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

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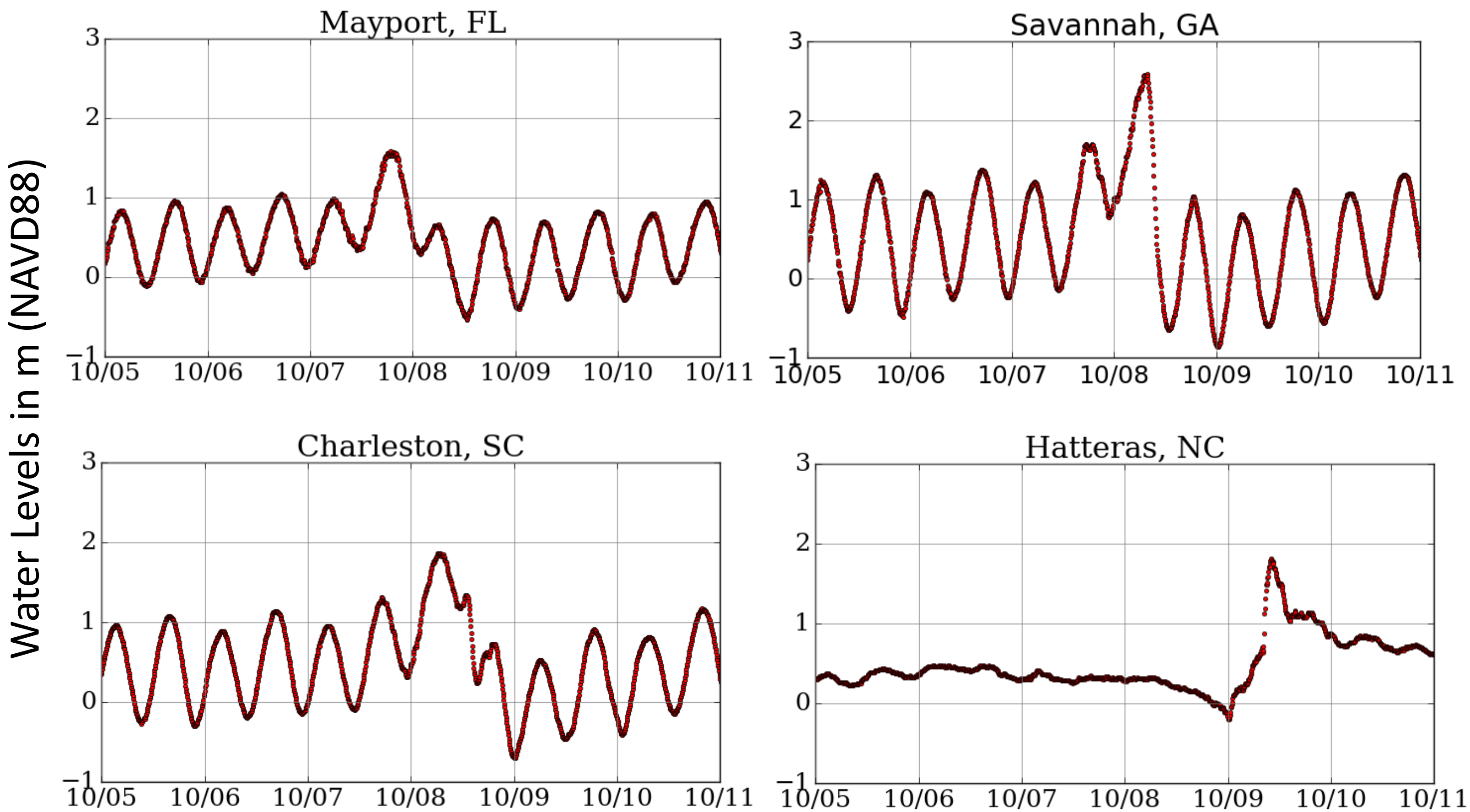
Introduction

- 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

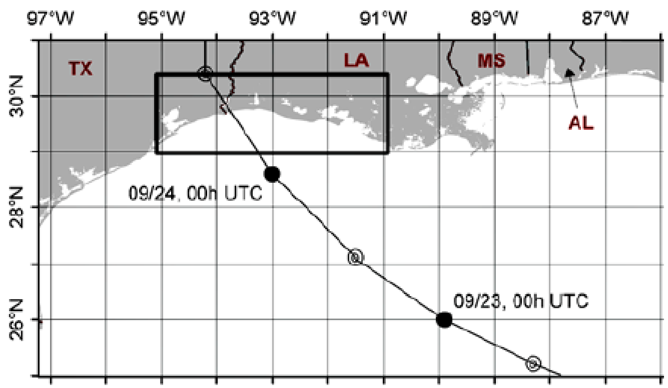


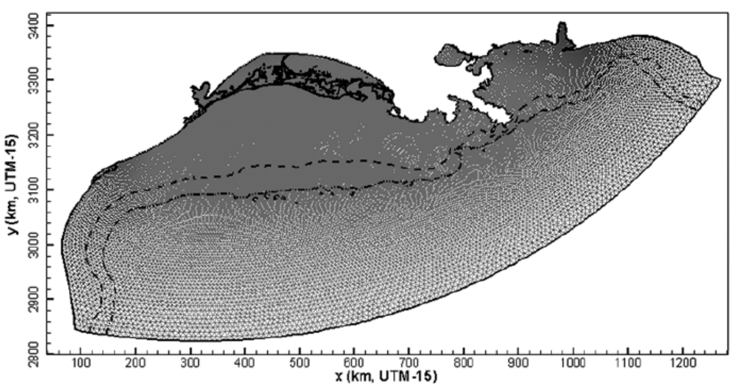
Observations at selected stations (South to North)

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



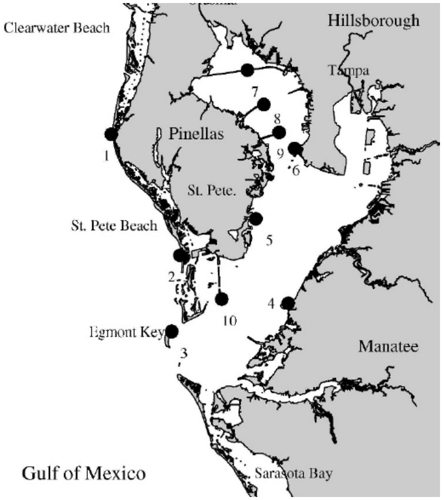


- **Common Limitation** - Shore-normal track, small extent of coastline
- **Remaining Questions**
  - How does a shore-parallel track affect tide-surge interactions over a large coastline?
  - What are the magnitude of these terms on the U.S. south-east coast?
  - What if the storm interacts with multiple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

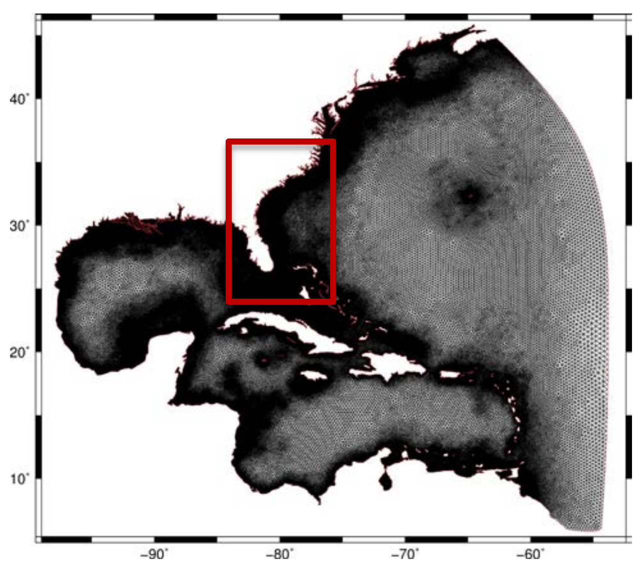
Objective #1: Validate winds, waves, and water levels during Matthew on a mesh with floodplains coverage over a large extent

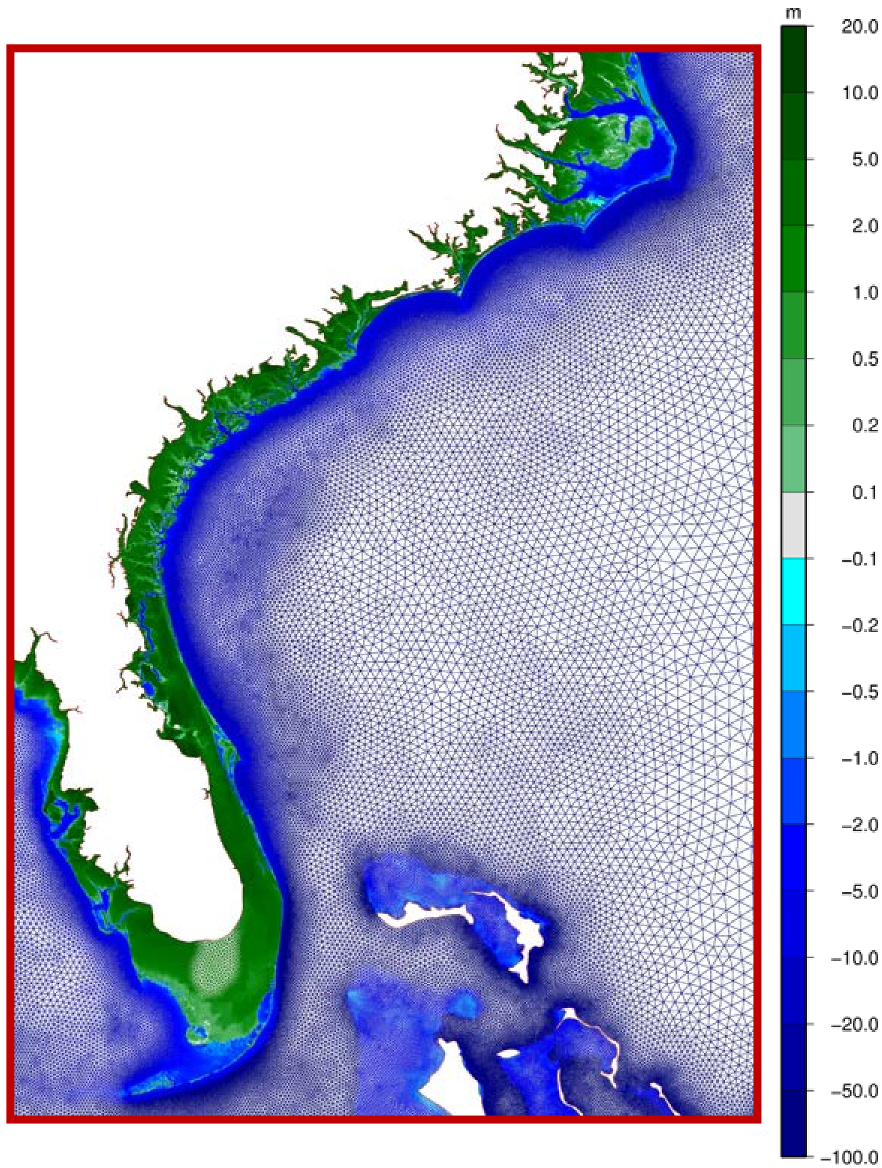
Objective #2: Quantify the contributions of nonlinear interactions to the total water levels

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

Methods

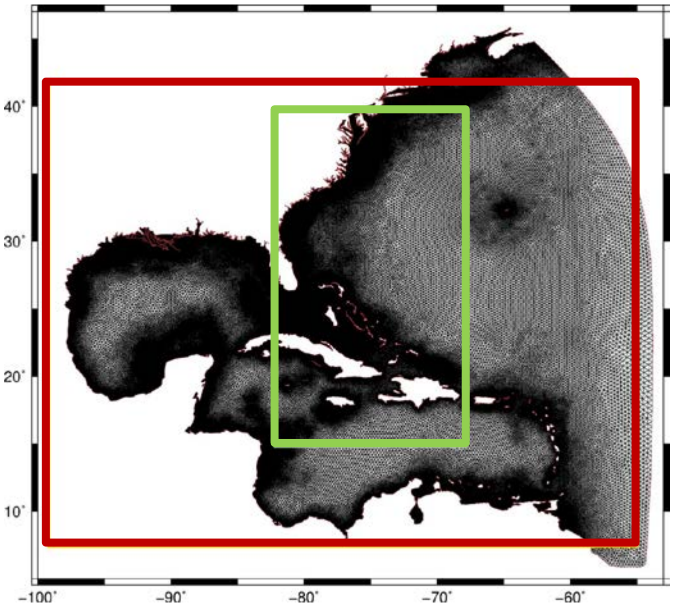
- Coupled ADCIRC + SWAN model
- The HSOFS unstructured mesh
  - Riverside, AECOM & NOAA - 2015
  - 500m average coastal resolution
  - 1.8 million vertices





Methods

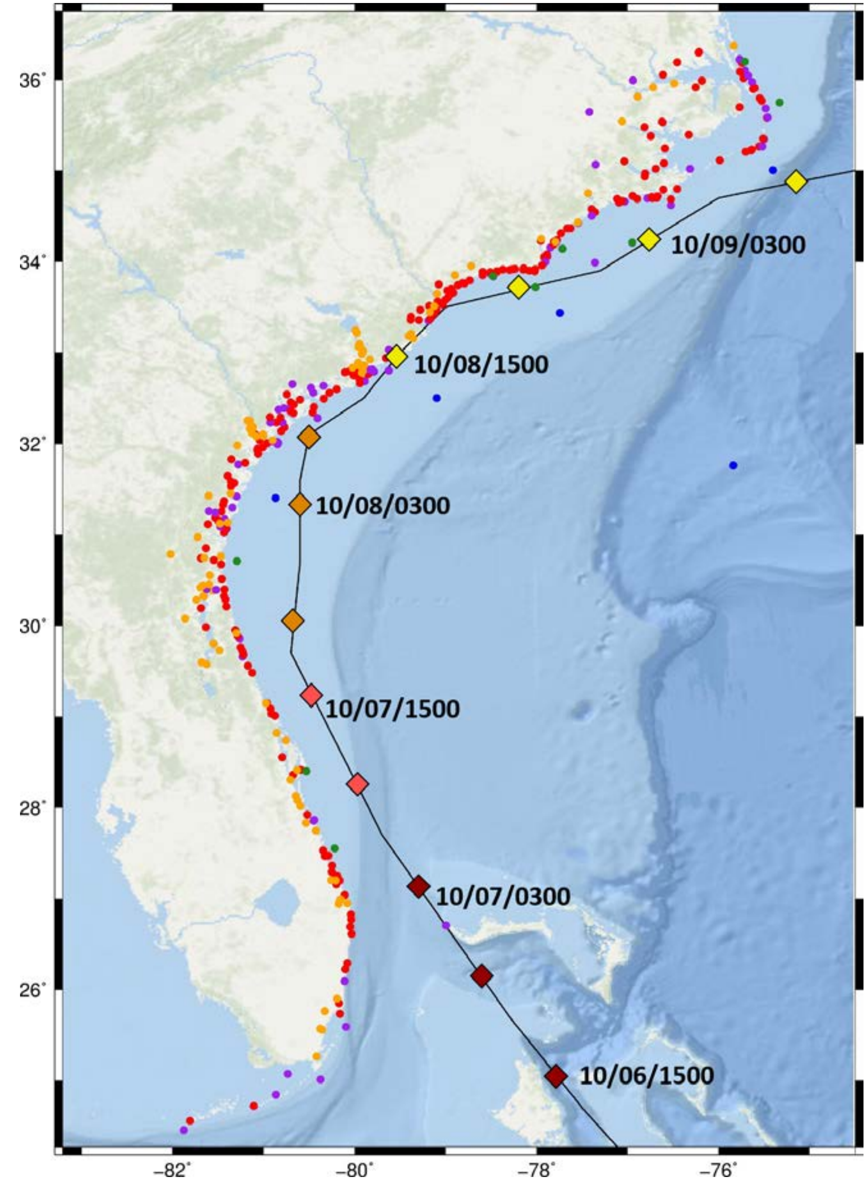
- Winds from OWI
  - Data-assimilated fields
  - Basin grid at resolution of 1/4°
  - Region grid at resolution of 1/20°



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**

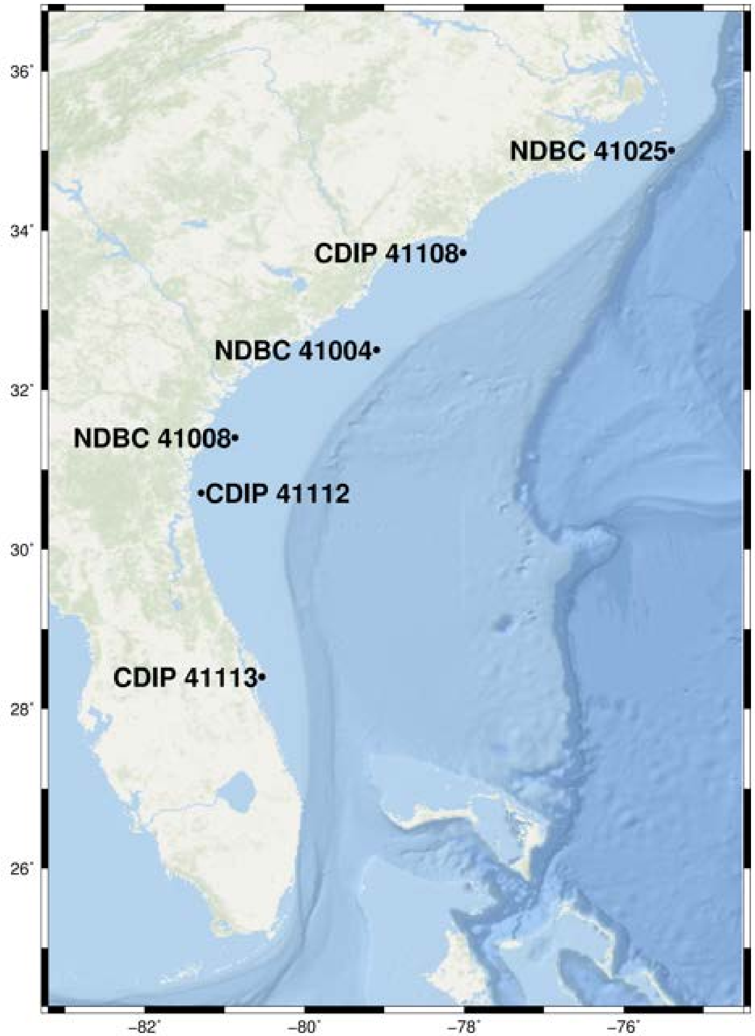
Model Validation – Observations

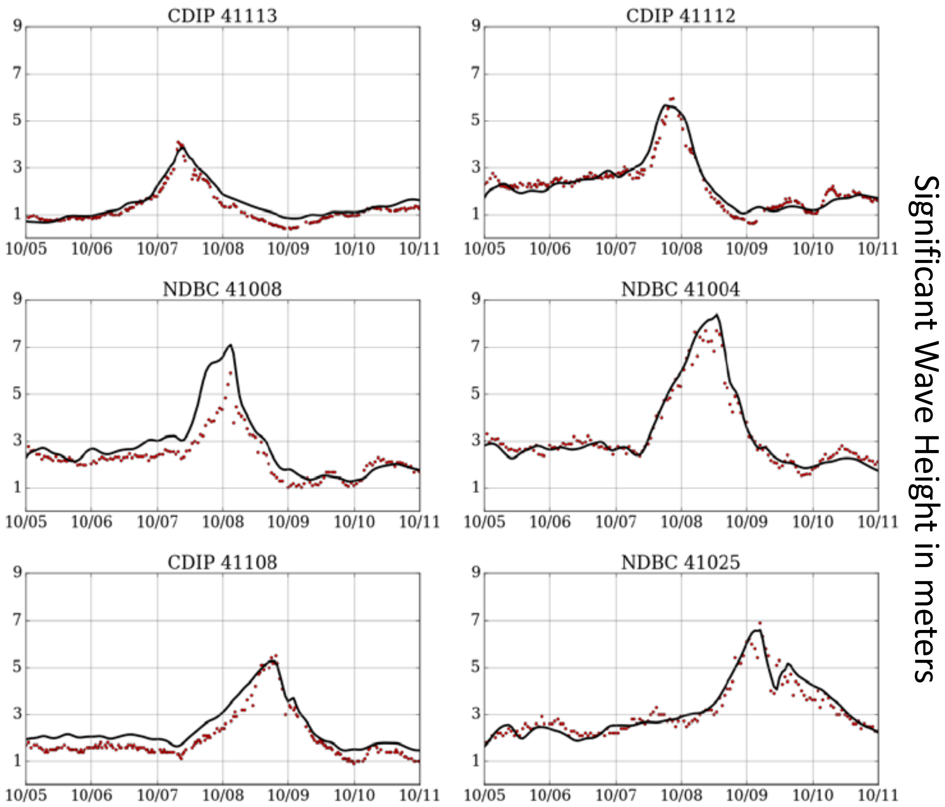
Symbol	Saffir-Simpson Category	Wind Speed (ms^{-1})
◆ (dark red)	4	59-69
◆ (light red)	3	50-58
◆ (orange)	2	43-49
◆ (yellow)	1	33-42



Symbol	Data Available
● (orange)	WL
● (red)	WL + MET
● (purple)	MET
● (blue)	MET + WH
● (green)	WH

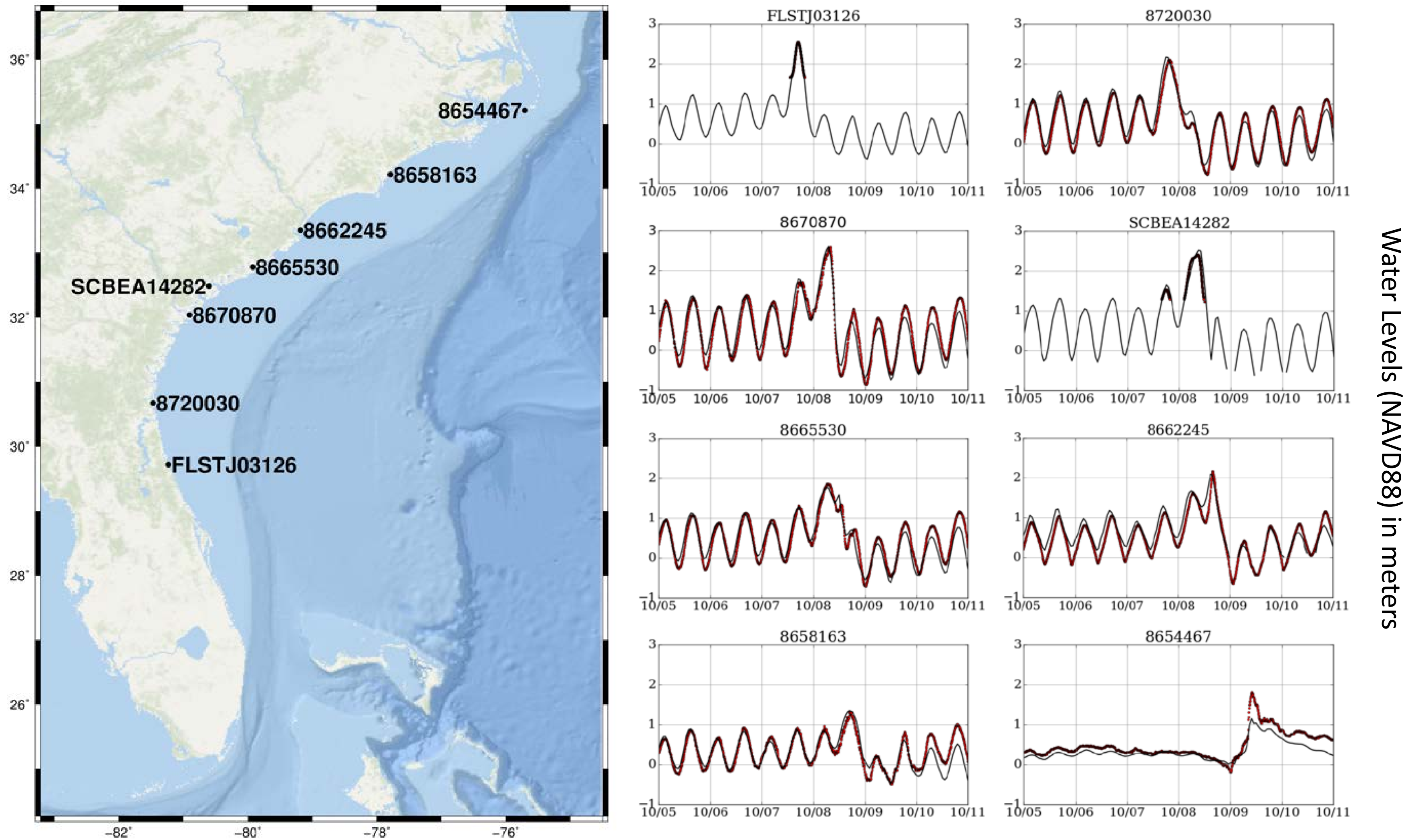
Model Validation – Waves





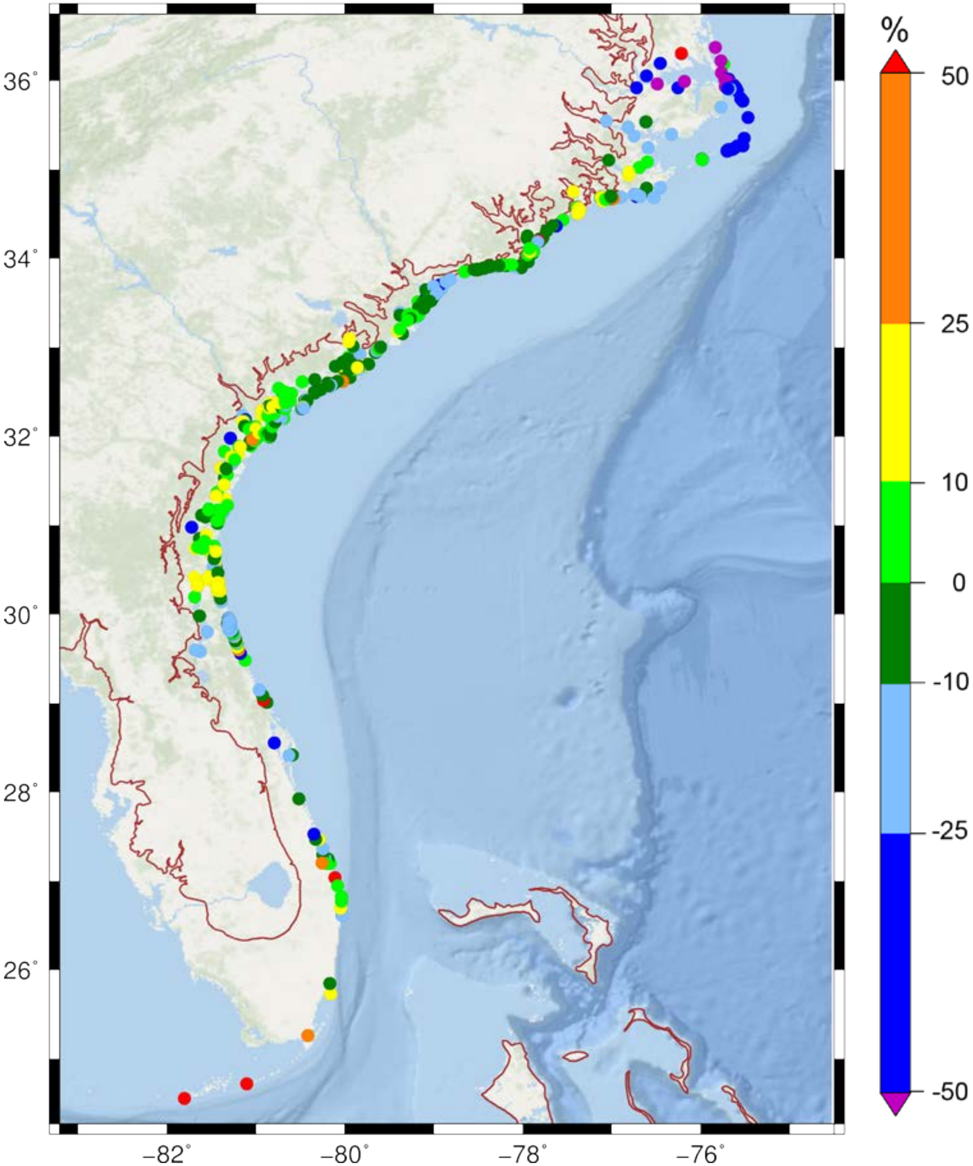
16 stations, RMSE of 0.46m, Bias of 0.11

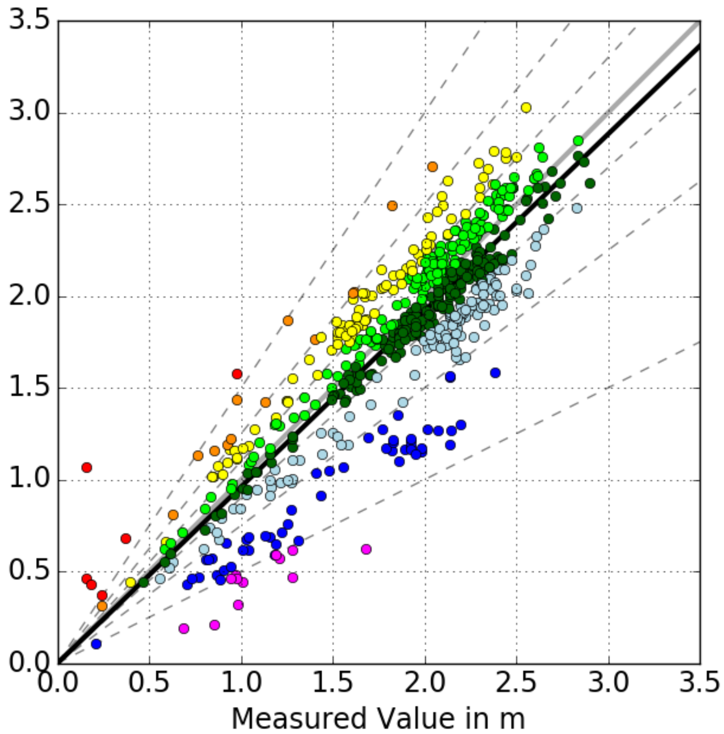
Model Validation – Water Levels



241 stations, RMSE of 0.28m, Bias of 0.04

Model Validation – High Water Marks





622 peaks
$R^2 = 0.78$
RMSE = 0.28m
Bias = -0.03
Best fit slope = 0.96

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

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

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

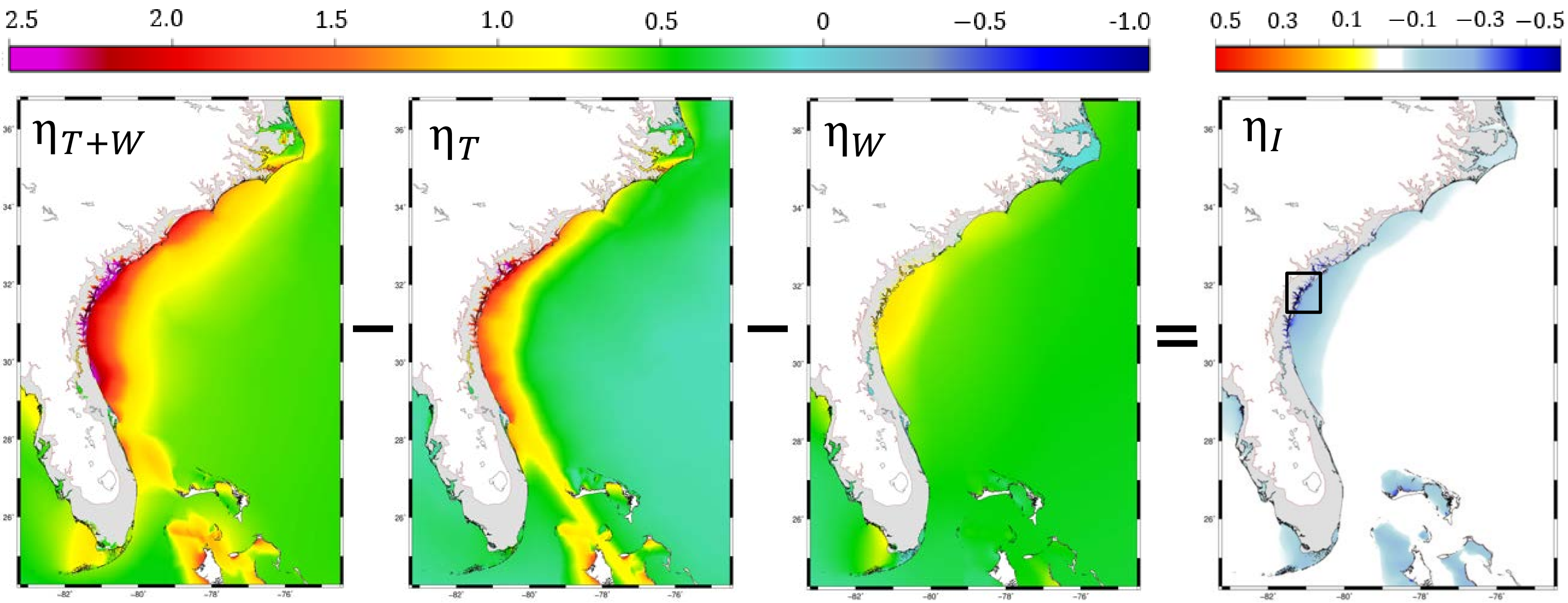
X Mom

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

Y Mom

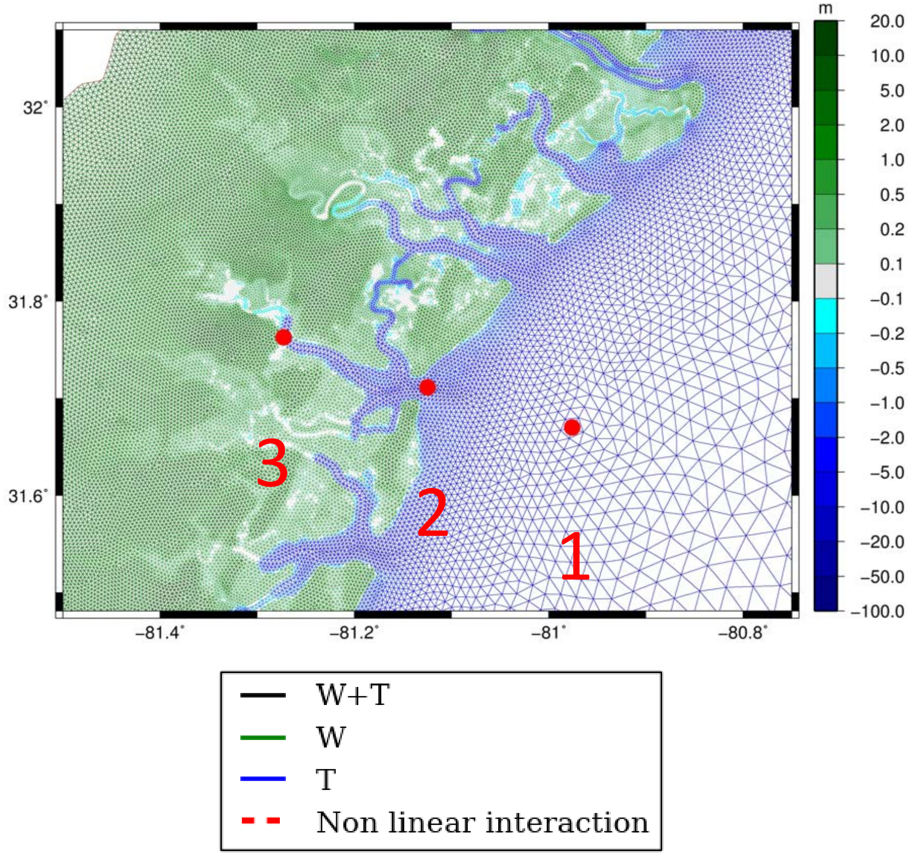
1

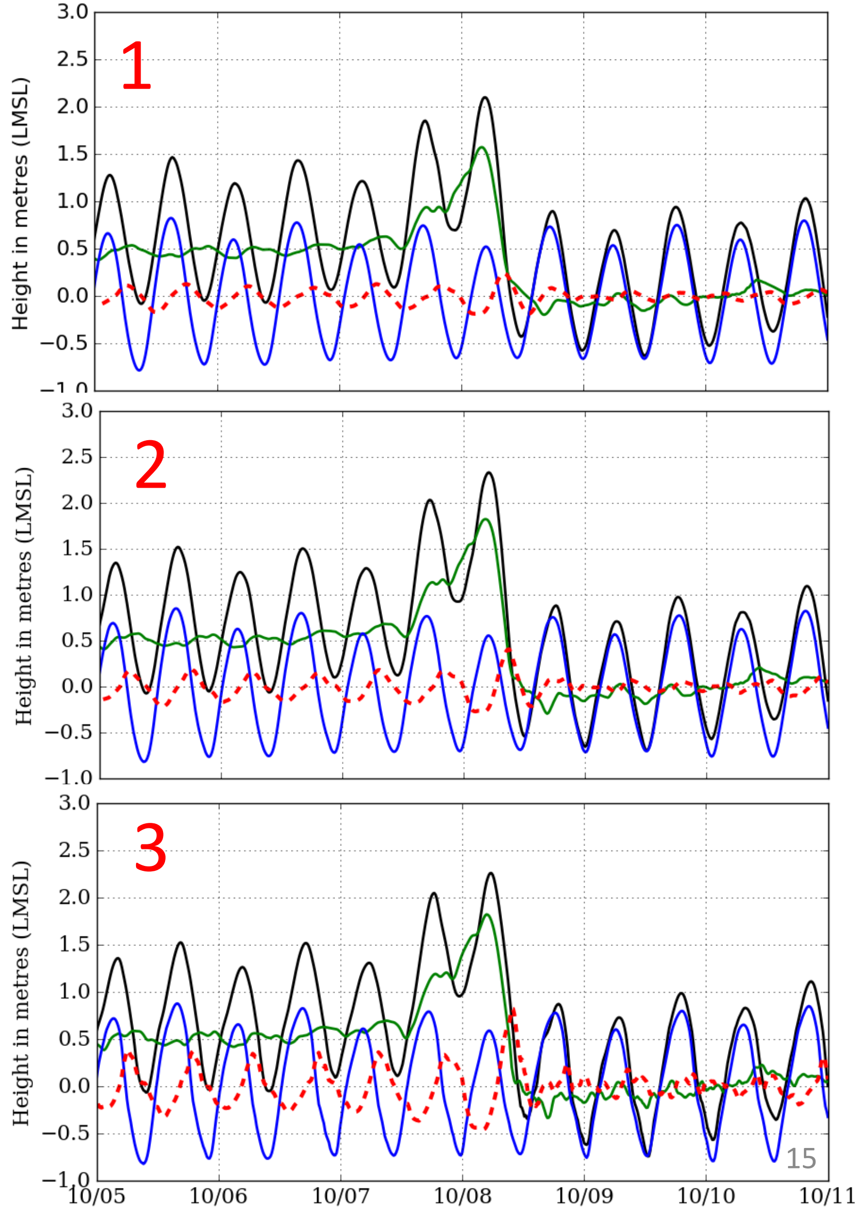
Non-Linear Interactions between Surge and Tides



Maximum water levels (m)

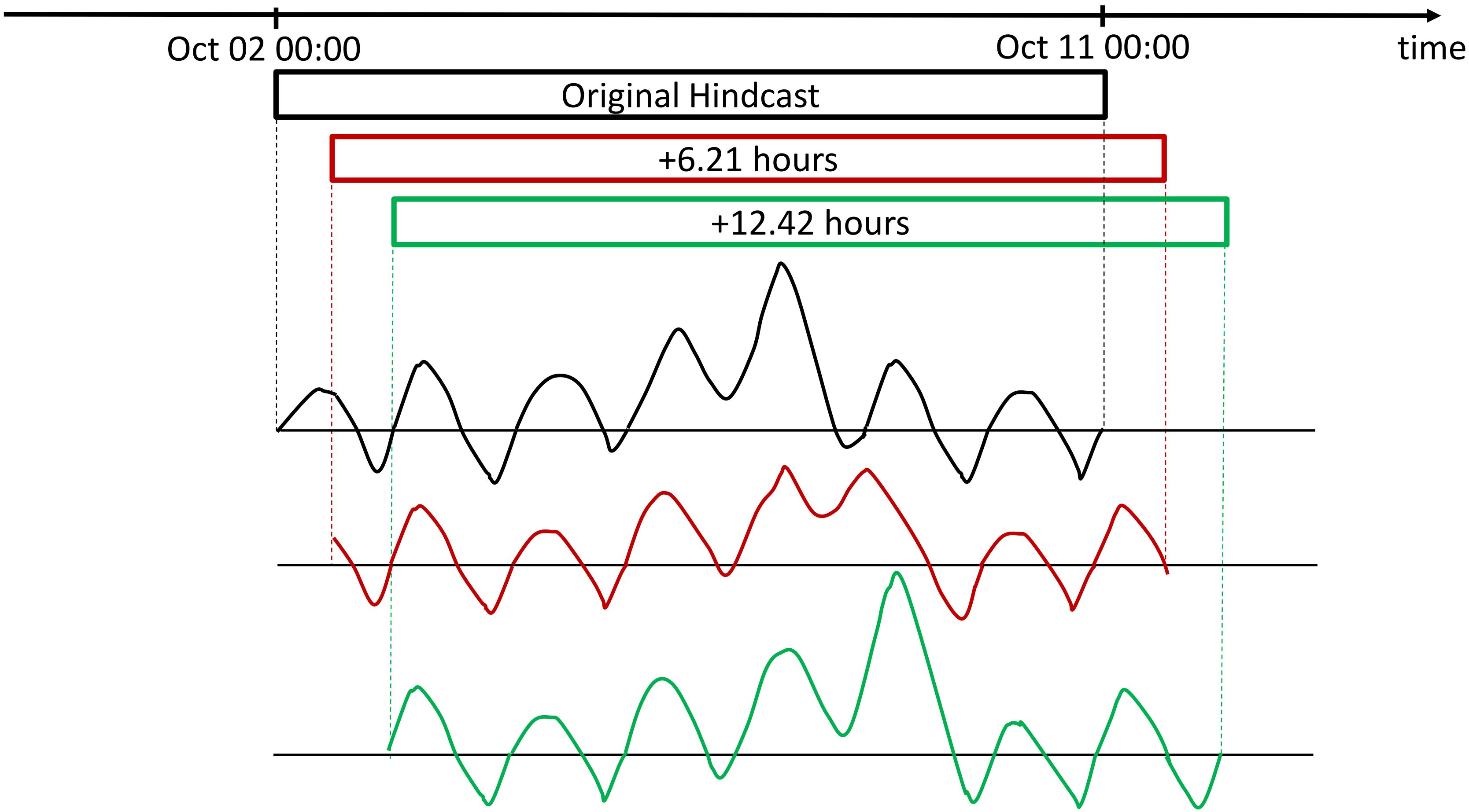
Non-Linear Interactions between Surge and Tides



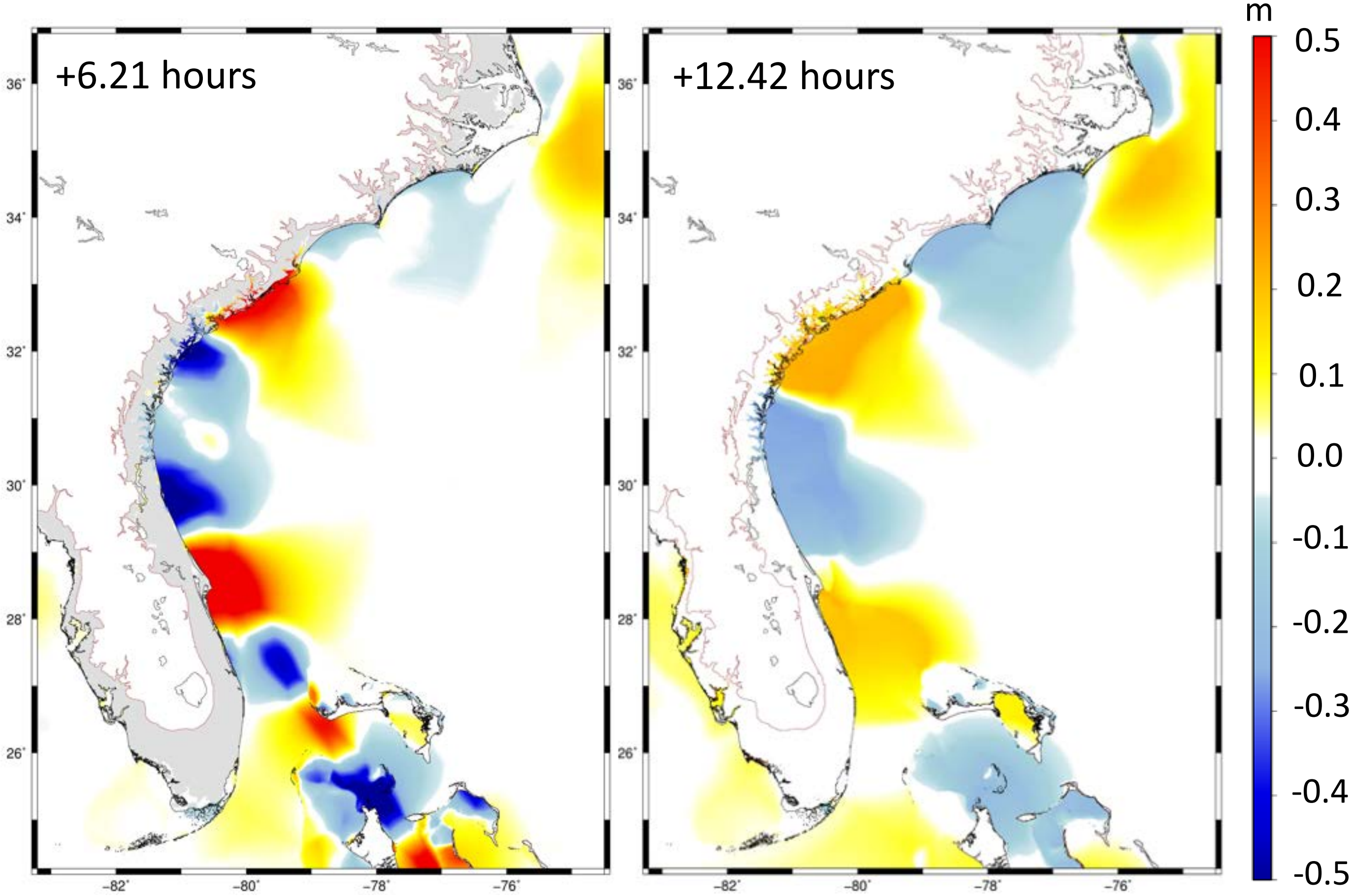


Variations in Timing

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

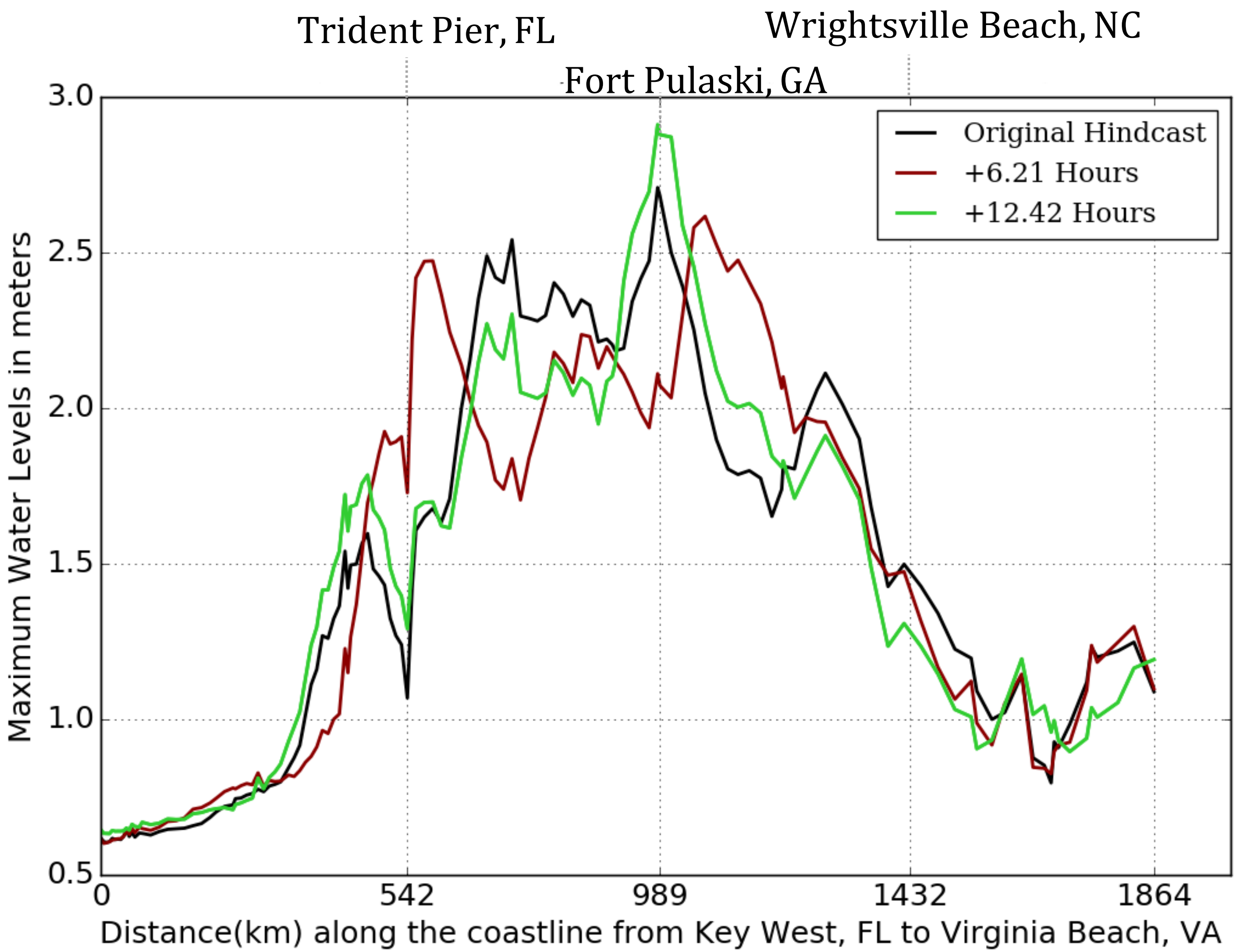


Variations in Timing



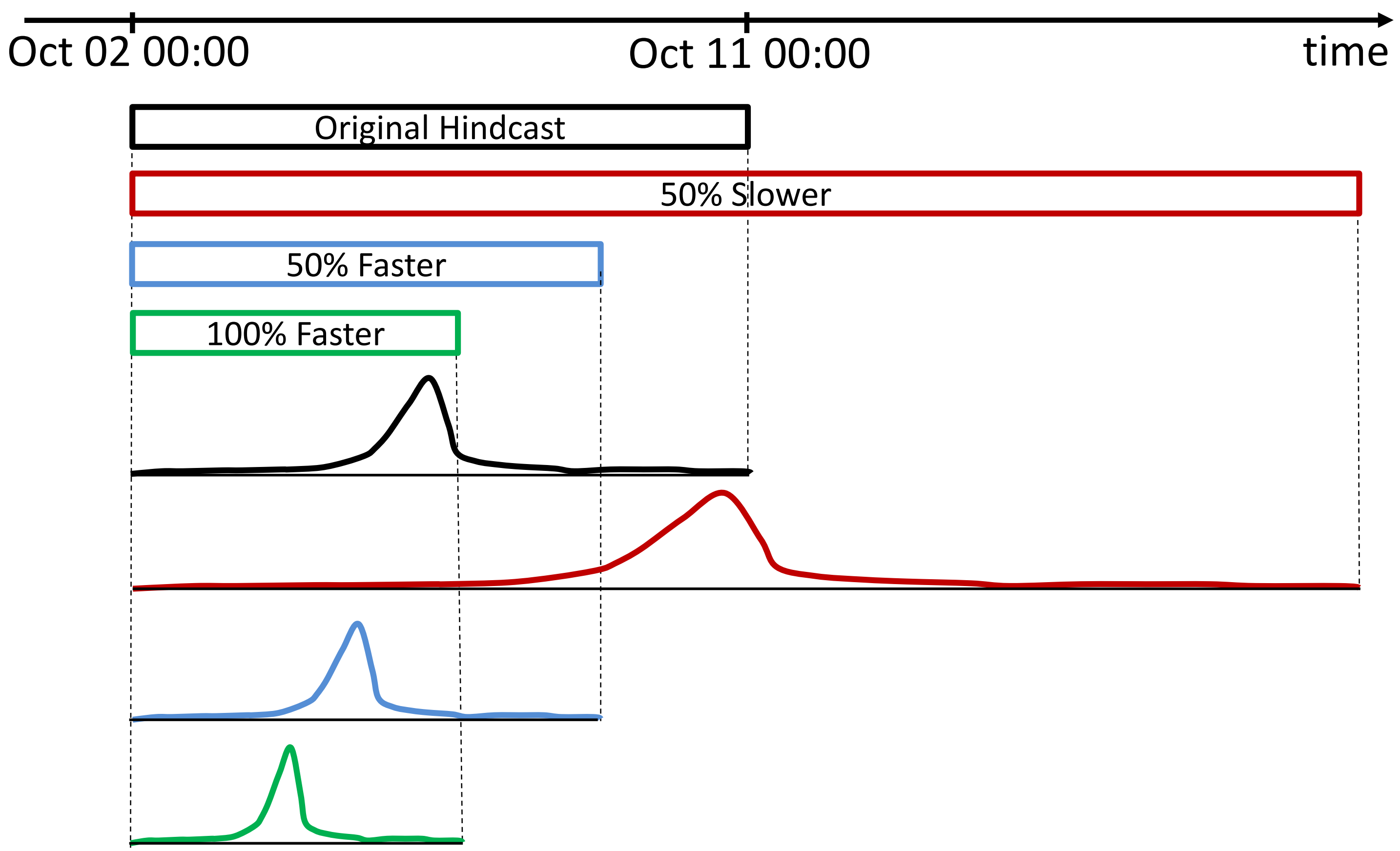
Change in maximum water levels

Variations in Timing

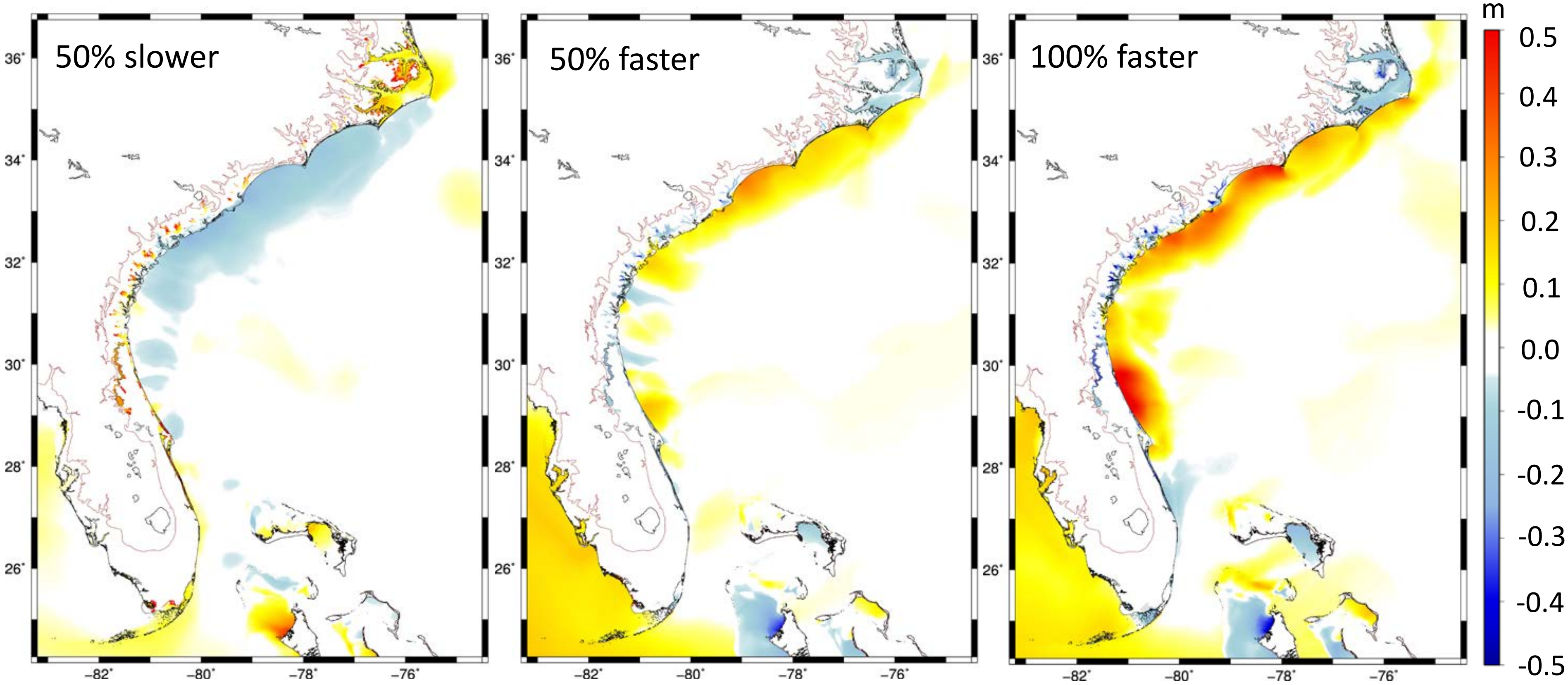


Variations in Forward Speed

- 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 50% slower, 50% faster and 100% faster simulations

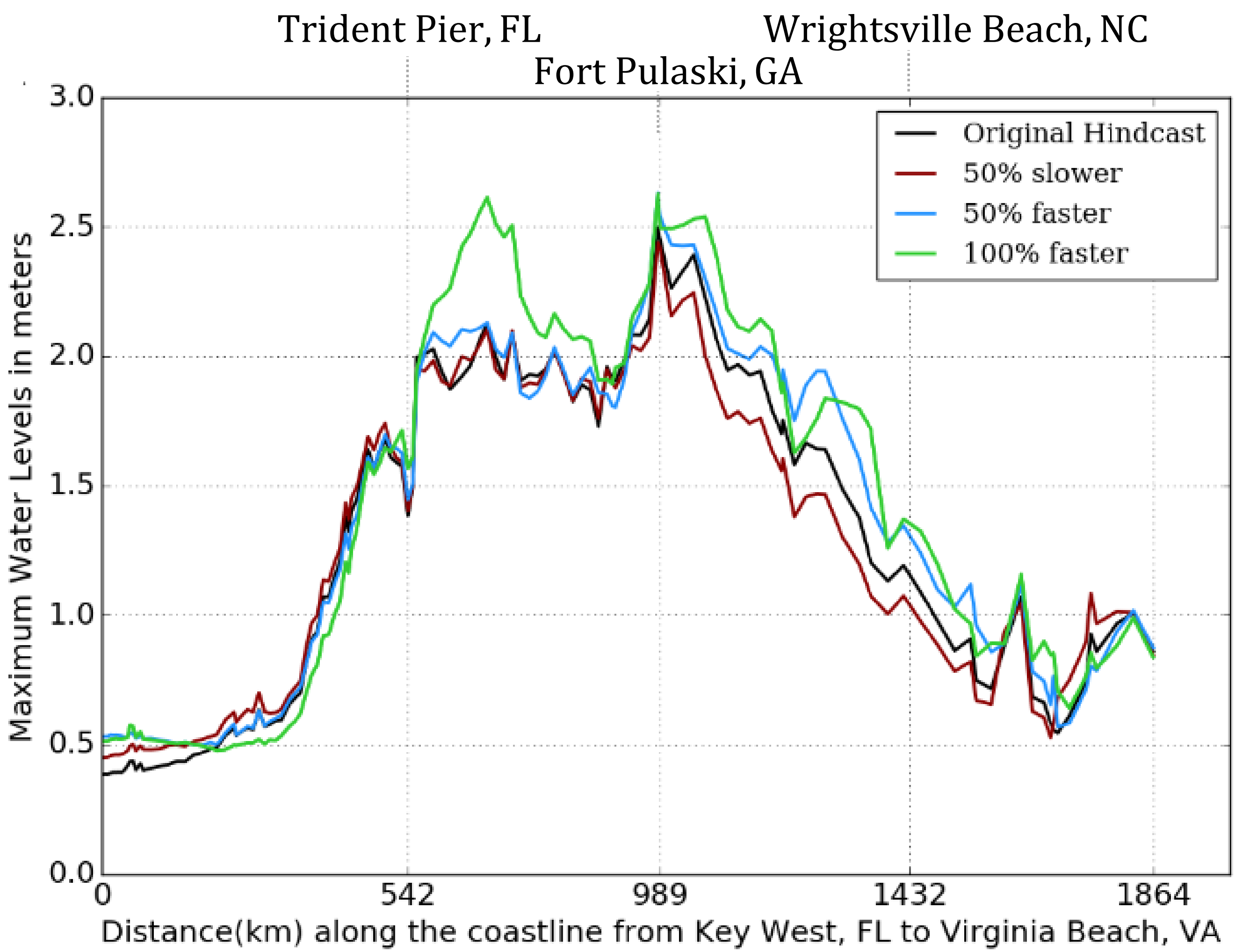


Variations in Forward Speed



Change in maximum water levels (no tides)

Variations in Forward Speed



Conclusions

Validation:

- Matthew's effects are well represented by the model even when applied on the relatively-coarse HSOFS mesh

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:

- Faster storm produced higher surges on the open coast whereas the slower storm produced more flooding in the bays and estuaries

Thank You!