NROC Marsh Migration Modeling & Policy Workshop

December 2-3, 2014

Hugh Gregg Coastal Conservation Center

Greenland, NH

Materials will be available post-workshop at: http://northeastoceancouncil.org/

NROC Marsh Migration Modeling & Policy Workshop

NROC
Northeast Regional Ocean Council

Goals, by the end of the workshop, participants will:

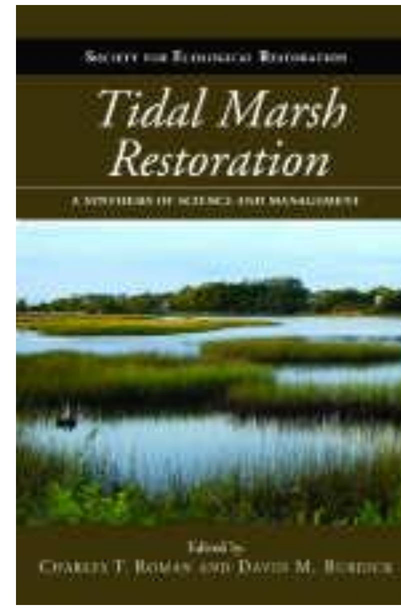
- Understand the availability of marsh migration models and current uses in the New England region
- Discuss model data and parameters to understand what elements matter most
- Discuss options and opportunities for developing a marsh migration policy based on modeling
- Understand requirements and identify strategies for marsh system monitoring
- Provide input into NROC draft Marsh Migration Guidance and identifying next steps for the NROC OCEH committee
- Network with state and regional marsh migration practitioners in the region

Can Salt Marshes Adapt to Climate Change? Yes, Within Limits

Planning for Marsh Migration is Urgently Needed

David Burdick

Jackson Estuarine Laboratory
Dep't of Natural Resources & the Environment
School of Marine Science and Ocean Engineering
University of New Hampshire, Durham, USA



NEW HAMPSHIRE COASTAL PROGRAM

GREAT BAY NATIONAL ESTUARINE RESEARCH RESERVE

Salt marshes are among our most productive and valuable ecosystems

Climate Change - the biggest threat to tidal marshes

- Sea Level Rise
- Increased Storms
- Increased Temperatures

Our Climate Continues to Change:

Global:

- Surface temperatures +0.74° C
- Arctic temperatures 2X

Snow and Ice:

- Snow cover decreasing
- Glaciers shrinking
- Arctic sea-ice decreasing
- Ice shelf losses

Thermal expansion of the oceans:

- SLR has increased from 1.7 to 3.2 mm/yr

Greenhouse Gasses (CO_2, H_2O, CH_4, N_2O) and Climate Change

- CO_2 Increased 30% in past 50 years
  - Typically, wetlands are a sink
  - warming and drying could make them sources

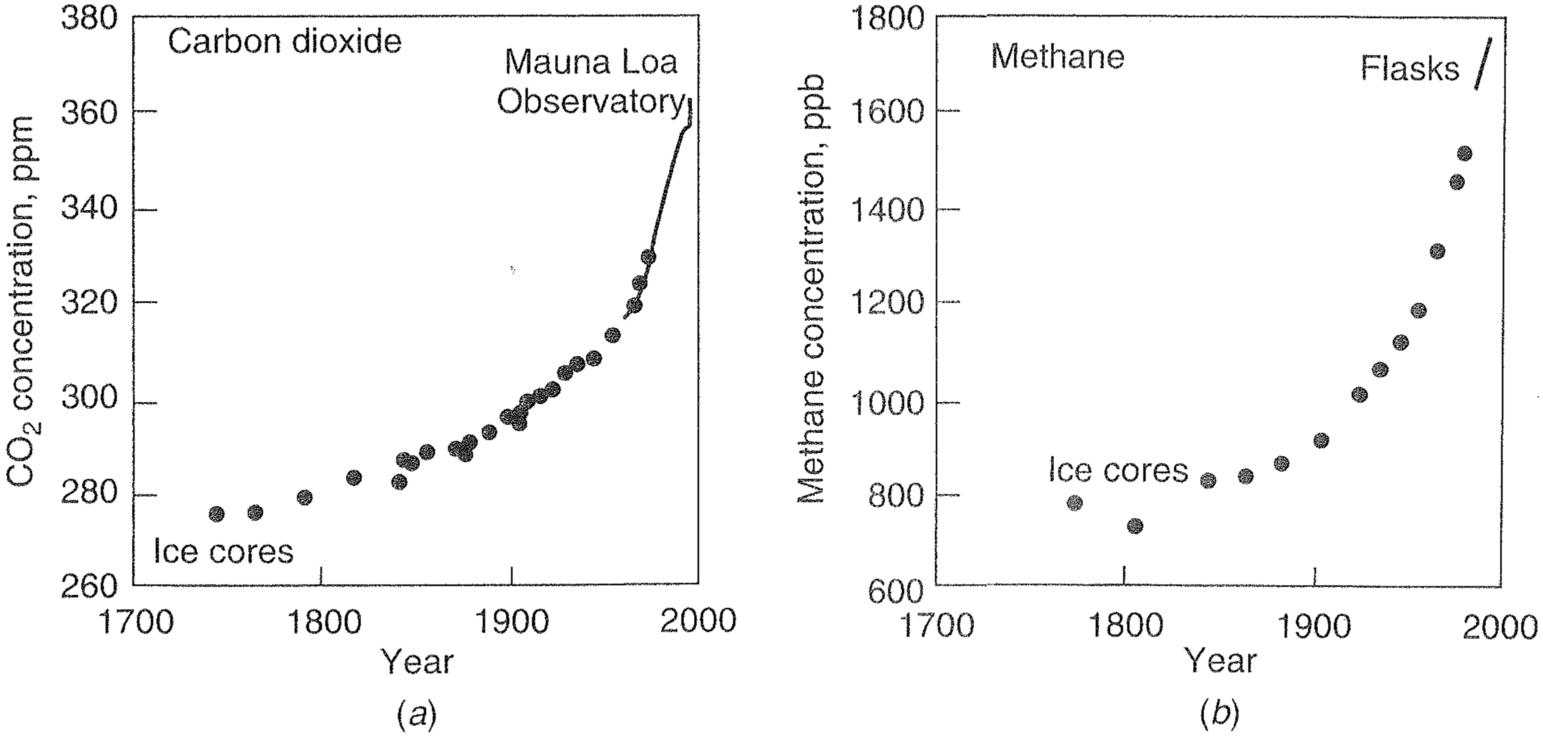
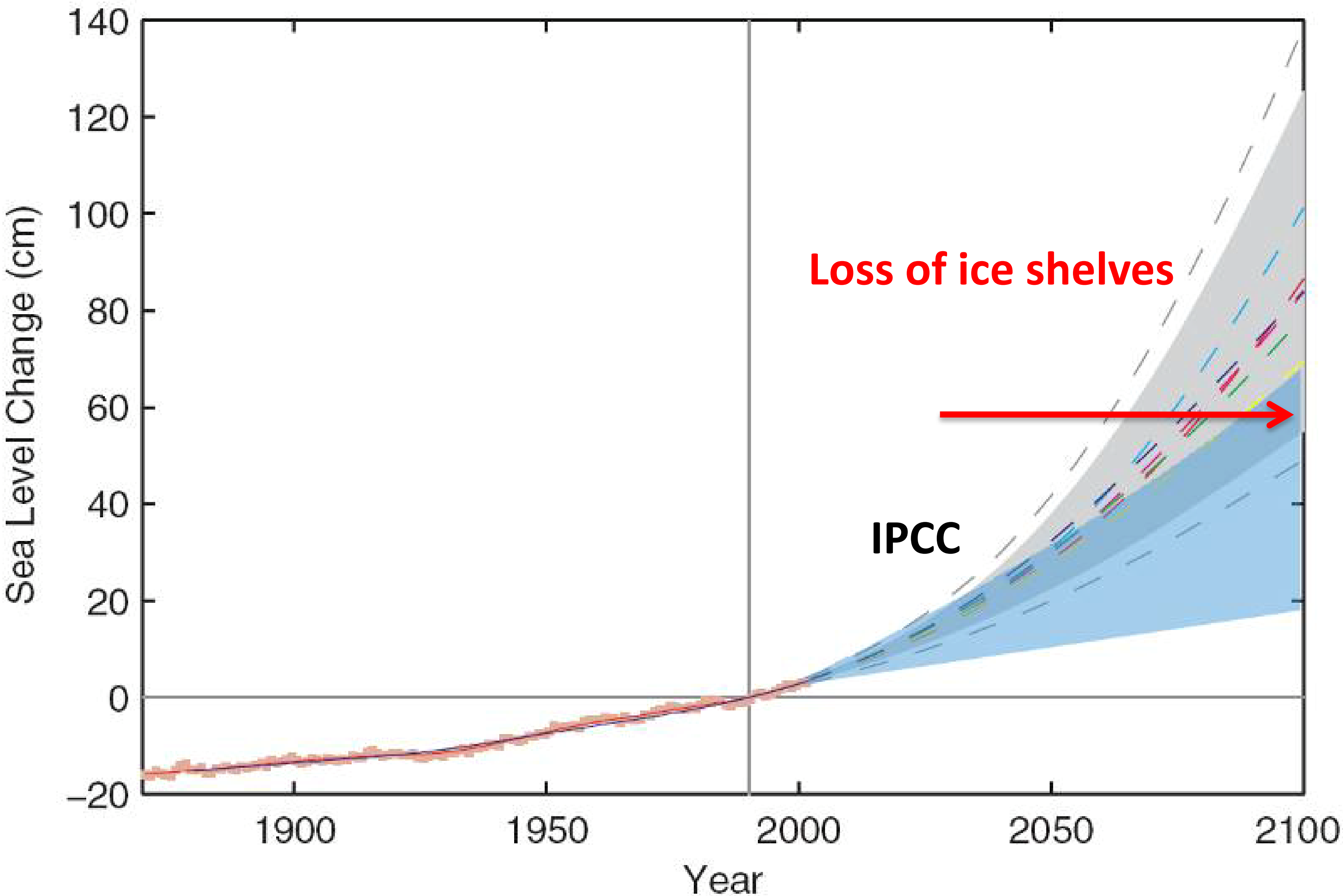
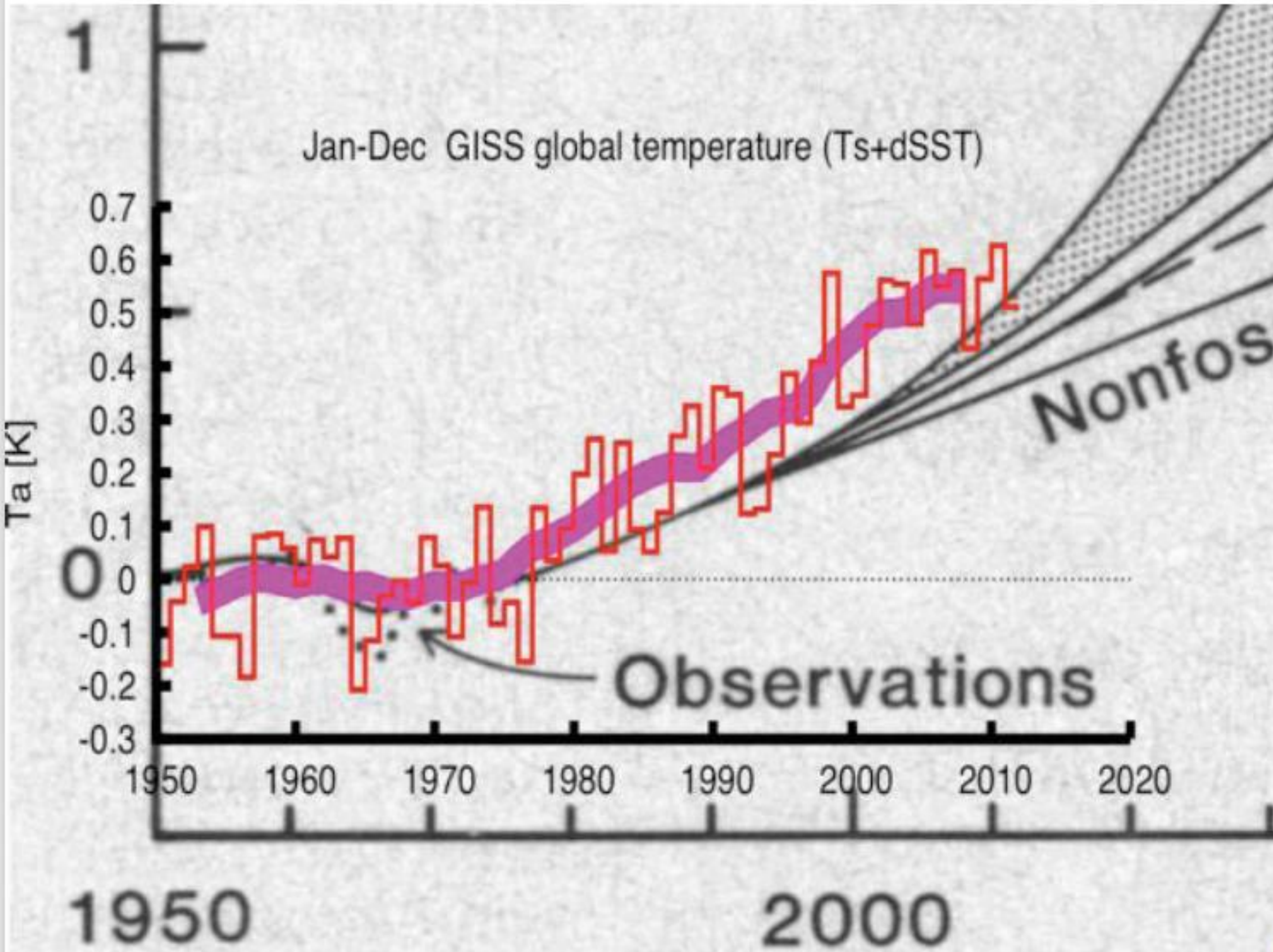


Figure 10.2 Estimated changes in concentrations of (a) carbon dioxide and (b) methane, since preindustrial times. ***(From IPCC, 2001.)***

SLR estimates



How Good Were Climate Models 30 Years Ago?

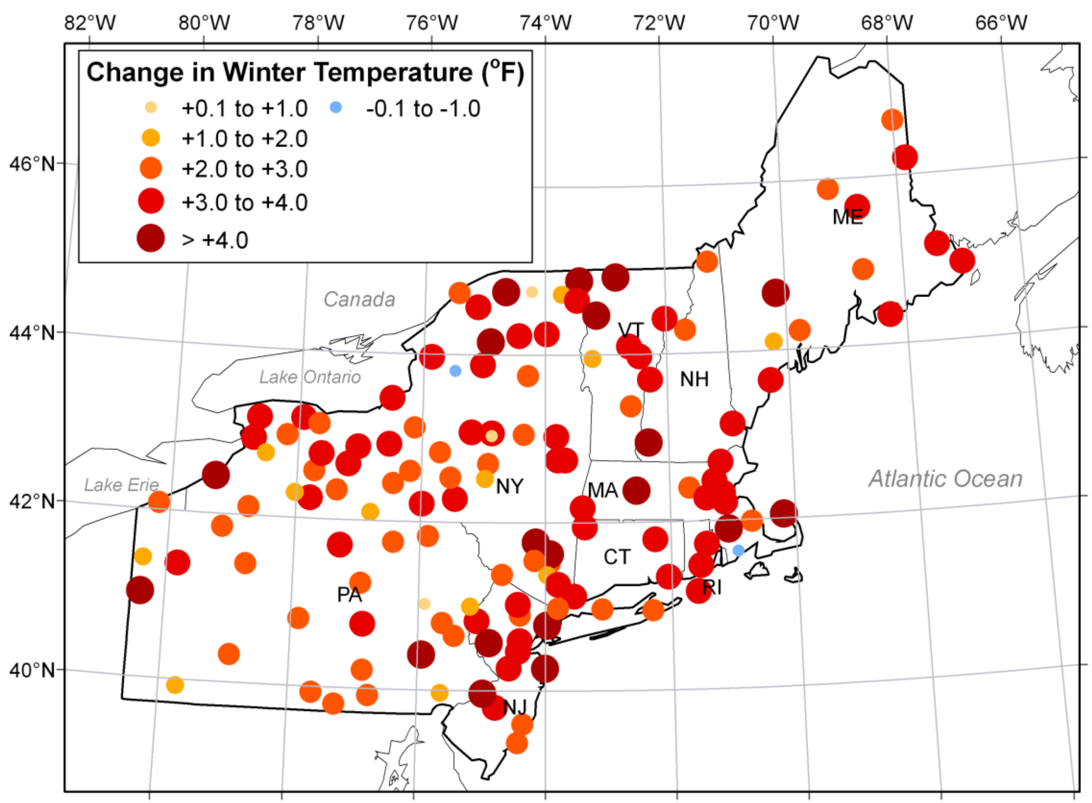


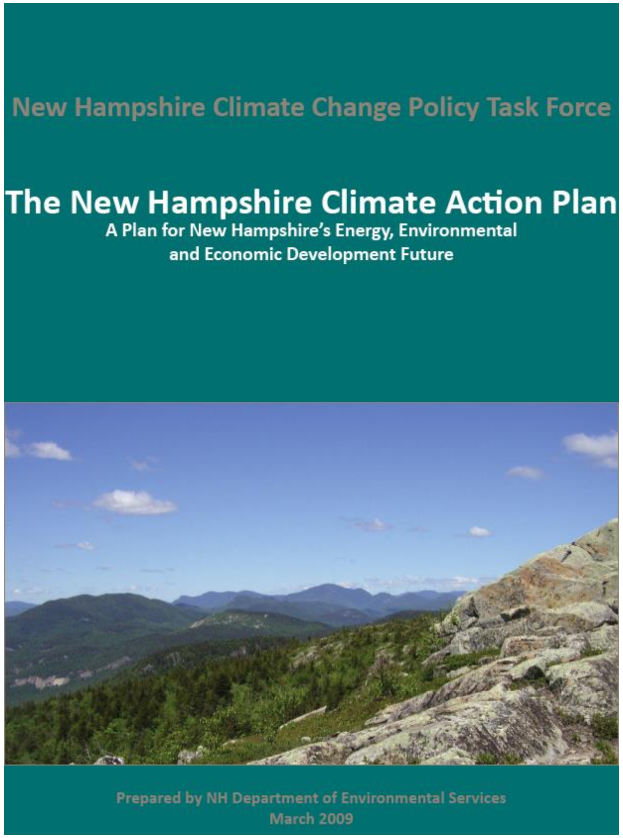
Credit Geert Jan van Oldenborgh and Rein Haarsma, KNMI, RealClimate

Climate change as predicted in 1981. Grey shows predictions from global temperature rise via computer models run of Hansen et al 198. Red shows real world data taken since paper was published.

Our LOCAL Climate is Changing:

Seasons changing (shorter, warmer winters; ice-out sooner)





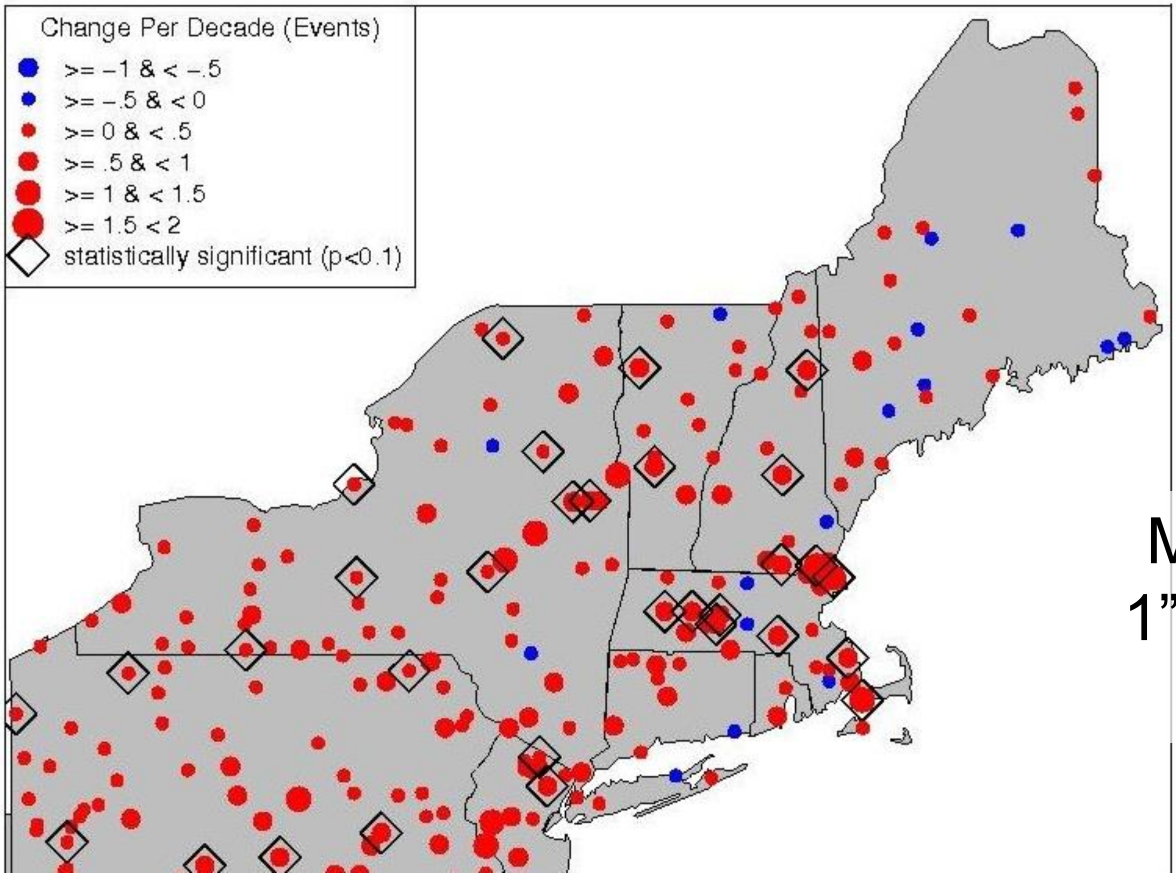
More info at: /CarbonSolutionsNE.org

CARBON SOLUTIONS NEW ENGLAND™ CarbonSolutionsNE.org

Our LOCAL Climate is Changing:

Local precipitation increased 20% since '30s (42 in/year)

Precipitation events larger



Mean Decadal Trend
1" Precipitation Events
1948-2007

Climate Change Impacts to Wetlands

- Increased sea level and storm activity
  - Seaward edges will retreat
- Temperature increases
  - Range expansions
  - Loss of forb pannes
  - Increased decomposition rates

Bromberg-Gedan web site

Climate Change Impacts to Wetlands

Most important impact is SLR
Already has increased from 1.7 to 3.26 mm/yr

- **What evidence have we seen?**
- Low marsh replacing high marsh, RI (Donnelly & Bertness 2001)
- Marsh Loss (Low and High) Jamaica Bay, NY (Hartig et al. 2002)
- Vegetation loss in high marsh Great Island, Cape Cod (Smith 2009)
- Vegetation loss in Blackwater NWR (Kirwan & Guntenspergen 2012)

from Smith 2009

Climate Change Impacts to Wetlands

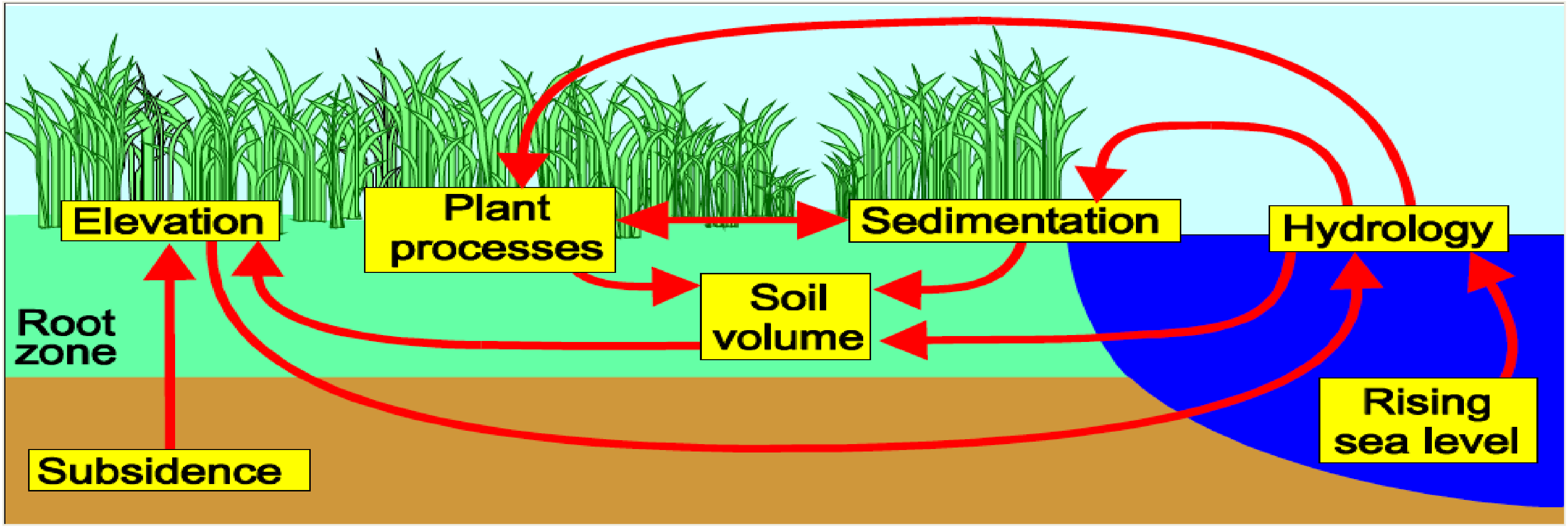
SLR already has increased to 3.26 mm/yr

- **Will all our marshes drown?**
- Marshes can build w/SLR up to 5 mm/yr (Morris et al. 2002) or 10 mm/yr (Kirwan & Guntenspergen 2010)
- IF tides are not restricted & sediment is available
- Marshes can move landward IF no barriers
- Steeper uplands will result in overall losses if seaward edges retreat

Burdick 2012

Salt Marshes are Poised Systems

- Reflect a dynamic balance of building processes;
  - Sediment trapping and binding
  - Root production and limited decomposition
  - Sea Level Rise (up to 5 mm /yr)



- . . . and eroding processes
  - Compaction (by floods and ice)
  - Decomposition of roots and peat (Temperature, Nitrogen)
  - Physical exposure to waves and ice

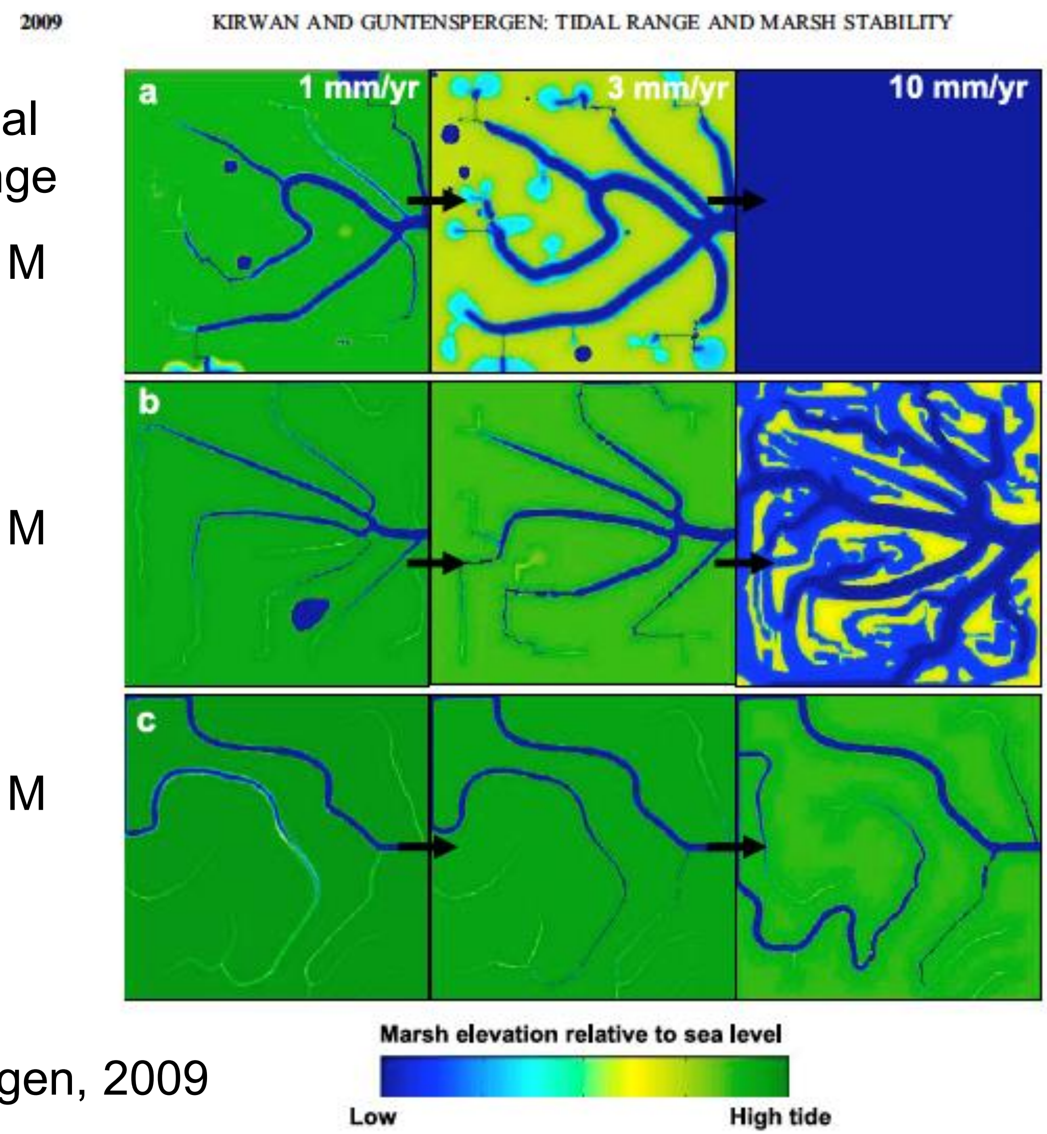
Marsh Responses to three SLR rates under three Tidal Ranges

Tidal Range

0.4 M

1.0 M

2.0 M



Matt Kirwan and Glen Guntenspergen, 2009

Global Sea Level Rise Measurements (Church & White 2011)

Reflected in Salt Marsh Responses Found in Great Bay

Portsmouth Tide Gauge:
1.76 mm/yr 1927-2001

Great Bay Elevation change
1.7 mm/yr 95-97
4.3 mm/yr 00-11

Elevation of salt marsh

Measurement period

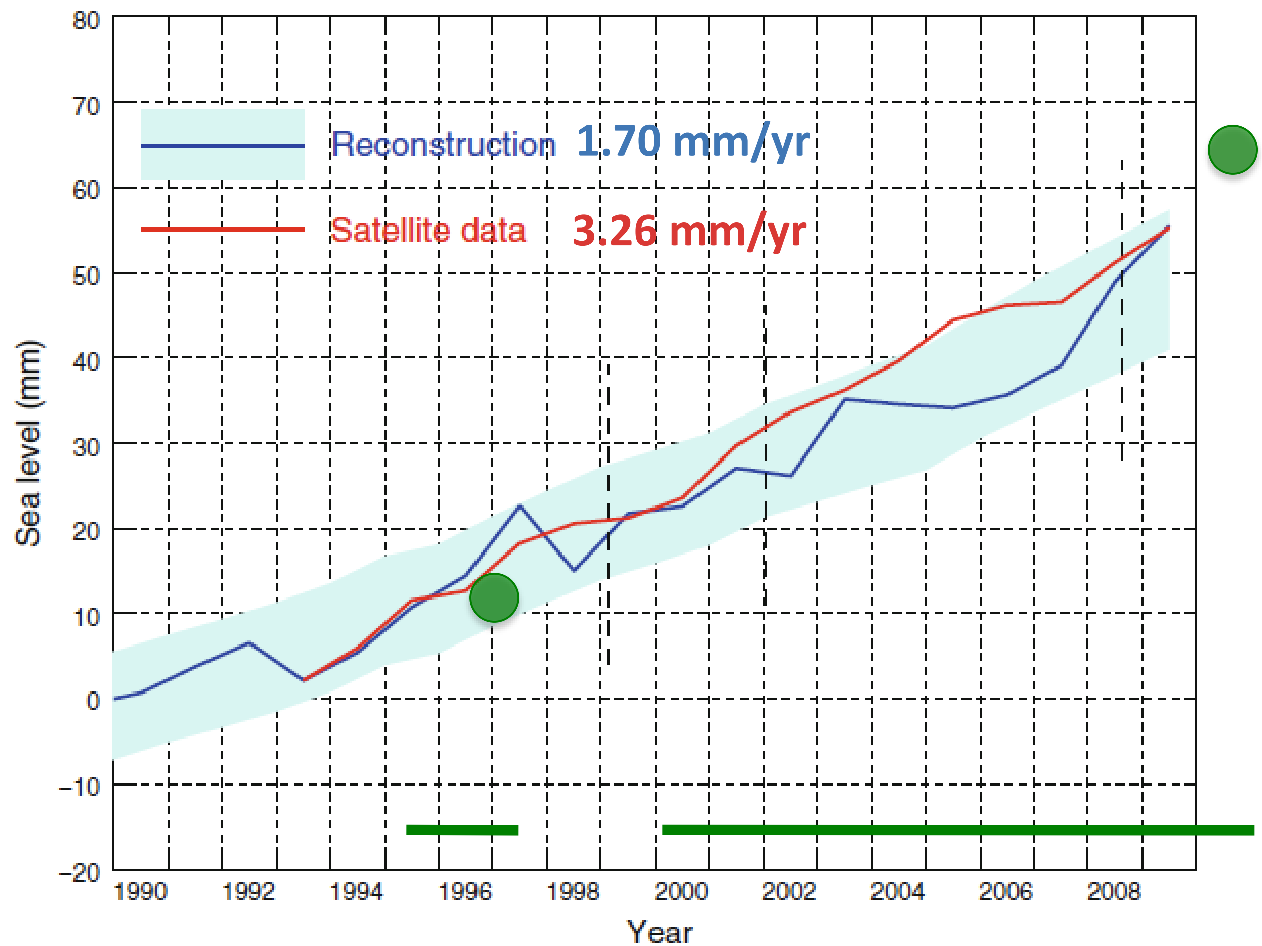
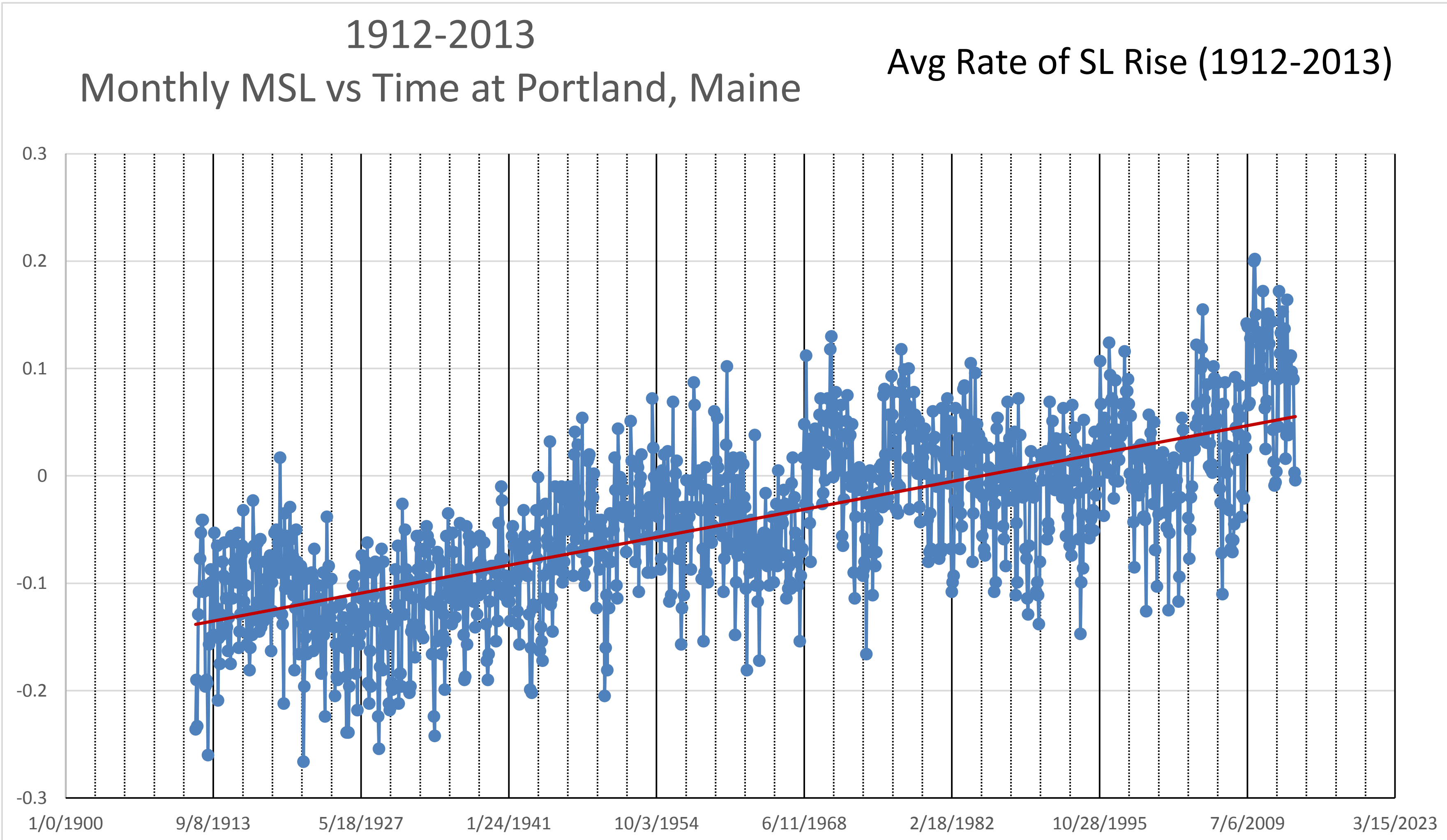
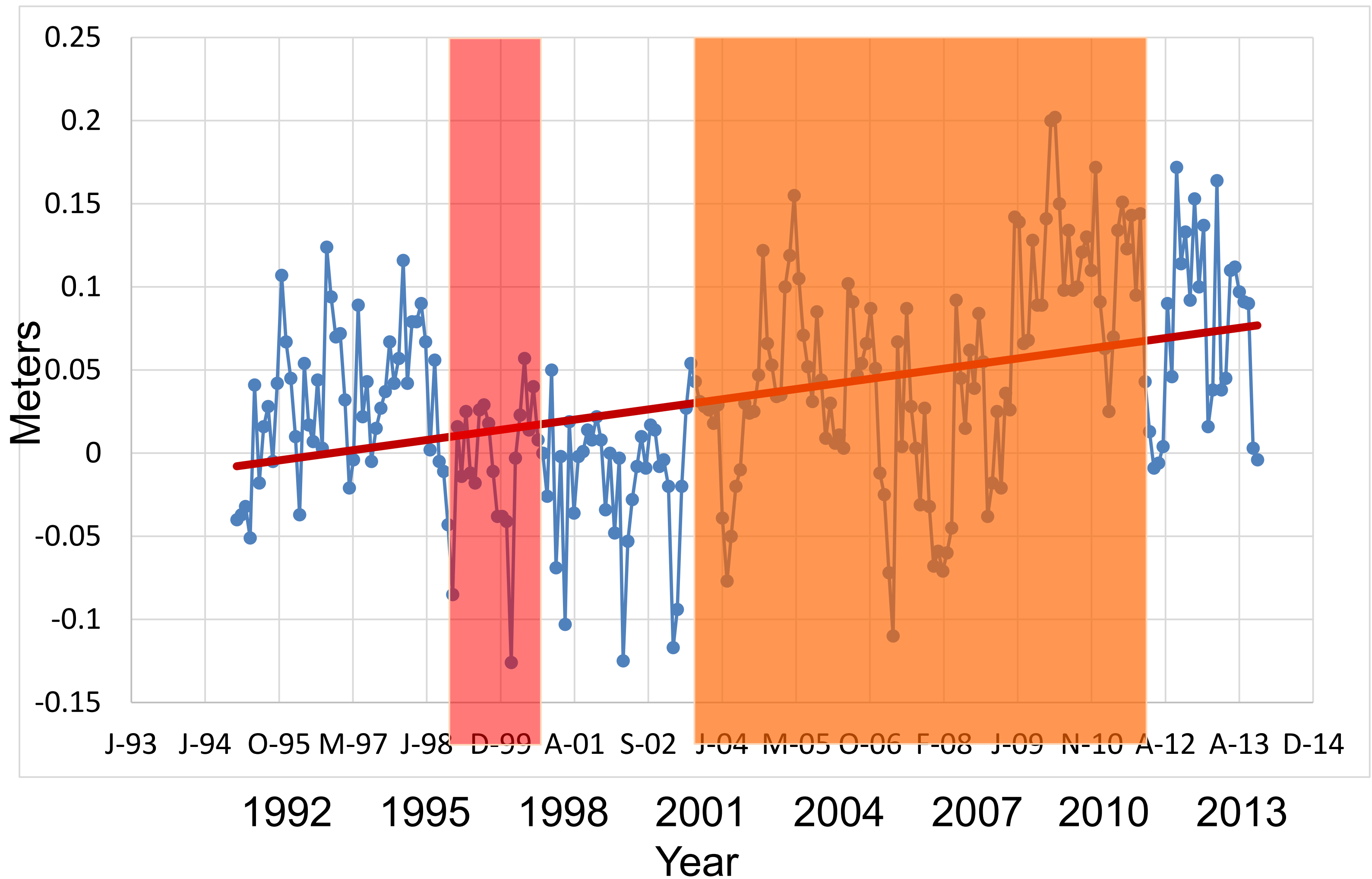


Fig. 4 Global average sea level from 1990 to 2009 as estimated from the coastal and island sea-level data (*blue* with one standard deviation uncertainty estimates) and as estimated from the satellite altimeter data from 1993 (*red*). The satellite and the in situ yearly averaged estimates have the same value in 1993 and the in situ data are zeroed in 1990. The *dashed vertical lines* indicate the transition from TOPEX Side A to TOPEX Side B, and the commencement of the Jason-1 and OSTM/Jason-2 records

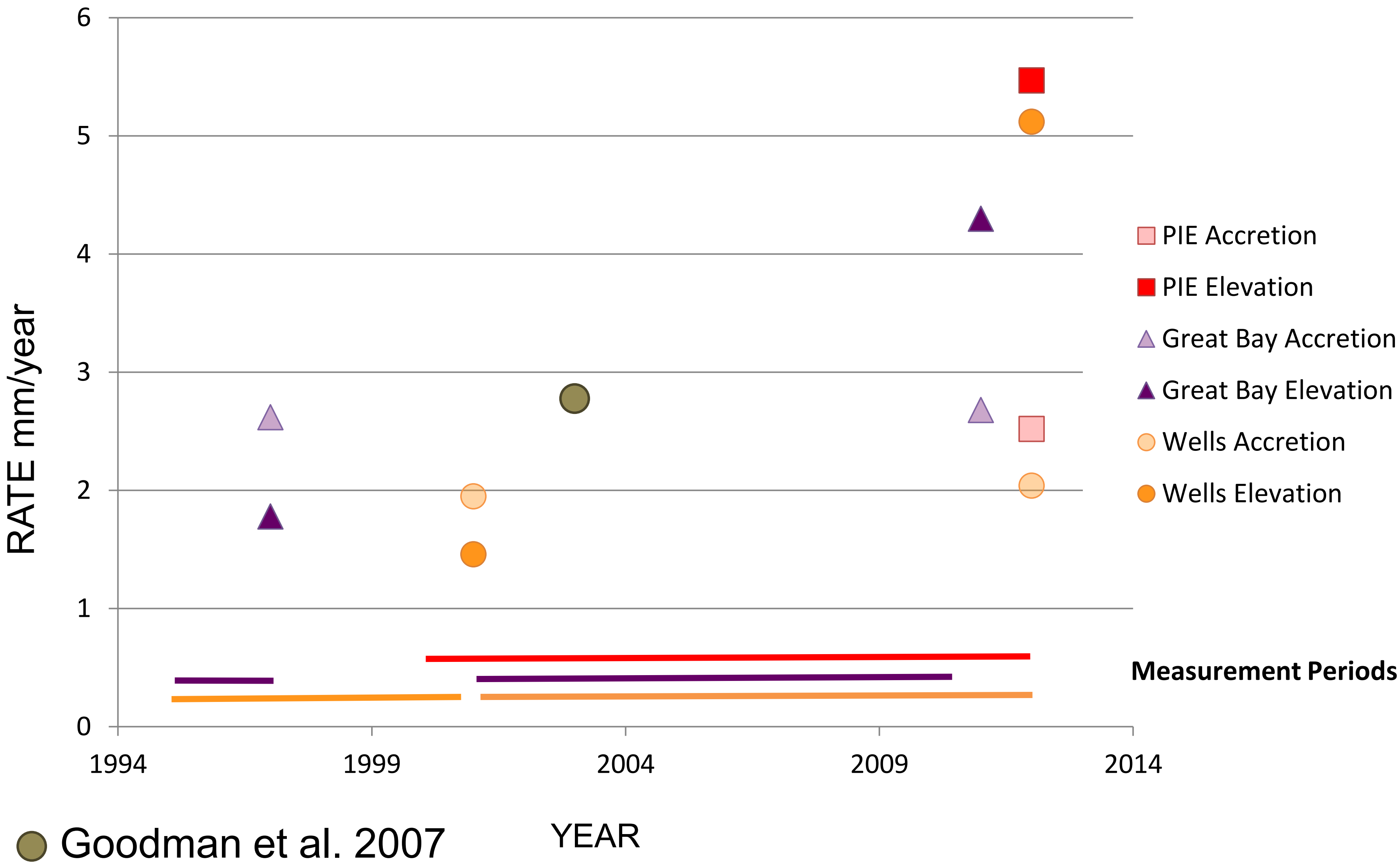
Church, J. A. and N.J. White. 2011. Sea-level Rise from the Late 19th to the early 21st Century. Survey Geophysics 32:585-602


1912-2013
Monthly MSL vs Time at Portland, Maine
Avg Rate of SL Rise (1912-2013)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1/0/1900
9/8/1913
5/18/1927
1/24/1941
10/3/1954
6/11/1968
2/18/1982
10/28/1995
7/6/2009
3/15/2023

1990-2013
Monthly MSL vs. Time at Portland, Maine

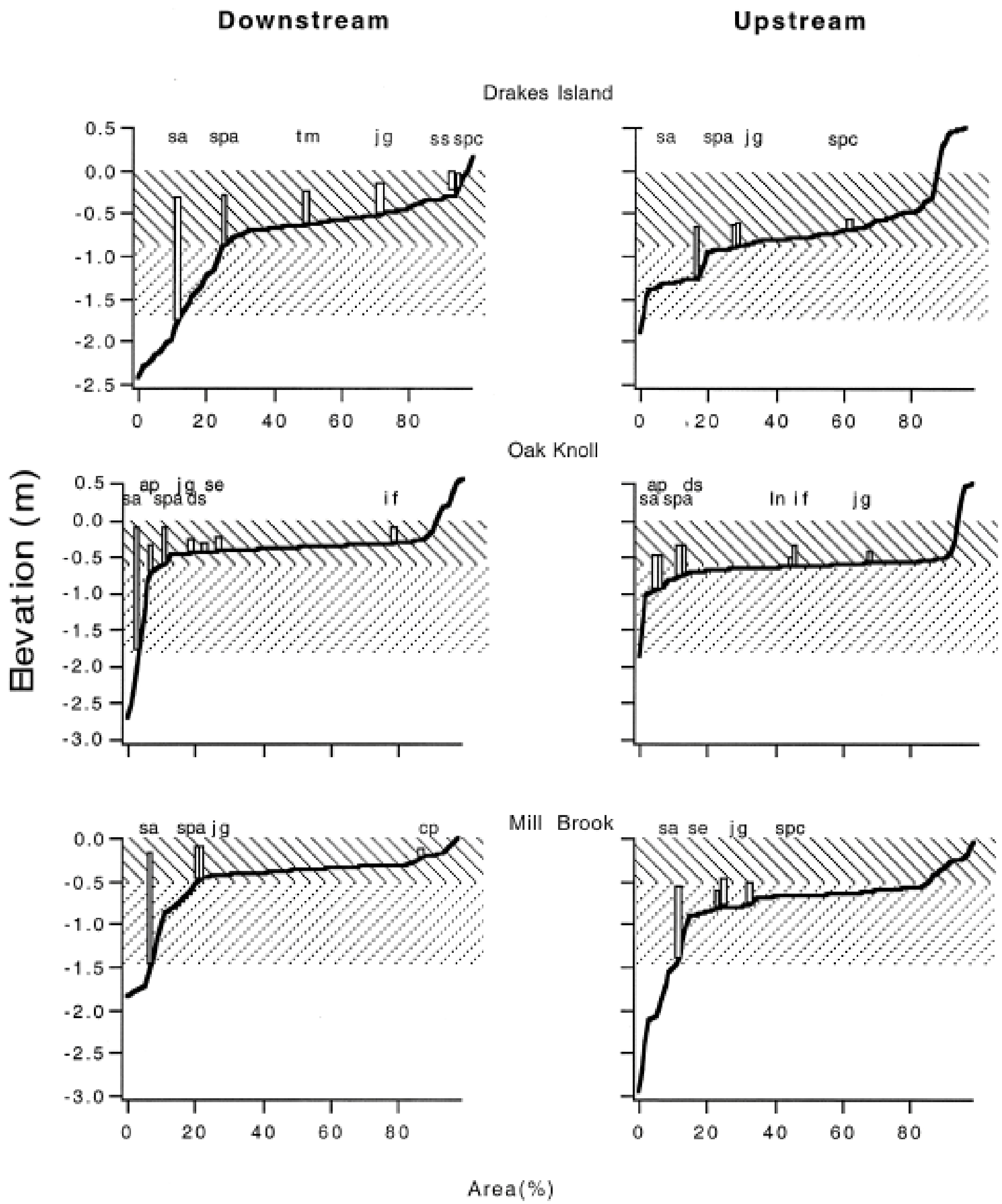


Accretion Rates and Elevation Change in Northern New England Salt Marshes



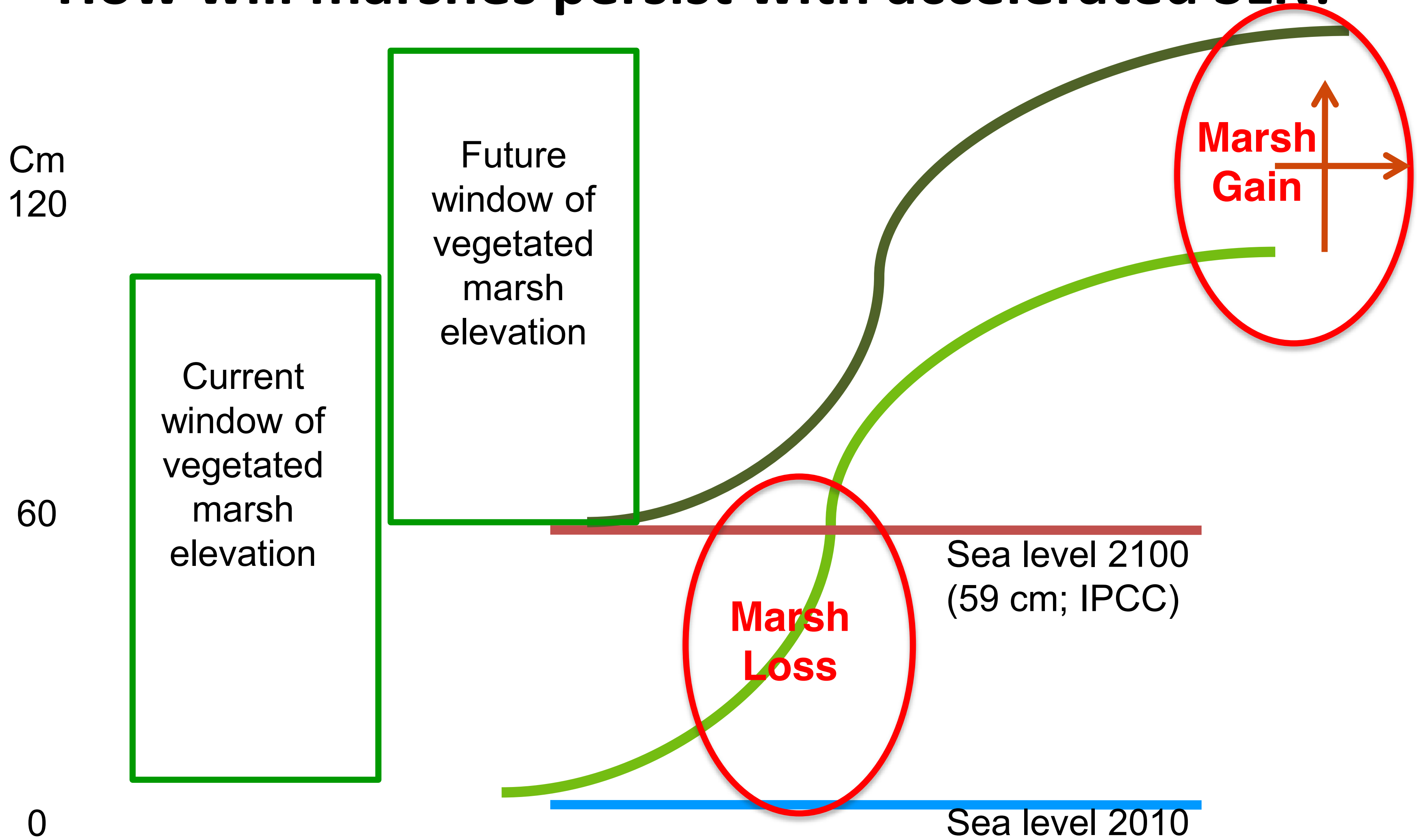
Tidal Restrictions lead to Subsidence

Our marshes appear to subside with lower tide levels and grow with higher tide levels



Boumans et al. 2002

How will marshes persist with accelerated SLR?



- At 0.5 cm/yr, marsh could build 45 cm in 90 years;
- At 1.0 cm/yr, it could build 90 cm (3.0 feet) by 2100.

Adapting to Climate Change

- Increasing SLR threatens tidal wetlands
  - Allow marshes to migrate landward (no barriers)

What are the other current threats to tidal marshes?

2. Alteration of tidal hydrology
3. Upstream dams (loss of tidal fresh habitat and sediments)
4. Marine structures that interfere with sediment supply
5. Berms, Seawalls and Lack of buffers (preventing landward migration)
6. Stormwater mis-management
7. Invasive species

What do marshes need to remain healthy in the 21st century?

a. Tidal flooding

b. Sediment source

c. Zone of retreat into upland buffer

How should we manage and restore marshes in the near future?

a. Remove barriers to hydrology

b. Remove barriers to sediment supply

c. Remove shoreline barriers

What do we need to know about marshes to manage and restore them in the 21st century?

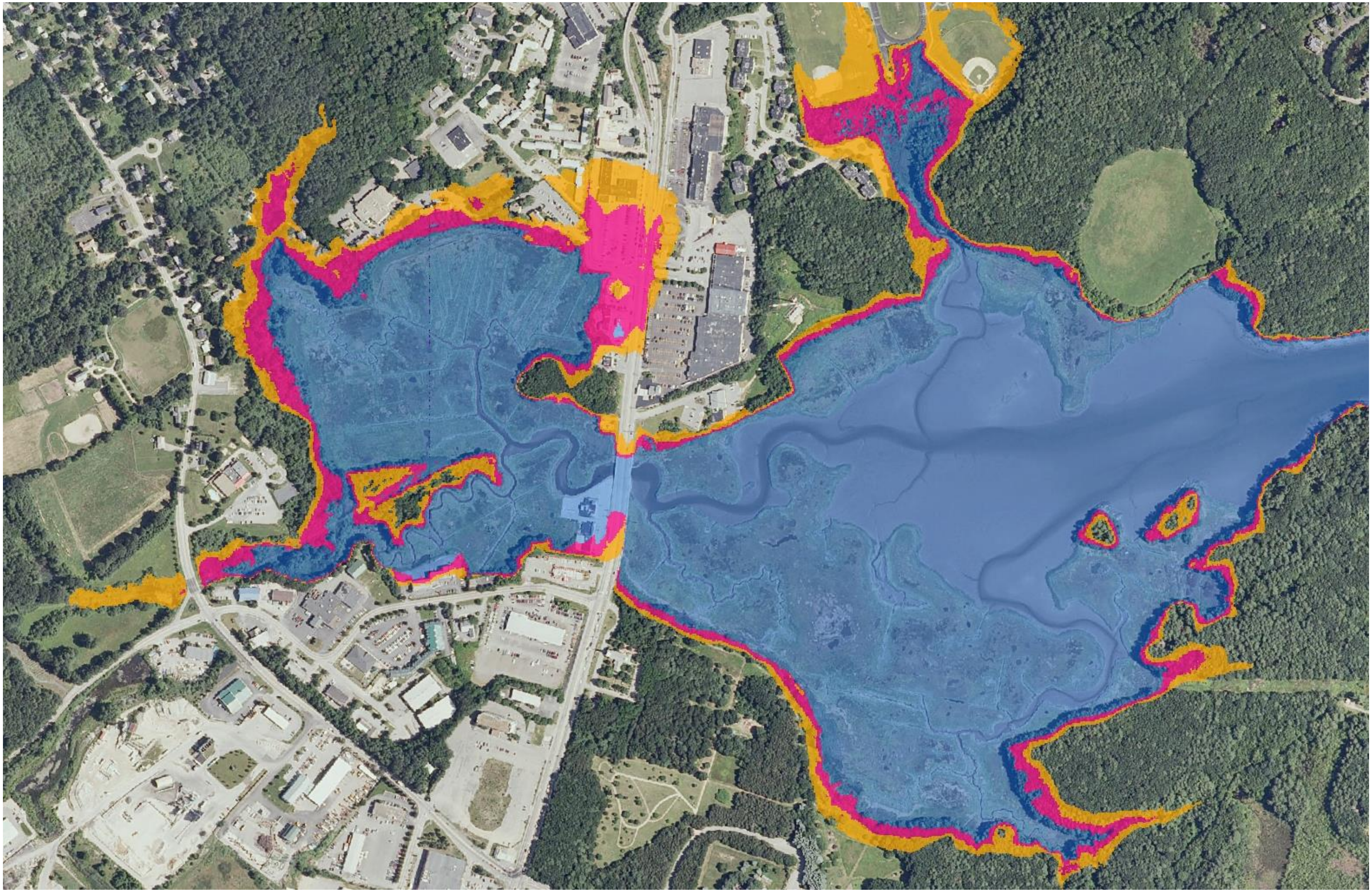
a. Better models

Combine marsh plain accretion and collapse with edge erosion modeling

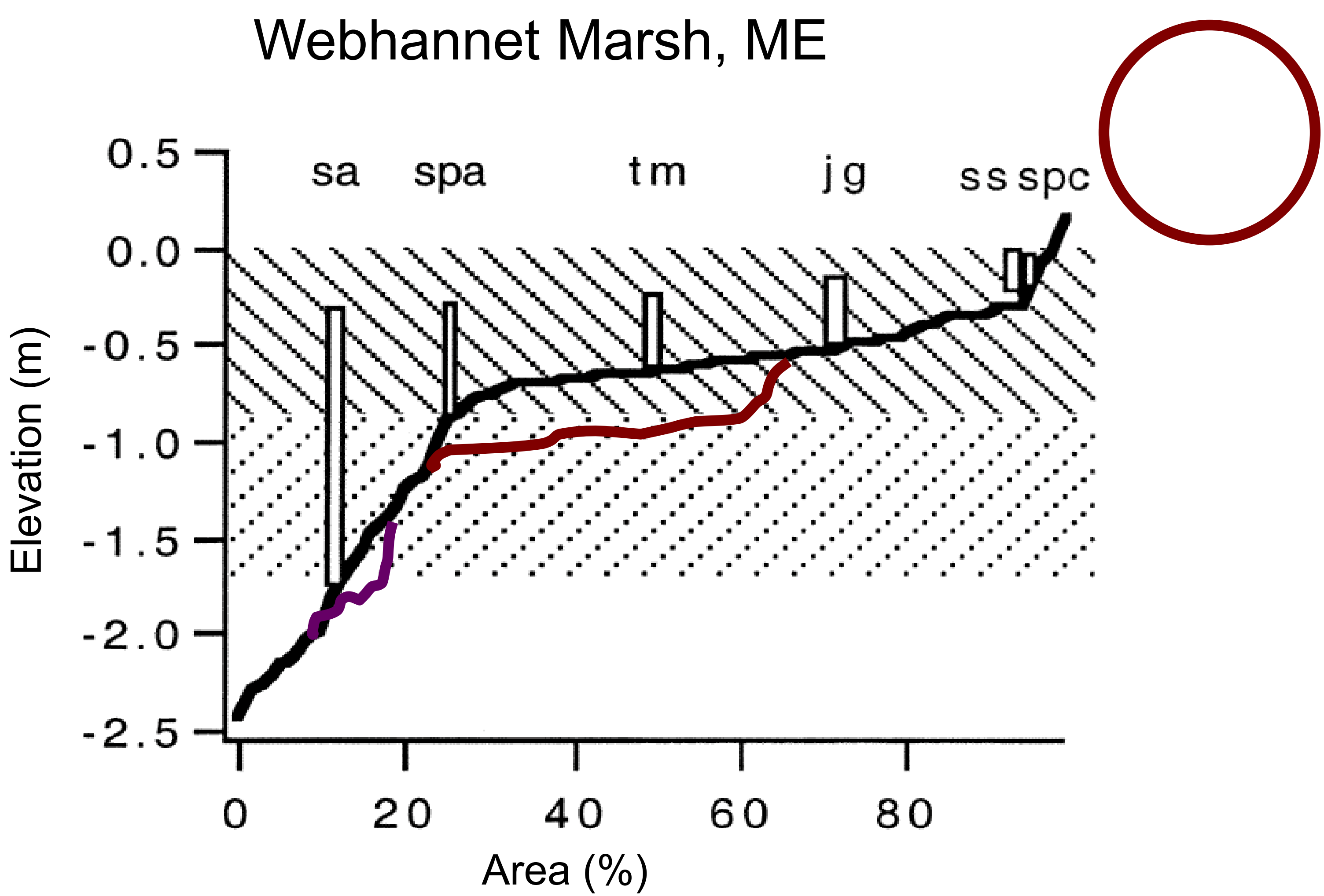
b. Sediment movement and supply

c. Process of retreat into upland buffer

SLAMM and other maps valuable



Another valuable tool:
Hypsometric Curves of -6 to +10 NAVD



Summary

- Sea Level Rise is accelerating
- 30% of our marshes have been lost to filling
- Remaining marshes:
  - 25% restricted
  - Most have reduced sediment supply
  - Reduced resilience
- In 50 years we will flood them out

Shall we roll out the red carpet? OR . . .
Pull the rug out from our tidal marshes?

With contributions and help from many students of marsh ecology, and:

Roel Boumans

Michele Dionne

Larry Ward

Chris Peter

Susan Adamowicz

Paul Kirshen

Paul Stacey and Rachel Stevens

Thank You!

Overview of Draft Guidance on Marsh Migration Modeling

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Waterview Consulting

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The Waterview Consulting Team

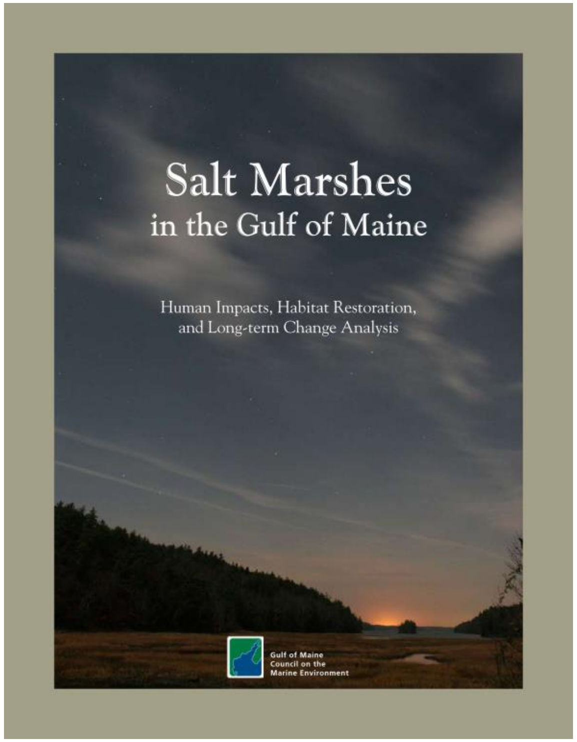
•Waterview Consulting founded 2002. Building linkages among science, management, and community.

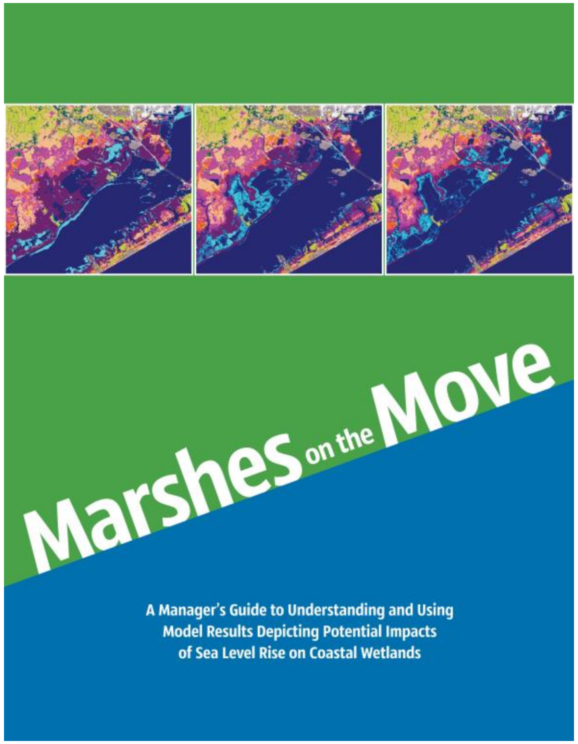
•*Among our clients:* NROC, NOAA, Maine DMR, GOMC, PISCO, AMNH, Nature Conservancy, Conservation Int'l

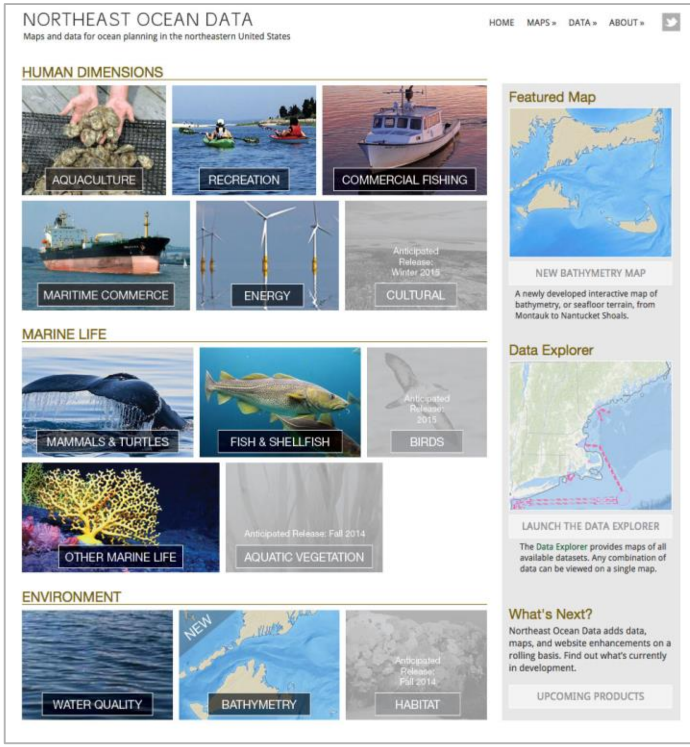
•Peter Taylor: M.A. Ecology (UCSB). Magazine editor & freelancer before founding Waterview Consulting. Also worked at Wells Reserve 1992-93.

•Project team: Molly Brown, Keil Schmid, Sally Ann Sims

•Some related projects:







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Guidance for Modeling Marsh Migration for Management Decision-Making

Goal: Support and catalyze the effective use of marsh models and their results to provide information for management decision-making

Audiences: State and federal government staff engaged in management and policy activities related to protecting and sustaining salt marshes
Municipal and NGO staff

Steering Committee: Representatives from State and Federal agencies

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Outline

Overview of Draft Guidance on Marsh Migration Modeling

- Are the content, structure, and take-home messages of the draft guidance document on target?
- What should be added? Removed? Reorganized?
- What recommendations for next steps should be made in the document?

Please contact Peter if you would like to talk more in-depth and/or have feedback or ideas.

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Marsh Modeling Overview

A Practitioner's Review of Existing Models and How They Compare

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Geoscience Consultants – Keil Schmid

- Working with Waterview Consulting on the Guidance Document
- Previously worked for NOAA Coastal Services Center
  - Sea Level Rise Viewer – Elevation data guy
  - Helped develop CSC marsh migration tool
  - Developed CSC uncertainty method (Schmid et al., 2014)
  - Worked on lidar and marshes (Schmid et al., 2011)
  - Worked with Waterview on “Marshes on the Move”
  - Grew up playing in/on mud flats on the North Shore of Boston (with Peter)

All Models Have Utility

Like any tool – user determines the outcome
One size *does not* fit all

- What are the questions being asked
- What data exists or will be gathered
- What parameters are being used/are important
- How far into the future are you looking (unknowns go up)
- Who is the audience
- How wrong are you willing to be
- How much time/money are you willing to invest
- Complexity does not necessarily equal better

Basic Model Categories (informal bins*)

- Rules Based – The 'Practical' Models we use
  - Elevation (Type I) = Tide Levels + SLR + Land Cover Zones
  - Elevation and Time (Type II) = Type I + Time x Accretion/subsidence
  - Geomorphic (Type III) = Type II + Land Cover and Geomorphic/Empirical Rules
- Mechanistic/Bio-Physical Models – High Data & Time Requirements
  - Ecogeomorphic Models
  - Fundamental Marsh Processes'
  - Bio-physical feedbacks

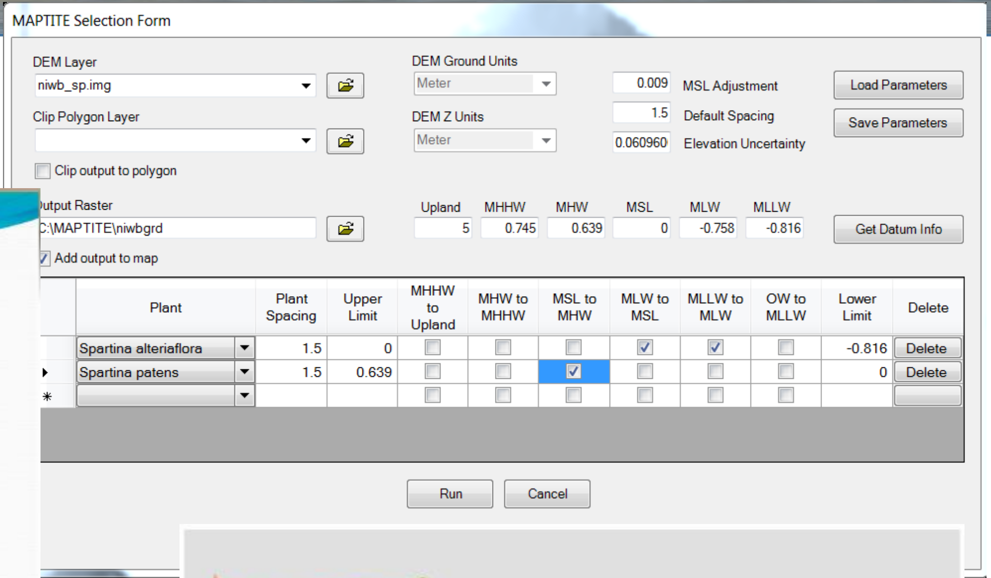
* Many ways to group including: tools, processes, viewers, equations, hybrids, etc.

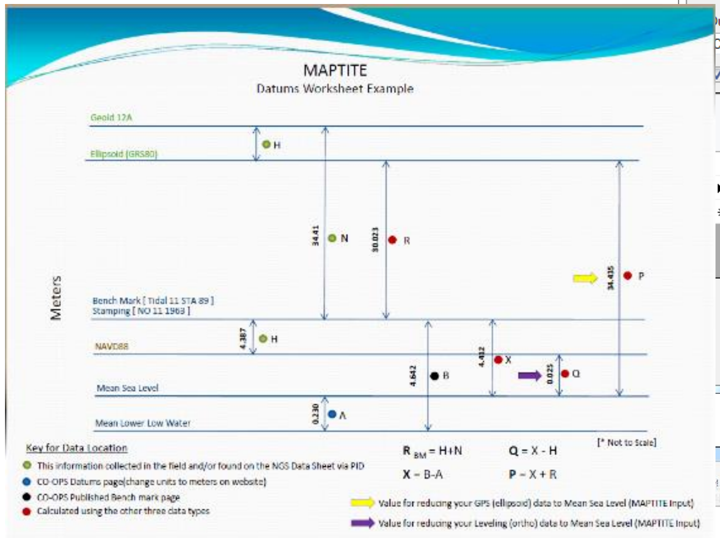
Rules Based Models – A sample of the many

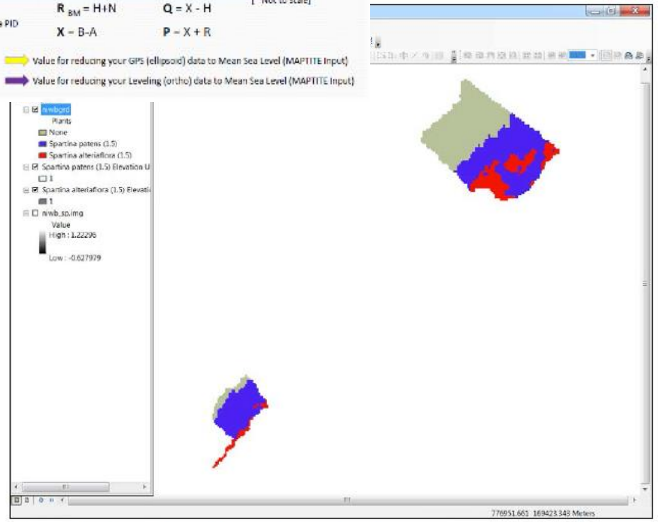
- Elevation (Type I)
  - MAPTITE
  - MAST Model
- Elevation and Time (Type II)
  - TNC Coastal Resilience Model
  - NOAA SLR and Inundation Viewer
  - TNC Salt Marsh Migration Tool (SMMT)
- Geomorphic (Type III)
  - SLAMM
  - Point Blue Conservation Science Model/Tool (Bridge to Eco-Geomorphic Models)

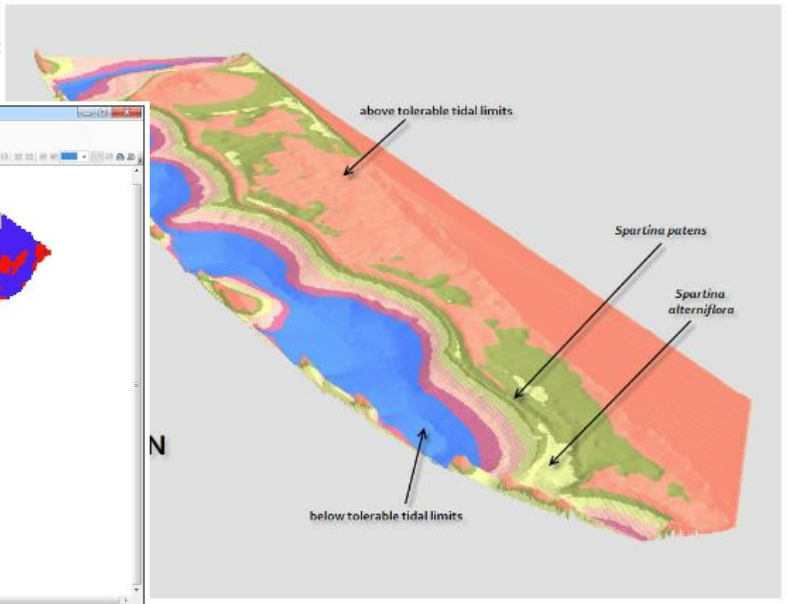
Type I: MAPTITE – NOAA NGS

- Strictly elevation based
- ArcGIS tool (requires spatial analyst)
- Designed for marsh restoration
- Can be used with projected SLR
- Plant specific
- Lots (!) of good datum info in the help



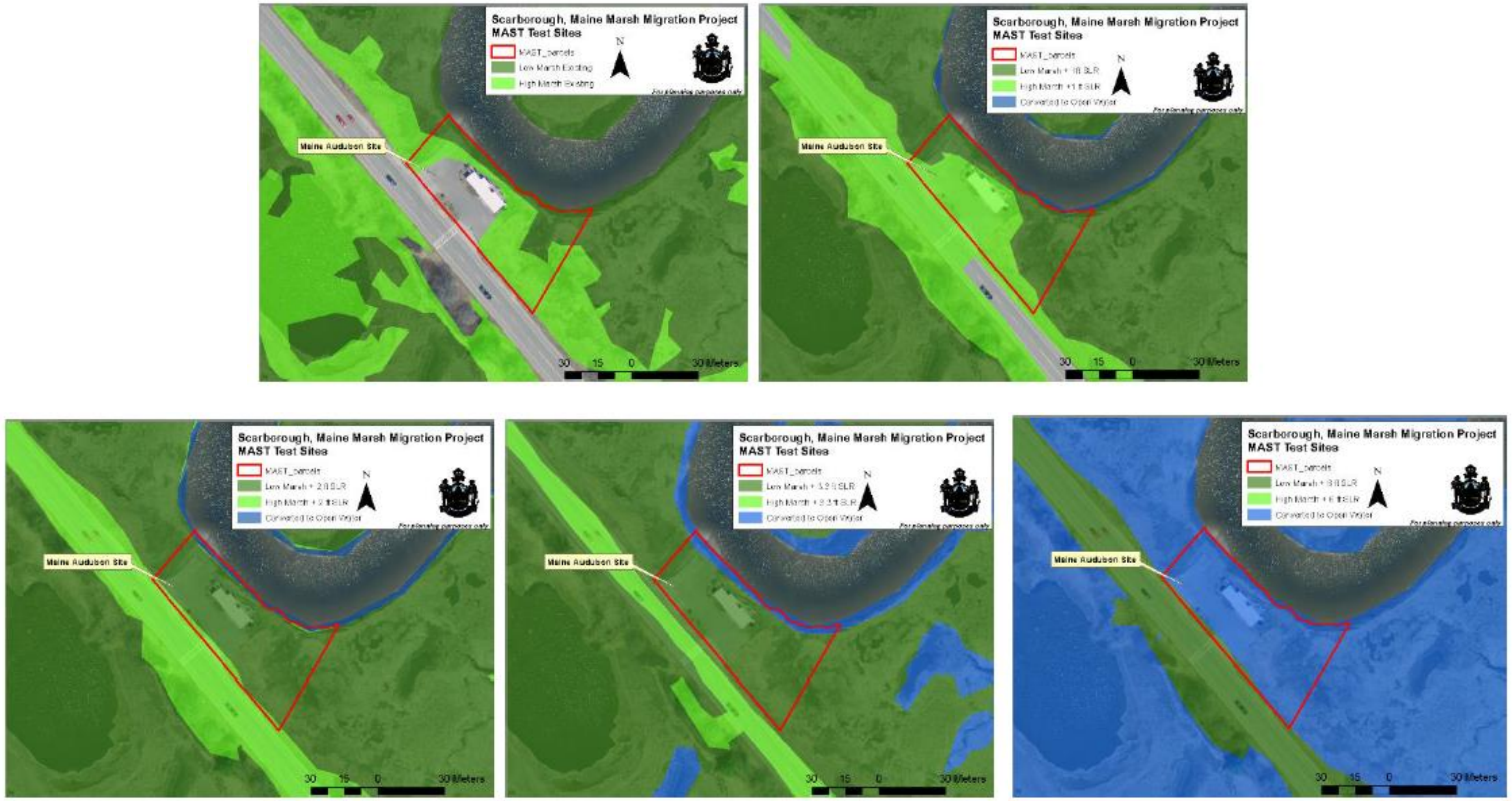






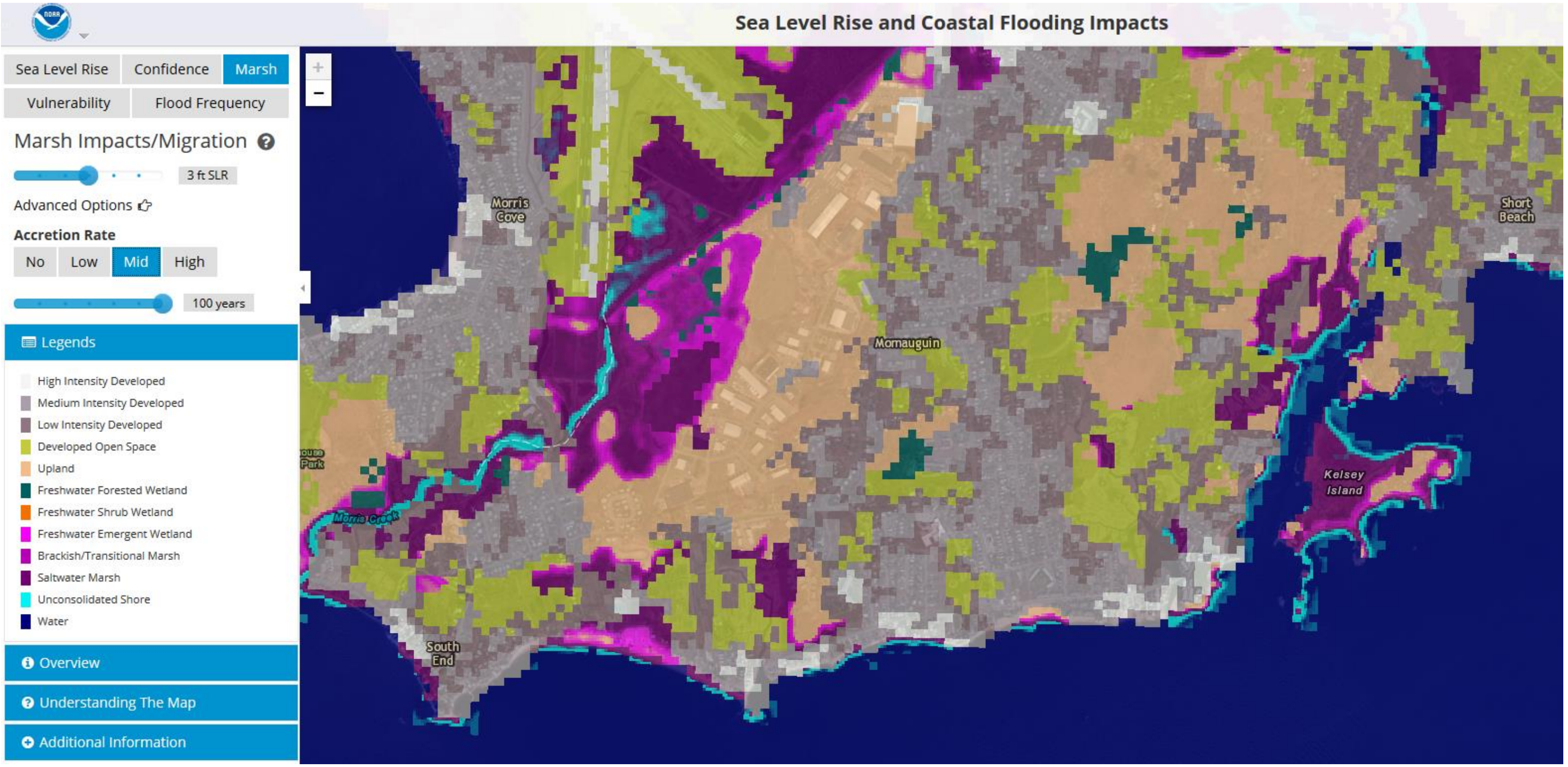
Type I: MAST (Marsh Adaptation Strategy Tool)

- Use of pre-made DEMs for various SLR scenarios (1, 2, 3.3, and 6 ft) by 2100.
- Run with Global Mapper GIS
- Patterned after COAST tool – depth/damage
- Merging polygon information
- Primary use is cost-benefit analysis (UNIQUE ASPECT)



Type II: NOAA SLR and Inundation Viewer

- Use of CCAP land cover
- Model runs in Erdas Imagine
- Varying accretion rates and times (flat rates for all land covers)
- SLAMM elevation rules (not transition rules)
- No connectivity assessment
- Error portrayed in outputs as shading
- VDatum tide data



Type II: TNC Marsh Migration Tools – Coastal Resilience Viewer

- Custom land cover base layer
- Connectivity accounted for
- Set dates using A2 scenario
- Only shows advancement zones
- Flat accretion rates

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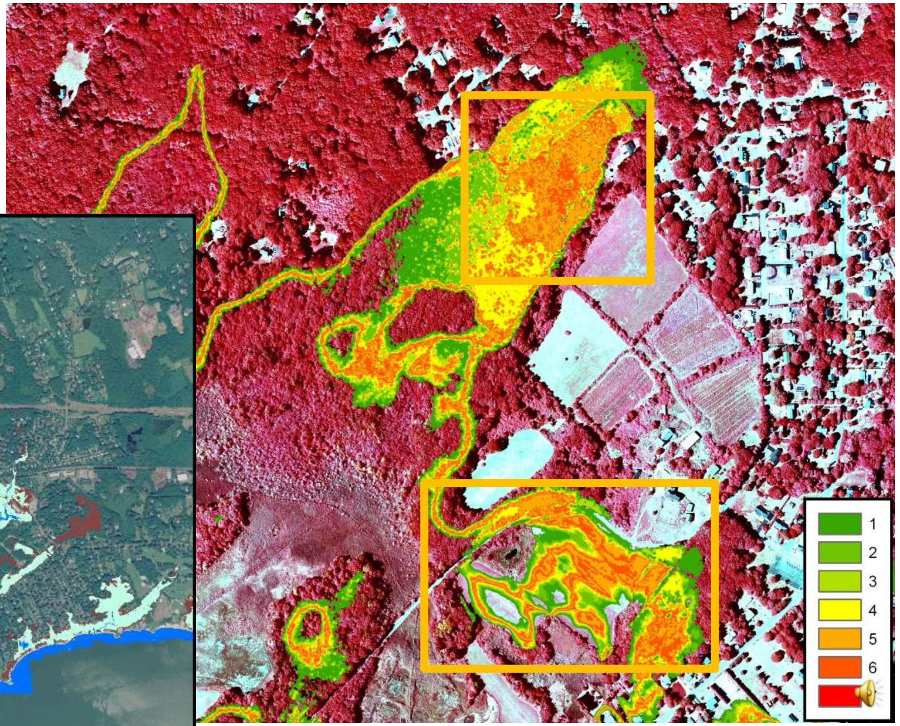
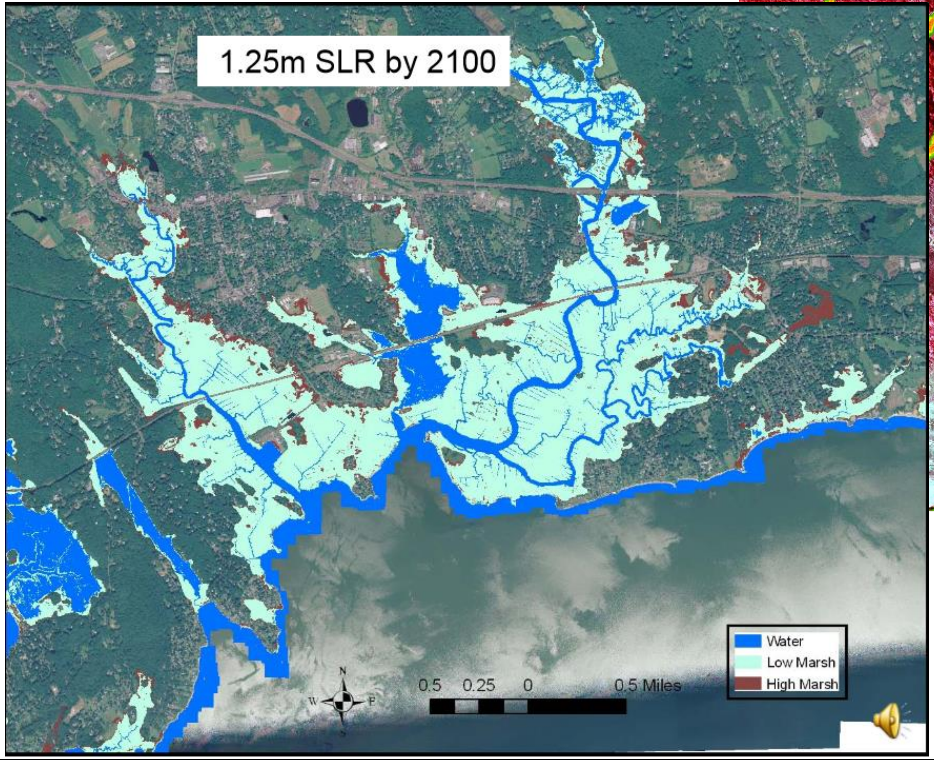
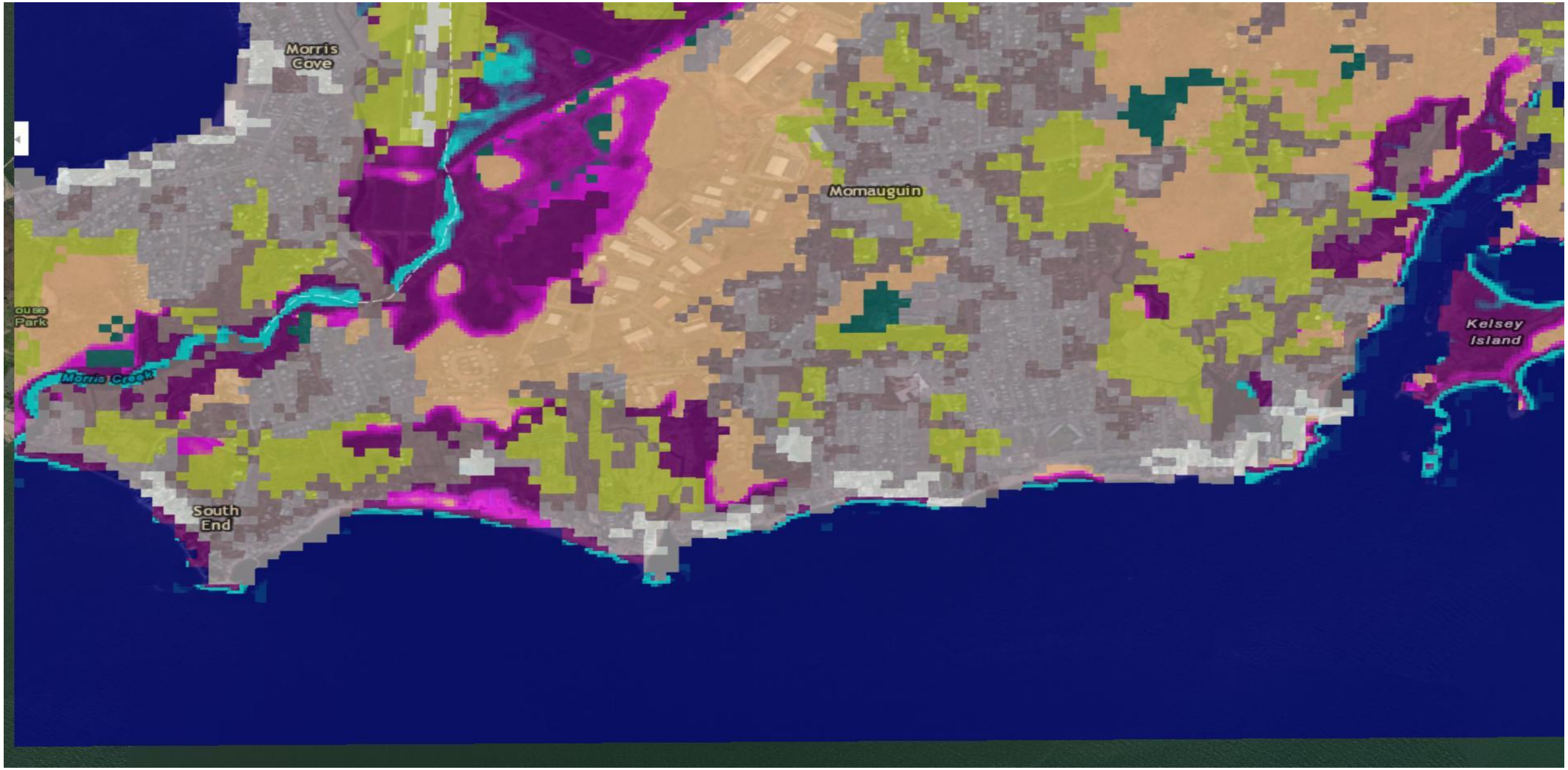
Type II: TNC Salt Marsh Migration Tool (Process)

- Same land cover categories as CR
- Hydro-enforced DEM
- Use of RMSE of lidar (errors) to provide ‘confidence’ in marsh migration (unique aspect)
- High and low marsh outputs
- Run in ArcGIS



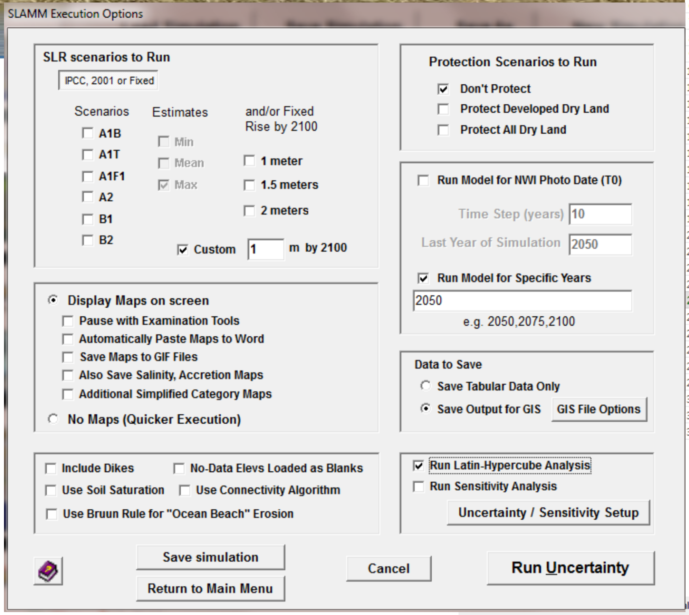


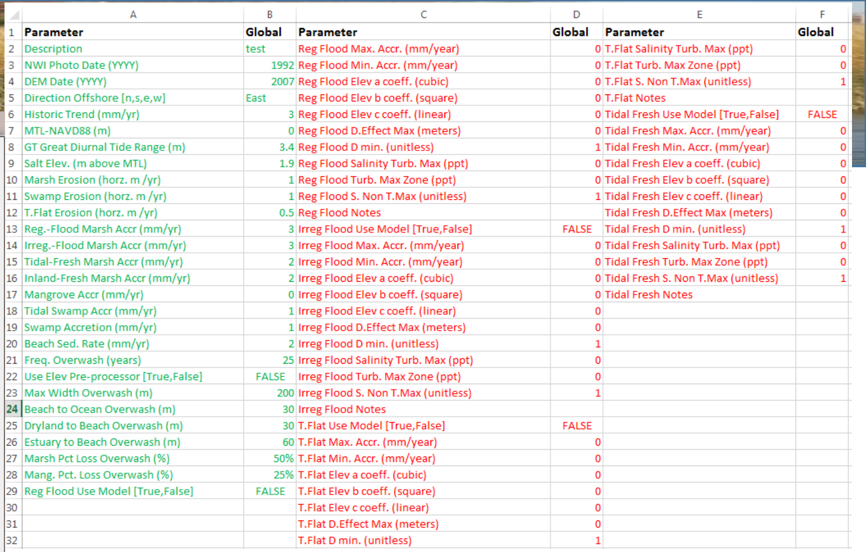
Comparison of NOAA and TNC Tools



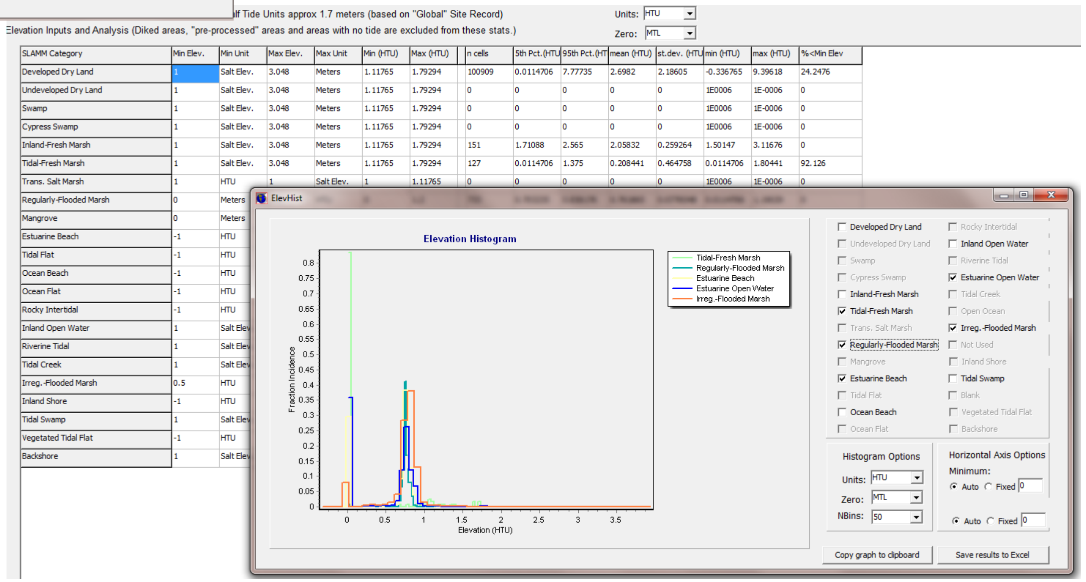
Type III: SLAMM

- Empirical accretion or Land cover based accretion options
- Rules based land cover transitions
- Geomorphic/landscape processes (overwash, erosion)
- Data and parameter ensemble and sensitivity analysis
- Vdatum use
- Use of NWI land cover (cross-walked)



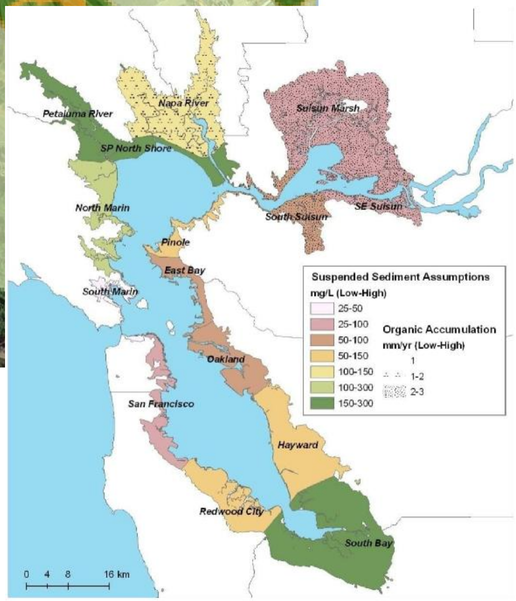


	A	B	C	D	E	F
1	Parameter	Global	Parameter	Global	Parameter	Global
2	Description	test	Reg Flood Max. Accr. (mm/year)	0	T.Flat Salinity Turb. Max (ppt)	0
3	NWI Photo Date (YYYY)	1992	Reg Flood Min. Accr. (mm/year)	0	T.Flat Turb. Max Zone (ppt)	0
4	DEM Date (YYYY)	2007	Reg Flood Elev a coeff. (cubic)	0	T.Flat S. Non T.Max (unitless)	1
5	Direction Offshore [n,s,e,w]	East	Reg Flood Elev b coeff. (square)	0	T.Flat Notes	
6	Historic Trend (mm/yr)	3	Reg Flood Elev c coeff. (linear)	0	Tidal Fresh Use Model [True,False]	FALSE
7	MTL-NAVD88 (m)	0	Reg Flood D.Effect Max (meters)	0	Tidal Fresh Max. Accr. (mm/year)	0
8	GT Great Diurnal Tide Range (m)	3.4	Reg Flood D min. (unitless)	1	Tidal Fresh Min. Accr. (mm/year)	0
9	Salt Elev. (m above MTL)	1.9	Reg Flood Salinity Turb. Max (ppt)	0	Tidal Fresh Elev a coeff. (cubic)	0
10	Marsh Erosion (horz. m /yr)	1	Reg Flood Turb. Max Zone (ppt)	0	Tidal Fresh Elev b coeff. (square)	0
11	Swamp Erosion (horz. m /yr)	1	Reg Flood S. Non T.Max (unitless)	1	Tidal Fresh Elev c coeff. (linear)	0
12	T.Flat Erosion (horz. m /yr)	0.5	Reg Flood Notes		Tidal Fresh D.Effect Max (meters)	0
13	Reg.-Flood Marsh Accr (mm/yr)	3	Irreg Flood Use Model [True,False]	FALSE	Tidal Fresh D min. (unitless)	1
14	Irreg.-Flood Marsh Accr (mm/yr)	3	Irreg Flood Max. Accr. (mm/year)	0	Tidal Fresh Salinity Turb. Max (ppt)	0
15	Tidal-Fresh Marsh Accr (mm/yr)	2	Irreg Flood Min. Accr. (mm/year)	0	Tidal Fresh Turb. Max Zone (ppt)	0
16	Inland-Fresh Marsh Accr (mm/yr)	2	Irreg Flood Elev a coeff. (cubic)	0	Tidal Fresh S. Non T.Max (unitless)	1
17	Mangrove Accr (mm/yr)	0	Irreg Flood Elev b coeff. (square)	0	Tidal Fresh Notes	
18	Tidal Swamp Accr (mm/yr)	1	Irreg Flood Elev c coeff. (linear)	0		
19	Swamp Accretion (mm/yr)	1	Irreg Flood D.Effect Max (meters)	0		
20	Beach Sed. Rate (mm/yr)	2	Irreg Flood D min. (unitless)	1		
21	Freq. Overwash (years)	25	Irreg Flood Salinity Turb. Max (ppt)	0		
22	Use Elev Pre-processor [True,False]	FALSE	Irreg Flood Turb. Max Zone (ppt)	0		
23	Max Width Overwash (m)	200	Irreg Flood S. Non T.Max (unitless)	1		
24	Beach to Ocean Overwash (m)	30	Irreg Flood Notes			
25	Dryland to Beach Overwash (m)	30	T.Flat Use Model [True,False]	FALSE		
26	Estuary to Beach Overwash (m)	60	T.Flat Max. Accr. (mm/year)	0		
27	Marsh Pct Loss Overwash (%)	50%	T.Flat Min. Accr. (mm/year)	0		
28	Mang. Pct. Loss Overwash (%)	25%	T.Flat Elev a coeff. (cubic)	0		
29	Reg Flood Use Model [True,False]	FALSE	T.Flat Elev b coeff. (square)	0		
30			T.Flat Elev c coeff. (linear)	0		
31			T.Flat D.Effect Max (meters)	0		
32			T.Flat D min. (unitless)	1		



Point Blue

- Use of mechanistic model (Marsh 98) runs
- Sediment concentration and elevation (length of inundation)
- Includes organic and mineral sedimentation
- No land cover data used
- Hybrid Model/Tool



Eco-Geomorphic Models

- Marsh 98 Model
- Marsh Equilibrium Model – 'MEM'
- Kirwan Model

MARSH 98

- Early mechanistic model
- Straight forward
- Point (1D) model
- Vegetation neutral

The MARSH 98 model assumes that the elevation of a marsh surface increases at a rate that depends on the (1) availability of suspended sediment and (2) depth and period of inundation by high tides. MARSH 98 is based on the mass balance of suspended sediment of the water column using Krone's (1987) mass balance equation:

$$\frac{d\eta}{dt} \geq 0 \qquad\qquad \frac{d\eta}{dt} < 0$$

$$(\eta - z)\frac{dC}{dt} = -V_s C + (C_o - C)\frac{d\eta}{dt} \qquad\qquad (\eta - z)\frac{dC}{dt} = -V_s C$$

where:
η = Water surface elevation,
z = Marsh plain elevation,
C = Suspended sediment concentration,
t = Time,
V_s = Settling velocity, and
C_o = Ambient suspended sediment concentration of flood laden waters.

The settling velocity for suspended particles has this relation ship:

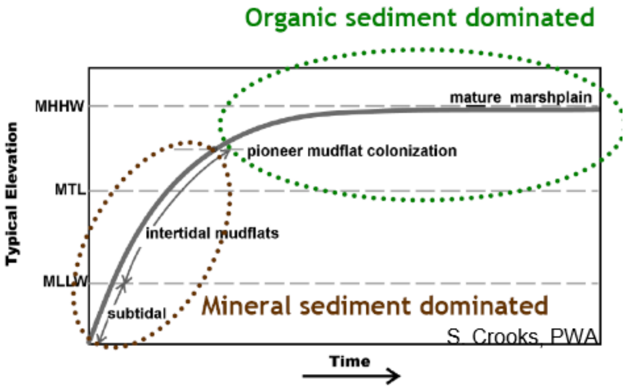
$$V_s = KC^{4/3}$$

Vs = Settling velocity,
K = A constant (0.00011 when units are S.I. Metric), and
C = Suspended sediment concentration.

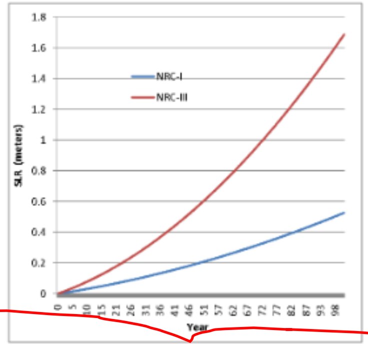
Accumulation of material on the bed is determined by:

$$\Delta z = \frac{\int_t V_s C dt}{C_d}$$

Δz = Change in bed elevation,
V_s = Settling velocity,
C = Suspended sediment concentration, and
C_d = Dry density of inorganic material in the deposit.



From National Research Council, adopted by ACOE

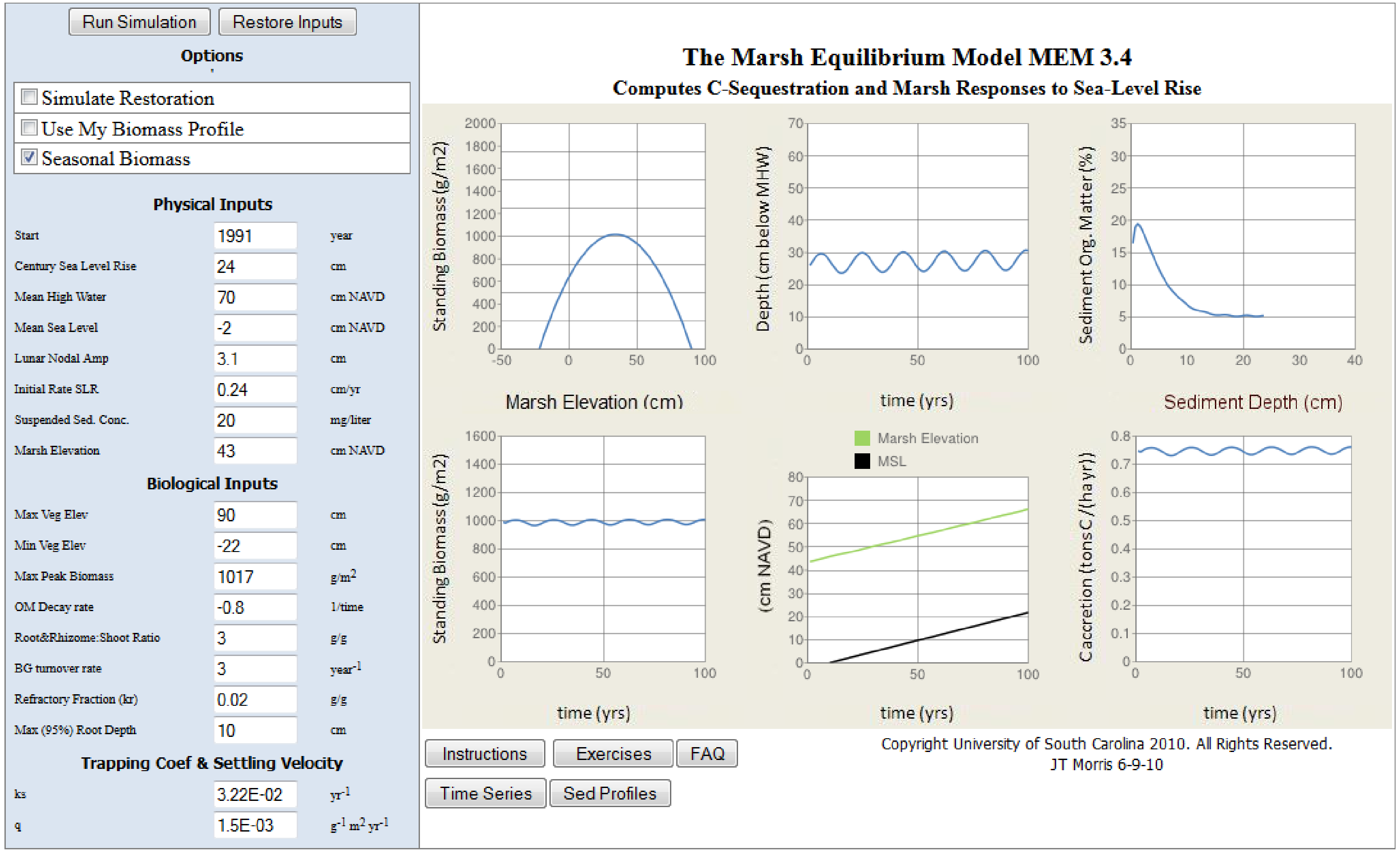


Weaknesses of the model
One dimensional , no sediment transport, erosion scouring underestimated, sediment accumulation from extreme tides underestimated

Strengths of the Model
Applied throughout the San Francisco Estuary and accurately reproduces observed accretion. Computationally efficient.

Marsh Equilibrium Model - MEM

- Online tool
- 1D model
- Developed for *Spartina alternaflora* (low marsh)
- Curves can be calibrated for other vegetation (done in a SF study)



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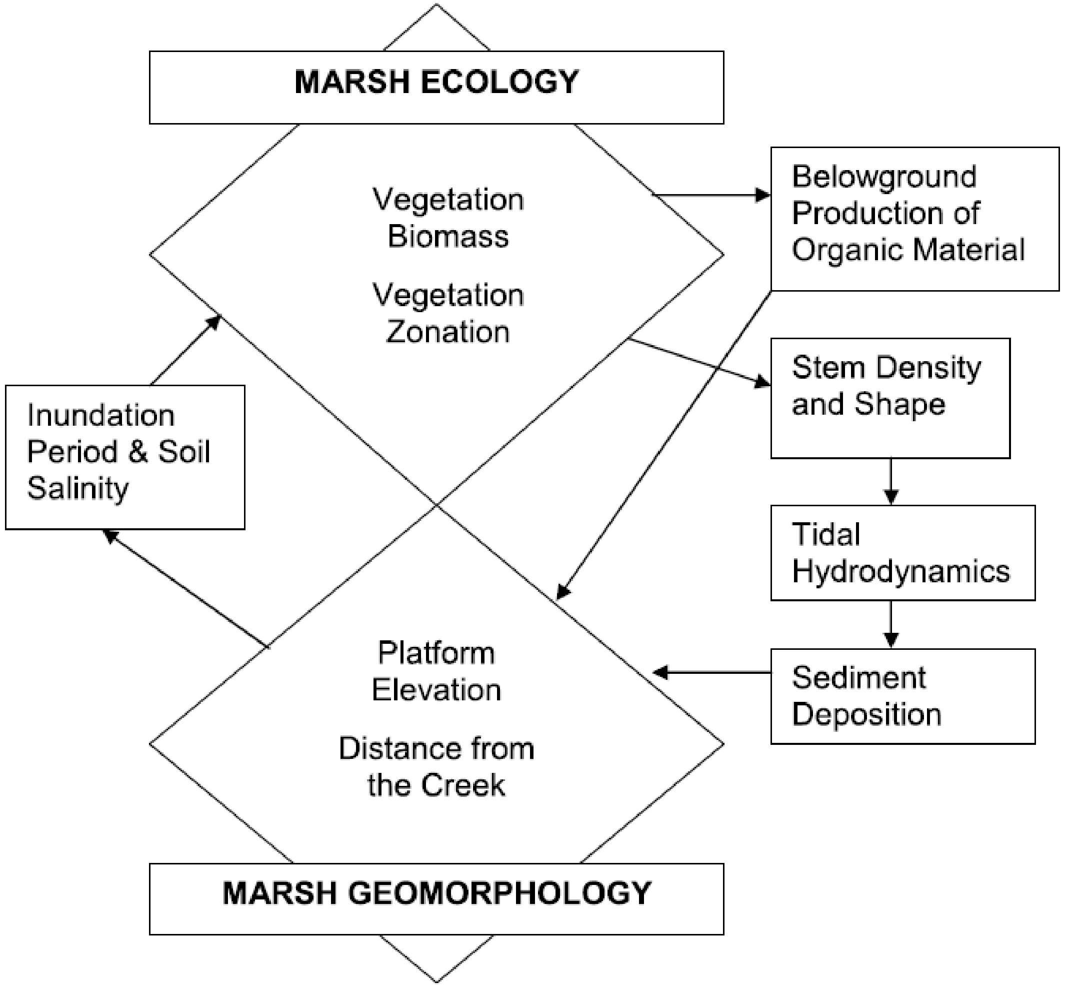
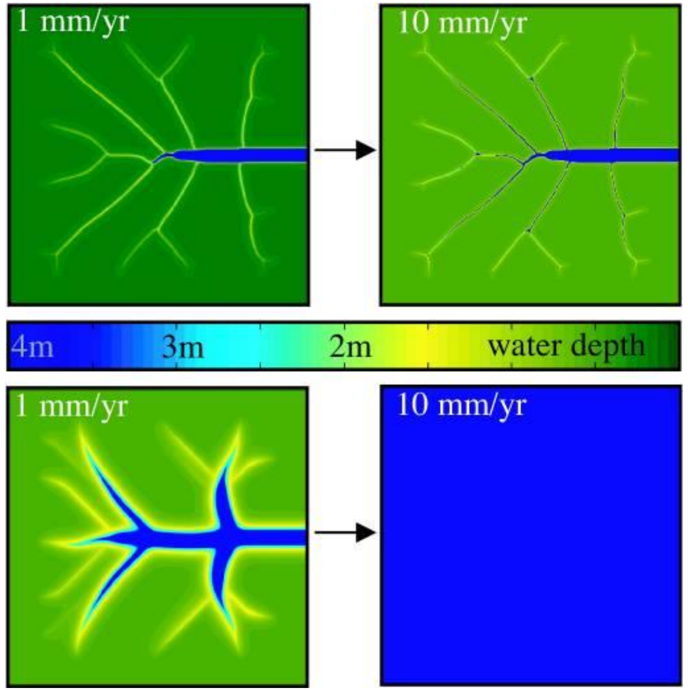
Waterview Consulting

Kirwan Model

- Ecogeomorphic Model
- Includes erosion/hydrologic processes
- 2D outputs





Quick Summary of Models/Tools

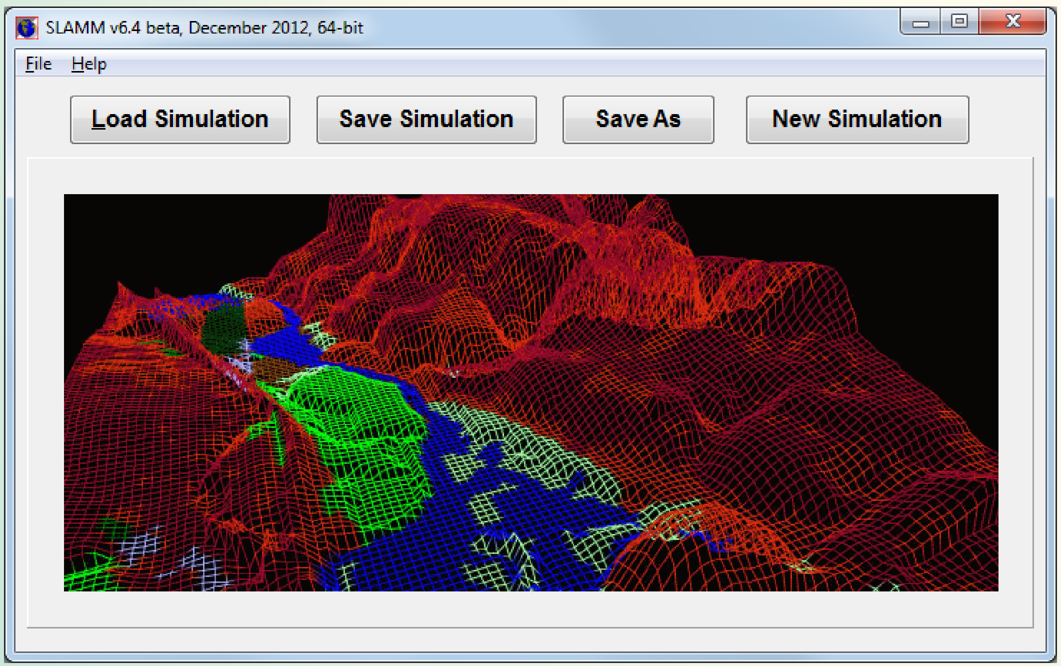
Model	Platform	Data Required	Notes
MAPTITE	Arc GIS	Veg, Elev, Tidal	Restoration based, Shp outputs, Datum info
MAST	Global Mapper	Elev, Wetland Benefit Unit	Similar to COAST,
NOAA Viewer	Internet/static	None	Outputs available, variable 'scenarios'
TNC Viewer	Internet/static	None	Location specific, single scenario other online tools
TNC SMMT	Arc GIS	Elev, LC, Tidal, RMSE	Nice use of uncertainty
SLAMM	Stand Alone	Variable (simple to complex)	Scalable, varying levels of expertise
Point Blue	Internet/static	None	SF specific, Hybrid model/tool, several scenarios
MARSH 98	Equation	Sed Conc, Elev, Tides	Robust, used in Point Blue, no vegetation interaction
MEM	Internet/Equation	Veg specs, Elev, Tides	Spartina specific, can be tuned to other veg
Kirwan	Program/custom	Custom, Elev, Tides, Veg specs	Ecogeomorphic – too complex for landscape modeling

Wrap Up/Food for Thought

- Question(s) being asked narrow the modeling field
- Outputs – life is getting better for us ‘practitioners’
- How to implement uncertainty in the final results
- How do urban settings affect models
- How much error is generated at time 0 and where does that lead
- Organic deposition vs. mineral deposition
- Glacial geology and landforms
- Ice rafting – does this affect models
- Sedimentation and timing (winter and storms)
- Great Reference: "Numerical Models of Salt Marsh Evolution: Ecological, Geomorphic, and Climatic Factors" (2012). *Environmental Science.* Paper 10. http://cedar.wwu.edu/esci_facpubs/10

Sea Level Affecting Marshes Model (SLAMM)

Model Overview



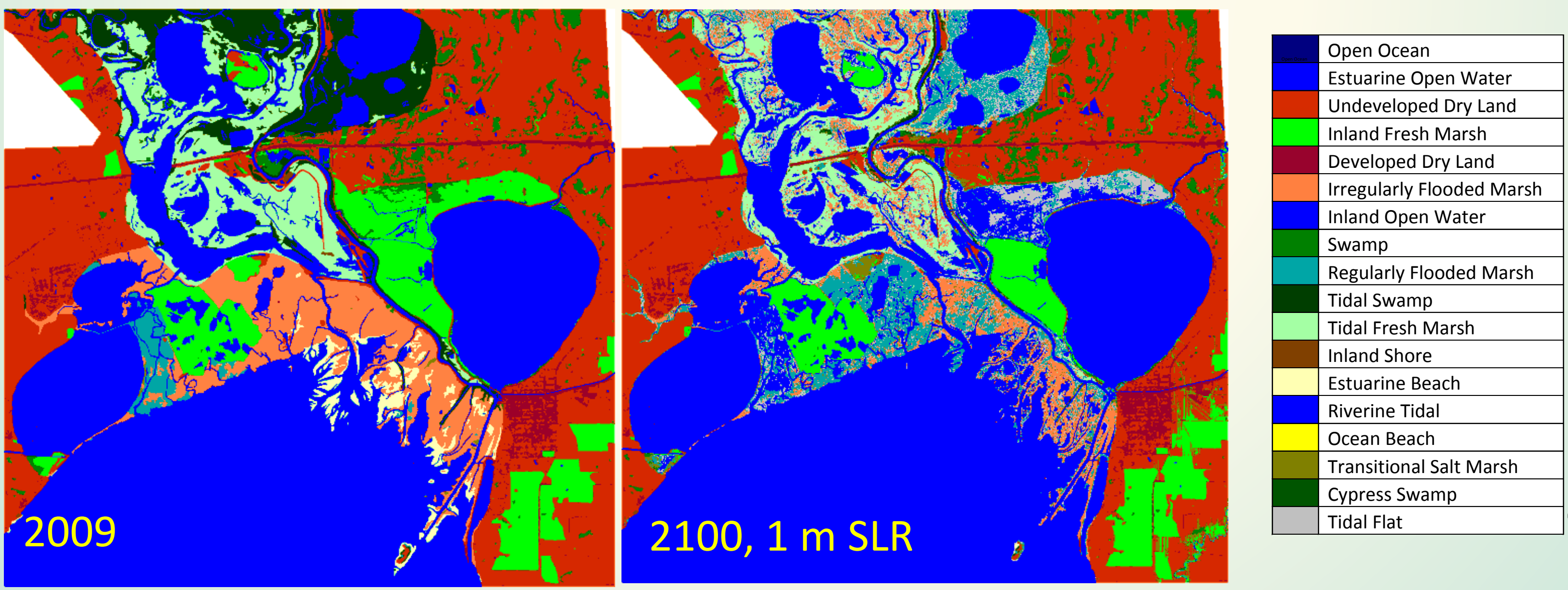
Jonathan Clough

warren pinnacle consulting, inc.

Dr. Marco Propato   Dr. Amy Polaczyk   Jonathan S. Clough

SLAMM
Sea Level Affecting Marshes Model

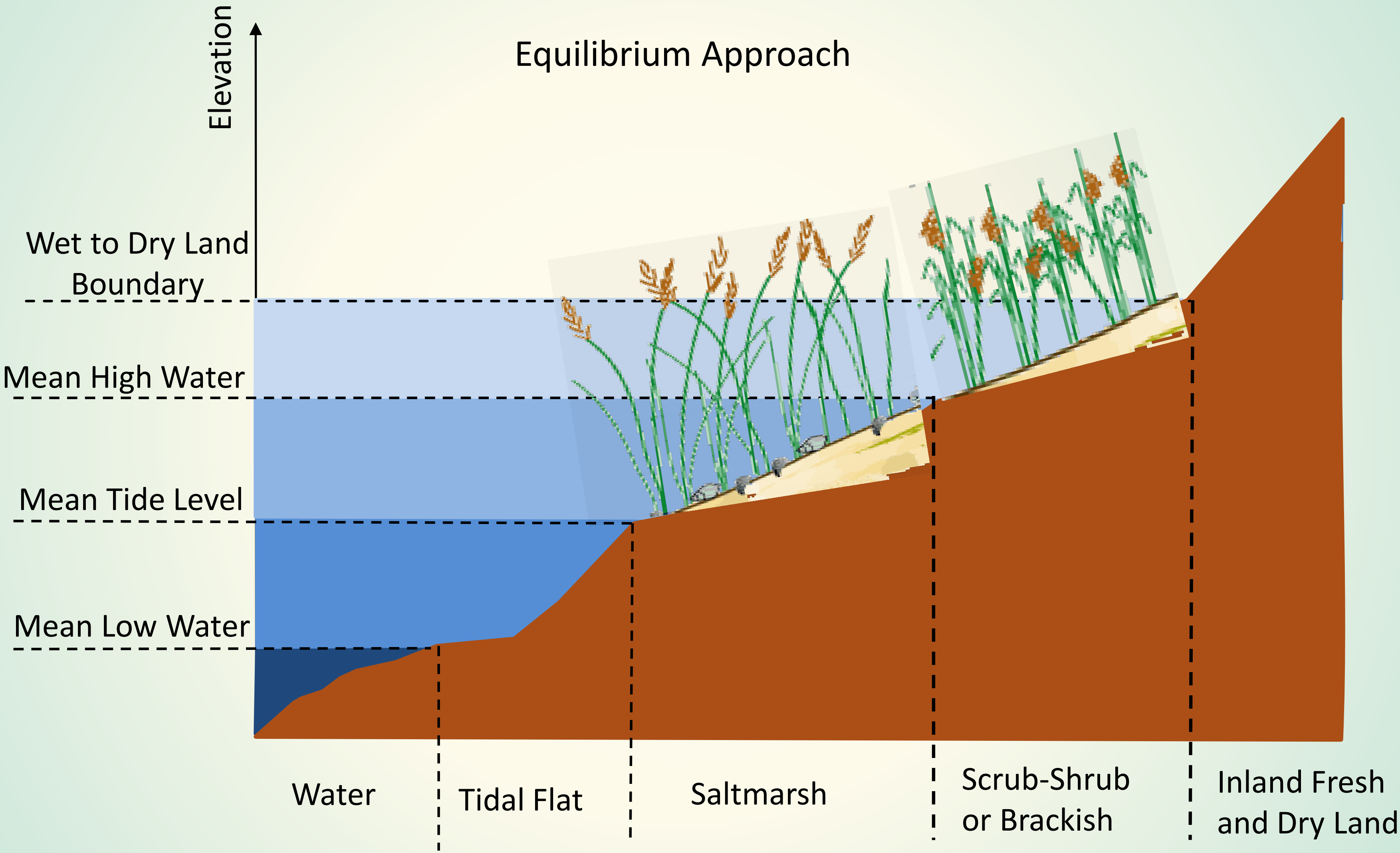
- Simulates the dominant processes involved in wetland conversions under different scenarios of sea level rise
- Uses a complex decision tree incorporating geometric and qualitative relationships to represent transfers among coastal classes
- Provides maps and projections of how coastal habitats will change in response to sea-level rise



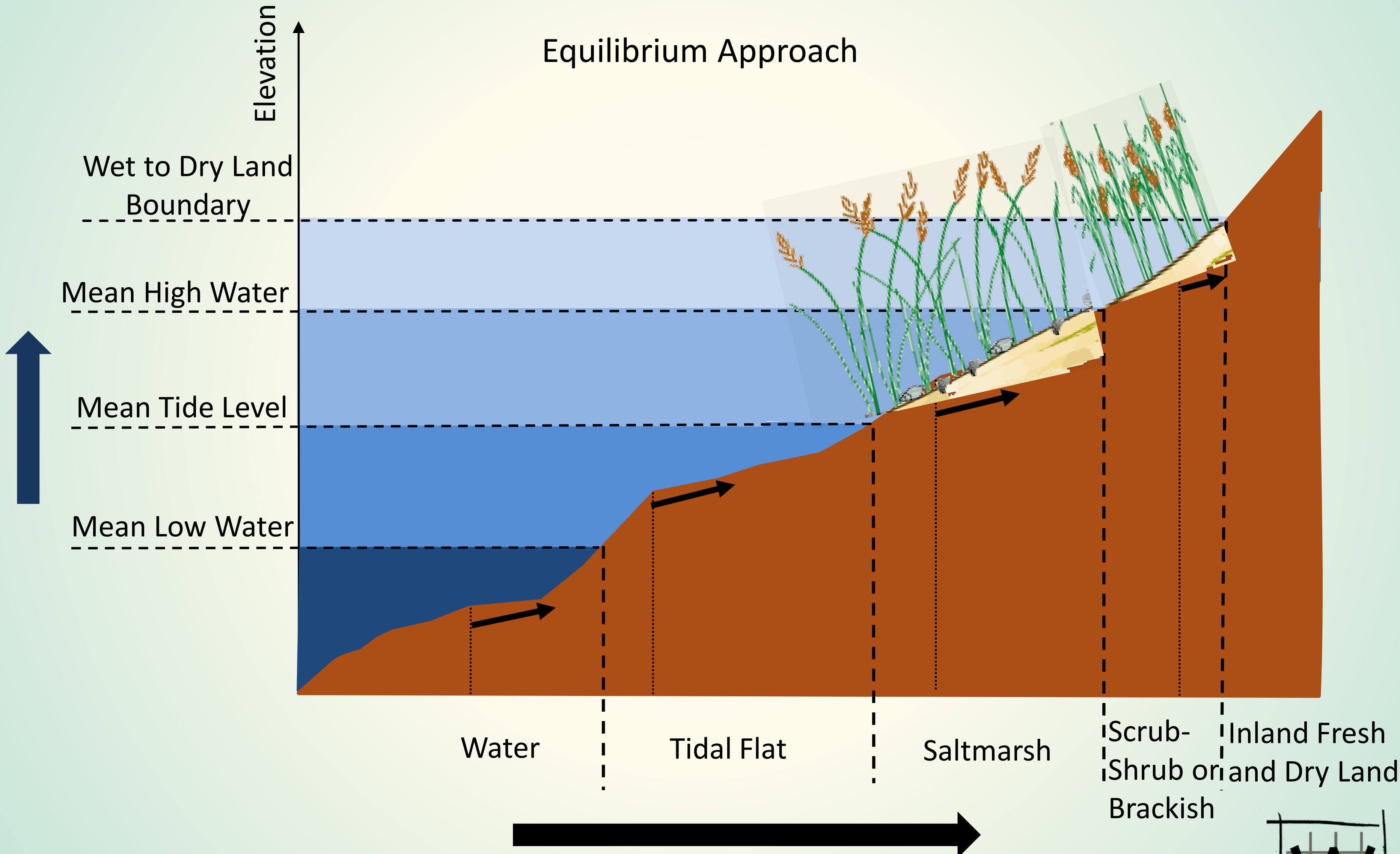
Model Strengths

- Relatively simple model
- Open source
- Minimal data requirements
- Ease and cost of application
- Quick to run
- Contains the major processes pertinent to wetland fate
- Mechanistic accretion feedbacks
- Provides information needed by policymakers

SLAMM Inundation Model

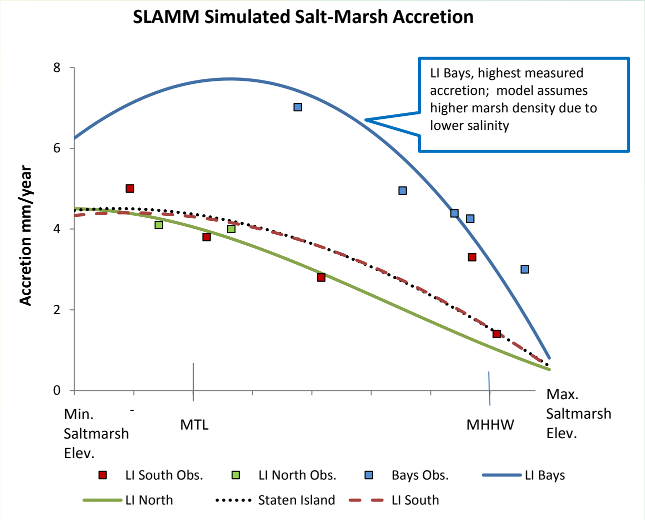


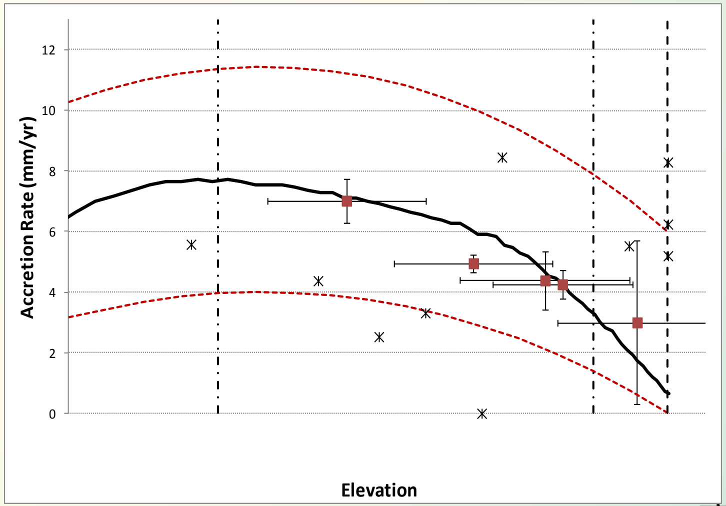
SLAMM Inundation Model

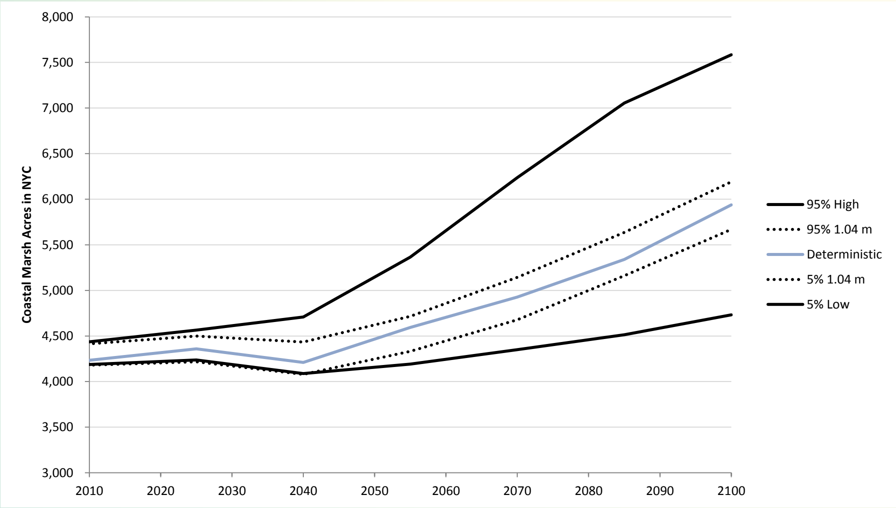


Complexity

- Hydraulic Connectivity
- Salinity
- Dikes & Levees
- Marsh Accretion Feedbacks
- Uncertainty Analysis







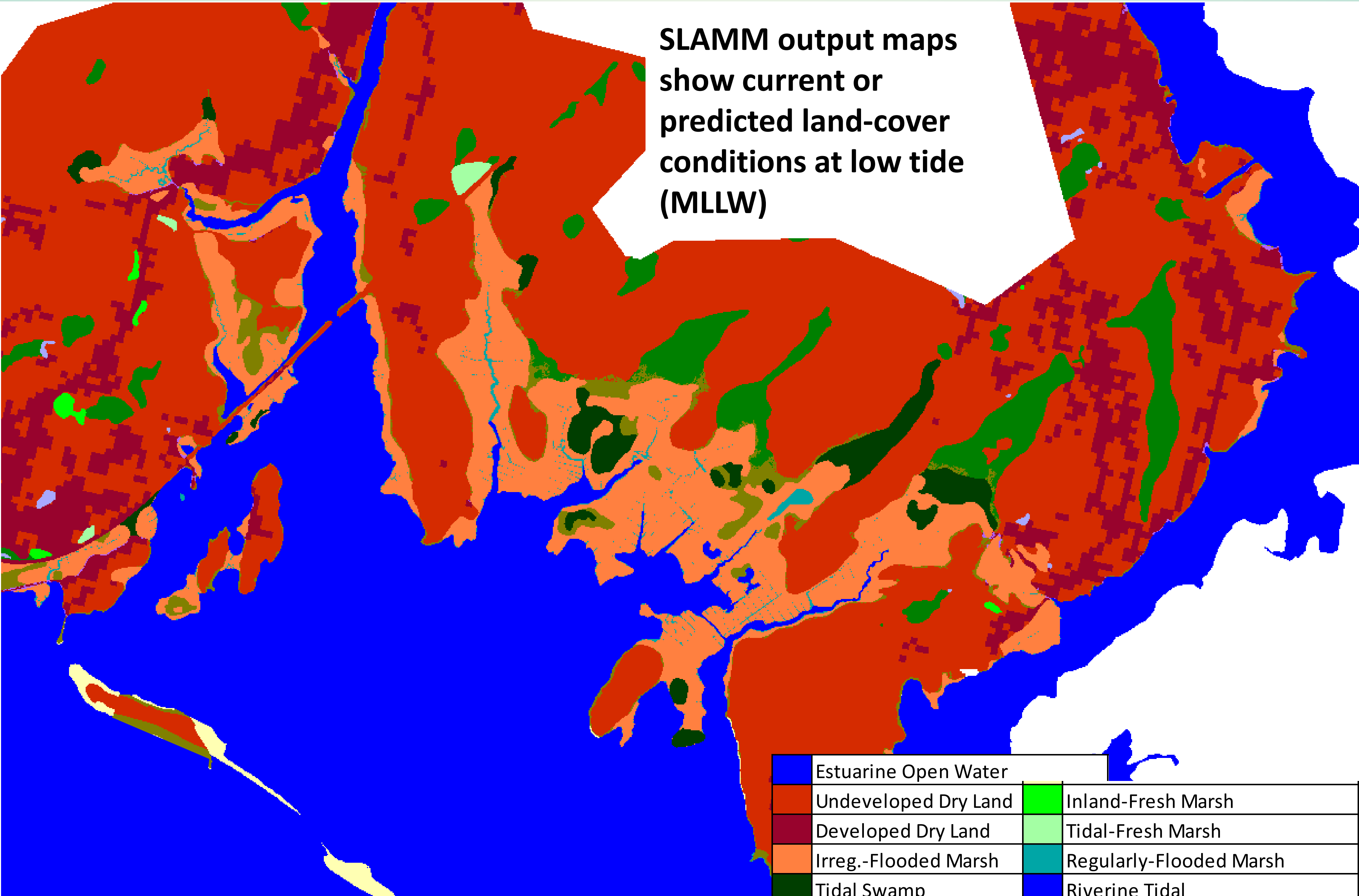
Model Limitations

- **Not a hydrodynamic model**
- **No sediment transport**
- **Some modeled processes are relatively simple**
  - **Beach Erosion**
  - **Barrier-Island Overwash**
- **Large Storm Effects undercounted**

Data Sources

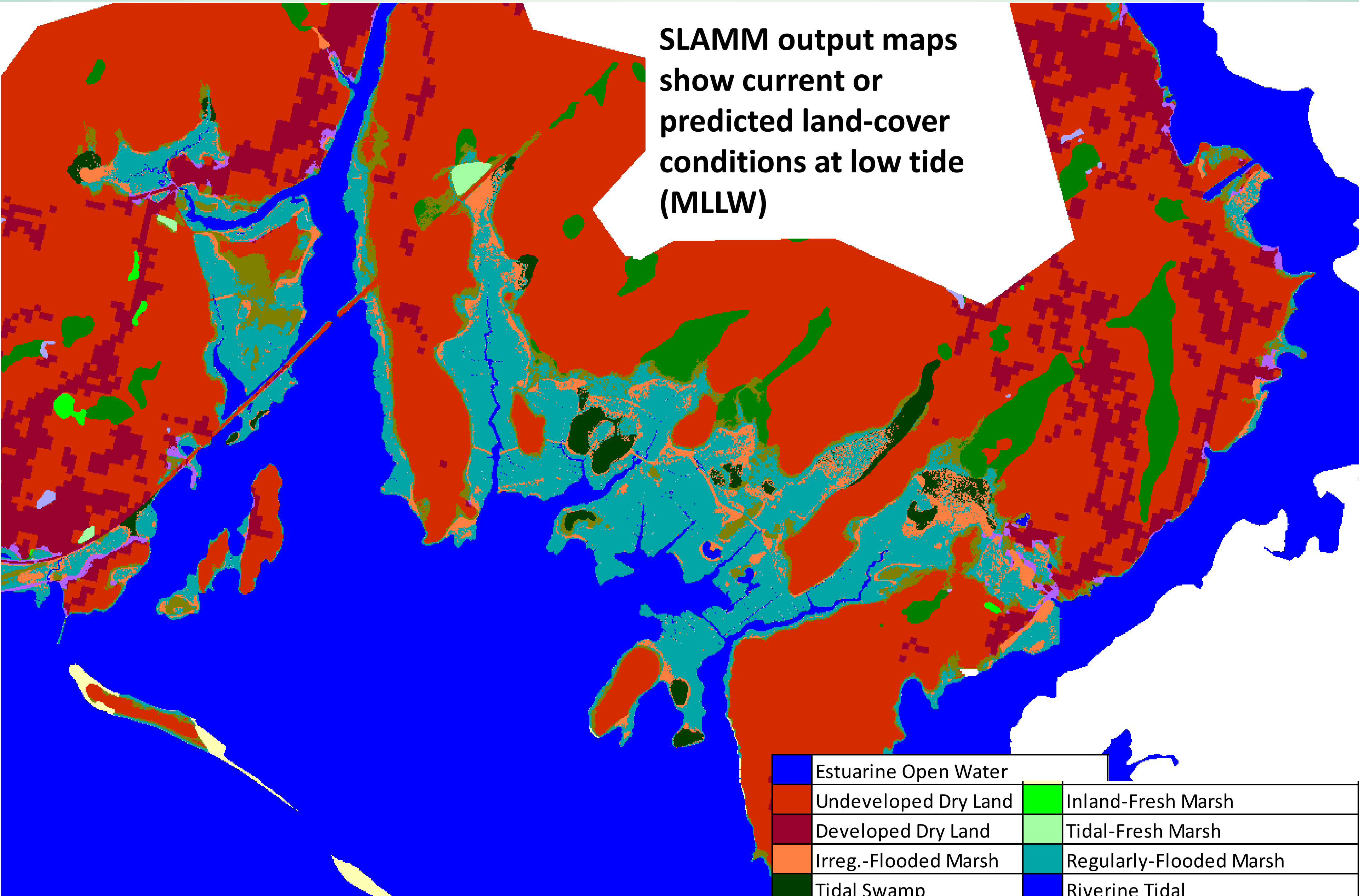
- Elevation Data
- Wetland Layers
- Tide Ranges & Frequency of Flooding
- Dikes and Impoundments
  - NWI, USACE NLD, manual additions
- Percent Impervious
- Accretion Rates
- Erosion Rates
- Uncertainty and Variability

SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)



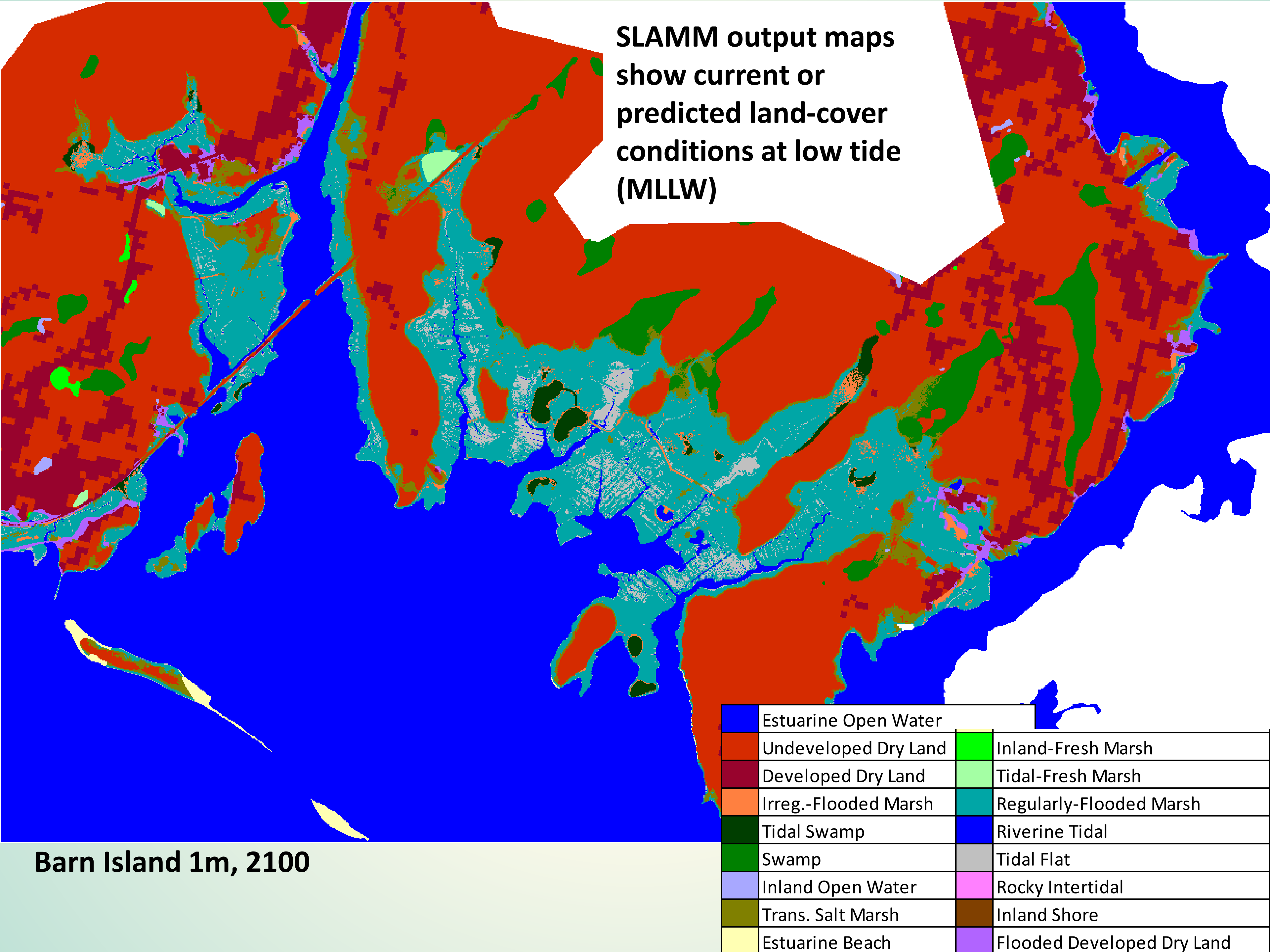
Barn Island Time Zero, 2010

SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)



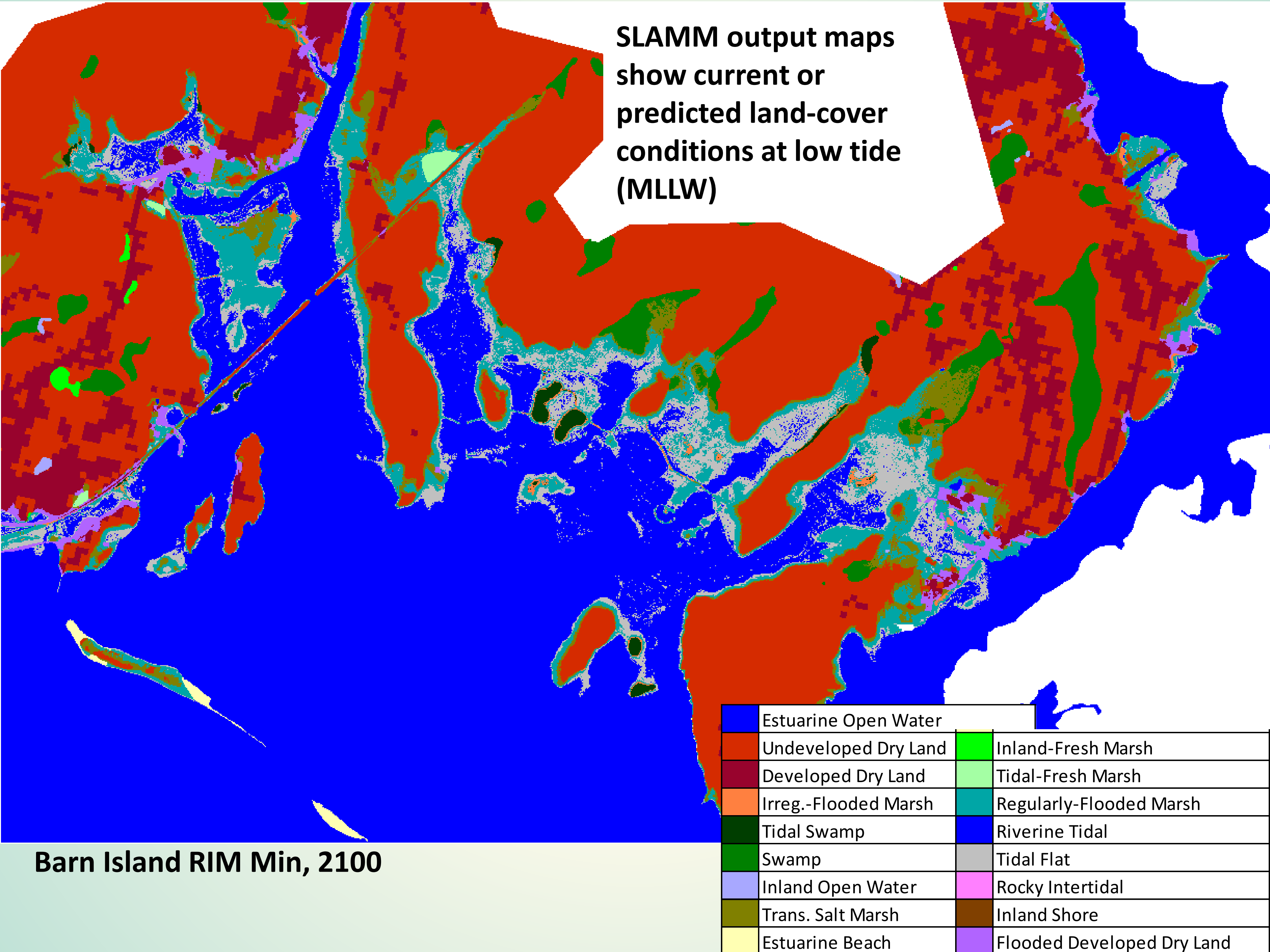
Barn Island GCM Max, 2100

SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)



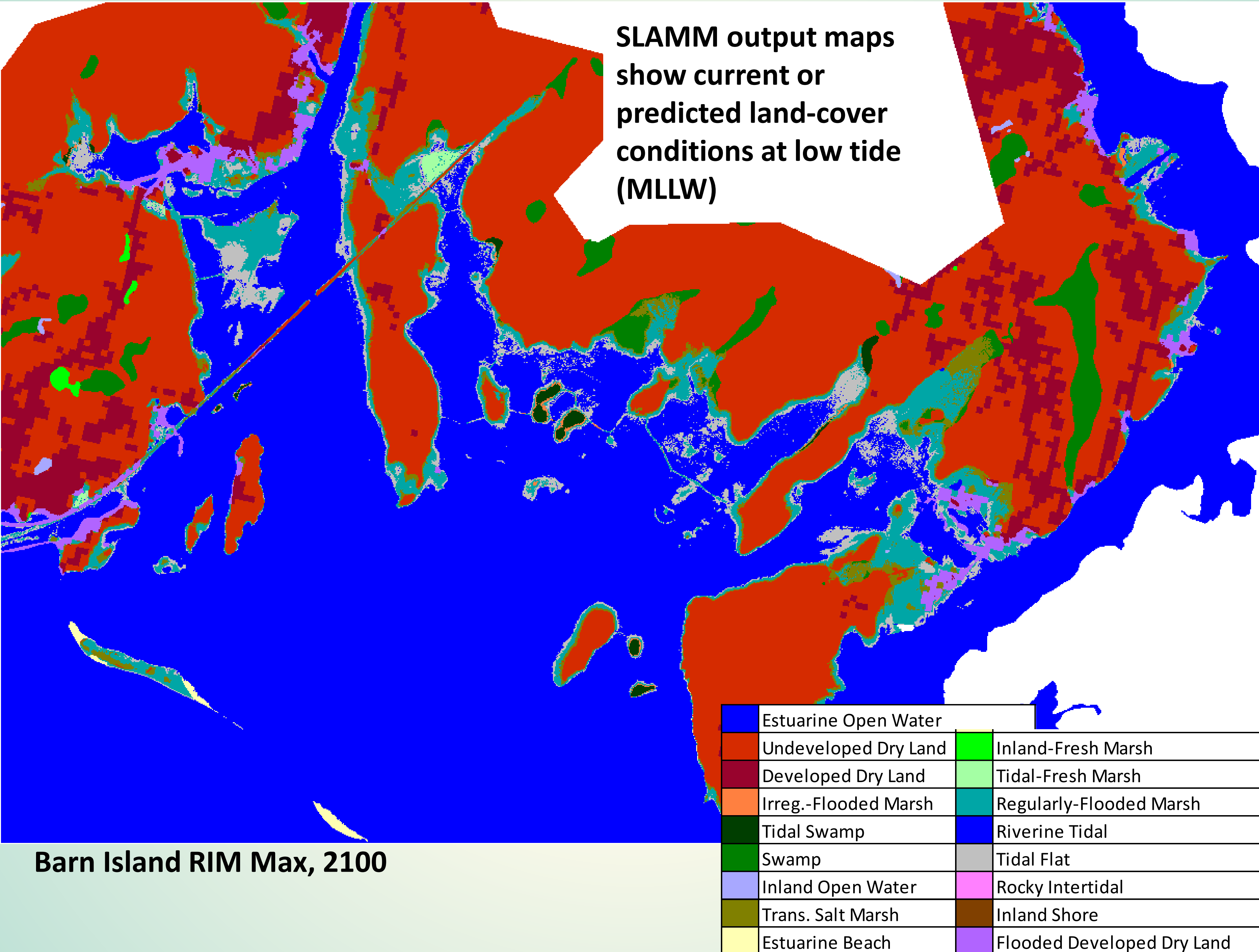
Barn Island 1m, 2100

SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)



Barn Island RIM Min, 2100

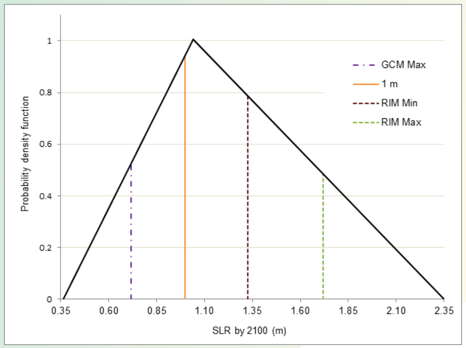
SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)

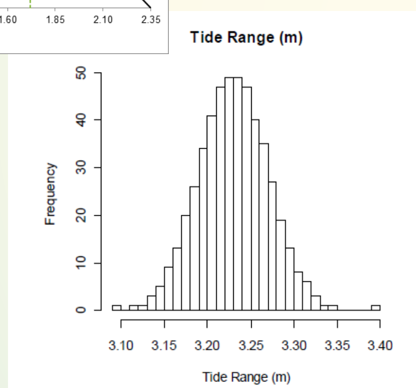


Barn Island RIM Max, 2100

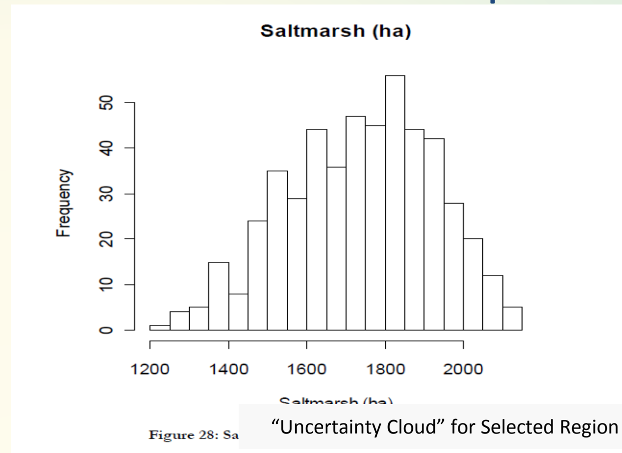
Uncertainty Setup

Parametric Model Input Distributions

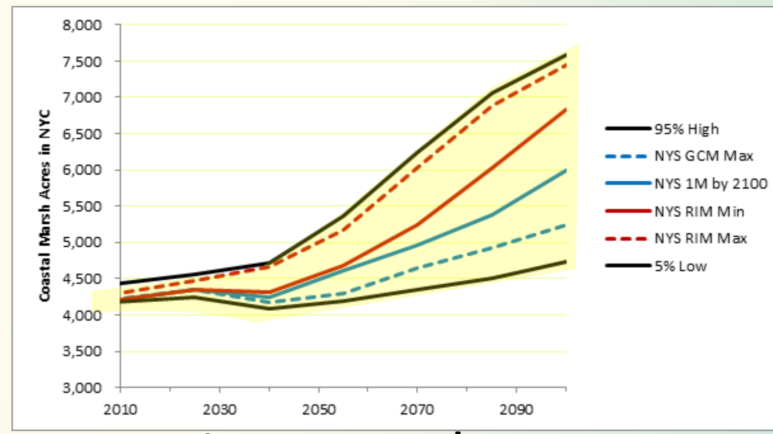




Model Output Distributions



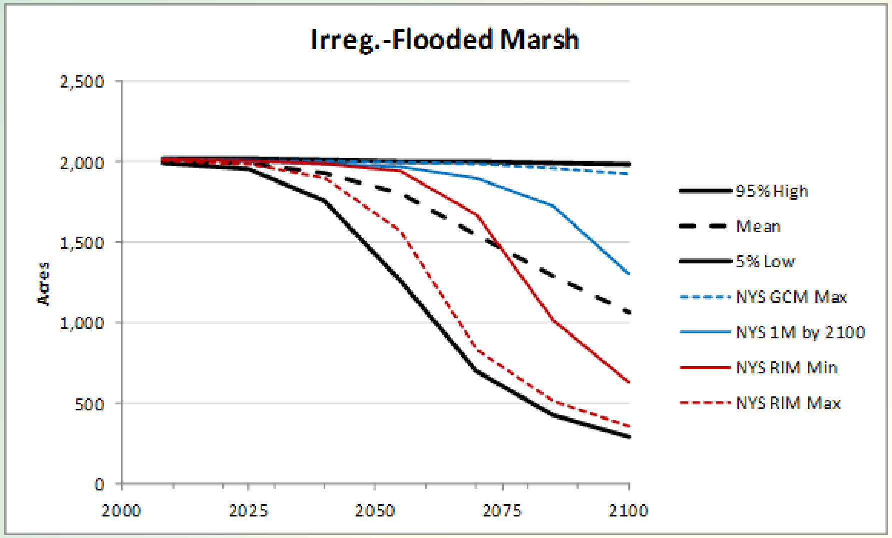
"Uncertainty Cloud" for Selected Region



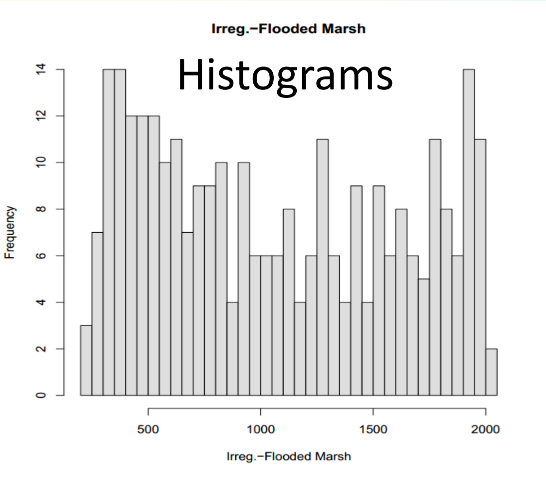
Examining SLAMM results as distributions can improve the decision making process

- Results account for parametric uncertainties
- Range of possible outcomes and their likelihood
- Robustness of deterministic results may be evaluated

Example Uncertainty Outputs



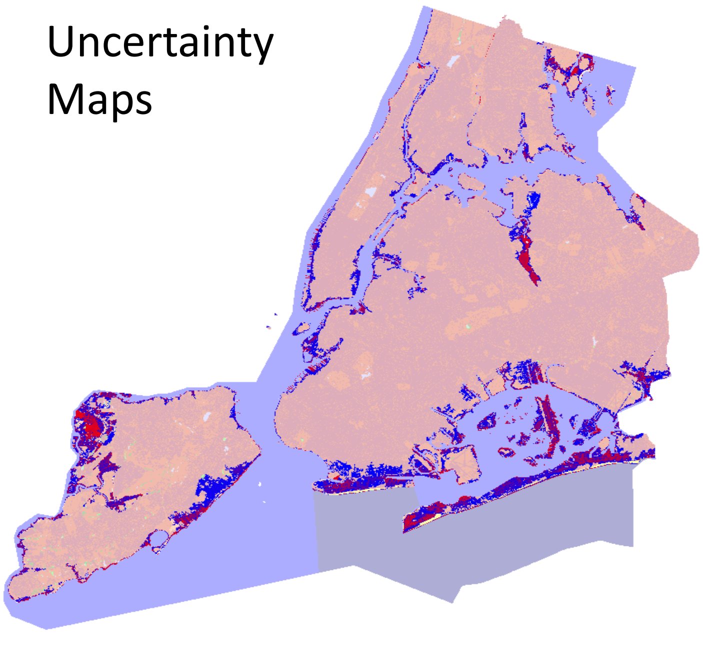
Time series with confidence intervals



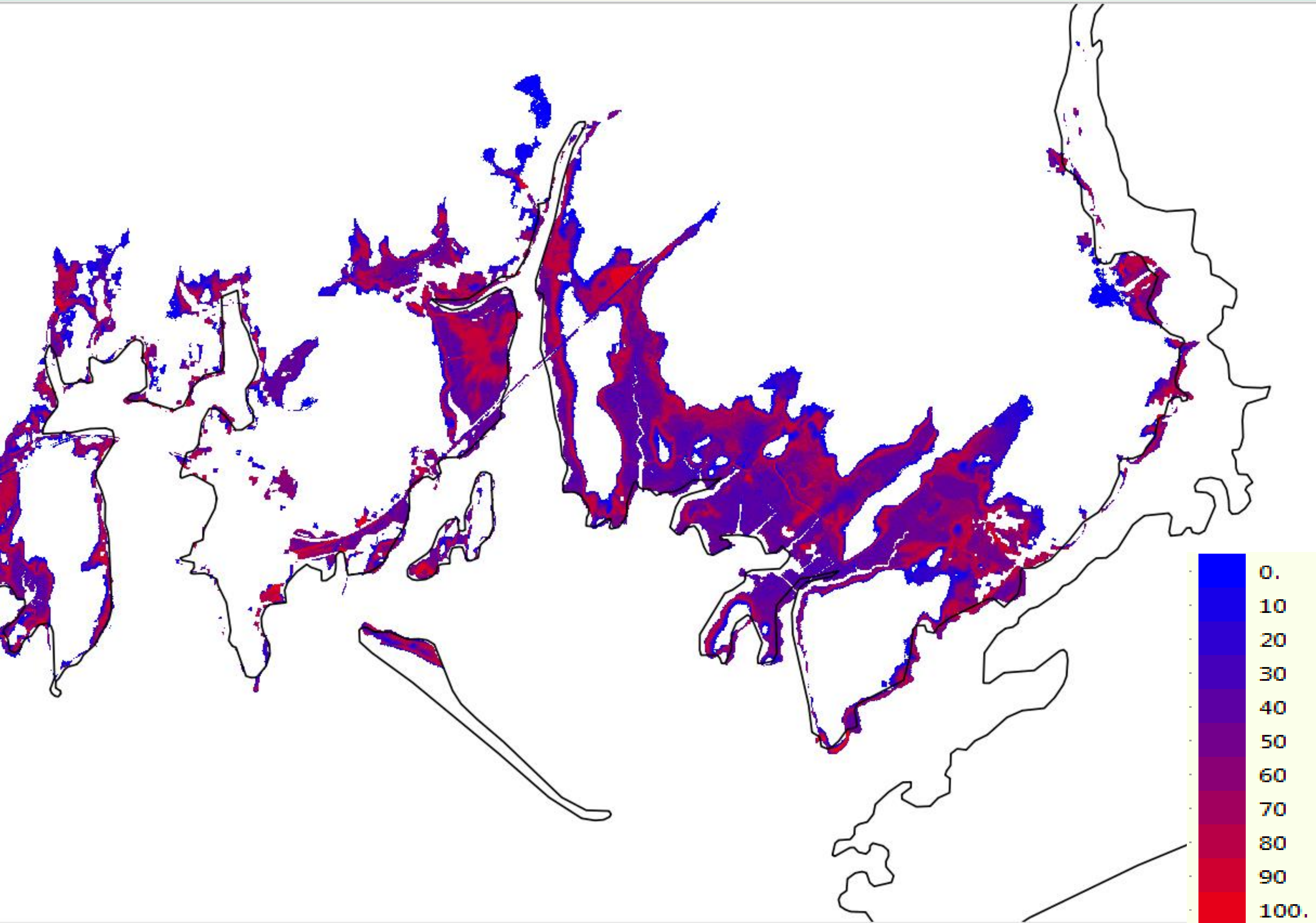
Tables of Results

Landcover Type	Min	5th Percentile (Low)	Mean	95th Percentile (High)	Max	Std. Dev.
Developed Dry Land	109,753	113,237	119,835	123,439	123,701	2,902
Estuarine Open Water	75,347	75,619	76,933	78,591	79,534	784
Undeveloped Dry Land	51,628	53,031	56,617	59,072	59,396	1,653
Open Ocean	32,746	32,790	32,887	32,975	33,007	46
Regularly-Flooded Marsh	1,823	1,949	3,795	5,154	5,312	1,020
Tidal Flat	815	853	1,200	2,030	2,231	312
Inland Open Water	623	659	742	1,015	1,021	92
Trans. Salt Marsh	613	789	1,446	2,288	2,597	385
Ocean Beach	523	550	790	1,042	1,147	144
Swamp	386	401	486	541	544	38
Flooded Developed Dry Land	273	535	4,139	10,736	14,220	2,902
Irreg.-Flooded Marsh	237	290	1,065	1,982	2,011	551
Inland-Fresh Marsh	177	192	332	413	420	66
Estuarine Beach	138	157	222	308	352	41

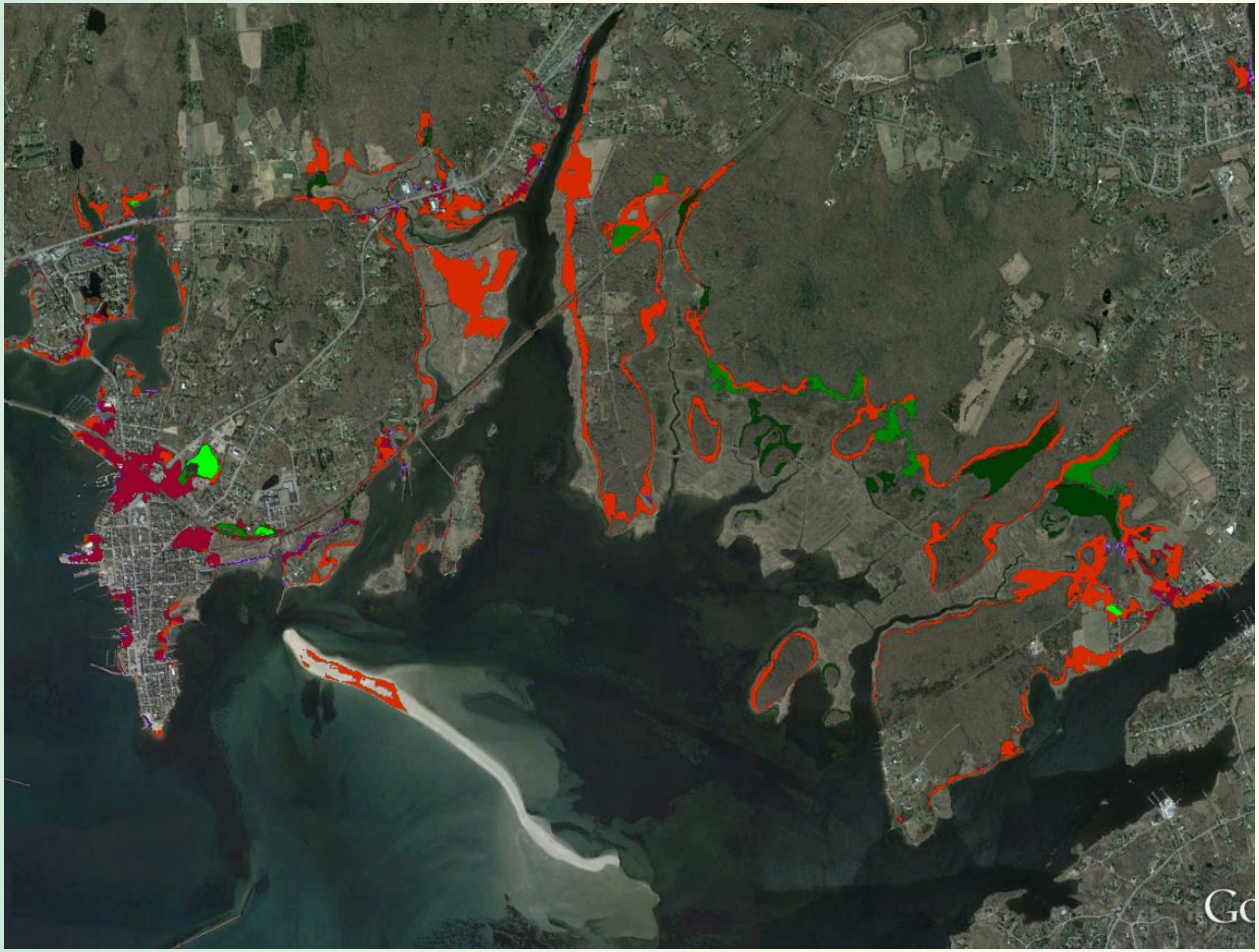
Uncertainty Maps



2100 Percent Likelihood of Coastal Marsh



GIS Analyses



- 1m SLR by 2100
- Locations of new marshes
  - Previous land cover type shown
- Potential marsh migration pathways

Planning, management and adaptation strategies

- Identify appropriate strategies regarding land acquisition, restoration, reduced infrastructure development, etc.
- Identify priorities and effectiveness in allocating available resources - e.g. protection and maintenance vs. migration pathways
- Risk identification