High-Resolution Modeling of Surge during Hurricane Matthew (2016)

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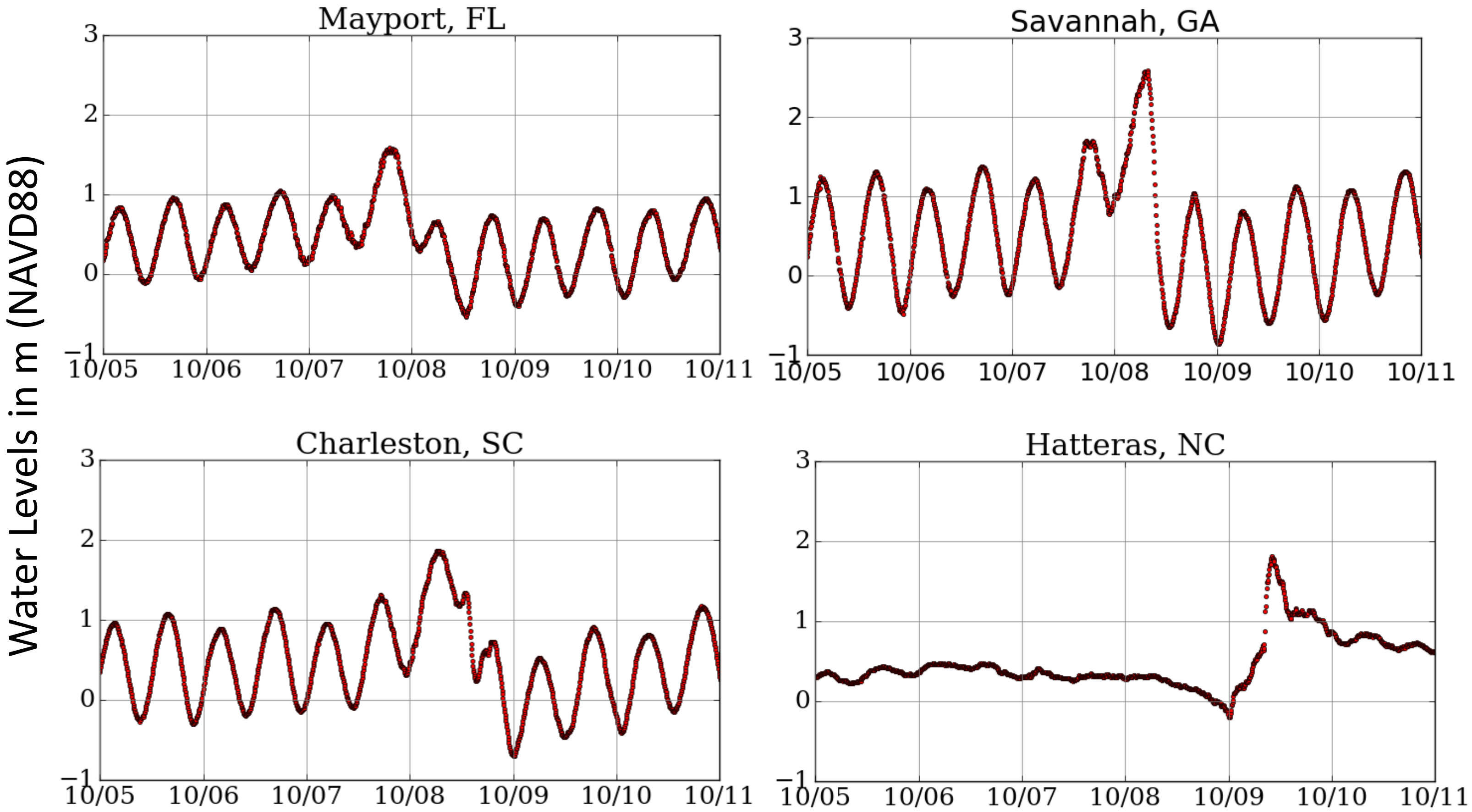
Introduction

- Matthew was a Category-5 storm that impacted the south-east coast of the United States during October 2016

Introduction

- Variation in impacts along the coast

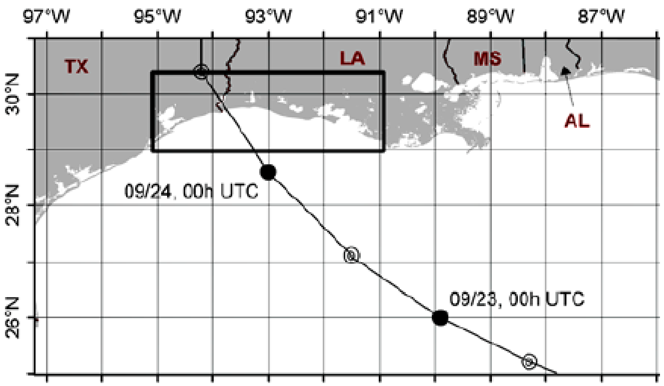


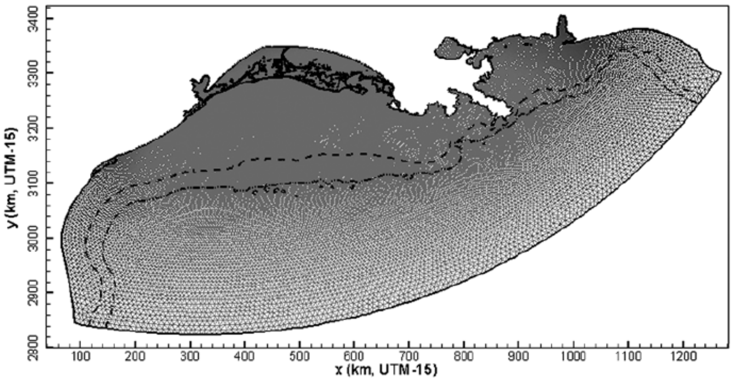
Observations at selected stations (South to North)

Literature Review

1. Surge-Tide Interactions

- **Several studies** - Proudman (1955,1957), Rossiter (1961), Tang et. al. (1996), Bernier et. al. (2007), Rego and Li (2010), Poulose et. al. (2017)
- **Example** - Rego and Li (2010) on the LATEX coast during Hurricane Rita, as high as 70% of the tidal amplitudes



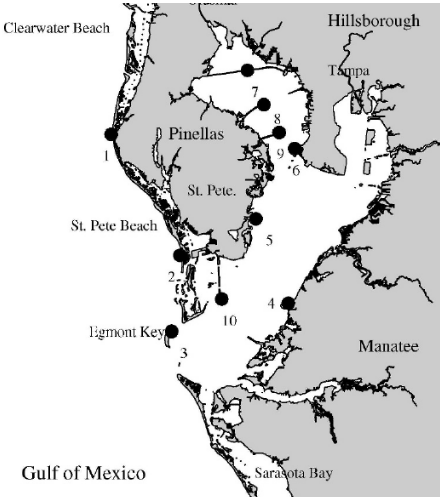


- **Common Limitation** - Shore-normal track, small extent of coastline
- **Remaining Questions**
  - How does a shore-parallel track affect tide-surge interactions over a large coastline?
  - What are the magnitude of these terms on the U.S. south-east coast?
  - What if the storm interacts with multiple phases of the tides?

Literature Review

2. Influence of Storm Parameters on Surge

- **Several studies** - Weisburg and Zheng (2006), Irish et. al. (2008), Rego and Li (2009), Berg (2013), Sebastian et. al. (2014)
- **Example -** Weisburg and Zheng (2006) studied storm surge response to forward speed in Tampa Bay, FL



- **Common Limitation** – modifying storm track and wind fields, shore-normal storms, small/idealized coastlines
- **Remaining Question**
    - What is the effect of storm parameters like timing and speed on surge during a shore-parallel storm and on a large complex coastline?

Goals and Objectives

Goal: Understand the influence of tide-surge interactions and storm forward speed on water levels along the U.S. south-east coast

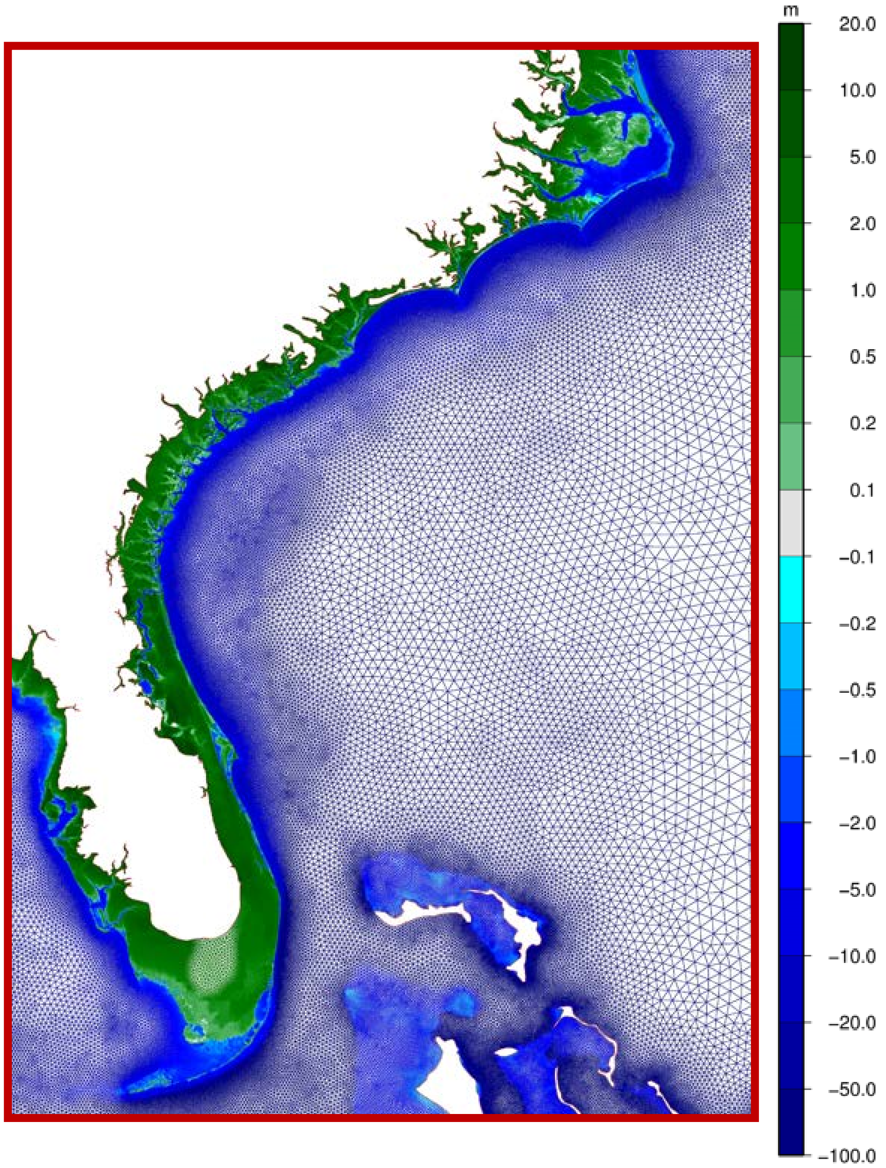
Objective #1: Validate winds, waves, and water levels during Matthew on a mesh with floodplains coverage over a large extent

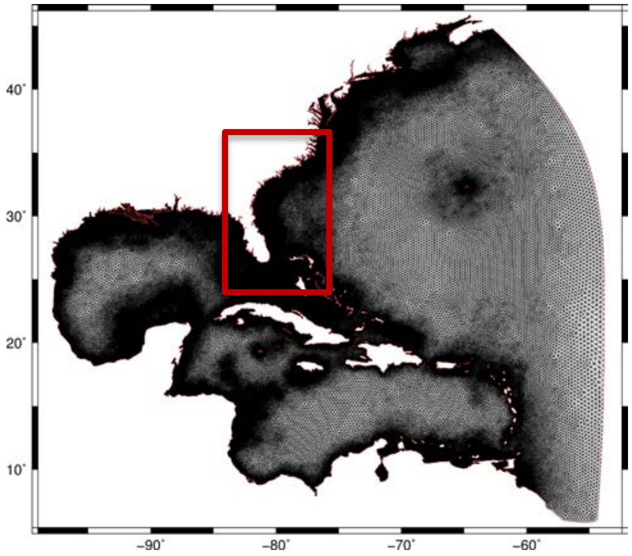
Objective #2: Quantify the contributions of nonlinear interactions to the total water levels

Objective #3: Compute the differences in flooding if the storm occurred at a different time or travelled at a different speed

Methods

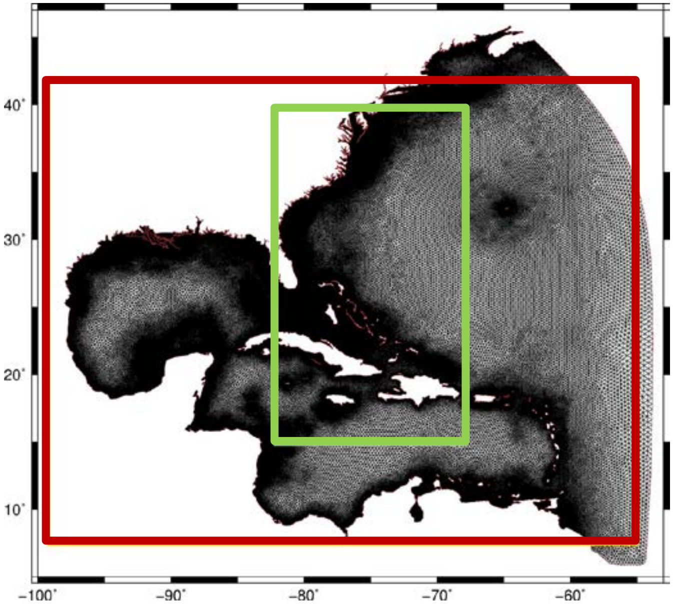
- The HSOFS unstructured mesh
  - Riverside, AECOM & NOAA - 2015
  - 500m average coastal resolution
  - 1.8 million vertices





Methods

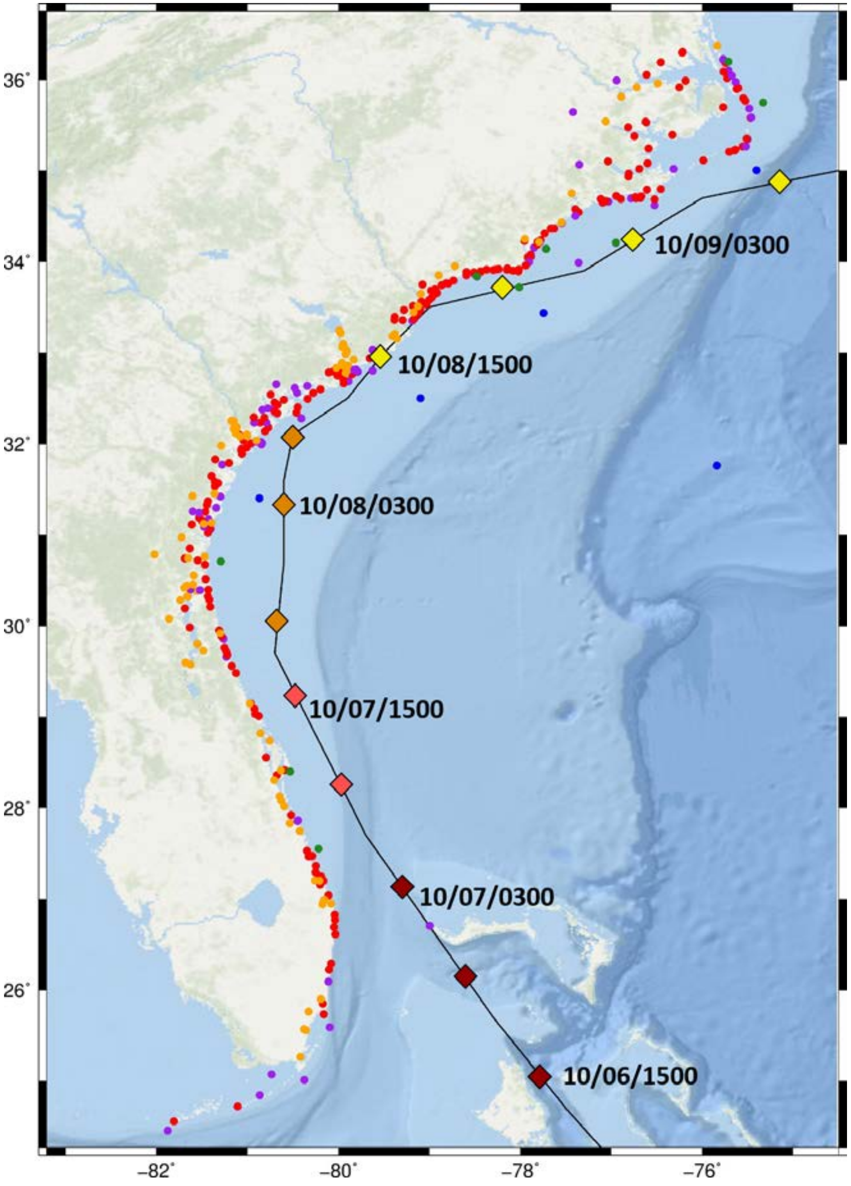
- Winds from OWI
  - Data-assimilated fields
  - Basin grid at resolution of 1/4°
  - Region grid at resolution of 1/20°



Parameter	Error	GAHM	WF	OWI
Surface Pressure	Stations	282	283	283
	RMSE (hPa)	6.72	4.23	**2.14**
	Bias	-0.16	-0.02	**0.06**
Wind Speed	Stations	66	61	66
	RMSE (m/s)	5.60	2.98	**2.29**
	Bias	-0.29	0.16	**0.06**

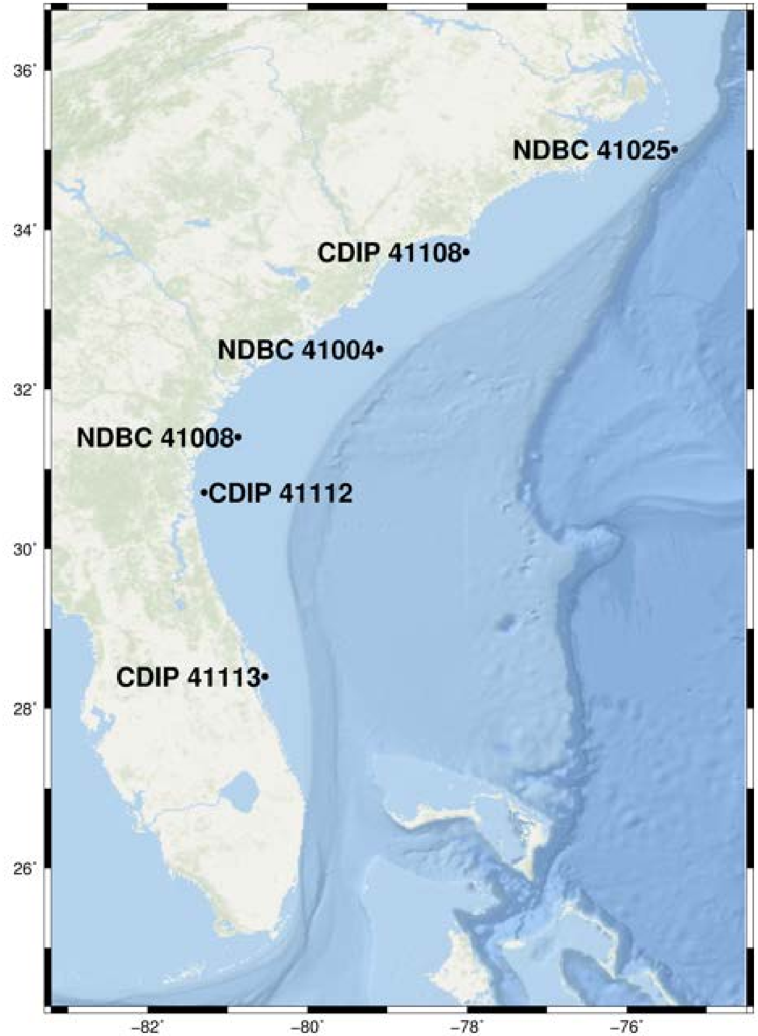
Model Validation – Observations

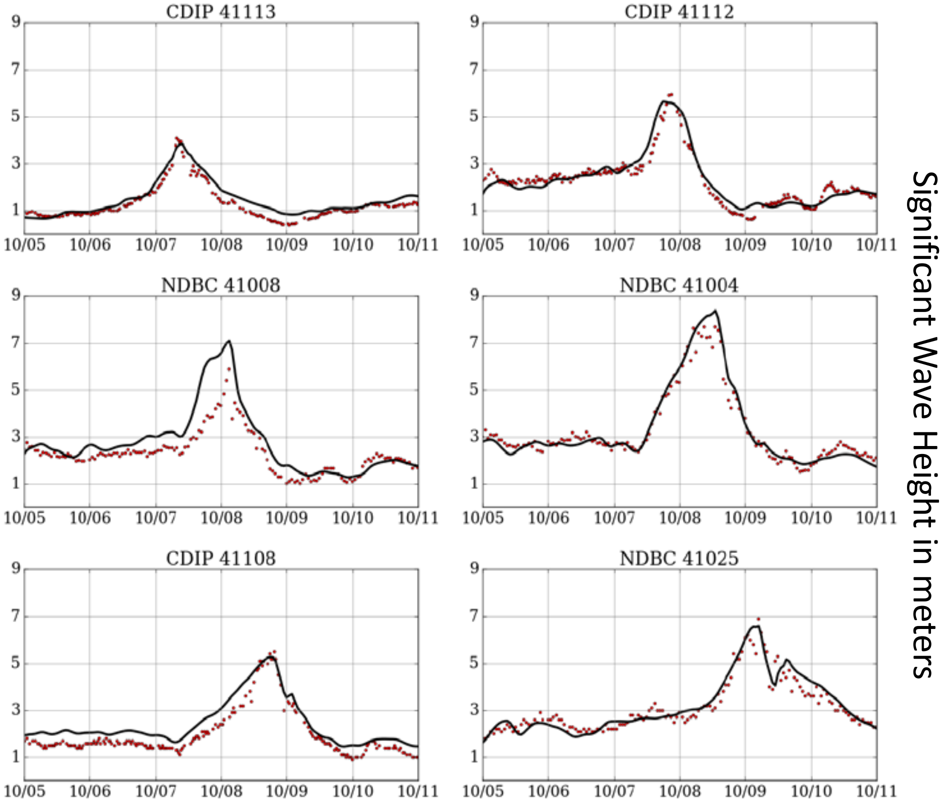
Symbol	Saffir-Simpson Category	Wind Speed (ms^{-1})
◆	4	59-69
◆	3	50-58
◆	2	43-49
◆	1	33-42



Symbol	Data Available
●	WL
●	WL + MET
●	MET
●	MET + WH
●	WH

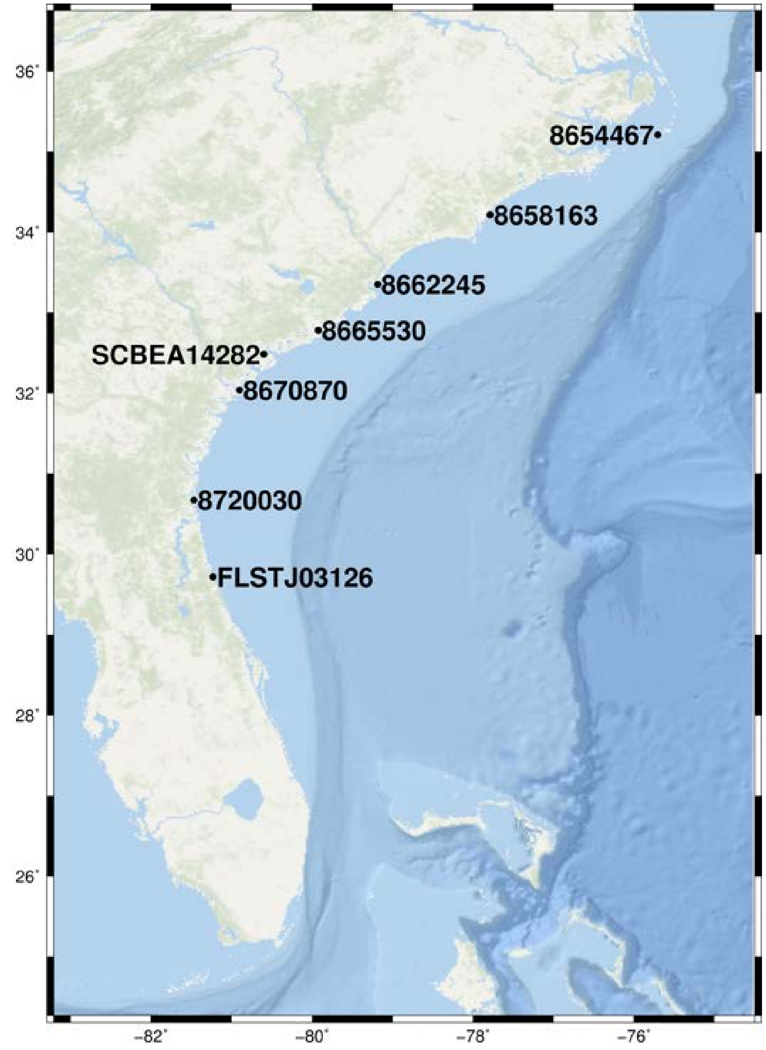
Model Validation – Waves

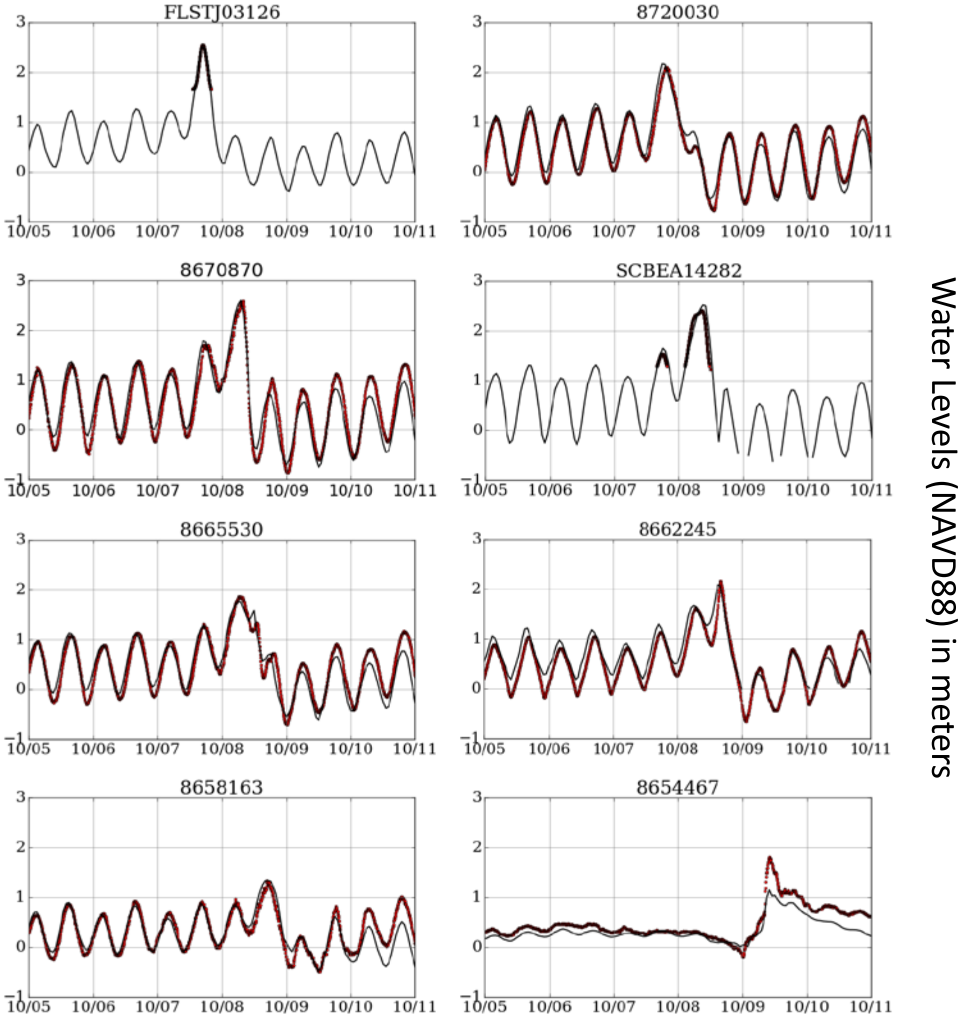




16 stations, RMSE of 0.53m, Bias of 0

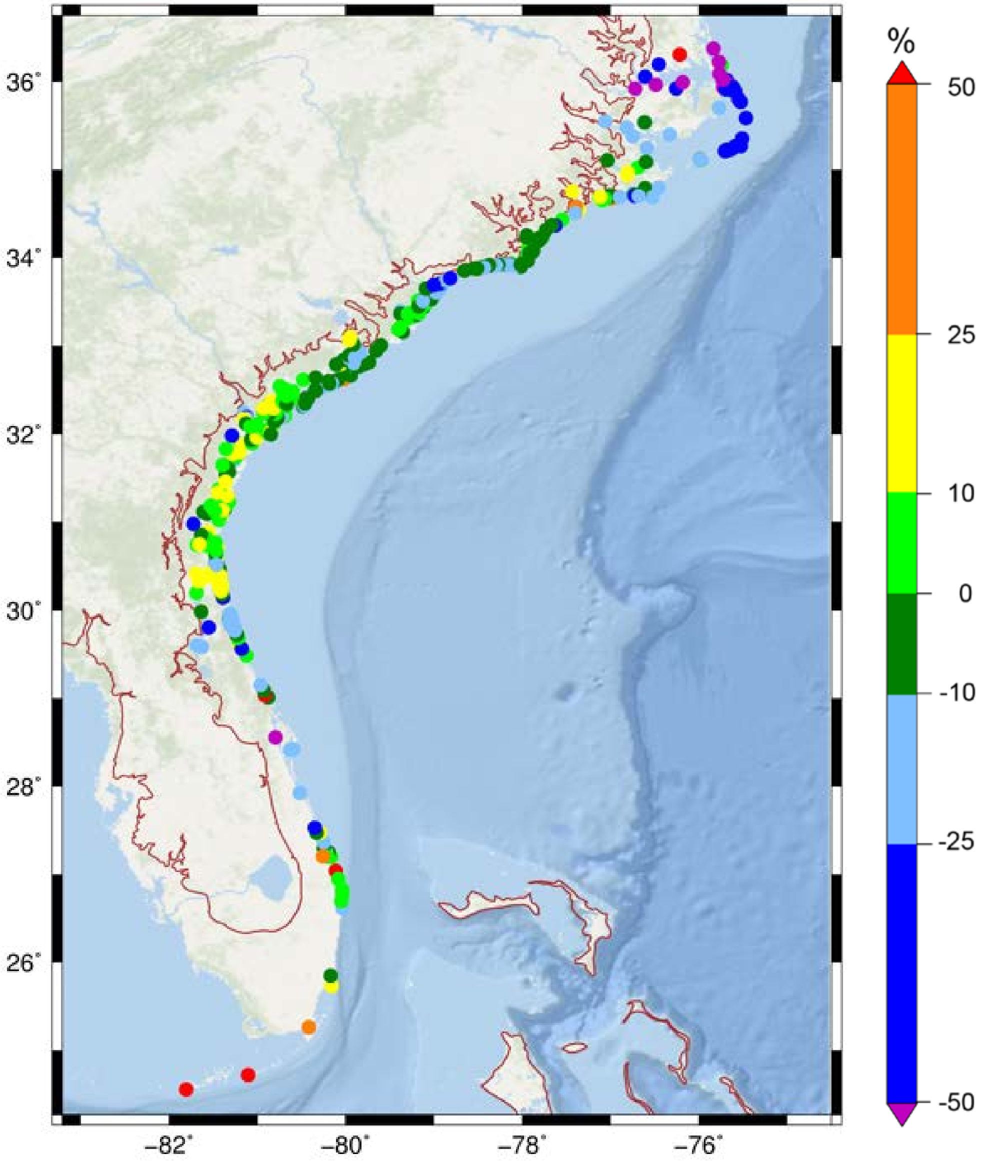
Model Validation – Water Levels

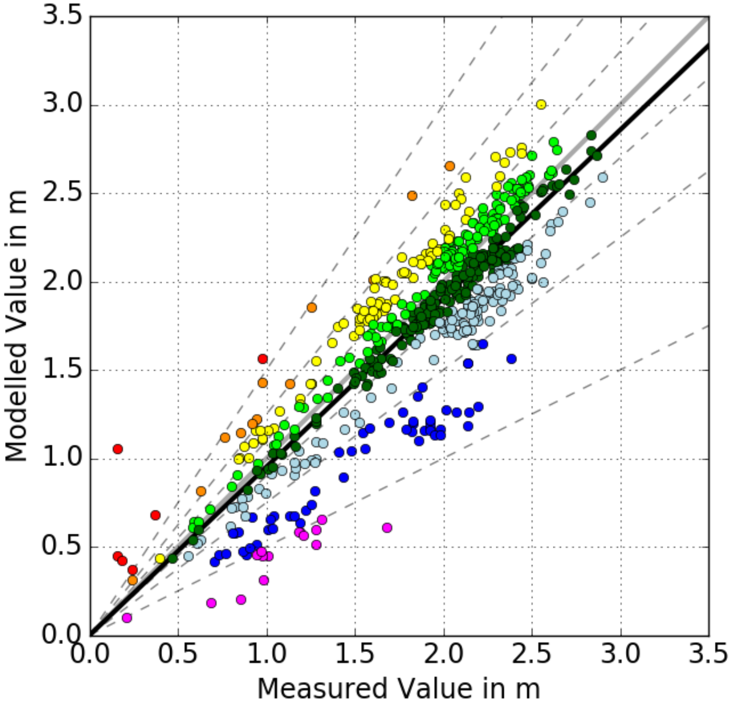




241 stations, RMSE of 0.28m, Bias of 0.01

Model Validation – High Water Marks





622 peaks
R^2 = 0.78
RMSE = 0.28m
Bias = -0.04
Best fit slope = 0.95

Non-Linear Interactions between Surge and Tides

- Attributed to the non-linear terms in the governing equations
    1. Non-linear bottom friction
    2. Momentum advection
    3. Shallow water effect

$$\frac{\partial^2\zeta}{\partial t^2}+\tau_o\frac{\partial\zeta}{\partial t}+\overbrace{\frac{\partial\tilde{J}_x}{\partial x}+\frac{\partial\tilde{J}_y}{\partial y}-UH\frac{\partial\tau_o}{\partial x}-VH\frac{\partial\tau_o}{\partial y}}^{③}=0$$

GWCE

$$\tilde{J}_x\equiv\frac{\partial}{\partial t}(UH)+\tau_o UH \qquad \tilde{J}_y\equiv\frac{\partial}{\partial t}(VH)+\tau_o VH$$

$$\frac{\partial U}{\partial t}+\overbrace{U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}}^{②}-fV=-g\frac{\partial\left[\zeta+P_s/g\rho_o-\alpha\eta\right]}{\partial x}+\overbrace{\frac{\tau_{sx}}{H\rho_o}-\frac{\tau_{bx}}{H\rho_o}+\frac{M_x}{H}-\frac{D_x}{H}-\frac{B_x}{H}}^{③}$$

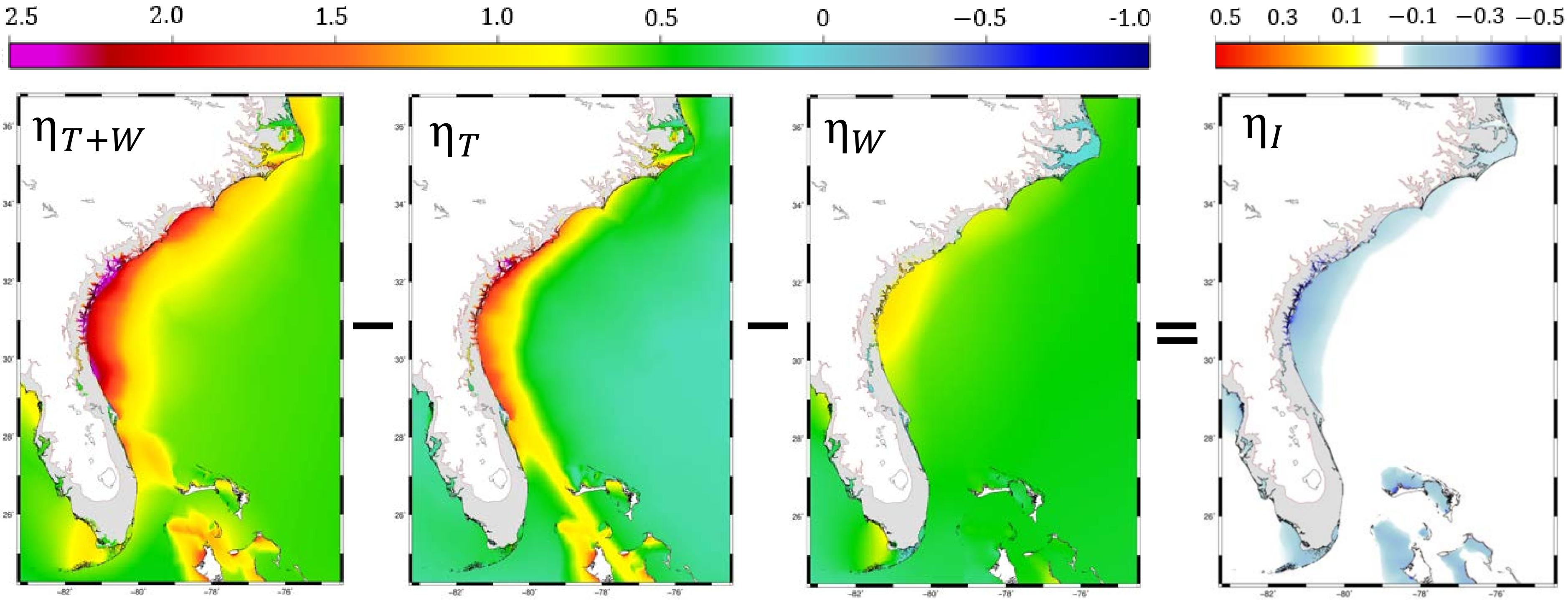
X Mom

①

$$\frac{\partial V}{\partial t}+\underbrace{U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}}_{②}+fU=-g\frac{\partial\left[\zeta+P_s/g\rho_o-\alpha\eta\right]}{\partial y}+\underbrace{\frac{\tau_{sy}}{H\rho_o}-\frac{\tau_{by}}{H\rho_o}+\frac{M_y}{H}-\frac{D_y}{H}-\frac{B_y}{H}}_{③}$$

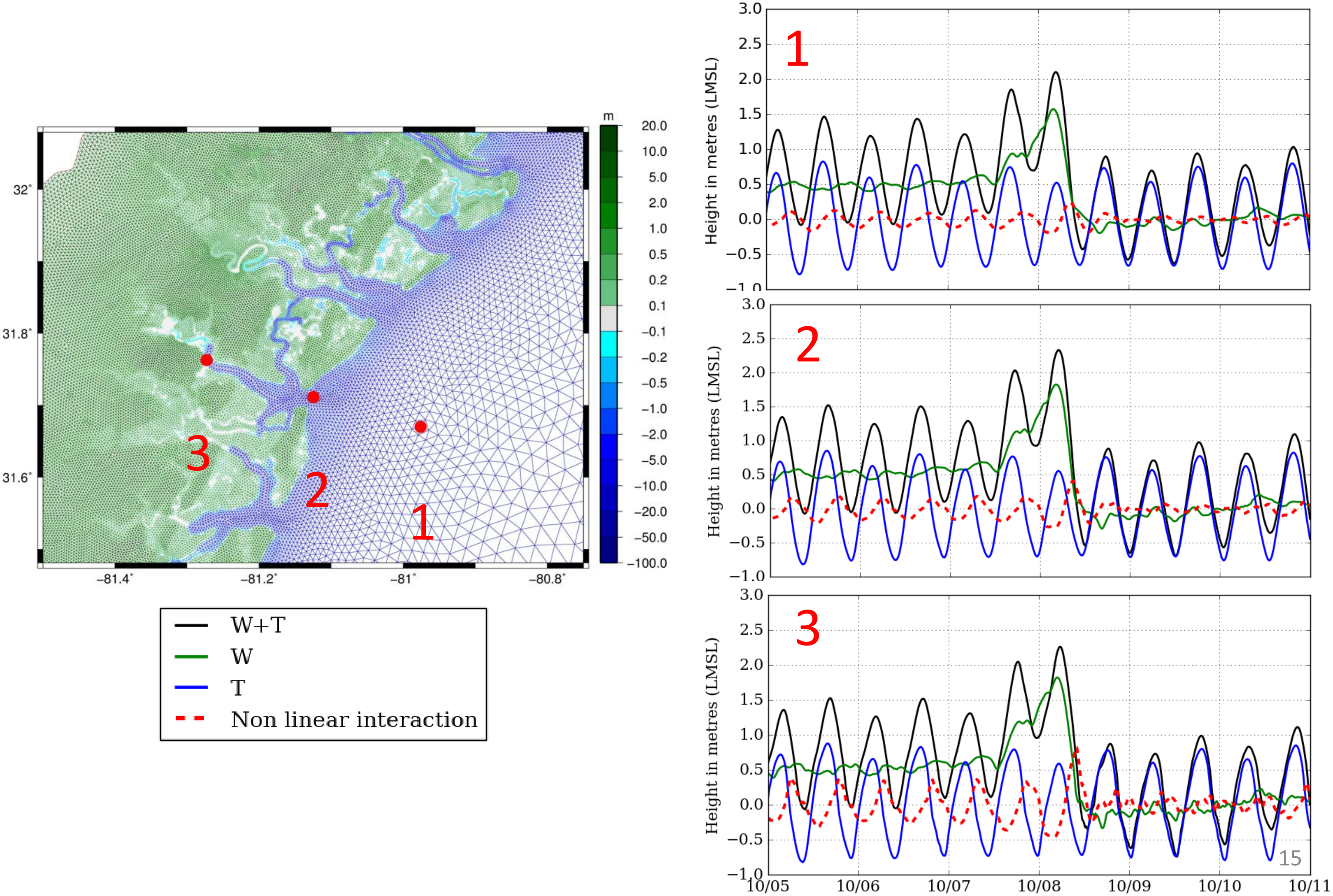
Y Mom

Non-Linear Interactions between Surge and Tides



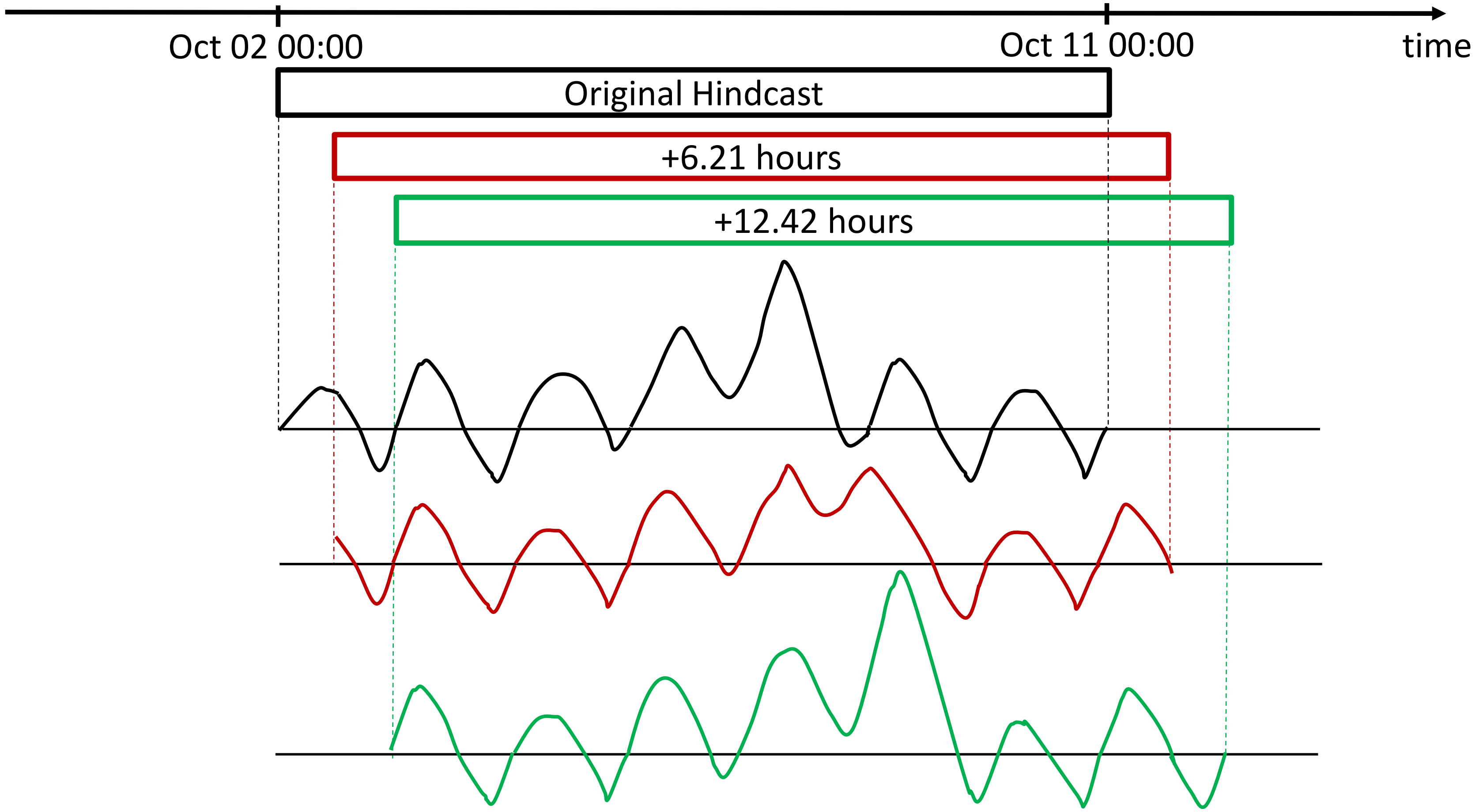
Maximum water levels (m)

Non-Linear Interactions between Surge and Tides

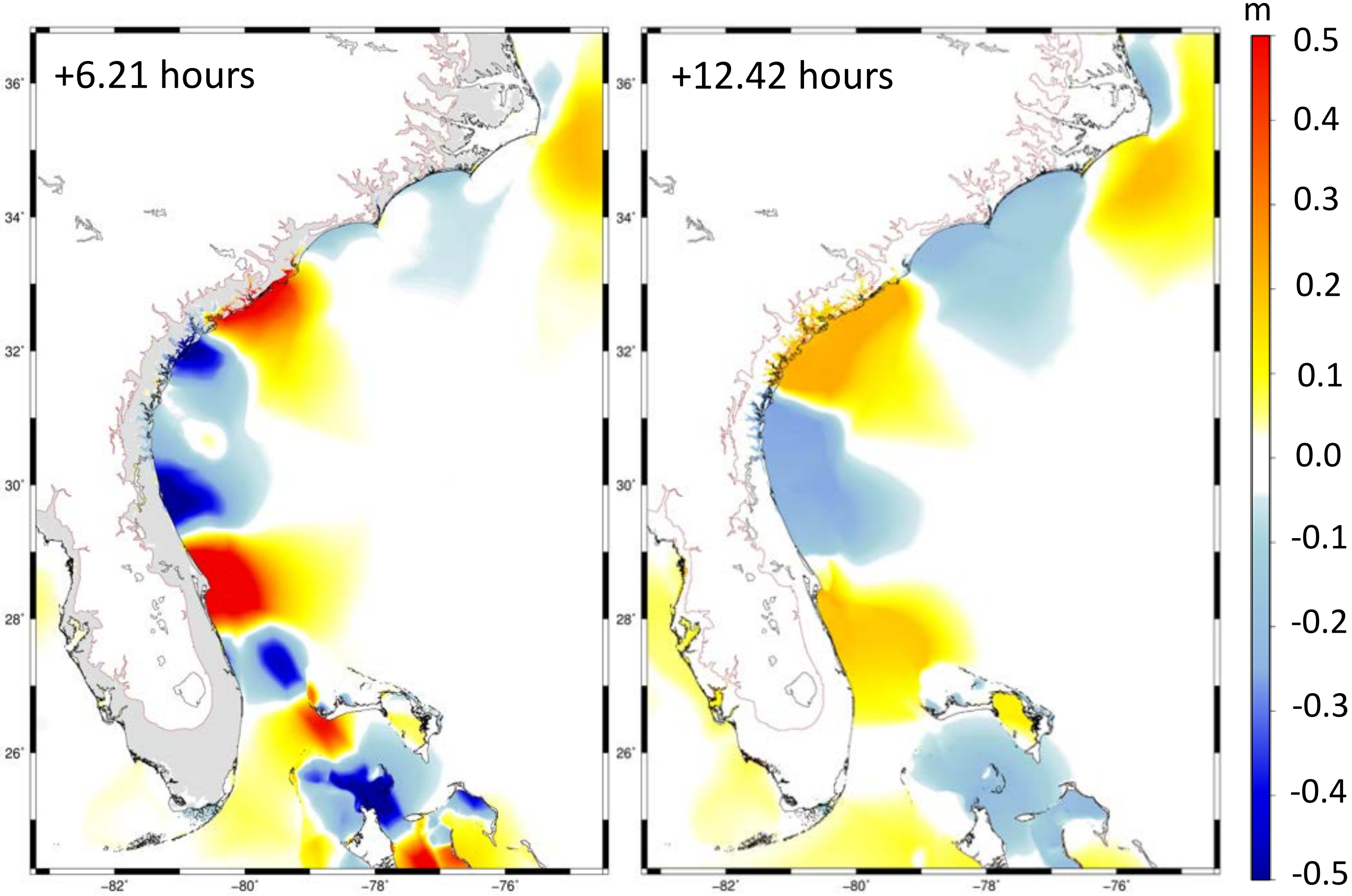


Variations in Timing

- Changing storm’s timing but keeping the speed constant
- ±6.21 hours and ±12.421 hours → advancing and delaying the storm by one-half and full M2 tidal constituent period

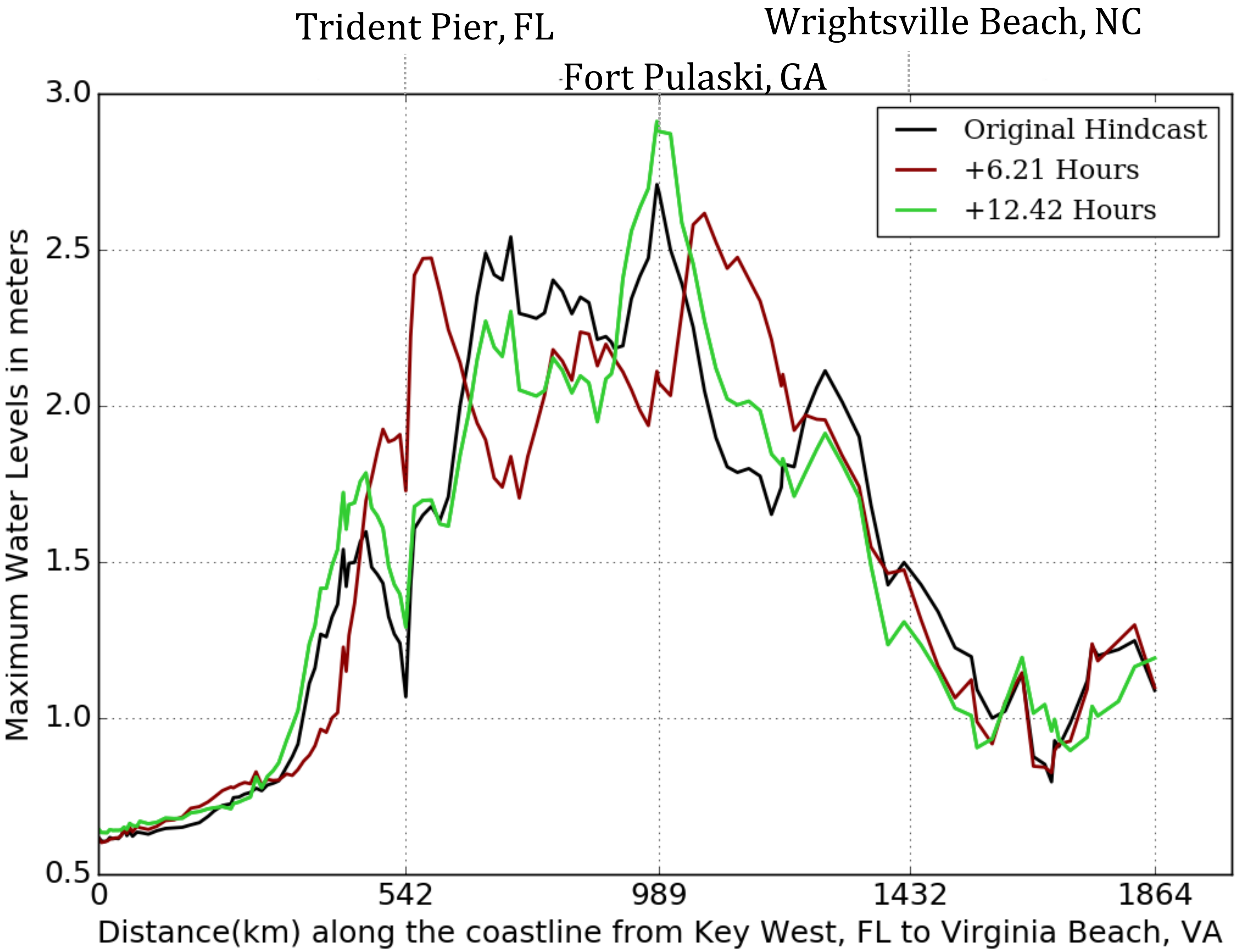


Variations in Timing



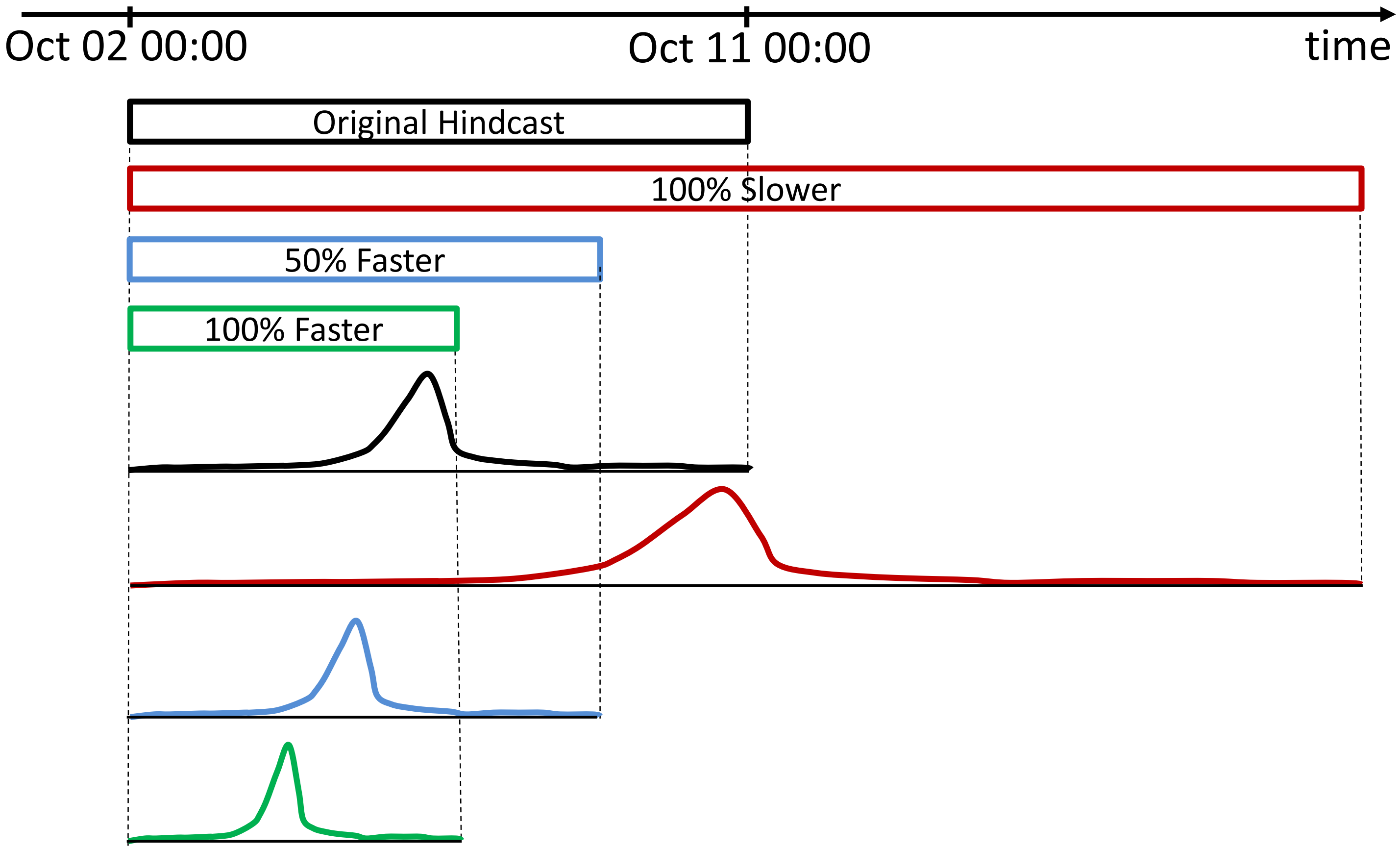
Change in maximum water levels

Variations in Timing

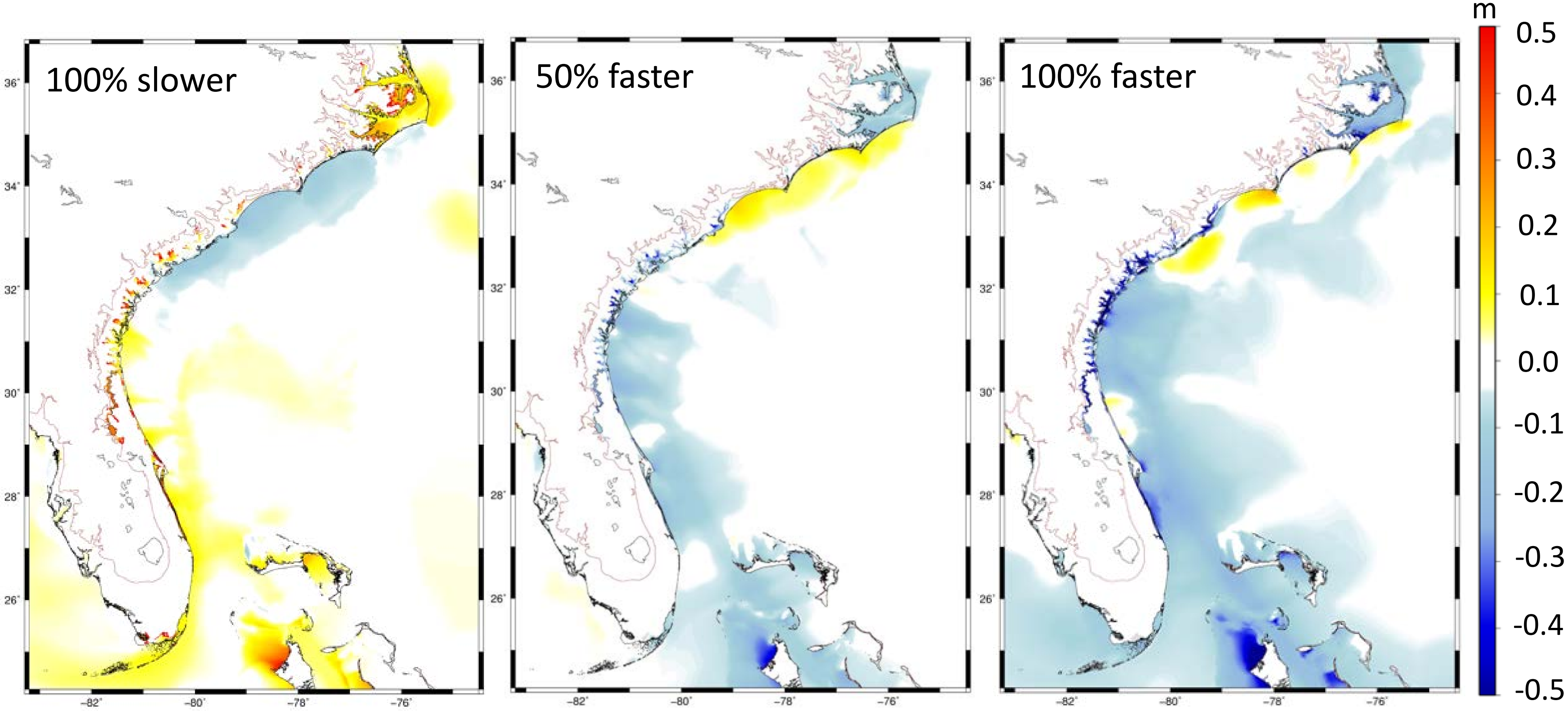


Variations in Forward Speed

- The forward speed of the storm was varied, keeping the tides off
- Blanton and Vickery (2008) - 2.9m/s, 7.2m/s and 10.5m/s
- Represent 100% slower, 50% faster and 100% faster simulations

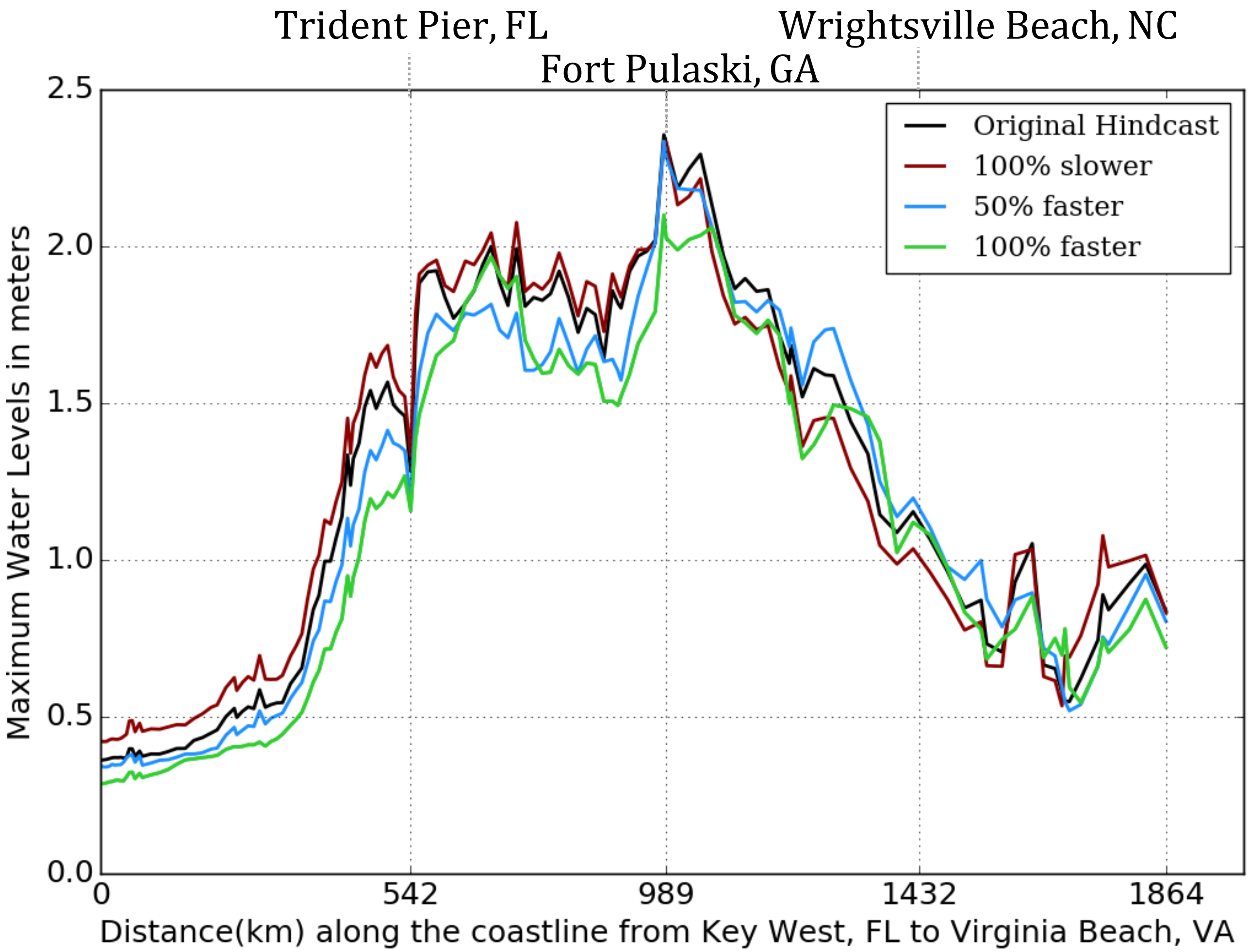


Variations in Forward Speed



Change in maximum water levels (no tides)

Variations in Forward Speed



Conclusions

Validation:

- HSOFS does **remarkably well**

Non-linear interactions:

- **Destructive** on a **high/rising tide** and **constructive** on a **low/falling tide**
- Negligible in the open ocean, increases landward, highest values (even **more than 1m**) occurs high up in the estuaries

Changes in timing:

- **Large differences** in water levels occurred due to the storm coinciding with different periods in the tidal cycles

Changes in speed:

- Inundation was seen to be **inversely** related to the storm speed

Thank You!