Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to St. Vincent NWR

Prepared For: Dr. Brian Czech, Conservation Biologist

U. S. Fish and Wildlife Service
National Wildlife Refuge System
Division of Natural Resources and Conservation Planning
Conservation Biology Program
4401 N. Fairfax Drive - MS 670
Arlington, VA 22203

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Jonathan S. Clough, Warren Pinnacle Consulting, Inc.
PO Box 253, Warren VT, 05674
(802)-496-3476

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) suggested that global sea level will increase by approximately 30 cm to 100 cm by 2100 (IPCC 2001). Rahmstorf (2007) suggests that this range may be too conservative and that the feasible range by 2100 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and brackish marsh (Park et al. 1991).

In an effort to address the potential effects of sea level rise on United States national wildlife refuges, the U. S. Fish and Wildlife Service contracted the application of the SLAMM model for most Region 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 5.0) that accounts for the dominant processes involved in wetland conversion and shoreline modifications during long-term sea level rise (Park et al. 1989; www.warrenpinnacle.com/prof/SLAMM).

Successive versions of the model have been used to estimate the impacts of sea level rise on the coasts of the U.S. (Titus et al., 1991; Lee, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, et al. 2007; Craft et al., 2009.

Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

- **Inundation:** The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell.
- **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site-specific data.
- **Overwash:** Barrier islands of under 500 meters width are assumed to undergo overwash during each 25-year time-step due to storms. Beach migration and transport of sediments are calculated.
- **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast.

- **Accretion:** Sea level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category. Accretion rates may be spatially variable within a given model domain.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Brackish) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, brackish marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used when creating results for St. Vincent NWR.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). This document is available at http://warrenpinnacle.com/prof/SLAMM

All model results are subject to uncertainty due to limitations in input data, incomplete knowledge about factors that control the behavior of the system being modeled, and simplifications of the system (CREM 2008).

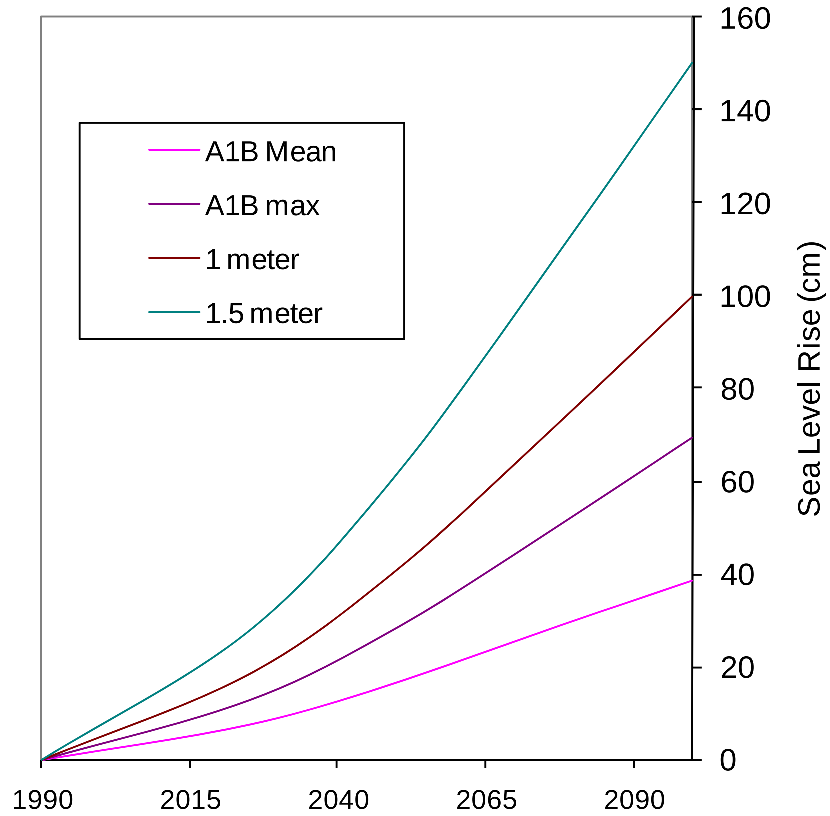
Sea-Level Rise Scenarios

The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent literature (Chen et al., 2006, Monaghan et al., 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf, 2007) suggests that, taking into account possible model error, a feasible range by 2100 might be 50 to 140 cm. To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

No LIDAR data were found for St. Vincent NWR so elevation data are based on the National Elevation Dataset (NED). (LIDAR data are currently being gathered for all of coastal Florida through the Florida Division of Emergency Management but at this time, this remains a work in progress.)

An examination of the metadata for the NED indicates that these data were derived from a 1977 survey illustrated, in part, in the USGS topographic map shown below. The contour intervals that resulted from this survey are five feet. The process of creating a digital elevation map (DEM) from a contour map does attempt to interpolate between contour lines but there is considerable uncertainty in this process.

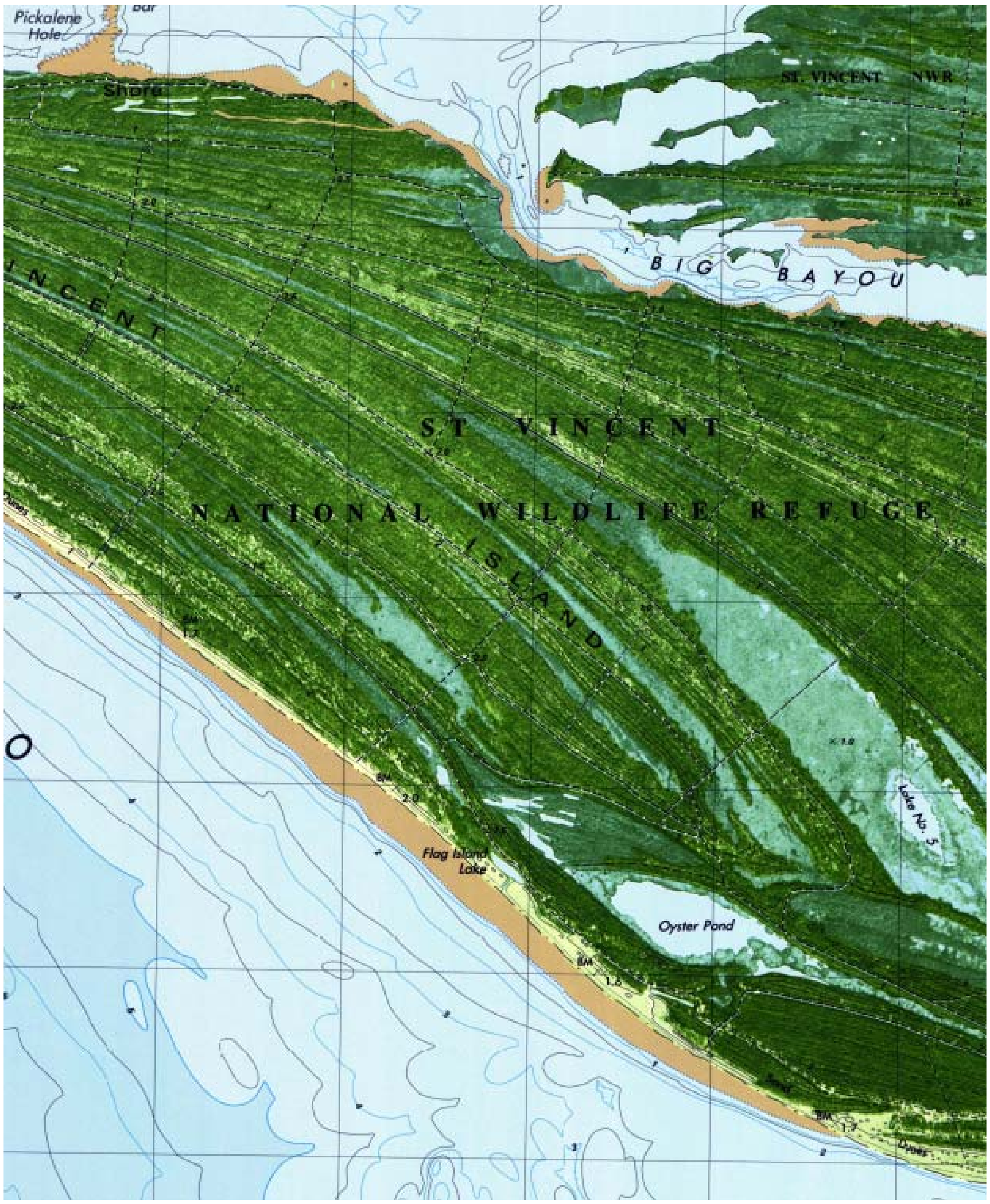


Figure 2: St. Vincent Excerpt from USGS Map.

The National Wetlands Inventory for St. Vincent is based on a photo date of 1996. This survey, when converted to 30 meter cells, suggests that on that date, the approximately twelve thousand acre refuge (approved acquisition boundary) was composed primarily of the categories as shown below:

Swamp	34.5%
Dry Land	23.3%
Brackish Marsh	21.9%
Inland Fresh Marsh	10.3%
Trans. Salt Marsh	5.0%
Estuarine Open Water	2.9%
Inland Open Water	1.2%
Saltmarsh	0.5%

There are no wetlands protected by dikes in the region of the St. Vincent NWR according to the National Wetlands Inventory survey.

The historic trend for Sea Level Rise was estimated at 1.38 mm/year based primarily on the long term trend measured at Appalachicola (NOAA station 8728690). This measured rate is similar to the global average for the last 100 years (approximately 1.5 mm/year).

The tide range at this site was estimated at 0.47 meters which is the average of the Cape San Blas, FL gage (8770520) and the gage at Eleven Mile, St. Vincent Sound, FL (8728786). The NED vertical datum of NAVD88 was related to mean tide level using the average of results from the same two gages.

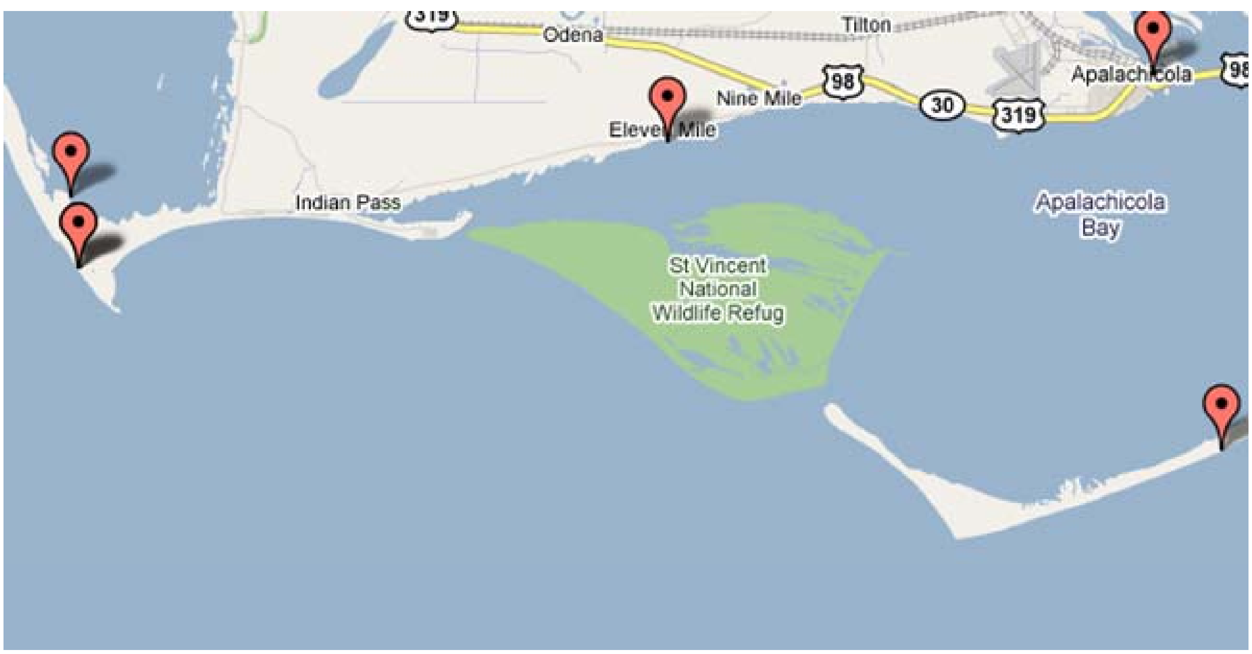


Figure 3: NOAA Gages Relevant to the Study Area.

Accretion rates in salt marshes were set to 4.0 mm/year. This value is the mean of two studies measuring accretion rates in the marshes of St. Marks, FL. (Cahoon et. al. 1995, and Hendrickson, J.C. 1997) The mean of two accretion rate observations taken from nearby Ochlockonee River, FL is similar (4.05 mm/year, Hendrickson, J.C. 1997)

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as received from Kimberly Eldridge, lead cartographer with U.S. Fish and Wildlife Service, and are current as of June 2008.

The cell-size used for this analysis was 30 meter by 30 meter cells. However, the SLAMM model does track partial conversion of cells based on elevation and slope.

SUMMARY OF SLAMM INPUT PARAMETERS FOR ST. VINCENT

Site	St. Vincent
NED Source Date (yyyy)	1977
NWI_photo_date (yyyy)	1996
Direction_OffShore (N|S|E|W)	S
Historic_trend (mm/yr)	1.38
NAVD88_correction (MTL-NAVD88 in meters)	0.005
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	0.47
TideRangeInland (meters)	0.47
Mean High Water Spring (m above MTL)	0.313
MHSW Inland (m above MTL)	0.313
Marsh Erosion (horz meters/year)	1.8
Swamp Erosion (horz meters/year)	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5
Salt marsh vertical accretion (mm/yr) Final	4.0
Brackish March vert. accretion (mm/yr) Final	4.7
Tidal Fresh vertical accretion (mm/yr) Final	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	1
Frequency of Large Storms (yr/washover)	25
Use Elevation Preprocessor for Wetlands	TRUE

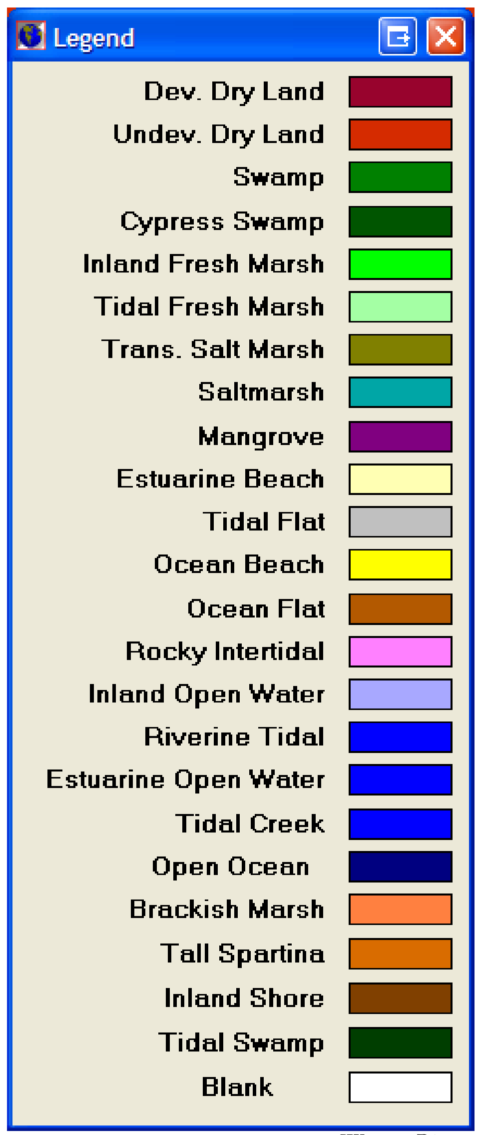
Results

Model results suggest that the resilience of St. Vincent National Wildlife Refuge to global sea level rise is largely a function of the rate at which this change takes place.

SLR by 2100 (m)	**0.39**	**0.69**	**1**	**1.5**
Swamp	2%	56%	68%	80%
Dry Land	13%	26%	35%	55%
Brackish Marsh	1%	96%	100%	100%
Inland Fresh Marsh	-4%	-4%	3%	78%
Trans. Salt Marsh	-10%	-302%	-1%	-101%
SLR by 2100 (m)	**0.39**	**0.69**	**1**	**1.5**

Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

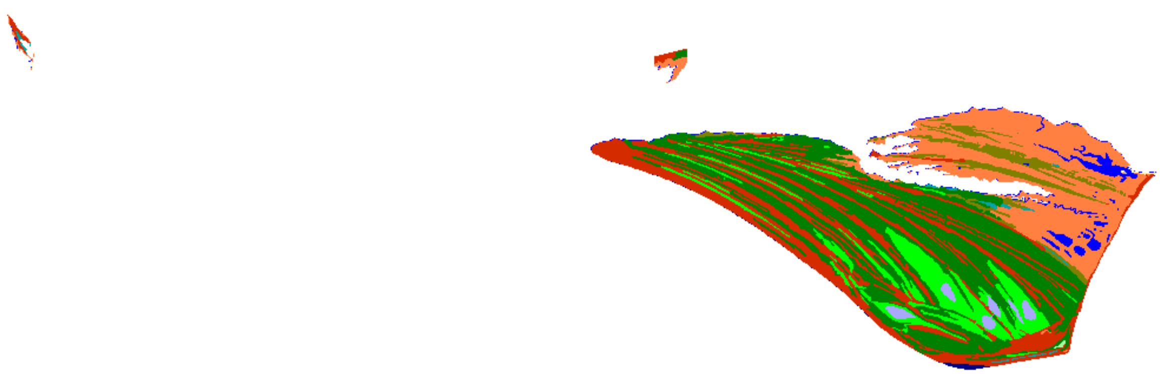
Maps of SLAMM input and output to follow will use the following legend:



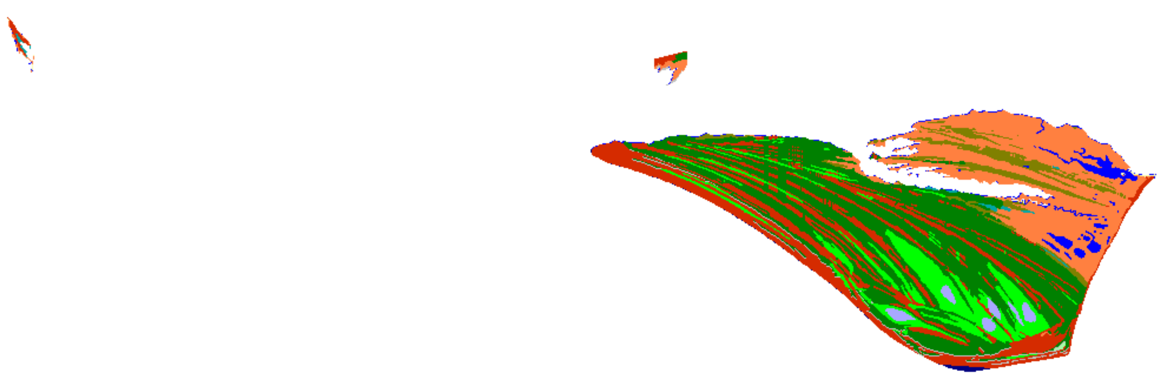
St. Vincent NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

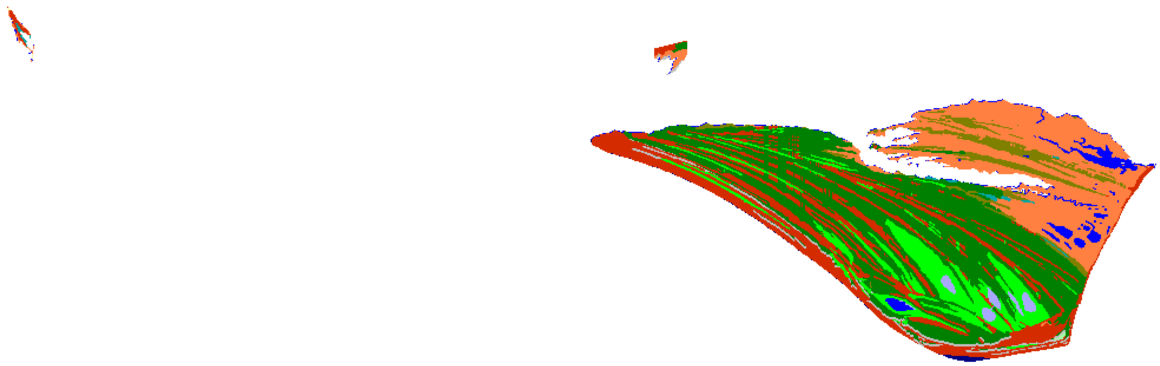
	Initial	2025	2050	2075	2100
Swamp	4202.1	4310.7	4253.7	4196.3	4127.6
Dry Land	2835.1	2581.5	2536.0	2499.6	2470.7
Brackish Marsh	2665.6	2656.7	2652.3	2651.8	2651.8
Inland Fresh Marsh	1255.6	1277.3	1290.4	1302.3	1311.7
Trans. Salt Marsh	604.5	607.3	615.7	637.2	665.8
Estuarine Open Water	348.3	350.9	444.7	507.6	560.8
Inland Open Water	151.9	151.9	118.8	116.5	113.9
Saltmarsh	57.2	44.3	43.6	43.6	46.2
Open Ocean	35.1	38.1	42.2	47.9	54.3
Estuarine Beach	9.3	8.5	5.8	3.7	5.1
Tidal Fresh Marsh	5.8	5.8	5.8	5.8	5.8
Tidal Flat	2.4	139.8	163.4	158.1	154.2
Ocean Beach	0.0	0.2	0.7	2.6	5.1
Total (incl. water)	**12173.0**	**12173.0**	**12173.0**	**12173.0**	**12173.0**



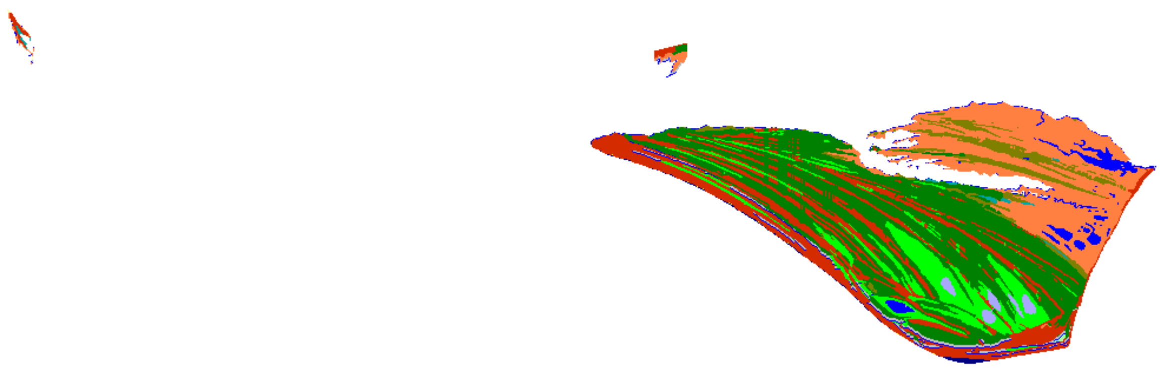
Saint Vincent, Initial Condition



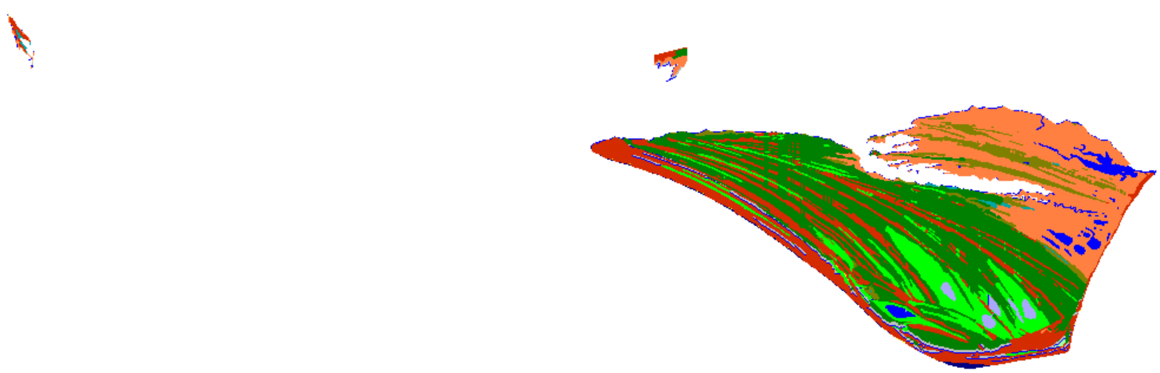
Saint Vincent, 2025, Scenario A1B Mean



Saint Vincent, 2050, Scenario A1B Mean



Saint Vincent, 2075, Scenario A1B Mean

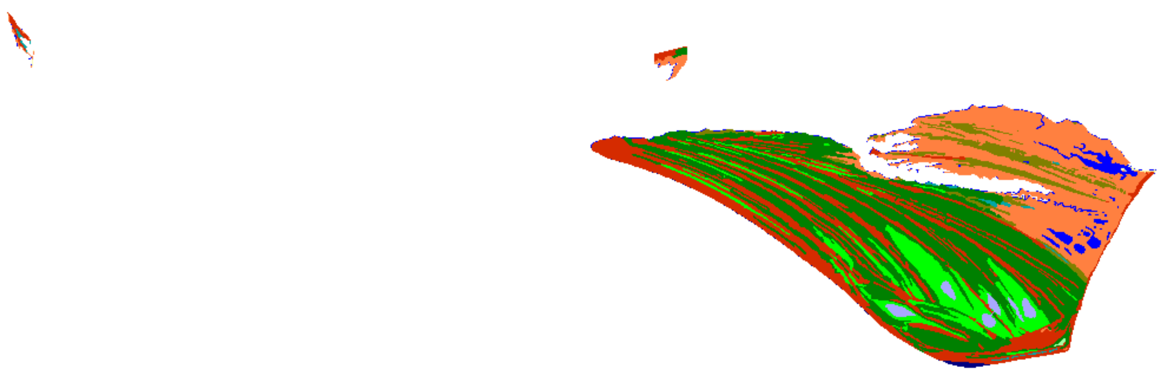


Saint Vincent, 2100, Scenario A1B Mean

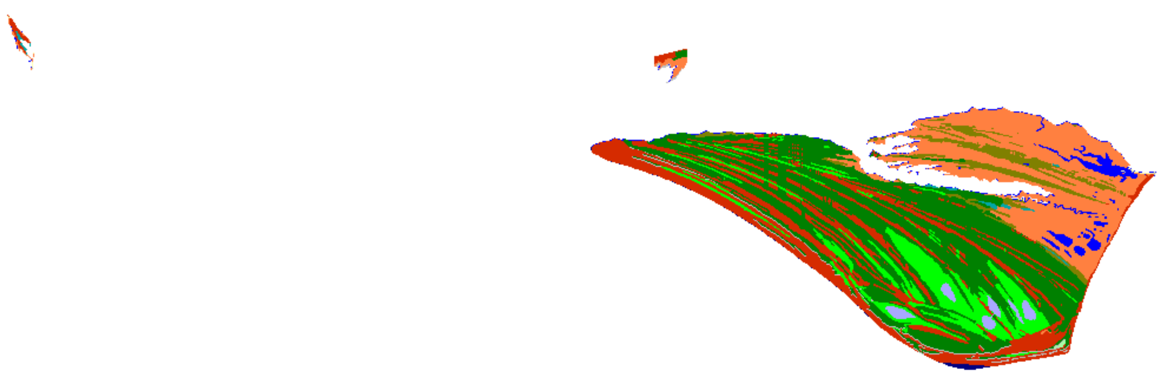
St. Vincent NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

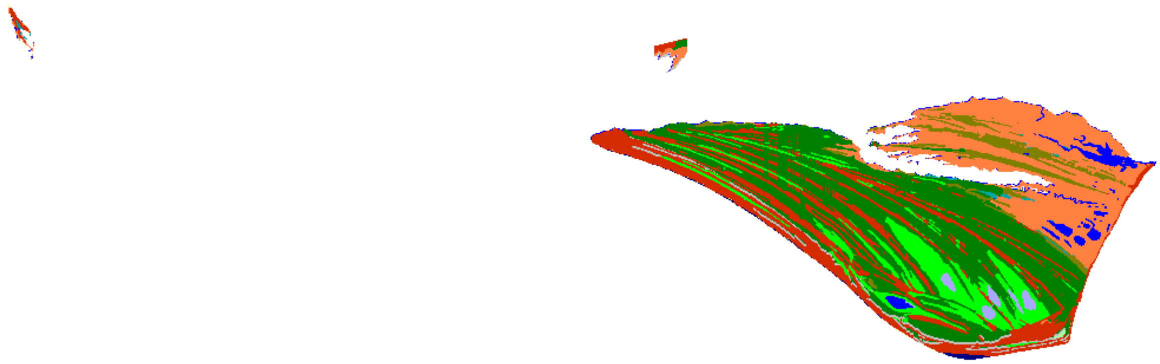
	Initial	2025	2050	2075	2100
Swamp	4202.1	4323.4	4255.7	4123.8	1831.5
Dry Land	2835.1	2559.9	2496.6	2427.9	2088.5
Brackish Marsh	2665.6	2656.7	2624.9	832.3	95.0
Inland Fresh Marsh	1255.6	1280.1	1294.4	1306.8	1310.3
Trans. Salt Marsh	604.5	610.4	622.6	99.8	2429.1
Estuarine Open Water	348.3	352.8	455.4	532.8	764.0
Inland Open Water	151.9	151.9	118.1	114.1	107.2
Saltmarsh	57.2	44.3	78.3	2468.5	1719.6
Open Ocean	35.1	40.0	47.9	61.5	82.2
Estuarine Beach	9.3	6.4	4.2	10.2	76.3
Tidal Fresh Marsh	5.8	5.8	5.8	5.8	5.8
Tidal Flat	2.4	140.9	166.5	180.9	1619.1
Ocean Beach	0.0	0.3	2.7	8.6	44.3
Total (incl. water)	**12173.0**	**12173.0**	**12173.0**	**12173.0**	**12173.0**



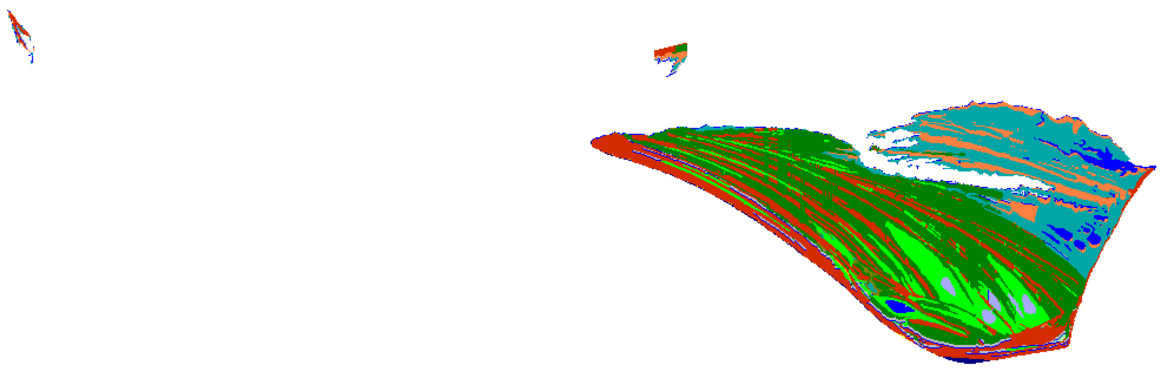
Saint Vincent, Initial Condition



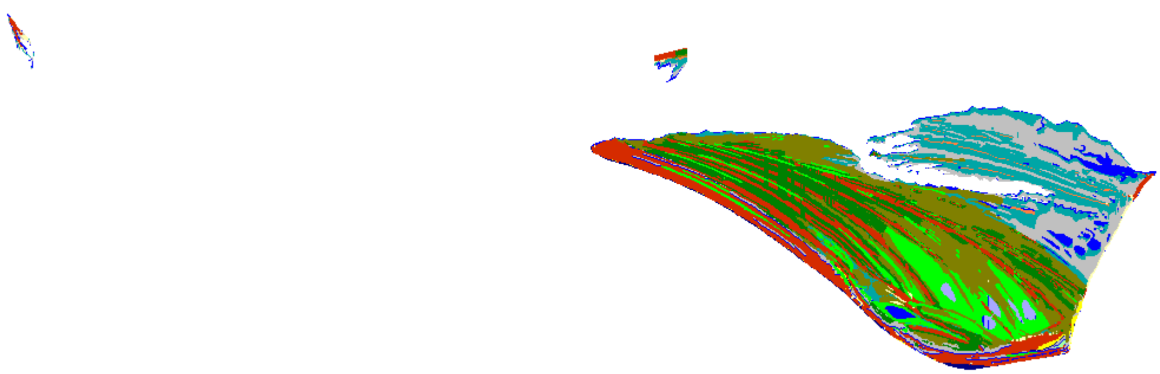
Saint Vincent, 2025, Scenario A1B Maximum



Saint Vincent, 2050, Scenario A1B Maximum



Saint Vincent, 2075, Scenario A1B Maximum

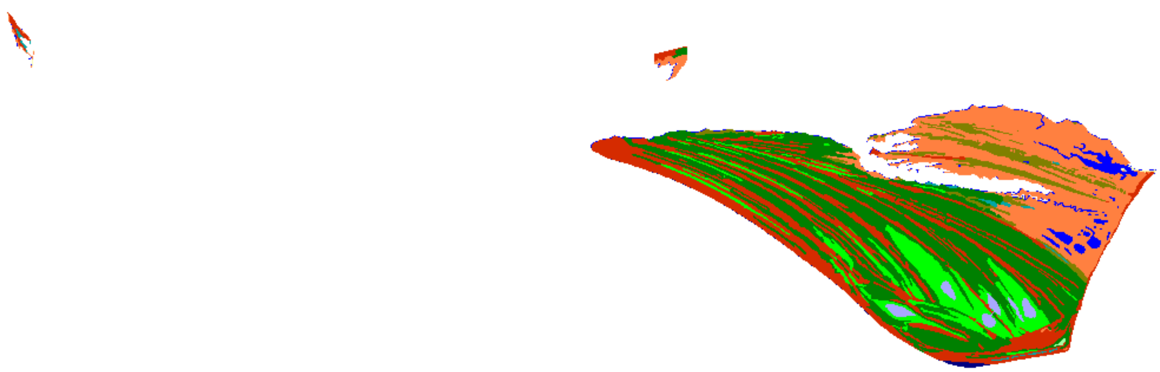


Saint Vincent, 2100, Scenario A1B Maximum

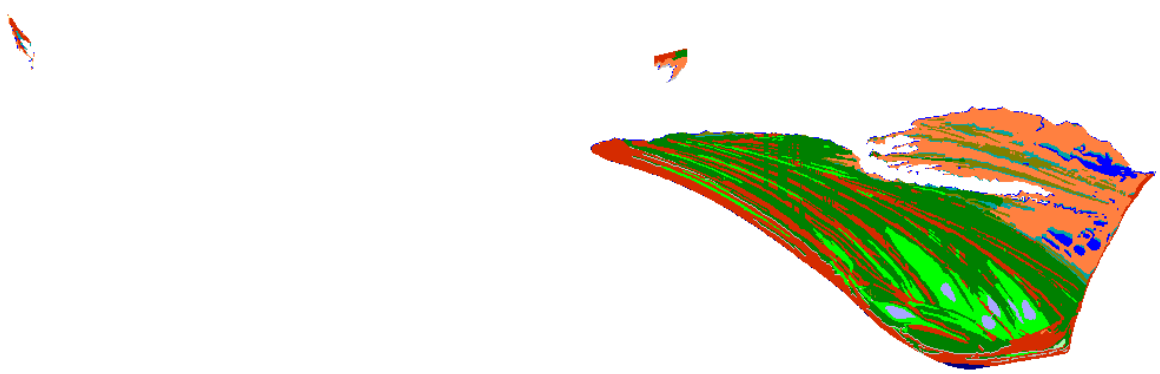
St. Vincent NWR
1 Meter Eustatic SLR by 2100

Results in Acres

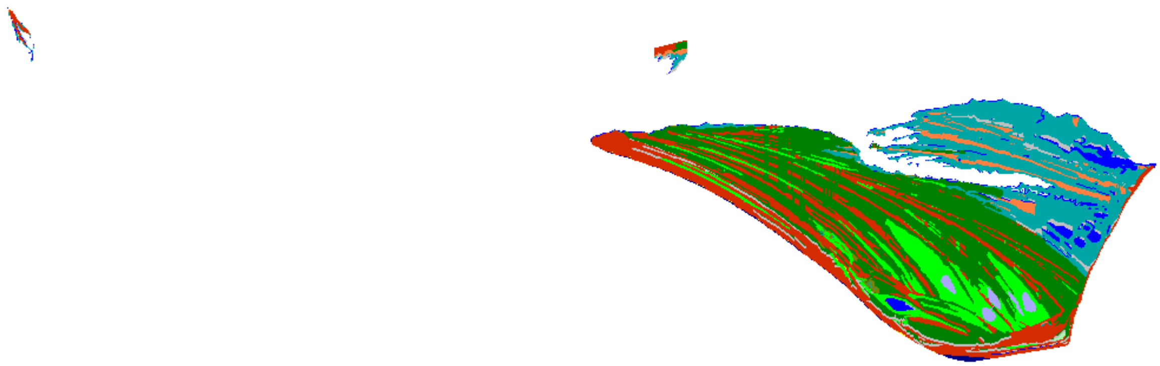
	Initial	2025	2050	2075	2100
Swamp	4202.1	4337.1	4238.4	1823.4	1340.7
Dry Land	2835.1	2532.9	2454.5	2083.2	1838.1
Brackish Marsh	2665.6	2414.0	396.9	0.0	0.0
Inland Fresh Marsh	1255.6	1282.8	1286.3	1256.3	1218.3
Trans. Salt Marsh	604.5	505.6	72.3	2580.4	608.9
Estuarine Open Water	348.3	361.1	559.5	988.4	3784.2
Inland Open Water	151.9	151.9	118.1	97.4	19.3
Saltmarsh	57.2	390.0	2641.5	506.6	2543.9
Open Ocean	35.1	42.2	55.5	83.6	132.1
Estuarine Beach	9.3	4.6	5.8	69.1	46.0
Tidal Fresh Marsh	5.8	5.8	5.8	5.8	5.7
Tidal Flat	2.4	144.1	332.5	2637.9	598.2
Ocean Beach	0.0	0.8	5.9	40.8	37.3
Total (incl. water)	**12173.0**	**12173.0**	**12173.0**	**12173.0**	**12173.0**



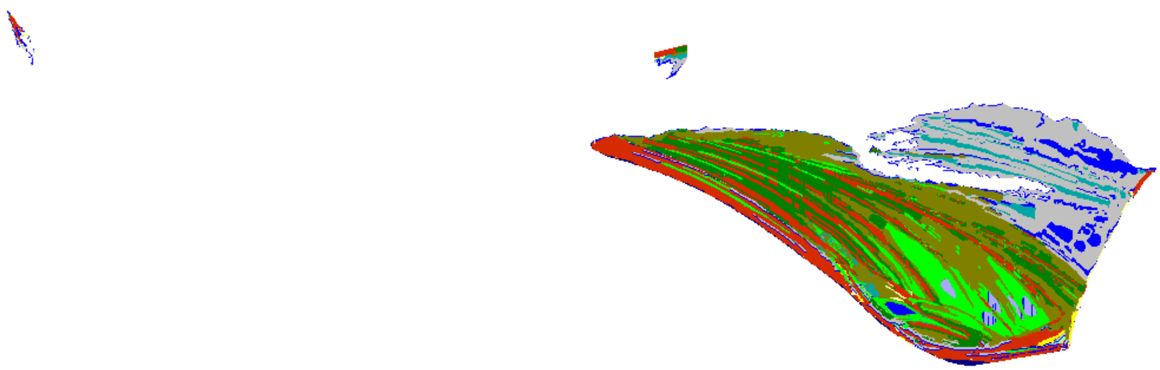
Saint Vincent, Initial Condition



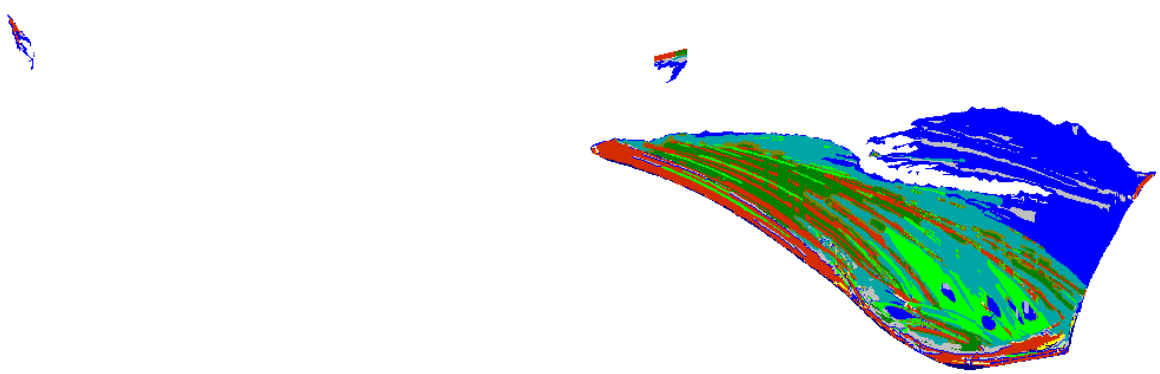
Saint Vincent, 2025, 1 meter eustatic SLR by 2100



Saint Vincent, 2050, 1 meter eustatic SLR by 2100



Saint Vincent, 2075, 1 meter eustatic SLR by 2100

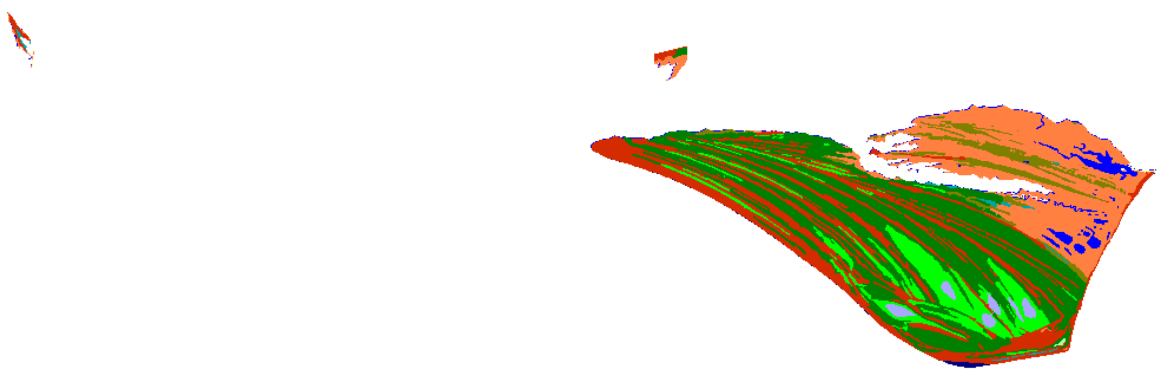


Saint Vincent, 2100, 1 meter eustatic SLR by 2100

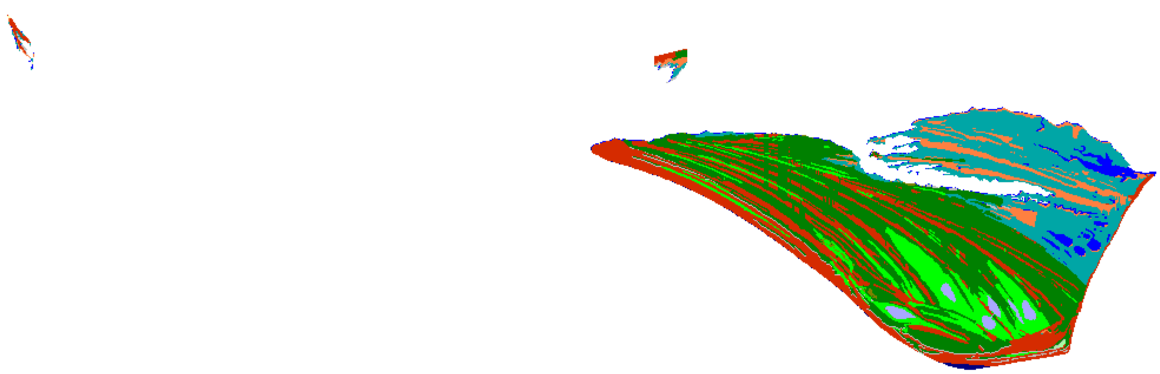
St. Vincent NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

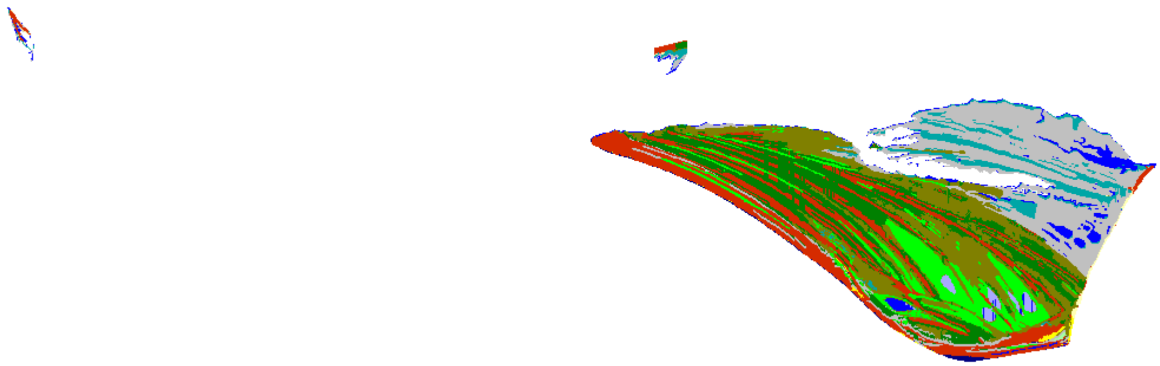
	Initial	2025	2050	2075	2100
Swamp	4202.1	4345.2	2282.4	1328.2	822.3
Dry Land	2835.1	2498.1	2157.8	1792.7	1284.6
Brackish Marsh	2665.6	669.9	0.0	0.9	0.4
Inland Fresh Marsh	1255.6	1274.2	1226.6	763.4	270.5
Trans. Salt Marsh	604.5	40.1	2224.1	1541.7	1213.5
Estuarine Open Water	348.3	373.2	654.8	3475.8	4547.2
Inland Open Water	151.9	151.9	103.4	17.6	0.0
Saltmarsh	57.2	2608.9	709.6	2198.9	1483.8
Open Ocean	35.1	46.0	72.5	153.5	251.0
Estuarine Beach	9.3	4.0	45.7	63.7	102.8
Tidal Fresh Marsh	5.8	5.8	5.8	2.9	0.5
Tidal Flat	2.4	153.4	2650.3	811.8	2175.4
Ocean Beach	0.0	2.3	39.9	21.7	20.9
Total (incl. water)	**12173.0**	**12173.0**	**12173.0**	**12173.0**	**12173.0**



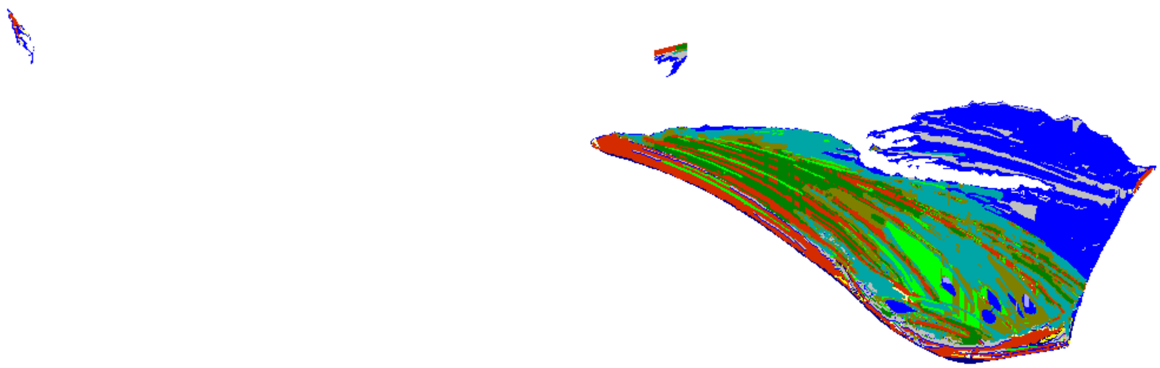
Saint Vincent, Initial Condition



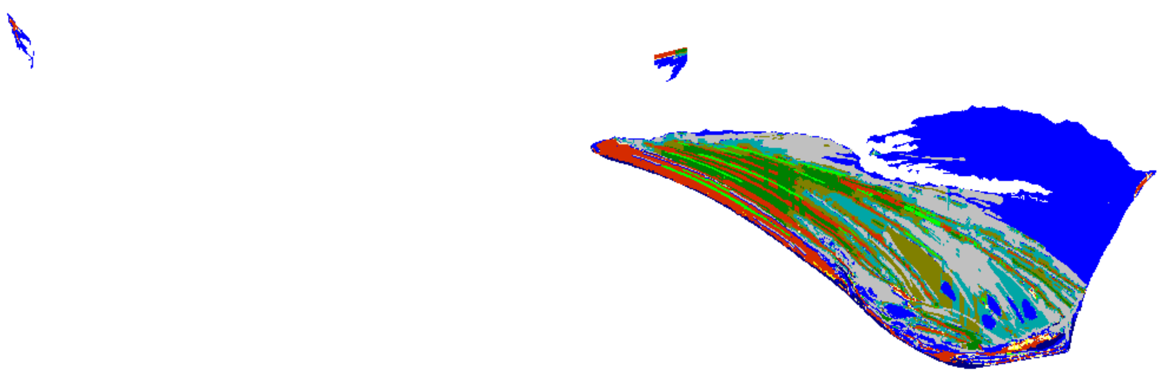
Saint Vincent, 2025, 1.5 meter eustatic SLR by 2100



Saint Vincent, 2050, 1.5 meter eustatic SLR by 2100



Saint Vincent, 2075, 1.5 meter eustatic SLR by 2100



Saint Vincent, 2100, 1.5 meter eustatic SLR by 2100

Discussion:

Saint Vincent National Wildlife Refuge is predicted to have varying degrees of resilience to sea level rise:

- Under fairly low estimates of Sea Level Rise (0.39 meters by 2100) only minimal effects are predicted for all land categories.
- Under moderate to high rates of sea level rise (0.69 to 1 meters by 2100) irregularly flooded marshes in the northeast of the site are predicted to be converted to salt marsh or tidal flats.
- Additionally under these moderate scenarios, some swamplands on the site are predicted to become inundated by salt water and therefore to convert to transitional saltmarsh.
- Under the highest scenarios of sea level rise (1.5 meters by 2100) the marshes in the northeast are predicted to be entirely converted to water and the rest of the island is largely converted to tidal flats and regularly inundated salt marshes.

Results at this site are subject to uncertainty due to the elevation data (that is based on contour intervals of five feet). Revisiting these results when higher vertical resolution elevation data come on-line may be warranted.

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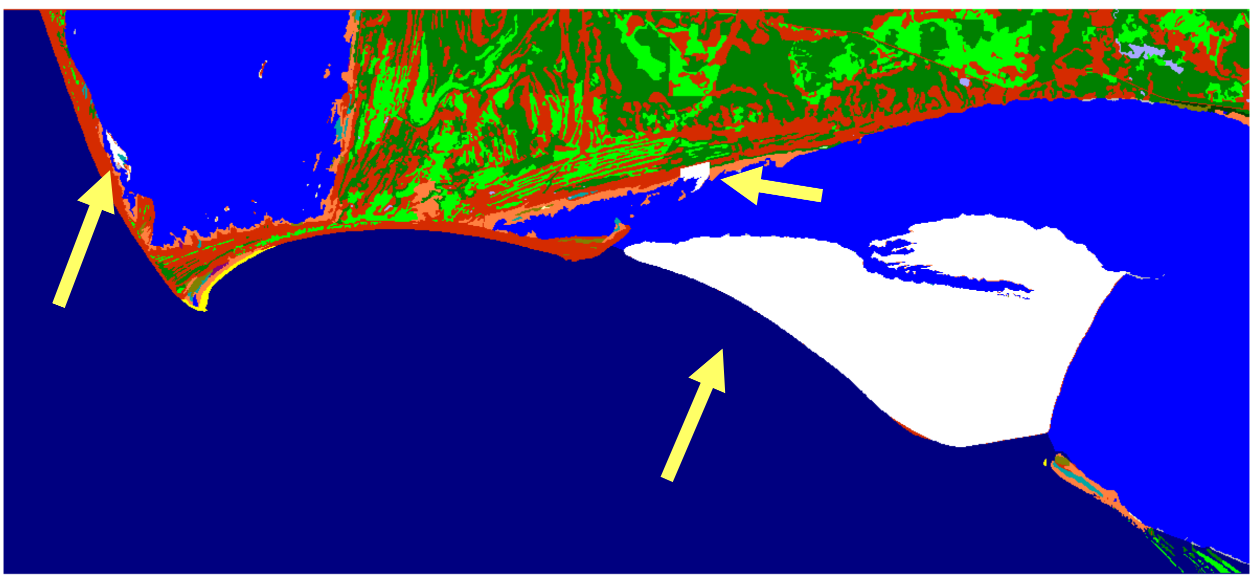
Appendix A: Contextual Results

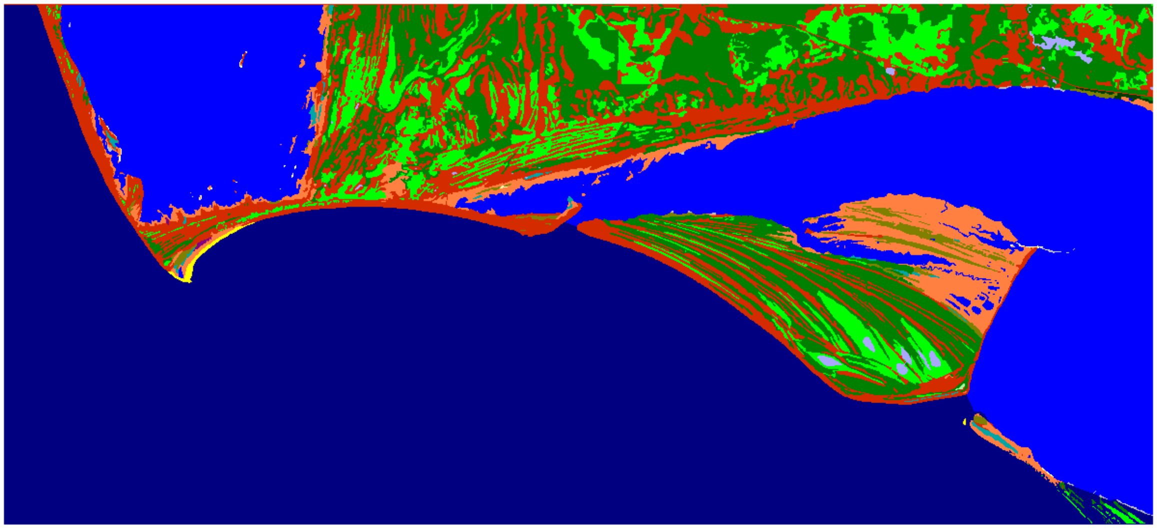
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean.

For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

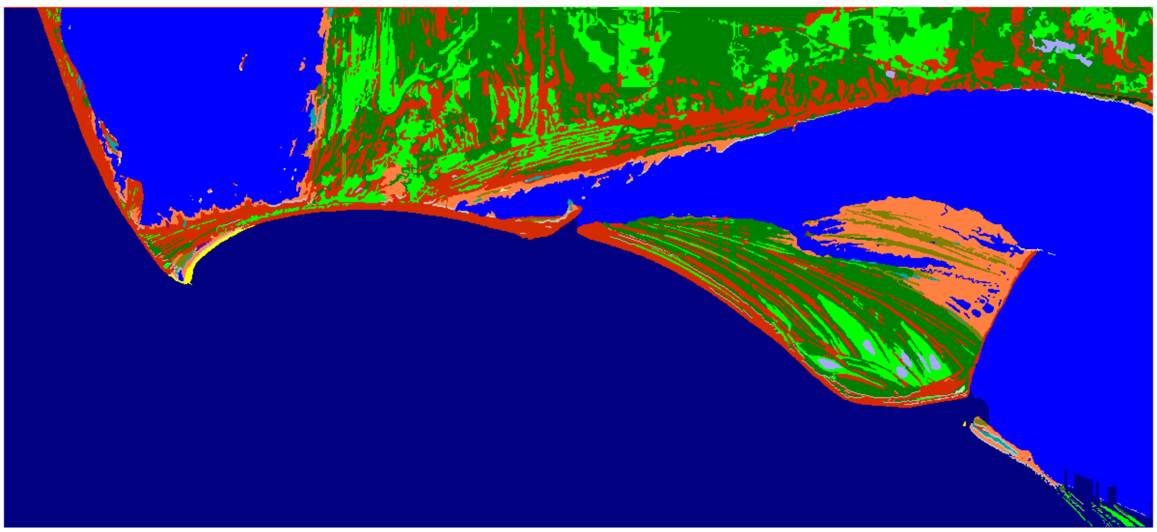
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.



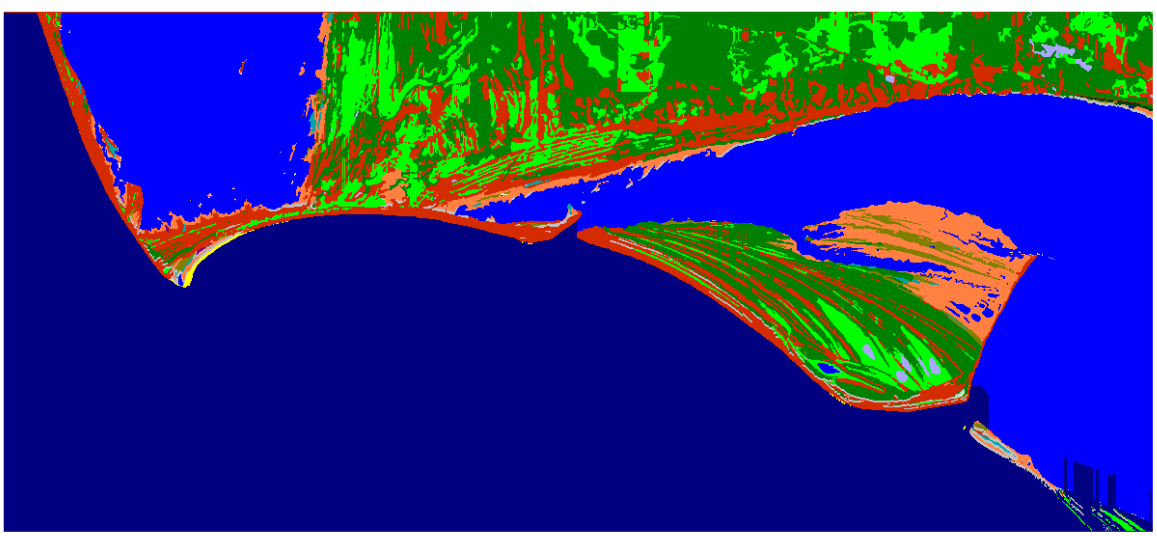
Location of St. Vincent National Wildlife Refuge (white areas) within simulation context



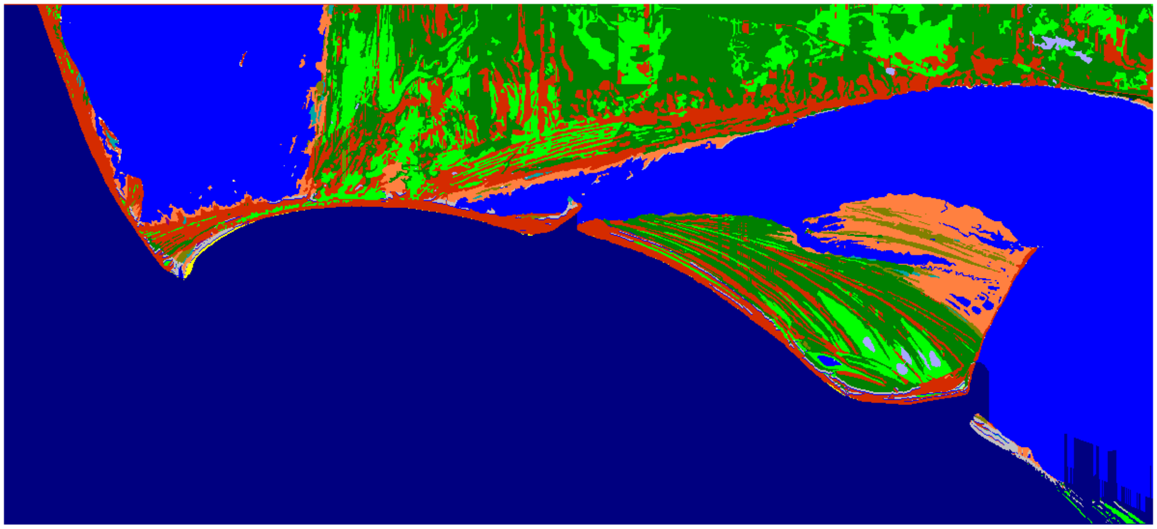
Saint Vincent Context, Initial Condition



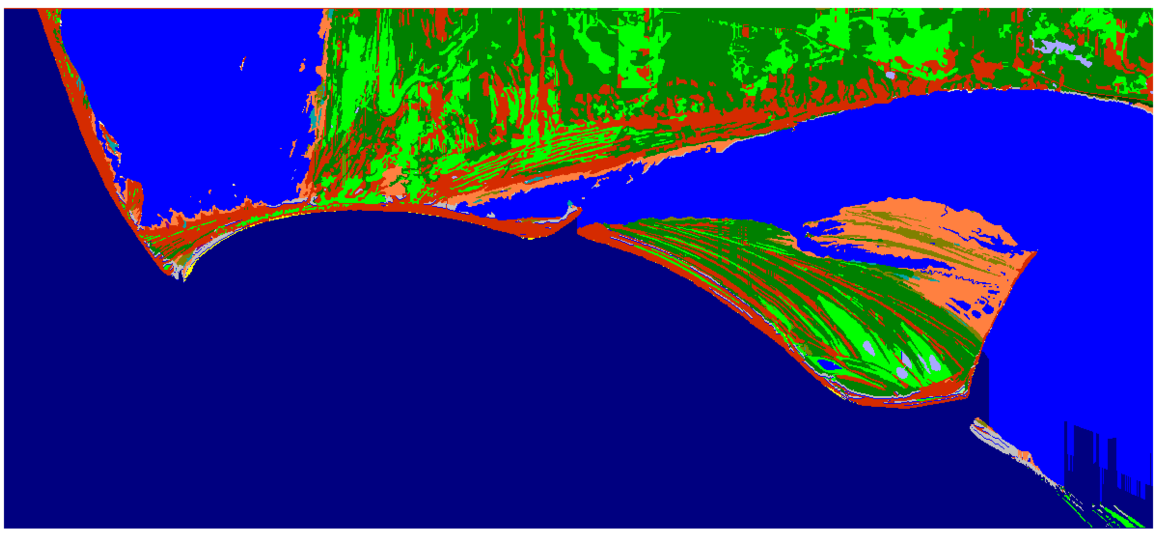
Saint Vincent Context, 2025, Scenario A1B Mean



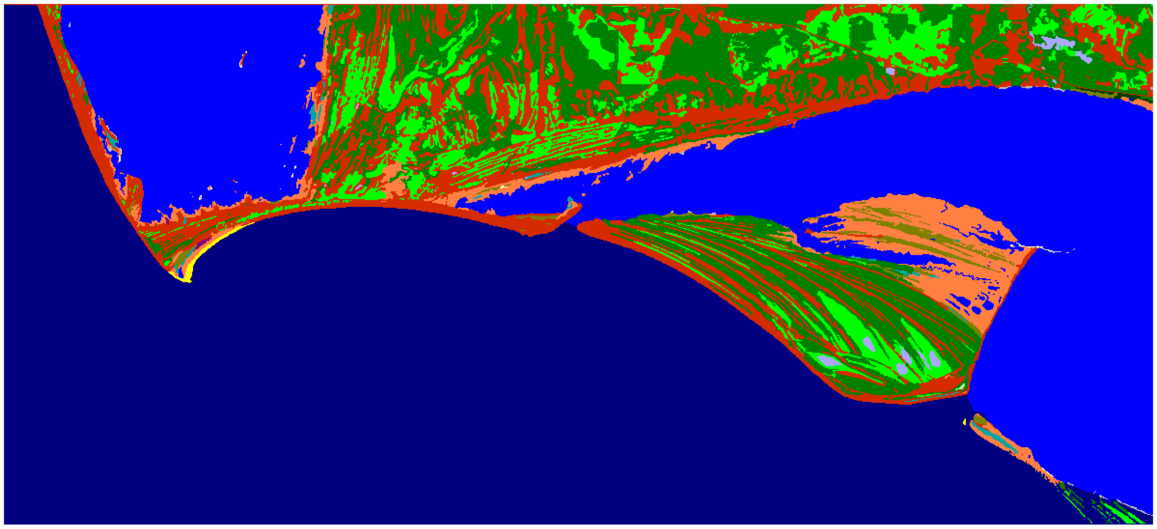
Saint Vincent Context, 2050, Scenario A1B Mean



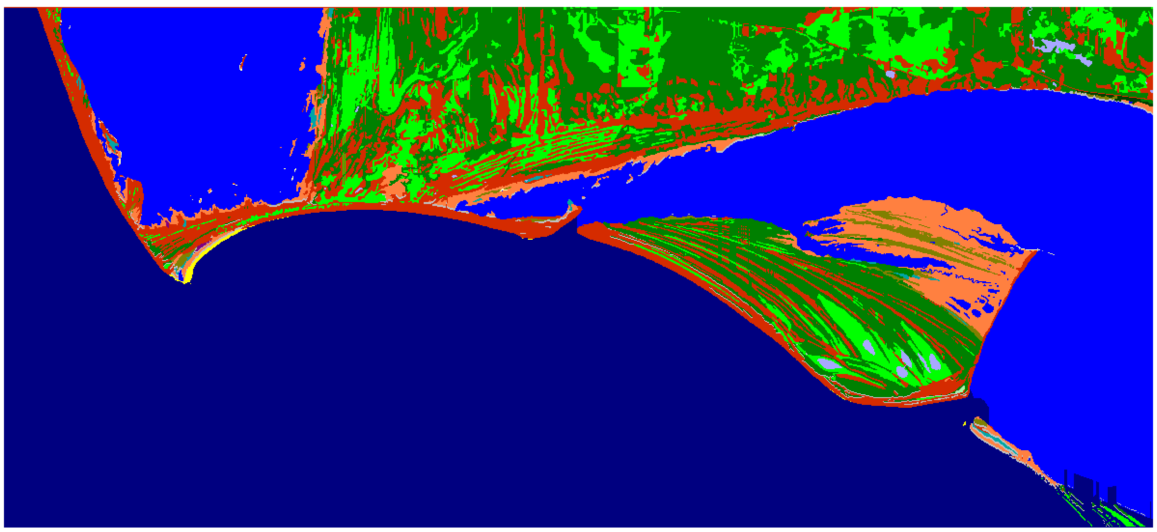
Saint Vincent Context, 2075, Scenario A1B Mean



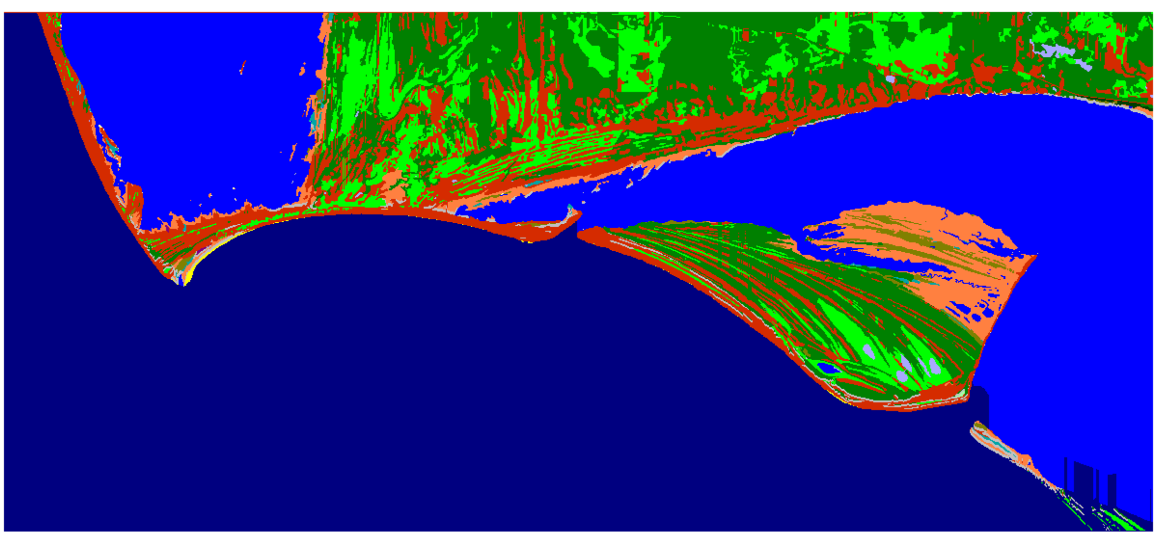
Saint Vincent Context, 2100, Scenario A1B Mean



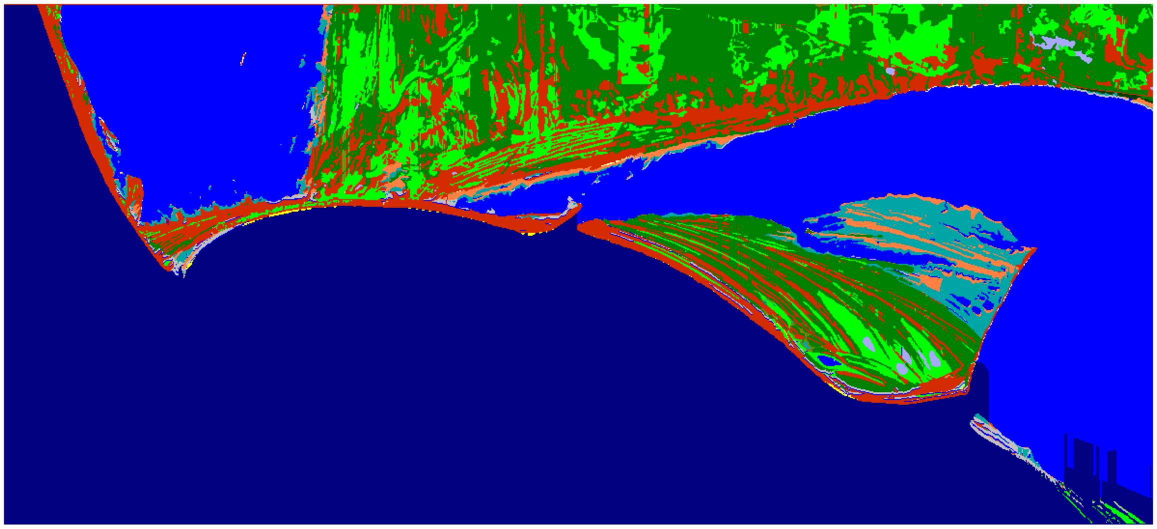
Saint Vincent Context, Initial Condition



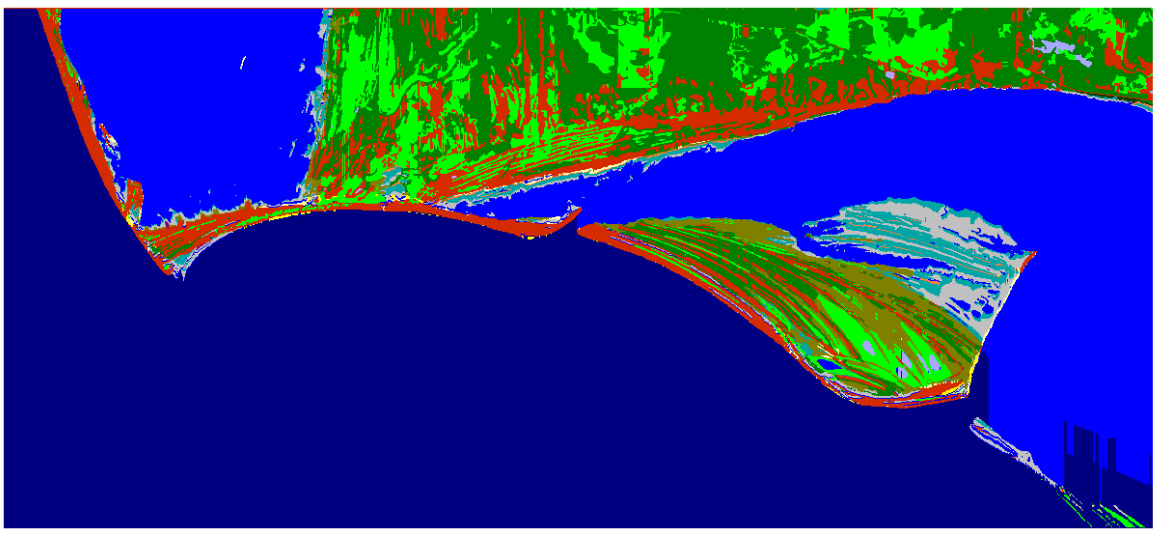
Saint Vincent Context, 2025, Scenario A1B Maximum



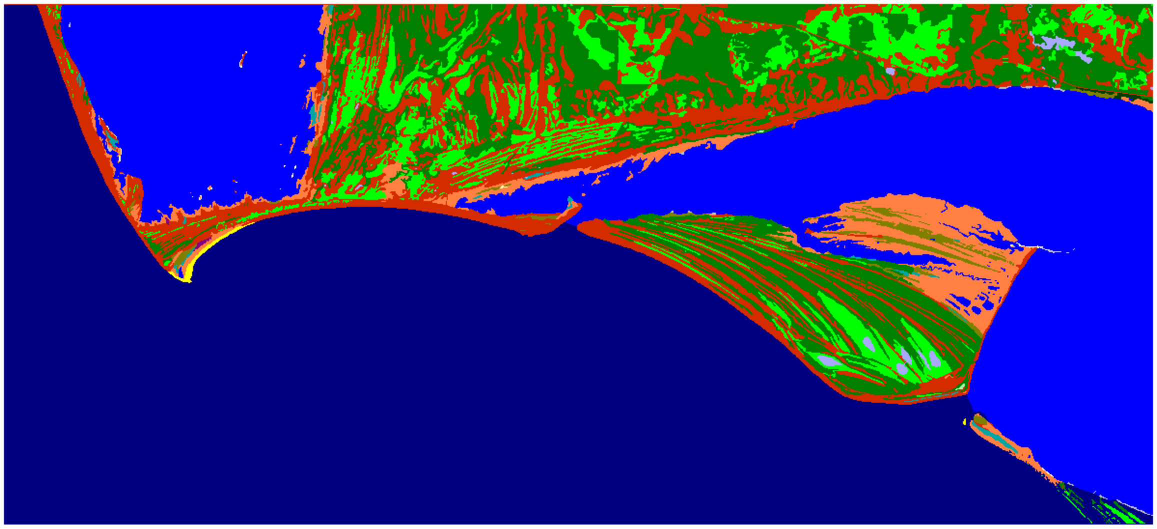
Saint Vincent Context, 2050, Scenario A1B Maximum



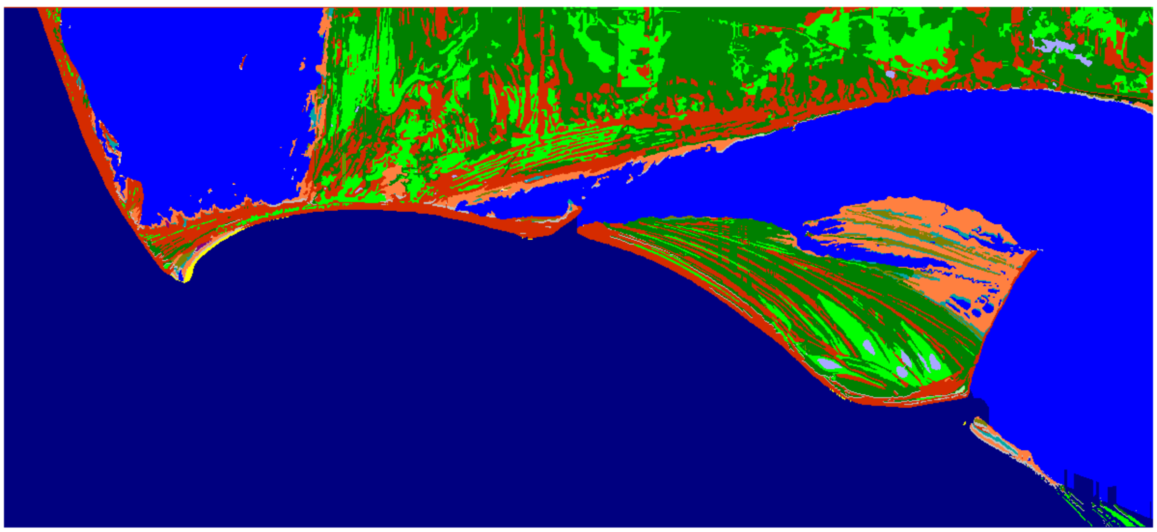
Saint Vincent Context, 2075, Scenario A1B Maximum



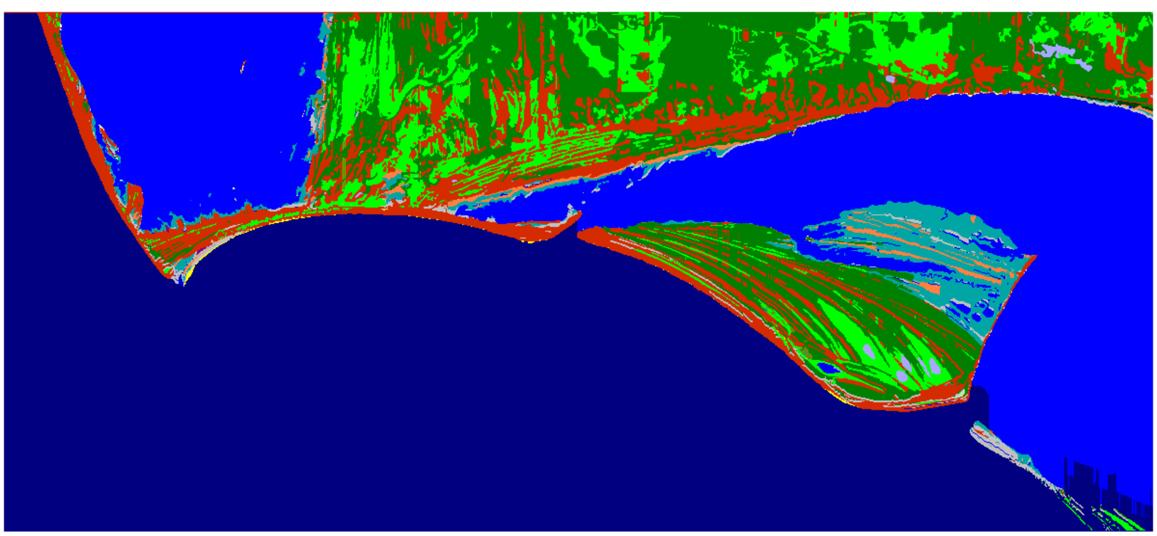
Saint Vincent Context, 2100, Scenario A1B Maximum



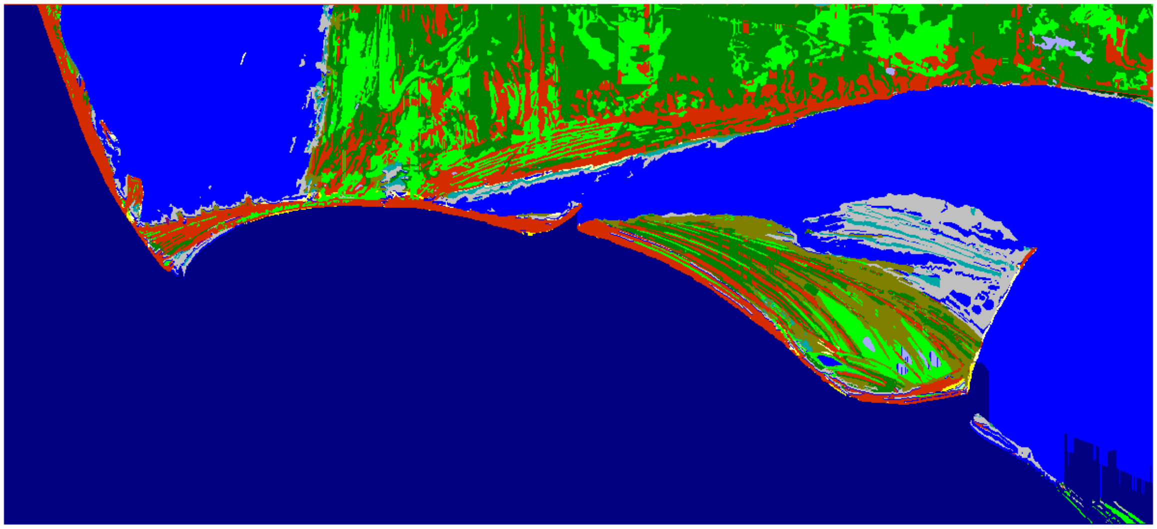
Saint Vincent Context, Initial Condition



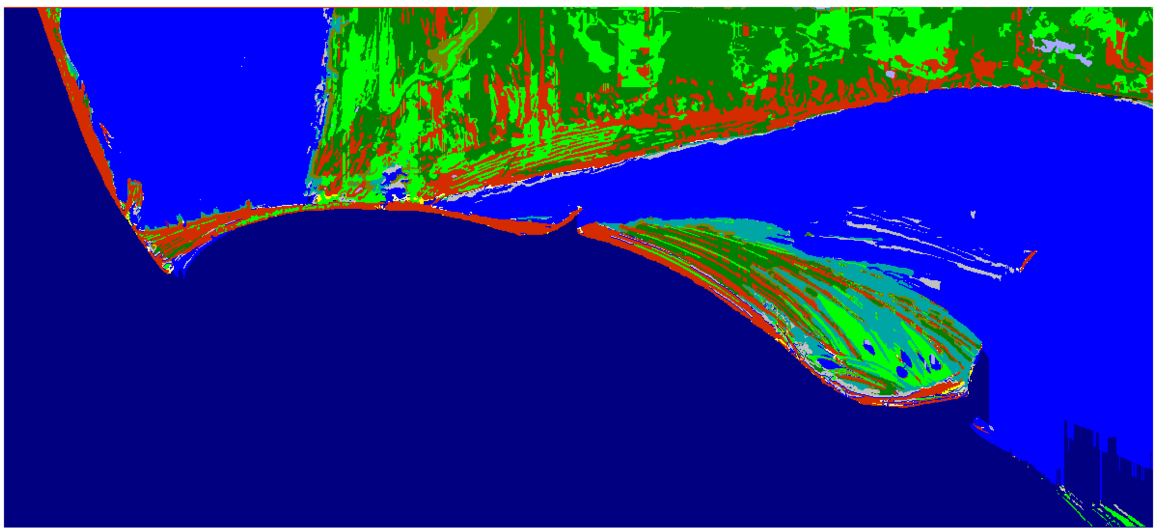
Saint Vincent Context, 2025, 1 meter eustatic SLR by 2100



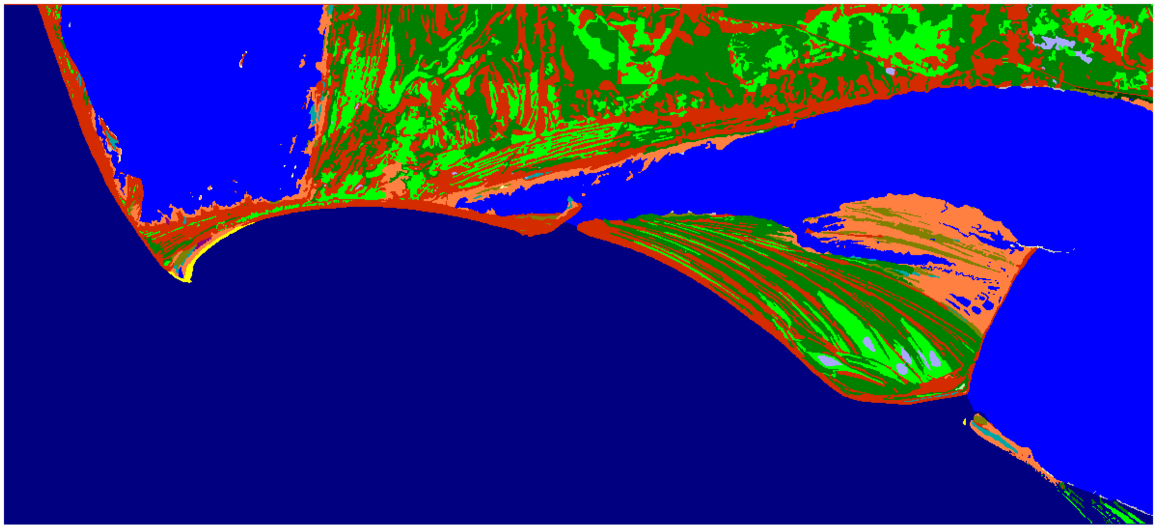
Saint Vincent Context, 2050, 1 meter eustatic SLR by 2100



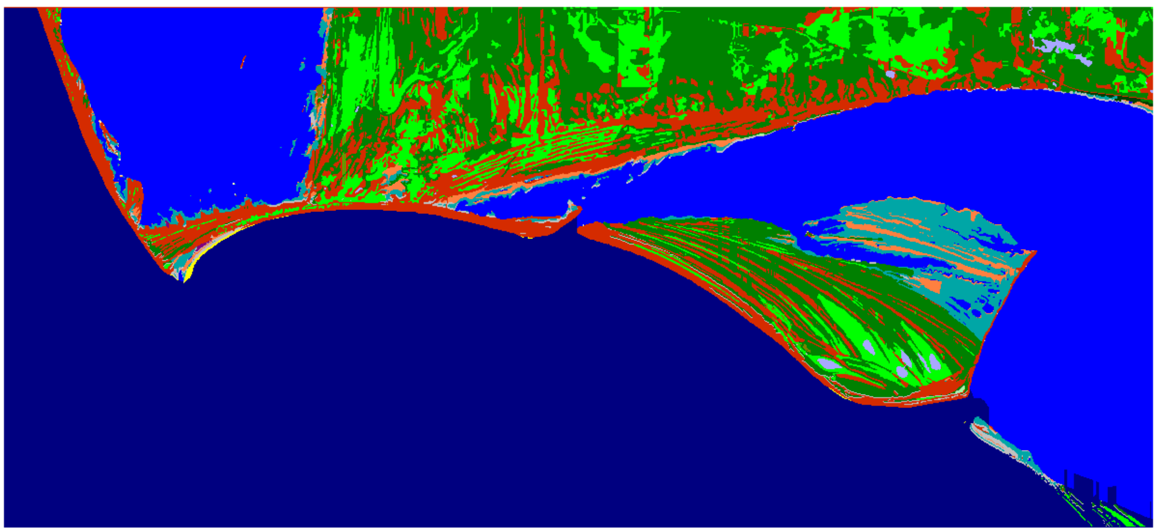
Saint Vincent Context, 2075, 1 meter eustatic SLR by 2100



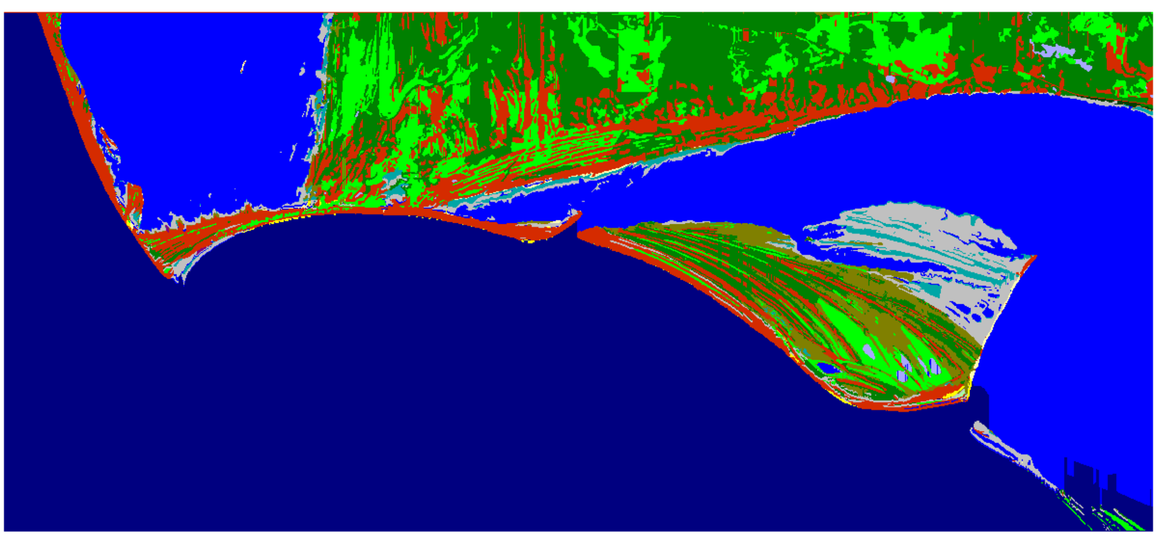
Saint Vincent Context, 2100, 1 meter eustatic SLR by 2100



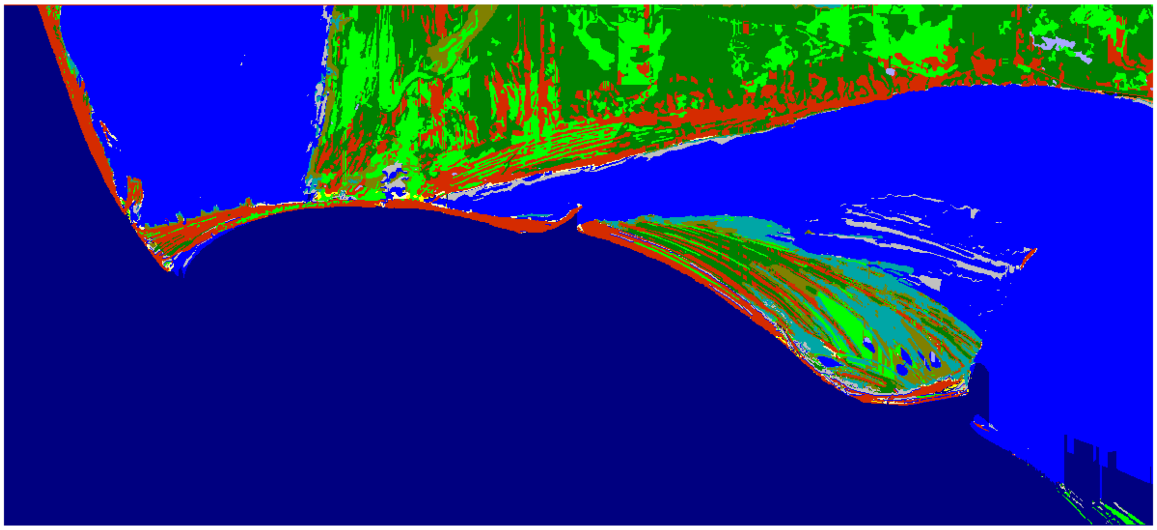
Saint Vincent Context, Initial Condition



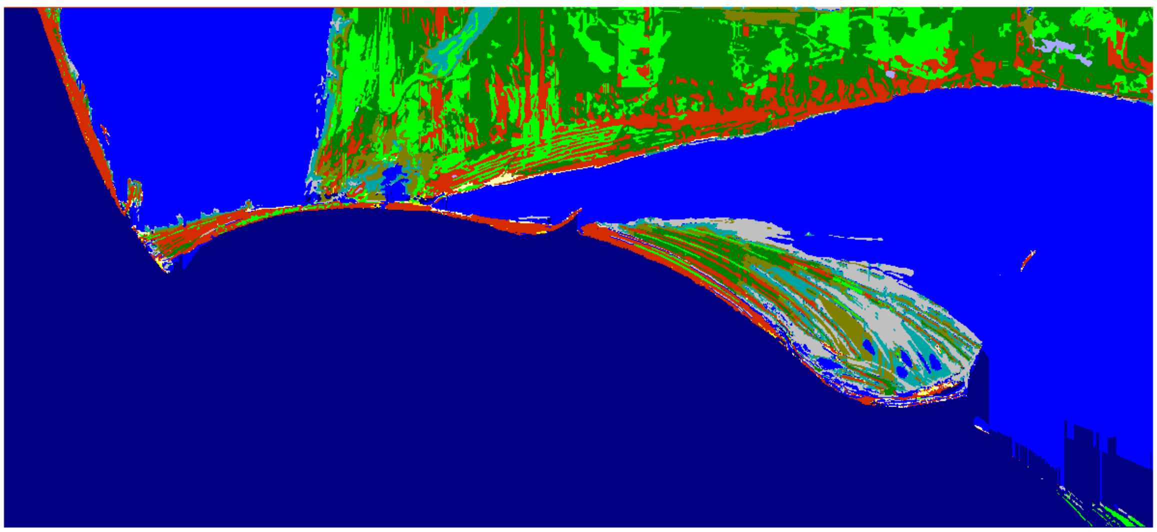
Saint Vincent Context, 2025, 1.5 meter eustatic SLR by 2100



Saint Vincent Context, 2050, 1.5 meter eustatic SLR by 2100



Saint Vincent Context, 2075, 1.5 meter eustatic SLR by 2100



Saint Vincent Context, 2100, 1.5 meter eustatic SLR by 2100