Forecasting the Effect of Accelerated Sea-level Rise on Tidal Marsh Extent and Distribution

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Wetland Workgroup Meeting

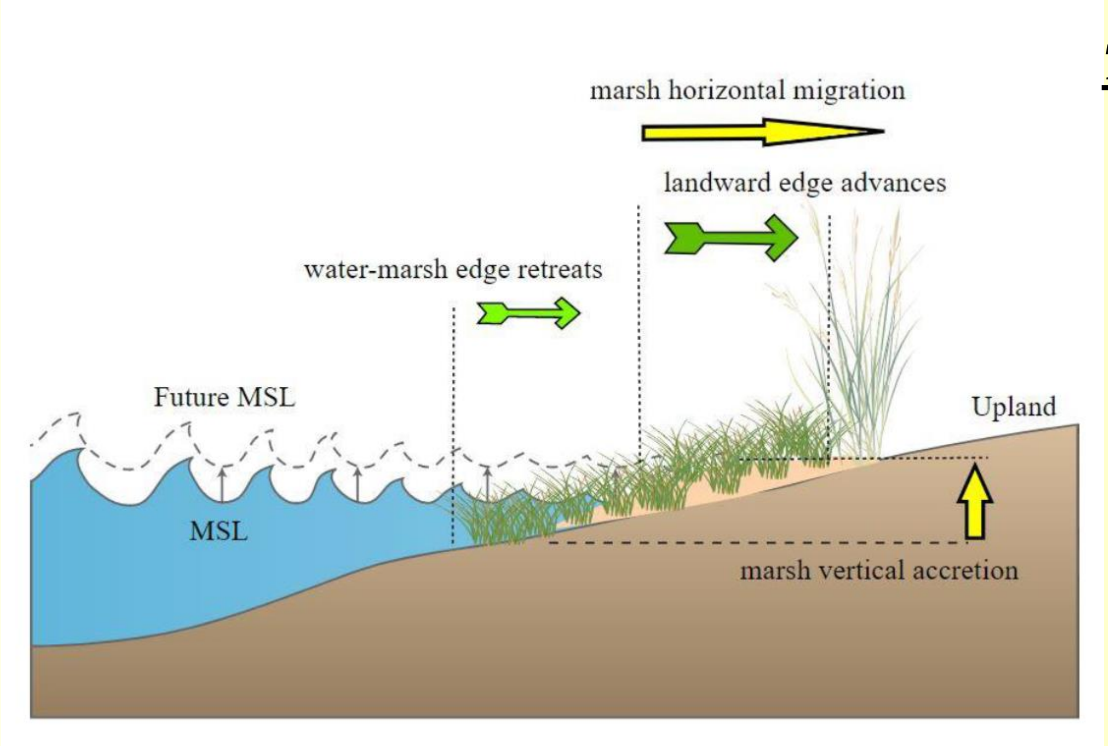
October 19th , 2021

VIMS | William & Mary
Virginia Institute of Marine Science

Tidal Marshes & Sea Level Rise (SLR)

The **Chesapeake Bay** region is one of the most vulnerable areas in the U.S., with mean relative SLR rate in the order of **5 mm yr^{-1}** and accelerating.
(Ezer and Atkinson 2015; Boon et al. 2018)

Tidal Marshes & Sea Level Rise (SLR)



(ian.umces.edu/symbols)

To keep pace with SLR:

- **Marshes accrete vertically** (organic accumulation & inorganic sediment deposition)
- **Marshes migrate horizontally**

Marsh Vertical Accretion & SLR

Marshes possess a **theoretical maximum vertical accretion rate of 5 mm yr^{-1}** (*Morris et al. 2016*)

This rate is commensurate with the mean relative SLR in the Chesapeake Bay **(~ 5 mm yr^{-1})**

Based on **accelerated projections of SLR**, it is expected that marshes will rely considerably on **inorganic sediment** supplies to offset changes in water level

Factors Affecting Vertical Accretion & Horizontal Migration

topography/land use

slope (near shore topography)

shoreline structures

Current Marsh Models

Large-scale landscape models

(e.g. SLAMM)

Site-specific models

(e.g. MEM)

Current Marsh Models

Large-scale landscape models

(e.g. SLAMM)

- Structured grids
- Fixed rates in the simulations
- Simulate general trends over large areas, but typically with a very coarse resolution
- MAIN LIMITATION: down scale model results to local levels

Current Marsh Models

- Mechanistic approach
- Simulate marsh responses for a specific site with a particular set of conditions and settings
- MAIN LIMITATION: Scaling issues - Using results from an individual marsh to make long-term projections at larger spatial extents is challenging due to the broad range of geomorphic settings across landscapes

Site-specific models
(e.g. MEM)

Current Marsh Models

Large-scale landscape models

(e.g. SLAMM)

Site-specific models

(e.g. MEM)

A Multi-scale Approach for Simulating Tidal Marsh Evolution

Advanced modeling framework
that integrates the
physical and human components
needed to simulate and assess the evolution
and persistence of tidal marshes under
different **sea-level rise scenarios**

Dynamic high-resolution model to evaluate marsh evolution:

TIDAL MARSH MODEL (TMM)

Nunez, K., Zhang, Y.J., Herman, J., Reay, W., Hershner, C. (2020). A multi-scale approach for simulating tidal marsh evolution. Ocean Dynamics, 70(9), 1187–1209. https://doi.org/10.1007/s10236-020-01380-6,

Ocean Dynamics (2020) 70:1187–1209
https://doi.org/10.1007/s10236-020-01380-6

A multi-scale approach for simulating tidal marsh evolution

Karinna Nunez[1] · Yinglong J. Zhang[1] · Julie Herman[1] · William Reay[1] · Carlton Hershner[1]

Received: 30 August 2019 / Accepted: 1 May 2020 / Published online: 30 June 2020

Abstract
This study presents a new approach to modeling marsh evolution. The Tidal Marsh Model (TMM) has been developed as a module within the SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) framework. Some unique features of the TMM are dynamic rates, cross-scale simulations, and incorporation of anthropogenic stressors, which allow it to overcome many limitations that current marsh models possess. To evaluate model performance, the TMM was applied in Carter Creek and Taskinas Creek within the York River system (Virginia, USA). We assessed model outputs against field observations focusing on two main aspects: marsh boundary evolution and distribution of marsh sediments. Marsh change is captured with an accuracy of 81% in Carter Creek and an accuracy of 78% in Taskinas Creek. Different statistical descriptors were used to evaluate the model's ability to reproduce the distribution of observed marsh sediment fractions. Results in both study areas show a satisfactory agreement between sediment model outputs and field observations. This innovative modeling approach will help close some critical knowledge gaps in the current understanding of the system dynamics and allow better implementation of management actions to preserve these ecosystems and their services.

Keywords Marsh evolution model · Sea-level rise · Cross-scale simulation · Unstructured grid · SCHISM

Unique Model Features

TIDAL MARSH MODEL

cross-scale model

Process at one temporal (e.g. day, year) or spatial (e.g. creek, ocean) scale can interact with processes at another scale.

dynamic rates

Varying rates in space and time

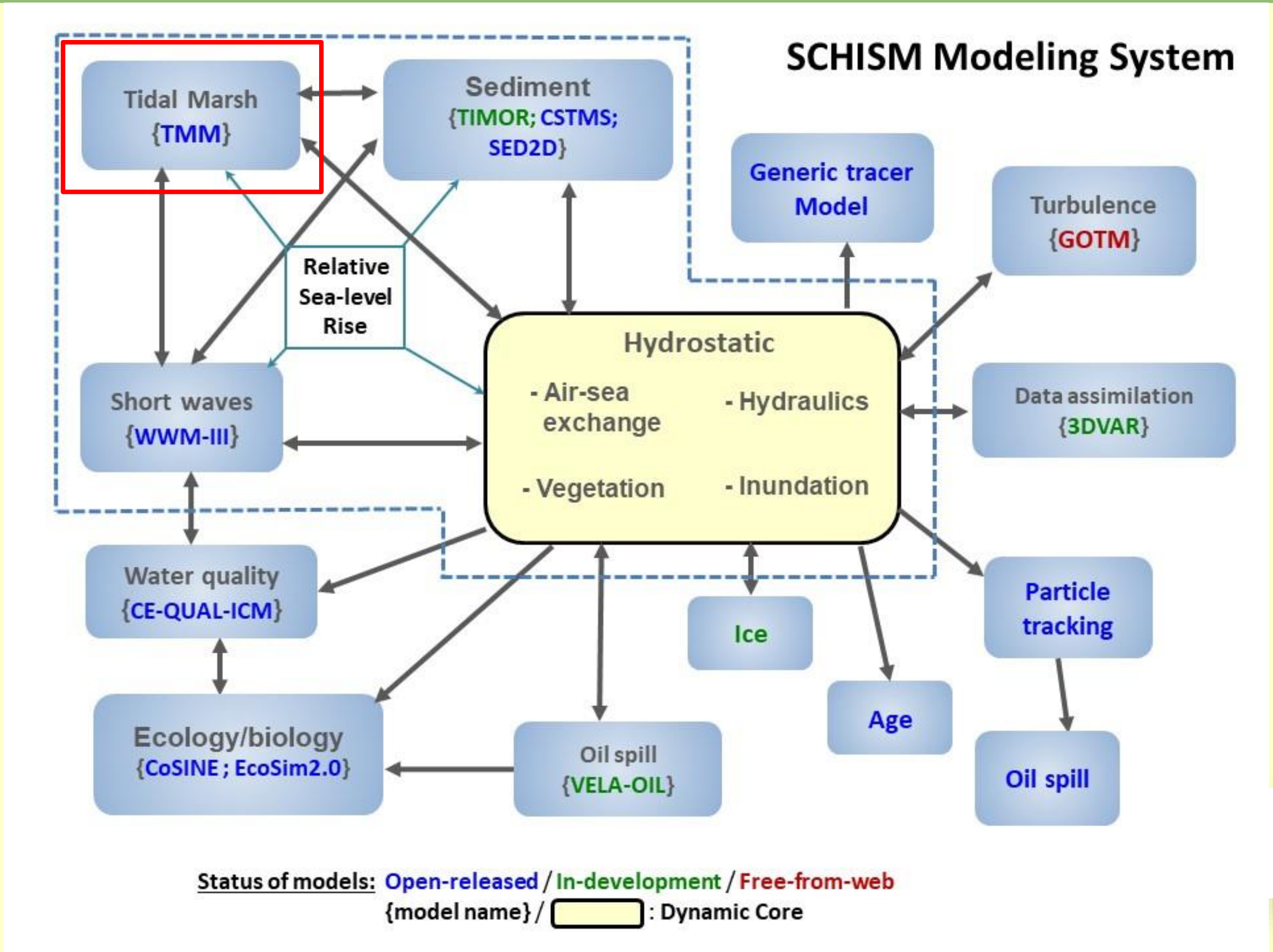
barriers to marsh migration

Coastal development & shoreline erosion control structures (e.g. bulkhead)

marsh plant data (physical characteristics)

Effect of marsh plants on the nearshore hydrodynamics

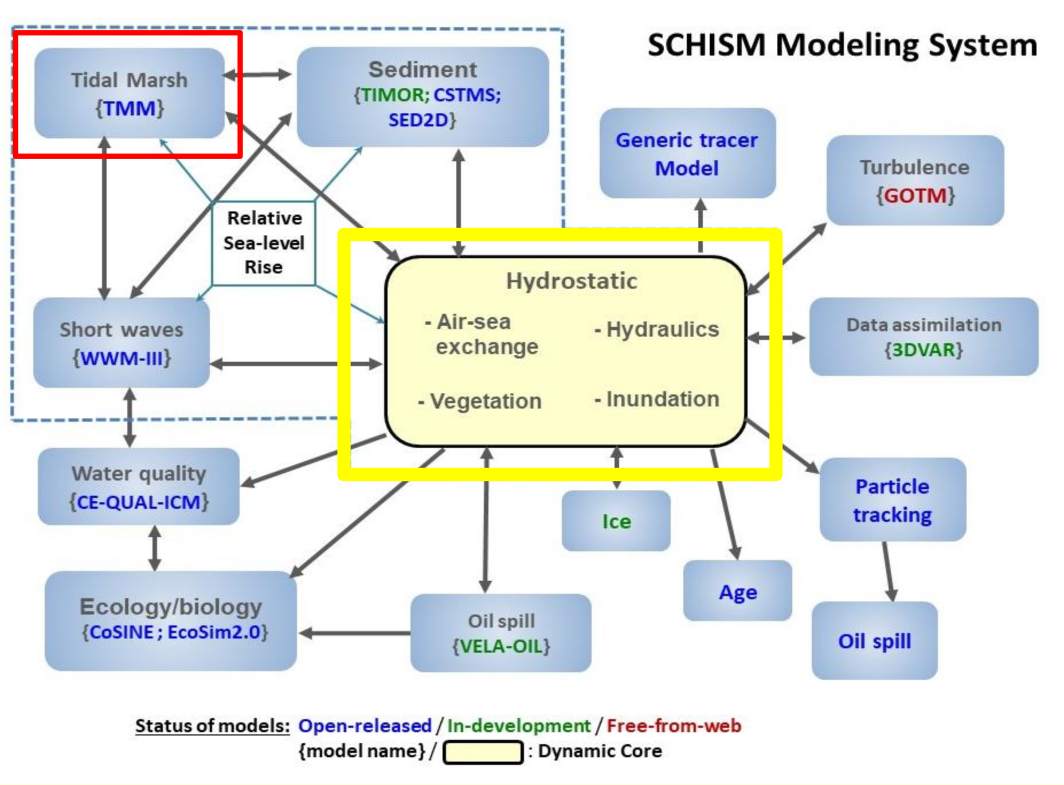
SCHISM
(Semi-implicit Cross-scale Hydroscience Integrated System Model)



SCHISM
(Semi-implicit Cross-scale Hydroscience Integrated System Model)

Major Characteristics of SCHISM

- Open-source community-supported modeling system
- Unstructured grids
- Finite element/volume formulation
- Higher-order Eulerian-Lagrangian treatment of momentum advection
- Semi-implicit time stepping (no mode splitting)



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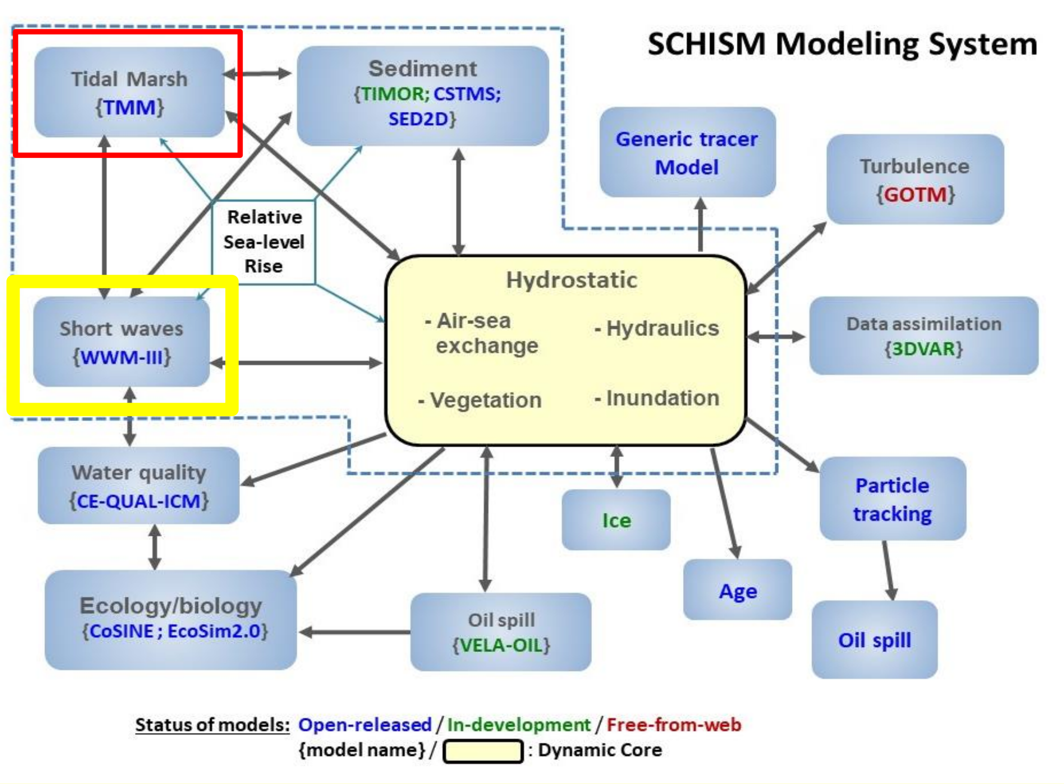

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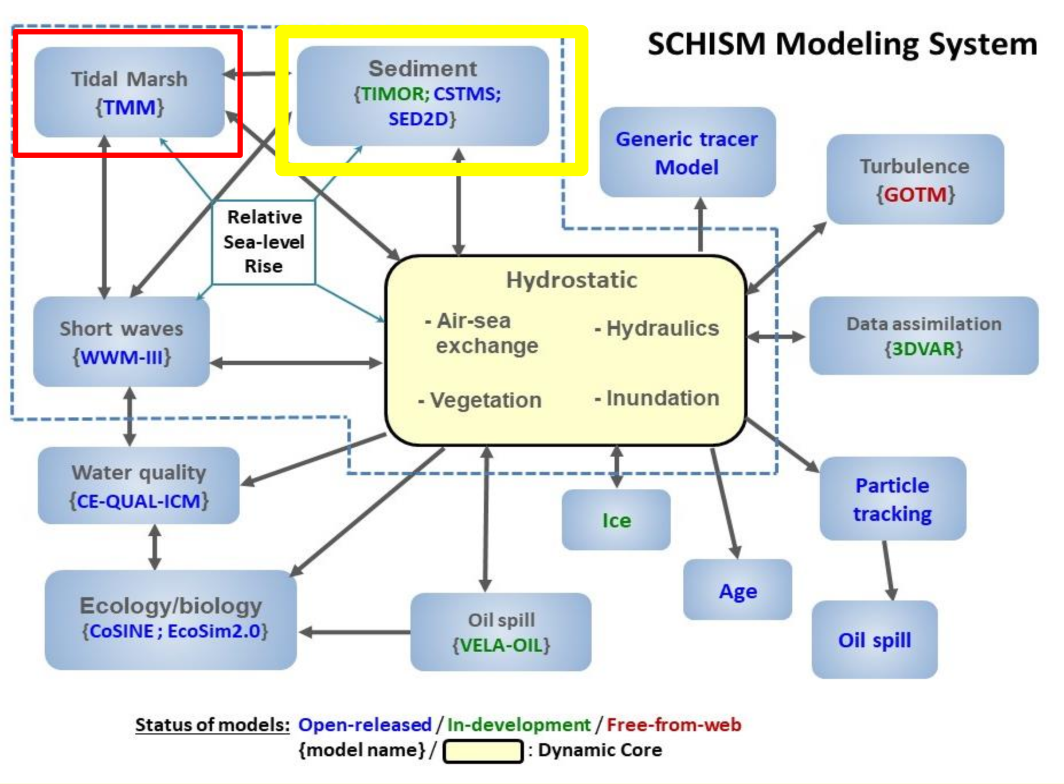

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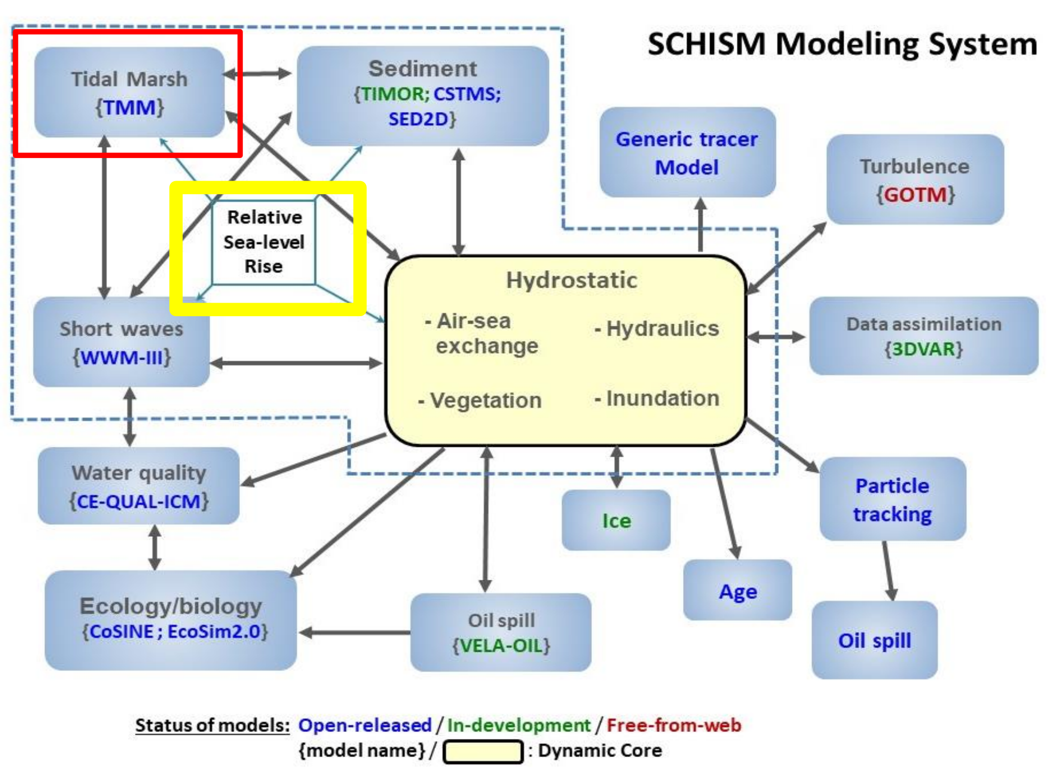
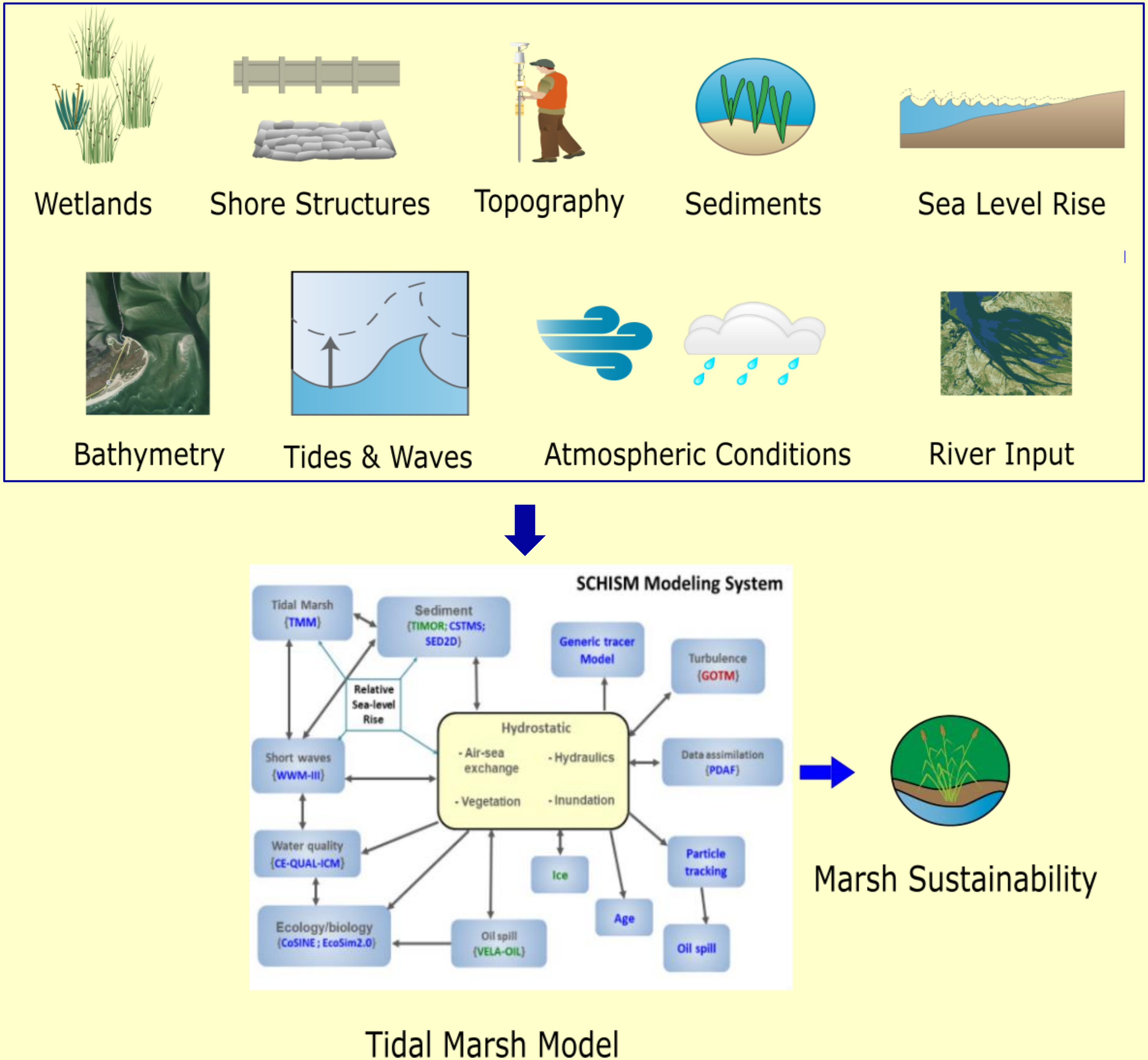


Primary input datasets used for the TMM and supporting models

Dataset	Source
Current Tidal Marshes (Scale: 1:1,000)	Tidal Marsh Inventories – CCRM, VIMS
Marsh Plant Data	This study-field samples, and (Bilkovic et al. unpublished data) – CCRM, VIMS
Shoreline Structures	Shoreline Inventory – CCRM, VIMS
Riparian Land use (distance: 100 ft.)	Shoreline Inventory Program – CCRM, VIMS
LIDAR data	United States Geological Survey (USGS)
Bathymetry	NOAA and CBNERR, VIMS
Bottom Type (grain sizes)	VIMS, Maryland Geological Survey (MGS), and this study -field samples
River Input (average daily values)	United States Geological Survey (USGS)
Total Suspended Solids (average monthly values)	Chesapeake Bay Program
Atmospheric Forcing	North American Regional Reanalysis (NARR)
Tides	US East Coast Tidal Database
Sea-level Rise Data (scenarios)	2017 NOAA Technical Report NOS CO-OPS 083


Wetlands
Shore Structures
Topography
Sediments
Sea Level Rise
Bathymetry
Tides & Waves
Atmospheric Conditions
River Input
SCHISM Modeling System
Tidal Marsh
(TMM)
Sediment
(TIMOR; CSTMS; SED2D)
Generic tracer
Model
Turbulence
(GOTM)
Relative
Sea-level
Rise
Hydrostatic
- Air-sea exchange
- Hydraulics
- Vegetation
- Inundation
Short waves
(WWM-III)
Data assimilation
(PDAF)
Water quality
(CE-QUAL-ICM)
Ice
Particle
tracking
Age
Ecology/biology
(CoSINE ; EcoSim2.0)
Oil spill
(VELA-OIL)
Oil spill
Marsh Sustainability
Tidal Marsh Model

TMM Code Specifications

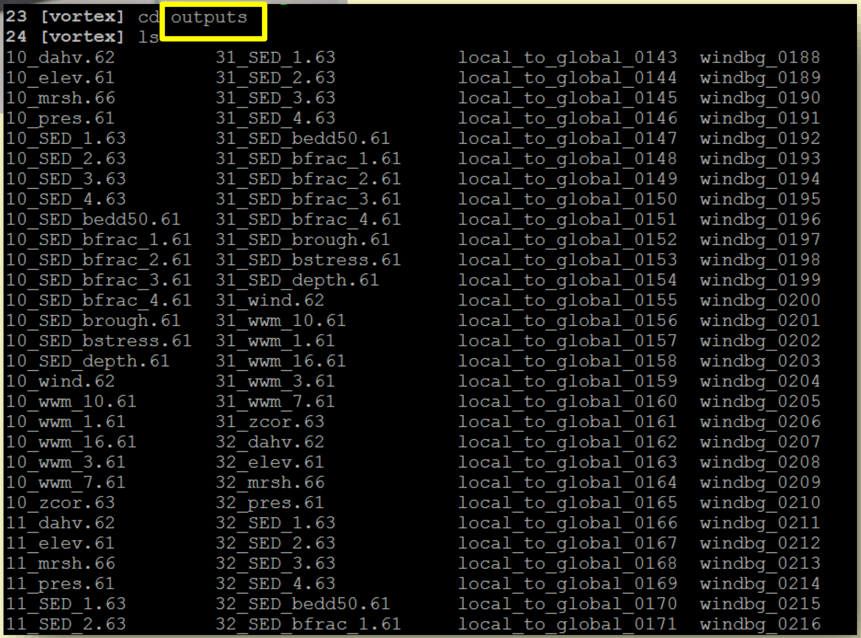
TMM simulates marsh migration under the joint influence from tides, wind waves, sediment transport, precipitation, and SLR

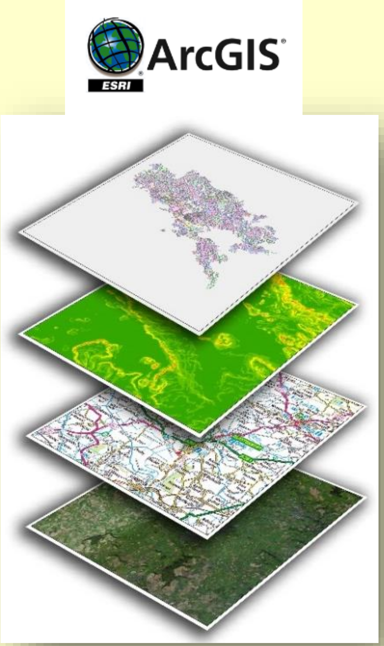
<u>TMM accounts for:</u>

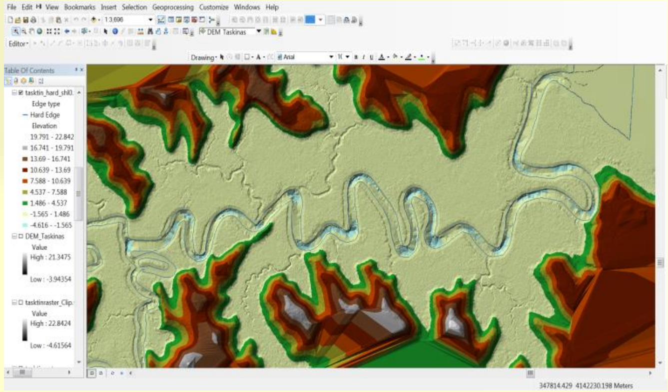
- shoreline bank erosion (water-marsh interphase)
- upland erosion inputs at the upland-marsh edge
- marsh vertical accretion through mineral sediment deposition
- marsh landward migration under changing sea levels with constraints from physical barriers (e.g. ripraps, bulkheads, etc.)

Model Simulations

High-Performance Computing (HPC)
system at
William & Mary

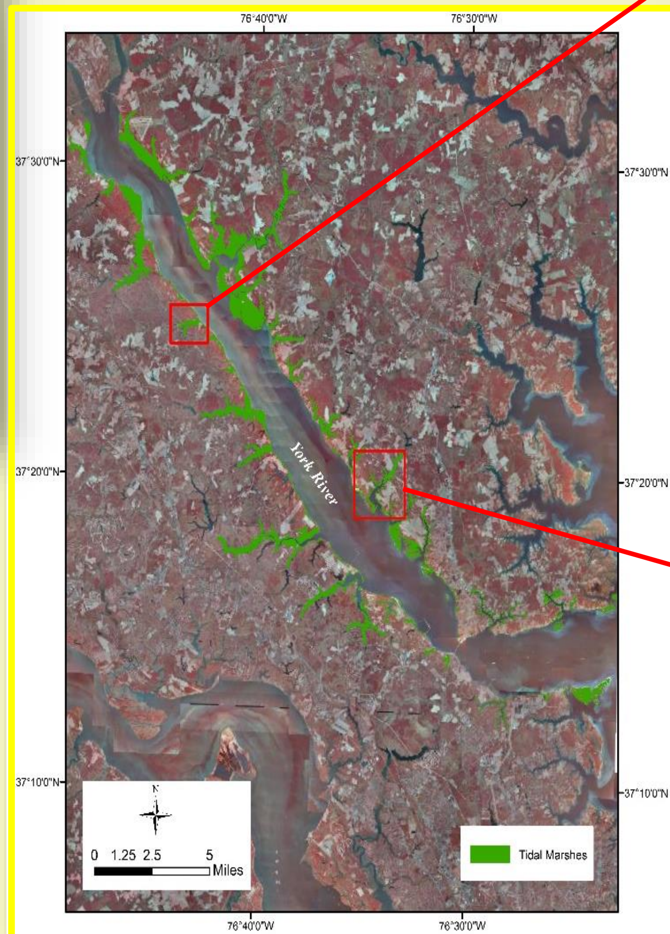


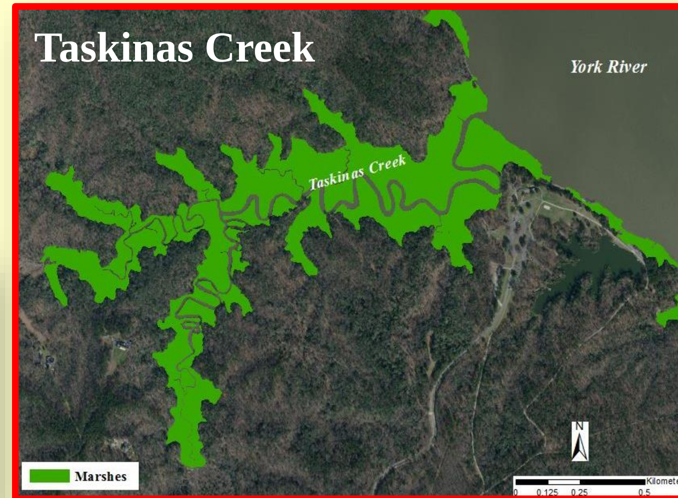




TMM outputs: files can be exported to the GIS environment for further spatial analysis and visualization (e.g. interactive map viewers).

Study Areas

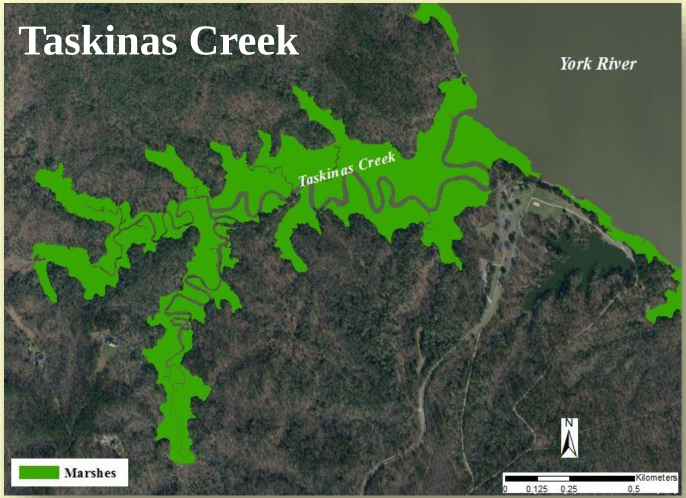




TMM

EXPORTABLE

Study Areas

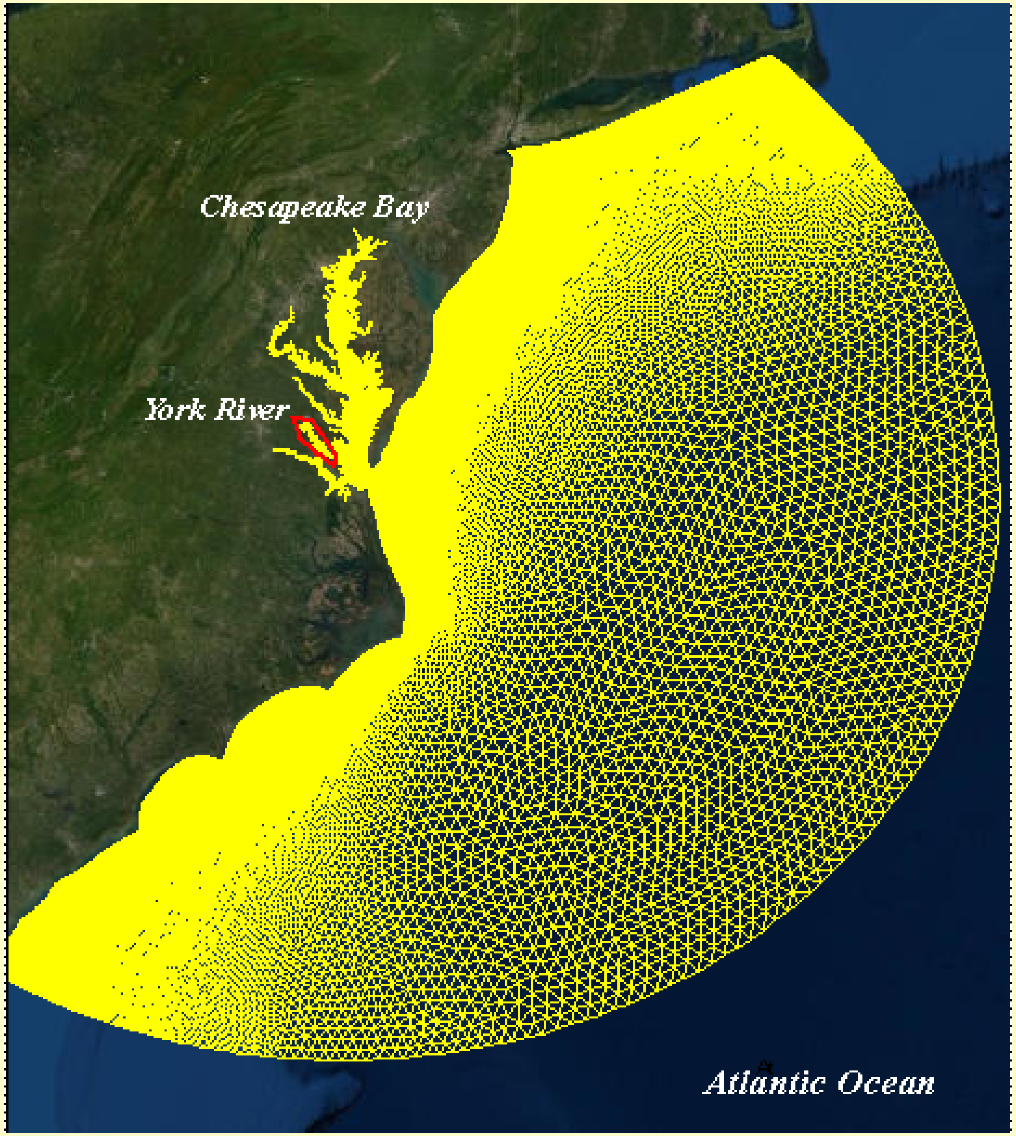


- CBNERR's reserve (pristine site)
- Embayed marshes
- Adjacent upland: forest and scrub shrubs
- No hardened shoreline structures
- **Mostly: steep slopes and upland bank heights >1.5m**

- Embayed and fringe marshes
- Adjacent upland: forest, agriculture and residential
- hardened shoreline structures / roads
- **Mostly: gradual slopes and upland bank heights < 1.5m**

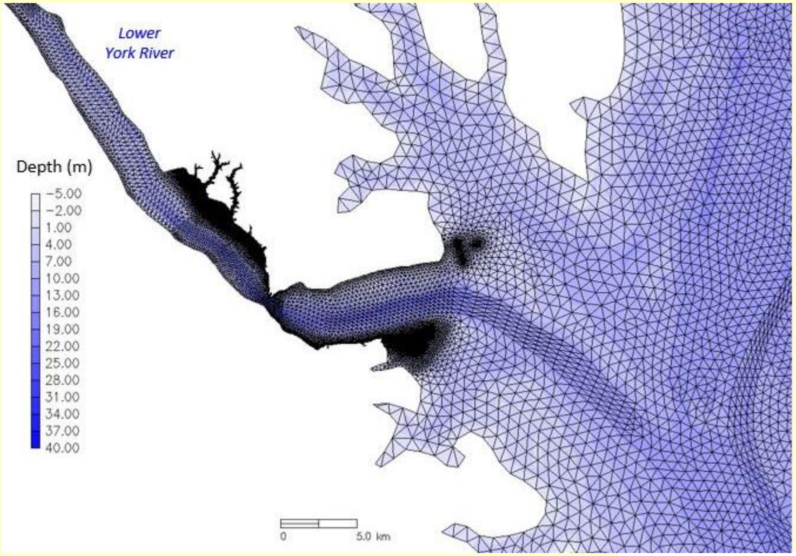
Grid Generation

One of the strengths of this model approach is that it uses an **<u>unstructured grid</u>** for the simulation



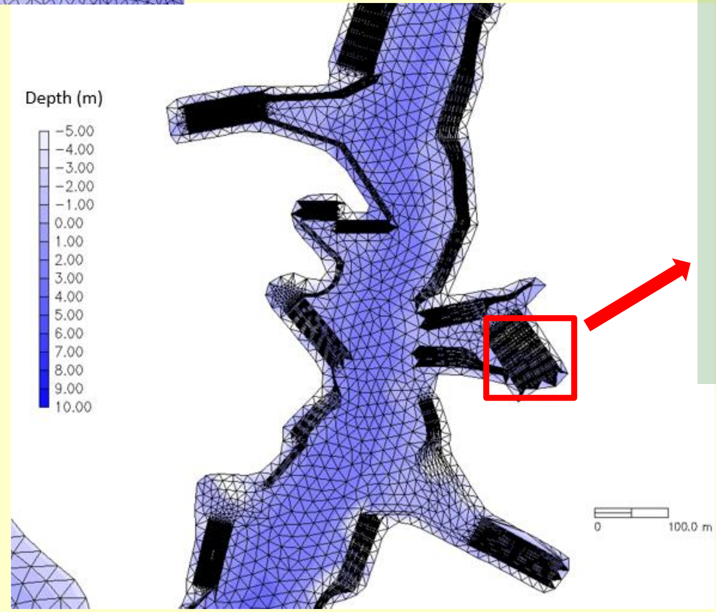
Grid generation software: SMS (Surface-water Modelling System) by Aquaveo.com

Grid Generation

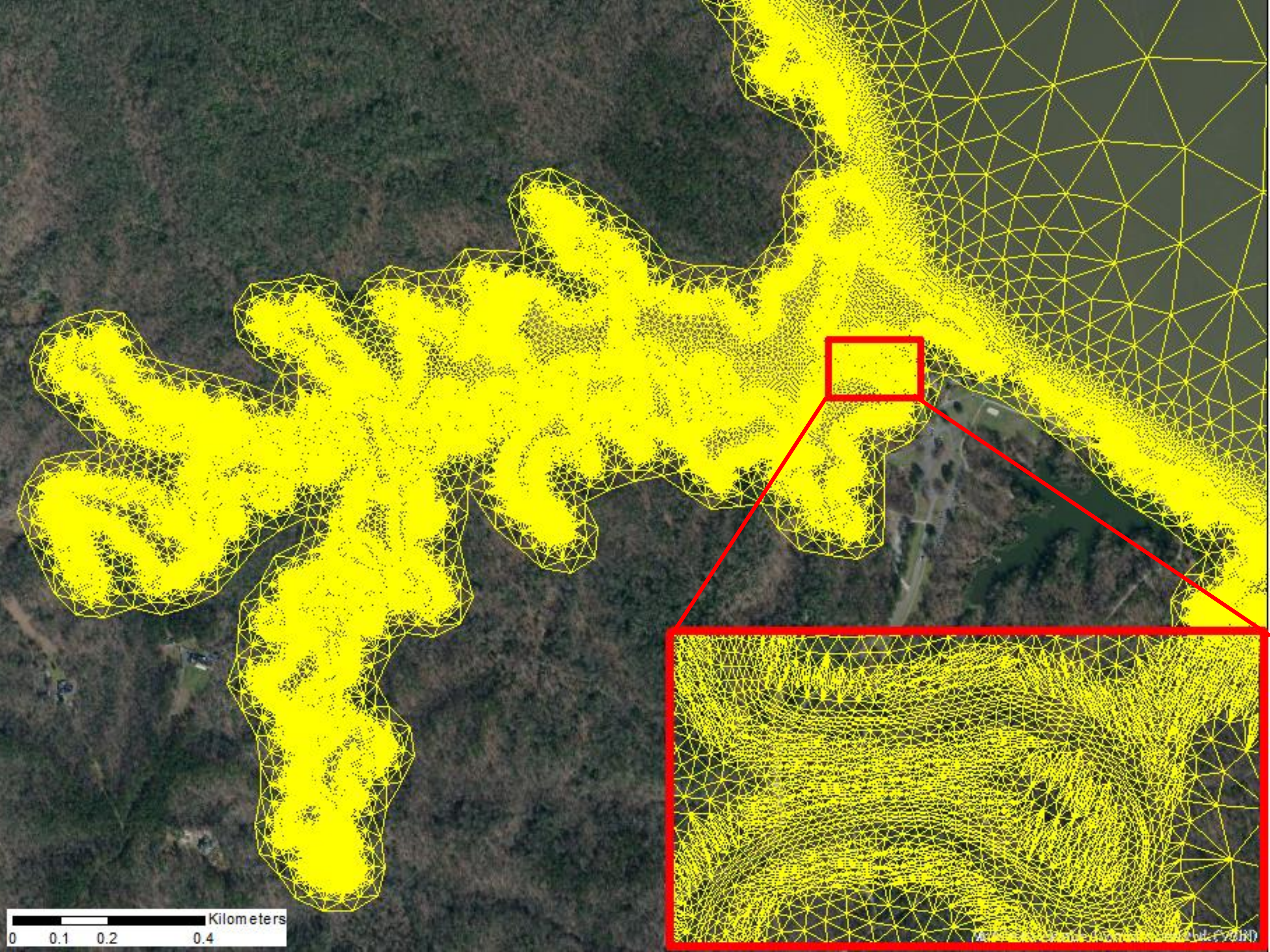


This type of grid allows multiple resolutions over the domain, and higher resolution where fine scales are important

Marsh areas were resolved at **1 m** cross-shore and **5-10 m** along-shore for fringe marshes

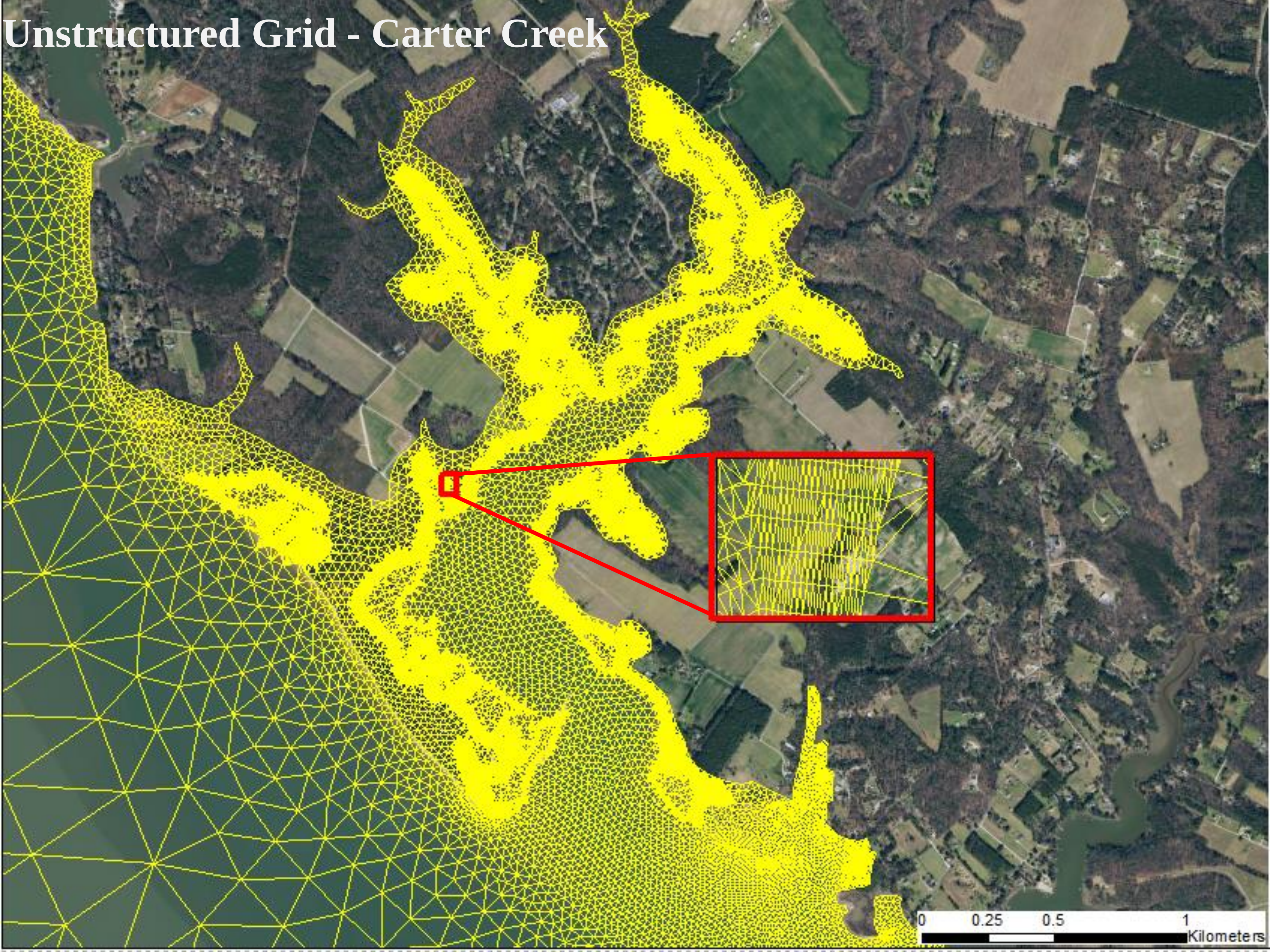


Marsh cells are defined in the grid by an **increased bottom roughness factor (RF)** (Ye et al. 2013)



Kilometers
0 0.1 0.2 0.4

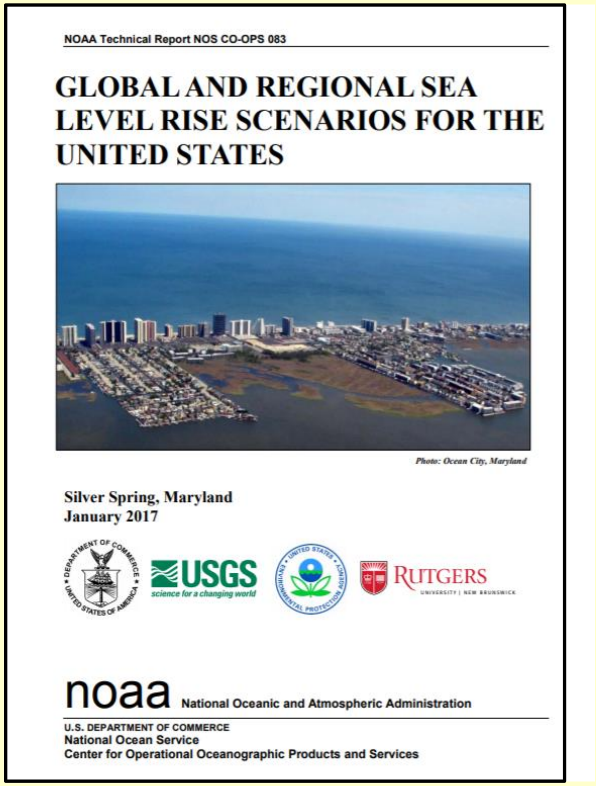
Unstructured Grid - Carter Creek



FORECASTS - Sea-level Rise (SLR) Scenarios

SLR scenarios selected for the forecasts were based on NOAA projections (Sweet et al. 2017)

Scenarios were adjusted by incorporating land subsidence rates documented in southeast Virginia by USGS (3.1 mm yr^{-1}) (Eggleston and Pope 2013)


NOAA Technical Report NOS CO-OPS 083

GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES

Photo: Ocean City, Maryland

Silver Spring, Maryland
January 2017

USGS science for a changing world

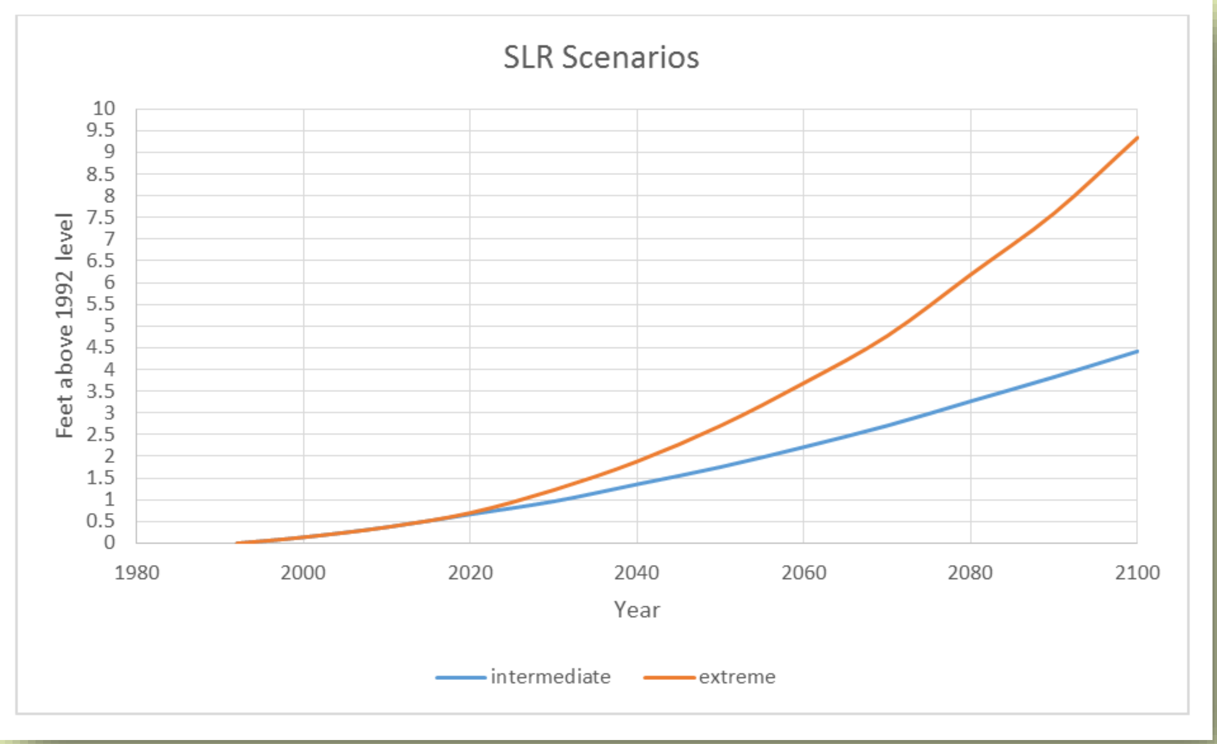
RUTGERS UNIVERSITY | NEW BRUNSWICK

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

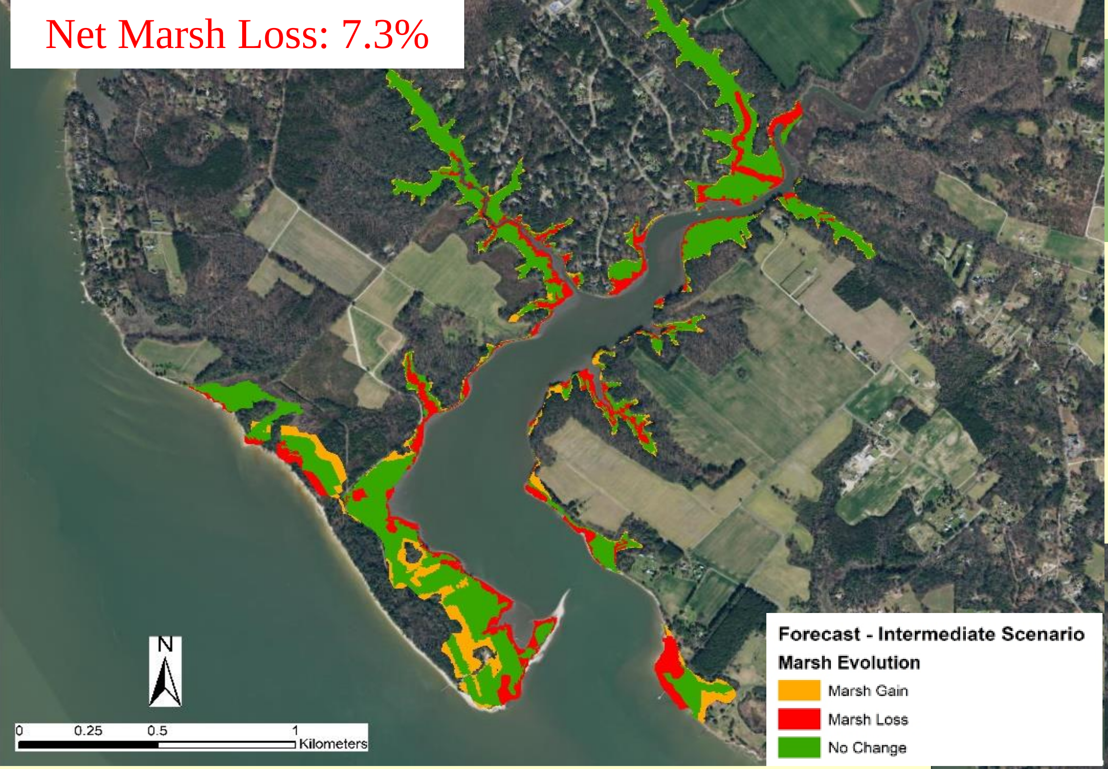
Sea-level Rise (SLR) Scenarios

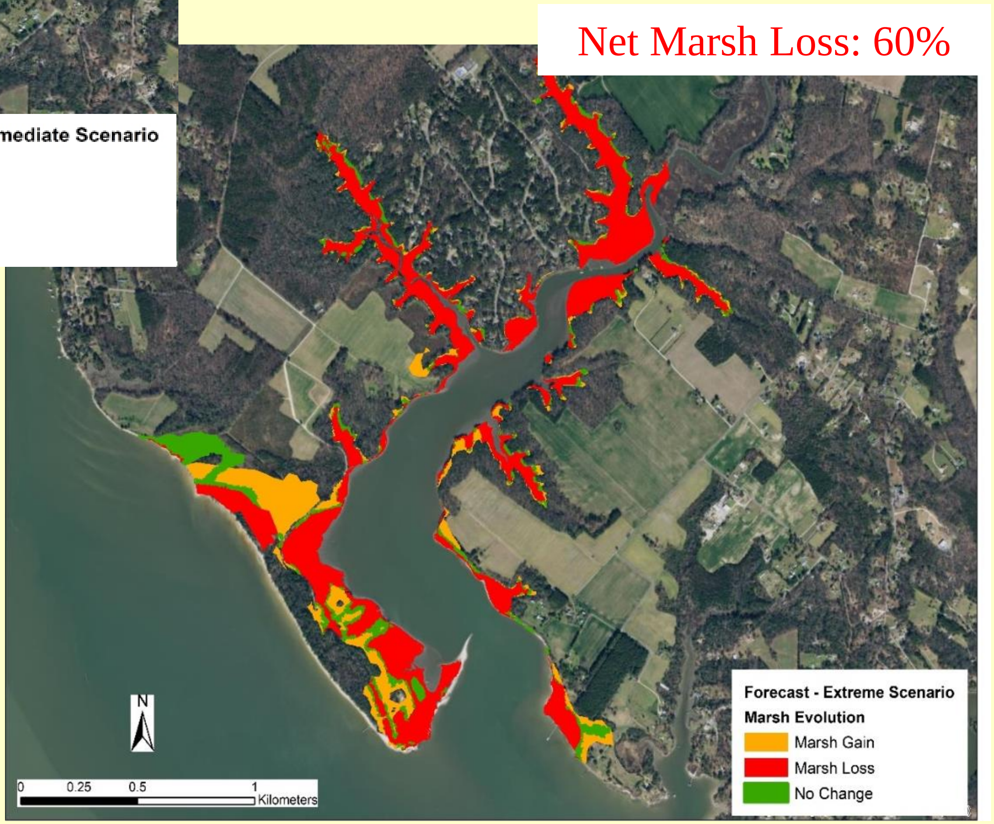
- The forecasts of marsh evolution under different SLR scenarios were run over a **50-year period (2020-2070)**
- Scenarios: **"intermediate"** and **"extreme"**



RESULTS – Marsh Boundary Evolution

Forecast Period:
50 years (2020-2070)





Increase in sea level by the end of the simulation:

- Intermediate Scenario: **622 mm** (2.04 ft)
- Extreme Scenario: **1,243 mm** (4.08 ft)

Nunez, K., Zhang, Y., Bilkovic, D.M., and C. Hershner (2021). Coastal setting determines tidal marsh sustainability with accelerating sea-level rise. Ocean & Coastal Management, 214, 105898. https://doi.org/10.1016/j.ocecoaman.2021.105898.

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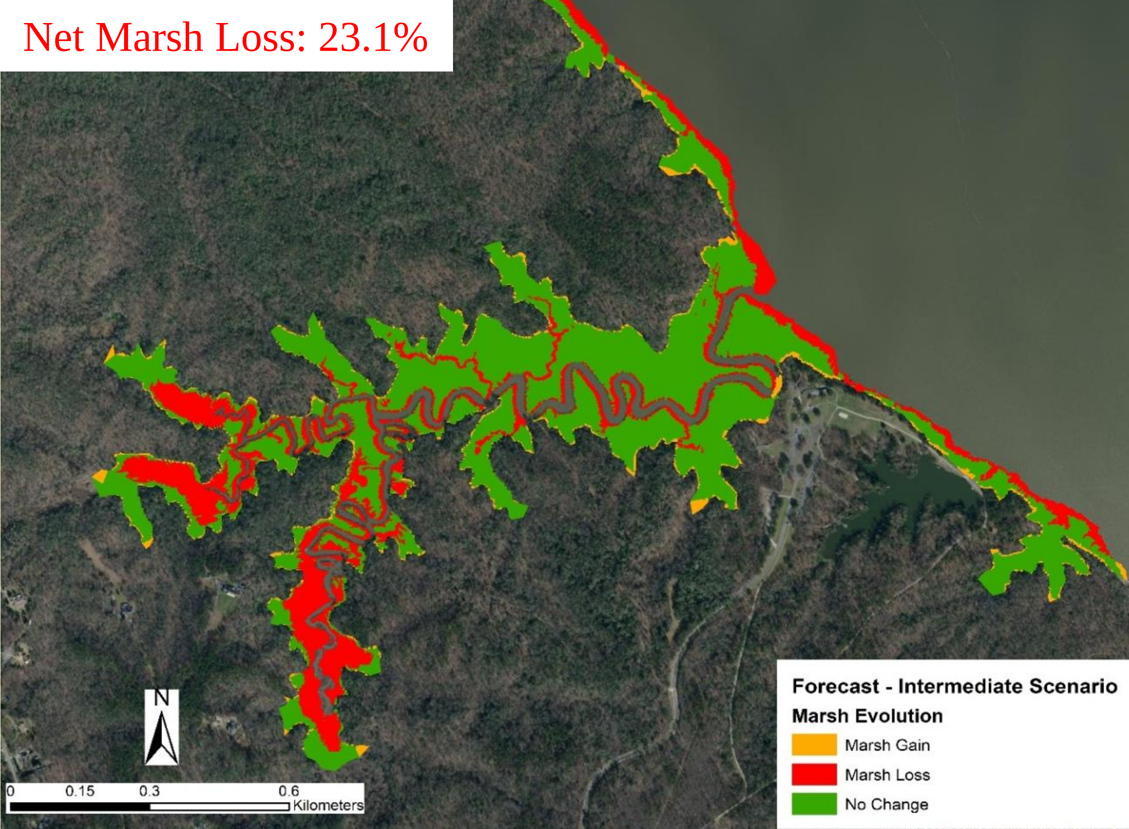

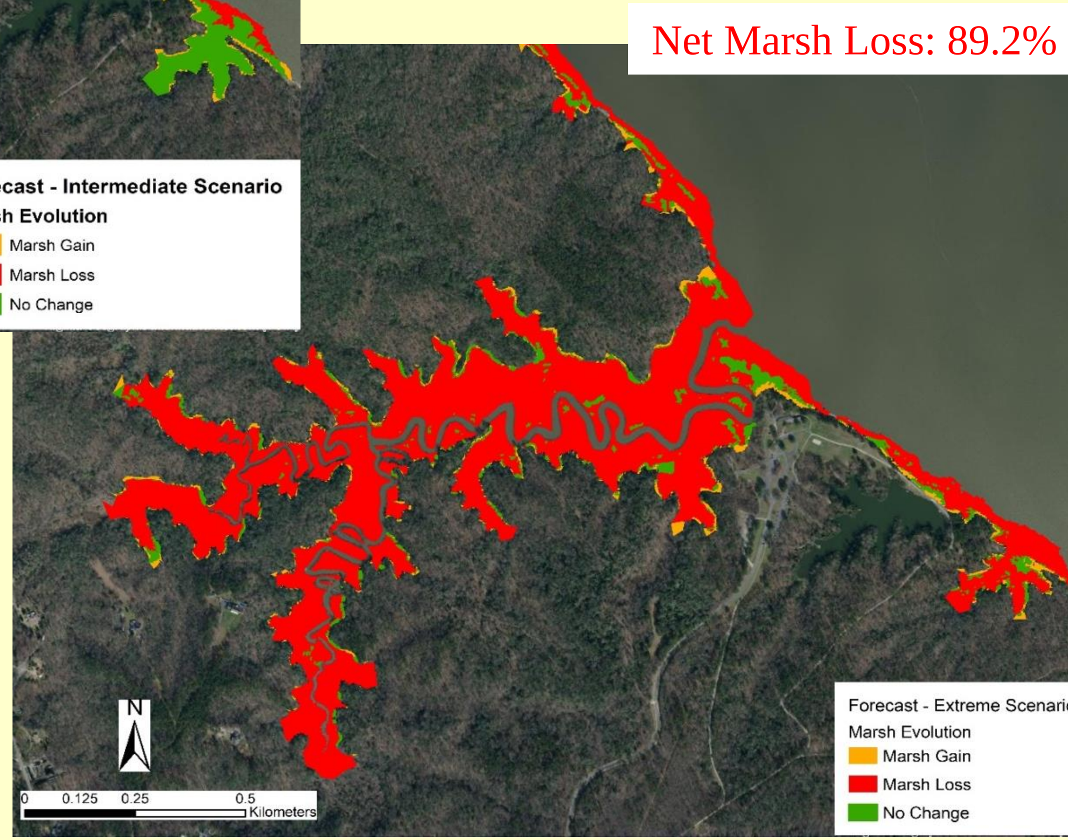

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Marsh Boundary Evolution Outputs

- The TMM was able to capture the influence of geomorphic settings and anthropogenic factors on the evolution of marsh habitat as the rate of sea level increased

- The persistence of marsh habitat in the **intermediate scenario** can be attributed to the **local topography and sediment supply** in the region

- In the **extreme scenario**, the **accelerated rate of SLR dominated** the **rate of vertical accretion** by marsh plants in most of the marshes

- In areas with high upland banks, extreme SLR rates facilitated the conversion to open water rather than marsh migration

Implications

Coastal managers and decision-makers can use these model outputs to improve the long-term effectiveness of conservation strategies by:

- maximizing the amount of marsh habitat in high-sediment regions
- prioritizing sediment allocation
- identifying key upland transitional sites

Summary

The TMM advances the state of the science by building a better foundation to simulate marsh extent and distribution in large areas, but with the kind of spatially explicit resolution currently only available from site-specific marsh evolution studies

TMM **overcomes some limitations** that the current marsh models present:

Current Models LIMITATIONS		TMM
scaling problems	➡	"cross-scale model" Semi-implicit time stepping
constant rates	➡	capacity for a much more **dynamic simulation** *(i.e. rates vary in space and time as determined by changes in the hydrodynamic conditions of the system)*
exclusion of hardened shoreline structure impacts	➡	highly resolves (~1m) marsh transgression

Thank you!

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