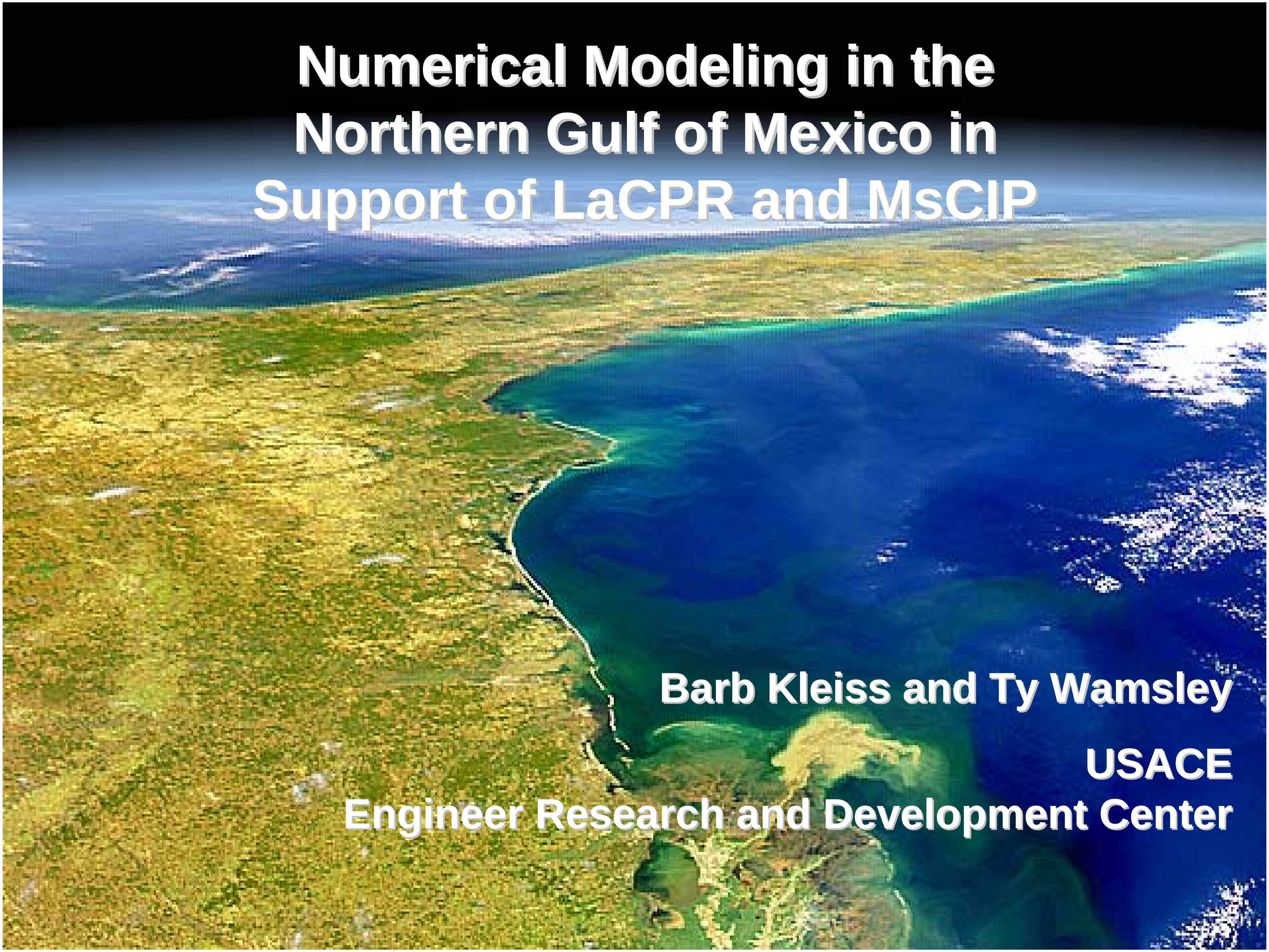
Numerical Modeling in the Northern Gulf of Mexico in Support of LaCPR and MsCIP



Barb Kleiss and Ty Wamsley

USACE
Engineer Research and Development Center

Team Effort

C. Cerco, R. Chapman, M. Cialone, M. Dortch, B. Jensen, S. Kim, P. Luong, M. Noel, A. Sleath, J. Smith, M. Zakikhani; USACE ERDC (EL and CHL)

J. Ratcliff; USACE MVN

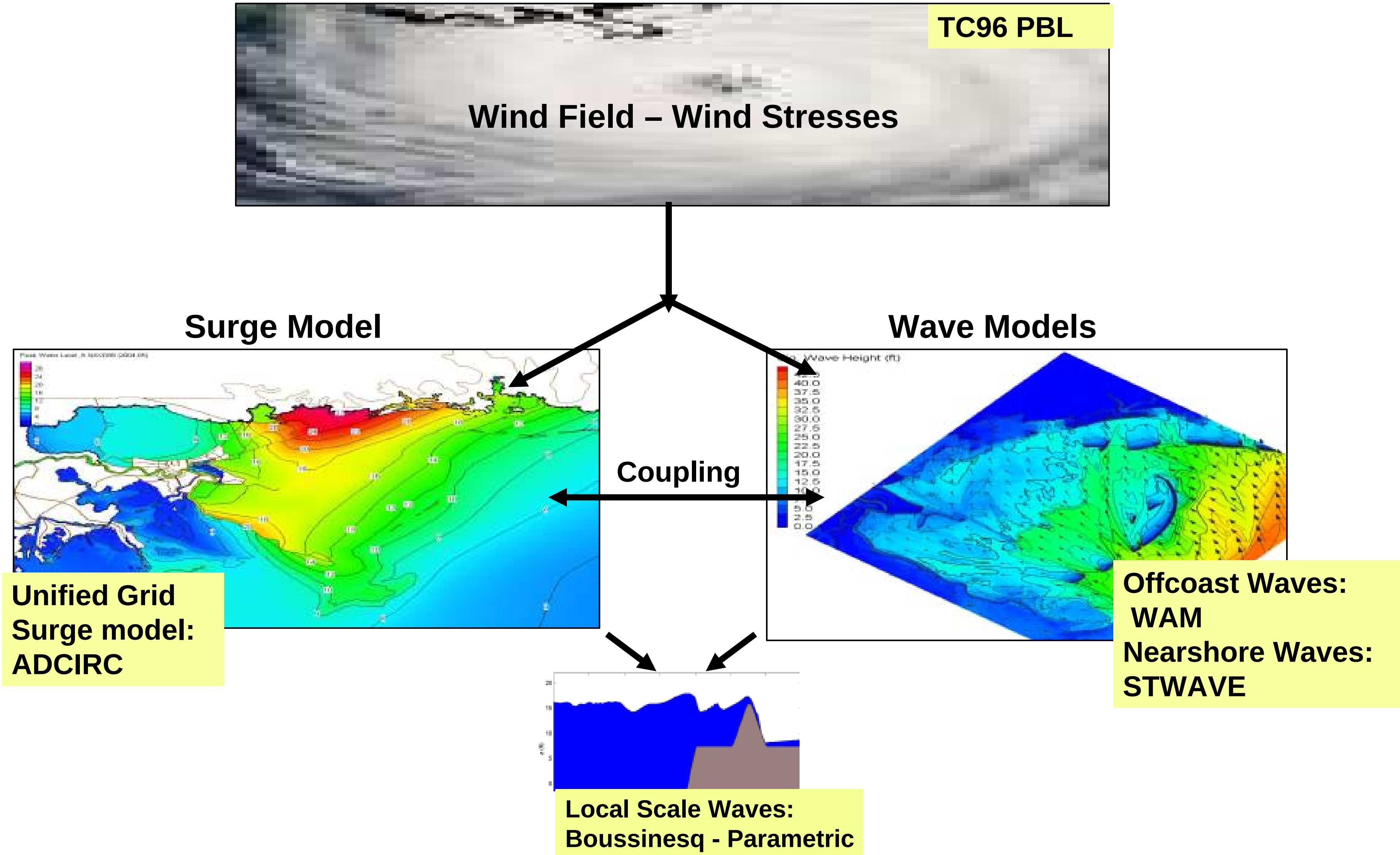
J. Westerink; University of Notre Dame

J. Atkinson; Ayres Associates

Brady Couvillon, USGS

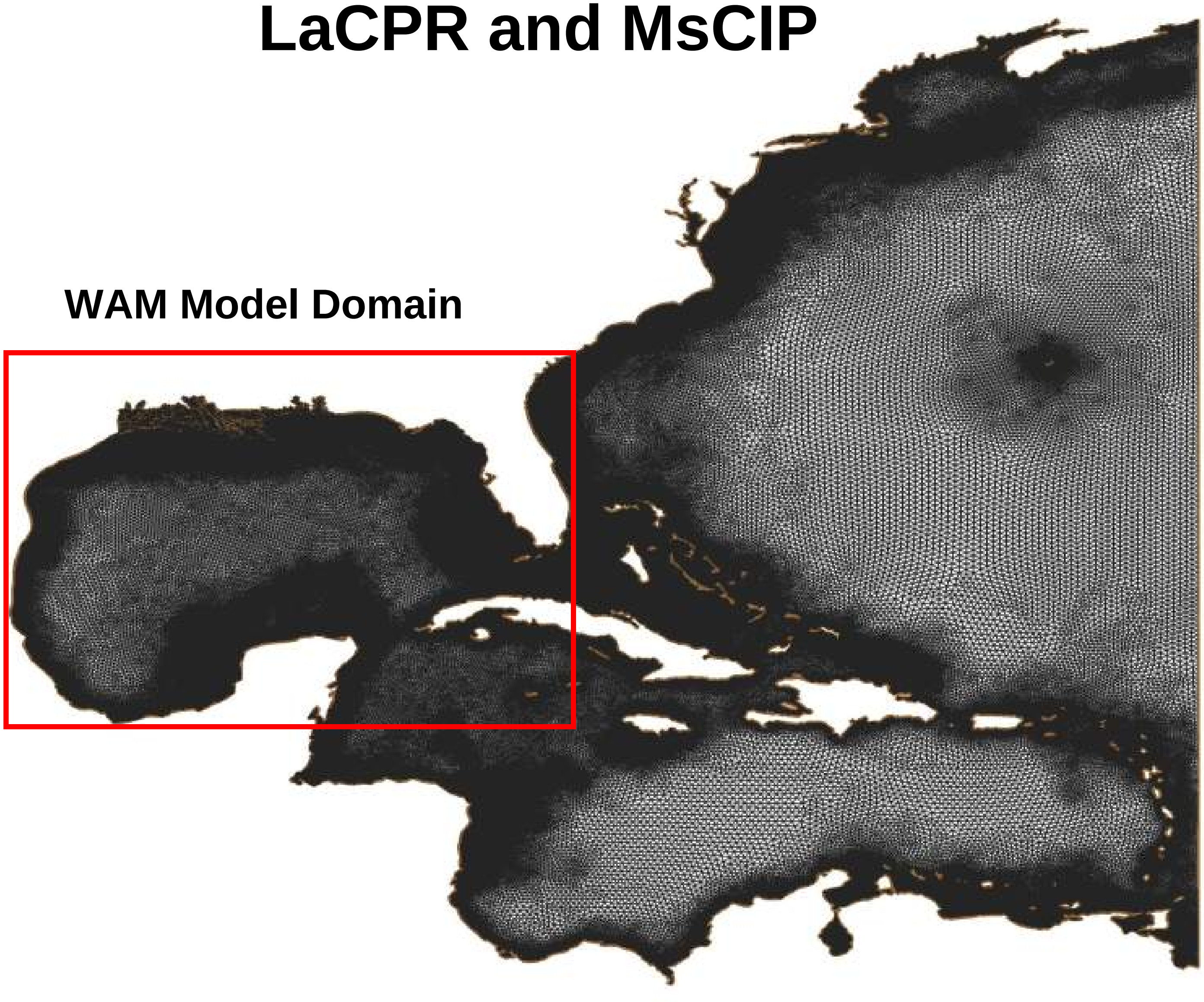
Robert Twilley, Louisiana State University

Modeling Methodology

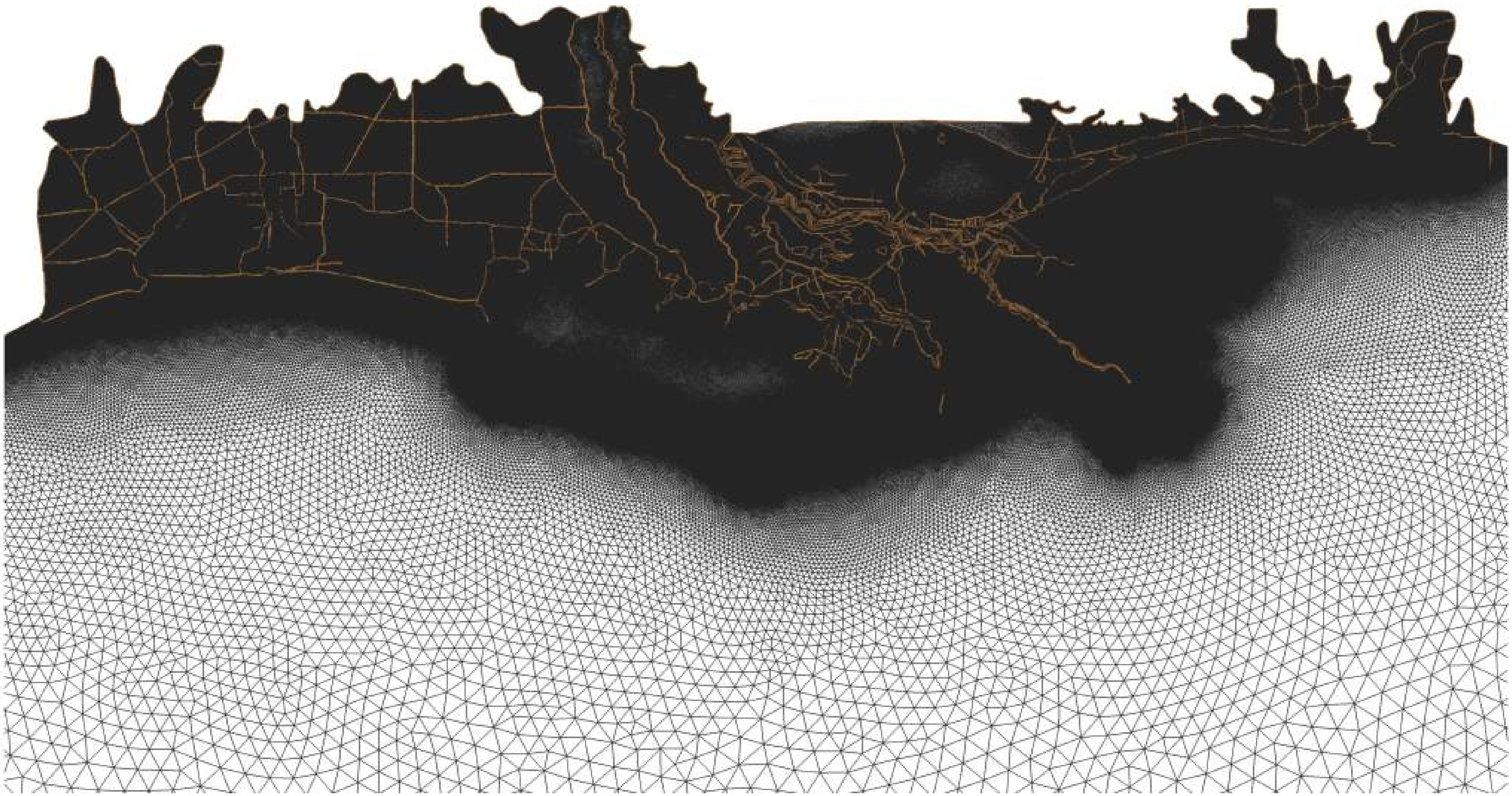


ADCIRC Grid Domain

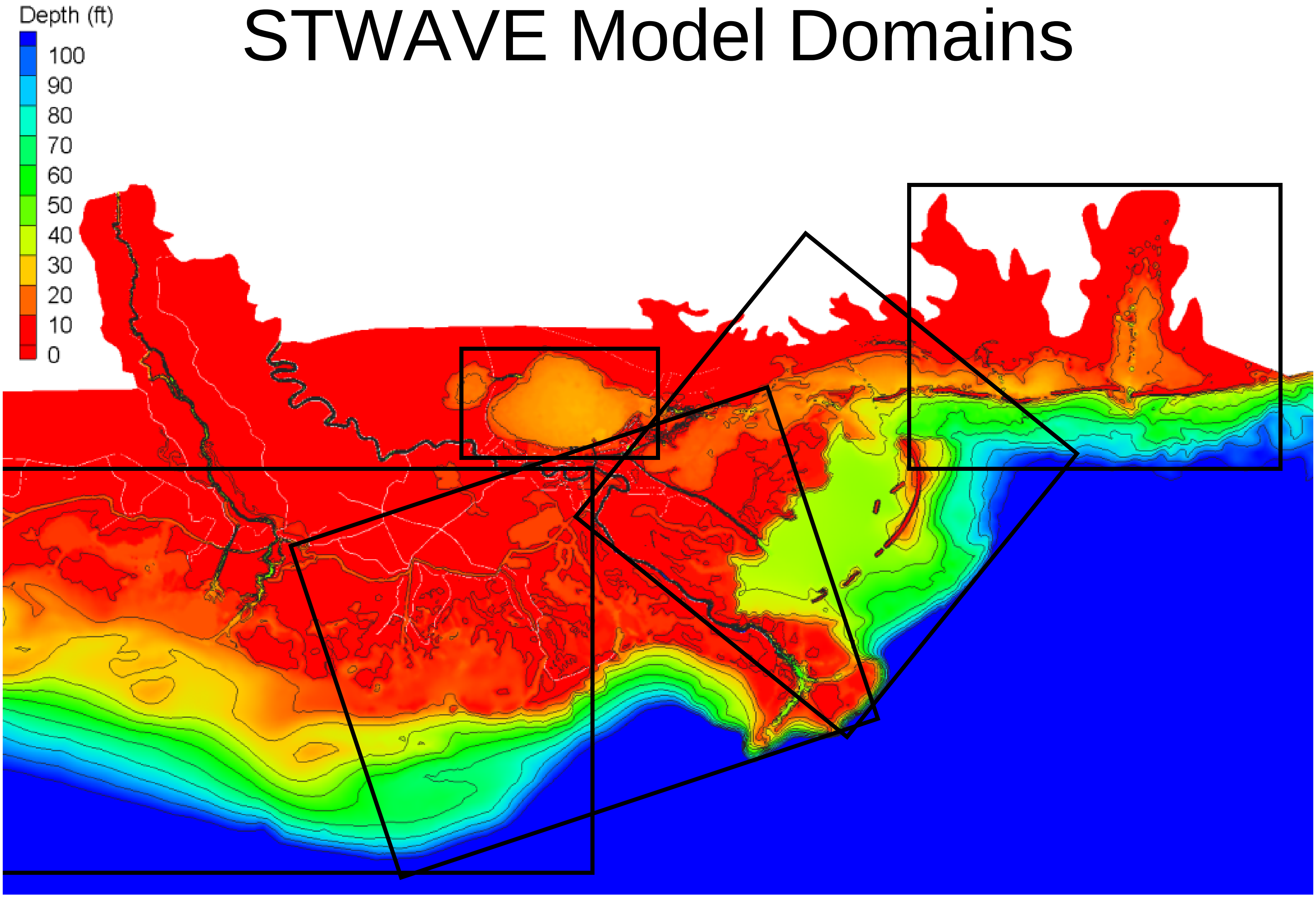
LaCPR and MsCIP



ADCIRC Grid
Louisiana and Mississippi



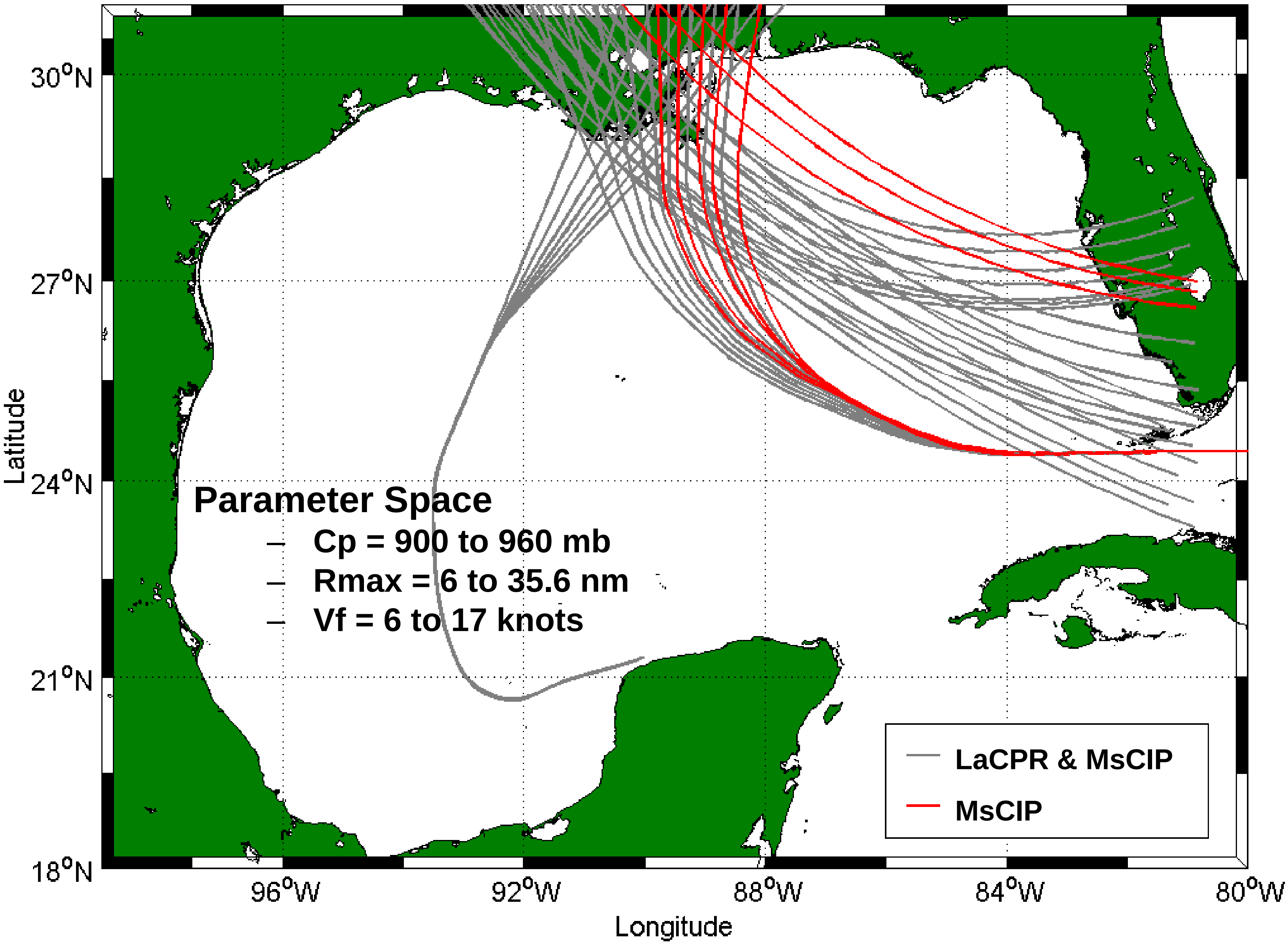
STWAVE Model Domains



LaCPR and MsCIP Models and Input

- Wind Model (TC96)
- Surge Model (ADCIRC)
- Offshore Wave Model (WAM cycle 4.5)
- Nearshore Wave Model (STWAVE)
- Base Conditions – Same grids for all models
- Storms – 152 identical storms

Storms



30°N
27°N
24°N
21°N
18°N
Latitude
96°W
92°W
88°W
84°W
80°W
Longitude
Parameter Space
– Cp = 900 to 960 mb
– Rmax = 6 to 35.6 nm
– Vf = 6 to 17 knots
LaCPR & MsCIP
MsCIP

MsCIP – FEMA Region 4 Coordination

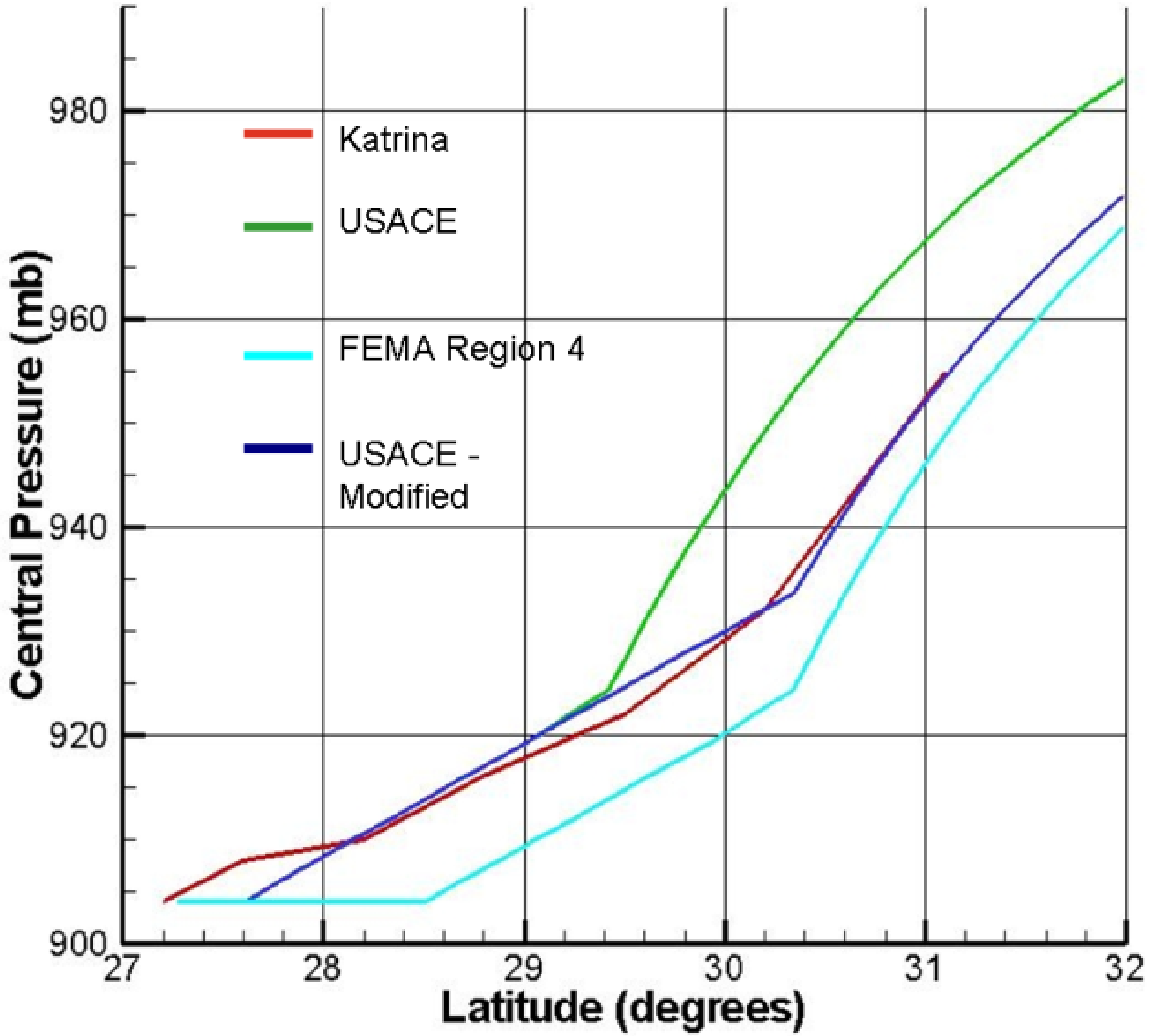
- Wind Model (TC96)
- Surge Model (ADCIRC)
- Offshore Wave Model (WAM cycle 4.5 / WAM OWI)
- Nearshore Wave Model (STWAVE / SWAN)
- Same ADCIRC grid east of the Mississippi river
- Different storms and implementation of JPM-OS statistical methodology

MsCIP – FEMA Region 4 Coordination

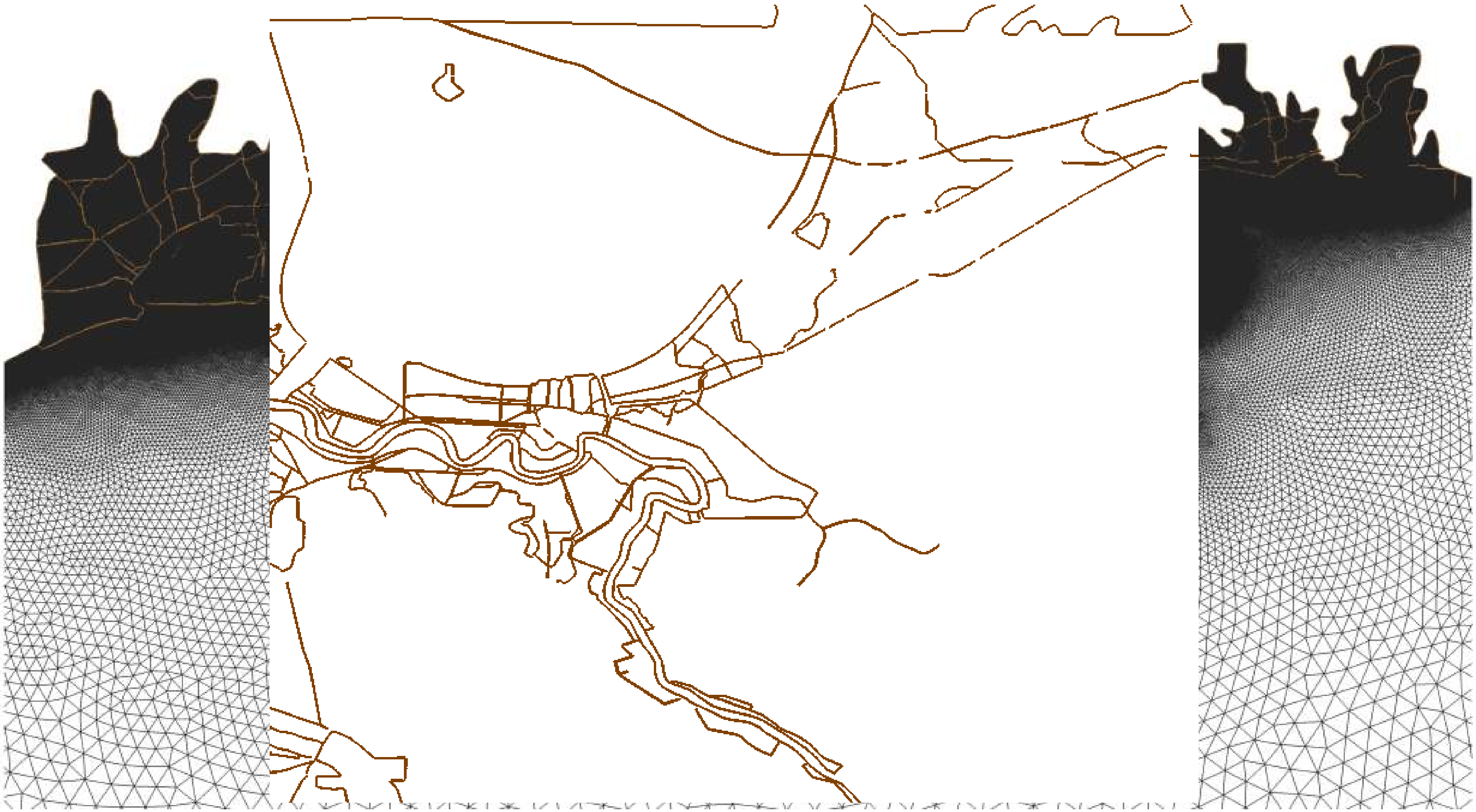
- Different Storms
  - Parameter space
  - Tracks
  - Landfall filling

Impact greatest on Mississippi coast

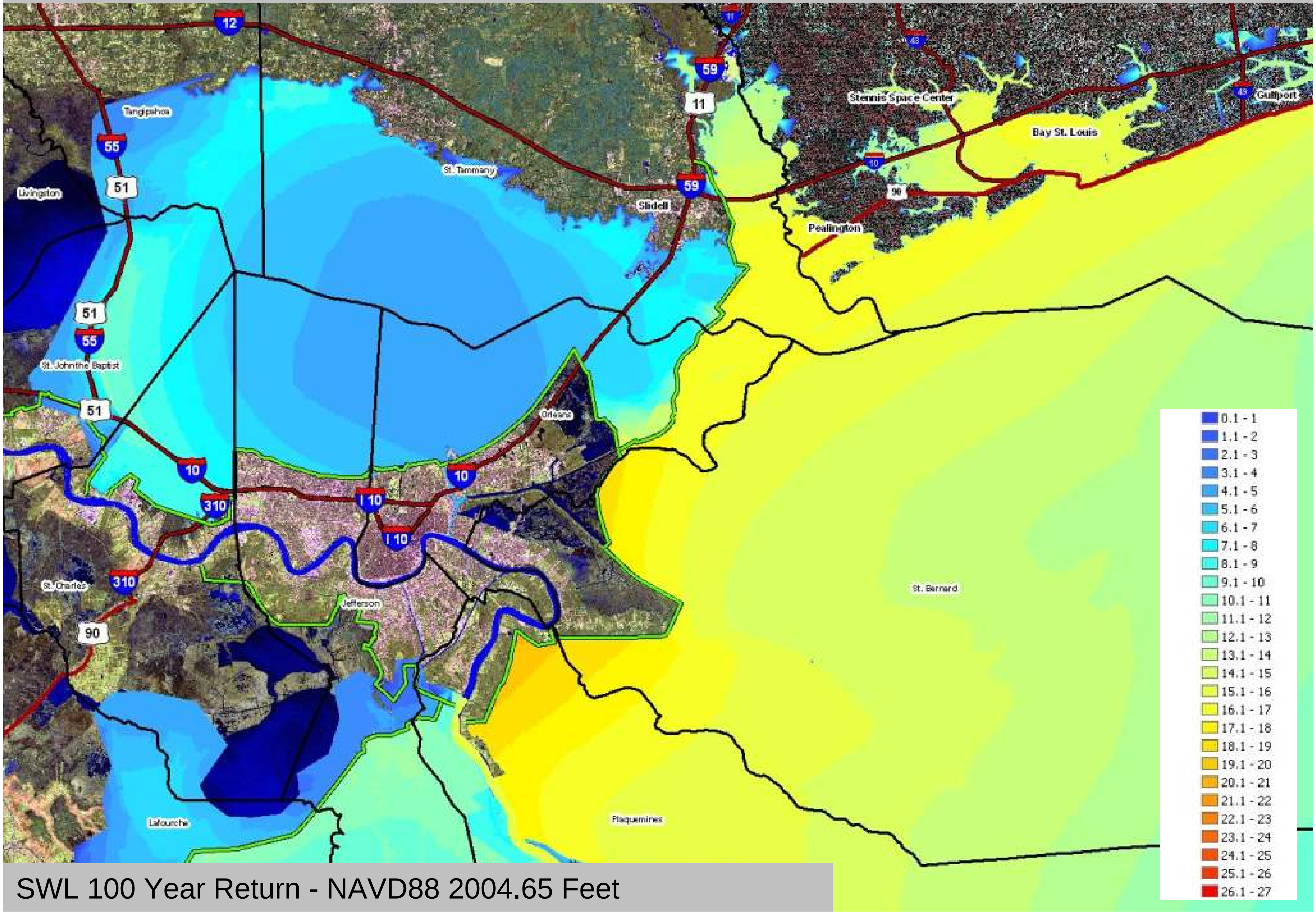
Blending algorithm used for consistency between FEMA Regions 4 and 6



ADCIRC Grid
Louisiana and Mississippi

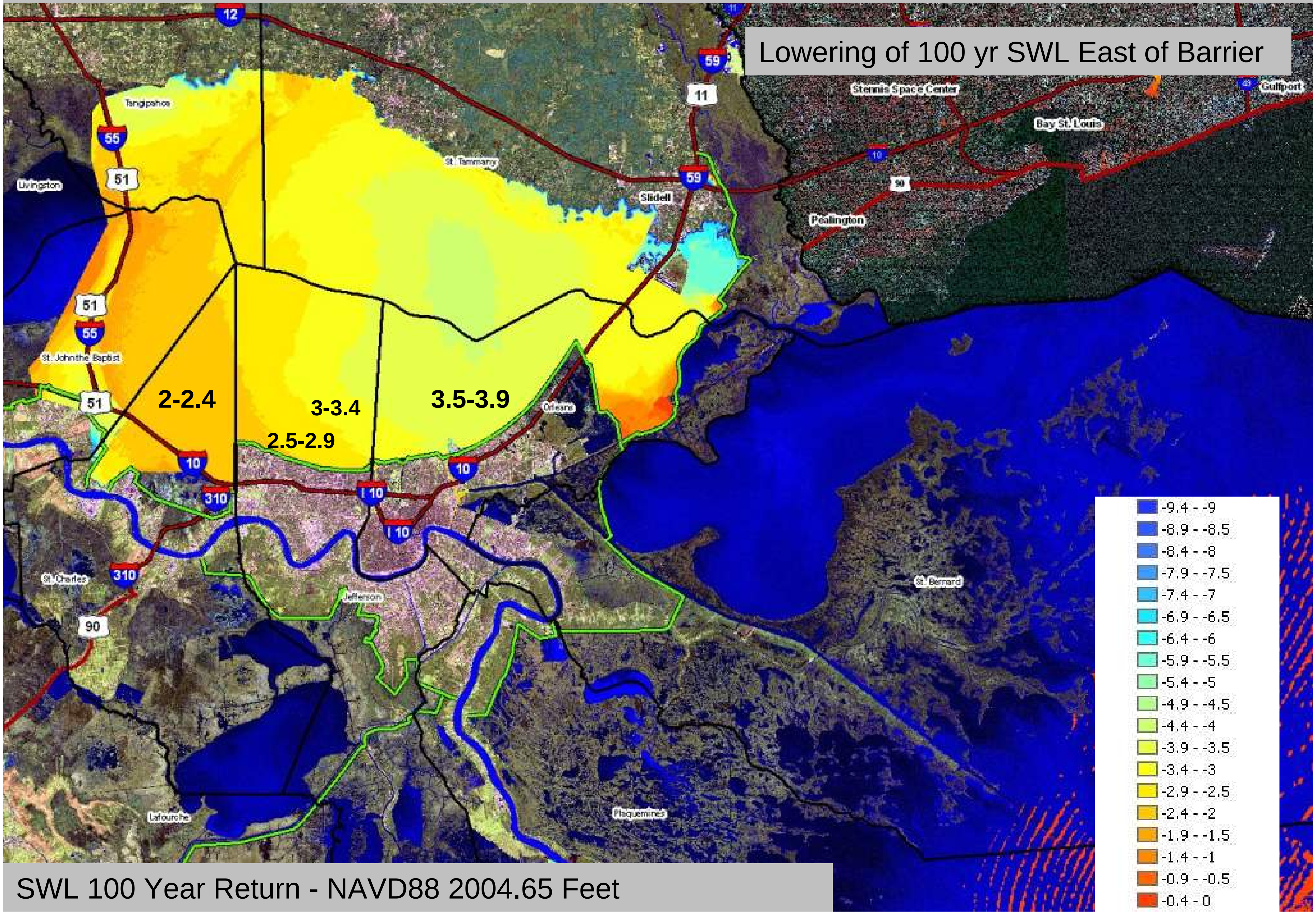


LACPR EB Barrier Conditions

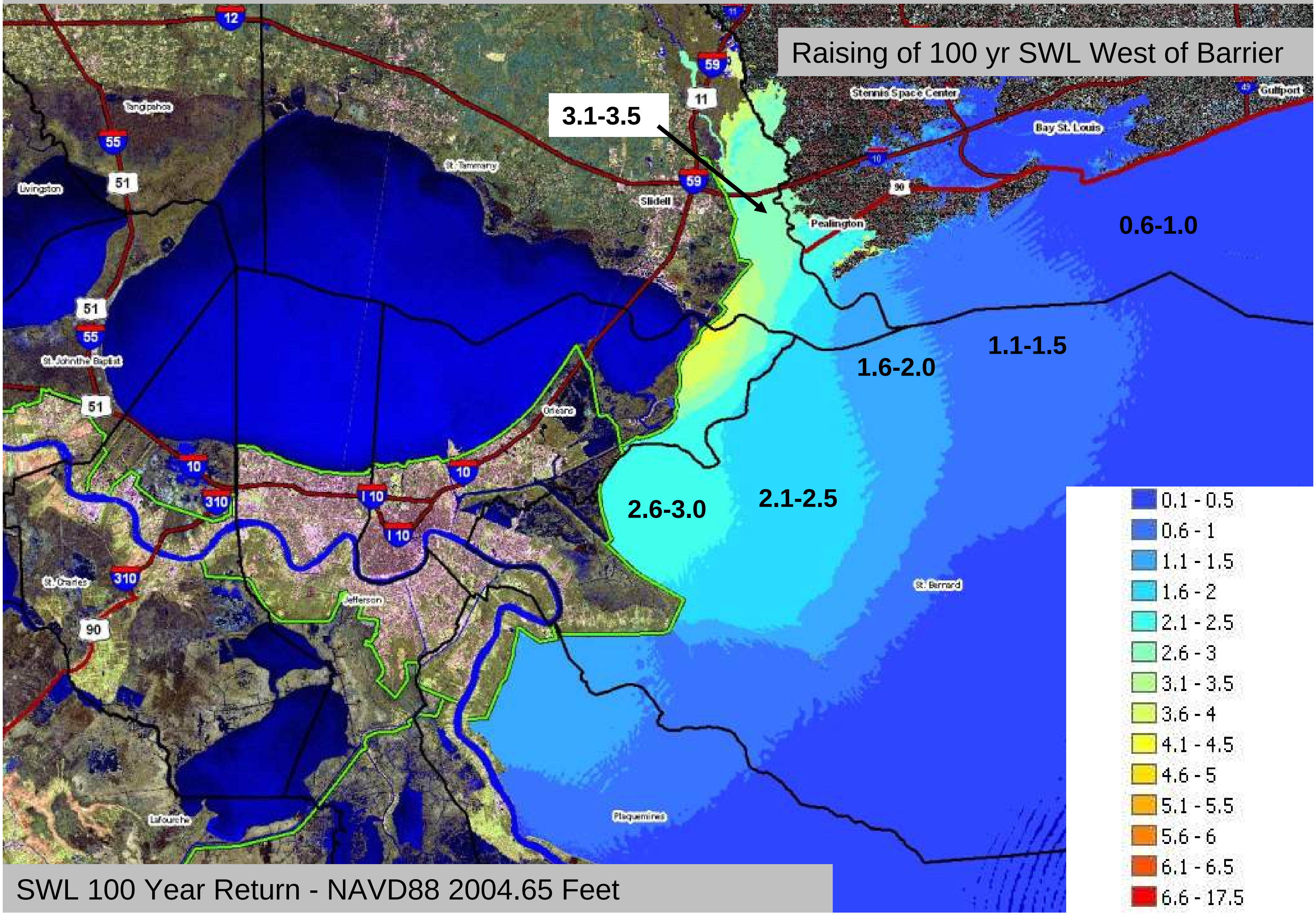


SWL 100 Year Return - NAVD88 2004.65 Feet

LACPR EB Barrier Conditions Minus 2010 Conditions

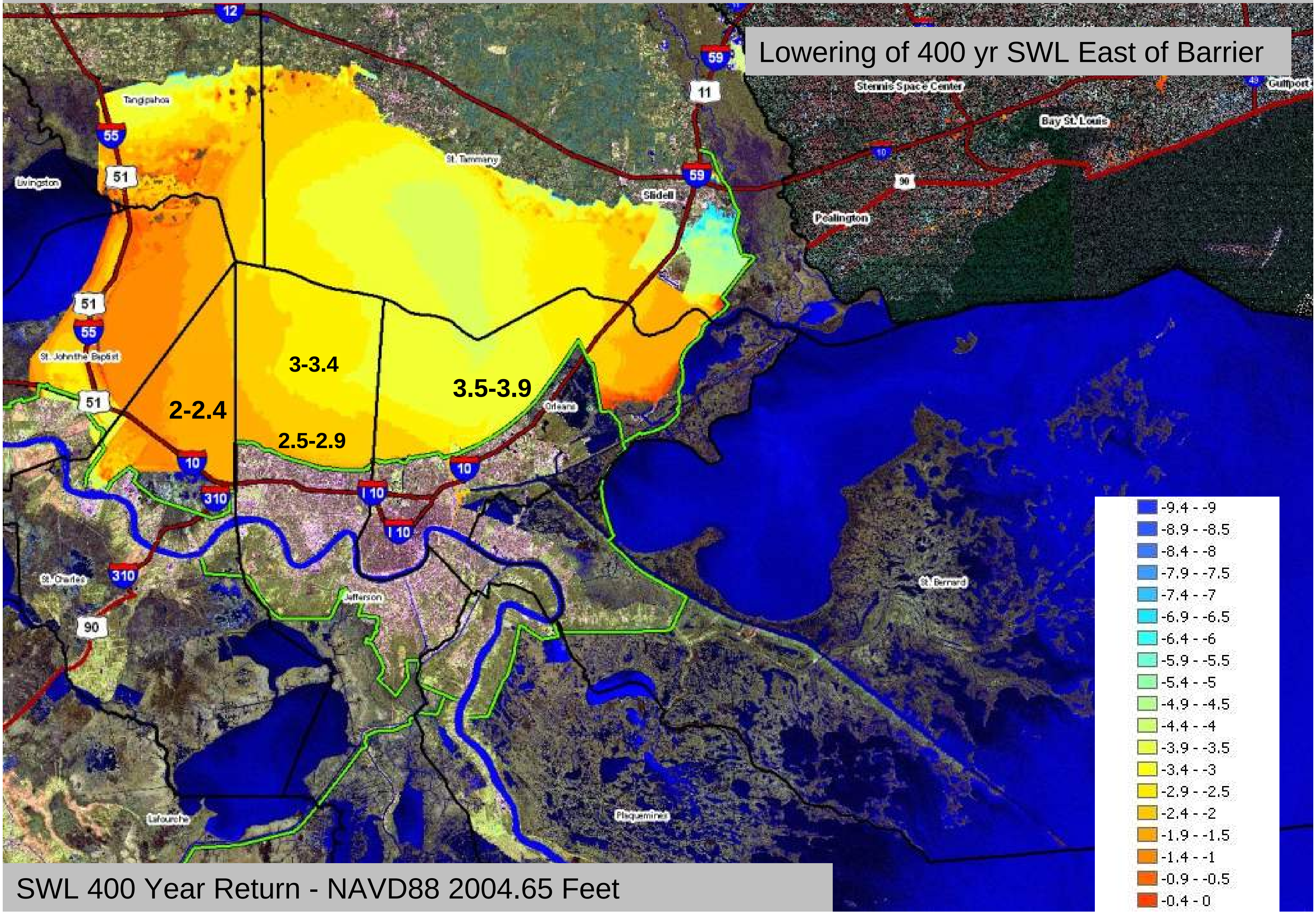


LACPR EB Barrier Conditions Minus 2010 Conditions



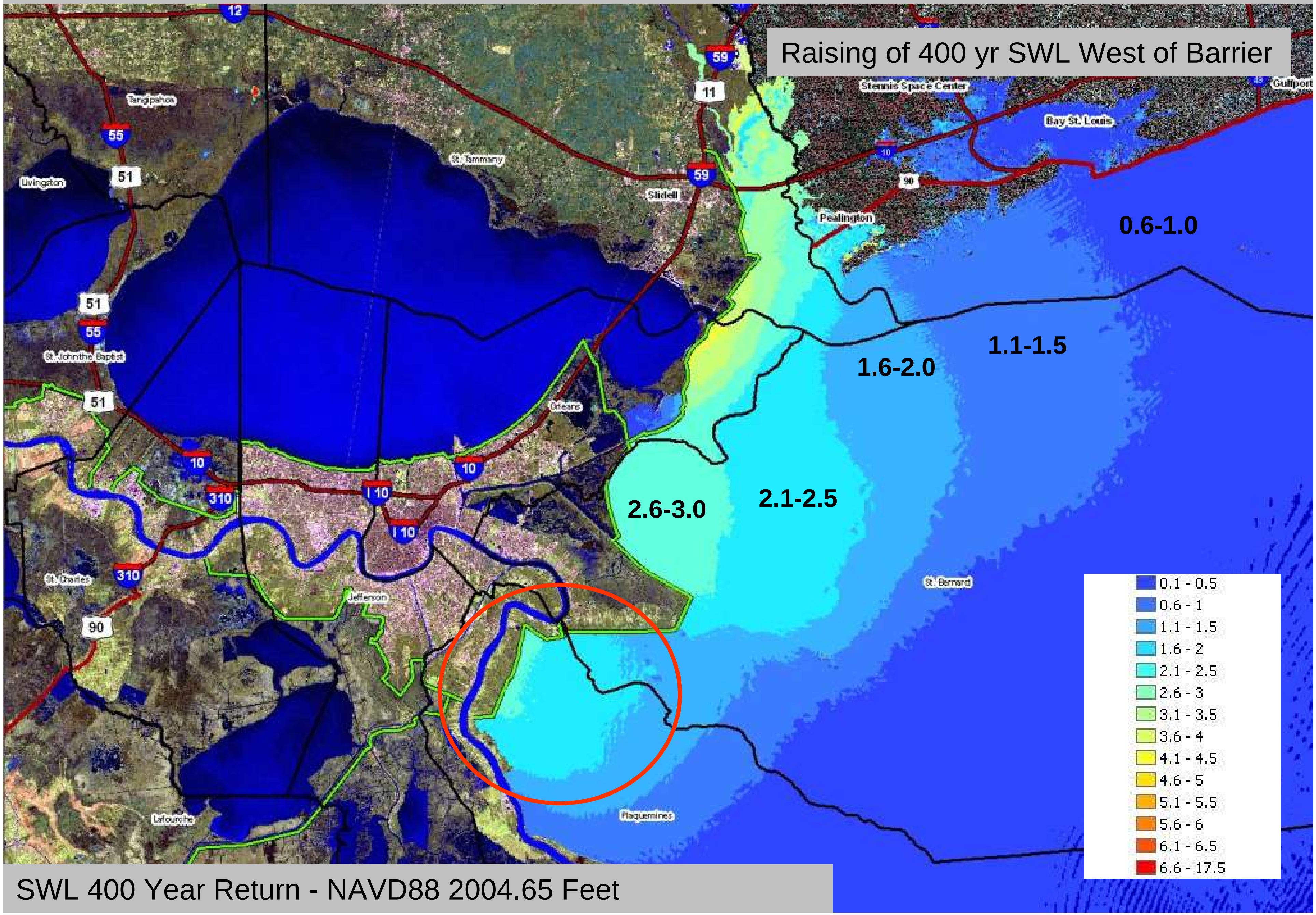
SWL 100 Year Return - NAVD88 2004.65 Feet

LACPR EB Barrier Conditions Minus 2010 Conditions



SWL 400 Year Return - NAVD88 2004.65 Feet

LACPR EB Barrier Conditions Minus 2010 Conditions



SWL 400 Year Return - NAVD88 2004.65 Feet

Structural Alternatives

- Base Conditions: LaCPR = MsCIP
- LaCPR Alternatives → MsCIP Base
- MsCIP Alternatives → LaCPR Base
- However, a combination of alternatives across the region can be modeled together.

Storm Surge and Wetlands

- Complicated Dynamics preclude application of simple “rules of thumb” (i.e. X miles of marsh reduces surge by Y feet)
  - Storm track
  - Storm intensity
  - Surrounding topography/bathymetry
  - Vegetation type

- Modeling is a tool for qualitative and/or semi-quantitative evaluation of the surge reduction potential of coastal restoration features.

Storm Surge and Wetlands

- Purpose: Assess the <u>potential</u> of coastal restoration features for reducing storm surge and waves for hurricanes with varying intensity.

- Trends and relative performance.

Storm Surge and Wetlands

Why the limitations?

- New application of the model and area of active research.
  - Complicated physics
  - Representation of physical system
  - Friction factors

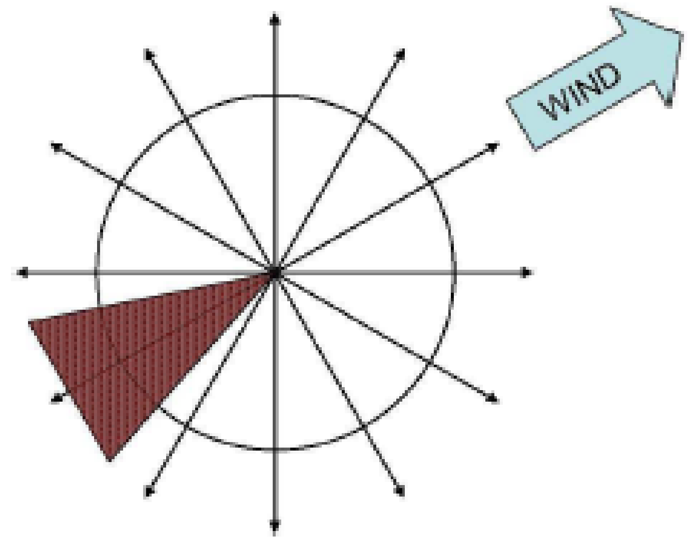
- Very limited data.
  - Need to fund research for field and laboratory studies

Storm Surge and Wetlands

- Considered:
  - Bathymetry and topography modify storm surge and waves.
  - Vegetation reduces surface winds and slows surge propagation .
- Not Considered:
  - Changes to the landscape that occur during storms passage (ie vegetation stripped, land mass eroded)
  - Changes in the structure of the hurricane itself due to landfall infilling phenomenon that may be influenced by landscape features

Parameterizations of Frictional Resistance

- Wind Reduction
  - Winds in ADCIRC and STWAVE are reduced to account for higher surface roughness through a directional land masking procedure



Roughness length scales

$$f_r = \left(\frac{z_{0_{marine}}}{z_{0_{land}}} \right)^{0.0706}$$

Varies w/land cover and quantified by FEMA-HAZUS study (NLCD)

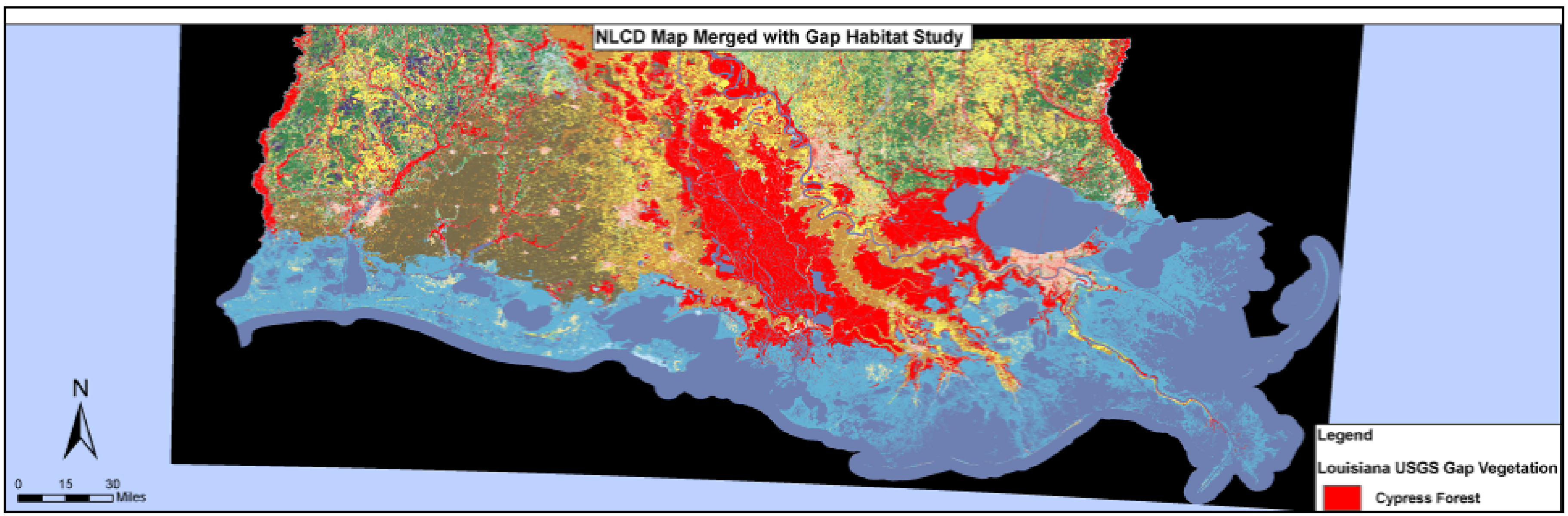
$$w_i = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{d_i^2}{2\sigma^2}}$$

As inundation takes place, roughness is reduced

$$z_0' = z_{0land} - \frac{d}{30} \quad \text{for} \quad z_0' \geq z_{0_{marine}}$$

Parameterizations of Frictional Resistance

- Wind Reduction
  - A canopy is applied to areas classified as NLCD/GAP forest precluding momentum transfer from the wind fields to the water column



Parameterizations of Frictional Resistance

- Manning-n scalar parameterization used to approximate flow resistance from a variety of physical mechanisms, including form drag, skin friction, and secondary currents.

Manning-n values for Louisiana GAP classes (FEMA 2005):

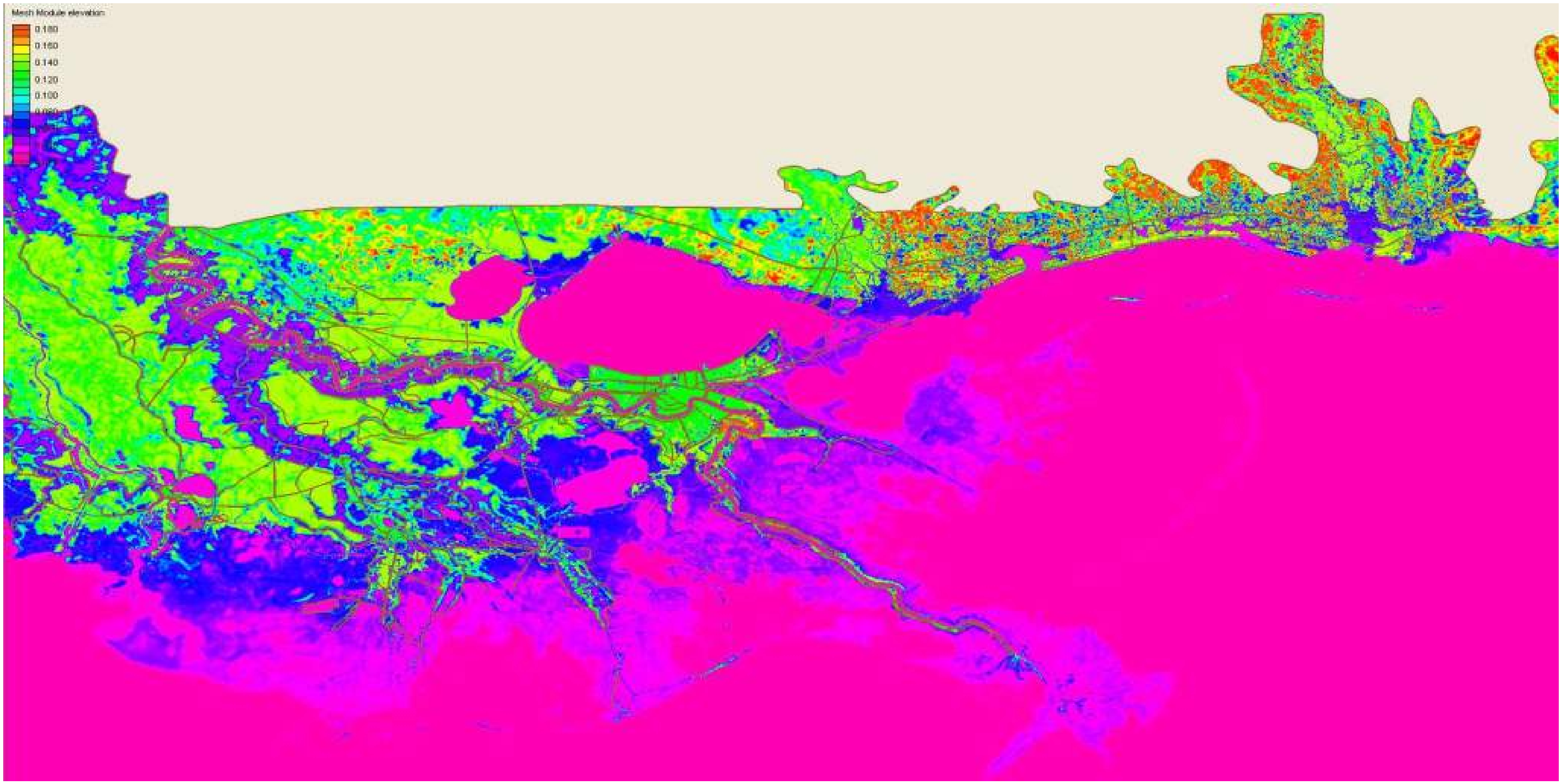
n = 0.055	! fresh marsh
n = 0.050	! intermediate marsh
n = 0.045	! brackish marsh
n = 0.035	! saline marsh
n = 0.15	! wetland forest - mixed
n = 0.17	! upland forest - mixed
n = 0.18	! dense pine thicket
n = 0.020	! water

-defined at appropriate grid scale

-published values

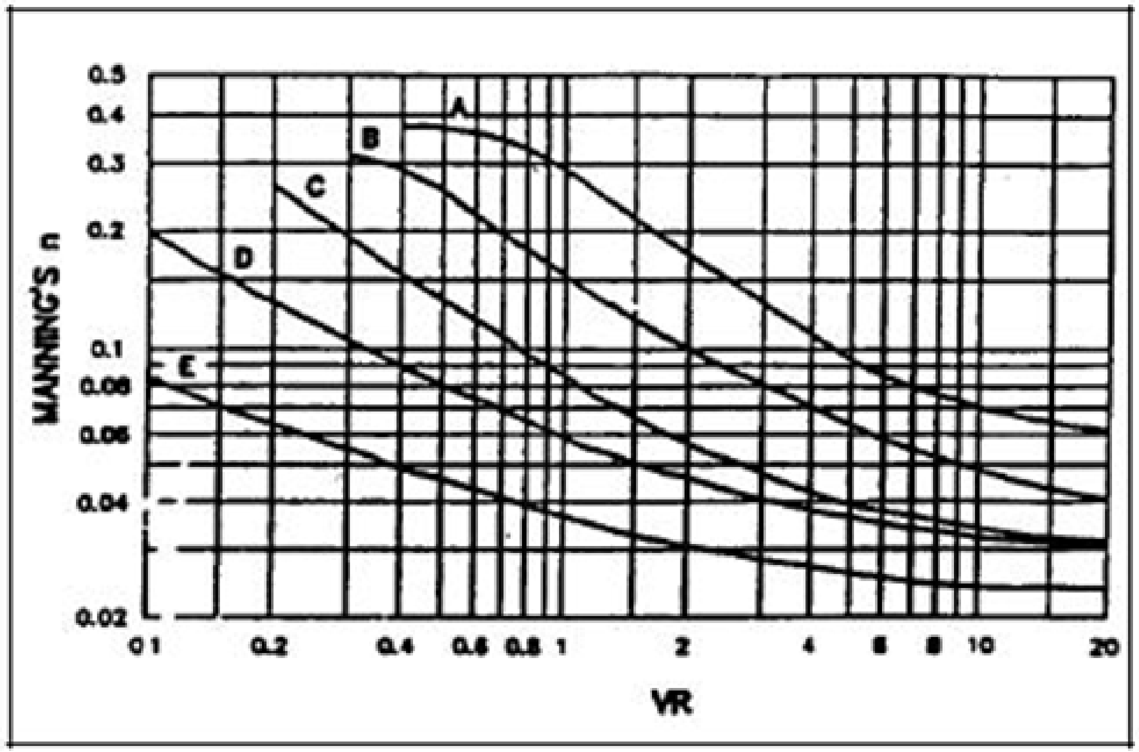
-validated against hindcasts of hurricanes Katrina and Rita

Manning-n Field



Parameterizations of Frictional Resistance

- Factors influencing Manning-n value.



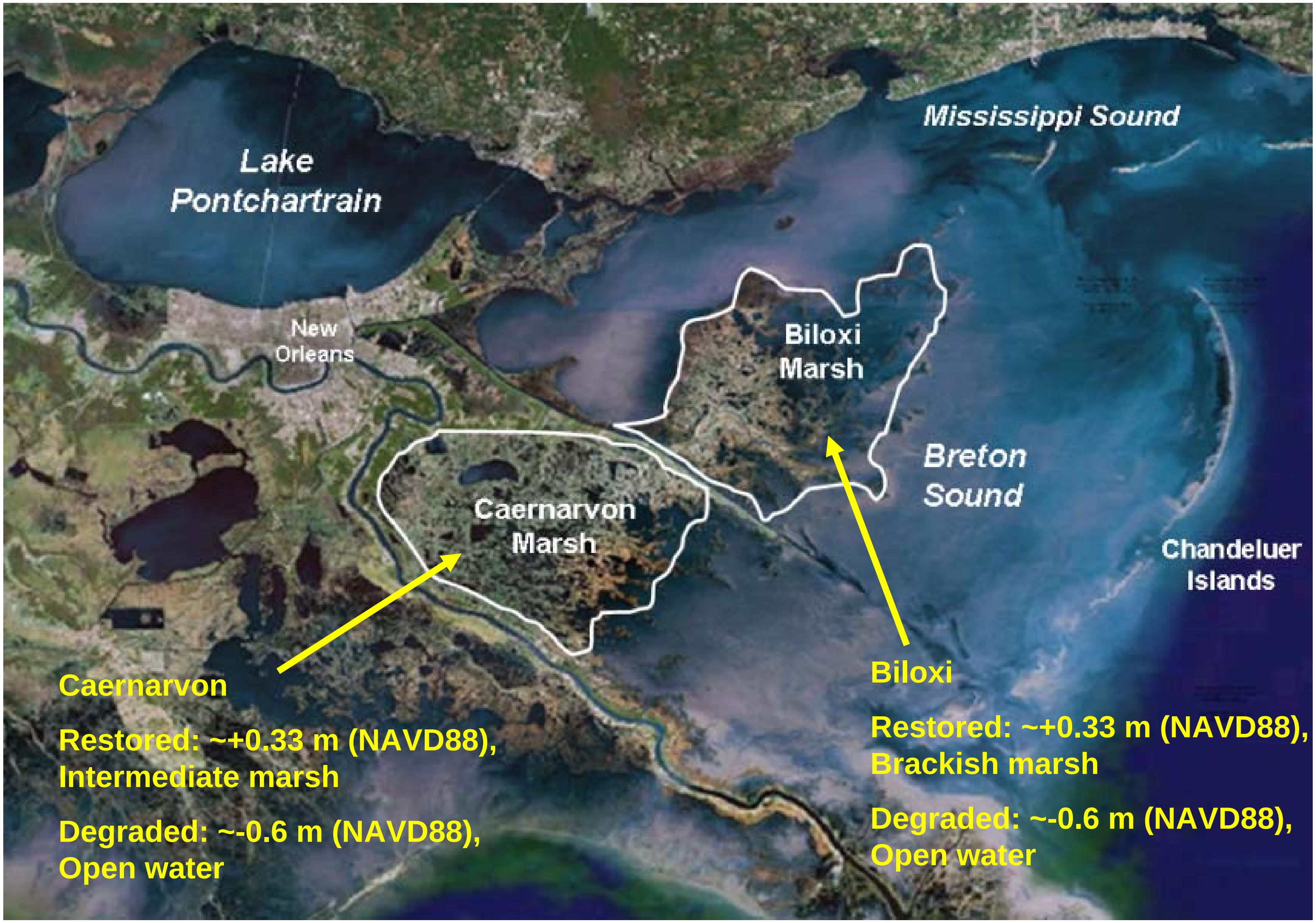
Turbulence ↑ => n ↓

Veg "damage" ↑ => n ↓

Modeling a 3D process with a depth-integrated model?? => n ↓

More data needed!

Wetland Restoration/Degradation

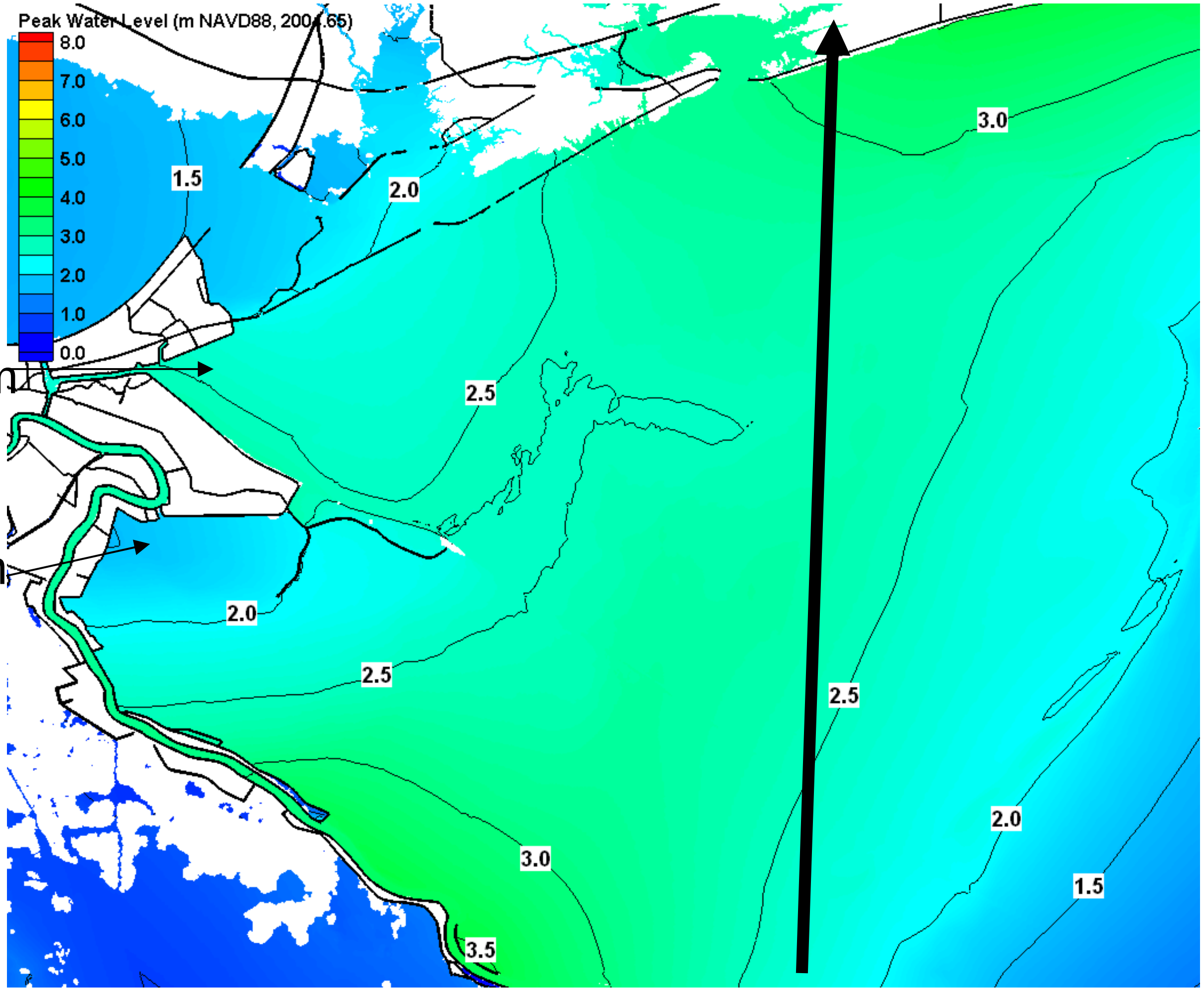


Storm HUR1

HUR1 (Hurricane Hilda-like)

- **Central Pressure: 960 mb**
- **Rmax: 22 nm**
- **Forward Speed: 11 knots**

Peak Surge



2.5 m

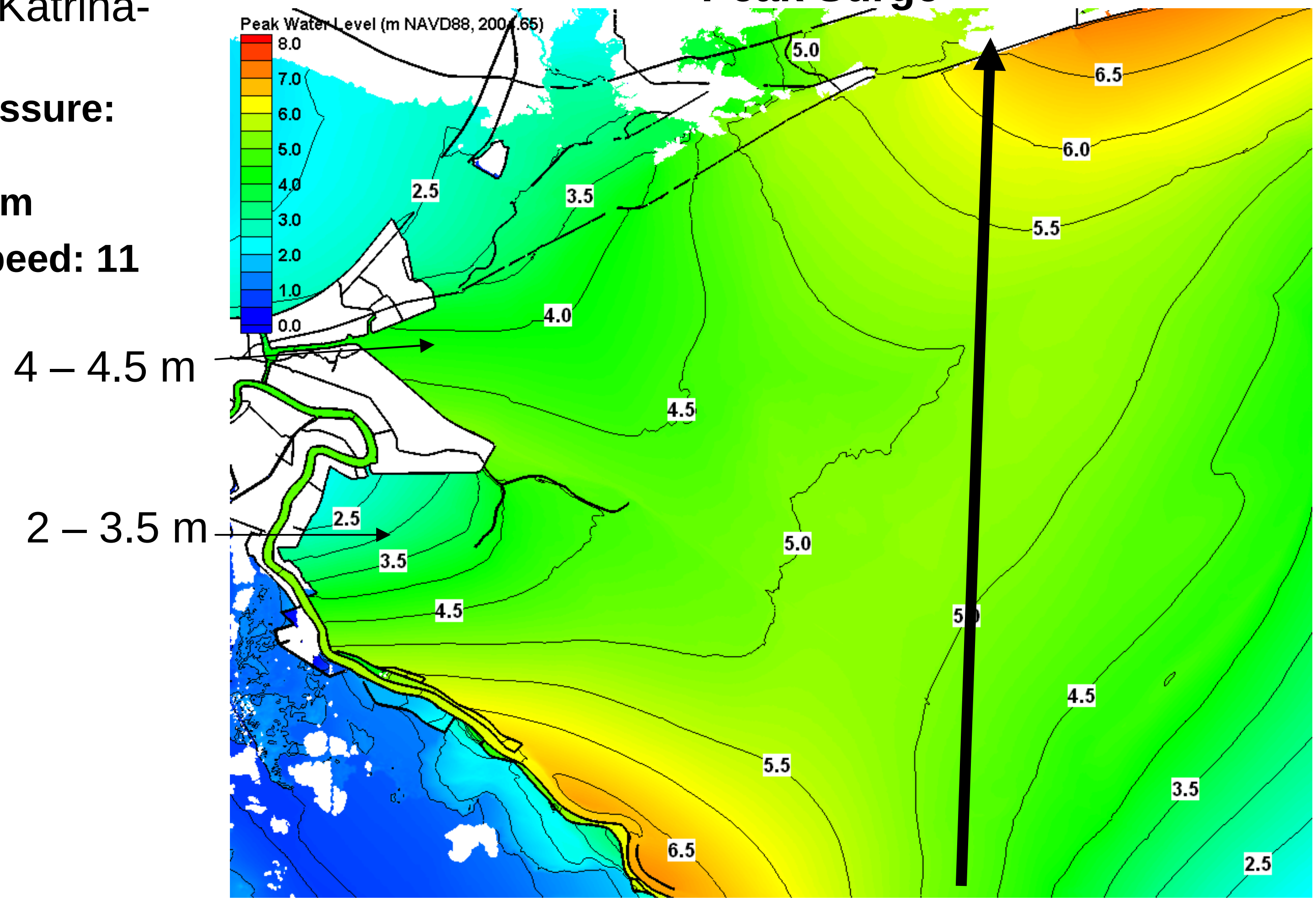
1.5 - 2 m

Storm HUR2

HUR2 (Hurricane Katrina-like)

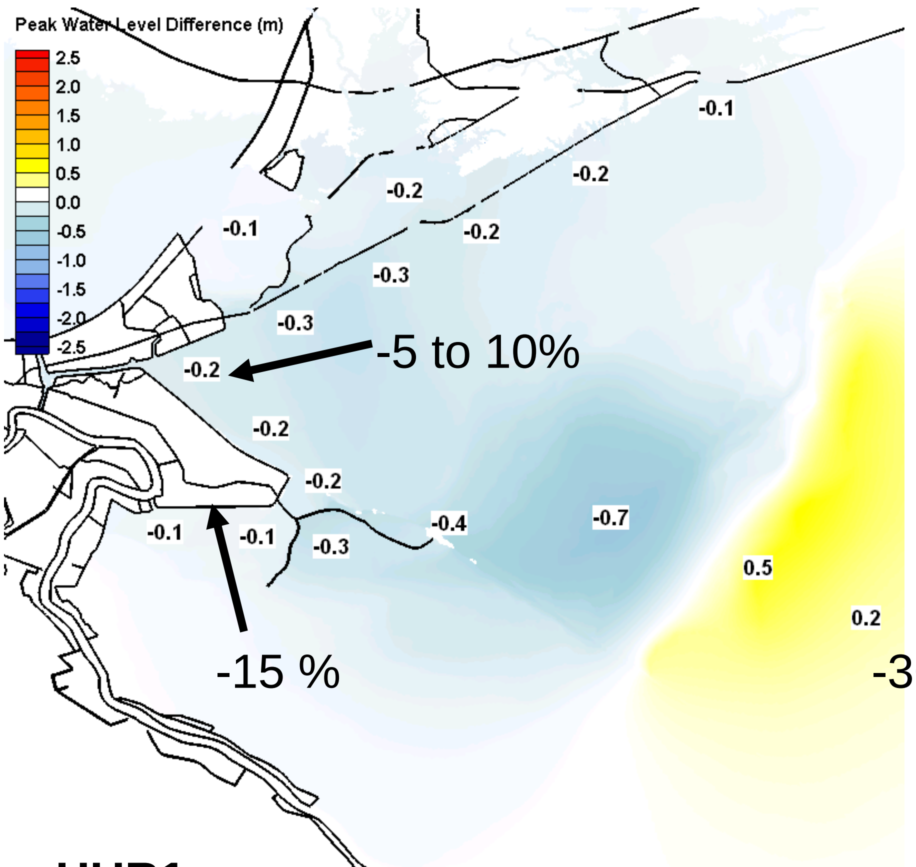
- **Central Pressure: 900 mb**
- **Rmax: 22 nm**
- **Forward Speed: 11 knots**

Peak Surge

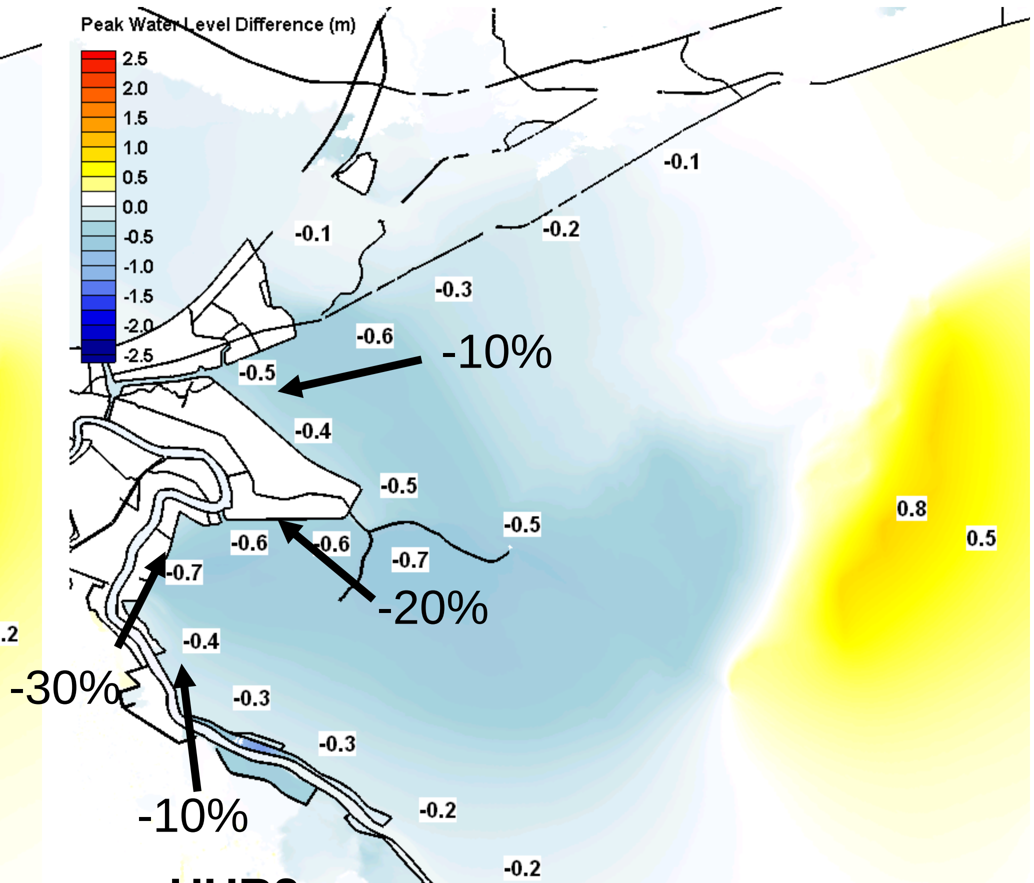


Biloxi Restoration

Surge: Restored - Base



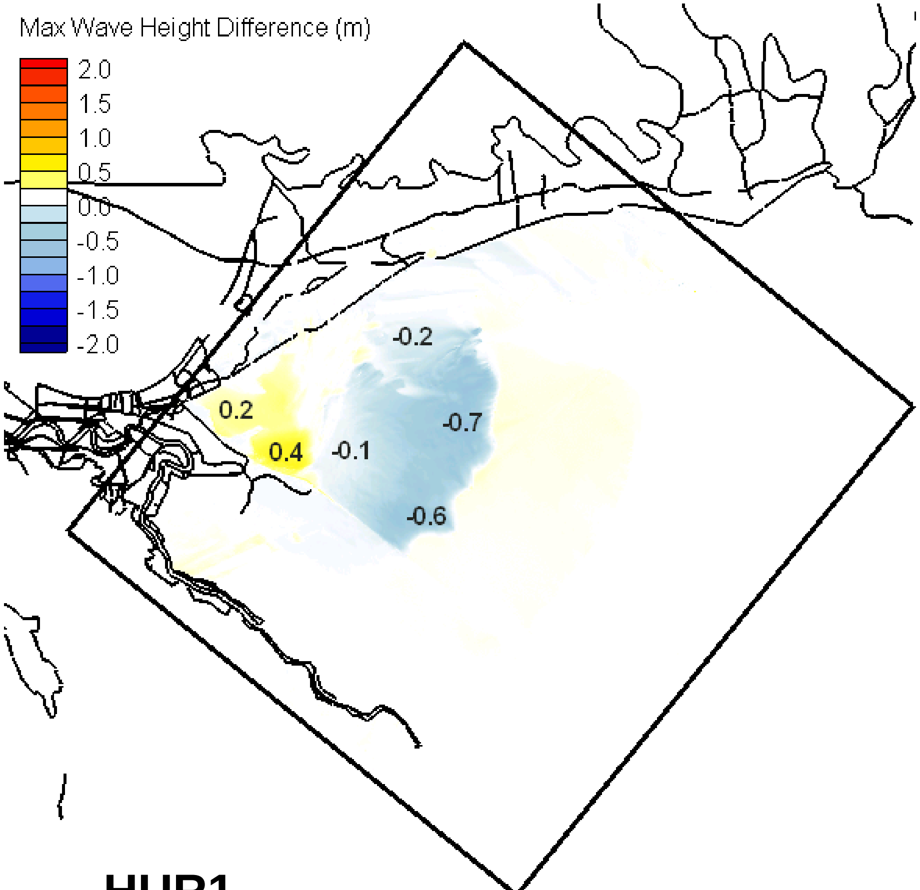
HUR1



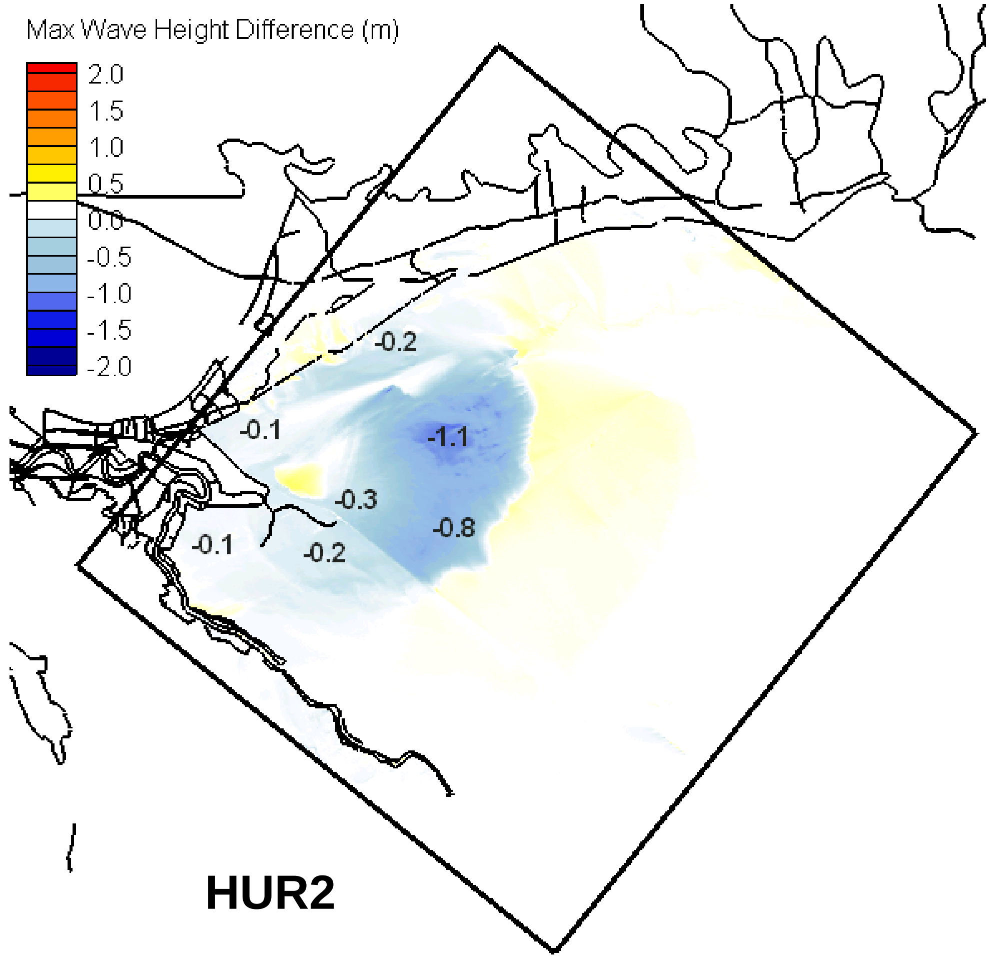
HUR2

Biloxi Restoration

Waves: Restored - Base



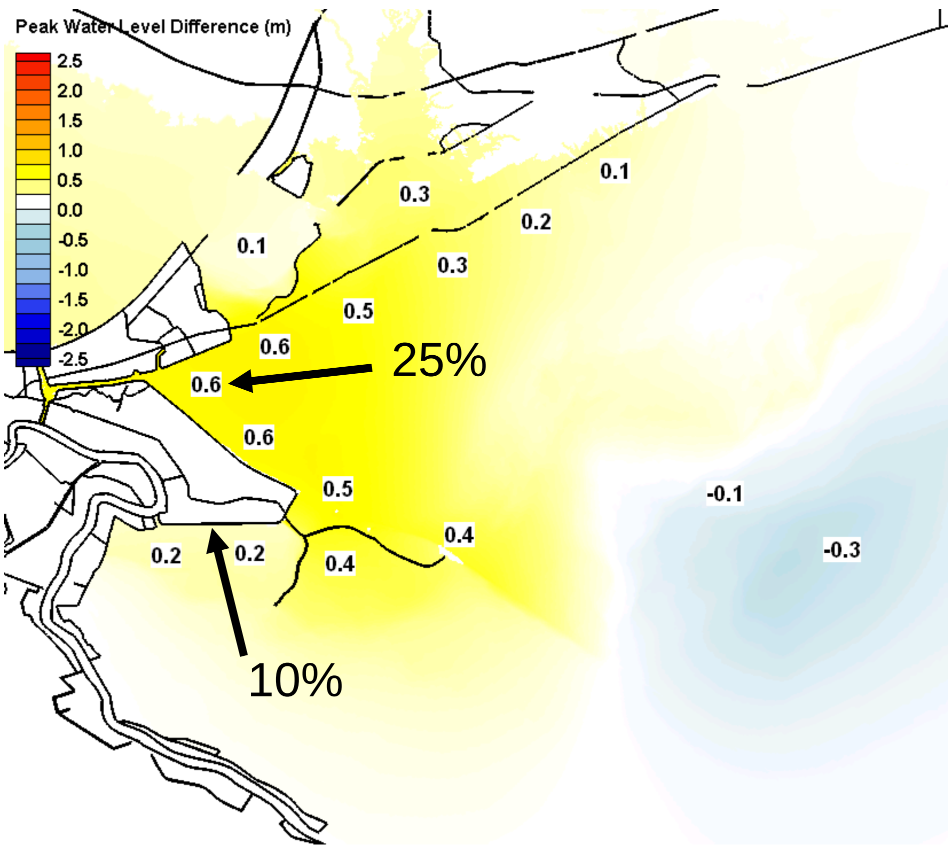
HUR1



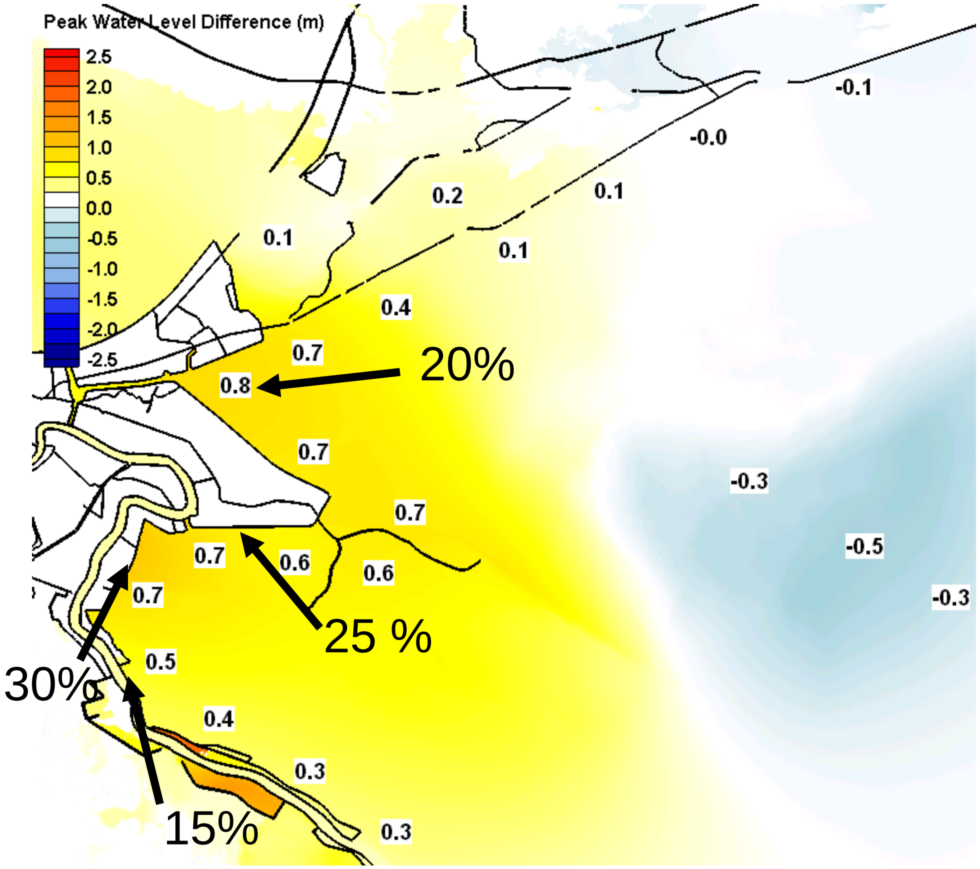
HUR2

Biloxi Degradation

Surge: Degraded - Base



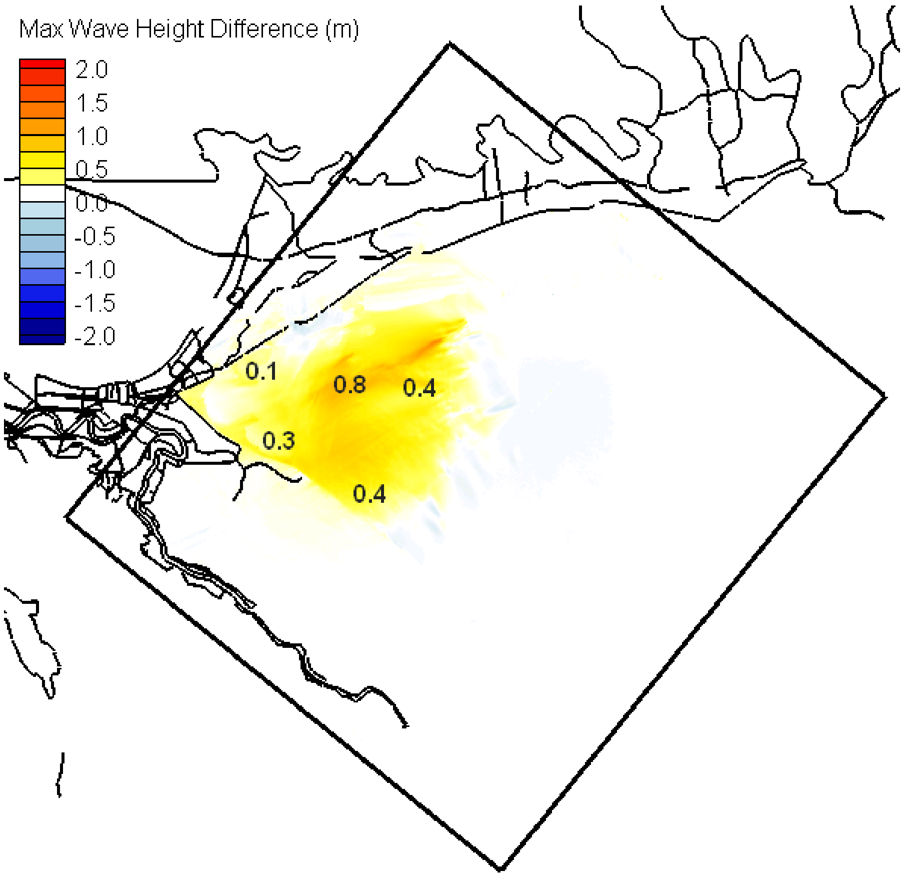
HUR1



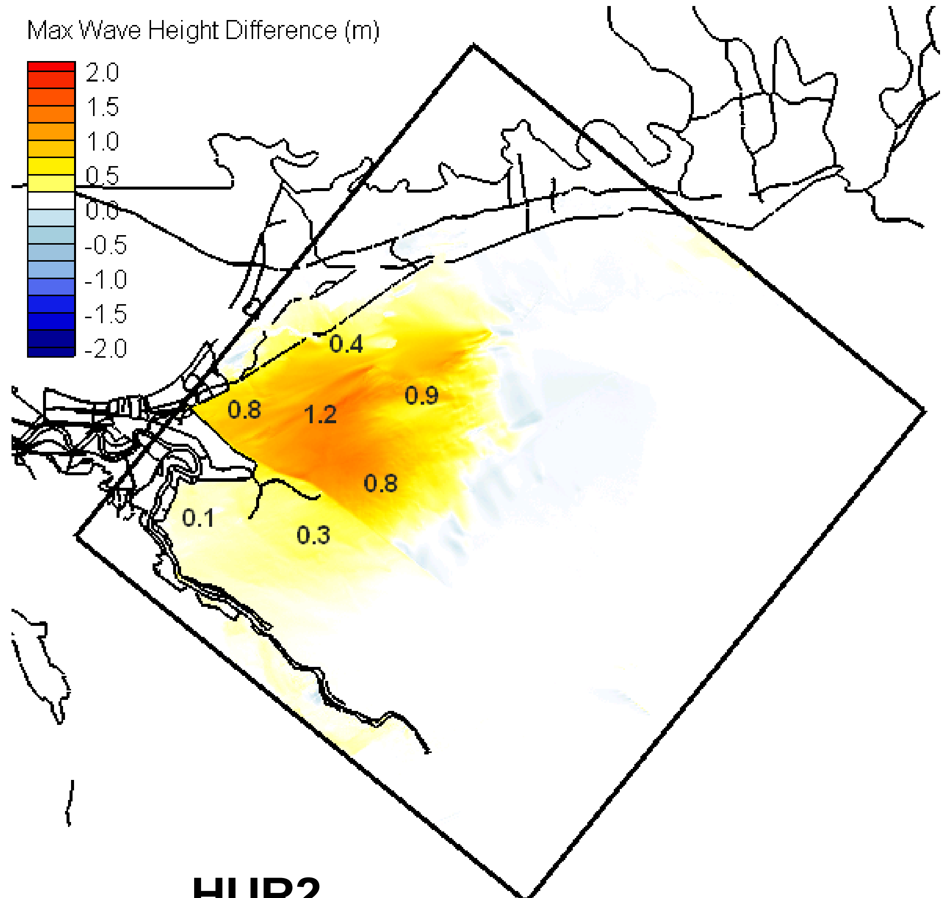
HUR2

Biloxi Degradation

Waves: Degraded - Base

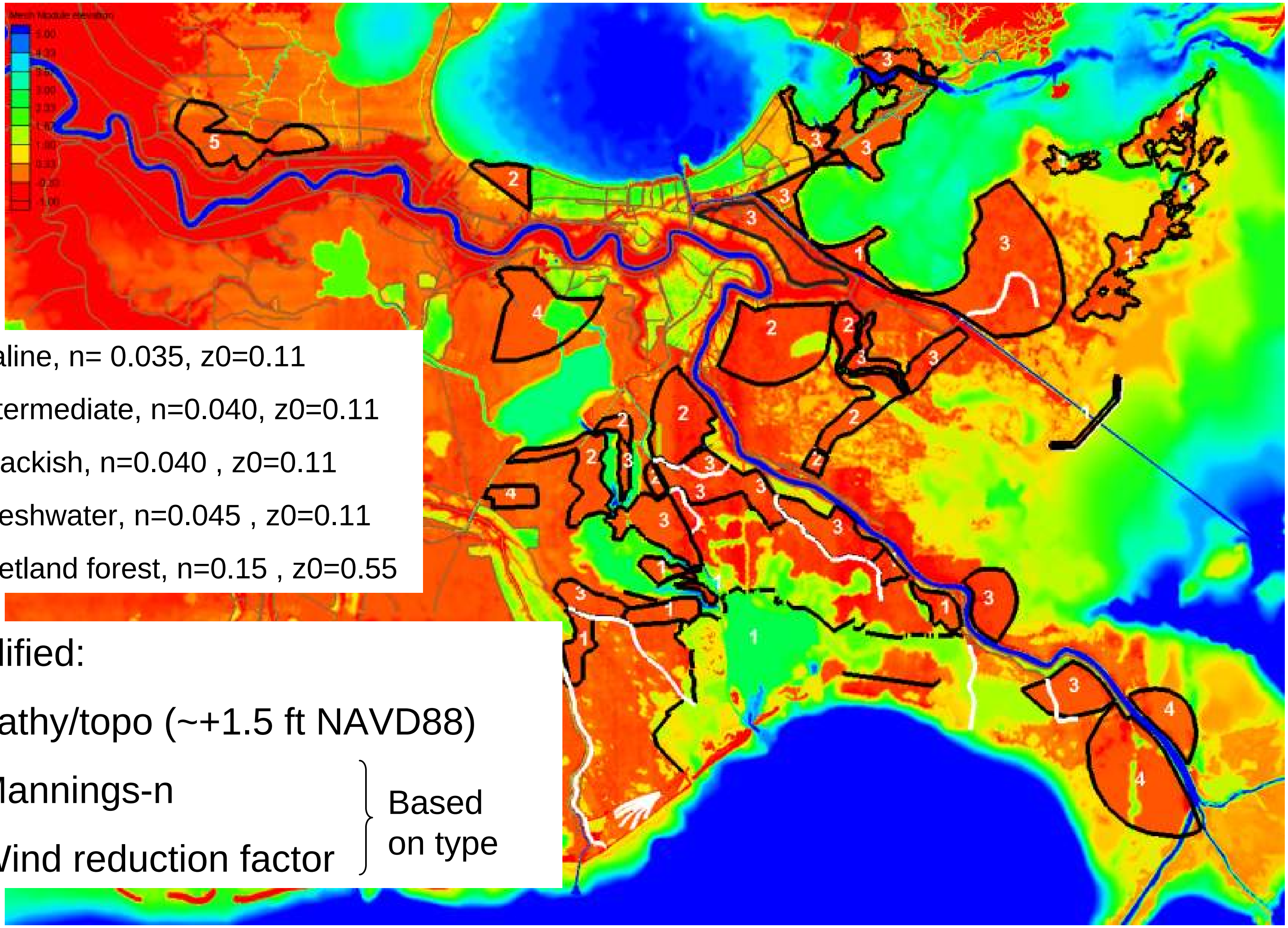


HUR1



HUR2

Restored Landscape - LaCPR



1-Saline, n= 0.035, z0=0.11

2-Intermediate, n=0.040, z0=0.11

3-Brackish, n=0.040 , z0=0.11

4-Freshwater, n=0.045 , z0=0.11

5-Wetland forest, n=0.15 , z0=0.55

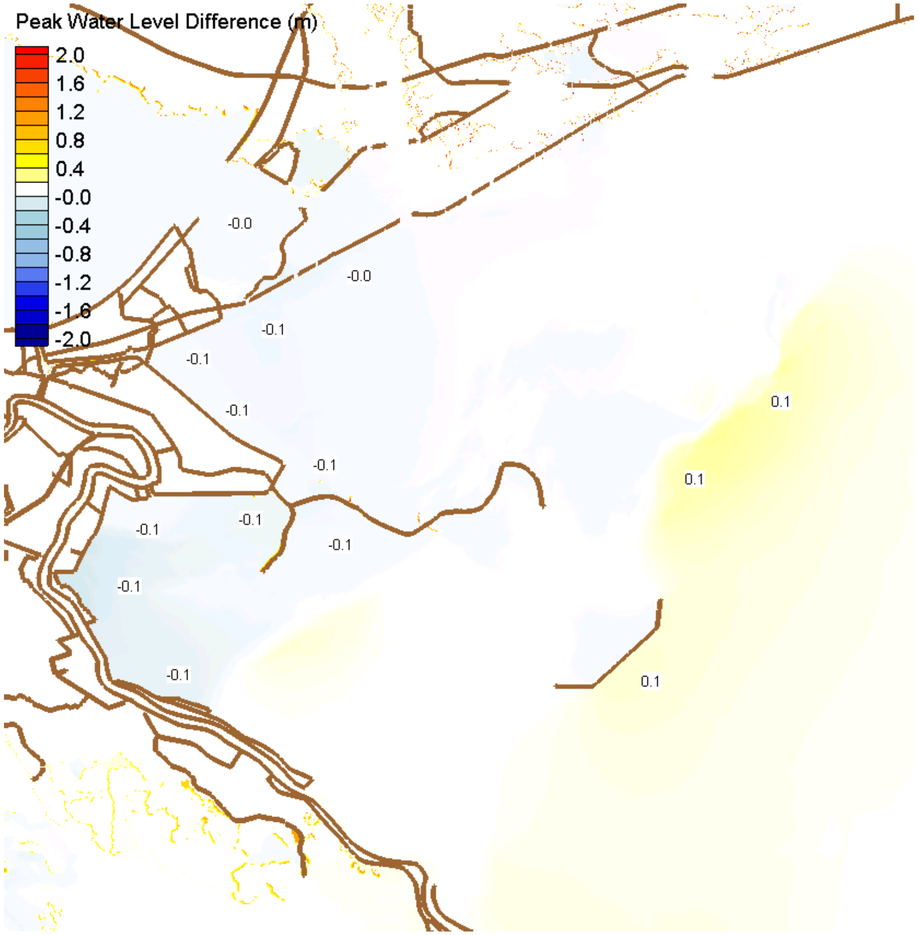
Modified:

- bathy/topo (~+1.5 ft NAVD88)
- Mannings-n
- Wind reduction factor

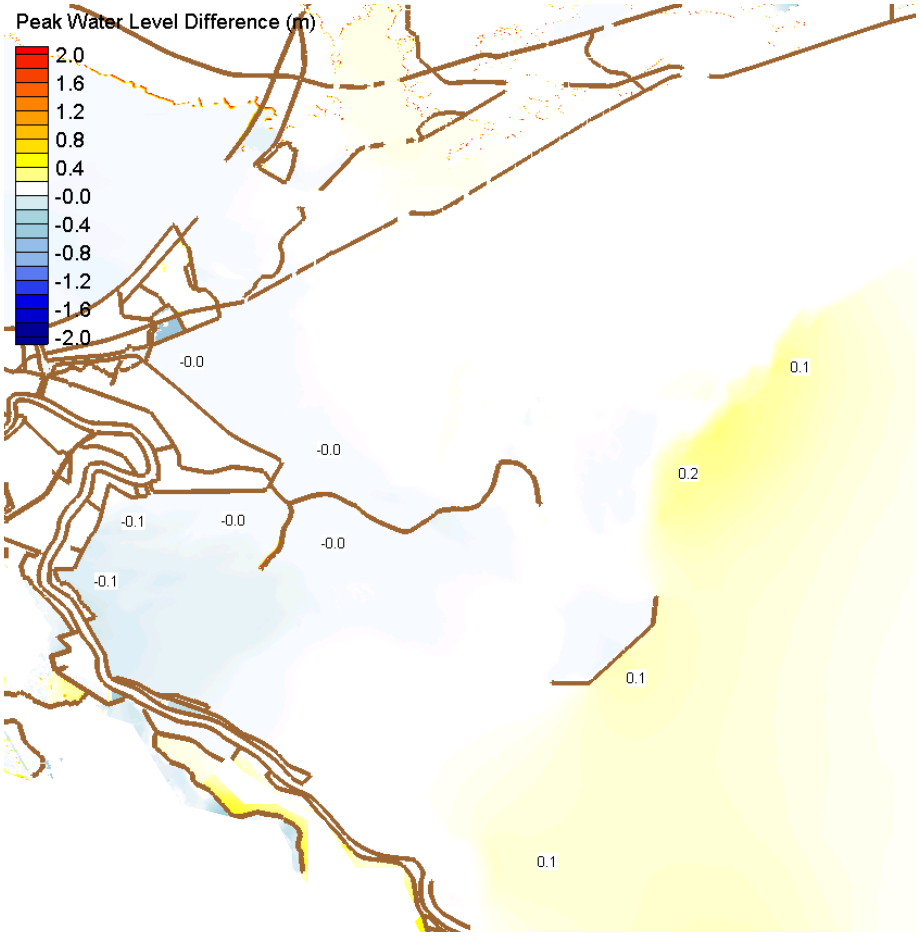
} Based on type

Restored Landscape

Surge: Restored - Base



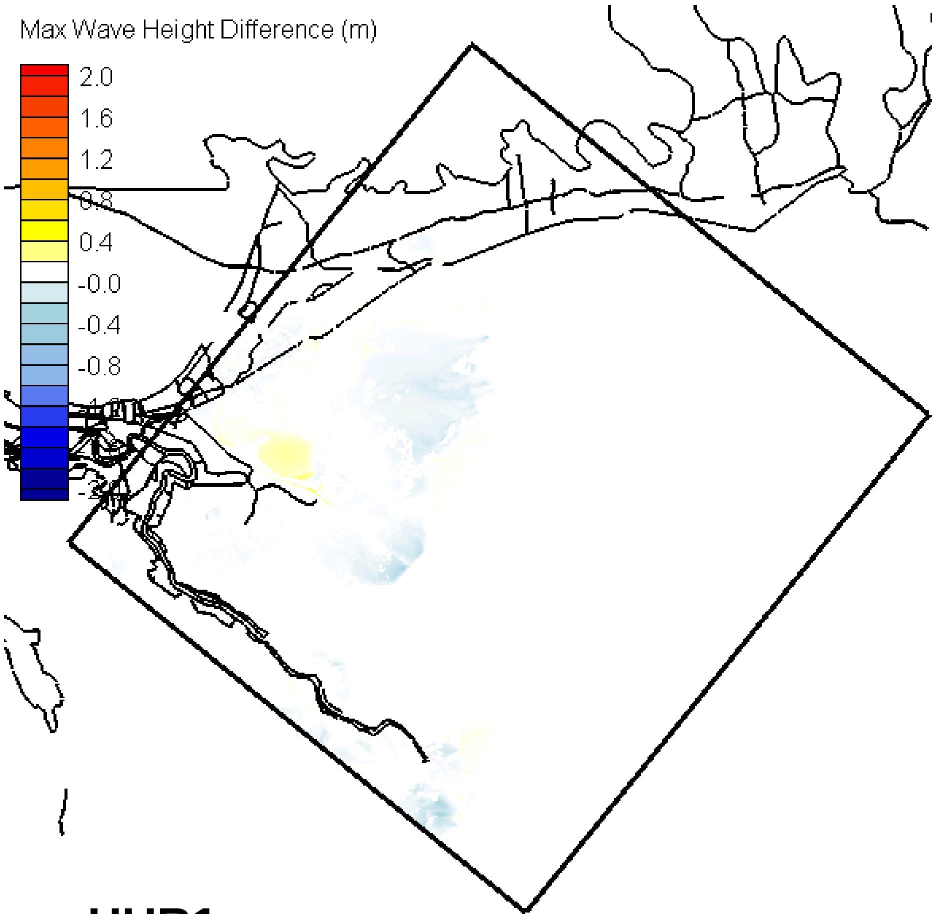
HUR1



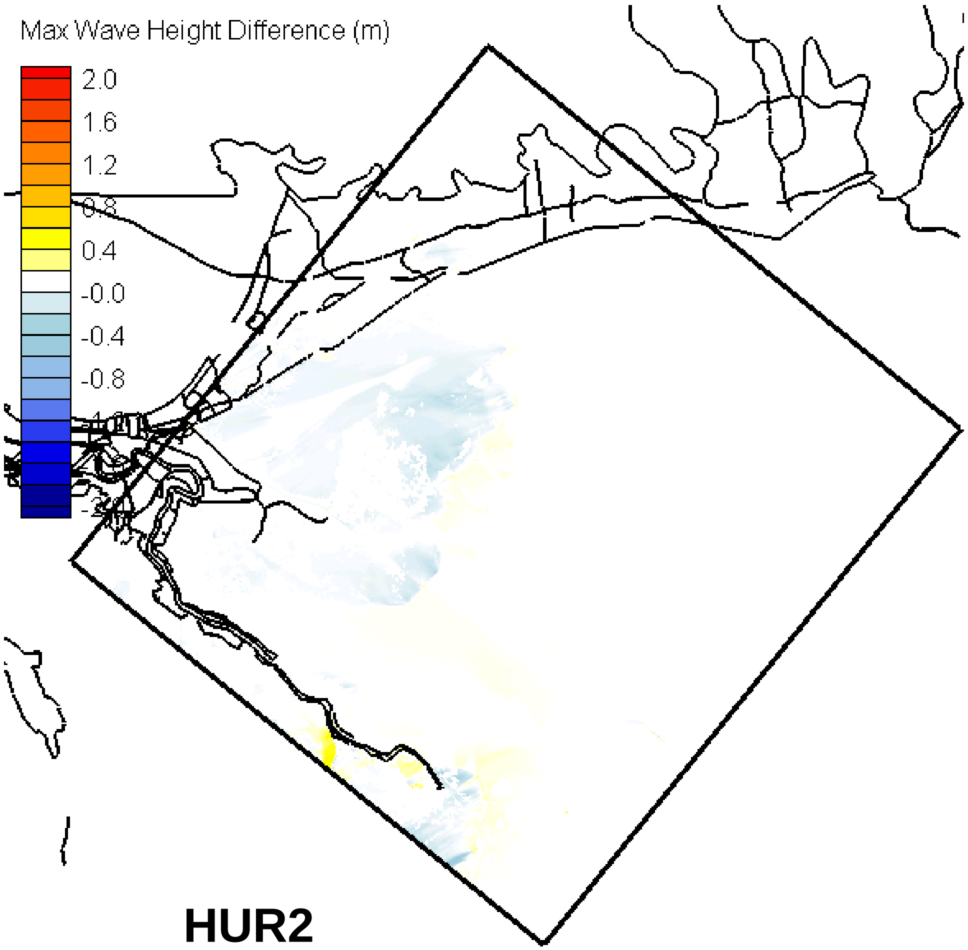
HUR2

Restored Landscape

Waves: Restored - Base



HUR1



HUR2

Future No Increased Action Coastal Landscape
CLEAR Output => ADCIRC

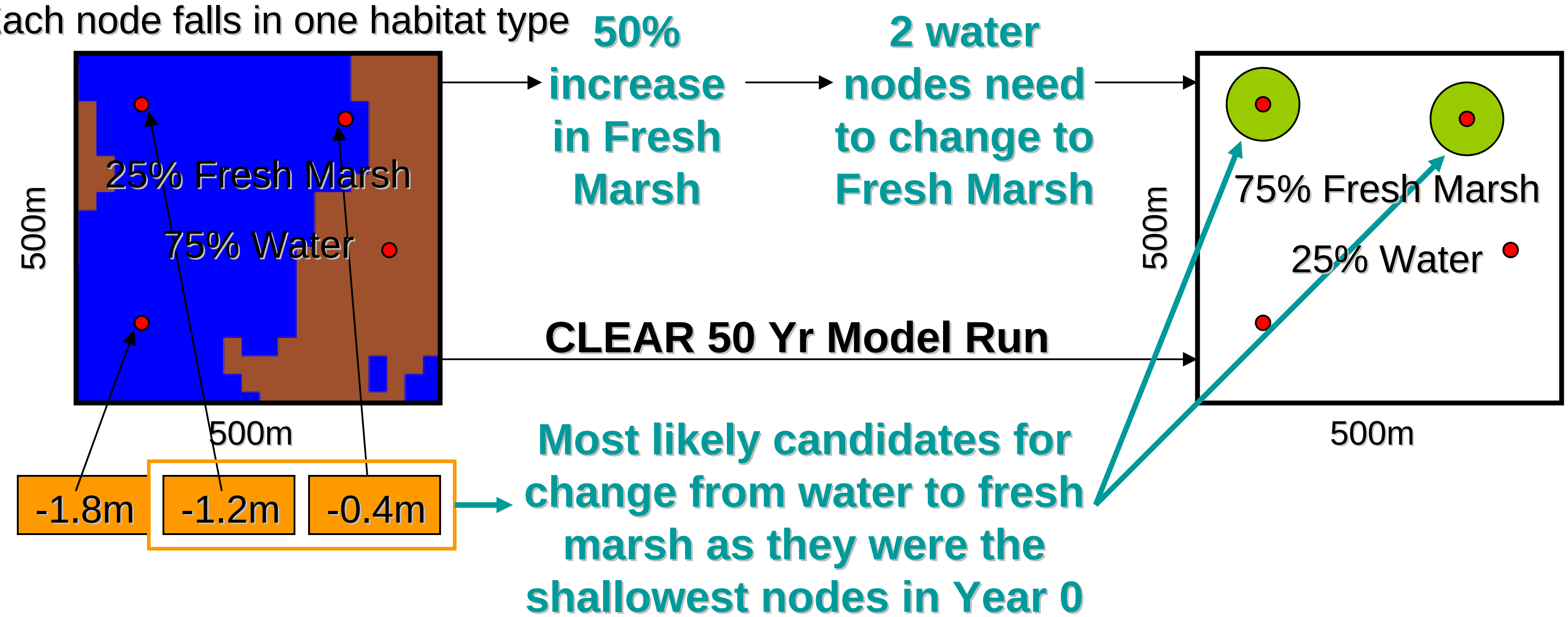
Bathy/Topo

CLEAR Input Cell Year 0

- LULC Data at 25m Res
- Each node falls in one habitat type

CLEAR Output Cell Year 50

- Spatial uncertainty



Slide provided by Brady Couvillon, USGS National Wetlands Research Center

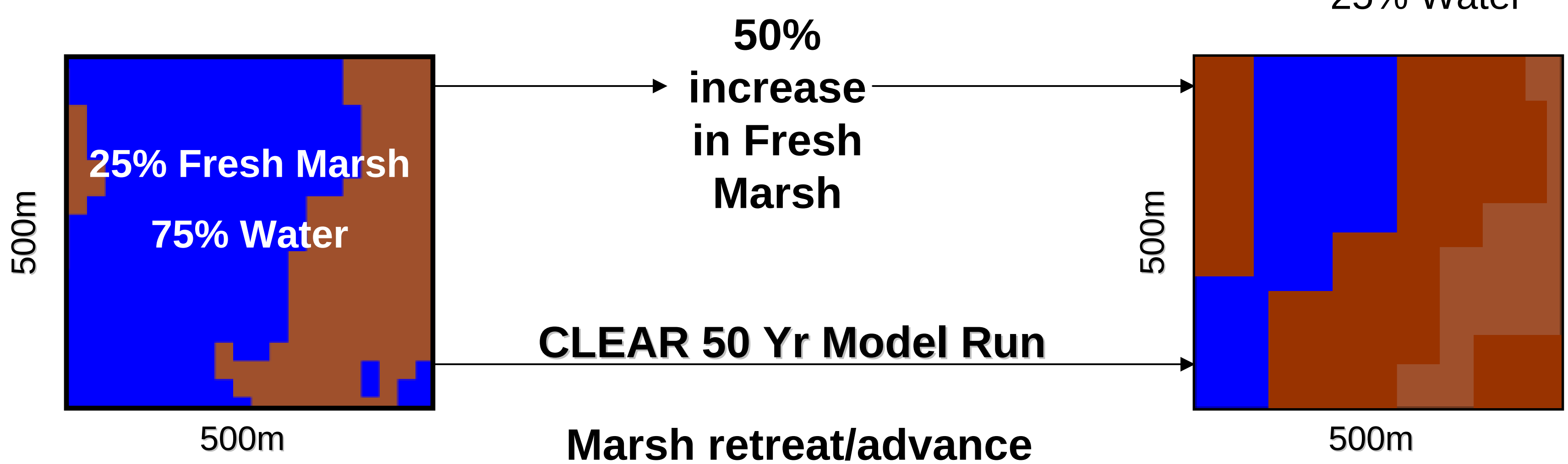
CLEAR => Coastal Louisiana Ecosystem Assessment and Restoration

NLCD/GAP Source Datasets Updated for Manning-n and z0

NLCD/GAP Data Year 0

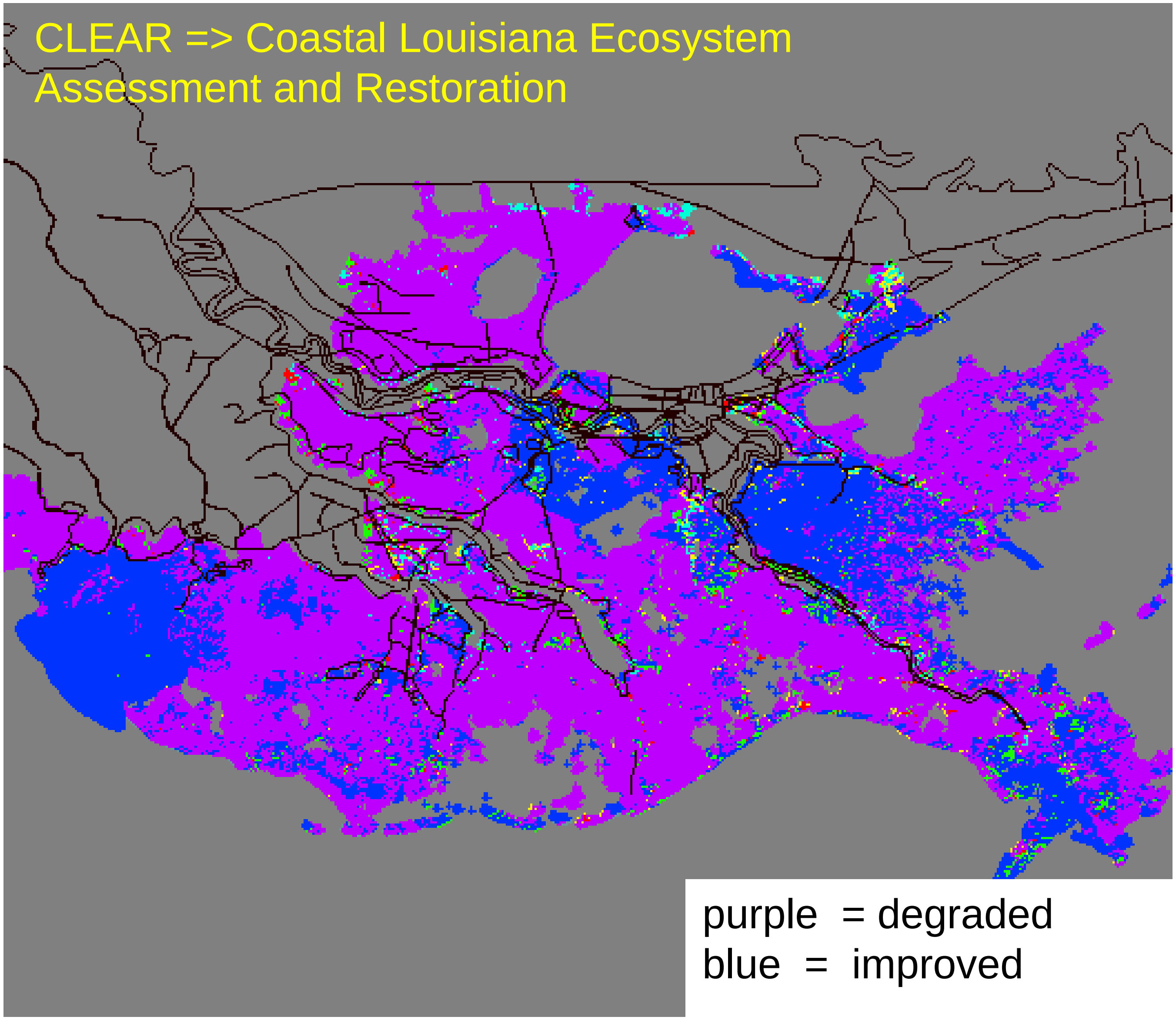
CLEAR Output Cell Year 50

Spatial uncertainty - 75% Fresh Marsh
25% Water

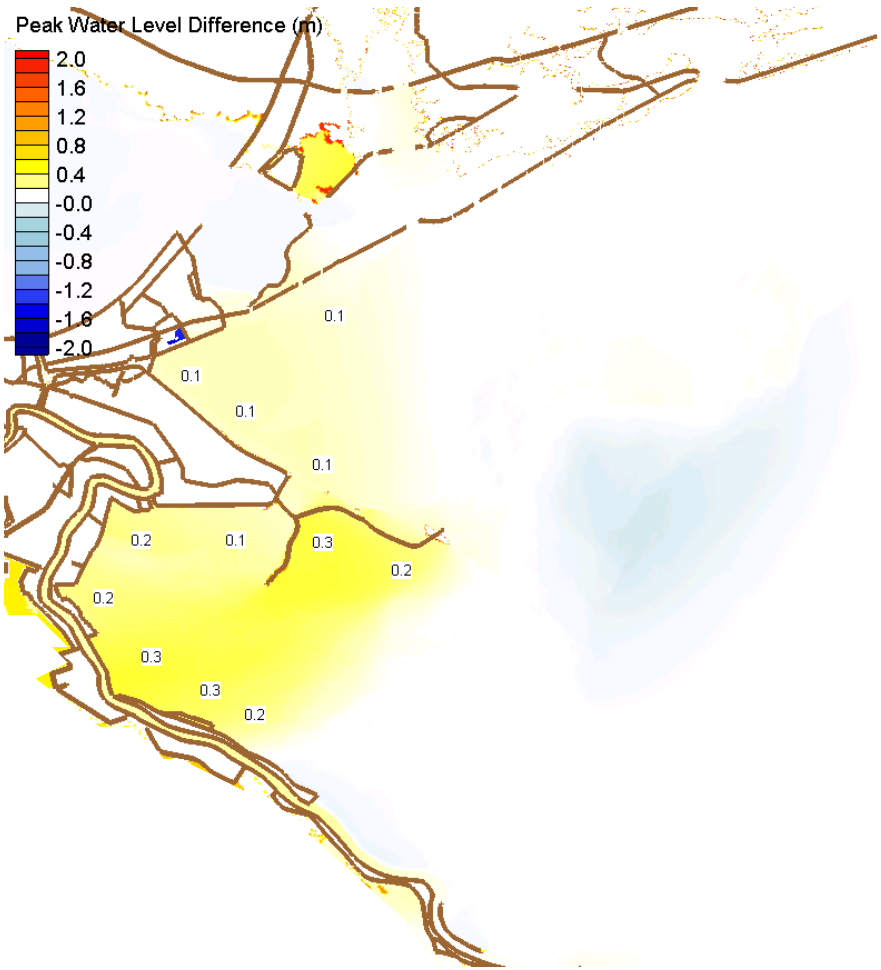


Marsh retreat/advance occurs from water's edge

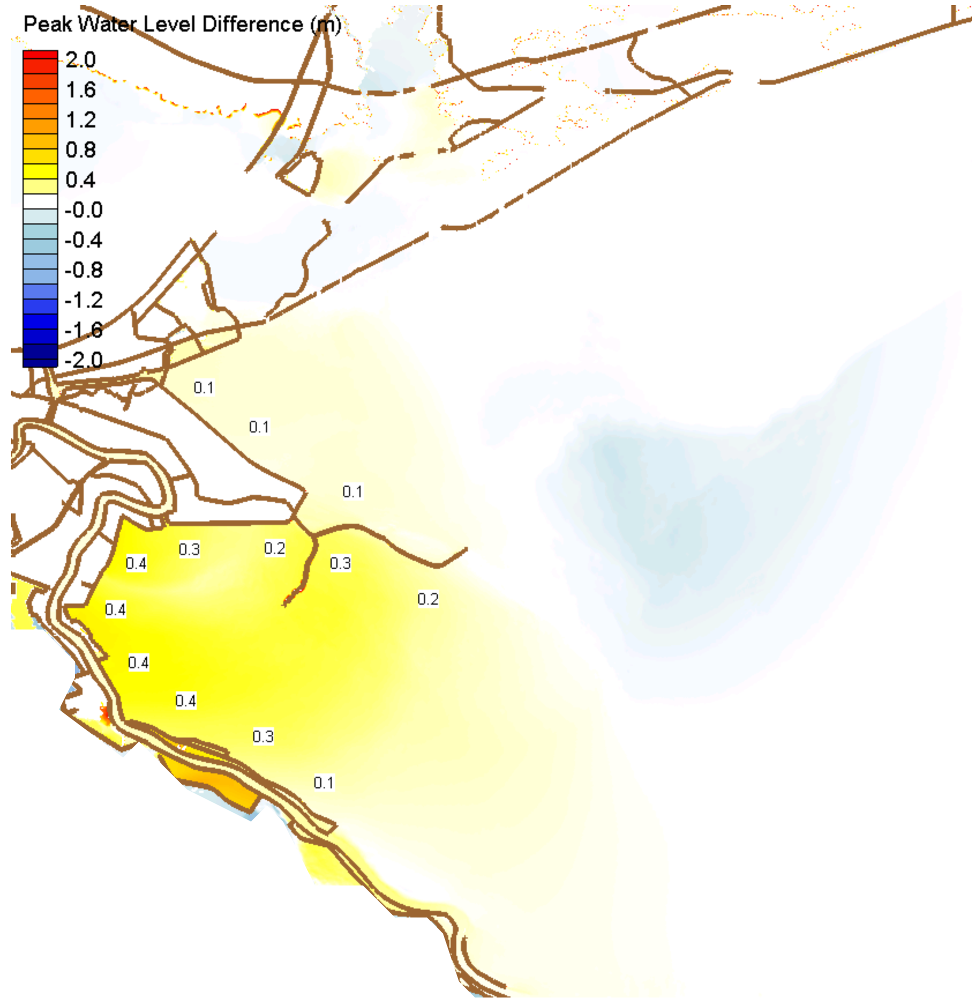
Future NIA Landscape Changes



Future NIA

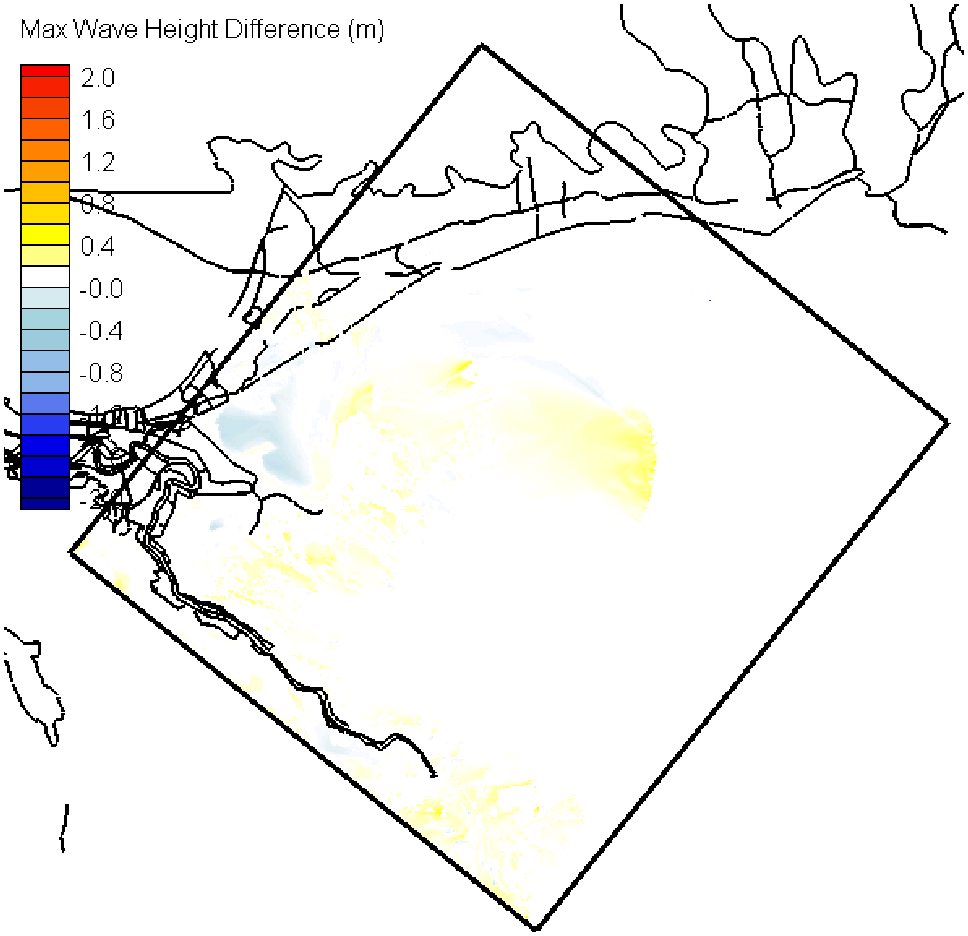


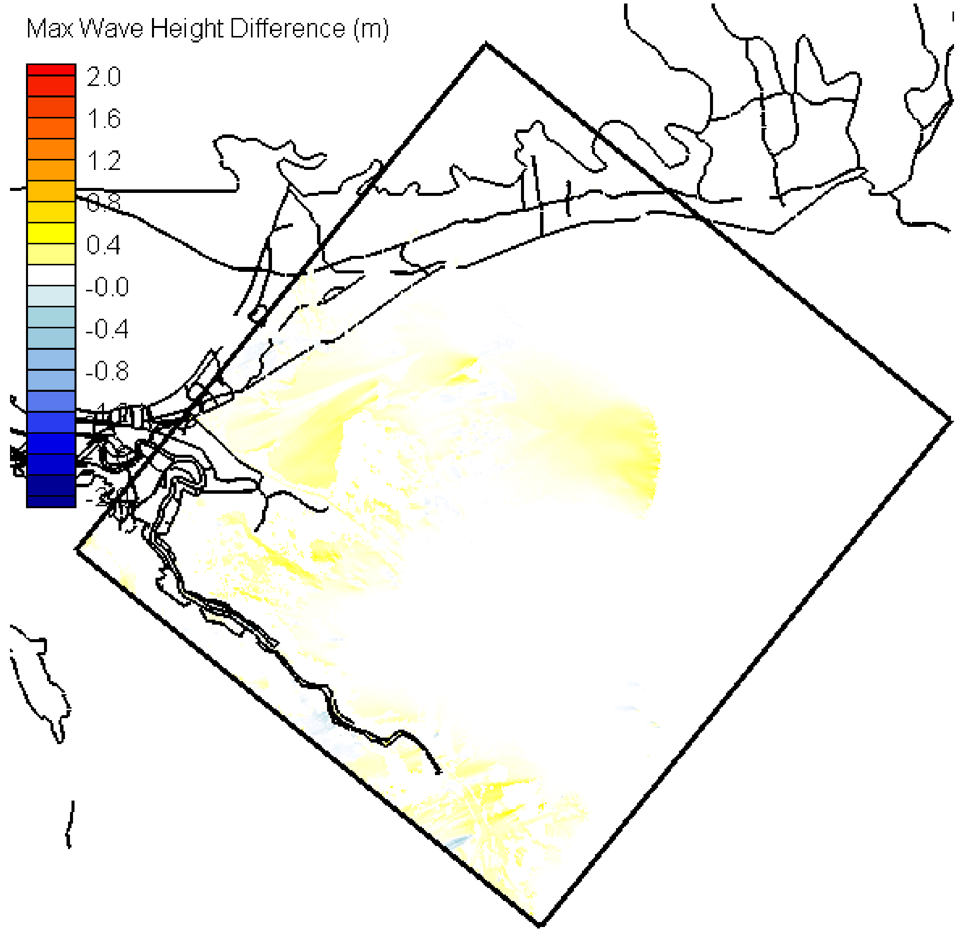
HUR1



HUR2

Future NIA


Max Wave Height Difference (m)
2.0
1.6
1.2
0.8
0.4
-0.0
-0.4
-0.8

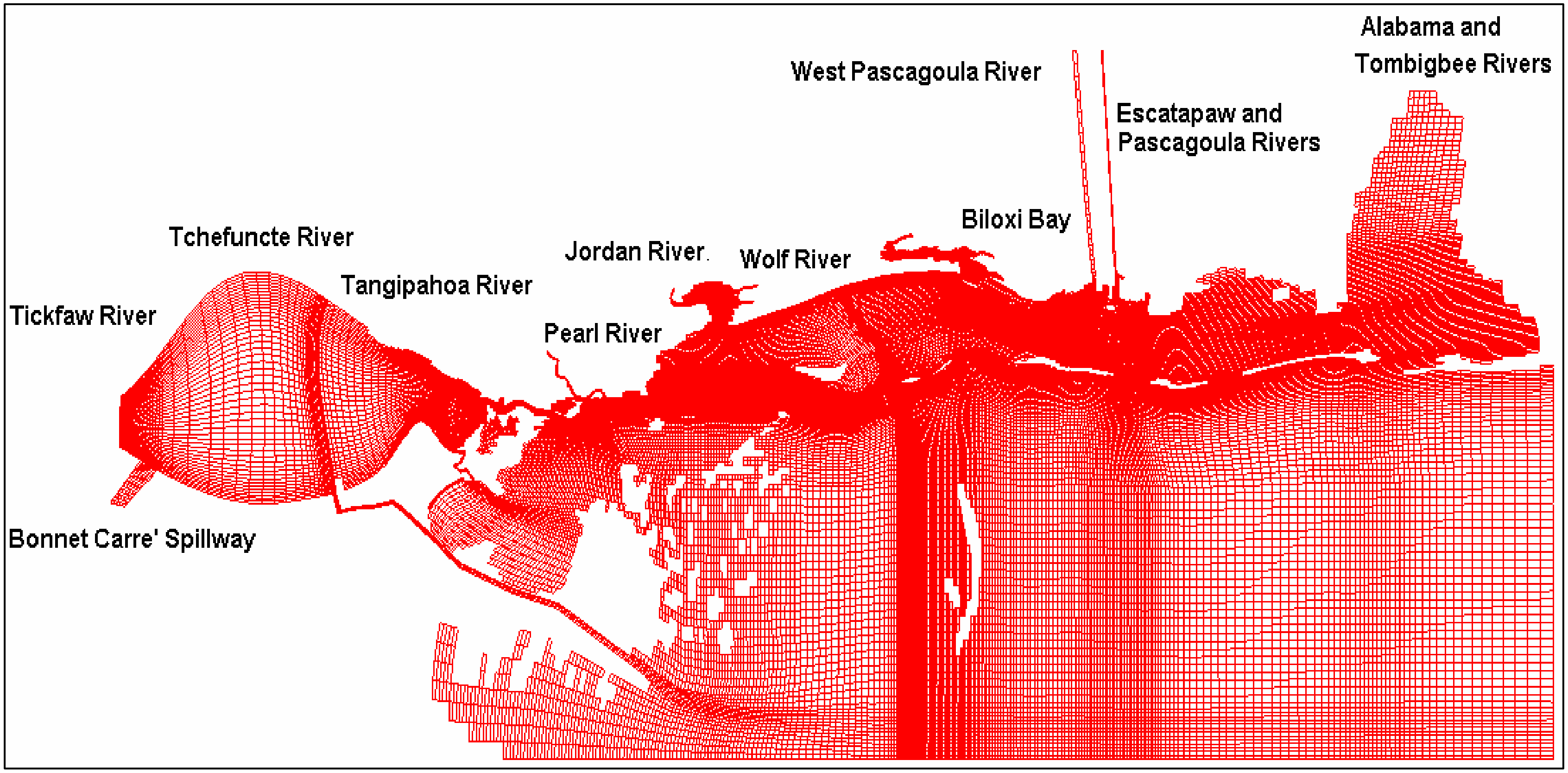

Max Wave Height Difference (m)
2.0
1.6
1.2
0.8
0.4
-0.0
-0.4
-0.8

Wetlands Summary

- Simulations indicate that vegetated landscape features do have surge and wave reduction potential.
- Large continuous restorations provide maximum benefit.
- Keep what we have!
- Impact can be amplified in areas with levee “pockets”.
- Absolute quantitative determinations should not be made.
- More research is needed.

Water Quality Modeling

Hydrodynamic and Water Quality Model Grid



- Regional grid
- CH3D-ICM linkage has been extensively tested and applied to numerous systems over several years

Opportunities/Problems and Objective

- Freshwater diversions can reduce salinity, thus increasing and improving habitat for oysters
- Freshwater diversions can also introduce elevated levels of nutrients, suspended sediment, thus increasing productivity, but decreasing underwater light, potentially impacting other resources, e.g., submerged aquatic vegetation

Objective: Develop Hydro-WQ model to screen alternatives and impacts of freshwater diversions

Modeling Approach

- Coupled, 3D, Hydro (CH3D-sigma) and WQ (CEQUAL-ICM) models
- Included adjacent water bodies that can impact the Sound
- Used 1998 for calibration and scenario testing
- Derived off-shore tides from ADCIRC
- Did not activate full model capabilities and limited the level of calibration due to fast time track of the study

CH3D

- 3D, time-varying, free surface Hydro model
- Transports salinity and temperature for density coupling and baroclinic forcing
- Curvilinear, non-orthogonal, boundary-fitted coordinates, finite difference method
- Block grid structure for parallelization

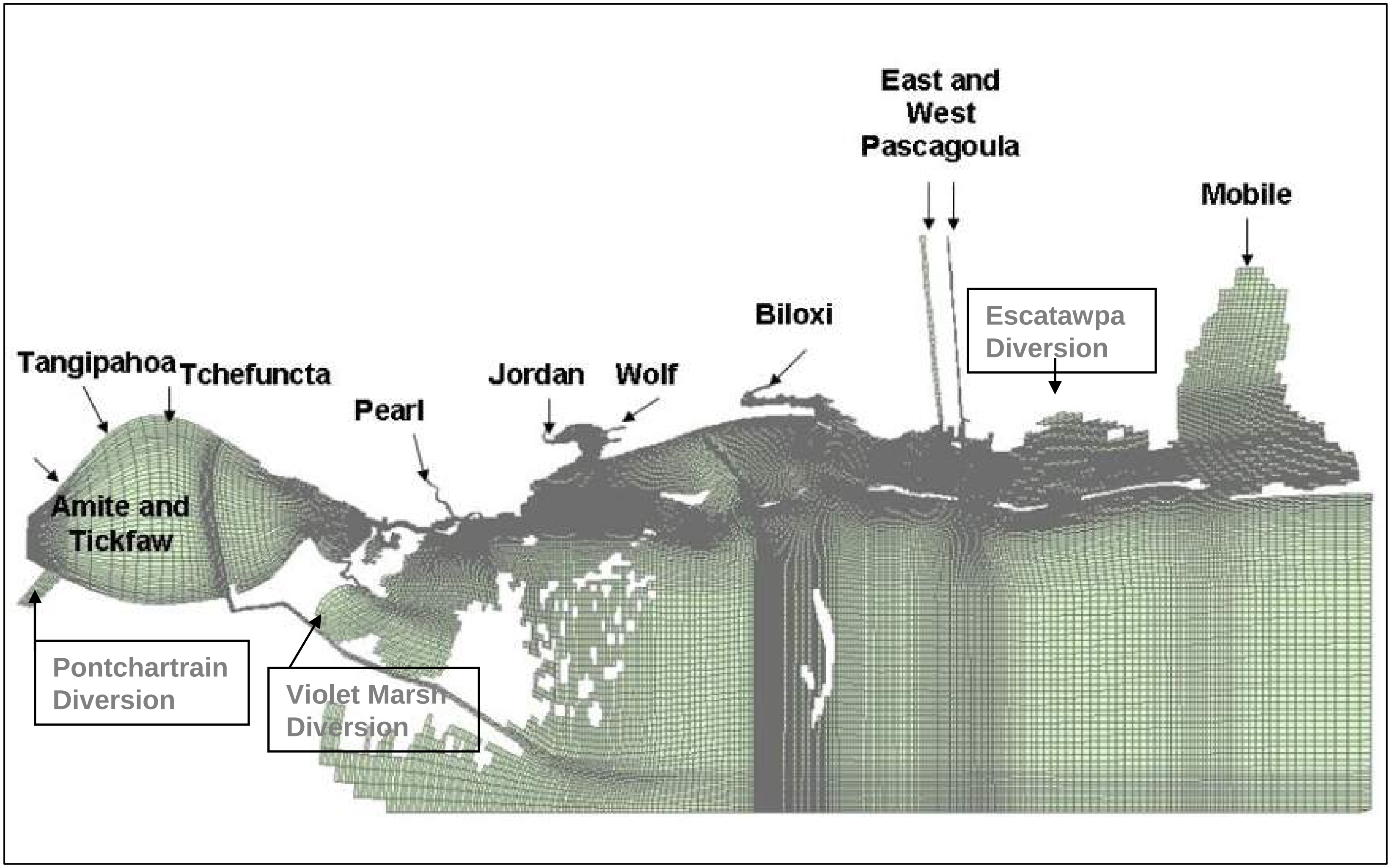
CEQUAL-ICM

- Multi-dimensional, finite volume surface water quality and eutrophication model
- Must provide hydro
- Developed on Chesapeake Bay, but has been applied to many other systems
- Over 30 state variables ranging from temperature, salinity, and nutrients to sea grass and lower food chain
- Benthic diagenesis sub-model for predicting bed-water column fluxes
- Domain decomp. with MPI for parallelization (using 32 processors on Cray XT3 for this study)

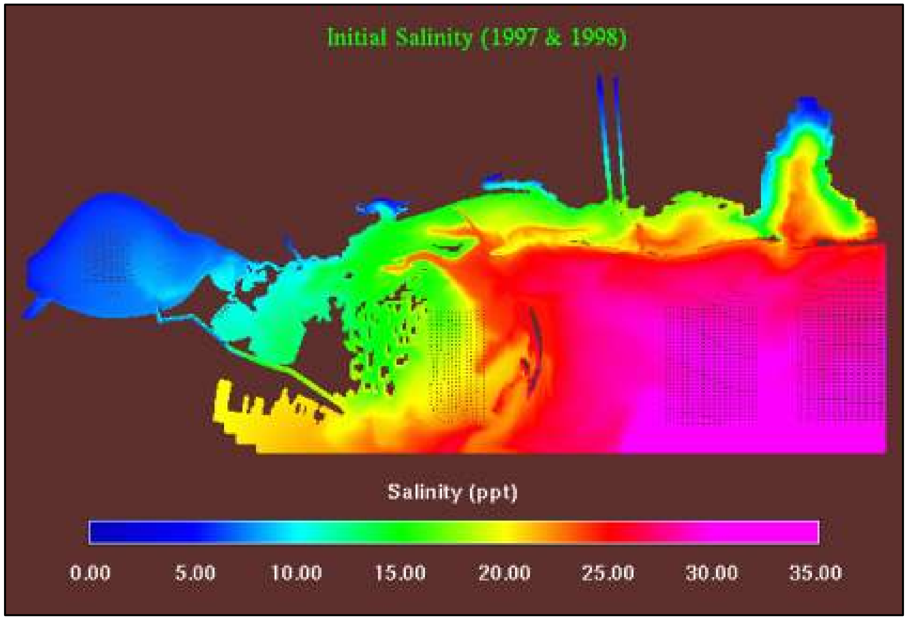
WQ Model State Variables for MS Sound Model

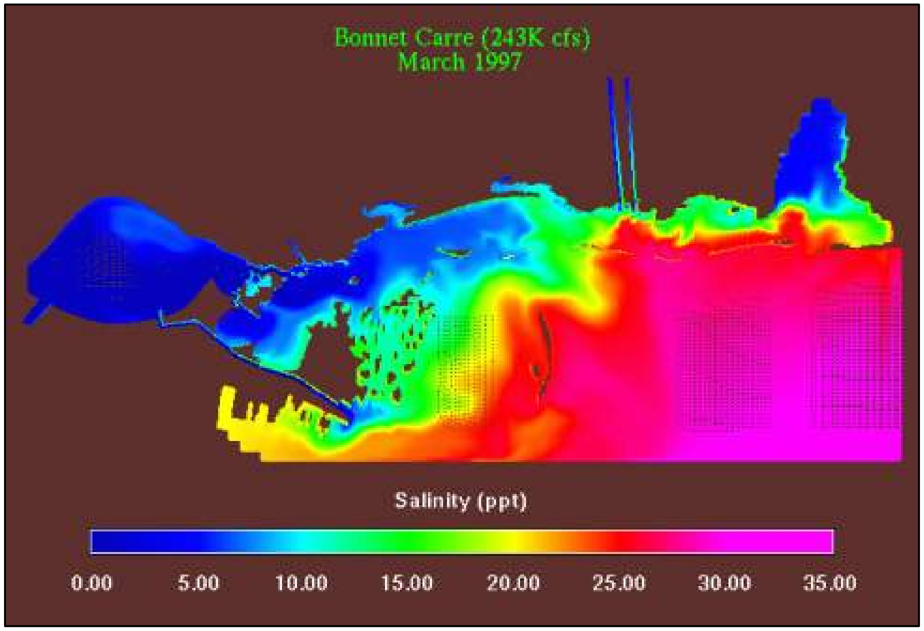
- Temperature
- Salinity
- Inorganic suspended solids
- Dissolved oxygen
- Phytoplankton carbon
- Total inorganic P
- Nitrate + nitrite N
- Ammonium N
- DOC
- POC
- DON
- PON
- DOP
- POP
- TSS (derived)
- Underwater light (derived)
- Chlorophyll a (derived)
- TOC (derived)
- TKN (derived)

Model Domain
(5 layers, 202,030 cells)
Modeled Tributaries and Diversions

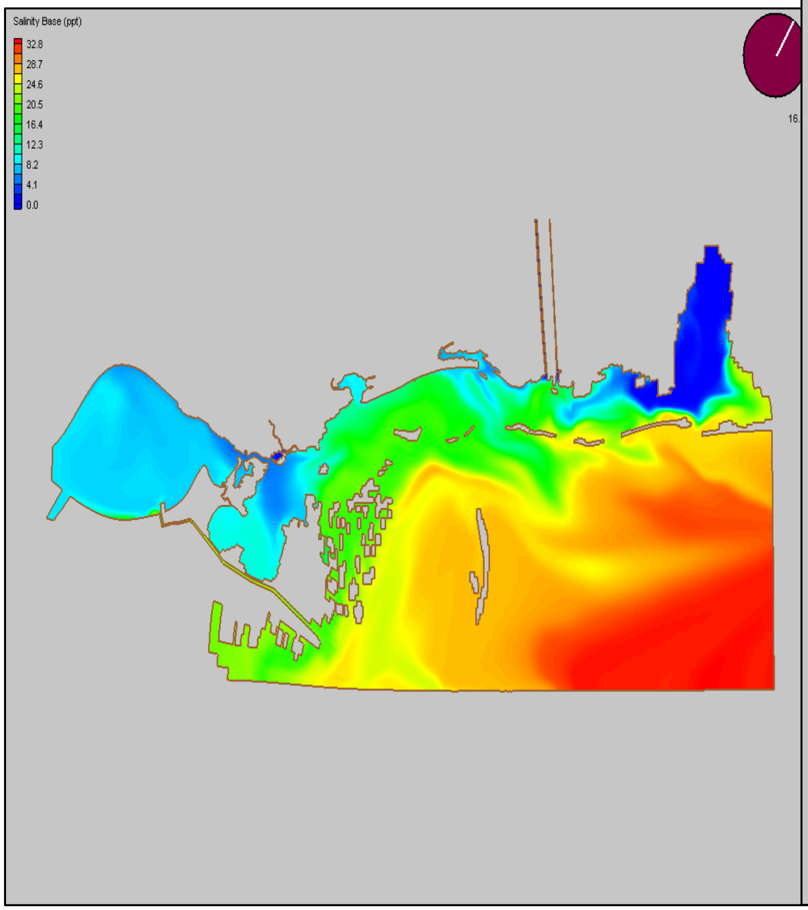


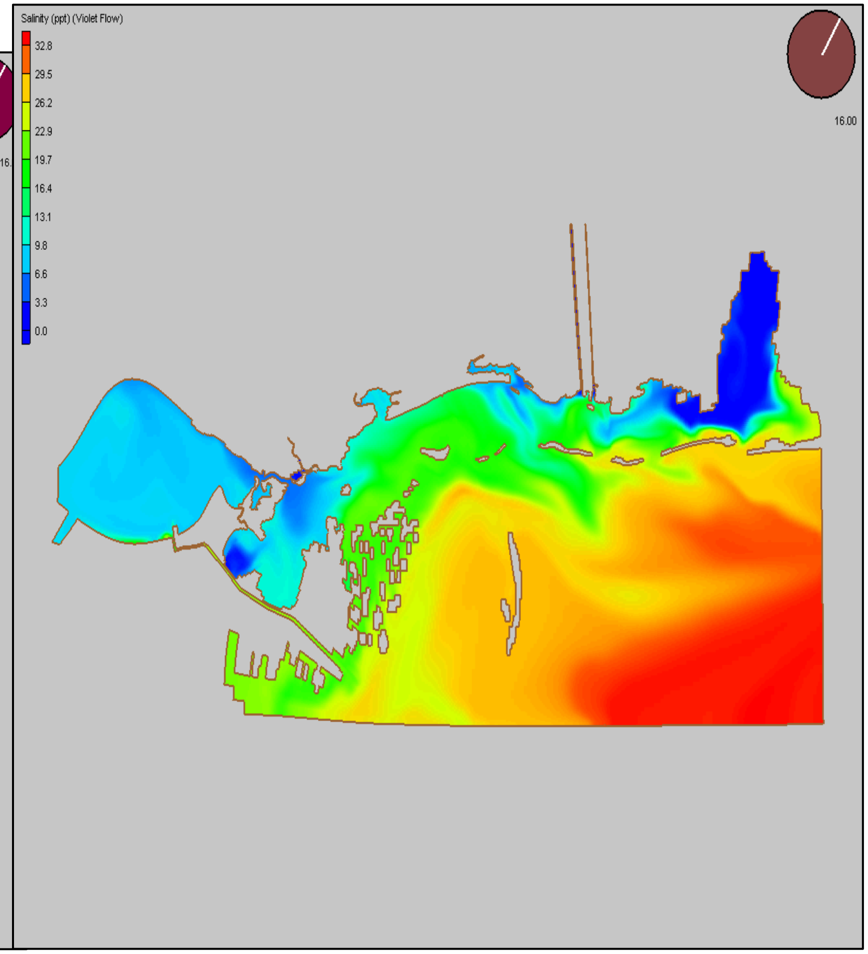
Effects of Bonnet Carre Release in 1997





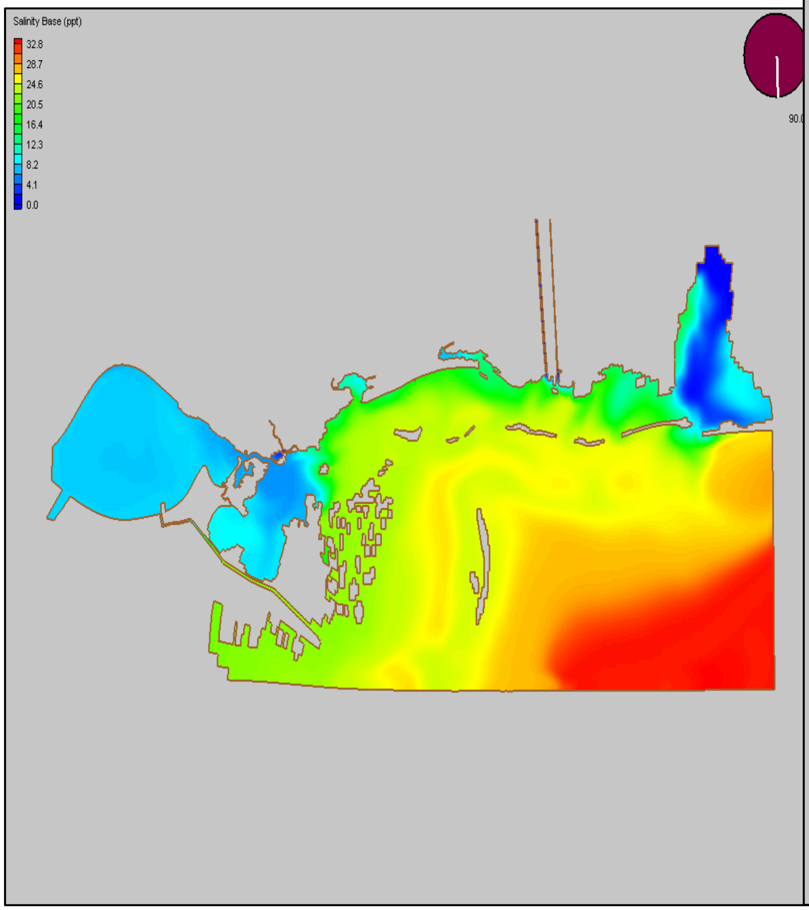
Salinity, Base and Violet, after 15 Days



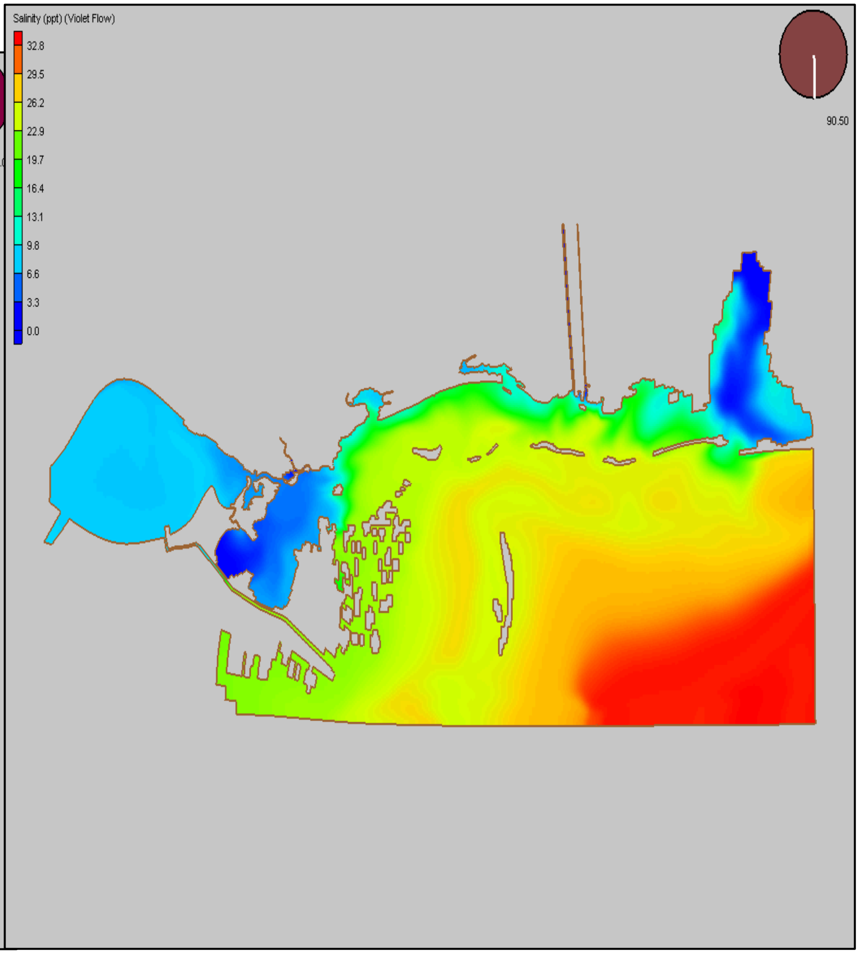


Base **Violet**

Salinity, Base and Violet after 90 Days

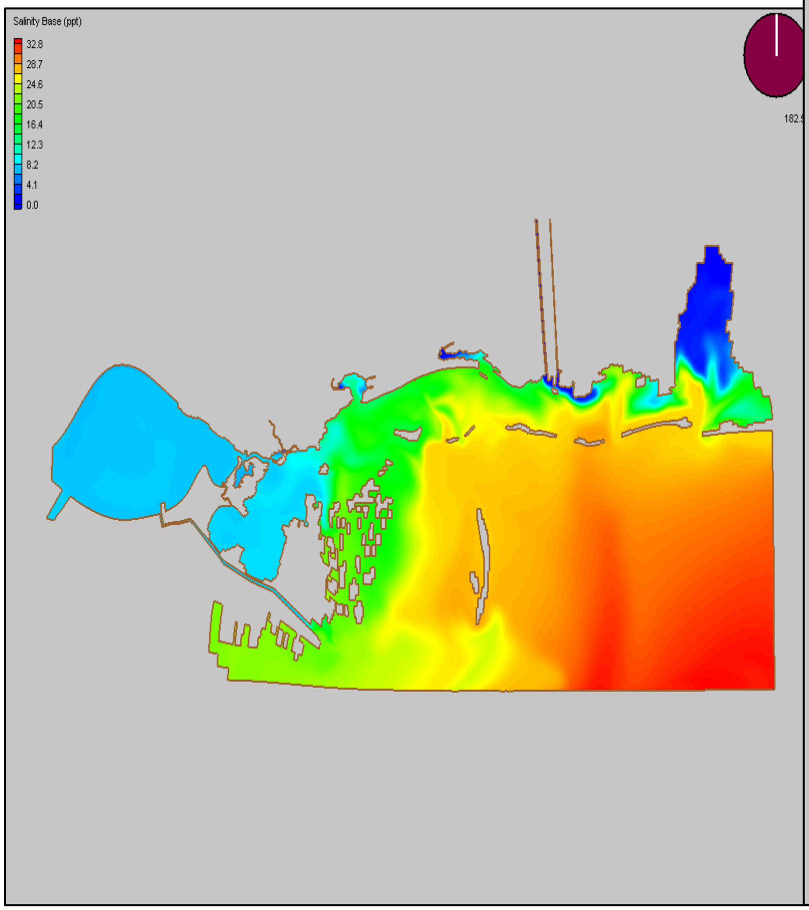


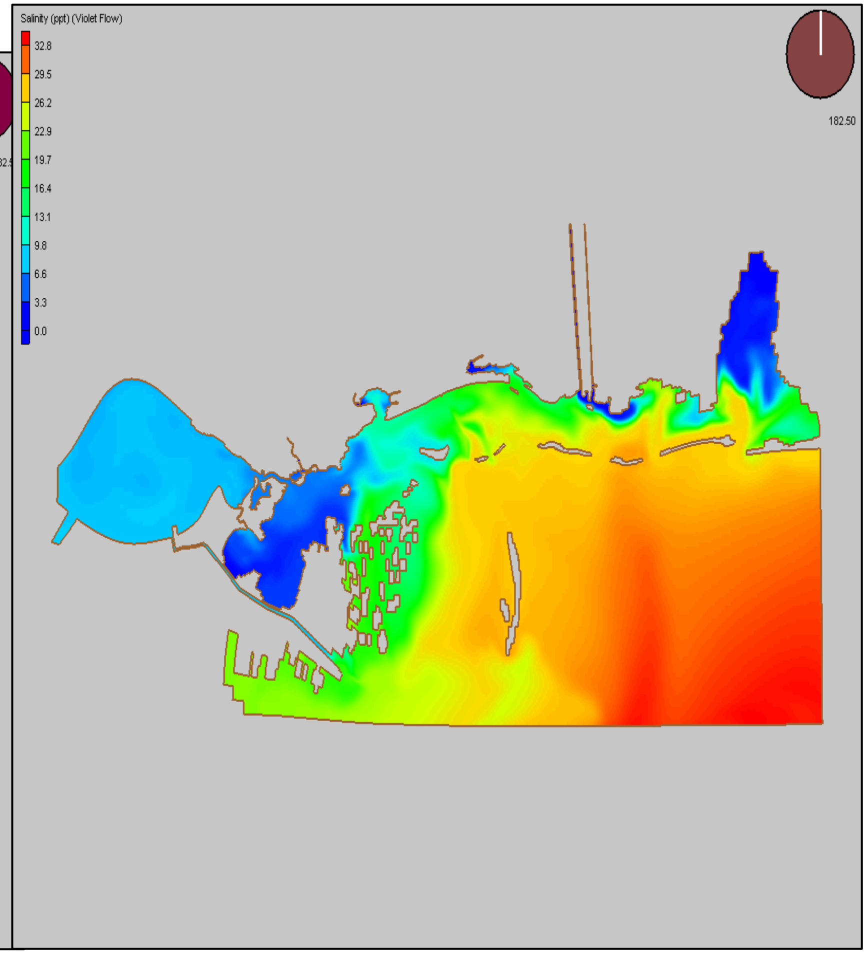
Base



Violet

Salinity, Base and Violet, after 180 days

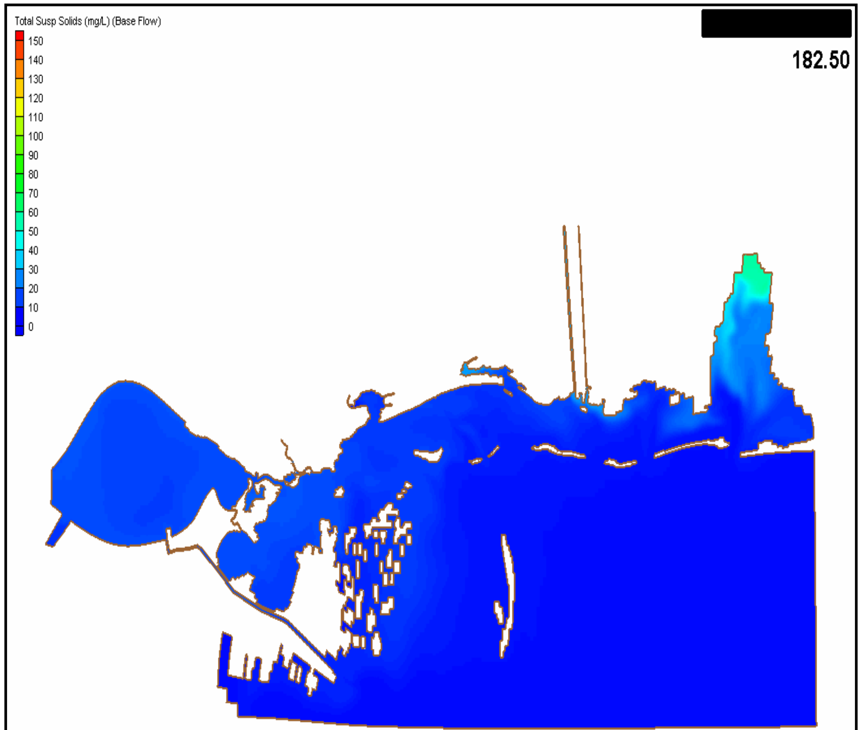




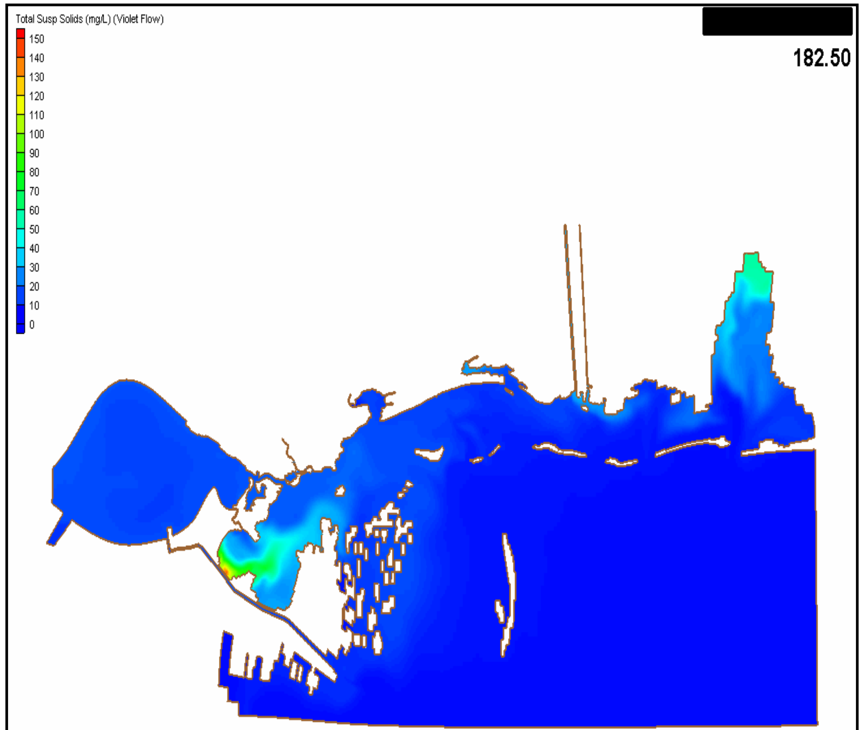
Base

Violet

TSS, Base and Violet, after 180 Days



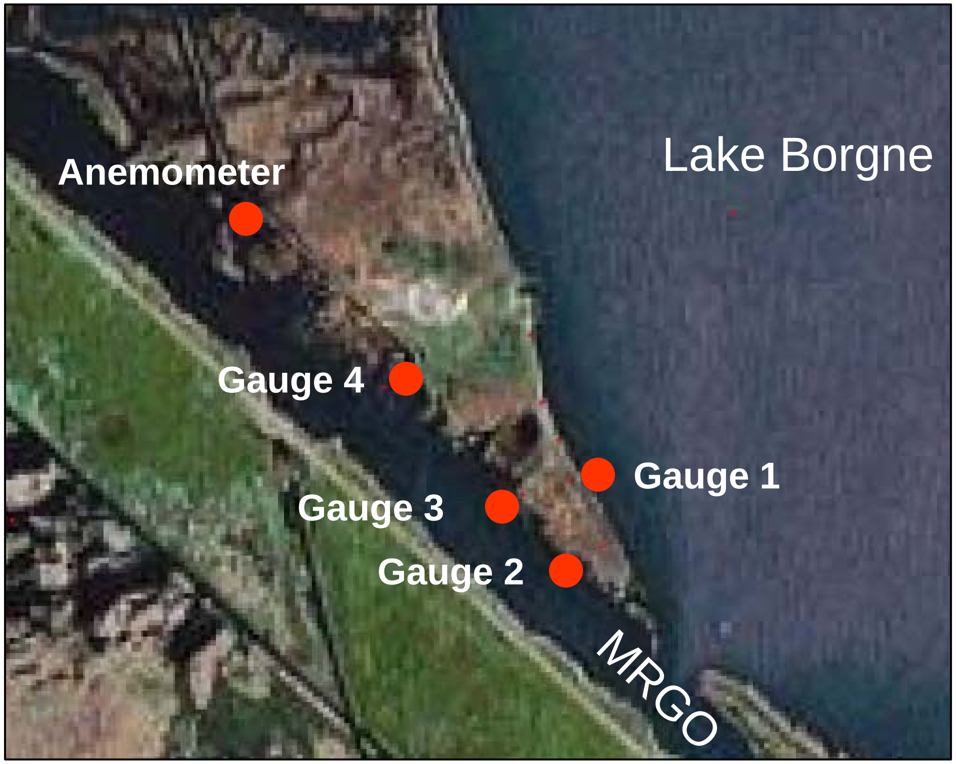
Base



Violet

Partnering with LCA

- Utilization of LCA S&T Funding
  - Field measurement wave attenuation and water levels across wetlands
    - 4 non-directional wave/water level gauges
    - Anemometer
    - Botanical characterization
  - Improve roughness estimates for modeling



Partnering with LCA

- Utilization of LCA S&T Funding to Improve Modeling Capabilities
  - Model scenario testing of "virtual wetlands"

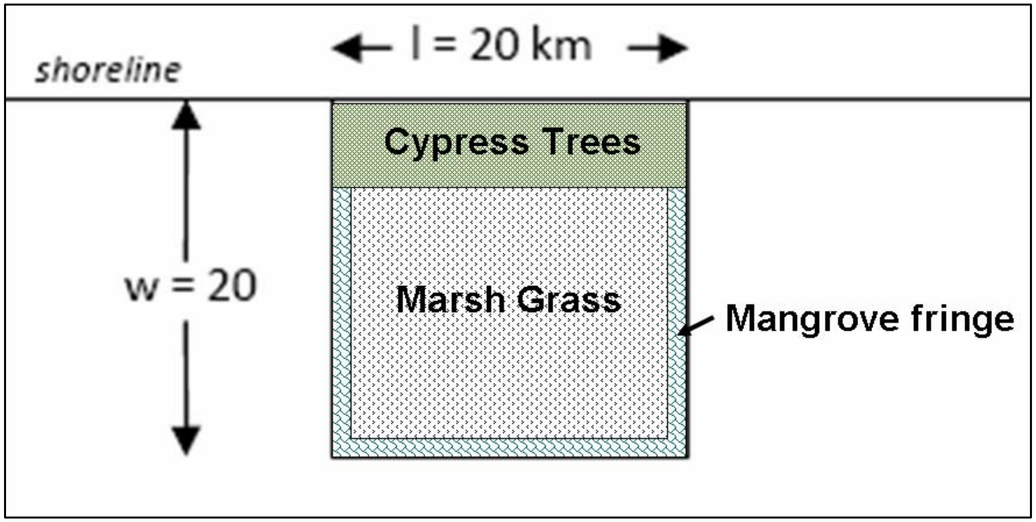
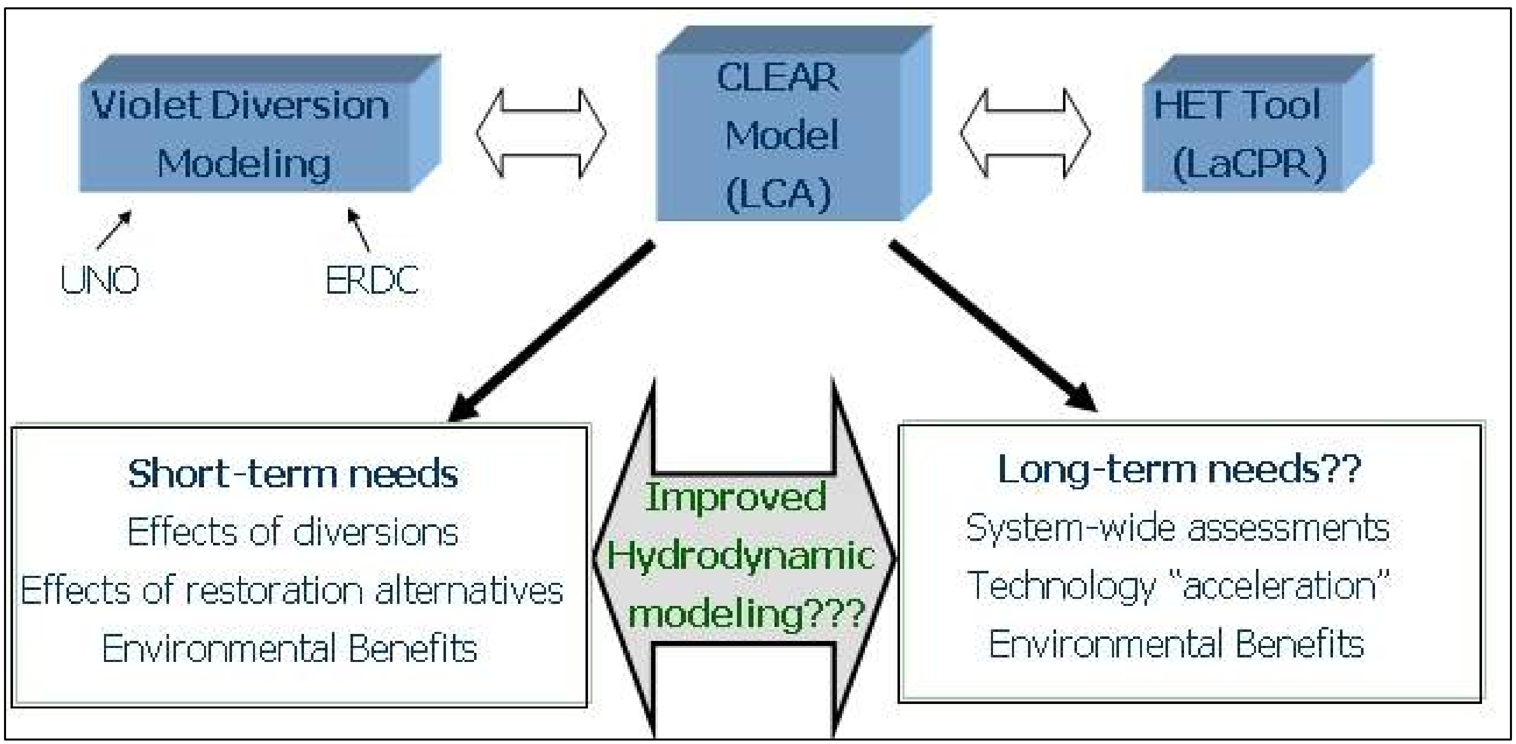


Figure 4. Idealized wetland with combination of vegetation types.

Partnering with LCA

- Linkage of CLEAR (LSU) ecological models to CH3D/ICM construct



End