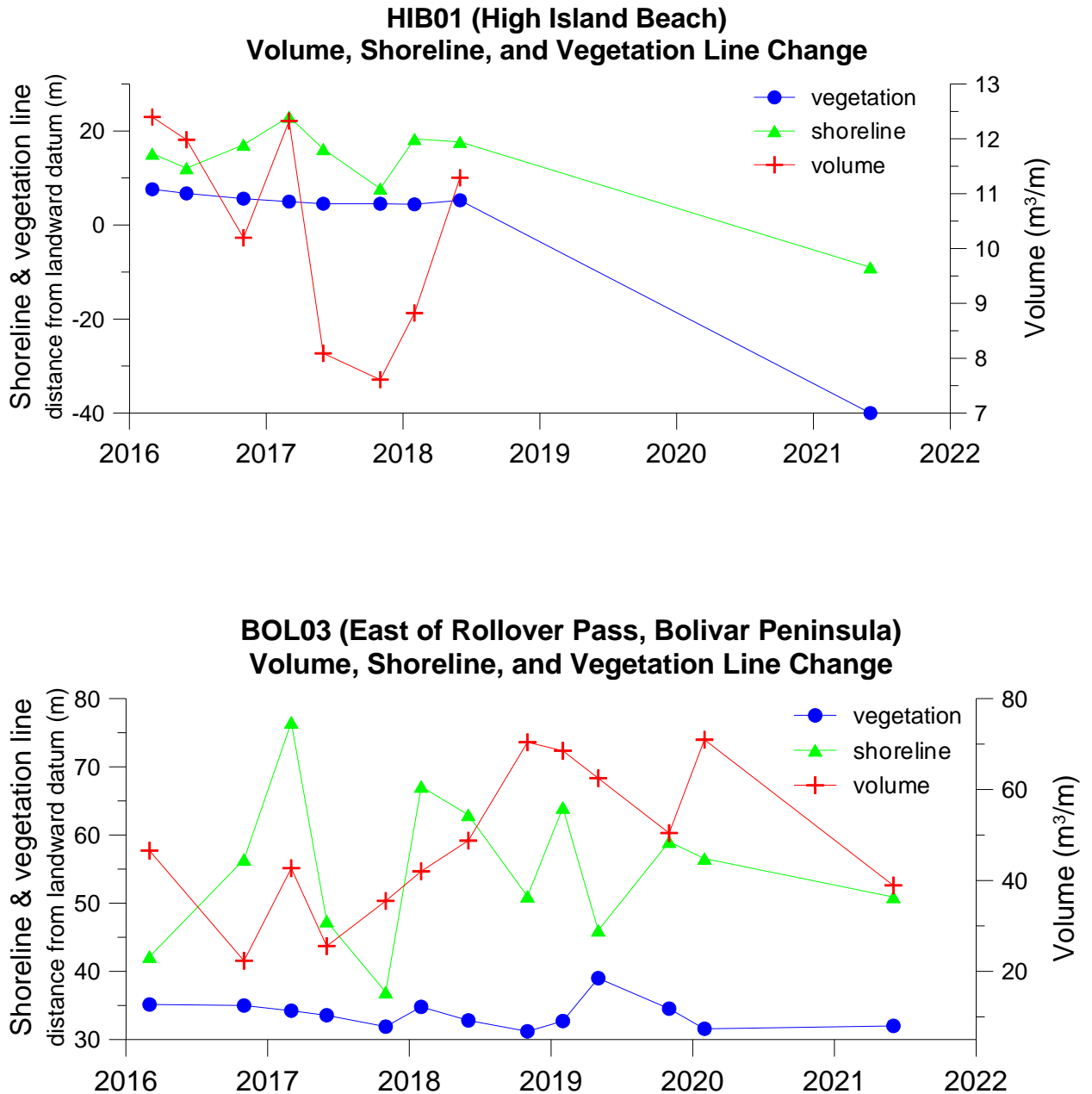
²GLO06 was monitored after post-Hurricane Ike until the Jamaica Beach (JAM02) site was added in October 2015. JAM02 was selected to monitor a CEPRA dune restoration project.

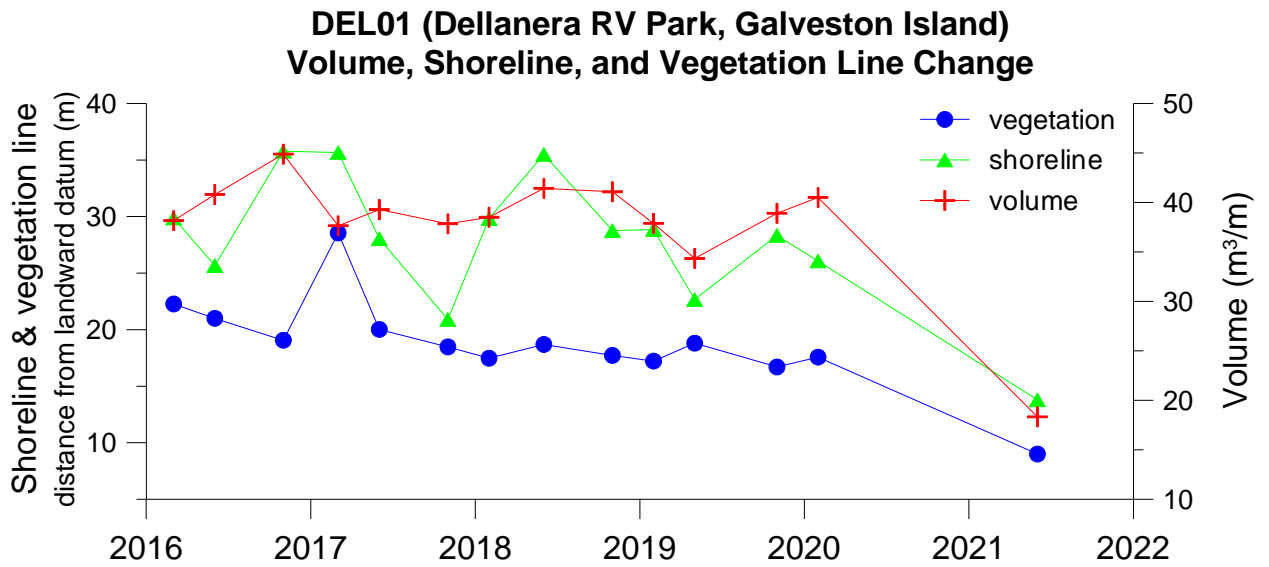
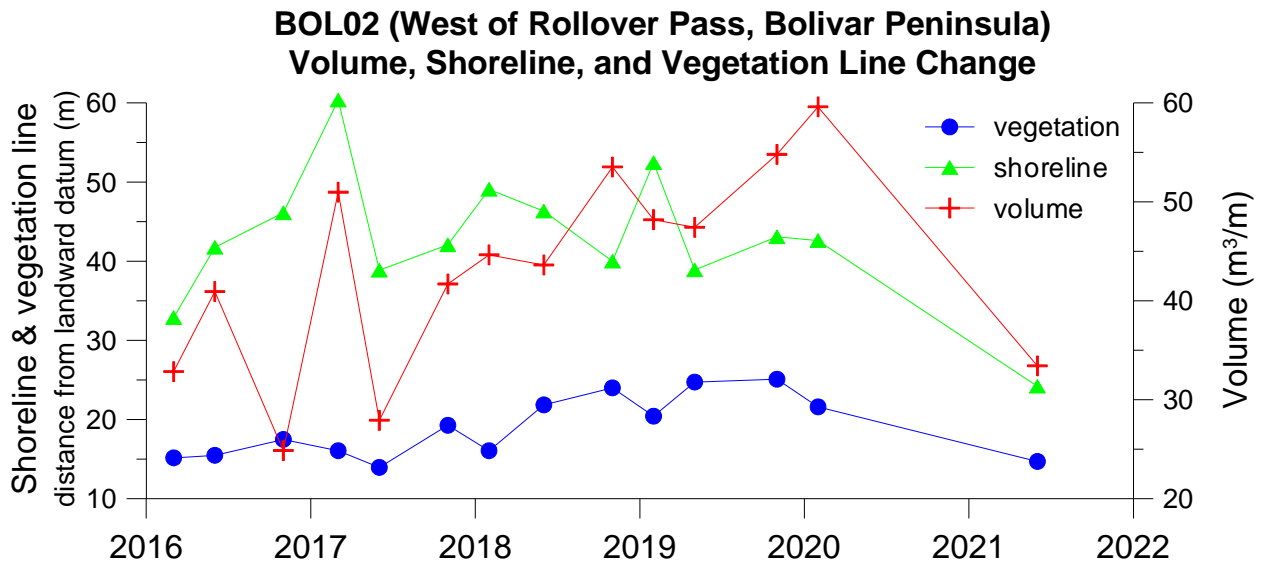
³BEG08 was lost due to Hurricane Ike in 2008. The new mark was reset landward of the Bluewater Highway making it too dangerous for students to monitor.

⁴SPI01 was lost due to construction at Isla Blanca Park.

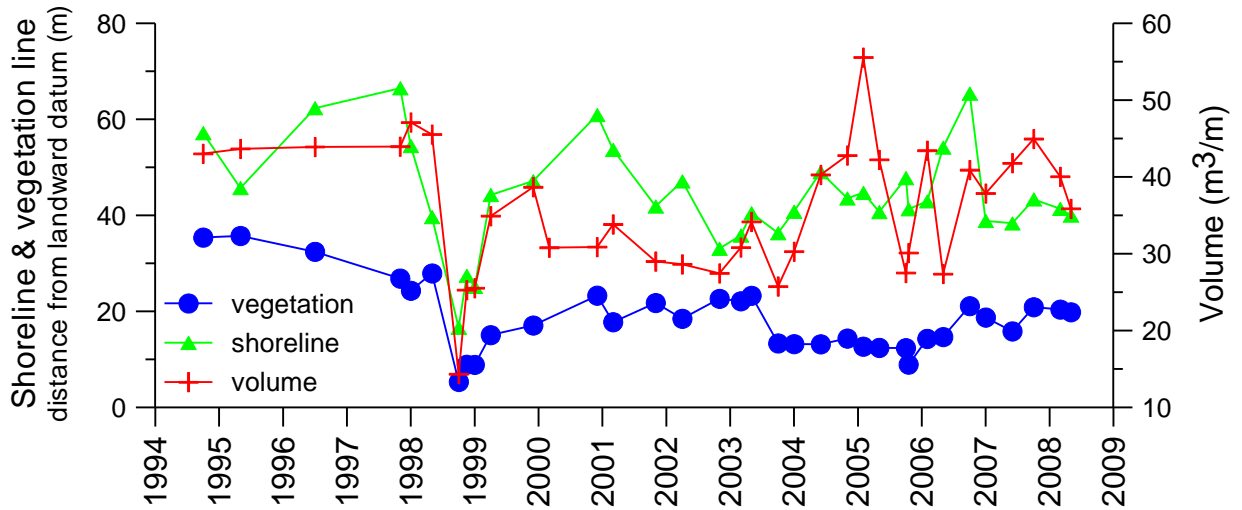
APPENDIX B: GRAPHS OF VOLUME, SHORELINE, AND VEGETATION-LINE CHANGE

Sediment volume was calculated above 1-meter NAVD88 for all profiles unless otherwise indicated. Profiles that did not extend below the 1-meter NAVD88 elevation were extrapolated.

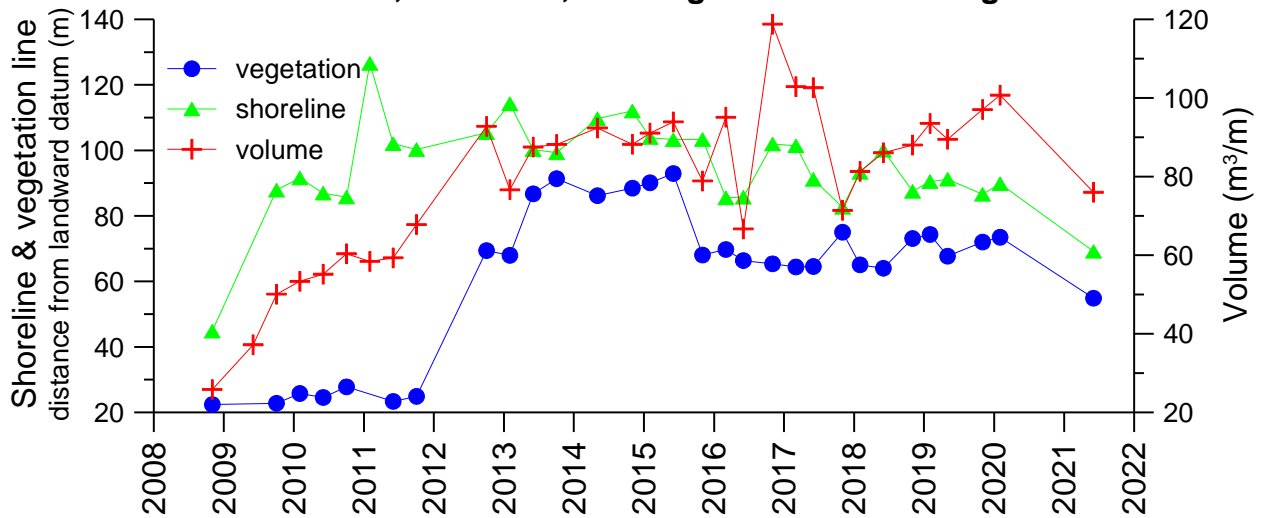


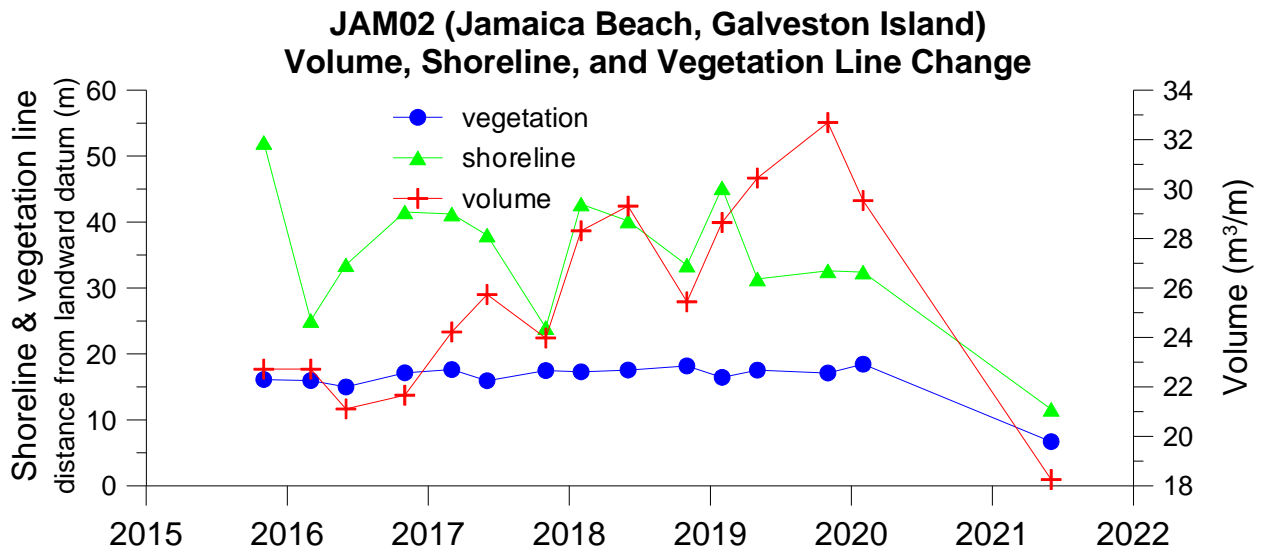
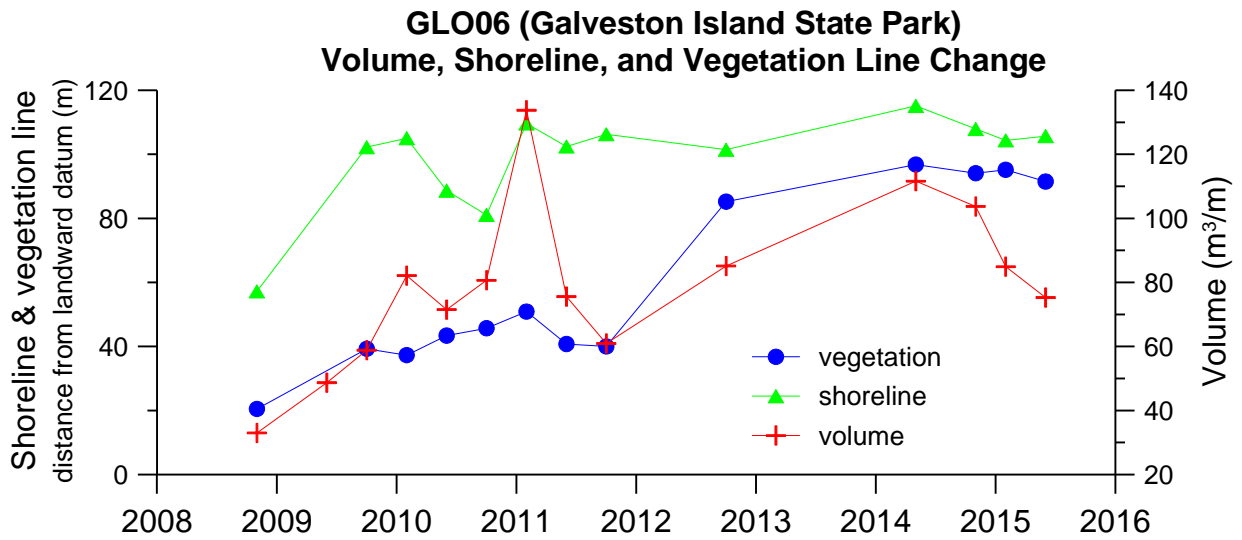


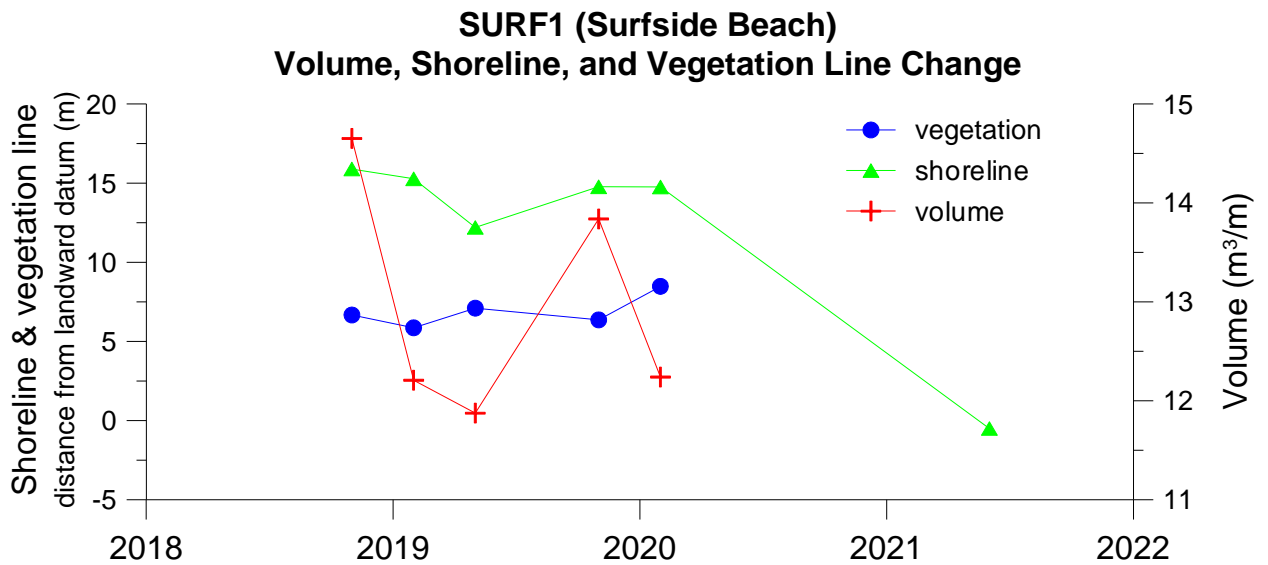
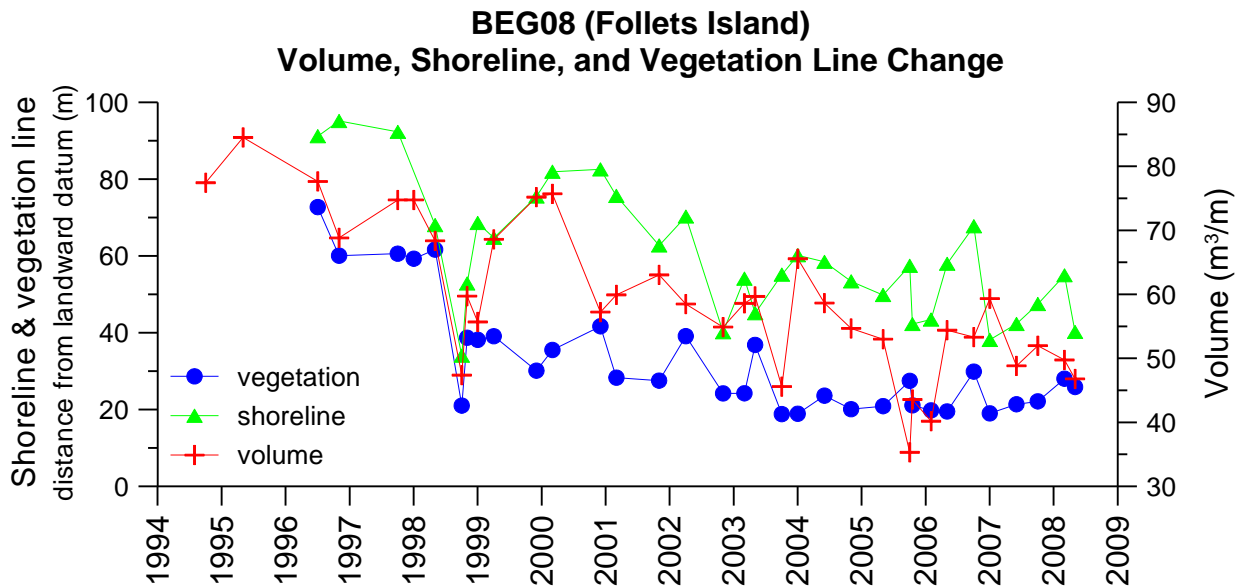
BEG02 (Galveston Island State Park)
Volume, Shoreline, and Vegetation Line Change

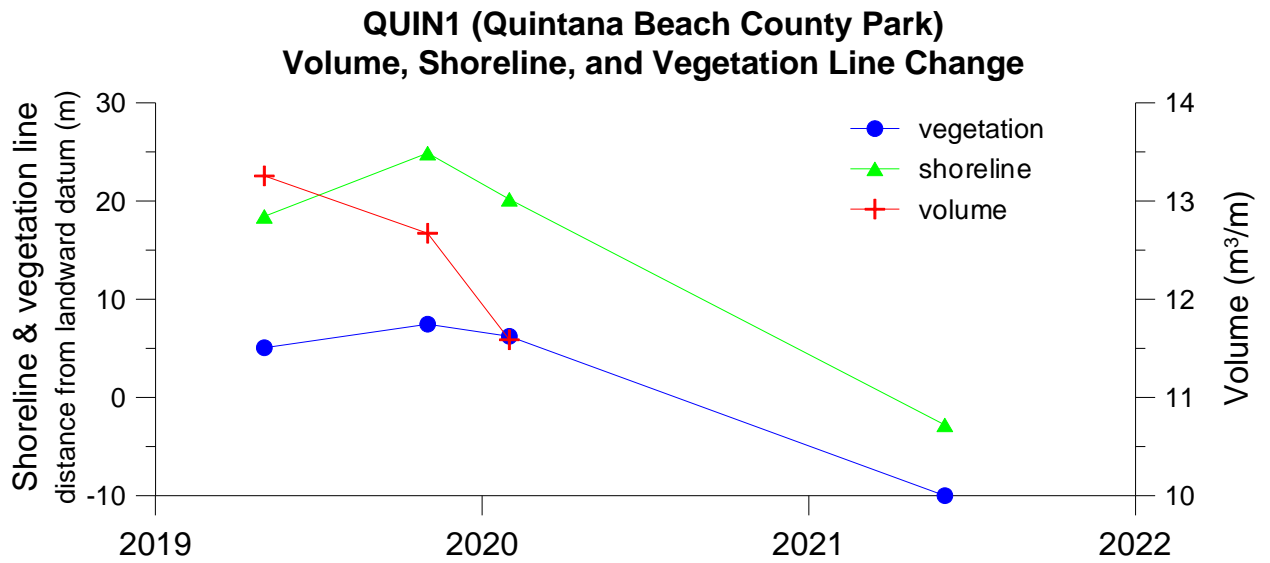
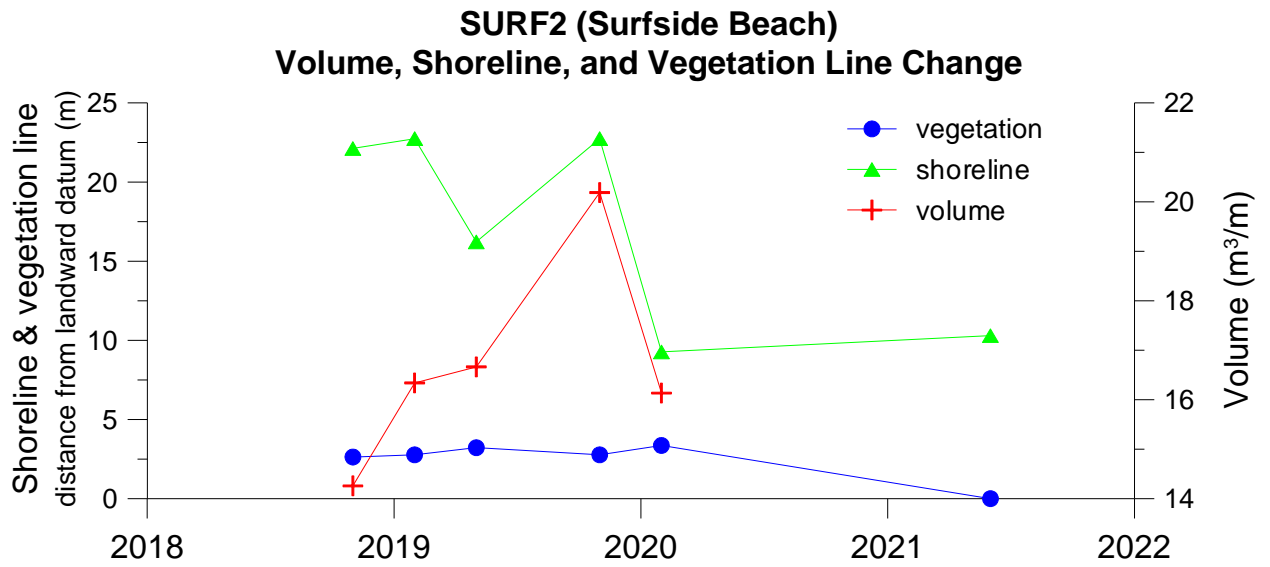


BEG02R (Galveston Island State Park)
Volume, Shoreline, and Vegetation Line Change

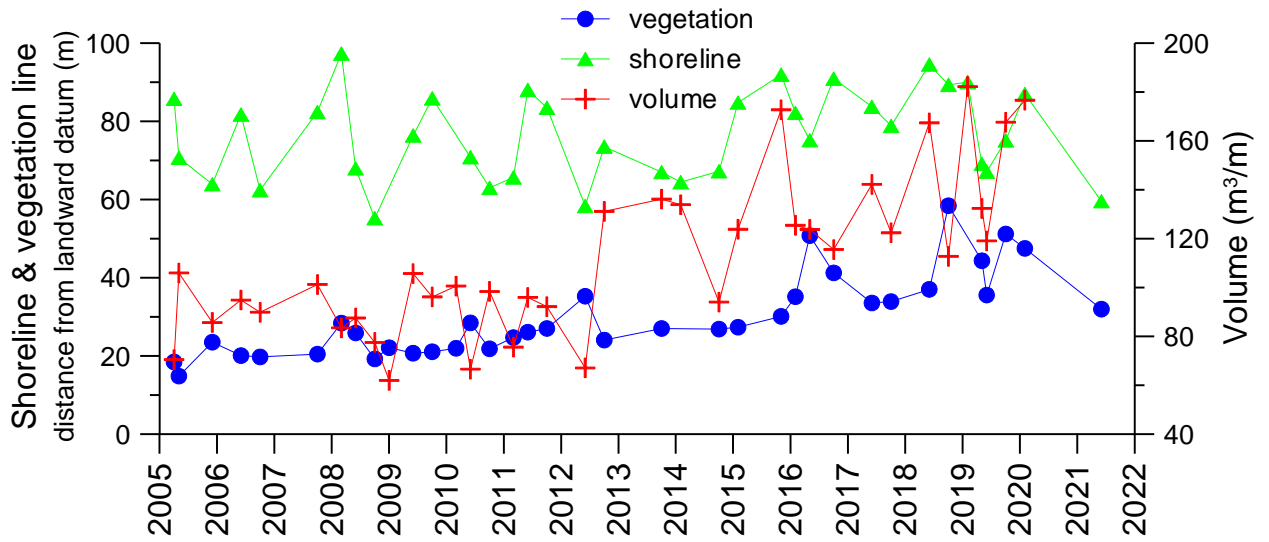




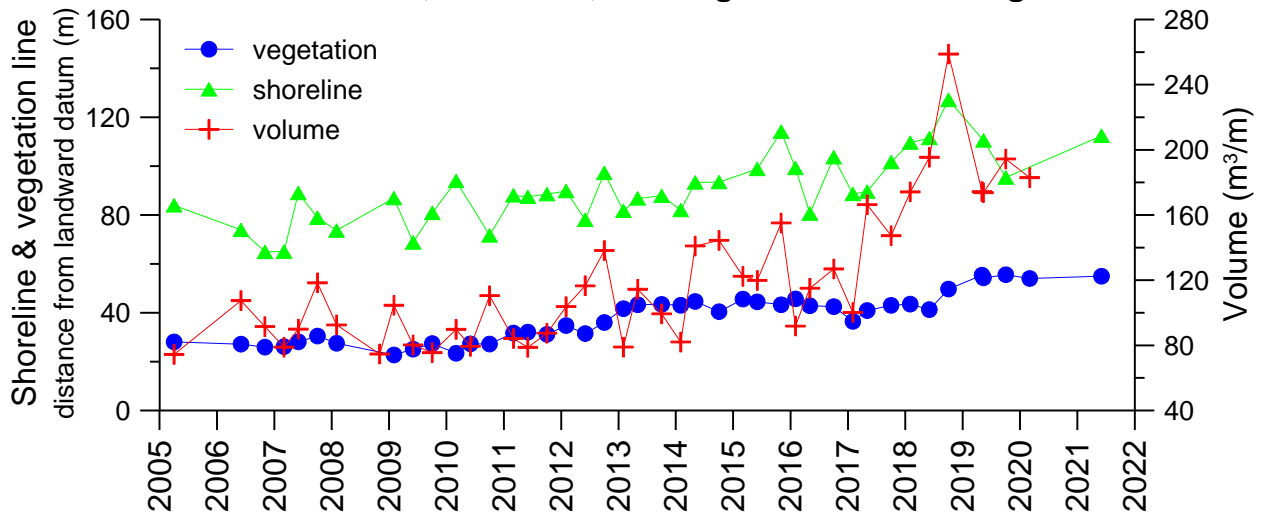


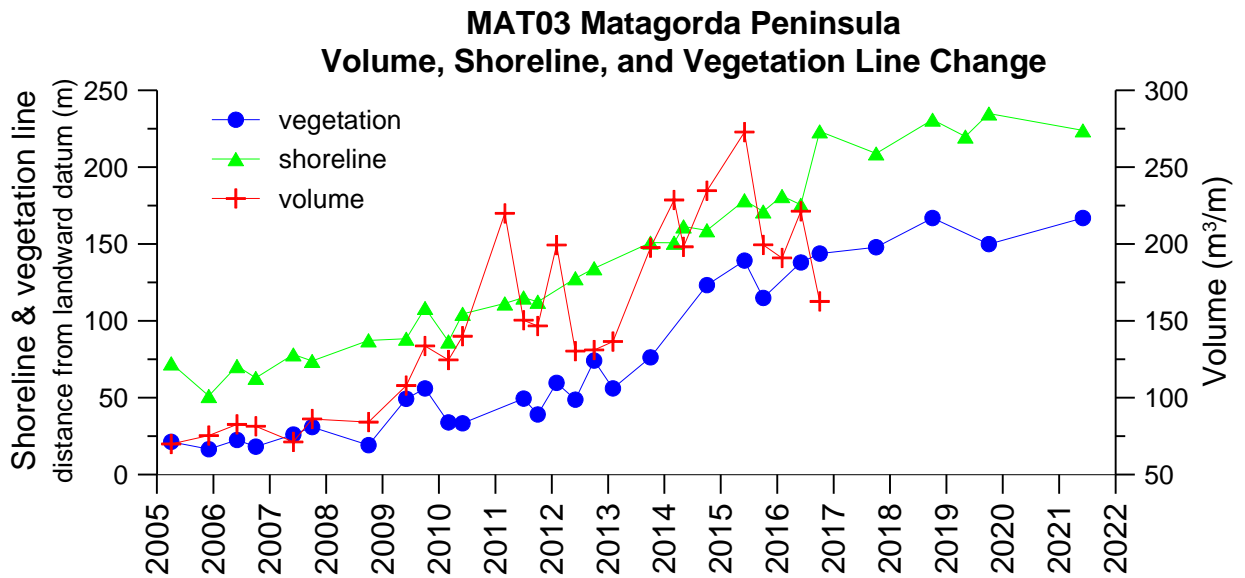


MAT01 (Matagorda Peninsula) Volume, Shoreline, and Vegetation Line Change

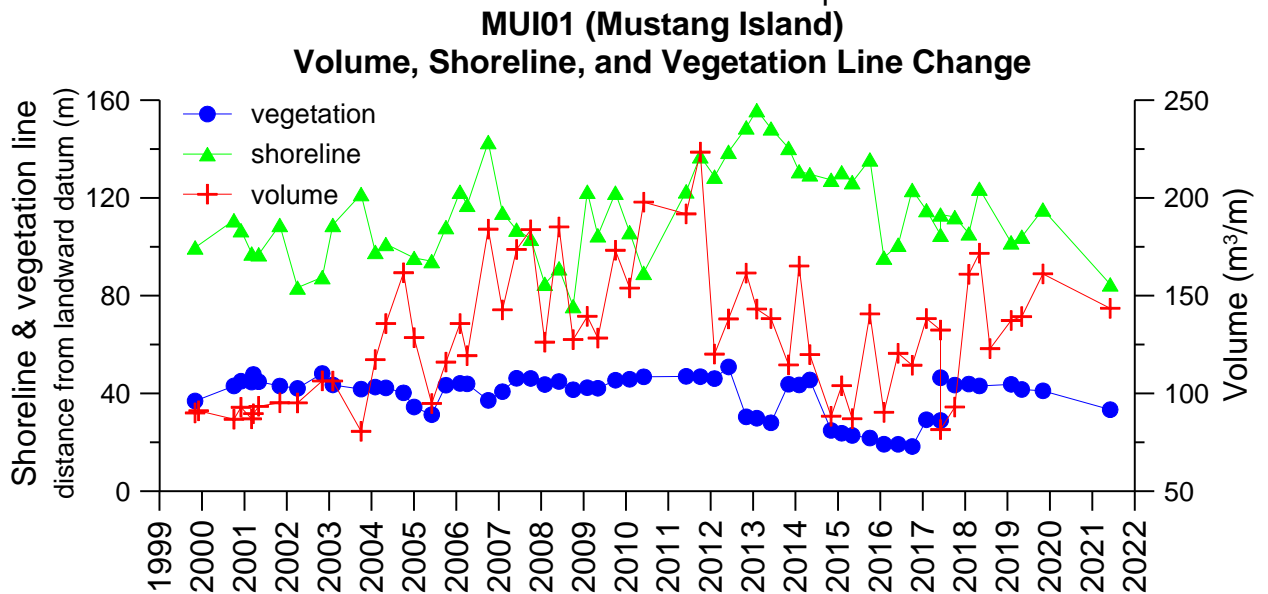


MAT02 (Matagorda Peninsula) Volume, Shoreline, and Vegetation Line Change

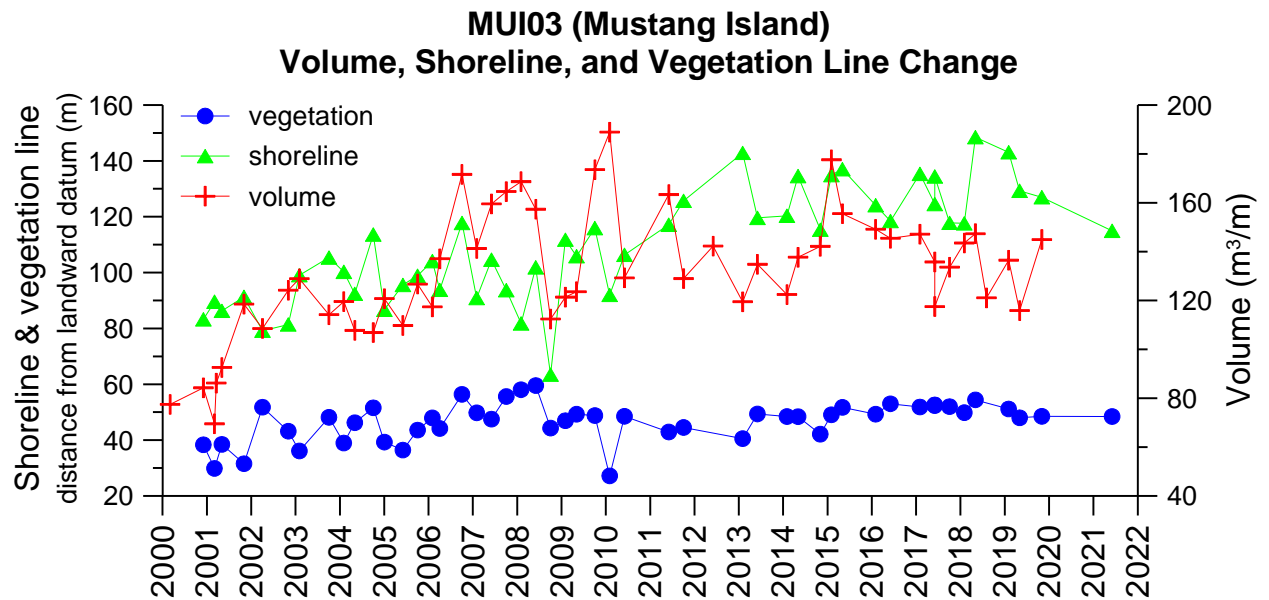




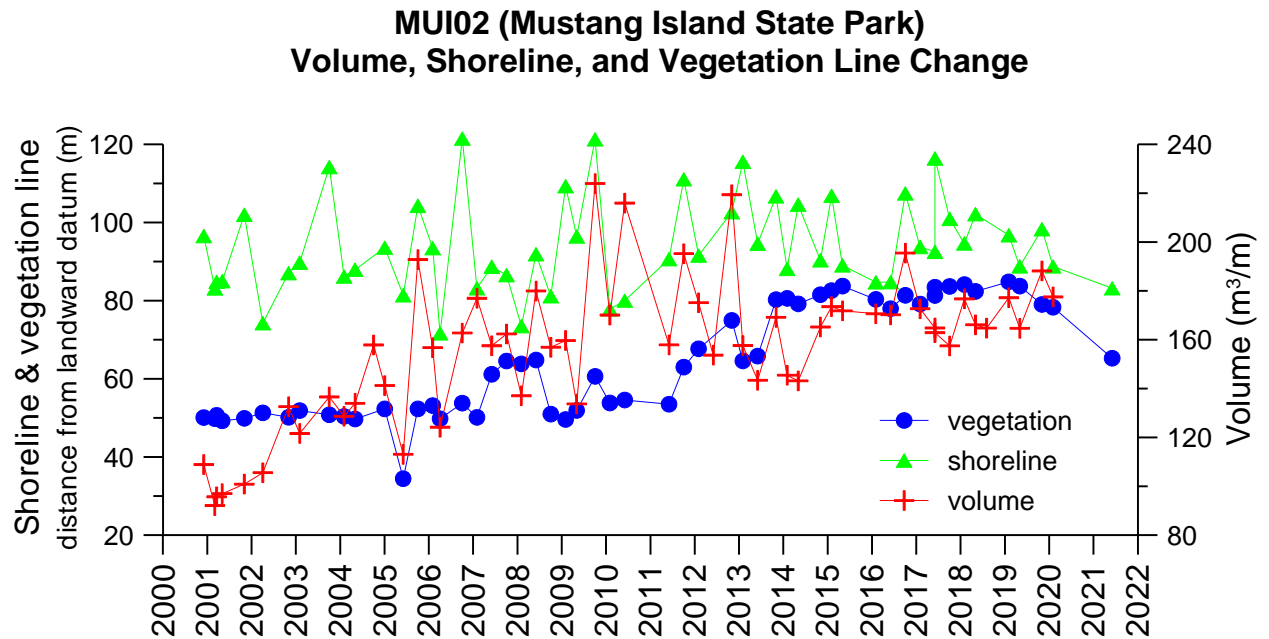
MUI01 volumes were calculated above 1.5 meters NAVD88. Profiles that did not extend below the 1.5-meter NAVD88 elevation were extrapolated.

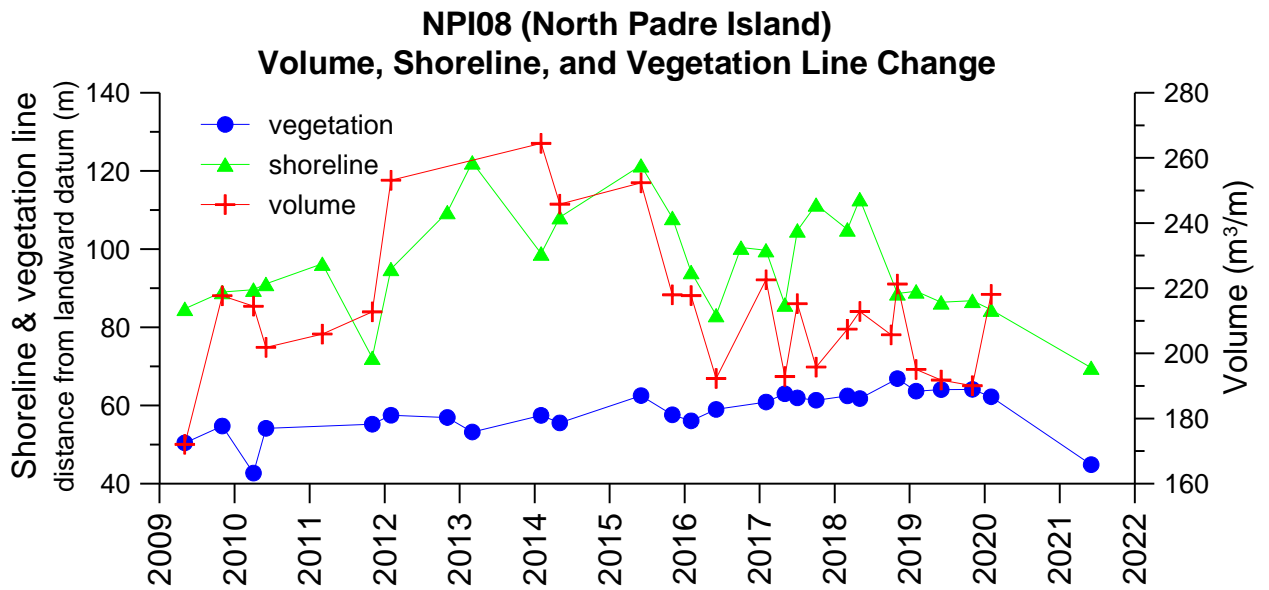
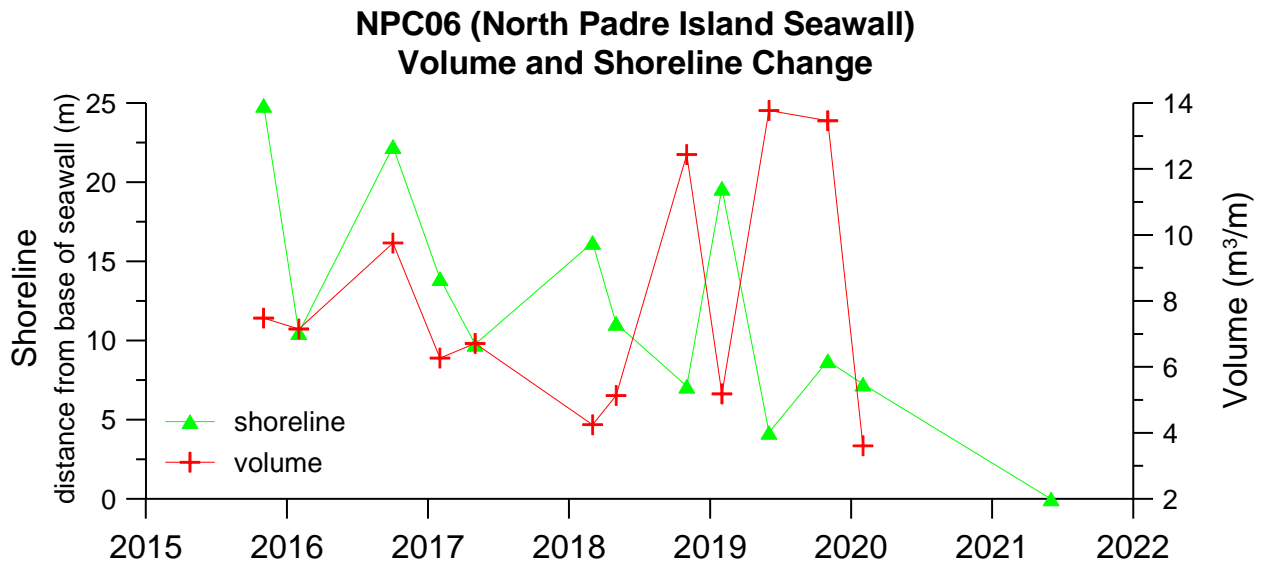


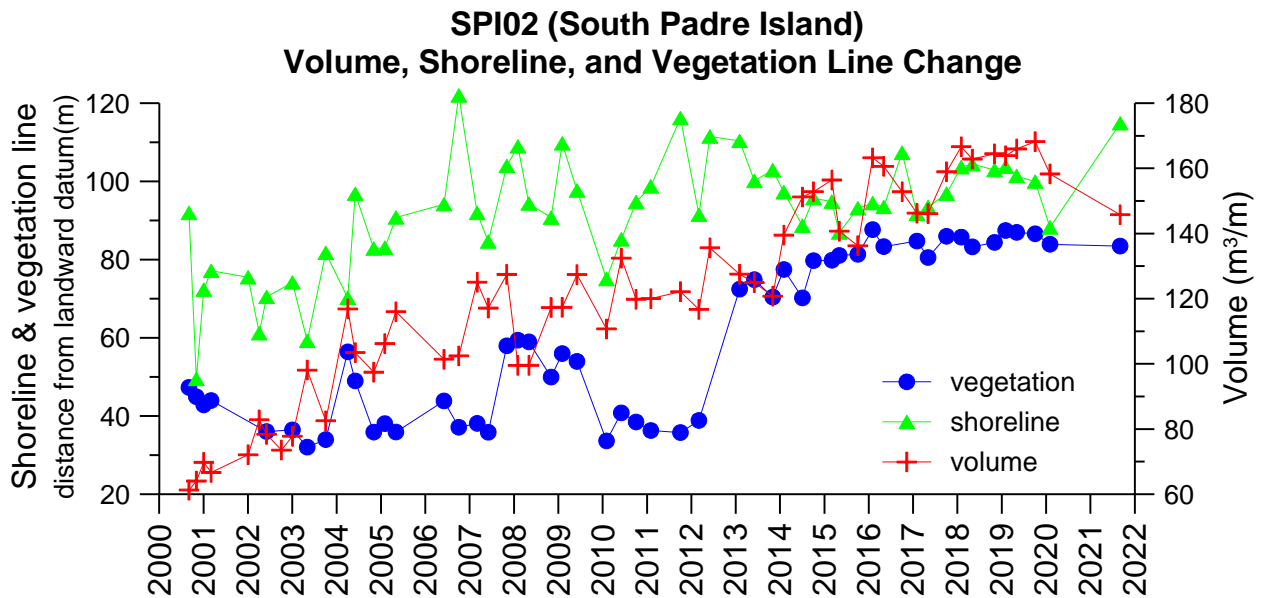
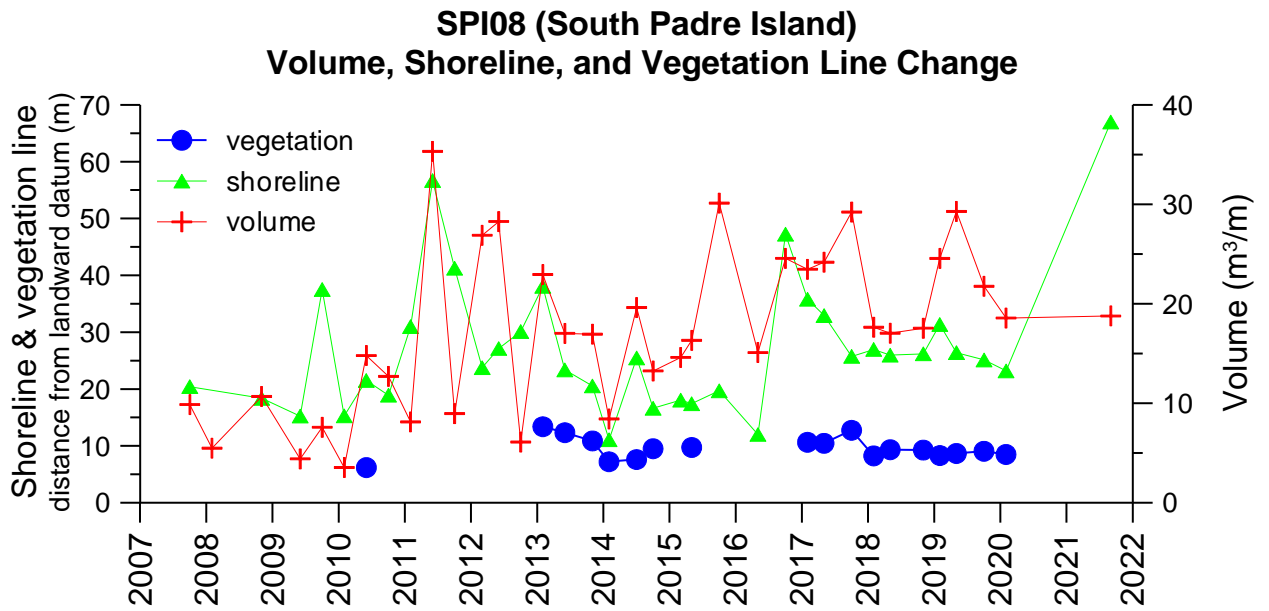
MUI03 volumes were calculated above 1.5 meters NAVD88. Profiles that did not extend below the 1.5-meter NAVD88 elevation were extrapolated.

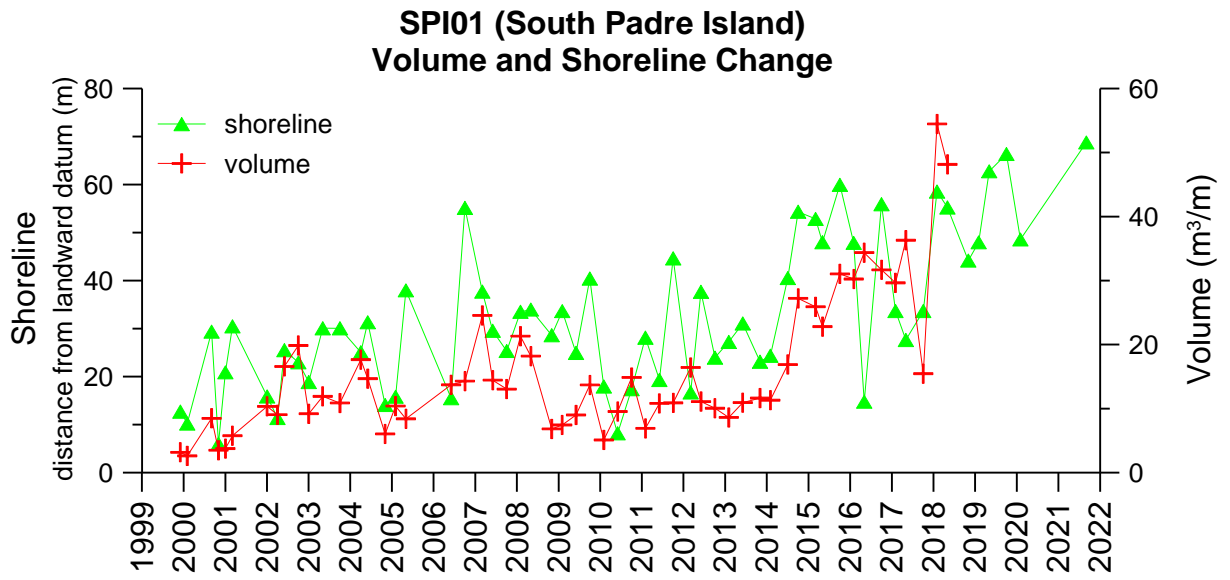


MUI02 volumes were calculated above 1.25 meters NAVD88. Profiles that did not extend below the 1.25-meter NAVD88 elevation were extrapolated.





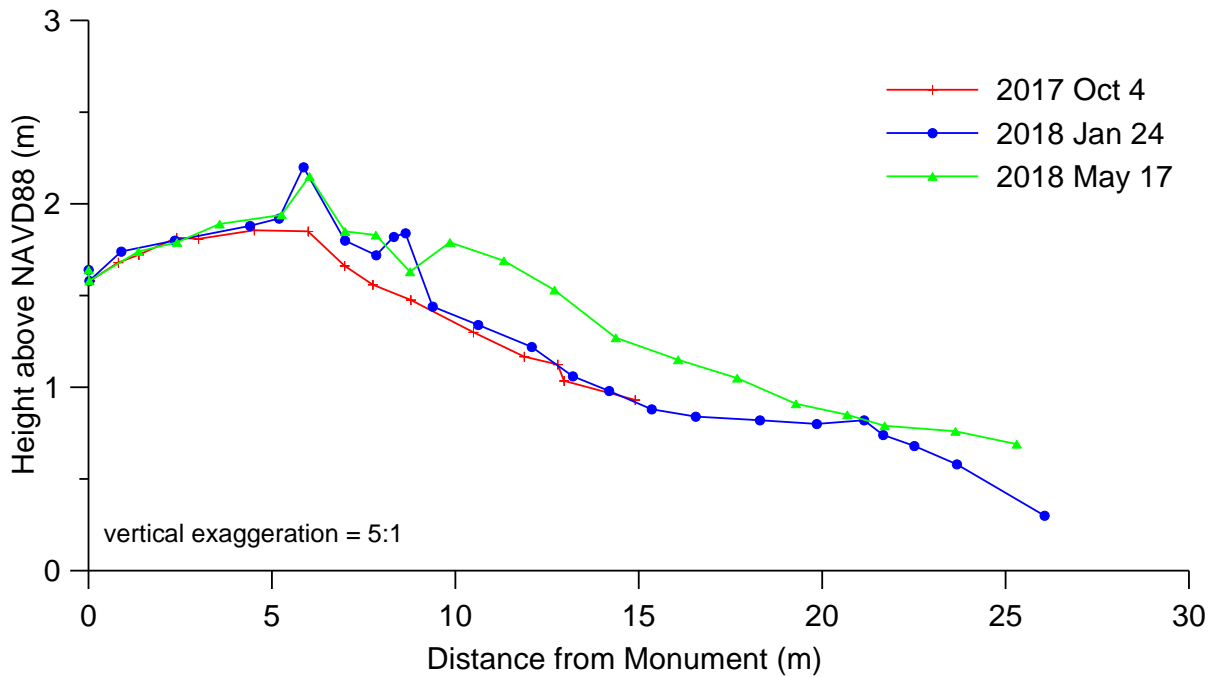
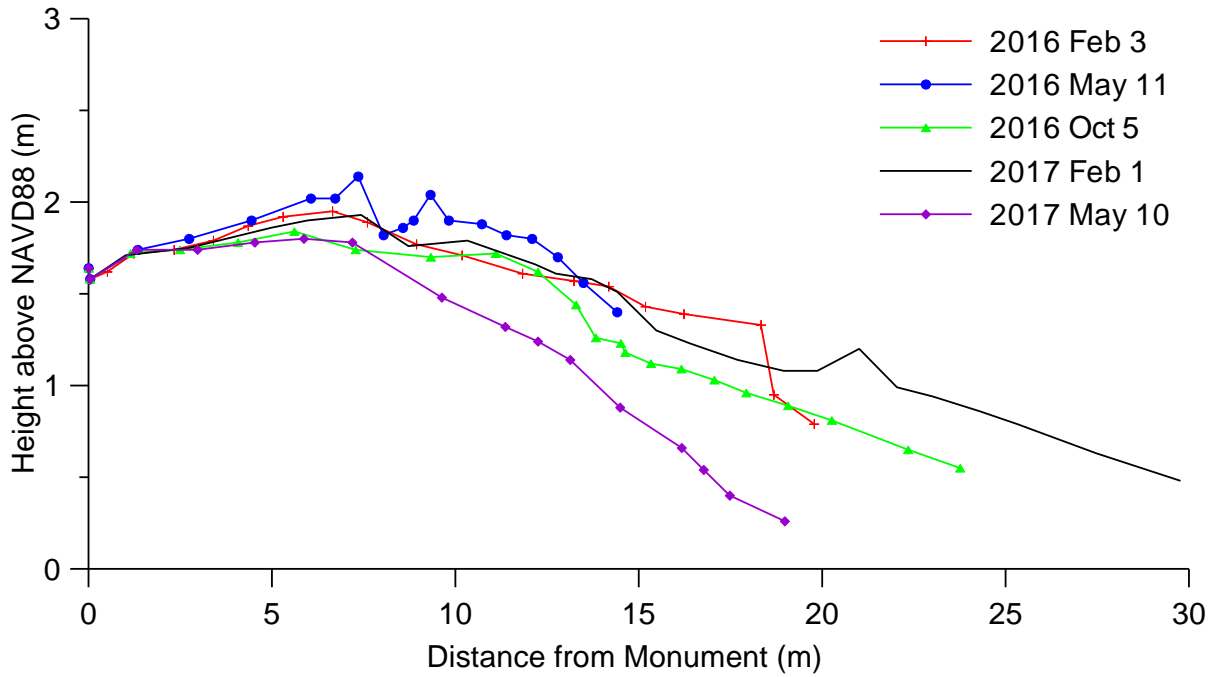




APPENDIX C: GRAPHS OF BEACH PROFILES

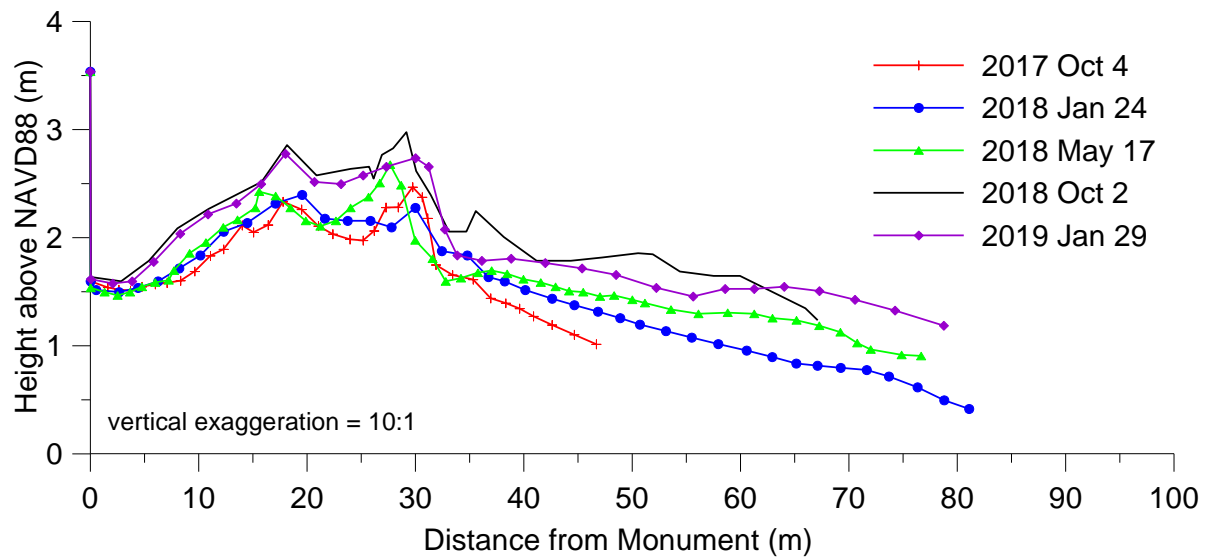
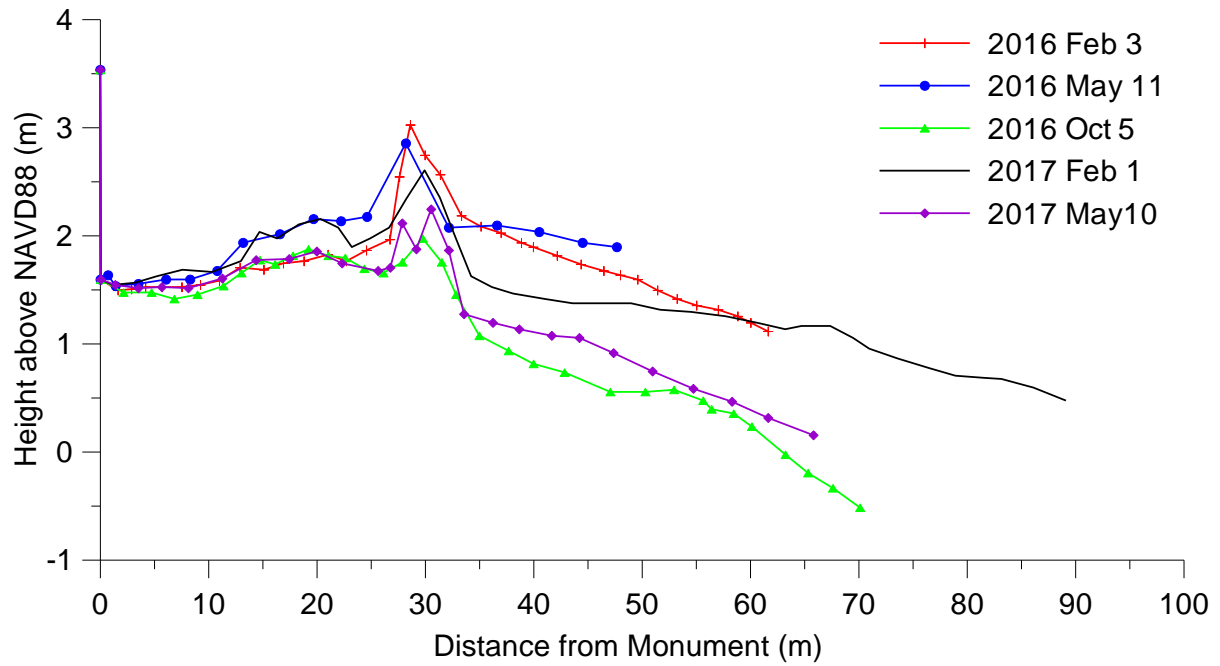
HIB01

HIB01 (High Island Beach)

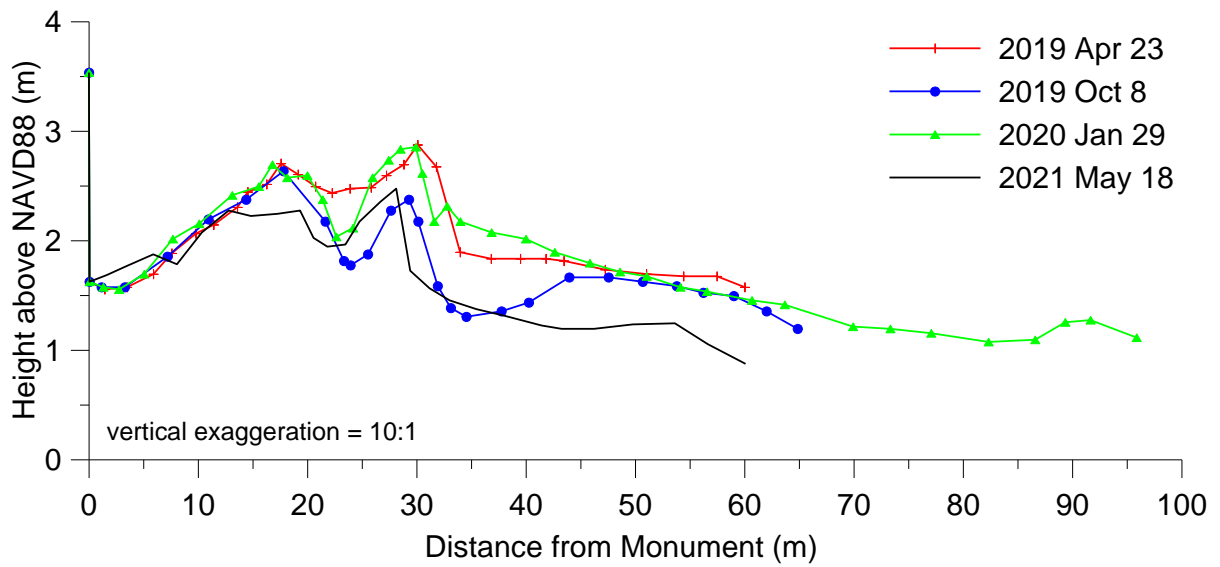


BOL03

BOL03 (East of Rollover Pass, Bolivar Peninsula)

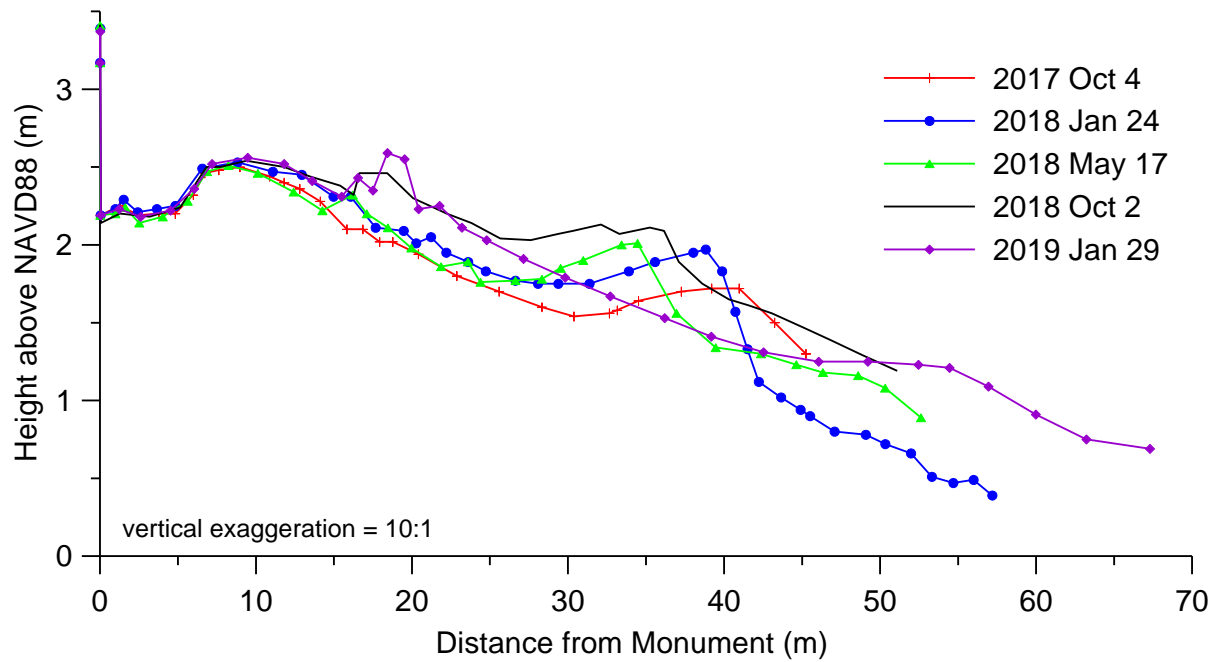
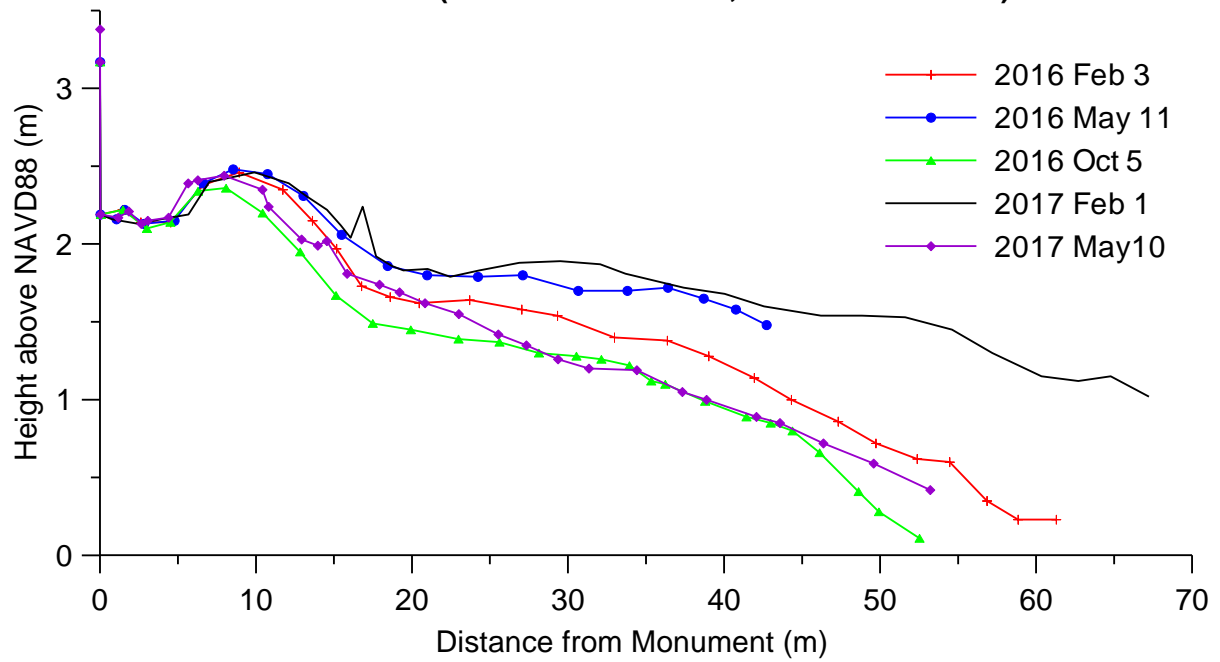


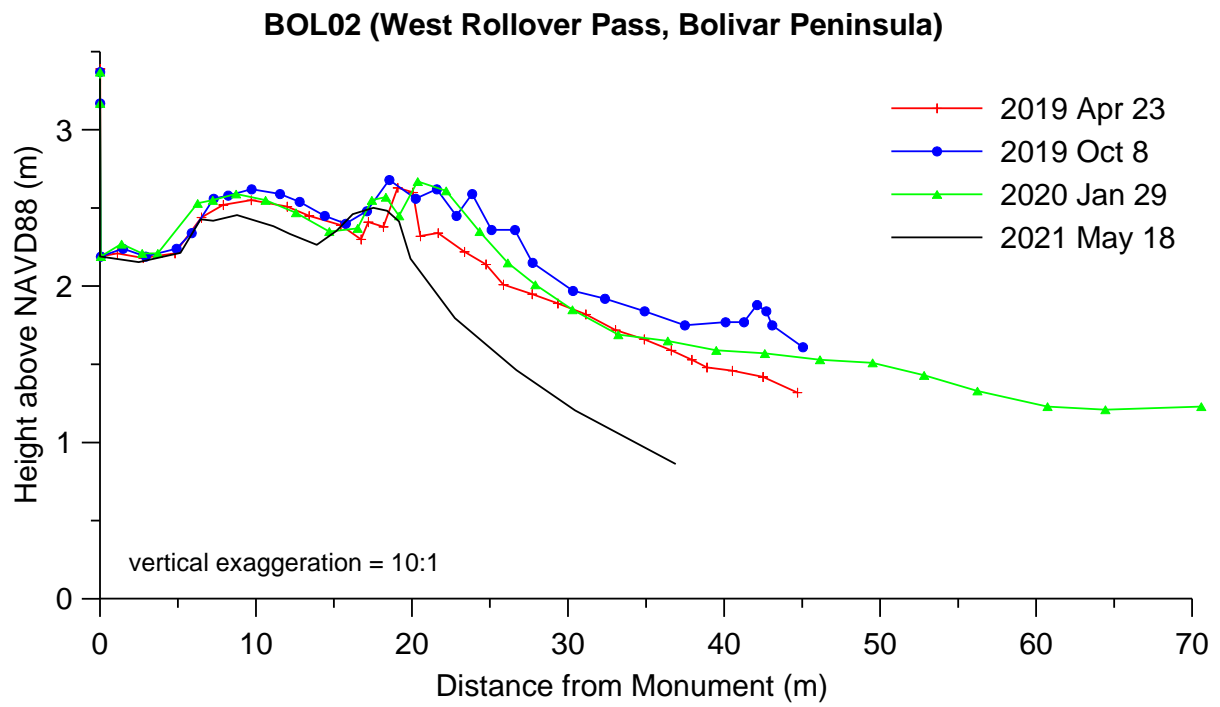
BOL03 (East of Rollover Pass, Bolivar Peninsula)



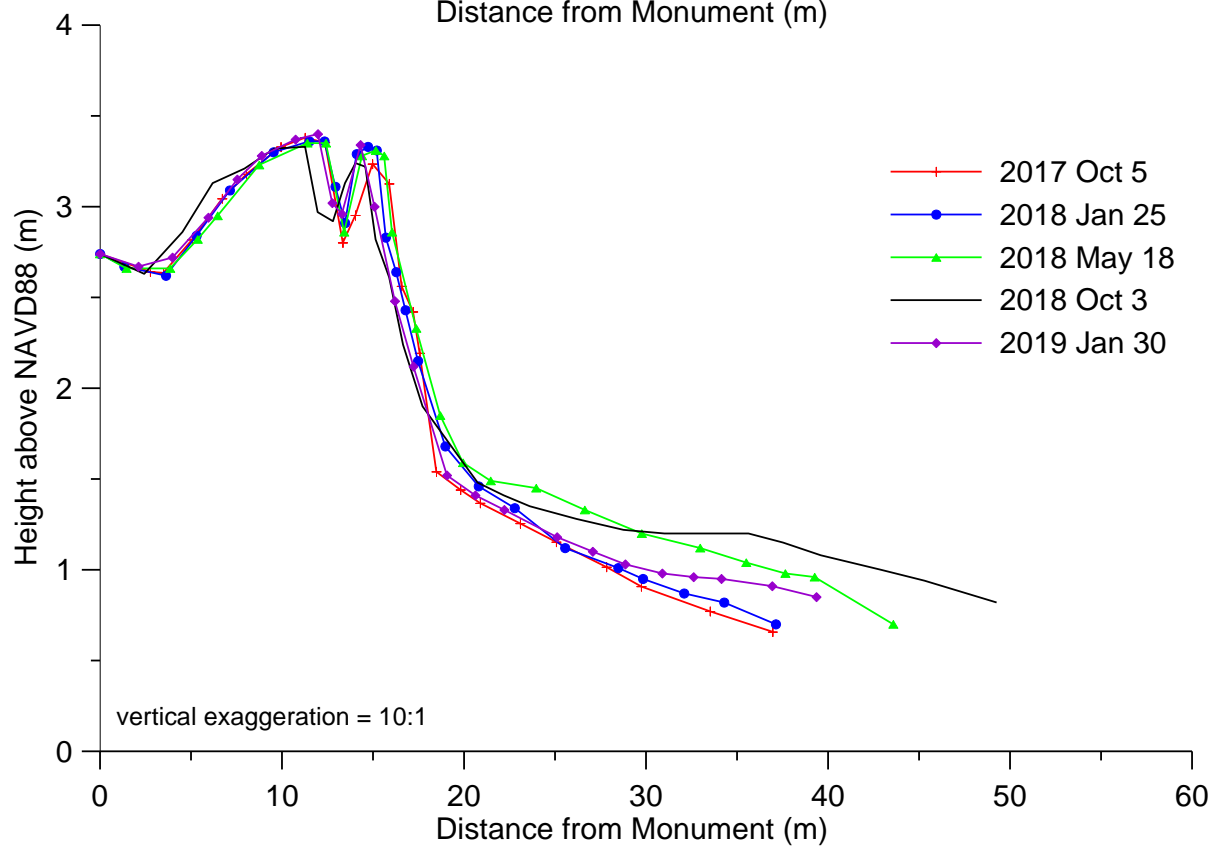
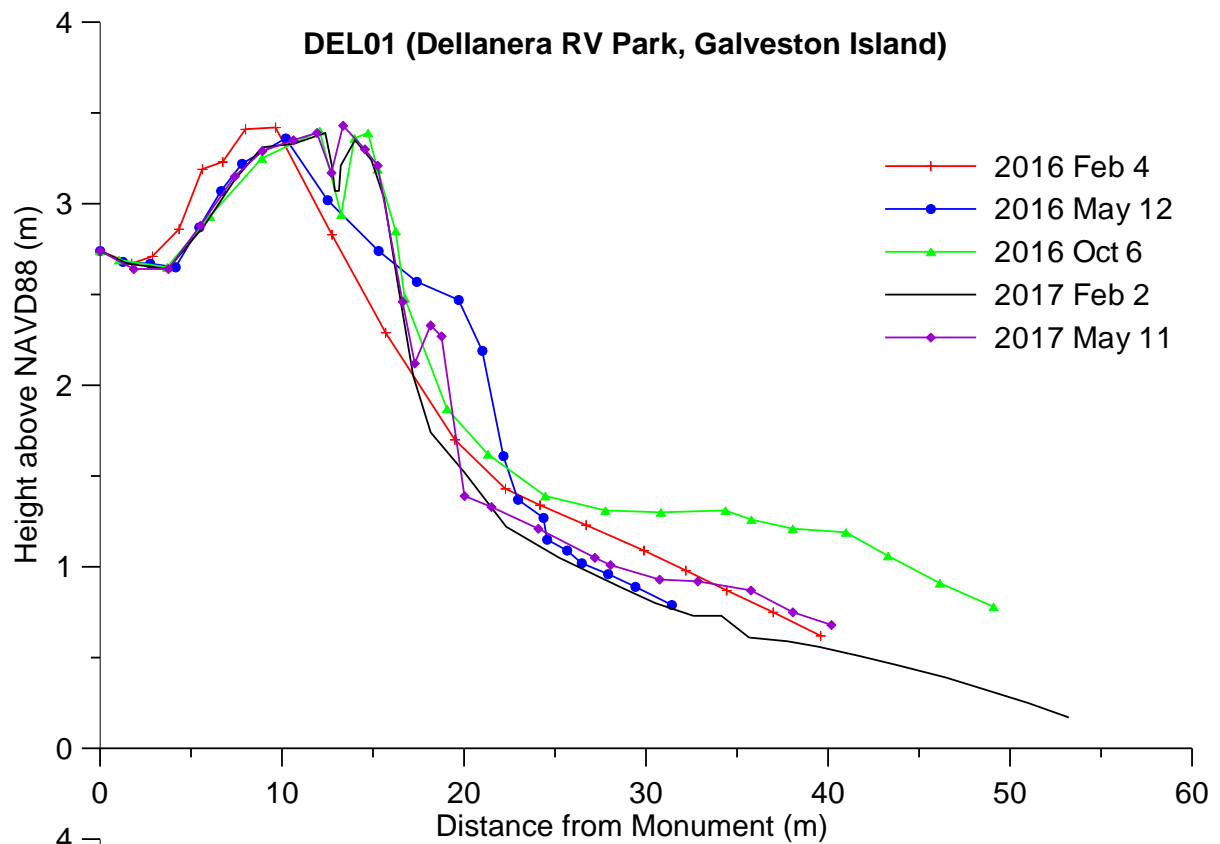
BOL02

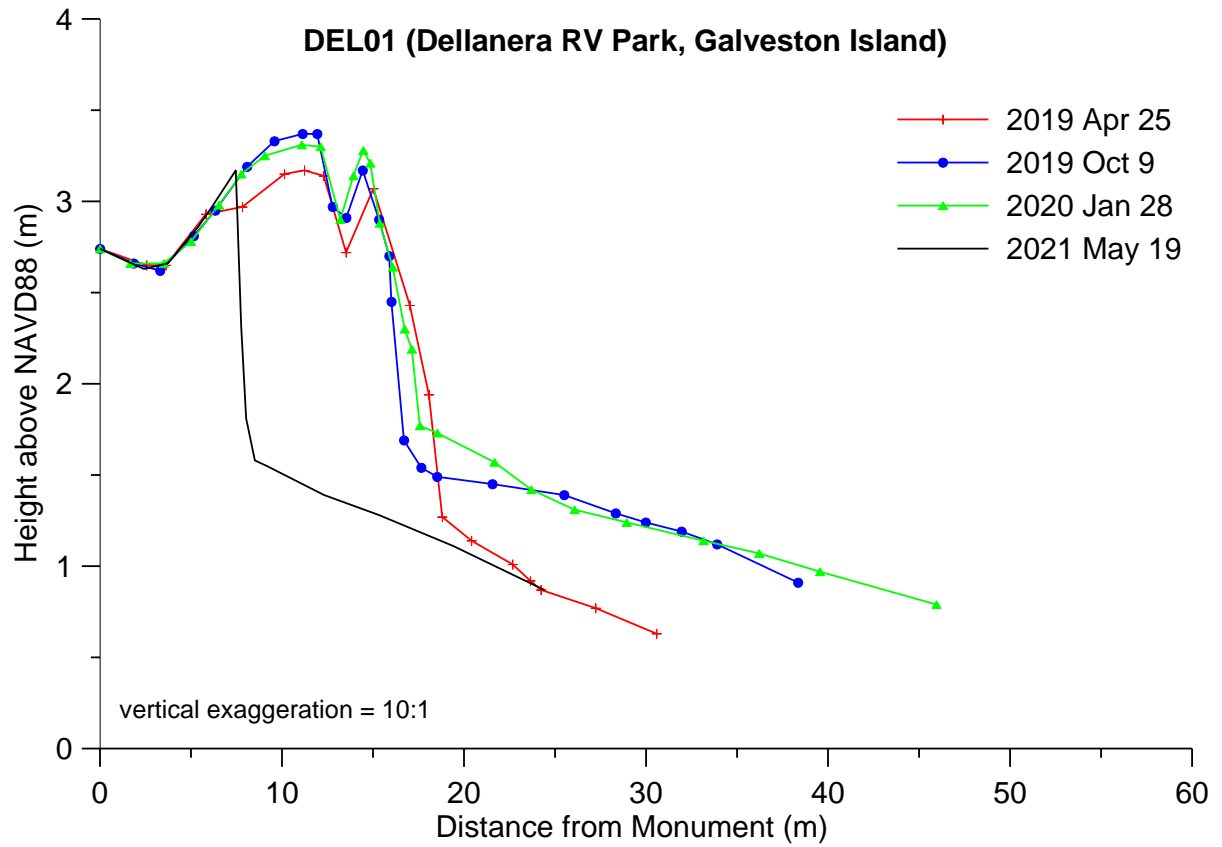
BOL02 (West Rollover Pass, Bolivar Peninsula)



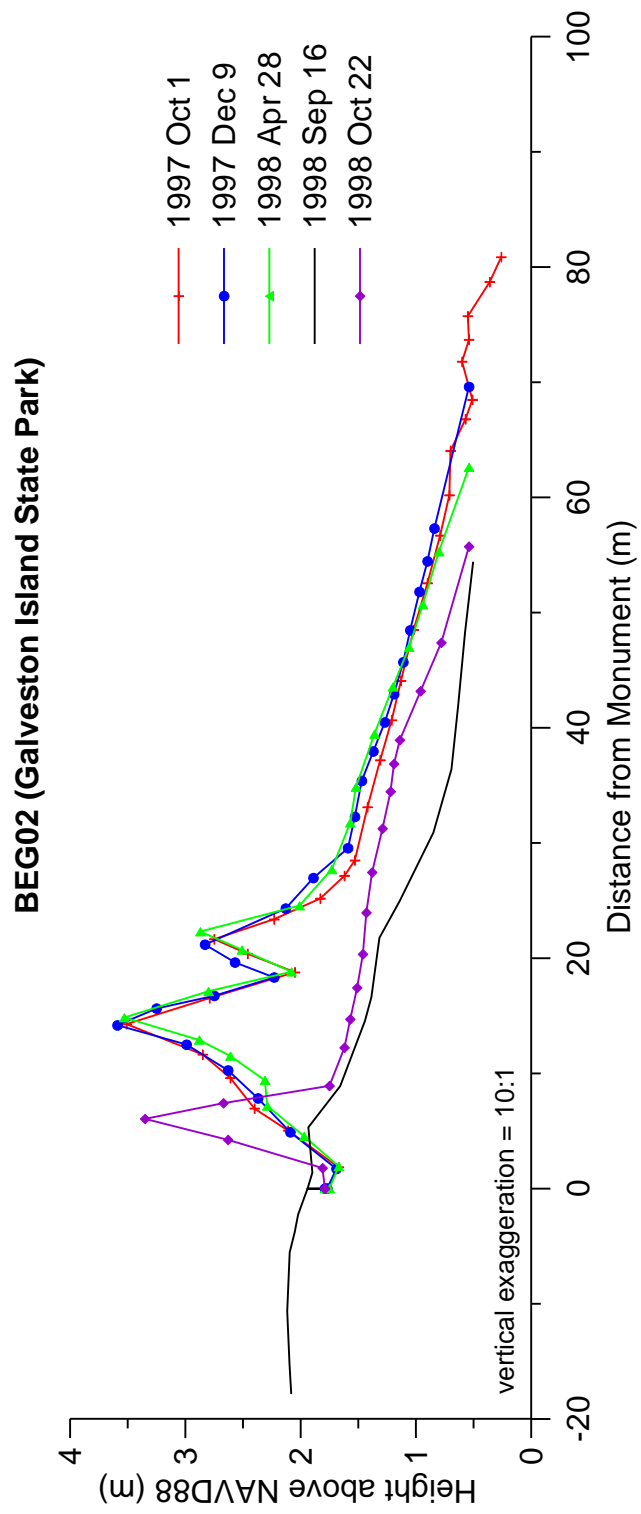


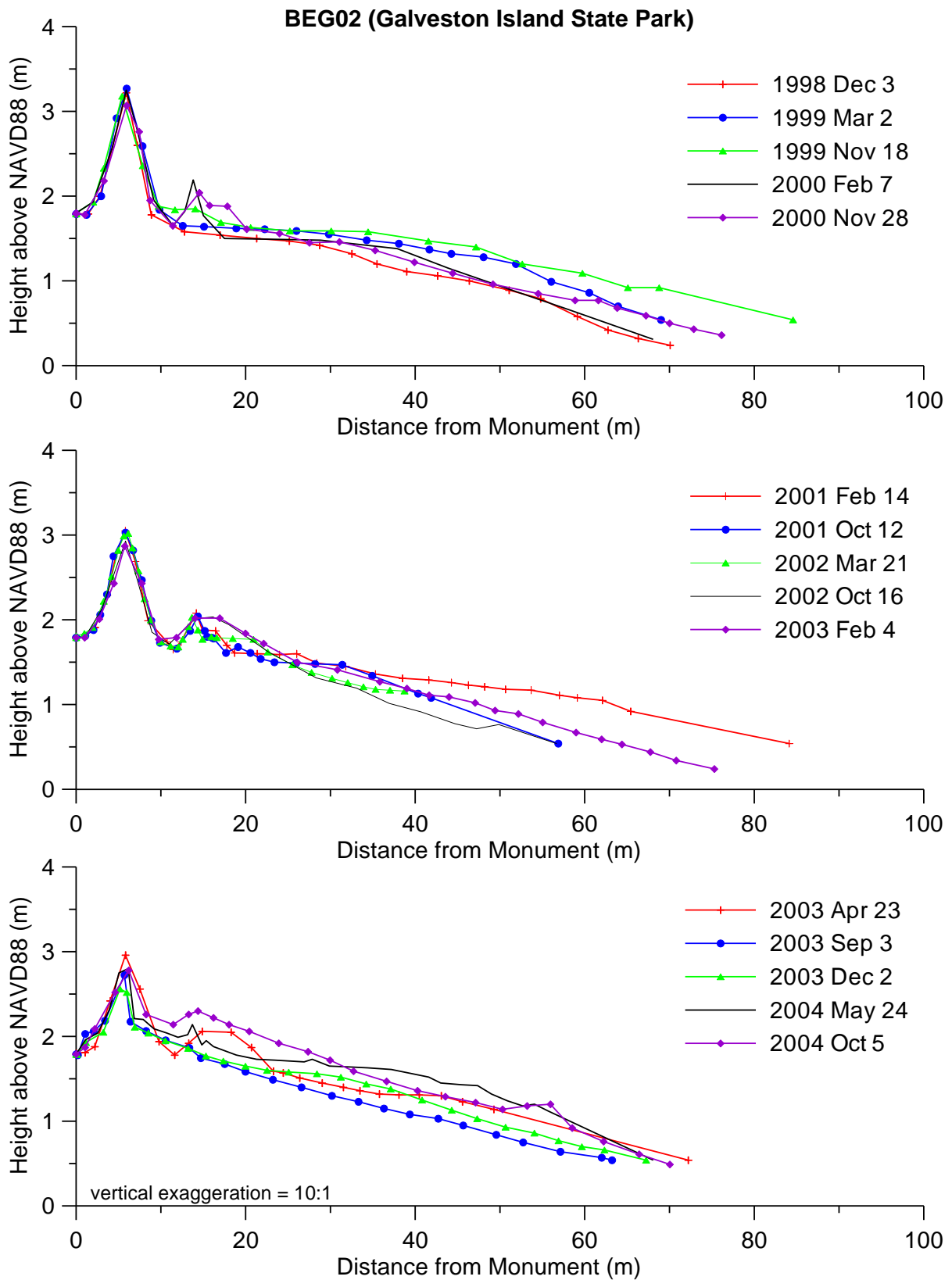
DEL01

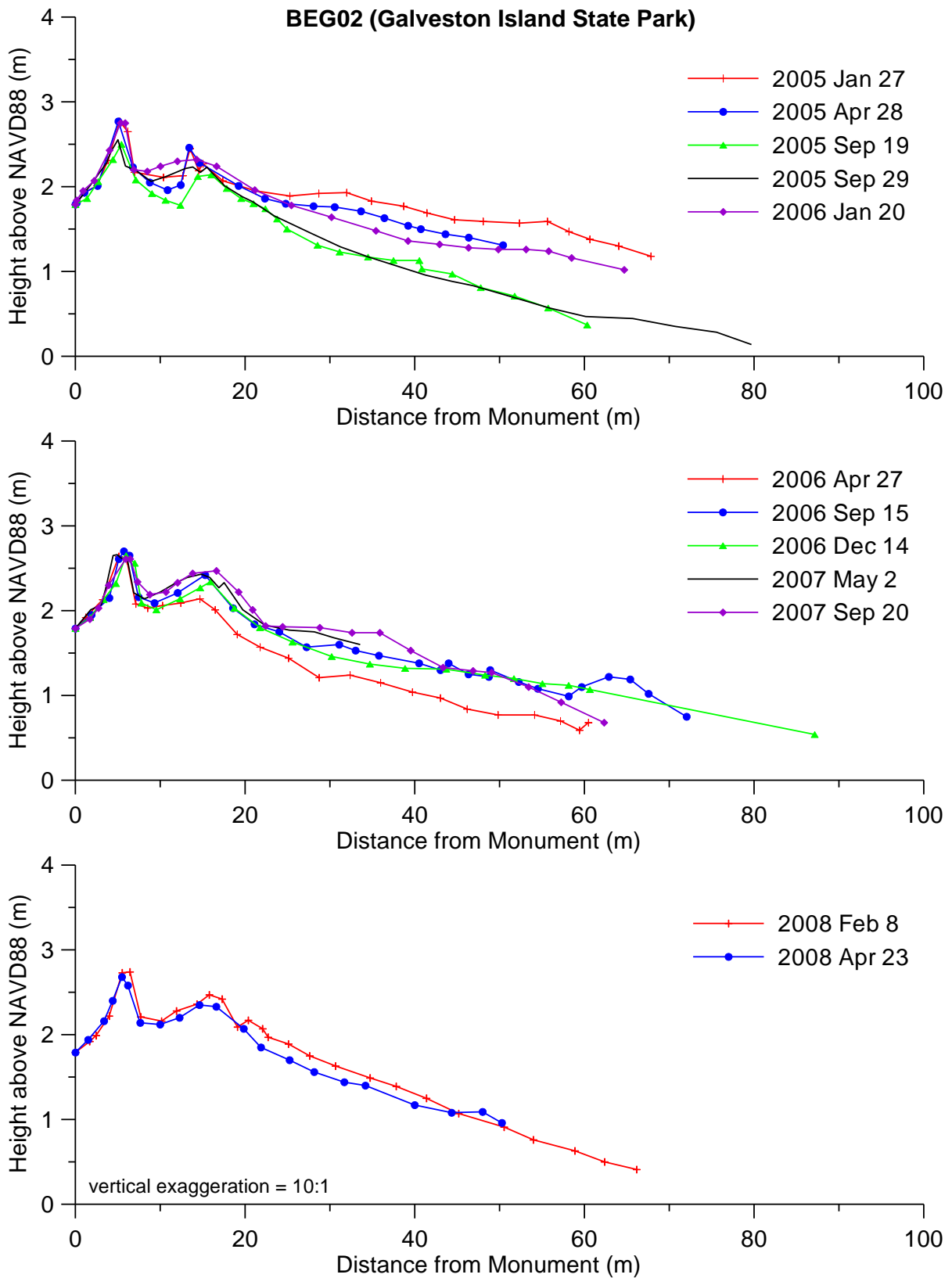




BEG02

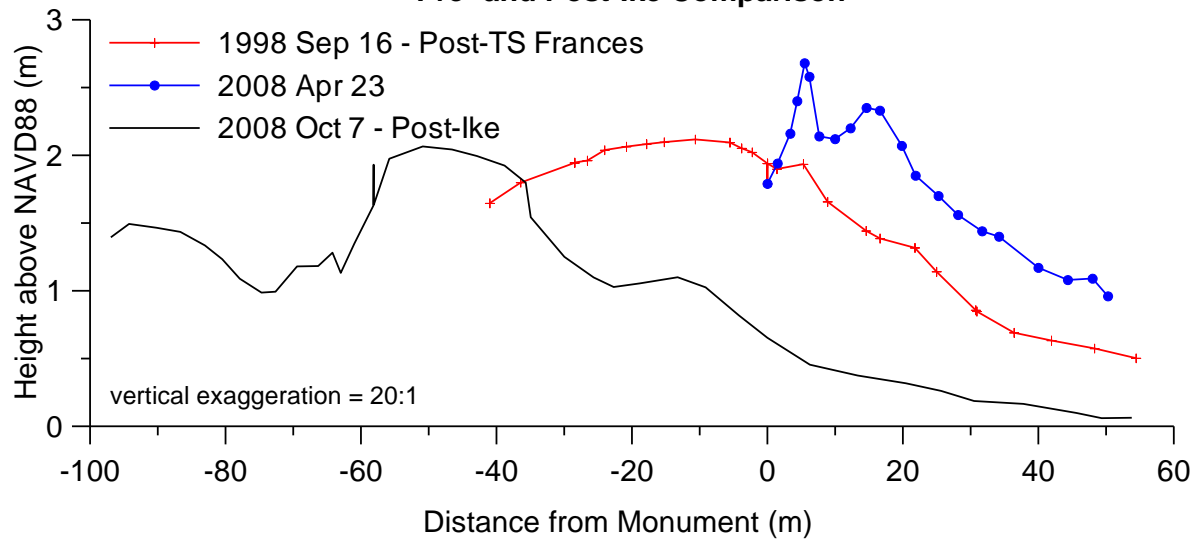




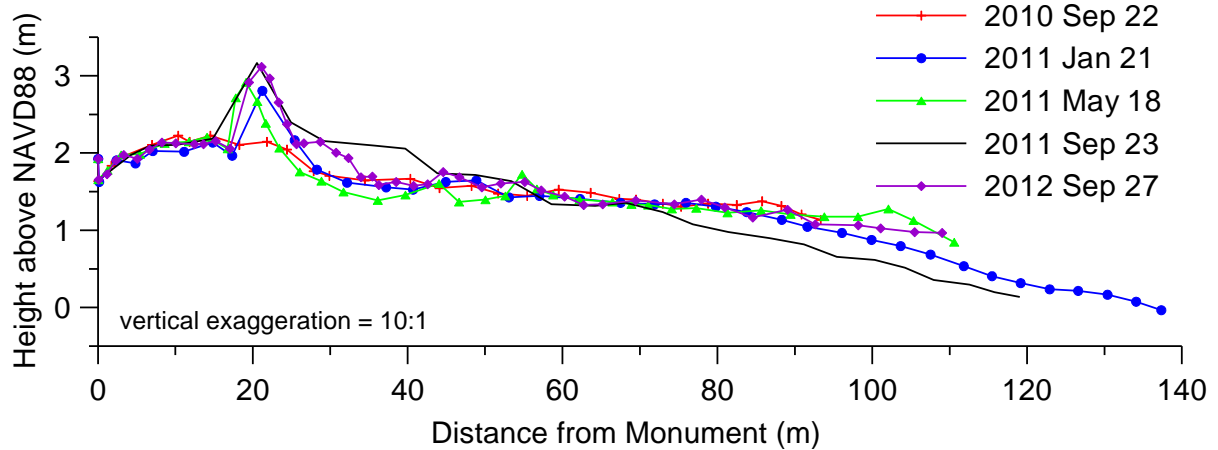
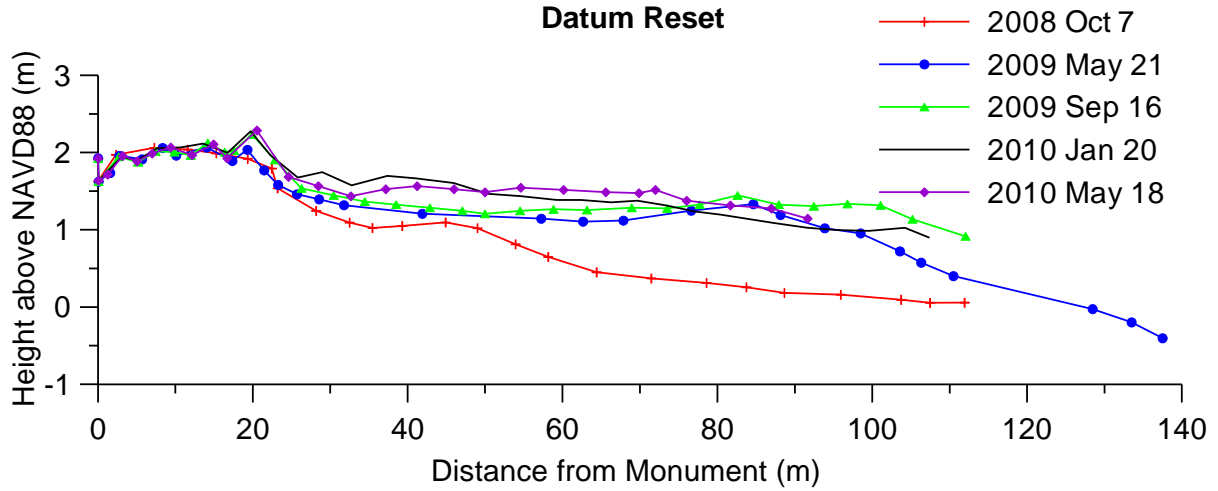


BEG02R

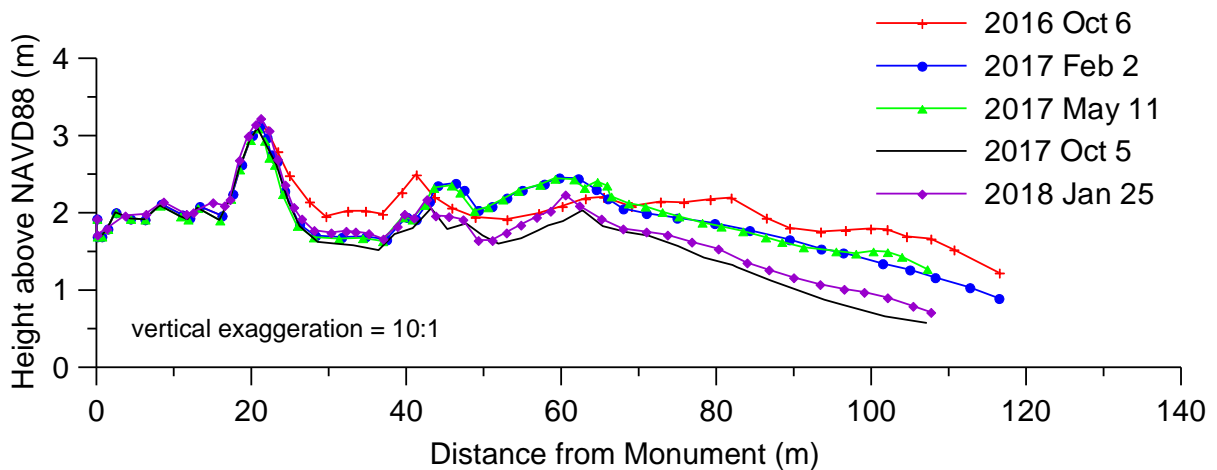
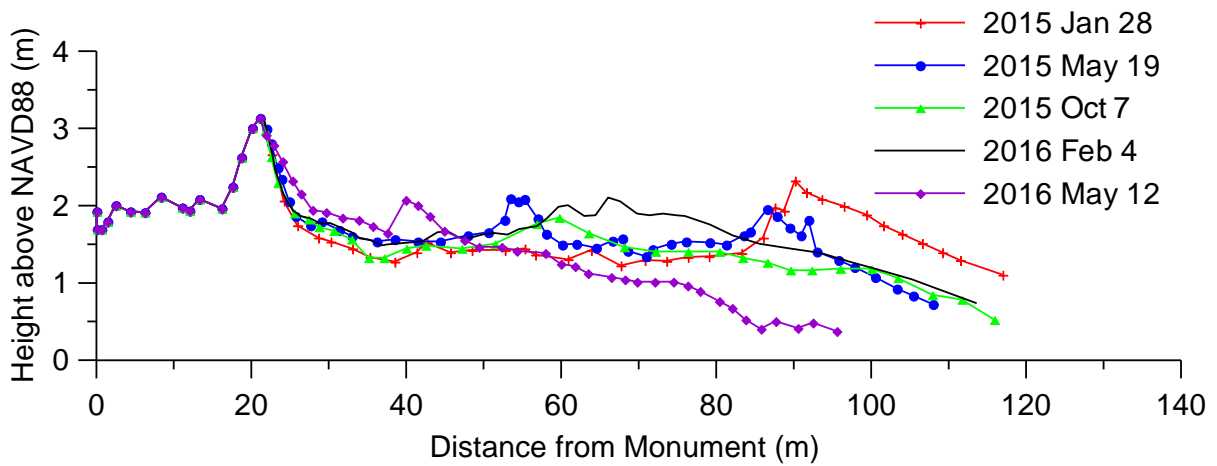
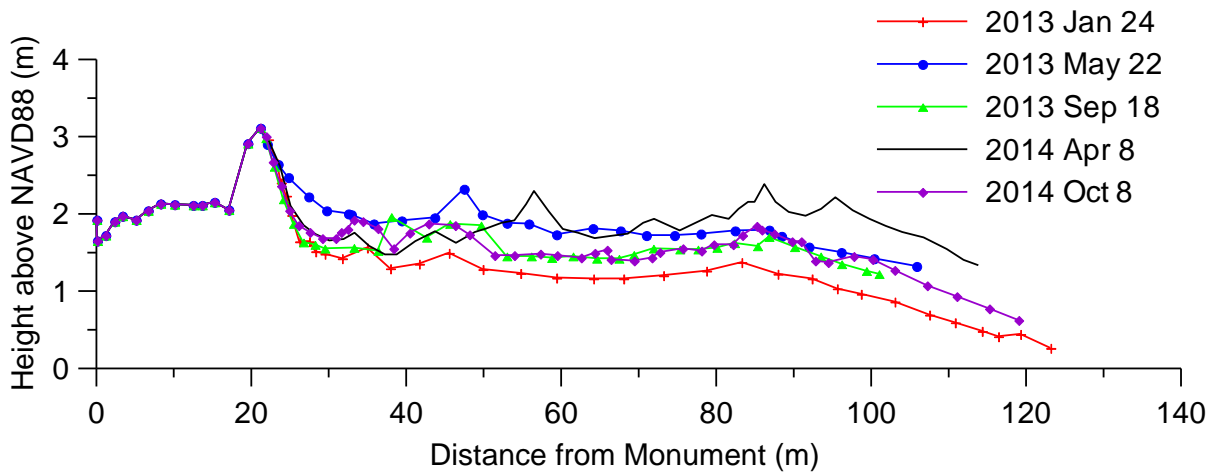
BEG02R (Galveston Island State Park) Pre- and Post-Ike Comparison



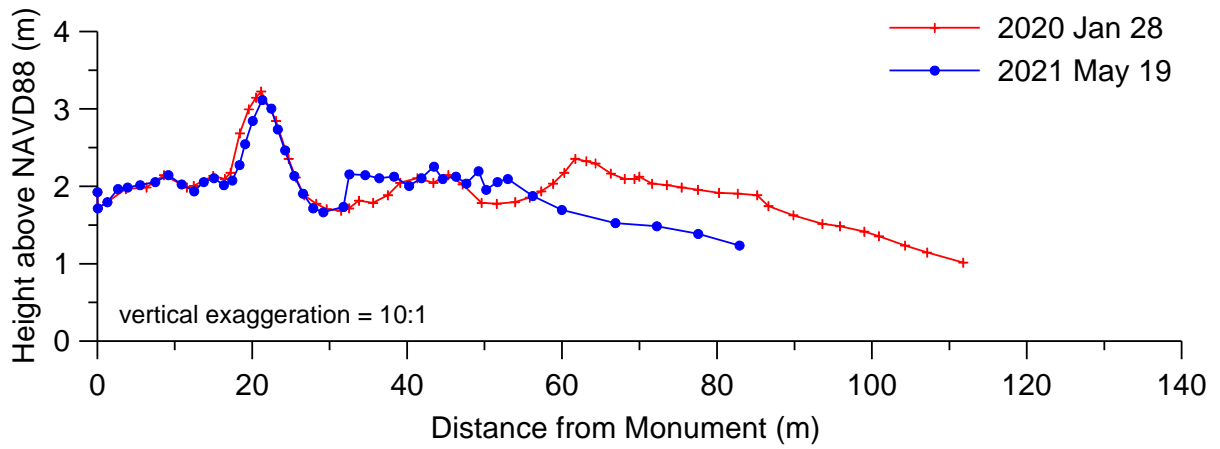
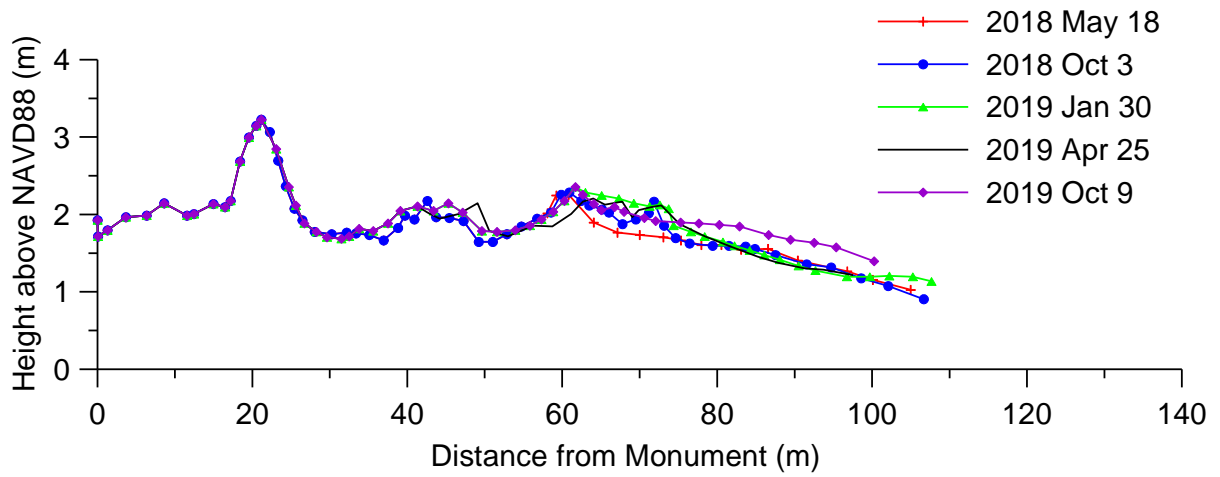
BEG02R (Galveston Island State Park) Datum Reset



BEG02R (Galveston Island State Park) Datum Reset

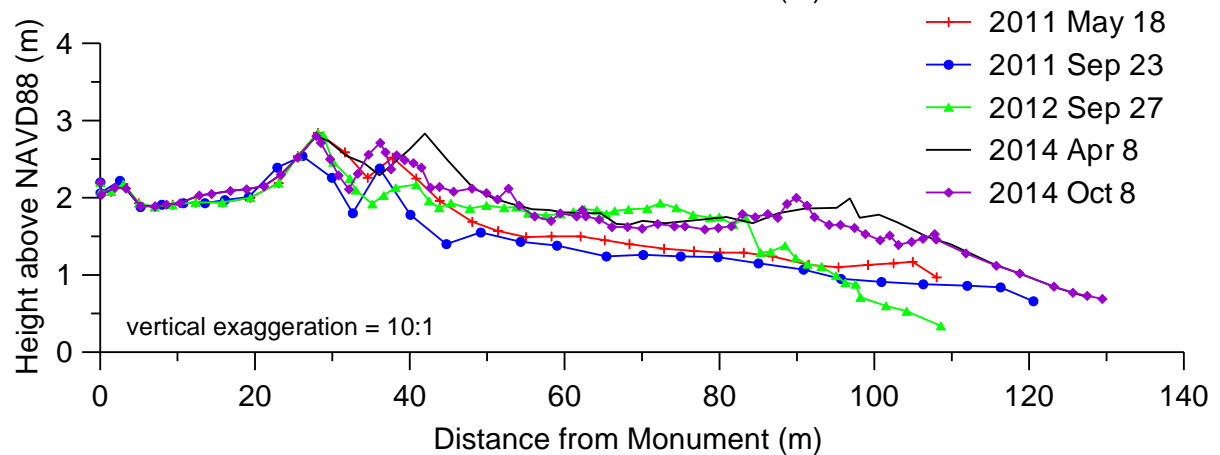
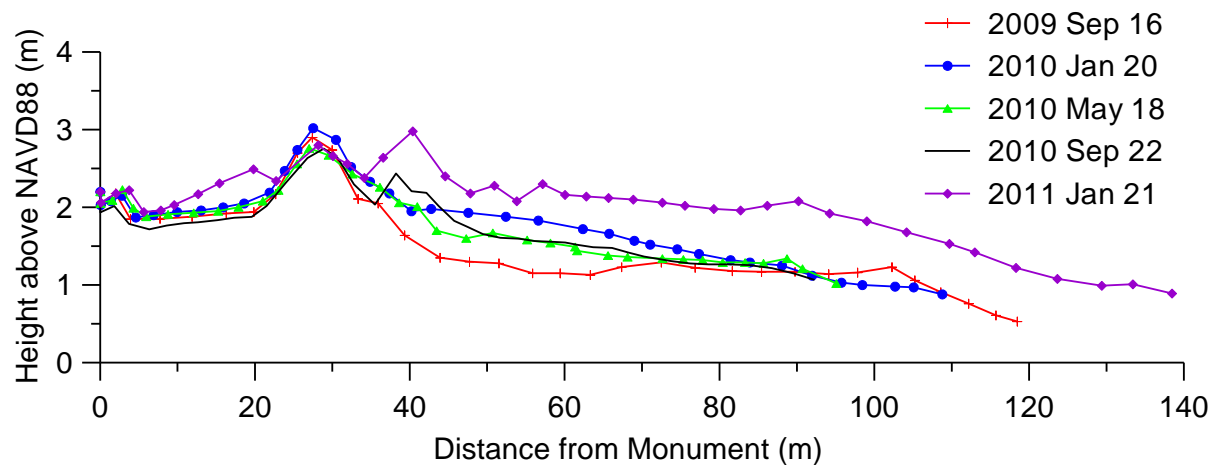
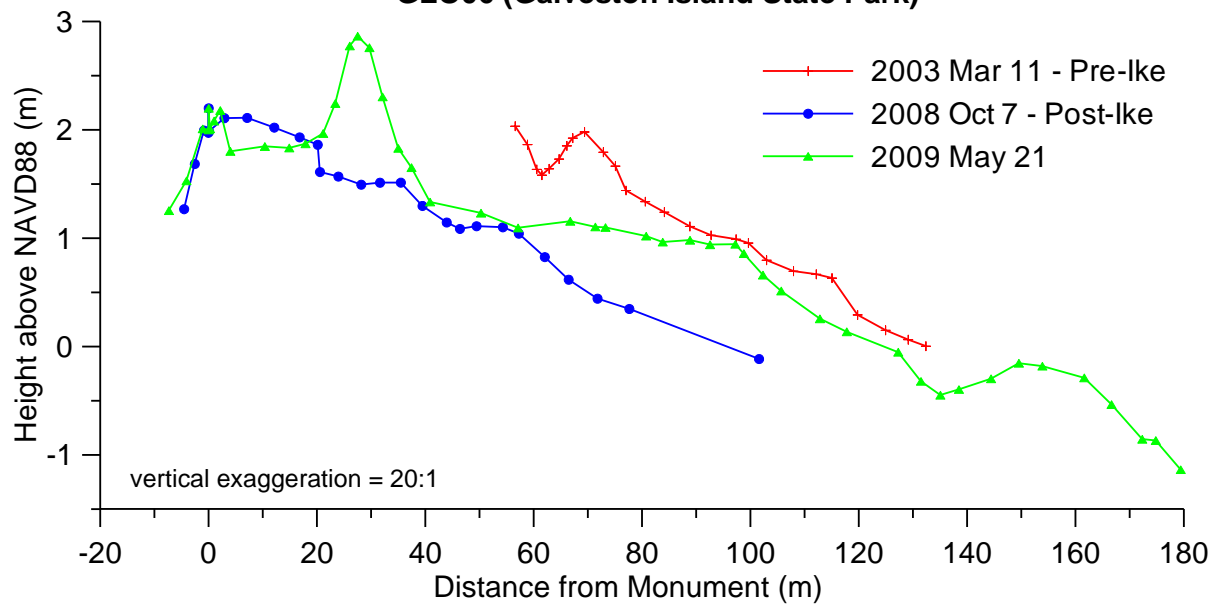


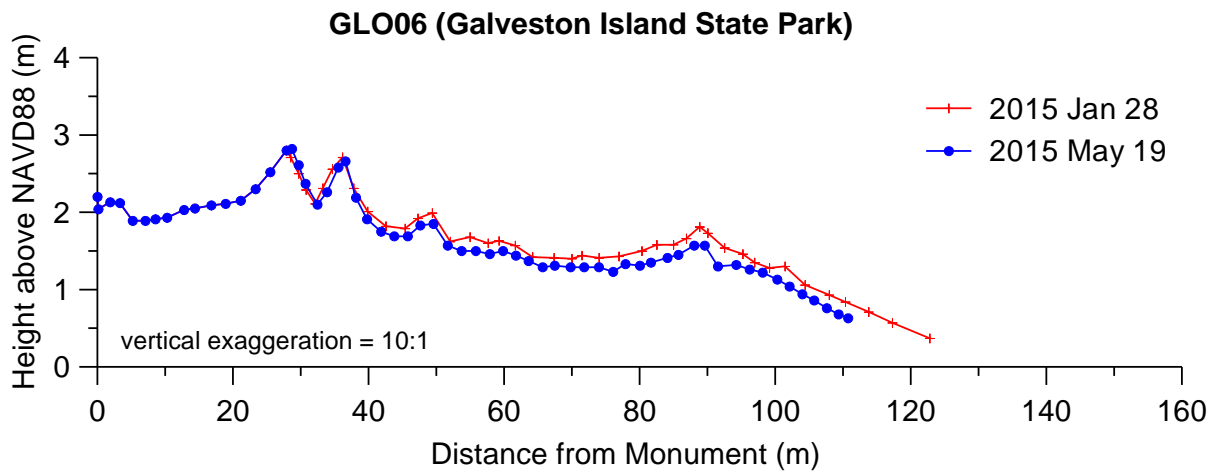
BEG02R (Galveston Island State Park)
Datum Reset



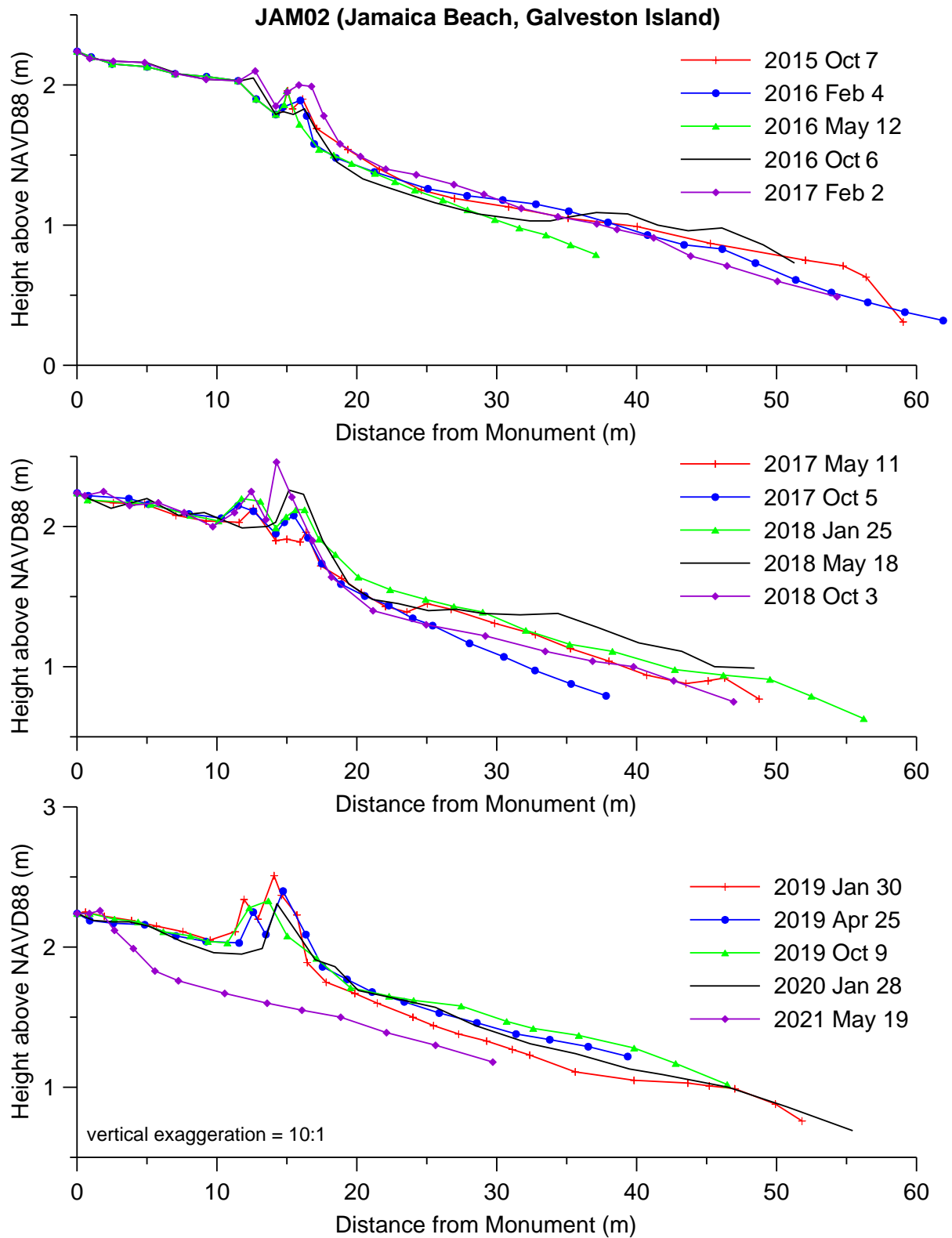
GLO06

GLO06 (Galveston Island State Park)

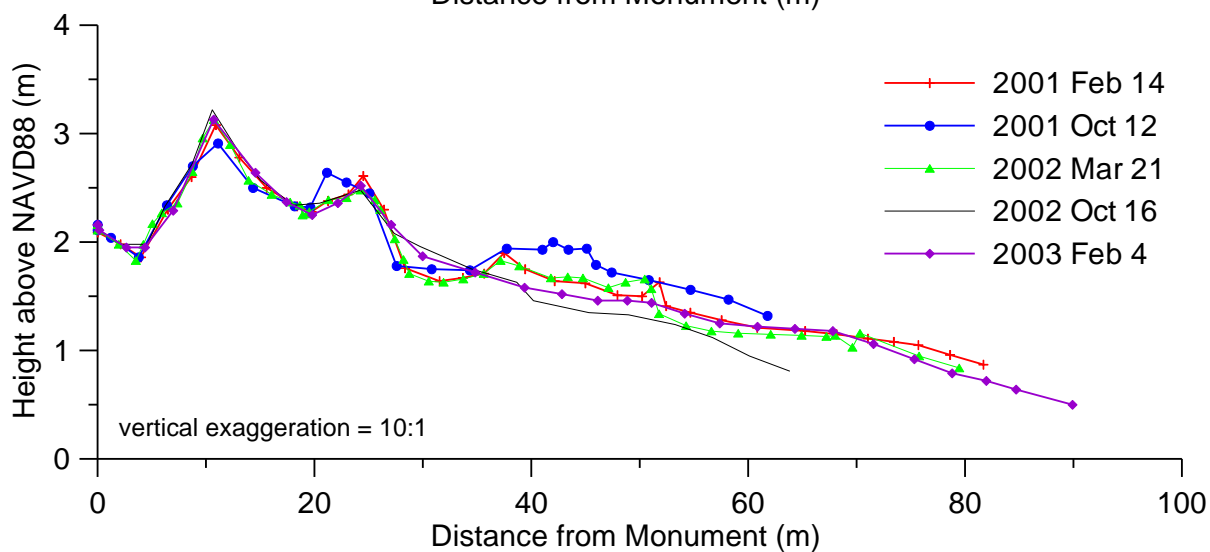
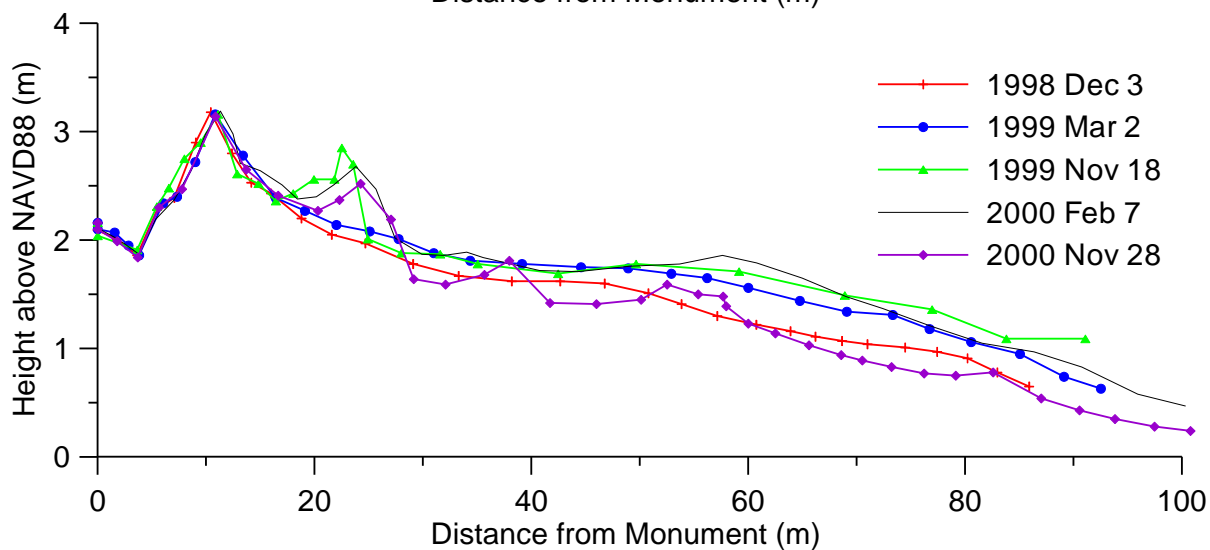
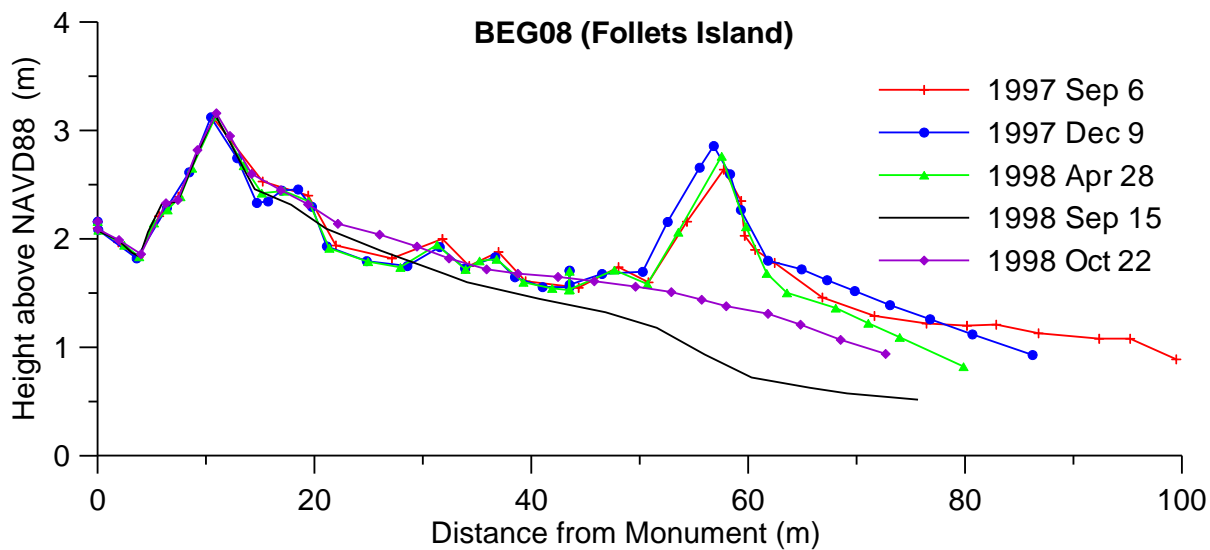


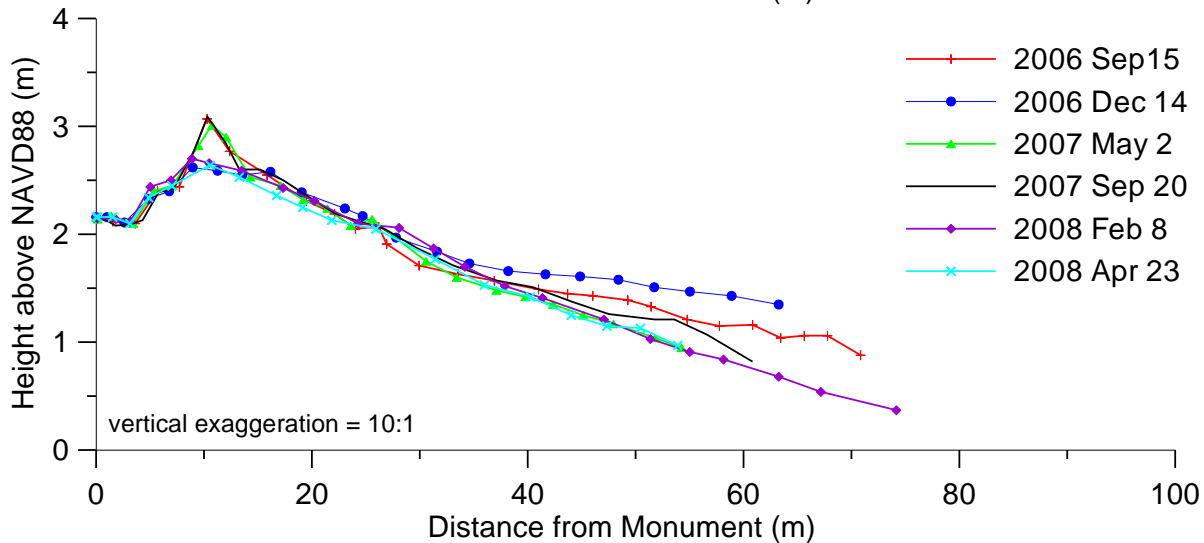
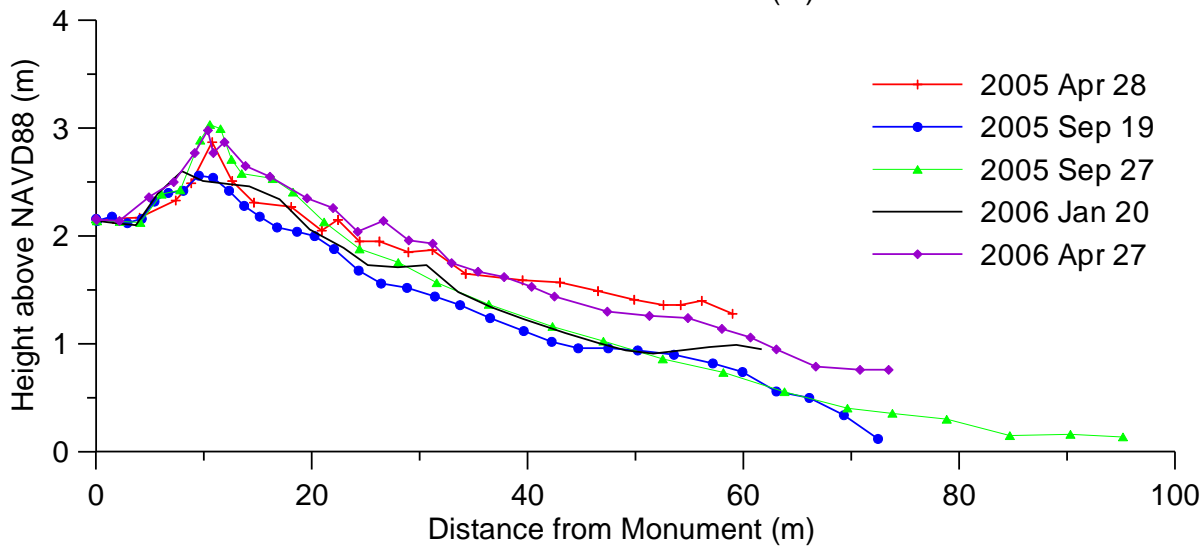
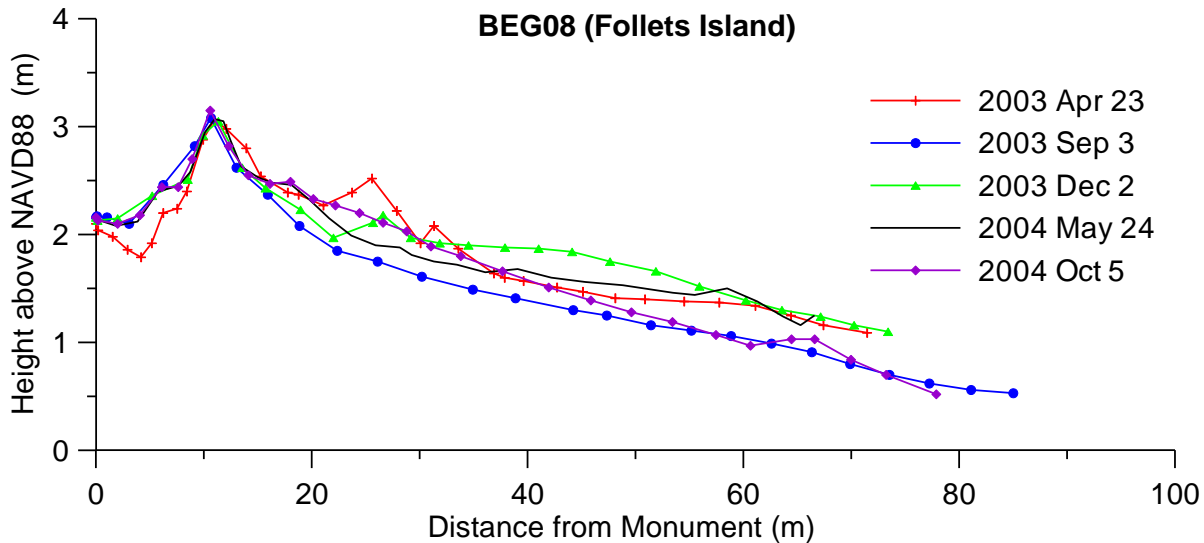


JAM02

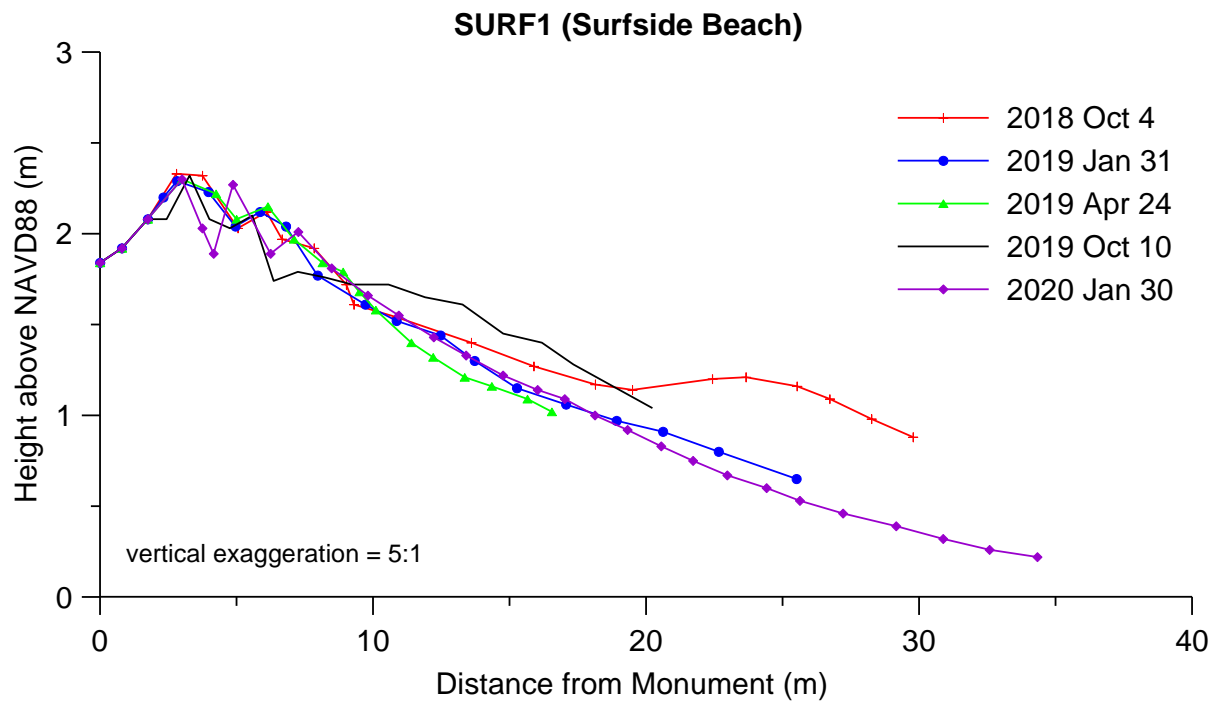


BEG08

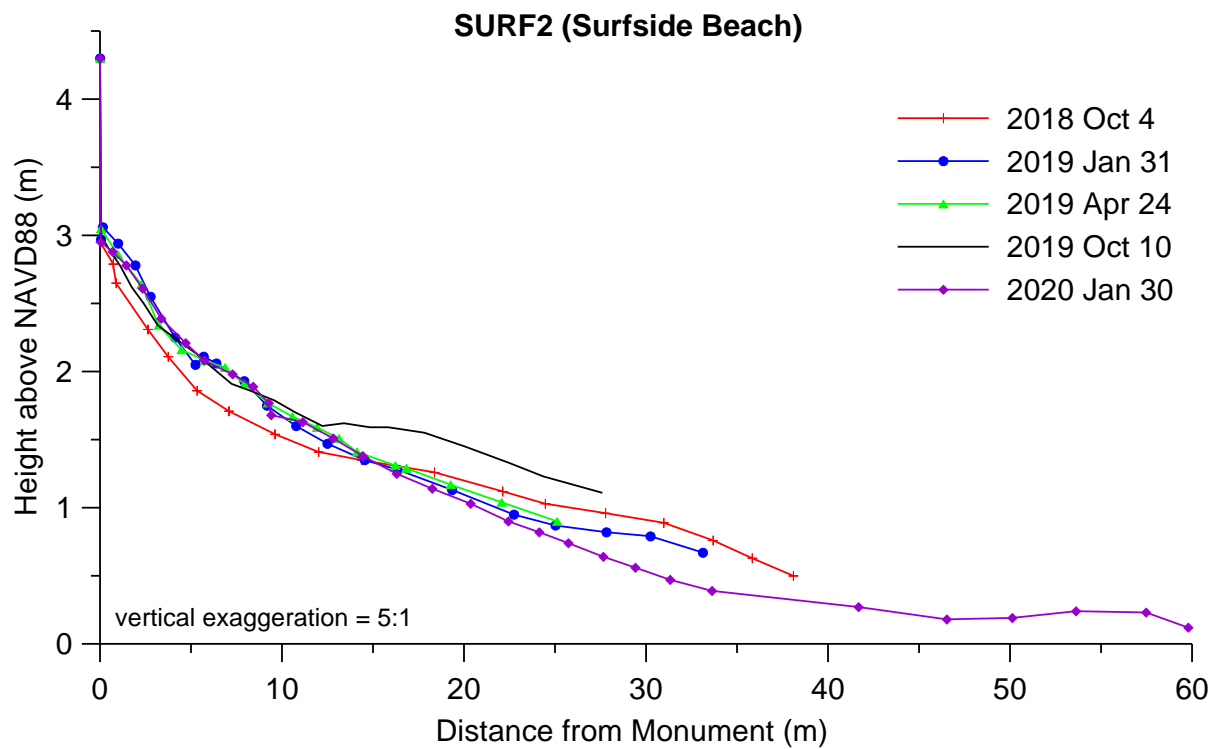




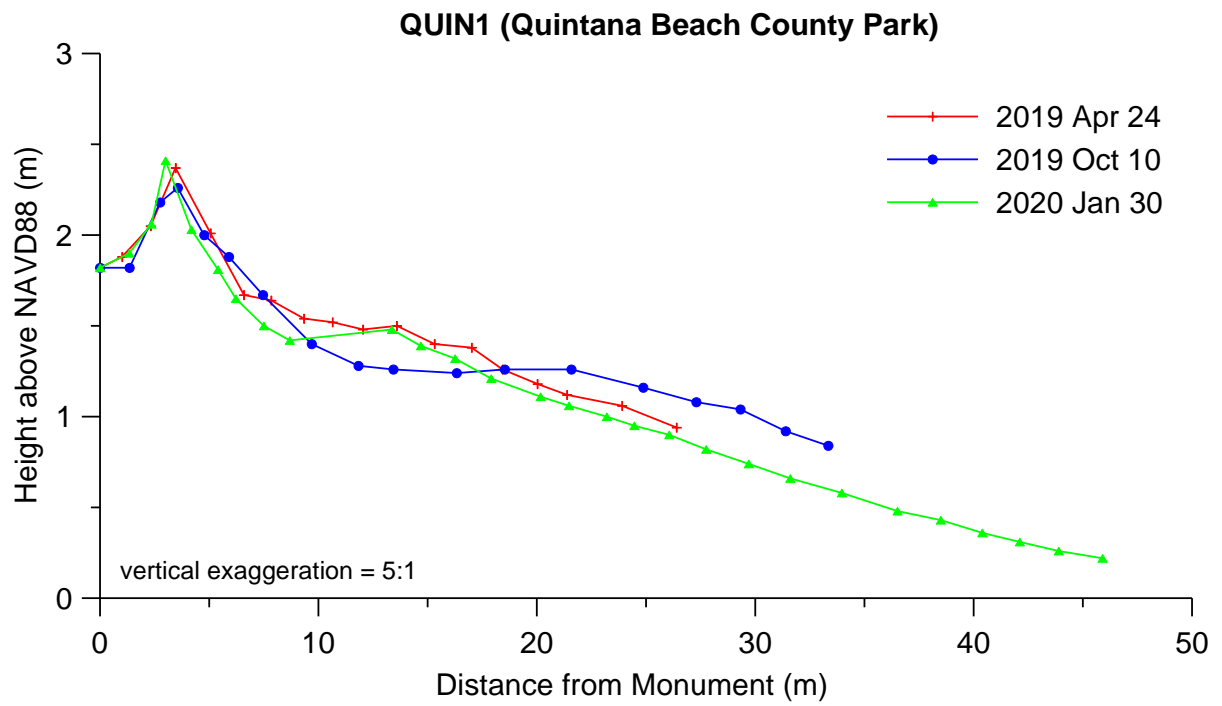
SURF1



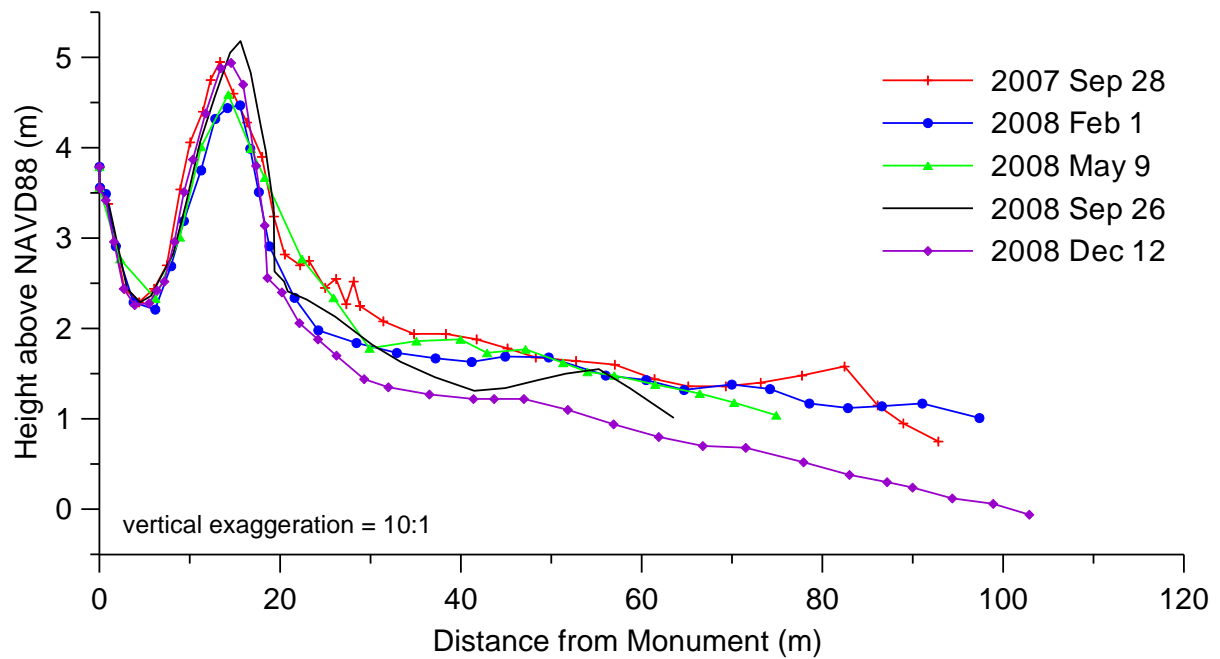
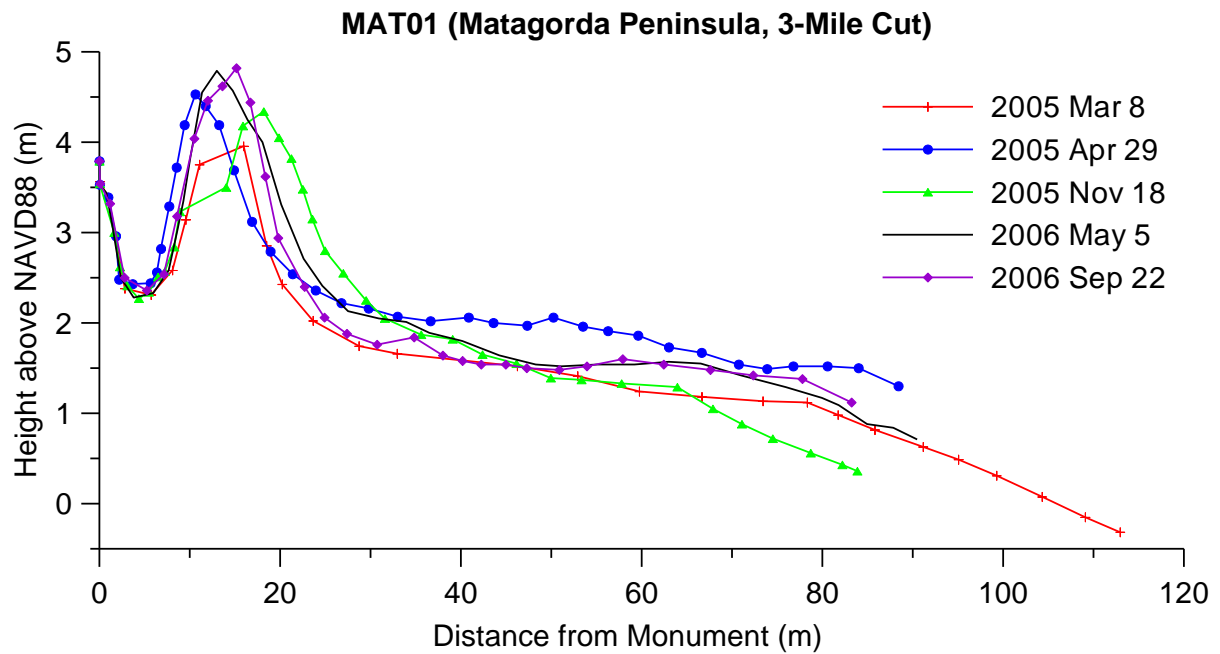
SURF2



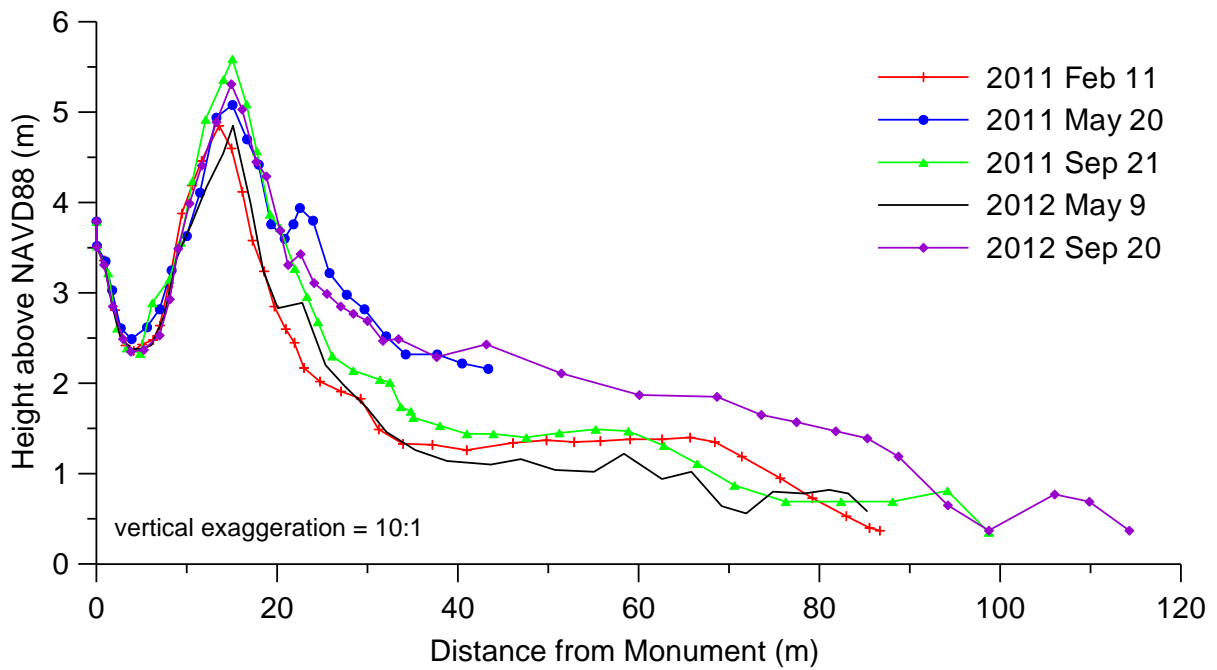
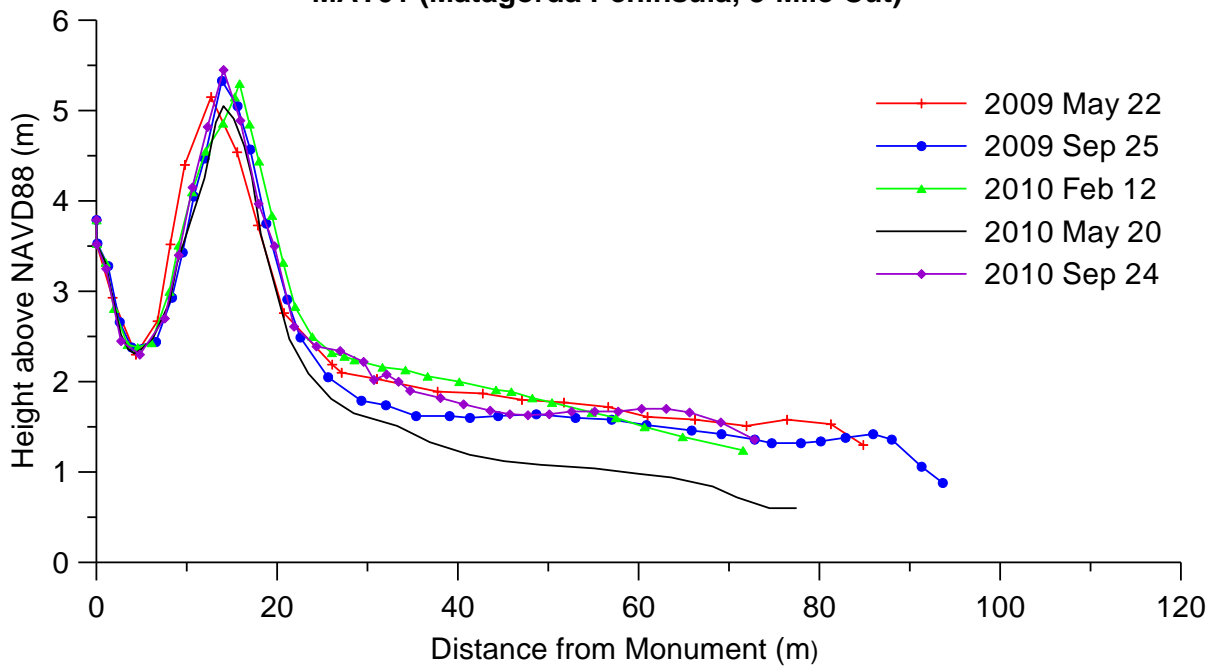
QUIN1



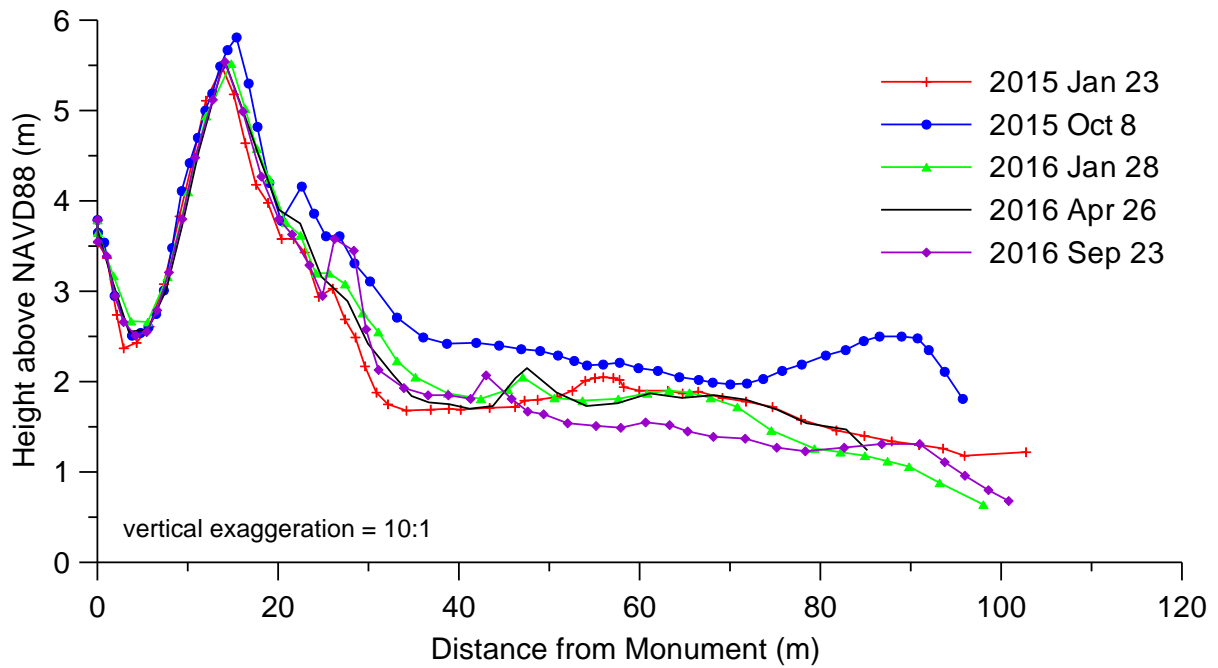
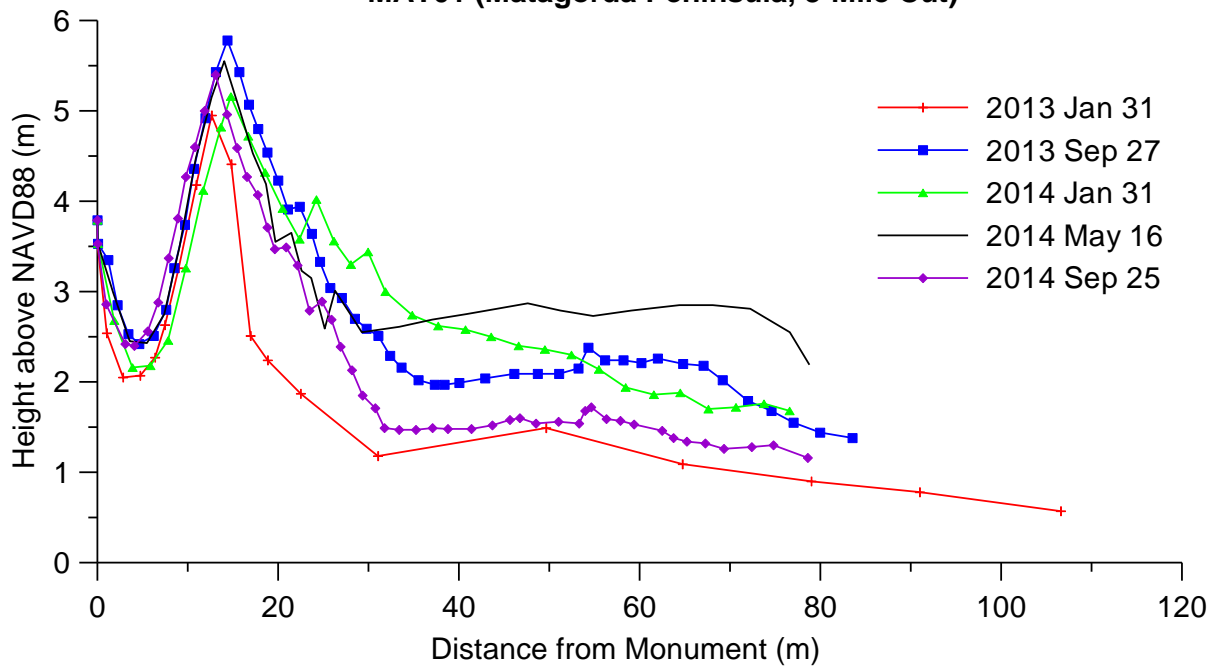
MAT01



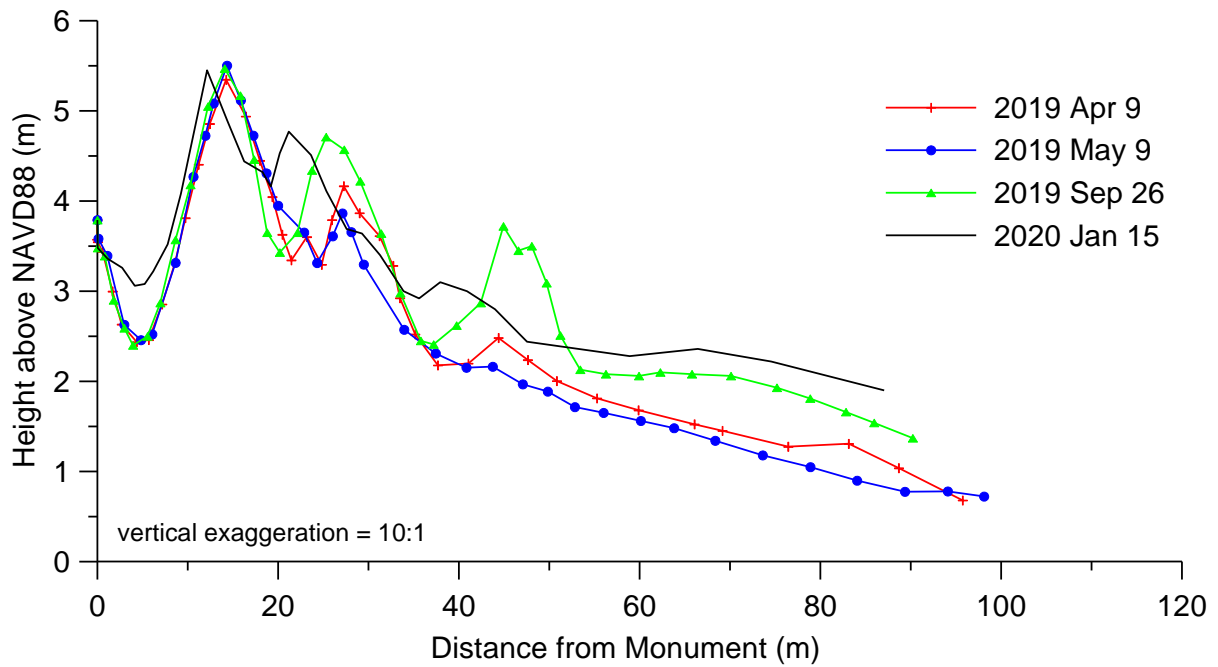
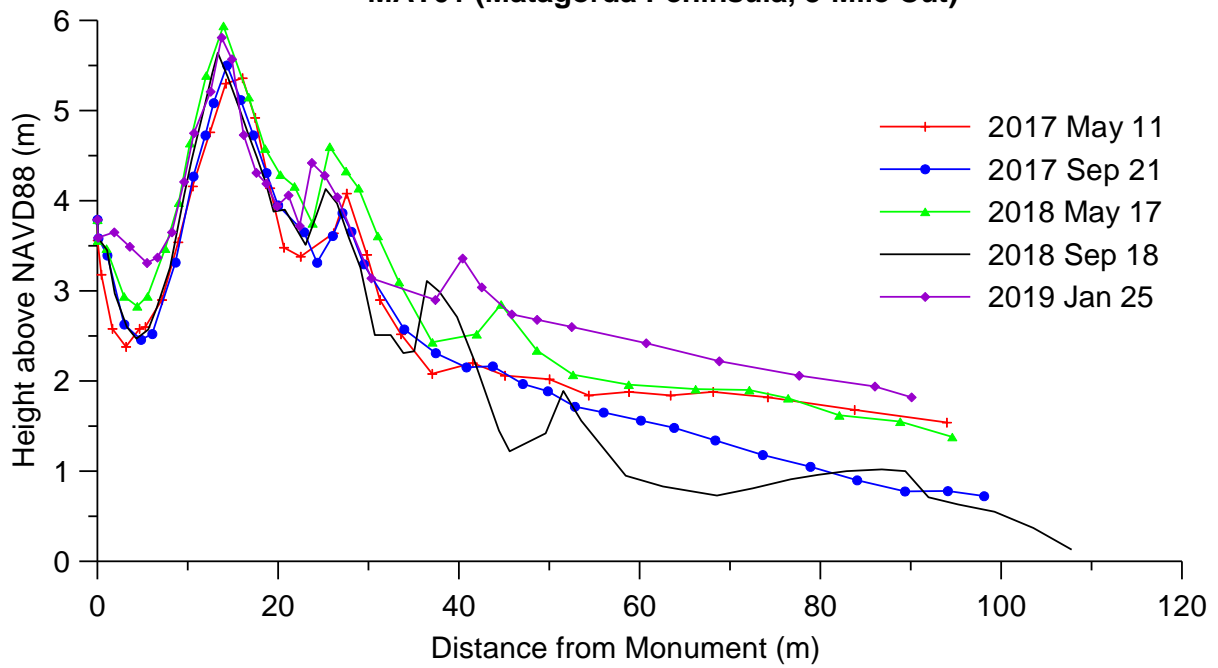
MAT01 (Matagorda Peninsula, 3-Mile Cut)



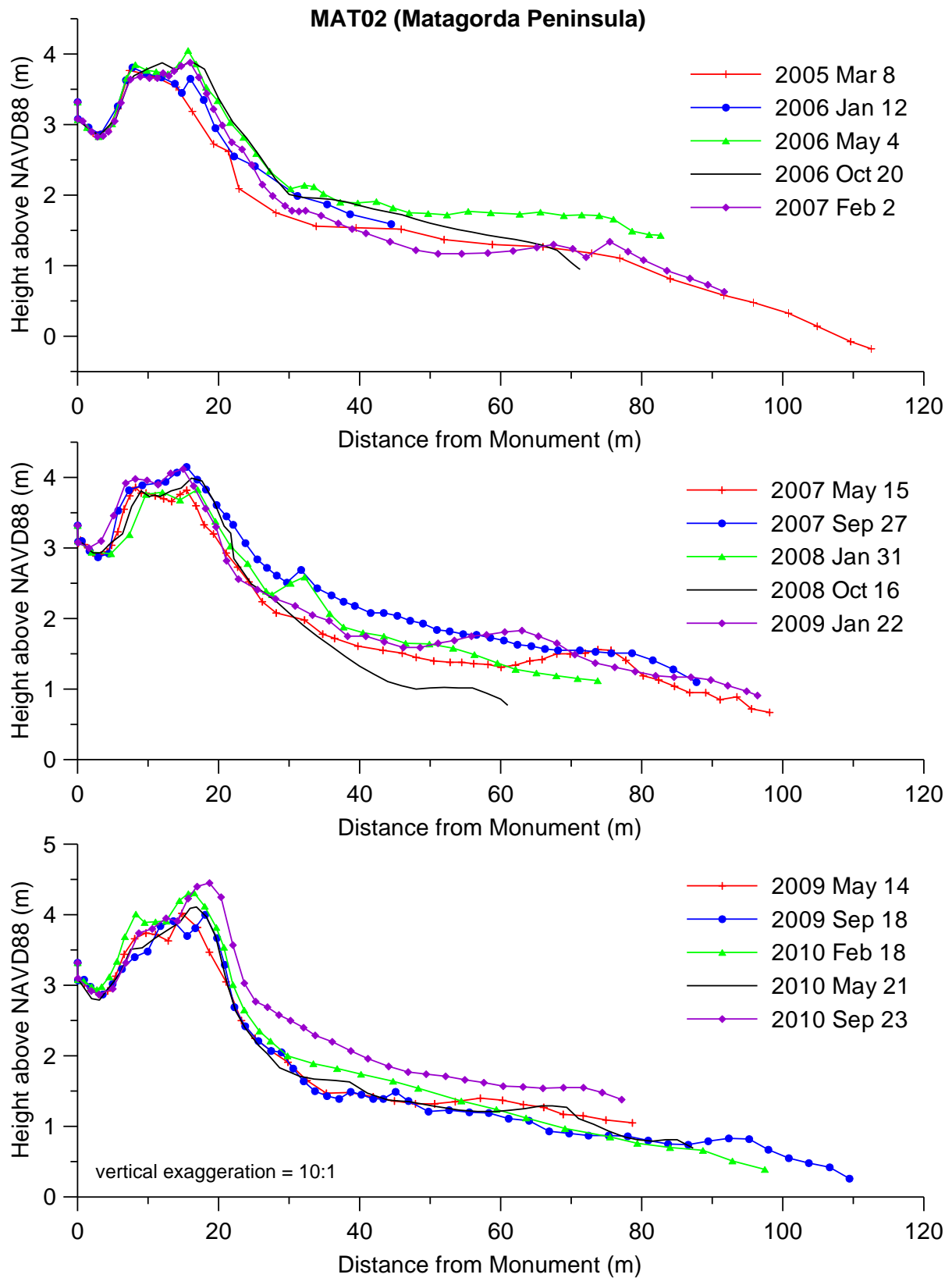
MAT01 (Matagorda Peninsula, 3-Mile Cut)

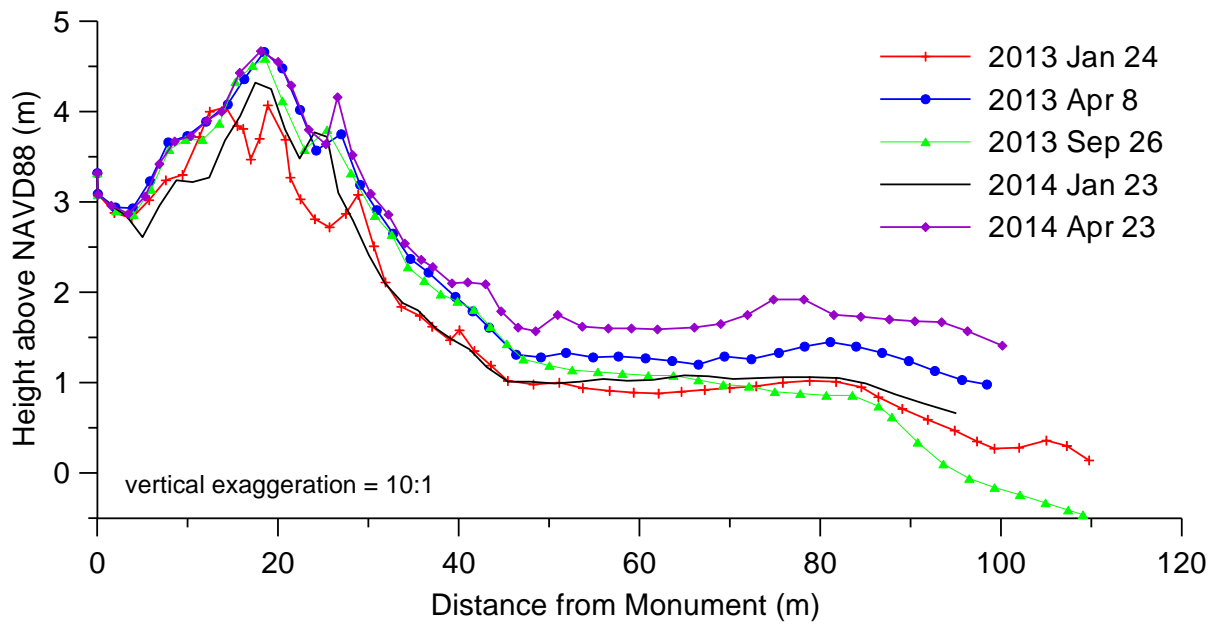
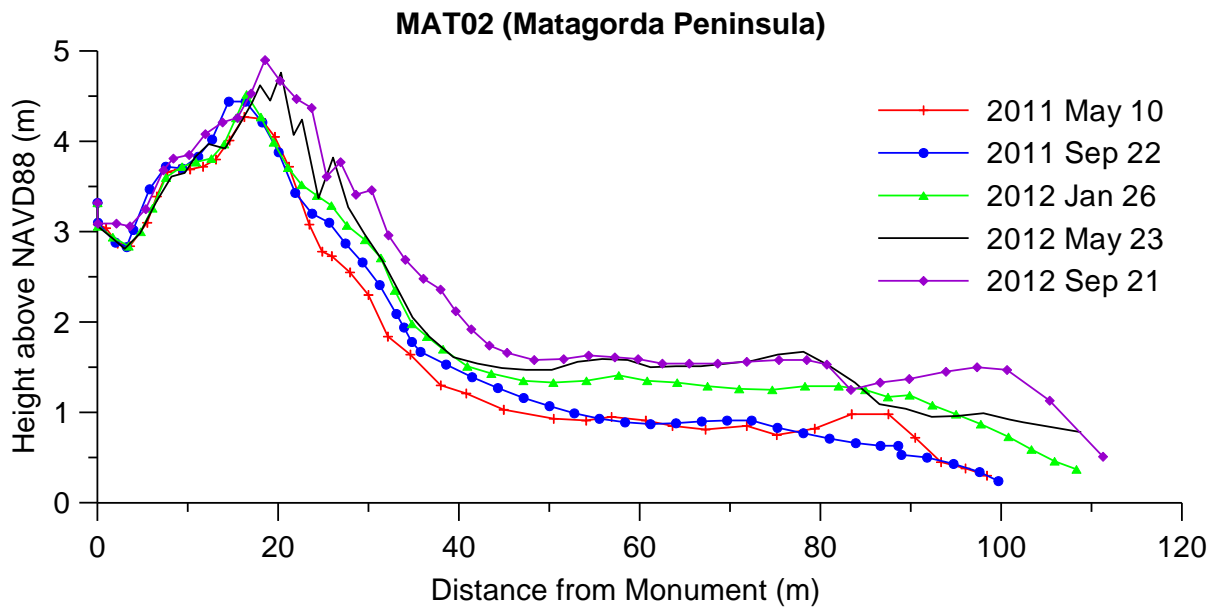


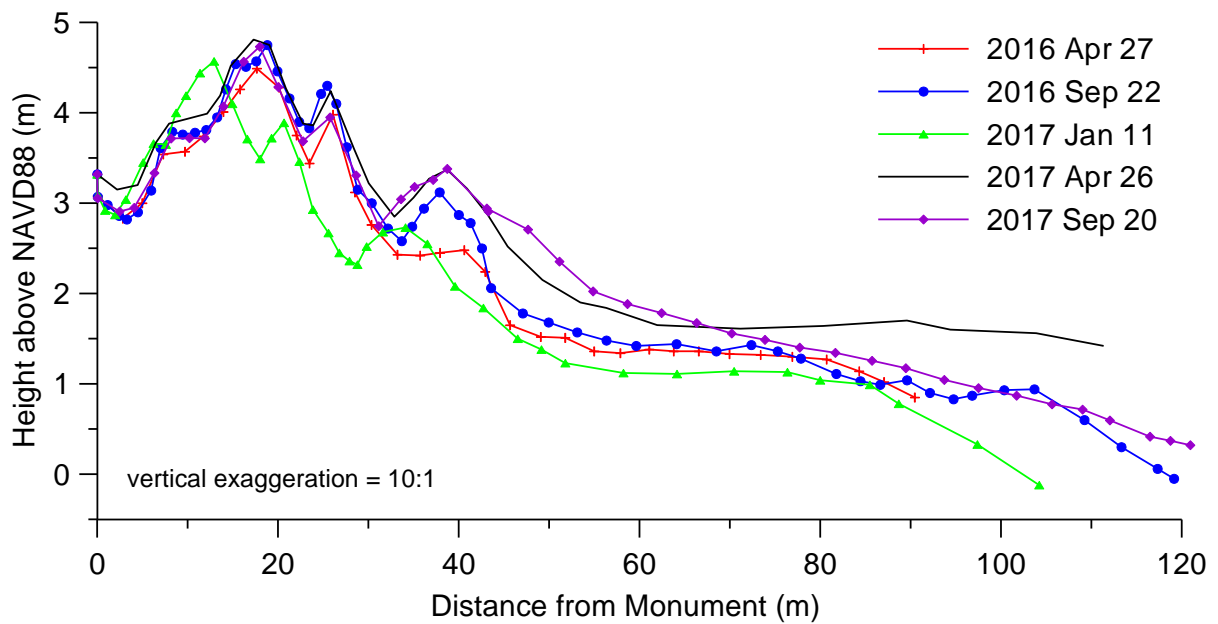
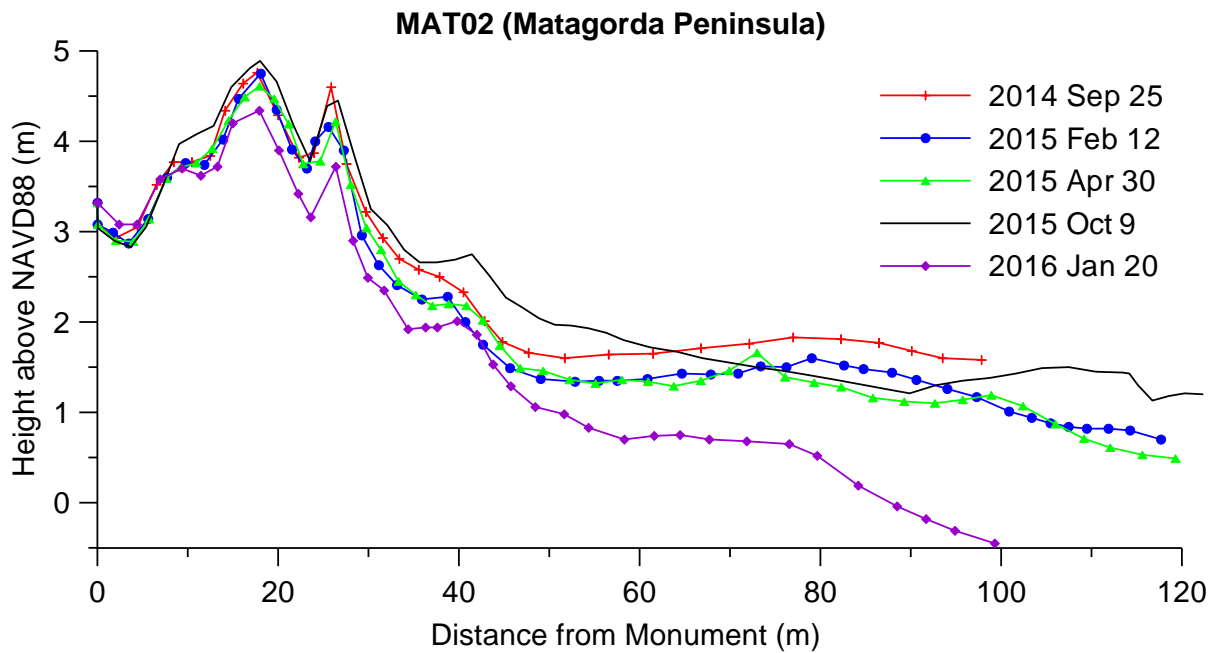
MAT01 (Matagorda Peninsula, 3-Mile Cut)

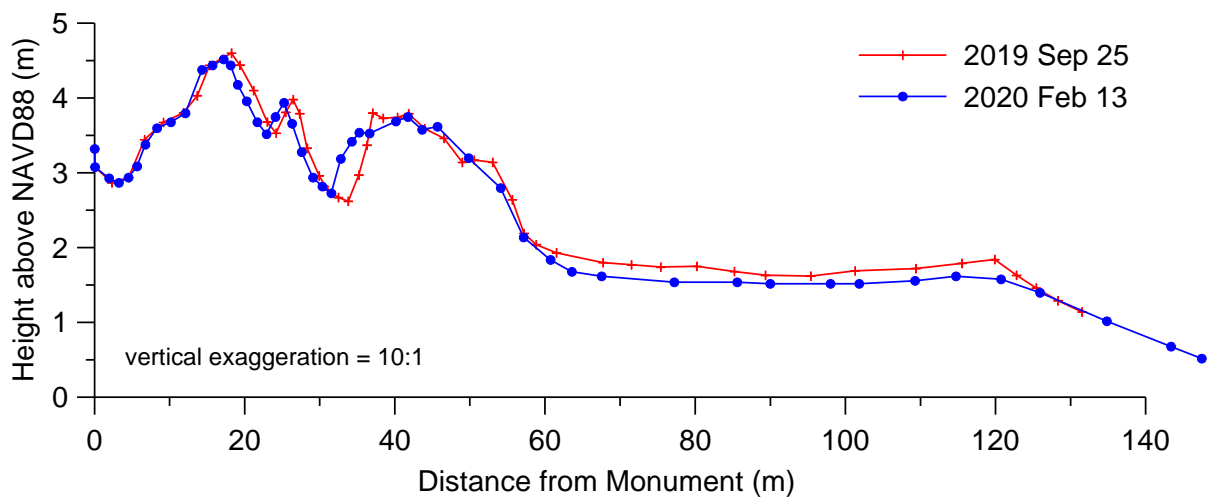
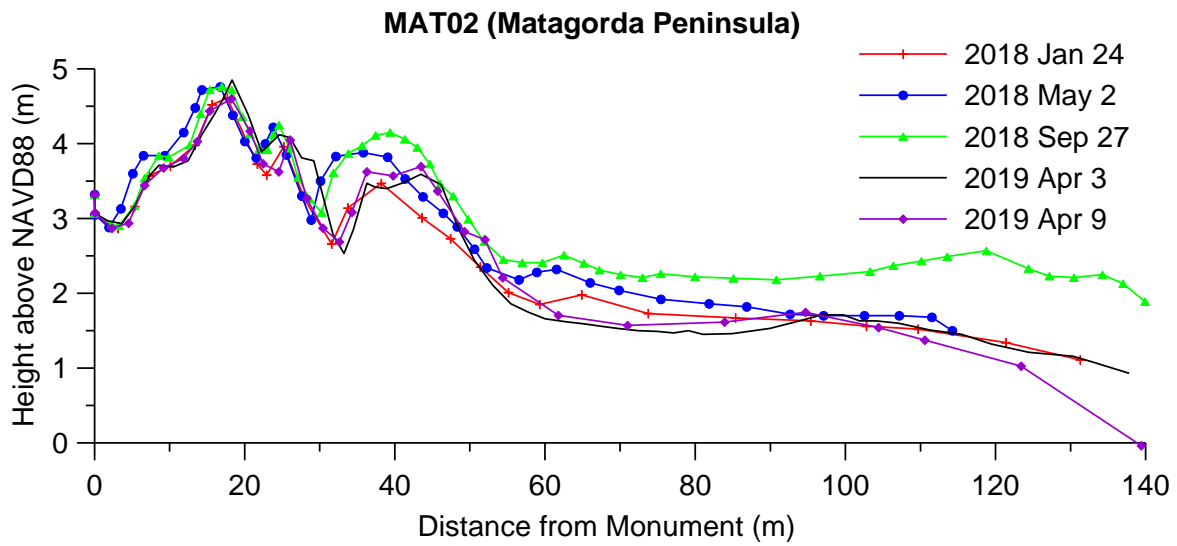


MAT02



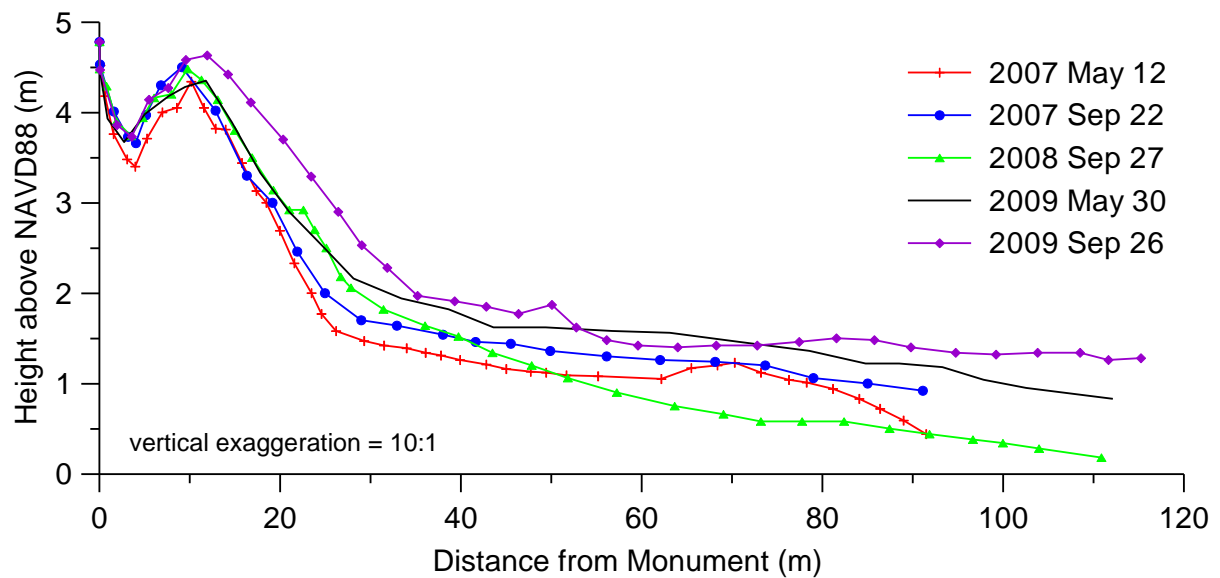
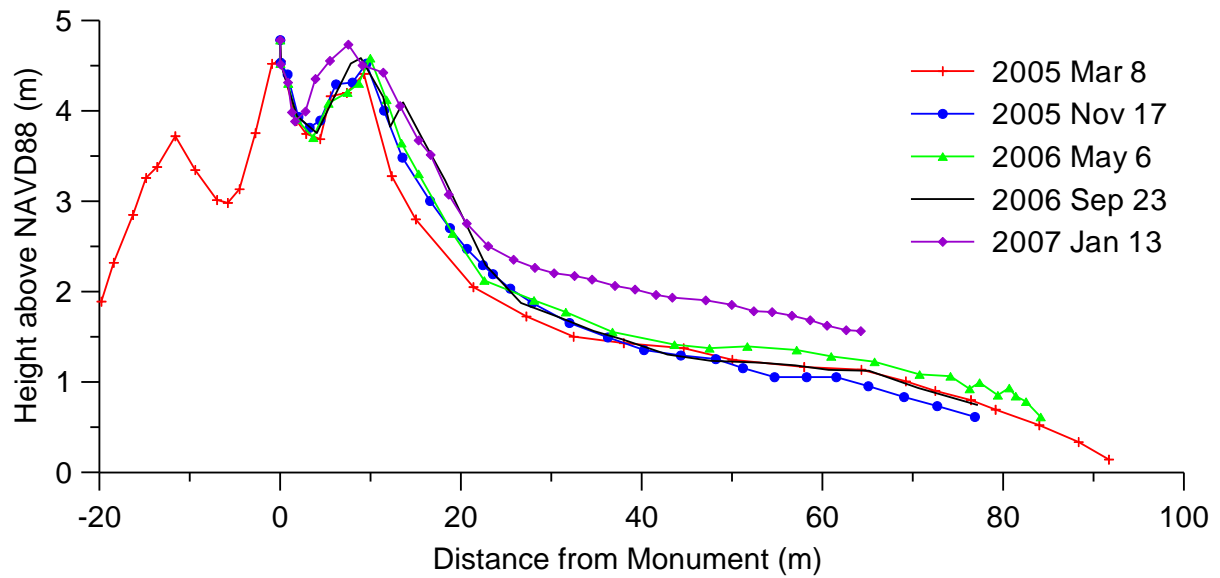




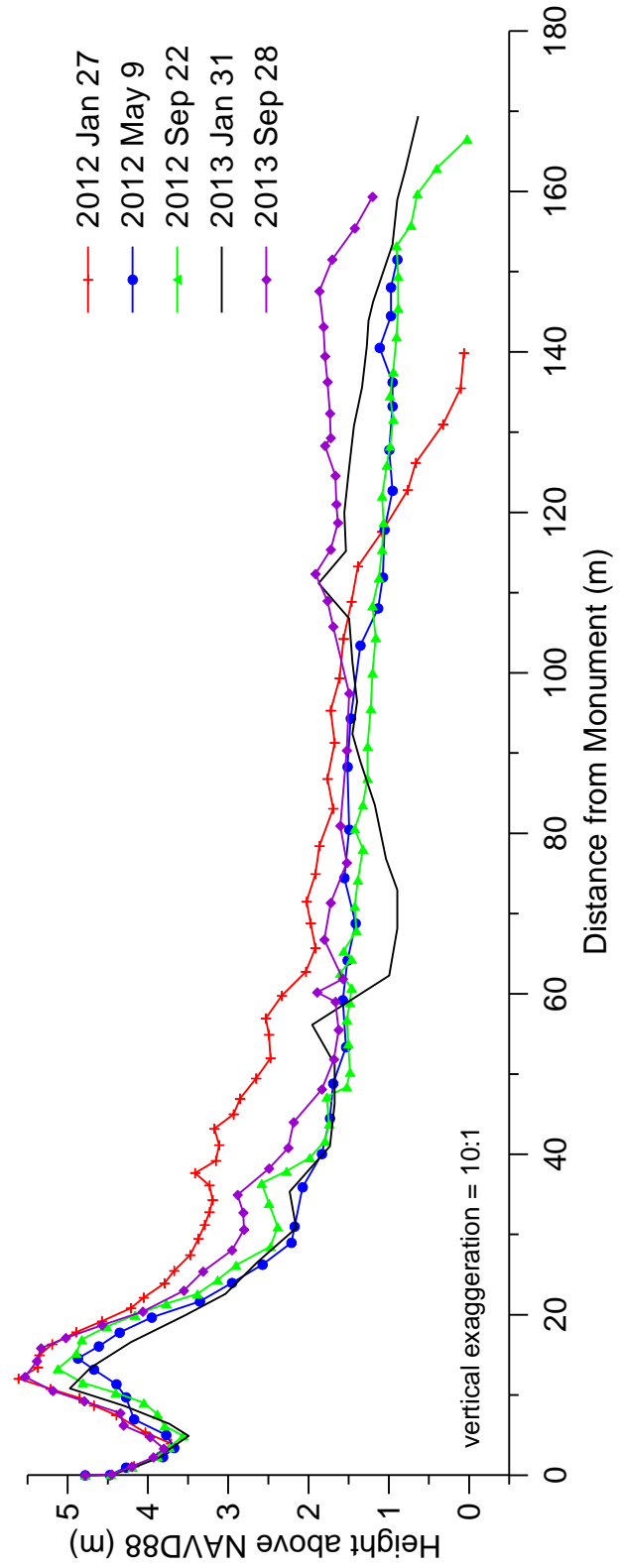
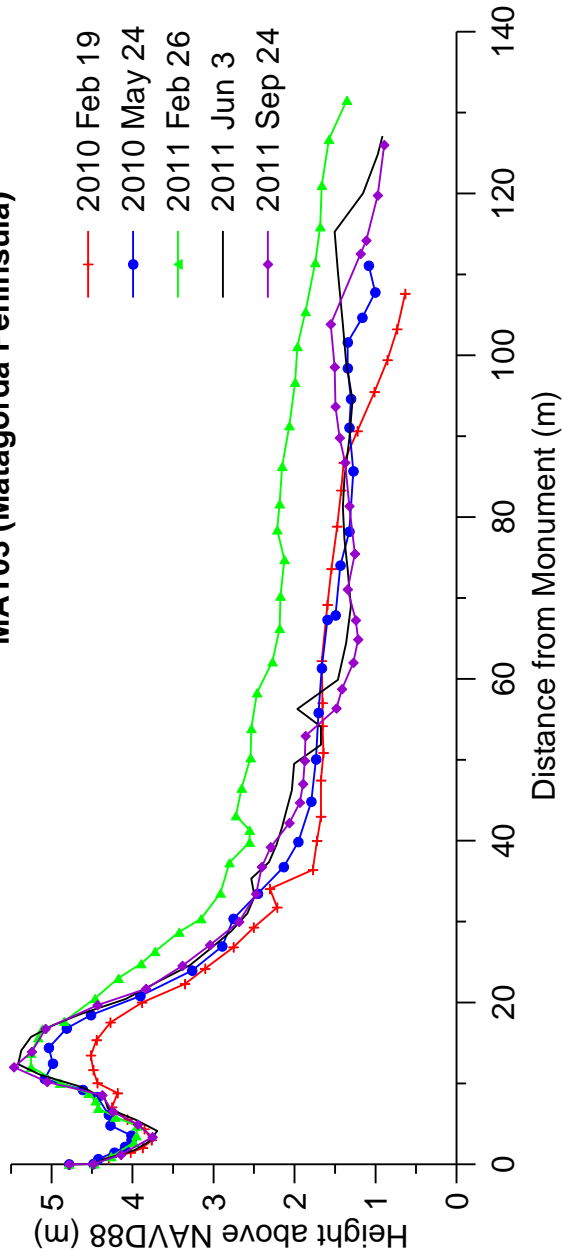


MAT03

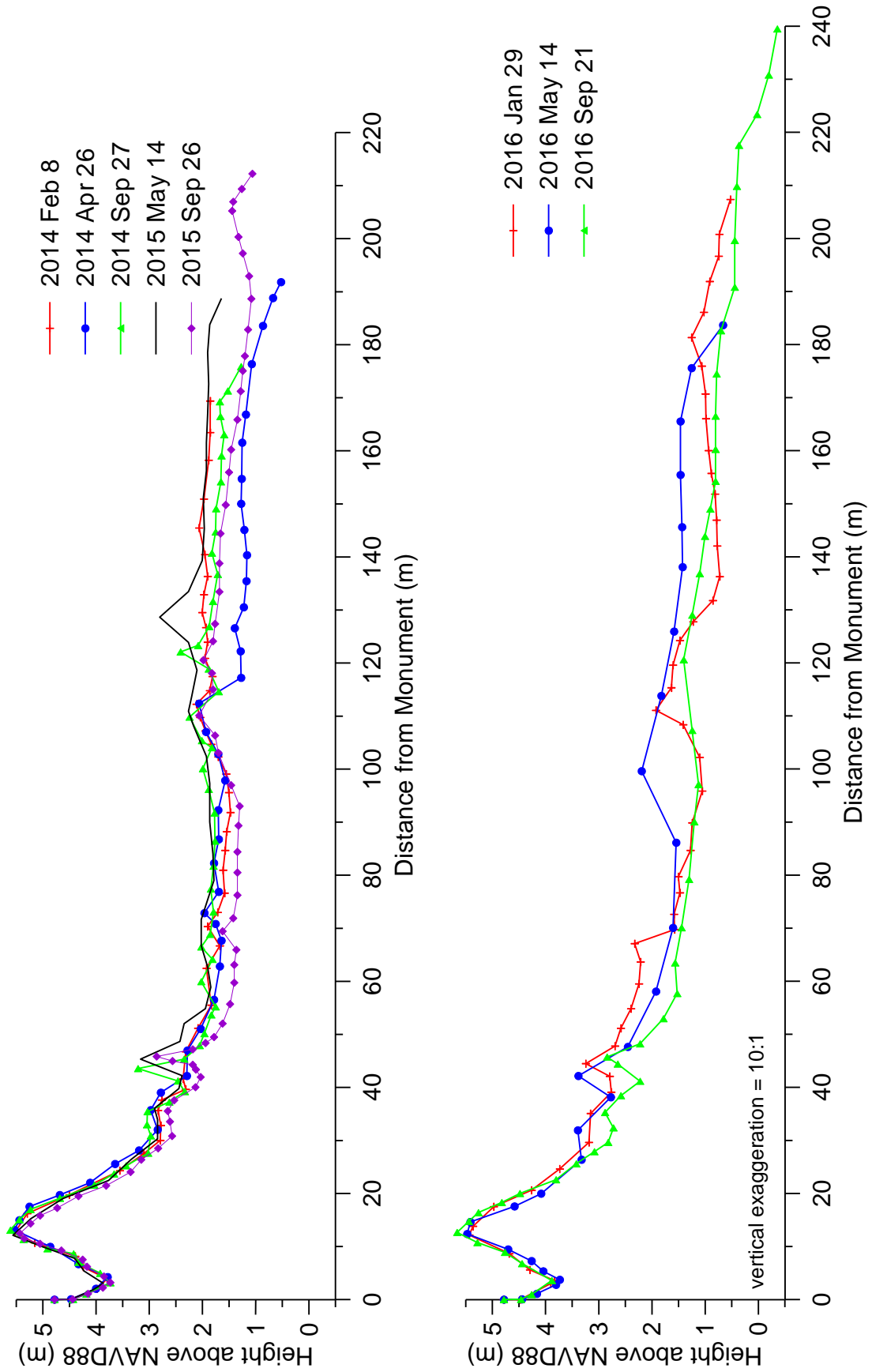
MAT03 (Matagorda Peninsula)



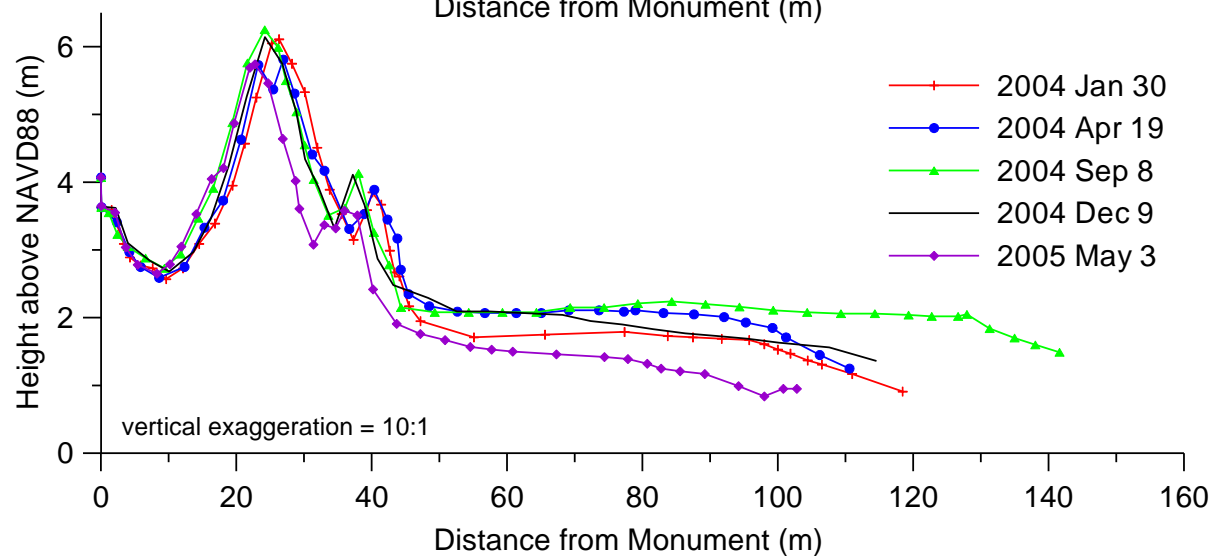
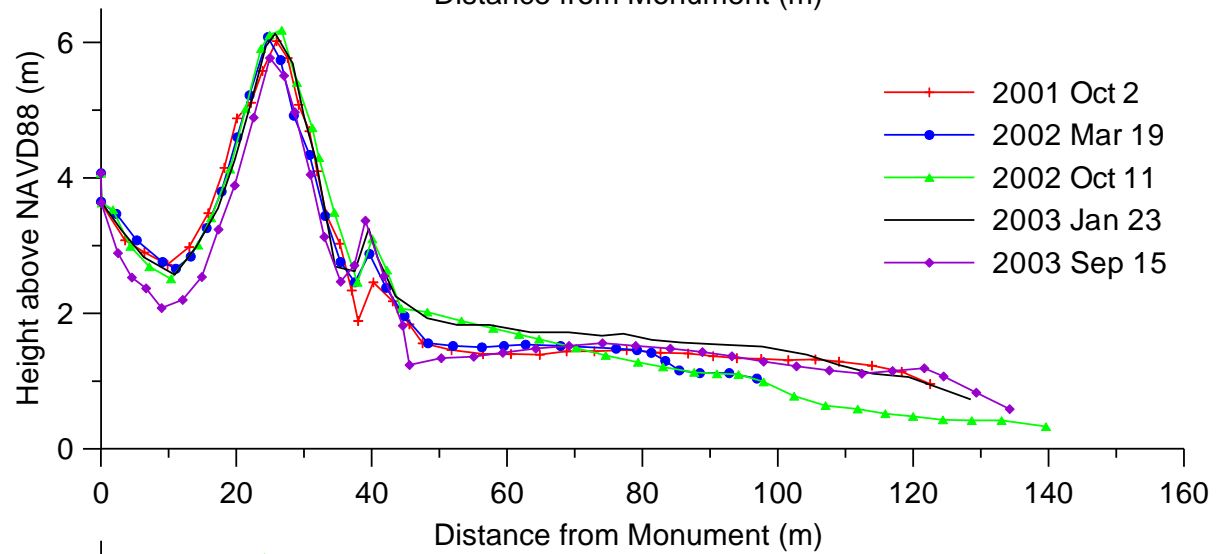
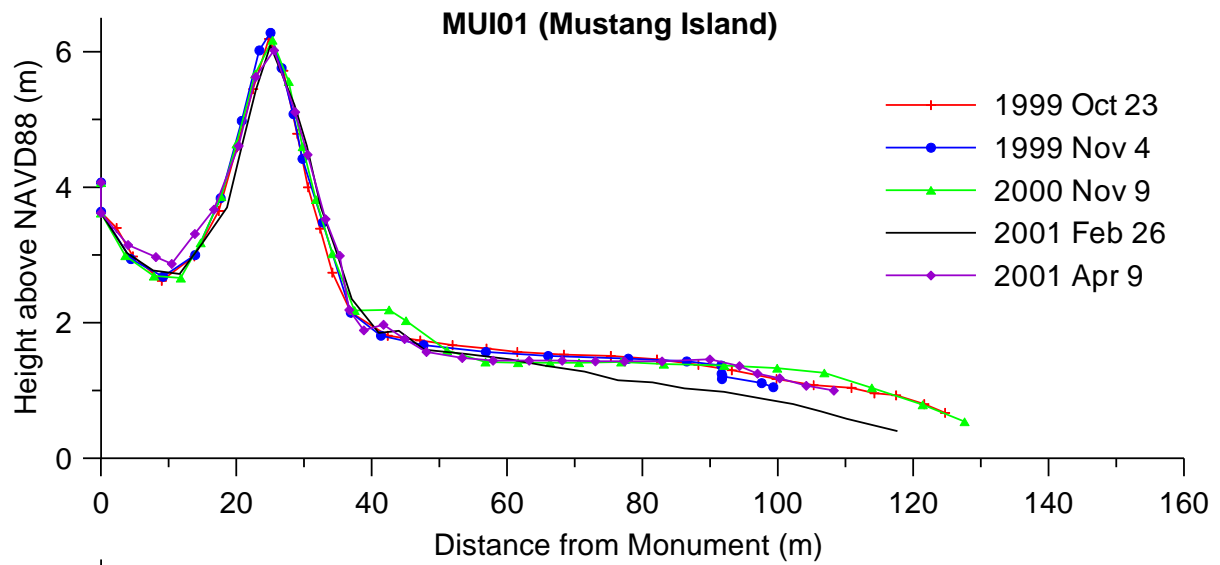
MAT03 (Matagorda Peninsula)

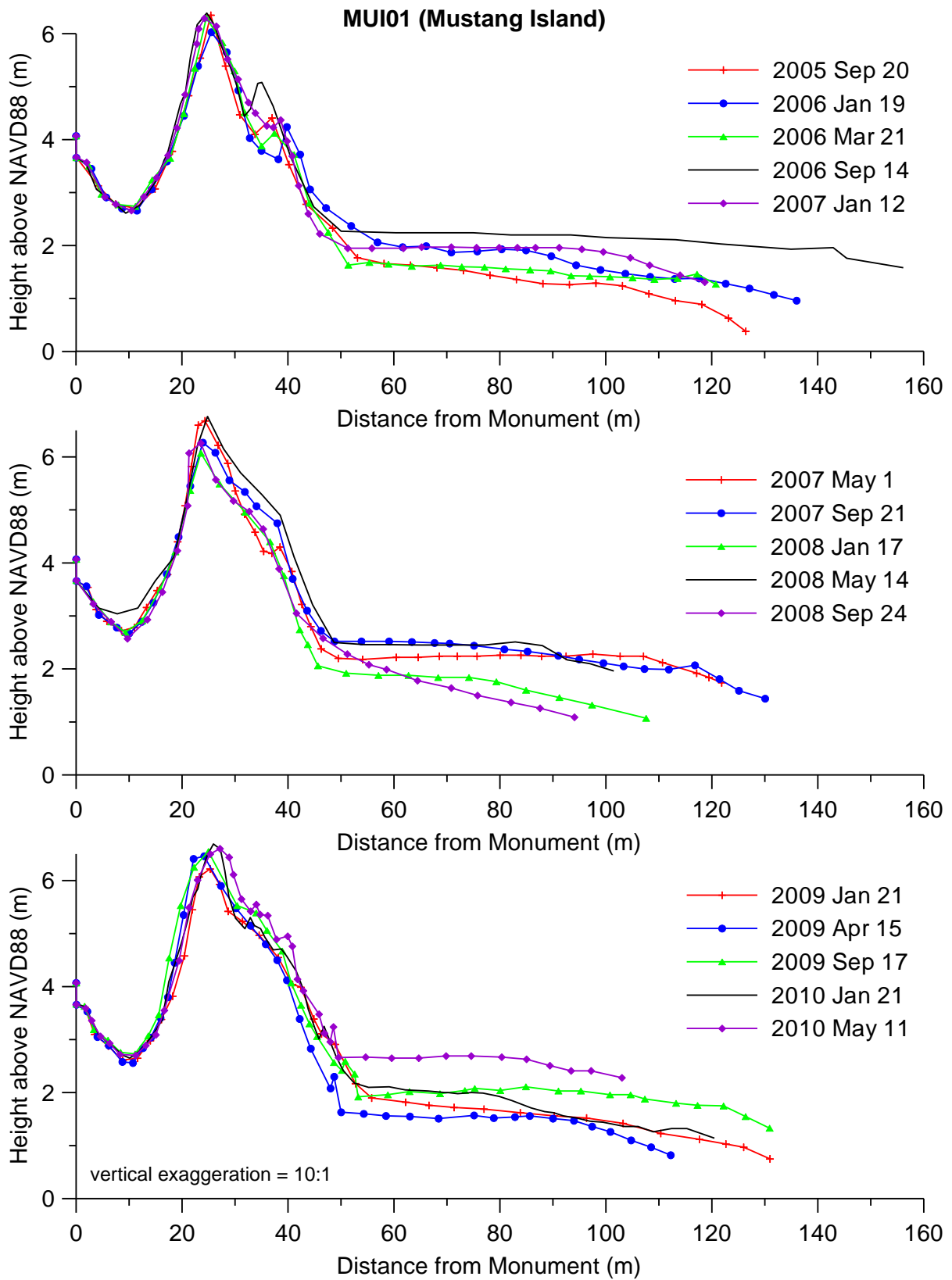


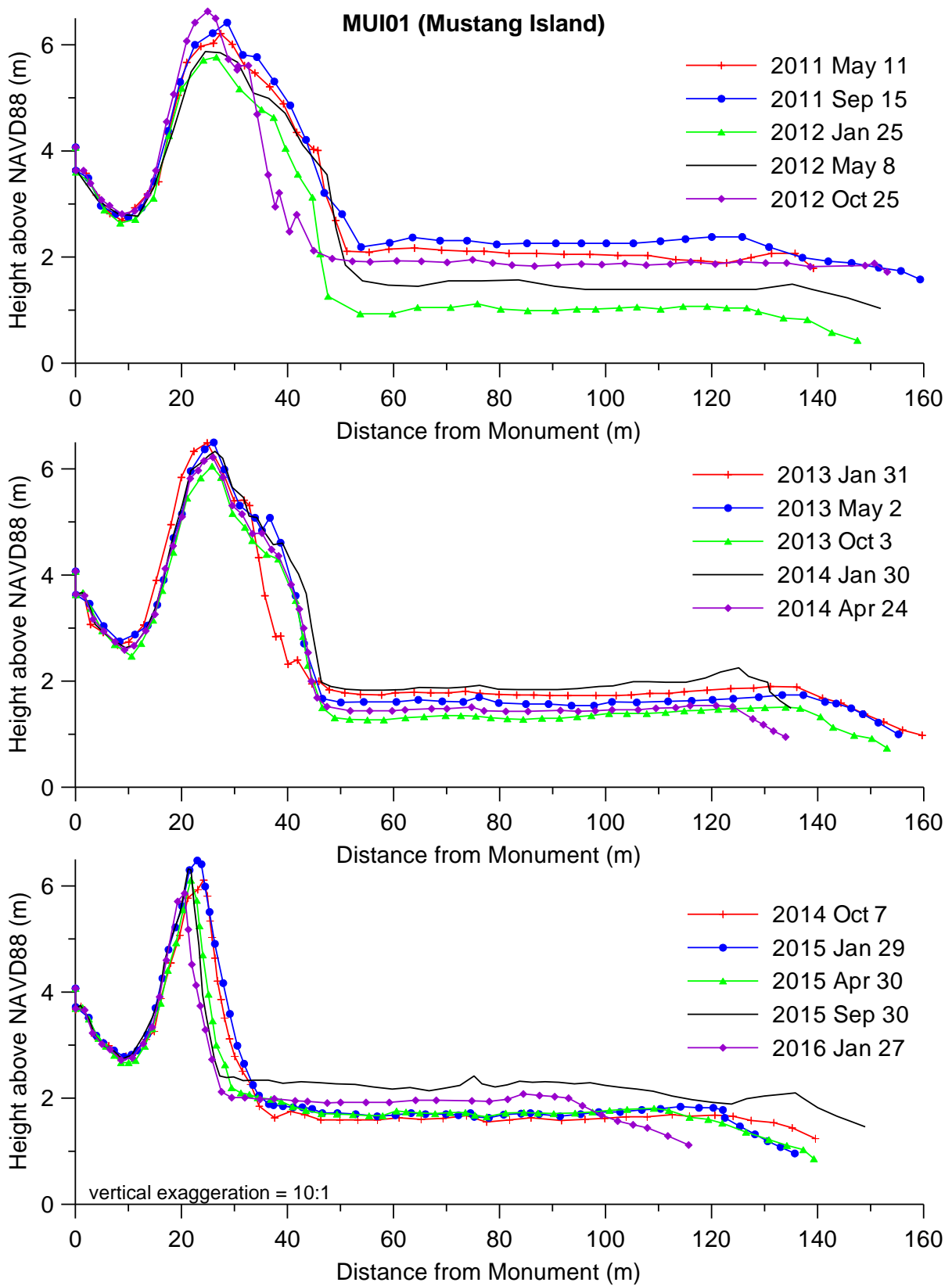
MAT03 (Matagorda Peninsula)

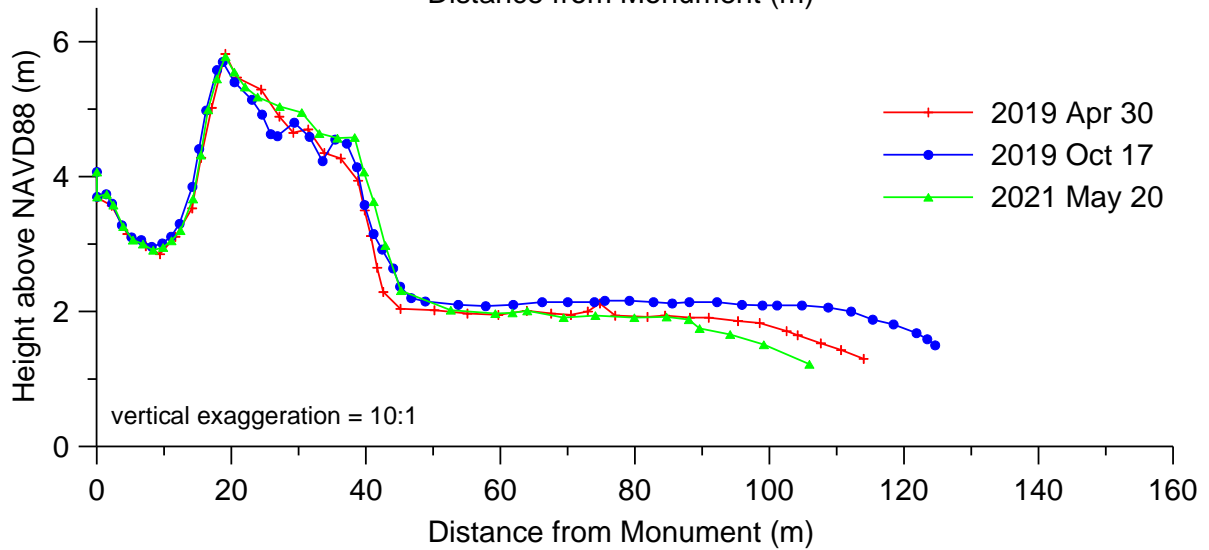
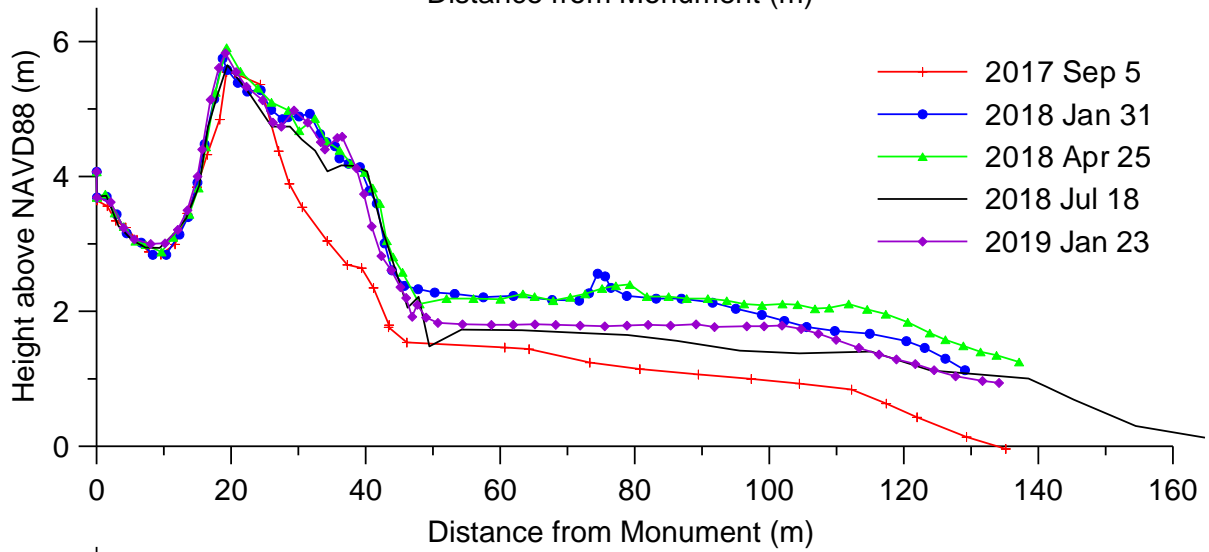
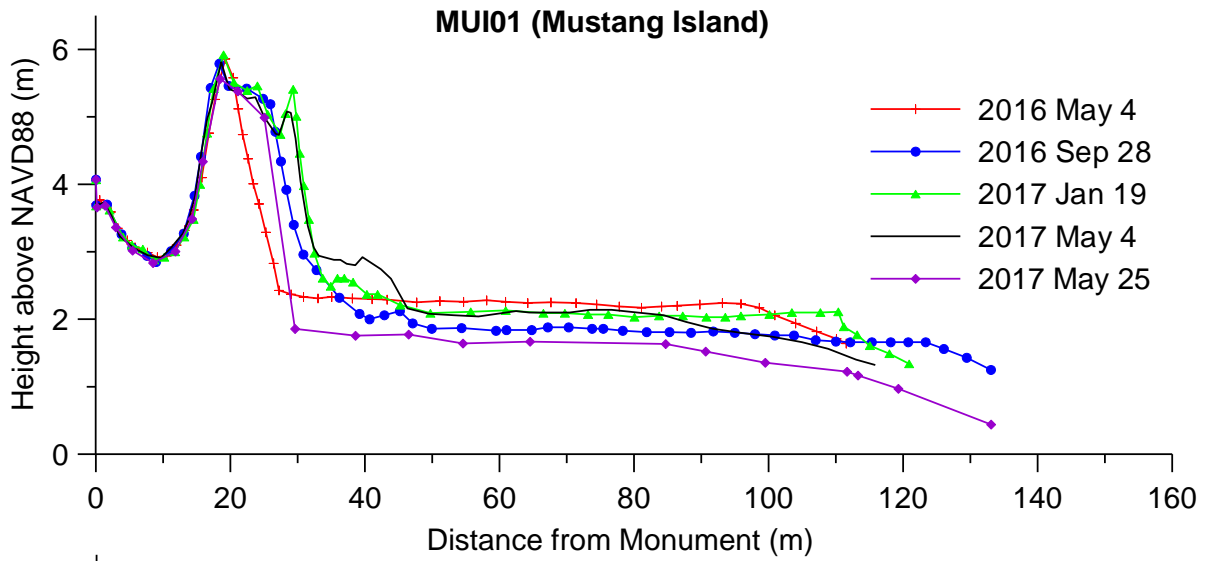


MUI01



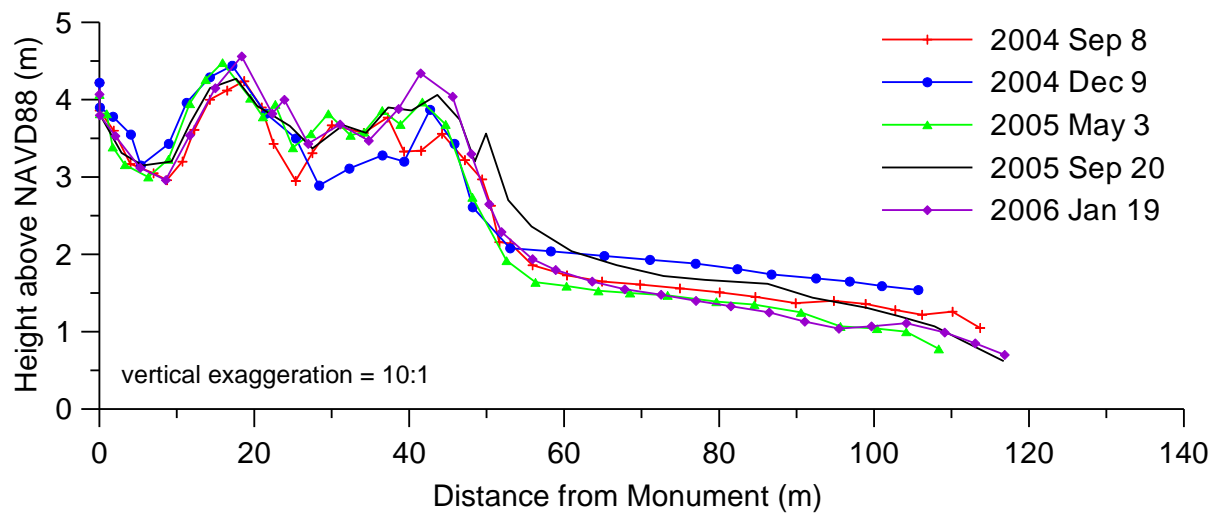
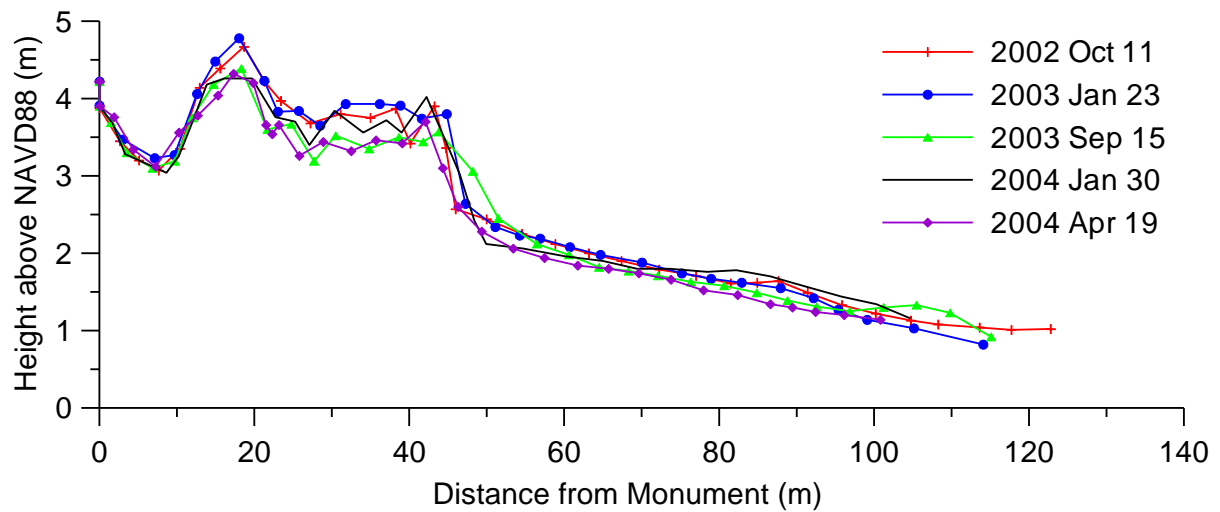
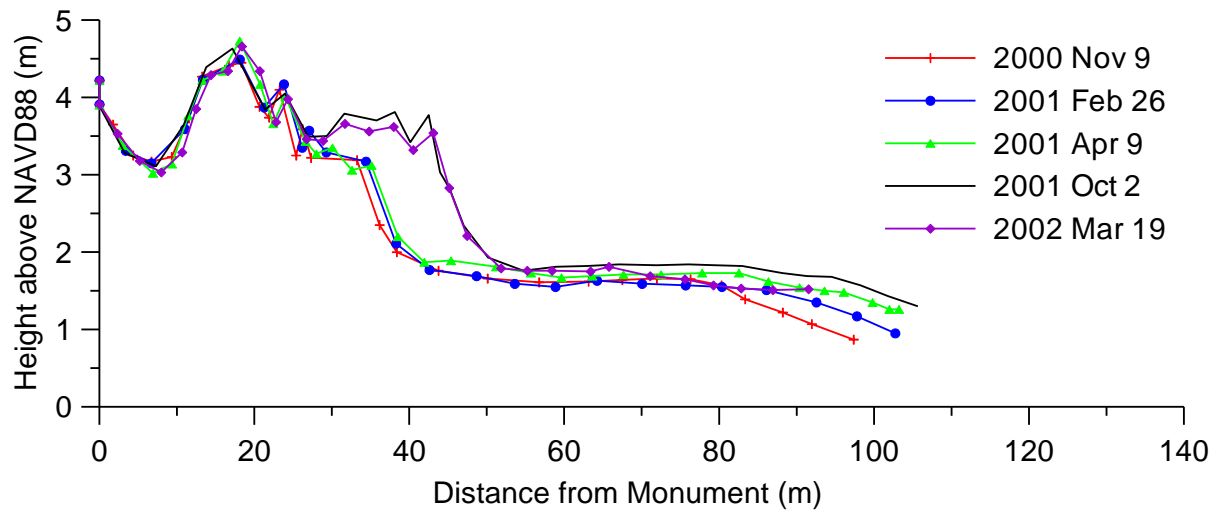


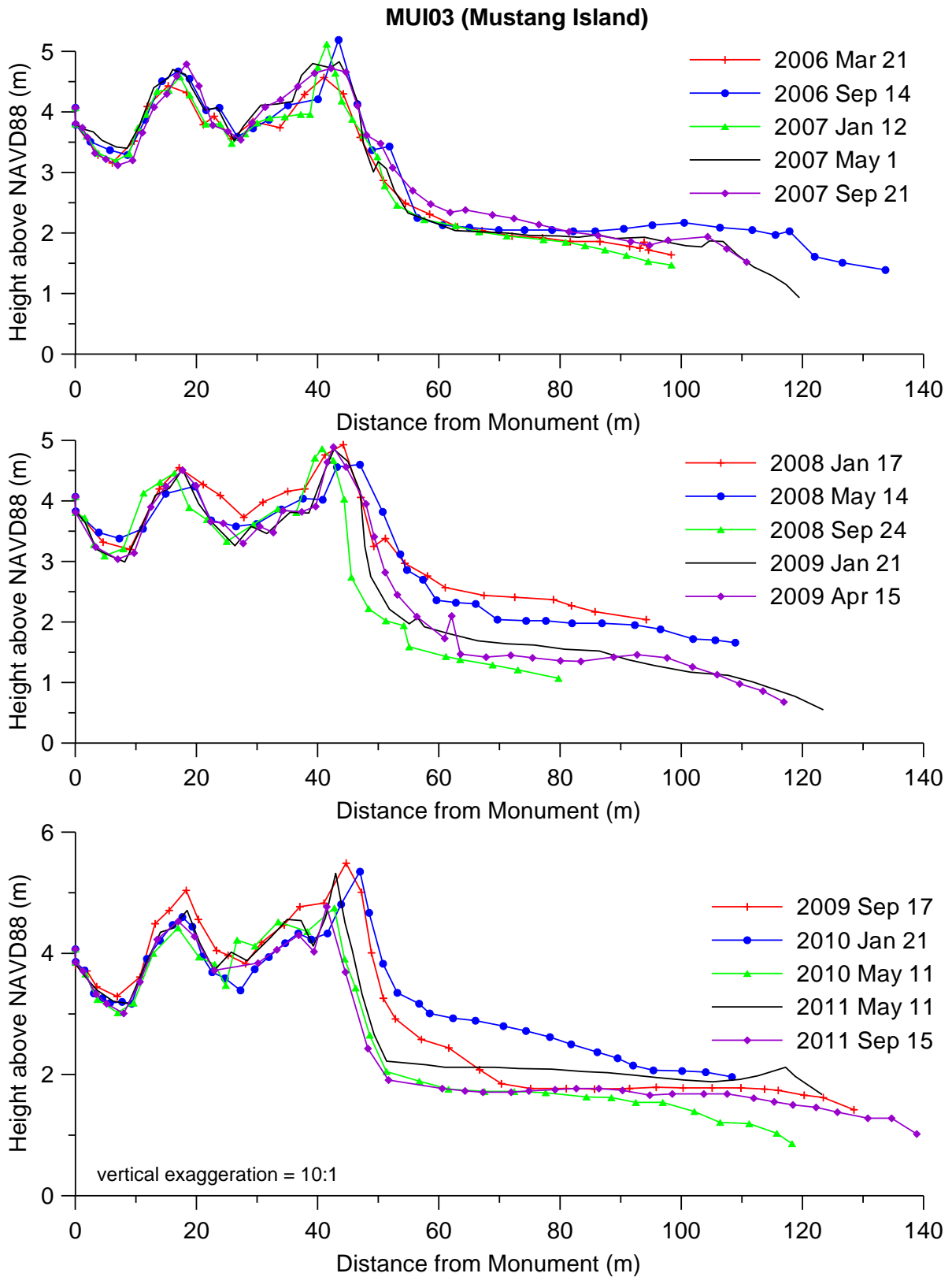


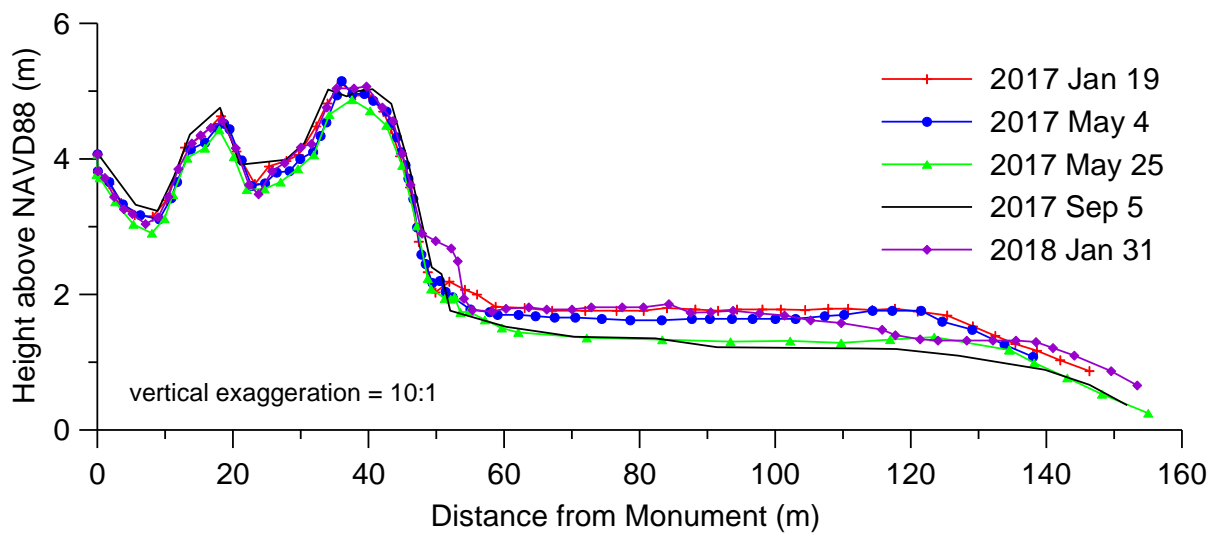
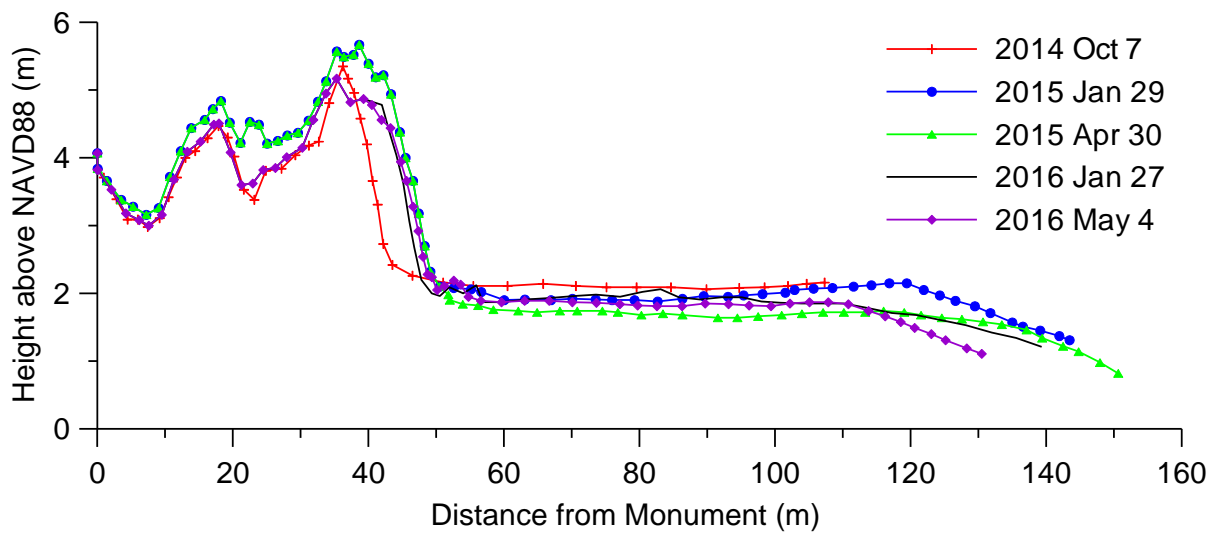
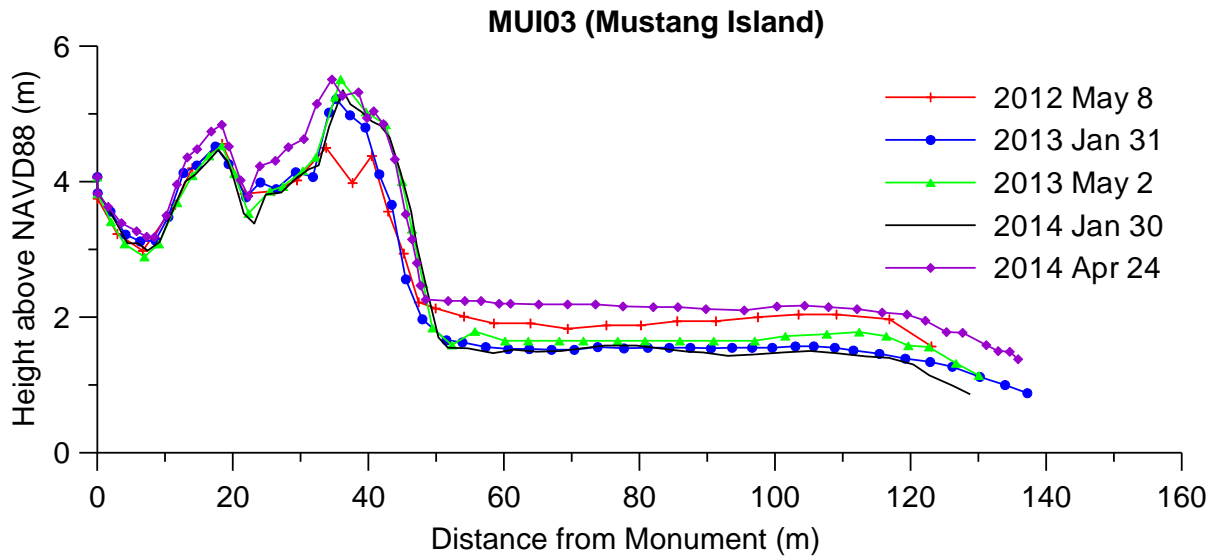


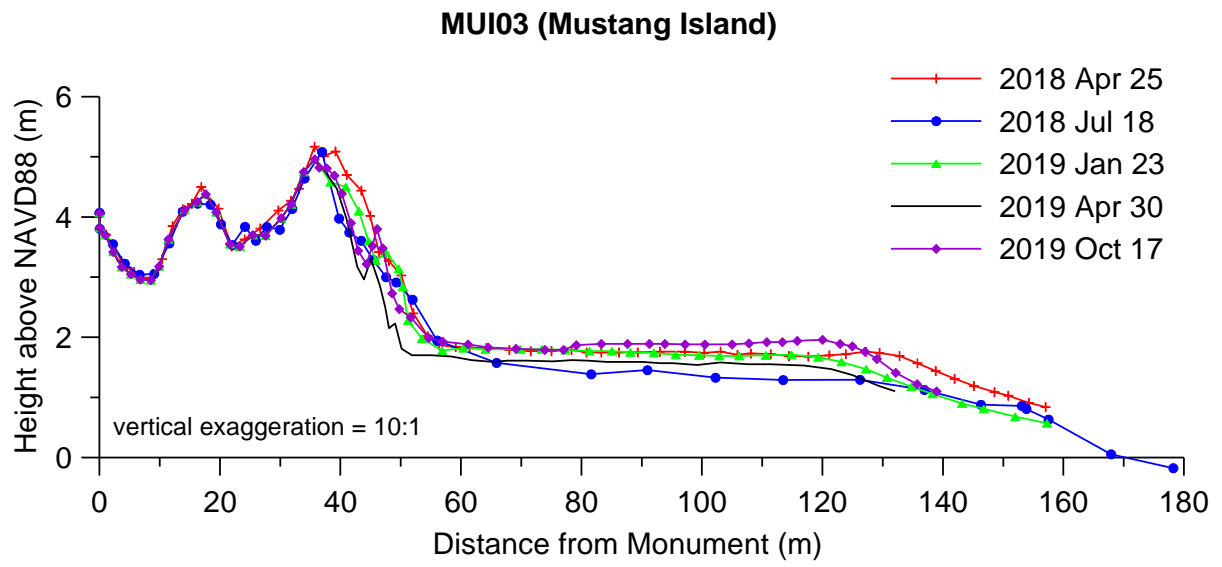
MUI03

MUI03 (Mustang Island)



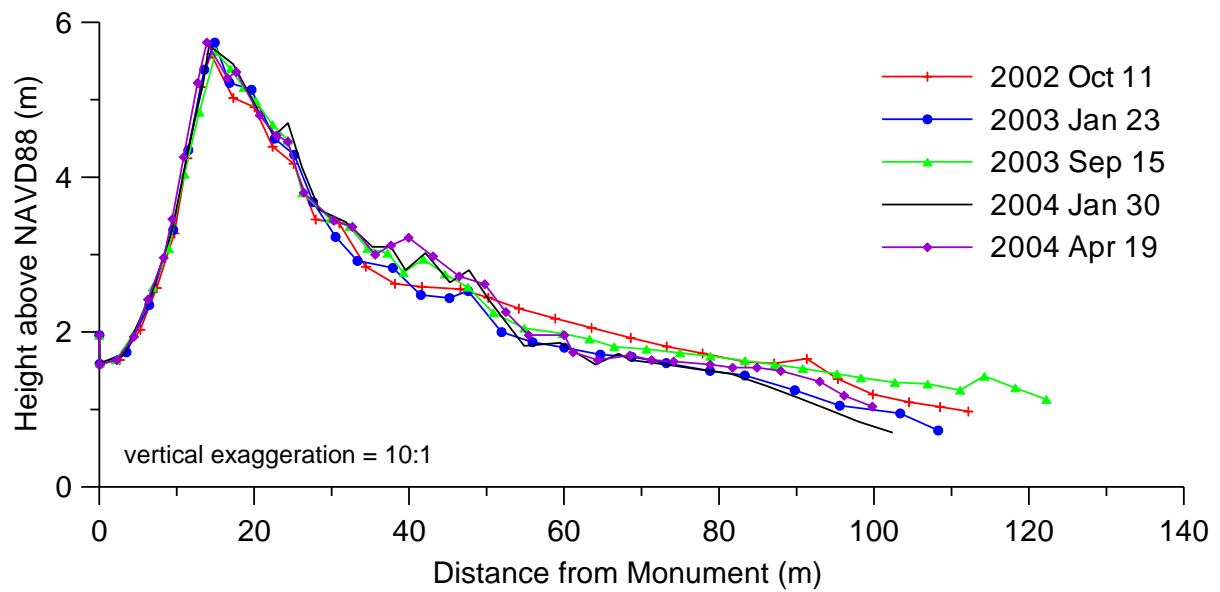
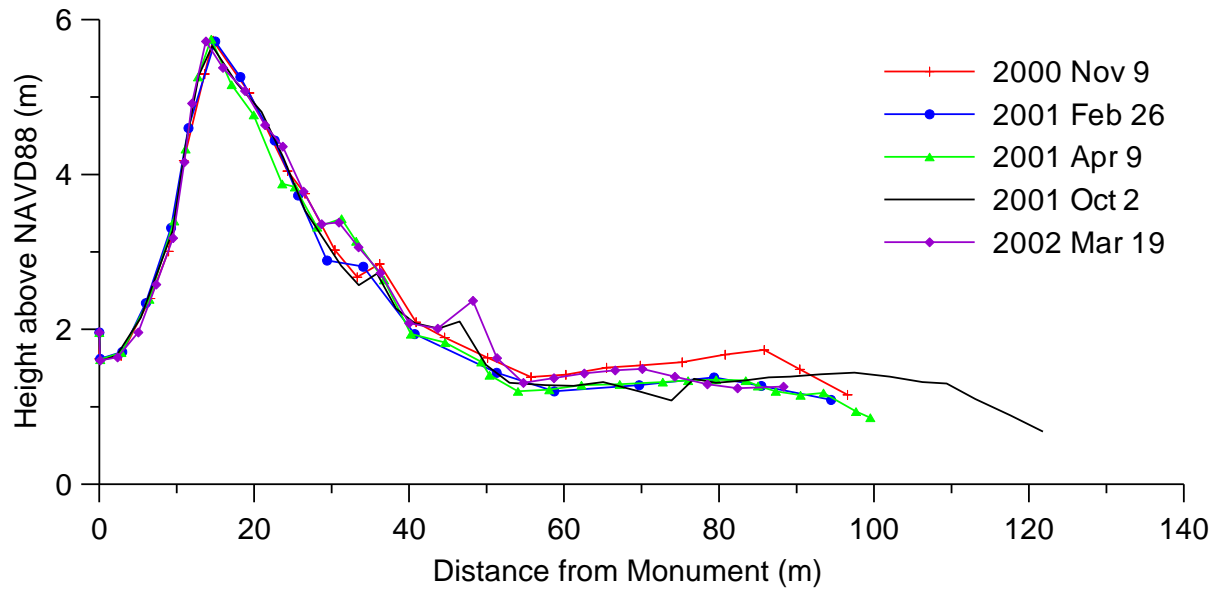




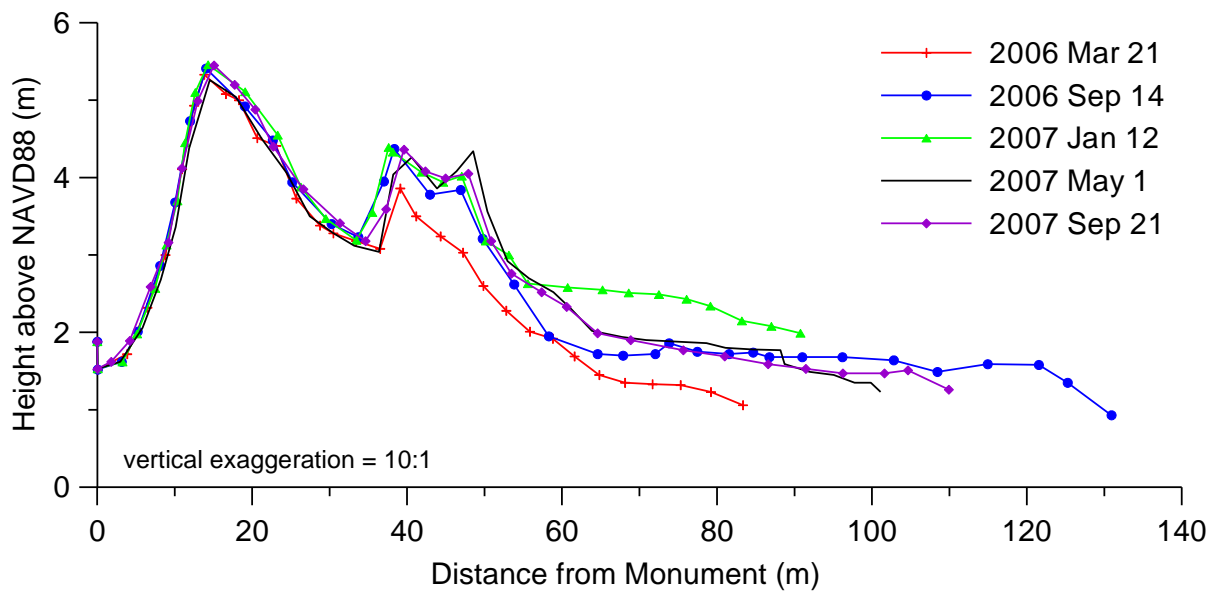
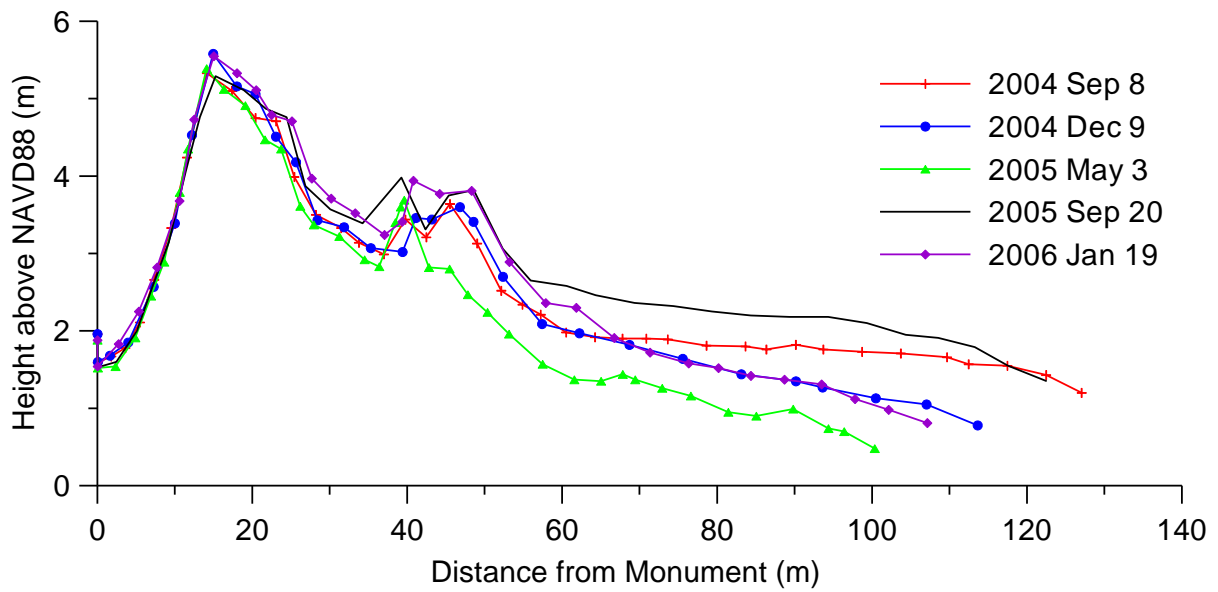


MUI02

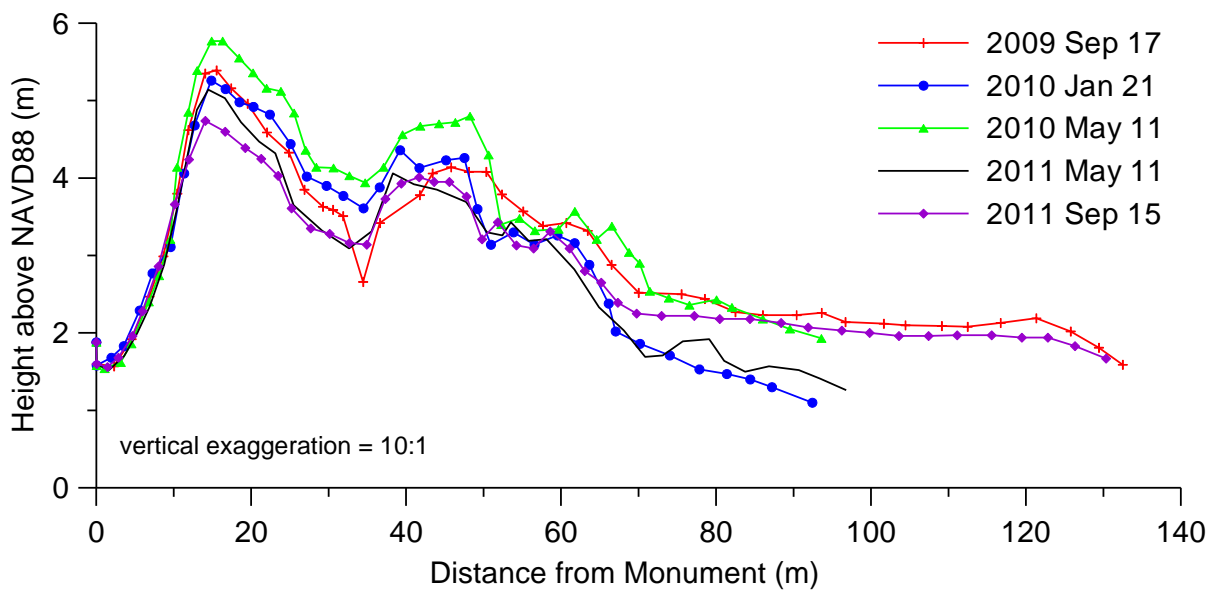
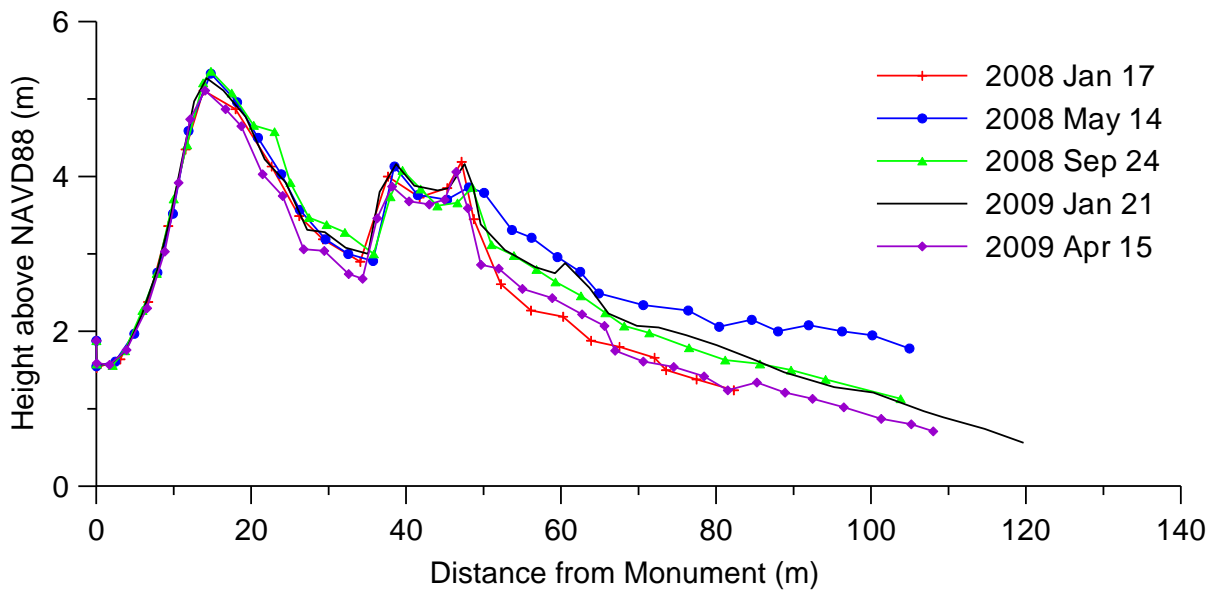
MUI02 (Mustang Island State Park)



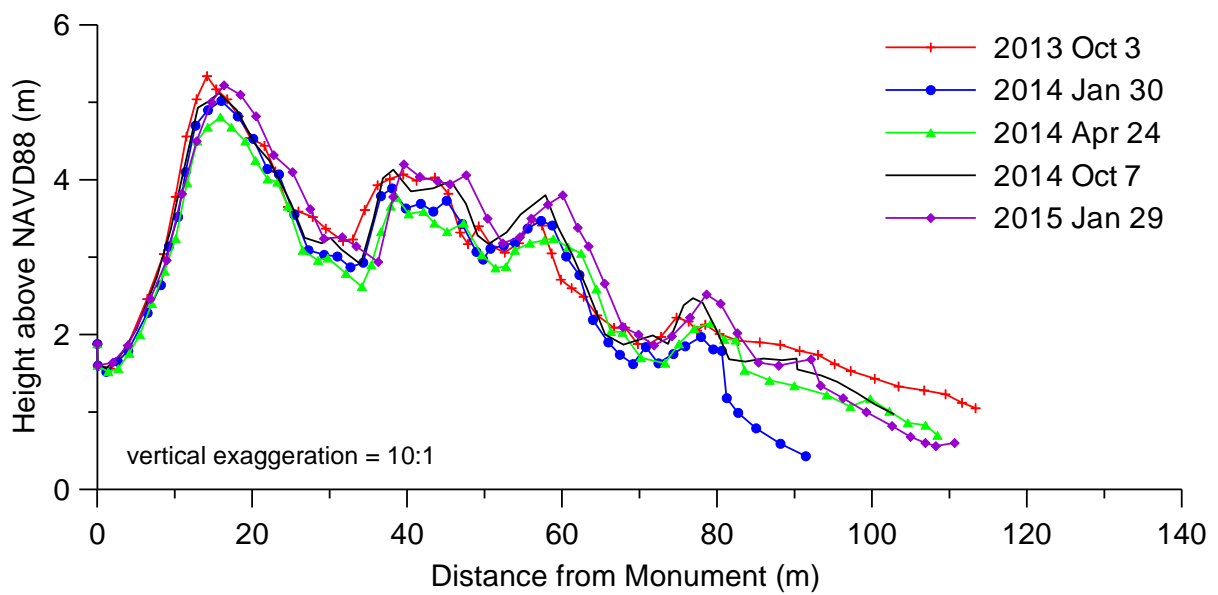
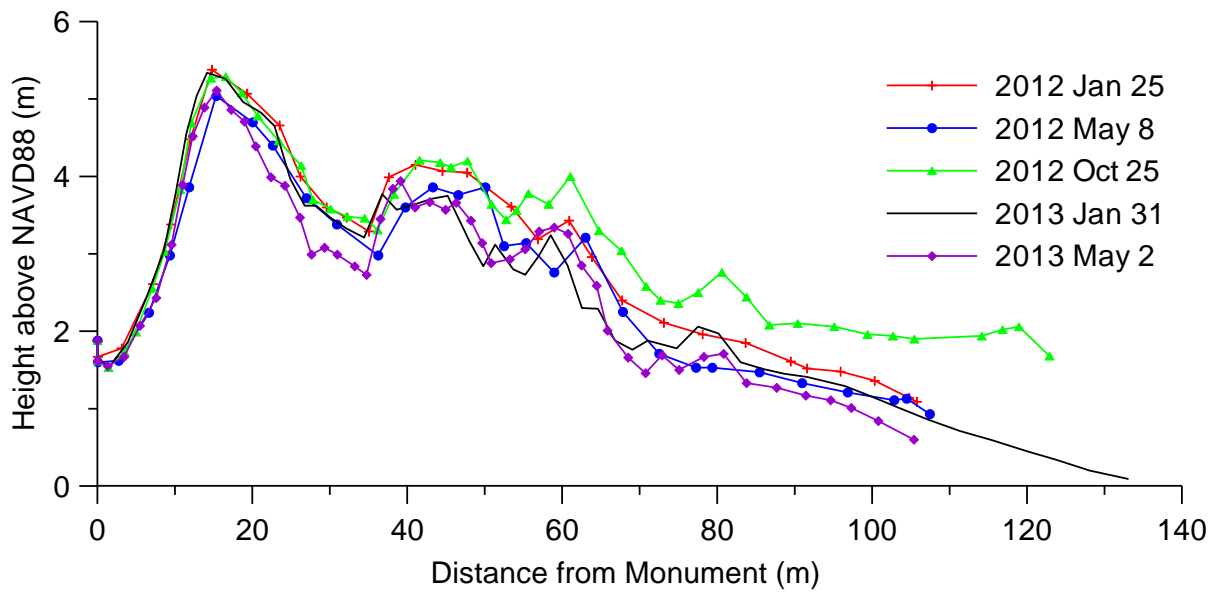
MUI02 (Mustang Island State Park)



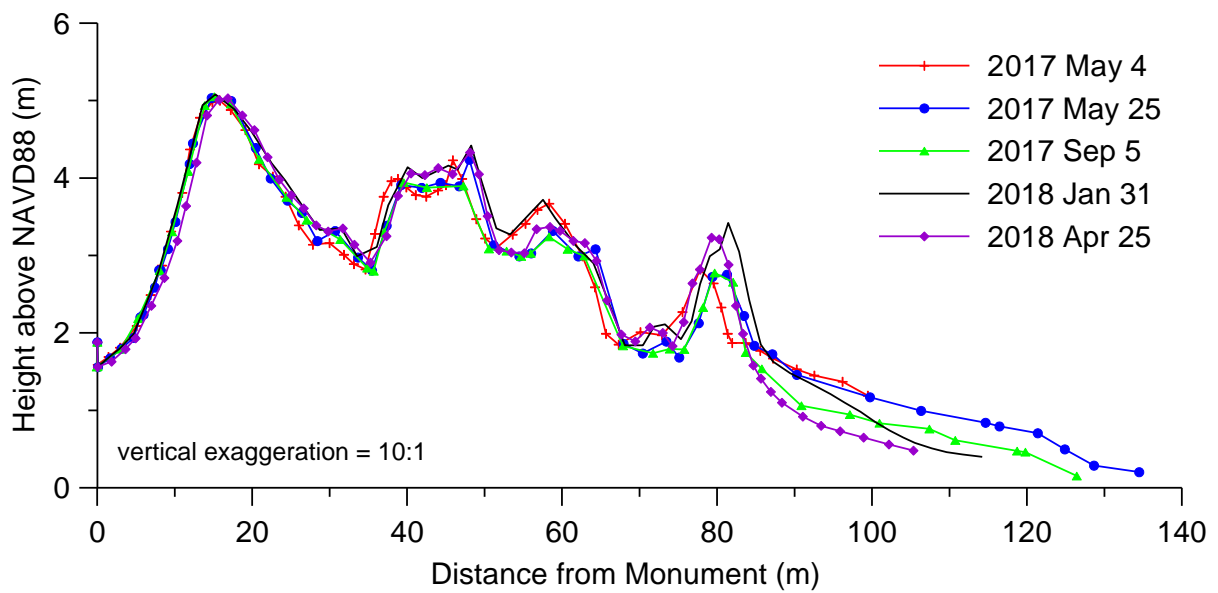
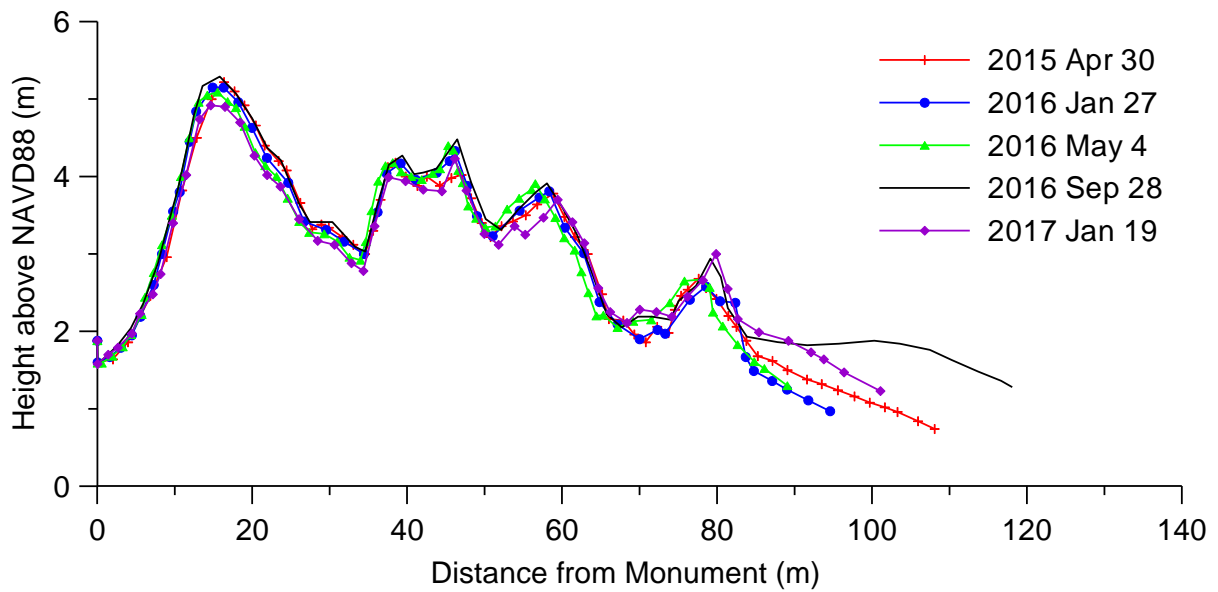
MUI02 (Mustang Island State Park)



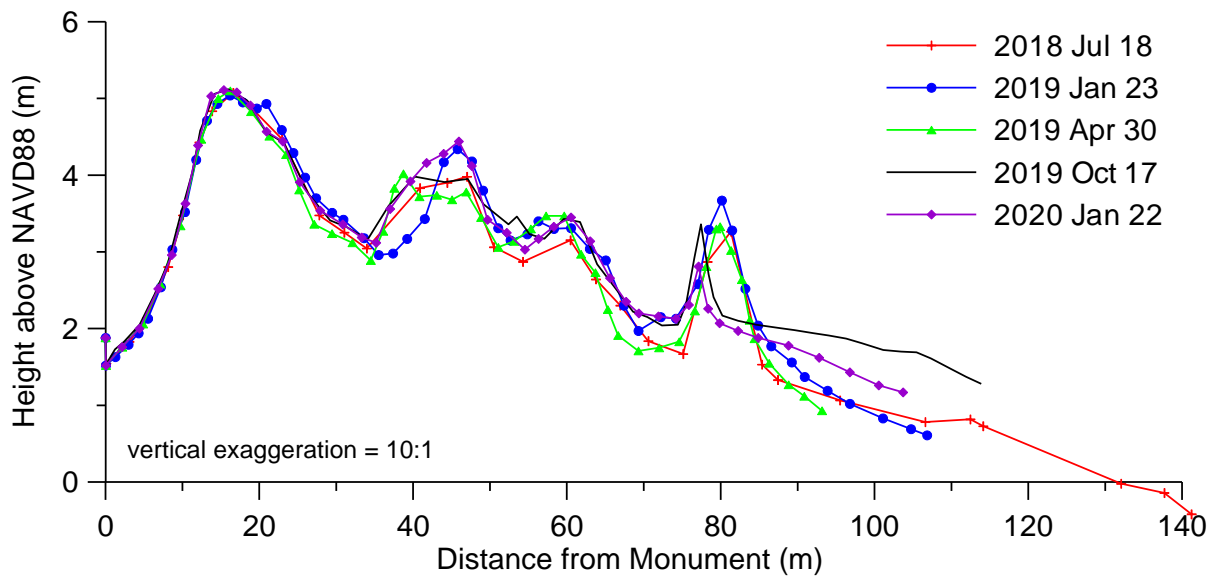
MUI02 (Mustang Island State Park)



MUI02 (Mustang Island State Park)

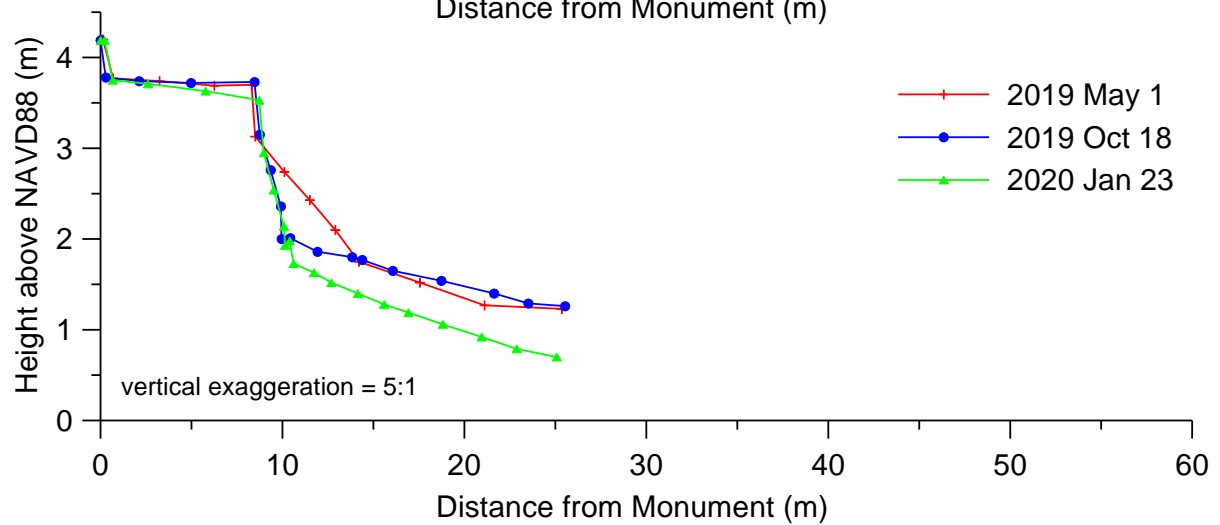
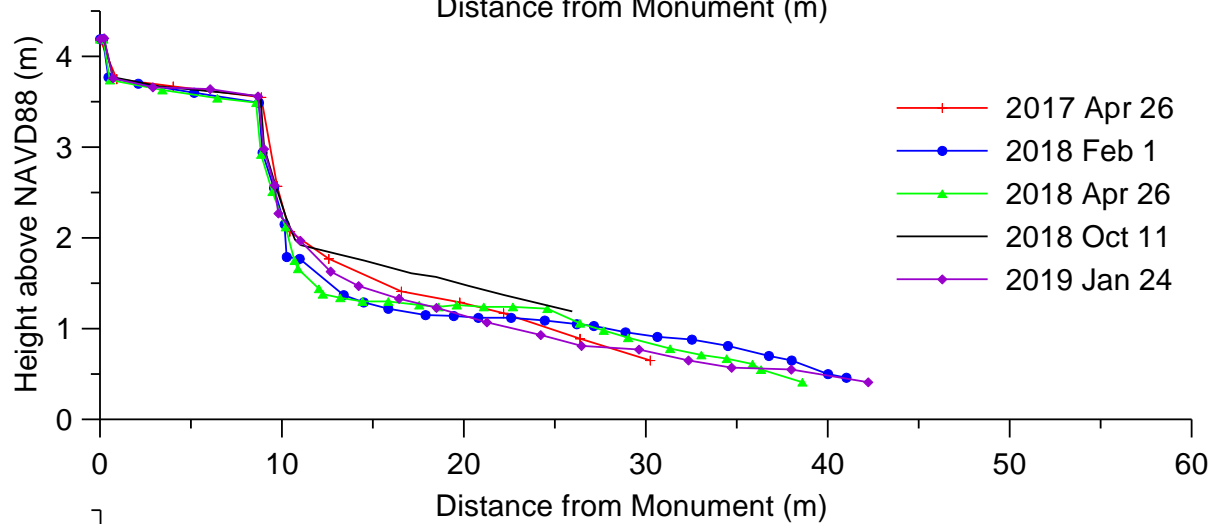
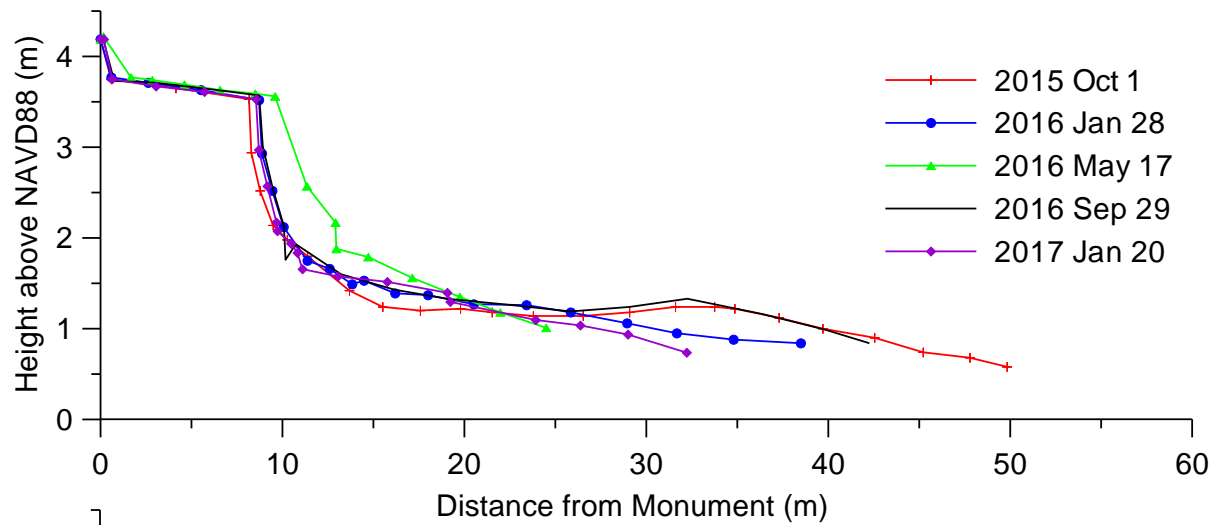


MUI02 (Mustang Island State Park)



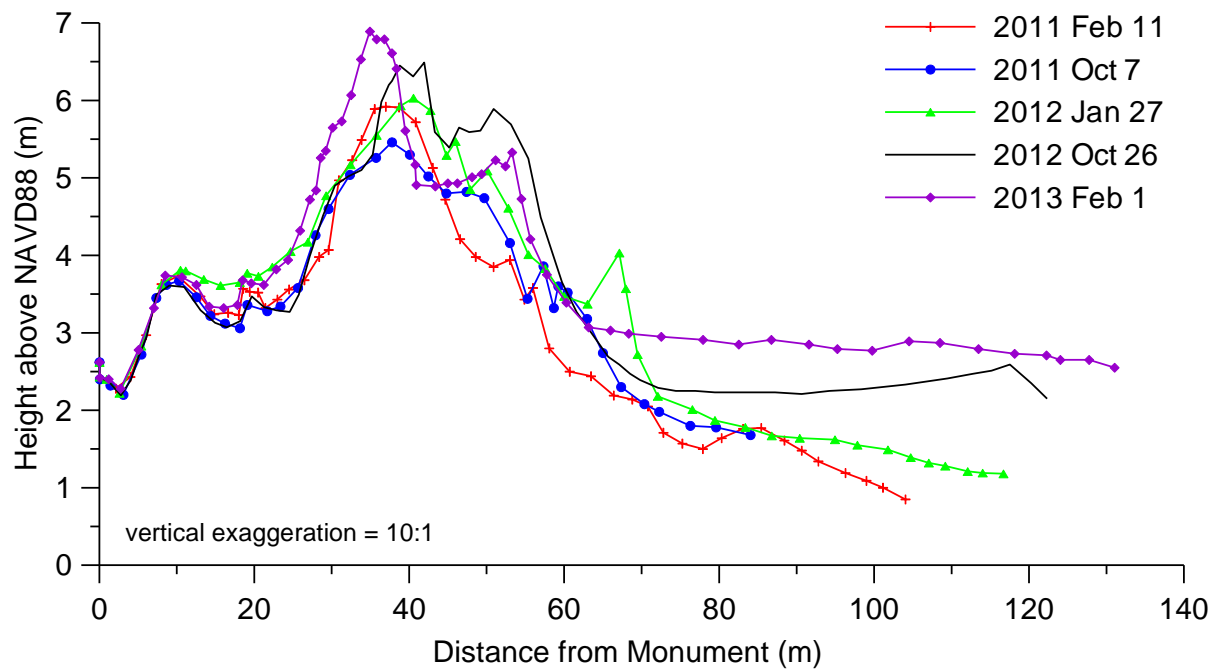
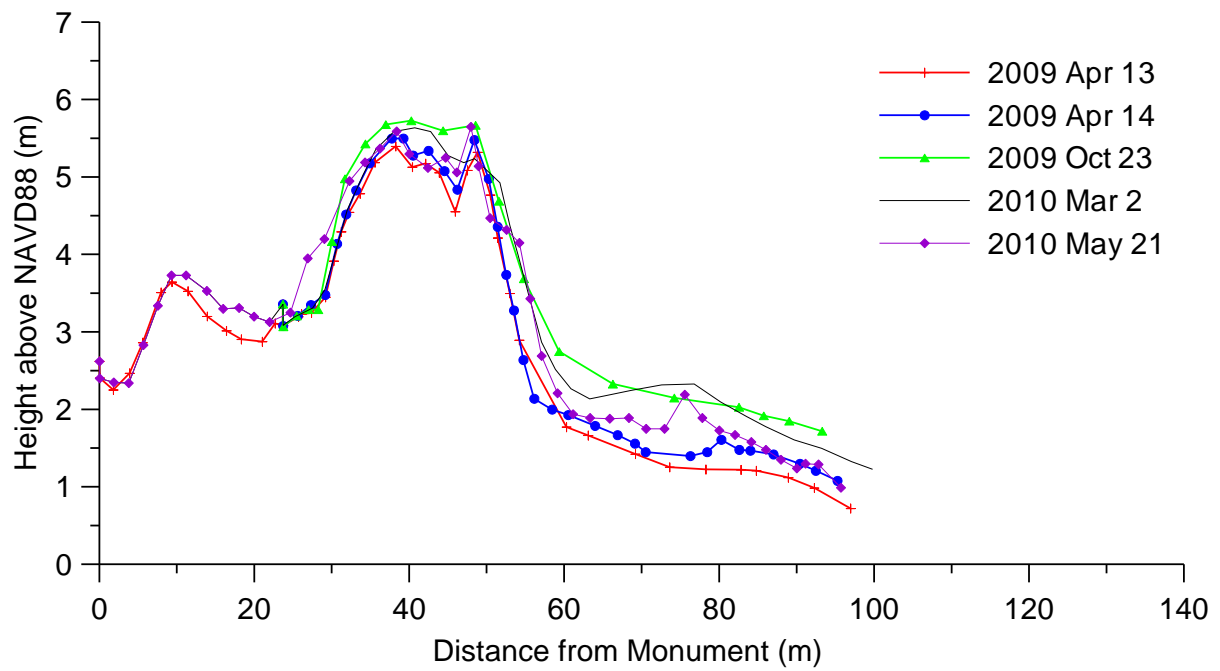
NPC06

NPC06 (North Padre Island Seawall)

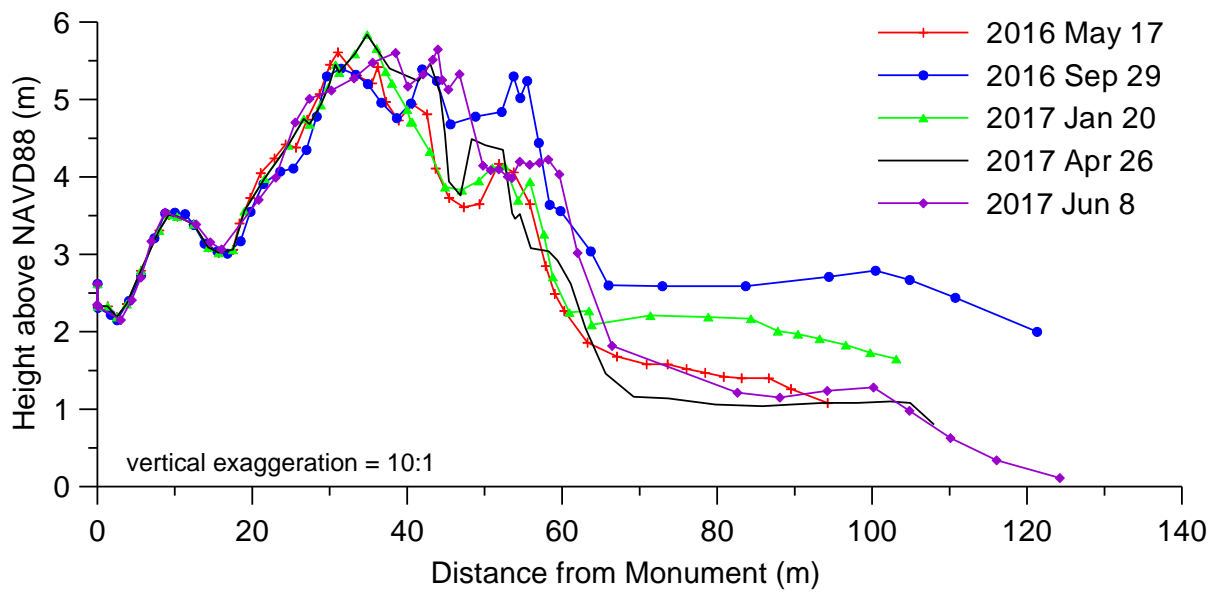
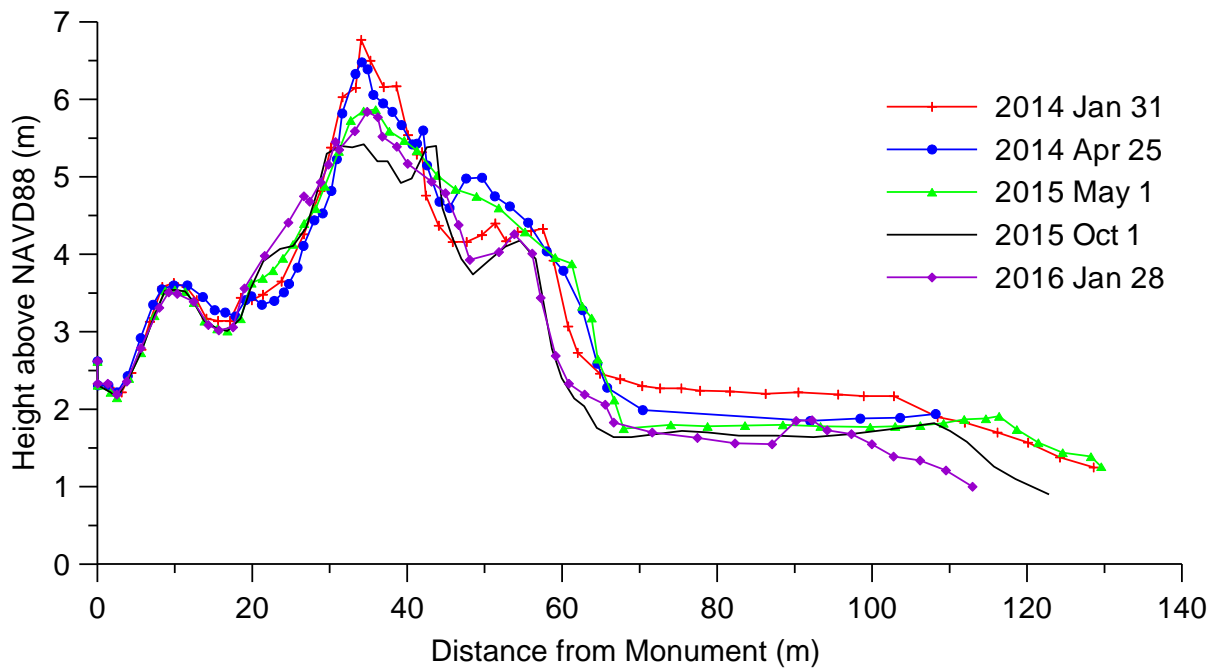


NPI08

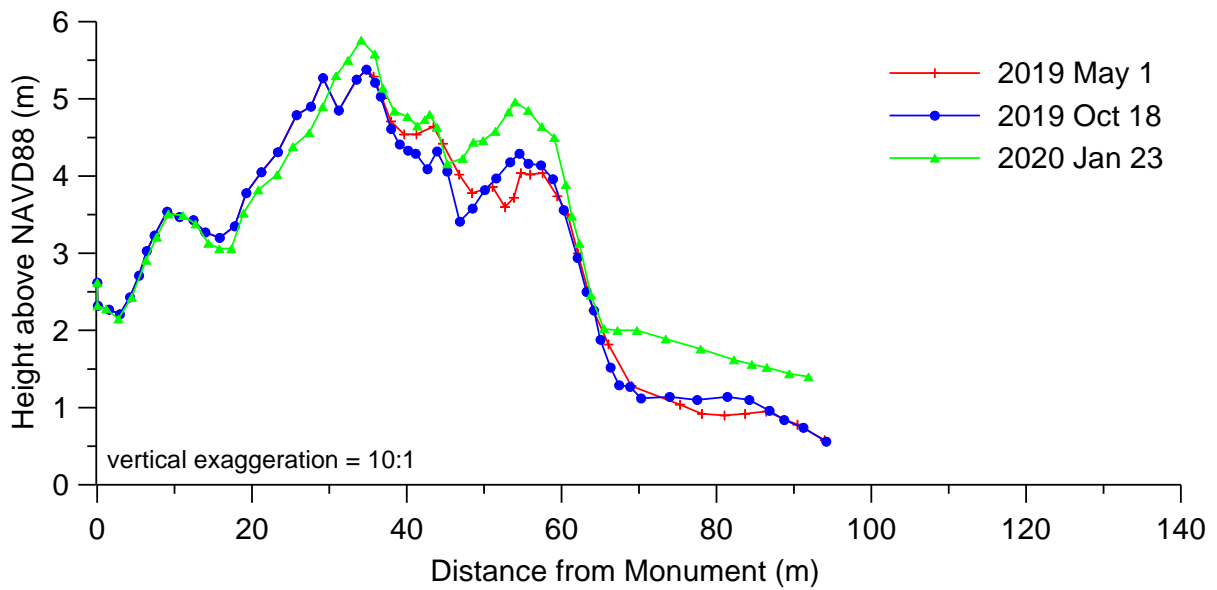
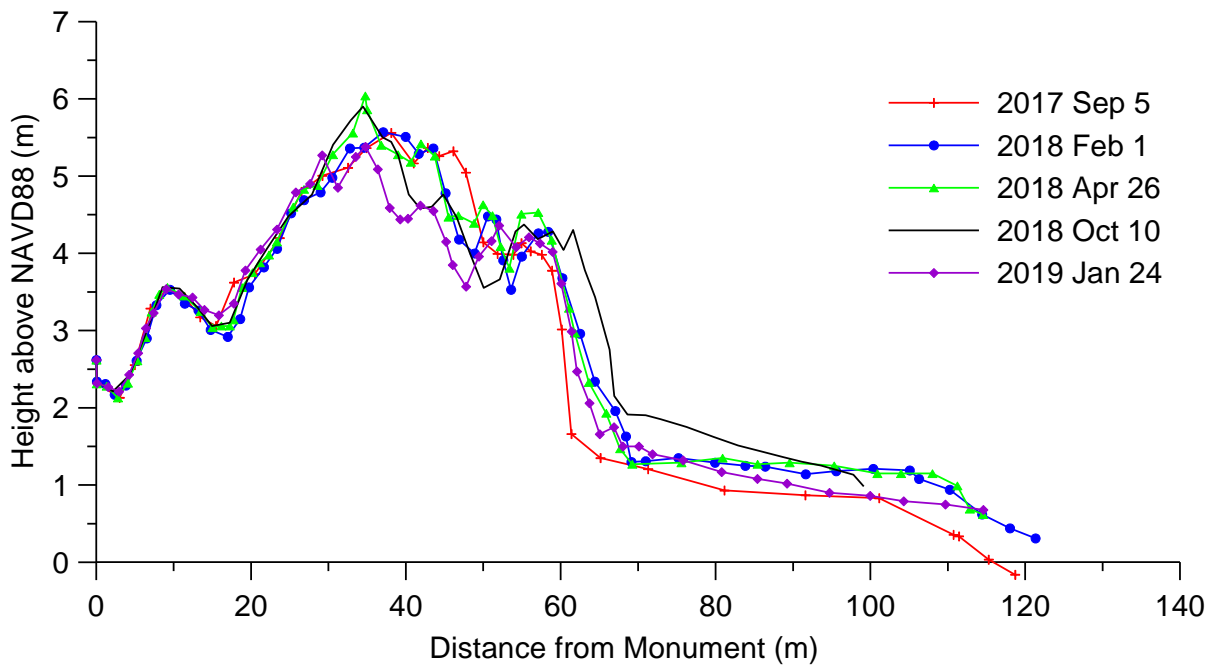
NPI08 (North Padre Island)



NPI08 (North Padre Island)

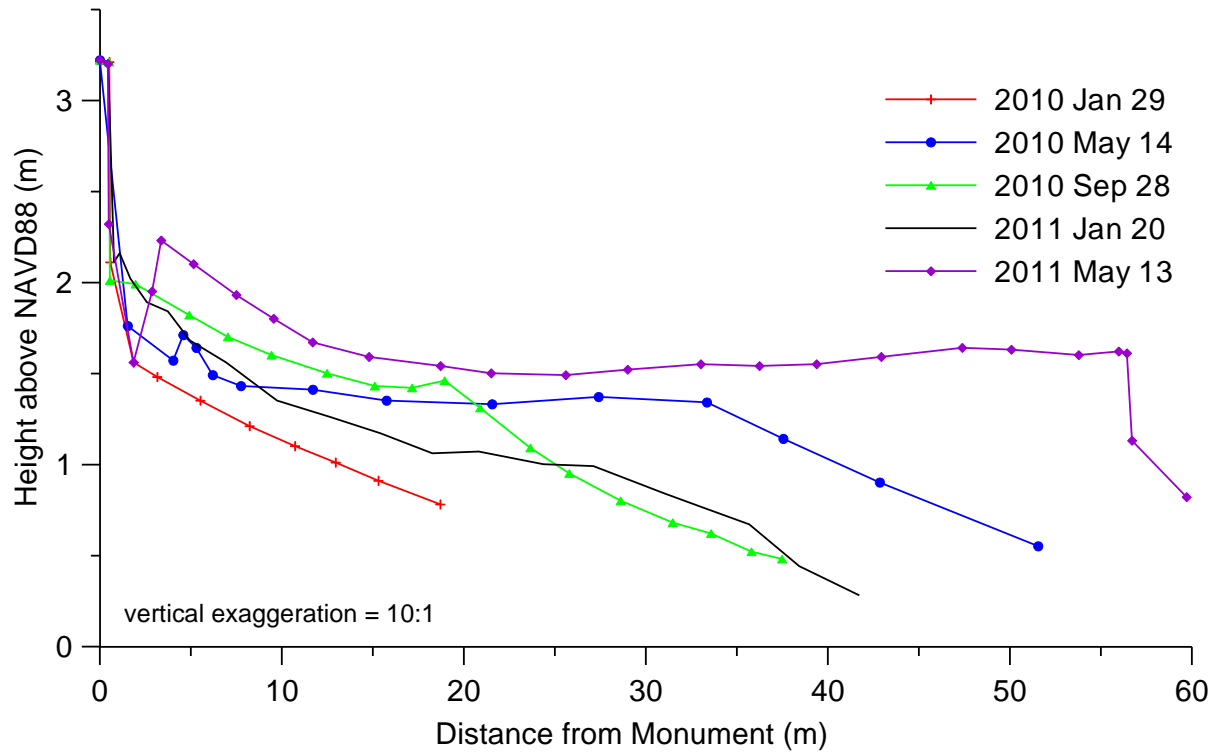
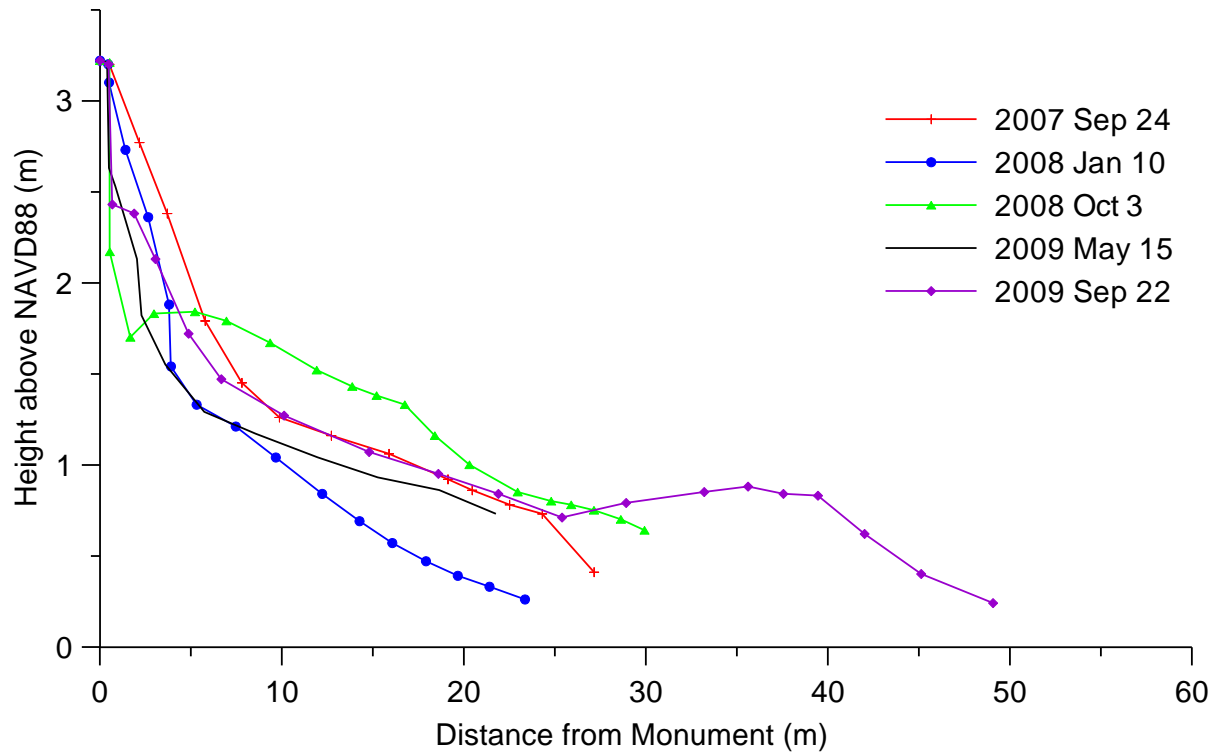


NPI08 (North Padre Island)

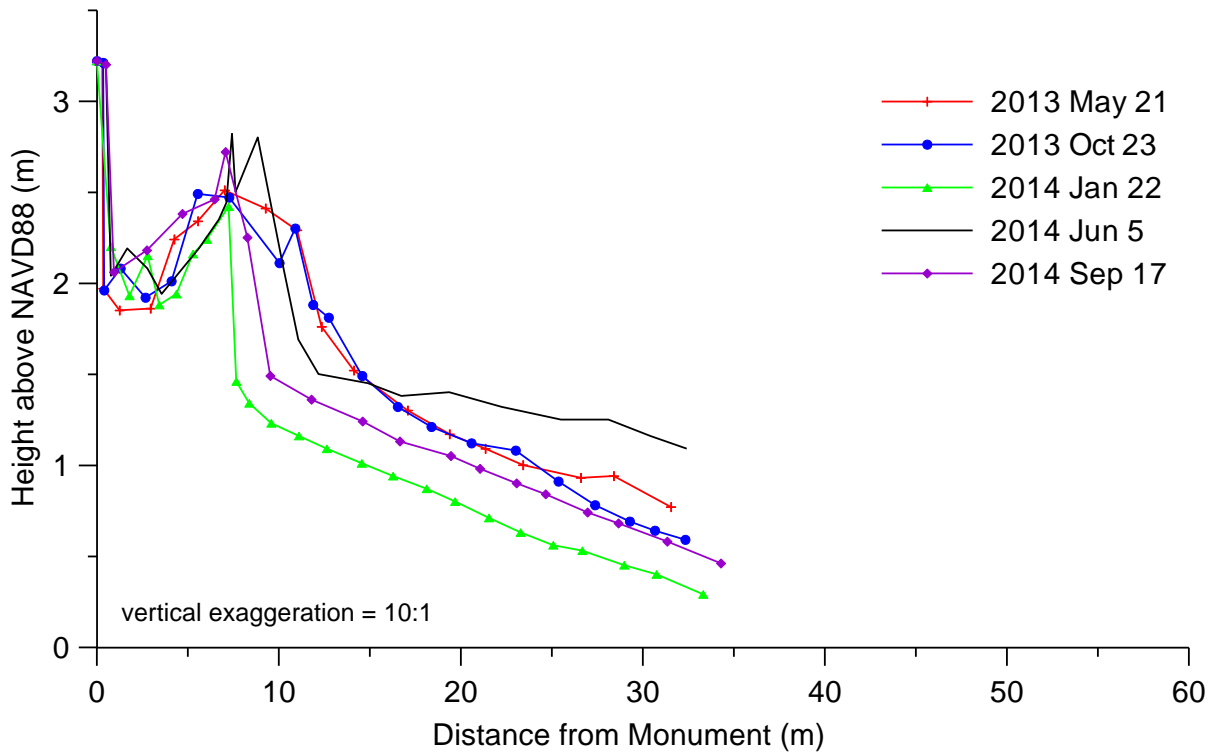
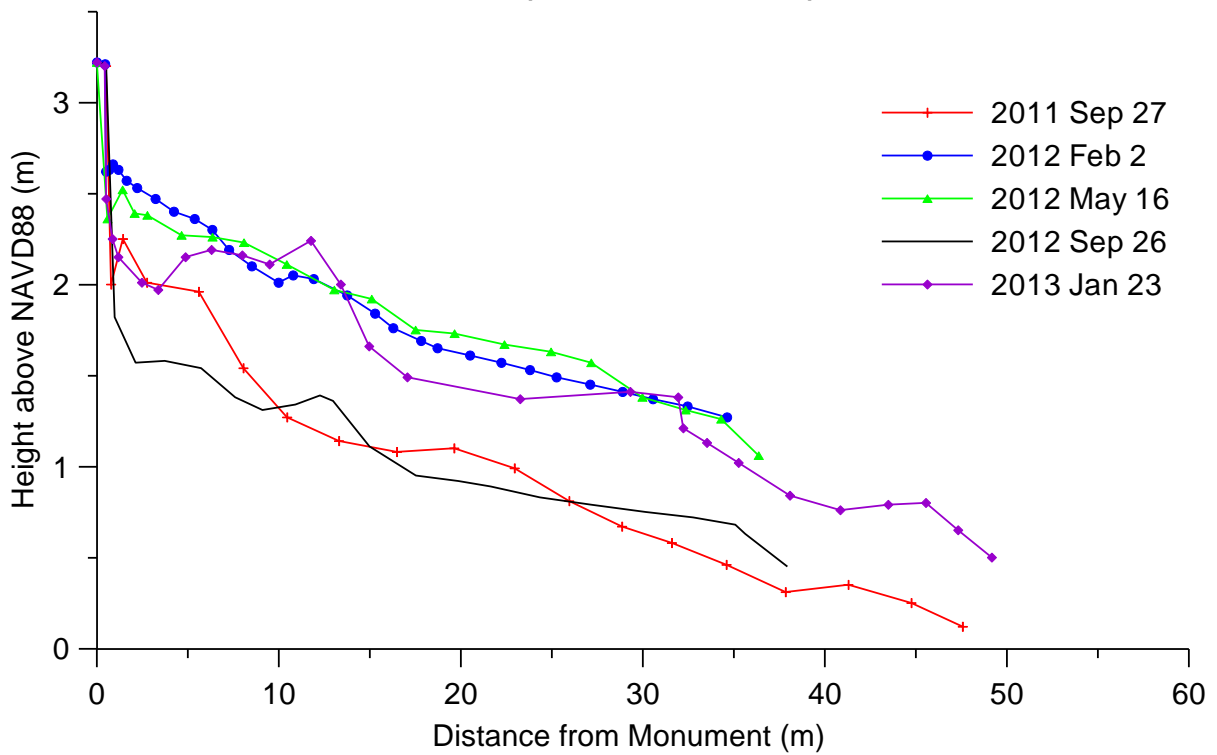


SPI08

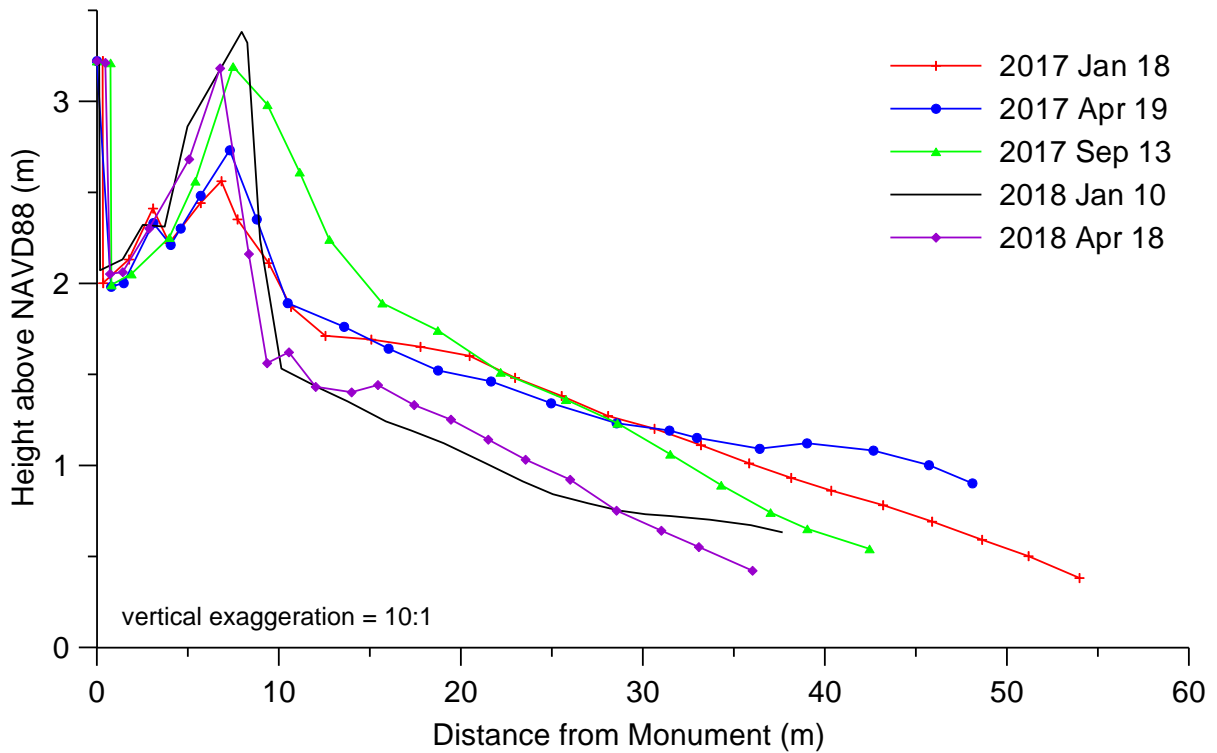
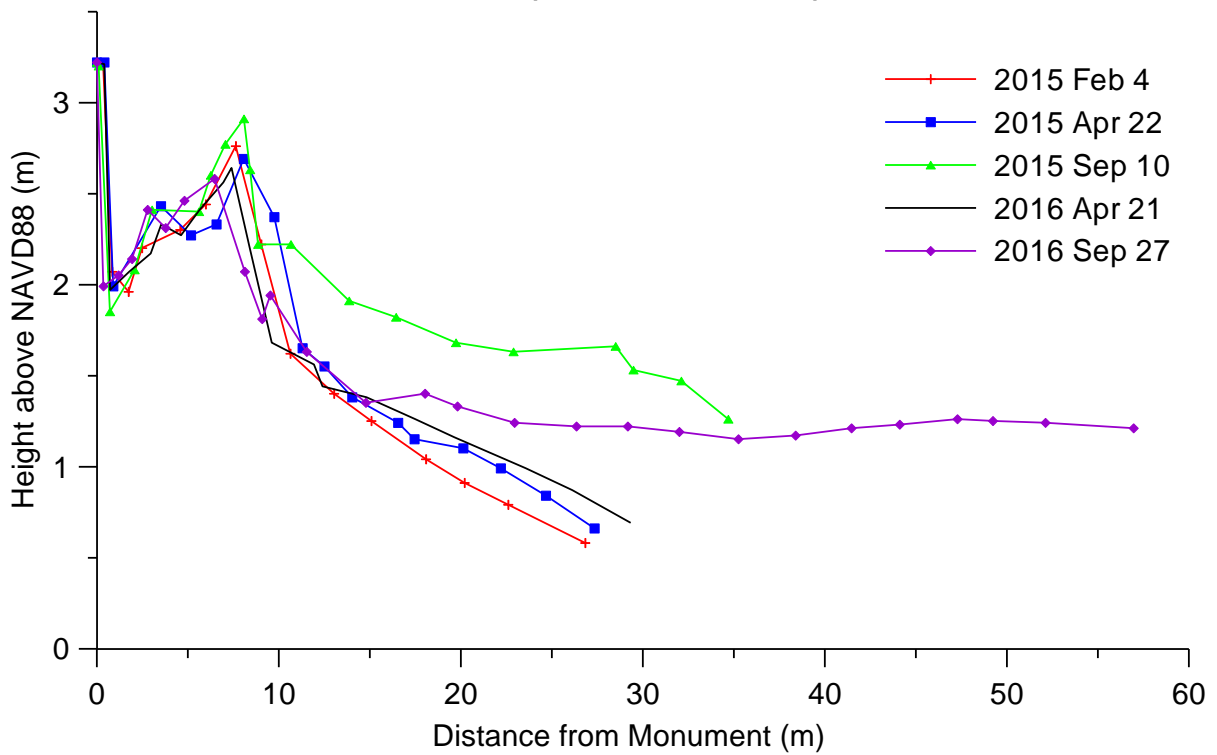
SPI08 (South Padre Island)

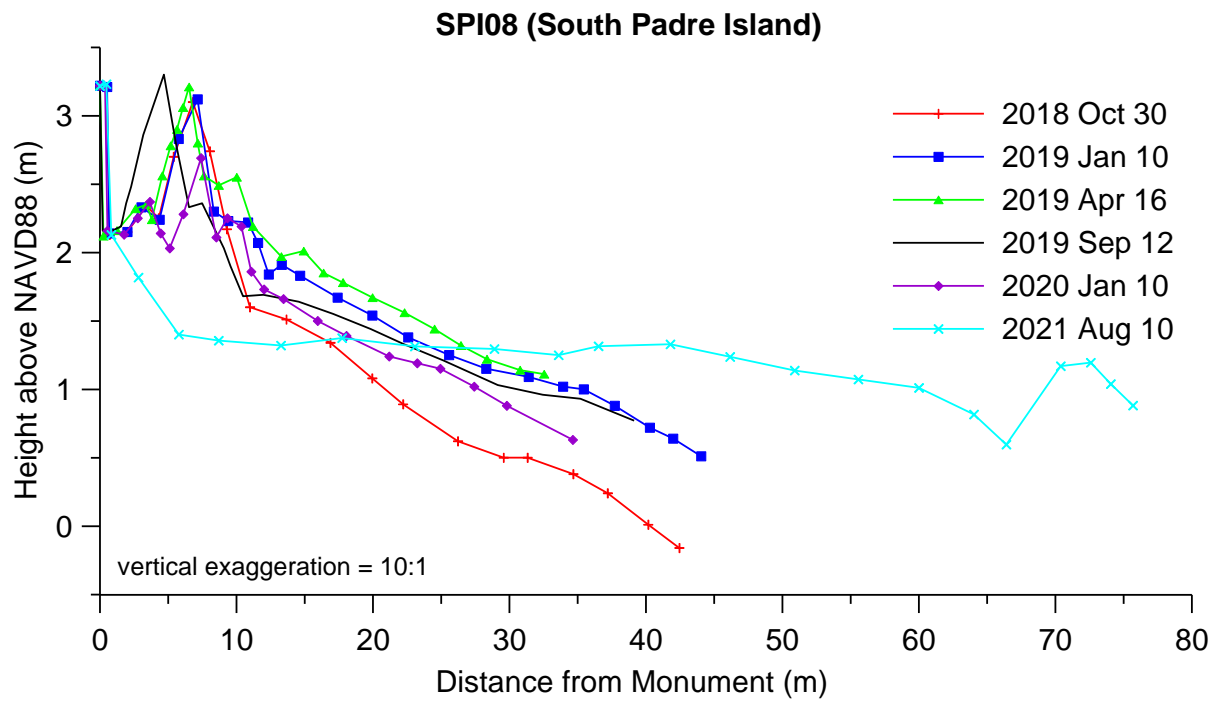


SPI08 (South Padre Island)



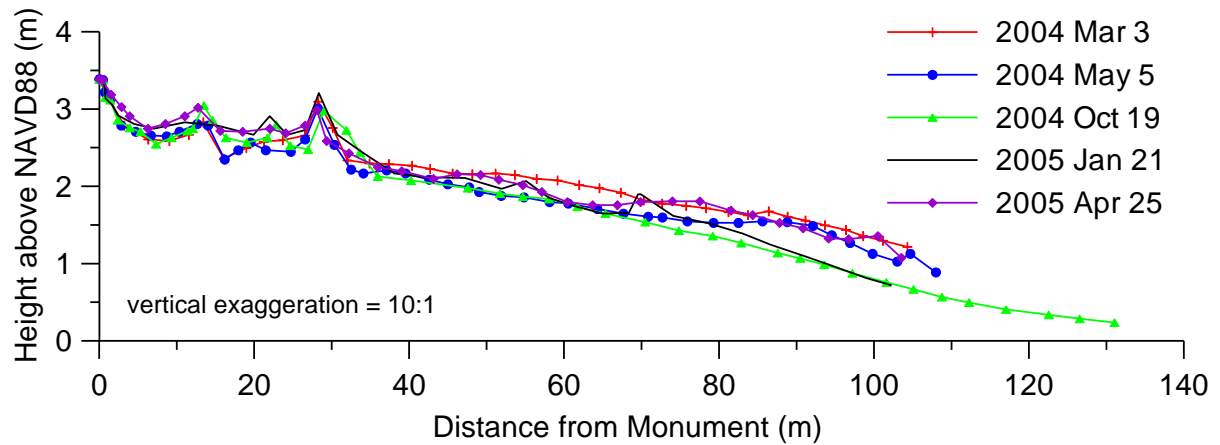
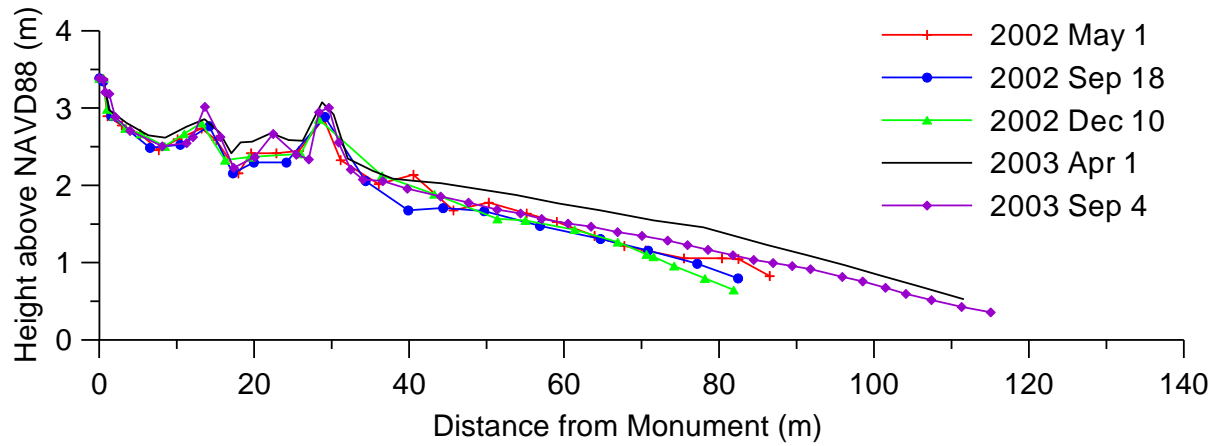
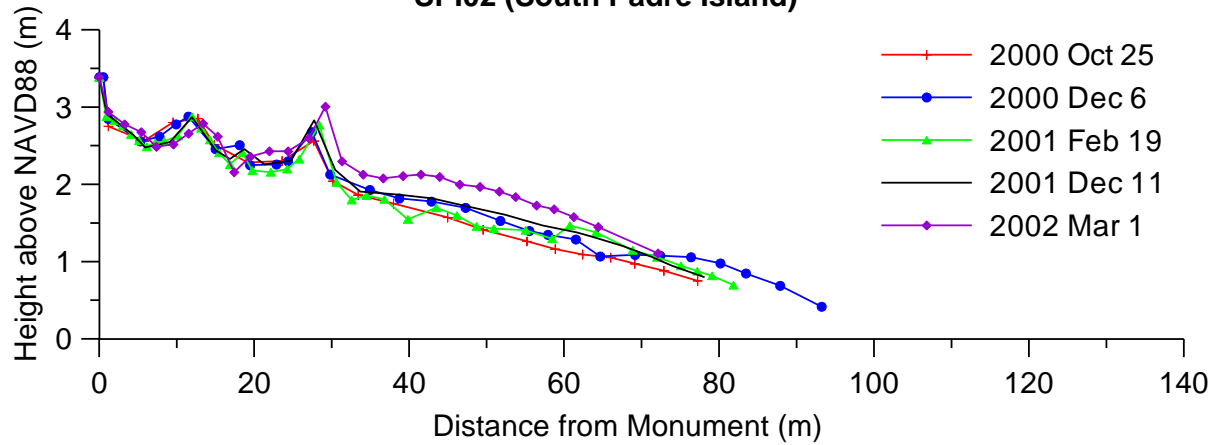
SPI08 (South Padre Island)

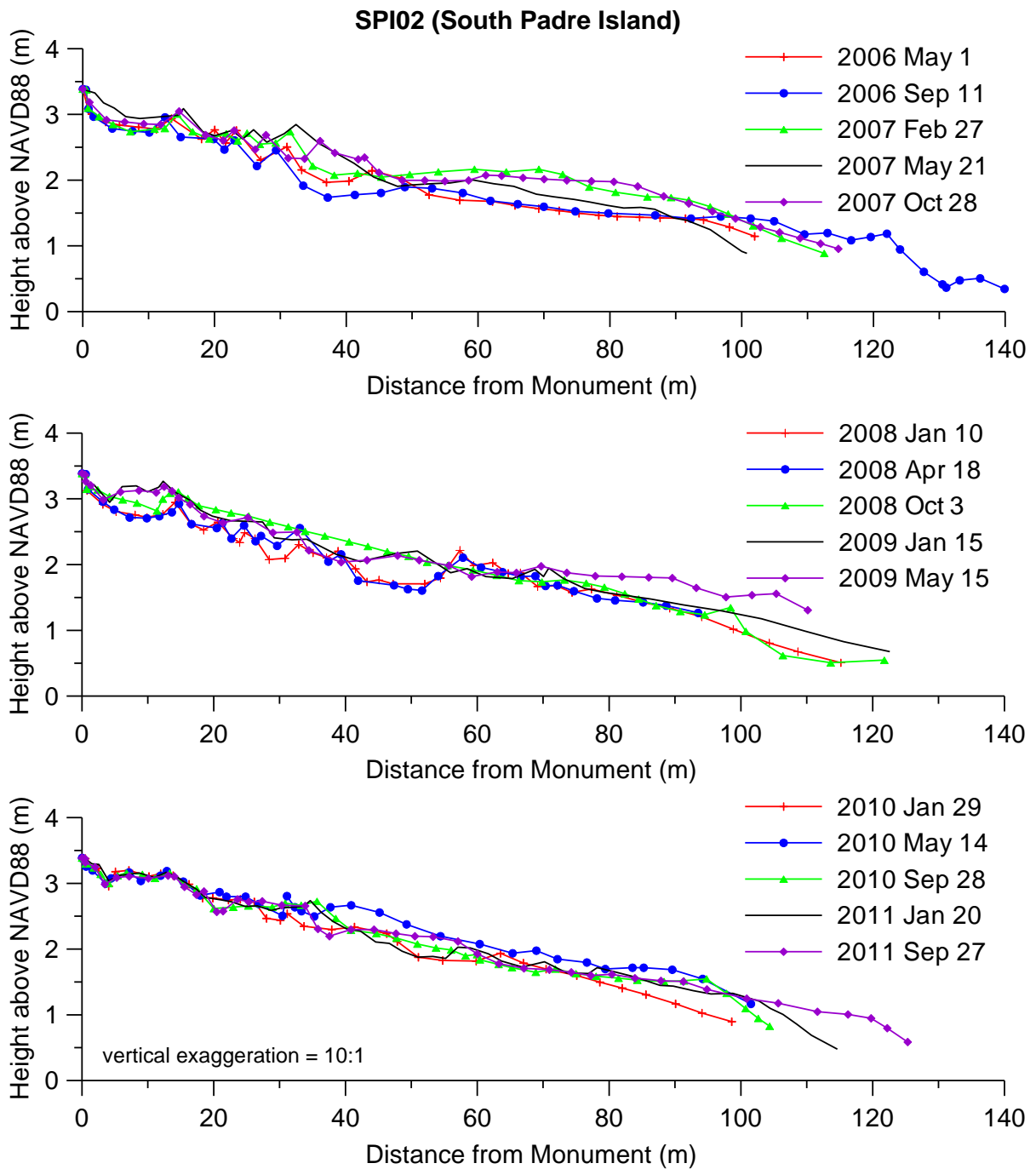


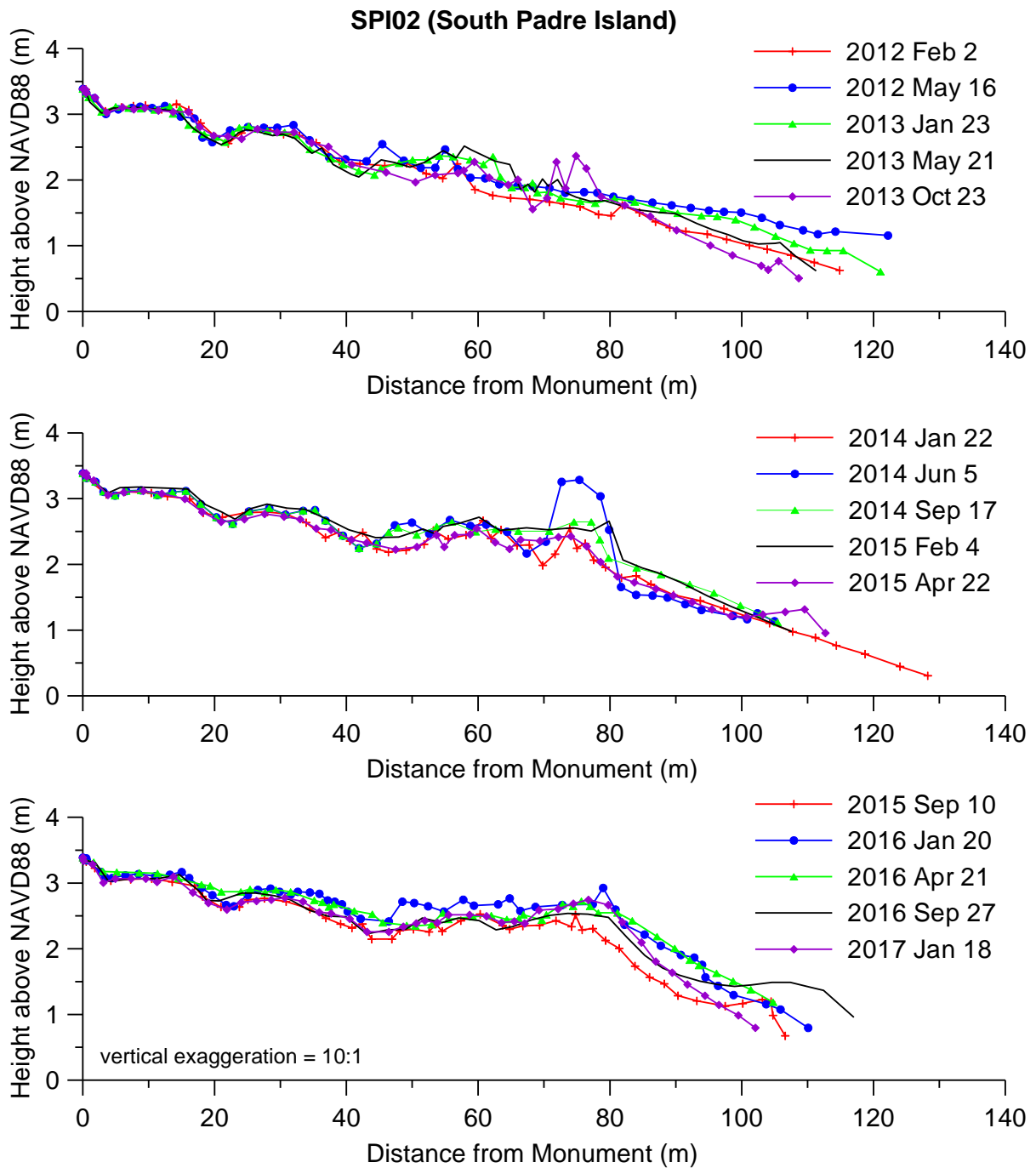


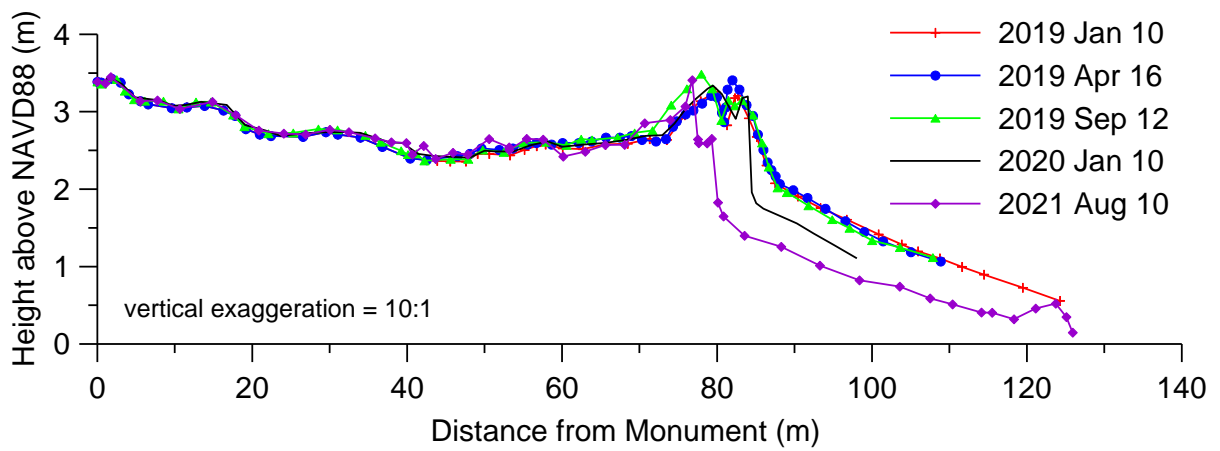
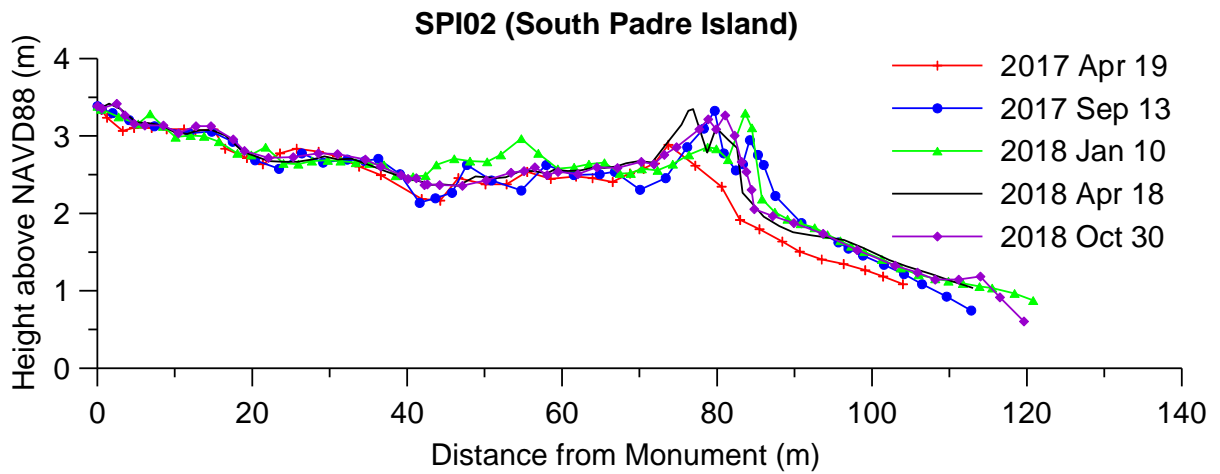
SPI02

SPI02 (South Padre Island)

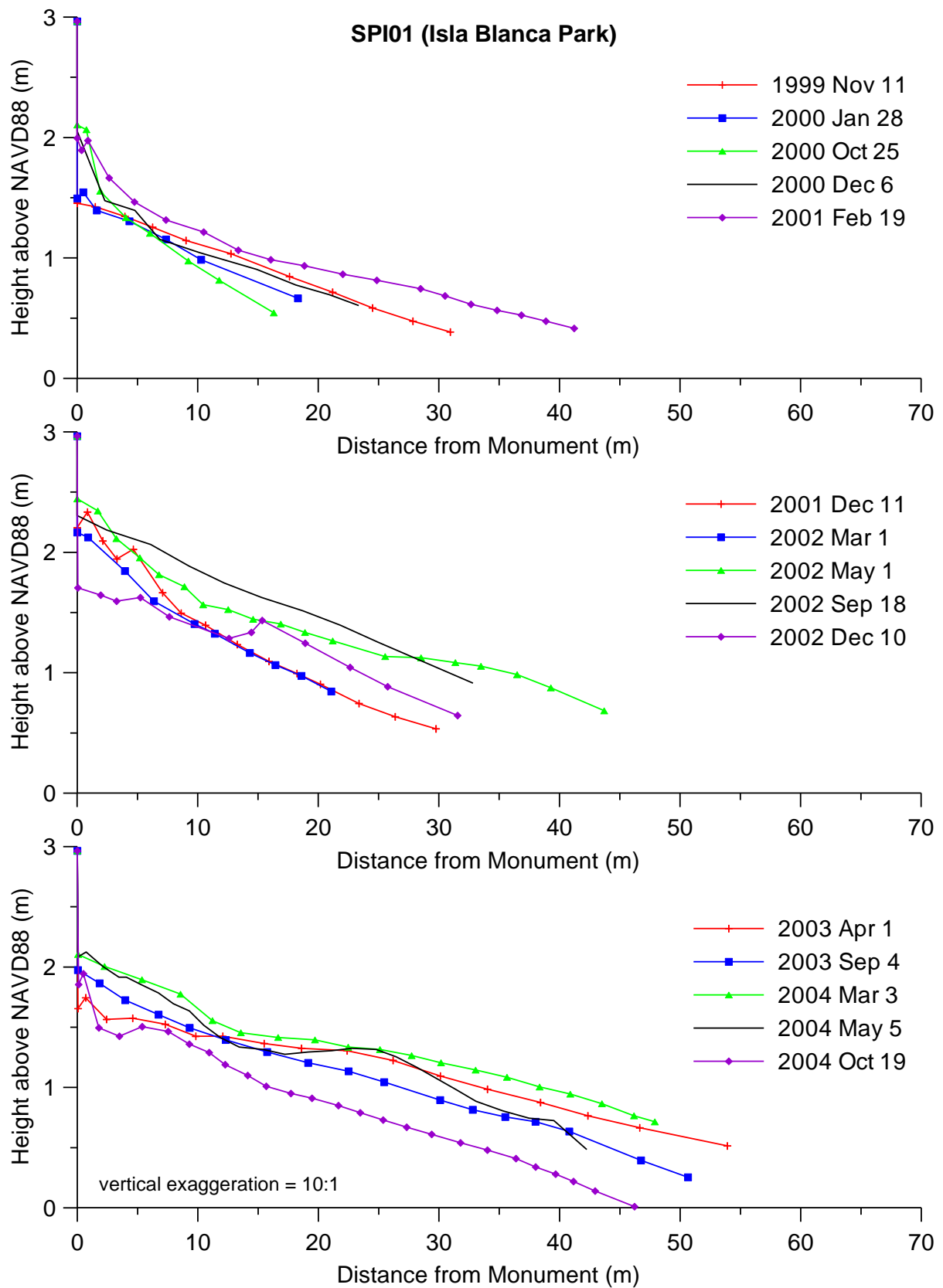


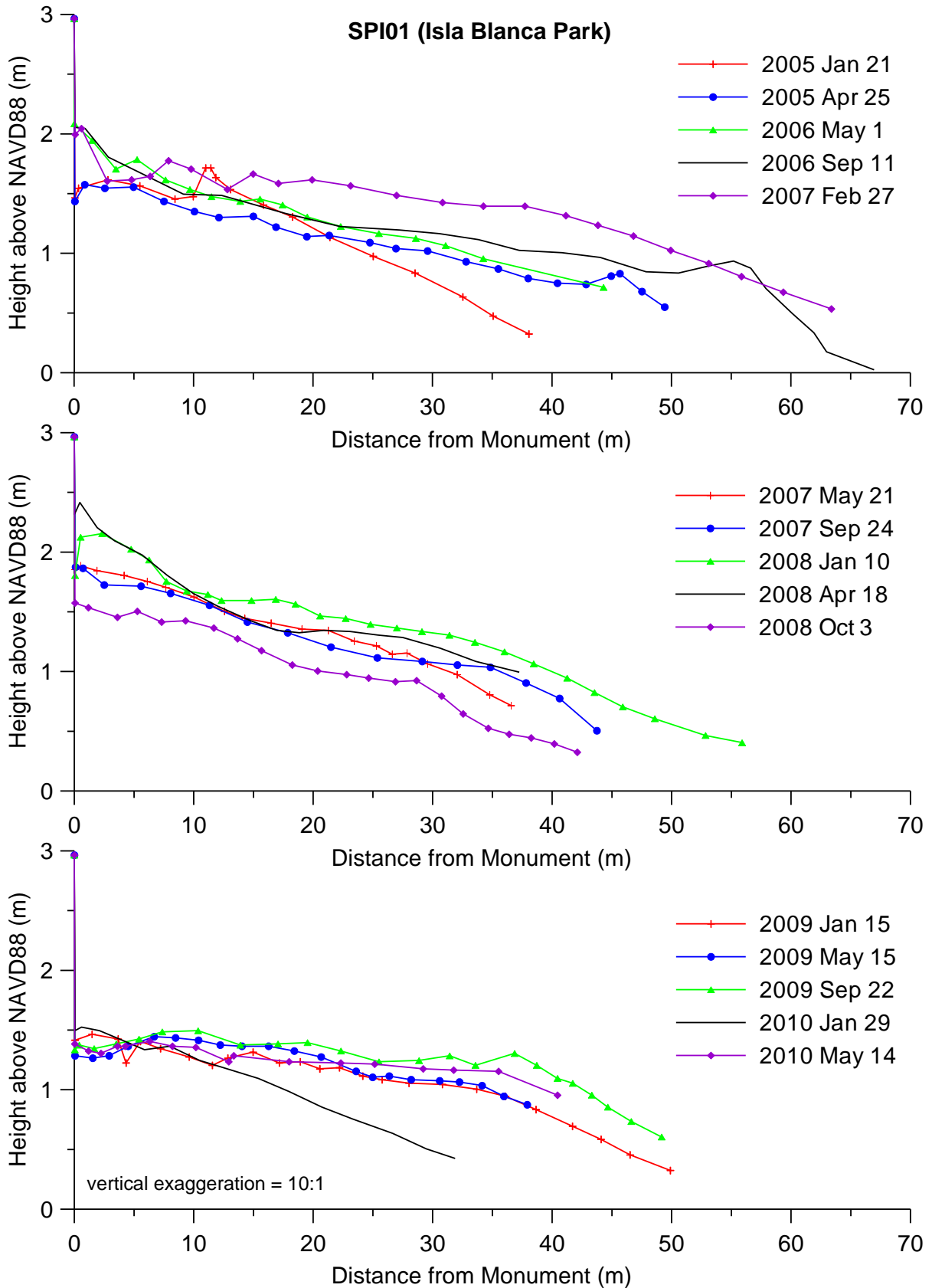


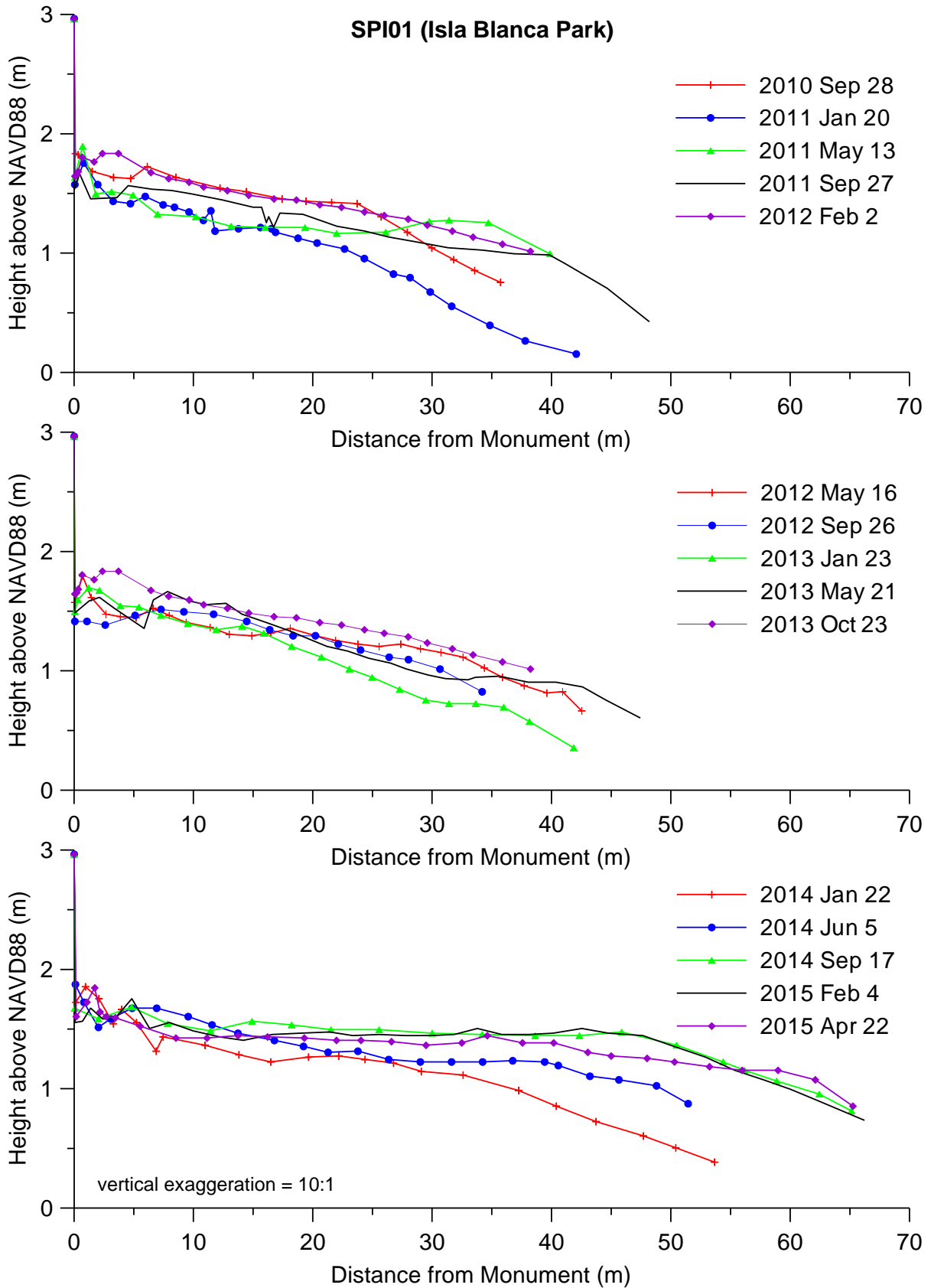


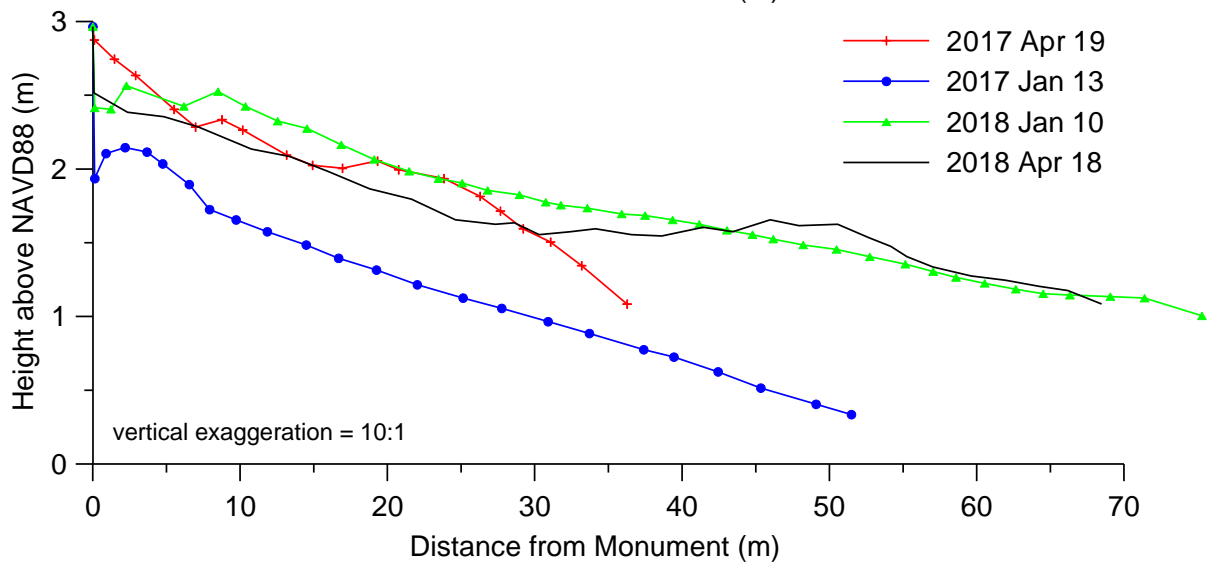
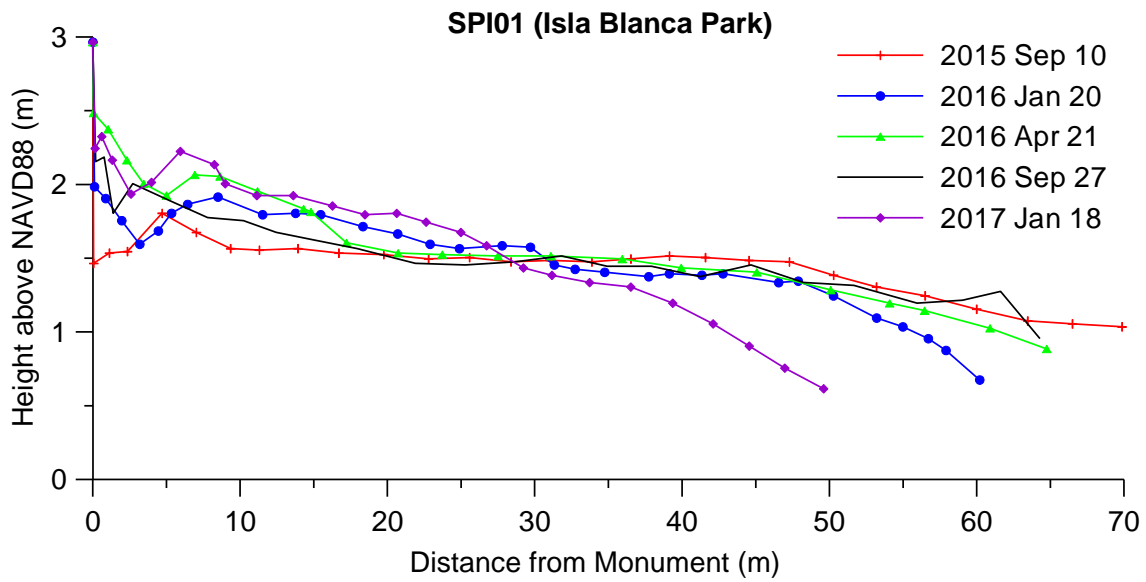


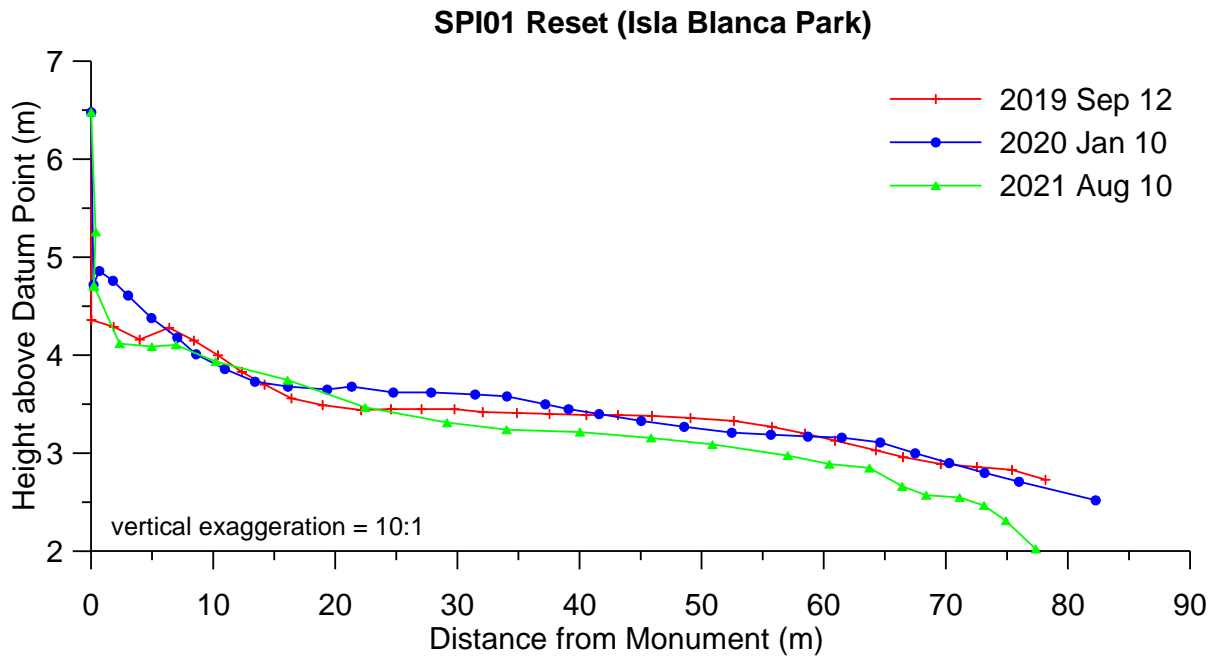
SPI01











APPENDIX D: MAPS OF GPS SHORELINE AND VEGETATION LINE POSITIONS

