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

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

July 10, 2008

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

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

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 Mandalay 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

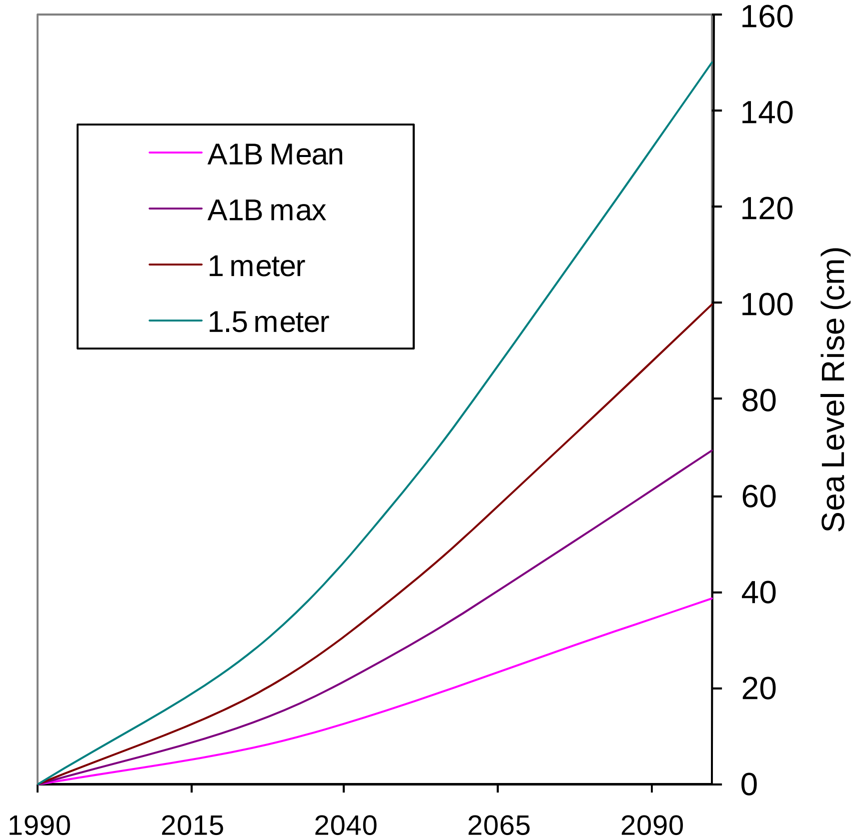
Sea-Level Rise Scenarios

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

High-resolution LIDAR data are available for Mandalay NWR based on a 2004 flight-date. These elevation data are available through the National Elevation Dataset (NED), which was updated to reflect these high-quality data. The error in vertical resolution for LIDAR data can be as low as 5-10 cm.

The National Wetlands Inventory for Mandalay is based on a photo date of 1989. This survey, when converted to 30 meter cells, suggests that on that date, the approximately eighty nine hundred acre refuge (approved acquisition boundary) was composed of the categories as shown below:

Inland Open Water	22%
Tidal Fresh Marsh	21%
Inland Fresh Marsh	20%
Swamp	17%
Tidal Swamp	11%
Riverine Tidal	6%
Cypress Swamp	2%
Dry Land	1%

The historic trend for Sea Level Rise was estimated at 9.8 mm/year using the average of the long term trends measured on Grand Isle, Louisiana (NOAA station 8761724) and Eugene Island, Louisiana (8764311). This historic trend is dramatically higher than the global average for the last 100 years (approximately 1.5 mm/year) indicating that significant land subsidence is occurring in this region. When estimating the local effects of eustatic sea level rise in this region, this rate of subsidence (approximately 8.3 mm/year) is projected to continue over the period of projection.

The oceanic tide range was estimated at 0.343 meters using the average of the two closest NOAA stations (Tesoro Marine Terminal, Atchafalaya River, La, 8764044 and Weeks Bay, La, 8765148).

There were no stations within 25 miles of the study area that relate the NED vertical datum of NAVD88 to mean tide level. To be conservative, the lower range of several of the nearest stations was used (0.155). Using the low end of this range means that land elevations are set to higher levels as compared to mean tide level and predicted effects will be minimized as a result of this uncertainty.

Station	Site Name	MTL-NAVD88 (m)
8771510	GALVESTON PLEASURE PIER	0.155
8771450	GALVESTON PIER 21	0.200
8761826	CHENIERE CAMINADA, CAMINADA PASS	0.331
8747437	BAY WAVELAND YC, BAY ST. LOUIS	0.164
8746819	PASS CHRISTIAN YC, MISS. SOUND	0.155
8761426	GREENS DITCH, LAKE ST. CATHERINE	0.217

Accretion rates were set based on an analysis of five studies of vertical accretion in Louisiana (Cahoon et al. 1994, Cahoon et al. 1995, Cahoon et al., 1999, Stevenson et al. 1986, White et al. 2002). Measured accretion rates for each marsh-type were averaged and are summarized in the table below. Accretion rates in Louisiana tend to be higher than those measured in other states.

Marsh Type	Accretion Rate (mm/yr)	
Freshwater	7.73	n=2
Brackish	7.67	n=5
Saline	9.75	n=6

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.

The National Wetlands Inventory does not indicate that any lands in Mandalay NWR are protected by dikes or impounded. U.S. FWS project managers also indicated that there are no dikes within the Mandalay NWR boundaries. For this reason, the refuge was not considered protected by dikes. This assumption may need to be revisited with respect to the northern plot of land within the refuge as it is surrounded by dry lands and may be protected by dikes. This is a source of uncertainty in the predictions for the northern portion of the map.

A conversation with Ken Litzenberger, the U.S. Fish and Wildlife Service project manager for Mandalay occurred in June of 2008. He stated that, to his knowledge, there are no site-specific erosion, wetland inventory, or accretion data better than the data cited above.

SUMMARY OF SLAMM INPUT PARAMETERS FOR MANDALAY

Site		**Mandalay**
NED Source Date (yyyy)	,	2002
NWI_photo_date (yyyy)	,	1989
Direction_OffShore (N|S|E|W)	,	S
Historic_trend (mm/yr)	,	9.795
NAVD88_correction (MTL-NAVD88 in meters)	,	0.155
Water Depth (m below MLW- N/A)	*,*	2
TideRangeOcean (meters: MHHW-MLLW)	,	0.343
TideRangeInland (meters)	,	0.343
Mean High Water Spring (m above MTL)	,	0.228
MHSW Inland (m above MTL)	,	0.228
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	,	9.75
Brackish March vert. accretion (mm/yr) Final	,	7.67
Tidal Fresh vertical accretion (mm/yr) Final	,	7.73
Beach/T.Flat Sedimentation Rate (mm/yr)	,	0.5
Frequency of Large Storms (yr/washover)	,	25
Use Elevation Preprocessor for Wetlands	,	FALSE

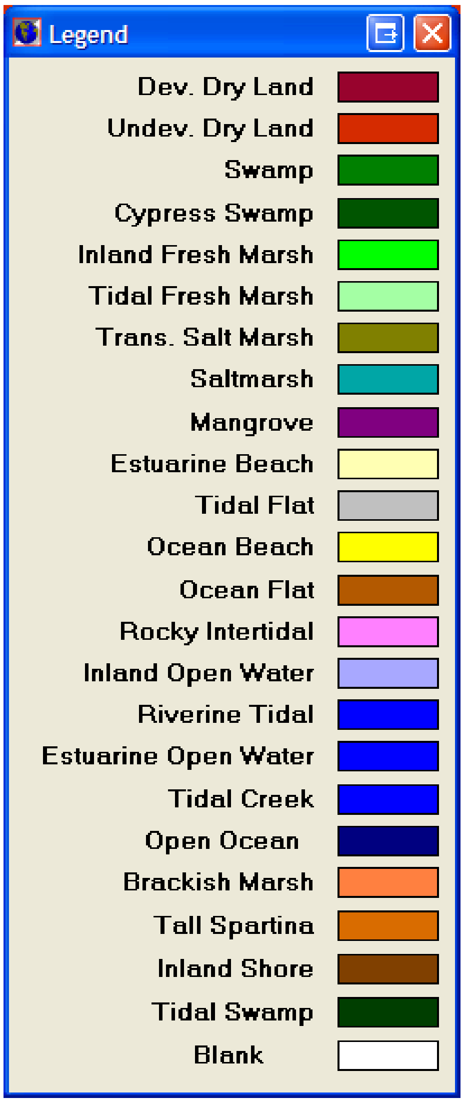
Results

Simulation results suggest that tidal fresh marsh will be at least 95% lost under all scenarios; it is predominantly a question of when. Under scenario A1B-Mean (0.39M eustatic by 2100), the loss is gradual with 95% of tidal fresh marsh being lost by 2100. Under A1B-Max (0.69M by 2100) the loss is more accelerated with 99% lost by 2075. Under the 1 and 1.5 meter scenarios, 90% and nearly 100% is lost by 2050 respectively. Inland fresh marsh follows much the same pattern but the loss rate is greater in most cases.

Swamps are actually predicted to fare worse than fresh marshes in these simulations, being 99% to 100% lost by the year 2100 under even the most moderate scenario run. Within the SLAMM model, swamps are not predicted to vertically accrete as quickly as marshes do.

Under all but the most extreme scenarios, migration of salt marsh into Mandalay National Wildlife Refuge is predicted.

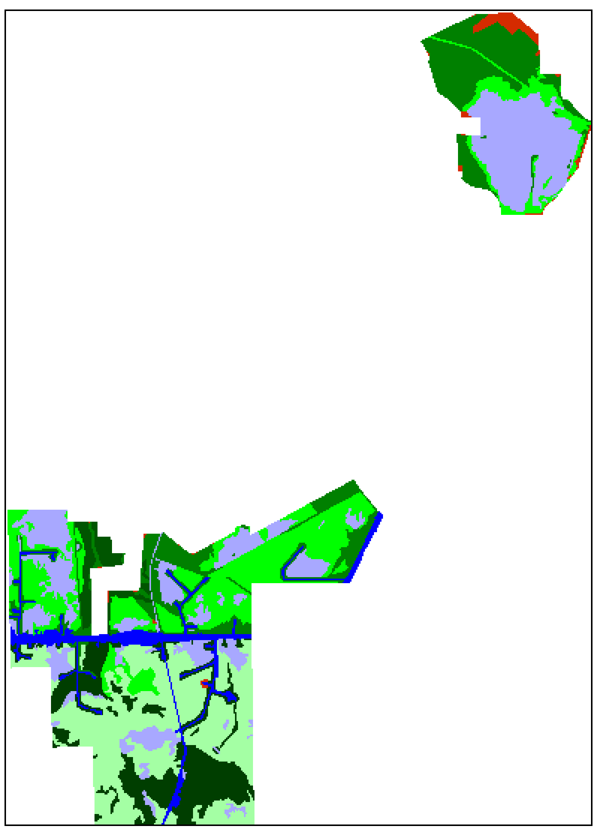
Maps of SLAMM input and output to follow will use the following legend:



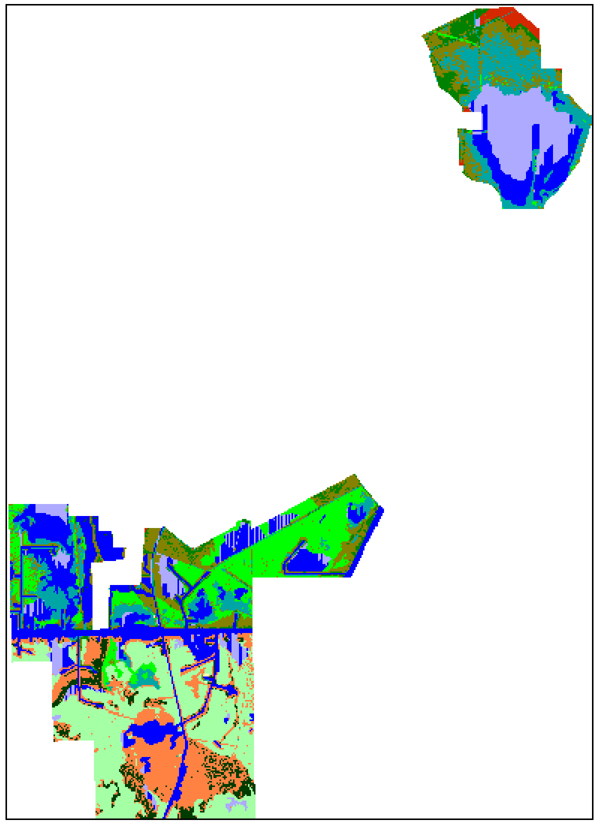
Mandalay
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

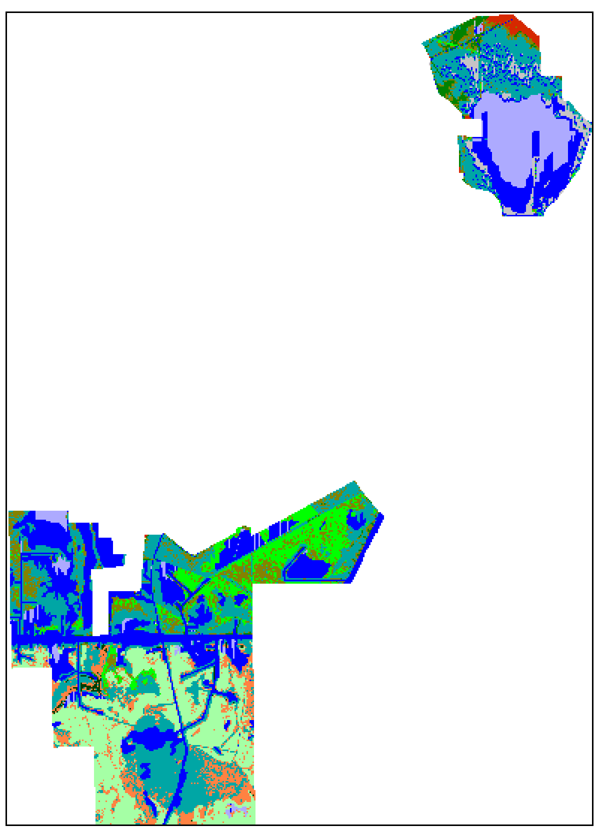
	Initial	2025	2050	2075	2100
Inland Open Water	1987.1	875.0	706.2	656.6	644.3
Tidal Fresh Marsh	1838.3	1525.5	1317.2	561.8	85.2
Inland Fresh Marsh	1760.0	1005.3	591.0	113.4	32.9
Swamp	1489.4	302.5	129.3	61.2	22.1
Tidal Swamp	974.5	304.7	33.2	8.0	4.0
Riverine Tidal	490.2	112.1	64.0	44.0	39.1
Cypress Swamp	211.5	7.8	2.0	0.4	0.0
Dry Land	116.1	79.8	63.6	40.8	23.5
Estuarine Open Water	0.0	1697.8	2120.1	3285.3	5371.3
Saltmarsh	0.0	958.8	2445.6	1355.0	1482.8
Brackish Marsh	0.0	957.4	601.4	834.1	594.1
Tidal Flat	0.0	0.0	191.9	1338.2	430.9
Trans. Salt Marsh	0.0	1035.7	601.1	558.4	129.1
Estuarine Beach	0.0	4.6	0.5	9.8	7.7
Total (incl. water)	8867.1	8867.1	8867.1	8867.1	8867.1



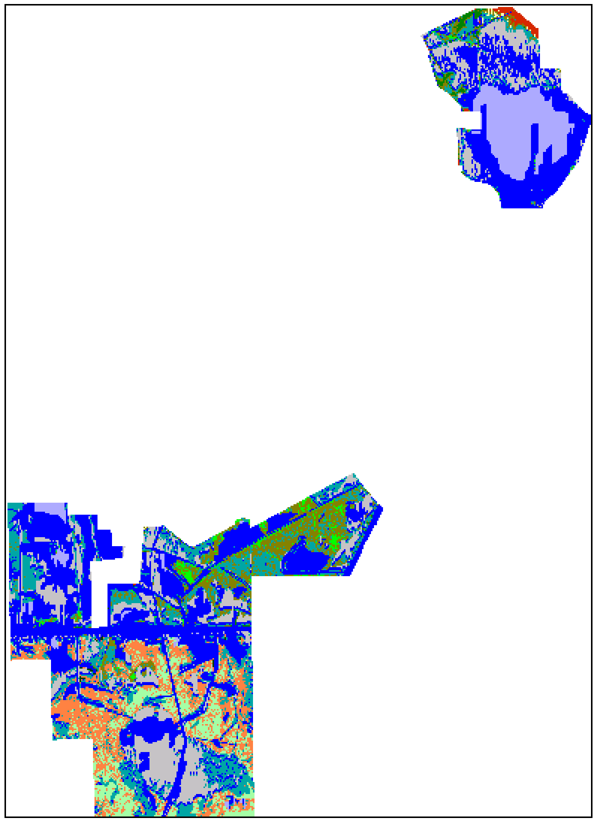
Mandalay NWR Initial Condition



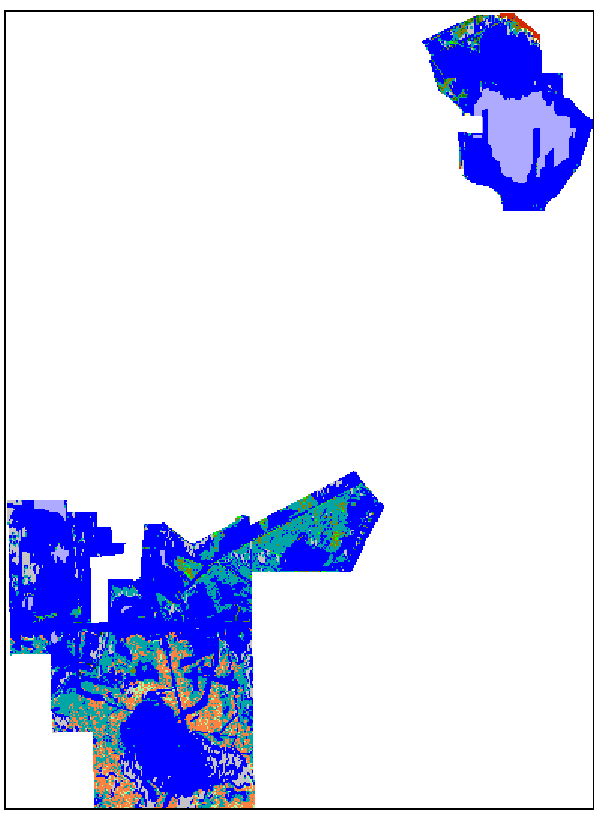
Mandalay NWR, 2025 IPCC Scenario A1B-Mean



Mandalay NWR, 2050 IPCC Scenario A1B-Mean



Mandalay NWR, 2075 IPCC Scenario A1B-Mean

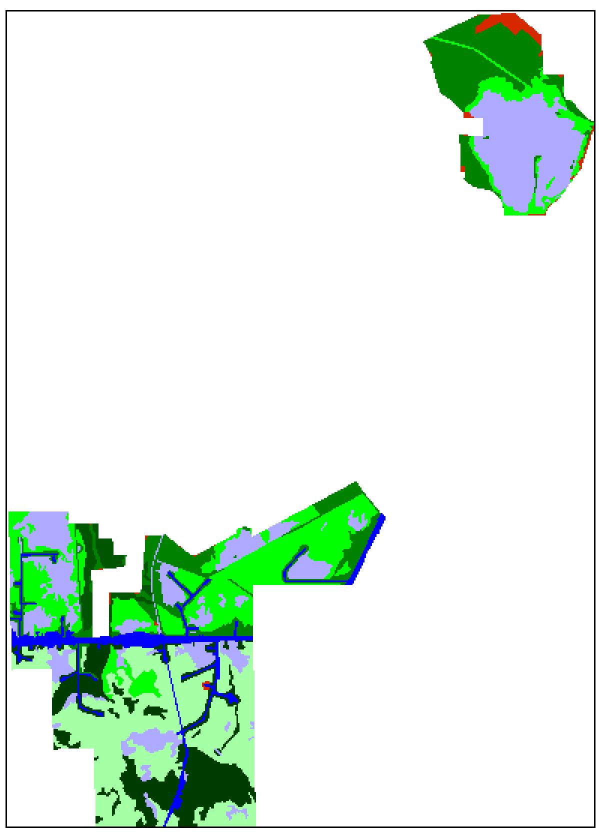


Mandalay NWR, 2100 IPCC Scenario A1B-Mean

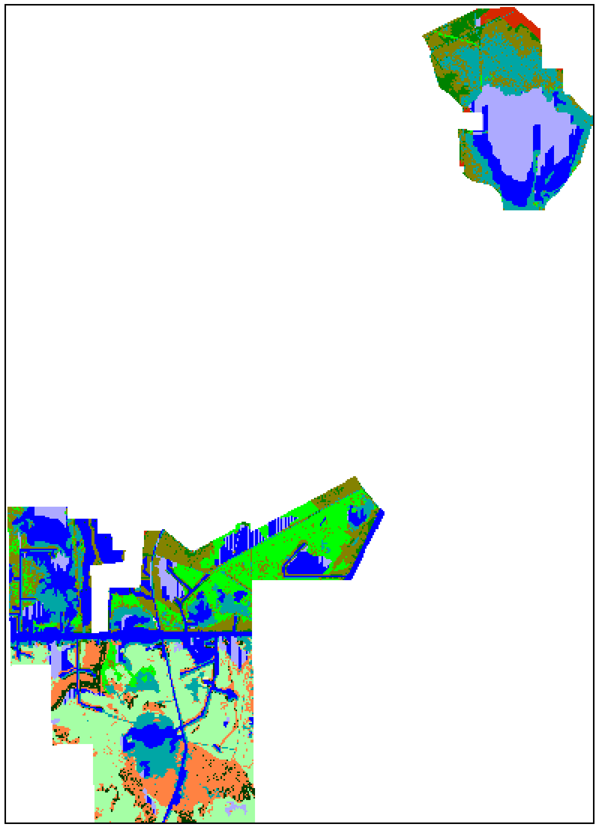
Mandalay
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

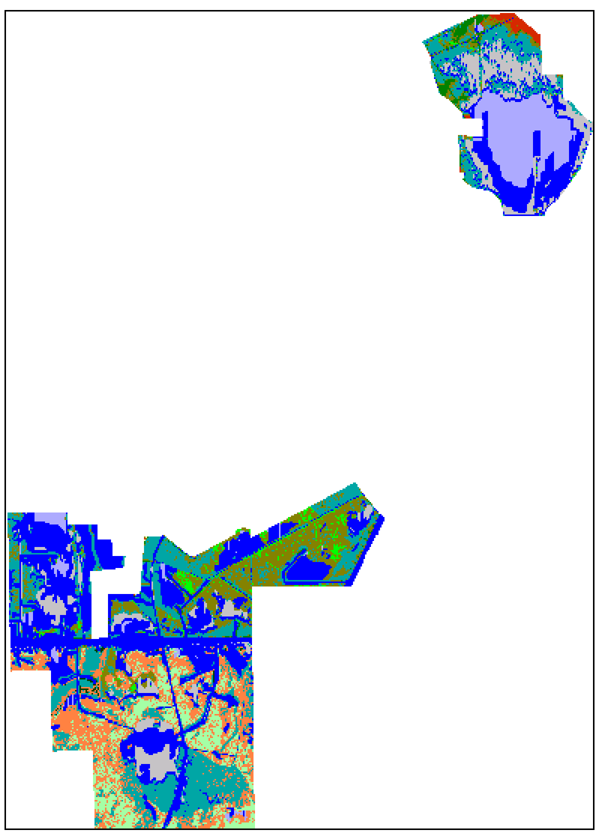
	Initial	2025	2050	2075	2100
Inland Open Water	1987.1	873.4	674.2	643.9	643.4
Tidal Fresh Marsh	1838.3	1454.9	614.8	18.0	1.1
Inland Fresh Marsh	1760.0	848.5	126.9	16.4	4.7
Swamp	1489.4	244.2	100.7	32.3	4.6
Tidal Swamp	974.5	186.9	18.4	4.7	2.5
Riverine Tidal	490.2	107.4	54.0	39.8	38.0
Cypress Swamp	211.5	5.7	1.2	0.0	0.0
Dry Land	116.1	77.9	54.1	29.1	10.6
Estuarine Open Water	0.0	1707.2	2452.6	4119.5	6266.3
Saltmarsh	0.0	1210.0	2146.1	1895.2	804.4
Brackish Marsh	0.0	893.3	1008.7	610.6	19.1
Tidal Flat	0.0	0.0	728.0	1253.7	1014.6
Trans. Salt Marsh	0.0	1252.8	886.6	193.8	45.9
Estuarine Beach	0.0	4.9	0.7	10.2	11.9
Total (incl. water)	8867.1	8867.1	8867.1	8867.1	8867.1



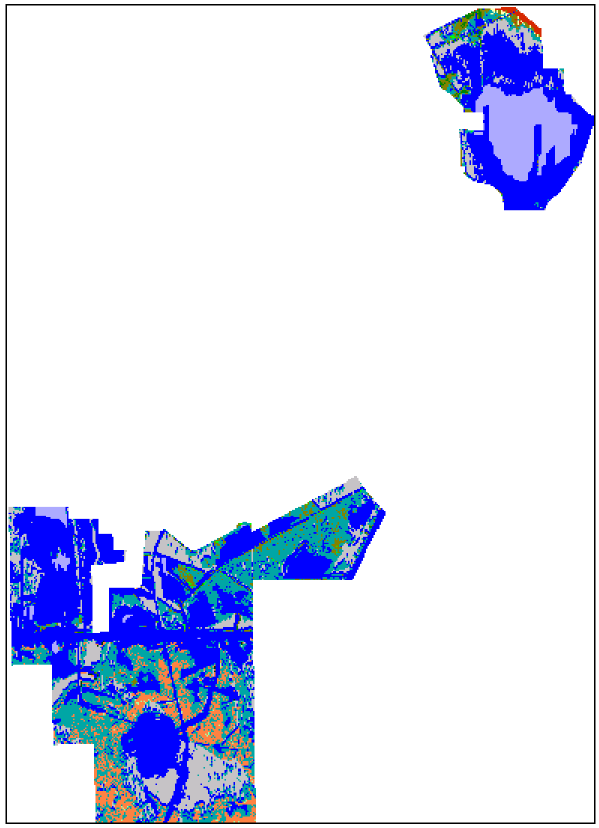
Mandalay NWR Initial Condition



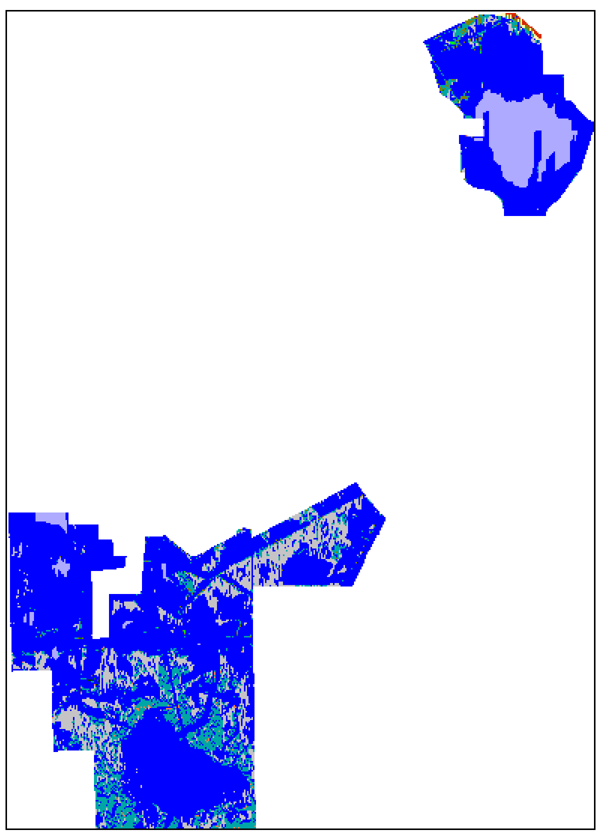
Mandalay NWR, 2025 IPCC Scenario A1B-Maximum



Mandalay NWR, 2050 IPCC Scenario A1B-Maximum



Mandalay NWR, 2075 IPCC Scenario A1B-Maximum

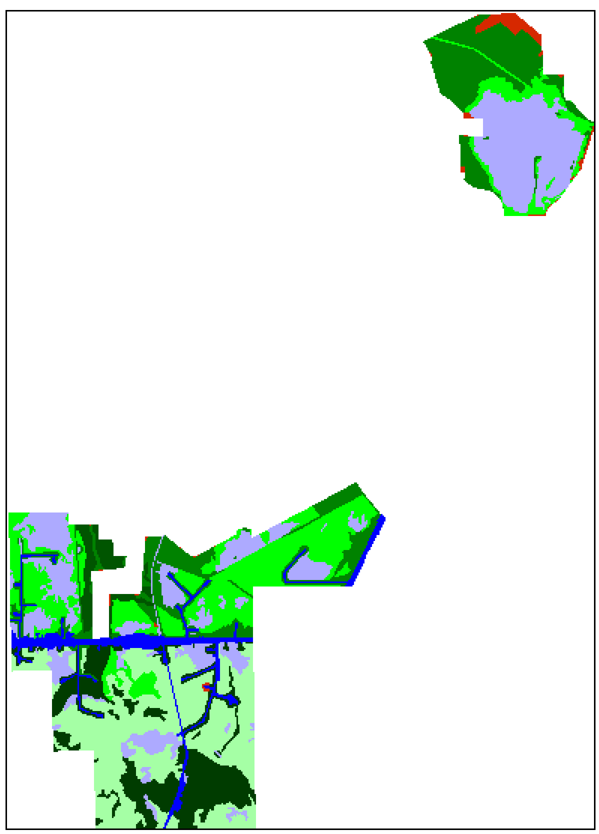


Mandalay NWR, 2100 IPCC Scenario A1B-Maximum

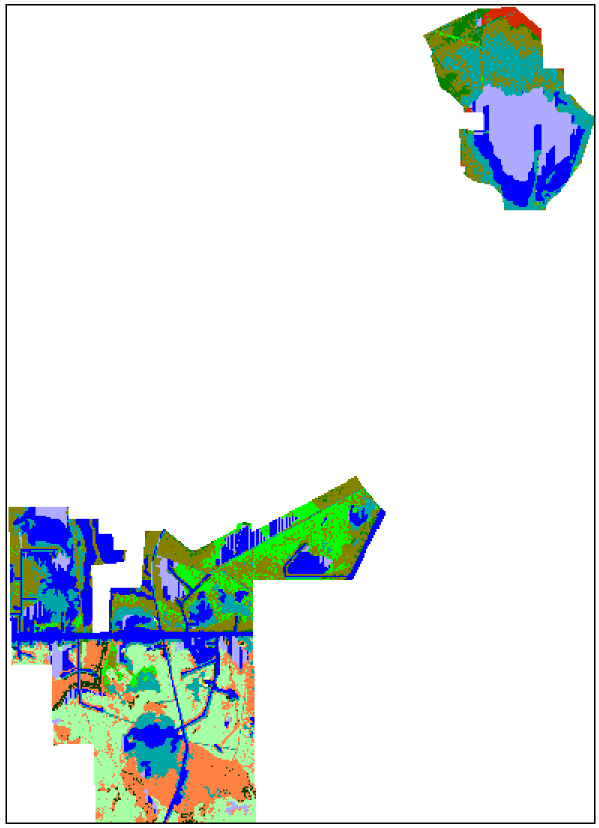
Mandalay
1 Meter Eustatic SLR by 2100

Results in Acres

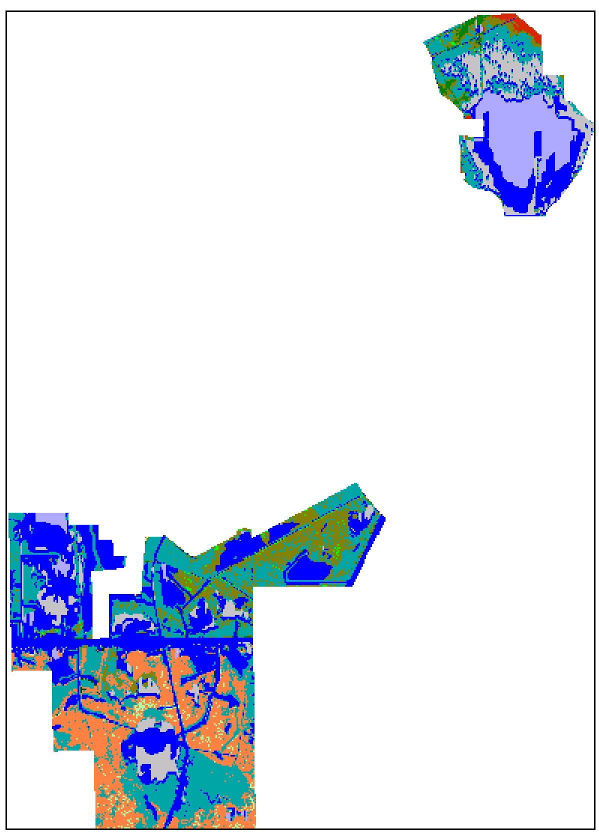
	Initial	2025	2050	2075	2100
Inland Open Water	1987.1	870.3	657.7	643.2	643.2
Tidal Fresh Marsh	1838.3	1304.0	95.3	1.1	0.0
Inland Fresh Marsh	1760.0	573.9	35.2	4.9	1.2
Swamp	1489.4	204.9	73.7	13.4	2.0
Tidal Swamp	974.5	107.3	9.8	3.2	1.8
Riverine Tidal	490.2	105.0	47.1	38.7	38.0
Cypress Swamp	211.5	4.5	0.7	0.0	0.0
Dry Land	116.1	76.3	45.5	18.7	2.6
Estuarine Open Water	0.0	1713.6	2475.5	4192.4	6657.0
Saltmarsh	0.0	1210.0	2692.2	2005.5	207.0
Brackish Marsh	0.0	1123.4	1306.4	100.8	2.5
Tidal Flat	0.0	0.0	728.0	1727.9	1280.7
Trans. Salt Marsh	0.0	1568.8	699.1	106.2	20.6
Estuarine Beach	0.0	5.0	0.9	11.2	10.6
Total (incl. water)	8867.1	8867.1	8867.1	8867.1	8867.1



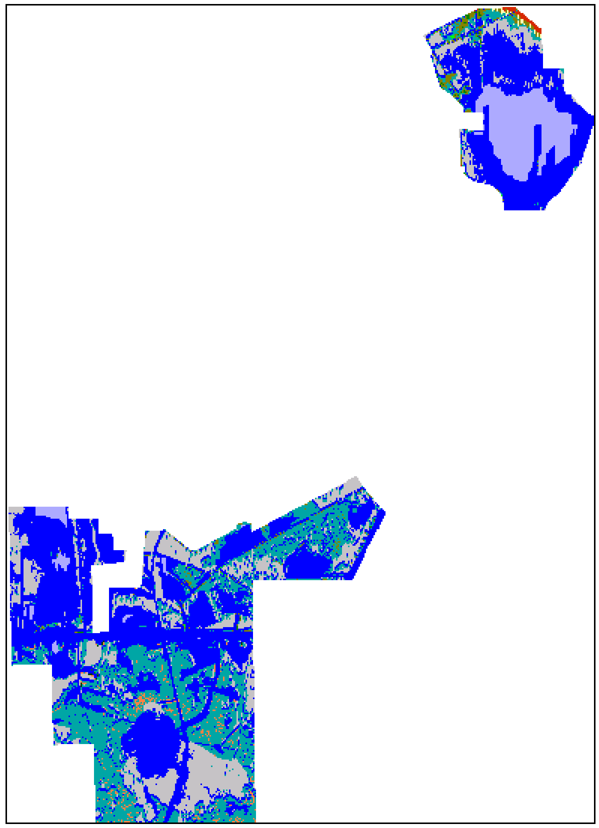
Mandalay NWR Initial Condition



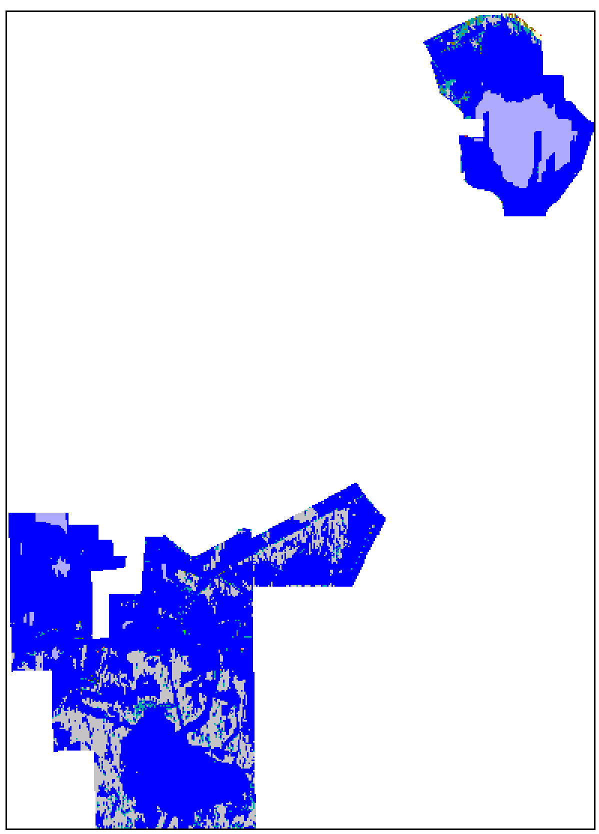
Mandalay NWR, 2025 1 meter Eustatic by 2100



Mandalay NWR, 2050 1 meter Eustatic by 2100



Mandalay NWR, 2075 1 meter Eustatic by 2100

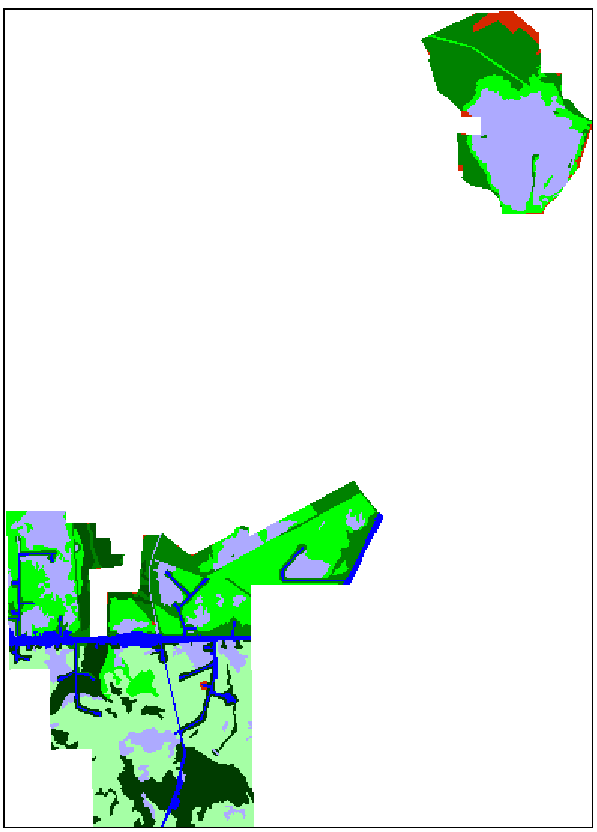


Mandalay NWR, 2100 1 meter Eustatic by 2100

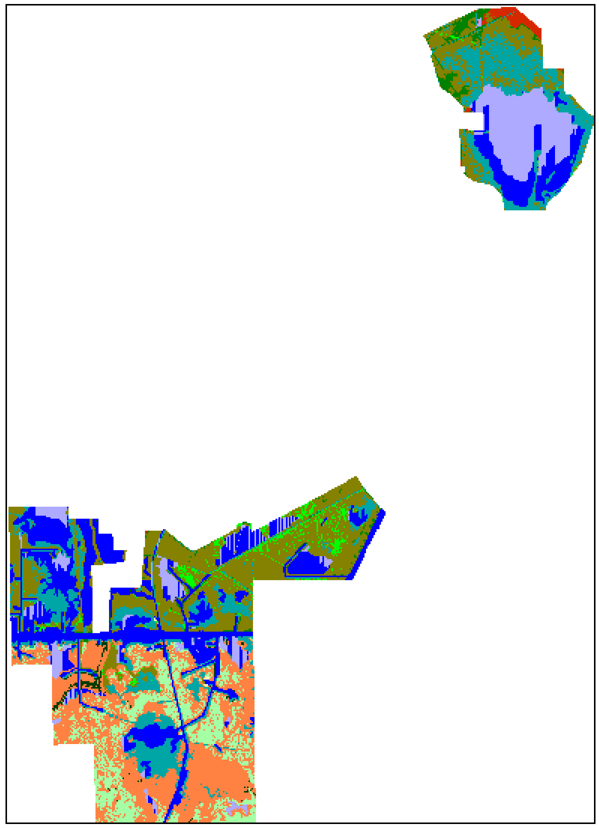
Mandalay
1.5 Meters Eustatic SLR by 2100

Results in Acres

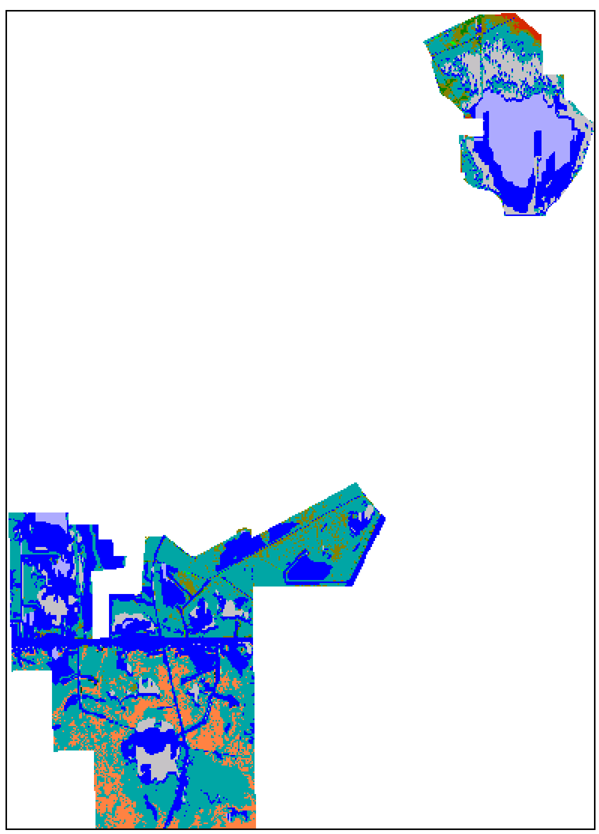
	Initial	2025	2050	2075	2100
Inland Open Water	1987.1	868.8	644.7	642.3	642.3
Tidal Fresh Marsh	1838.3	754.5	2.7	0.0	0.0
Inland Fresh Marsh	1760.0	175.7	8.0	1.0	0.1
Swamp	1489.4	159.7	41.4	2.8	0.7
Tidal Swamp	974.5	51.5	5.2	2.0	1.0
Riverine Tidal	490.2	99.6	39.8	38.0	38.0
Cypress Swamp	211.5	3.3	0.0	0.0	0.0
Dry Land	116.1	71.1	33.7	4.8	0.1
Estuarine Open Water	0.0	1721.4	2495.7	4188.2	7556.0
Saltmarsh	0.0	1210.0	3746.3	1120.6	68.4
Brackish Marsh	0.0	1728.8	798.1	5.9	0.9
Tidal Flat	0.0	0.0	728.0	2787.0	551.8
Trans. Salt Marsh	0.0	2017.5	322.4	62.5	5.2
Estuarine Beach	0.0	5.0	1.0	12.0	2.6
Total (incl. water)	8867.1	8867.1	8867.1	8867.1	8867.1



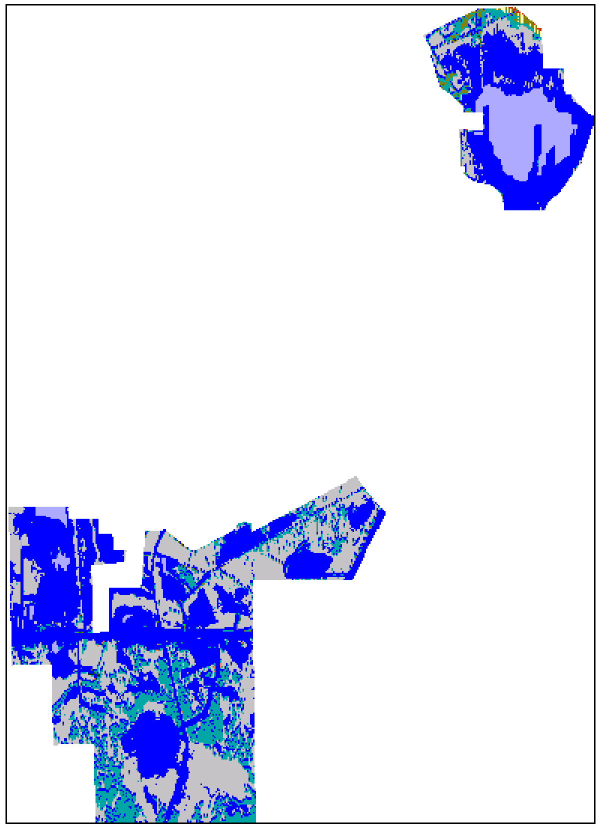
Mandalay NWR Initial Condition



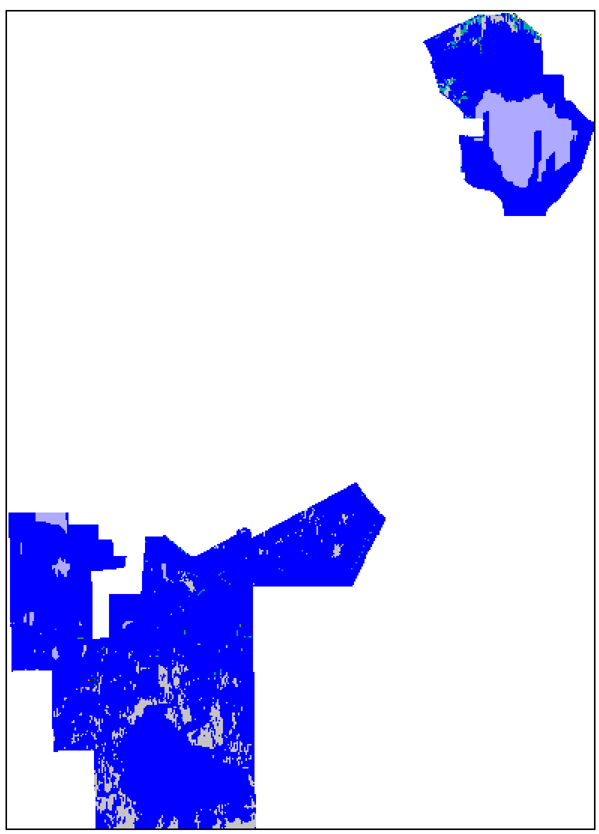
Mandalay NWR, 2025 1.5 meter Eustatic by 2100



Mandalay NWR, 2050 1.5 meter Eustatic by 2100



Mandalay NWR, 2075 1.5 meter Eustatic by 2100



Mandalay NWR, 2100 1.5 meter Eustatic by 2100

Discussion:

The high-resolution elevation data for Mandalay NWR indicate that much of the fresh water habitat there is relatively close to the salt boundary (vertically). Therefore, additional sea level rise combined with the continuation of local subsidence is predicted to have a dramatic effect at this site.

Accretion rates are high in Louisiana and subject to spatial variation. However subsidence rates are also high meaning that vertical accretion is likely to be outpaced under most plausible scenarios of sea level rise.

Within this modeling exercise, accretion rates were modeled on an average basis and kept constant spatially. In fact, losses of marshes are likely to be more spatially variable, occurring first in areas of lower accretion rates and later in areas with higher accretion rates. Furthermore, loss of marsh lands in one location may add sediment to marshes in another location thereby increasing accretion rates. This type of mass balance of solids and feedback between sea level rise and accretion rates is not currently included in the SLAMM model. To reduce model uncertainties additional evaluations of accretion rates could be undertaken at this site to determine both rates of land subsidence and site-specific vertical accretion rates.

As a screening-model evaluation, this model's results indicates that fresh water habitats in Mandalay NWR will be subject to saline inundation in the near future and therefore will be severely impacted.

References

Cahoon, D.R., J. W. Day, Jr., and D. J. Reed, 1999. "The influence of surface and shallow subsurface soil processes on wetland elevation: A synthesis." *Current Topics in Wetland Biogeochemistry*, 3, 72-88.

Chen, J. L., Wilson, C. R., Tapley, B. D., 2006 "Satellite Gravity Measurements Confirm Accelerated Melting of Greenland Ice Sheet" *Science* 2006 0: 1129007

Clough, J.S. and R.A. Park, 2007, *Technical Documentation for SLAMM 5.0.1* February 2008, Jonathan S. Clough, Warren Pinnacle Consulting, Inc, Richard A. Park, Eco Modeling. http://warrenpinnacle.com/prof/SLAMM

Craft C, Clough J, Ehman J, Guo H, Joye S, Machmuller M, Park R, and Pennings S. Effects of Accelerated Sea Level Rise on Delivery of Ecosystem Services Provided by Tidal Marshes: A Simulation of the Georgia (USA) Coast. *Frontiers in Ecology and the Environment.* 2009; 7, doi:10.1890/070219

Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002. Global Climate Change and Sea Level Rise: Potential Losses of Intertidal Habitat for Shorebirds. *Waterbirds* 25:173-183.

Glick, Clough, et al. *Sea-level Rise and Coastal Habitats in the Pacific Northwest An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon* July 2007 http://www.nwf.org/sealevelrise/pdfs/PacificNWSeaLevelRise.pdf

IPCC, 2001: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K.Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

Lee, J.K., R.A. Park, and P.W. Mausel. 1992. Application of Geoprocessing and Simulation Modeling to Estimate Impacts of Sea Level Rise on the Northeast Coast of Florida. *Photogrammetric Engineering and Remote Sensing* 58:11:1579-1586.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ and Zhao ZC. 2007. Global climate projections. Pp. 747-845. In: Solomon S, Qin, D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor, M and Miller HL, (eds.) *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Monaghan, A. J. *et al,* 2006 "Insignificant Change in Antarctic Snowfall Since the International Geophysical Year" *Science* 2006 313: 827-831.

Moorhead, KK and Brinson MM. 1995. Response of wetlands to rising sea level in the lower coastal plain of North Carolina. *Ecological Applications* 5: 261-271.

National Wildlife Fed 'n et al., *An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida* 4, 6 (2006). http://www.targetglobalwarming.org/files/AnUnfavorableTideReport.pdf

Park, R.A., J.K. Lee, and D. Canning. 1993. Potential Effects of Sea Level Rise on Puget Sound Wetlands. *Geocarto International* 8(4):99-110.

Park, R.A., M.S. Trehan, P.W. Mausel, and R.C. Howe. 1989a. The Effects of Sea Level Rise on U.S. Coastal Wetlands. In *The Potential Effects of Global Climate Change on the United States: Appendix B - Sea Level Rise,* edited by J.B. Smith and D.A. Tirpak, 1-1 to 1-55. EPA-230-05-89-052. Washington, D.C.: U.S. Environmental Protection Agency.

Rahmstorf, Stefan 2007, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," *Science* 2007 315: 368-370.

Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 2008: "Site-Specific Scenarios for Wetlands Accretion in the Mid-Atlantic Region. Section 2.1" in *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, J.G. Titus and E.M. Strange (eds.), EPA430R07004, Washington, DC: U.S. EPA. http://www.epa.gov/climatechange/effects/downloads/section2_1.pdf

Stevenson and Kearney, 2008, "Impacts of Global Climate Change and Sea-Level Rise on Tidal Wetlands" Pending chapter of manuscript by University of California Press.

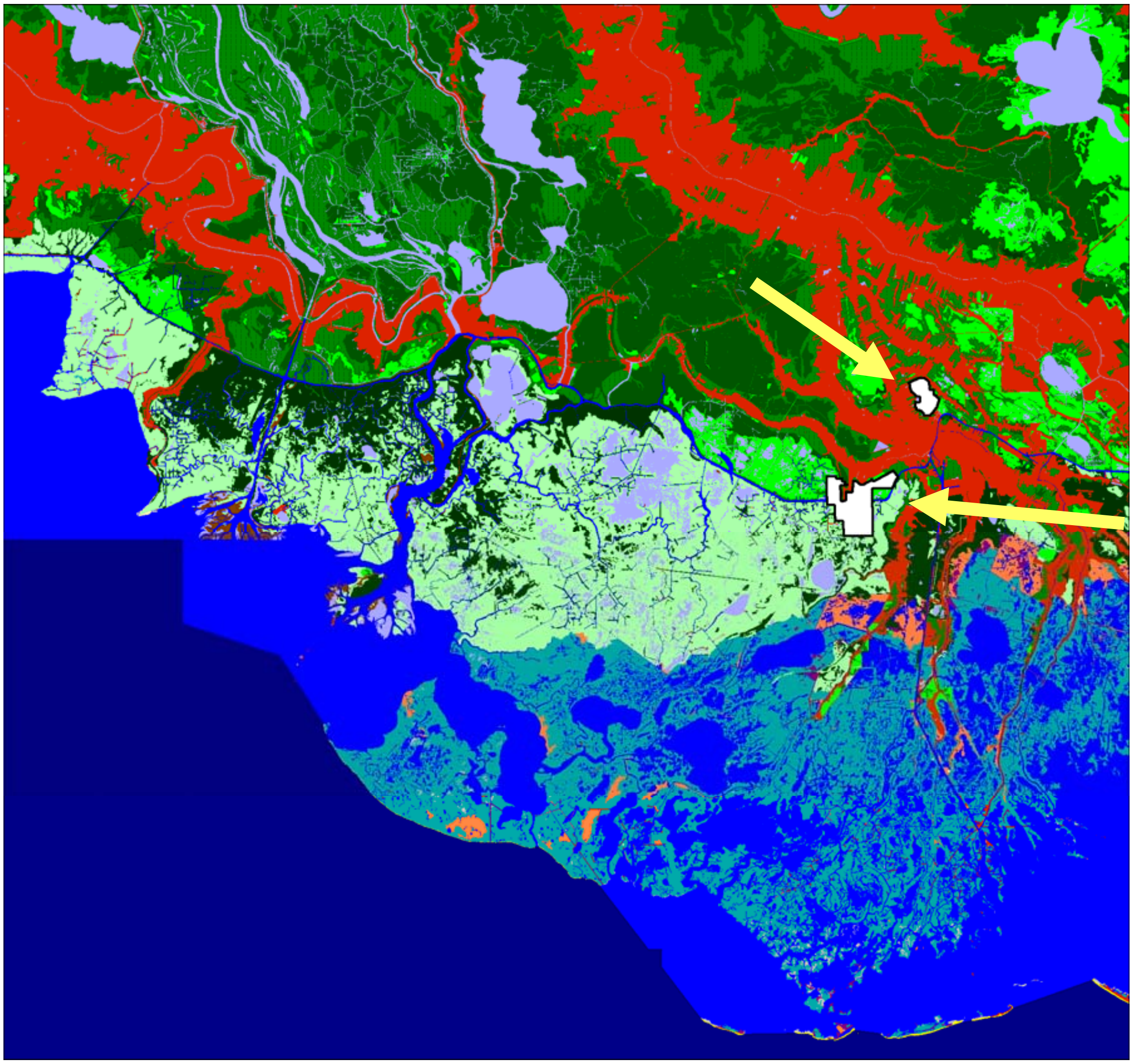
Titus, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mausel, M.S. Trehan, S. Brown, C. Grant, and G.W. Yohe. 1991. Greenhouse Effect and Sea Level Rise: Loss of Land and the Cost of Holding Back the Sea. *Coastal Management* 19:2:171-204.

Appendix A: Contextual Results

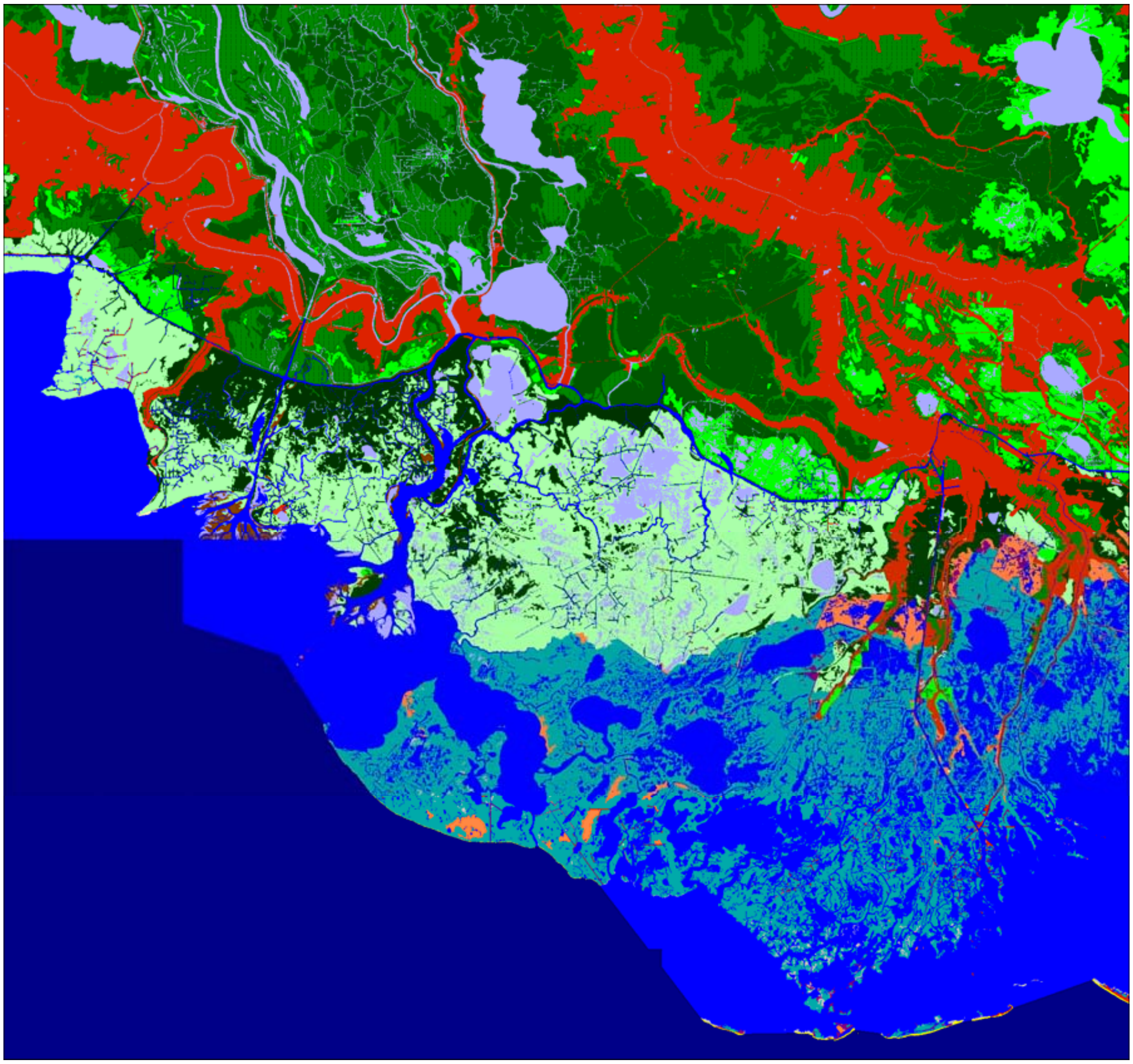
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

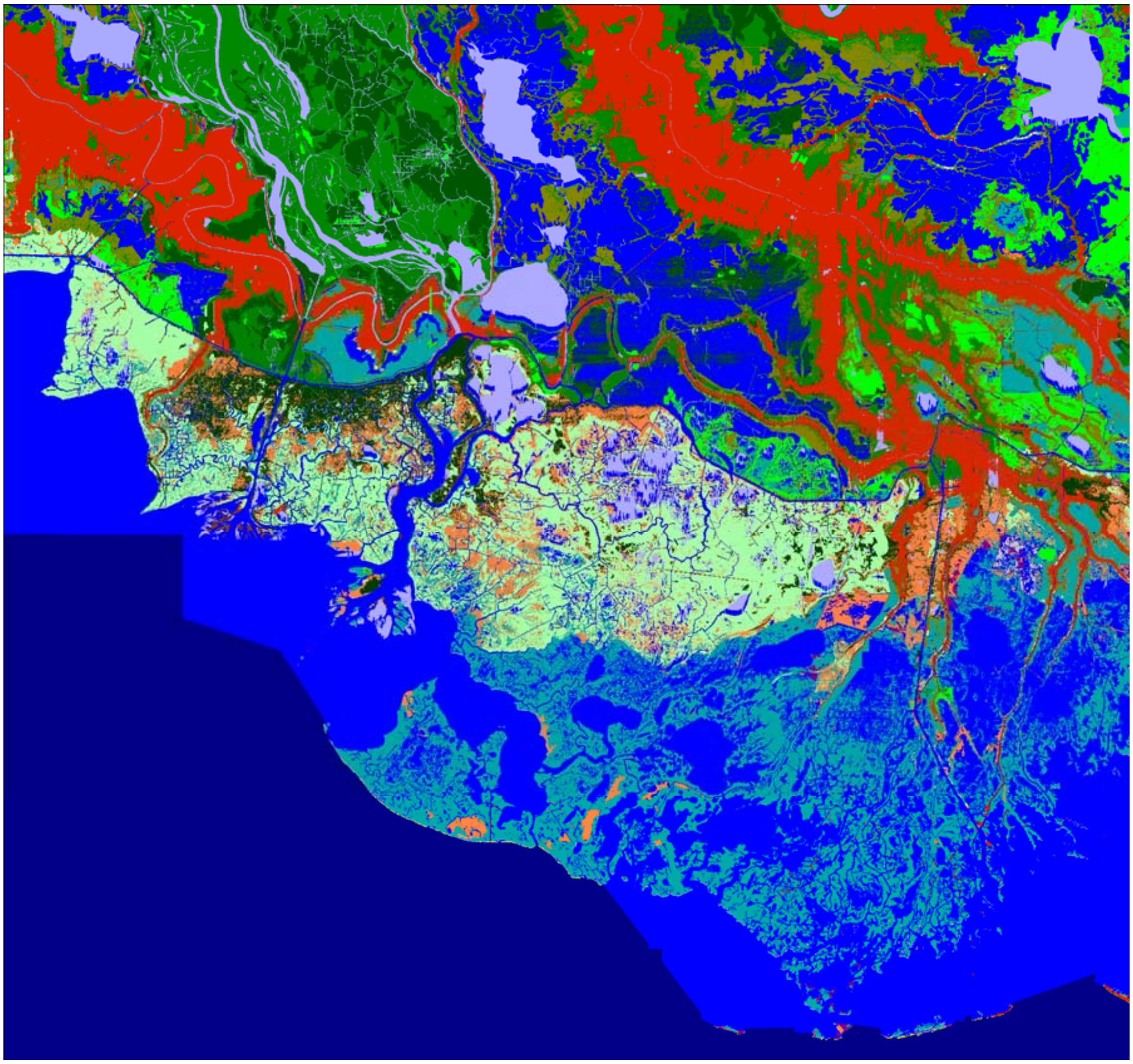
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



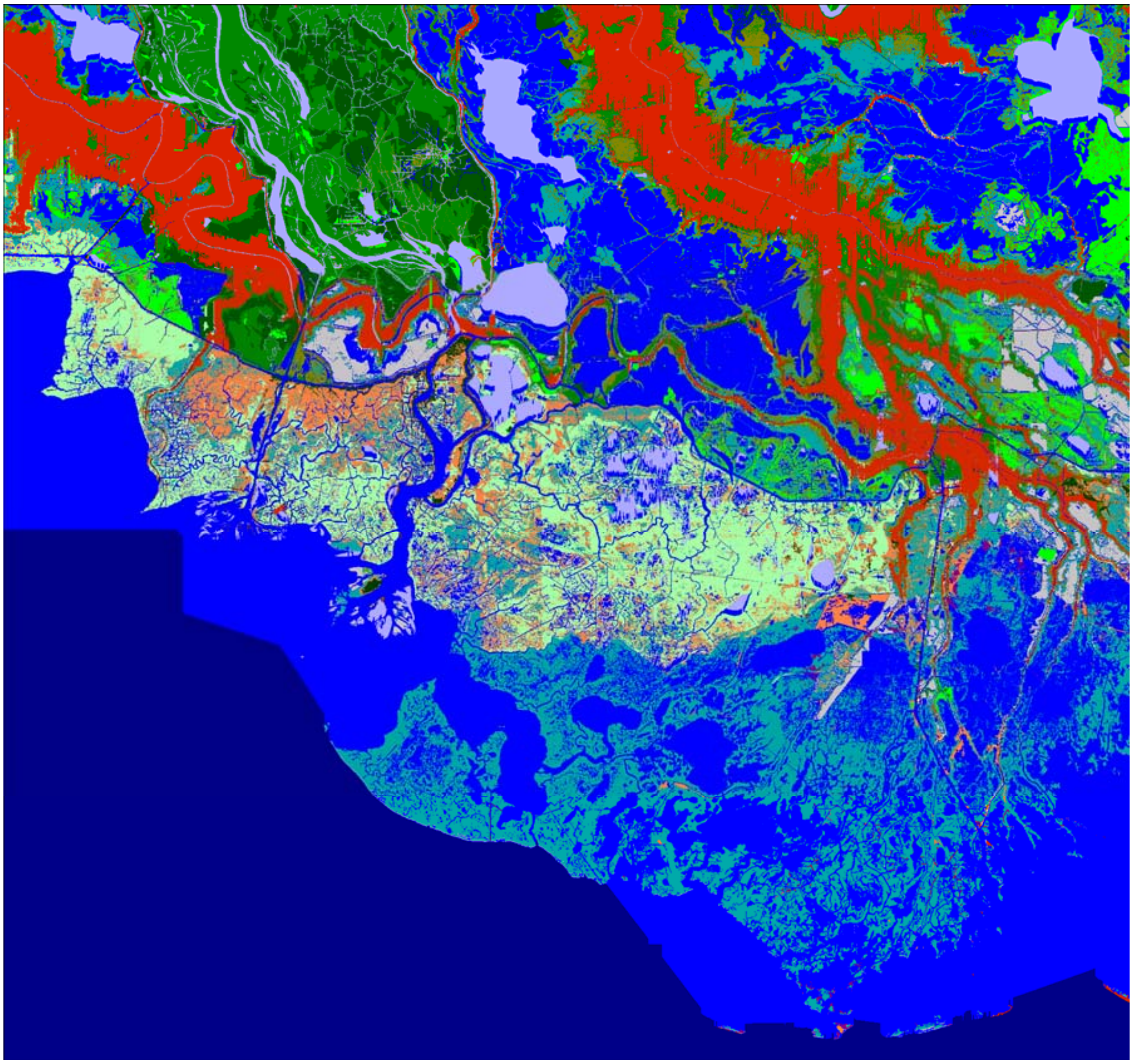
Location of Mandalay National Wildlife Refuge (white area with black boundary) within Louisiana simulation context



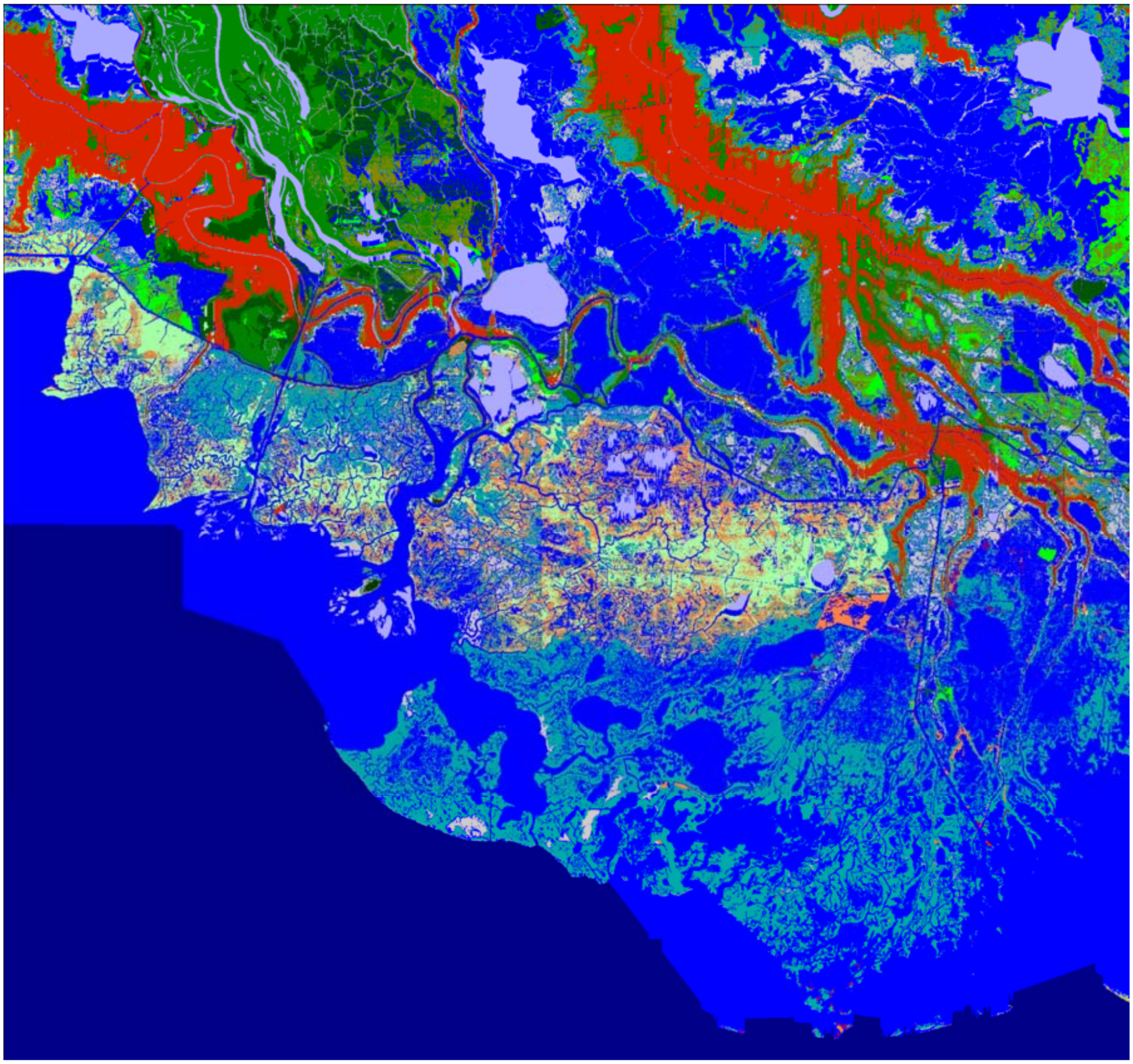
Louisiana Initial Condition



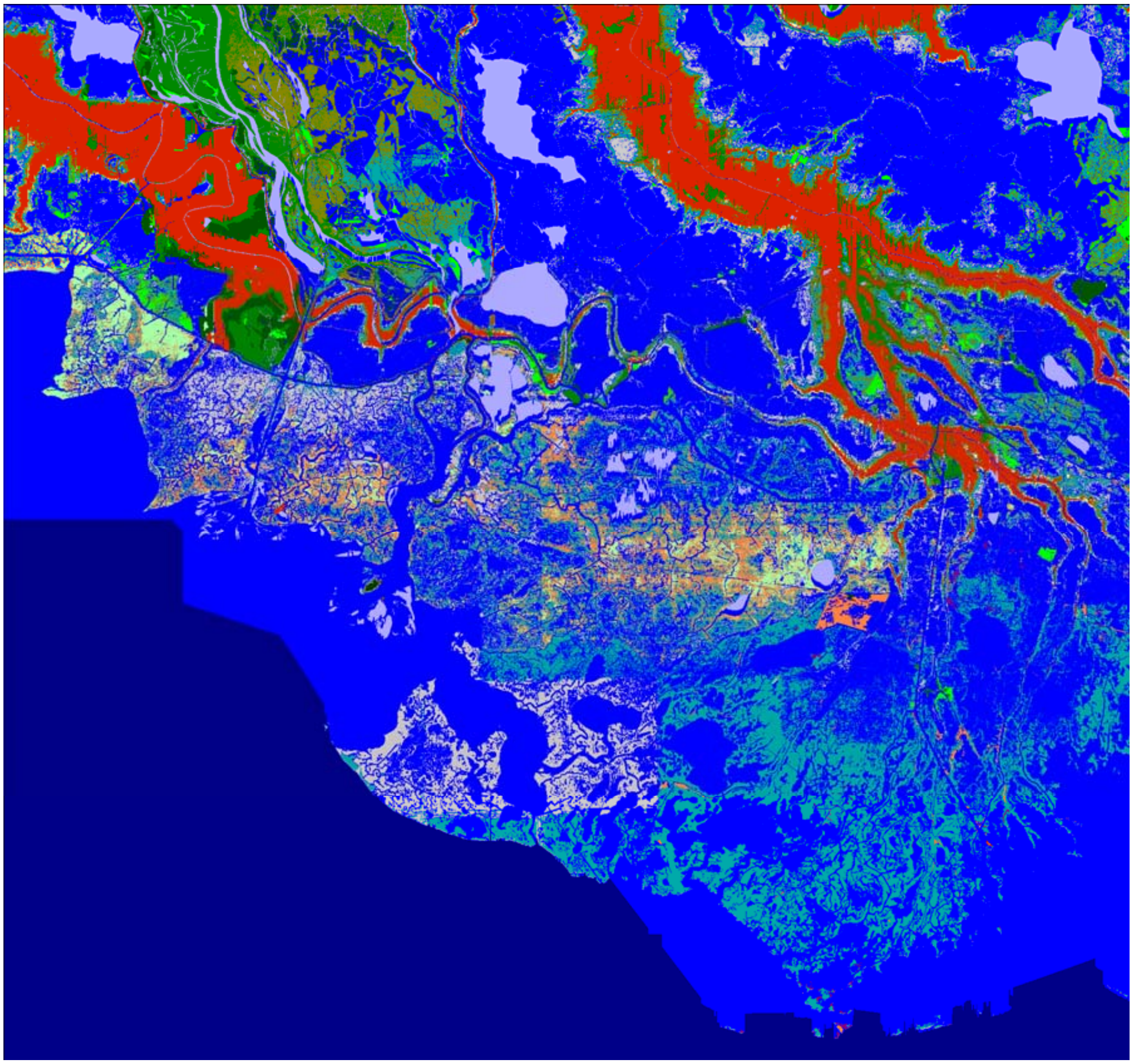
Louisiana 2025 IPCC Scenario A1B-Mean



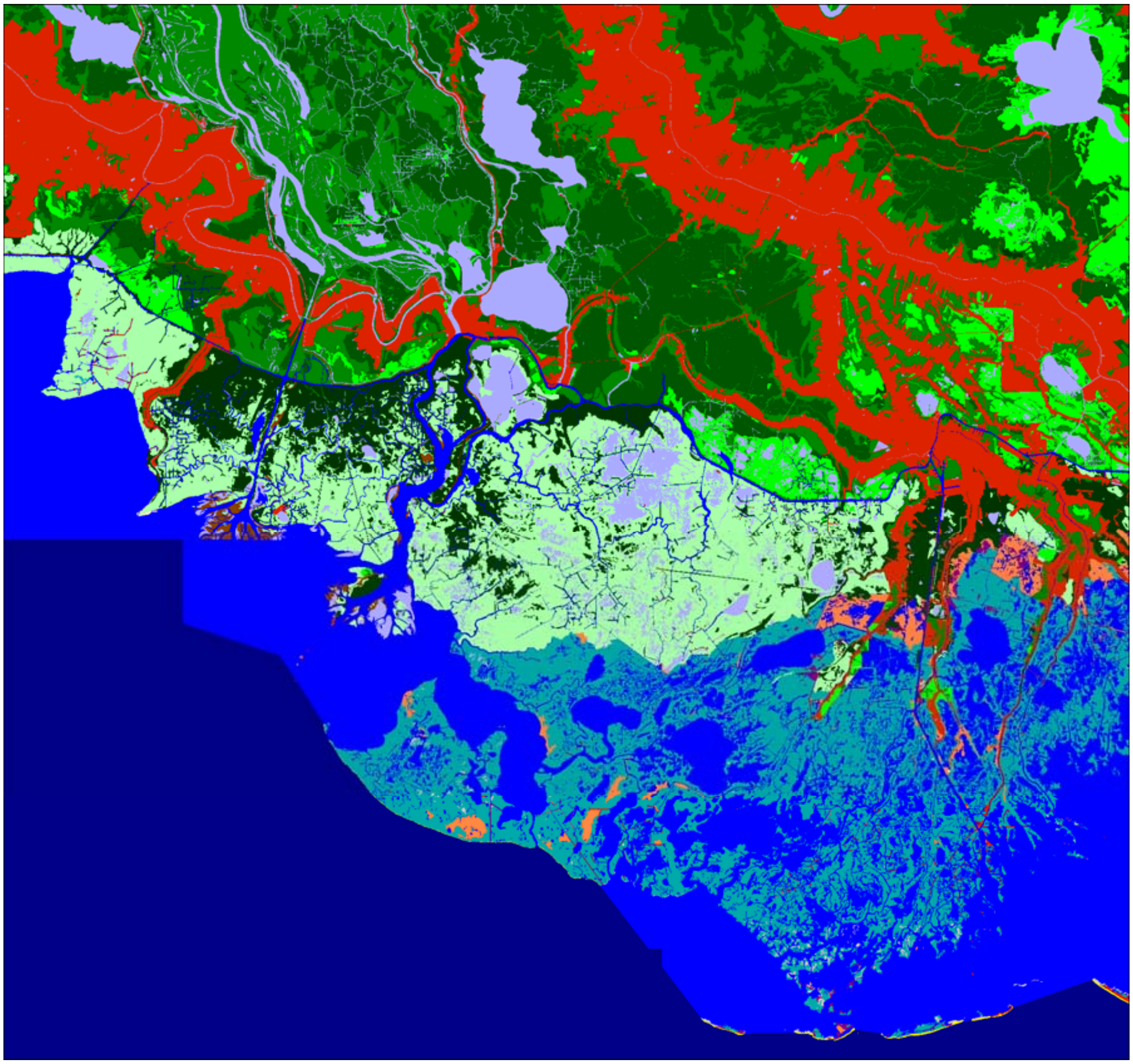
Louisiana 2050 IPCC Scenario A1B-Mean



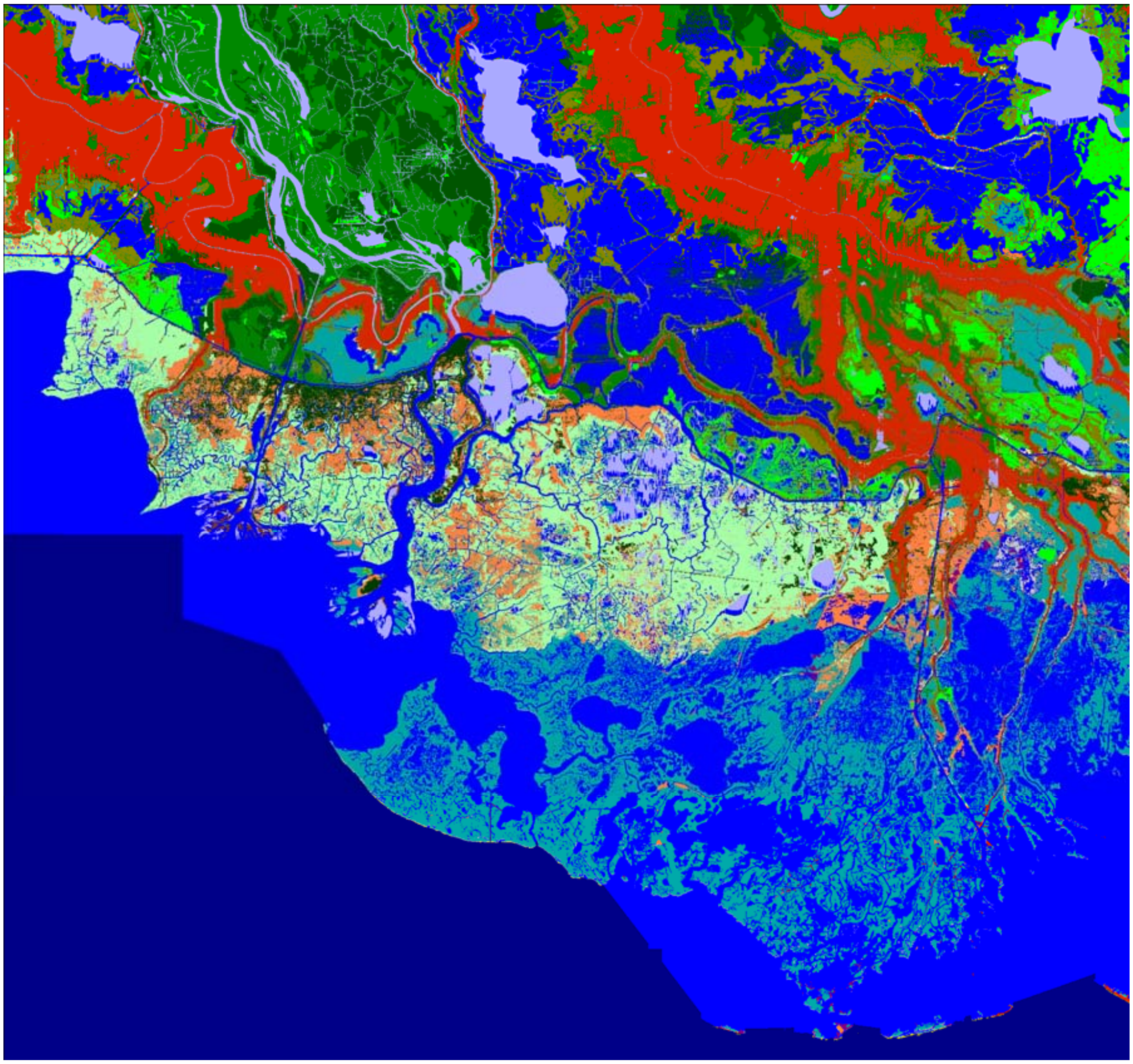
Louisiana 2075 IPCC Scenario A1B-Mean



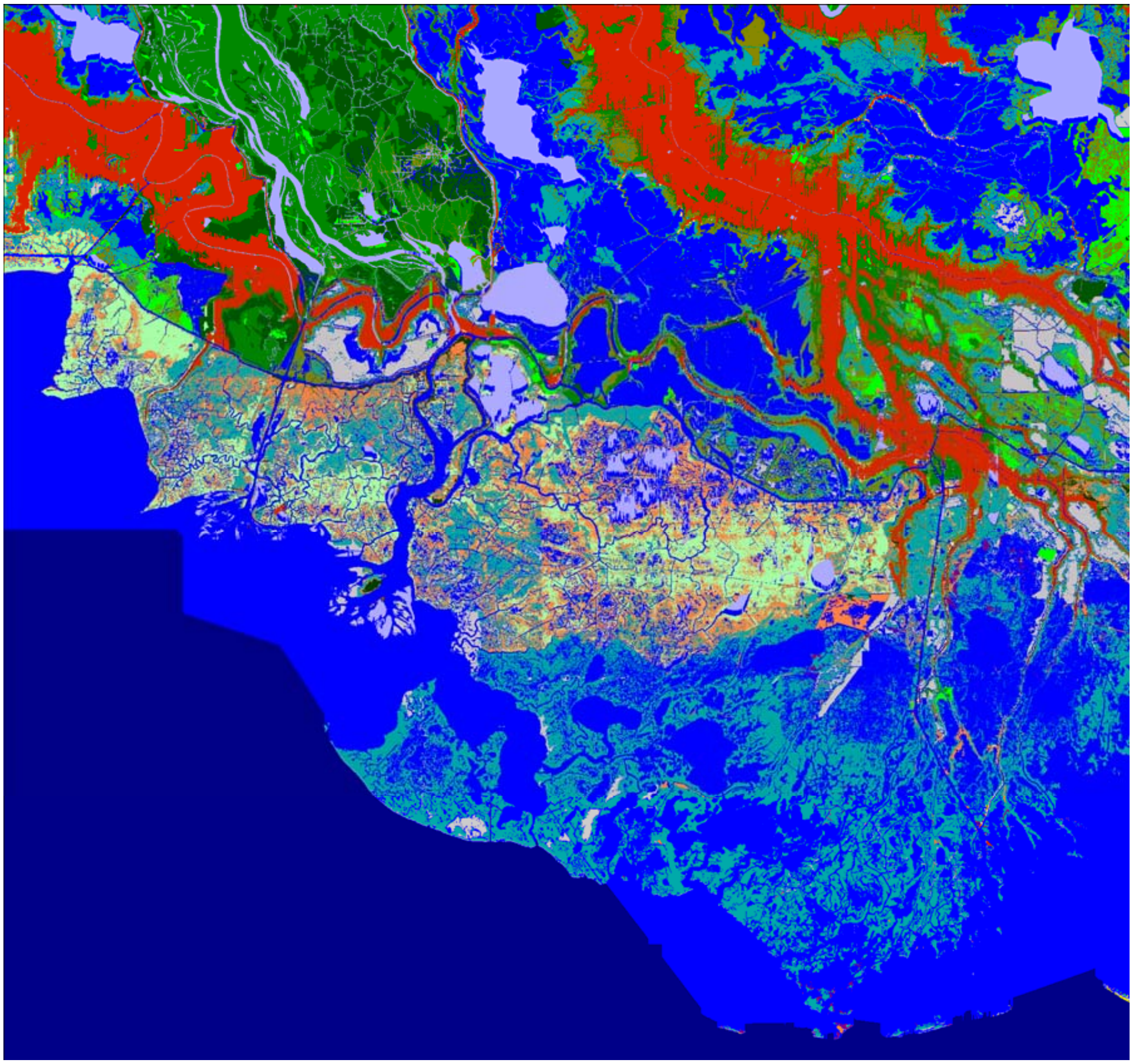
Louisiana 2100 IPCC Scenario A1B-Mean



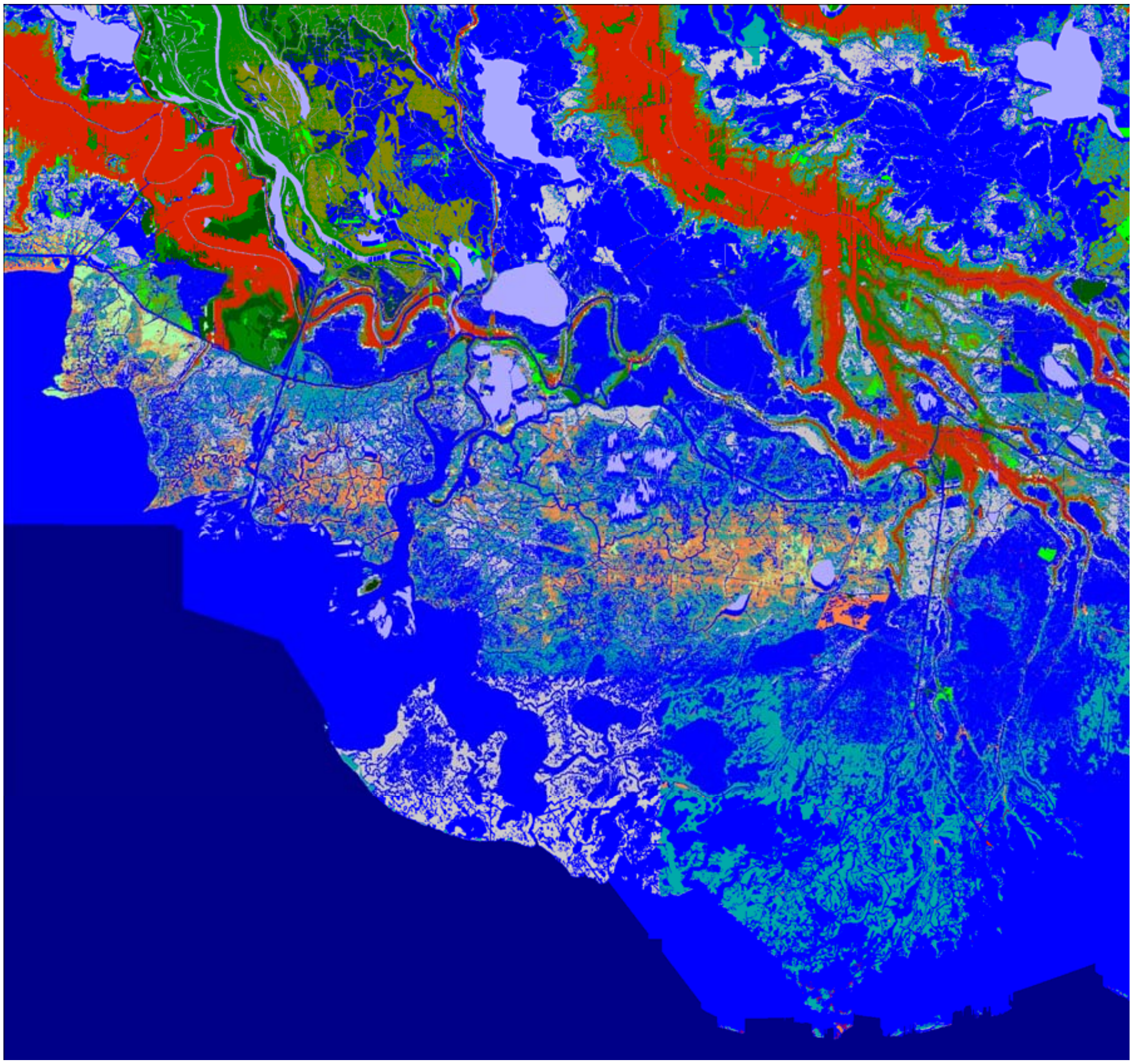
Louisiana Initial Condition



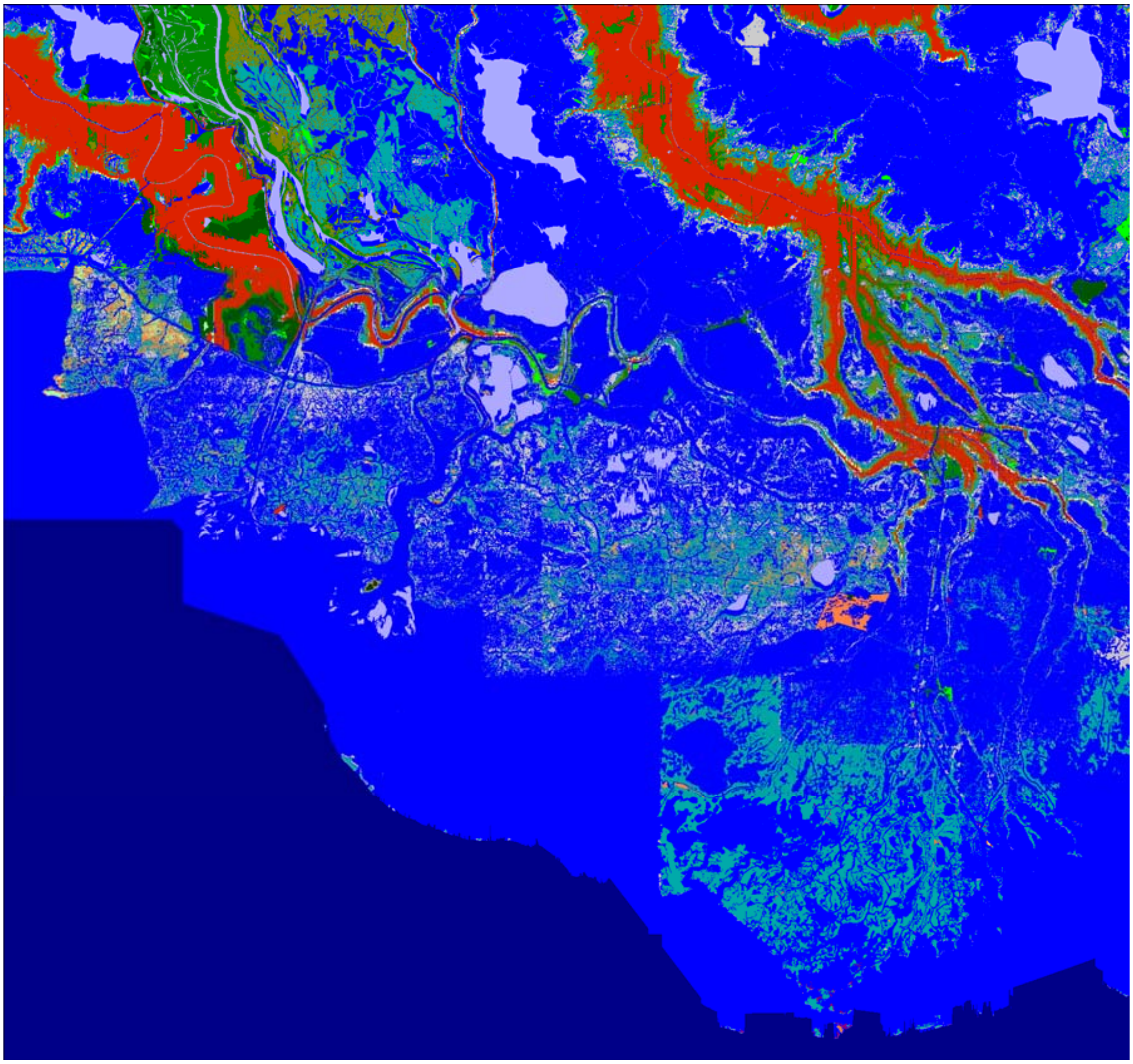
Louisiana 2025 IPCC Scenario A1B-Maximum



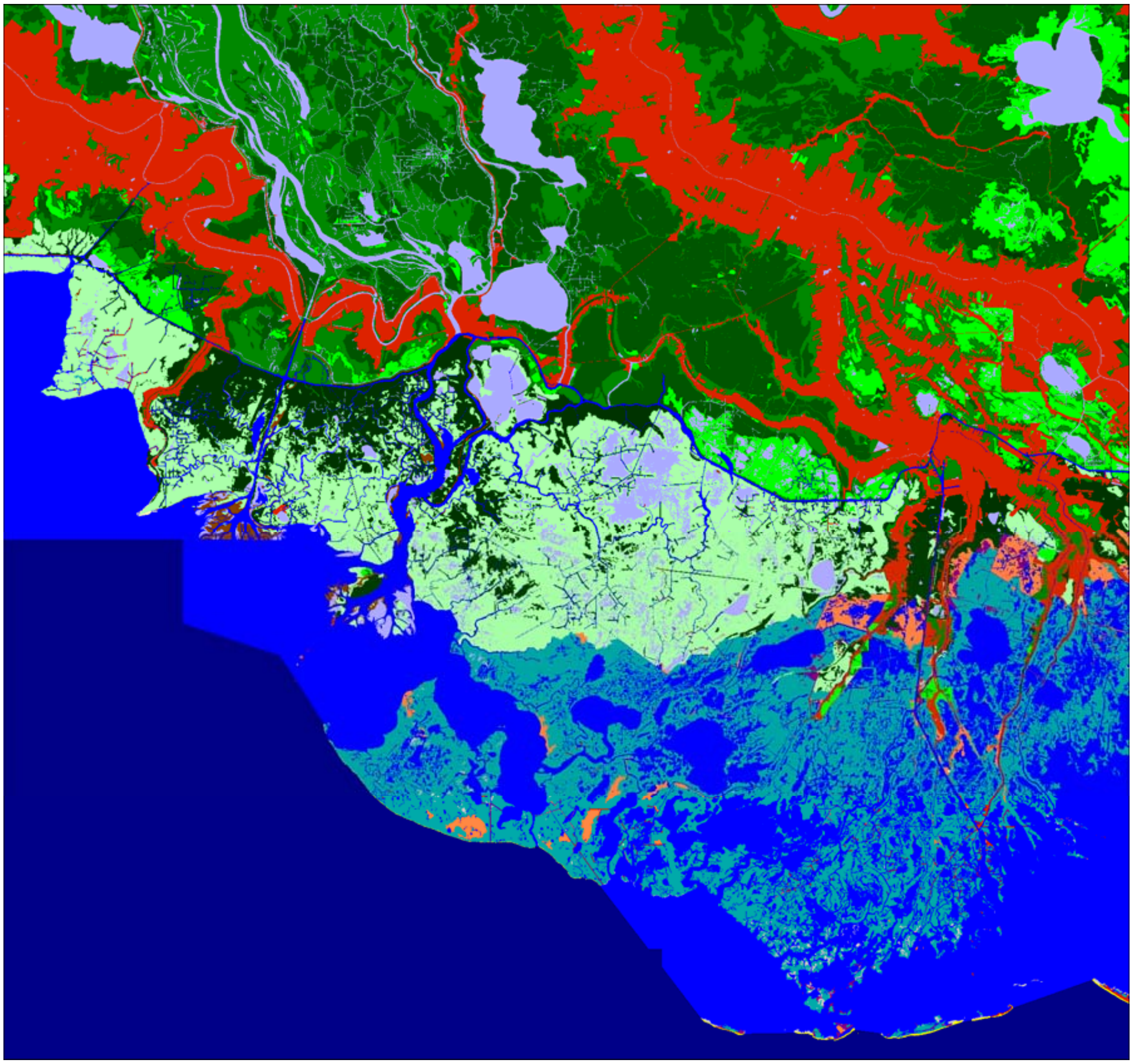
Louisiana 2050 IPCC Scenario A1B-Maximum



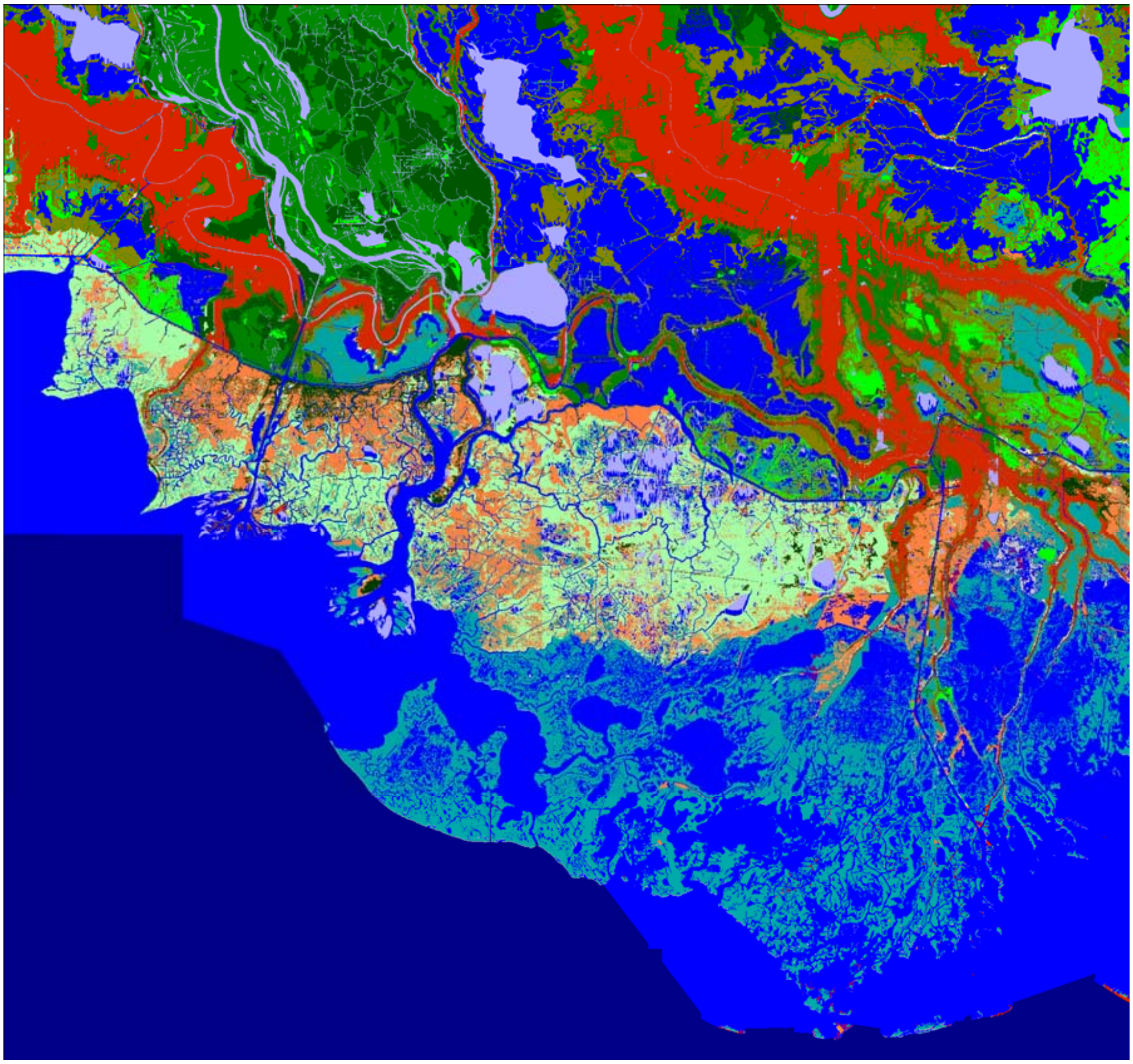
Louisiana 2075 IPCC Scenario A1B-Maximum



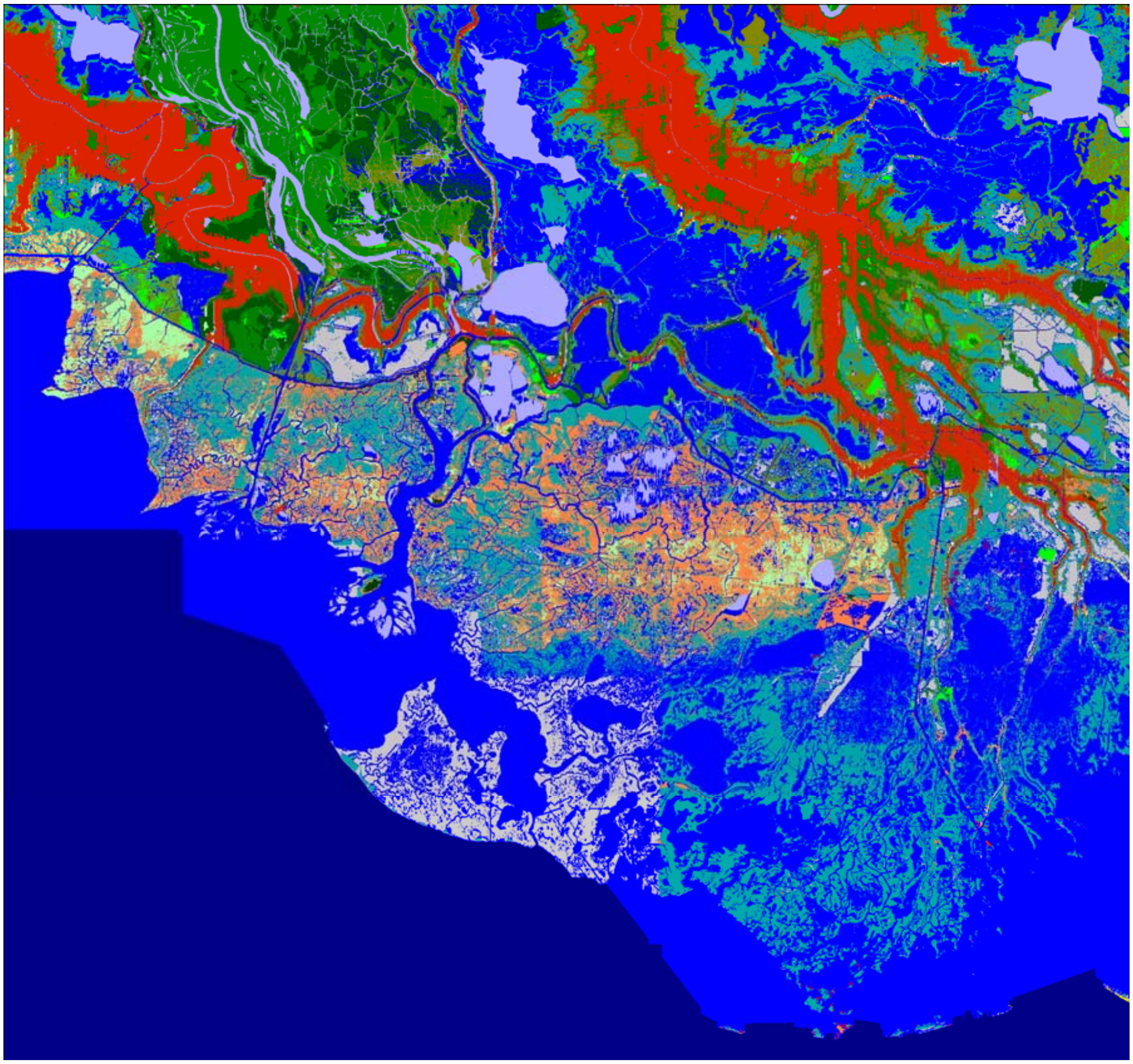
Louisiana 2100 IPCC Scenario A1B-Maximum



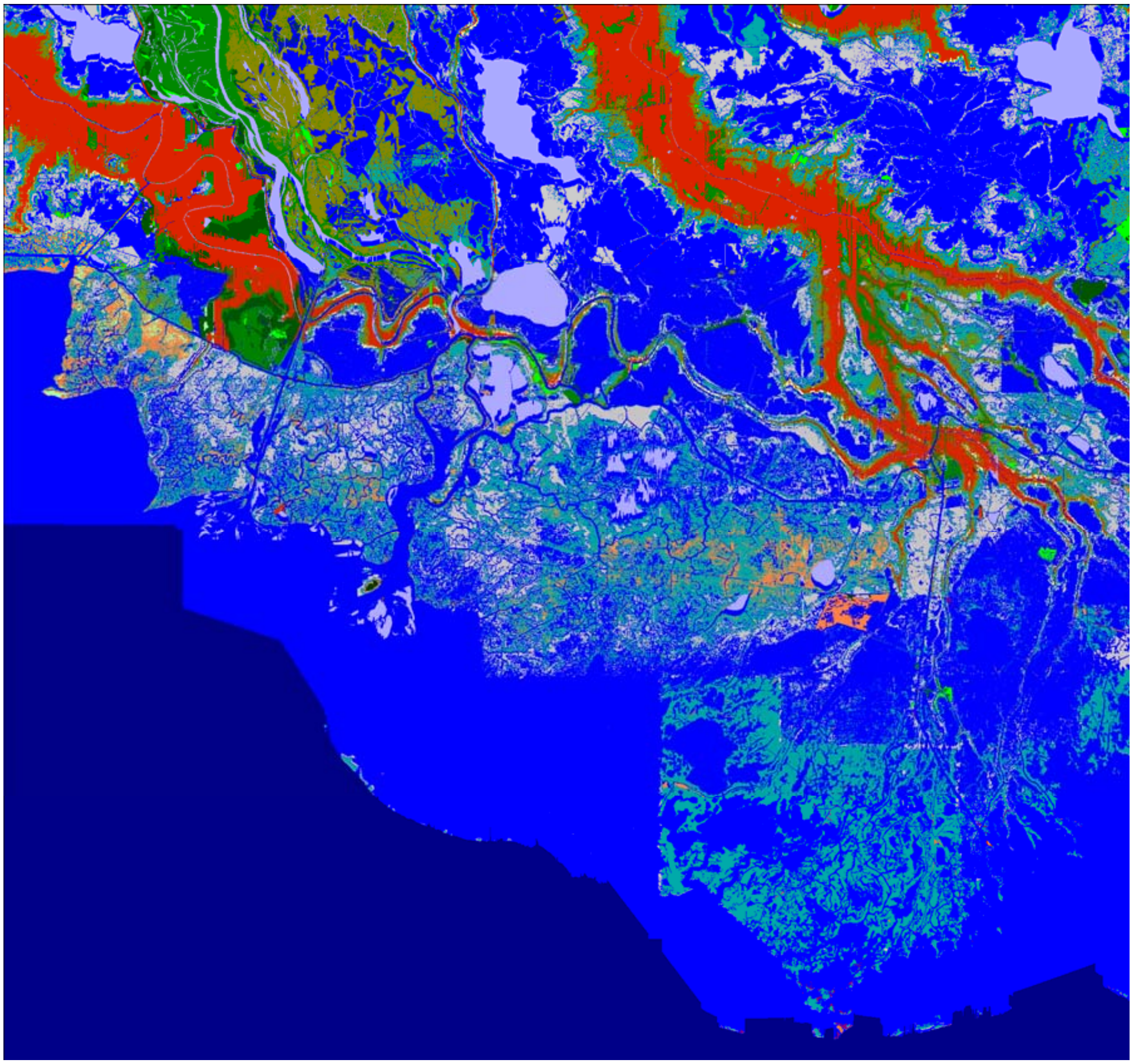
Louisiana Initial Condition



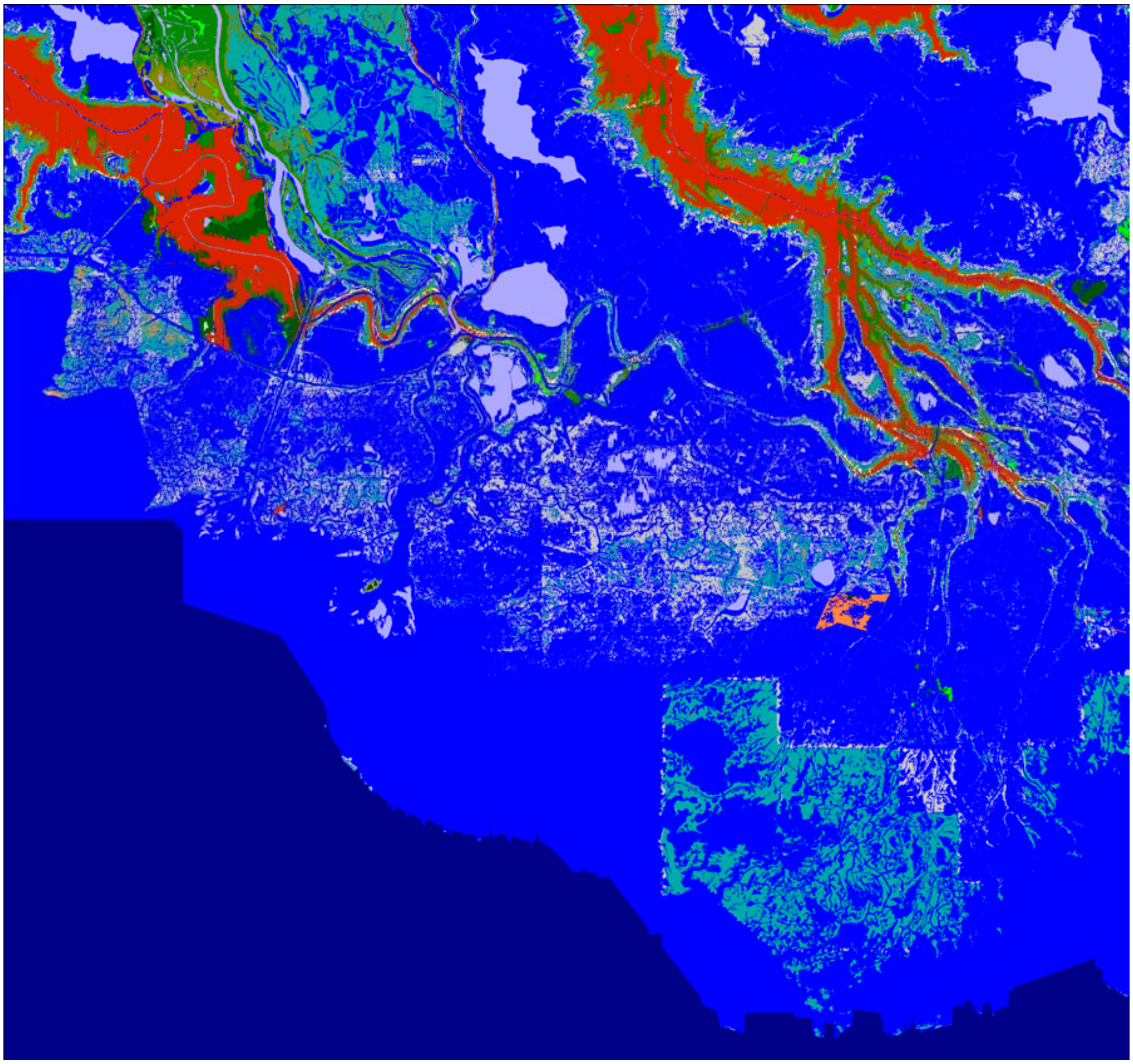
Louisiana 2025, 1 meter Eustatic by 2100



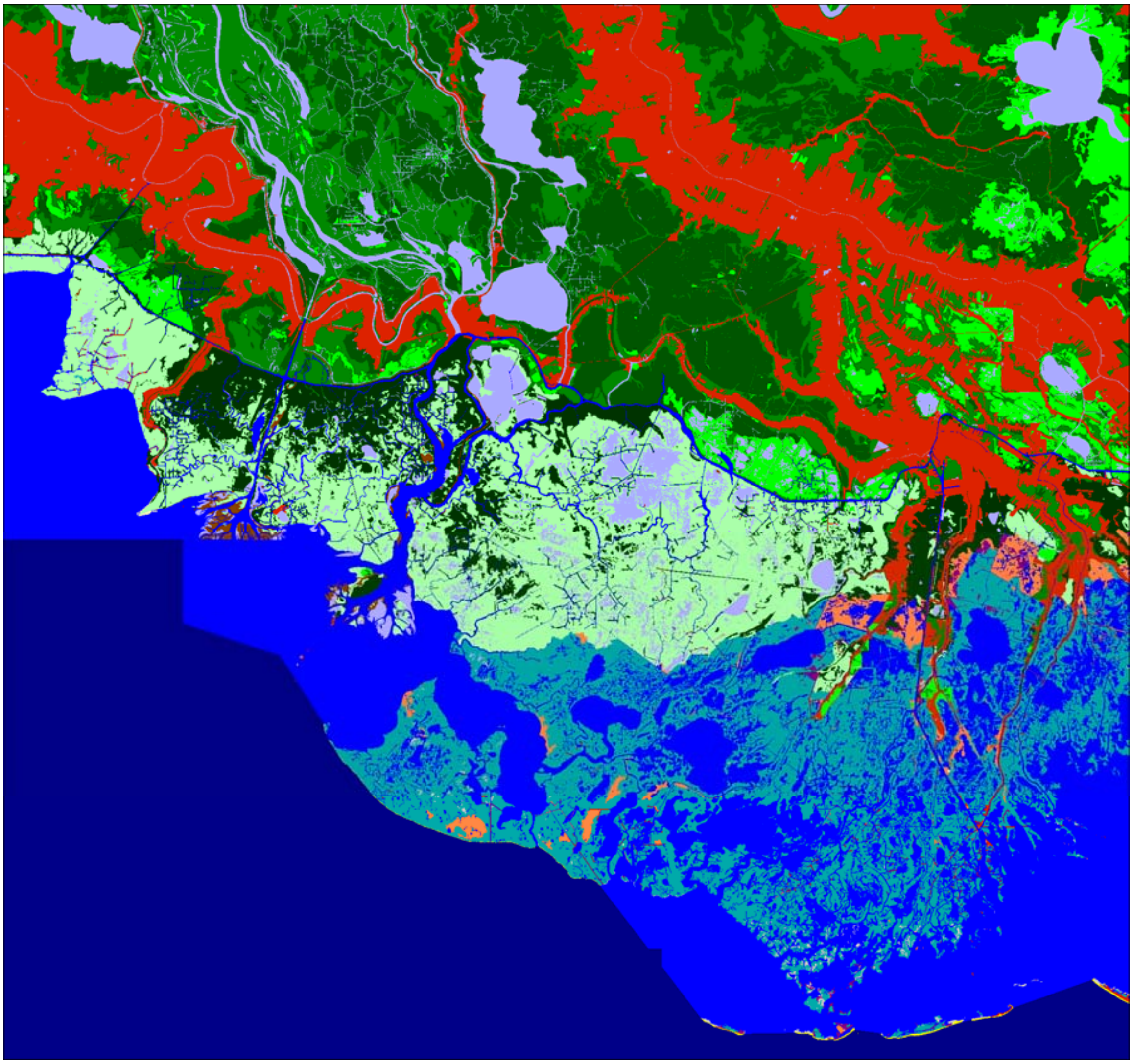
Louisiana 2050, 1 meter Eustatic by 2100



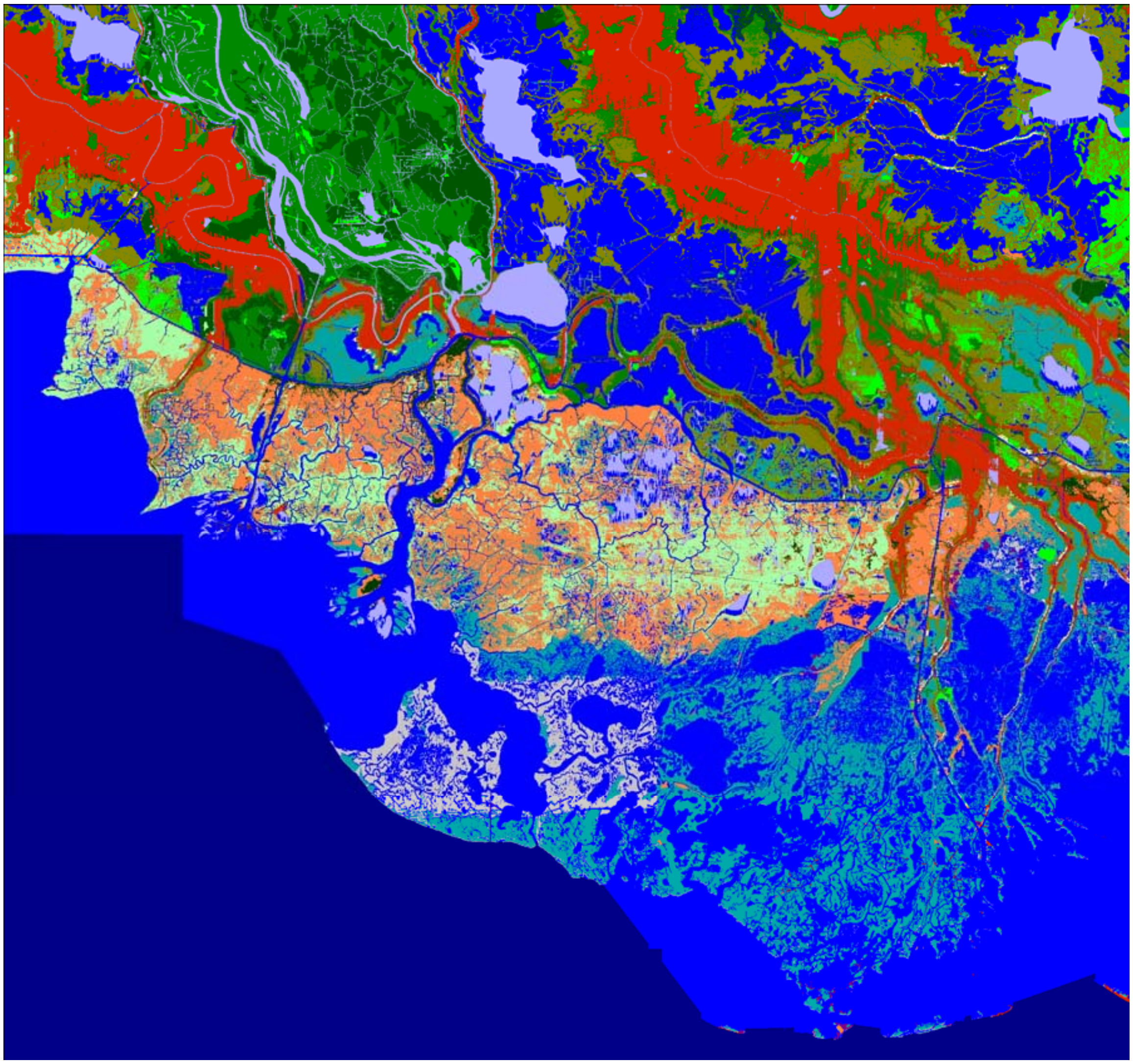
Louisiana 2075, 1 meter Eustatic by 2100



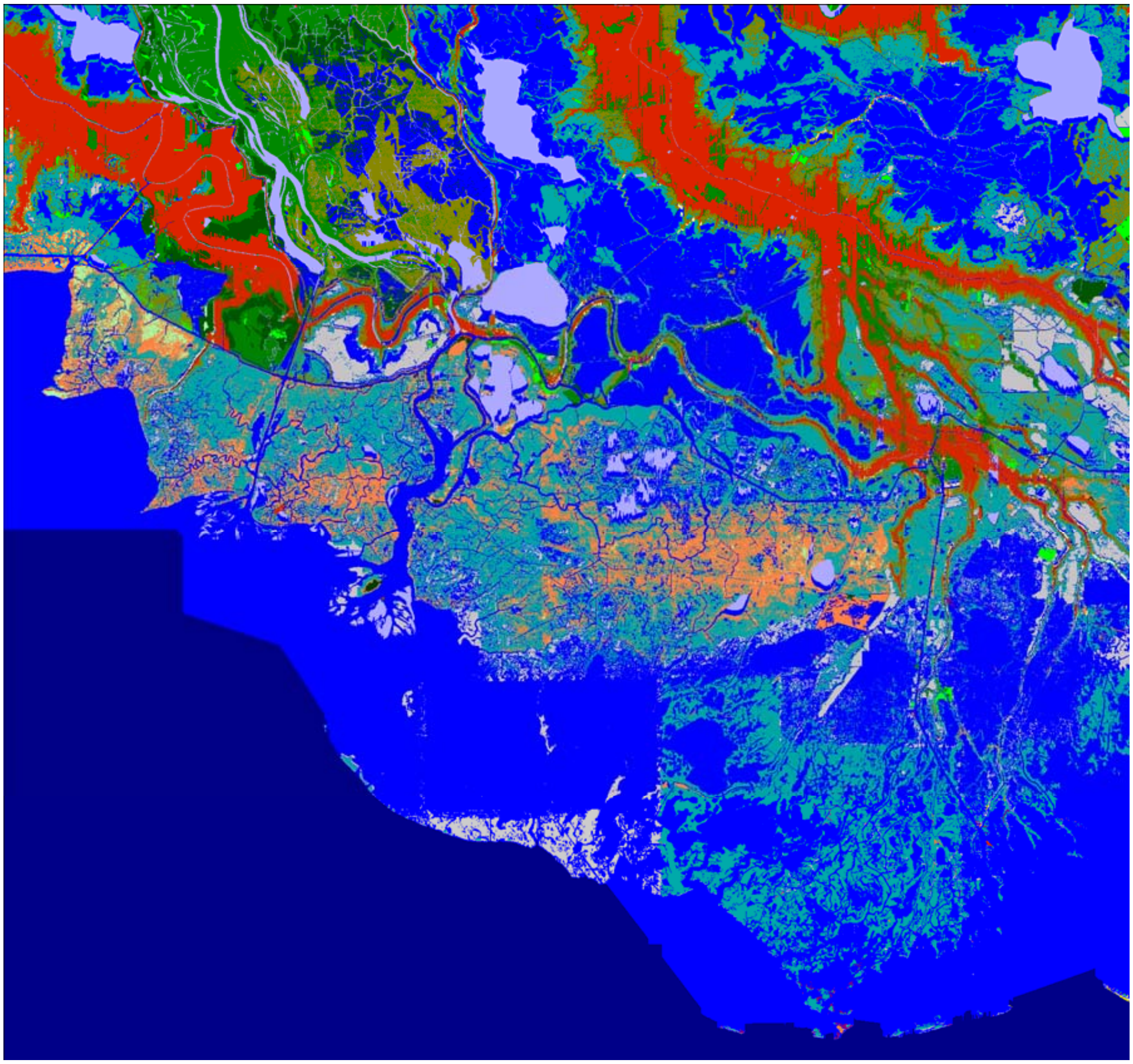
Louisiana 2100, 1 meter Eustatic by 2100



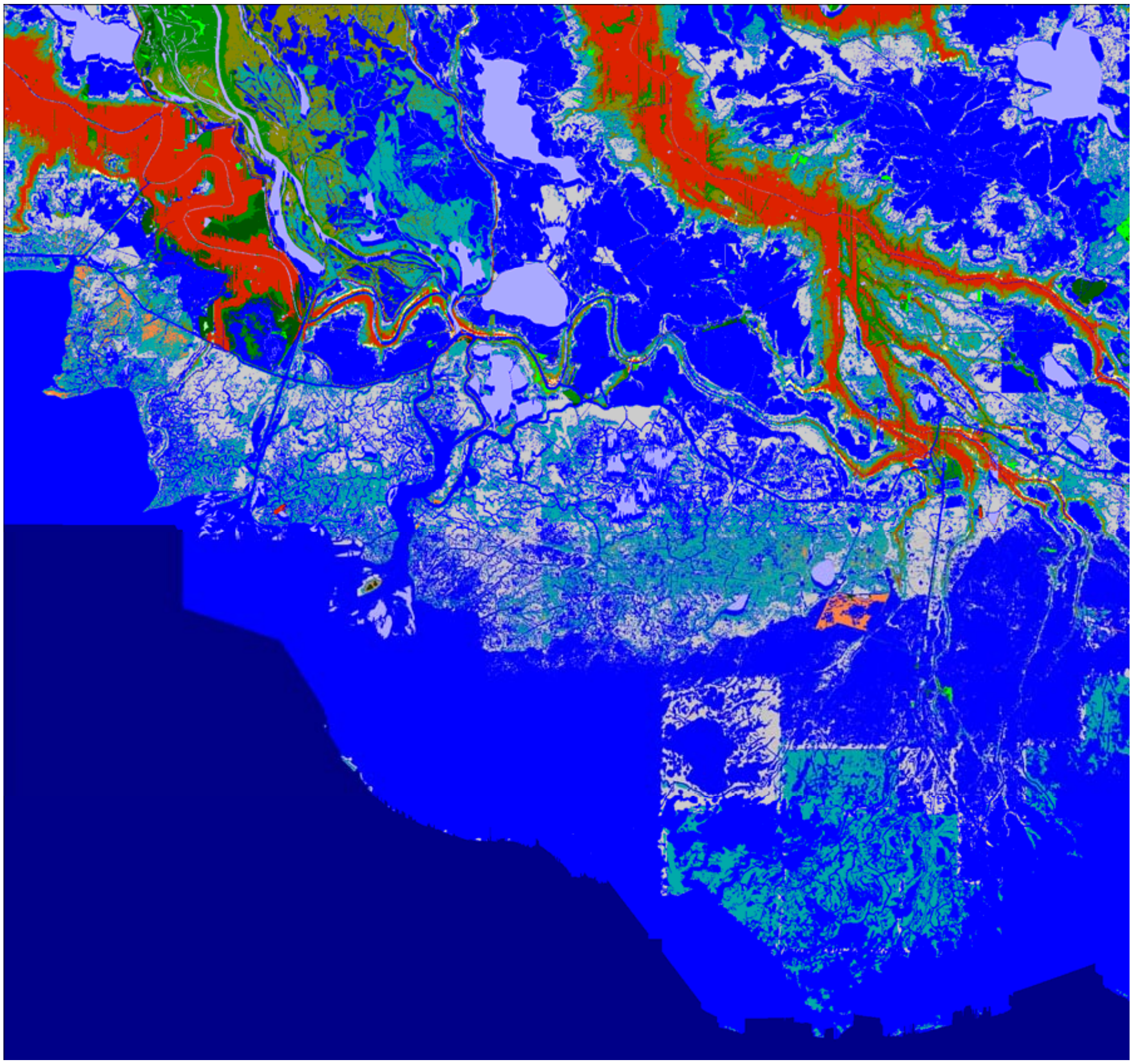
Louisiana Initial Condition



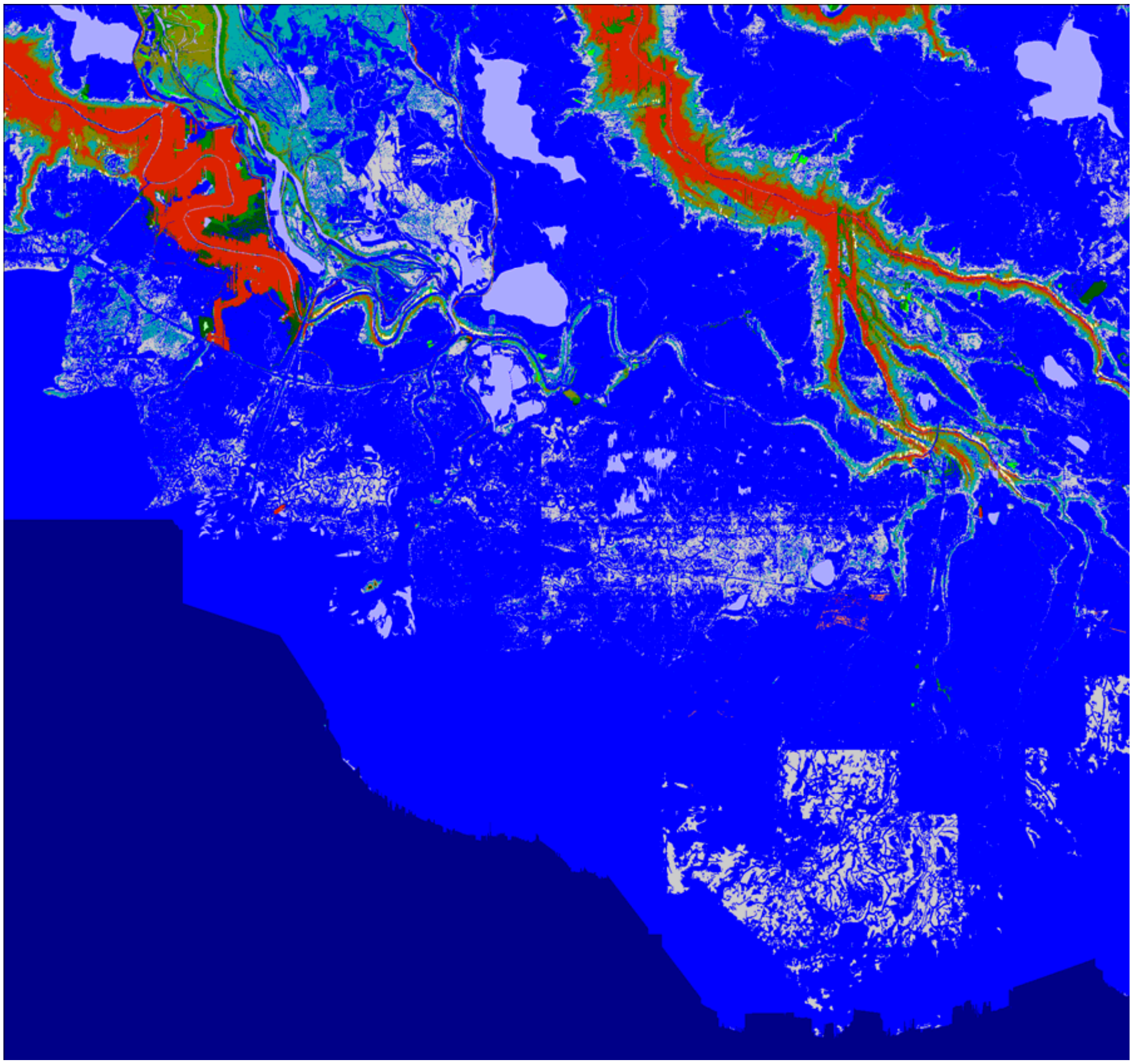
Louisiana 2025, 1.5 meter Eustatic by 2100



Louisiana 2050, 1.5 meter Eustatic by 2100



Louisiana 2075, 1.5 meter Eustatic by 2100



Louisiana 2100, 1.5 meter Eustatic by 2100