US Army Corps of Engineers®

Engineering With Nature

Engineering With Nature® (EWN) Toolkit for ERDC's Coastal Storm (CSTORM) Modeling System

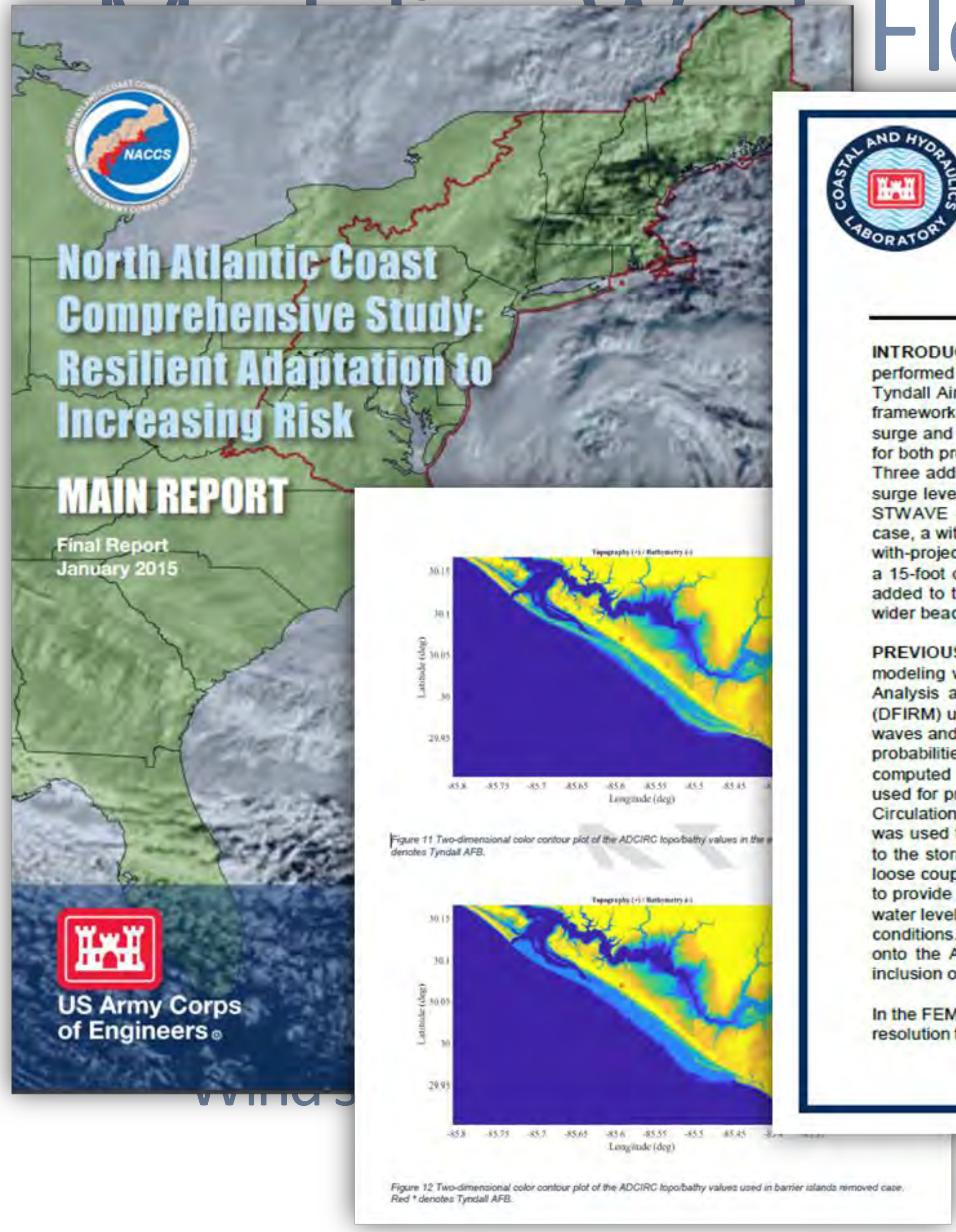
A streamlined and standardized method for hydrodynamic modeling of Natural Based Solutions

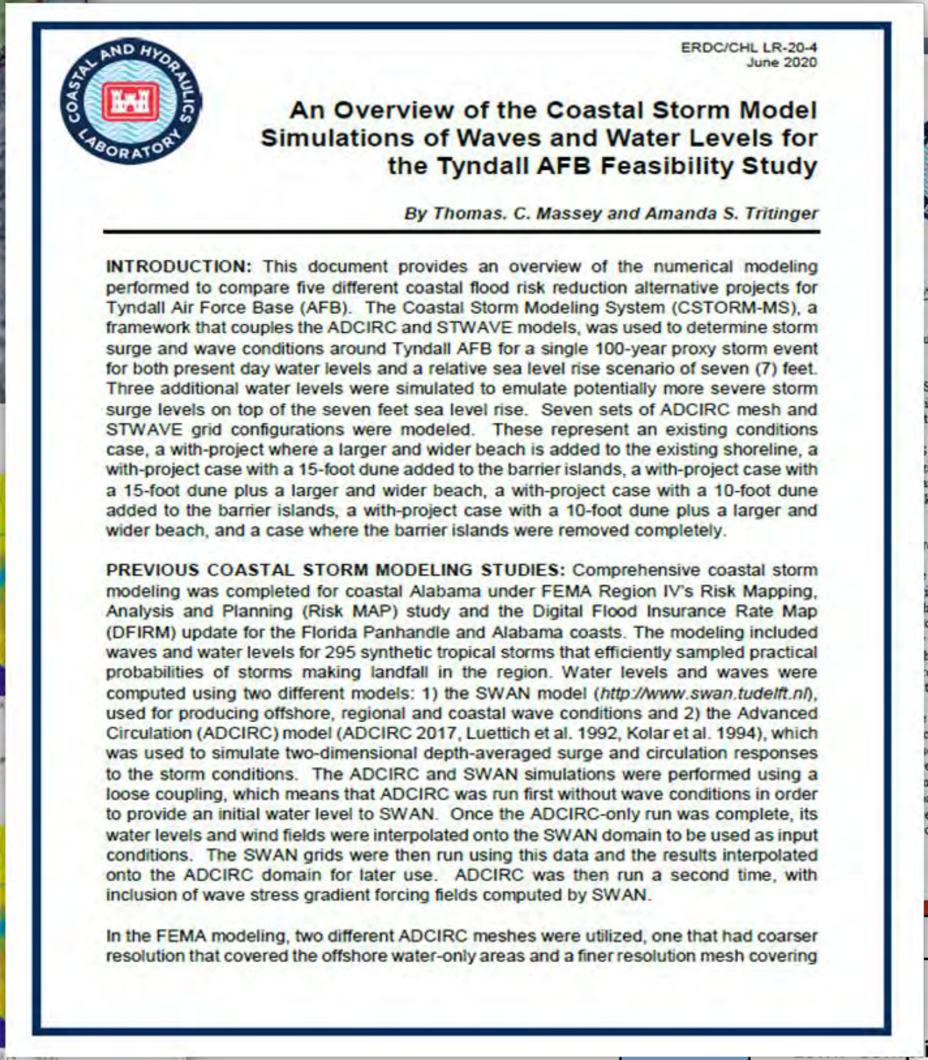
Amanda Tritinger, Margaret Owensby, Chris Massey, Candice Piercy, Mary Bryant, Fatima Bukhari, Rachel Innocenti, Abigail Wallace, and more!

US Army Engineer R&D Center - Coastal and Hydraulics Laboratory

Amanda.s.Tritinger@erdc.dren.mil

Modeling Work Flow – Cultivate





COASTAL AND HYDRAULICS LABORATORY

ERDC/CHL LR-20-4
June 2020

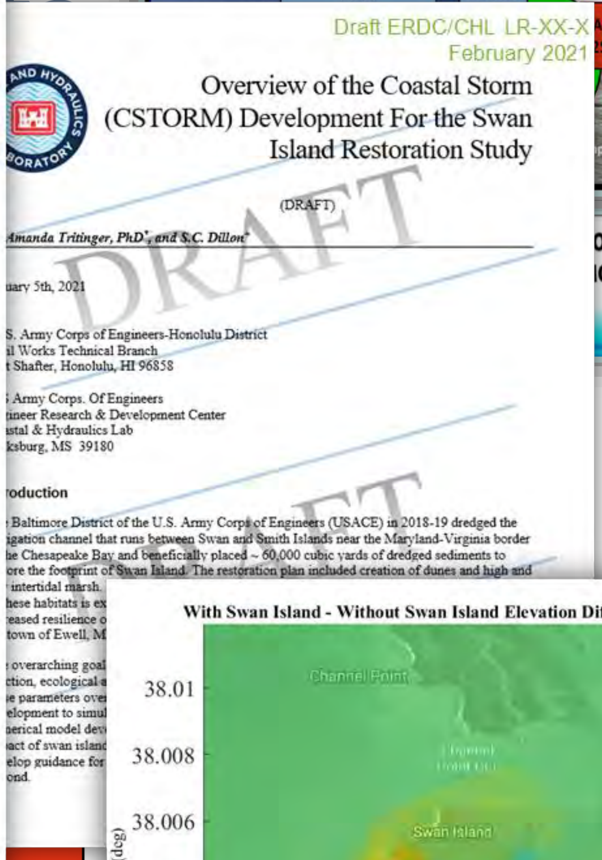
An Overview of the Coastal Storm Model Simulations of Waves and Water Levels for the Tyndall AFB Feasibility Study

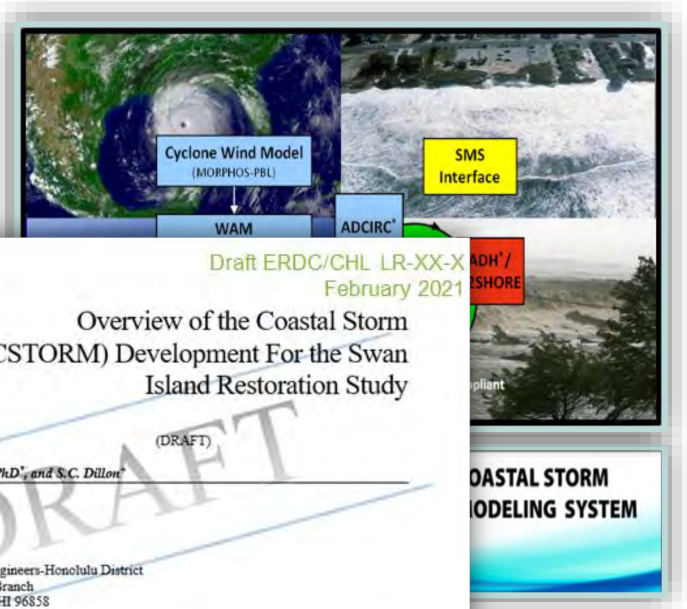
By Thomas. C. Massey and Amanda S. Tritinger

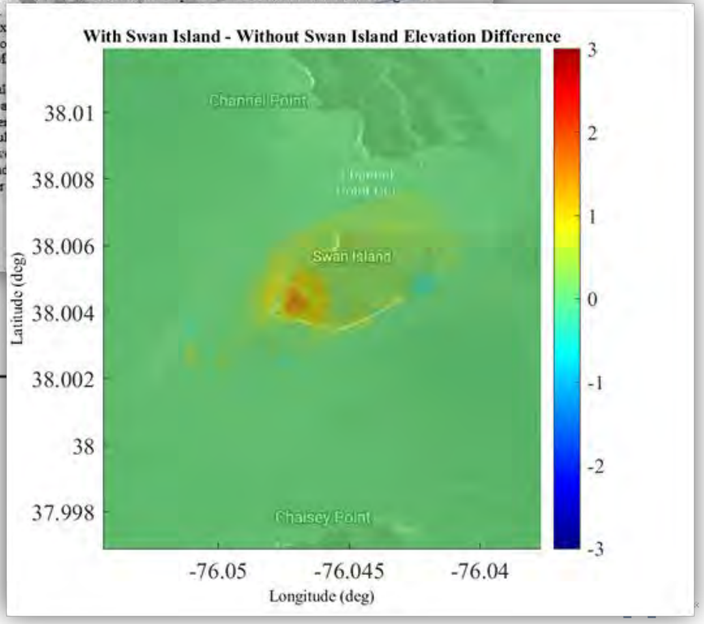
INTRODUCTION: This document provides an overview of the numerical modeling performed to compare five different coastal flood risk reduction alternative projects for Tyndall Air Force Base (AFB). The Coastal Storm Modeling System (CSTORM-MS), a framework that couples the ADCIRC and STWAVE models, was used to determine storm surge and wave conditions around Tyndall AFB for a single 100-year proxy storm event for both present day water levels and a relative sea level rise scenario of seven (7) feet. Three additional water levels were simulated to emulate potentially more severe storm surge levels on top of the seven feet sea level rise. Seven sets of ADCIRC mesh and STWAVE grid configurations were modeled. These represent an existing conditions case, a with-project where a larger and wider beach is added to the existing shoreline, a with-project case with a 15-foot dune added to the barrier islands, a with-project case with a 15-foot dune plus a larger and wider beach, a with-project case with a 10-foot dune added to the barrier islands, a with-project case with a 10-foot dune plus a larger and wider beach, and a case where the barrier islands were removed completely.

PREVIOUS COASTAL STORM MODELING STUDIES: Comprehensive coastal storm modeling was completed for coastal Alabama under FEMA Region IV's Risk Mapping, Analysis and Planning (Risk MAP) study and the Digital Flood Insurance Rate Map (DFIRM) update for the Florida Panhandle and Alabama coasts. The modeling included waves and water levels for 295 synthetic tropical storms that efficiently sampled practical probabilities of storms making landfall in the region. Water levels and waves were computed using two different models: 1) the SWAN model (*http://www.swan.tudelft.nl*), used for producing offshore, regional and coastal wave conditions and 2) the Advanced Circulation (ADCIRC) model (ADCIRC 2017, Luettich et al. 1992, Kolar et al. 1994), which was used to simulate two-dimensional depth-averaged surge and circulation responses to the storm conditions. The ADCIRC and SWAN simulations were performed using a loose coupling, which means that ADCIRC was run first without wave conditions in order to provide an initial water level to SWAN. Once the ADCIRC-only run was complete, its water levels and wind fields were interpolated onto the SWAN domain to be used as input conditions. The SWAN grids were then run using this data and the results interpolated onto the ADCIRC domain for later use. ADCIRC was then run a second time, with inclusion of wave stress gradient forcing fields computed by SWAN.

In the FEMA modeling, two different ADCIRC meshes were utilized, one that had coarser resolution that covered the offshore water-only areas and a finer resolution mesh covering

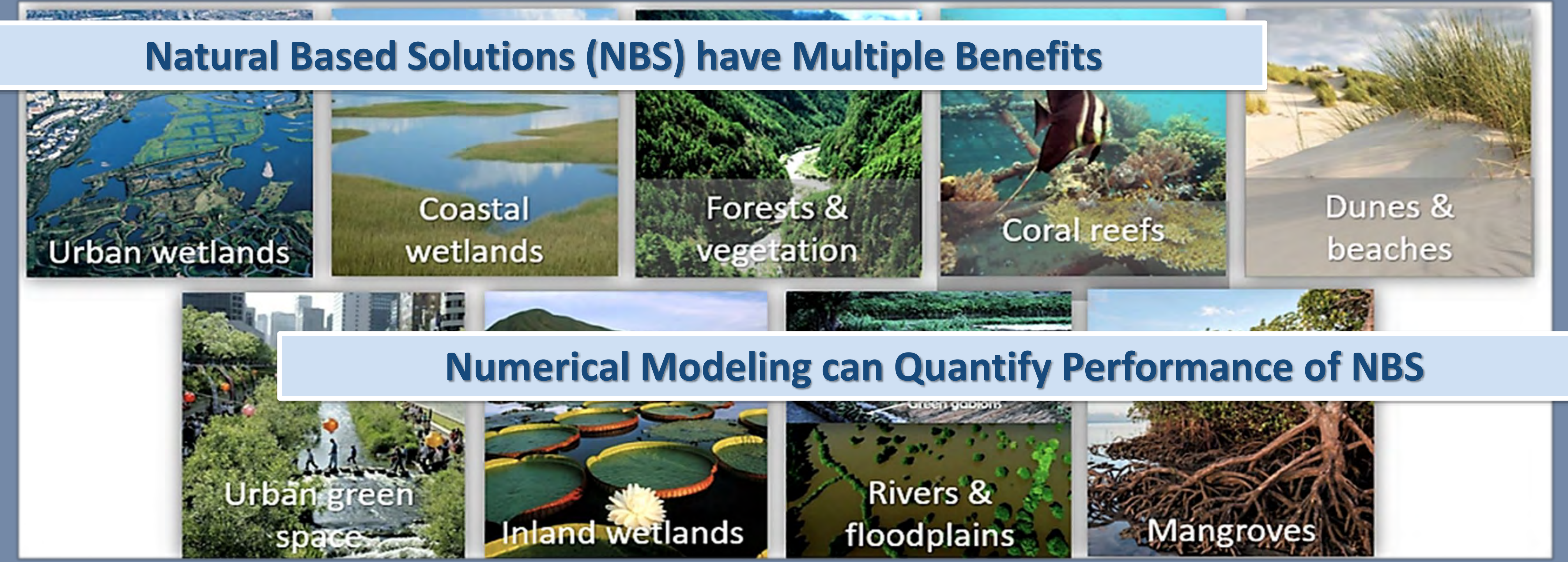






EWN® Toolkit for ERDC's CSTORM

Streamlining & Standardizing Augmentation of Natural Based Solutions within the Numerical Modeling Framework



EWN® Toolkit for ERDC's CSTORM

Problem

- Inclusion of NNBFs into numerical modeling is time consuming, and needs expert level commitment
- Approach has not been standardized, so effort tends to be completed differently per model.

Solution

- Develop a semi-automatic GUI that rapidly integrates NNBFs into existing models by;
- Adjusting topography/bathymetry
- Enhancing resolution accurately
- Setting roughness coefficient based on extensive literature review

Impact

- Time commitment, expert level needed per modeling project
- Allows for MORE designs to be tested
- Allows for more innovation opportunities using NNBFs in flood risk management
- Expands the EWN practice

Why model?!

Modeling of Long-Wave Hydrodynamics (and short waves too)

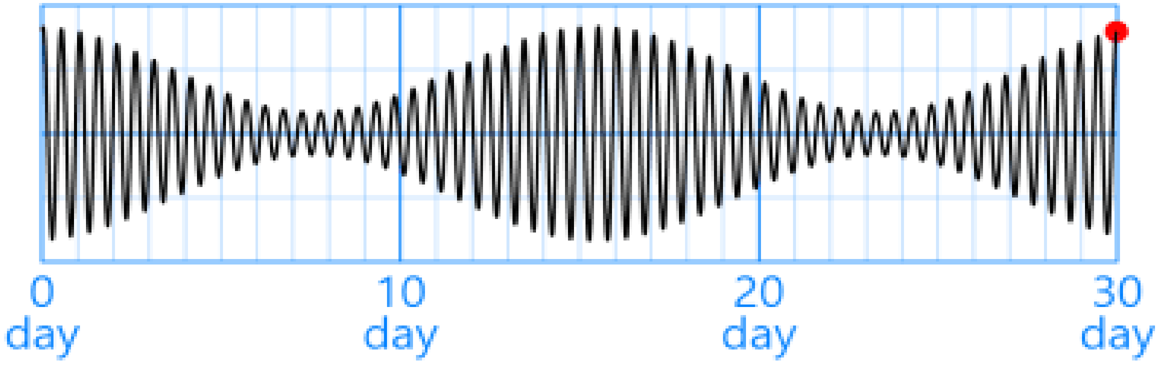
- What we are modeling:
  - Astronomical Tides
  - Water Surface Elevation Datums
  - Storm Surge
  - Wave Heights, Period, & Length

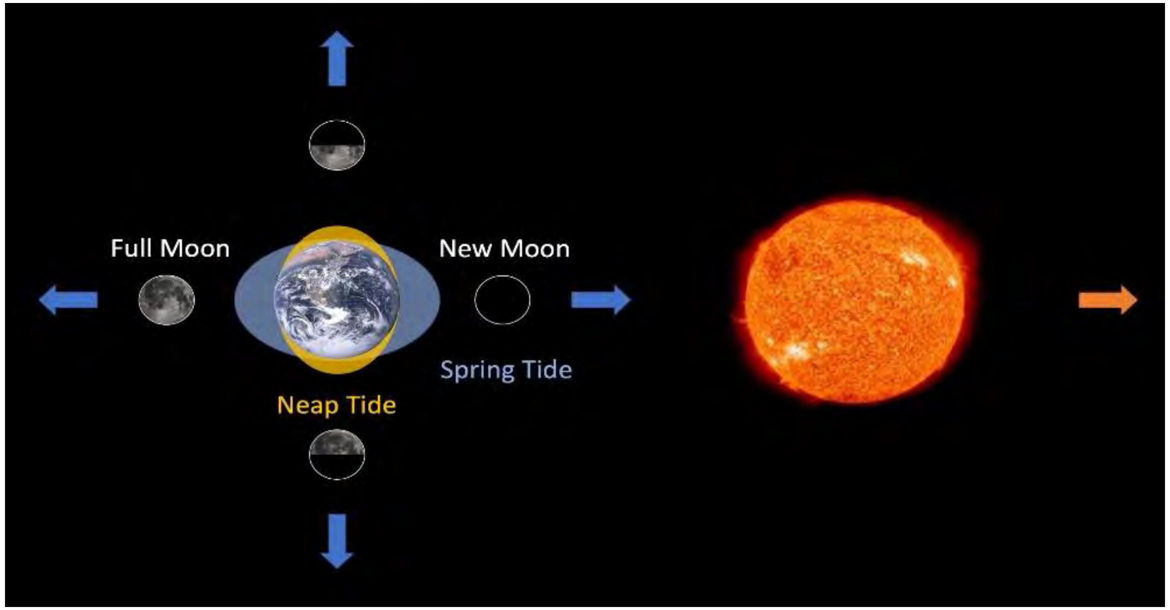
Water Levels and Long Waves

and modeling them.

EWN®

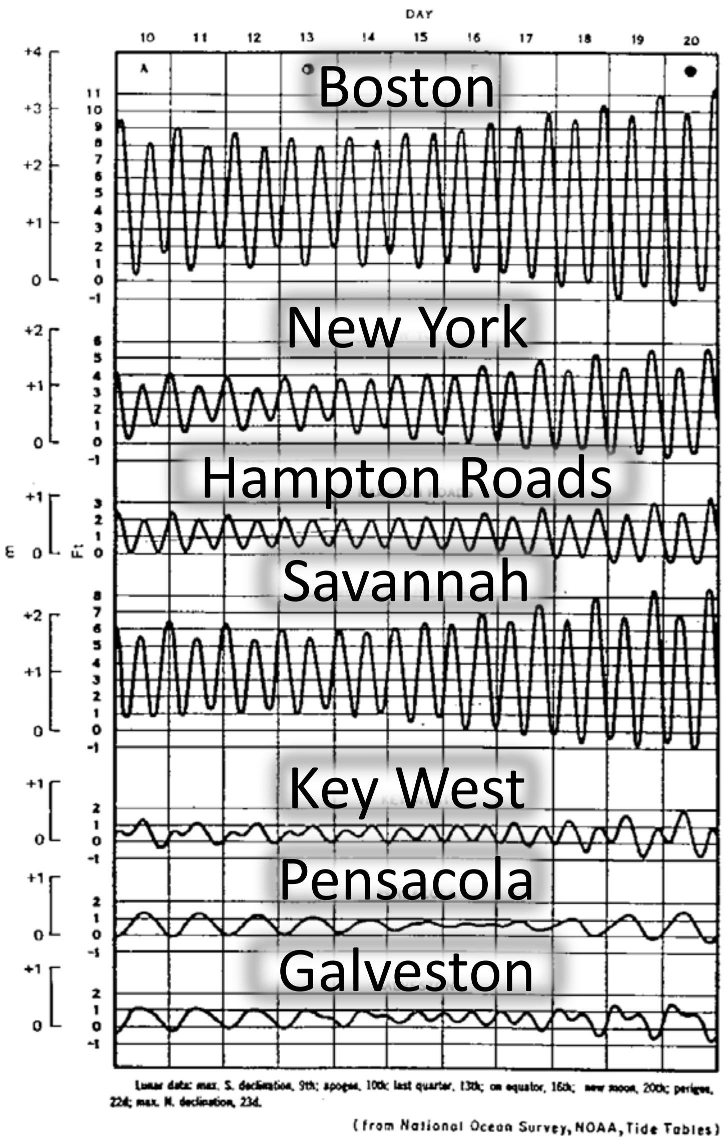
Tides


0
day
10
day
20
day
30
day

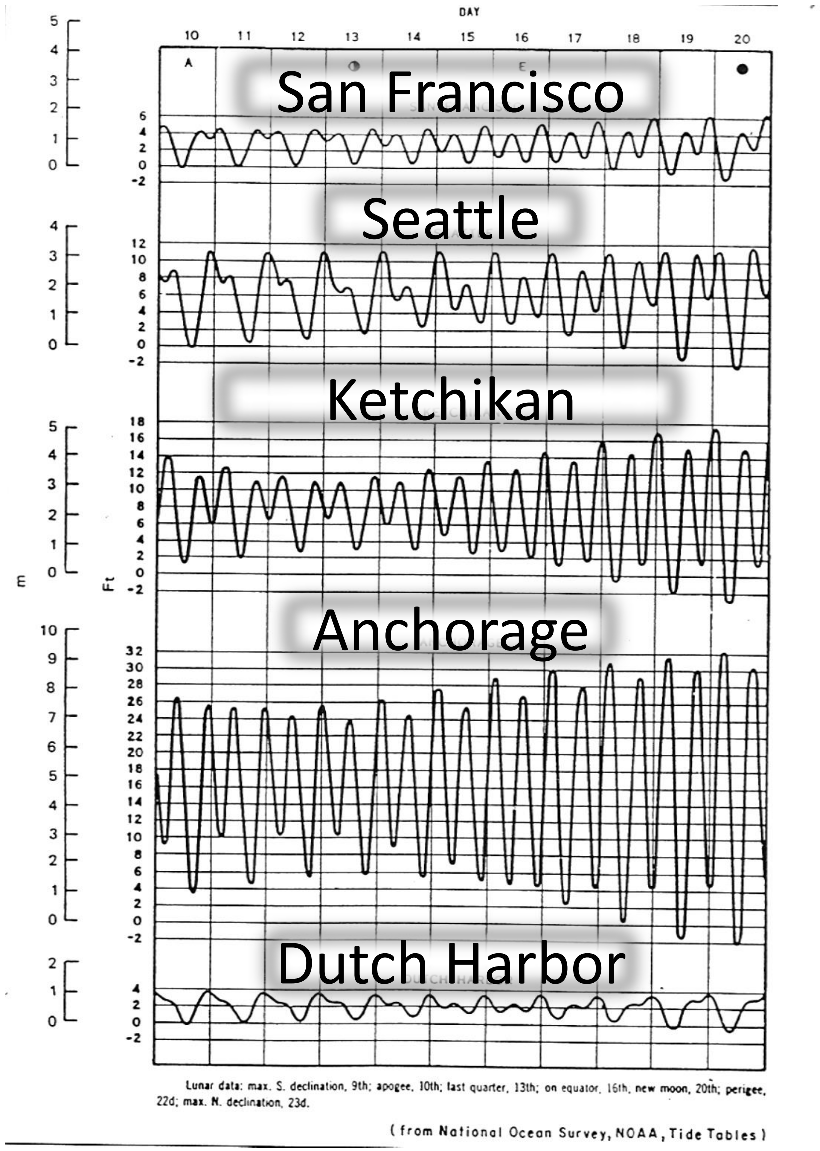

Full Moon
New Moon
Spring Tide
Neap Tide


Sun
Spring Tide
Earth
Resultant Tide
Solar Tide
Lunar Tide
Moon

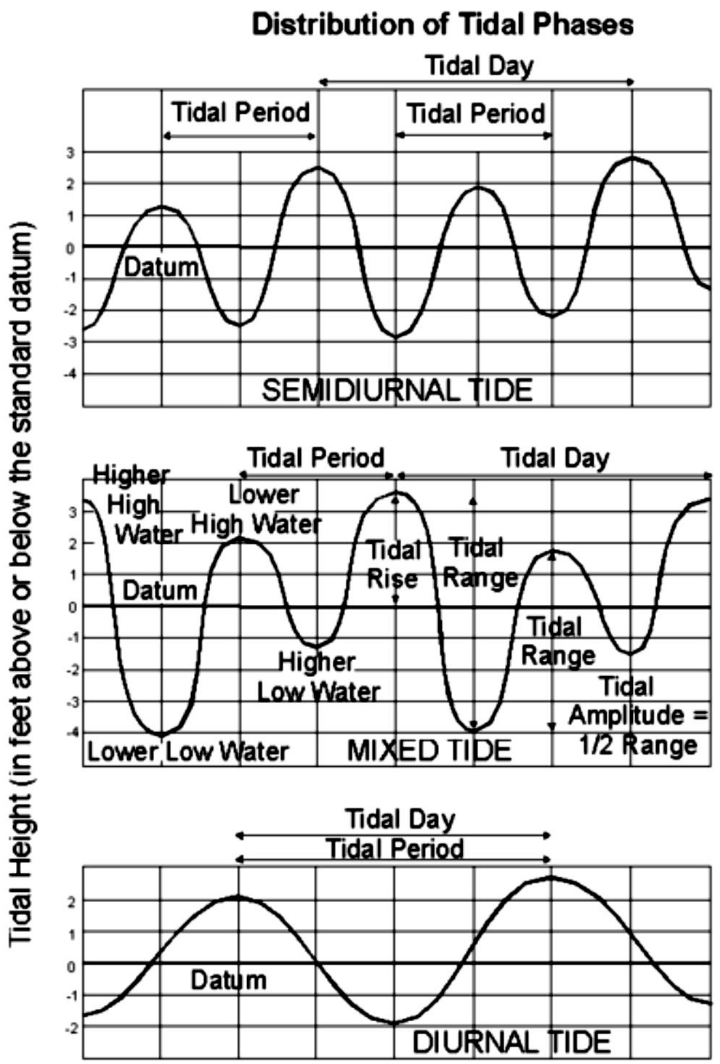
Tides in Atlantic/Gulf



Tides in Pacific Coast



Types of Tides



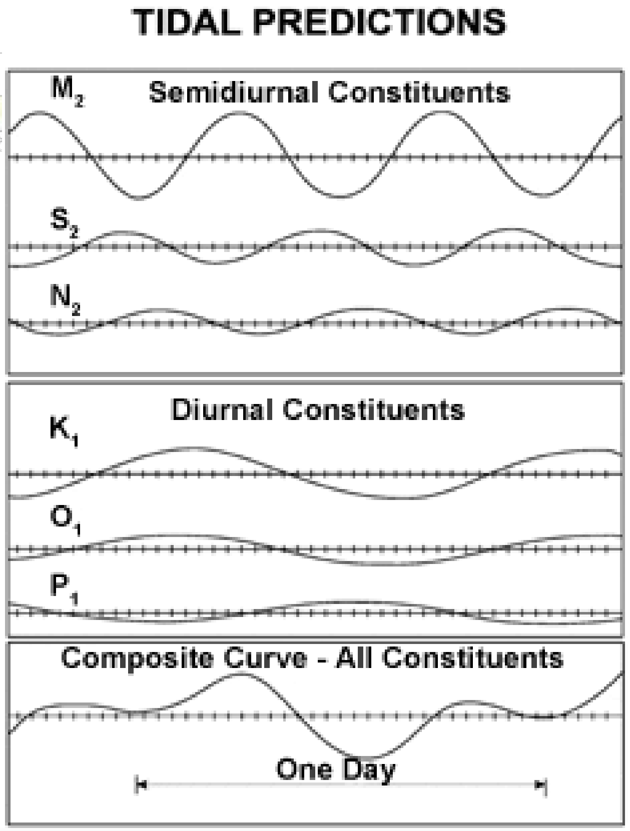
Calculate Tides

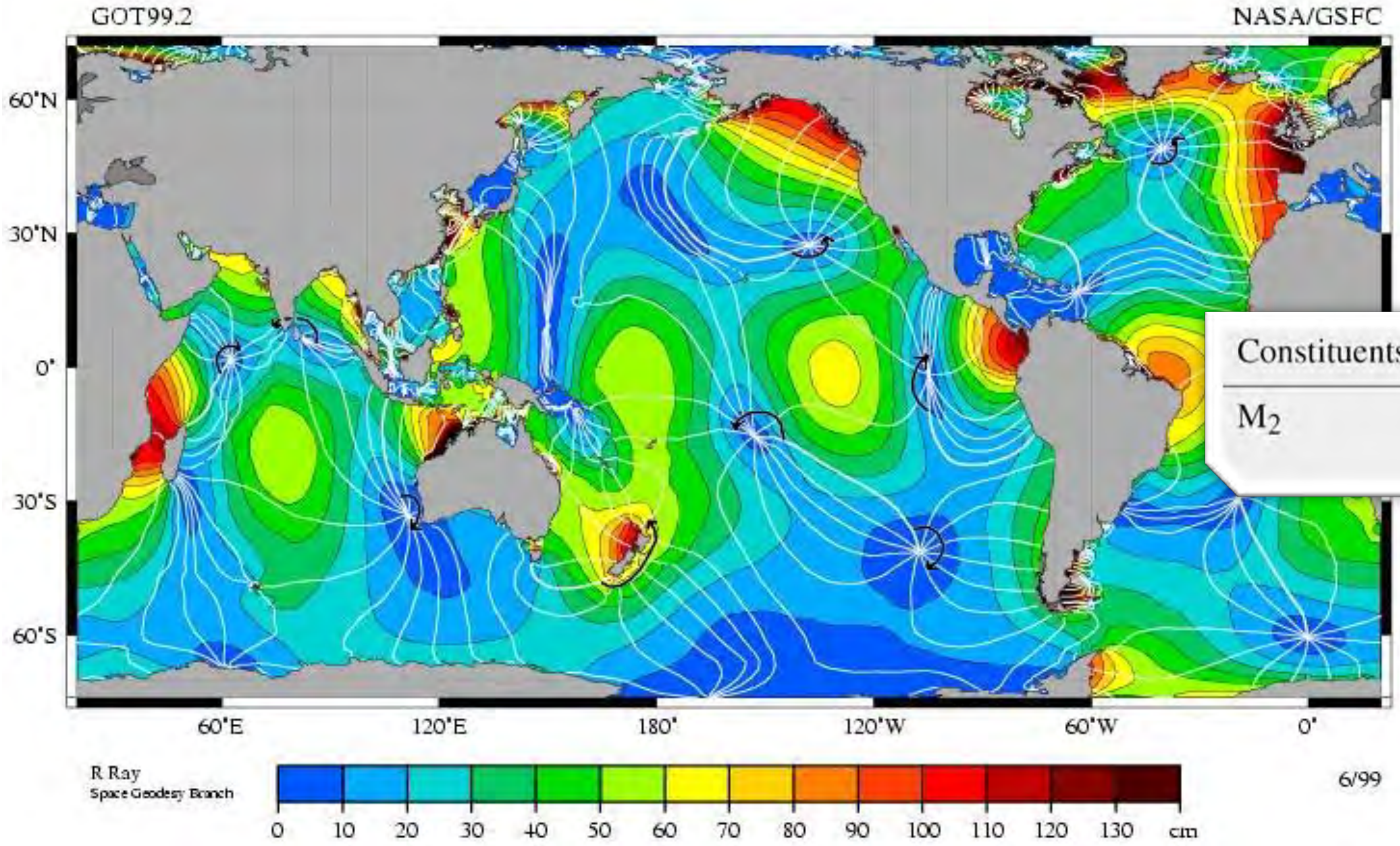
the tide equation and tidal constituents

$$H(t) = H_0 + \sum_{n=1}^{N} f_n H_n \cos[a_n t + (V_0 + u)_n - \kappa_n]$$

$$R = (A_{K_1} + A_{O_1})/(A_{M_2} + A_{S_2})$$

Where A is the amplitude of the constituent,
R < 0.25 is semidiurnal,
R > 1.5 is diurnal,
and in between is mixed.

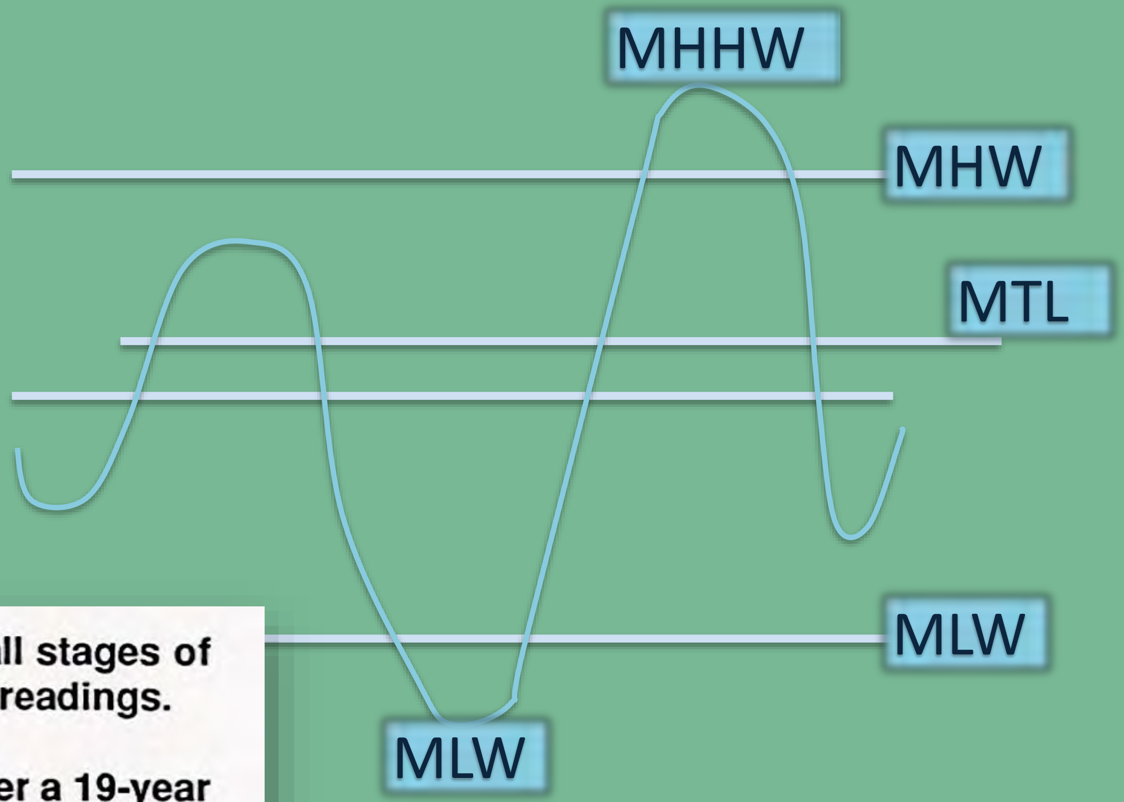




Constituents	Parameter	Annual	Winter	Spring	Summer	Autumn
M_2	Amplitude	97.32	97.53	96.79	97.96	97.00
	Phase lag	54.25	52.93	53.43	55.34	55.28
	Amplitude	30.89	32.54	30.91	29.1	31.02
	Phase lag	100.12	99.45	102.47	101.08	97.44
	Amplitude	25.32	25.02	24.78	26.18	25.3
	Phase lag	240.94	242.44	239.91	239.31	242.15
	Amplitude	17.91	17.41	18.05	17.88	18.29
	Phase lag	210.29	212.4	208.54	209.62	210.65

Water Surface Elevations

And Datums



MEAN SEA LEVEL (MSL) - The average height of the sea surface for all stages of the tide over a 19-year period, usually determined from hourly height readings.

MEAN HIGH WATER (MHW) - The average height of the high waters over a 19-year period.

MEAN LOW WATER (MLW) - The average height of the low waters over a 19-year period.

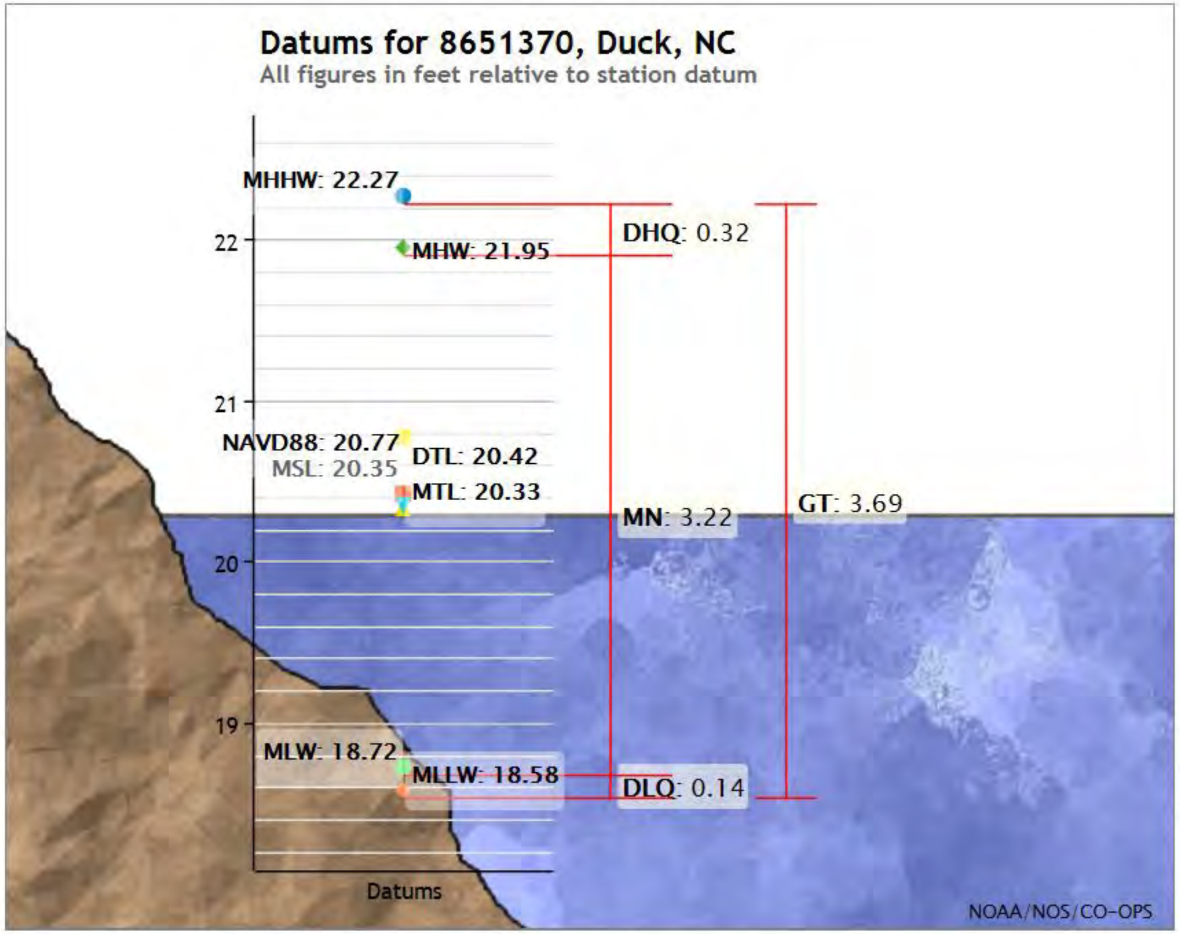
MEAN TIDE LEVEL (MTL) - A plane midway between MEAN HIGH WATER and MEAN LOW WATER. Not necessarily equal to MEAN SEA LEVEL.

MEAN HIGHER HIGH WATER (MHHW) - The average height of the higher high waters over a 19-year period.

MEAN LOWER LOW WATER (MLLW) - The average height of the lower low waters over a 19-year period.

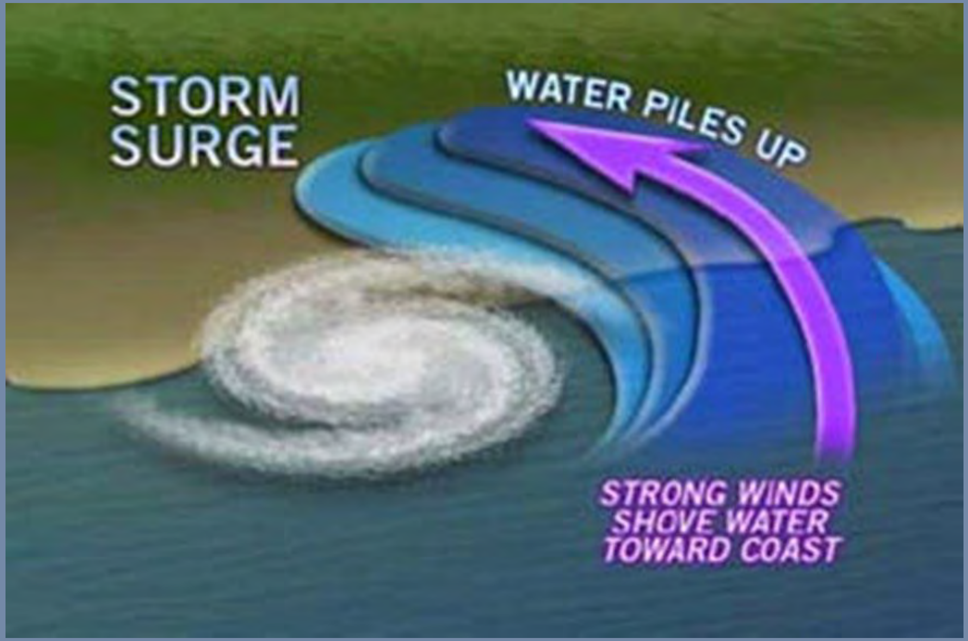
Fixed reference datums

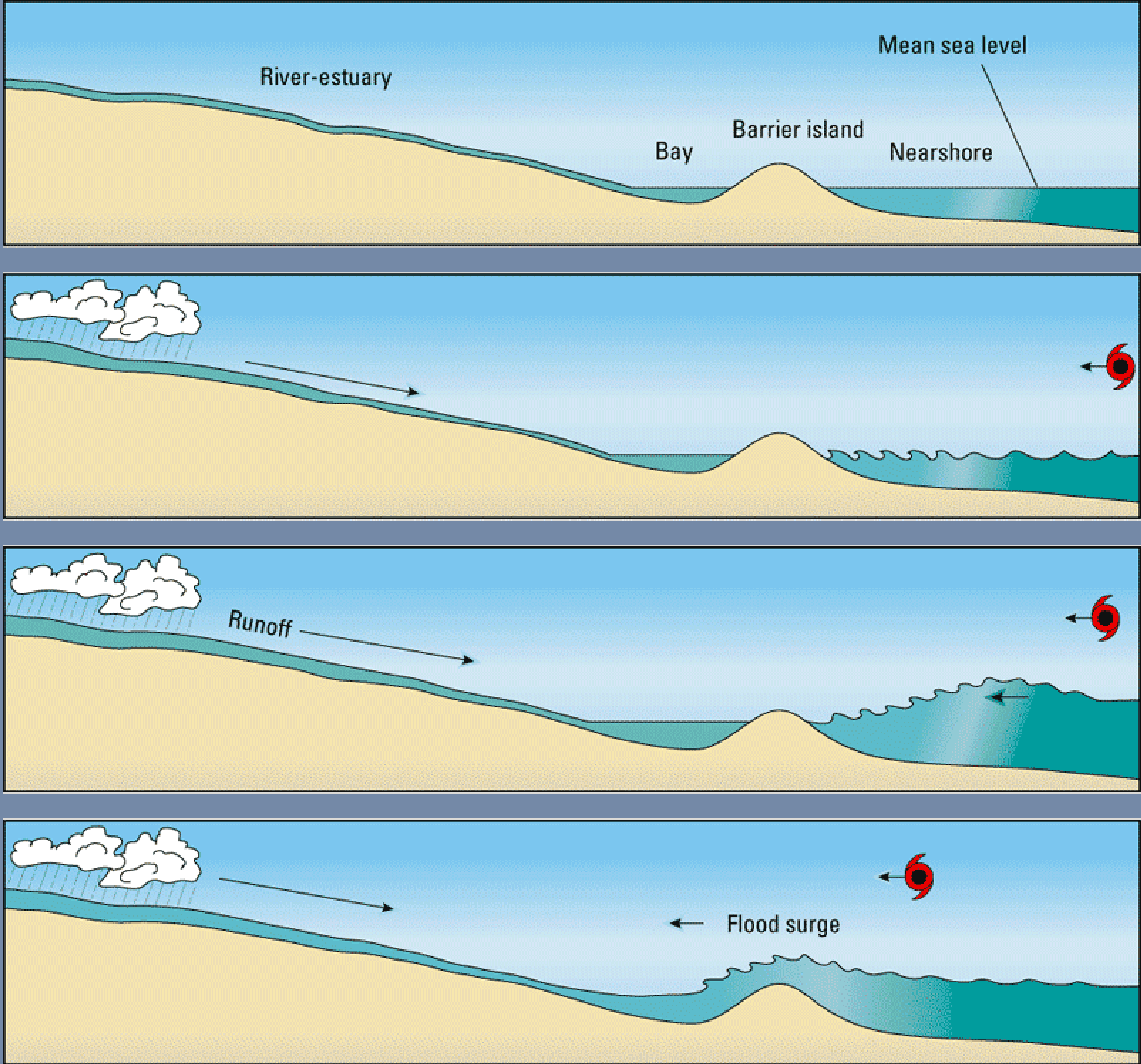
- Usually preferred as the primary datum for engineering design
  - National Geodetic Vertical Datum (NGVD) A fixed reference adopted as a standard geodetic datum for elevations determined by leveling
  - Established in 1929
  - "National Geodetic Vertical Datum of 1929" and "Sea Level Datum of 1929"
- North American Vertical Datum of 1988 (NAVD 1988) –updated version of NGVD



Storm Surge

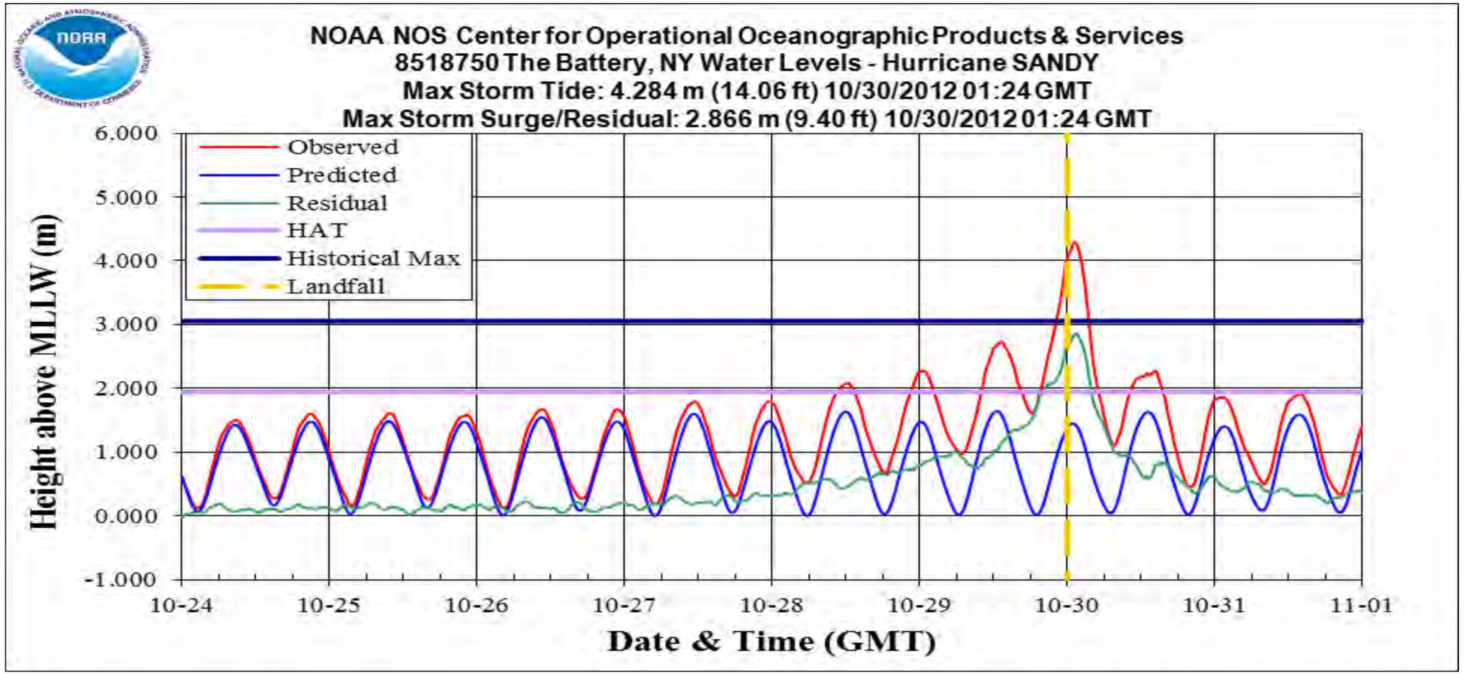
Wind-induced surge, accompanied by wave action causes most damage to beaches and estuaries.

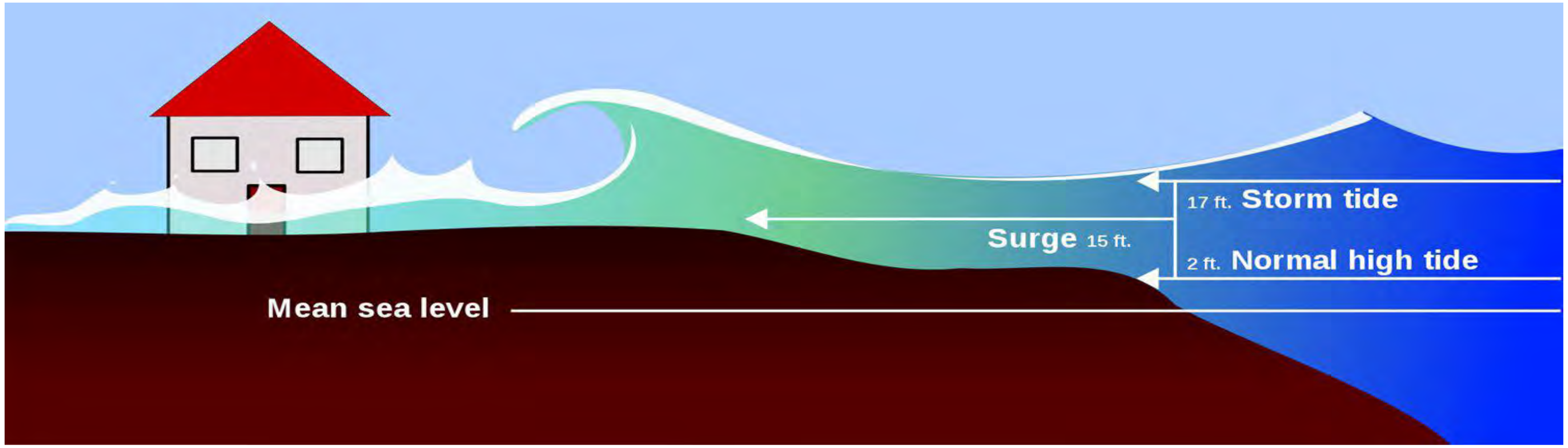




Storm Surge – Generation Processes

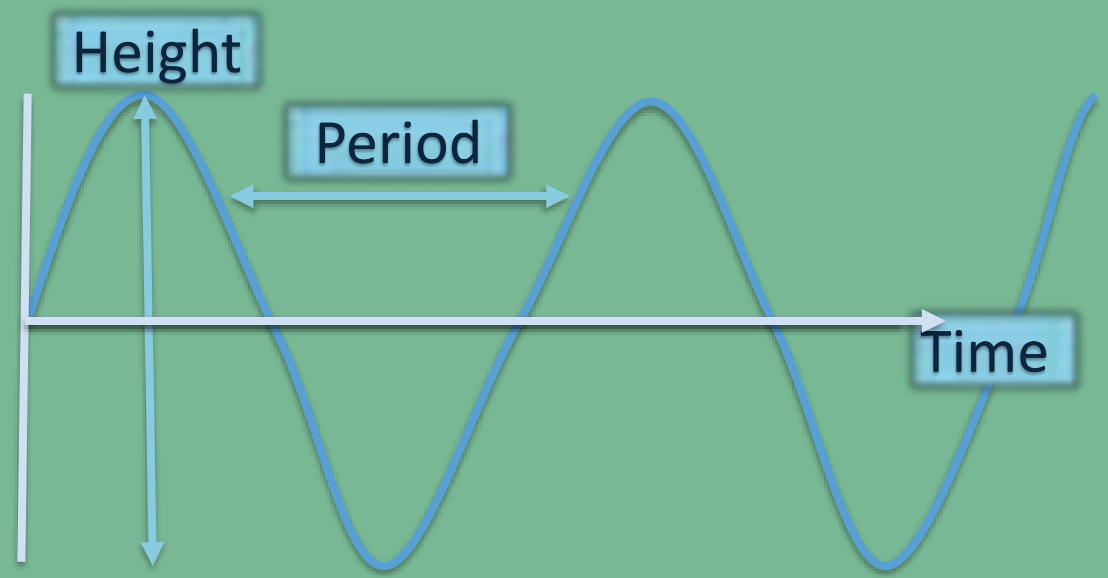
- Direct wind
- Pressure (Barometric)
- Storm motion
- Earth's rotation
- Rainfall
- Wave setup

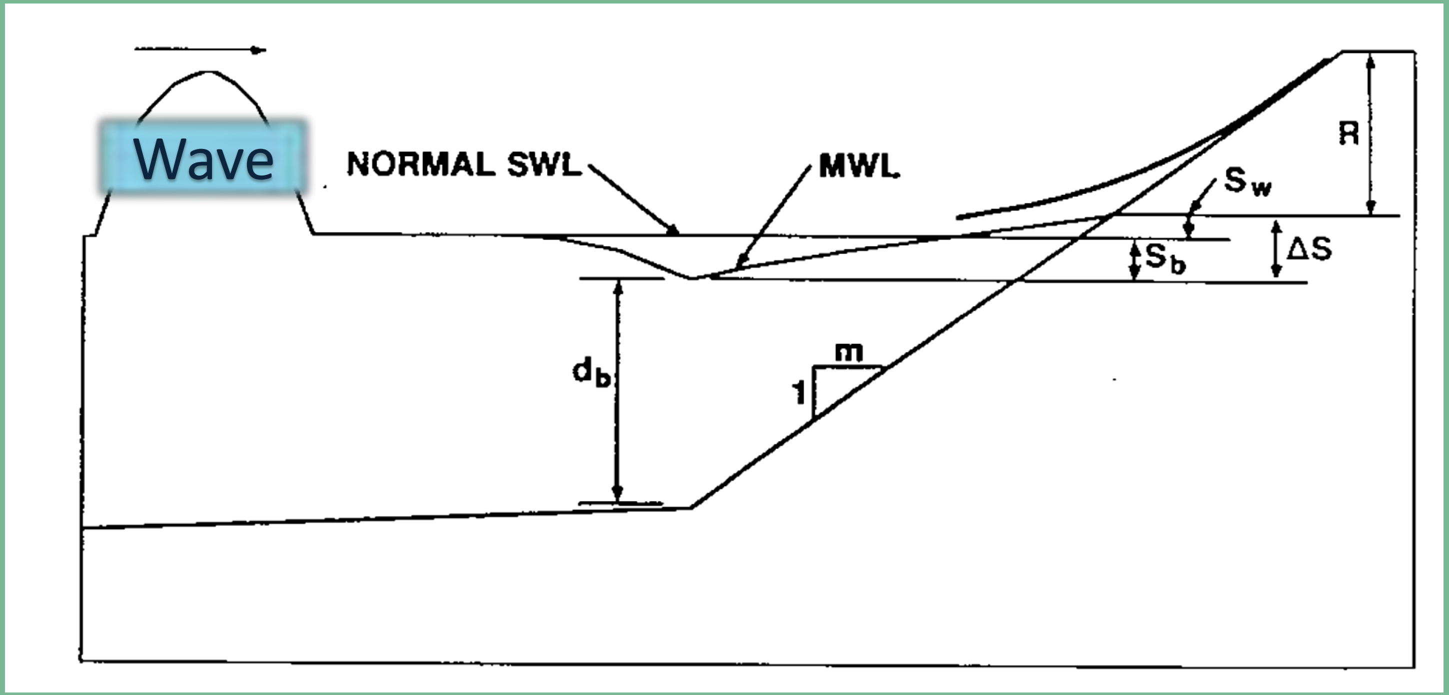




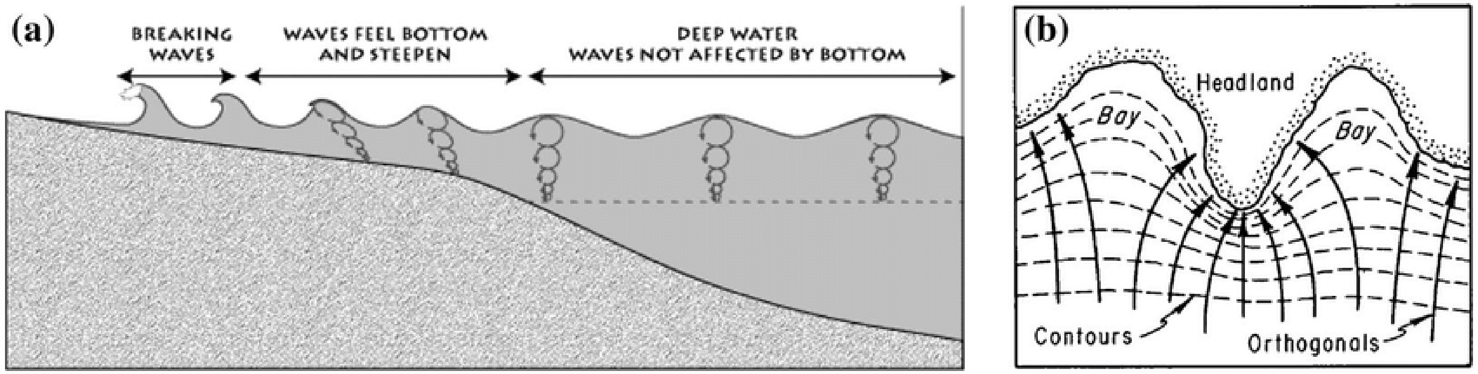
Wave Setup

increases water level at coast during storms

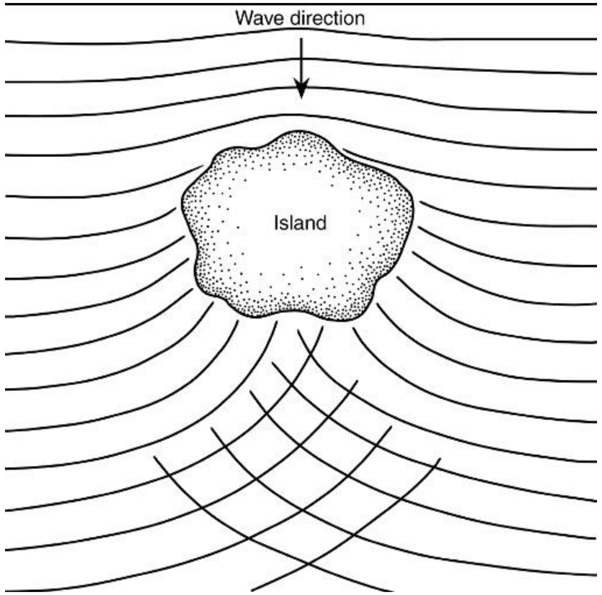




Wave Dynamics

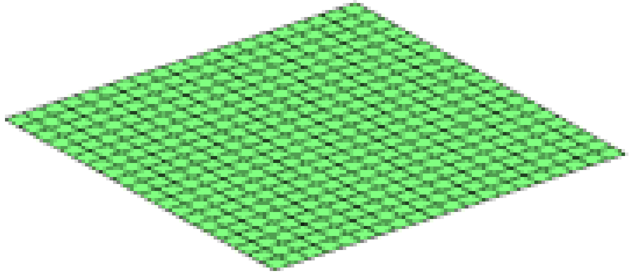


(a) Wave shoaling diagram. (b) Wave refraction diagram. source: USACE coastal engineering Manual.



Kenneth J. Lohmann, Catherine M. F. Lohmann, Courtney S. Endres
The sensory ecology of ocean navigation

shutterstock.com · 581444137



The **wave equation** is a linear second-order partial differential equation which describes the propagation of oscillations at a fixed speed in some quantity y:

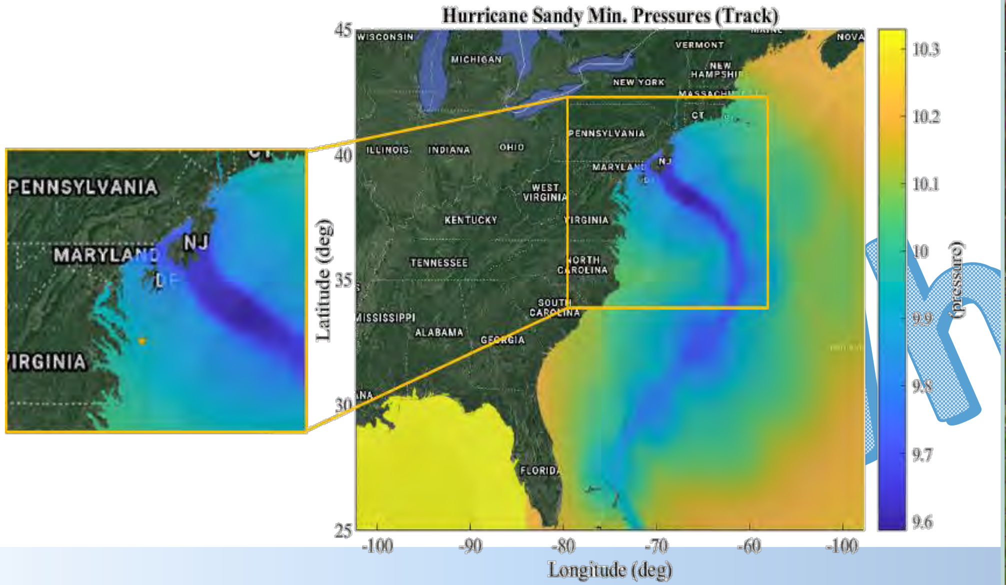
$$\frac{1}{v^2}\frac{\partial^2 y}{\partial t^2} = \frac{\partial^2 y}{\partial x^2},$$

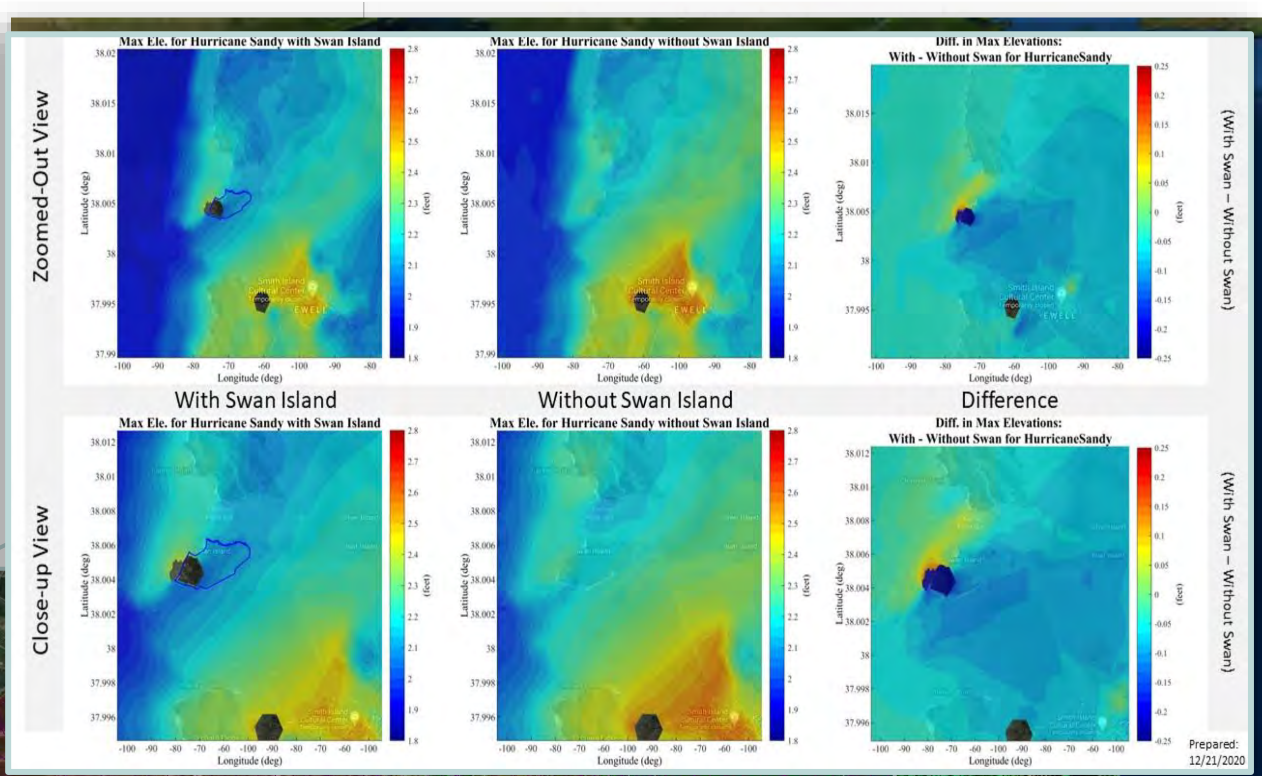
where v is the velocity of the wave.

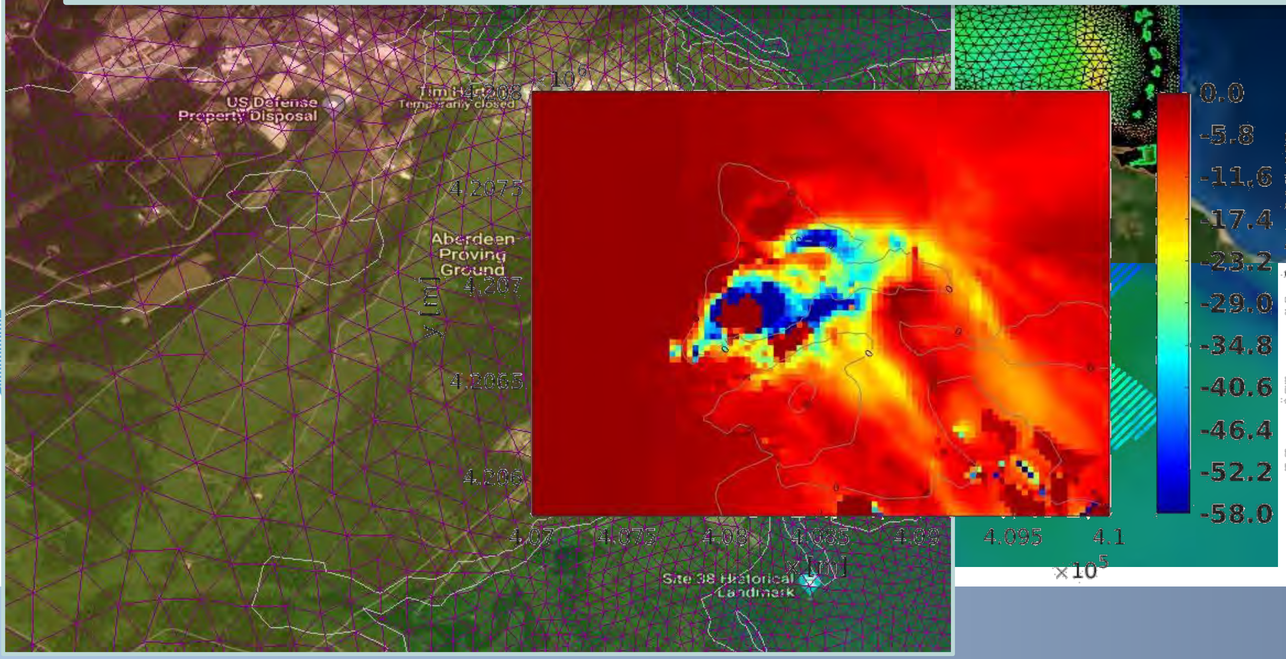
https://brilliant.org/wiki/wave-equation

Modeling Hydrodynamics

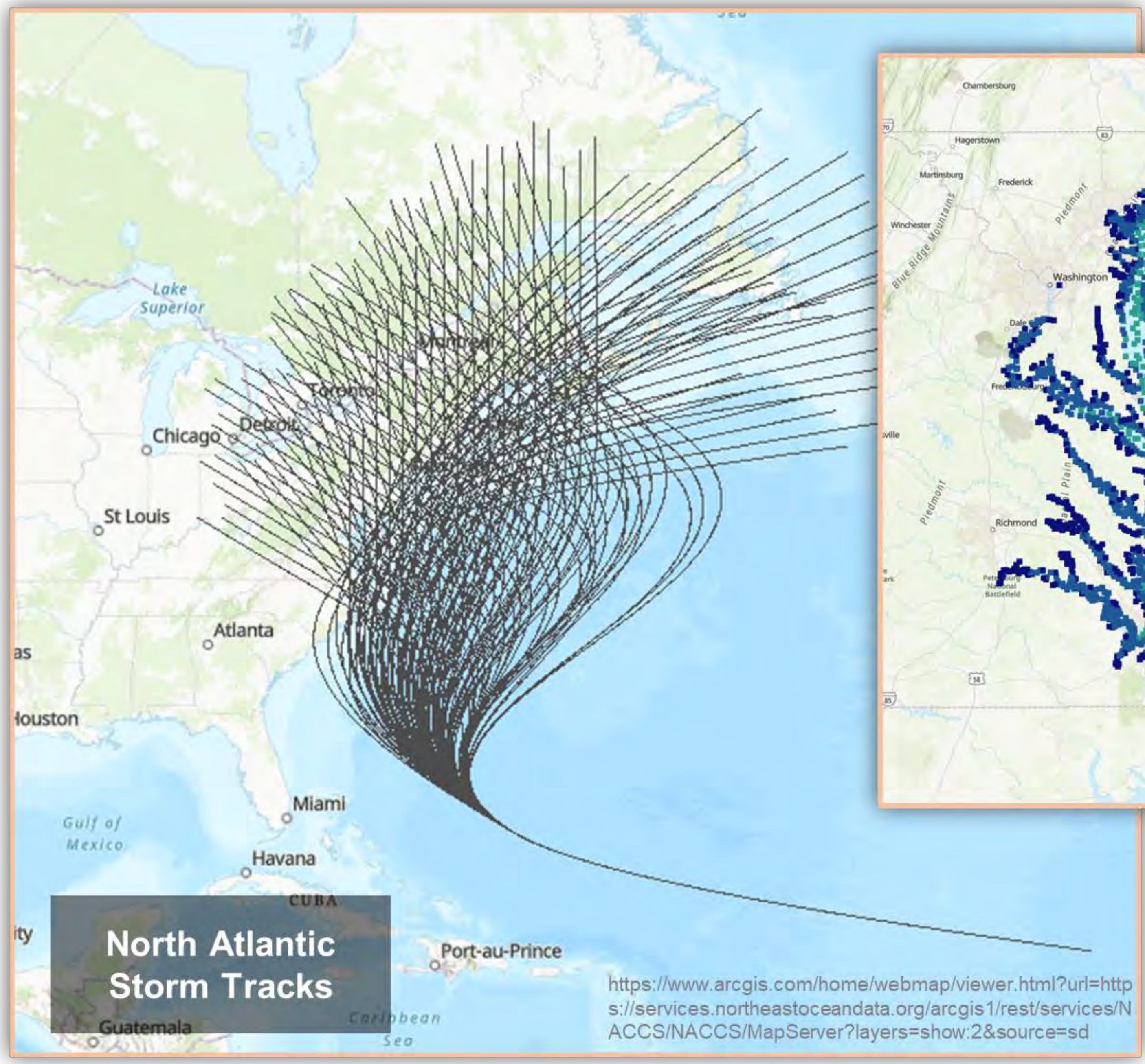
- What we are modeling:
  - Astronomical Tides
  - Water Surface Elevation Datums
  - Storm Surge
  - Wave Heights, Period, & Length

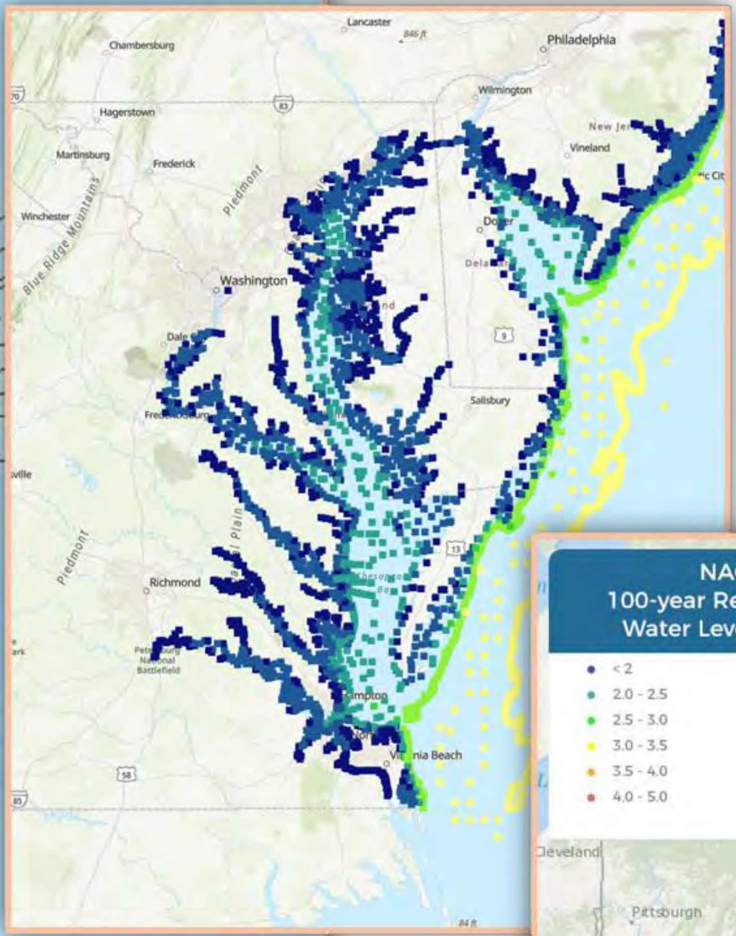


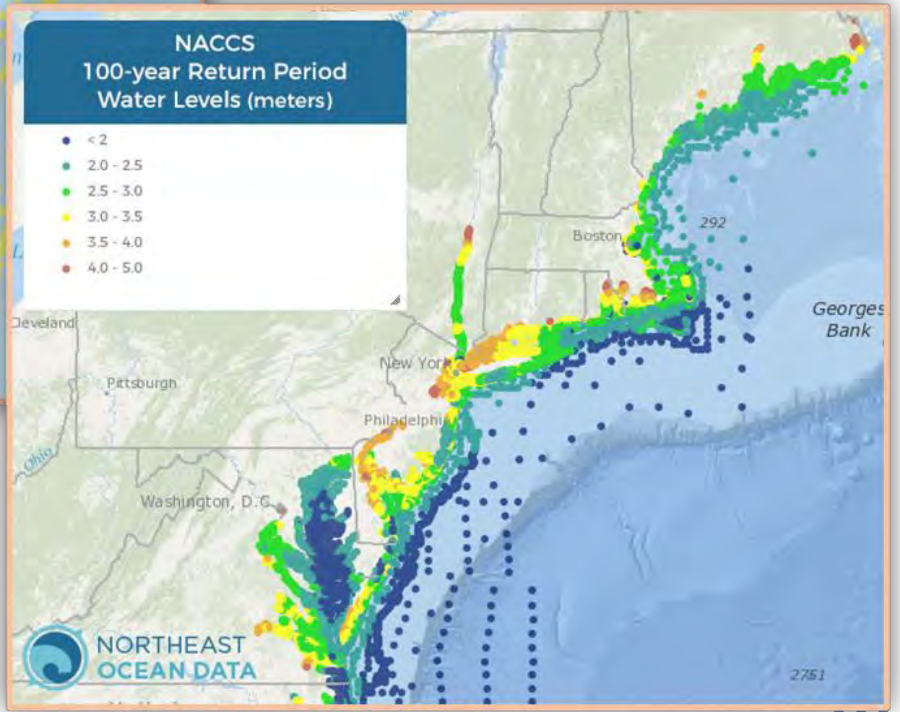




North Atlantic Storm Suite







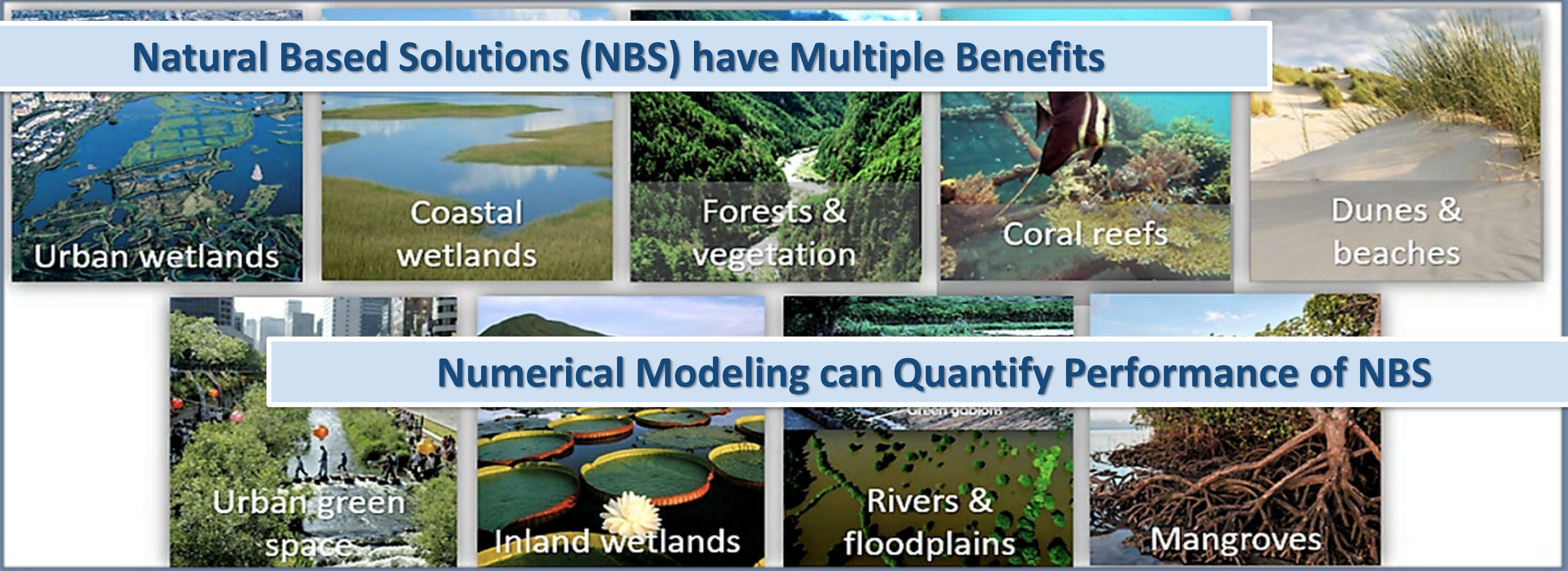
EWN

EWN® Toolkit for ERDC's CSTORM

Streamlining & Standardizing Augmentation of Natural Based Solutions within the Numerical Modeling Framework

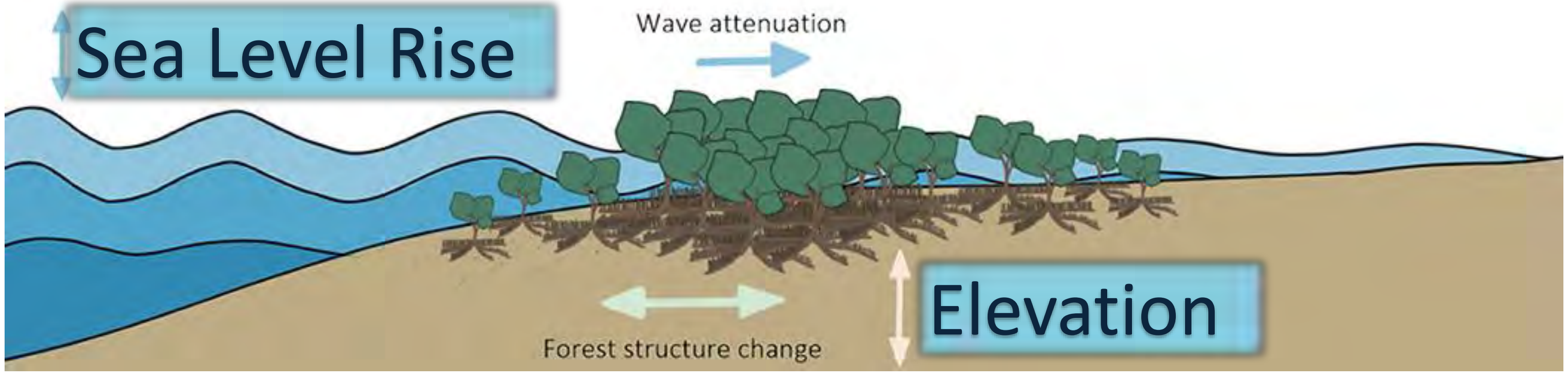
Natural Based Solutions (NBS) have Multiple Benefits

Numerical Modeling can Quantify Performance of NBS

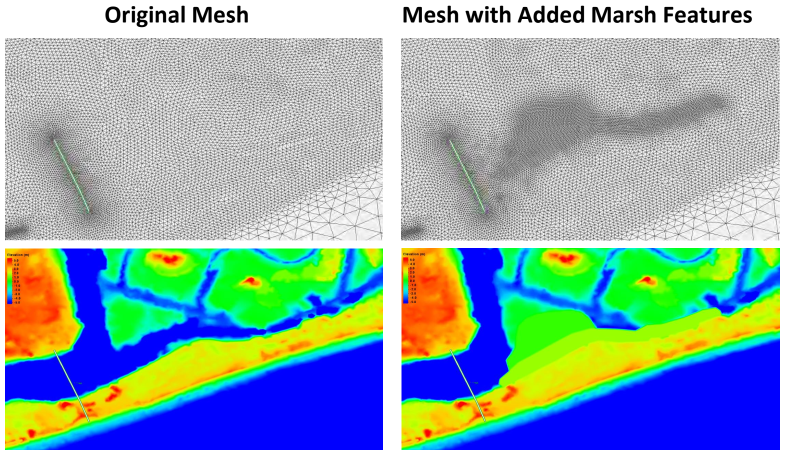


Modeling Hydrodynamics with Natural Based Solution (NBS) Features

- Adjust for;
  - Elevation
  - Drag
  - Model Resolution
  - *Sea Level Rise*



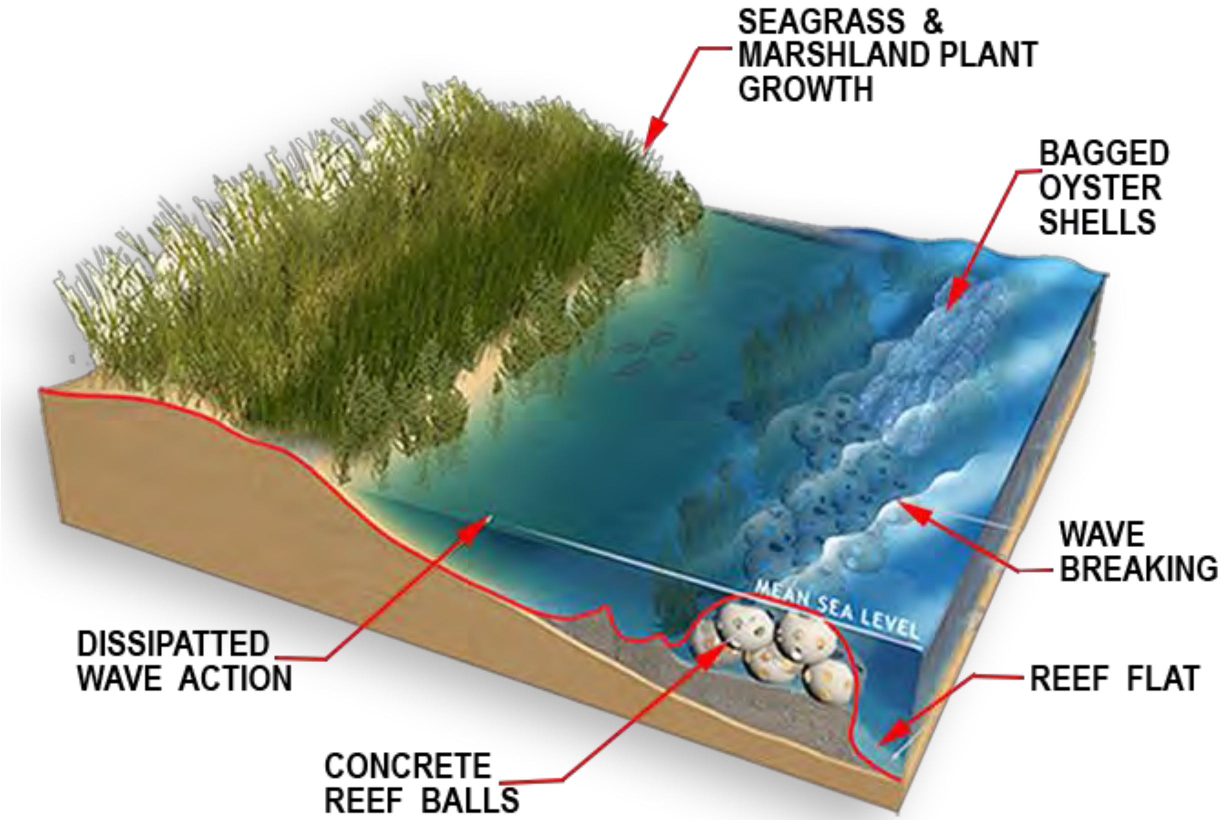
Gijsman Rik, Horstman Erik M., van der Wal Daphne, Friess Daniel A., Swales Andrew, Wijnberg Kathelijne M.
Nature-Based Engineering: A Review on Reducing Coastal Flood Risk With Mangroves



Elevation Adjustment

Topography

Bathymetry

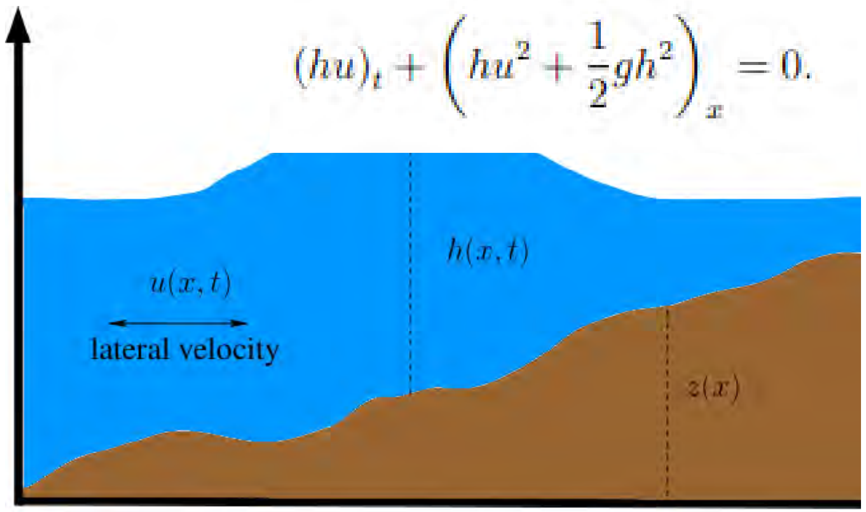


https://ewn.el.erdc.dren.mil/nnbf.html

--> Momentum Flux

Essentially, change in pressure,

$$(hu)_t + \left(hu^2 + \frac{1}{2}gh^2\right)_x = 0.$$



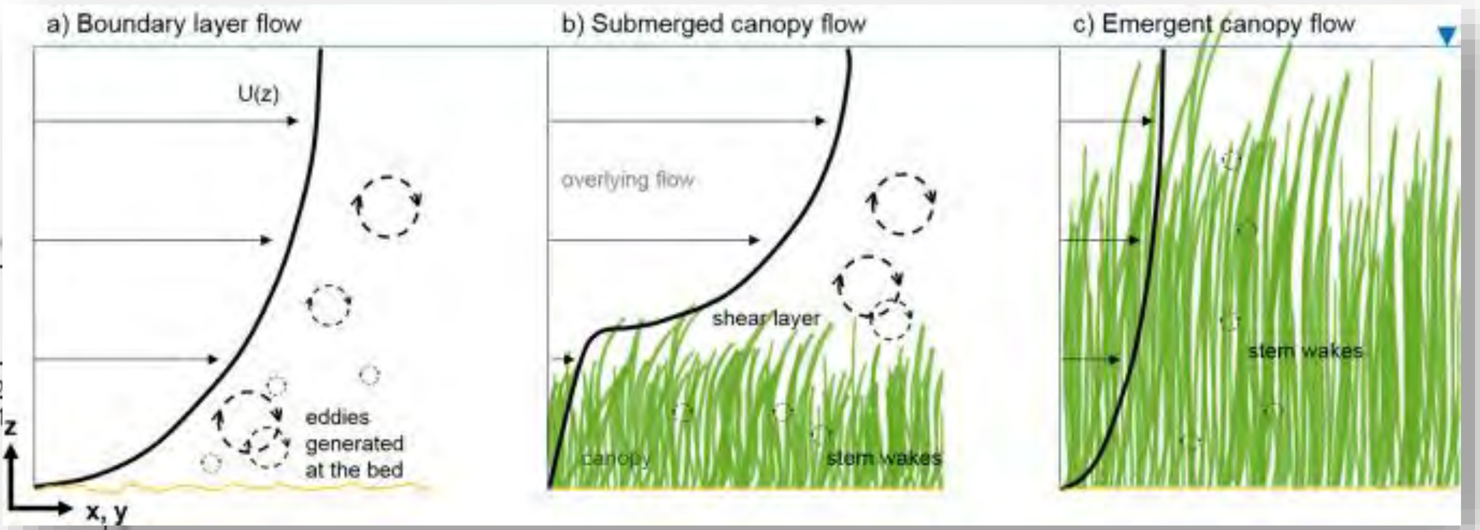
Numerical simulation of shallow water equations and related models
H. Gunawan

and changes wave energy calc.

Flow Through Vegetation Adjustment

- Coef. Of Drag

Nature-based Feature	Region	Grouped species	Mannings n	Drag Coefficient	Source
Mangroves	East coast	Rhizophora mangle	0.124 - 3.00 (depending on the range of Re and Fr)	0.4 – 10 (an inverse relationship between Re and CD)	Narayanan et al 2[illegible] Vanegas et al 201[illegible]
	Gulf coast	Avicennia germinans, Rhizophora mangle (Florida)	0.124 - 3.00 (depending on the range of Re and Fr)	0.4 – 10 (an inverse relationship between Re and CD)	Noarayanan et al 2012; Vanegas et al 2019
Low and High marsh	East and Gulf coast	Spartina patens, Spartina alterniflora, Distichlis spicata, Bolboschoenus robustus, Juncus roemerianus		0.1-1.1; 1-2.5; 1-4 (bulk drag coefficient); 0.2-3.2 (depending on the distribution)	Augustin et al 2009, Anderson and Smith 2014; Jadhav and Chen 2012; Peruzzo et al 2018
		Phragmites australis, Solidago sempervirens, Typha domingensis	0.018-0.024 (depending on location in the furrow and inflow rates; unsure of plant properties!!)	1.49-26.24 (decreased as the flow rate increased)	Mailapalli et al 2008; Zhao et al 2017



Alexis Beudin, Tarandeep S.Kalra, Neil K.Ganju, John C.Warner
Development of a coupled wave-flow-vegetation interaction model

Suggested Vegetation Roughness for Numerical Modeling in the Coastal Region – A Lookup Table tool

A journal publication *Title subject to change*

Rachel Innocenti, Candice Piercy, Amanda Tritinger, Chris Massey, and Mary Bryant

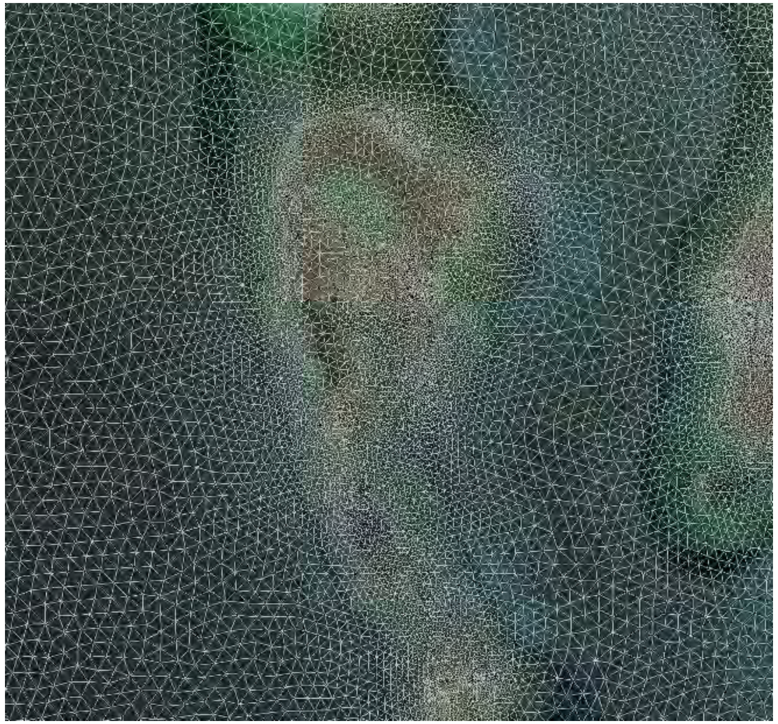
Coastal and Hydraulics Laboratory [Text Wrapping Break] *U.S. Army Engineer Research and Development Center* [Text Wrapping Break] *3909 Halls Ferry Road* [Text Wrapping Break] *Vicksburg, MS 39180-6199*

Abstract: USACE storm surge and wave model users typically adjust the drag coefficient, or bottom roughness, in order to capture the effects of vegetation in their model. A vegetation roughness look up table was developed as a tool to propose default values for various vegetation representations in these models. The table accounts for varying species of

Resolution Adjustment

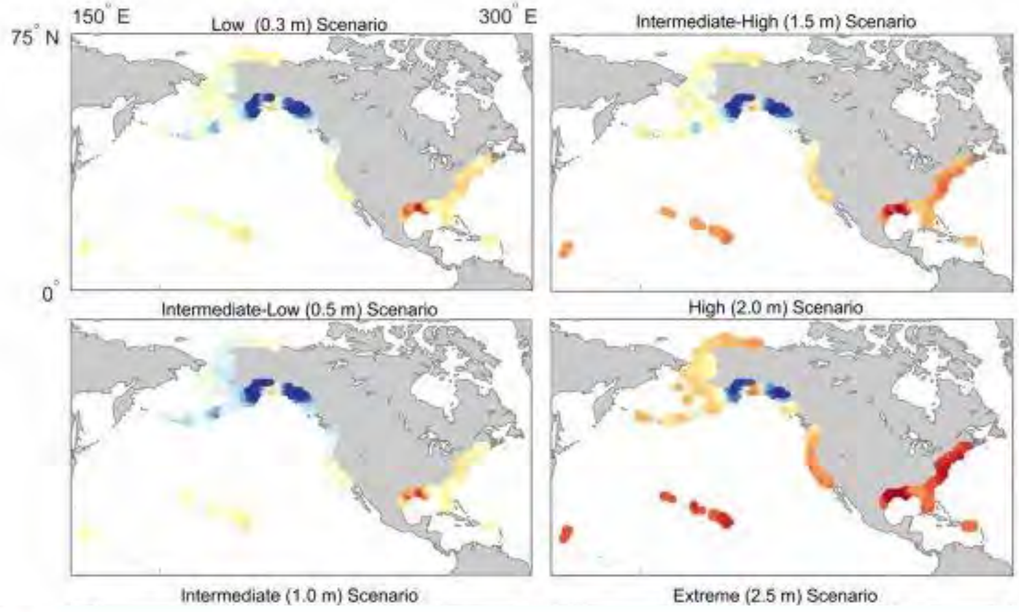
Area of Interest

Mesh Resolution



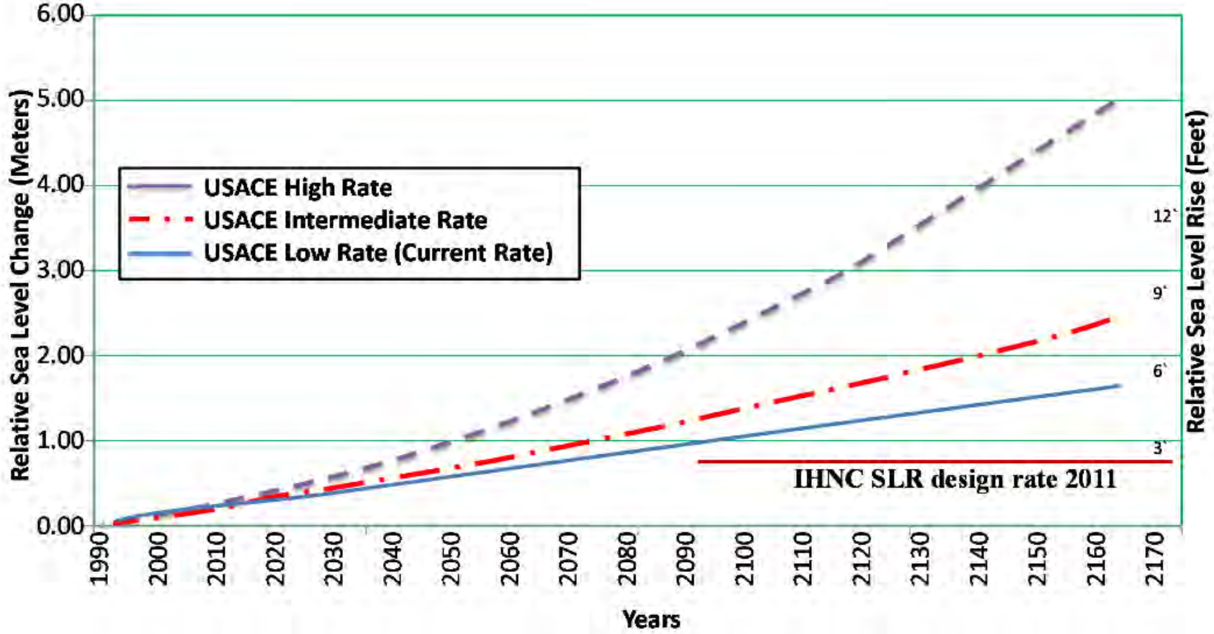
Resolved for Features

Sea Level Rise (SLR) Adjustment



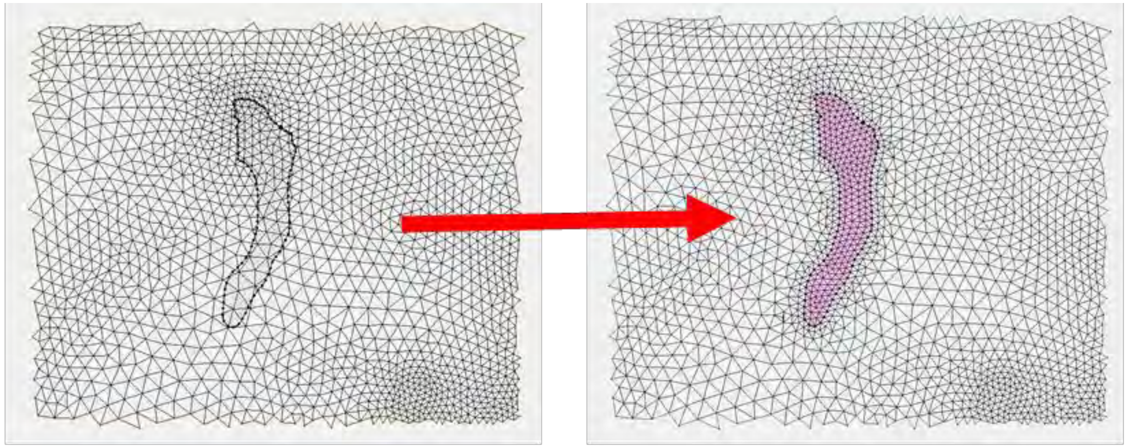
SLR Considerations:

- Eng. Regulation 1110-2-8162 (June 2019) -- Incorporating Sea Level Change in Civil Works Programs
- Eng. Pamphlet 1100-2-1 (June 2019) – Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation
- USACE Sea Level Change Curve Calculator (Version 2021.12) (https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html)



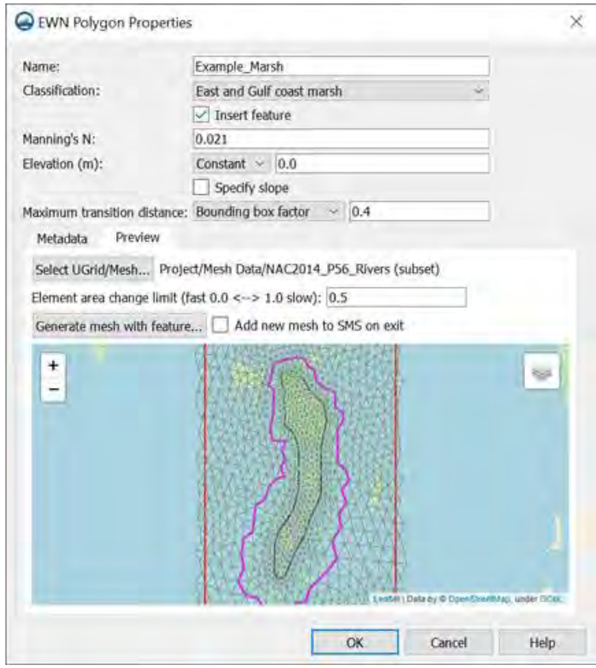
The EWN® Toolkit for ERDC’s CSTORM

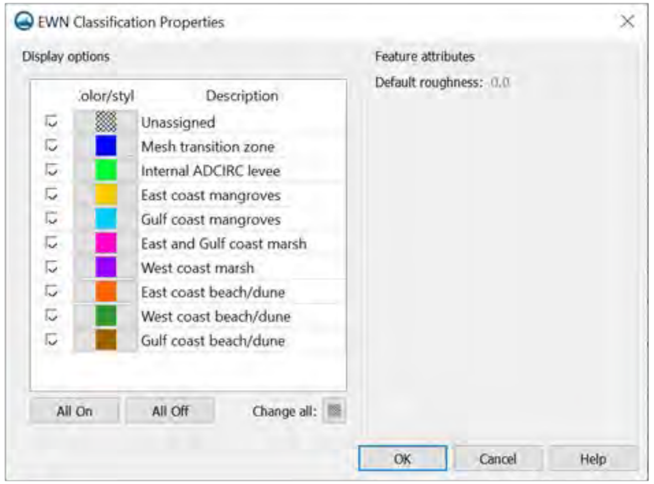
- The Toolkit allows for rapid representation of EWN features within a coastal, estuarine, and fluvial numerical model background.
- EWN properties will be assigned as the polygons that represent those features are generated.
- The topographic and bathymetric changes will be assigned by the user and the Manning’s n value will be available in a look up table.

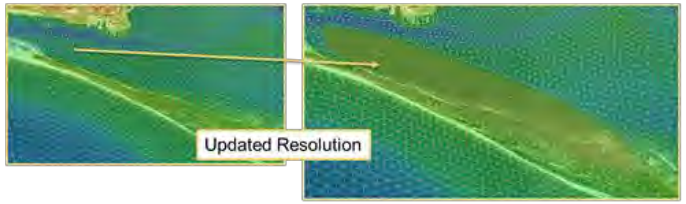


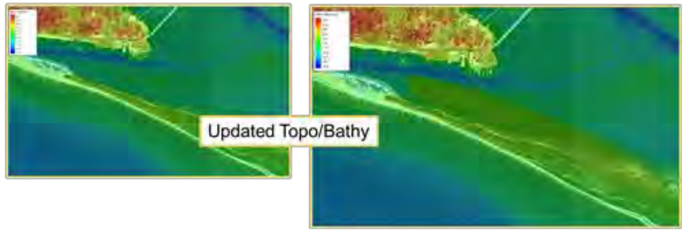
Before Feature Incorporation

After Feature Incorporation





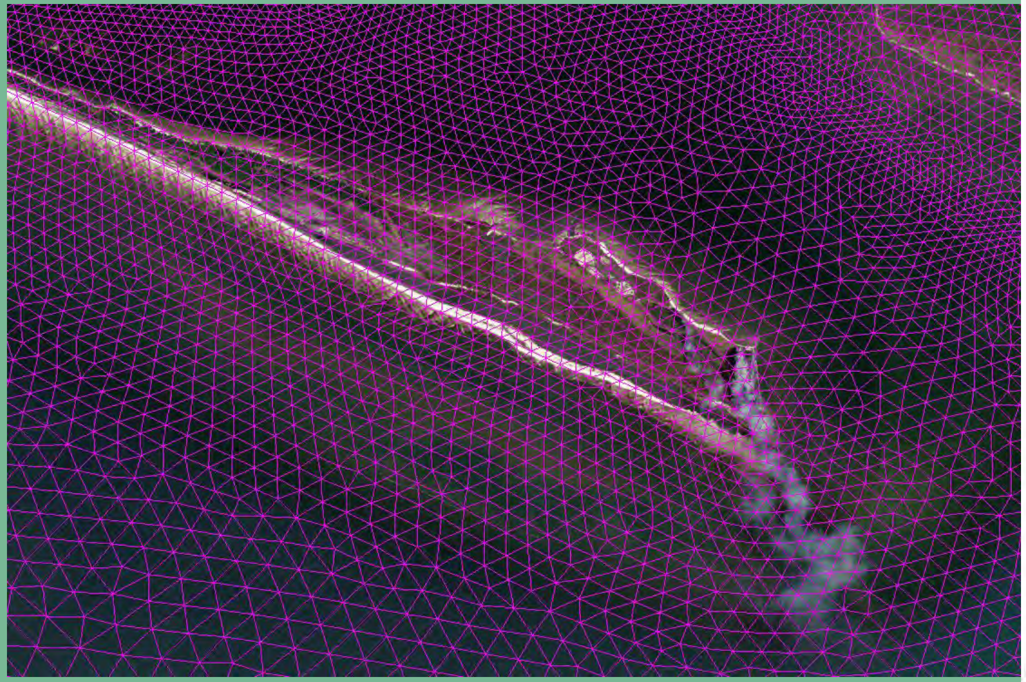


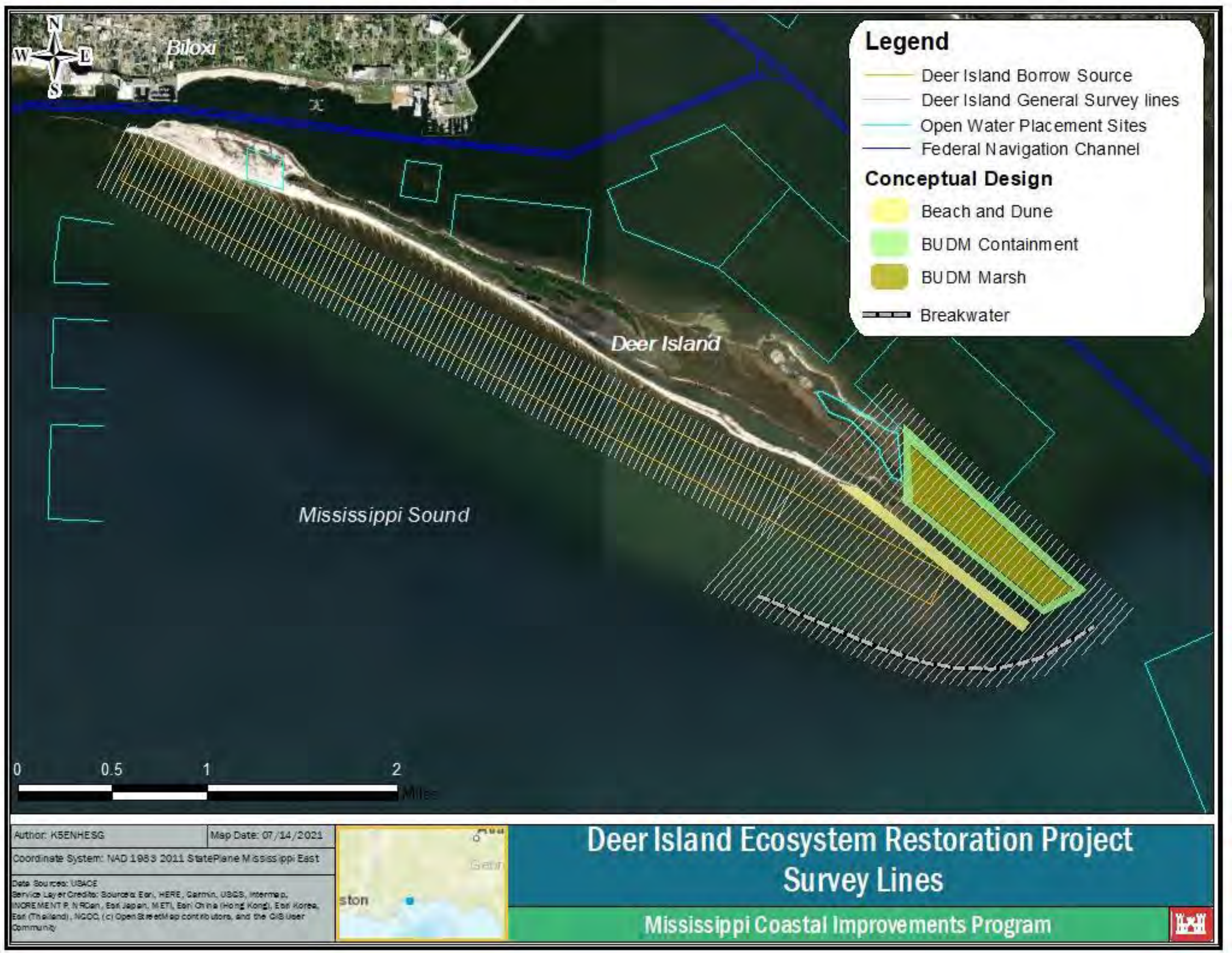


EWN® Toolkit for ERDC's CSTORM

Example Resolution Adjustment

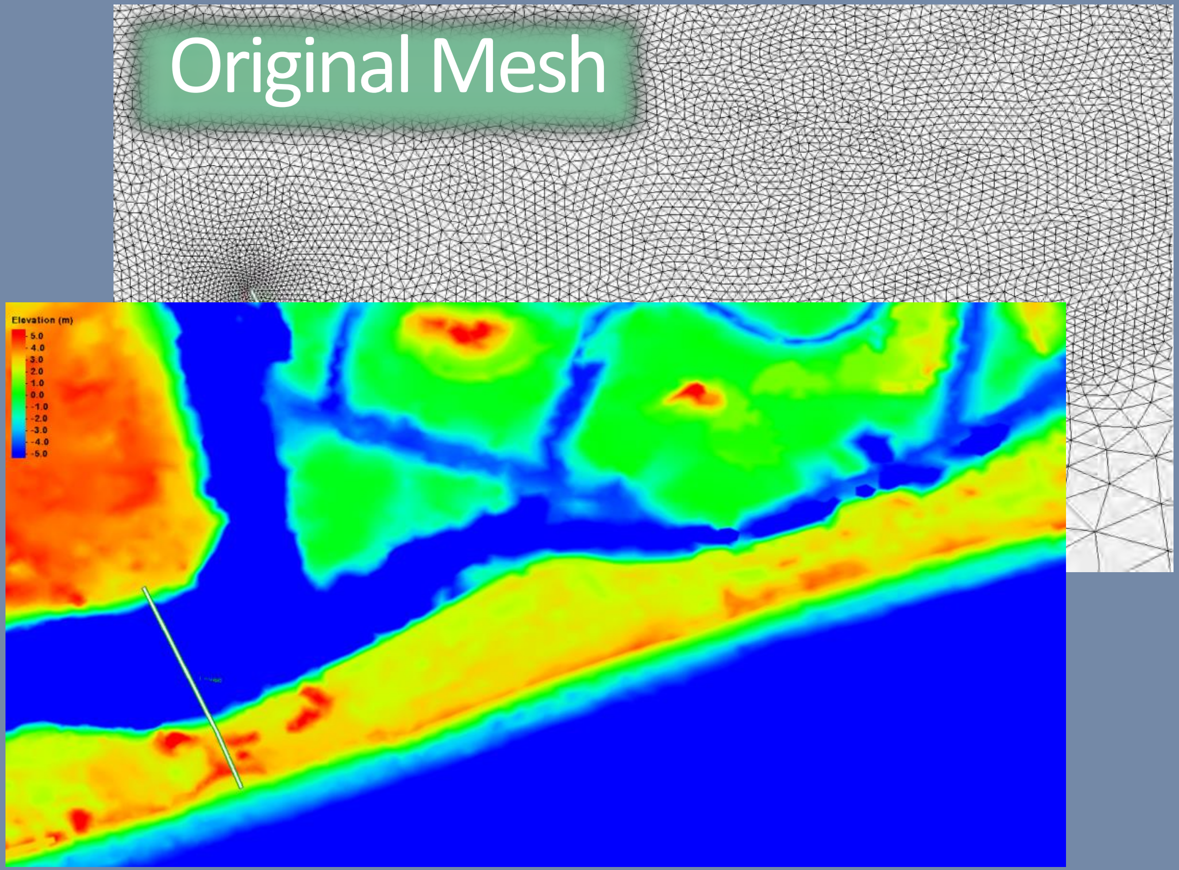
Initial Regional Scale Mesh

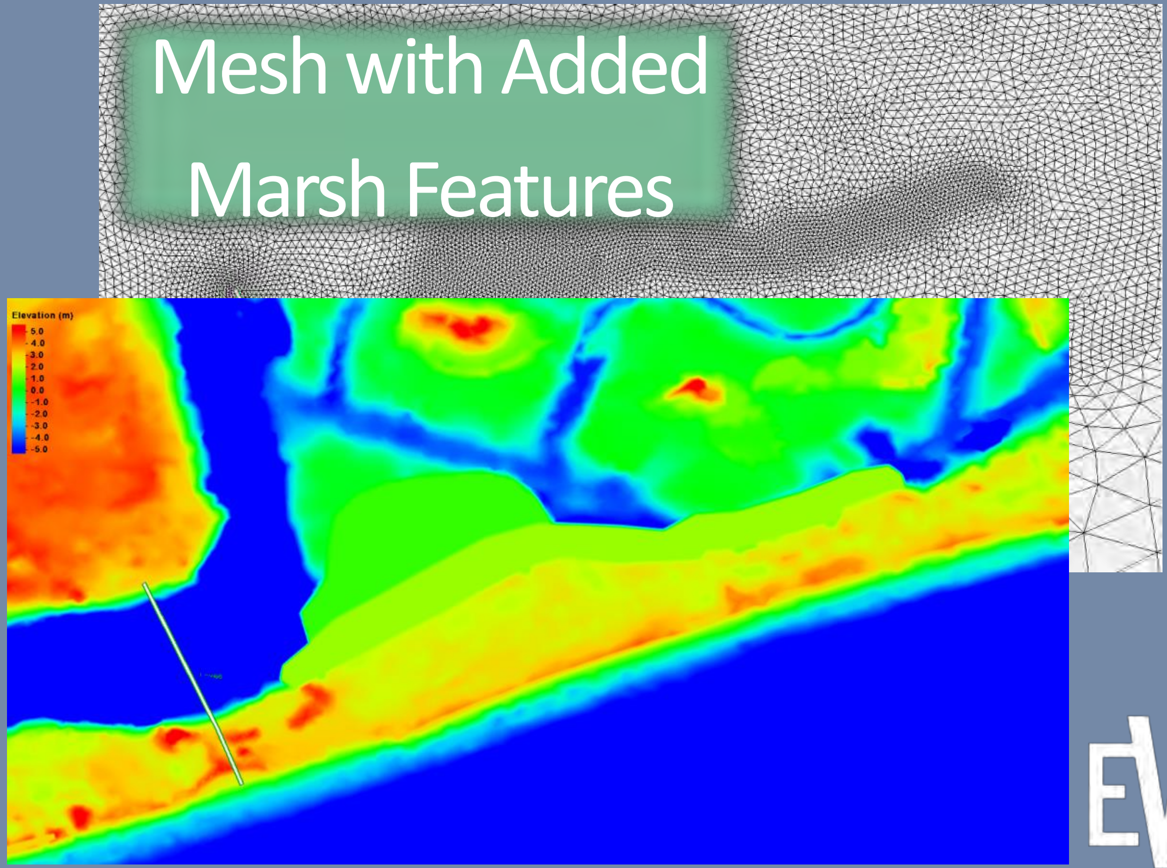




EWN® Toolkit for ERDC's CSTORM

Example Topo/Bathy Adjustment



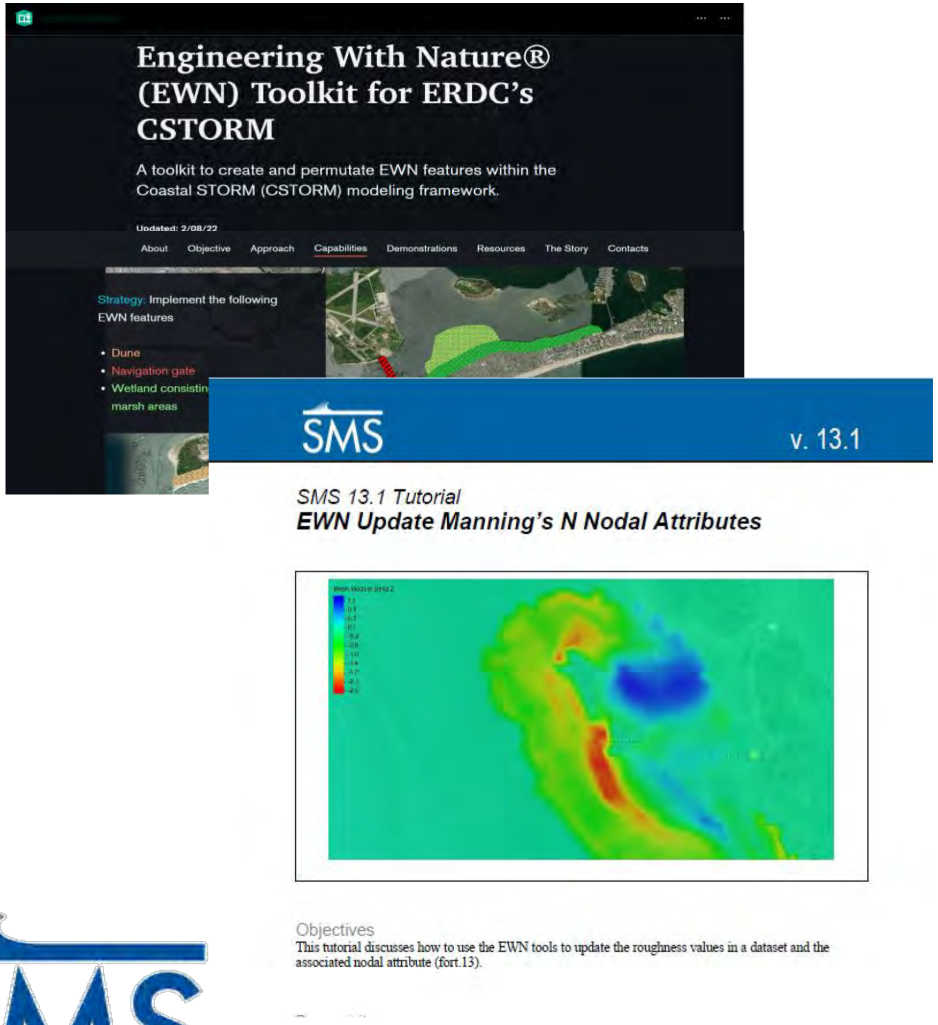


EWN®

EWN Toolkit Resources

To learn more about the EWN Toolkit, check out the following resources:

- EWN Toolkit Story Map
- SMS Tutorials from Aquaveo
- EWN Toolkit Coastal Storm Risk Management (CSRM) Course Lecture Video/Tutorial
- CSRM course being offered at Coastal and Hydraulics Laboratory in Vicksburg, MS in late winter/early spring 2023 – details forthcoming



Any Questions?

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