Field and numerical investigations of coastal hazards and nature based defenses from hurricane storm surge and waves in the Chesapeake Bay

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Where Innovation Is Tradition

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Introduction and goals

1. Introduction and goals

Coastal storms at the United States mid-Atlantic region

Hurricane Isabel, 2003

Hurricane Sandy, 2012

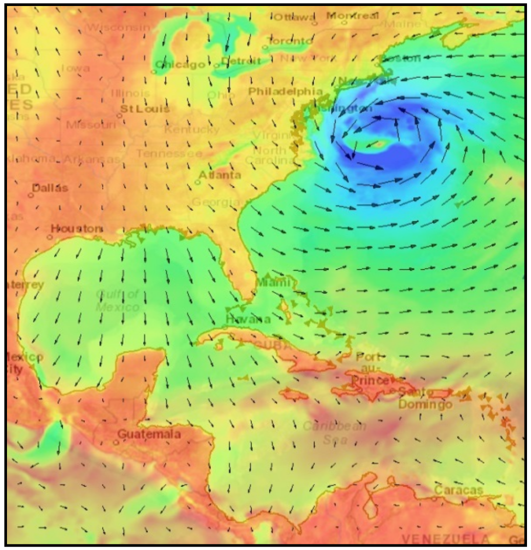
Hurricane Maria, 2017

1. Introduction and goals

Support coastal storm hazards resilience and protection

Goal 1 – Explore the effectiveness of natural defenses such as saltmarshes of the Chesapeake Bay to attenuate storm surge and waves

Goal 2 – Improve our ability to simulate hazards in coastal areas including large estuaries such as the Chesapeake Bay

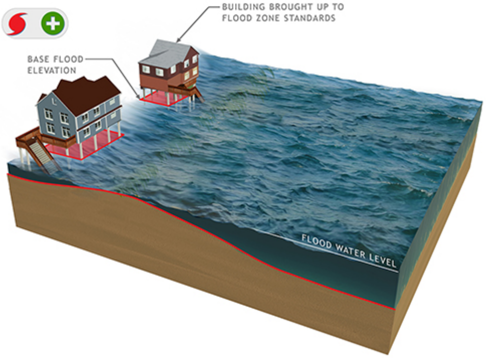


Natural solutions for coastal defenses at the Chesapeake Bay

2. Natural solutions for coastal defenses at the Chesapeake Bay

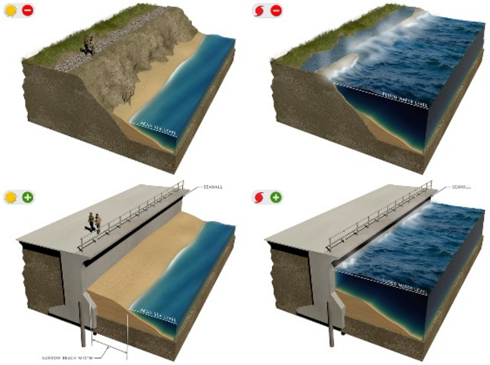
Background

Resilient buildings



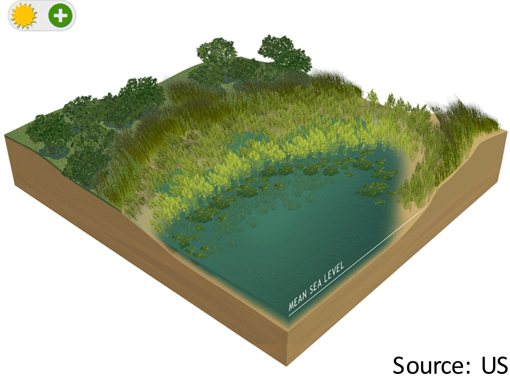
Source: USACE

Hard structures



Source: USACE

Nature-based defenses



Source: USACE

Multiple defenses

Source: Pontchartrain Basin Foundation

2. Natural solutions for coastal defenses at the Chesapeake Bay

Background. Wave protection by using field observations.

Several laboratory (Agustin et al. 2009; Maza et al. 2015; Anderson and Smith 2014, Moller et al. 2014; Bouma et al. 2014) and **field experiments** (Paul 2011, Ysebaert et al. 2011; Jadhav et al. 2013; Bradley and Houser 2009) have demonstrated the capacity of vegetation fields to reduce incoming wave heights.

Maza et al. (2015) and Bouma et al. (2014) found that wave attenuation within a vegetated region depends on a combination of vegetation characteristics, inundation height and wave conditions

A necessity for enhanced new formulations predicting wave height decay inside marshes

2. Natural solutions for coastal defenses at the Chesapeake Bay

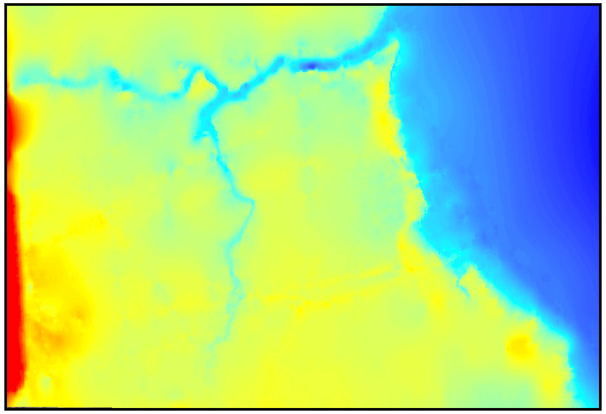
Background. Wave protection by using numerical modelling at local scale.

Phase-averaged models such as SWAN, X-Beach (surf beat mode), STAWE and MDO (Marsooli et al. 2017, Suzuki et al. 2012, van Rooijen et al. 2015) have extended their numerical equations to represent explicitly wave-vegetation interactions.

Drag coefficient (C_d), used to account for the wave energy reduction, represents one of the main uncertainties in this approach. (van Rooijen et al. 2015, Vuik et al. 2016)

C_d Calibration

C_d formulations

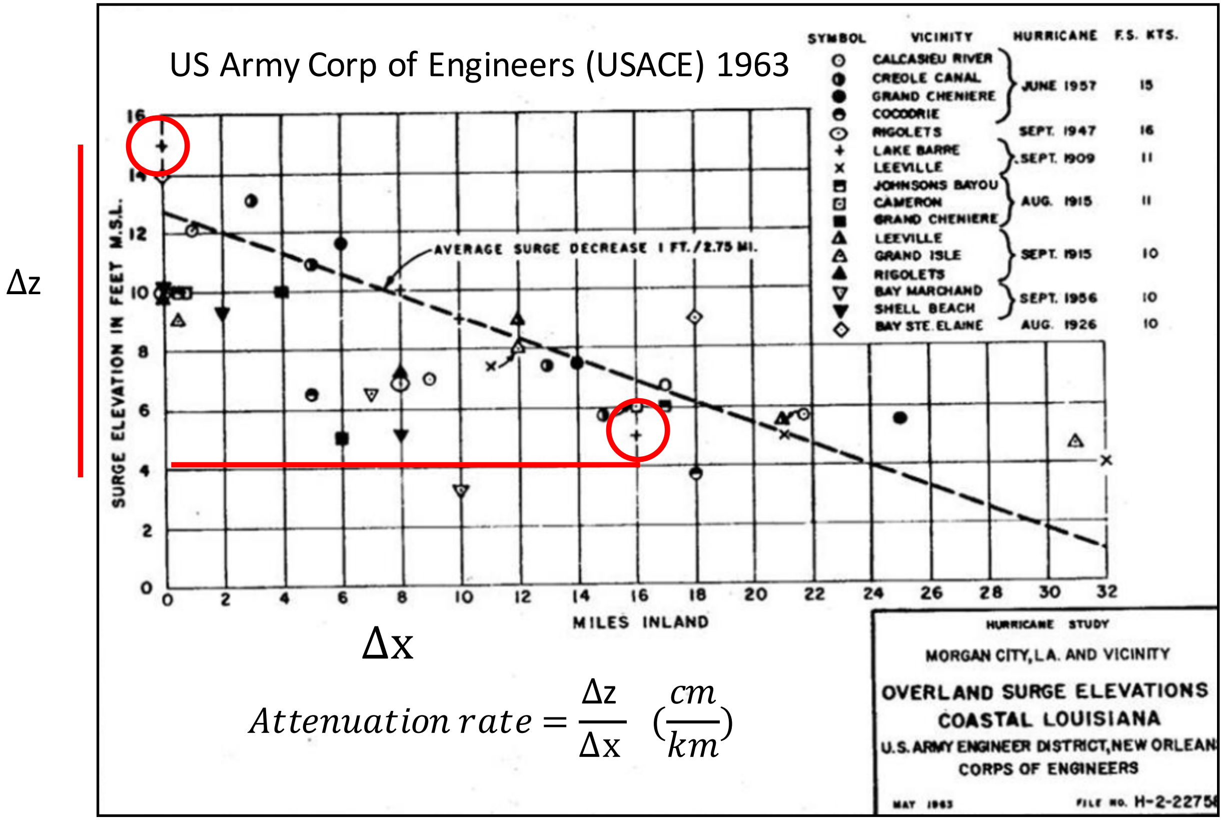


The performance of these models has not been fully explored without a previous C_d calibration process and real conditions in the field.

2. Natural solutions for coastal defenses at the Chesapeake Bay

Background. Coastal flooding protection by using field observations.

US Army Corp of Engineers (USACE) 1963



SYMBOL	VICINITY	HURRICANE	F.S. KTS.
⊙	CALCASIEU RIVER	JUNE 1957	15
◐	CREOLE CANAL		
●	GRAND CHENIERE		
◒	COCODRIE		
⊙	RIGOLETS	SEPT. 1947	16
+	LAKE BARRE	SEPT. 1909	11
×	LEEVILLE		
⬒	JOHNSONS BAYOU	AUG. 1915	11
⊡	CAMERON		
■	GRAND CHENIERE		
△	LEEVILLE	SEPT. 1915	10
△	GRAND ISLE		
▲	RIGOLETS		
▽	BAY MARCHAND	SEPT. 1956	10
▼	SHELL BEACH		
◇	BAY STE. ELAINE	AUG. 1926	10

HURRICANE STUDY

MORGAN CITY, L.A. AND VICINITY

OVERLAND SURGE ELEVATIONS
COASTAL LOUISIANA

U.S. ARMY ENGINEER DISTRICT, NEW ORLEAN
CORPS OF ENGINEERS

MAY 1963 FILE NO. H-2-2275

$$Attenuation\ rate = \frac{\Delta z}{\Delta x}\ (\frac{cm}{km})$$

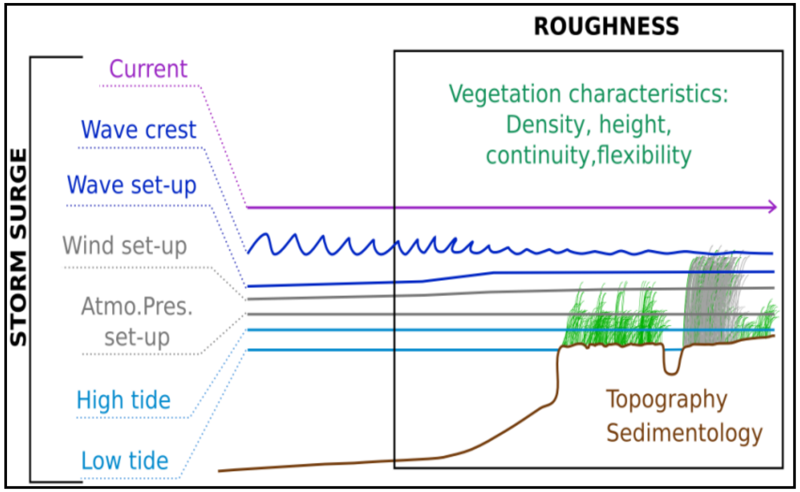
Commonly stated “rule of thumb” 6.9 cm/km

2. Natural solutions for coastal defenses at the Chesapeake Bay

Science questions:

1. What is the actual storm surge and wave energy attenuation capacity of wetlands and marshes?
2. Is there a relationship between ecosystem properties and storm surge hydrodynamics over coastal wetlands?
3. Can we provide insights towards engineering nature-based flood defenses?

Source: Mason Flood Hazards Research Lab

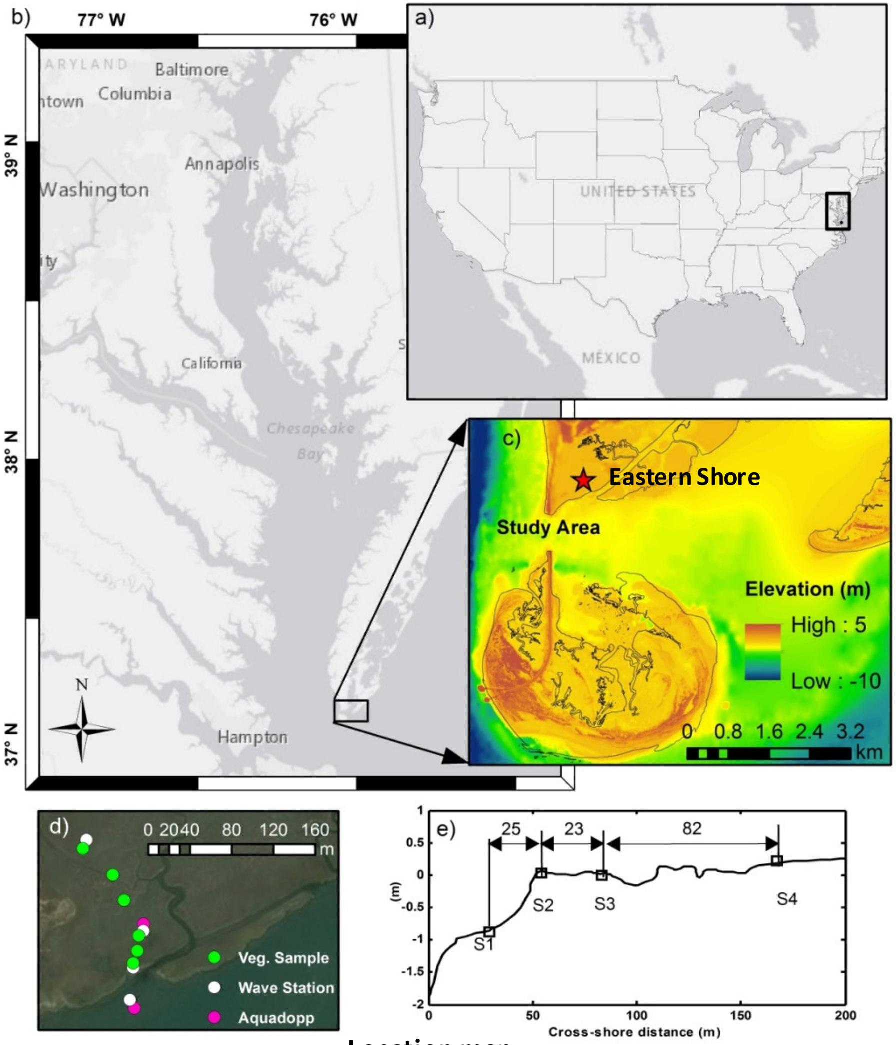


Source: Pacquier, E., ***Haddad, J., Lawler, S. and Ferreira, C.M.*** **2015 (AGU)**

a) Wave attenuation by *Spartina alterniflora* saltmarshes in the Chesapeake Bay under storm surge conditions

2-a) Wave attenuation by *Spartina alterniflora*

Methods



Location map

Vegetation survey

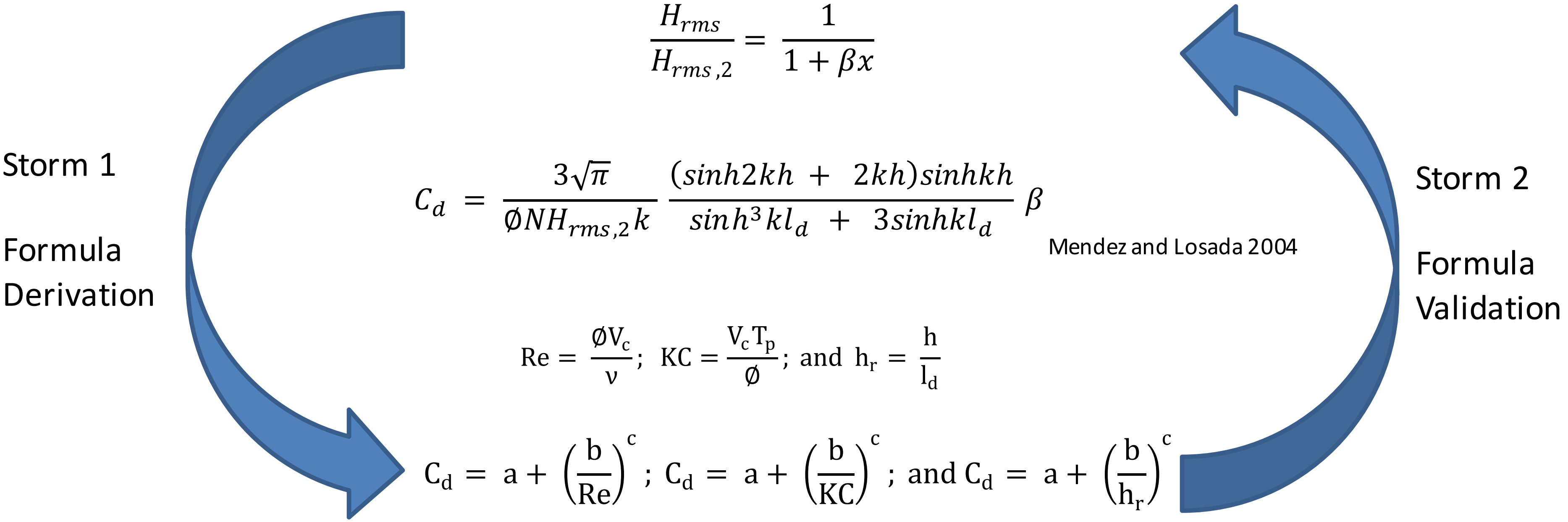
Wave survey (Pressure, 4 Hz)

Current Survey (Vel. and dir. profiles, 1meas./ 10 min)

2-a) Wave attenuation by *Spartina alterniflora*

Methods

Models for wave attenuation



$$\frac{H_{rms}}{H_{rms,2}} = \frac{1}{1+\beta x}$$

Storm 1

Formula Derivation

$$C_d = \frac{3\sqrt{\pi}}{\emptyset N H_{rms,2} k} \frac{(sinh2kh + 2kh)sinhkh}{sinh^3 kl_d + 3sinhkl_d} \beta$$

Mendez and Losada 2004

Storm 2

Formula Validation

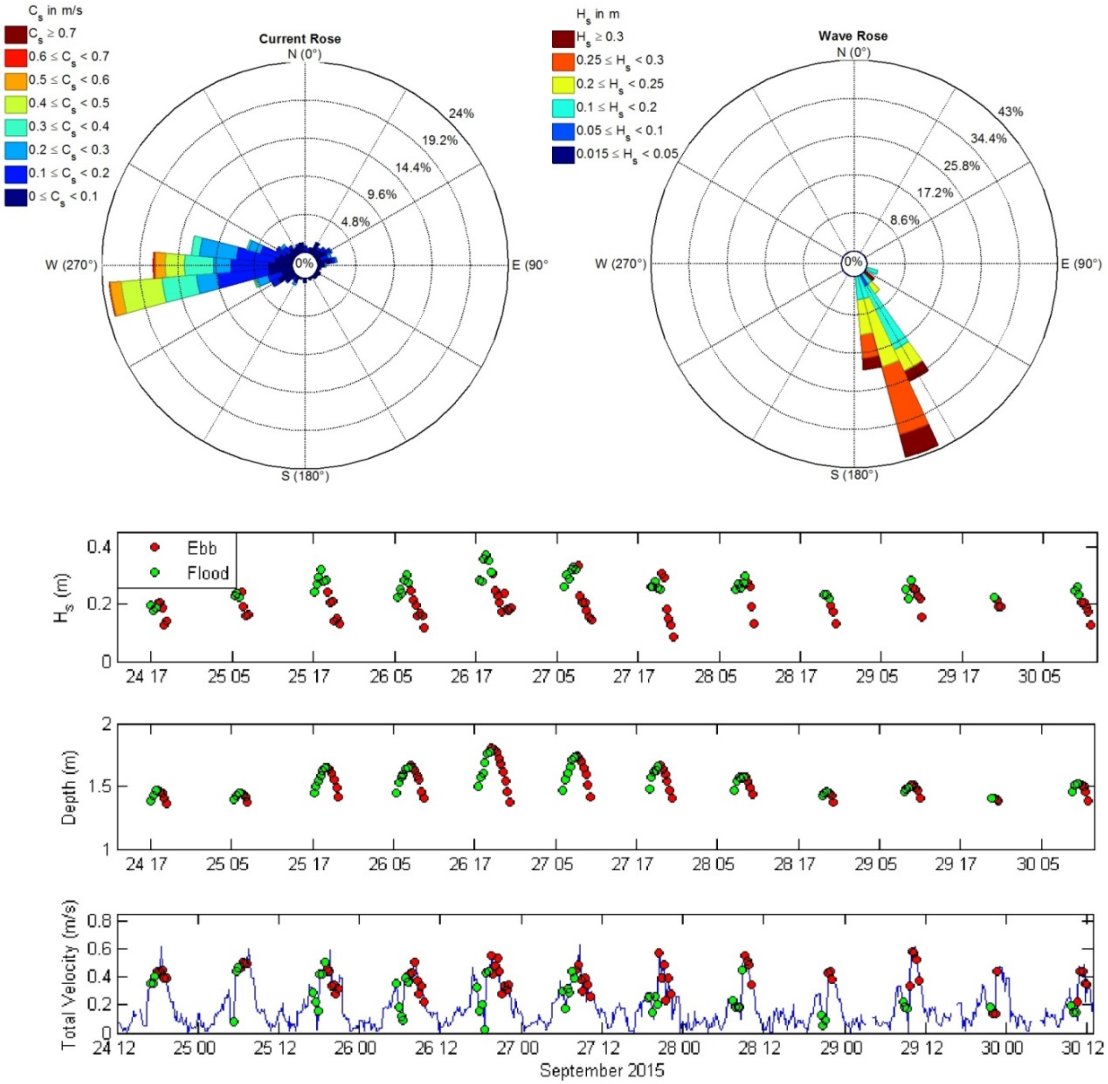
$$\mathrm{Re} = \frac{\emptyset V_c}{\nu};\ \mathrm{KC} = \frac{V_c T_p}{\emptyset};\ \text{and}\ h_r = \frac{h}{l_d}$$

$$C_d = a + \left(\frac{b}{\mathrm{Re}}\right)^c;\ C_d = a + \left(\frac{b}{\mathrm{KC}}\right)^c;\ \text{and}\ C_d = a + \left(\frac{b}{h_r}\right)^c$$

2-a) Wave attenuation by *Spartina alterniflora*

Results

Wave and current interactions at the seaward

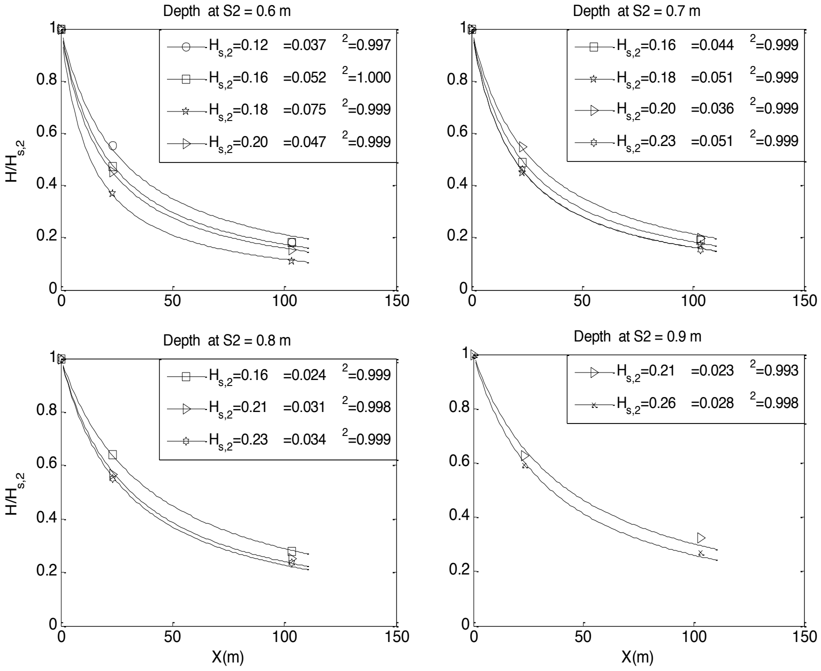


Garzon et al. 2018a (under review)

2-a) Wave attenuation by *Spartina alterniflora*

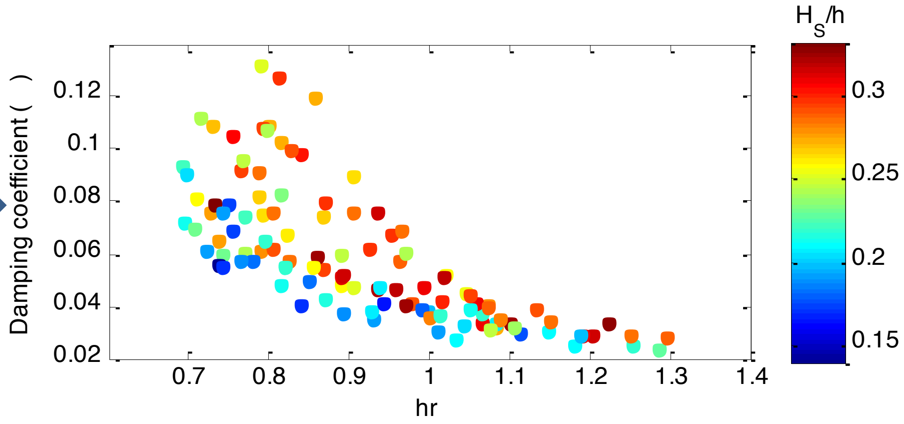
Results

The effects of varying hydrodynamic conditions on wave attenuation within the vegetation field



Examples of wave damping between S2-S4. Symbols represent observations and curve lines depict the best fit line

$$\frac{H_{rms}}{H_{rms,2}} = \frac{1}{1+\beta x}$$

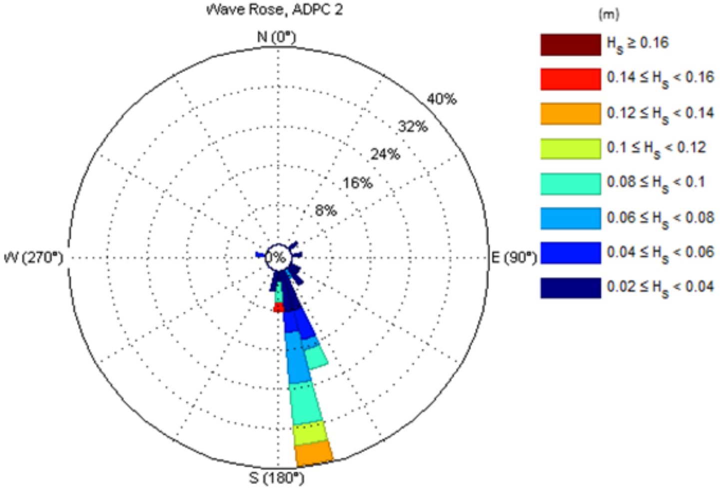


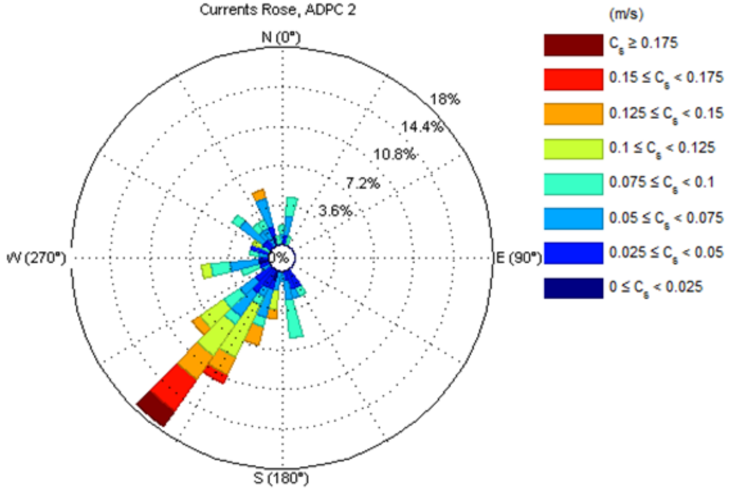
Wave damping coefficient as a function of the hr (h /l_d) at S2 (marsh platform)

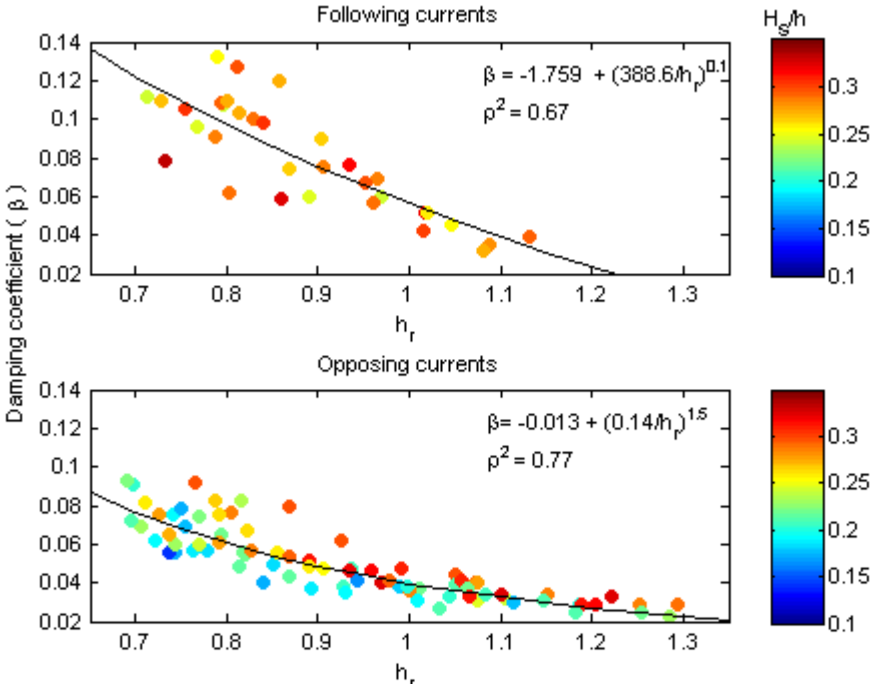
2-a) Wave attenuation by *Spartina alterniflora*

Results

The effects of varying hydrodynamic conditions on wave attenuation within the vegetation field







Wave damping coefficient for following and opposing currents. The markers are colored by the $H_{S,2}/h$.

Garzon et al. 2018a (under review)

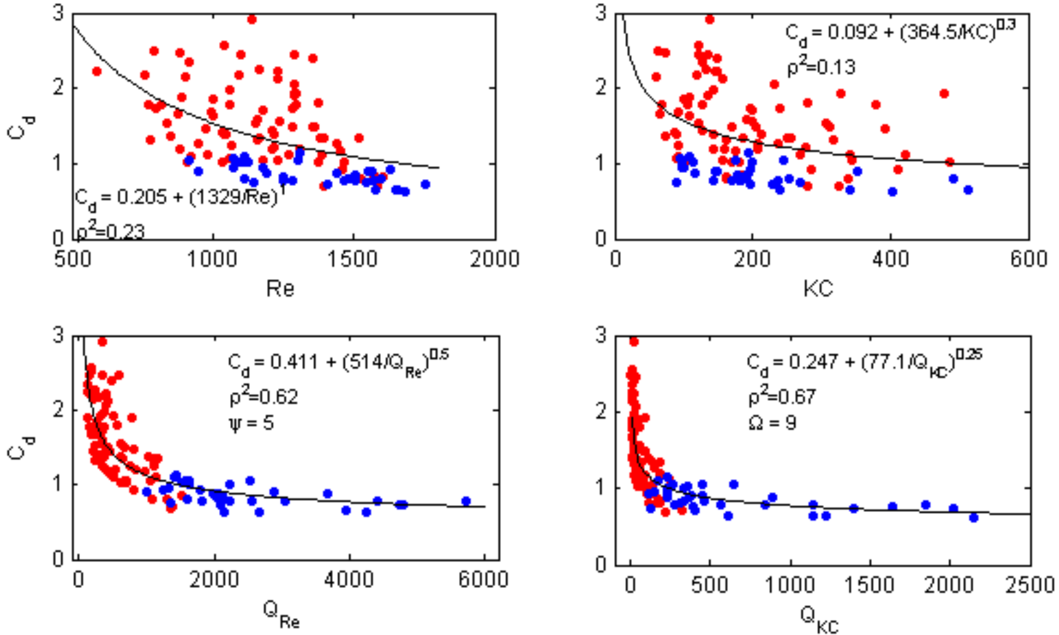
2-a) Wave attenuation by *Spartina alterniflora*

Results

Bulk drag coefficient formulation

$$C_d = \frac{3\sqrt{\pi}}{\emptyset N H_{rms,2} k} \frac{(\sinh 2kh + 2kh)\sinh kh}{\sinh^3 kl_d + 3\sinh kl_d} \beta$$

Following + opposing currents



Drag coefficients as a function of the Re number (upper plot) and KC number and for following currents: Re (upper plot) KC and opposing currents (lower plot). Red dots represent emergent conditions and blue dots display near-emergent conditions

Drag coefficient as a function of the modified Re number and KC number for following (upper plot) and opposing (lower plot) currents.

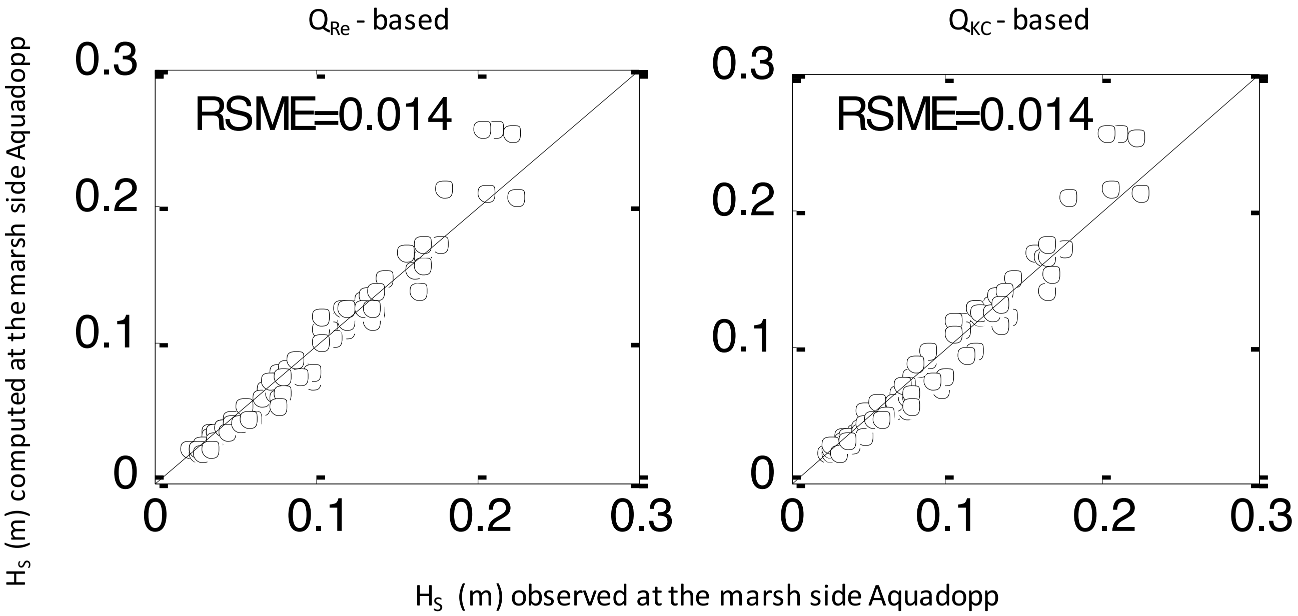
$$Q_{Re} = \frac{Re}{\left(h_r^{-1}\right)^{\Psi}} \qquad Q_{KC} = \frac{KC}{\left(h_r^{-1}\right)^{\Omega}}$$

Garzon et al. 2018a (under review)

2-a) Wave attenuation by *Spartina alterniflora*

Results

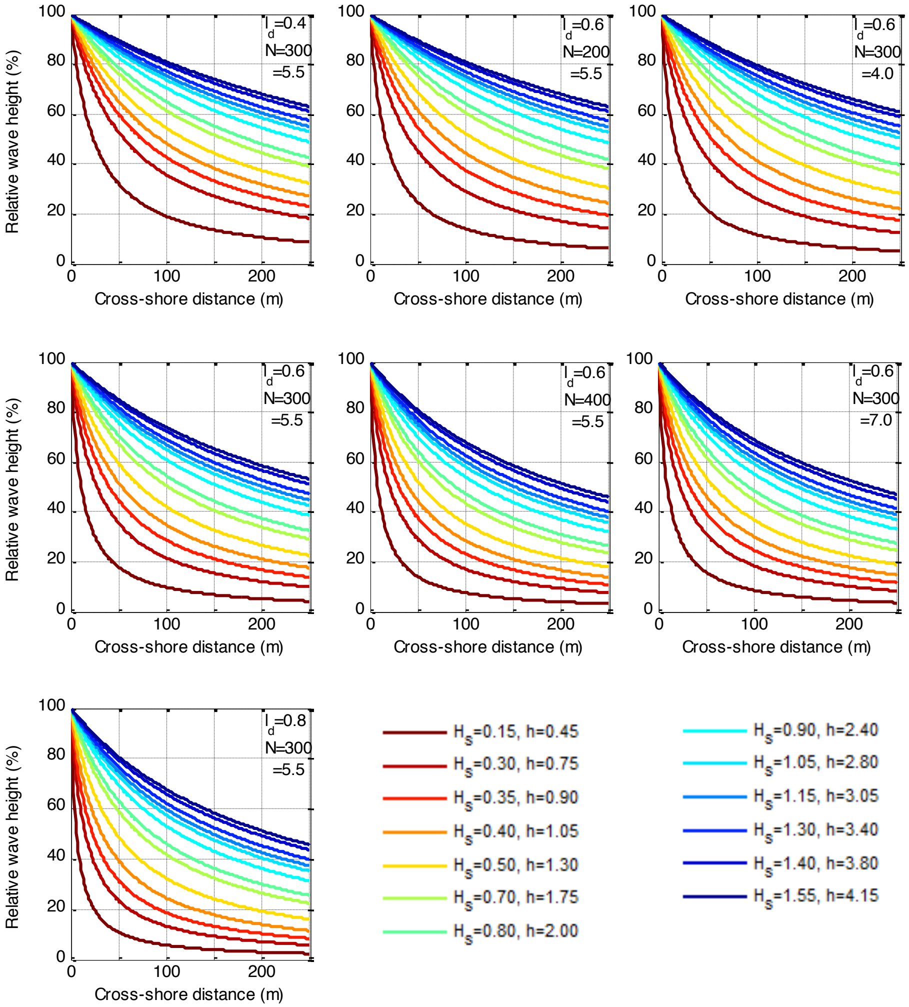
Model Validation (following+opposing currents)



Garzon et al. 2018a (under review)

2-a) Wave attenuation by *Spartina alterniflora*

Providing some empirical basic information about the protection ecosystem services



Garzon et al. 2018a (under review)

2-a) Wave attenuation by *Spartina alterniflora*

Conclusions

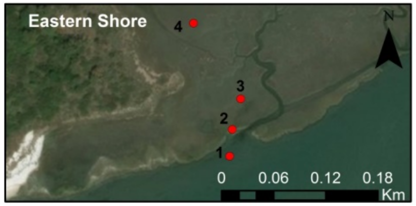
- ✓ The ratio between water depth and plant height (**h_r**) highly impacted the wave height decay. **Larger attenuation with emergent than submerged conditions**.
- ✓ **Higher H_S/h** ratios resulted in **higher damping coefficients with following currents** in comparison to those coefficients computed with opposing currents under similar h_r.
- ✓ The empirical representation of the **C_d as a function of KC and Re exhibited a low agreement**. However, the **h_r-based modified Re and KC** numbers improved the relationship with C_d, yielding correlations almost up to **70%**.
- ✓ The wave height computed during the **validation** within the marsh resulted in root-square-mean error **of 0.014m**, overestimating the largest waves (0.22 m) about 18%.
- ✓ Wave decay was clearly reduced under these observed and hypothetical severe conditions, but marshlands with spatial scales of the order of 200–400 m can be a **viable option for coastal protection strategies** against wave attack.

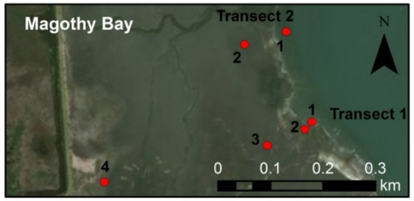
b) Field-based numerical model investigation of wave propagation across marshes in the Chesapeake Bay under storm conditions

2-b) Field-based numerical model investigation of wave propagation across marshes

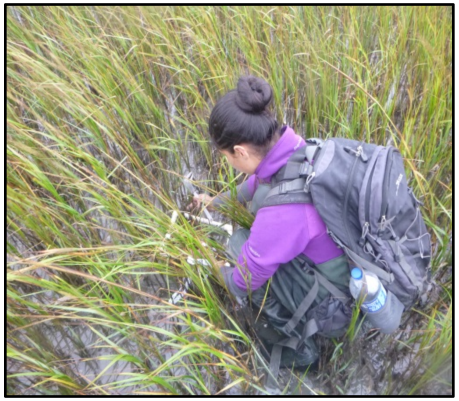
Methods

Study Area



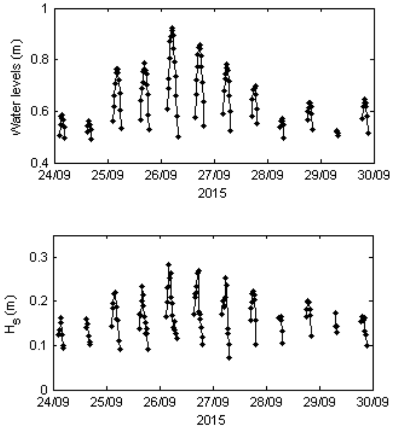


Field Measurements

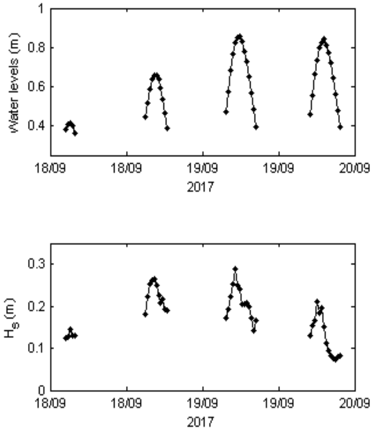


Hydrodynamic conditions

Water levels and the incoming H_S at station 2 at Eastern Shore



Water levels and the incoming H_S at station 2 at transect 1 at Magothy Bay



2-b) Field-based numerical model investigation of wave propagation across marshes

Methods

Numerical model and Drag Coefficient (C_d) formulations

The high-resolution numerical model X-Beach (Roelvink et al. 2009) was originally developed to simulate hydrodynamic and morphodynamics processes and impacts on sandy beaches

The model extended their equations to explicitly account for the wave attenuation by vegetation (van Rooijen et al. 2015).

The model relies on Mendez and Losada (2004) formulation.

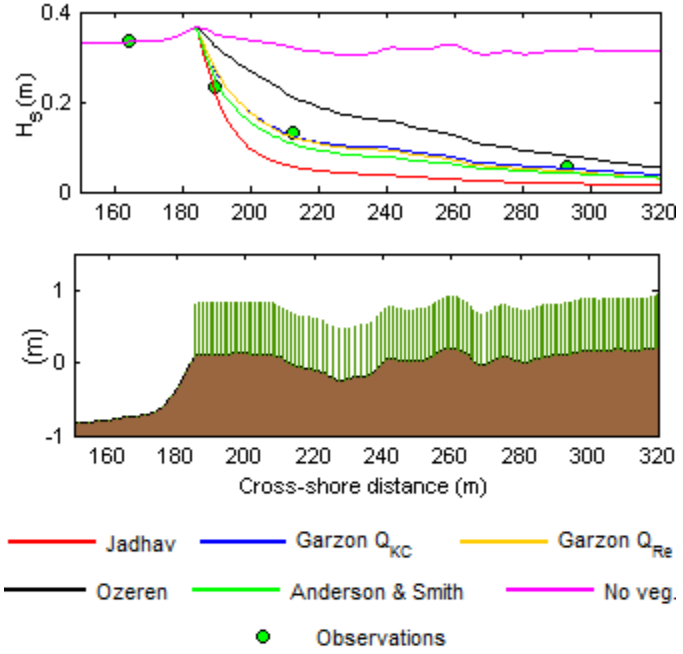
$$D_{veg,i} = \frac{1}{2\sqrt{\pi}} \frac{\rho C_D b_v N \left(\frac{kg}{2\sigma}\right)^3 \left(\left(\sinh^3 k\alpha_i h - \sinh^3 k\alpha_{i-1} h\right) + \left(\sinh k\alpha_i h - \sinh k\alpha_{i-1} h\right)\right)}{3k\cosh^3 kh} H_{rms}^3$$

Drag coefficient formulations

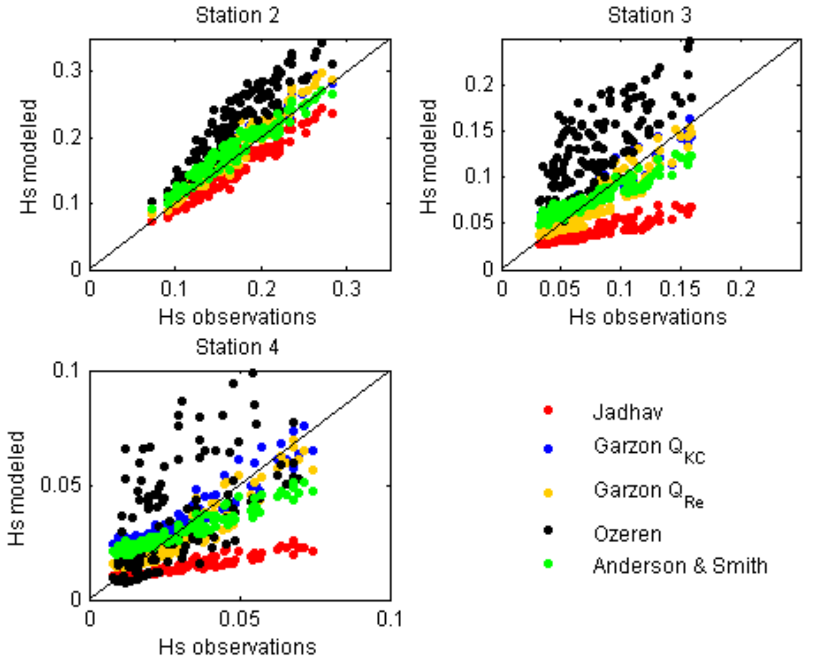
Formulation	Eq	Type	Vegetation	Expression	Range
Jadhav	1	Field	Real	$C_d = 0.36+(2600/Re)^1$	$600<Re<3200$
Garzon Q_{KC}	2	Field	Real	$C_d = 0.247+(77.1/Q_{KC})^{0.25}$	$0< Q_{KC}<2000$
Garzon Q_{Re}	3	Field	Real	$C_d = 0.411+(514/Q_{Re})^{0.5}$	$0< Q_{Re}<6000$
Ozeren	4	Flume	Real	$C_d = 0.036+(65.72/KC)^{1.07}$	$10<KC<70$
Anderson & Smith	5	Flume	Synth.	$C_d = 1.10+(27.4/KC)^{3.08}$	$26<KC<112$

2-b) Field-based numerical model investigation of wave propagation across marshes

Results. Eastern Shore



Wave evolution along the marsh platform (upper panel). The lower panel displays the vegetation and topo-bathymetry of the Eastern Shore



Scatter plots of the three stations located inside the marsh platform at Eastern Shore

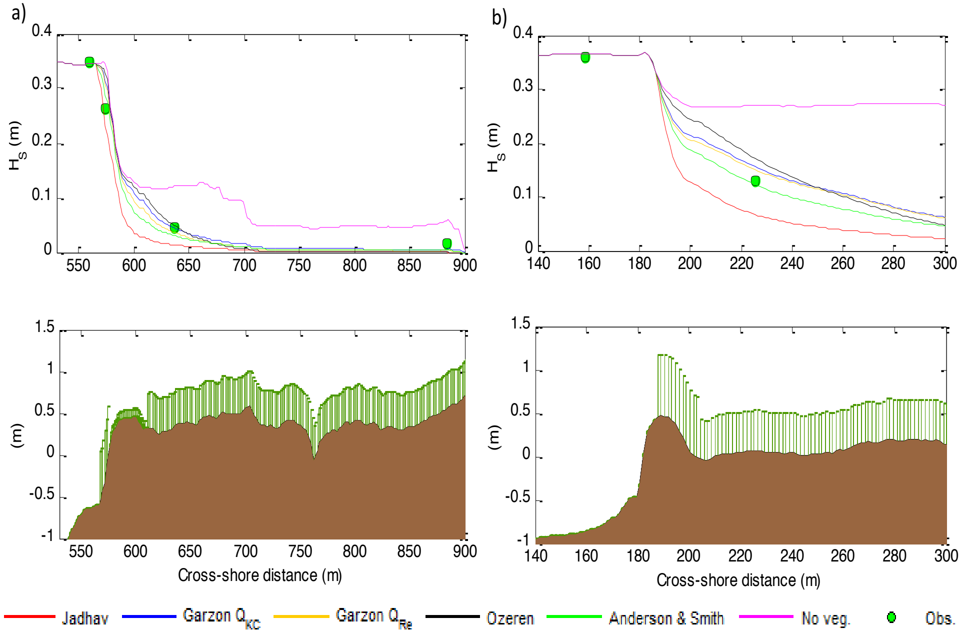
Error statistics for Easter Shore stations

	Station 2			Station 3			Station 4		
	SCI	R2	R. bias	SCI	R2	R. bias	SCI	R2	R. bias
Jadhav	0.124	**0.945**	-0.103	0.566	0.854	-0.481	0.694	0.883	-0.531
Garzon Q_{KC}	**0.088**	0.938	0.110	0.184	0.847	0.049	**0.173**	0.884	0.284
Garzon Q_{Re}	0.095	0.939	**0.063**	**0.158**	0.891	-0.089	0.224	0.885	**-0.095**
Ozeren	0.333	0.854	0.302	0.745	0.575	0.647	0.714	0.398	0.281
Smith & Anderson	0.094	0.940	0.065	0.215	**0.901**	**-0.007**	0.310	**0.921**	**-0.015**

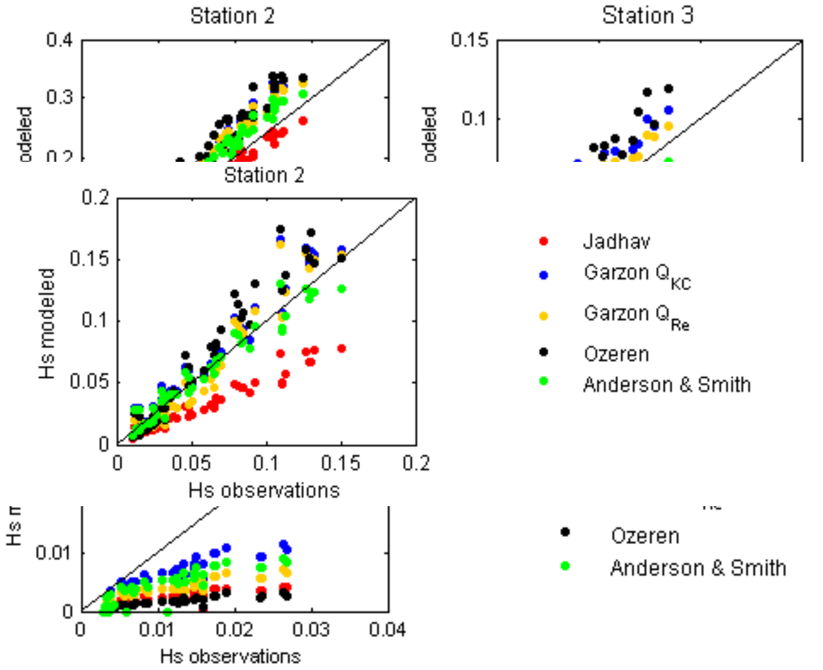
Garzon et al. 2018b (under review)

2-b) Field-based numerical model investigation of wave propagation across marshes

Results: Magothy Bay



Plots a) represent transect 1 and b) transect 2



Scatter plots of the three stations inside the marsh platform at transect 1 of the Magothy Bay

Scatter plot of the station located inside the marsh platform transect 2 of the Magothy Bay

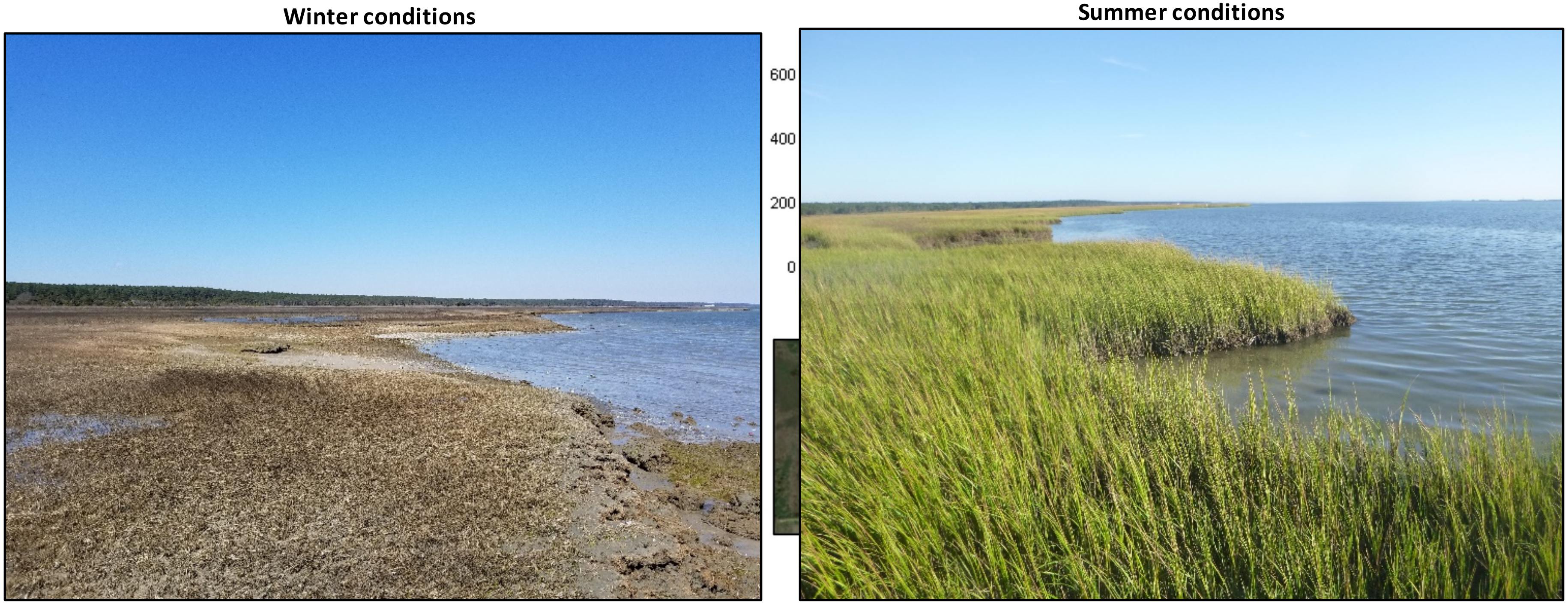
Garzon et al. 2018b (under review)

Error statistics for Magothy Bay stations

	Transect 1-Station 2			Transect 1-Station 3			Transect 1-Station 4			Transect 2-Station 2		
	SCI	R2	R. bias	SCI	R2	R. bias	SCI	R2	Rel. bias	SCI	R2	R. bias
Jadhav	**0.077**	**0.978**	**-0.054**	0.731	0.861	-0.603	1.022	0.726	-0.831	0.554	0.951	-0.451
Garzon Q_{KC}	0.218	0.969	0.193	0.376	0.902	0.130	**0.679**	0.800	**-0.544**	0.238	0.943	0.128
Garzon Q_{Re}	0.206	0.967	0.182	0.306	0.913	**-0.034**	0.887	0.797	-0.721	0.222	0.941	**0.004**
Ozeren	0.280	0.933	0.242	0.504	**0.957**	0.239	1.080	**0.803**	-0.883	0.324	0.940	0.182
Anderson & Smith	0.147	0.973	0.130	**0.258**	0.917	-0.155	0.787	0.795	-0.636	**0.148**	**0.950**	-0.012

2-b) Field-based numerical model investigation of wave propagation across marshes

Results. Coastal protection seasonal variability


Winter conditions

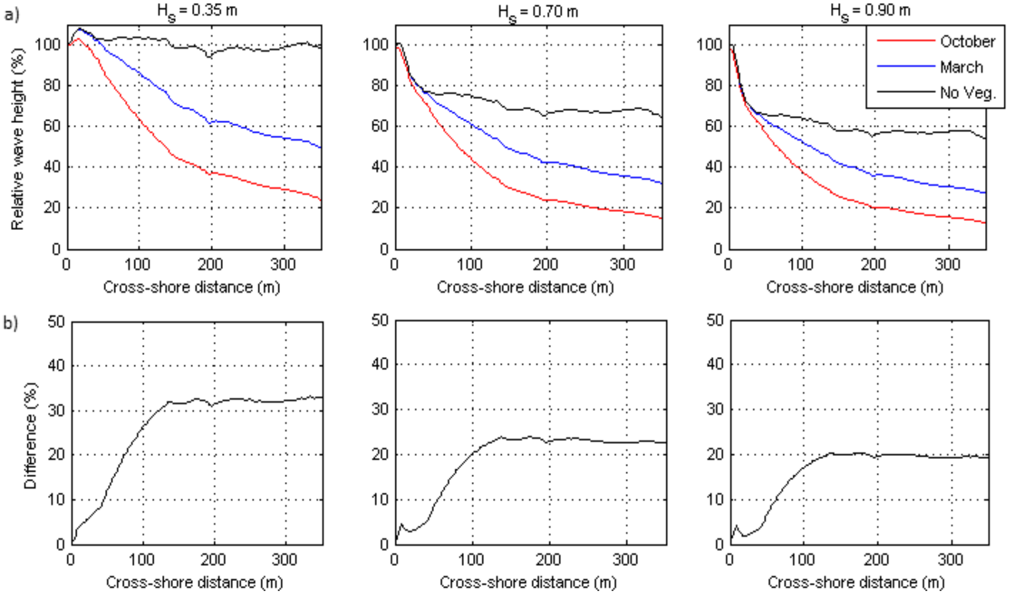
Summer conditions

Seasonal fluctuations in stem heights, densities and diameters reported at transect 1 in Magothy Bay

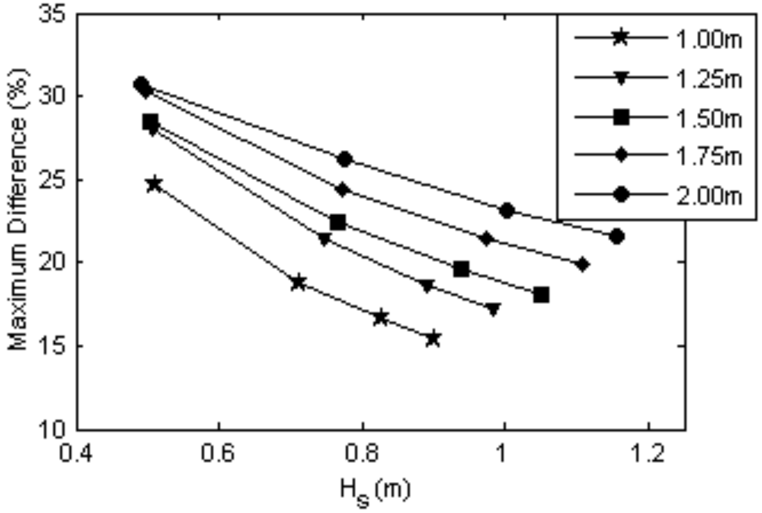
Garzon et al. 2018b (under review)

2-b) Field-based numerical model investigation of wave propagation across marshes

Results. Coastal protection seasonal variability



Relative wave height evolution along the vegetation field at transect 1 under fall, winter and no vegetation conditions. WL = 1.5m



Maximum difference observed between the relative wave heights estimated for winter and fall conditions

Garzon et al. 2018b (under review)

2-b) Field-based numerical model investigation of wave propagation across marshes

Conclusions

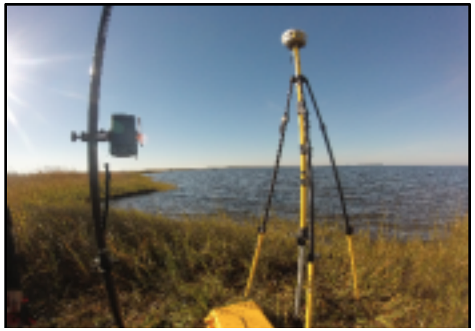
- ✓ **Unique combination** of field **measurements** (wave parameters, topo-bathymetric survey and vegetation characteristics) and numerical **modelling** (X-Beach).
- ✓ This analysis revealed that:
  - ➢ **Garzon 2018 (based on Re number) and Anderson & Smith 2014** formulations provided reliable results (**relative bias lower than 20%**), especially at the first 100 m across the vegetation field
  - ➢ Results provided by **Garzon 2018 (based on Keulegan-Carpenter number**) formulation exhibited **good skills**, although they overestimated wave heights.
  - ➢ **Jadhav 2012** simulations clearly **underestimated** wave heights.
  - ➢ **Ozeren 2014** (currently in the model) simulations highly **overestimated** wave heights over the marsh field.
- ✓ The validated formulation (Garzon 2018 Re based) demonstrated that that under similar hydrodynamic conditions, marshes offered between **15% and 30% less protection against waves in winter than in fall**.
- ✓ Marshes would provide **additional** coastal **protection from hurricanes** in comparison to **nor'easters,** but they would still offer **more protection than non-vegetated** fields in both seasons.

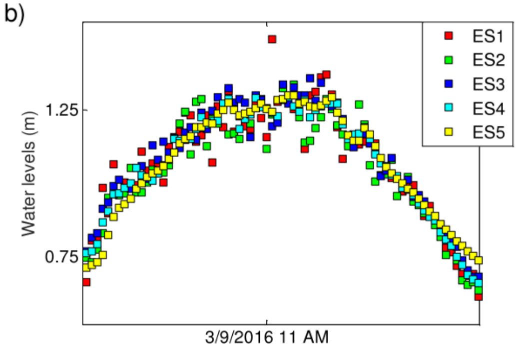
c) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

2. Natural solutions for coastal defenses at the Chesapeake Bay

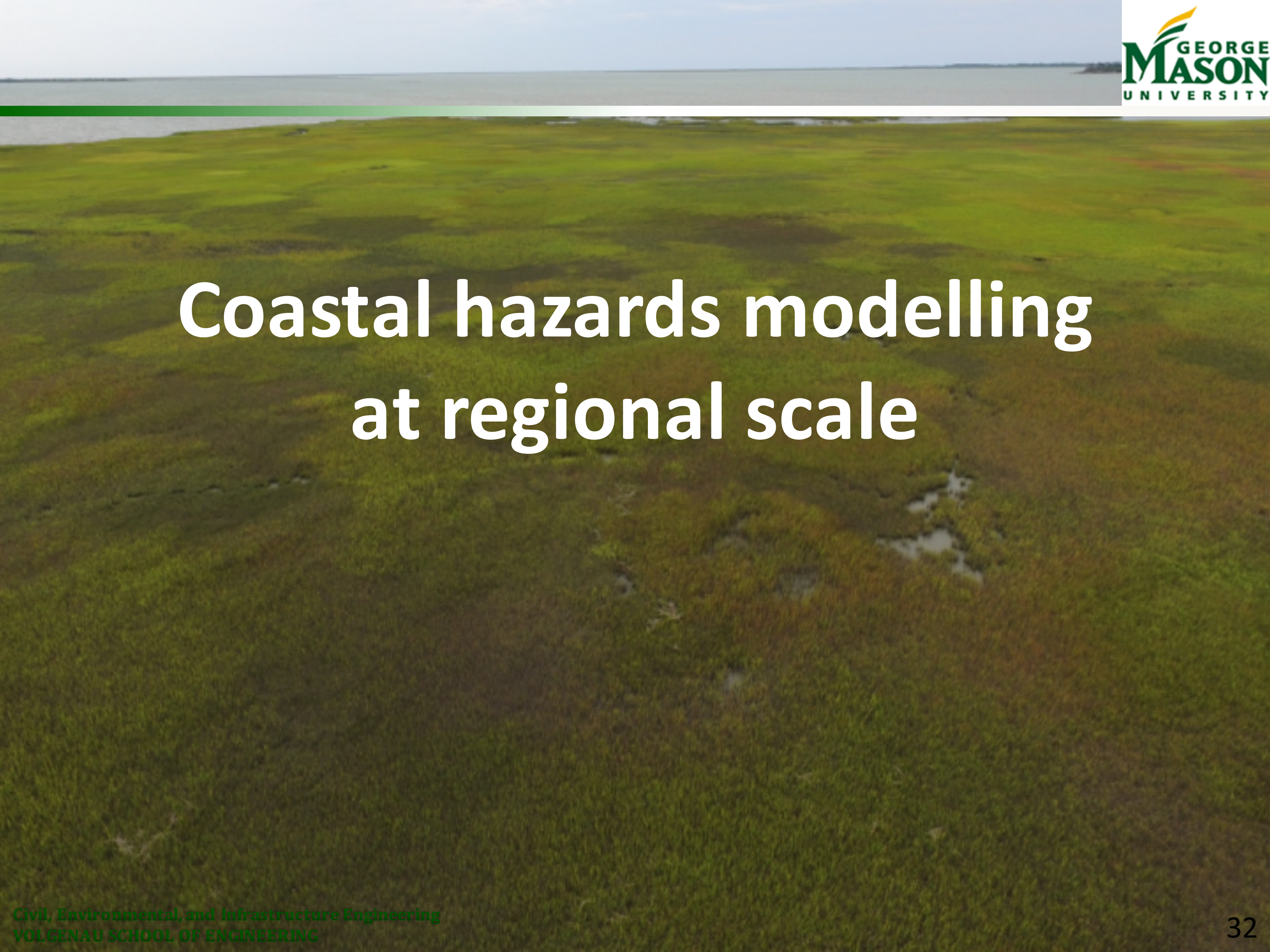
2-c) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

- ✓ A large collection (**52 flood events**) of attenuation rates from two marsh transects located in the US mid-Atlantic region.
- ✓ Major events corroborated that **attenuation rates** were very **low** or even negative (amplification) during the **peak of the storms** at the upper marsh of ES.
- ✓ This type of saltmarsh (200-400m) would **moderately attenuate storm** surge during **low inundation** heights, but it would provide **less coastal flood protection during extreme events**.





Glass et al. (2017)

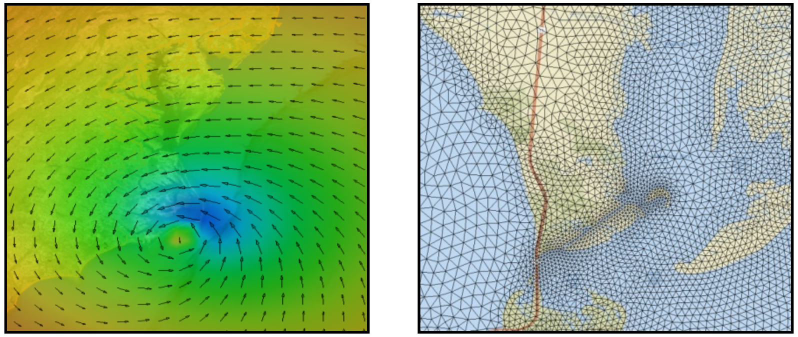


Coastal hazards modelling at regional scale

3. Coastal hazards modelling at regional scale

1. Storm surge modeling in large estuaries: sensitivity analyses to parameters and physical processes in the Chesapeake Bay

   - Manning's *n* value
   - Interaction of Wind Waves and Circulation
   - Minimum water depth
   - Spatially constant horizontal eddy viscosity



Garzon & Ferreira 2016

2. Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay

NAM The North American Mesoscale Forecast System

NCEP Climate Forecast System CFS Environmental Modeling Center

GFS Global Forecast System

ECMWF EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS

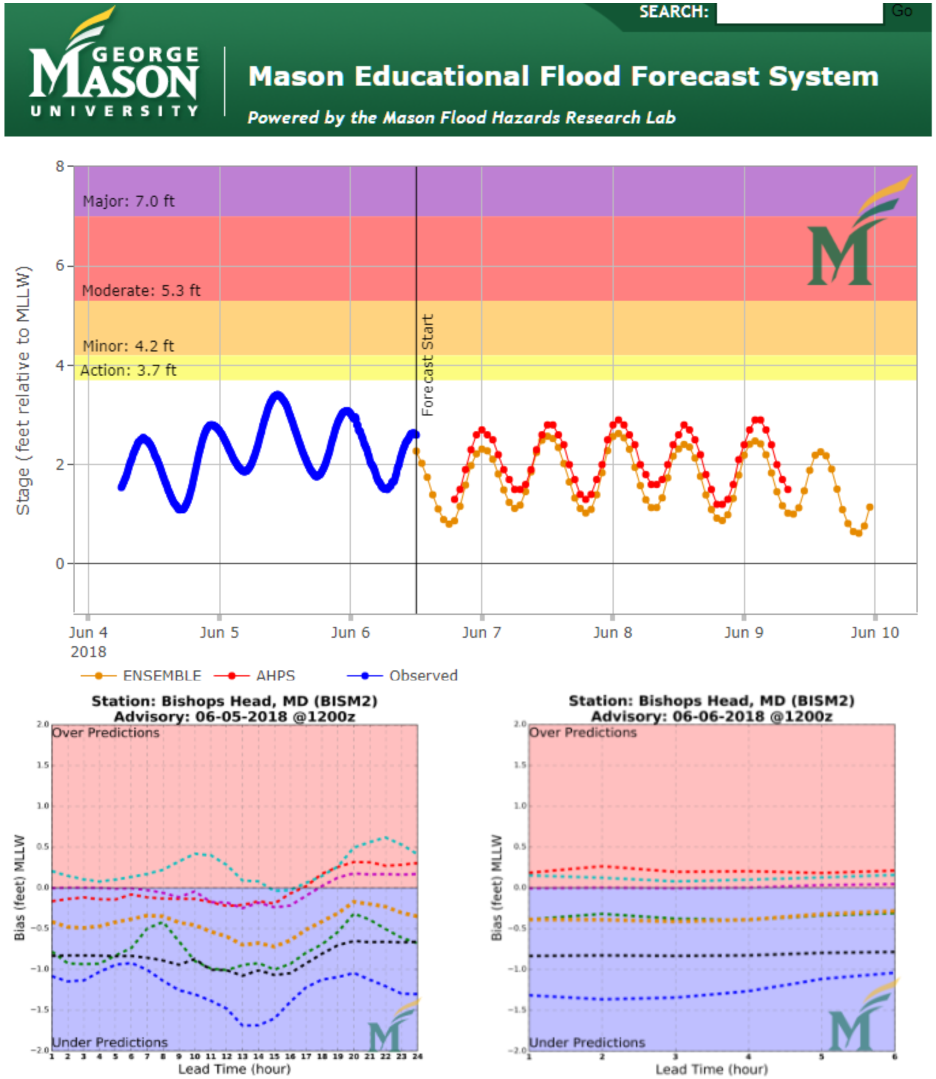
NOAA Earth System Research Laboratory Rapid Refresh (RR)

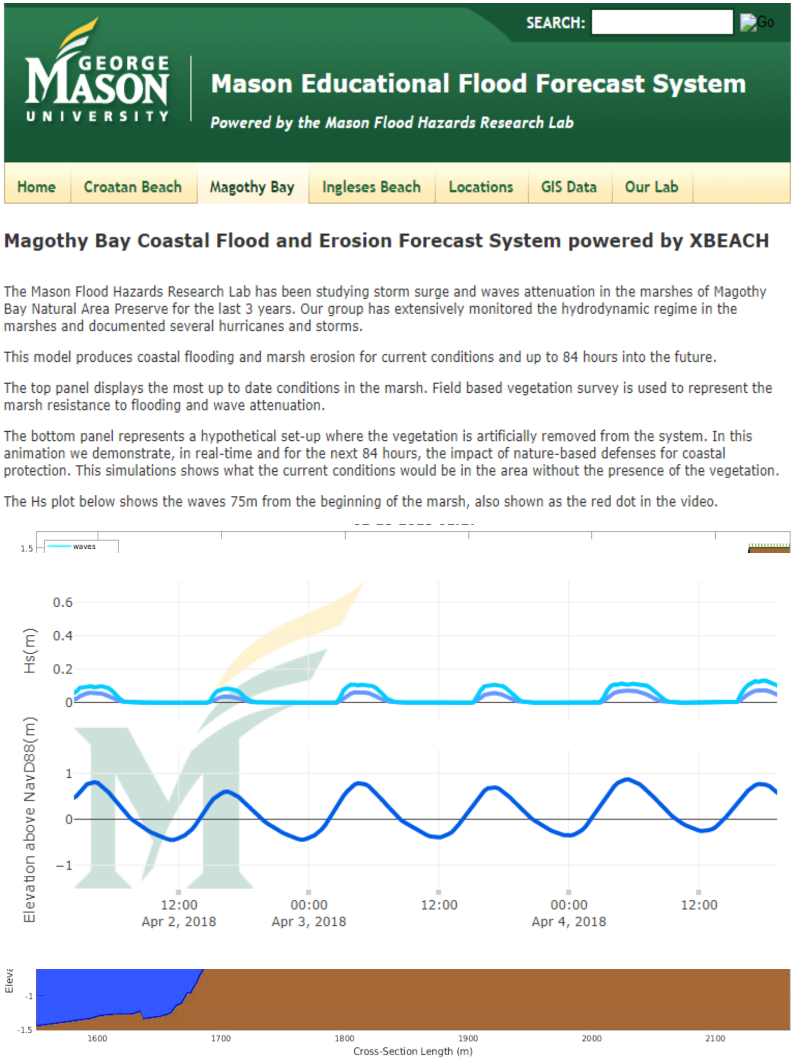
NATIONAL HURRICANE CENTER NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Garzon et al. 2017

3. Coastal hazards modelling at regional scale

Real-time flood forecasts





Magothy Bay Coastal Flood and Erosion Forecast System powered by XBEACH

The Mason Flood Hazards Research Lab has been studying storm surge and waves attenuation in the marshes of Magothy Bay Natural Area Preserve for the last 3 years. Our group has extensively monitored the hydrodynamic regime in the marshes and documented several hurricanes and storms.

This model produces coastal flooding and marsh erosion for current conditions and up to 84 hours into the future.

The top panel displays the most up to date conditions in the marsh. Field based vegetation survey is used to represent the marsh resistance to flooding and wave attenuation.

The bottom panel represents a hypothetical set-up where the vegetation is artificially removed from the system. In this animation we demonstrate, in real-time and for the next 84 hours, the impact of nature-based defenses for coastal protection. This simulations shows what the current conditions would be in the area without the presence of the vegetation.

The Hs plot below shows the waves 75m from the beginning of the marsh, also shown as the red dot in the video.

Click on the point to access real-time time series forecasts at NHPS/NOAA monitoring stations

Publications

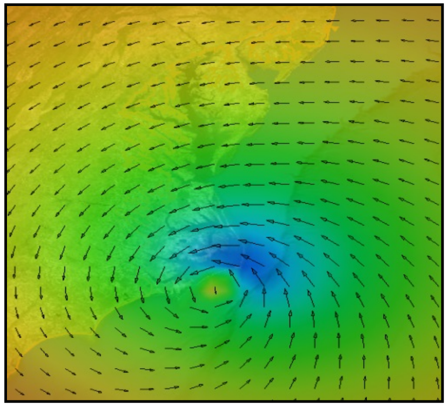
1. **Garzon, J.L.** & Ferreira, C., 2016. Storm Surge Modeling in Large Estuaries: Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay. *Journal of Marine Science and Engineering*, 4(3), p.45. Available at: http://www.mdpi.com/2077-1312/4/3/45.

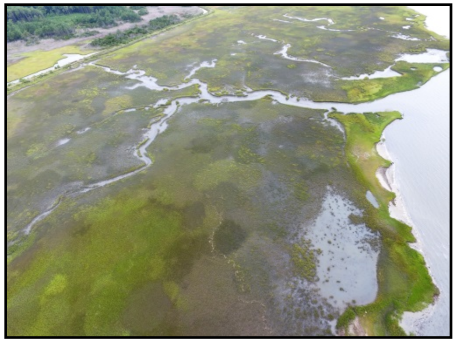
2. **Garzon, J.L.**., Ferreira, C.M. & Padilla-Hernandez, R., 2017. Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay. *Ocean Dynamics*, 68(1), pp.91–107. Available at: https://doi.org/10.1007/s10236-017-1120-x.

3. Glass, E.M., **Garzon, J.L.** et al. 2017. Potential of marshes to attenuate storm surge water level in the Chesapeake Bay. *Limnology and Oceanography*. Available at: http://doi.wiley.com/10.1002/lno.10682

4. **Garzon, J.L.**. et al. 2018a. Wave attenuation by Spartina saltmarshes in the Chesapeake Bay under storm surge conditions. (Under review). *Journal of Geophysical Research: Oceans*.

5. **Garzon, J.L.**., Miesse T. & Ferreira C.M, 2018b. Field-based numerical model investigation of wave propagation across marshes in the Chesapeake Bay under storm conditions. (Under review). *Coastal Engineering*

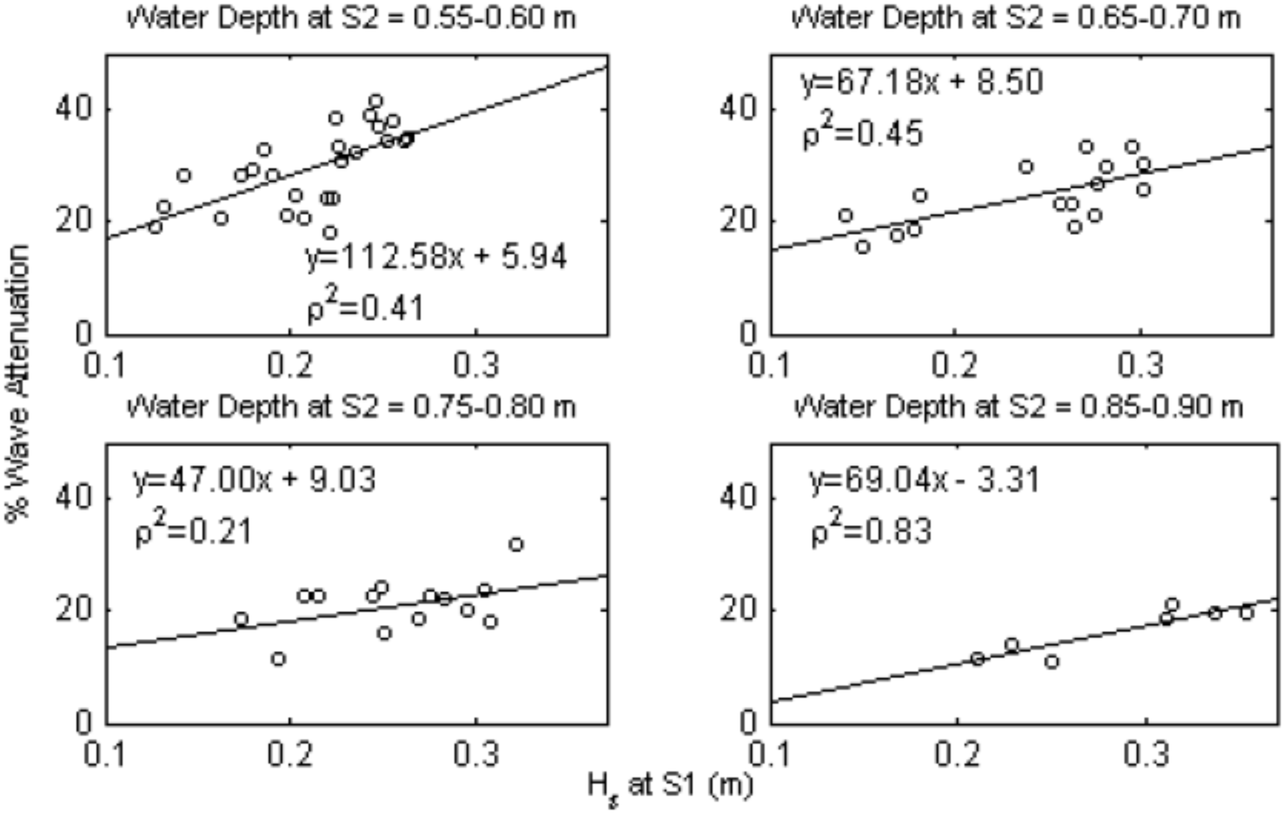




Acknowledgments

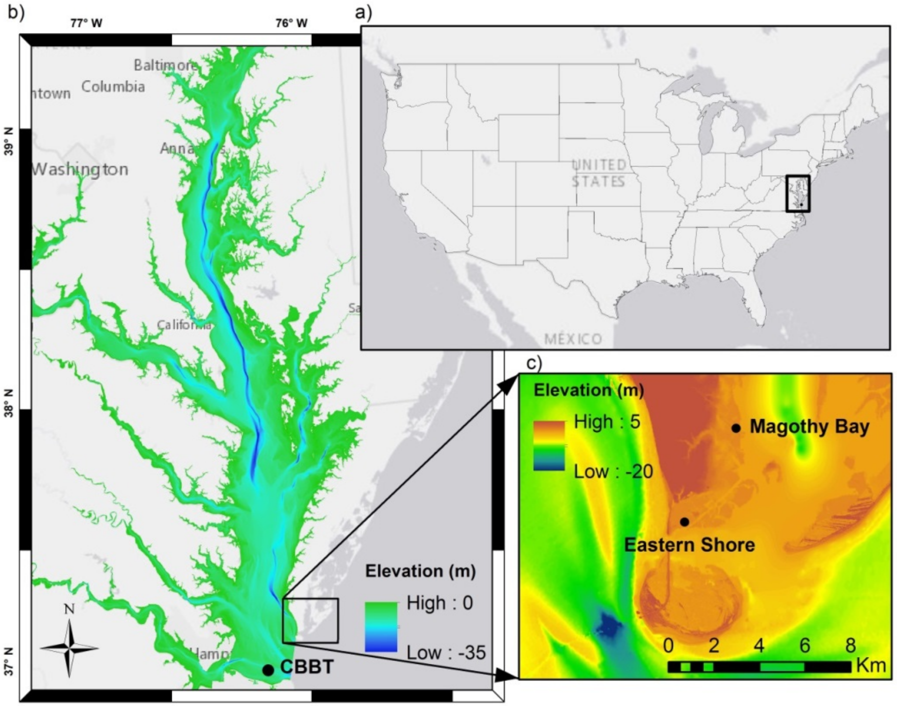
Questions?

2-a) Wave attenuation by *Spartina alterniflora*



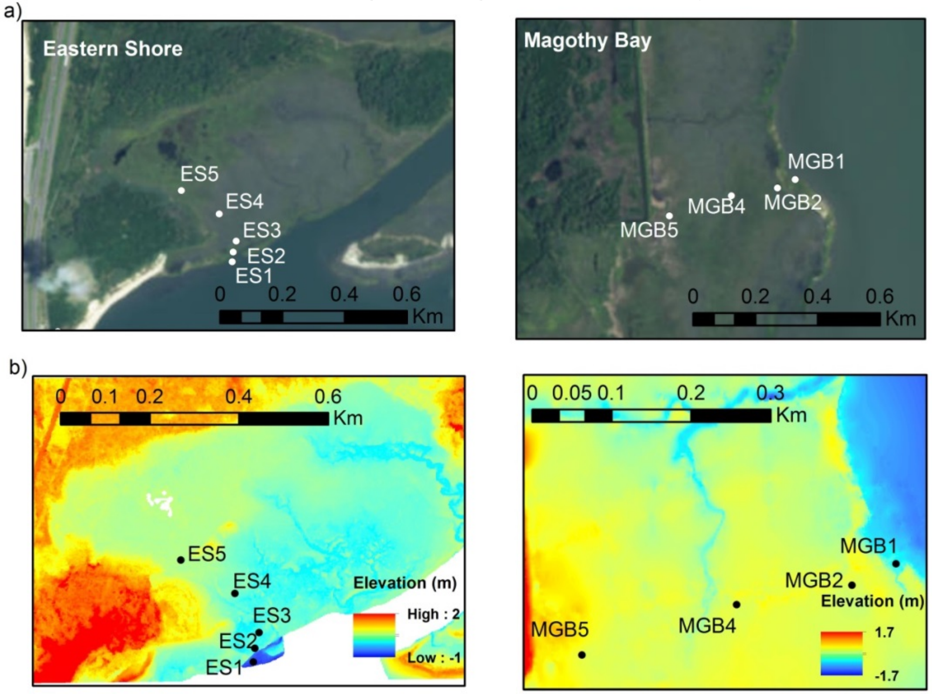
3-a) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

Methods



Location map

Aerial image and digital elevation map

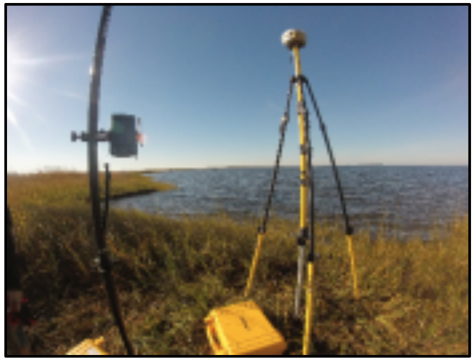


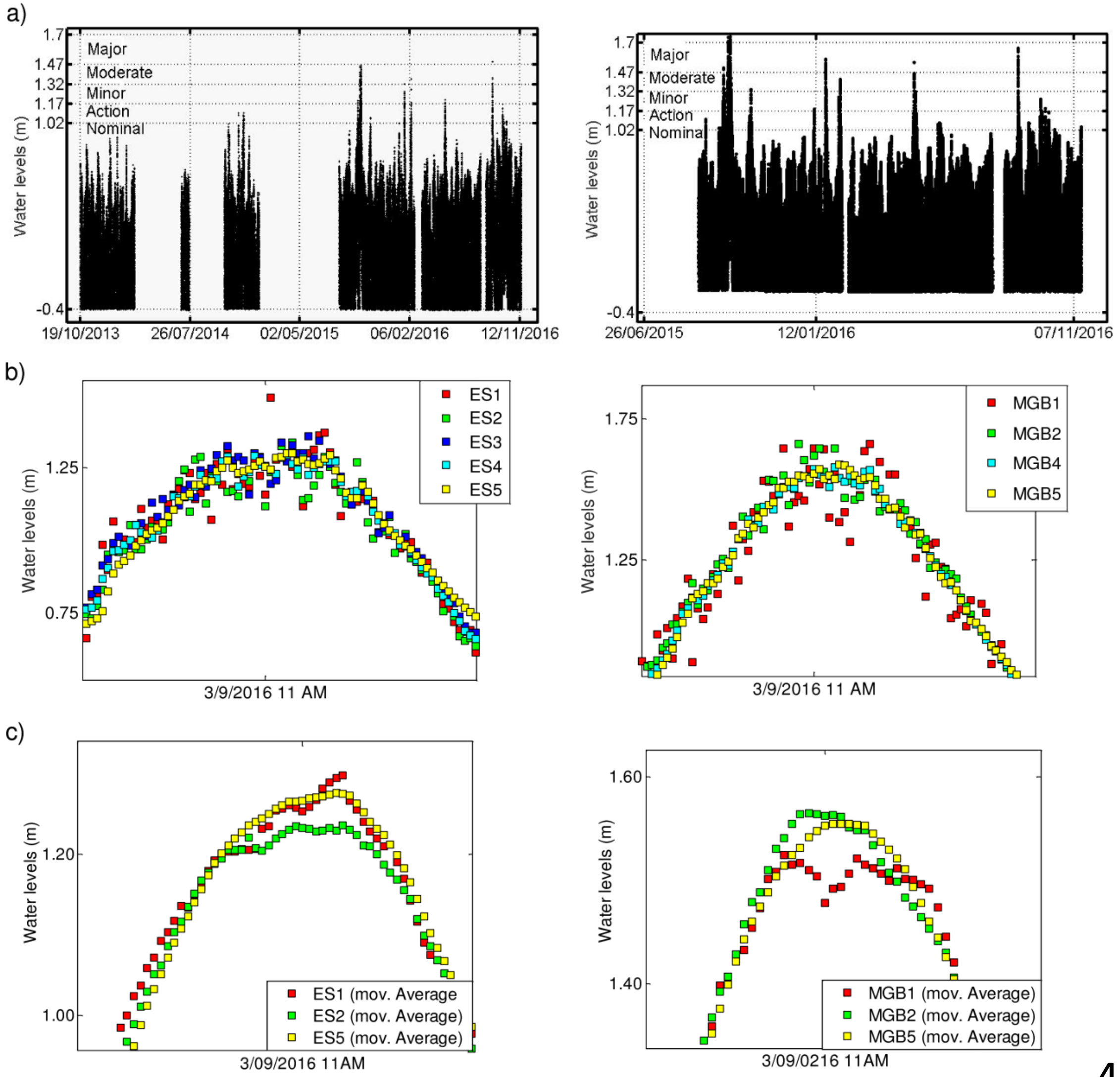
2-a) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

Methods

Water level survey
(Pressure, 1meas./6min)

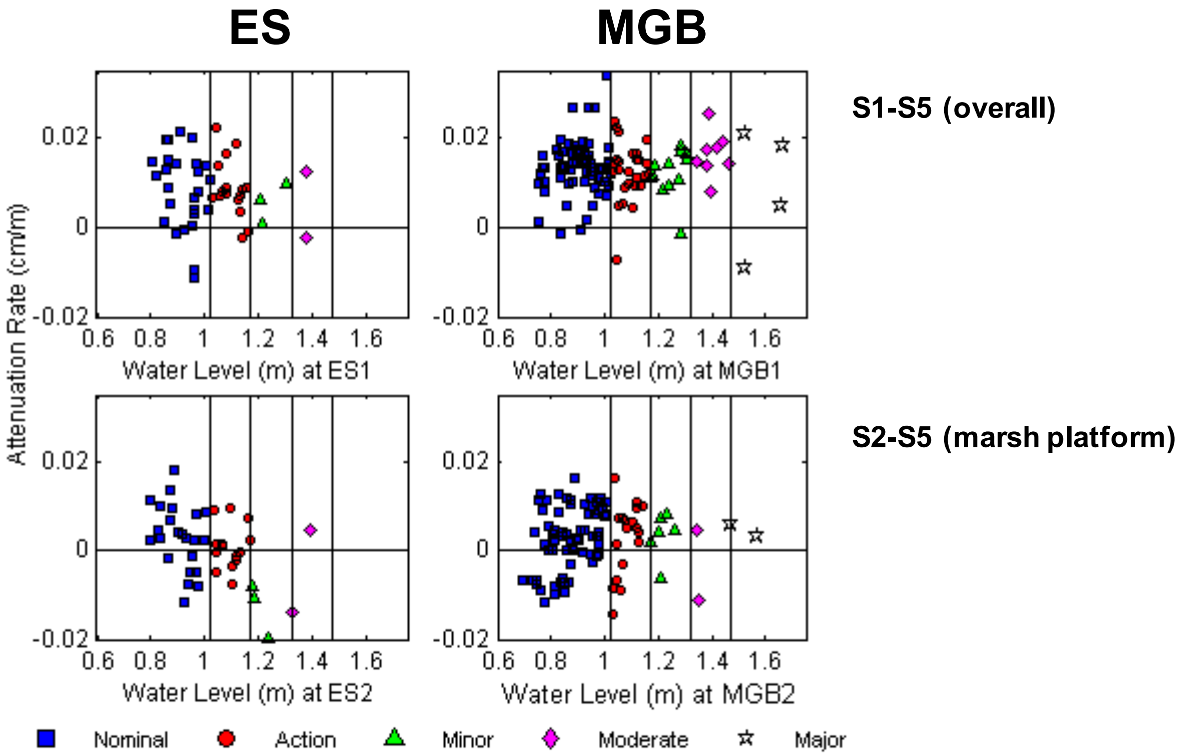
Topographical survey





2-a) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

Results



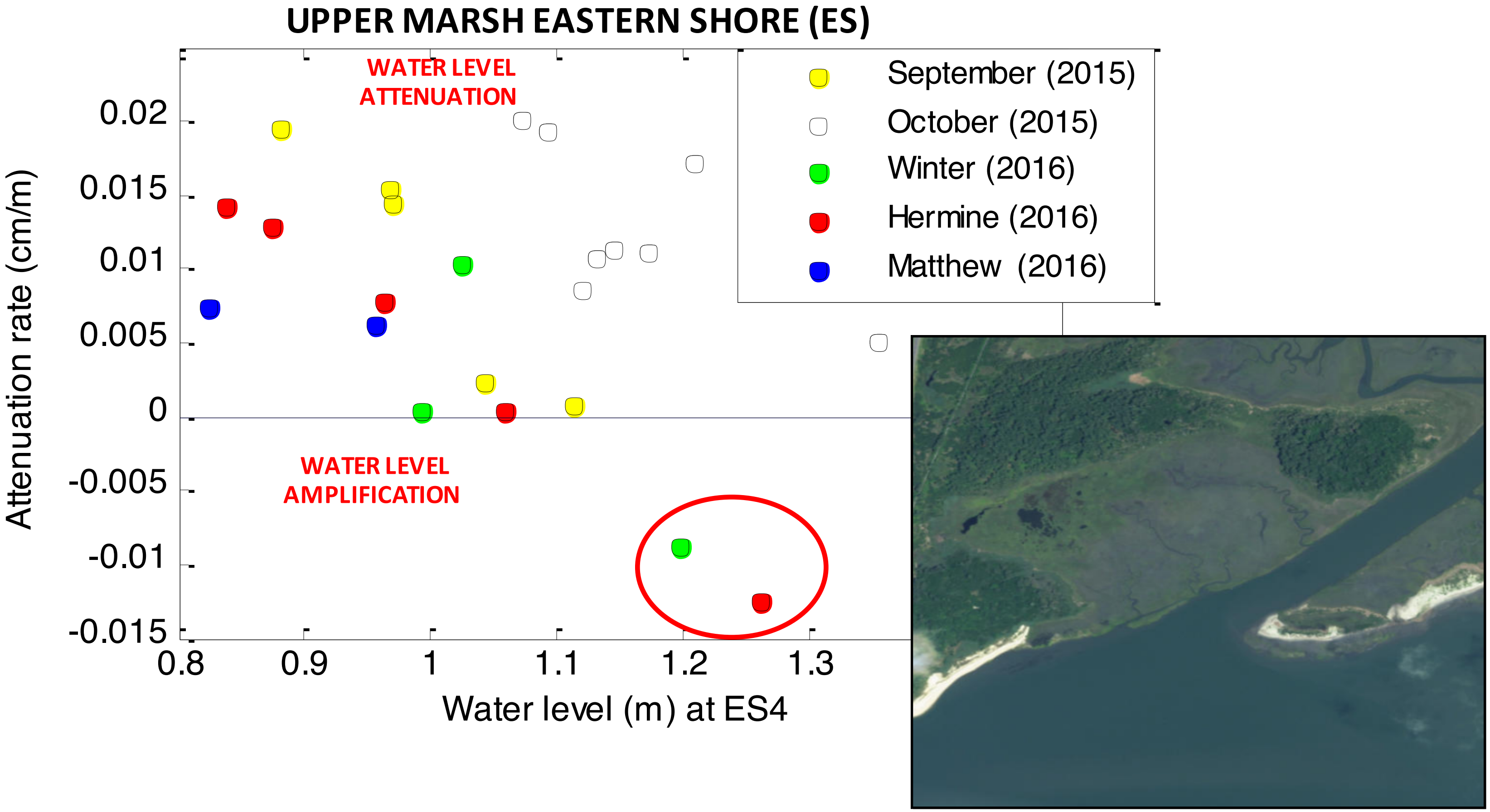
Positive ⟶ **Water level attenuation**

Negative ⟶ **Water level amplification**

Glass et al. (2017)

2-a) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

Results



Glass et al. (2017)

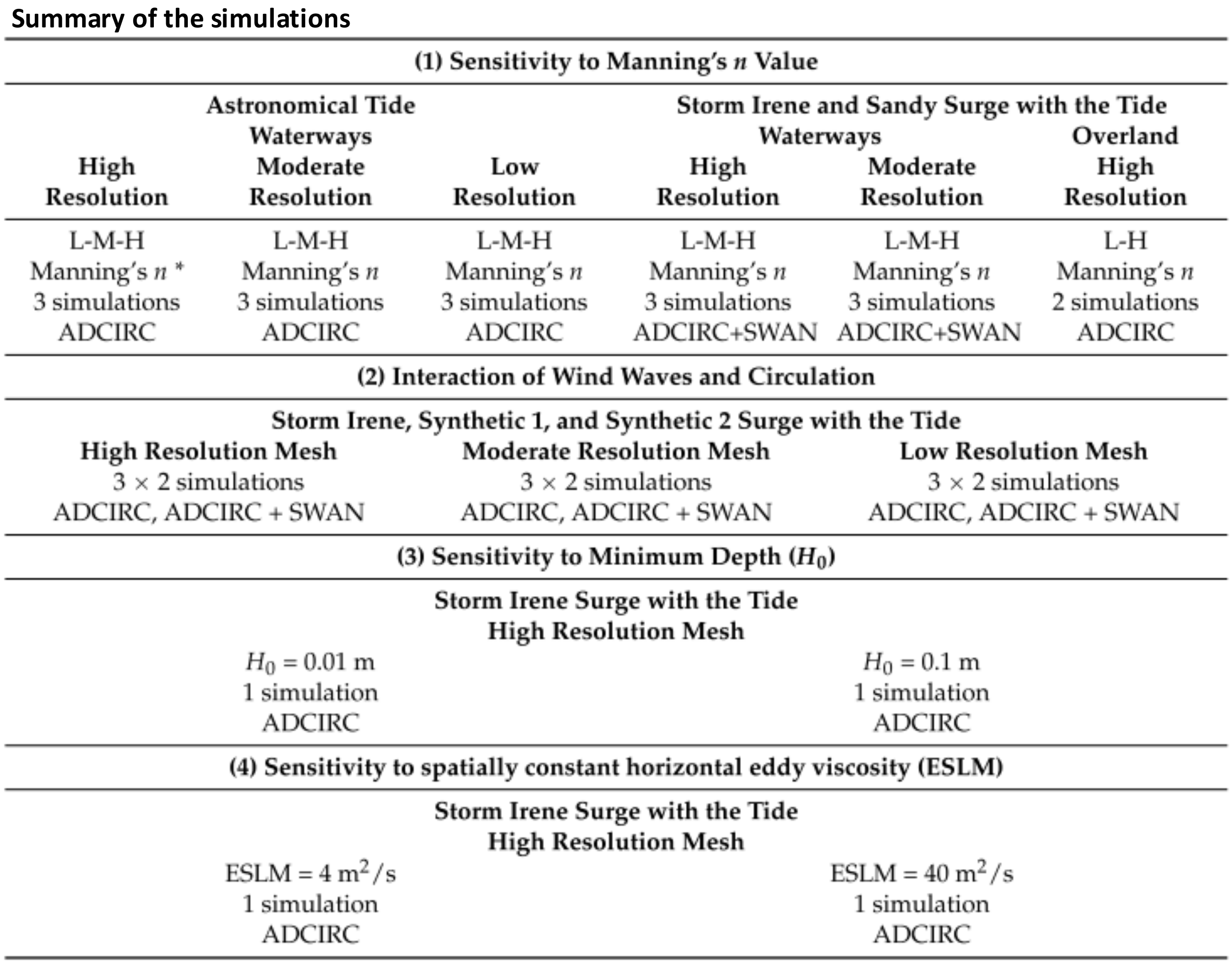
2-a) Potential of marshes to attenuate storm surge wave level in the Chesapeake Bay

Conclusions

- ✓ A large collection (**52 flood events**) of attenuation rates from two marsh transects located in the US mid-Atlantic region.
- ✓ Results show that the overall marsh attenuated water levels, exhibiting values up to **0.02 cm/m** at ES and **0.03 cm/m** at MGB.
- ✓ At the upper marsh of **ES** the ability to attenuate storm surge decreased with increasing HWL. Major events corroborated that **attenuation rates** were very **low** or even negative (amplification) during the **peak of the storms** at the upper marsh of ES.
- ✓ This type of saltmarsh (200-400m) would **moderately attenuate storm** surge during **low inundation** heights, but it would provide **less coastal flood protection during extreme events**.

3-a) Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay

Methods



Summary of the simulations

(1) Sensitivity to Manning's *n* Value

Astronomical Tide Waterways High Resolution	Astronomical Tide Waterways Moderate Resolution	Astronomical Tide Waterways Low Resolution	Storm Irene and Sandy Surge with the Tide Waterways High Resolution	Storm Irene and Sandy Surge with the Tide Waterways Moderate Resolution	Storm Irene and Sandy Surge with the Tide Overland High Resolution
L-M-H Manning's *n* * 3 simulations ADCIRC	L-M-H Manning's *n* 3 simulations ADCIRC	L-M-H Manning's *n* 3 simulations ADCIRC	L-M-H Manning's *n* 3 simulations ADCIRC+SWAN	L-M-H Manning's *n* 3 simulations ADCIRC+SWAN	L-H Manning's *n* 2 simulations ADCIRC

(2) Interaction of Wind Waves and Circulation

Storm Irene, Synthetic 1, and Synthetic 2 Surge with the Tide

High Resolution Mesh	Moderate Resolution Mesh	Low Resolution Mesh
3 × 2 simulations ADCIRC, ADCIRC + SWAN	3 × 2 simulations ADCIRC, ADCIRC + SWAN	3 × 2 simulations ADCIRC, ADCIRC + SWAN

(3) Sensitivity to Minimum Depth (H_0)

Storm Irene Surge with the Tide
High Resolution Mesh

$H_0 = 0.01$ m 1 simulation ADCIRC	$H_0 = 0.1$ m 1 simulation ADCIRC

(4) Sensitivity to spatially constant horizontal eddy viscosity (ESLM)

Storm Irene Surge with the Tide
High Resolution Mesh

ESLM = 4 m^2/s 1 simulation ADCIRC	ESLM = 40 m^2/s 1 simulation ADCIRC

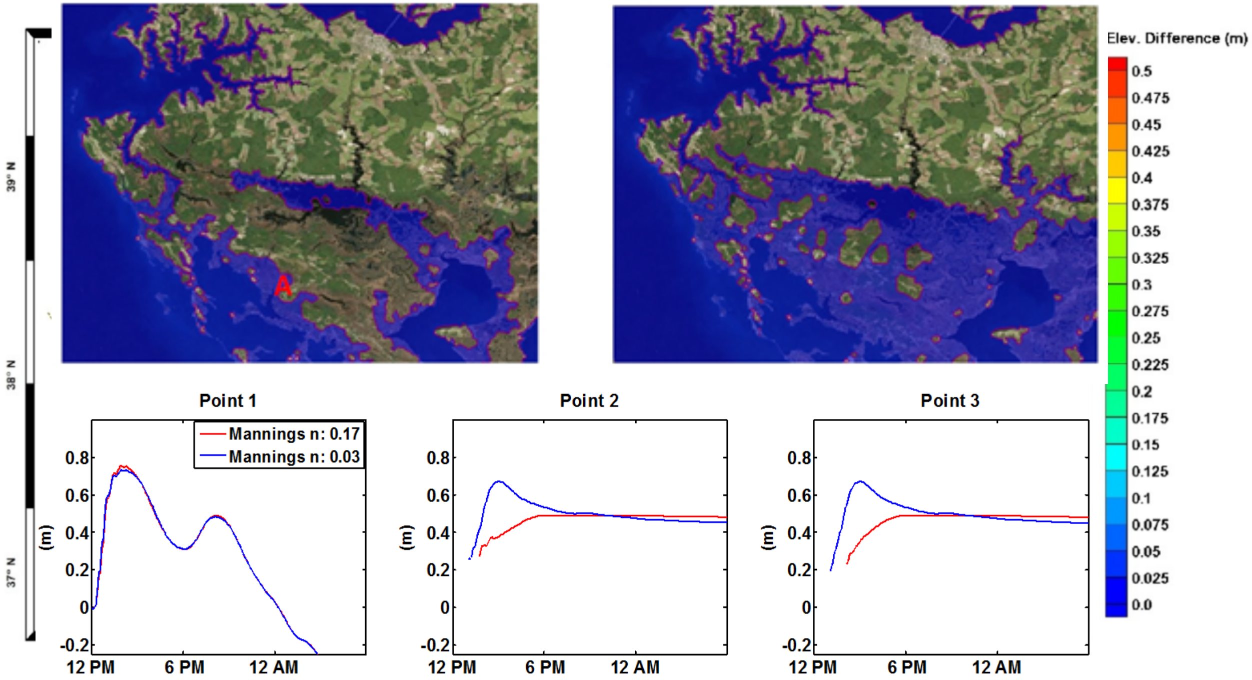
Garzon & Ferreira (2016)

3-a) Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay

Results

Sandy 2012

Manning’s *n*



Upper panels-Flood extension simulated during Hurricane Sandy for a high level of friction (left) and low level of friction (right). Lower pannels-Time series water levels modeled for the high friction and low friction cases during Hurricane Sandy.

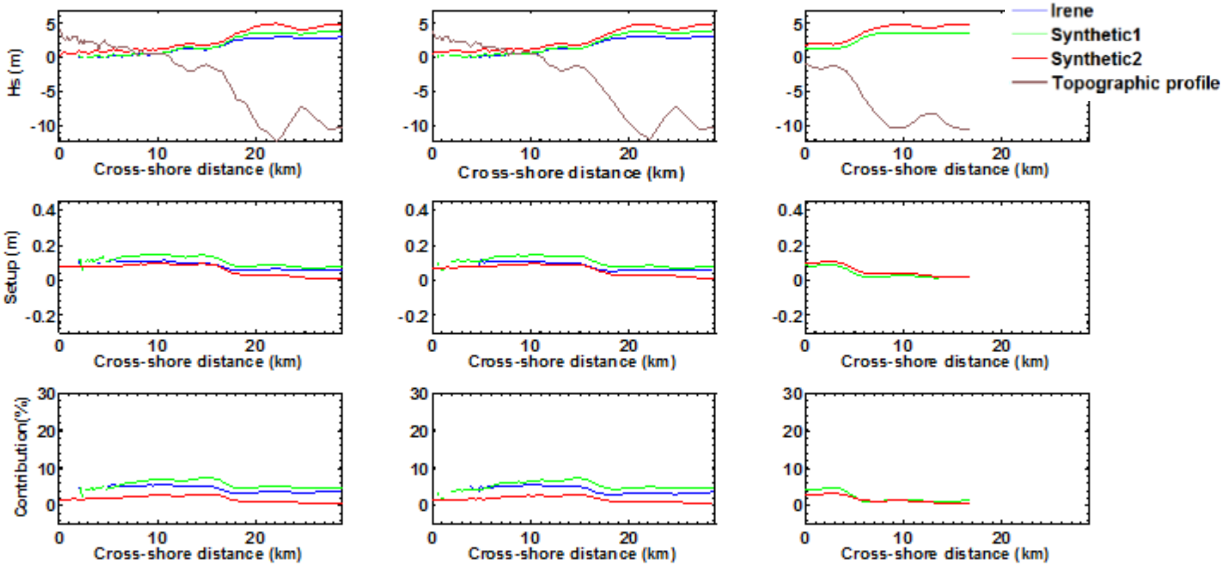
Effects of high friction and low friction on maximum water levels for Hurricane Sandy.

Garzon & Ferreira (2016)

3-a) Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay

Results

Interaction waves
and circulation



Maximum significant wave height, wave setup and relative contribution of wave setup to the overall water levels during the peak of the storm

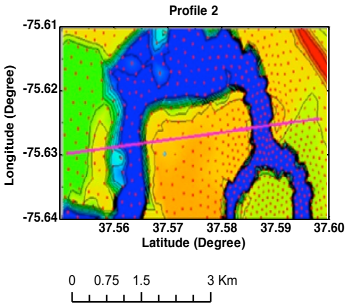
Profile	High Res. Mesh		Moderate Res. Mesh		Low Res. Mesh	
	Setup (m)	(%)	Setup (m)	(%)	Setup (m)	(%)
1	0.32	17	0.31	16	0.25	20
2	0.19	10	0.20	10	0.16	9
3	0.15	7	0.14	7	0.09	5
4	0.15	12	0.16	12	0.10	8
5	0.12	10	0.13	10	0.02	2
6	0.15	15	0.19	18	0.05	5
7	0.08	8	0.08	7	0.02	2
8	0.08	8	0.08	7	0.02	2

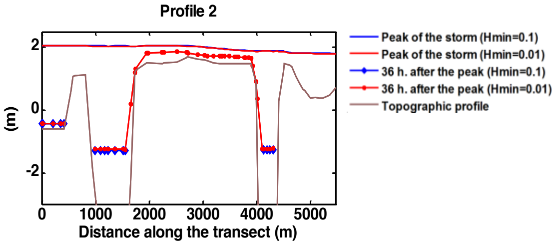
Garzon & Ferreira (2016)

3-a) Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay

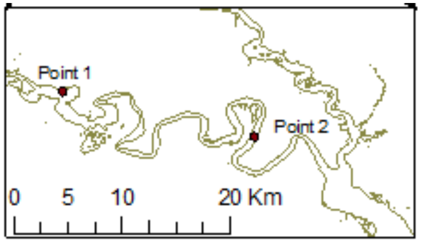
Results

Ho (W/D algorithm)

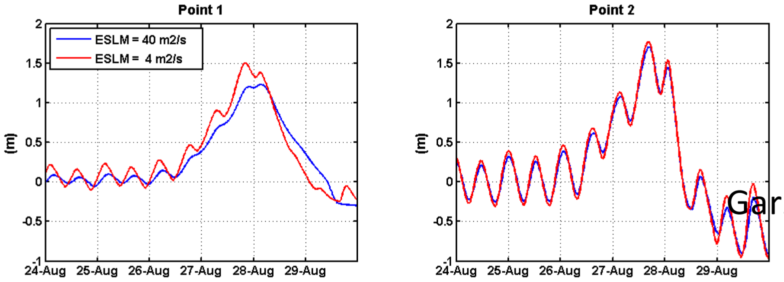




Eddy viscosity



Garzon & Ferreira (2016)



Garzon & Ferreira (2016)

2-a) Sensitivity Analyses to Parameters and Physical Processes in the Chesapeake Bay

Conclusions

- ✓ Maximum water elevations during this storm were very sensitive to Manning’s n coefficient in riverine regions, where they were reduced **0.56 m** by using **high friction** values. High friction reduced also maximum water levels up to **0.30** m in overland areas.

- ✓ The wave s contribution to total water levels depended on the offshore wave height, angle of breaking, the profile morphology and the mesh resolution, accounting for up to **0.19** m setup inside the bay.

- ✓ Minimum depth analysis showed that H_0 **= 0.01** added an **artificial mass of water** in marshes and channels, meanwhile H **= 0.1** partially **solved this problem**.

- ✓ The Eddy viscosity study demonstrated that the **ESLM = 40** values reduced up to **0.40 m** the peak of the maximum water levels in the upper side of narrow rivers.

3-b) Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay

Methods

NAM The North American Mesoscale Forecast System

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GFS Global Forecast System

ECMWF EUROPEAN CENTRE FOR MEDIUM RANGE WEATHER FORECASTS

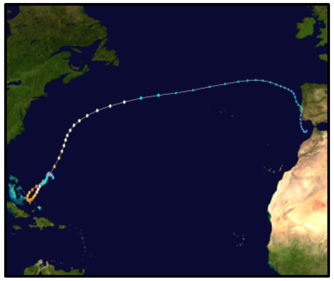
Earth System Research Laboratory Rapid Refresh (RR)

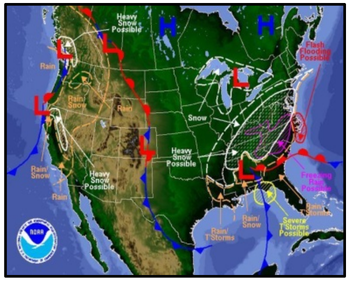
NATIONAL HURRICANE CENTER NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Irene 2011

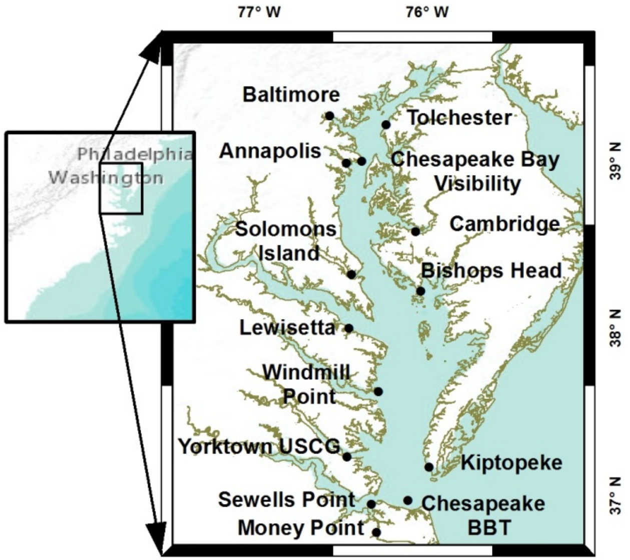
Sandy 2012

Joaquin 2015



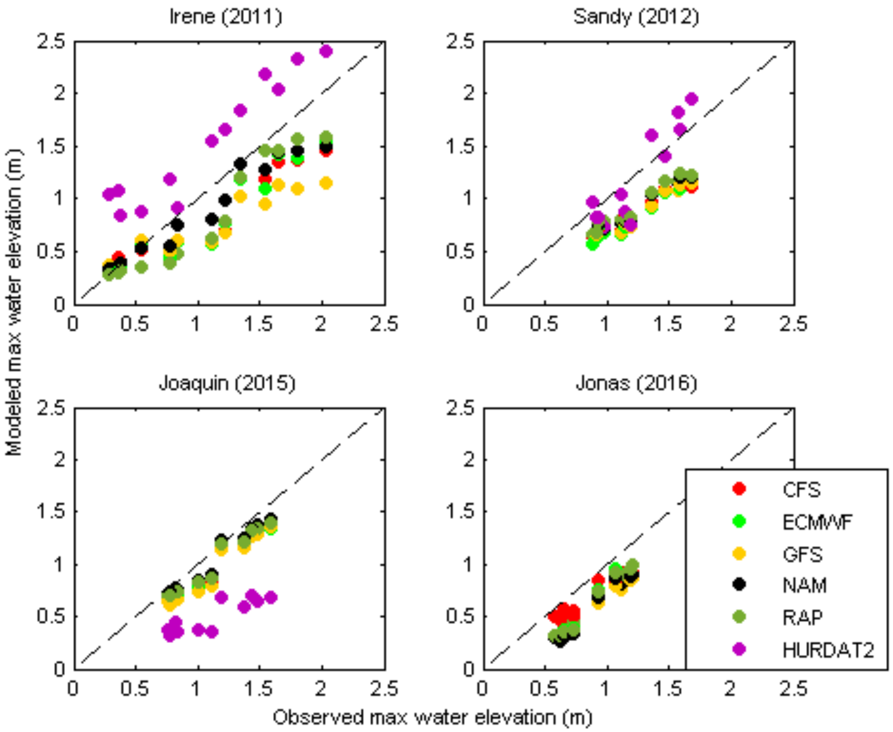


Jonas 2016

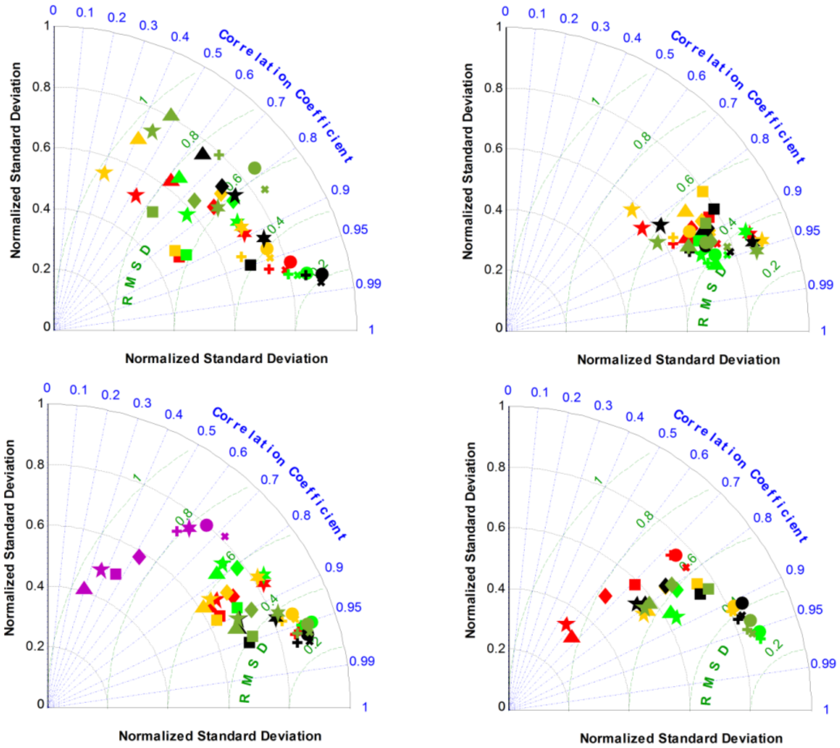


3-b) Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay

Results



Maximum water levels observed (x-axis) against maximum water levels modeled (y-axis)



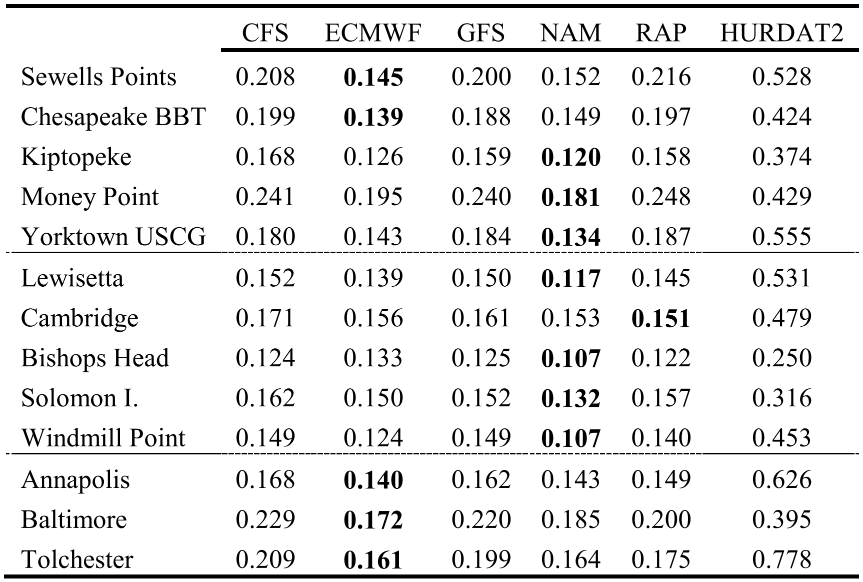
Sewells Point (✚), Chespeake Bay Bridge Tunnel (○), Kiptopeke (✖), Lewisetta (□), Cambridge (◇), Bishops Head (✡), Annapolis (★), Baltimore (△).

Garzon, Ferreira & Padilla-Hernandez (2017)

3-b) Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay

Results

Root mean square (RMS) averaged for the four events



	CFS	ECMWF	GFS	NAM	RAP	HURDAT2
Sewells Points	0.208	**0.145**	0.200	0.152	0.216	0.528
Chesapeake BBT	0.199	**0.139**	0.188	0.149	0.197	0.424
Kiptopeke	0.168	0.126	0.159	**0.120**	0.158	0.374
Money Point	0.241	0.195	0.240	**0.181**	0.248	0.429
Yorktown USCG	0.180	0.143	0.184	**0.134**	0.187	0.555
Lewisetta	0.152	0.139	0.150	**0.117**	0.145	0.531
Cambridge	0.171	0.156	0.161	0.153	**0.151**	0.479
Bishops Head	0.124	0.133	0.125	**0.107**	0.122	0.250
Solomon I.	0.162	0.150	0.152	**0.132**	0.157	0.316
Windmill Point	0.149	0.124	0.149	**0.107**	0.140	0.453
Annapolis	0.168	**0.140**	0.162	0.143	0.149	0.626
Baltimore	0.229	**0.172**	0.220	0.185	0.200	0.395
Tolchester	0.209	**0.161**	0.199	0.164	0.175	0.778

Garzon, Ferreira & Padilla-Hernandez (2017)

3-b) Evaluation of weather forecast systems for storm surge modeling in the Chesapeake Bay

Conclusions

- ✓ Our simulations demonstrated that ADCIR+SWAN System forced by:
  - ➢ the **HURDAT2** based system exhibited the weakest statistical skills owing to a noteworthy **overprediction** of the simulated wind speed.
  - ➢ the **ECMWF, RAP, and NAM** products captured the moment of the peak and **moderately** its magnitude during all storms.
  - ➢ the **CFS** system exhibited the **worst averaged root-mean-square** difference (excepting HURDAT2)
  - ➢ the **GFS** system (the lowest horizontal resolution product tested) resulted in a clear **underprediction** of the maximum water elevation

- ✓ Overall, the simulations forced by **NAM and ECMWF** systems induced the **most accurate** results to support water level forecasting in the Chesapeake Bay