Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Passage Key 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 Passage Key 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

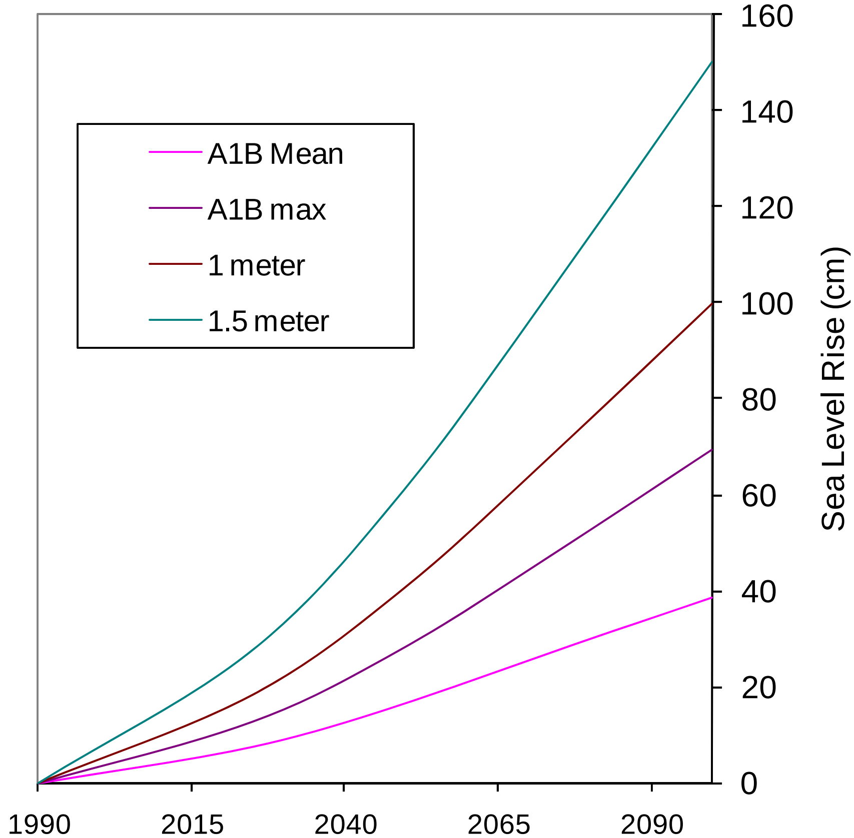
Sea-Level Rise Scenarios

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).

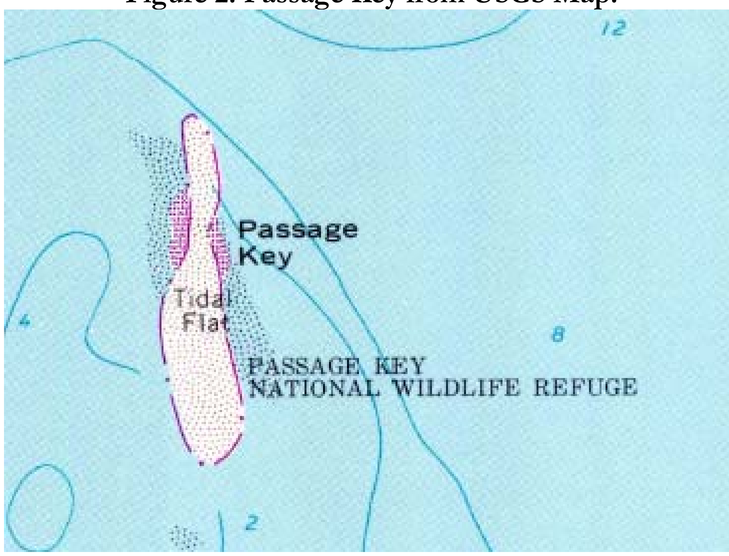
Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

No LIDAR data were found for Passage Key NWR so elevation data are based on the National Elevation Dataset (NED). (LIDAR data are available near the study area but the geographic domain of that survey was on the mainland to the east of Passage Key.) An examination of the metadata for the NED indicates that the data were derived from a 1963 survey illustrated 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: Passage Key from USGS Map.



Looking at this map for Passage Key, there are no contours drawn on this island indicating that all land is below the five foot contour.

The National Wetlands Inventory for Passage Key is based on a photo date of 1983. This survey, when converted to 30 meter cells, suggests that at that time, the island was composed of approximately 60 acres of tidal flats, 21 acres of estuarine beach, and 10.5 acres of dry land. Model predictions of effects due to sea level rise are run forward from 1983 as this was the date of the wetlands survey for this site.

The historic trend for Sea Level Rise was calculated at 2.4 mm/year based on long term trends measured at St. Petersburg, Florida (NOAA station 8726520). Other long term trends measured within the vicinity of St. Petersburg range from 2.3 mm/year in Fort Myers (8725520) to 2.8 mm/year measured at Clearwater Beach (8726724). This historical trend is higher than the global average for the last 100 years (approximately 1.5 mm/year) indicating that local sea level rise is somewhat greater than eustatic sea level rise in this region.

The oceanic tide range was estimated at 0.657 meters using the closest NOAA station, Egmont Key, Tampa Bay, FL (8726347). Data from Anna Maria City Pier (8726282) and Mullet Key, Tampa Bay (8726364) were within 4% of this level. The map vertical datum of NAVD88 was related to mean tide level using data gathered from Egmont Key (8726347).

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, nor are any wetlands predicted to appear. 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.

A conference call was held with the refuge managers for Passage Key in June of 2008. Apparently, as of the present date, the refuge is permanently inundated with water due to recent storm activity.

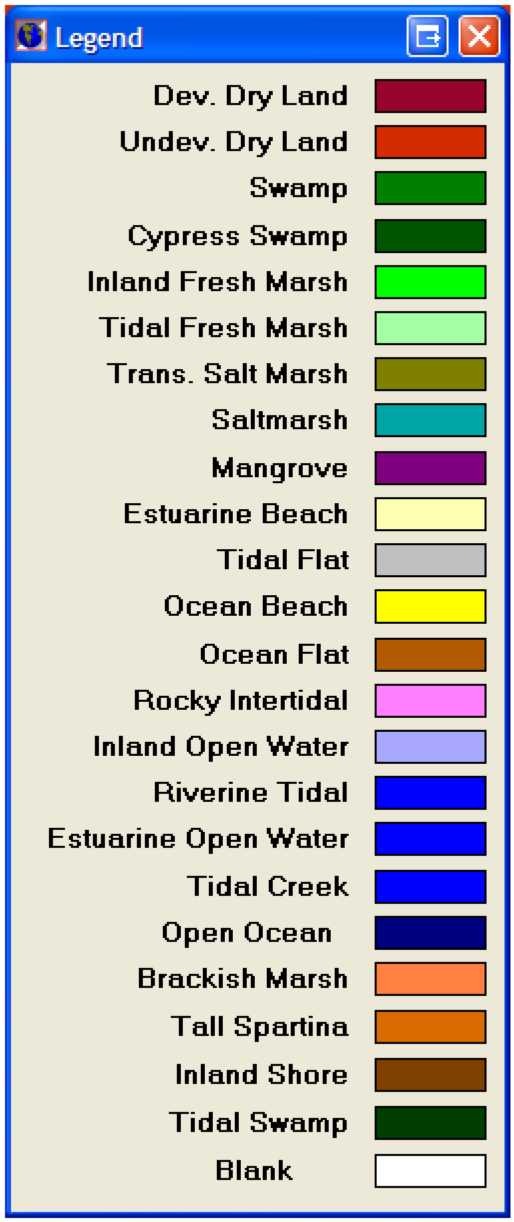
SLAMM INPUT PARAMETERS FOR PASSAGE KEY

Site	Passage Key
NED Source Date (yyyy)	1963
NWI_photo_date (yyyy)	1983
Direction_OffShore (N|S|E|W)	W
Historic_trend (mm/yr)	2.4
NAVD88_correction (MTL-NAVD88 in meters)	-0.138
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	0.657
TideRangeInland (meters)	0.657
Mean High Water Spring (m above MTL)	0.437
MHSW Inland (m above MTL)	0.437
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	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

Under even the lowest rate of sea level rise tested, the island is predicted to all-but disappear as a function of inundation, erosion, and overwash events. However, given that the island has already been submerged at the present date, this indicates that the model predictions are, in fact, too conservative for this region.

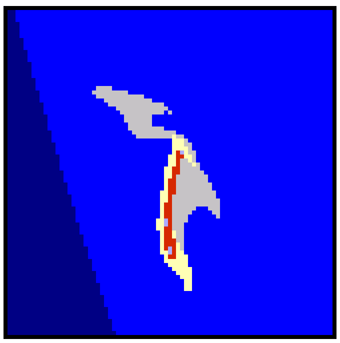
Maps of SLAMM input and output to follow will use the following legend:

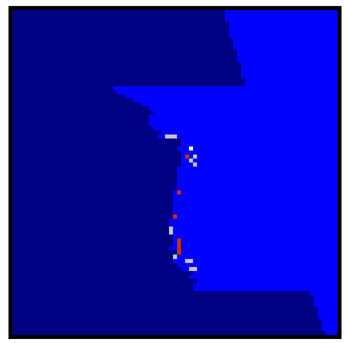


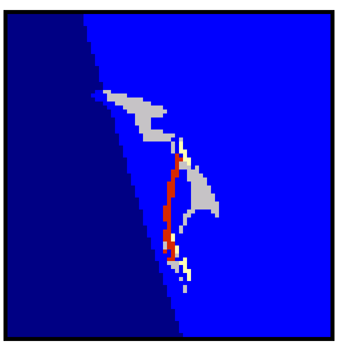
Passage Key
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

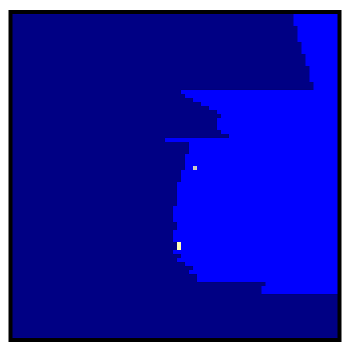
Results in Acres

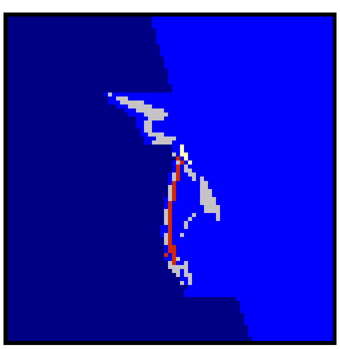
	Initial	2025	2050	2075	2100
Open Water	1366.6	1400.9	1424.7	1451.9	1457.7
Tidal Flat	60.0	43.9	28.1	4.4	0.8
Estuarine Beach	20.9	6.2	1.2	0.8	0.4
Dry Land	10.5	8.0	5.1	2.1	0.2
Inland Open Water	1.1	0.0	0.0	0.0	0.0
Ocean Beach	0.0	0.0	0.1	0.0	0.0
Inland Shore	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**1459.1**	**1459.1**	**1459.1**	**1459.1**	**1459.1**


Initial Condition, Passage Key


2075 IPCC Scenario A1B-Mean Passage Key


2025 IPCC Scenario A1B-Mean Passage Key

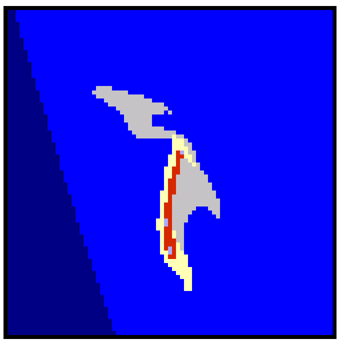

2100 IPCC Scenario A1B-Mean Passage Key


2050 IPCC Scenario A1B-Mean Passage Key

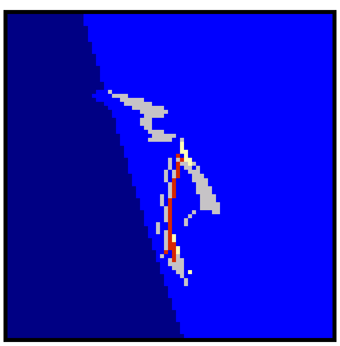
Passage Key
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

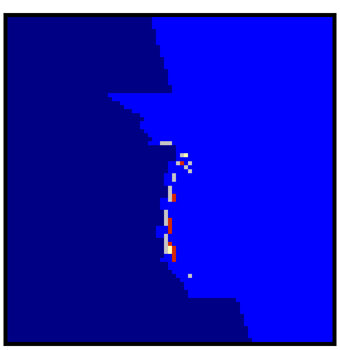
	Initial	2025	2050	2075	2100
Open Water	1366.6	1410.0	1449.9	1456.4	1458.9
Tidal Flat	60.0	38.5	5.3	1.7	0.0
Estuarine Beach	20.9	3.7	1.5	1.0	0.2
Dry Land	10.5	6.8	2.4	0.0	0.0
Inland Open Water	1.1	0.0	0.0	0.0	0.0
Ocean Beach	0.0	0.0	0.0	0.0	0.0
Inland Shore	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**1459.1**	**1459.1**	**1459.1**	**1459.1**	**1459.1**



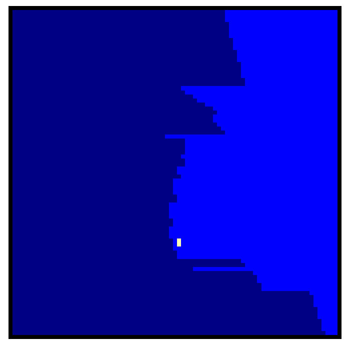
Initial Condition, Passage Key



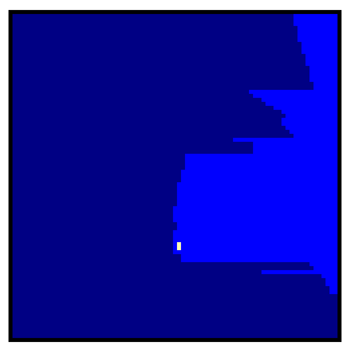
2025 IPCC Scenario A1B-Max. Passage Key



2050 IPCC Scenario A1B-Max.Passage Key



2075 IPCC Scenario A1B-Max. Passage Key

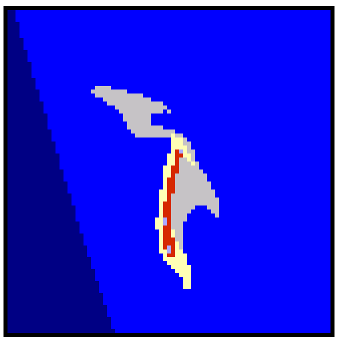


2100 IPCC Scenario A1B-Max. Passage Key

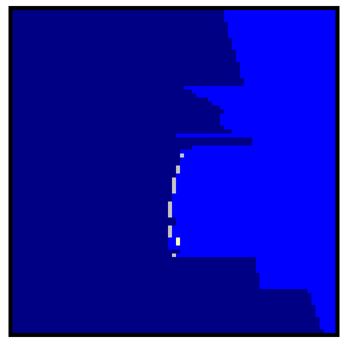
Passage Key
1 Meter Eustatic SLR by 2100

Results in Acres

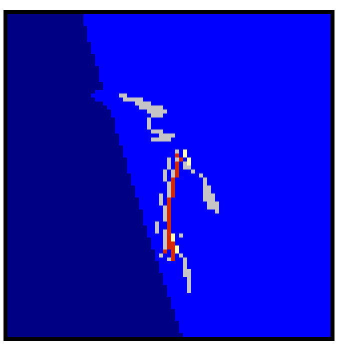
	Initial	2025	2050	2075	2100
Open Water	1366.6	1423.8	1451.4	1456.2	1459.1
Tidal Flat	60.0	28.0	5.5	2.7	0.0
Estuarine Beach	20.9	1.9	2.0	0.2	0.0
Dry Land	10.5	5.2	0.3	0.0	0.0
Inland Open Water	1.1	0.0	0.0	0.0	0.0
Ocean Beach	0.0	0.0	0.0	0.0	0.0
Inland Shore	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**1459.1**	**1459.1**	**1459.1**	**1459.1**	**1459.1**



Initial Condition, Passage Key

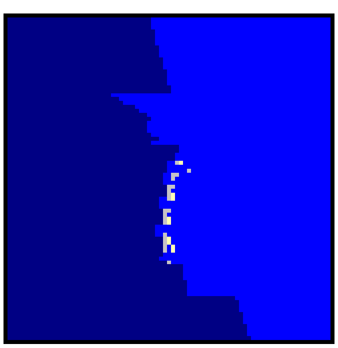


2075 1 meter Eustatic by 2100 Passage Key



2025 1 meter Eustatic by 2100 Passage Key

2100 1 meter Eustatic by 2100 Passage Key

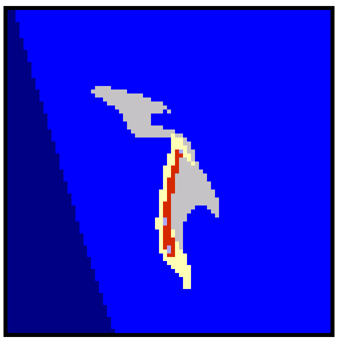


2050 1 meter Eustatic by 2100 Passage Key

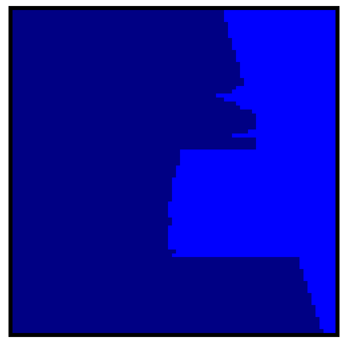
Passage Key
1.5 Meters Eustatic SLR by 2100

Results in Acres

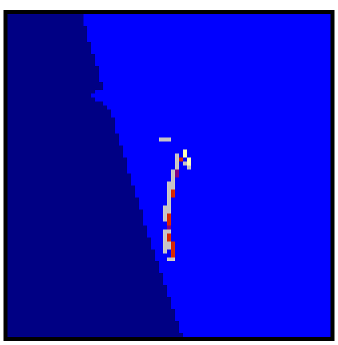
	Initial	2025	2050	2075	2100
Open Water	1366.6	1445.4	1452.7	1459.0	1459.1
Tidal Flat	60.0	9.1	5.6	0.1	0.0
Estuarine Beach	20.9	1.0	0.7	0.0	0.0
Dry Land	10.5	3.1	0.0	0.0	0.0
Inland Open Water	1.1	0.0	0.0	0.0	0.0
Ocean Beach	0.0	0.0	0.0	0.0	0.0
Inland Shore	0.0	0.0	0.0	0.0	0.0
Total (incl. water)	**1459.1**	**1459.1**	**1459.1**	**1459.1**	**1459.1**



Initial Condition, Passage Key

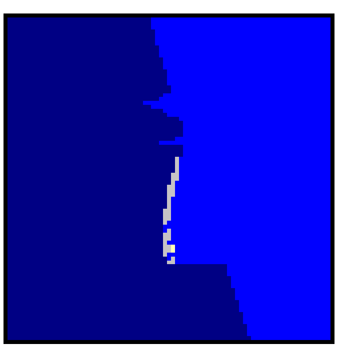


2075 1.5 meter Eustatic by 2100 Passage Key



2025 1.5 meter Eustatic by 2100 Passage Key

2100 1.5 meter Eustatic by 2100 Passage Key



2050 1.5 meter Eustatic by 2100 Passage Key

Discussion

SLAMM model predictions for Passage Key predict severe results in this location. Furthermore, these results have been verified to be overly conservative with respect to submergence, as the island is currently constantly submerged. This overly conservative prediction is likely due to uncertainty in the low vertical-resolution elevation data and uncertainty as to the frequency and intensity of large storms (and therefore predicted overwash effects).

A conversation with refuge managers for this site suggests that Passage Key may reappear due to additional consolidation of submerged sediments and storm activities. The SLAMM model does not estimate such potential consolidation and reemergence of submerged lands. However, the results from this model indicate that permanent reemergence is unlikely due to the increased pressures of rising sea levels.

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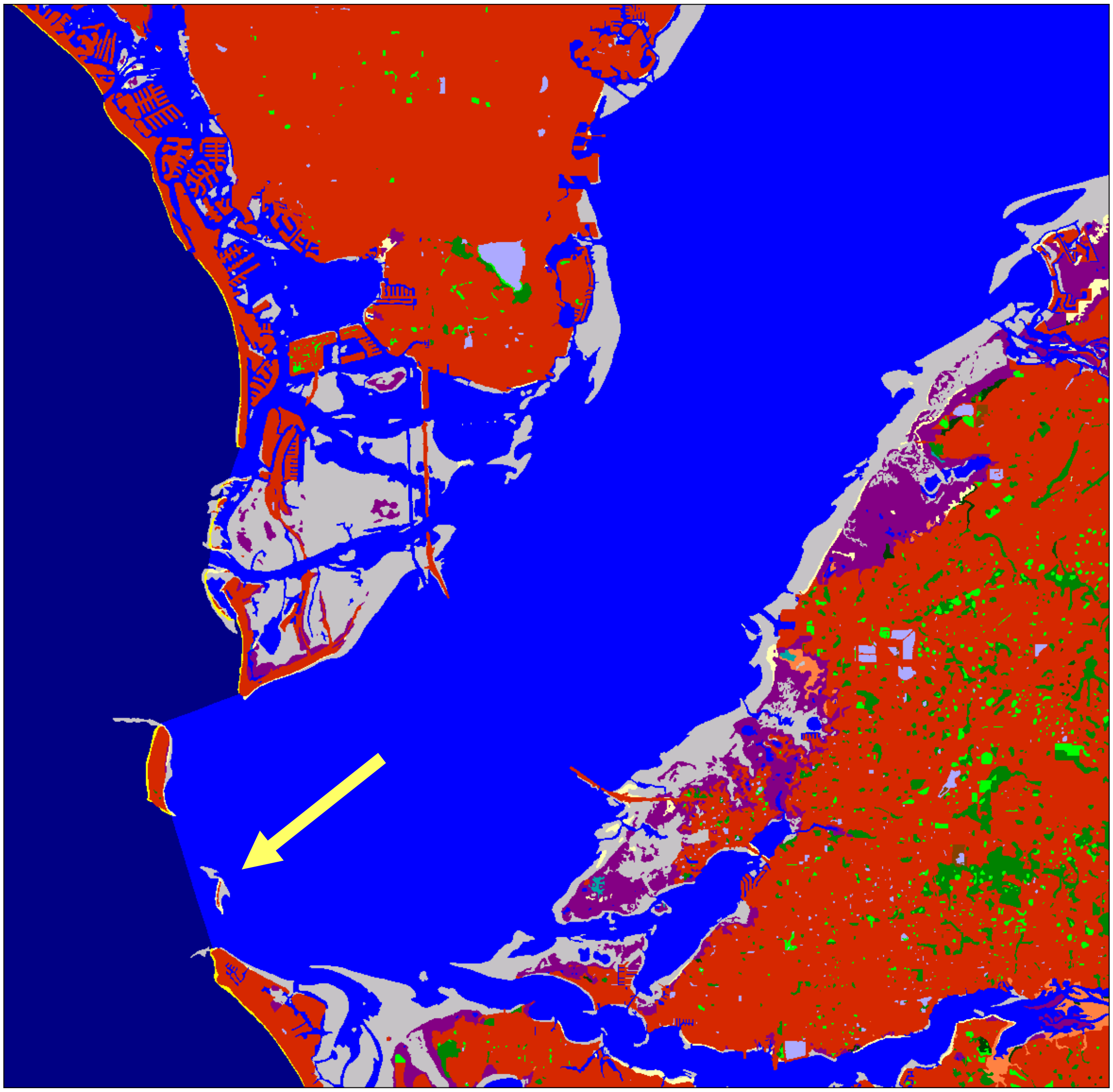
Appendix A: Contextual Results

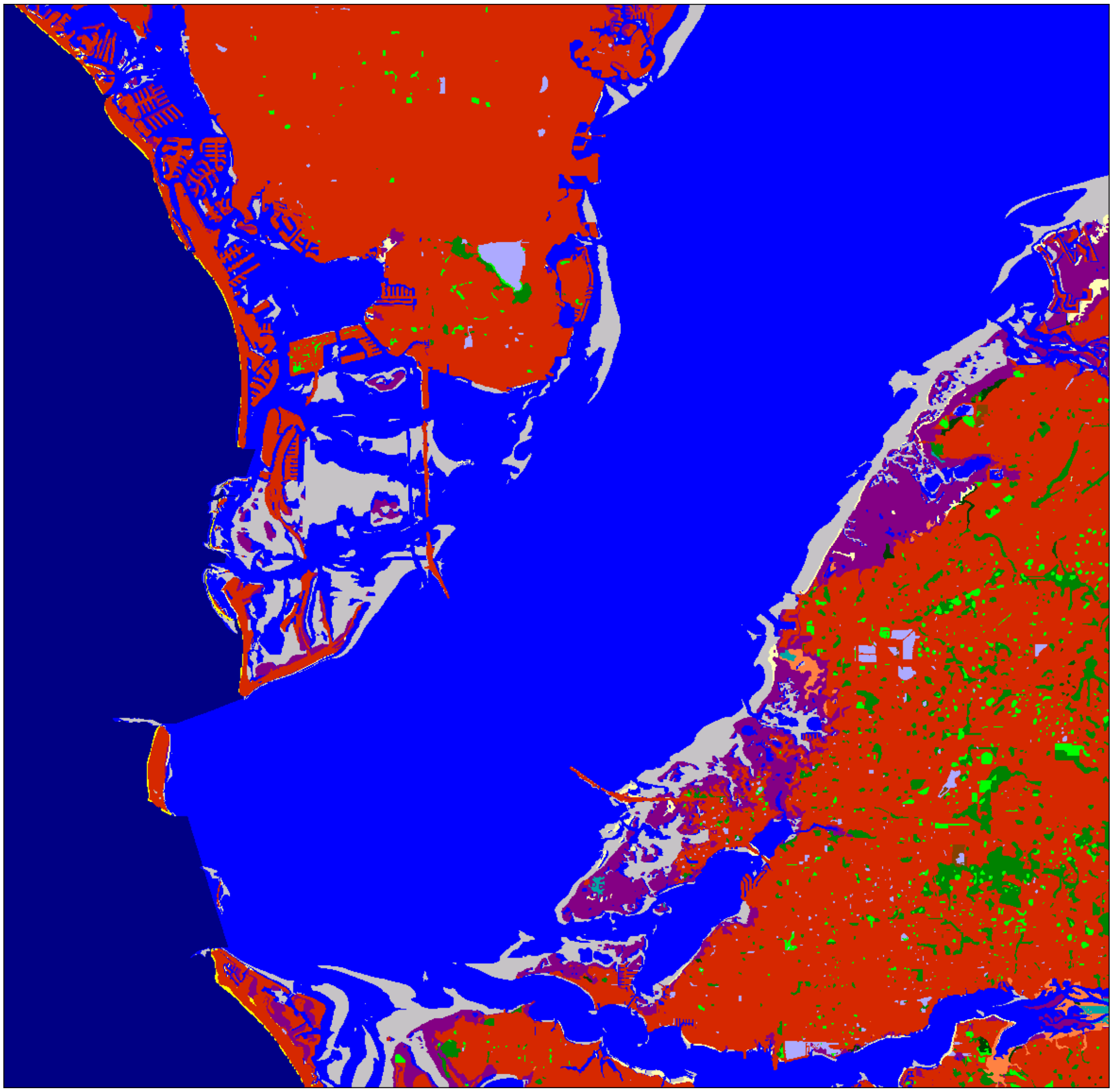
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

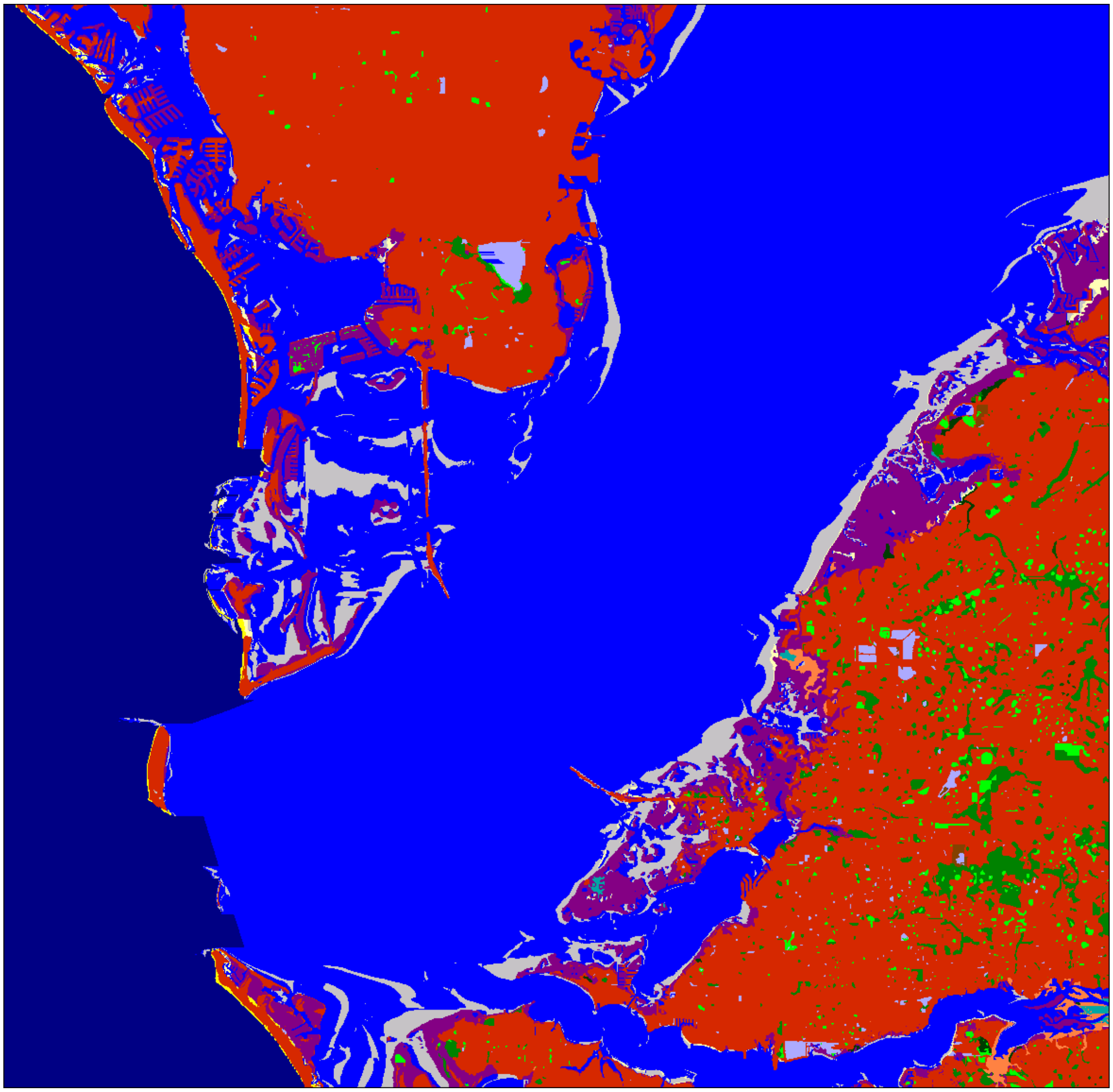
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



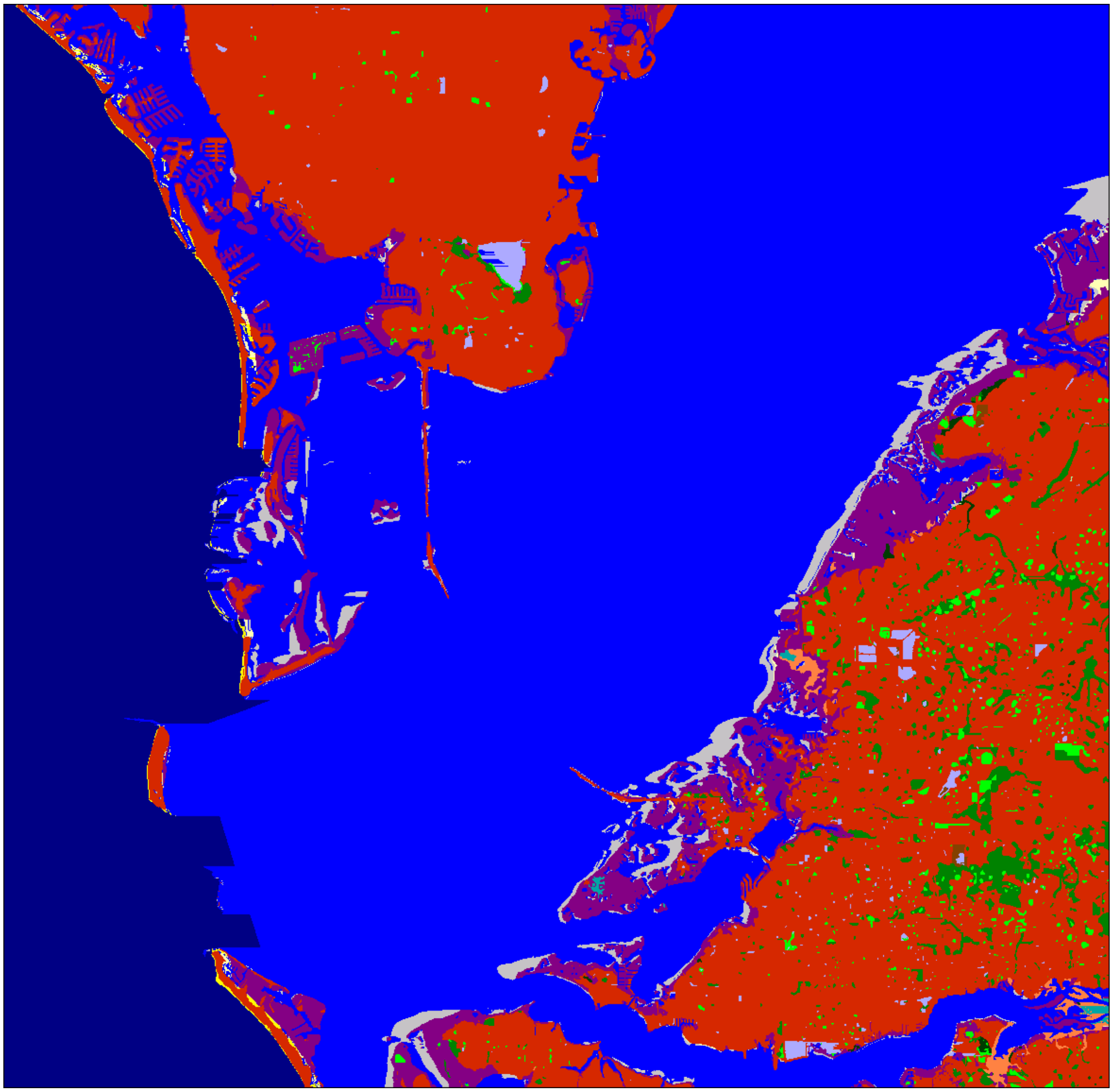
St. Petersburg Area, Initial Condition, Passage Key indicated by yellow arrow



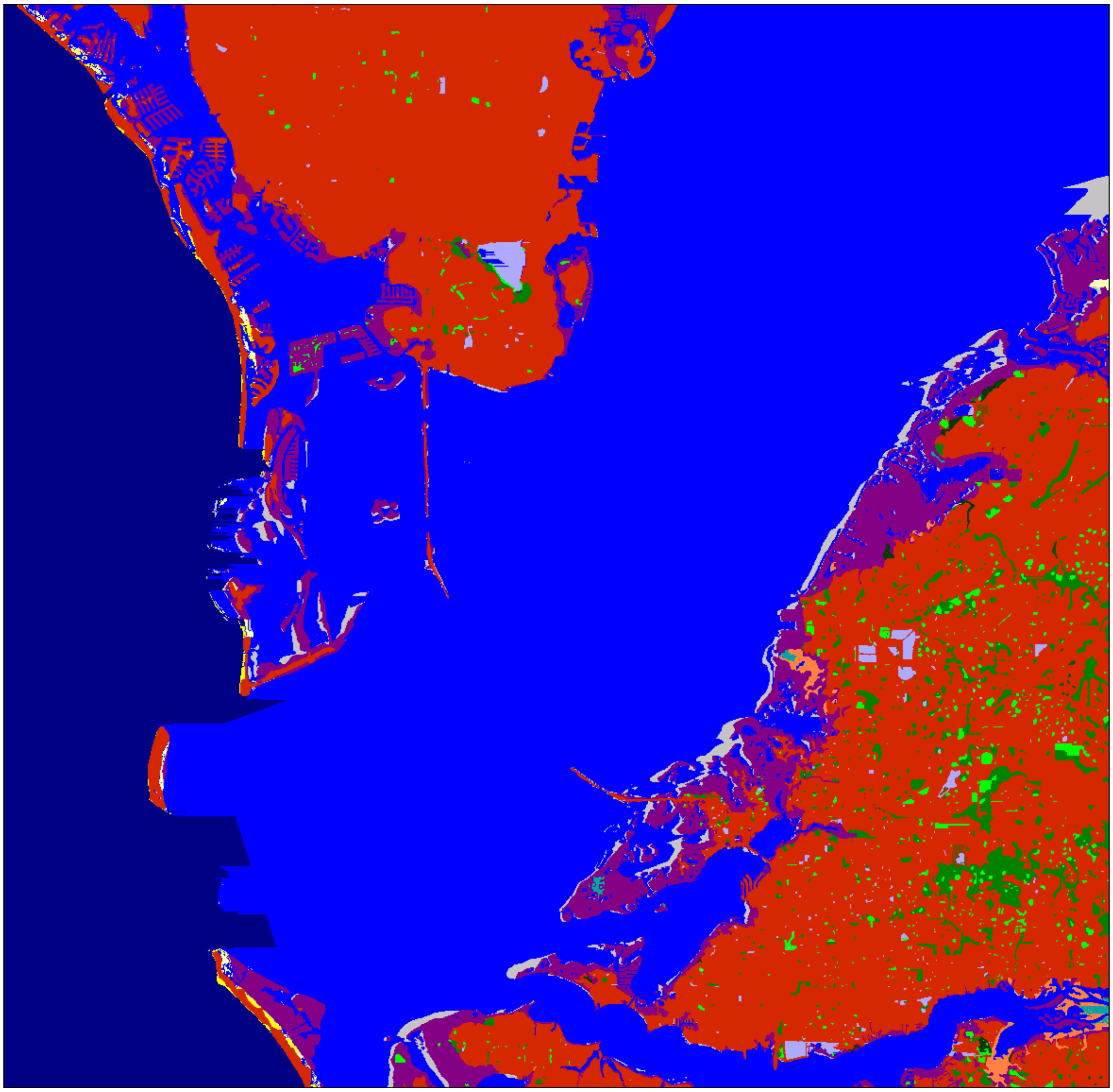
St. Petersburg Area, 2025 IPCC Scenario A1B-Mean



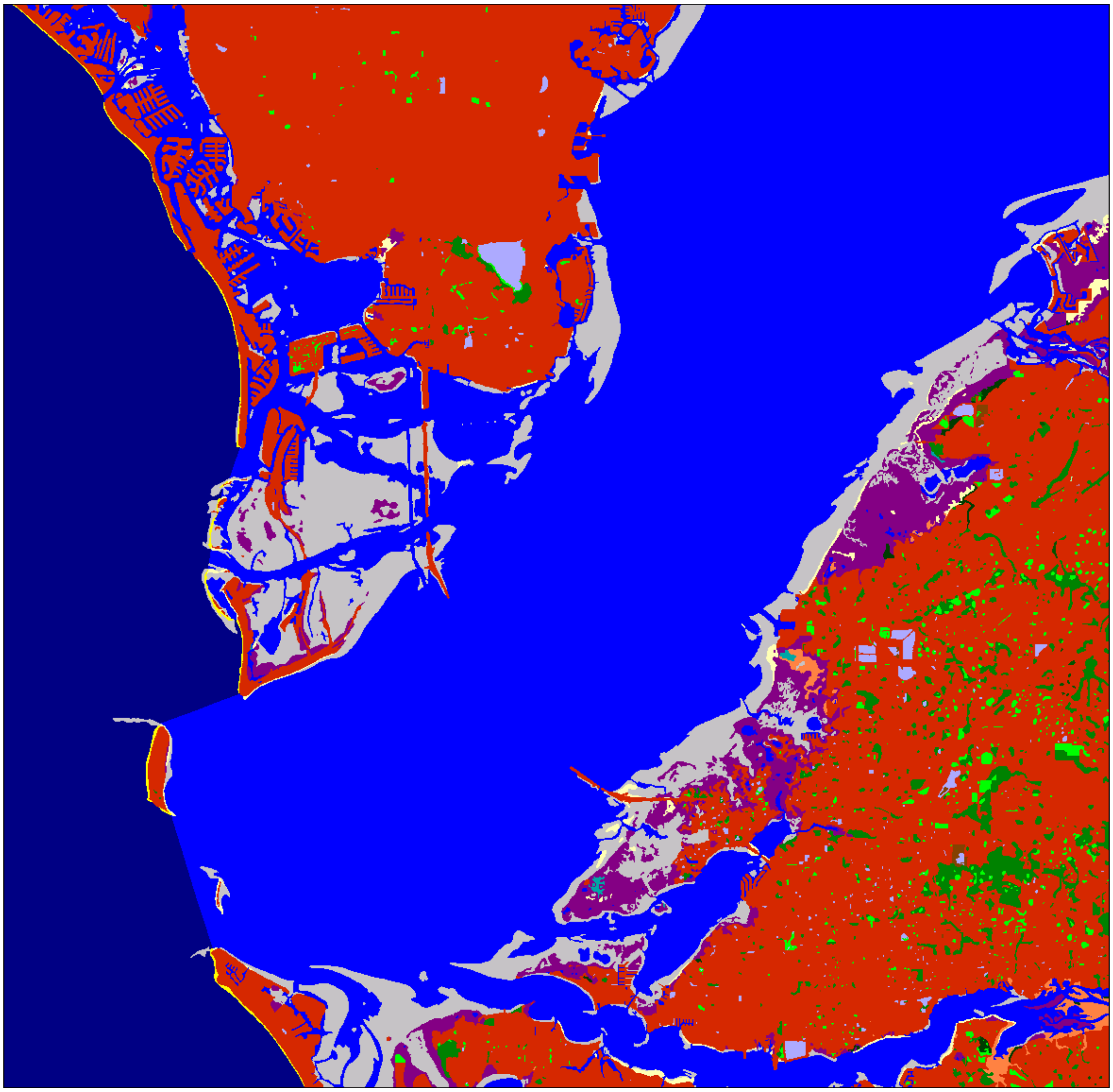
St. Petersburg Area, 2050 IPCC Scenario A1B-Mean



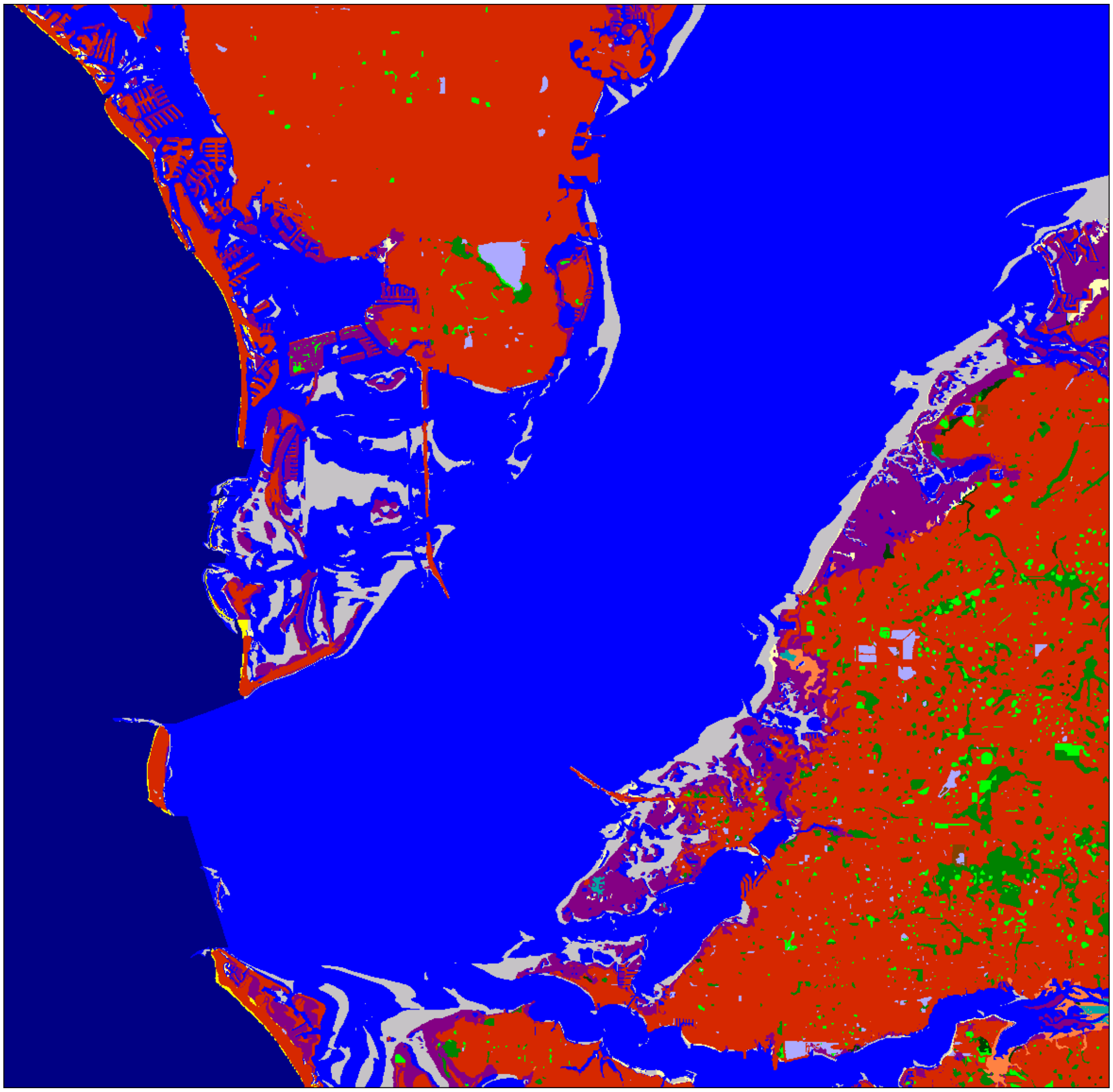
St. Petersburg Area, 2075 IPCC Scenario A1B-Mean



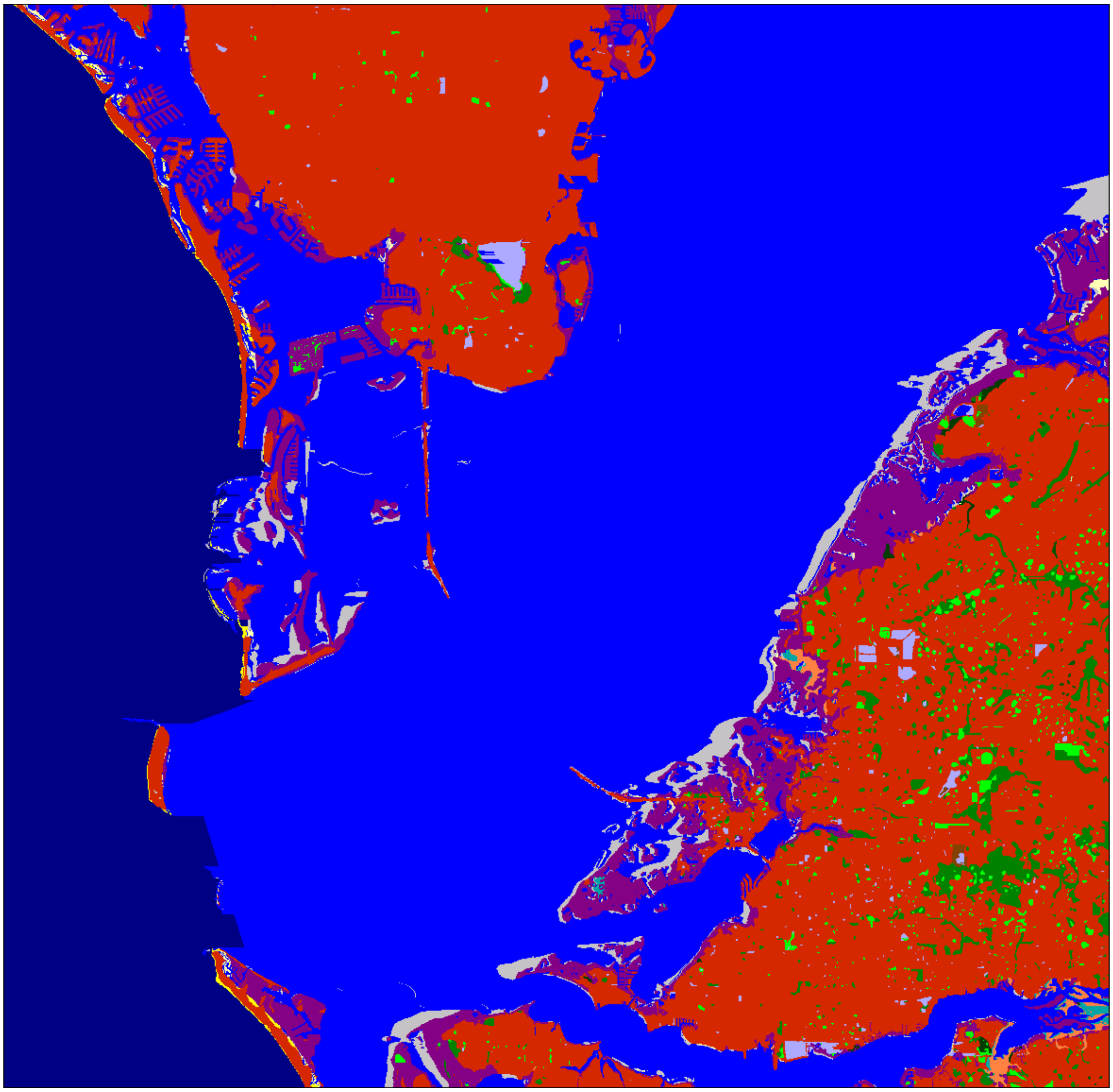
St. Petersburg Area, 2100 IPCC Scenario A1B-Mean



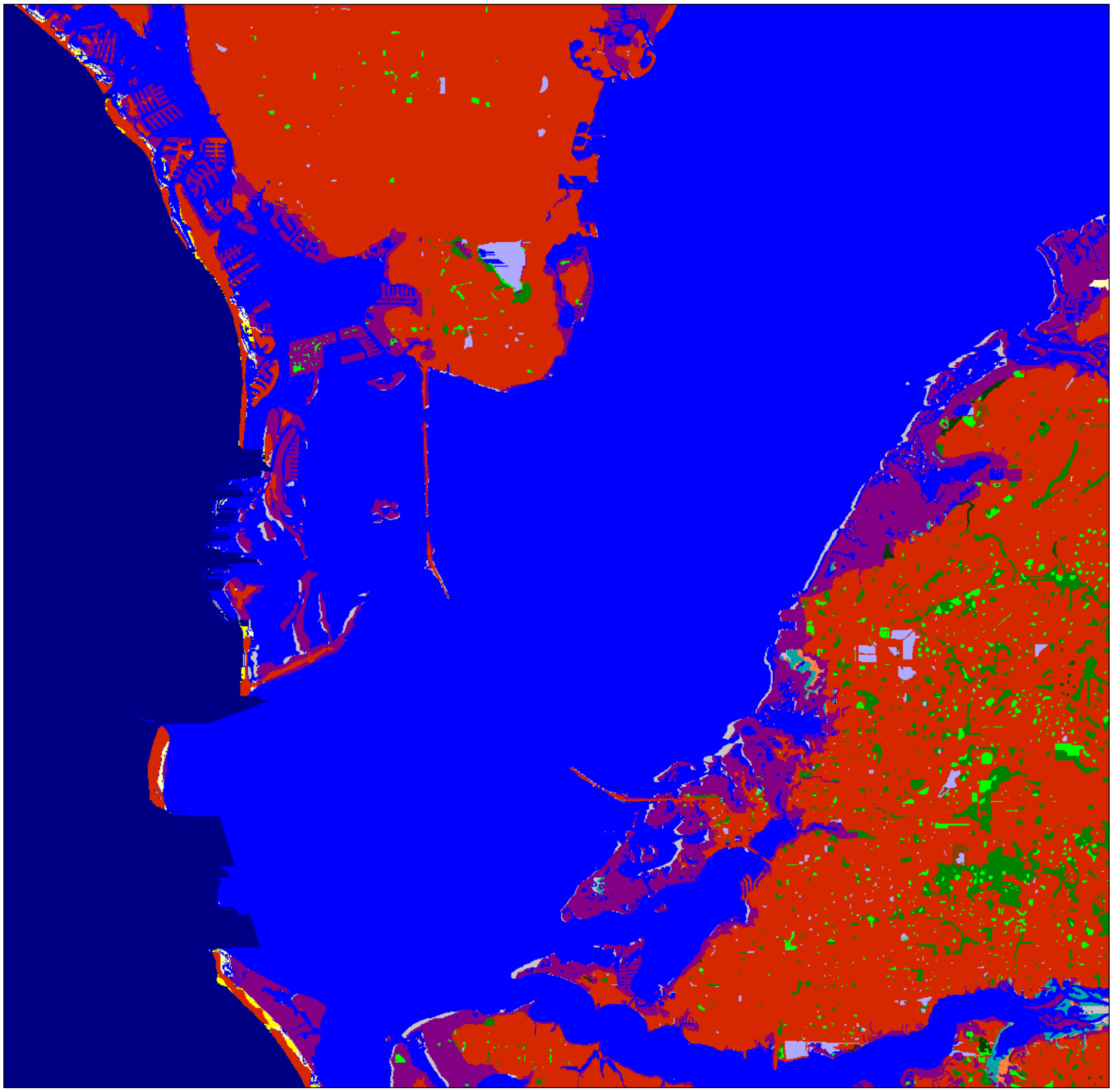
St. Petersburg Area, Initial Condition



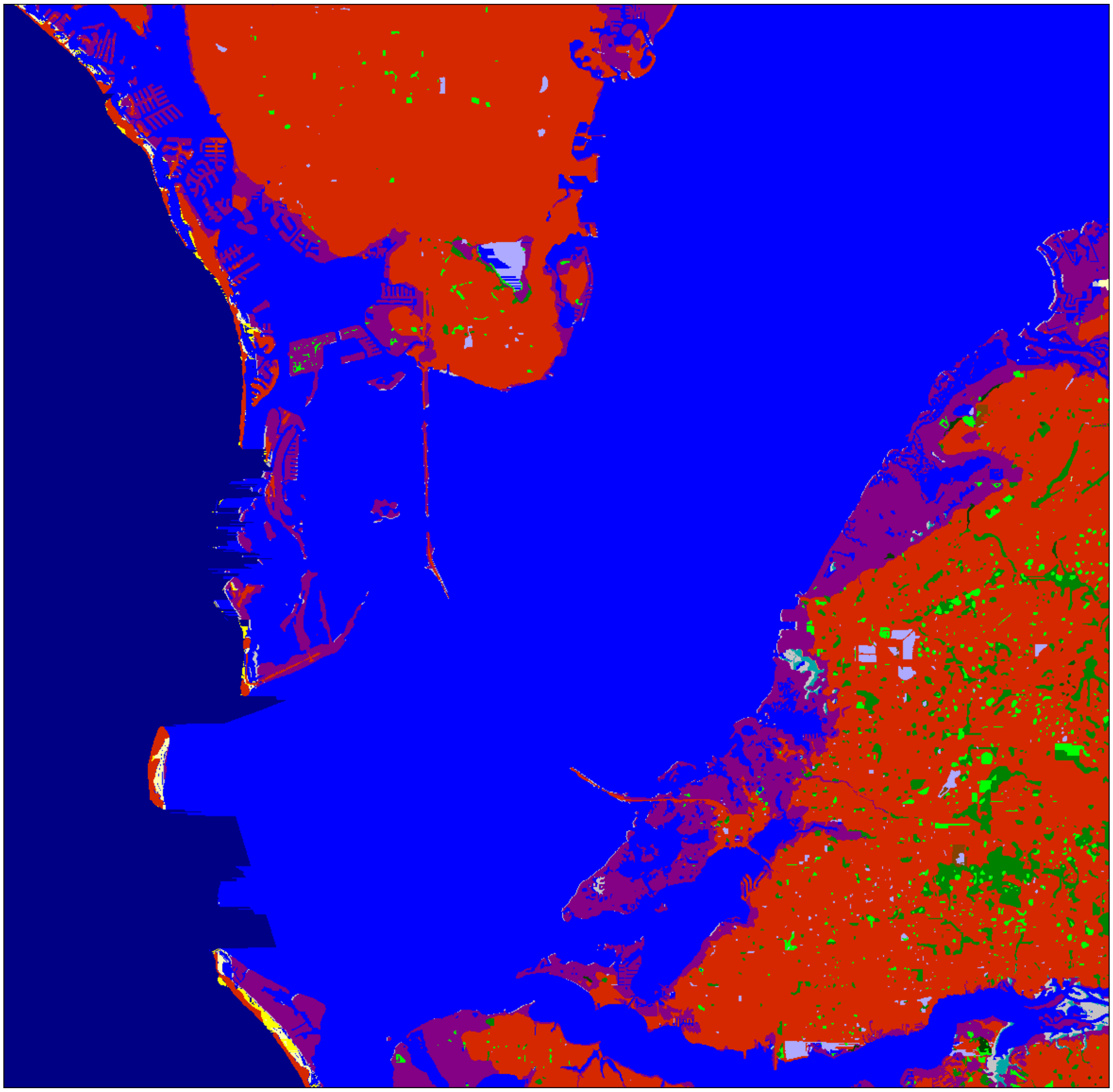
St. Petersburg Area, 2025 IPCC Scenario A1B-Maximum



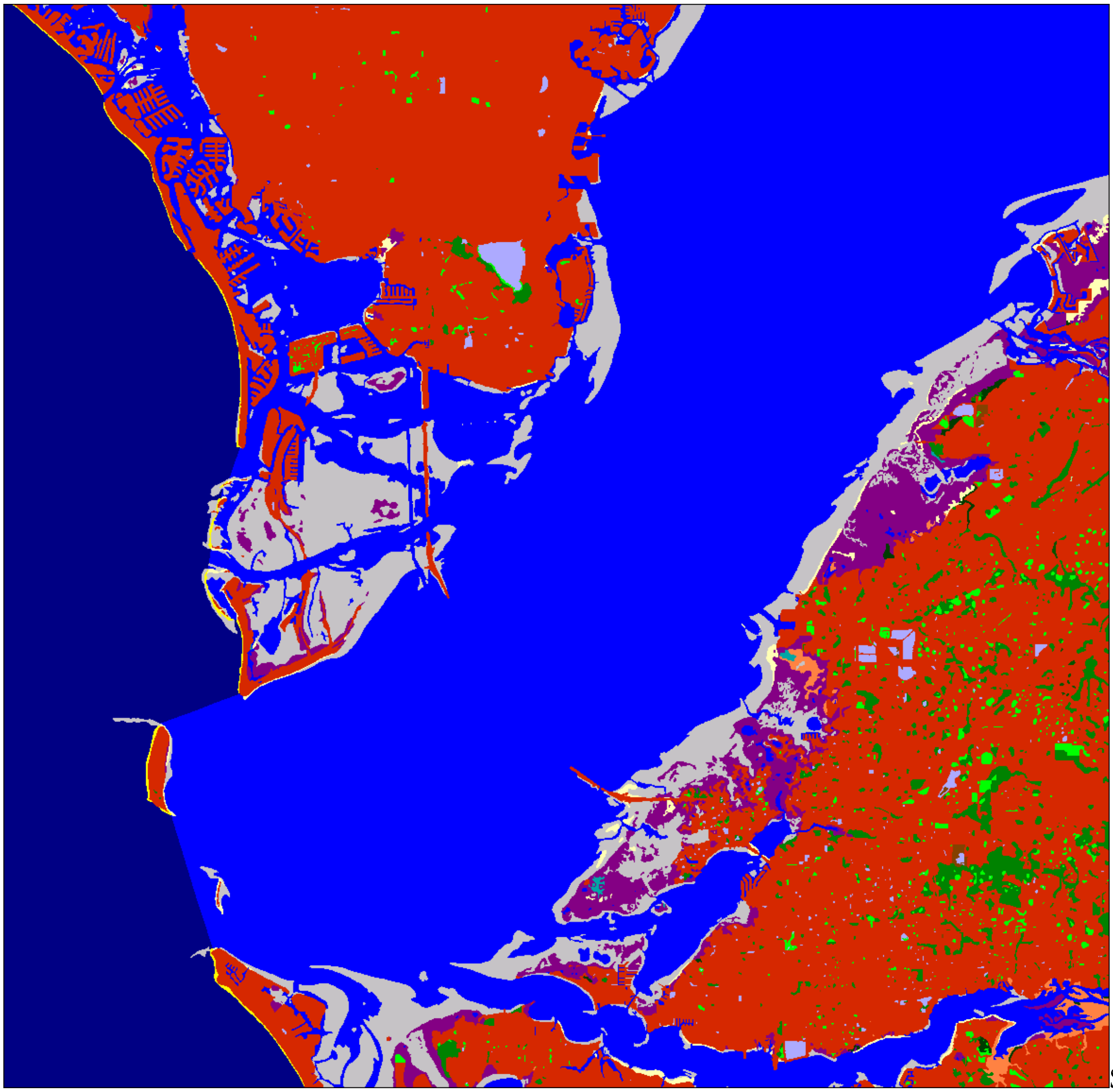
St. Petersburg Area, 2050 IPCC Scenario A1B-Maximum



St. Petersburg Area, 2075 IPCC Scenario A1B-Maximum



St. Petersburg Area, 2100 IPCC Scenario A1B-Maximum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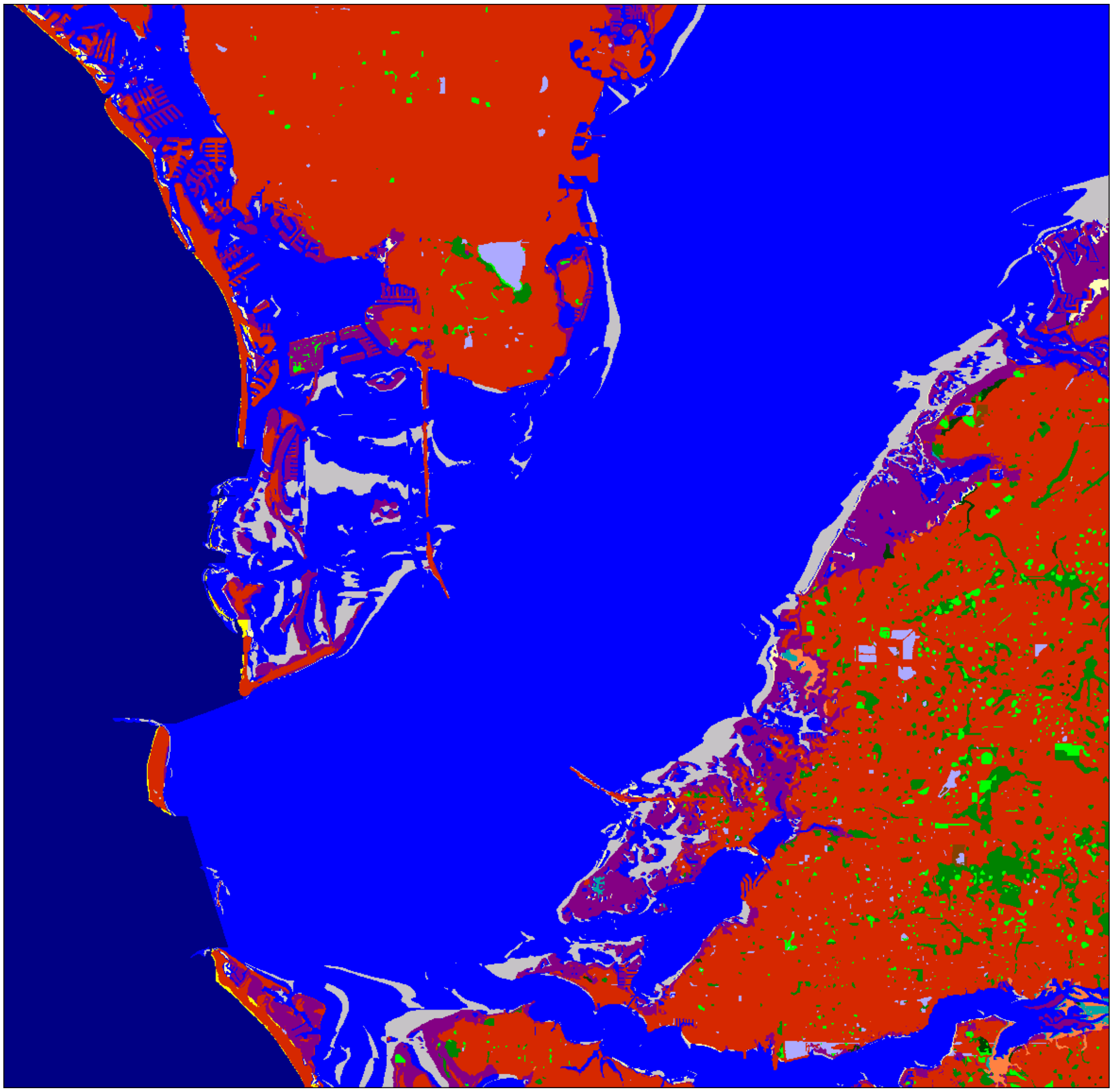
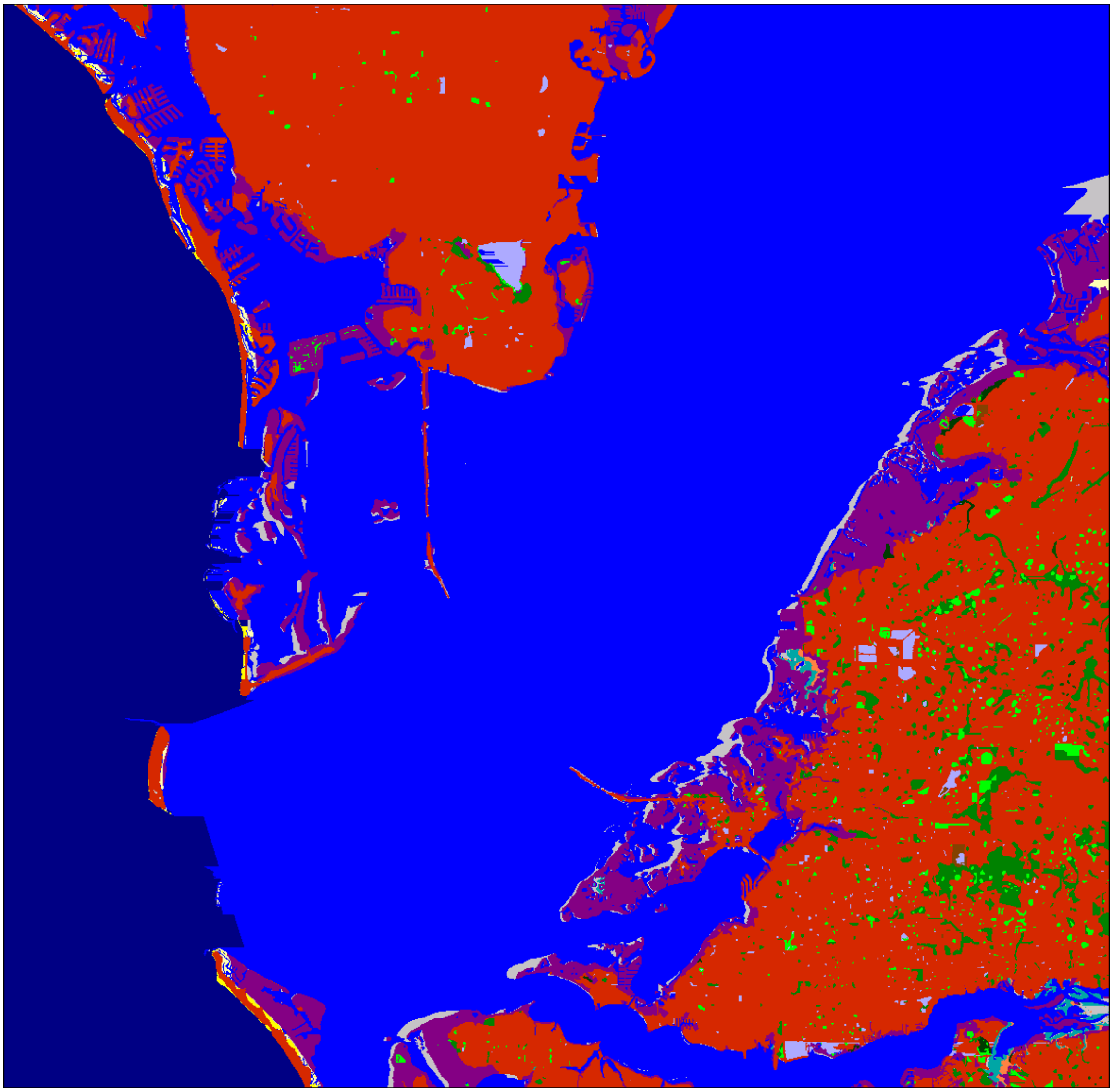
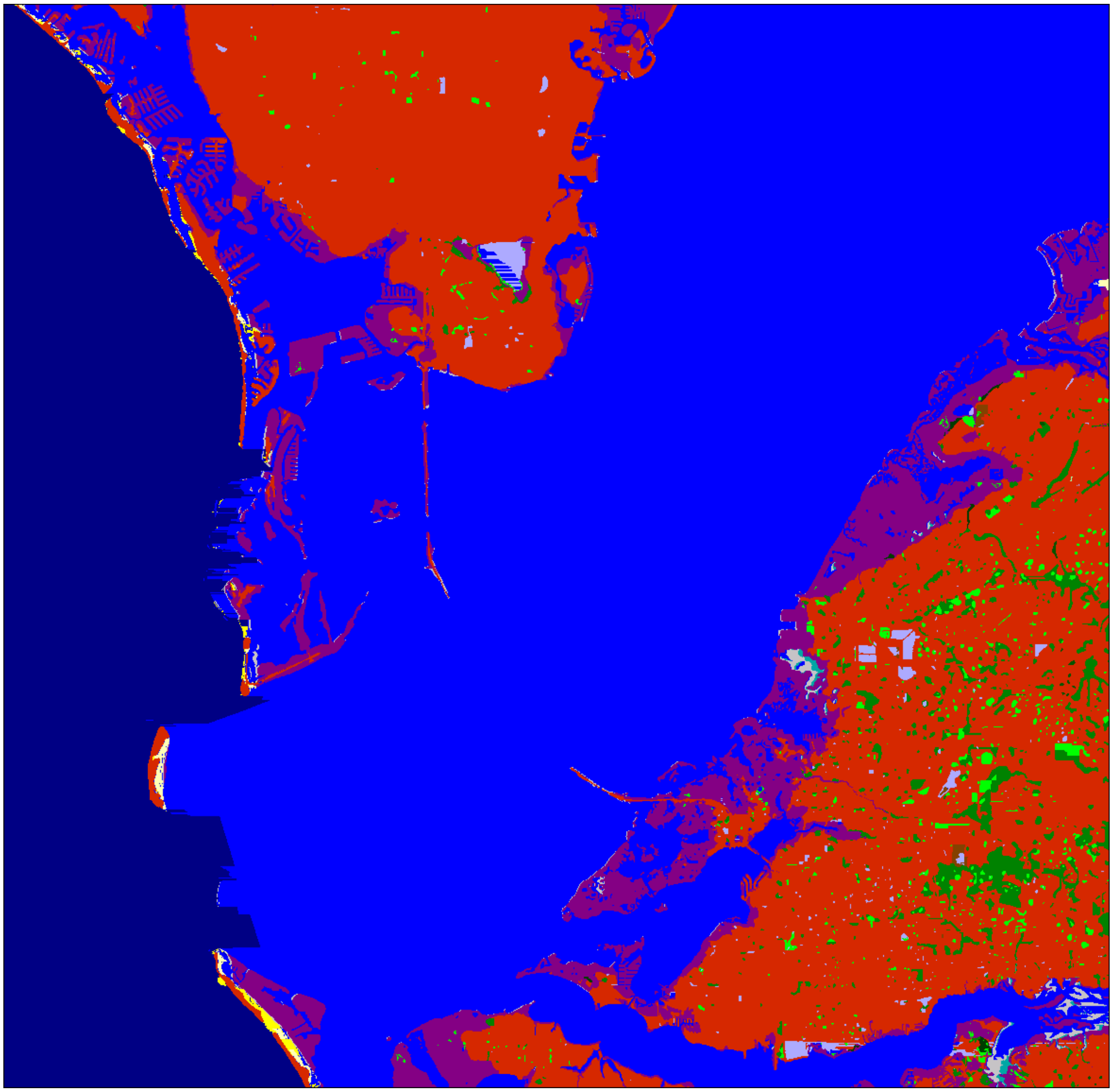
St. Petersburg Area, Initial Condition



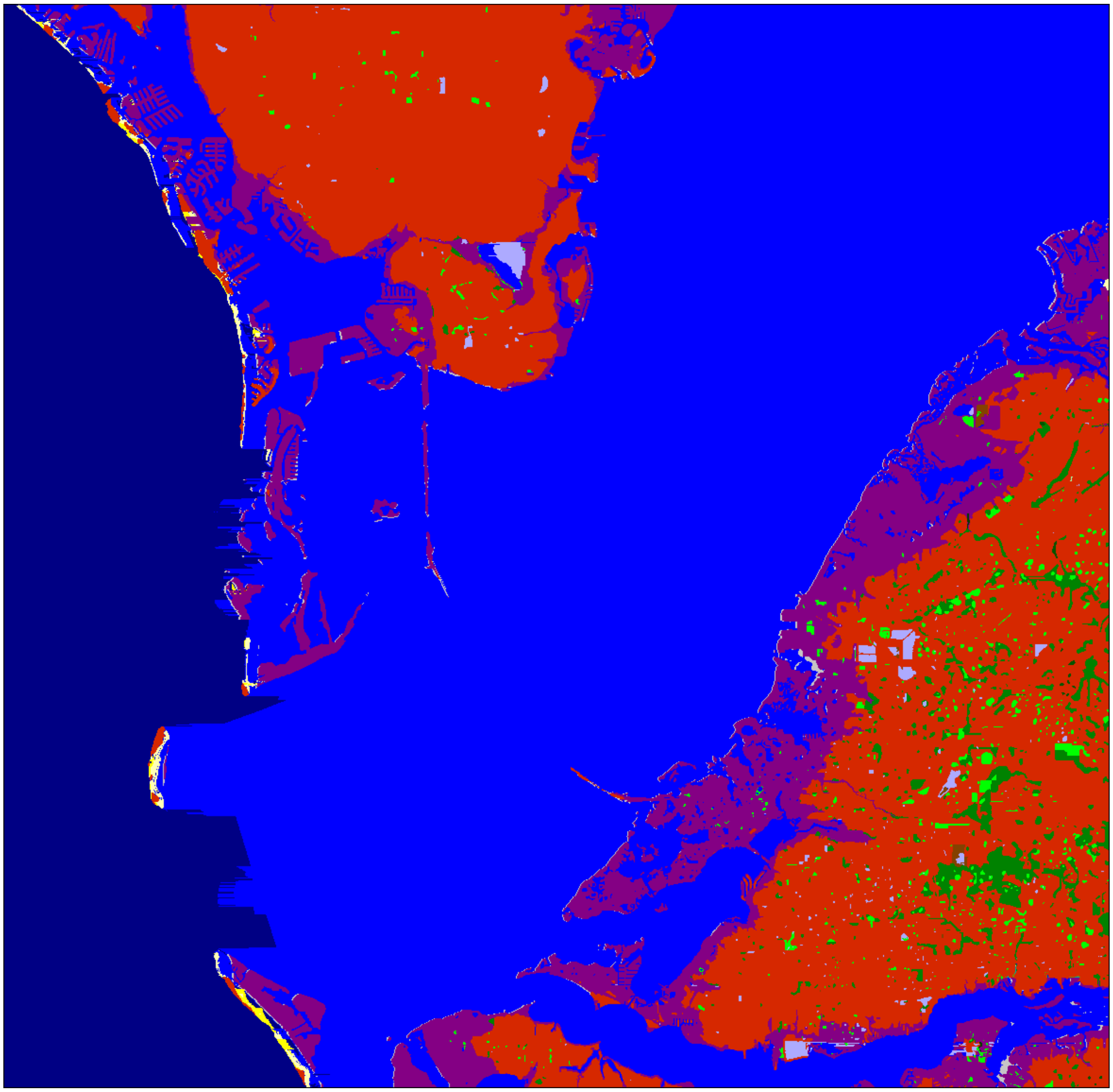
St. Petersburg Area, 2025, 1 meter Eustatic by 2100



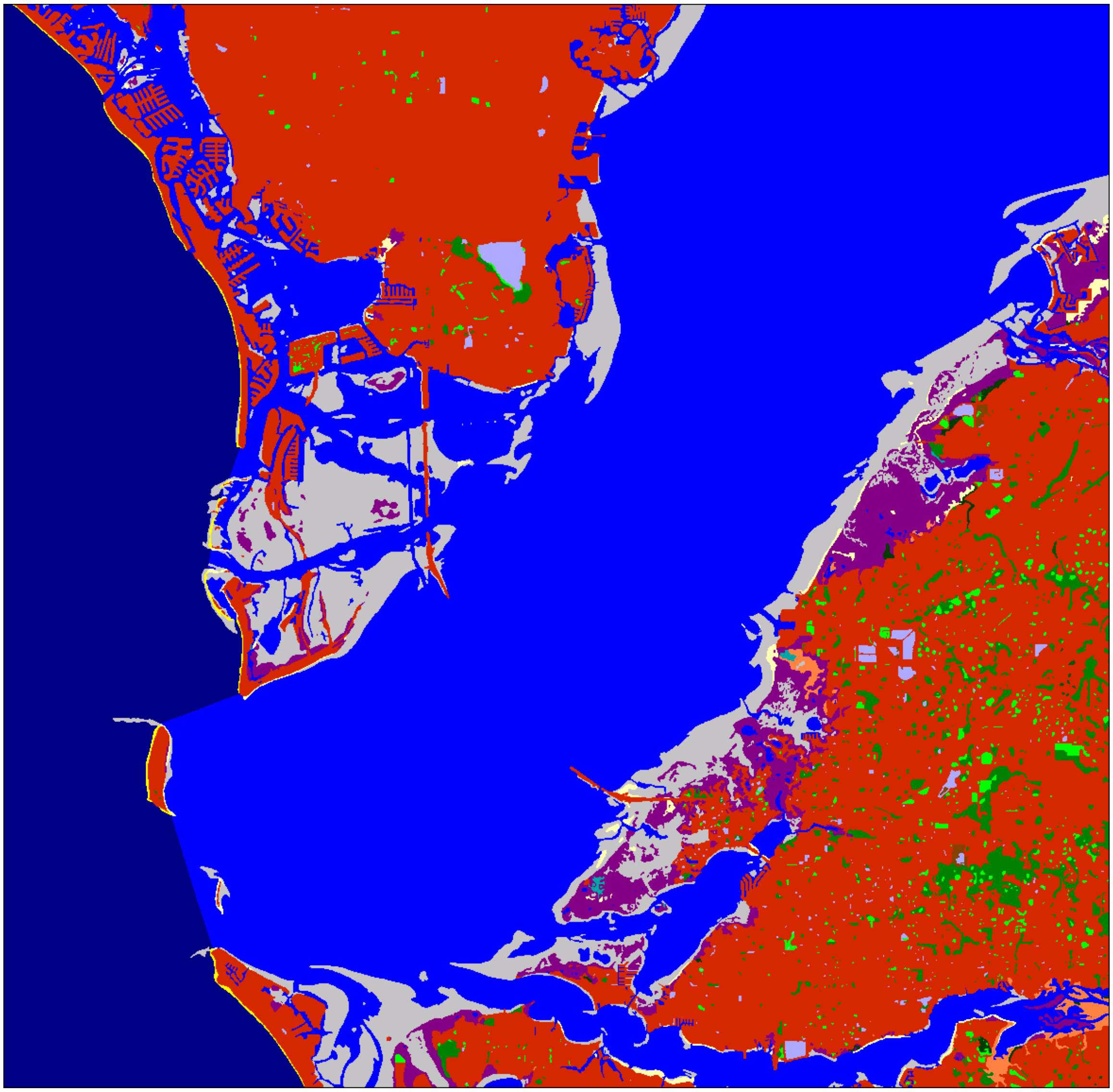
St. Petersburg Area, 2050, 1 meter Eustatic by 2100



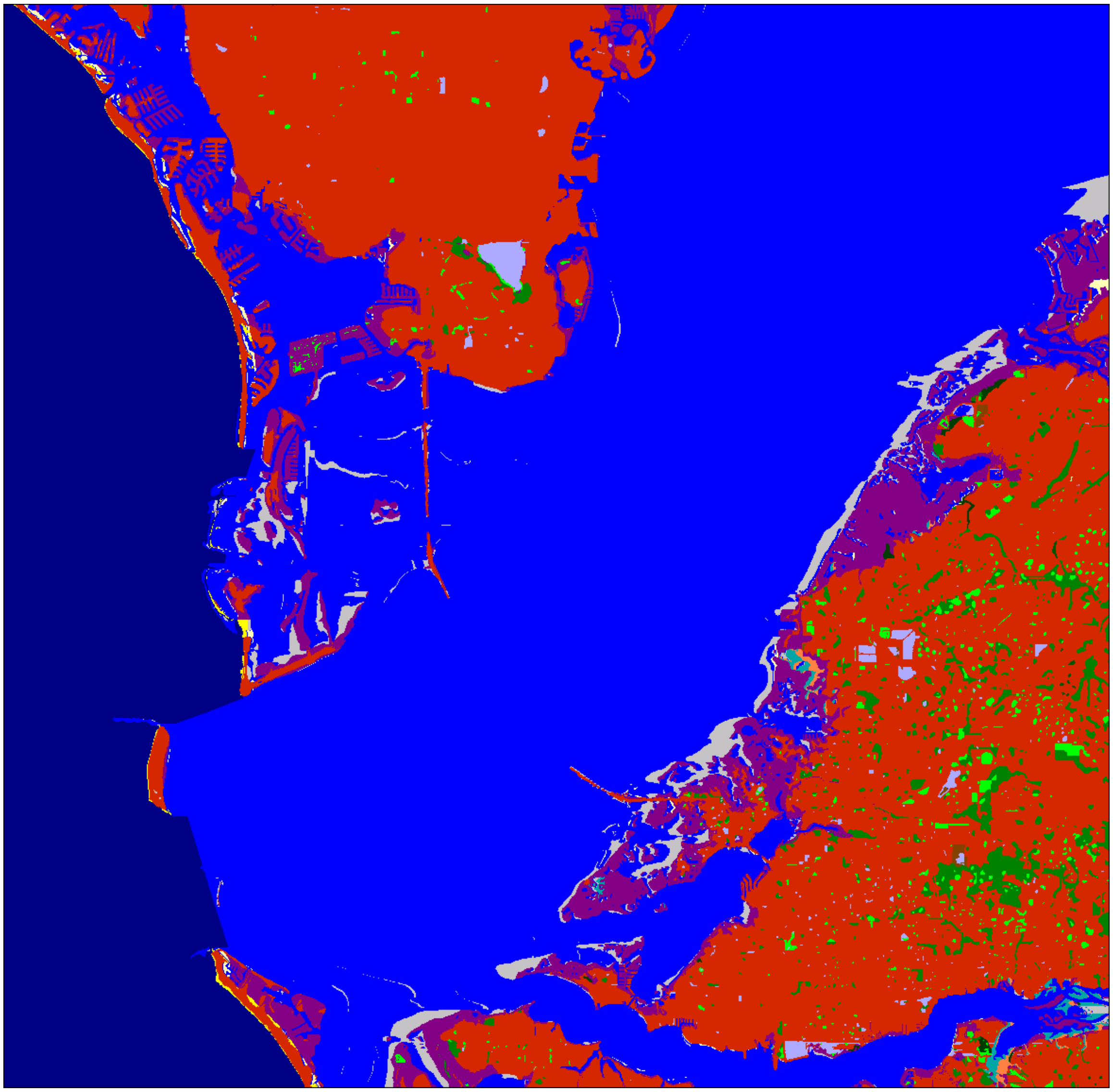
St. Petersburg Area, 2075, 1 meter Eustatic by 2100



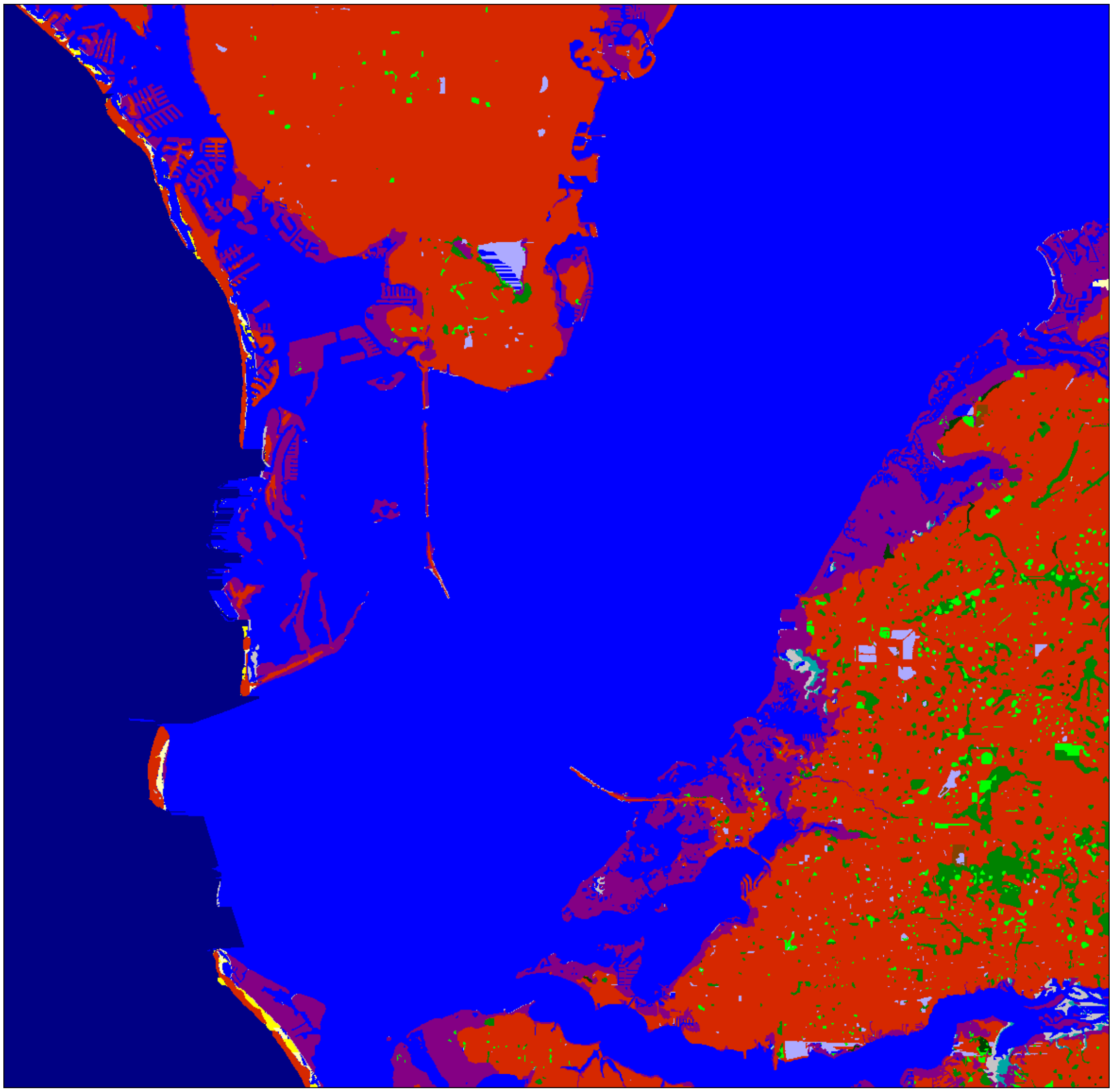
St. Petersburg Area, 2100, 1 meter Eustatic by 2100



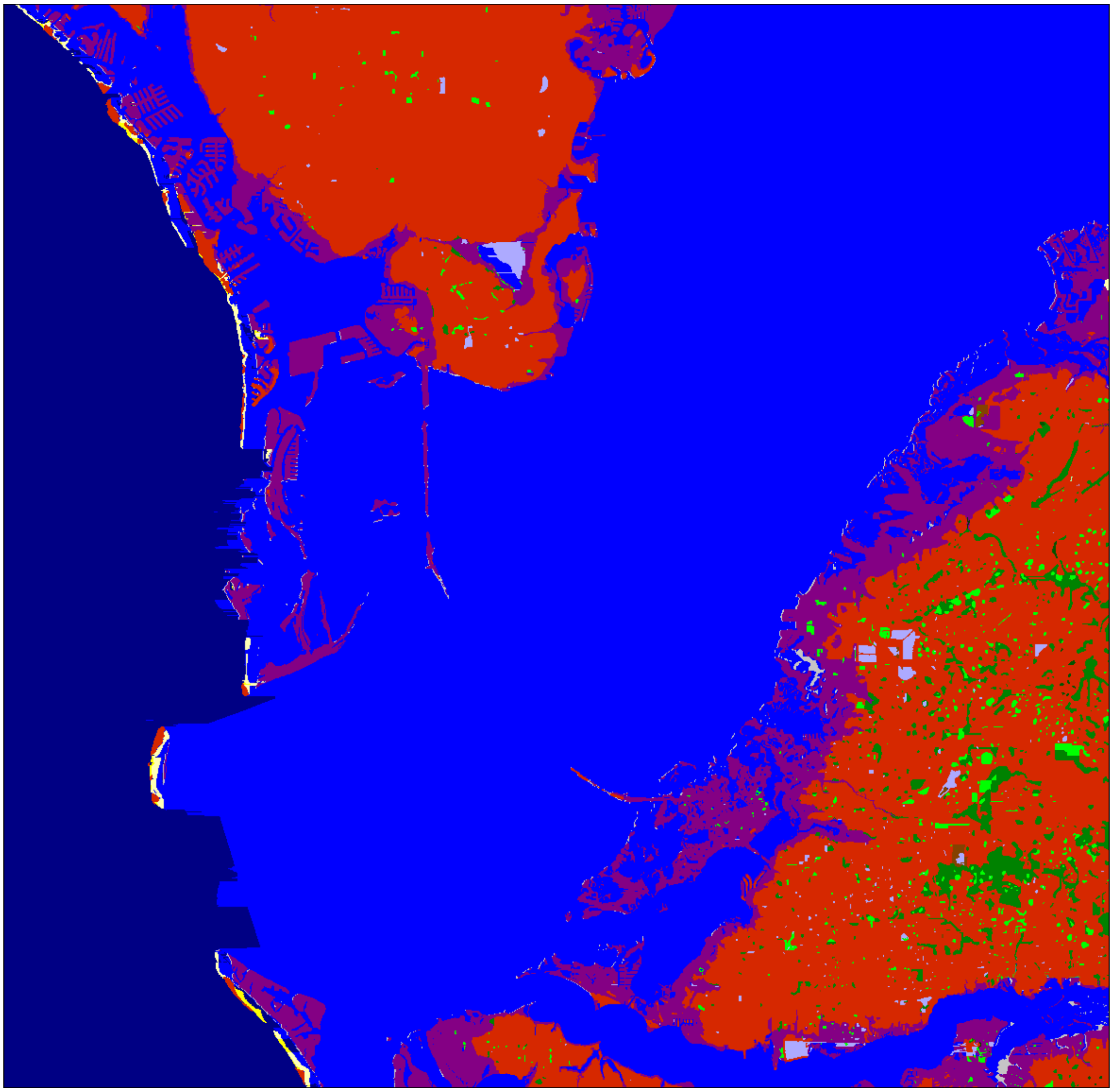
St. Petersburg Area, Initial Condition



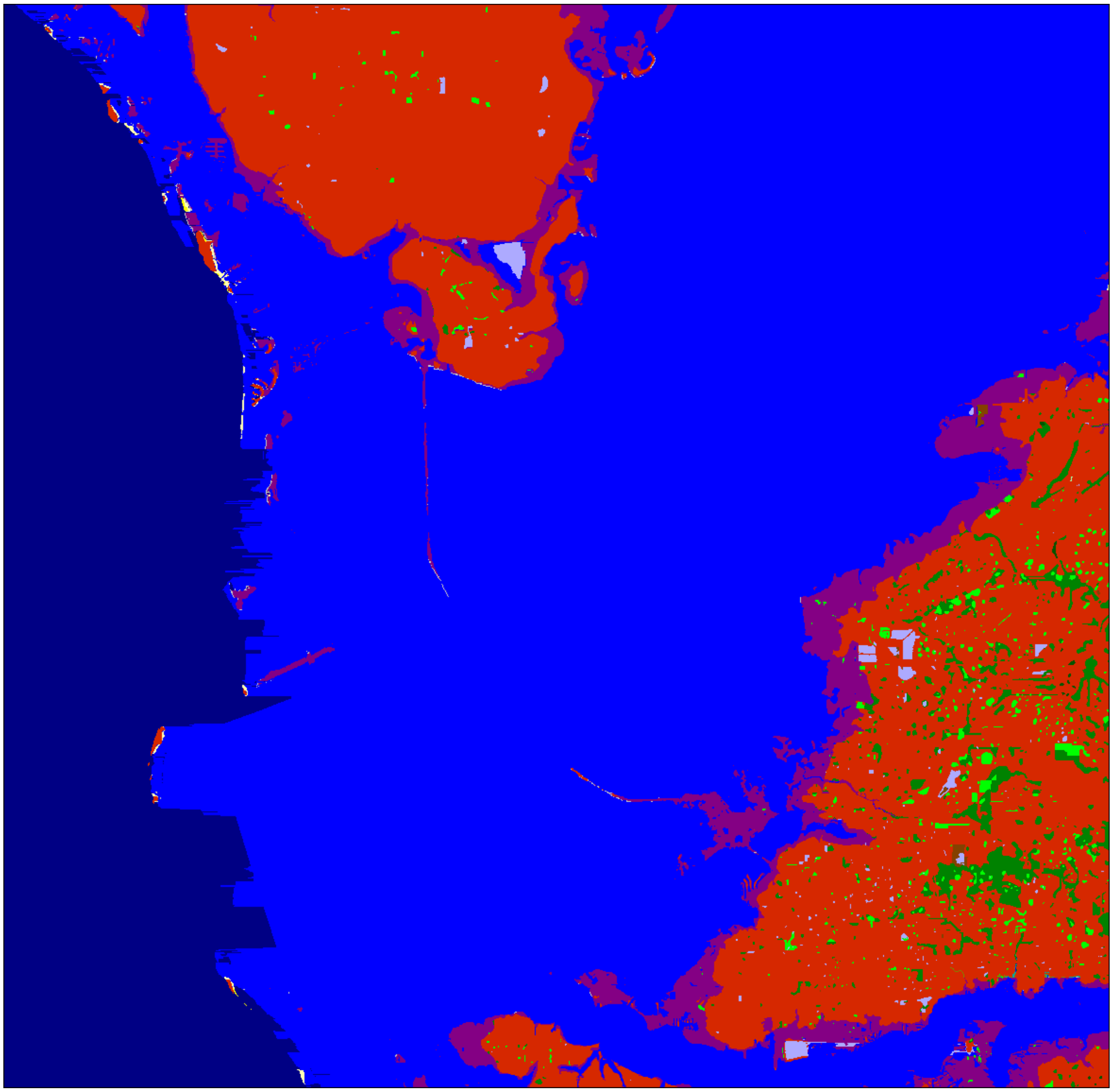
St. Petersburg Area, 2025, 1.5 meter Eustatic by 2100



St. Petersburg Area, 2050, 1.5 meter Eustatic by 2100



St. Petersburg Area, 2075, 1.5 meter Eustatic by 2100



St. Petersburg Area, 2100, 1.5 meter Eustatic by 2100