# COASTAL VULNERABILITY ASSESSMENT OF CUMBERLAND ISLAND NATIONAL SEASHORE (CUIS)TO SEA-LEVEL RISE

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See the National Park Unit Coastal Vulnerability study at
http://woodshole.er.usgs.gov/project-pages/nps-cvi/,
the National Coastal Vulnerability study at http://woodshole.er.usgs.gov/project-pages/cvi/,
or view the USGS online fact sheet for this project in PDF format at
http://pubs.usgs.gov/fs/fs095-02/.
To visit Cumberland Island National Seashore go to http://www.nps.gov/cuis/index.htm.

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## ABSTRACT

A coastal vulnerability index (CVI) was used to map the relative vulnerability of the coast to future sea-level rise within Cumberland Island National Seashore in Georgia. The CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: geomorphology, regional coastal slope, rate of relative sea-level rise, historical shoreline change rates, mean tidal range and mean significant wave height. The rankings for each input variable were combined and an index value calculated for 1-minute grid cells covering the park. The CVI highlights those regions where the physical effects of sea-level rise might be the greatest. This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural vulnerability to the effects of sea-level rise. The CVI provides an objective technique for evaluation and long-term planning by scientists and park managers. Cumberland Island National Seashore consists of stable to washover-dominated portions of barrier beach backed by wetland, marsh, mudflat and tidal creek. The areas within Cumberland that are likely to be most vulnerable to sea-level rise are those with the lowest foredune ridge and highest rates of shoreline erosion.

## INTRODUCTION

The National Park Service (NPS) is responsible for managing nearly 12,000 km (7,500 miles) of shoreline along oceans and lakes. In 2001, the U.S. Geological Survey (USGS), in partnership with the NPS Geologic Resources Division, began conducting hazard assessments of future sea-level change by creating maps to assist NPS in managing its valuable coastal resources. This report presents the results of a vulnerability assessment for Cumberland Island National Seashore, highlighting areas that are likely to be most affected by future sea-level rise.

Global sea level has risen approximately 18 centimeters (7.1 inches) in the past century (Douglas, 1997). Climate models predict an additional rise of 48 cm (18.9 in.) by 2100 (IPCC, 2002), which is more than double the rate of rise for the 20th century. Potential coastal impacts of sea-level rise include shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources as well as infrastructure. Predicted accelerated global sea-level rise has generated a need in coastal geology to determine the likely response of a coastline to sea-level rise. However, an accurate and quantitative approach to predicting coastal change is difficult to establish. Even the kinds of data necessary to predict shoreline response are the subject of scientific debate. A number of predictive approaches have been proposed (National Research Council, 1990 and 1995), including: 1) extrapolation of historical data (e.g., coastal erosion rates), 2) static inundation modeling, 3) application of a simple geometric model (e.g., the Bruun Rule), 4) application of a sediment dynamics/budget model, or 5) Monte Carlo (probabilistic) simulation based on parameterized physical forcing variables. However, each of these approaches has inadequacies or can be invalid for certain applications (National Research Council, 1990). Additionally, shoreline response to sea-level change is further complicated by human modification of the natural coast such as beach nourishment projects, and engineered structures such as seawalls, revetments, groins, and jetties. Understanding how a natural or modified coast will respond to sea-level change is essential to preserving vulnerable coastal resources.

The primary challenge in predicting shoreline response to sea-level rise is quantifying the important variables that contribute to coastal evolution in a given area. In order to address the multi-faceted task of predicting sea-level rise impact, the USGS has implemented a methodology to identify areas that may be most vulnerable to future sea-level rise. (See Hammar-Klose and Thieler, 2001.) This technique uses different ranges of vulnerability (low to very high) to describe a coast's susceptibility to physical change as sea level rises. The vulnerability index determined here focuses on six variables that strongly influence coastal evolution:

1) Geomorphology
2) Historical shoreline change rate
3) Regional coastal slope
4) Relative sea-level change
5) Mean significant wave height
6) Mean tidal range

These variables can be divided into two groups: 1) geologic variables and 2) physical process variables. The geologic variables are geomorphology, historic shoreline change rate, and coastal slope; they account for a shoreline's relative resistance to erosion, long-term erosion/accretion trend, and its susceptibility to flooding, respectively. The physical process variables include significant wave height, tidal range, and sea-level change, all of which contribute to the inundation hazards of a particular section of coastline over time scales from hours to centuries. A relatively simple vulnerability ranking system (Table 1) allows the six variables to be incorporated into an equation that produces a coastal vulnerability index (CVI). The CVI can be used by scientists and park managers to evaluate the likelihood that physical change may occur along a shoreline as sea level continues to rise. Additionally, NPS staff will be able to incorporate information provided by this vulnerability assessment technique into general management plans.

## DATA RANKING

Table 1 shows the six variables described in the Introduction, which include both quantitative and qualitative information. The five quantitative variables are assigned a vulnerability ranking based on their actual values, whereas the non-numerical geomorphology variable is ranked qualitatively according to the relative resistance of a given landform to erosion. Shorelines with erosion/accretion rates between -1.0 and +1.0 m/yr are ranked as being of moderate vulnerability in terms of that particular variable. Increasingly higher erosion or accretion rates are ranked as correspondingly higher or lower vulnerability. Regional coastal slopes range from very high vulnerability, <0.3 percent, to very low vulnerability at values >1.2 percent. The rate of relative sea-level change is ranked using the modern rate of eustatic rise (1.8 mm/yr) as very low vulnerability. Since this is a global or "background" rate common to all shorelines, the sea-level rise ranking reflects primarily local to regional isostatic or tectonic adjustment. Mean wave height contributions to vulnerability range from very low (<0.55 m) to very high (>1.25 m). Tidal range is ranked such that microtidal (<1 m) coasts are very high vulnerability and macrotidal (>6 m) coasts are very low vulnerability.

## CUMBERLAND ISLAND NATIONAL SEASHORE

The barrier islands of South Carolina, Georgia, and northernmost Florida are wide and short when compared to many other East Coast barriers for two reasons. First, the mean tidal range is greater than 1 meter along the Georgia Bight, which creates a large tidal prism in the backbarrier; therefore inlet spacing is closer in order to accommodate the volume of water exchanged during a tidal cycle (Hayes, 1979). Second, two generations of barrier islands have welded together to make up the present-day Georgia barriers. The core of the barrier islands was formed during the late Pleistocene when sea level was approximately a meter higher than present (Oertel, 1979). The Holocene (modern) portion of the barriers in southern Georgia is thin and generally comprises only the foredunes and shoreface. Along the central portion of Cumberland Island, parts of the Pleistocene barrier are exposed at the shoreface.

Cumberland Island and Little Cumberland Island stretch about 30 km (~ 19 miles) from St. Andrews Sound to the Florida border (Figure 1). Christmas Creek separates Little Cumberland Island from 'big' Cumberland Island to the south. Little Cumberland Island lies within National Park Service legislative boundaries, but it remains privately owned and is not subject to park jurisdiction. Cumberland Island National Seashore has a rich archeological history that began about 4,000 years ago with Native American inhabitants, followed by European explorers, British occupation during the War of 1812, and Civil War fortification. Other major historical influences on the archeology and also the present character of Cumberland Island include the Plantation Era and the Carnegie Estate (for more information on the history of Cumberland Island see: http://koransky.com/Trip/History/CumberlandIslandGA/History.html). In 1972, the park service began acquiring land through purchases and donations. Since the establishment of Cumberland Island National Seashore, the Park Service has tried to preserve the important cultural and natural resources on Cumberland Island. Threats to resource preservation include feral pigs and horses, regional development, and erosion of the backbarrier shore.

## METHODOLOGY

In order to develop a database for a park-wide assessment of coastal vulnerability, data for each of the six variables mentioned above were gathered from state and federal agencies (Table 2). The database is based on that used by Thieler and

Hammar-Klose (1999) and loosely follows an earlier database developed by Gornitz and White (1992). A comparable assessment of the sensitivity of the Canadian coast to sea-level rise is presented by Shaw and others (1998).

The database was constructed using a 1:70,000-scale shoreline for Cumberland Island that was produced from the medium-resolution digital vector U.S. shoreline provided by the Strategic Environmental Assessments Division of NOAA's Office of Ocean Resources Conservation and Assessment (http://spo.nos.noaa.gov/projects/shoreline/shoreline.html). Data for each of the six variables (geomorphology, shoreline change, coastal slope, relative sea-level rise, significant wave height, and tidal range) were added to the shoreline attribute table using a 1-minute (approximately 1.5 km) grid (Figure 2). Next each variable in each grid cell was assigned a vulnerability value from 1-5 (1 is very low vulnerability, 5 is very high vulnerability) based on the potential magnitude of its contribution to physical changes on the coast as sea level rises (Table1).

## GEOLOGIC VARIABLES

The **geomorphology** variable expresses the relative erodibility of different landform types (Table 1). These data were derived from USGS 1-meter resolution digital orthophotos of Cumberland Island (Table 2). In addition, field visits were made within the park to ground-truth the geomorphologic classification. A USGS open-file report (Elko and others, 2002), and Living with the Georgia Shore (Clayton and others, 1992) were also used to help constrain the geomorphologic classification. Areas of Cumberland Island with a discontinuous foredune ridge less than 2 meters in height were classified as very high vulnerability, while areas with a continuous foredune ridge greater than 2 meters were classified as high vulnerability (Figure 3 A_H).

**Shoreline erosion and accretion rates** for Cumberland Island were calculated from data provided by the USGS National Assessment of Coastal Change Hazards project (Table 2). Shoreline rates of change (m/yr) were calculated at 200 m intervals (transects) along the coast using Digital Shoreline Analysis System (DSAS) software (http://woodshole.er.usgs.gov/project-pages/dsas/) to derive the rate of shoreline change. The change rates for each transect within a 1-minute grid cell were averaged to determine the shoreline change value used here, with positive numbers indicating accretion and negative numbers indicating erosion. Shoreline change rates on Cumberland Island range from greater than 2 m/yr of accretion (very low vulnerability) to almost 2 m/yr of erosion (high vulnerability) (Figure 4 A-E).

The determination of **regional coastal slope** is an indication of the relative vulnerability to inundation and the potential rapidity of shoreline retreat because low-sloping coastal regions should retreat faster than steeper regions (Pilkey and Davis, 1987). The regional slope of the coastal zone was calculated from a grid of topographic and bathymetric elevations extending 10 km landward and seaward of the shoreline. Elevation data were obtained from the National Geophysical Data Center (NGDC) as gridded topographic and bathymetric elevations at 0.1 meter vertical resolution for 3 arc-second (~90 m) grid cells. Regional coastal slopes for Cumberland fall within the high vulnerability category (0.3 - 0.6 % slope).

## PHYSICAL PROCESS VARIABLES

The **relative sea-level change** variable is derived from the change in annual mean water elevation over time as measured at tide gauge stations along the coast. The rate of sea-level rise for Fernandina Beach in FL is 2.04 +/- 0.12 mm/yr based on 103 years of data (Zervas, 2001). This variable inherently includes both eustatic sea-level rise as well as regional sea-level rise due to isostatic and tectonic adjustments of the land surface. Relative sea-level change data are a historical record, and thus portray only the recent sea-level trend (< 150 years). Relative sea-level rise for Cumberland Island falls within low vulnerability based on water elevation data at Fernandina Beach in Florida.

**Mean significant wave height** is used here as a proxy for wave energy which drives coastal sediment transport. Wave energy is directly related to the square of wave height:

$$E = 1/8\ \rho g H^2$$

where *E* is energy density, *H* is wave height, ρ is water density and *g* is acceleration due to gravity. Thus, the ability to mobilize and transport coastal sediments is a function of wave height squared. In this report, we use hindcast nearshore mean significant wave height data for the period 1976-95 obtained from the U.S. Army Corps of Engineers Wave Information Study (WIS). (See references in Hubertz and others, 1996.) The model wave heights were compared to historical measured wave height data obtained from the NOAA National Data Buoy Center to ensure that model values were representative of the study area. For Cumberland Island, mean significant wave heights are between 1.0 and 1.1 m, which represents moderate and high vulnerability, respectively.

**Tidal range** is linked to both permanent and episodic inundation hazards. Tide range data were obtained from NOAA/NOS for tide gauges at Jekyll Point and the north jetty at St. Mary's entrance. Cumberland Island is classified as moderate (2.0 - 4.0 meters) with respect to tidal range.

## CALCULATING THE VULNERABILITY INDEX

The coastal vulnerability index (CVI) presented here is the same as that used in Thieler and Hammar-Klose (1999) and is similar to that used in Gornitz and others (1994), as well as to the sensitivity index employed by Shaw and others (1998). The CVI allows the six variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise. This method yields numerical data that cannot be equated directly with particular physical effects. It does, however, highlight areas where the various effects of sea-level rise may be the greatest. Once each section of coastline is assigned a vulnerability value for each specific data variable, the coastal vulnerability index (CVI) is calculated as the square root of the product of the ranked variables divided by the total number of variables;

$$\text{CVI} = \sqrt{\frac{(a*b*c*d*e*f)}{6}}$$

where, a = geomorphology, b = shoreline erosion/accretion rate, c = coastal slope, d =relative sea-level rise rate, e = mean significant wave height, and f = mean tide range. The calculated CVI value is then divided into quartile ranges to highlight different vulnerabilities within the park. The CVI ranges (low - very high) reported here apply specifically to Cumberland Island National Seashore, and are not comparable to CVI ranges in other parks where the CVI has been employed (i.e. while very high vulnerablity has the same meaning among parks; it is the numeric values that differ, such that a numeric value that equals very high vulnerability in one park may equal moderate vulnerability in another). To compare vulnerability between coastal parks, the national-scale studies should be used (Thieler and Hammar-Klose, 1999, 2000a, and 2000b). We feel this approach best describes and highlights the vulnerability specific to each park.

## RESULTS

The CVI values calculated for Cumberland Island range from 7.75 to 17.89. The mean CVI value is12.66; the mode is 16.00 and the median is 13.06. The standard deviation is 3.27 . The 25th, 50th, and 75th percentiles are 9.0, 13.0 and 15.5, respectively.

Figure 5 shows a map of the coastal vulnerability index for Cumberland Island National Seashore. The CVI scores are divided into low, moderate, high, and very high-vulnerability categories based on the quartile ranges and visual inspection of the data. CVI values below 9.0 are assigned to the low vulnerability category. Values from 9.0 to 13.0 are considered moderate vulnerability. High-vulnerability values lie between 13.01 and 15.5. CVI values above 15.5 are classified as very high vulnerability. Figure 6 shows the percentage of Cumberland Island shoreline in each vulnerability category. Nearly 30 km (19 miles) of shoreline is evaluated along the national seashore. Of this total, twenty-two percent of the mapped shoreline is classified as being at very high vulnerability due to future sea-level rise. Twenty-eight percent is classified as high vulnerability, twenty-eight percent as moderate vulnerability, and twenty-two percent as low vulnerability.

## DISCUSSION

The data within the coastal vulnerability index (CVI) show variability at different spatial scales (Figure 5). However, the ranked values for the physical process variables vary less over the extent of the shoreline. The value of the relative sea-level rise variable is constant at low vulnerability for the entire study area. The significant wave height vulnerability is moderate to high. The tidal range is moderate vulnerability (2.0- 4.0 m) for all of Cumberland.

The geologic variables show the most spatial variability and thus have the most influence on CVI variability (Figure 5). Geomorphology in the park includes high vulnerability barrier island shoreline with continuous dune ridges and very high vulnerability washover-dominated or low discontinuous dune areas. Vulnerability assessment based on historical shoreline change trends varies from very low to high (Figure 4 A-E). Regional coastal slope is in the high vulnerability range over the entire extent of Cumberland Island.

The area along central Cumberland Island that may be most vulnerable to future sea-level rise (high vulnerability) has some of the highest rates of shoreline change on Cumberland Island (Figure 4 C) and high wave heights. Although some of the dunes in this area are the highest on the island, they are also actively migrating inland over maritime forest (Figure 3 C).

The most influential variables in the CVI are geomorphology, historical shoreline change rates, and significant wave height; therefore they may be considered the dominant factors determining how Cumberland Island will evolve as sea level rises. Geomorphology and significant wave height vary only between high and very high and moderate and high vulnerability, respectively; whereas the shoreline change variable ranges from very low to high.

## CONCLUSIONS

The coastal vulnerability index (CVI) provides insight into the relative potential of coastal change due to future sea-level rise. The maps and data presented here can be viewed in at least two ways:

1) as an indication of where physical changes are most likely to occur as sea level continues to rise; and

2) as a planning tool for the Cumberland Island National Seashore.

As ranked in this study, geomorphology, historical rates of shoreline change, and significant wave height and are the most important variables in determining the spatial variability of the CVI for Cumberland Island. Regional coastal slope, tidal range, and sea-level rise rate do not contribute to the spatial variability in the coastal vulnerability index.

Cumberland Island National Seashore preserves a dynamic natural environment, which must be understood in order to be managed properly. The CVI is one way that park managers can assess objectively the natural factors that contribute to the evolution of the coastal zone, and thus how the park may evolve in the future.

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**Figure 1.** Location of Cumberland Island National Seashore, Georgia. For NPS park map see http://www.nps.gov/cuis/pp html/maps. html.

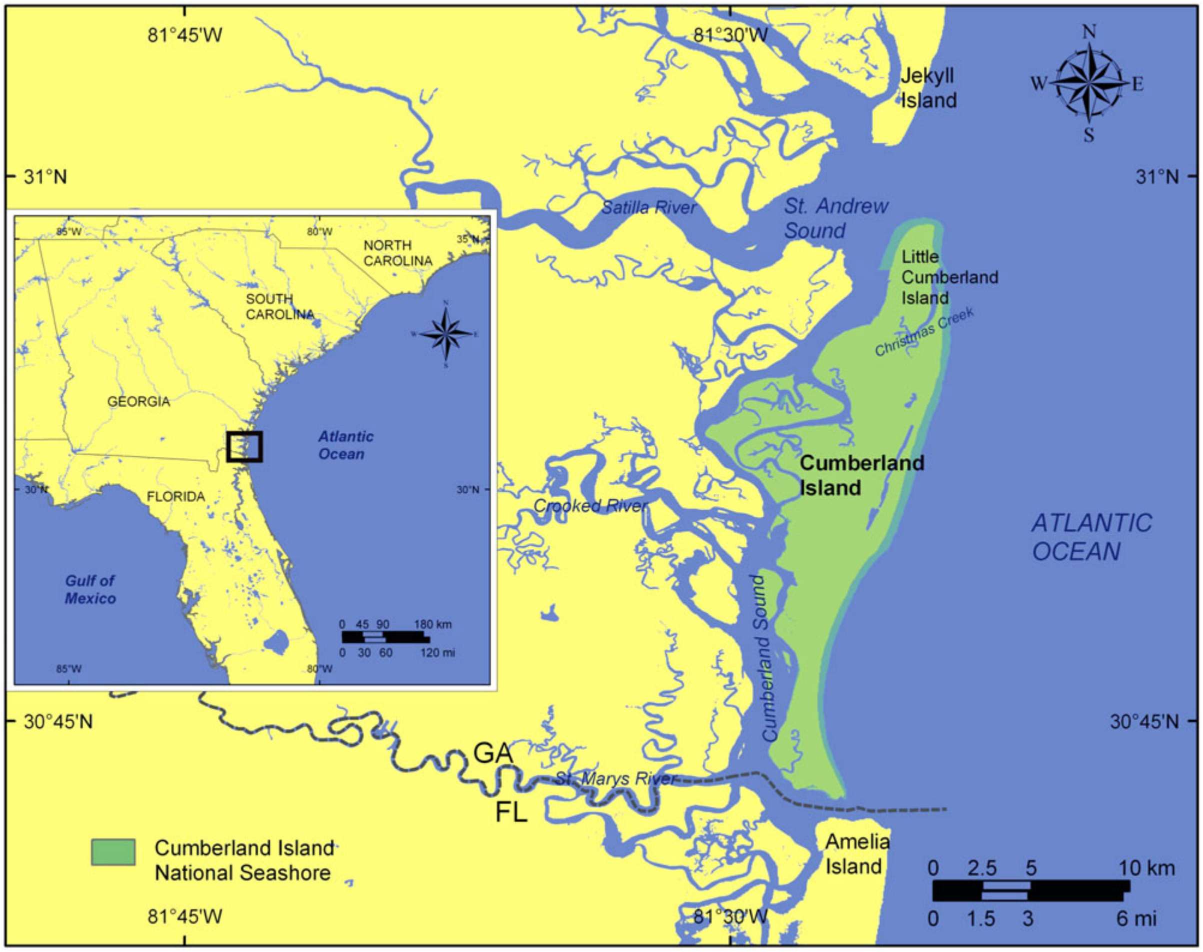


**Figure 2.** Shoreline grid for Cumberland Island National Seashore.

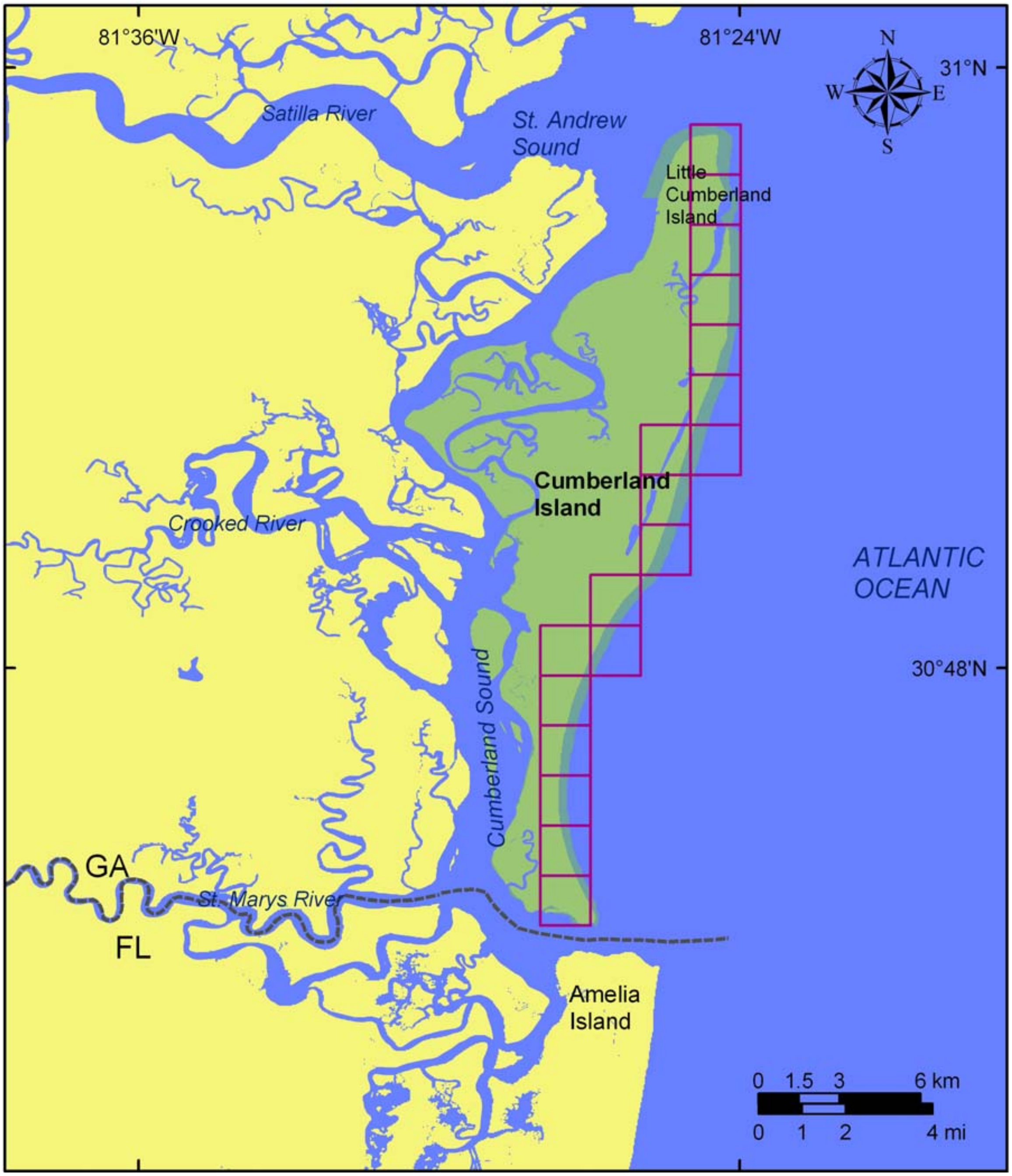


**Figure 3.** The colorbar indicates geomorphology along the ocean shore of Cumberland Island National Seashore. Geomorphology within the red area consists of low discontinuous foredunes (< 2m), while the orange area consists of high or more continuous foredunes (> 2m). A) Photo taken from Long Point looking towards Christmas Creek. The dunes are low and generally coppice mounds near Long Point. B) Low elevation dunes located south of Christmas Creek. C) A location where the height of the foredune ridge changes. The photo is taken looking north from a high dune (> 5m). D) A high elevation foredune ridge that is actively migrating into maritime forest. E) and F) These are low elevation overwash areas where the foredune ridge is low or absent. G) and H) Although the dunes are lower here than at location C and D, they are more stable and continuous. H) The person is 1.8 m tall for scale.

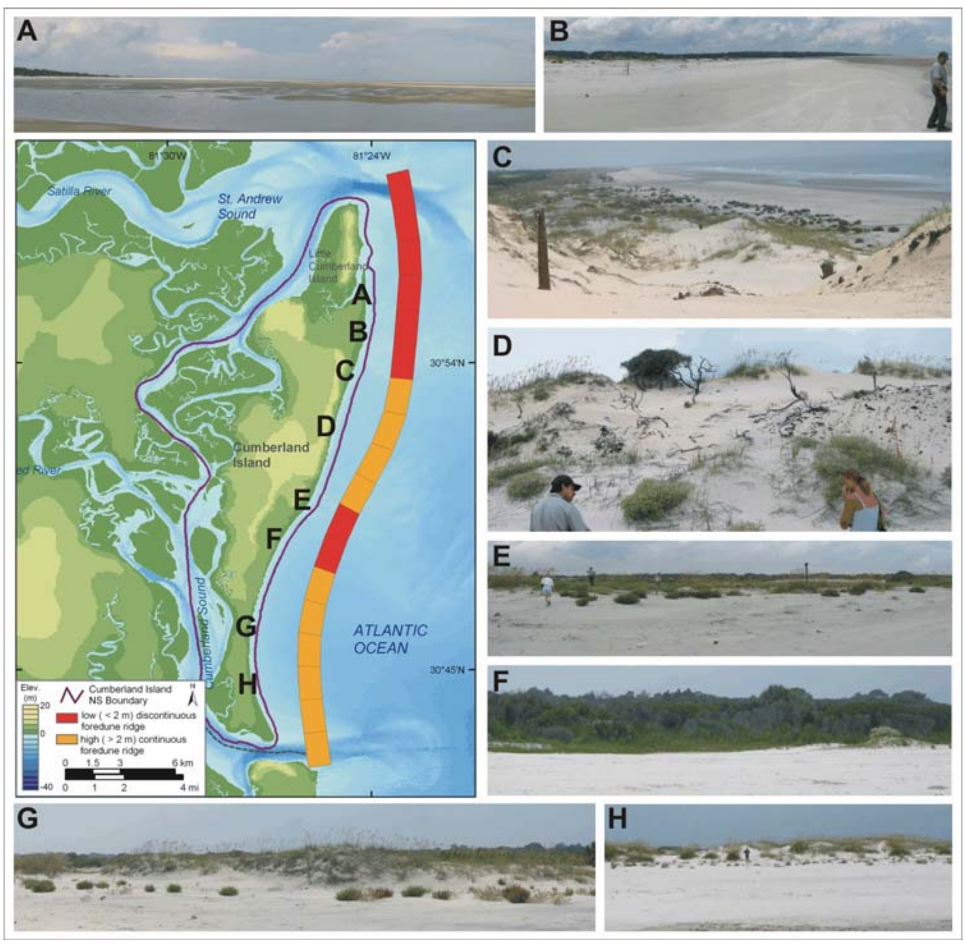


**Figure 4A-E.** Historic shoreline positions for A) Little Cumberland Island, Christmas Creek area, and Long Point B) Lake Whitney and Wilderness Area C) Sweetwater Lake Complex D) Stafford Beach E) Sea Camp Beach to north jetty at St. Marys entrance.

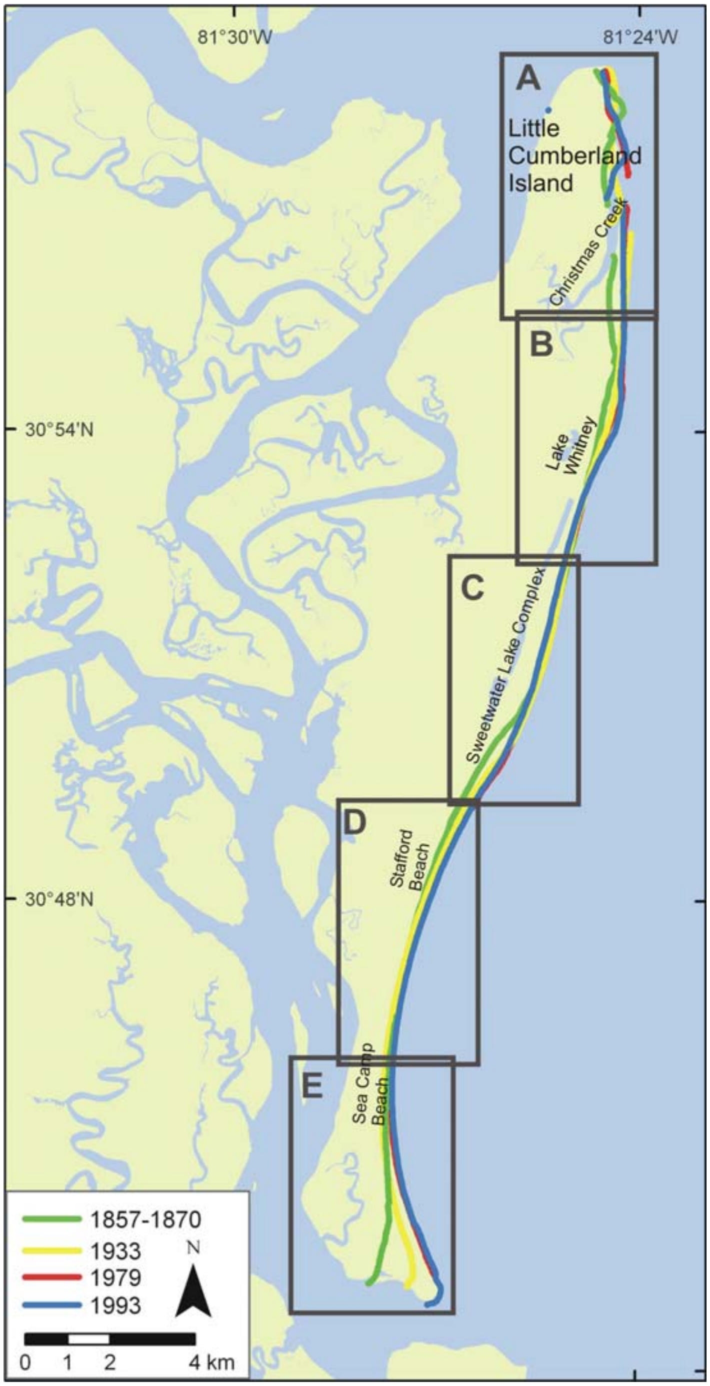


**Figure 4**: Historic Shoreline positions for A) Little Cumberland Island, Christmas Creek area, and Long Point, B) Lake Whitney and Wilderness Area, C) Sweetwater Lake Complex, D) Stafford Beach, E) Sea Camp Beach to north jetty at St. Marys entrance.

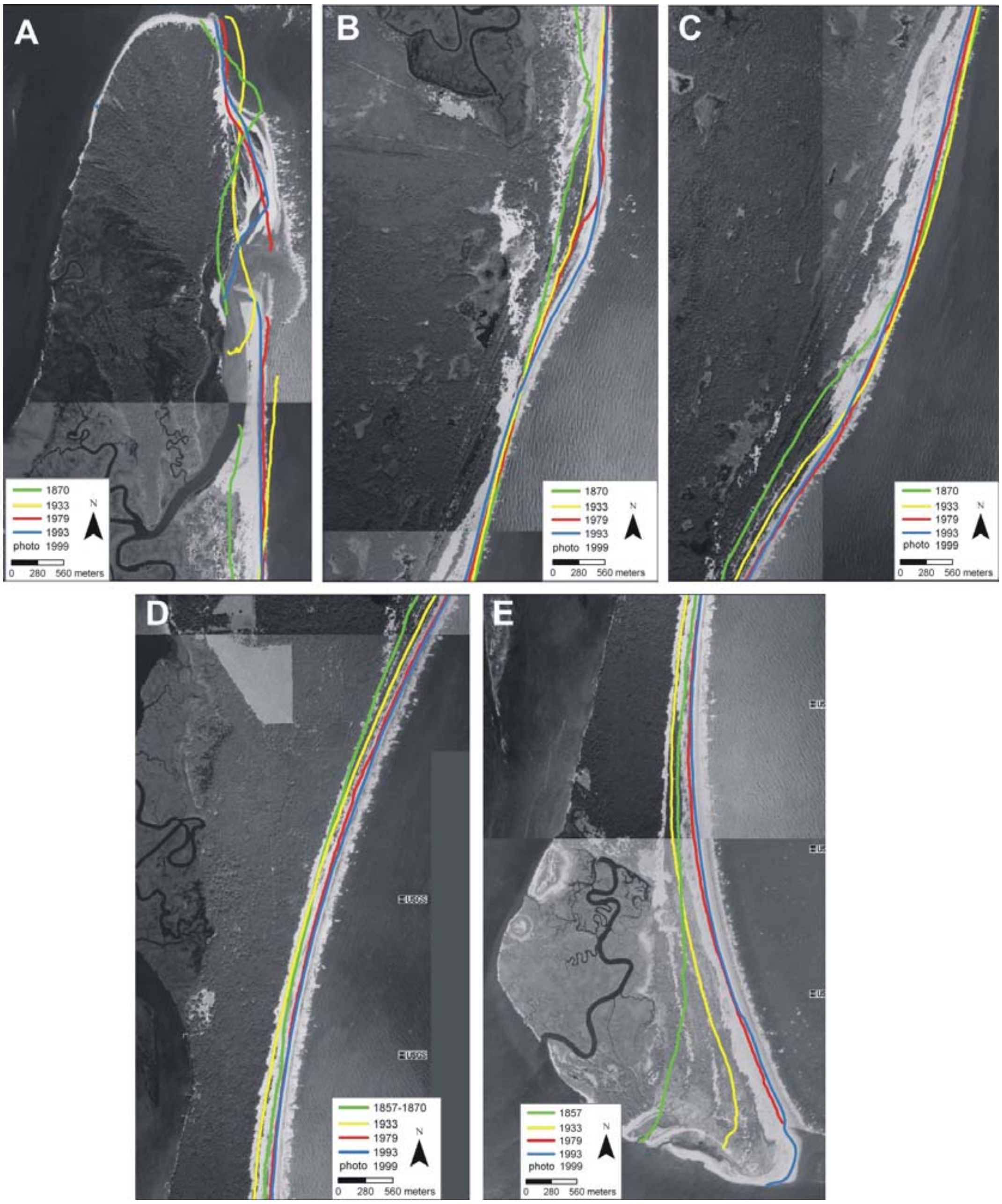


**Figure 5.** Relative Coastal Vulnerability for Cumberland Island National Seashore. The innermost color bar is the relative coastal vulnerability index (CVI). The remaining color bars are separated into the geologic variables (1-3) and physical process variables (4 - 6). The very high vulnerability shoreline is located where rates of shoreline erosion and significant wave heights are highest. The low vulnerability shoreline is located at the southern end of Cumberland Island and near Christmas Creek where shoreline accretion is common.

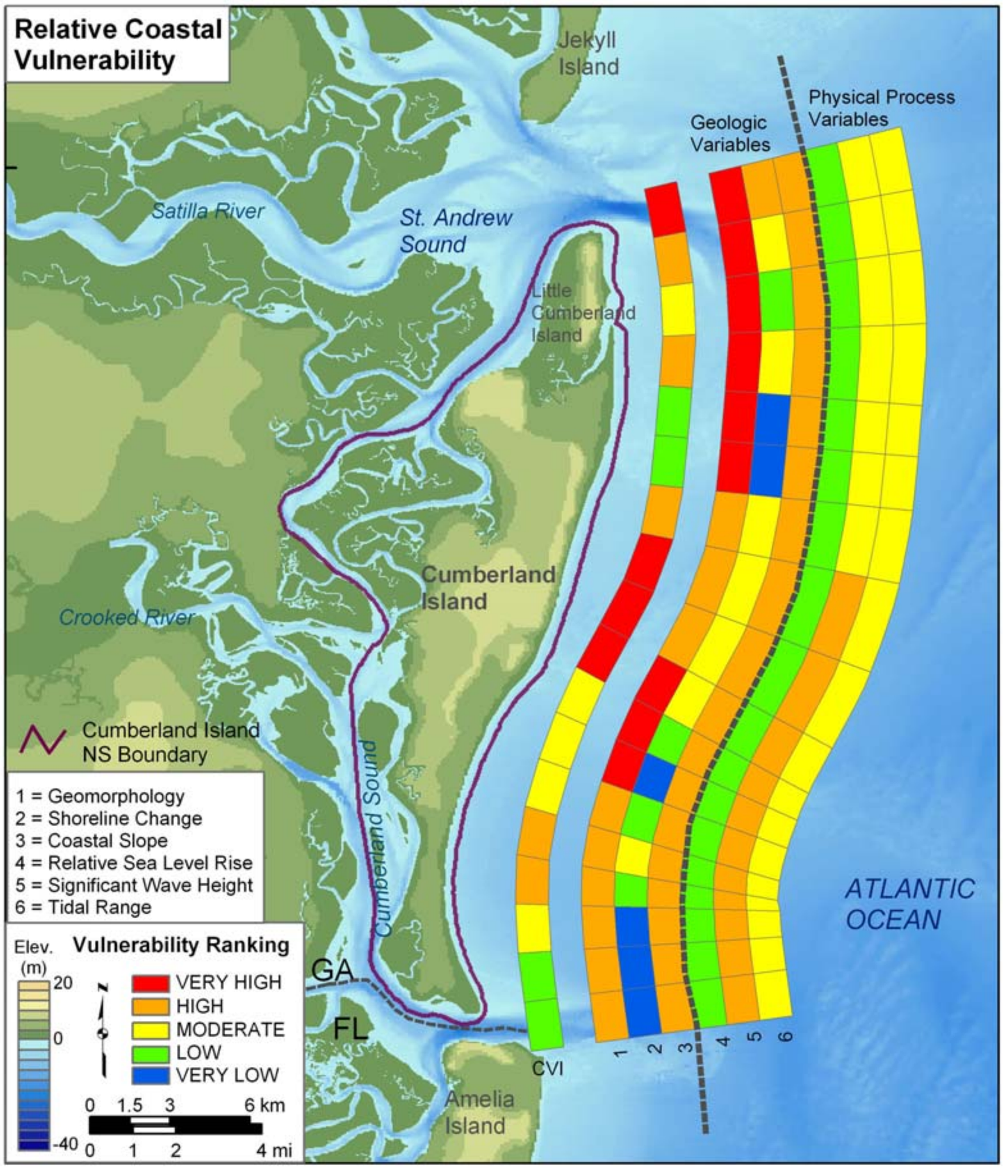
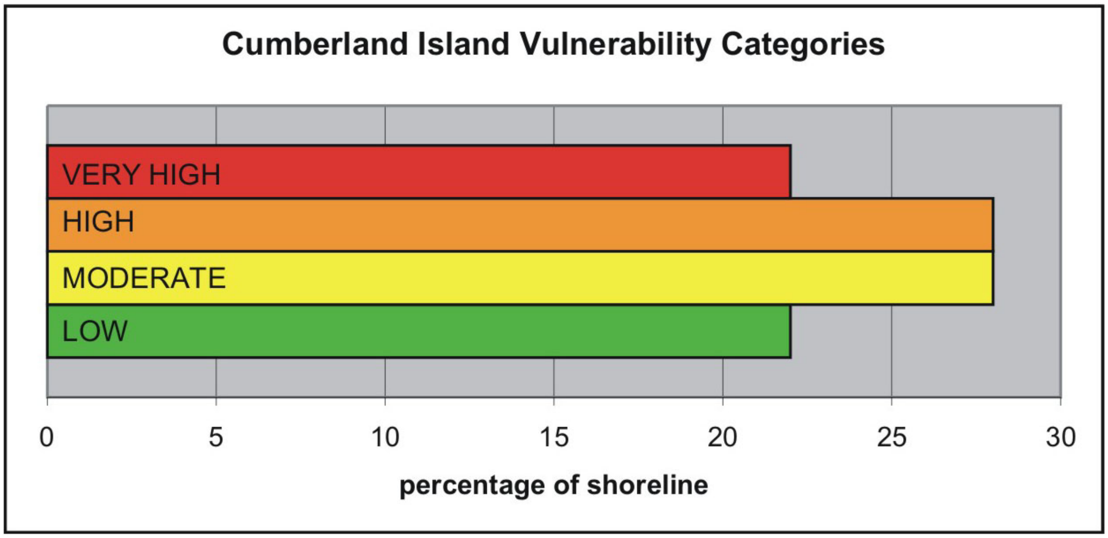


**Figure 6.** Percentage of Cumberland Island shoreline in each CVI category.



| Table 1: Ranges for Vulnerability Ranking of Variables on the US Atlantic Coast. | | | | | |
|---|---|---|---|---|---|
| **Variable** | **Very Low 1** | **Low 2** | **Moderate 3** | **High 4** | **Very High 5** |
| GEOMORPHOLOGY | Rocky cliffed coasts, Fjords | Medium cliffs, Indented coasts | Low cliffs, Glacial drift, Alluvial plains | Cobble Beaches, Estuary, Lagoon | Barrier beaches, Sand beaches, Salt marsh, Mud flats, Deltas, Mangrove, Coral reefs |
| SHORELINE EROSION/ACCRETION (m/yr) | > 2.0 | 1.0 - 2.0 | -1.0 - 1.0 | -2.0 - -1.0 | < -2.0 |
| COASTAL SLOPE (%) | > 1.20 | 1.20 - 0.90 | 0.90 - 0.60 | 0.60 - 0.30 | < 0.30 |
| RELATIVE SEA-LEVEL CHANGE (mm/yr) | < 1.8 | 1.8 - 2.5 | 2.5 - 3.0 | 3.0 - 3.4 | > 3.4 |
| MEAN WAVE HEIGHT (m) | < 0.55 | 0.55 - 0.85 | 0.85 - 1.05 | 1.05 - 1.25 | > 1.25 |
| MEAN TIDE RANGE (m) | > 6.0 | 4.0 - 6.0 | 2.0 - 4.0 | 1.0 - 2.0 | < 1.0 |

| Table 2: Sources of Data | | |
|---|---|---|
| Variables | Source | URL |
| GEOMORPHOLOGY | 1999 USGS Orthophotos (DOQQs) | http://terraserver.microsoft.com/ |
| SHORELINE EROSION/ACCRETION (m/yr) | Georgia coast shoreline data (1857-1993) from the USGS National Assessment of Coastal Change Project | http://coastal.er.usgs.gov/national_assessment/ |
| COASTAL SLOPE (%) | NGDC Coastal Relief Model Vol 02-03 | http://www.ngdc.noaa.gov/mgg/coastal/coastal.html |
| RELATIVE SEA-LEVEL CHANGE (mm/yr) | NOAA Technical Report NOS CO-OPS 36 SEA LEVEL VARIATIONS OF THE UNITED STATES 1854-1999 (Zervas, 2001) | http://www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf |
| MEAN WAVE HEIGHT (m) | North Atlantic Region WIS Data (Phase II) and NOAA National Data Buoy Center | http://chl.erdc.usace.army.mil/ http://seaboard.ndbc.noaa.gov/ |
| MEAN TIDE RANGE (m) | NOAA/NOS CO-OPS Historical Water Level Station Index | http://www.co-ops.nos.noaa.gov/usmap.html |