Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Green Cay National Wildlife Refuge

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). Sea level is predicted to increase by 30 cm to 100 cm by 2100 based on the International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Meehl et al. 2007). 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. A CCP is a document that provides a framework for guiding refuge management decisions. All refuges are required by law to complete a CCP by 2012.

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 Green Cay National Wildlife Refuge.

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

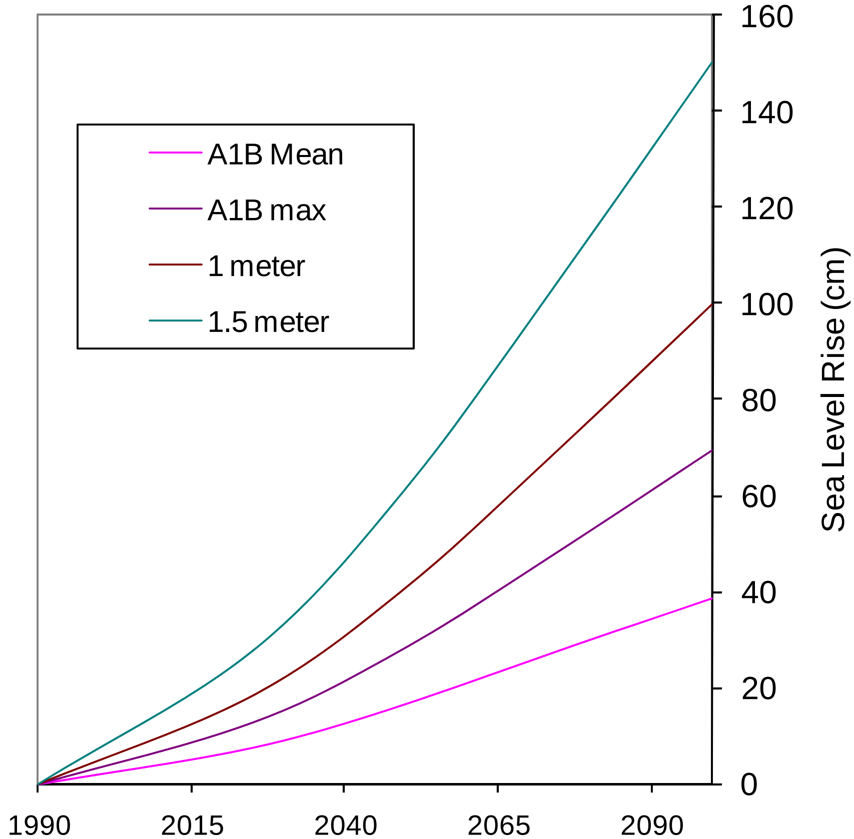
Sea-Level Rise Scenarios

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 the 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).

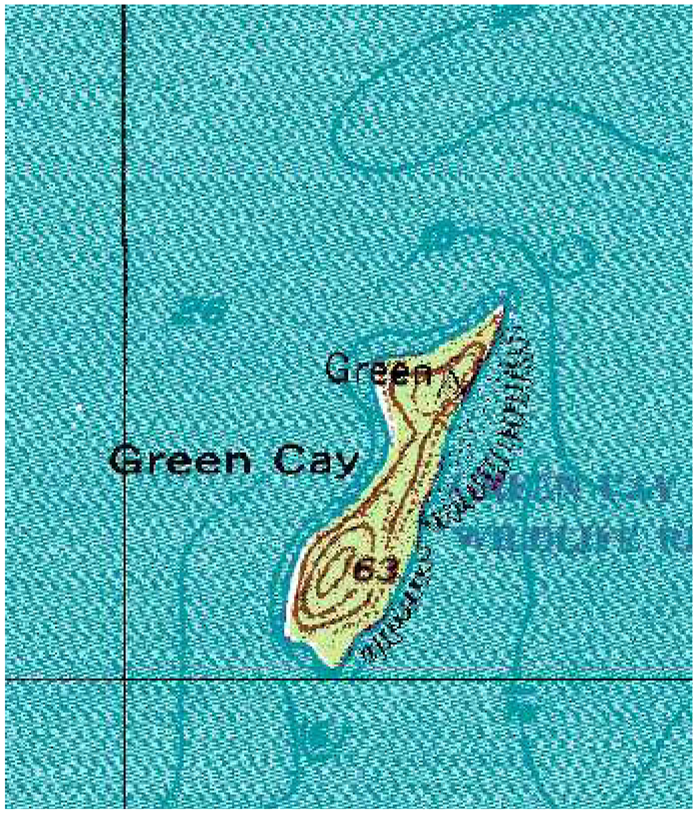
Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

No LIDAR data were found for the Green Cay NWR so elevation data for Green Cay are based on the National Elevation Dataset (NED). An examination of the metadata for the NED indicates that it was derived from a 1954 survey illustrated in the USGS topographic map shown below (Figure 2).

Figure 2: Green Cay from USGS Map.
Dotted line is 10 foot contour other lines are 20 foot contours.



Examining this map, the vertical resolution of the National Elevation Dataset is 10 feet at best thanks to the supplemental 10 foot contour. This significantly increases the uncertainty for calculating effects of a maximum of 1.5 meters of sea level rise. On the other hand looking at Figure 2 it seems as though approximately 90% of the island is above 10 feet in elevation suggesting that effects from SLR will be minor despite the uncertainty in the elevation data set.

The National Wetlands Inventory for Green Cay suggests that it is exclusively composed of dry land. No other wetlands categories are indicated in that data set.

The historic trend for Sea Level Rise was calculated at 0.965 mm/year based on long term trends measured at Charlotte Amalie, Virgin Islands (NOAA station 9751639) and San Juan, Puerto Rico (9755371). This historical trend is lower than the global average that is approximately 1.5 mm/year indicating that local effects in this region protect it to some degree from the effects of sea level rise.

There is significant uncertainty relating the elevation data which is listed as having a vertical datum of NAVD88 to Mean Sea Level for the Caribbean Region. The NAVD88 correction is generally available through the NOAA CO-OPS database but not for the Caribbean region, possibly because

NAVD88 is not considered "relevant" to the Caribbean. Nonetheless, NED metadata indicates that elevation data from the Caribbean are related to the NAVD88 basis.

The estimate for this relationship used in modeling was derived using the average of the closest NOAA stations in the CO-OPS database being Ocean Reef Harbor, Key Largo (#8723519); Rock Harbor Inside (#8723688); Duck Key (#8723927); Key Colony Beach (#8723962), and Islamorada, Whale Harbor Channel (#8723797). The average correction was -0.28 meters. This was the same procedure used in (Padilla Nieves, 2008) when the model was applied to Puerto Rico. That paper states: "transferring such leveling data carries significant uncertainty because NAVD88 elevation is based on site specific mean sea levels that may not be consistent from one location to another."

The oceanic tide range was calculated using the average of the two closest NOAA stations, being: St. Johns Island, Coral Harbor, VI (9751373) and Lime Tree Bay, St. Croix, VI (9751401).

Parameters pertaining to marshes (i.e. accretion rates and erosion rates) are not relevant to this site as there are no wetlands identified based on the National Wetlands Inventory. Default values are therefore used, though the model will not be sensitive to those choices.

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.

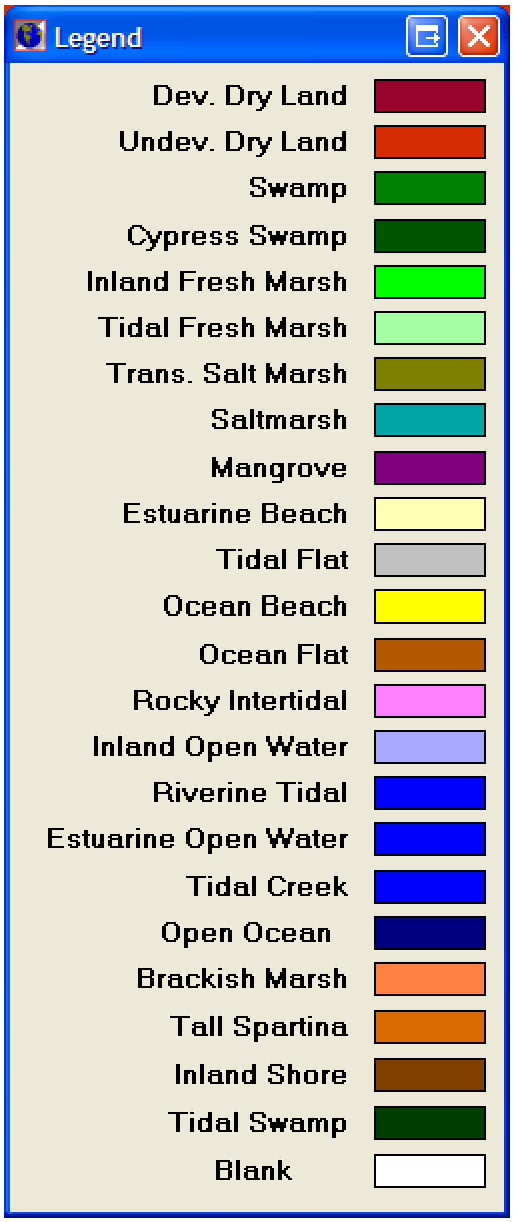
SLAMM INPUT PARAMETERS FOR GREEN CAY

Site	Green Cay
NED Source Date (yyyy)	1954
NWI_photo_date (yyyy)	1985
Direction_OffShore (N|S|E|W)	N
Historic_trend (mm/yr)	0.965
NAVD88_correction (MTL-NAVD88 in meters)	-0.28
TideRangeOcean (meters: MHHW-MLLW)	0.216
TideRangeInland (meters)	0.216
Mean High Water Spring (m above MTL)	0.144
MHSW Inland (m above MTL)	0.144
Marsh Erosion (horz meters/year)	1.8
Swamp Erosion (horz meters/year)	1
TFlat Erosion (horz meters/year) [from 0.5]	2
Salt marsh vertical accretion (mm/yr) Final	3.9
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)	0.5
Frequency of Large Storms (yr/washover)	25
Use Elevation Preprocessor for Wetlands	TRUE

Results

Results for this site indicate that there are no effects for this site until there is at least one meter of sea level rise at which point 4% of dry land is lost to open water or ocean beach. When 1.5 meters of eustatic sea level rise occurs, 7% of dry land is predicted to be lost.

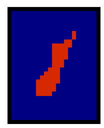
Maps of SLAMM input and output to follow will use the following legend:



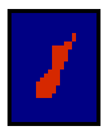
Green Cay
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

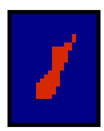
	Initial	2025	2050	2075	2100
Open Ocean	113.0	113.0	113.0	113.0	113.0
Dry Land	13.1	13.1	13.1	13.1	13.1
Ocean Beach	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	126.1	126.1	126.1	126.1	126.1



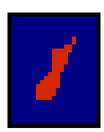
Initial Condition



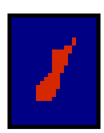
2025 IPCC Scenario A1B-Mean Green Cay



2050 IPCC Scenario A1B-Mean Green Cay



2075 IPCC Scenario A1B-Mean Green Cay

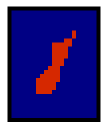


2100 IPCC Scenario A1B-Mean Green Cay

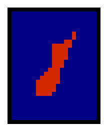
Green Cay
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

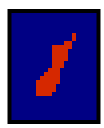
	Initial	2025	2050	2075	2100
Open Ocean	113.0	113.0	113.0	113.0	113.1
Dry Land	13.1	13.1	13.1	13.1	13.0
Ocean Beach	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	126.1	126.1	126.1	126.1	126.1



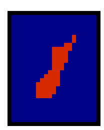
Initial Condition



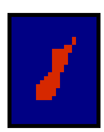
2025 IPCC Scenario A1B-Maximum Green Cay



2050 IPCC Scenario A1B-Maximum Green Cay



2075 IPCC Scenario A1B-Maximum Green Cay

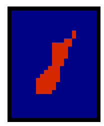


2100 IPCC Scenario A1B-Maximum Green Cay

Green Cay
1 Meter Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Open Ocean	113.0	113.0	113.0	113.1	113.2
Dry Land	13.1	13.1	13.1	13.0	12.6
Ocean Beach	0.0	0.0	0.1	0.0	0.3
Total (incl. water)	126.1	126.1	126.1	126.1	126.1



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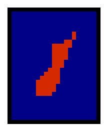
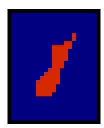
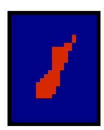


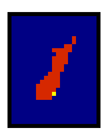
2025, 1 meter Eustatic by 2100 Green Cay



2050, 1 meter Eustatic by 2100 Green Cay



2075, 1 meter Eustatic by 2100 Green Cay

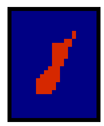


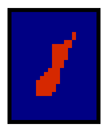
2100, 1 meter Eustatic by 2100 Green Cay

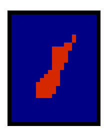
Green Cay
1.5 Meters Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Open Ocean	113.0	113.0	113.1	113.2	113.9
Dry Land	13.1	13.1	13.0	12.5	12.2
Ocean Beach	0.0	0.0	0.0	0.3	0.0
Total (incl. water)	126.1	126.1	126.1	126.1	126.1


Initial Condition


2025, 1.5 meter Eustatic by 2100 Green Cay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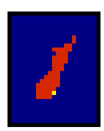
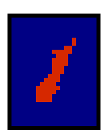

2075, 1.5 meter Eustatic by 2100 Green Cay


2100, 1.5 meter Eustatic by 2100 Green Cay

Discussion

Green Cay does not appear to be particularly susceptible to damage due to global sea level rise within the next century. The most obvious uncertainty in this analysis is the poor resolution of the elevation data. However, given the significant vertical relief at this location, it seems unlikely that predicted losses will be greater than 7%, even given a better data set.

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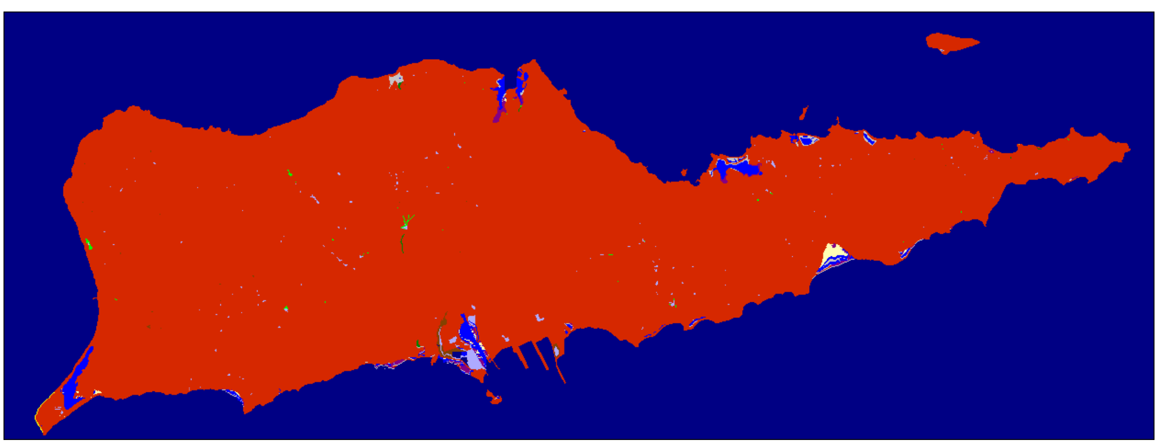
Appendix A: Contextual Results

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.

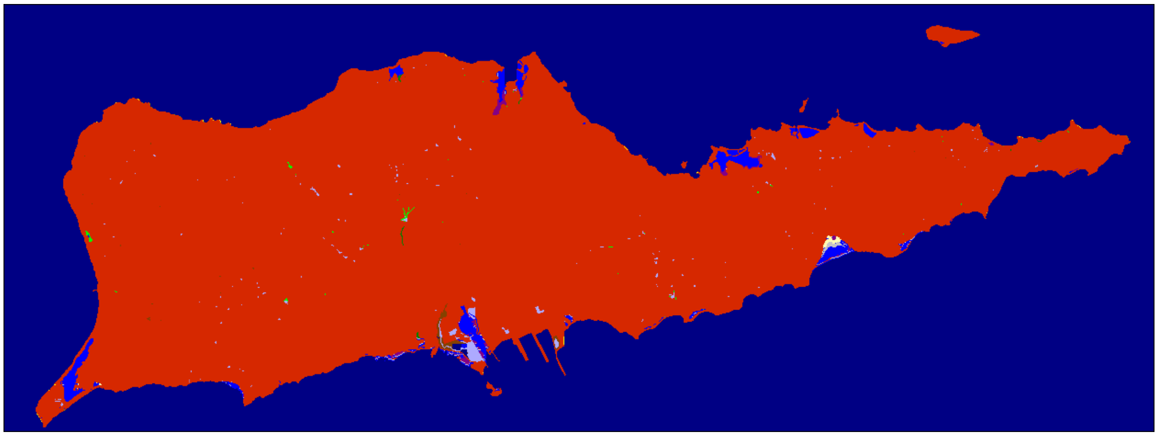
For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

- 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.

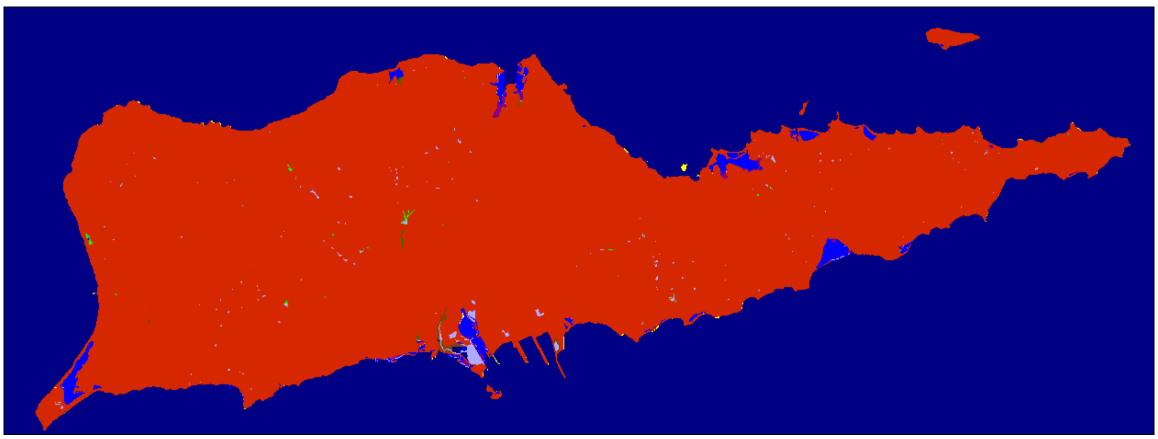
Croix Initial Condition IPCC Scenario A1B-Mean



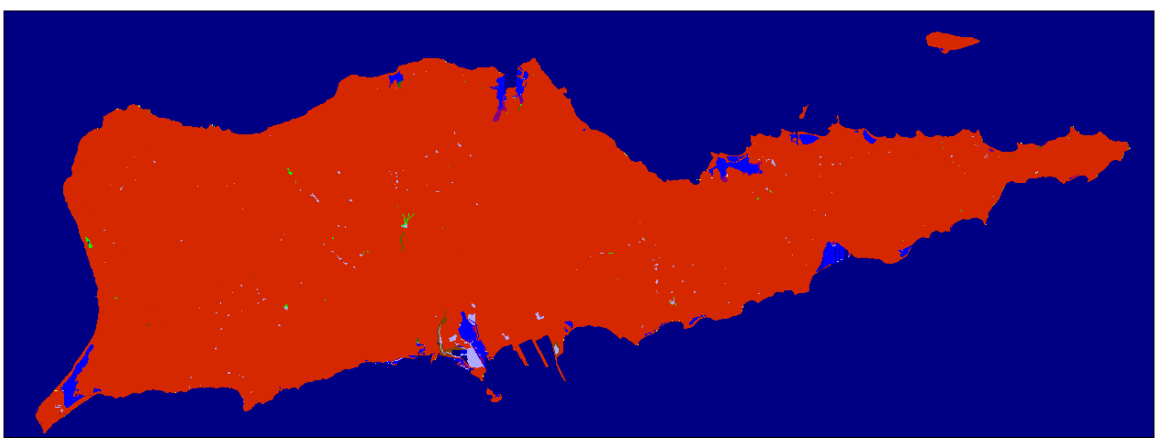
Croix 2025 IPCC Scenario A1B-Mean



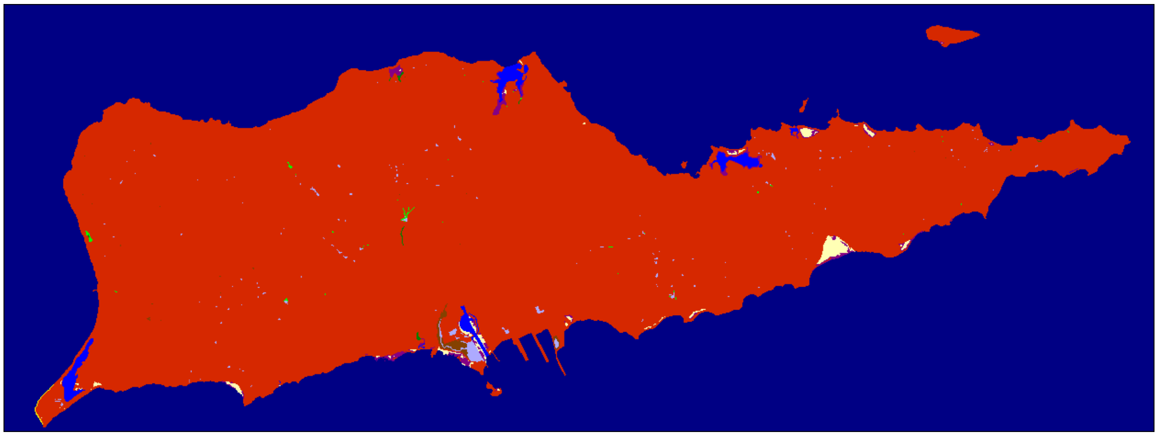
Croix 2050 IPCC Scenario A1B-Mean



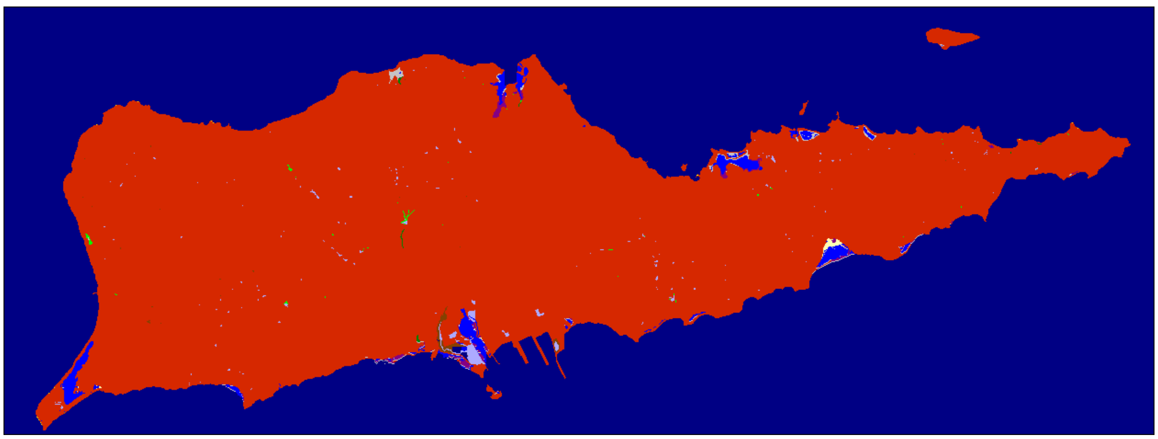
Croix 2075 IPCC Scenario A1B-Mean



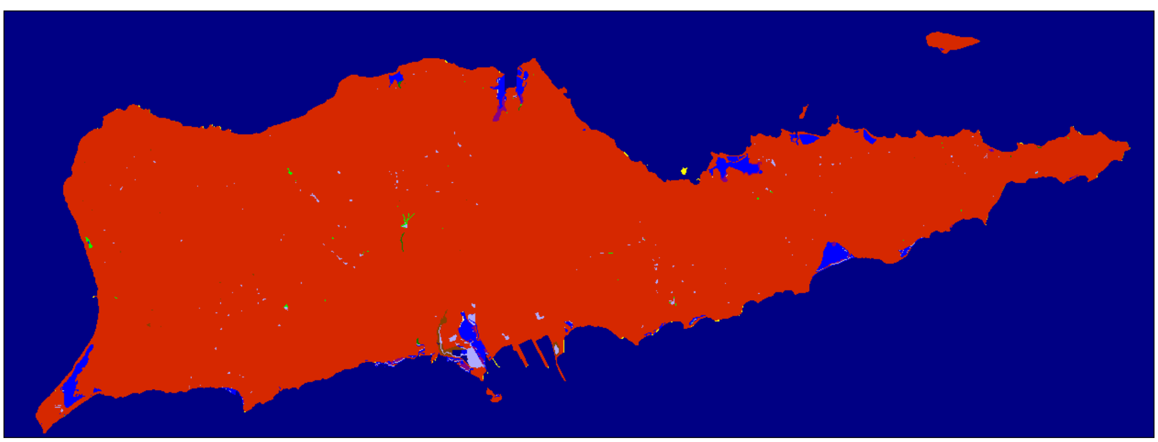
Croix 2100 IPCC Scenario A1B-Mean



Croix Initial Condition



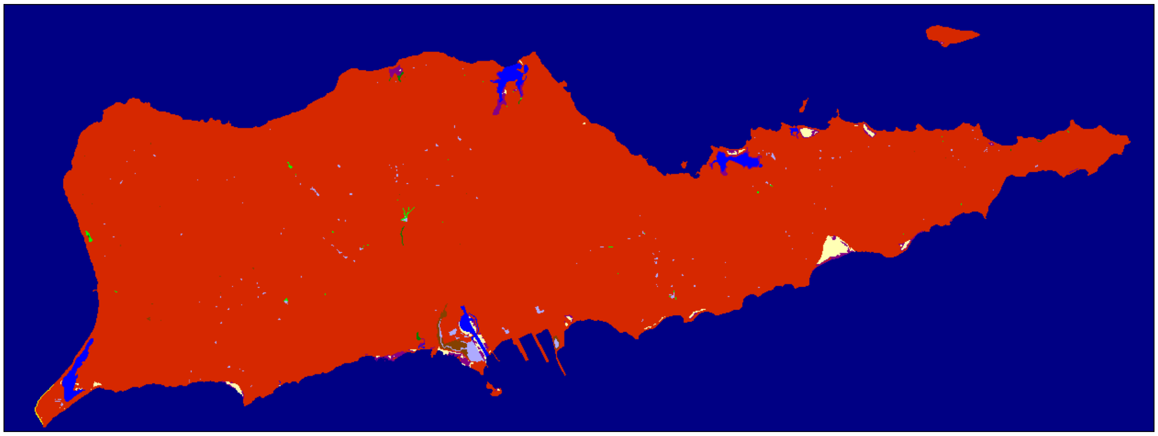
Croix 2025 IPCC Scenario A1B-Maximum



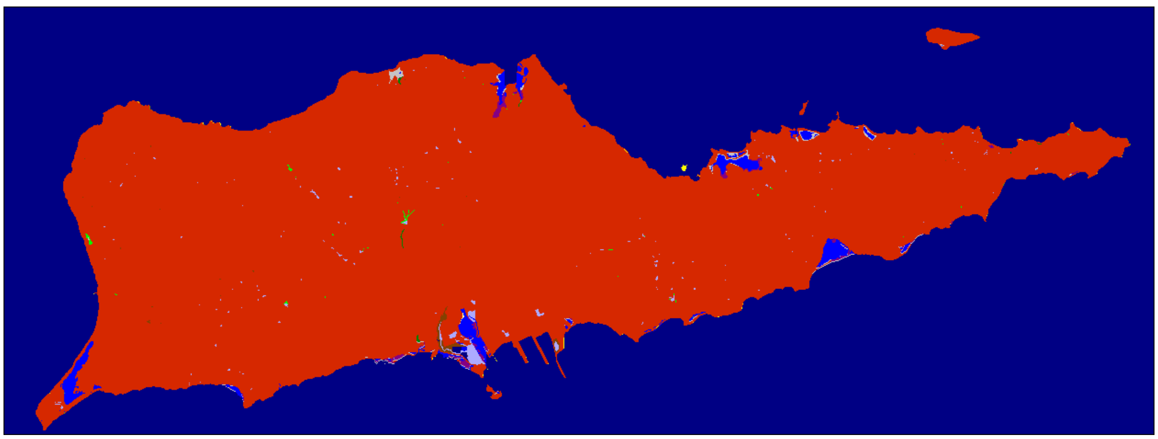
Croix 2050 IPCC Scenario A1B-Maximum


Croix 2075 IPCC Scenario A1B-Maximum

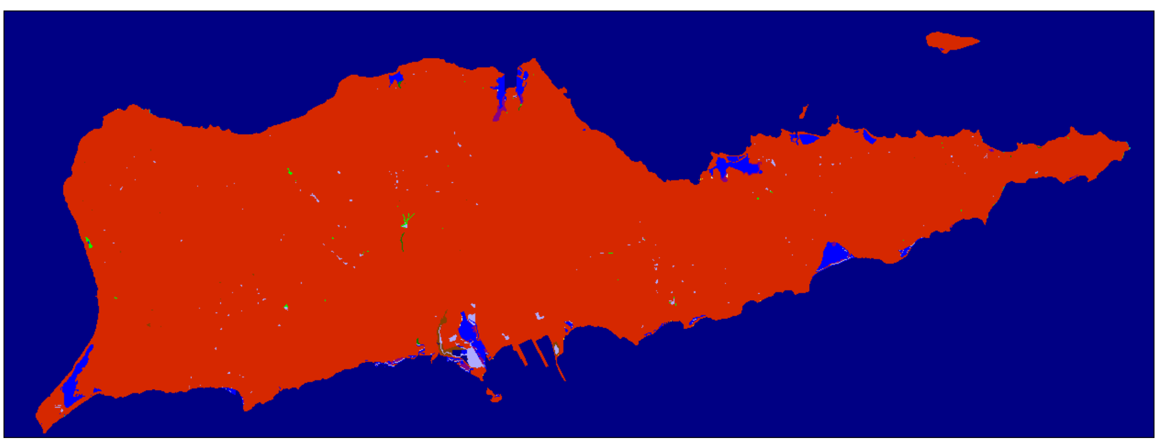

Croix 2100 IPCC Scenario A1B-Maximum



Croix Initial Condition



Croix 2025 1 meter Eustatic by 2100



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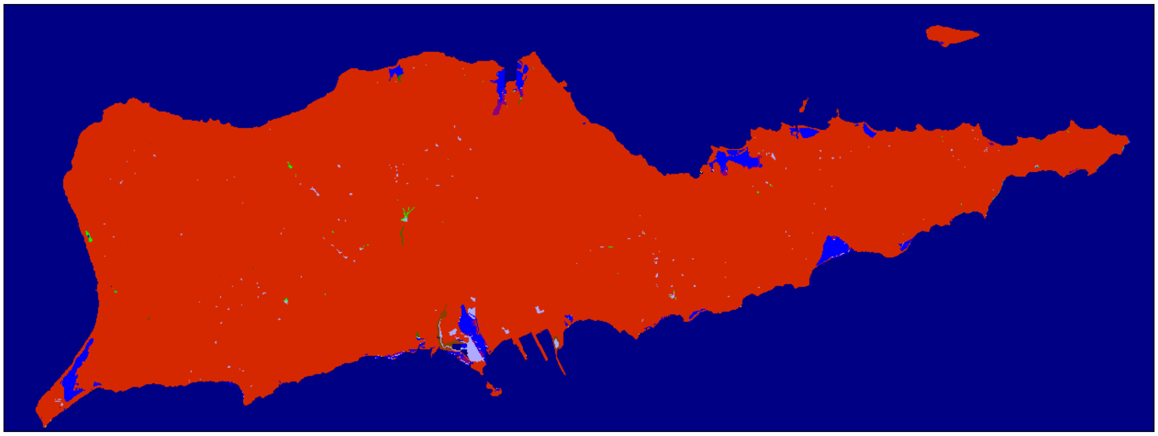
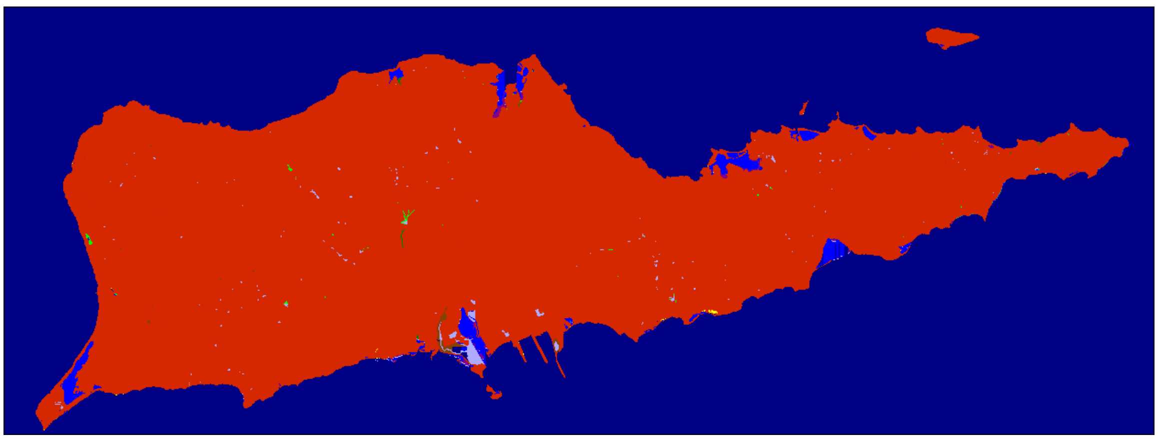


Croix 2075 1 meter Eustatic by 2100



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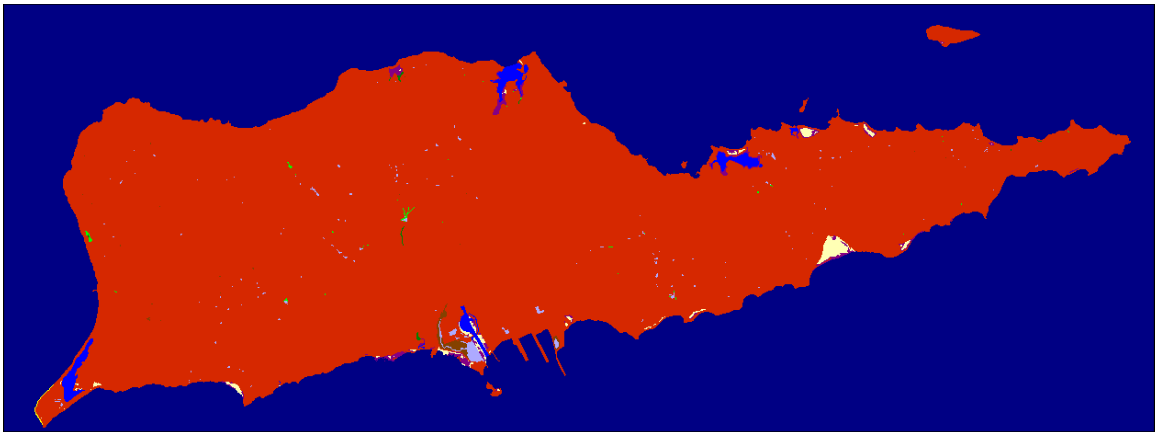
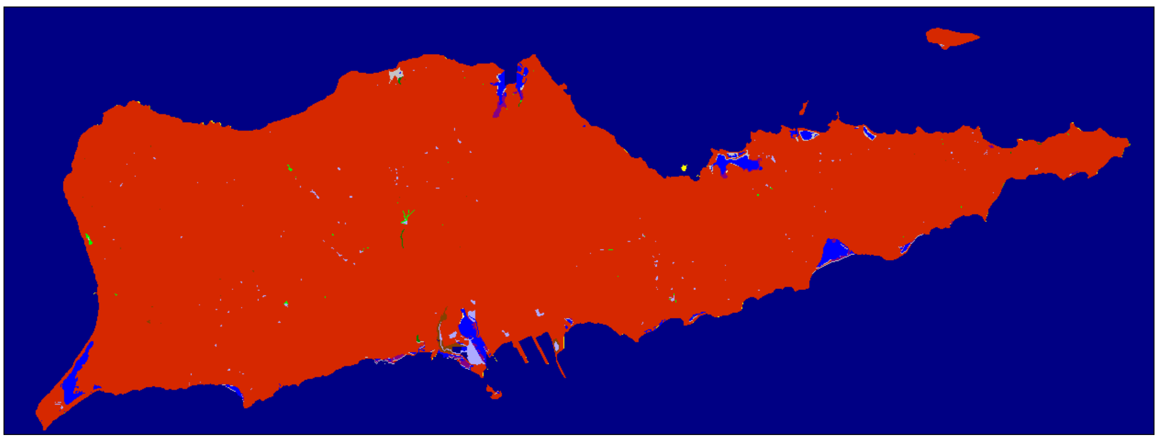

Croix Initial Condition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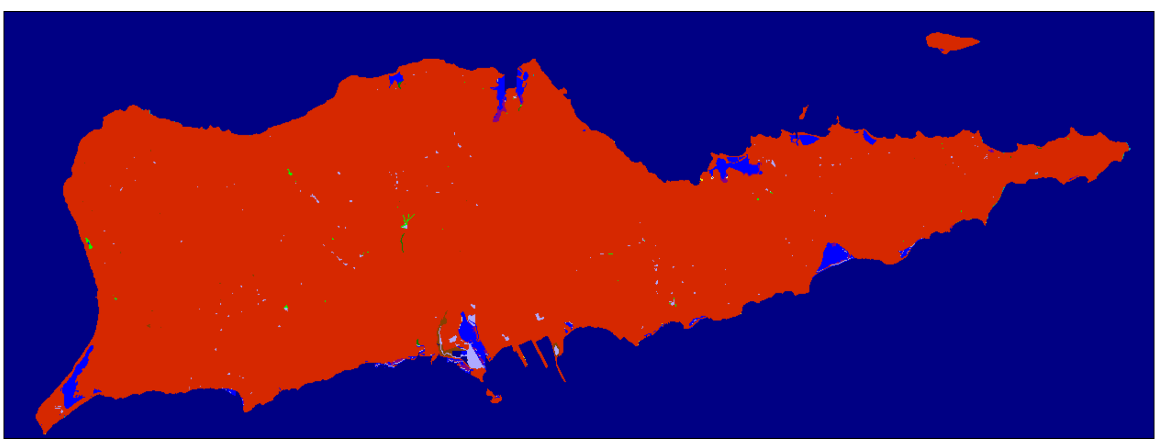
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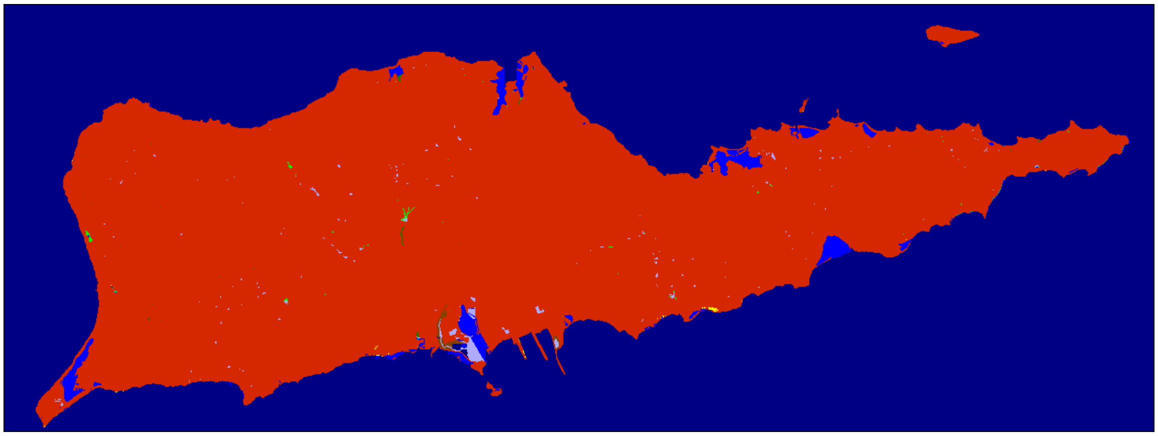
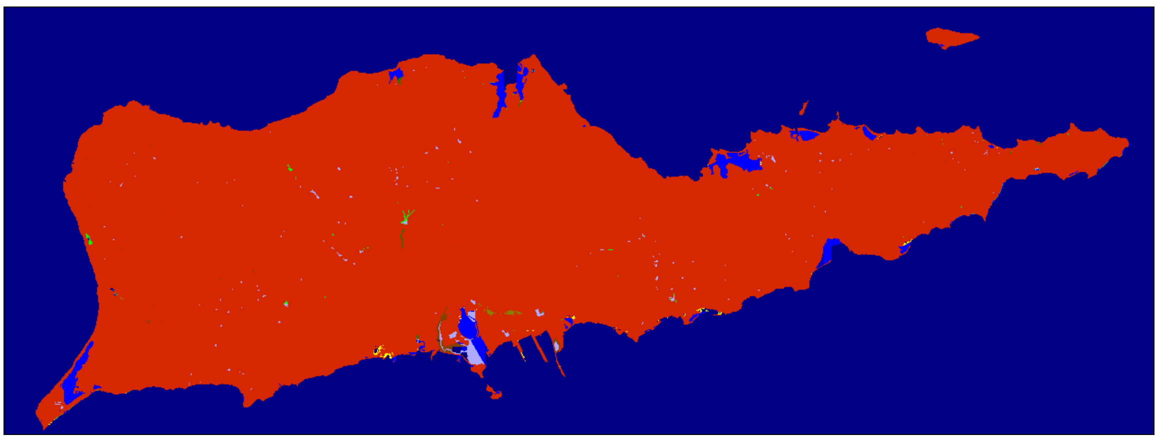

Croix 2075 1.5 meter Eustatic by 2100


Croix 2100 1.5 meter Eustatic by 2100