INTEGRATED COMPARTMENT MODEL

ICM FRAMEWORK, DEVELOPMENT AND OVERVIEW OF APPLICATION IN MODELING THE 2017 LOUISIANA COASTAL MASTER PLAN

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Model Integration, HSIs, Metrics, etc.

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Presentation Outline

Overview and Intro

- Coastal Master Plan Background
- 2017 Model Improvement Plan & ICM Development
- Non-ICM models used in Master Plan process

Model Output

- Calibration
- Results!!

Model Guts

- Hydrodynamic Model
- Wetland Morphology Model
- Vegetation Model
- Barrier Island Model
- Habitat Suitability Indices

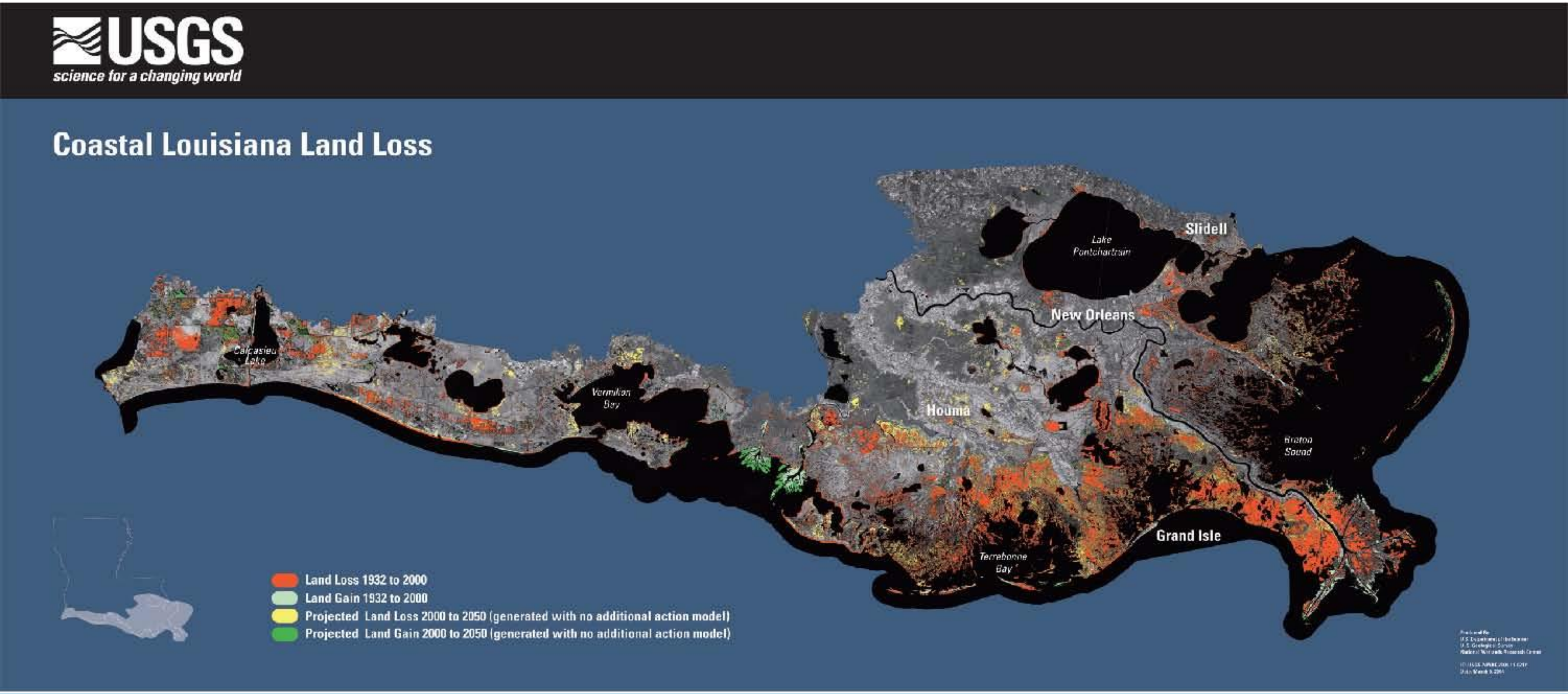
Model Application

- Future Environmental Scenarios
- Project Implementation

Background on Louisiana Coastal Master Plan

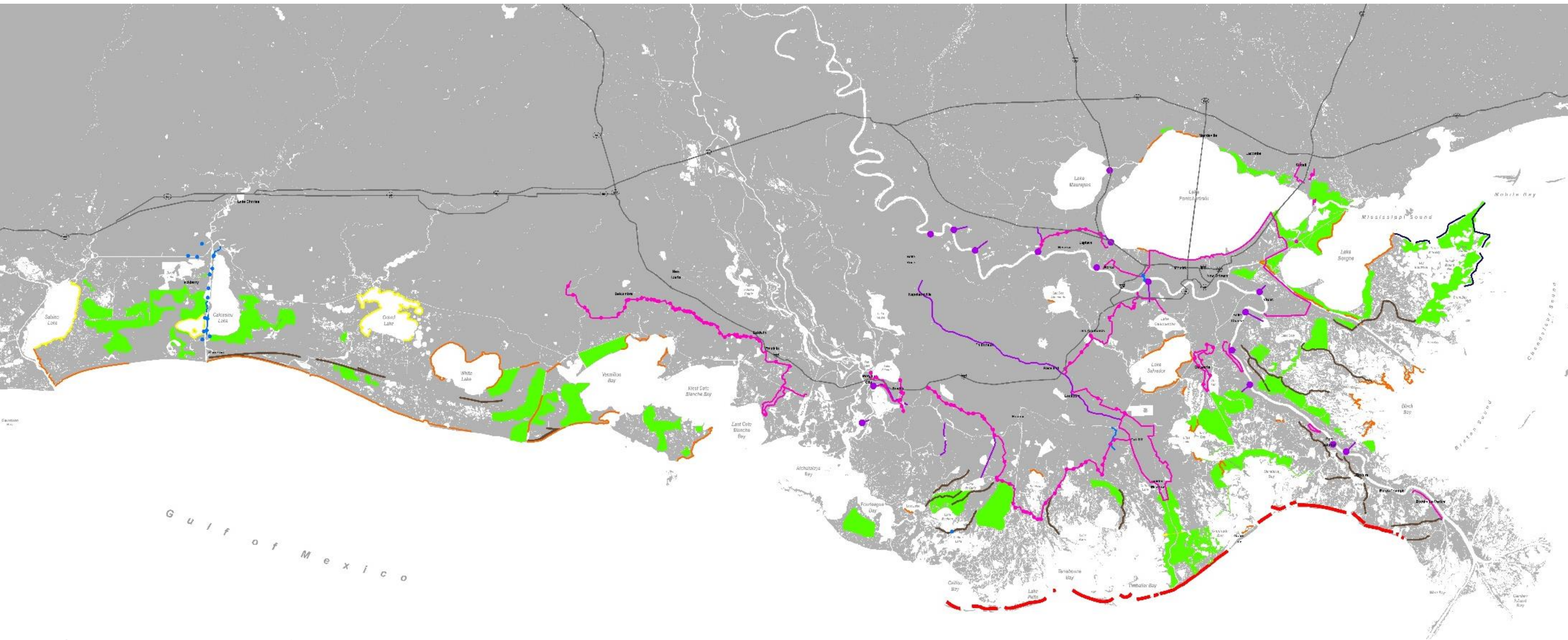
Coastal land loss in Louisiana

– 1900 sq km from 1932-2000
– 56 sq km/year from 1984-2010



Louisiana Coastal Master Plan

- 50 year, ~$50 billion comprehensive engineering plan
  - Restoration & protection projects



Information online:
http://coastal.la.gov/a-common-vision/2017-master-plan-update/

Louisiana Coastal Master Plan

- How are the models used?
  - Compare the *relative impact* of various proposed engineering projects
  - Analyze model performance across a variety of *possible future scenarios*
  - *Objectively rank projects* based on performance and cost
    - Cost is informed by engineering estimates with aid from model output
    - Performance is a multi-objective function:
      - Land area sustained
      - Flood protection
      - Ecosystem Services
      - Dozens of outputs and metrics are provided for decision makers

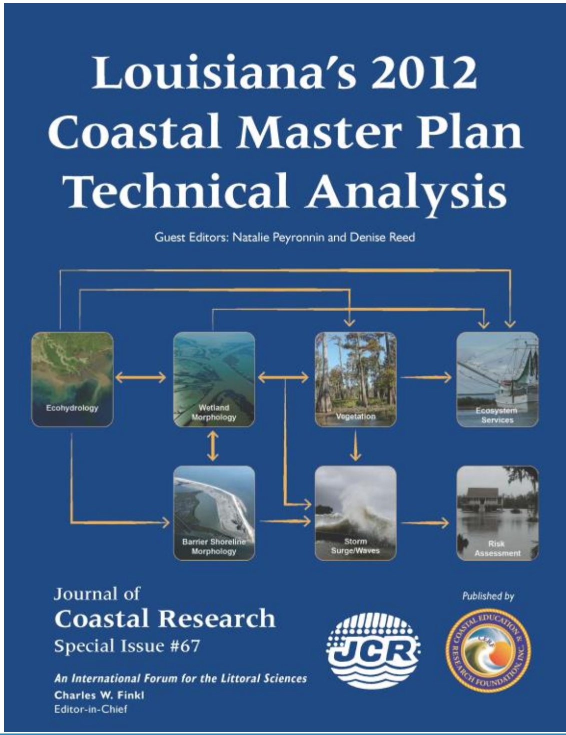
2012 Master Plan Documentation

- 2012 Master Plan
  - http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/
- 2012 Master Plan Appendices
  - Appendix D – Predictive Models
  - http://coastal.la.gov/a-common-vision/2012-coastal-master-plan/cmp-appendices/
- *Journal of Coastal Research* Special Issue #67 has many papers describing model framework

– Ehab Meselhe, John A. McCorquodale, Jeff Shelden, Mark Dortch, T. Stokka Brown, Peter Elkan, Mallory D. Rodrigue, Jennifer K. Schindlerand Zhanxian Wang. 2013. *Ecohydrology Component of Louisiana's 2012 Coastal Master Plan: Mass-Balance Compartment Model.*

– Jenneke Visser, Scott Duke-Sylvester, Jacoby Carter, and Whitney Broussard III. 2013. *A Computer Model to Forecast Wetland Vegetation Changes Resulting from Restoration and Protection in Coastal Louisiana.*

– Brady R. Couvillion, Gregory D. Steyer, Hongqing Wang, Holly J. Beckand John M. Rybczyk. 2013. *Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios*

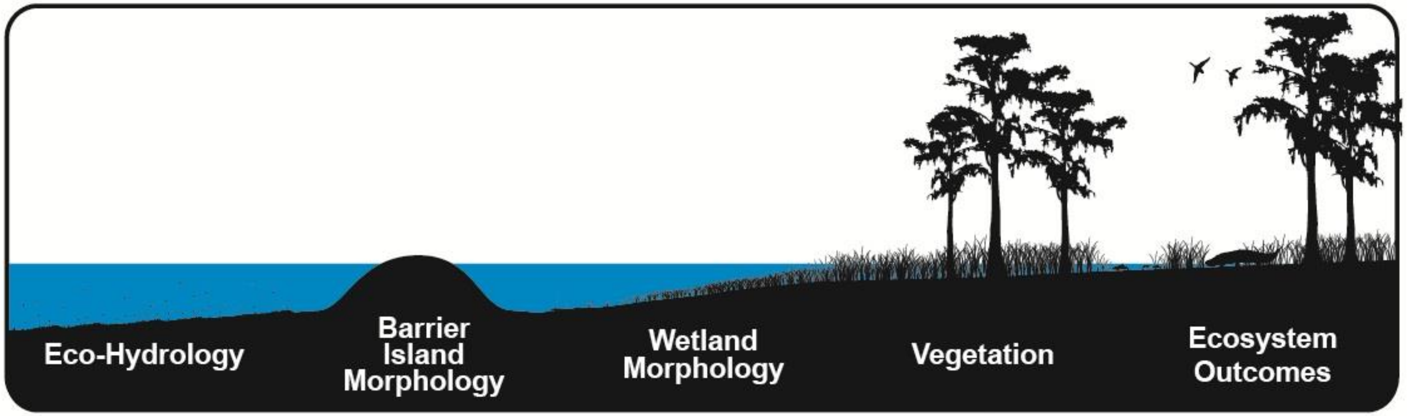


2017 Master Plan Draft Documentation

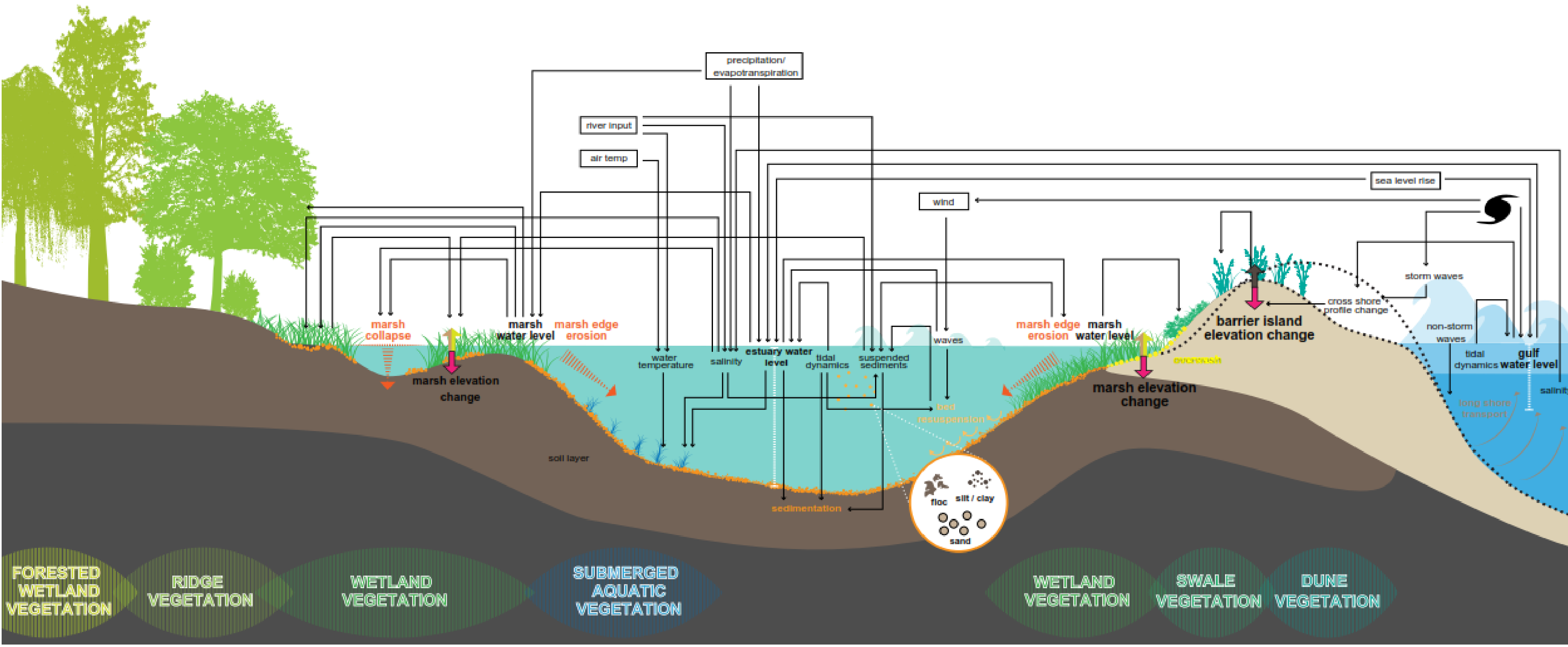
- 2017 Master Plan
  - http://coastal.la.gov/a-common-vision/2017-master-plan-update/
- 2017 Model Improvement Plan
  - http://coastal.la.gov/wp-content/uploads/2015/06/modelImprovementPlanMarch-2014.pdf
- Appendix C – Modeling
  - http://coastal.la.gov/wp-content/uploads/2016/04/Appendix-C-Modeling-.pdf
  - Chapter 3 – Modeling Components and Overview
    - http://coastal.la.gov/a-common-vision/2017-master-plan-update/technical-analysis/
    - Attachment C3-1 – Sediment Distribution
    - Attachment C3-4 – Barrier Island Model Development
    - Attachment C3-5 – Vegetation
    - Attachment C3-22 – ICM Integration
    - Attachment C3-23 – ICM Calibration and Validation
  - These are still in draft form – check back for updates
  - **Modeling Update Webinar from September 2015**
    - https://vimeo.com/140946351
    - http://coastal.la.gov/wp-content/uploads/2015/09/Louisianas-2017-Coastal-Master-Plan-Modeling-Update_092215_FINAL_ac.pdf

2017 Model Improvement Plan & Development of Integrated Compartment Model

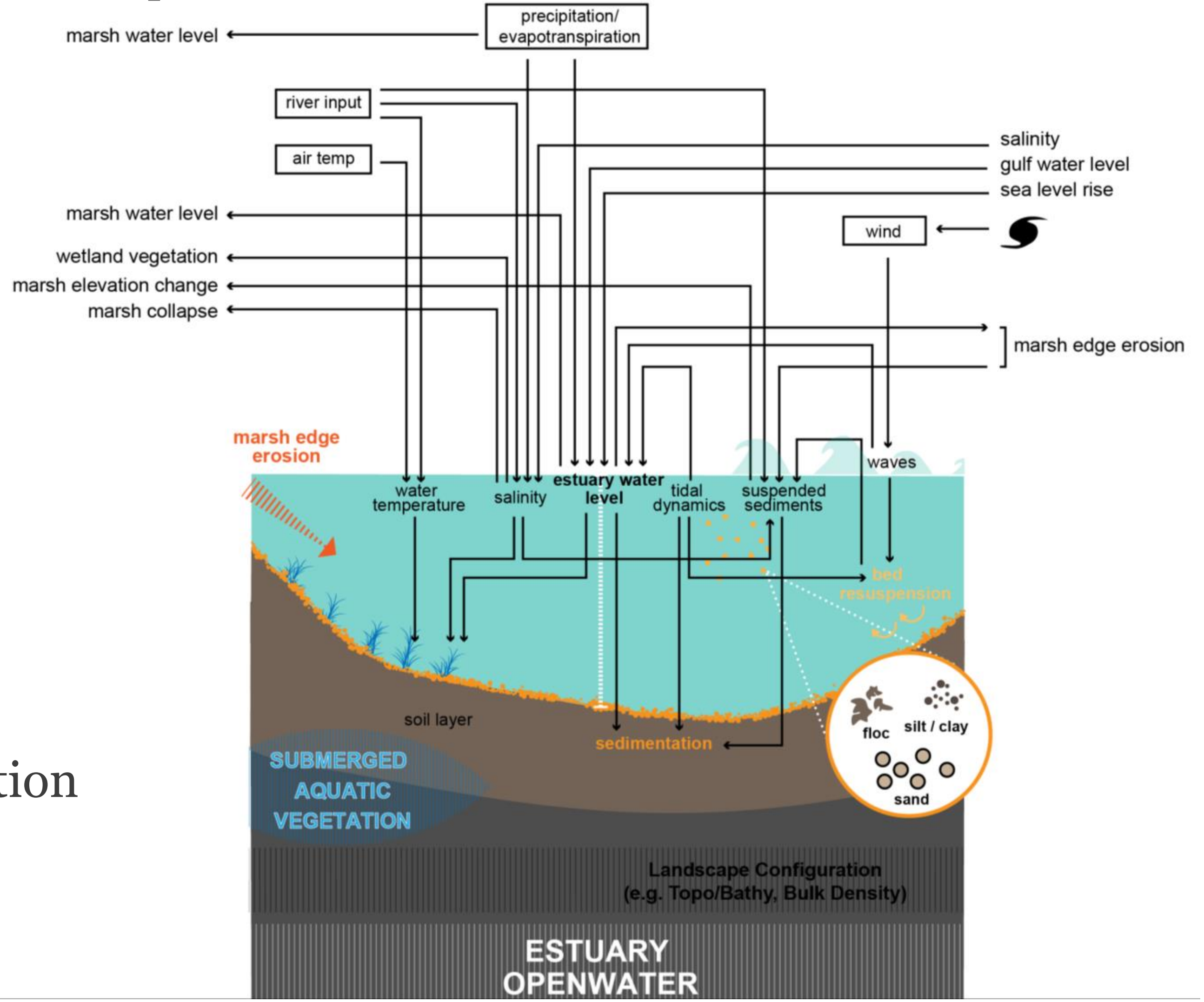
Integrated Compartment Model (ICM)



Integrated Compartment Model

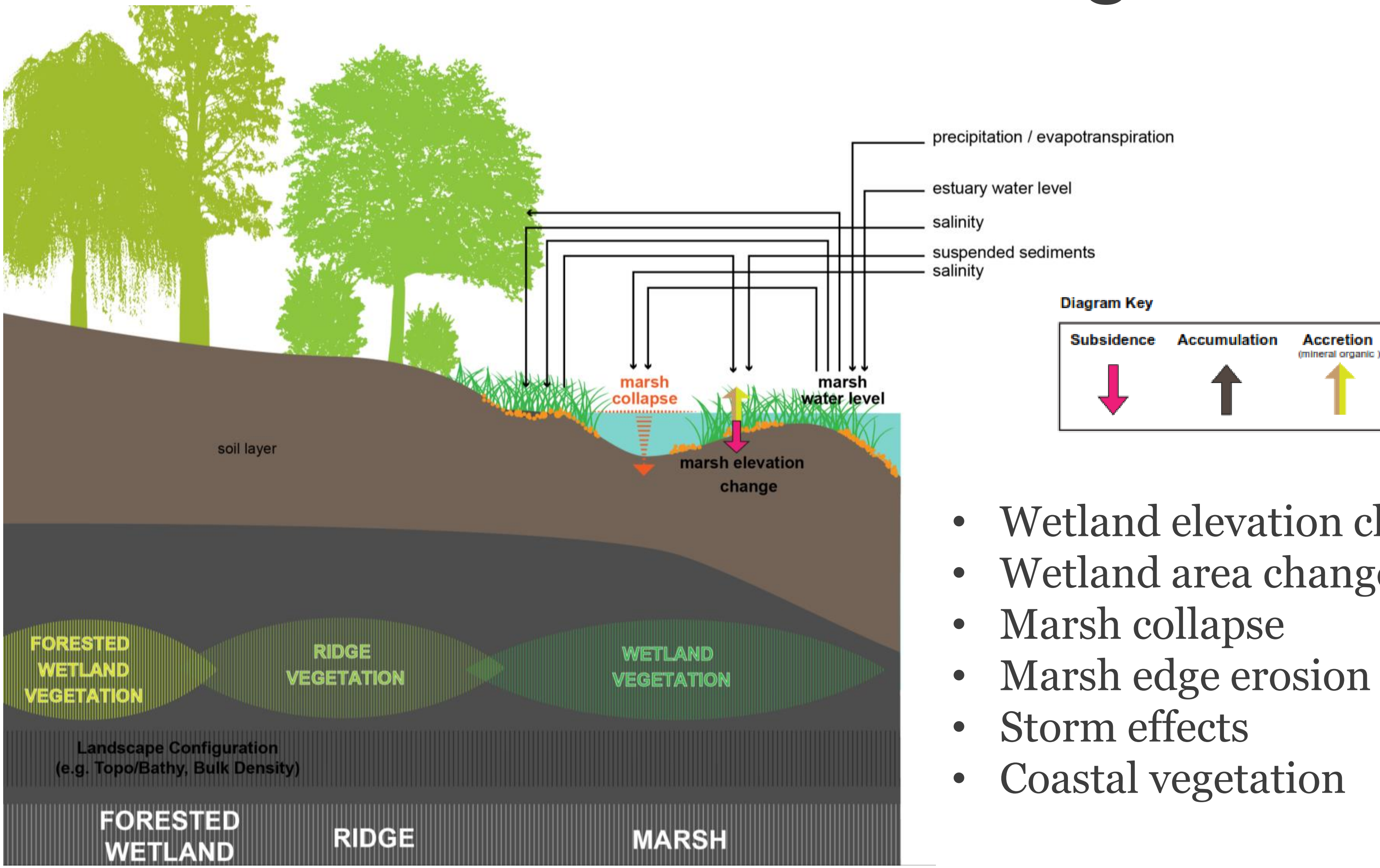


Estuary and Open Water Processes



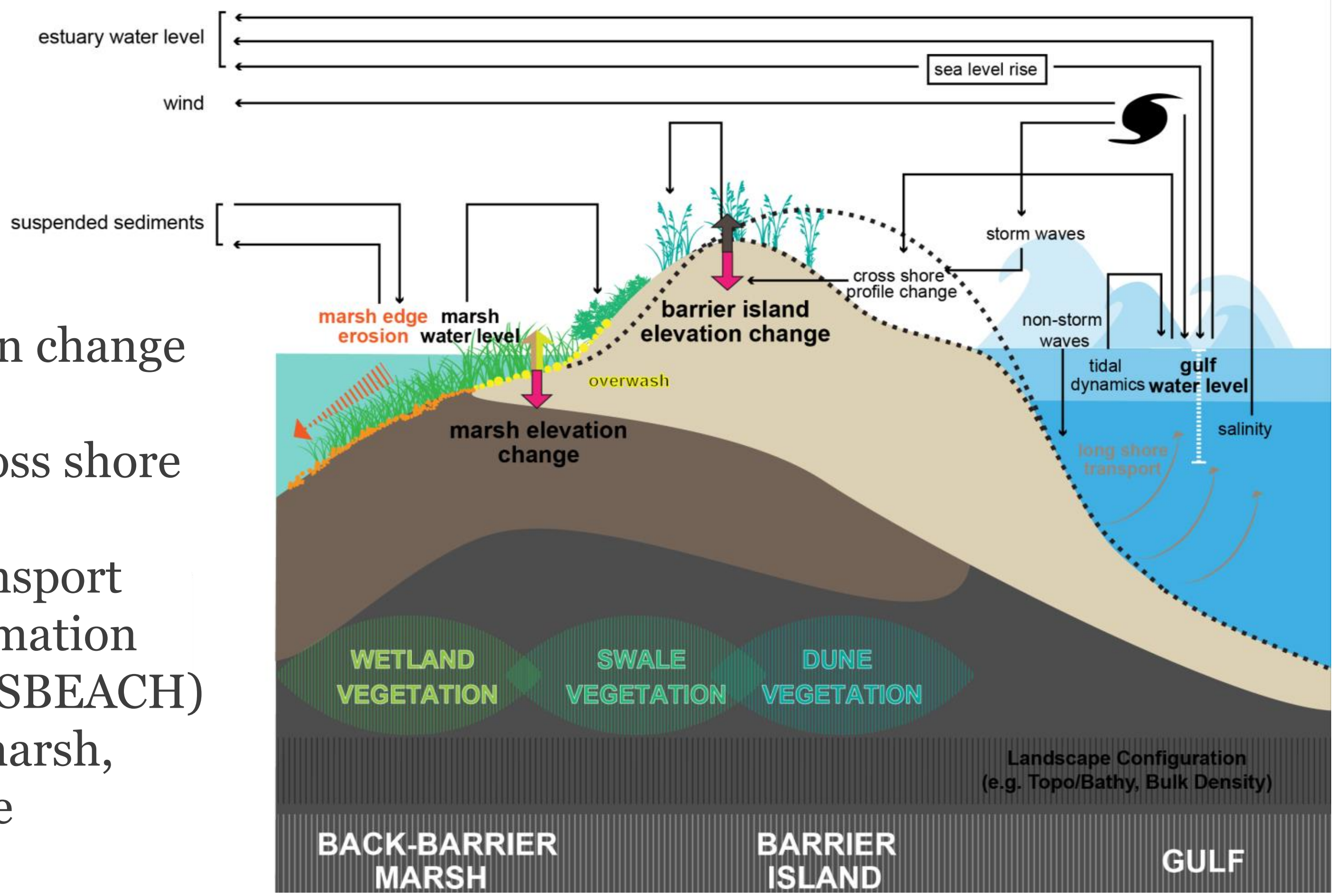
- Hydrodynamics
- Water quality
- Sedimentation
- Bed resuspension
- Sediment distribution

Wetland Processes and Vegetation



- Wetland elevation change
- Wetland area change
- Marsh collapse
- Marsh edge erosion
- Storm effects
- Coastal vegetation

Barrier Island Processes



- Island elevation change
- Breaching
- Overwash / cross shore profile change
- Longshore transport
- Wave transformation
- Storm effects (SBEACH)
- Back-barrier marsh, dune and swale vegetation

Fish and Shellfish

- 19 fish, shellfish, and wildlife Habitat Suitability Indexes (HSIs)
  - Statistical analysis
  - Revised equations from 2012
  - Added several new HSIs
  - Coded into the ICM

- EwE (Ecopath with Ecosim)
  - Community fish and shellfish model
  - Dynamically coupled to the ICM

Metrics

- Nitrogen uptake
- Sustainability of land
- Support for navigation
- Traditional fishing communities
- Support for oil and gas
- Support for agricultural communities
- Use of natural processes
- Potential coastal flood attenuation

Technical miscellanea

- Coded in:
  - Fortran
  - Python 2.7
    - *arcpy*
    - *numpy*
    - *Pandas*
    - *dbfpy*
    - *pysftp* (optional sFTP functionality)
- Currently reliant on proprietary software package for geomorphology routine (*arcpy* from ESRI)
  - Non-*arcpy* version of the morphology geoprocessing functions are being developed by the USGS
  - Once complete, can go to Linux
  - Until then, Windows only

Technical miscellanea

- Most I/O is human readable:
  - *.csv*
  - *.xslx*
  - *.txt*
  - *.asc (*ESRI Ascii grid raster format)
- Some geospatial I/O is only readable in GIS software:
  - File geodatabase structure used(ESRI *.gdb)*
  - Some output formatted as *.img* rasters

- For a full coast-wide, 50-year run:
  - 300 GB I/O data
  - 10 GB RAM
  - 10 day runtime

Other (non-ICM) Modeling Tools in 2017 Master Plan Analysis:

- Fisheries (Kim de Mutsaert, George Mason University)
- Storm Surge (Hugh Robert, ARCADIS)
- Risk (Jordan Fischbach, RAND Corporation)

Ecopath with Ecosim and Ecospace (EwE) Fisheries Model Development:

Key inputs:
- Ecopath model
- Basemap of model area; coastal Louisiana with 1 km2 grid
- Ecosim fishing effort (annual pattern kept constant for future)
- Spatial and temporal dynamic environmental drivers: values per grid cell, per month for each decadal simulation
- Habitat features (can be dynamic when habitat changes through time)

Key outputs:
- Monthly estimated biomass and catch projections for each km2 grid cell for every 50-year simulation
- Used to determine if/where increases and/or decreases in biomass and catch can be expected under various future restoration options relative to a future without action

Groups in the EwE Model

Fish

Atlantic croaker[1]
bay anchovy[1]
black drum[1]
blue catfish[1]
coastal sharks[1]
Gulf menhaden[1]
Gulf sturgeon[1]
killifishes
largemouth bass[1]
red drum[1]
sea catfishes[1]
sheepshead[1]

Fish

silversides
southern flounder[1]
spot[1]
spotted seatrout[1]
striped mullet[1]
sunfishes[1]

Invertebrates

benthic crabs
blue crab[1]
brown shrimp[1]
eastern oyster[2]
grass shrimp

Invertebrates

mollusks
white shrimp[1]
zoobenthos
zooplankton

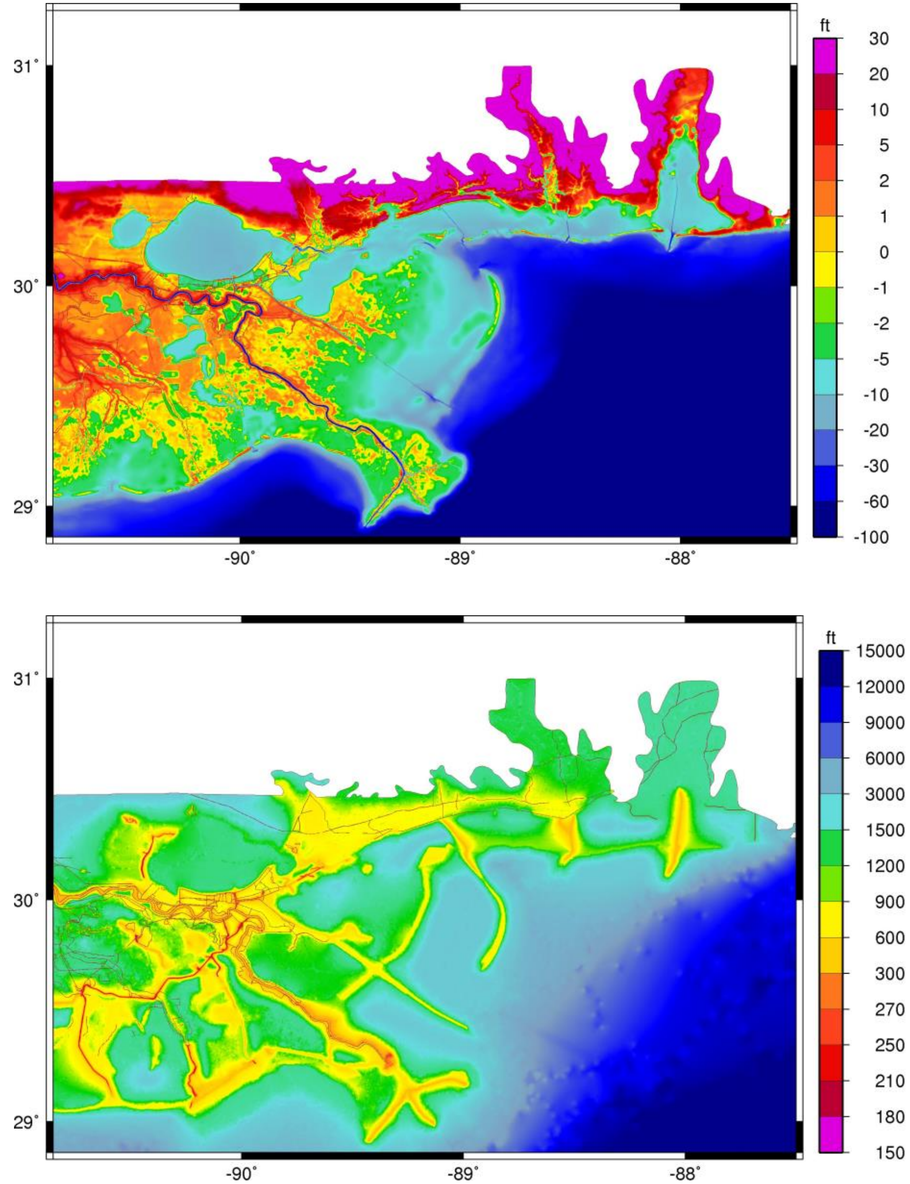
Primary producers

phytoplankton
SAV[3]
benthic algae

Other

seabirds
dolphins
detritus

[1]Juvenile and adult; [2]spat, seed, and sack; [3]submerged aquatic vegetation



Computing Surge and Waves

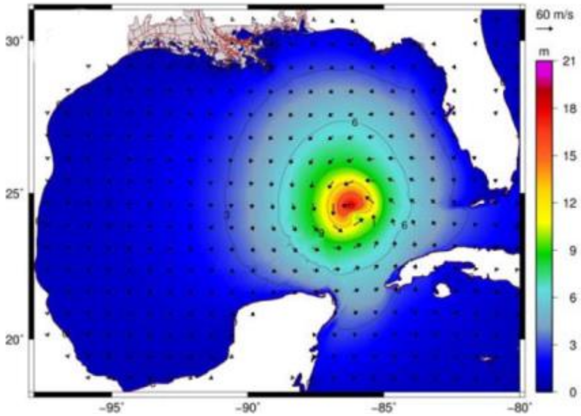
- ADCIRC
  - Computes wind and tide driven circulation
  - Unstructured mesh allows for flexibility to capture natural features
  - Highly efficient parallel model framework
- SWAN
  - Computes wind and circulation driven waves
  - Nonstationary waves
  - Uses same mesh as ADCIRC

Coastal LA Risk Assessment Model (CLARA)

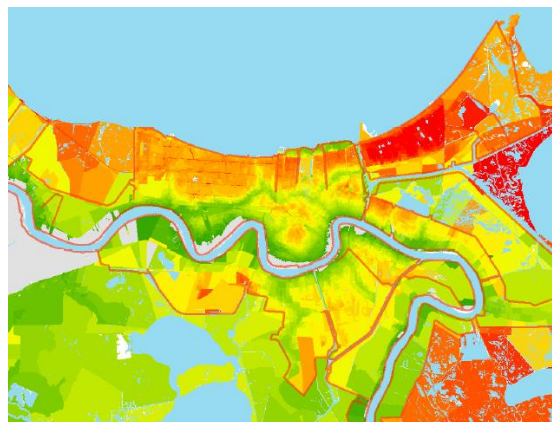
- Built on 2012 Coastal Master Plan modeling efforts
- Incorporated parametric uncertainty
- Updated geospatial domain and unit of analysis
- Updated datasets
- Improved fragility assumptions
- Improved economic damage module
- Improved storm suite

CLARA Consists of Three Primary Modules

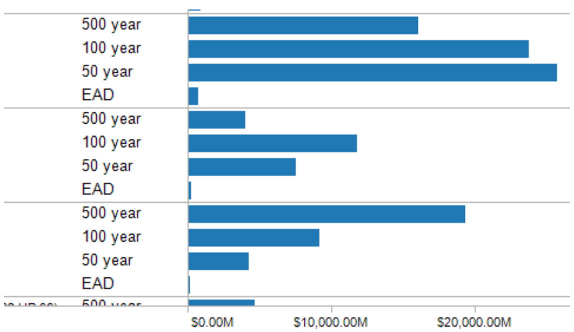
1. Statistical Pre-Processing Module



2. Flood Depth Module

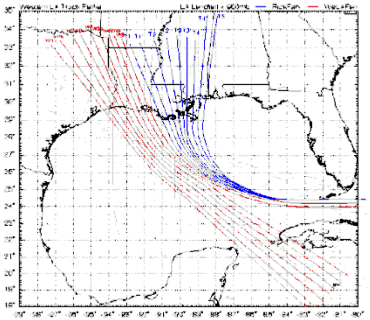


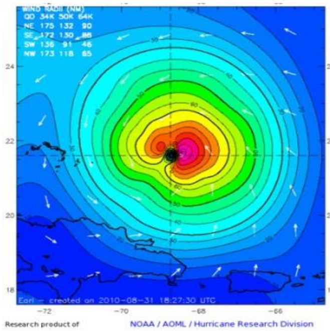
3. Economic Damage Module



Response Surface Model Predicts Surge and Wave Response as a Function of Storm Parameters

Storms are parameterized by a set of characteristics





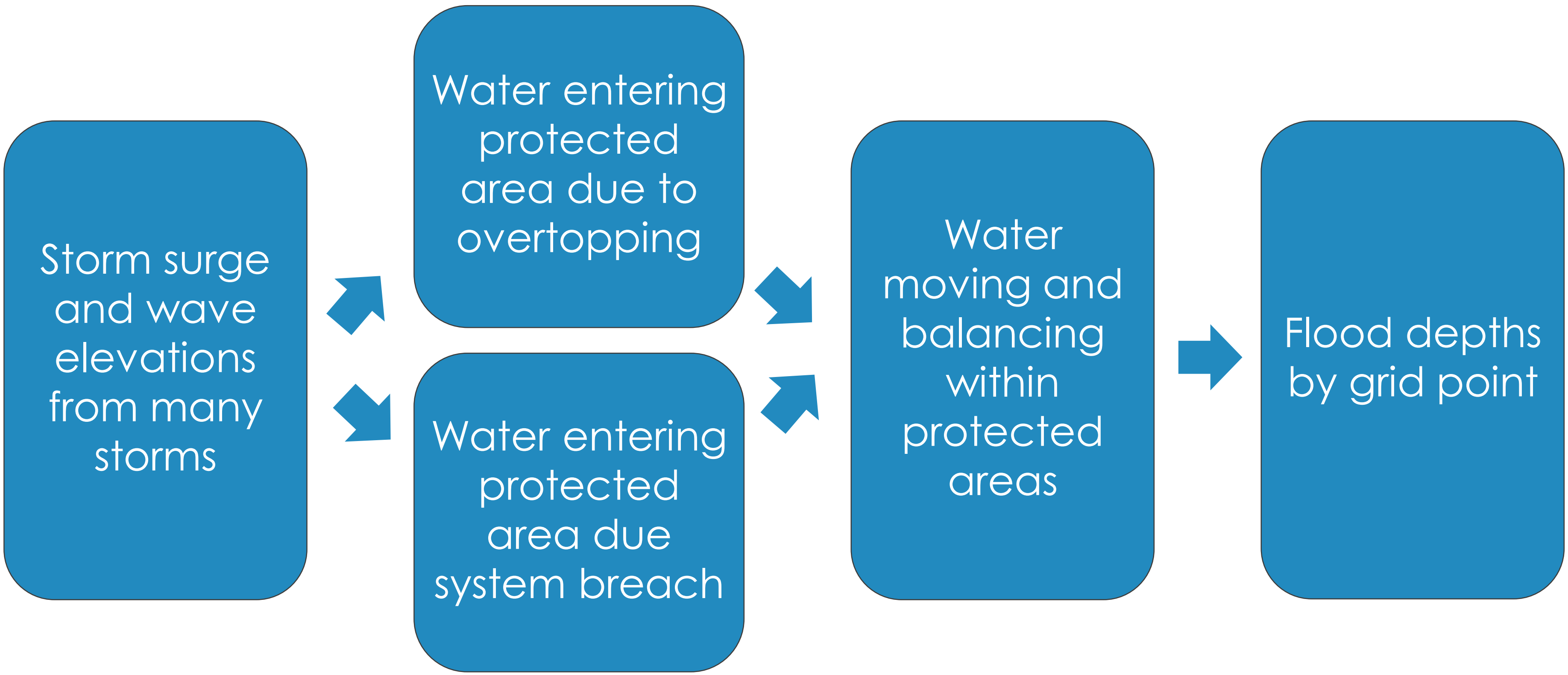
- Central pressure
- Radius
- Track
- Landfall angle
- Forward velocity

Response surface estimation

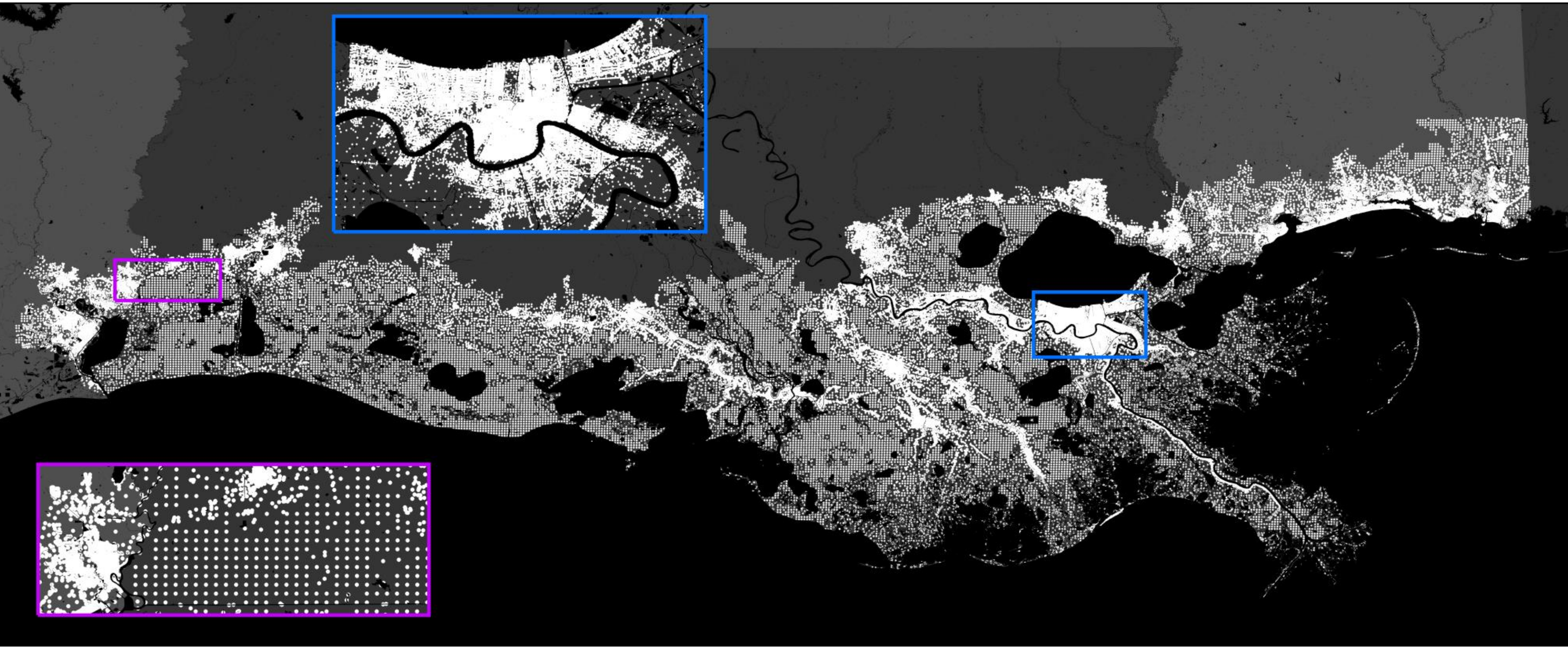
Surge and wave effects from training storms (ADCIRC/UnSWAN)

Surge and wave effects from "synthetic" storms

CLARA Then Estimates Final Flood Depths in Enclosed Areas



Developed a New Spatial Grid to Support Higher Resolution Analysis for Coastal Communities

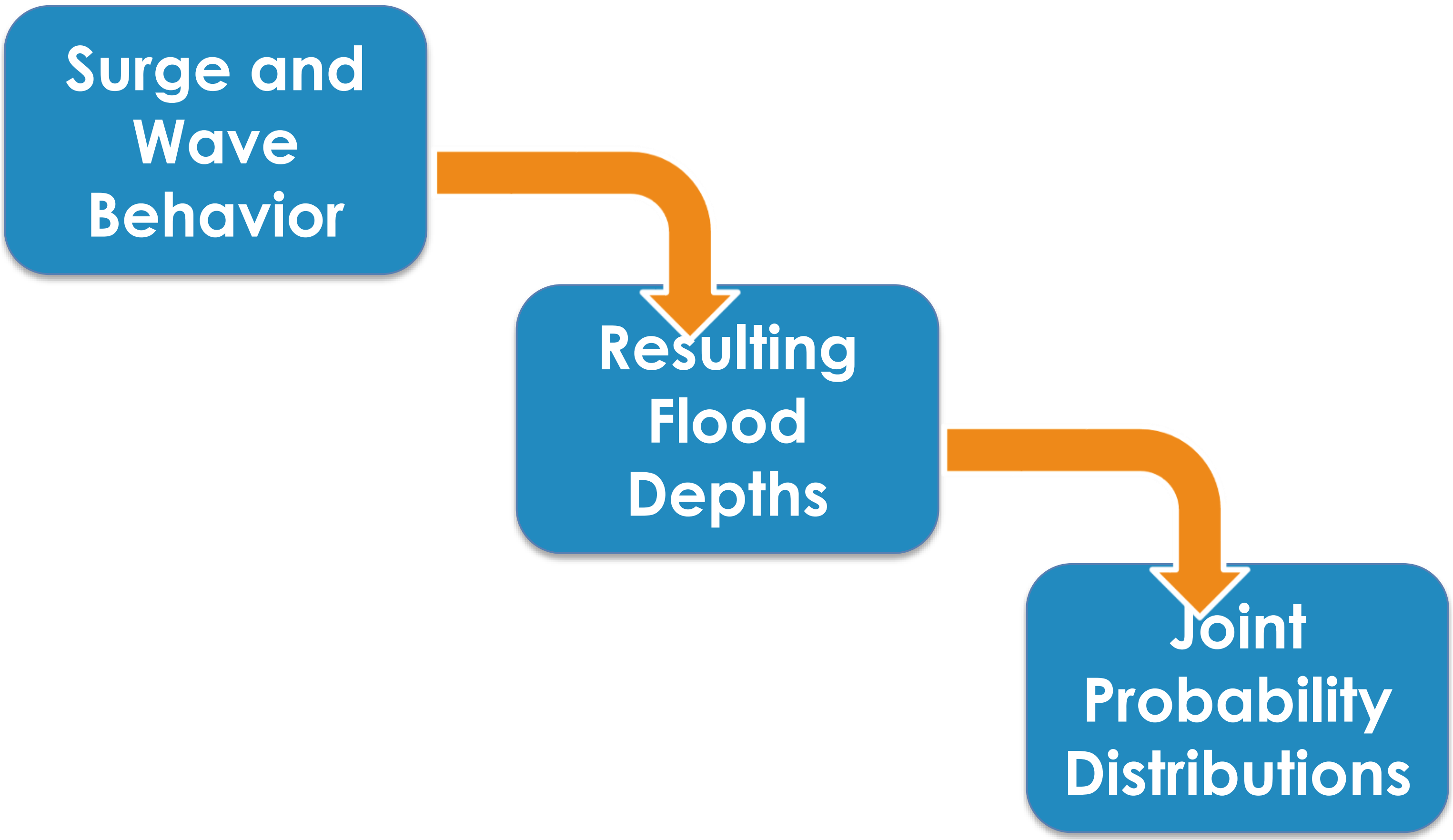


- **CLARA 2017 grid points**

2017 model includes approx. 114,000 grid points (90,000 in Louisiana)

Uncertainty Propagates Through Each Model Step

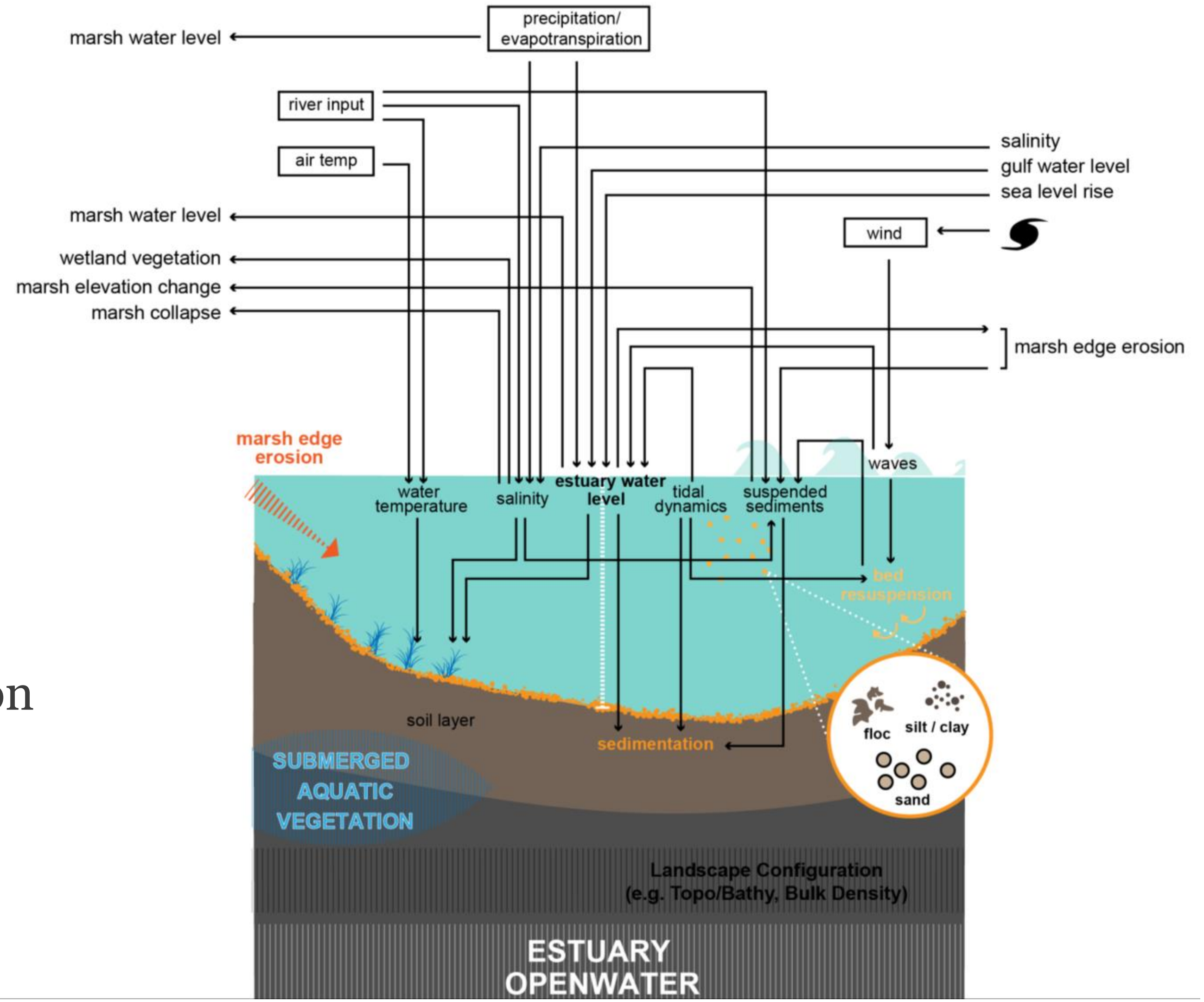
Individual Storms **Aggregate Statistics**



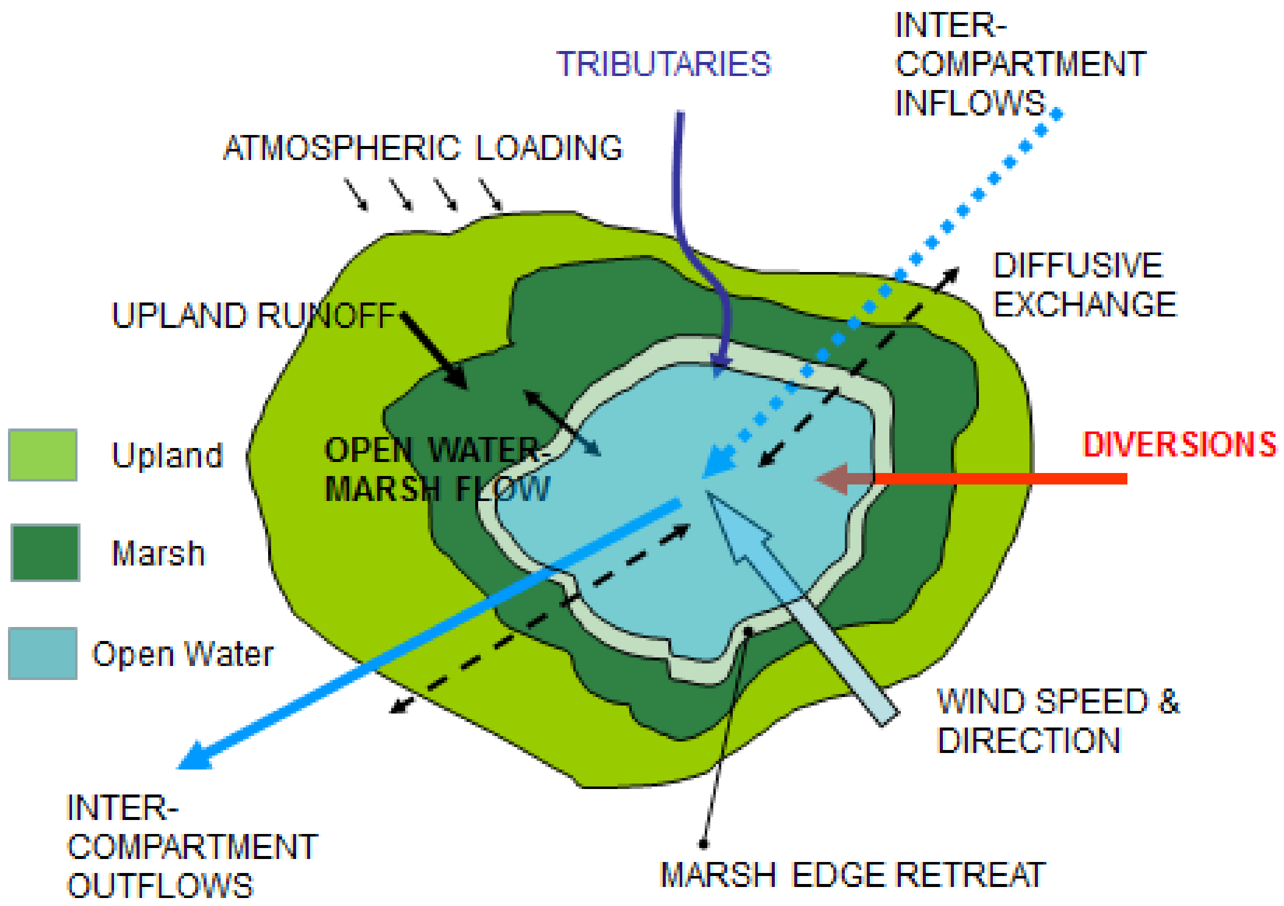
Hydrodynamic model structure and components

Estuary and Open Water Processes

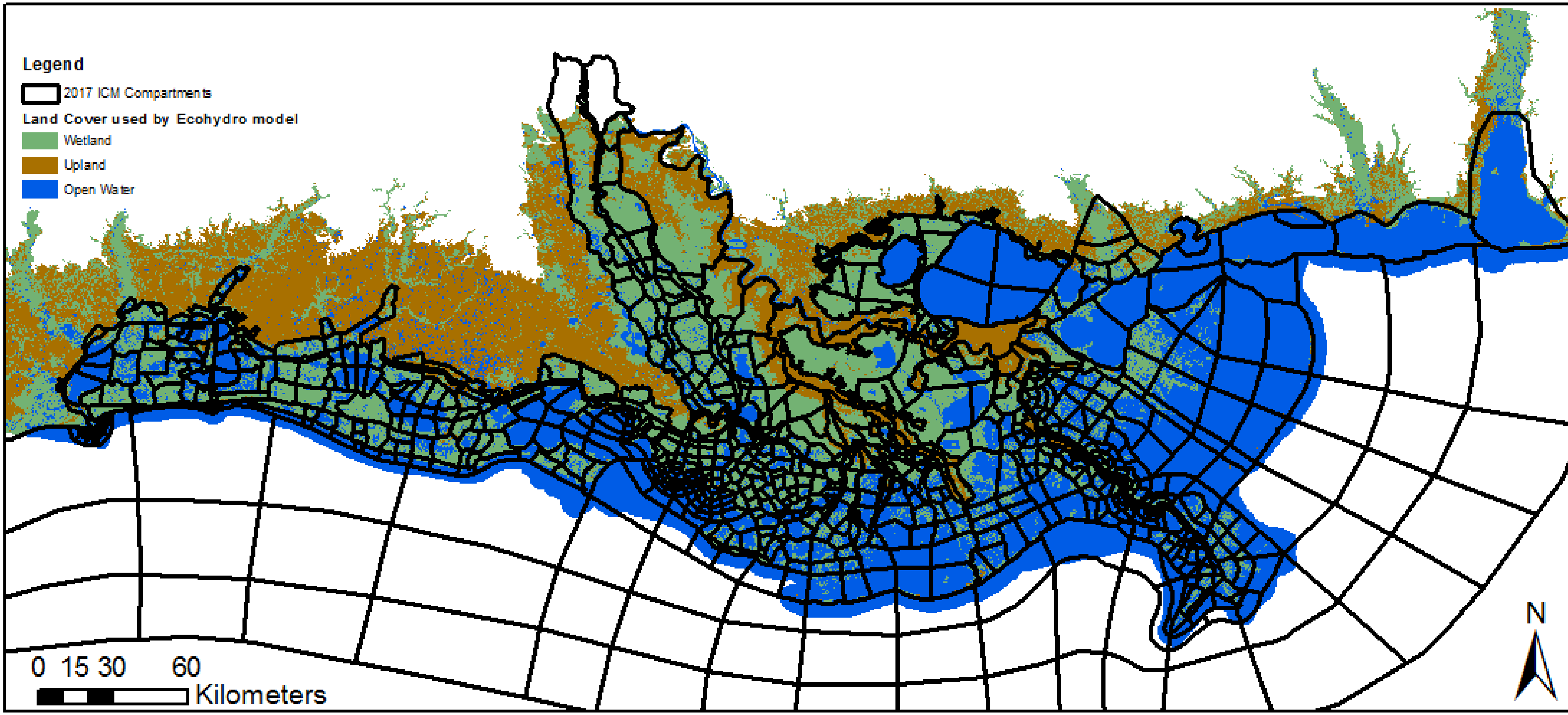
- Hydrodynamics
- Water quality
- Sedimentation
- Bed resuspension
- Sediment distribution



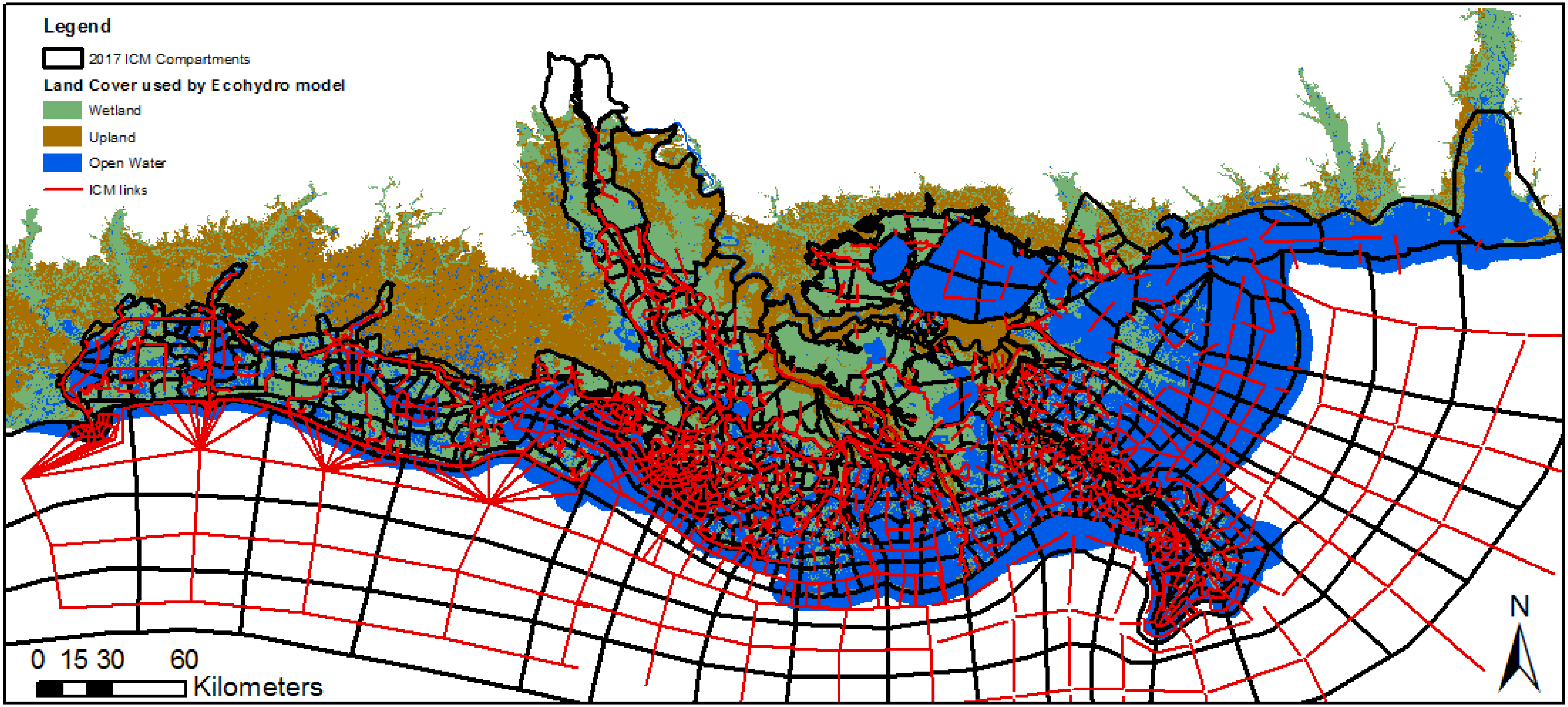
Hydrologic Compartment Layout



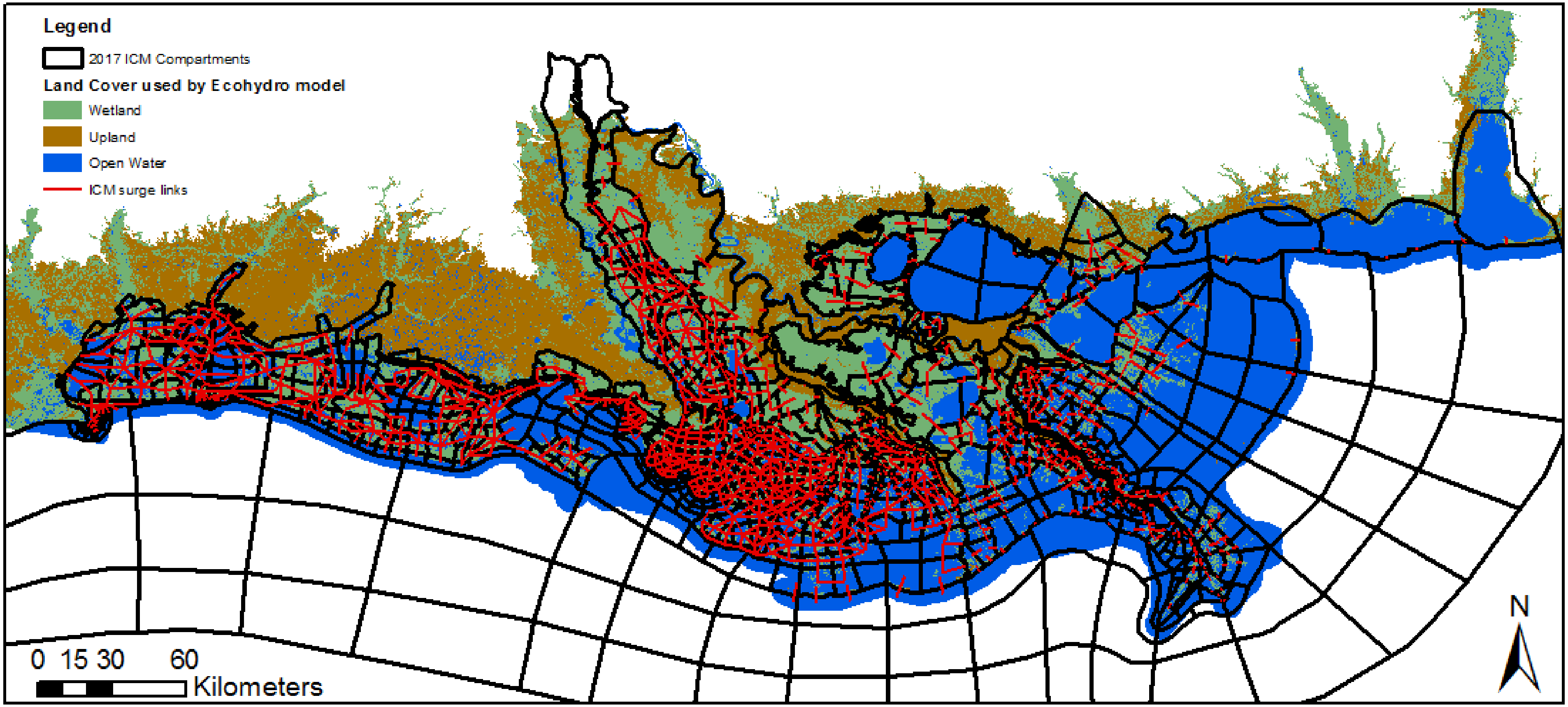
ICM Compartments



Hydraulic Link Network



Hydraulic Overland Flow (e.g. surge) Link Network



Constituent Mass Balance

$$\frac{\partial C_{k,j}}{\partial t} = -\frac{C_{k,j}\eta'_j}{y_j} + \frac{\sum_i \sum_{trib} \sum_{div} \left[C_{k,j,i,trib,div} Q_{i,trib,div}\right]}{y_j A_{s,j}} + \frac{f_{dis} \sum_i \lambda_i \frac{A_i}{L_i}(C_{k,j} - C_{k,nb})}{y_j A_{s,j}} + \frac{\sum_l S_{r,k,j,l}}{y_j A_{s,j}}$$

k	=	species (sediment class)
j	=	number of subcompartment
i	=	number of link
trib	=	tributary
div	=	diversion
nb	=	neighboring subcompartment
dis	=	dispersivity
r	=	source-sink
s	=	surface
l	=	source/sink index
$C_{k,j}$	=	concentration of constituent k in subcompartment j
Q	=	water discharge
$A_{s,j}$	=	subcompartment water surface area
$h_,$	=	subcompartment water elevation
eta'	=	rate of change of elevation = dh/dt
$S_{r,k,j,l}$	=	subcompartment sources/sink
$y_{,j}$	=	subcompartment water depth
t	=	time
f_{dis}	=	calibration factor
lamda	=	diffusivity in link i
A_i	=	link cross-sectional area
L_i	=	effective link length
$\frac{\partial C}{\partial t}$	=	rate of change of concentration in a cell.

Hydraulic link types

- Rectangular open channel
- Rectangular open channel with control logic
- Bridge/culverts
- Weirs
- Tide gates/orifices
- Pumps (pump rate assigned based on upstream drainage area/rainfall rate)
- Overland flow links
  - Marsh flow connection
  - Ridge/levee barriers
- Regime channels in delta outlets

Open channels

- Flow calculated as a flow capacity at each time step based on differential head - Manning’s equation
- Loss coefficients can be added to each link
  - Entrance
  - Exit losses
  - Structure losses

Open channels with hydraulic control rules

- Hydraulic control logic can be applied based upon:
  - Downstream salinity
  - Differential stage
  - Downstream stage
  - Time of day
  - Observed open/close record
  - Both downstream stage and salinity

Weir links

$$Q = KL\sqrt{2g}H^{\frac{3}{2}}$$

$$K = K_{sub}\left\{C_w + \frac{H}{20P}\right\}MAX\{0.6, \left(1 - \frac{0.2H}{P}\right)\}$$

H = Max(H1,H2);

L = Crest Length;

P = P1 or P2 depending on which H is selected;

C_w = weir coefficient (approximately 0.4 for a sharp-edge weir)

K_{sub} = submergence reduction factor (from HEC-RAS)

If weir is not submerged downstream, K = 0.66

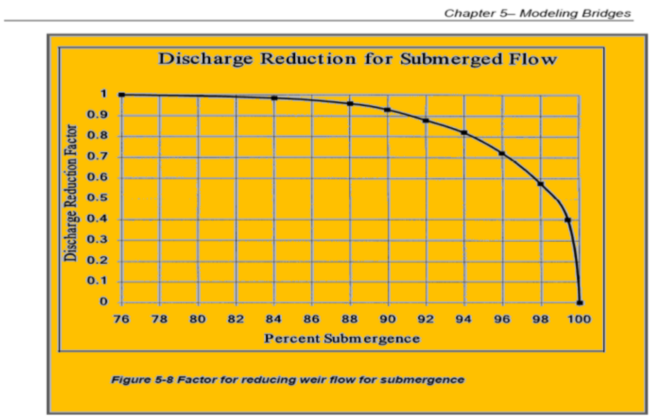
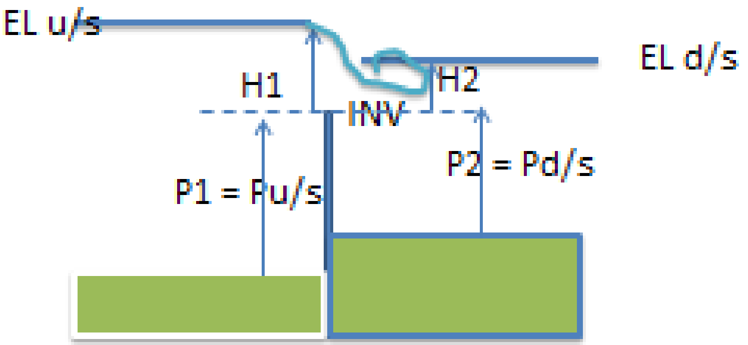


Figure 5-8 Factor for reducing weir flow for submergence



Sediment distribution

- Mass balance on each hydro compartment on:
  - Mass in
    - Flows
    - Marsh edge erosion sediment load
  - Mass out
    - Flows
    - Marsh surface deposition
  - Resuspension of bed material
    - Critical shear stresses calculated from flow & wave velocities
    - Separate routines for cohesive (silt & clay) and sand particles
  - Deposition of bed material
    - Settling velocities calculated for particle class
    - Flocculation of clay modeled
- Non-uniform deposition in marsh; particles with higher fall-velocities deposit in near-edge zone (30 m)
- Procedure for sediment deposition and resuspension, also applied during storm events

Sediment deposition/resuspension - fines

Cohesive sediments

- silt
- clay
- and flocculated clay

$$v_{d,k} = w_{s,k}\left(1 - \frac{\tau_{bed}}{\tau_{d,k}}\right)$$

$w_{s,k}$ = settling velocity for class k;

k = subscript indicating the class of cohesive sediment;

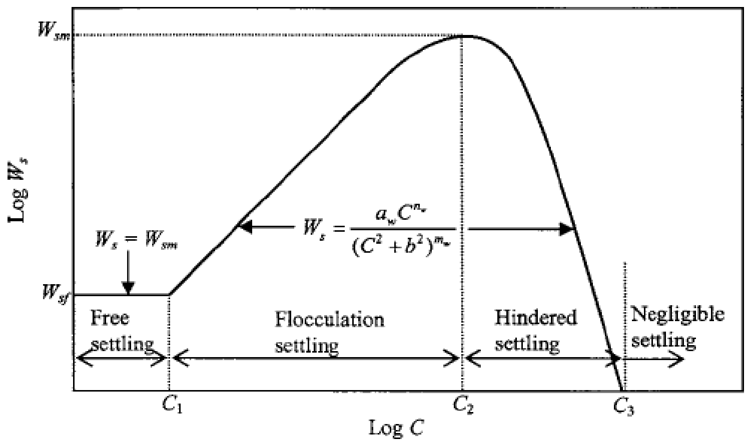
τ_{bed} = bed shear stress;

$\tau_{d,k}$ = critical shear stress for initiation of deposition of class k.

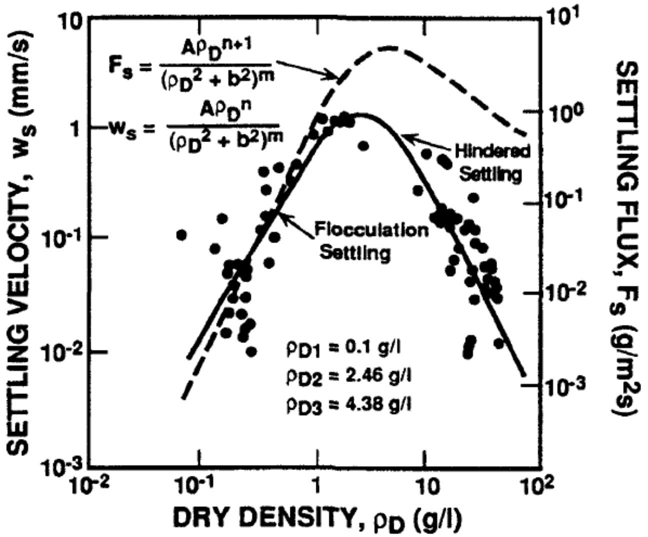
Flocculation of clay

$$P_{floc} = \begin{cases} \dfrac{C_{sal}}{C_{sal,max}} P_{floc,max} & C_{sal} < C_{sal,max} \\ P_{floc,max} & C_{sal} \geq C_{sal,max} \end{cases}$$

$$w_{s,floc} = \begin{cases} w_s & C_{clay} < C_1 \\ a\dfrac{{C_{clay}}^n}{\left({C_{clay}}^2 + b^2\right)^m} & C_1 < C_{clay} < C_3 \\ negligible & C_3 < C_{clay} \end{cases}$$



- Flocculation calculated as function of:
  - Fines concentration
  - Salinity
- McAnally et al., 2007
- Mehta



Sediment deposition/resuspension - sand

- Dimensionless shear stress determines resuspension or deposition

$$\vartheta_{cr} = \frac{\tau_{cr}}{(\rho_s - \rho_w) g D_{50}}$$

- Dimensionless shear stress for initiation of sand motion (van Rijn, 2007)

$$\vartheta_{cr} = \begin{cases} 0.115 D_*^{-0.5} & D_* < 4 \\ 0.14 D_*^{-0.64} & 4 \le D_* < 10 \end{cases}$$

- van Rijn estimates sediment flux as:

$$q_s = \alpha_s \rho_s u D_{50} M_e^{2.4} D_*^{-0.6} \qquad M_e = \frac{(u_e - u_{cr})}{\sqrt{g D_{50} \left(\frac{\rho_s}{\rho_w} - 1\right)}} \qquad D_* = D_{50} \left[\frac{g \left(\frac{\rho_s}{\rho_w} - 1\right)}{\upsilon^2} \right]^{1/3}$$

u_e, and u_{cr} are various flow and wave velocity terms that are functions of sediment grain size

Bed Shear Stress for Sediment Deposition/Resuspension

- Resuspension if bed shear is greater than critical shear for sediment class
- Deposition if bed shear is less than critical shear for sediment class

$$\tau_{bed} = C_f \rho_w {U_{bed}}^2$$

$$U_{bed} = \mathrm{U} + U_{tide} + U_{wind} + U_{orb}$$

- Orbital velocity at bed from Linear Wave Theory:

$$U_{orb} = \frac{g H_s T}{2L \cosh\left(\frac{2\pi d}{L}\right)}$$

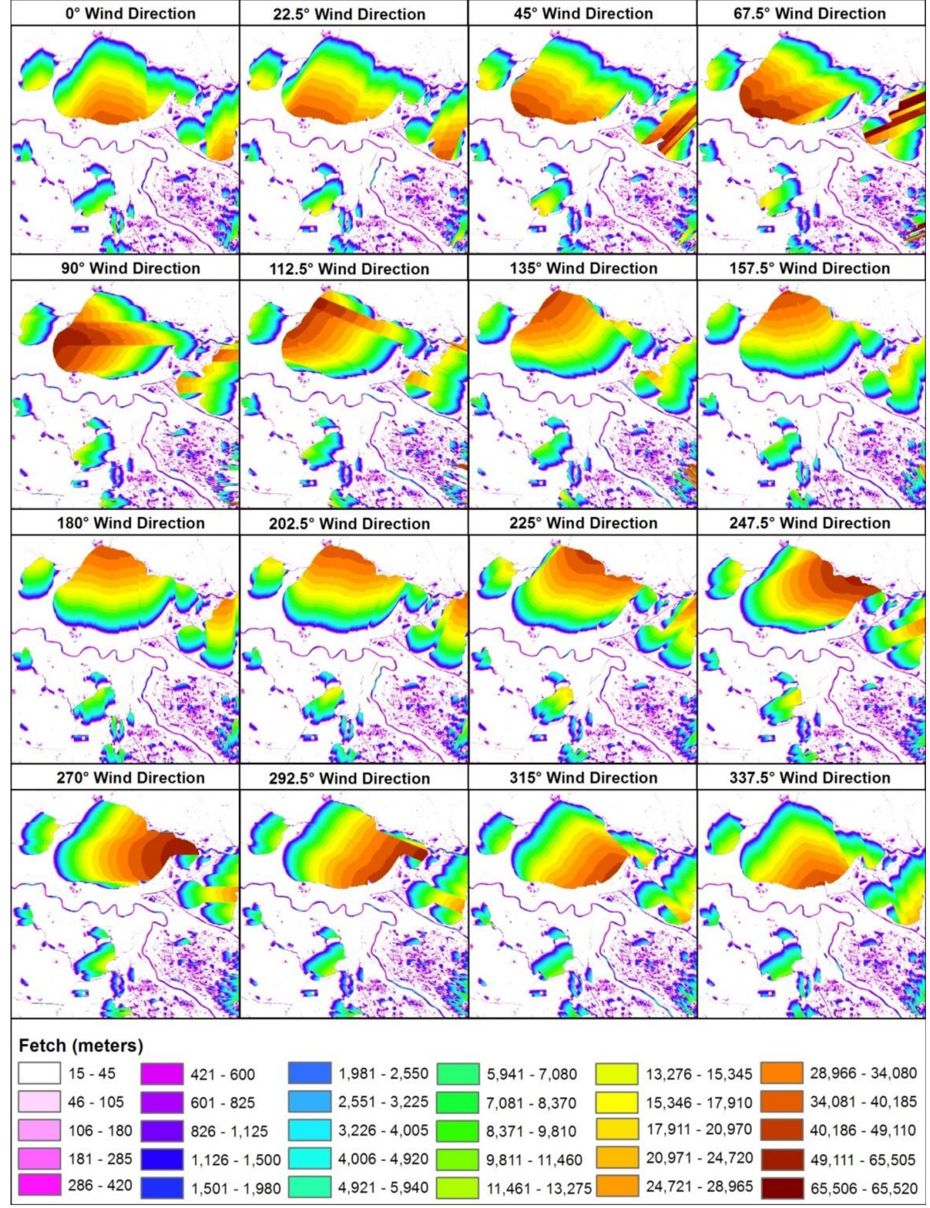
Wave Model

- Wave energy and frequency from Young and Verhagen wave model:

$$E = E_{lim}\left\{\tanh A_1 \tanh\left(\frac{B_1}{\tanh A_1}\right)\right\}^n \left(\frac{{U_{10}}^2}{g}\right)^2$$

$$\frac{1}{T} = f = f_{lim}\left\{\tanh A_2 \tanh\left(\frac{B_2}{\tanh A_2}\right)\right\}^m \left(\frac{g}{U_{10}}\right)$$

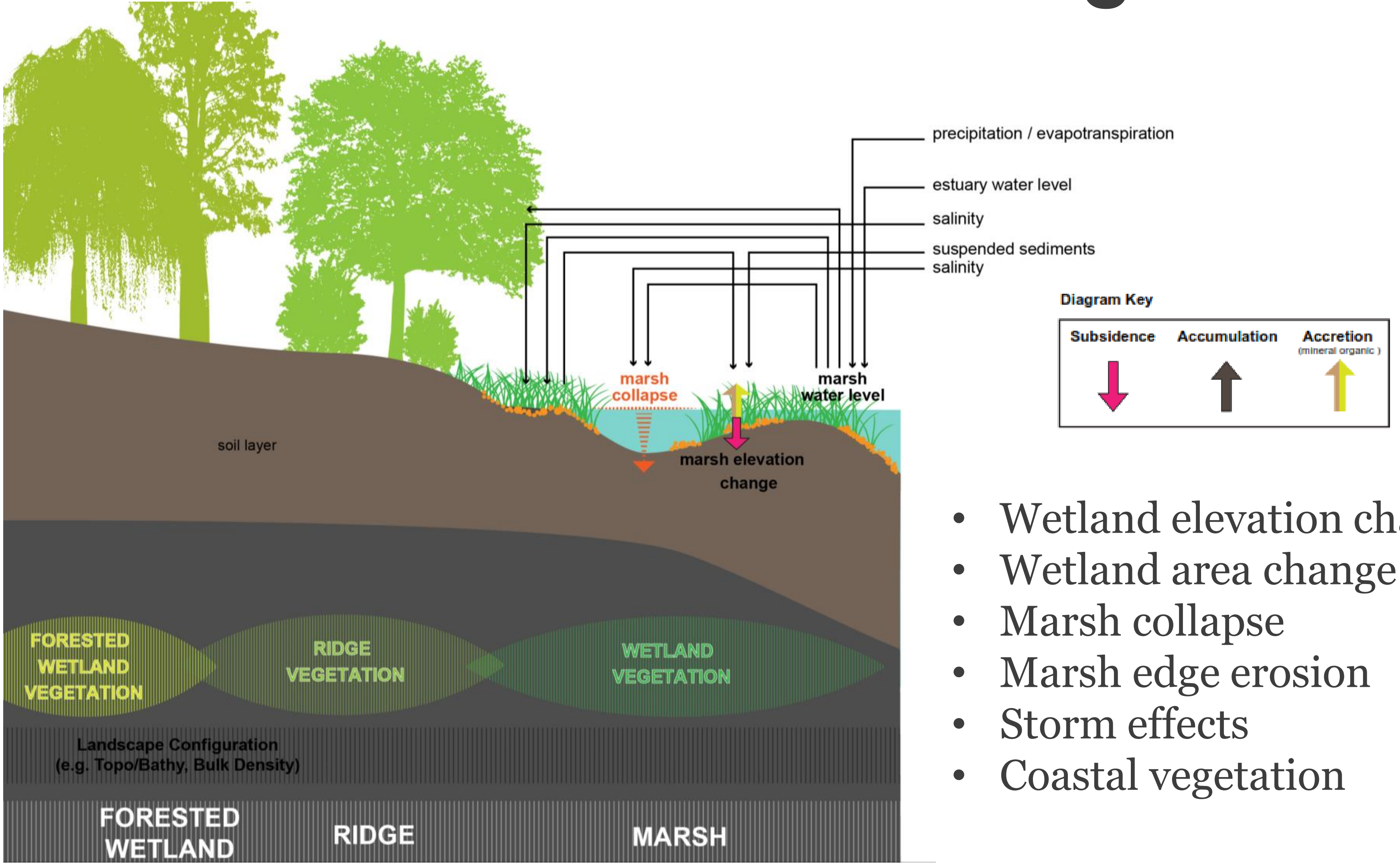
- A_1 and A_2 are empirical functions of water depth
- B_1 and B_2 are empirical functions of fetch
- U_{10} is wind velocity at 10 meters above surface
- Wind timeseries input to model
- Fetch in 16 directions are pre-calculated and considered static throughout model run



Calculated fetch for 16 wind directions for a portion of coastal Louisiana including Lake Pontchartrain and parts of the Breton and Barataria basins.

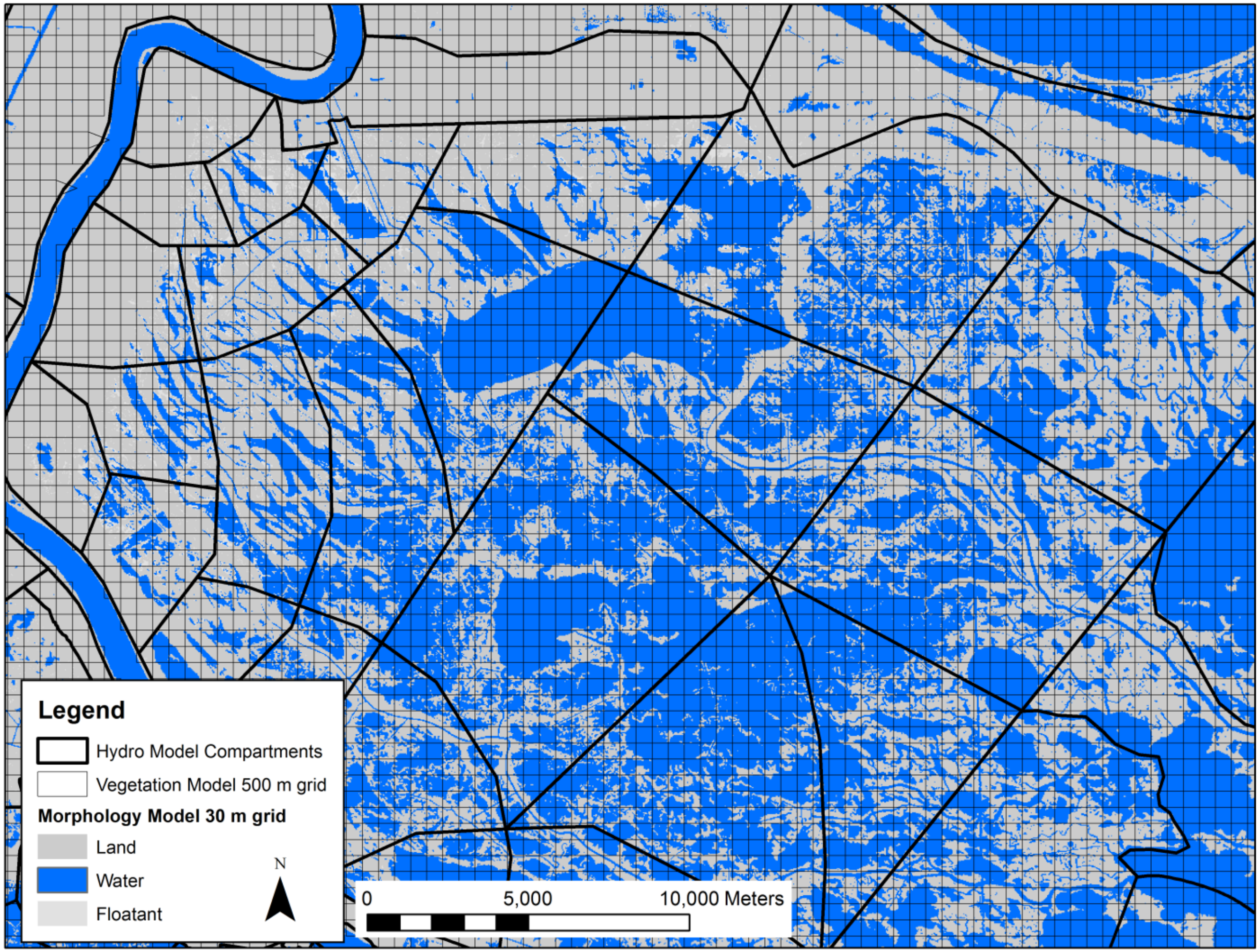
Wetland morphology model structure and components

Wetland Processes and Vegetation



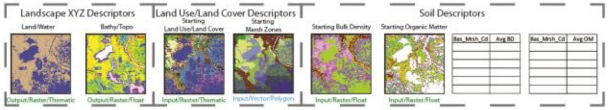
- Wetland elevation change
- Wetland area change
- Marsh collapse
- Marsh edge erosion
- Storm effects
- Coastal vegetation

Spatial Resolution of Models

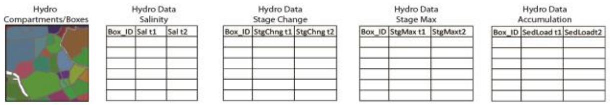


Wetland Morphology Model Conceptual Diagram

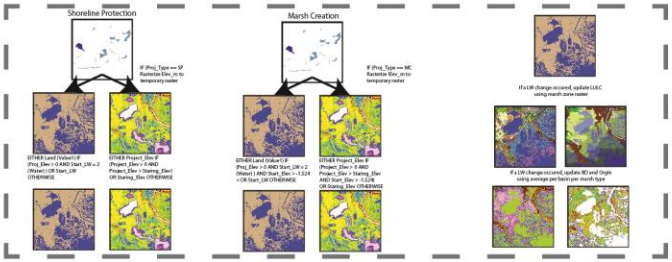
Primary Intitialization Inputs



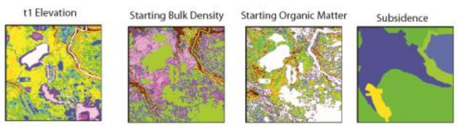
Input from Hydrology Subroutine



Incorporate Projects



Accretion Calcultions



$$H = \frac{Q_{sed} + Q_{org}}{10,000 \times \mathrm{BD}}, \quad (1)$$

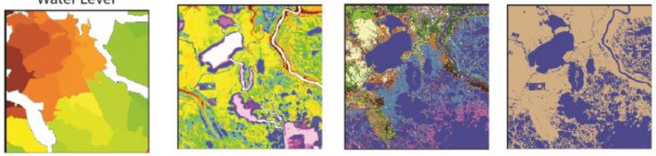
where H is the rate of vertical accretion (cm/y), Q_{sed} is mineral sediment accumulation rates (g/m^2/y) forecasted by the ecohydrology model (Meselhe *et al.*, 2013), Q_{org} is organic matter accumulation rates (g/m^2/y), the constant 10,000 is a conversion factor from cm^2 to m^2, and BD is soil bulk density (g/cm^3).

Relative Elevation Model - Elevation Change subroutine

$$E_{t2} = E_{t1} + H - S, \quad (3)$$

where E_{t2} is the adjusted surface elevation (m NAVD88); E_{t1} is the starting surface elevation (m NAVD88); H is the vertical accretion, as defined in Equation 1 (converted to m and summed over the $t_1 - t_2$ time period); and S is subsidence (m).

Relative Elevation Model - Elevation Change subroutine (cont.)

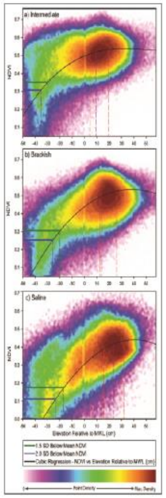


CONDITIONAL { (IF starting_lw == 0) No Change ,
(IF t+1 Land/Water == 1 AND Starting_mean_water_level_meters == 0) No Change ,
(IF t+1 Land/Water == 2 AND Relative Elevation t+1 <= MWL t+1) No Change ,
(IF t+1 Land/Water == 2 AND Starting_mean_water_level_meters == 0) No Change ,

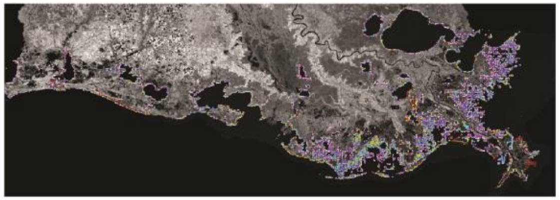
Marsh Collapse - Salinity Stress
(IF t+1 Land/Water == 1 AND LULC Recode == 1 AND Salinity t+1 <= 5.5) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 1 AND Salinity t+1 > 5.5 AND MWL t+1 < Relative Elevation t+1) No Change,
(IF t+1 Land/Water == 1 AND LULC Recode == 1 AND Salinity t+1 > 5.5 AND MWL t+1 >= Relative Elevation t+1) Change to Water ,
(IF t+1 Land/Water == 1 AND LULC Recode == 2 AND Salinity t+1 <= 7.0) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 2 AND Salinity t+1 > 7.0 AND MWL t+1 < Relative Elevation t+1) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 2 AND Salinity t+1 > 7.0 AND MWL t+1 >= Relative Elevation t+1) Change to Water ,

Marsh Collapse - Inundation Stress
(IF t+1 Land/Water == 1 AND LULC Recode == 3 AND (MWL t+1-0.3436) <= Relative Elevation t+1) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 3 AND (MWL t+1-0.3436) > Relative Elevation t+1) Change to Water ,
(IF t+1 Land/Water == 1 AND LULC Recode == 4 AND (MWL t+1-0.2278) <= Relative Elevation t+1) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 4 AND (MWL t+1-0.2278) > Relative Elevation t+1) Change to Water ,
(IF t+1 Land/Water == 1 AND LULC Recode == 5 AND (MWL t+1-0.2050) <= Relative Elevation t+1) No Change ,
(IF t+1 Land/Water == 1 AND LULC Recode == 5 AND (MWL t+1-0.2050) > Relative Elevation t+1) Change to Water ,

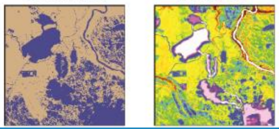
Land Building
(IF t+1 Land/Water == 2 AND Relative Elevation t+1 > (MWL t+1 + 0.2)) Change to Land



Marsh Edge Erosion



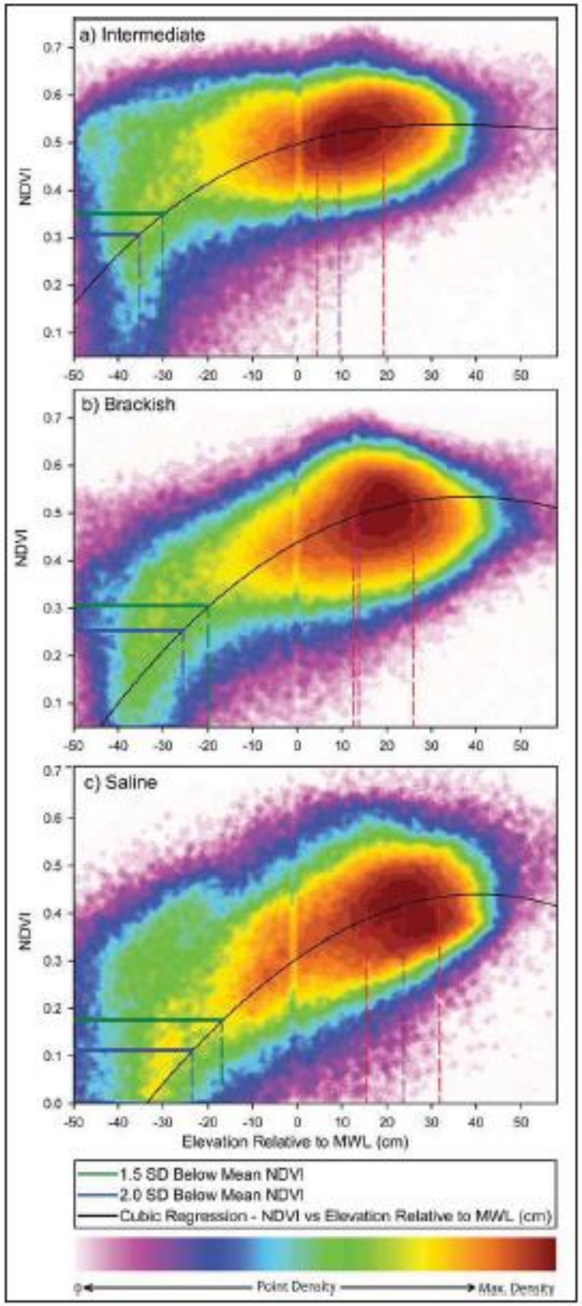
Output t2 Landscape XYZ Descriptors



Wetland morphology

Goal is to model long-term, coastwide land loss and land gain trends via:

- Sediment supply from tributaries and estuaries
  - Marsh surface
  - Bed
- Marsh collapse due to:
  - salinity stress
  - inundation stress
- Marsh edge erosion
- Subsidence
- Eustatic level rise



Wetland morphology

Land Gain and Collapse Threshold Values

Land Type	Collapse threshold
Fresh Forested Wetlands	Land will convert to water if it is at, or below, the annual mean water level for the year and the maximum two-week mean salinity during the year is above: 7 ppt
Fresh Marsh	Land will convert to water if it is at, or below, the annual mean water level for the year and the maximum two-week mean salinity during the year is above: 5.5 ppt
Intermediate Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive yearsis greater than: 0.358 m
Brackish Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive years is greater than: 0.256 m
Saline Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive years is greater than: 0.235 m

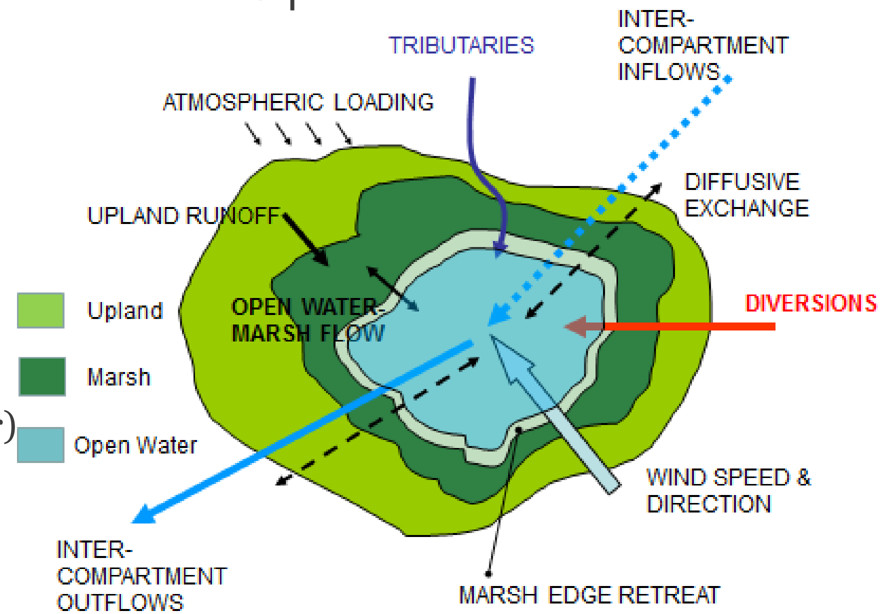
Land Type	Land Gain Threshold
Water	Water will be converted to land if the mean water level for two consecutive years is at least 0.2 m lower than the bed elevation of the water area

Wetland morphology

Vertical Accretion, H, within Marsh and Open Water Areas

$$H = \frac{Q_{sed} + Q_{org}}{10{,}000 * BD}$$

H = vertical accretion (cm/yr)
Q_{sed} = mineral sediment accumulation rates ($g/m^2/yr$)
Q_{org} = soil organic matter accumulation rates ($g/m^2/yr$)
BD = soil bulk density (g/cm^3)



- Only marsh area inundated at some point will receive sediment accumulation
- Organic matter and bulk density values assigned by marsh type (fresh, brackish, etc)
  - These values vary spatially – based on measured OM/BD data within CRMS
  - Adjustments to 'representative' OM/BD for marsh type made during calibration process
    - Settled on using mean OM/BD

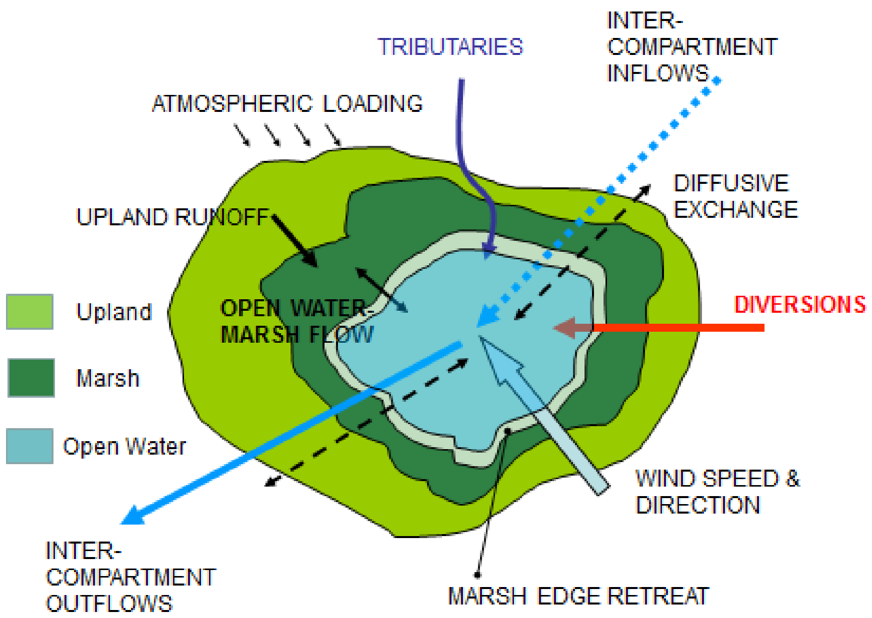
Wetland morphology

Three zones for mineral sediment accumulation rate (Q

- Open water deposition
  - sediments settled on bed of open water
  - high bulk density (input parameter)
  - low organic content (input parameter)

- Marsh edge zone (30-m edge width)
  - All sand deposits here
  - Silt deposits here if depth on marsh is <0.3 m

- Marsh interior zone
  - Clay and floc deposit within marsh interior
  - Silt deposits here if depth on marsh >0.3 m



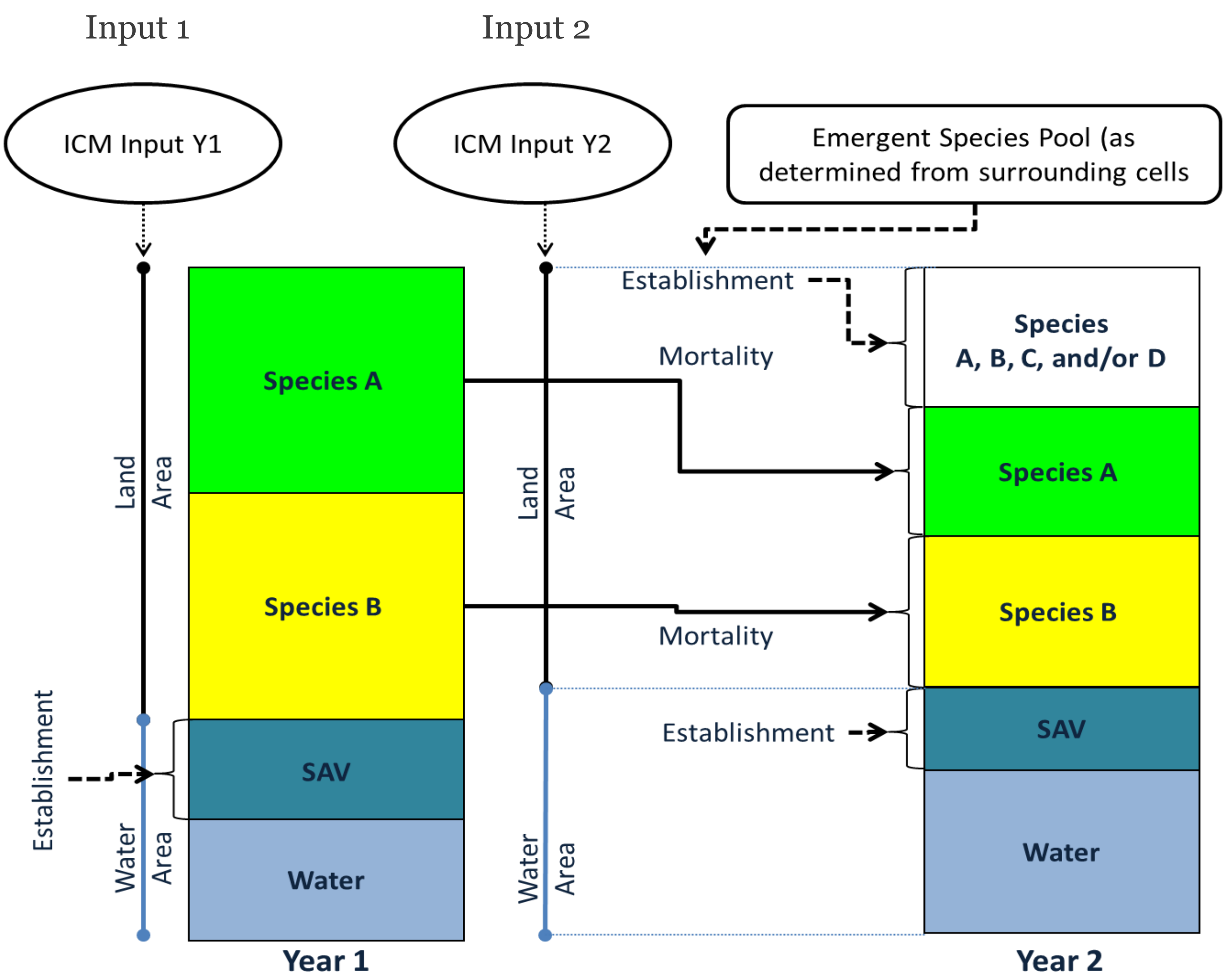
LaVegMod

Vegetation Model Overview

Vegetation Model Improvements

- Species Dispersal
- Germination requirements (Tree species only)
- Proportional establishment
- Updated mortality matrices
- Updated establishment matrices

Habitats and Species



Establishment & Mortality Likelihoods

Likelihood of establishment for *Spartina patens*

Water Level Variability (weighted standard deviation of water level relative to marsh surface elevation)

Salinity (weighted annual median, ppt)

SPPA	0	0.04	0.08	0.12	0.16	0.2	0.24	0.28	0.32	0.36	0.4	0.44	0.48	0.52	0.56	0.6	0.64	0.68	0.72	0.76	10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.8	0.1	0.2	0.3	0.05	0.1	0.1	0.1	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0.2	0.3	0.4	0.2	0.25	0.3	0.25	0.15	0.1	0.05	0	0	0	0	0	0	0	0	0	0	0
1.2	0.3	0.4	0.5	0.35	0.4	0.4	0.4	0.35	0.3	0.25	0.2	0.1	0.05	0	0	0	0	0	0	0	0
1.4	0.4	0.5	0.6	0.5	0.55	0.6	0.55	0.5	0.45	0.4	0.4	0.3	0.25	0.15	0.1	0.05	0	0	0	0	0
1.6	0.5	0.6	0.7	0.65	0.7	0.7	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.15	0.1	0.05	0	0
1.8	0.6	0.7	0.8	0.8	0.85	0.9	0.85	0.8	0.75	0.7	0.7	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0
2	0.7	0.8	0.9	0.95	1	1	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.55	0.5	0.45	0.4	0.35	0.3	0
3	0.7	0.8	0.9	0.95	1	1	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.55	0.5	0.45	0.4	0.35	0.3	0
4	0.7	0.8	0.9	0.95	1	1	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.55	0.5	0.45	0.4	0.35	0.3	0
5	0.7	0.8	0.9	0.95	1	1	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.55	0.5	0.45	0.4	0.35	0.3	0
6	0.5	0.6	0.7	0.75	0.8	0.8	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.15	0.1	0
7	0.3	0.4	0.5	0.55	0.6	0.6	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.15	0.1	0.05	0	0	0	0
8	0.1	0.2	0.3	0.35	0.4	0.4	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05	0	0	0	0	0	0	0
9	0	0	0.1	0.15	0.2	0.2	0.2	0.15	0.1	0.05	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Establishment & Mortality Likelihoods

Likelihood of mortality for *Spartina patens*

Water Level Variability (weighted standard deviation of water level relative to marsh surface elevation)

Salinity (weighted annual median, ppt)

SPPA	0	0.04	0.08	0.12	0.16	0.2	0.24	0.28	0.32	0.36	0.4	0.44	0.48	0.52	0.56	0.6	0.64	0.68	0.72	0.76	10
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1.2	1	1	0.95	0.9	0.9	0.9	0.95	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1.4	1	0.9	0.85	0.8	0.8	0.8	0.85	0.9	0.95	1	1	1	1	1	1	1	1	1	1	1	1
1.6	0.95	0.85	0.75	0.7	0.7	0.7	0.75	0.85	0.9	0.95	1	1	1	1	1	1	1	1	1	1	1
1.8	0.85	0.7	0.65	0.6	0.6	0.6	0.65	0.7	0.75	0.85	0.9	0.95	1	1	1	1	1	1	1	1	1
2	0.7	0.6	0.55	0.5	0.5	0.5	0.55	0.6	0.65	0.7	0.75	0.85	0.9	0.95	1	1	1	1	1	1	1
3	0.2	0.1	0.05	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.65	0.7	0.75	1
4	0.2	0.1	0.05	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.65	0.7	0.75	1
5	0.2	0.1	0.05	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.65	0.7	0.75	1
6	0.2	0.1	0.05	0	0	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.65	0.7	0.75	1
7	0.45	0.35	0.3	0.25	0.25	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.85	0.9	0.95	1	1
8	0.65	0.6	0.55	0.5	0.5	0.5	0.55	0.6	0.65	0.7	0.75	0.85	0.9	0.95	1	1	1	1	1	1	1
9	0.85	0.8	0.75	0.7	0.7	0.7	0.75	0.8	0.85	0.9	0.95	1	1	1	1	1	1	1	1	1	1
10	1	1	0.95	0.9	0.9	0.9	0.95	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Habitats and Species

Habitat	Species
Bottomland Hardwood Forest	*Quercus lyrata, Quercus texana, Quercus laurifolia, Ulmus americana, Quercus nigra, Quercus virginiana*
Swamp Forest	*Salix nigra, Taxodium distichum, Nyssa aquatica*
Fresh Floating Marsh	*Panicum hemitomon, Eleocharis baldwinii, Hydrocotyle umbellata*
Fresh Attached Marsh	*Morella cerifera, Panicum hemitomon, Sagittaria latifolia, Zizaniopsis miliacea, Cladium mariscus, Typha domingensis*
Intermediate Marsh	*Sagittaria lancifolia, Phragmites australis, Schoenoplectus californicus, Iva frutescens, Baccharis halimifolia*
Brackish Marsh	*Spartina patens, Paspalum vaginatum*
Saline Marsh	*Juncus roemerianus, Distichlis spicata, Spartina alterniflora, Avicennia germinans*
Dune	*Uniola paniculata, Panicum amarum, Sporobolus virginicus*
Swale	*Spartina patens, Distichlis spicata, Solidago sempervirens, Strophostyles helvola, Baccharis halimifolia*

BIMODE

Barrier Island Model Overview

BIMODE Summary

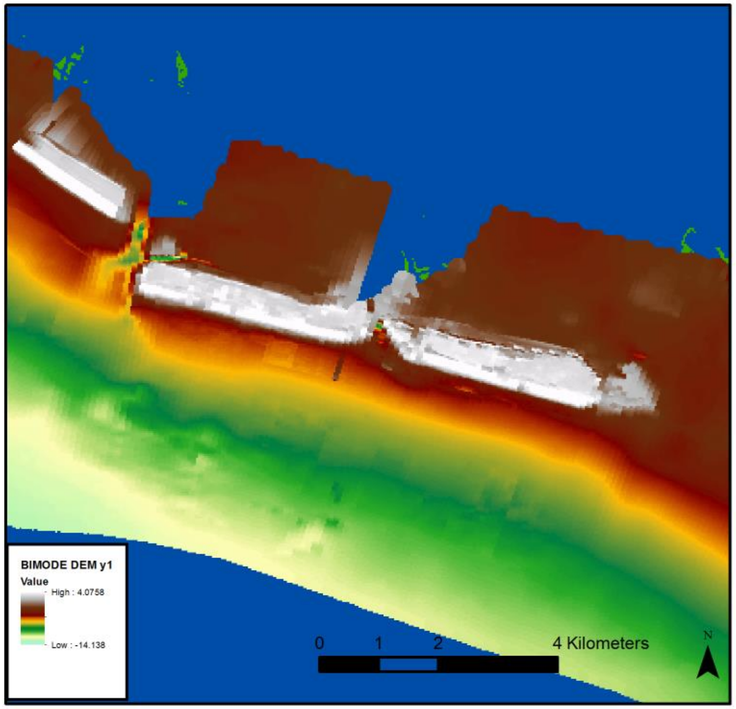
- Longshore Component
  - Hourly data was transformed from offshore to the nearshore (-4m) using the SWAN model, though the wave data was combined to provide a monthly time step
  - The longshore sediment transport rate was approximated by applying the CERC sediment transport equation
  - Longshore sediment transport flux was used to determine shoreline advance or retreat between adjacent profiles; the change in flux was distributed over the active profile height to determine the shoreline advance or retreat
  - The profile seaward of the dune crest was assumed to be constant (one-line model)
  - Shoreline location due to longshore transport was updated monthly

BIMODE Summary

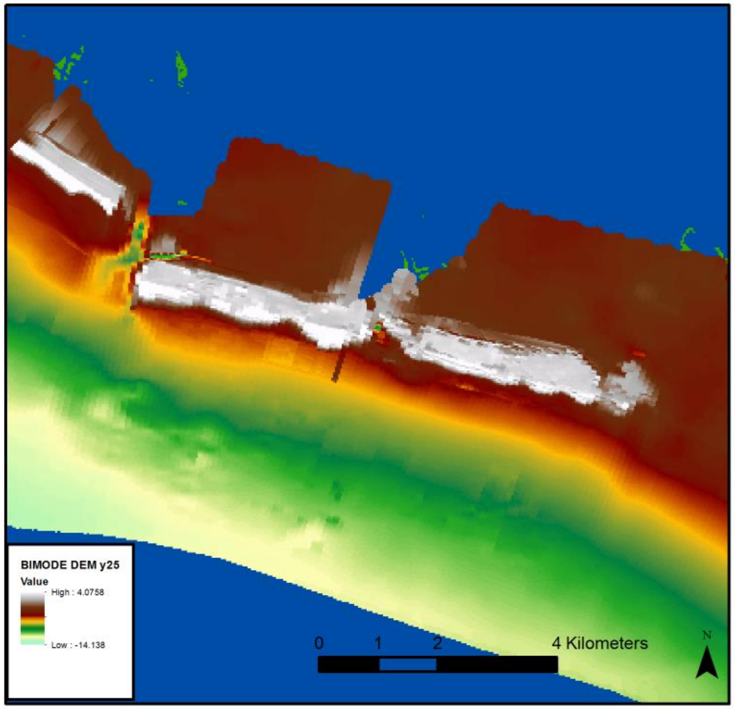
- Cross-shore Component
  - Storm induced changes were performed outside of the ICM using the Storm Induced Beach Change (SBEACH) Model (USACE model)
  - A wide variety of dune widths, dune elevations, berm widths and berm elevations were modeled. The pre-storm ICM profile was matched to the SBEACH modeled profile, accessing the results through a look-up table
  - Changes in the SBEACH modeled profile due to a storm event was applied to the profile within the ICM
  - The SBEACH model used the synthetic storm events
  - Storm(s) could be applied at a specified month within the 50-year model period

Example Outputs
Barrier Island Change Over Time

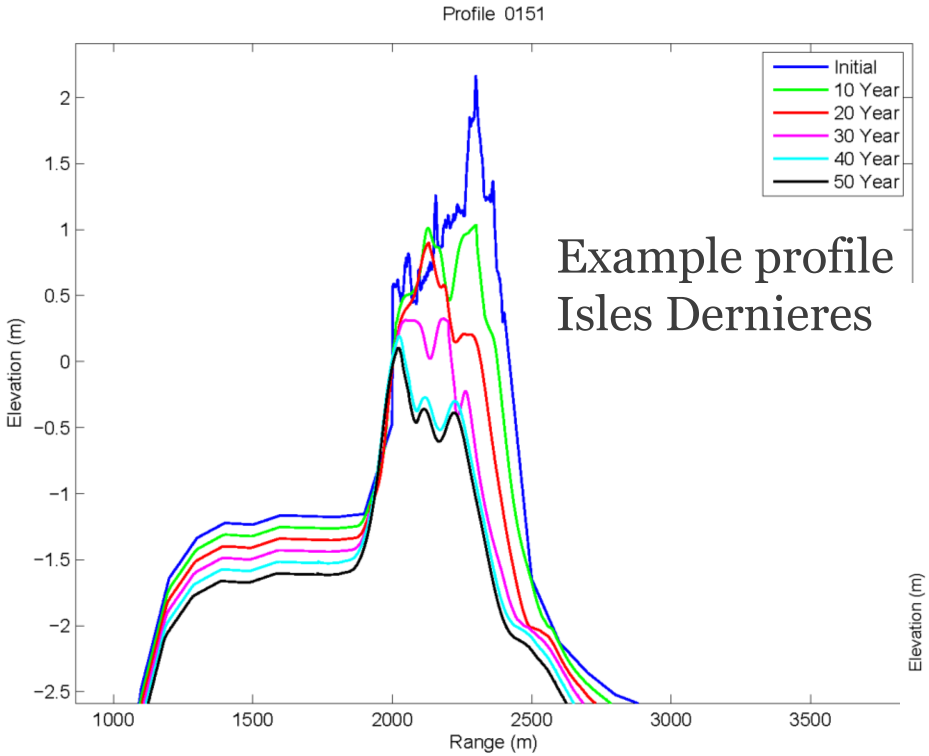
Barrier Island Elevations - End of Year 1



Barrier Island Elevations - End of Year 25

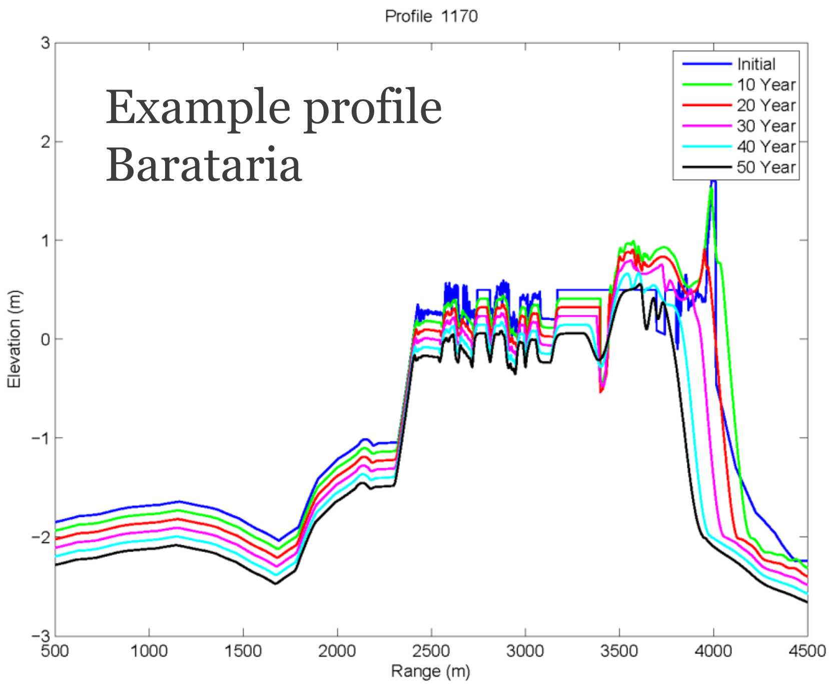


Example Outputs
Barrier Island Change – Cross-shore



Example profile
Isles Dernieres

Example outputs only – retreat turned off in model.



Example profile
Barataria

Habitat Suitability Indices Overview

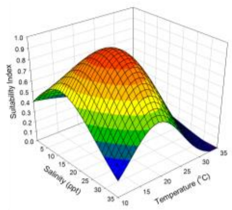
Overview of Statistical Analysis used for HSI Development

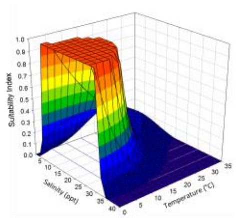
- Predict mean catch per unit effort (CPUE) in response to environmental variables
- Used polynomial regressions and commonly used SAS procedures (PROC GLMSELECT, PROC MIXED)
  - Designed for systematic application across the coast.
  - Analysis needed to be consistently and efficiently applied to count data for species with different life histories and environmental tolerances.
- Same statistical approach was used for each of the fish and shellfish species

Overview of Statistical Analysis used for HSI Development

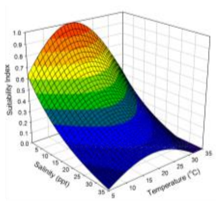
Seines Trawls

white shrimp

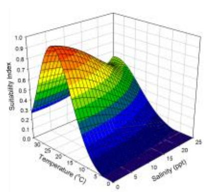


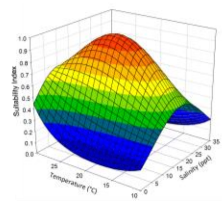


blue crab

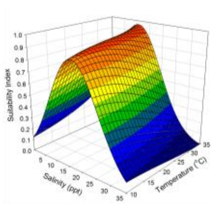


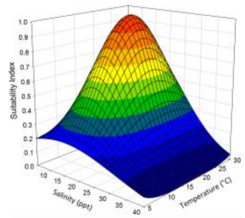
bay anchovy





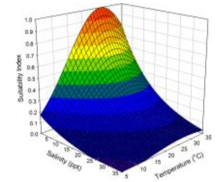
brown shrimp

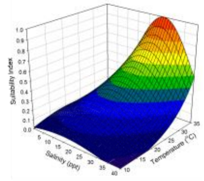




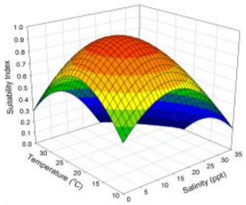
Seine Gillnets

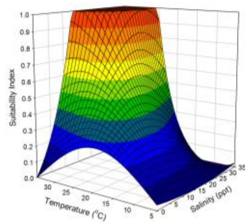
Gulf menhaden





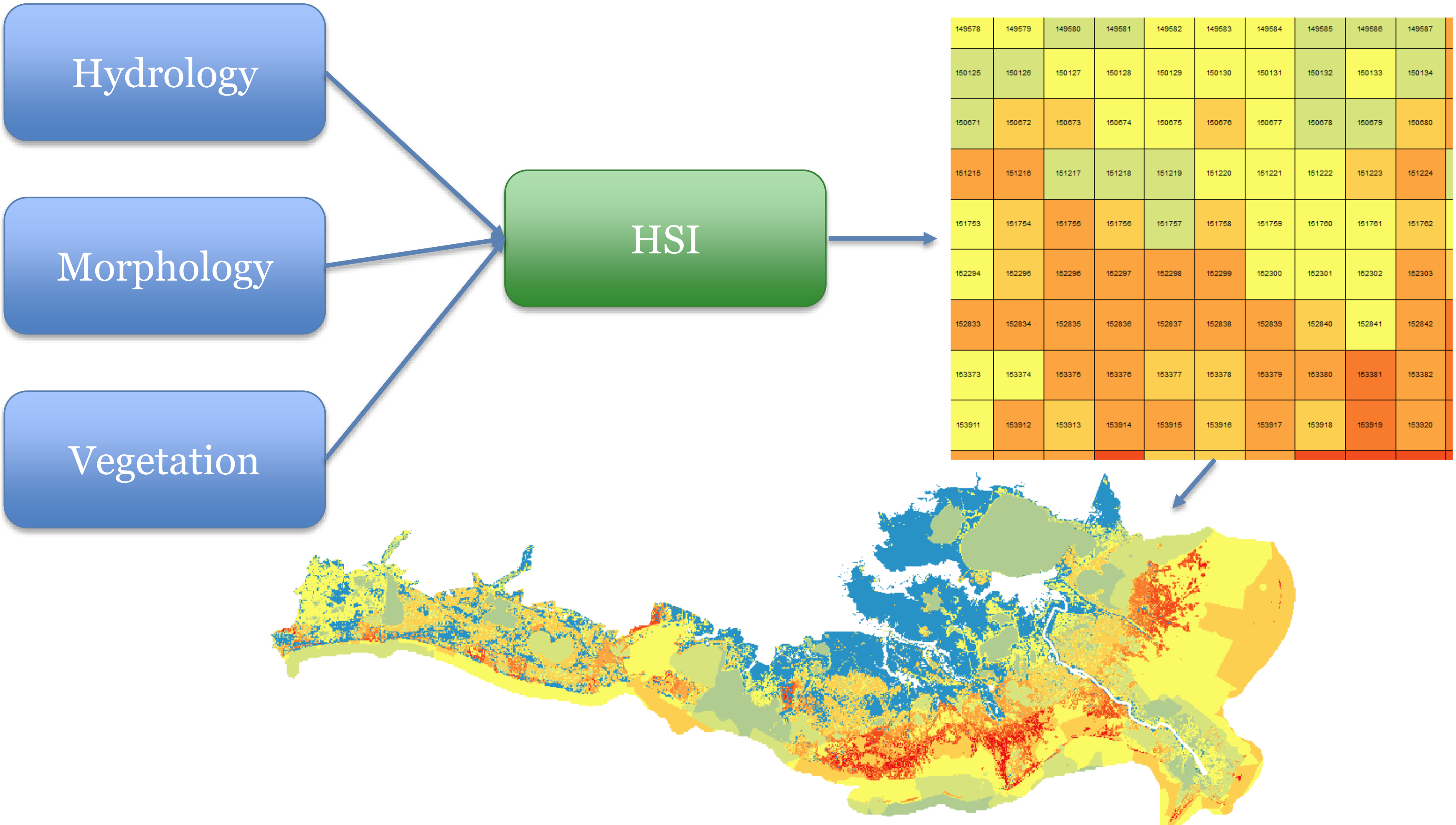
spotted seatrout





Integration into ICM

Input data feeds into HSI → Calculations performed annually → HSI scores generated per grid cell per species



Model Calibration and Validation

Boundary Conditions & Landscape Data

- Boundary Conditions
  - Hydrology (updated through late 2014); Stokka Brown, M&N
  - Water quality (updated through late 2014); Stokka Brown, M&N
  - Tropical cyclones (synthetic history with 23 storms, 11 major hurricanes); John Atkinson, Haihong Zhao, and Hugh Roberts, Arcadis
- Landscape Data
  - DEM (late 2014) based on LA Coastal National Elevation Database (LACoNED); Brady Couvillion, USGS
  - Vegetation base map (2014) 2013 helicopter survey as training for a remotely sensed classification, Jenneke Visser, ULL and Brady Couvillion, USGS

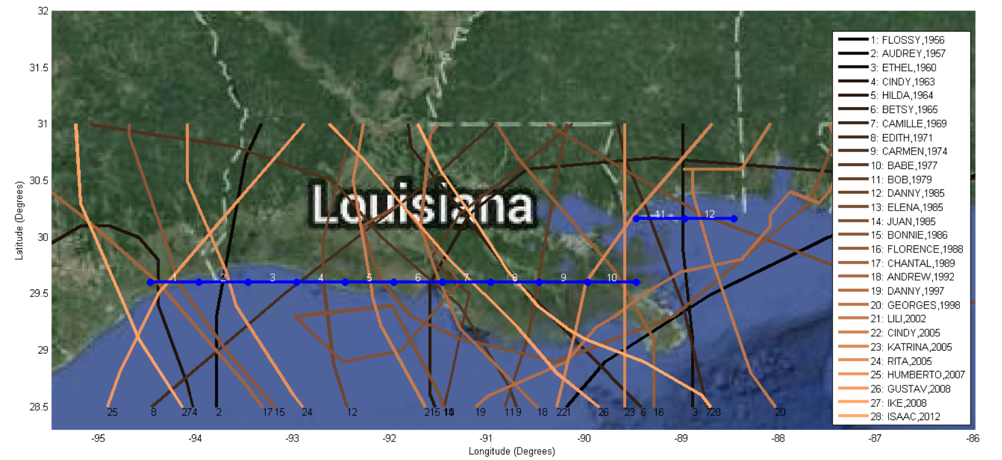
Storms in the ICM Boundary Conditions

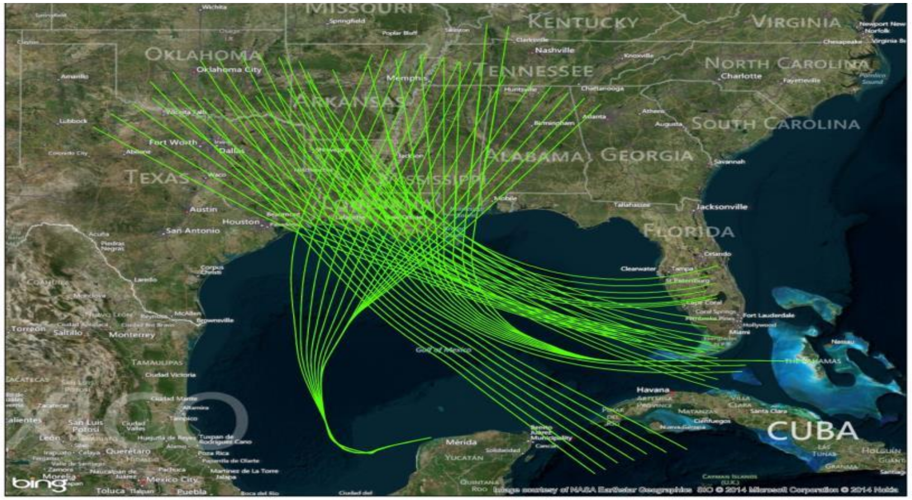
(1) Identify historical hurricane strikes (1950-2013)

(2) Locate ‘matching’ synthetic storms from JPMOS suite

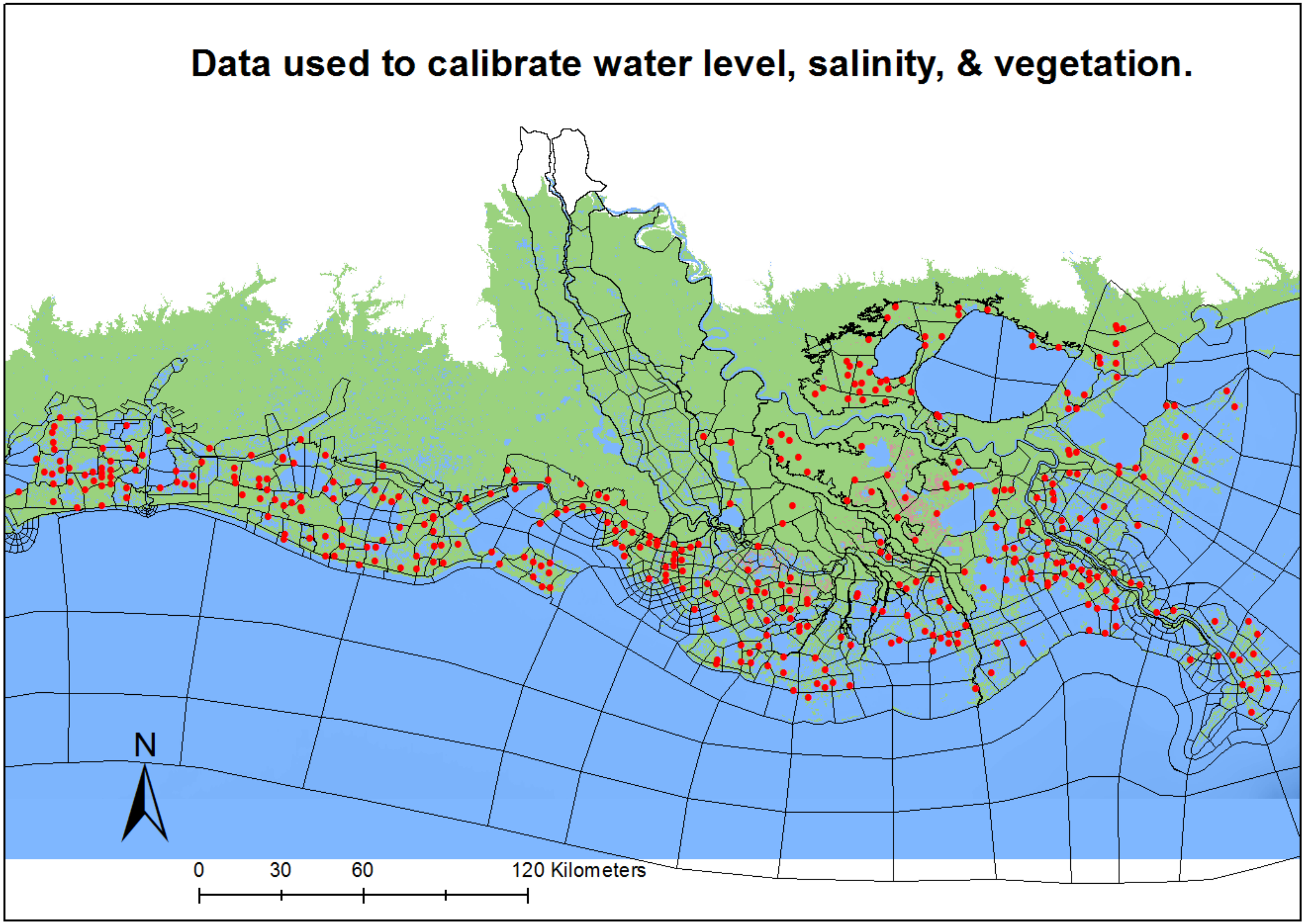
(3) Apply storms as forcings in both the 8-year calibration/validation runs (5 storms) as well as the 50-year Master Plan (23 storms; 11 major hurricanes)

(4) Impacts to the landscape, including islands





2017 Coastal Master Plan Integrated Compartment Model
Coastwide Reference Monitoring System (CRMS)



Model Calibration and Validation

- Calibration Period: 2010-2013
- Validation Period: 2006-2009

Hydrology

- Mean water level (daily & monthly comparisons)
  - ~200 CRMS and USGS stations
- Mean flowrate
  - Limited USGS data
- Mean salinity (daily & monthly comparisons)
  - ~180 CRMS and USGS stations

Suspended Sediment

- 166 observation stations
  - Limited data available (all discrete samples); Morphology model's accretion patterns used to fine-tune sediment distribution deposition and resuspension parameters

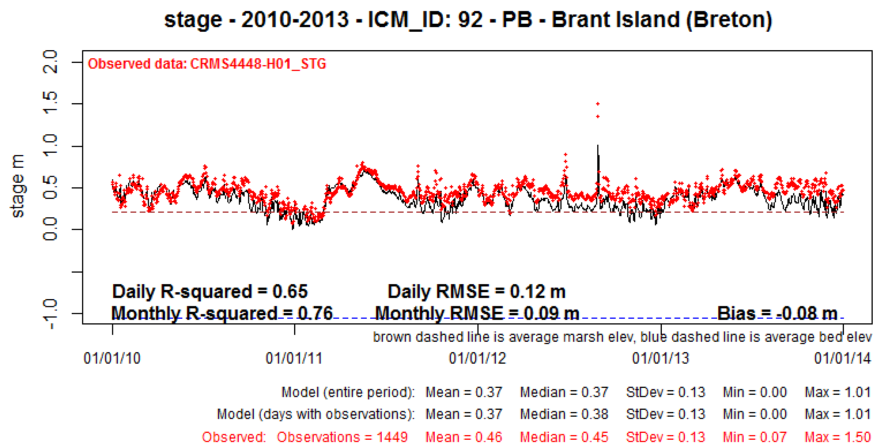
Hydrodynamic Calibration Summary 2010-2013

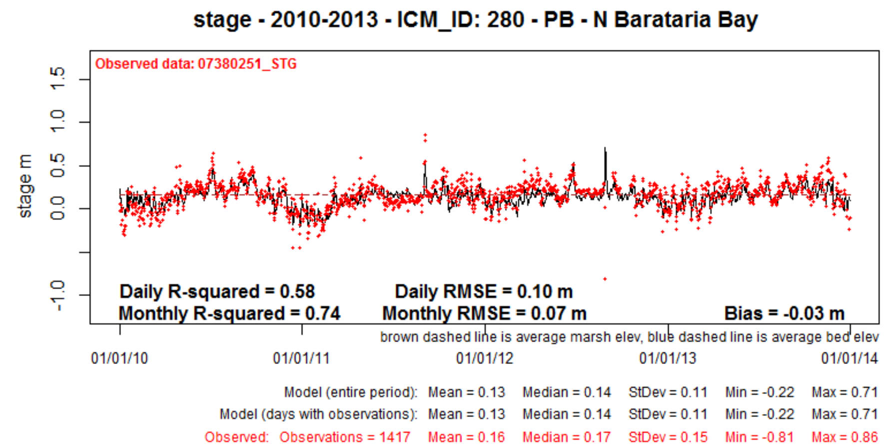
Parameter	units	No. Stns	Mean		Median		St. Deviation		RMSE			
			Obs	Pred	Obs	Pred	Obs	Pred	Daily	2-week	Monthly	Annual
Stage	*m*	204	0.24	0.24	0.24	0.24	0.17	0.14	0.12	0.10	0.10	0.08
Flowrate	*m³/s*	14	968	1031	911	984	656	684	221	208	124	157
Salinity (0-1 ppt)	*ppt*	55	0.4	0.5	0.2	0.3	0.4	0.4	0.6	0.48	0.4	0.3
Salinity (1-5 ppt)	*ppt*	51	2.8	3.2	2.2	2.4	2.1	2.4	2.4	2.2	2.1	1.2
Salinity (5-20 ppt)	*ppt*	74	11.6	11.2	11.2	10.9	5.0	4.4	4.4	3.9	3.7	2.1
Salinity (>20 ppt)	*ppt*	4	22.0	23.8	21.8	24.4	6.2	3.9	6.4	5.84	5.6	4.0
TSS	*mg/L*	146	41	24	32	23	31	13	-	-	22	-
Temperature	*mg/L*	144	21.7	21.4	22.6	21.7	7.2	6.4	-	-	1.8	-
Total Kjedahl N	*mg/L*	144	0.9	0.5	0.9	0.5	0.4	0.1	-	-	0.3	-
Total P	*mg/L*	143	0.2	0.1	0.2	0.1	0.3	0.0	-	-	0.2	-

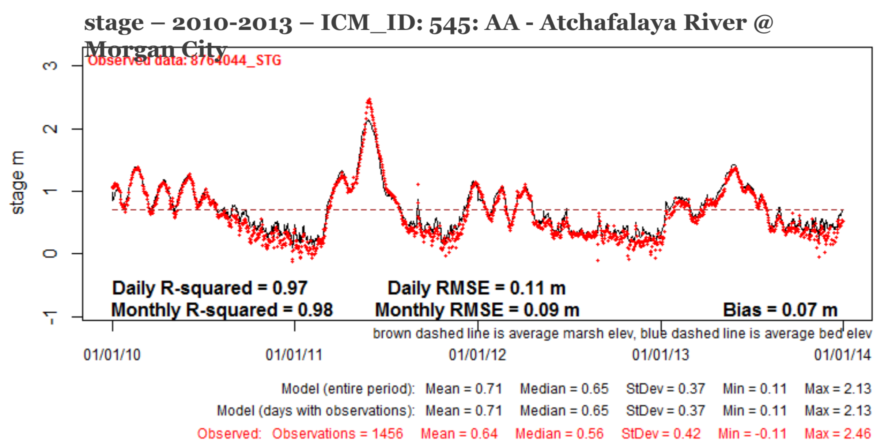
Hydrodynamic Validation Summary 2006-2009

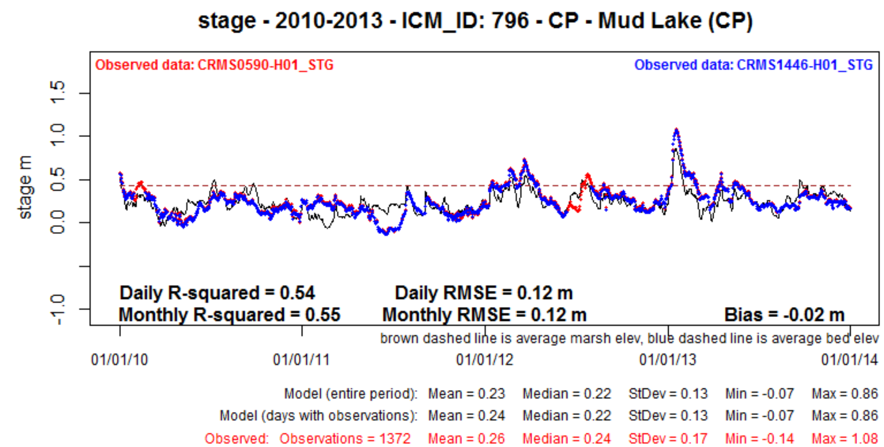
Parameter	units	No. Stns	Mean		Median		St. Deviation		RMSE			
			Obs	Pred	Obs	Pred	Obs	Pred	Daily	2-week	Monthly	Annual
Stage	*m*	*204*	0.24	0.27	0.23	0.26	0.18	0.15	0.14	0.12	0.09	0.07
Flowrate	*m³/s*	*14*	1088	1163	1042	1112	525	523	229	214	122	151
Salinity (0-1 ppt)	*ppt*	*47*	0.4	0.5	0.2	0.3	0.4	0.5	0.8	0.6	0.4	0.5
Salinity (1-5 ppt)	*ppt*	*59*	3.3	3.8	2.7	3.2	2.2	2.5	3.1	2.9	2.2	1.9
Salinity (5-20 ppt)	*ppt*	*74*	11.3	11.7	10.9	11.6	4.4	3.9	5.0	4.8	3.7	3.1
Salinity (>20 ppt)	*ppt*	*4*	21.7	23.8	22.0	24.3	5.4	3.1	6.6	6.0	4.2	3.2
TSS	*mg/L*	*148*	41.0	23.6	31.3	22.6	31.7	11.6	-	-	20.2	-
Temperature	*mg/L*	*145*	22.2	21.3	22.9	21.0	6.7	6.2	-	-	1.7	-
Total Kjedahl N	*mg/L*	*145*	0.9	0.6	0.8	0.6	0.5	0.1	-	-	0.3	-
Total P	*mg/L*	*145*	0.2	0.1	0.2	0.0	0.1	0.0	-	-	0.1	-

Stage Calibration – 201 sites

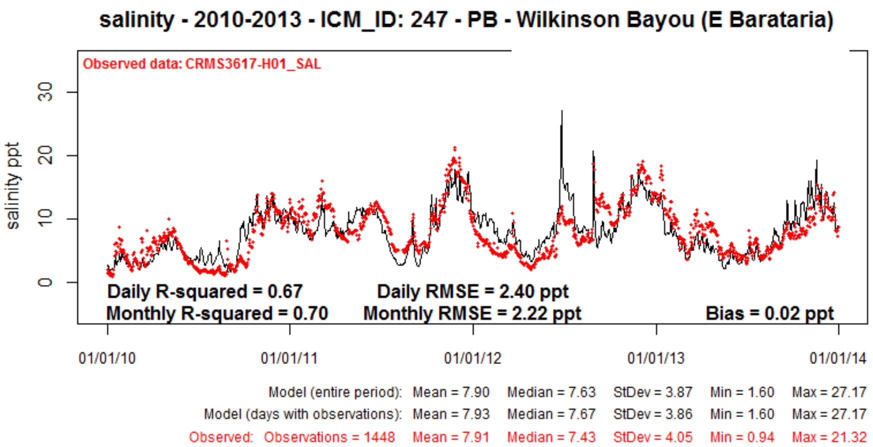


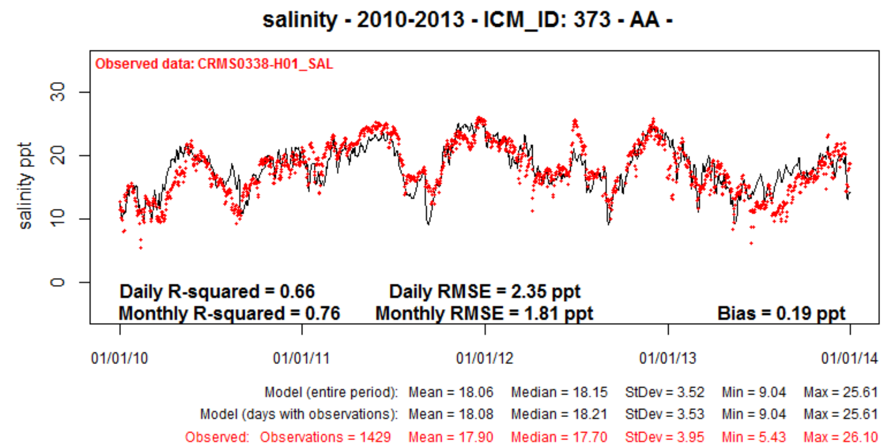


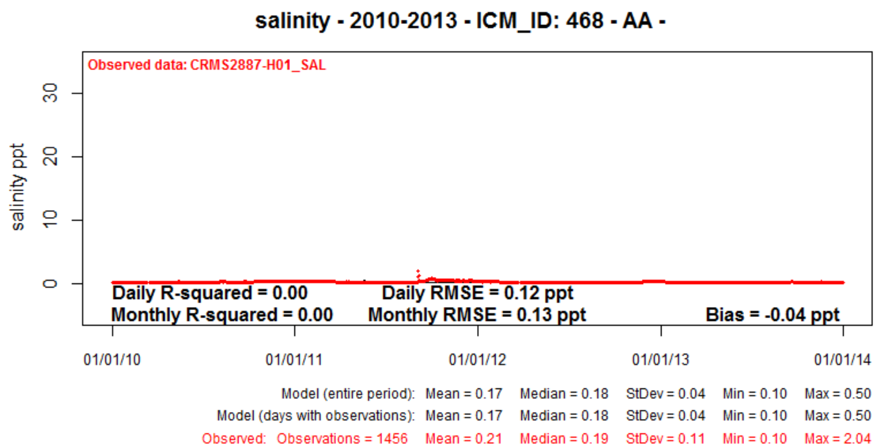


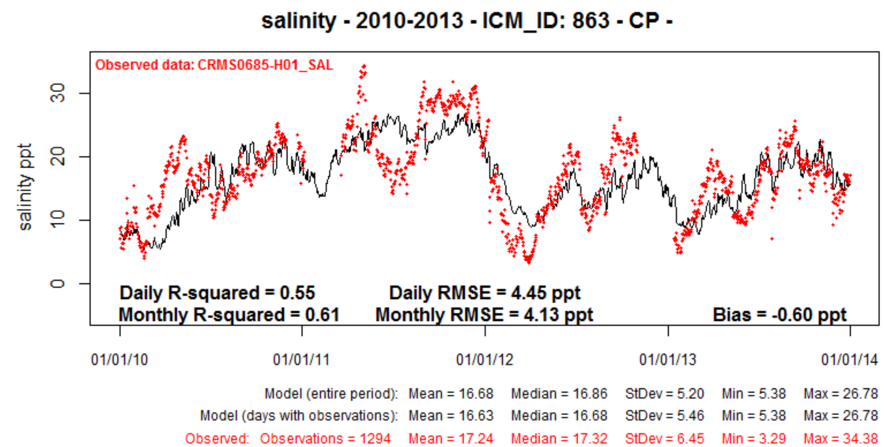


Salinity Calibration Example

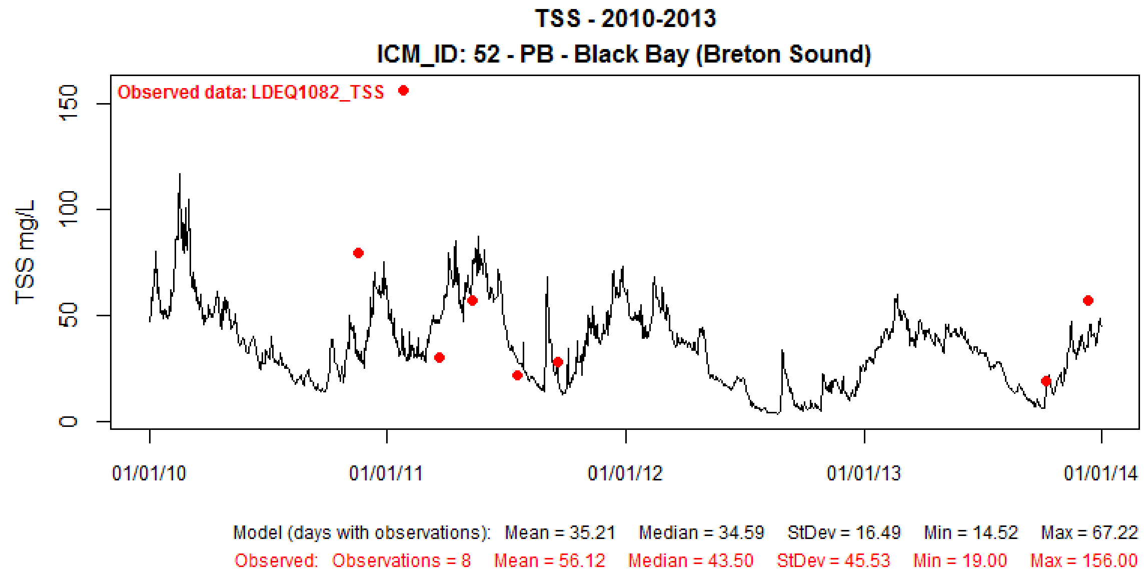


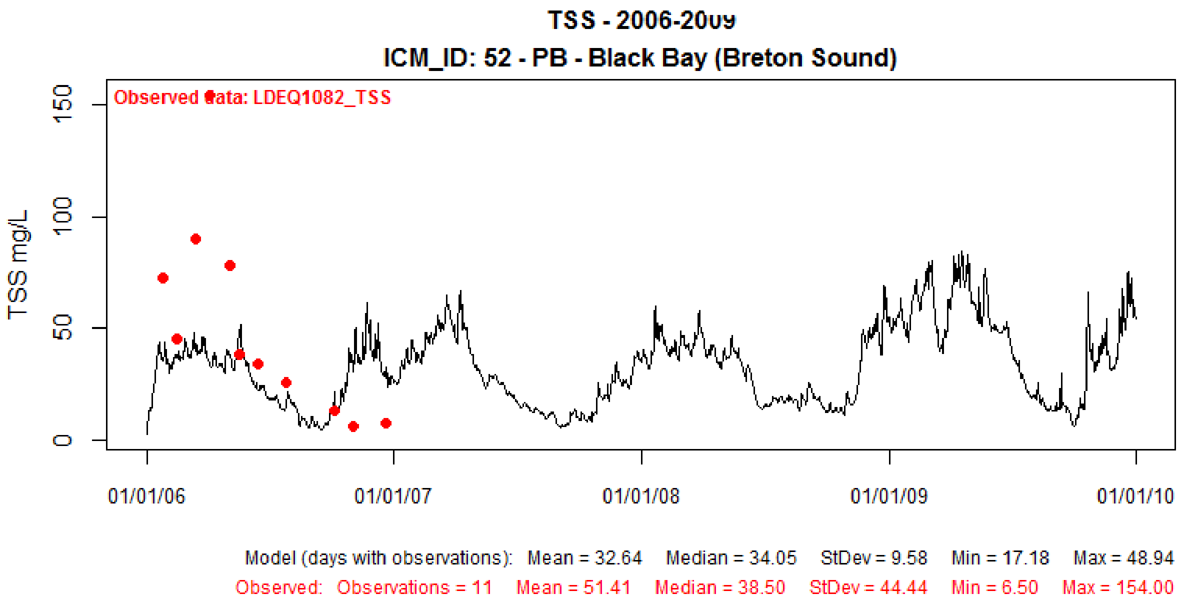






Total Suspended Solids Results - Sample





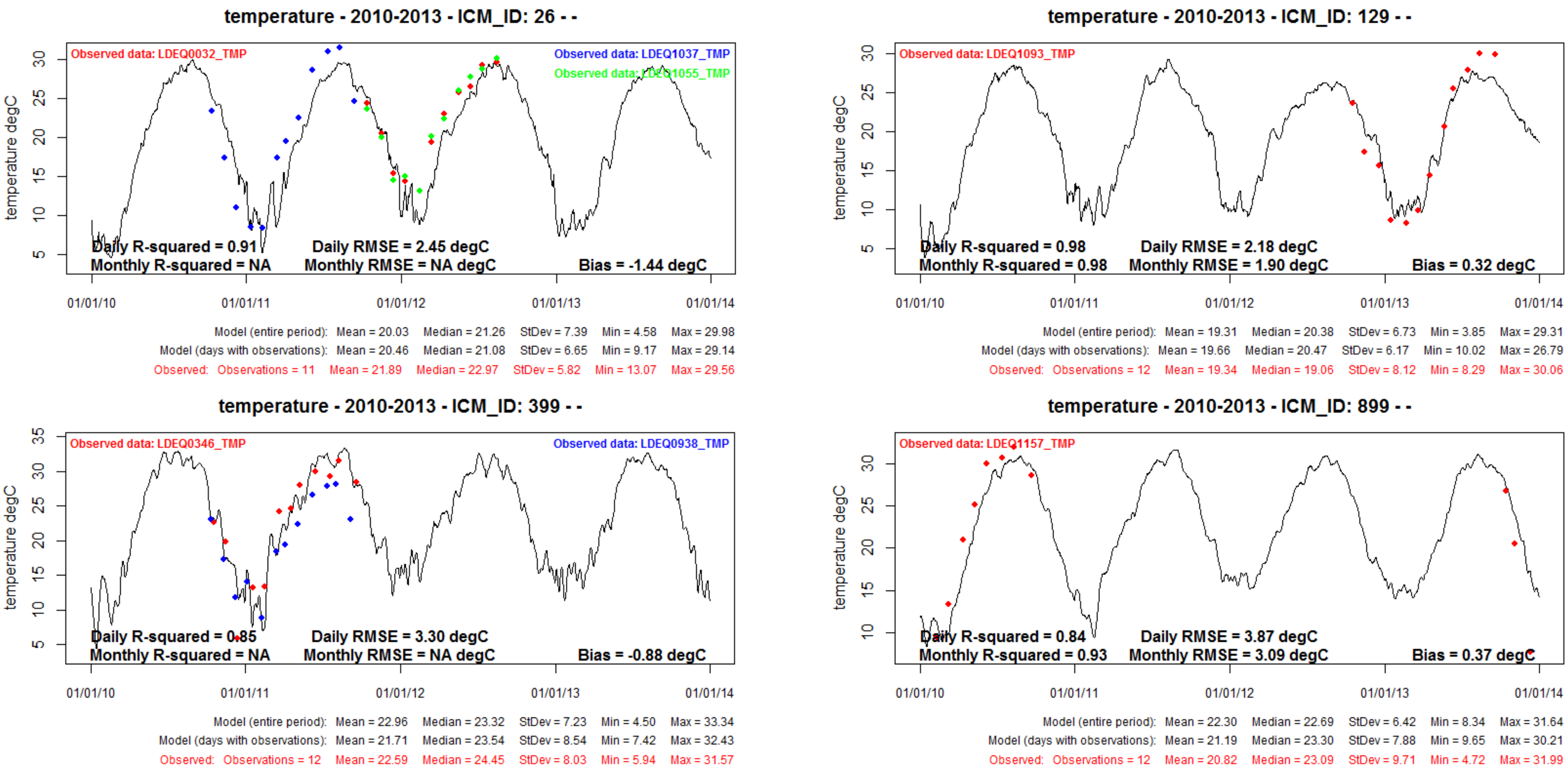
WQ Model Calibration and Validation

- Calibration Period: 2010-2013
- Validation Period: 2006-2009

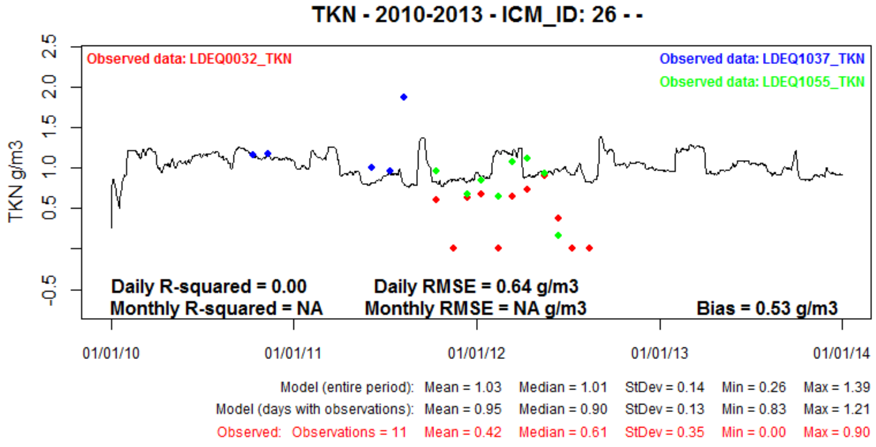
Water Quality

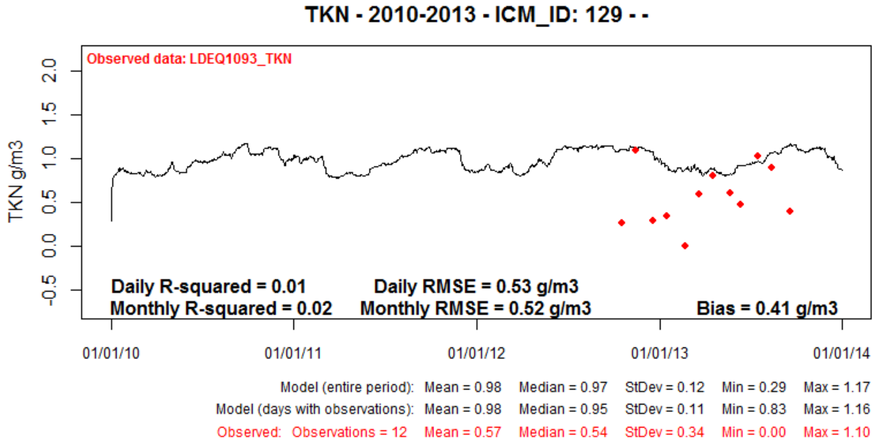
- Mean water quality concentrations: ~200 LDEQ stations used
  - water temperature
  - total inorganic phosphorus
  - dissolved organic phosphorus
  - dissolved organic nitrogen
  - blue-green algae
  - detritus
- Limited input data available as timeseries
  - Long term monthly mean values are used to define input concentrations
  - Model-wise monthly averages are used when no data is available

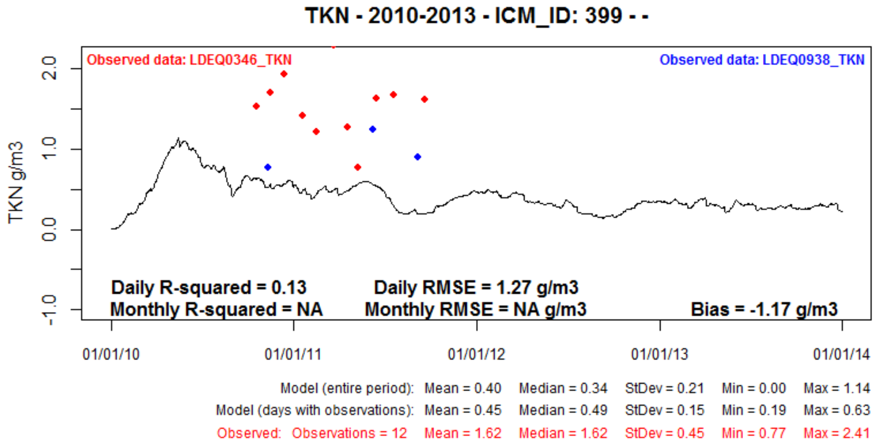
Temperature Calibration Example

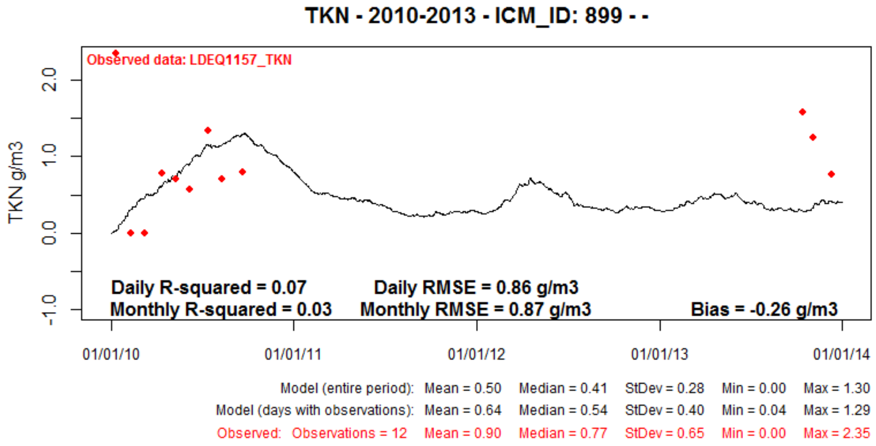


Total Kjeldahl Nitrogen Calibration Example

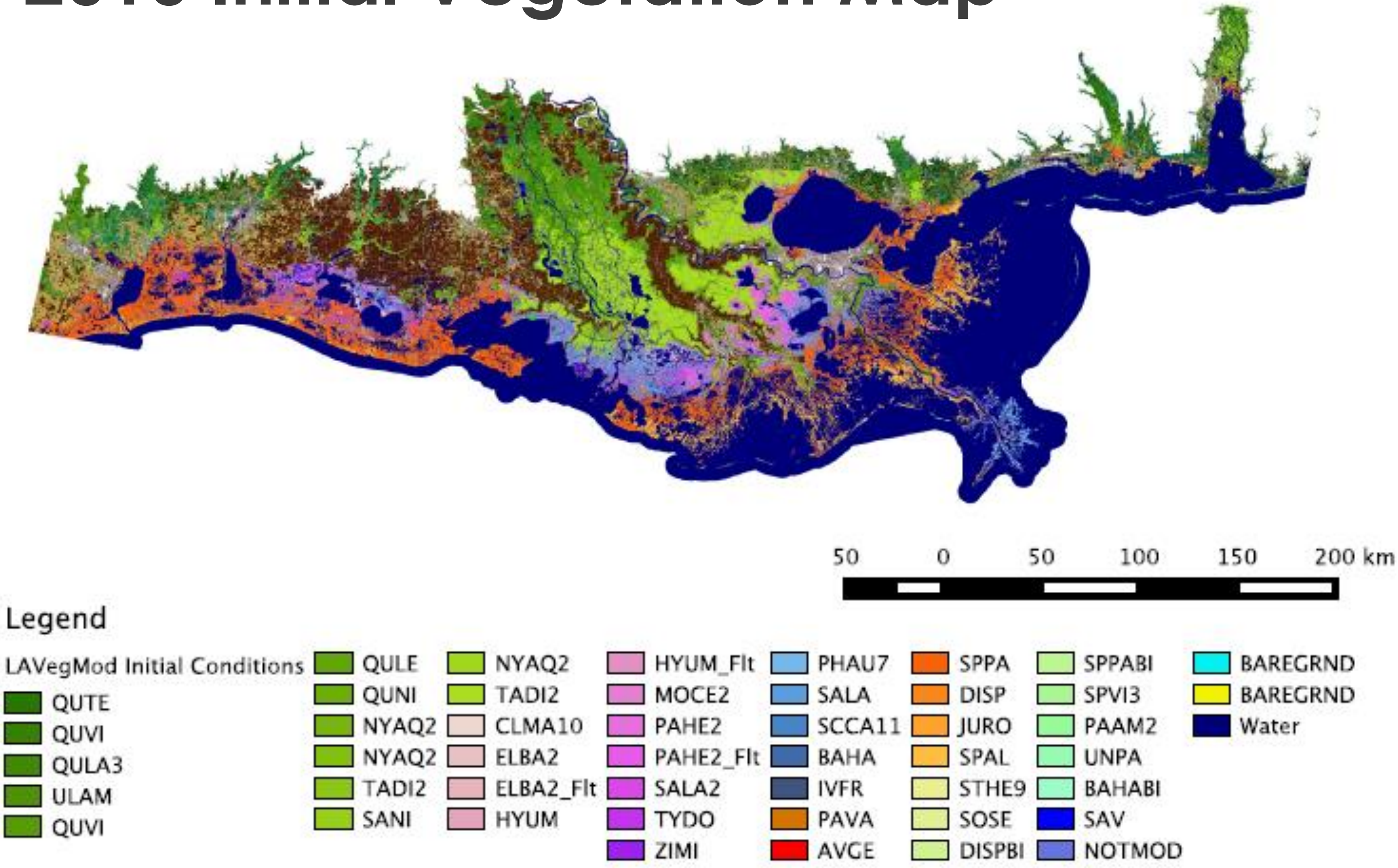






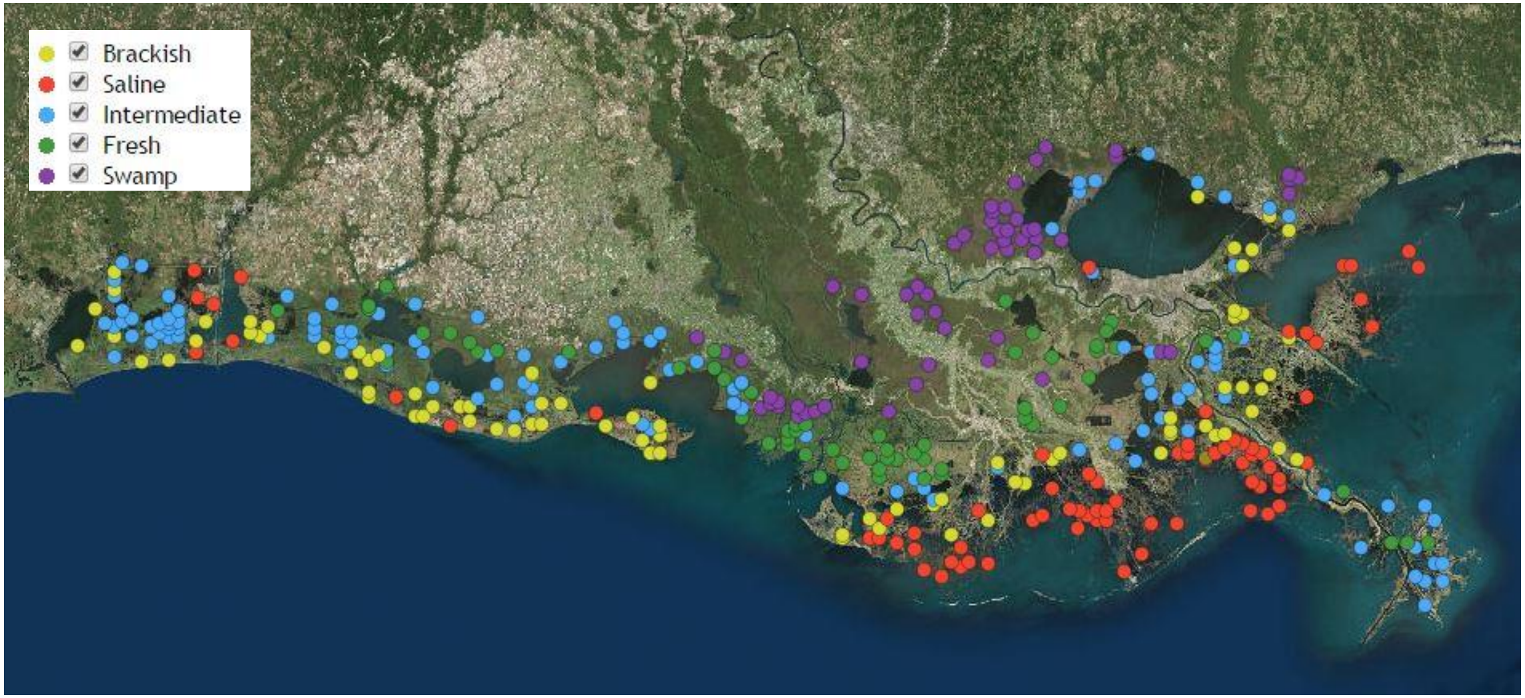


2010 Initial Vegetation Map



Data for Calibration

- Coast-wide Reference Monitoring System
  - 56 Swamp stations surveyed in 2012
  - 336 Marsh stations surveyed annual from 2007 through 2014



Vegetation Calibration Procedure

	LaVegMod	CRMS
Area	500 x 500 = 250,000 m^2	10 x 2 x 2 = 40 m^2
Represents	All habitat Includes ridges	Target habitat Marsh or Swamp
Cover	Dominants	All species
Presence	> 5% cover	> 5% cover in one of the plots

Because of these differences we only considered presence/absence not % cover

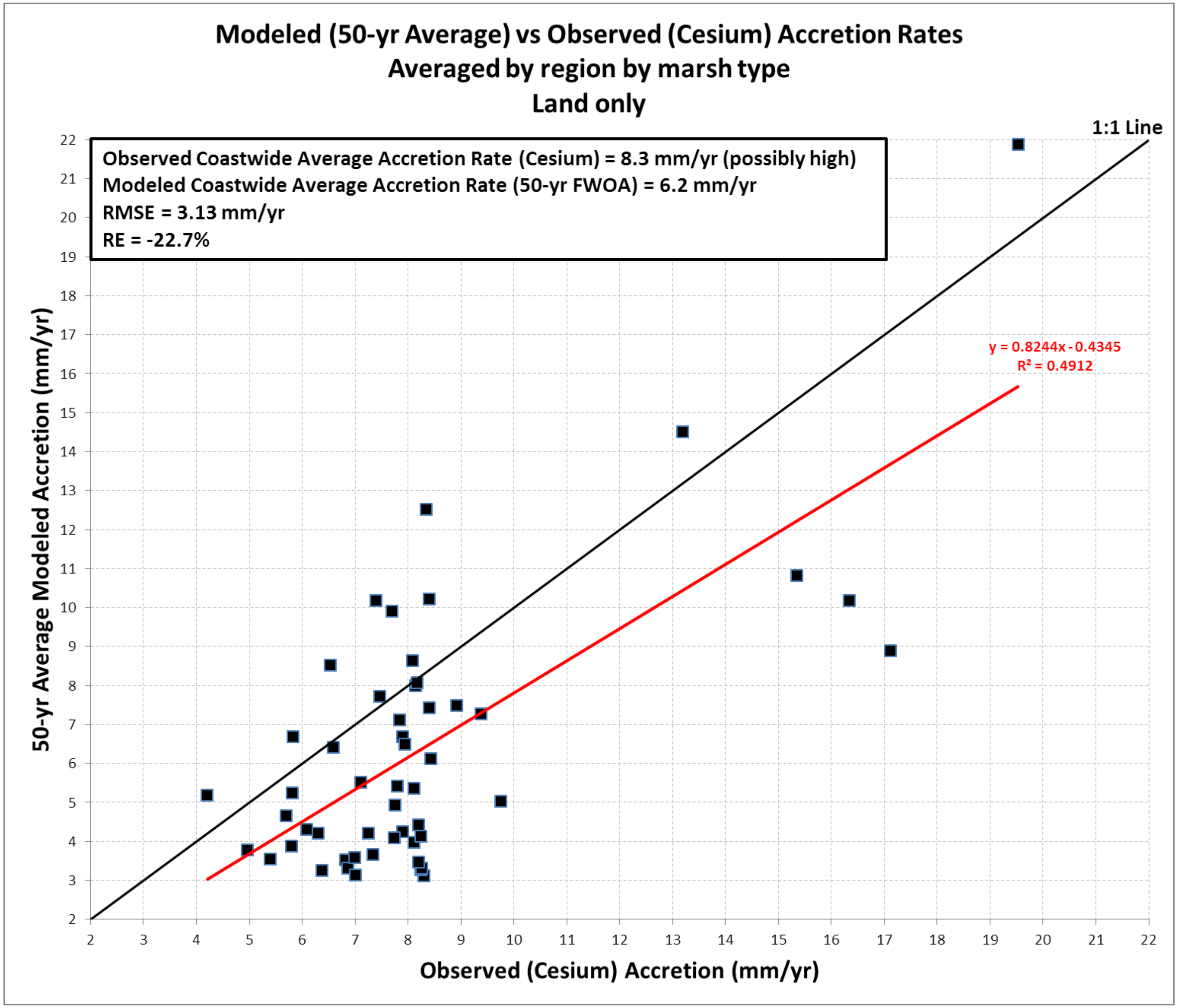
Bottomland Hardwood and Barrier Islands are not included in the CRMS design. However they make up only a small percentage of the coastal zone.

Vegetation Calibration Results

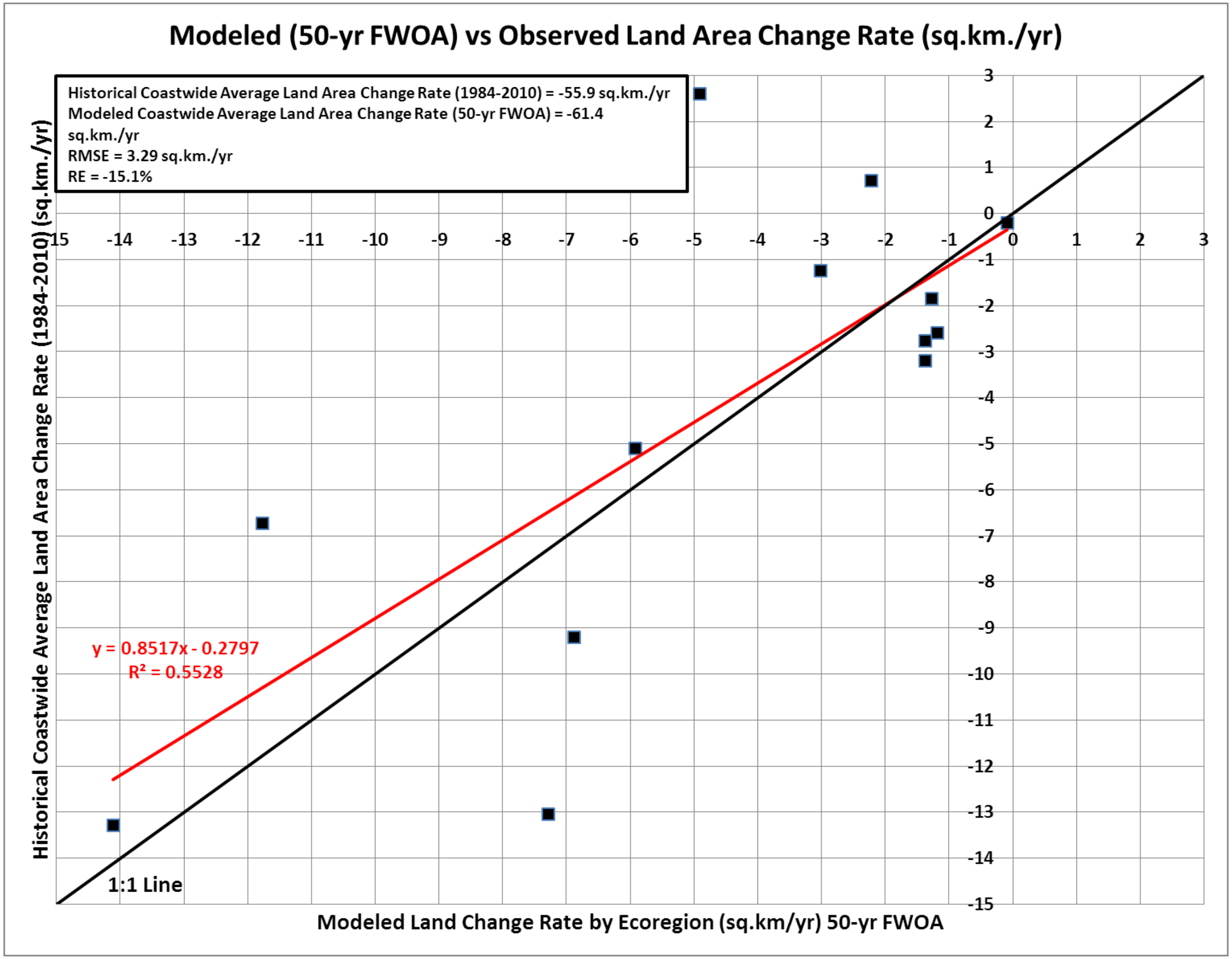
Swamp		Fresh Marsh		Intermediate Marsh		Brackish Marsh		Saline Marsh	
Species	Fit	Species	Fit	Species	Fit	Species	Fit	Species	Fit
TADI2	**79**	TYDO	82	SALA	82	SPPA	**63**	SPAL	**79**
NYAQ2	91	PAHE2	95	PHAU7	86	JURO	87	DISP	**69**
SANI	93	HYUM	99	IVFR	92	PAVA	88	AVGE	99
		SALA2	98	BAHA	92				
		ZIMI	97	SCCA11	96				
		CLMA10	97						
		MOCE2	99						

Fit is percentage of CRMS stations that were correctly classified for presence/absence of the species at the end of the 4 year 2010-2014 run.
For all species fit at the end of the run was better than at the start. Only 4 of the 21 species did not reach the 80% fit goal.

Wetland Morphology Calibration Results



Wetland Morphology Calibration Results



Model Output from 50-year simulation: Future Without Action

Questions?

coastal.la.gov

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