ODU Climate Change and Sea Level Rise Initiative

10th IWMO-2018
Santos, Brazil
25-28 June 2018

Numerical modeling of the interactions between hurricanes, the Gulf Stream and coastal sea level

Tal Ezer
Center for Coastal Physical Oceanography (CCPO)
Department of Ocean, Earth and Atmospheric Sciences (OEAS)
Old Dominion University, Norfolk, VA, USA

Motivation: “clear day” flooding with no storm in the area.
Could this be due to remote influence from the Gulf Stream?

The role of the Gulf Stream in sea level rise received special attention in recent years

October 2014

CHESAPEAKE QUARTERLY

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Home > CQ Issues > Current Issue October 2014 > What's Happening to the Gulf Stream?

THE RISING: *Why Sea Level Is Increasing*

What's Happening to the Gulf Stream?

The great offshore current could be increasing sea level on the Chesapeake Bay, but not all scientists are convinced

Daniel Strain

March 2018

The Virginian-Pilot

Sunday

Our 152nd year | 03.18.18 | PILOTONLINE.

The Gulf Stream: A "wild card" for sea level rise

SCIENTISTS MONITOR the current for signs of long-term weakening. They've noticed that when it slows, even temporarily, coastal flood risk rises.

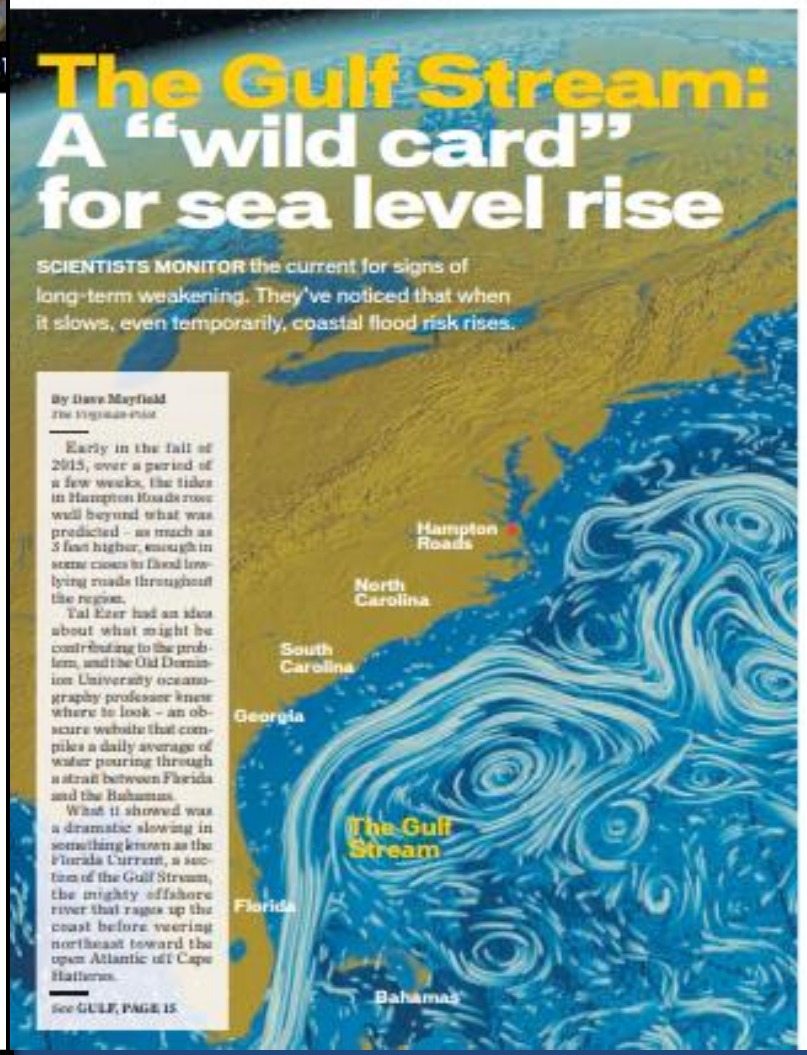
By Dave Mayfield
The Virginian-Pilot

Early in the fall of 2015, over a period of a few weeks, the tides in Hampton Roads rose well beyond what was predicted – as much as 3 feet higher, enough in some cases to flood low-lying roads throughout the region.

Tal Ezer had an idea about what might be contributing to the problem, and the Old Dominion University oceanography professor knew where to look – an obscure website that compiles a daily average of water pouring through a strait between Florida and the Bahamas.

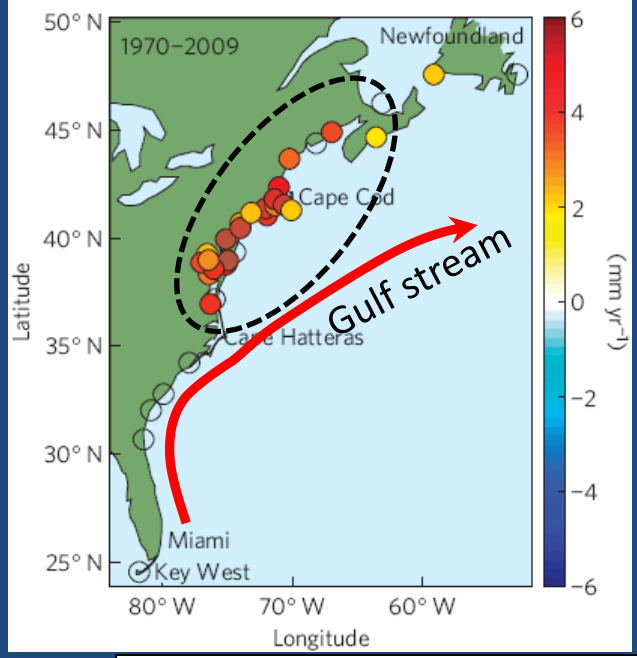
What it showed was a dramatic slowing in something known as the Florida Current, a section of the Gulf Stream, the mighty offshore river that rages up the coast before veering northeast toward the open Atlantic off Cape Hatteras.

See GULF, PAGE 15



Impact of ocean dynamics on sea level rise:

Research triggered by 3 separate studies (2012) that indicate a "**hotspot of accelerated SLR**" in the mid-Atlantic coast north of Cape Hatteras.



nature climate change

LETTERS

PUBLISHED ONLINE: 24 JUNE 2012 | DOI: 10.1038/NCLIMATE1597

Hotspot of accelerated sea-level rise on the Atlantic coast of North America

Asbury H. Sallenger Jr*, Kara S. Doran and Peter A. Howd

USGS

(Method: linear trends over different periods)

Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America

John D. Boon

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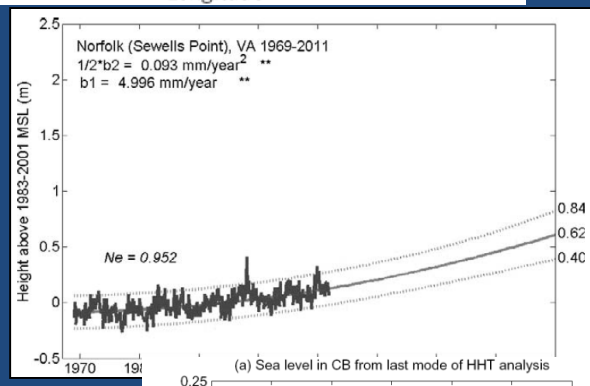
boon@vims.edu

www.cerf-jcr.org

J. Coastal Res. 2012

VIMS



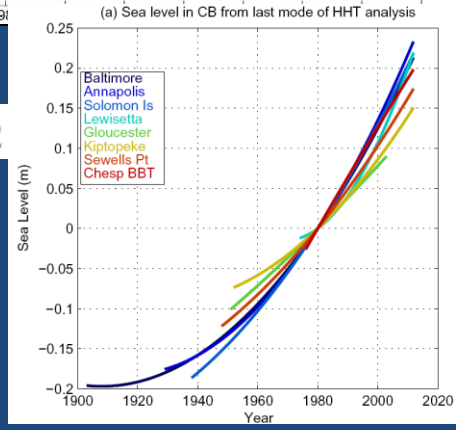
(Method: quadratic line fit)

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L19605, doi:10.1029/2012GL053435, 2012

Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach for analyzing sea level data

Tal Ezer[1] and William Bryce Corlett[1,2]

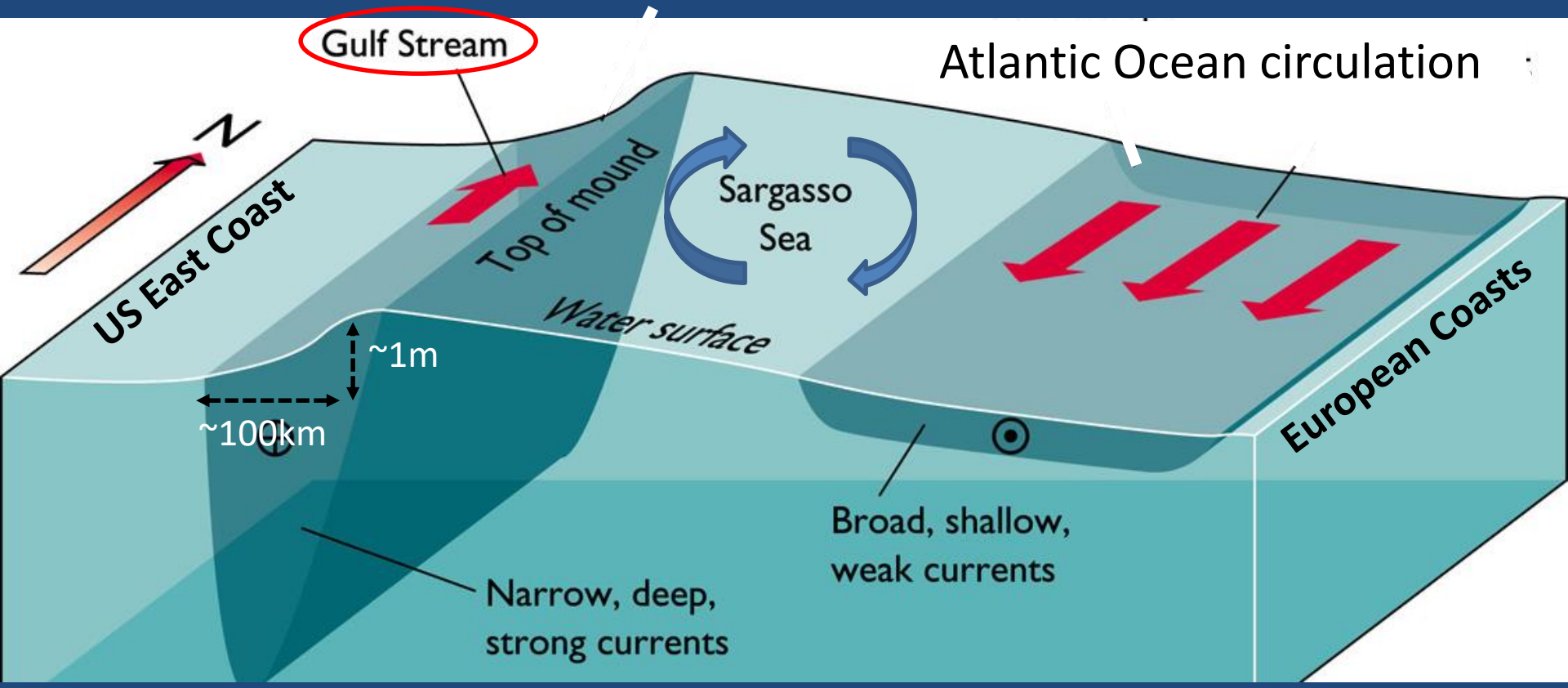
ODU



(Method: non-linear Empirical Mode Decomposition)

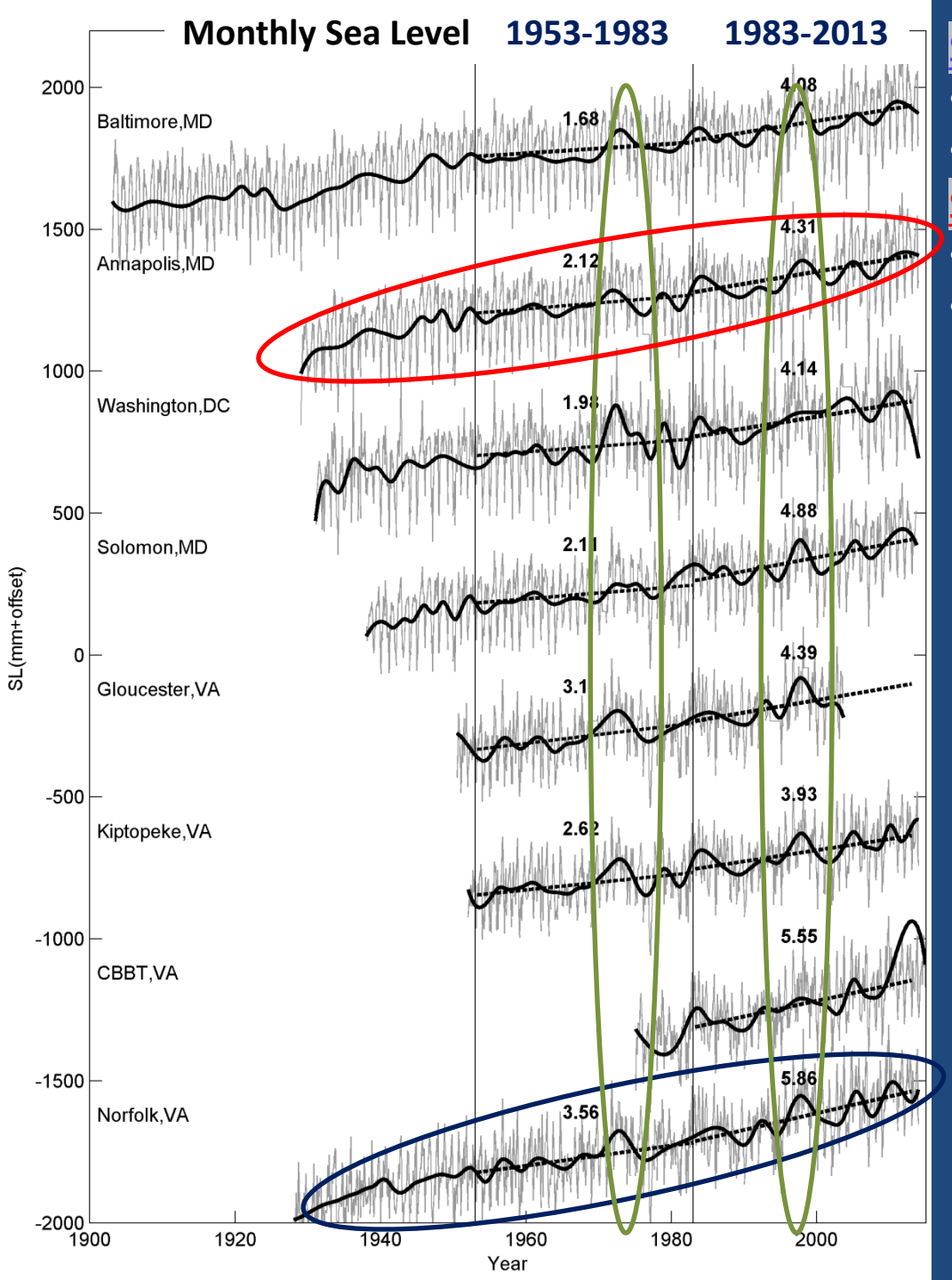
How can ocean dynamics affect coastal sea level?

Sea level is not level: ocean currents → sea level slope (Geostrophic balance)



The Gulf Stream keeps sea level on the US East Coast ~1-1.5 m (3-5 feet) lower than water offshore.

In warmer climate the Atlantic Ocean circulation is expected to weaken
If the Gulf Stream slows down → coastal sea level would rise!!!



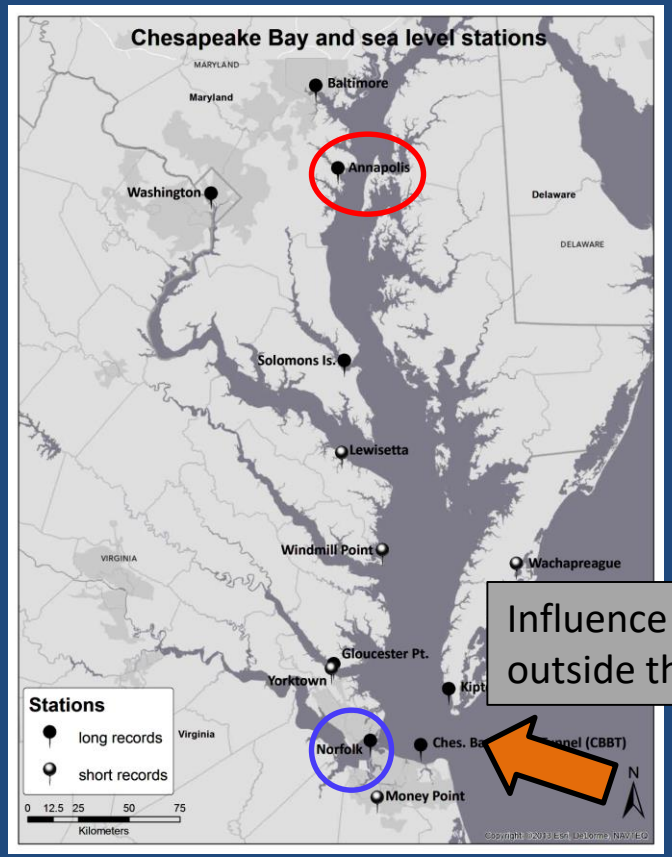
SLR in Norfolk:

- ~**3.5 mm/y** (1950s-80s) ~1.1 ft/century
- ~**6 mm/y** (1980s-today) ~1.9 ft/cen

SLR in Annapolis:

- ~**2.1 mm/y** (1950s-80s) ~0.7 ft/cen
- ~**4.3 mm/y** (1980s-today) ~1.4 ft/cen

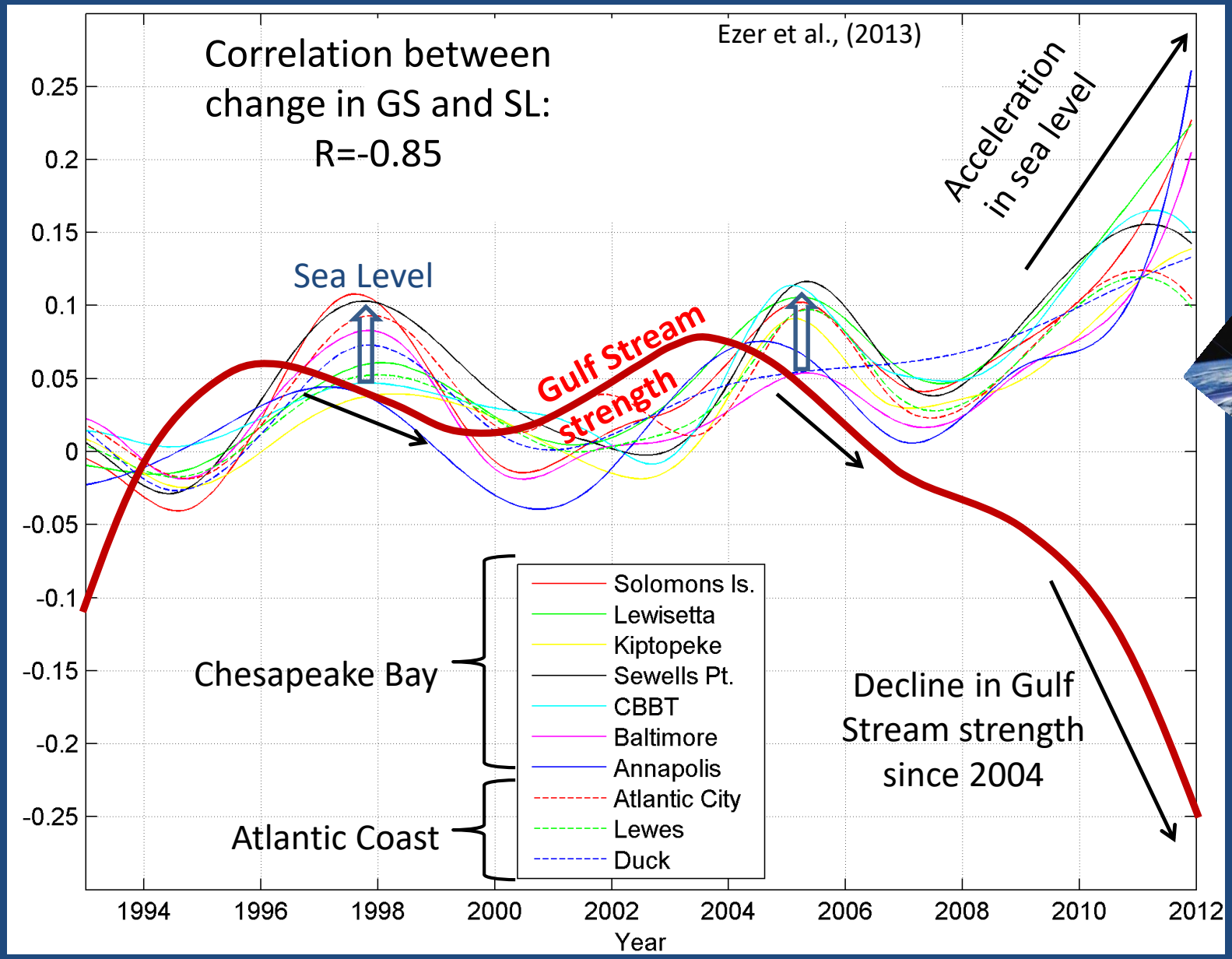
why in some years sea level is higher than normal everywhere? (more floods!)

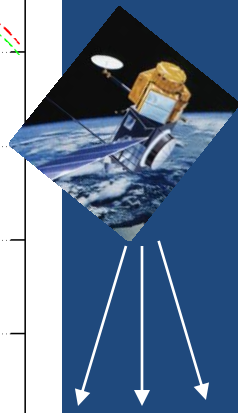


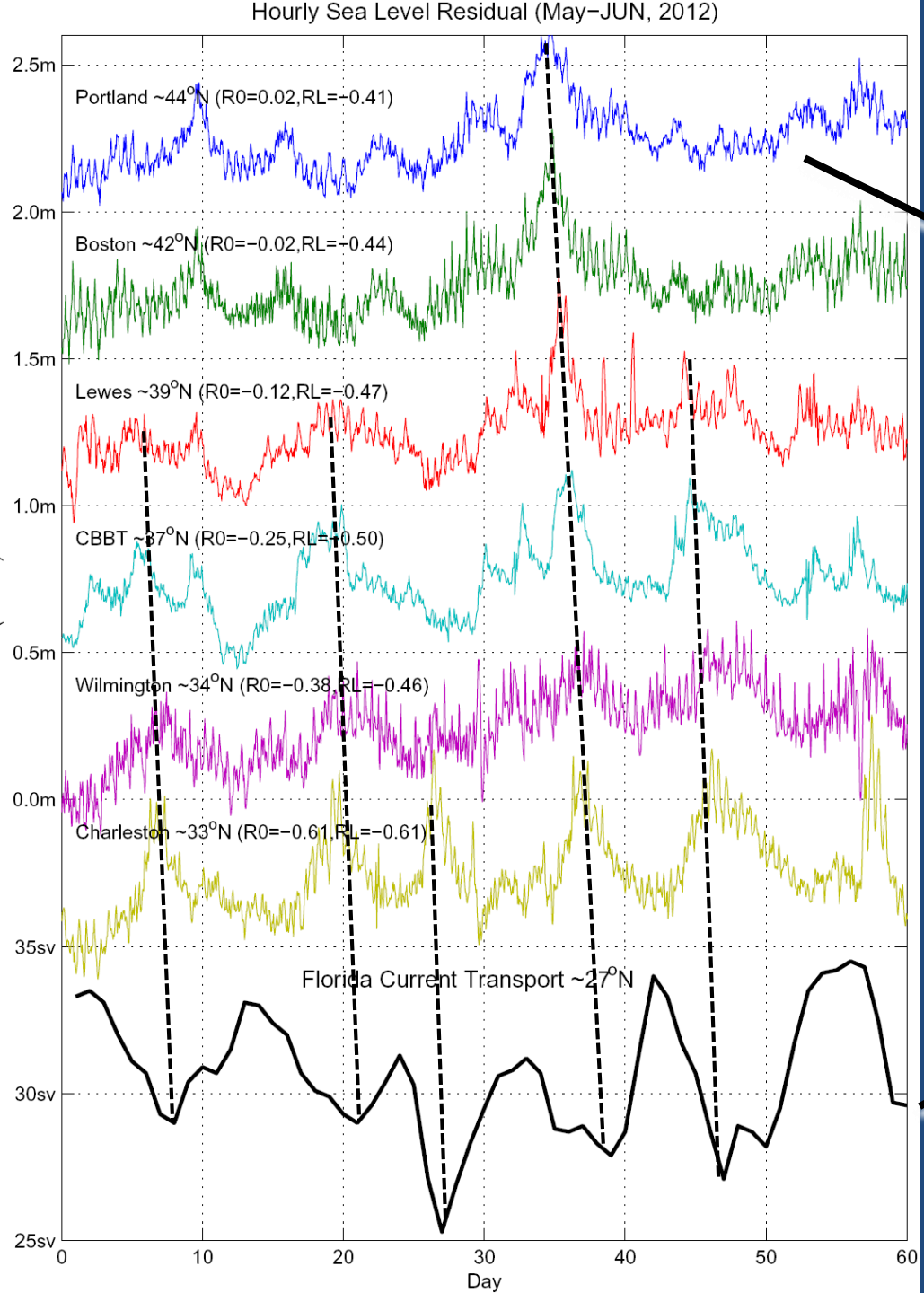
Influence from outside the Bay?

Decadal variations of sea level from tide gauge stations

Why do stations in different locations show the same pattern?

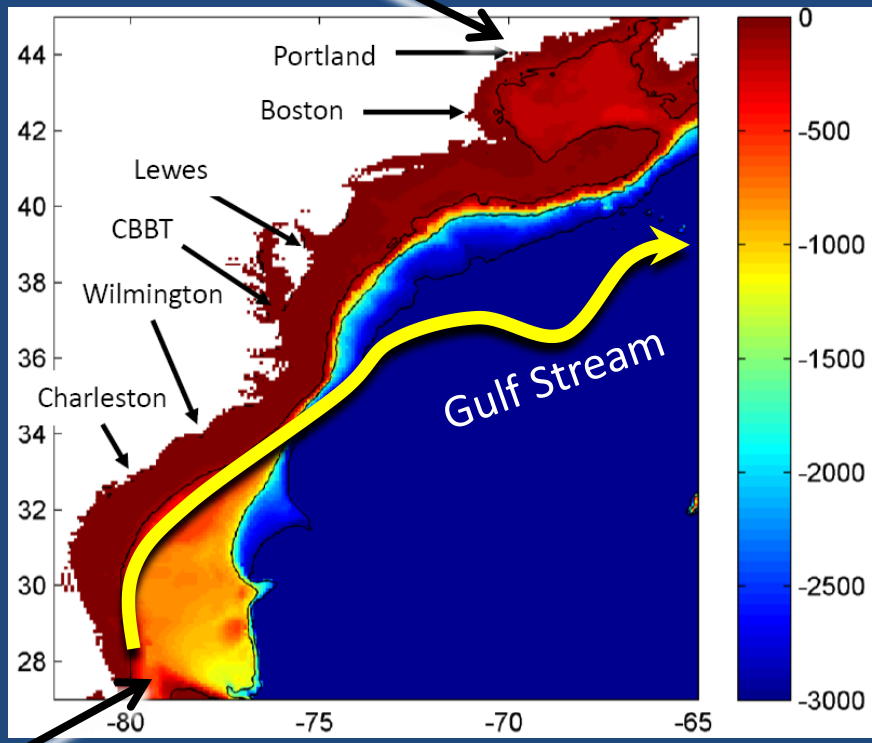






Short-term fluctuations:

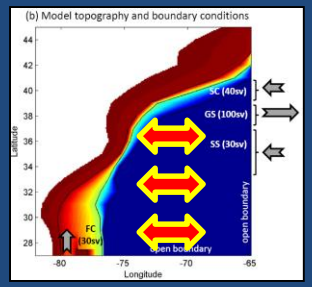
Coherent variations in coastal sL along the entire U.S. East Coast are **anti-correlated with the transport of the Gulf Stream** measured in the Florida Straits



Florida Current Transport

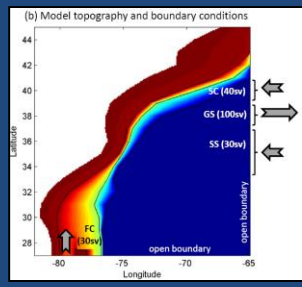
Ocean circulation models help to understand the mechanism of the Gulf Stream-coastal sea level relations

(from Ezer, 2016)



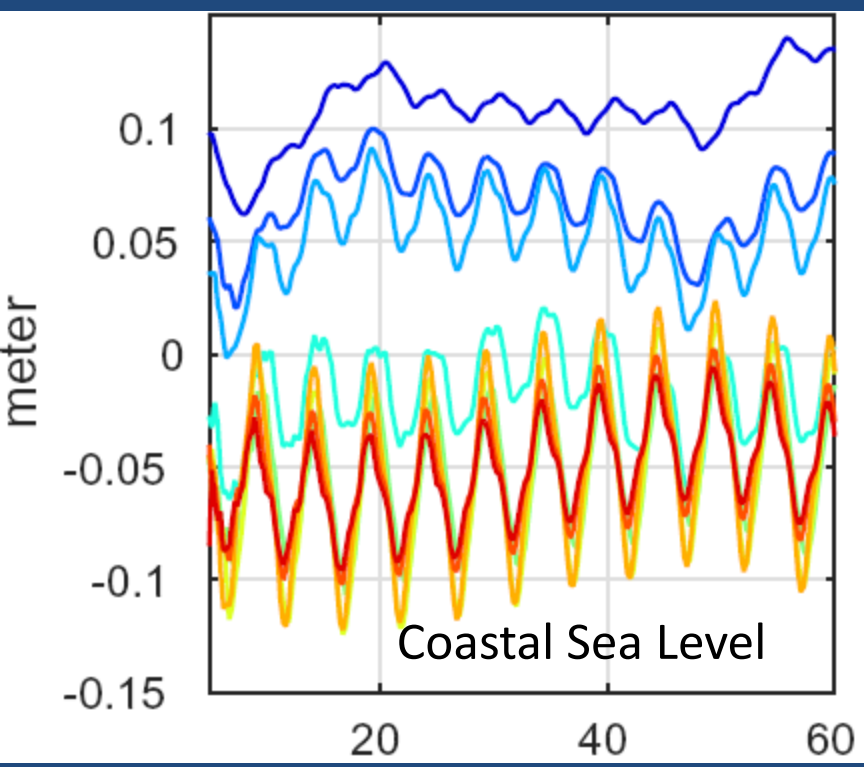
Wind-driven
(zonal wind ±5 m/s)
[response depends on shelf width]

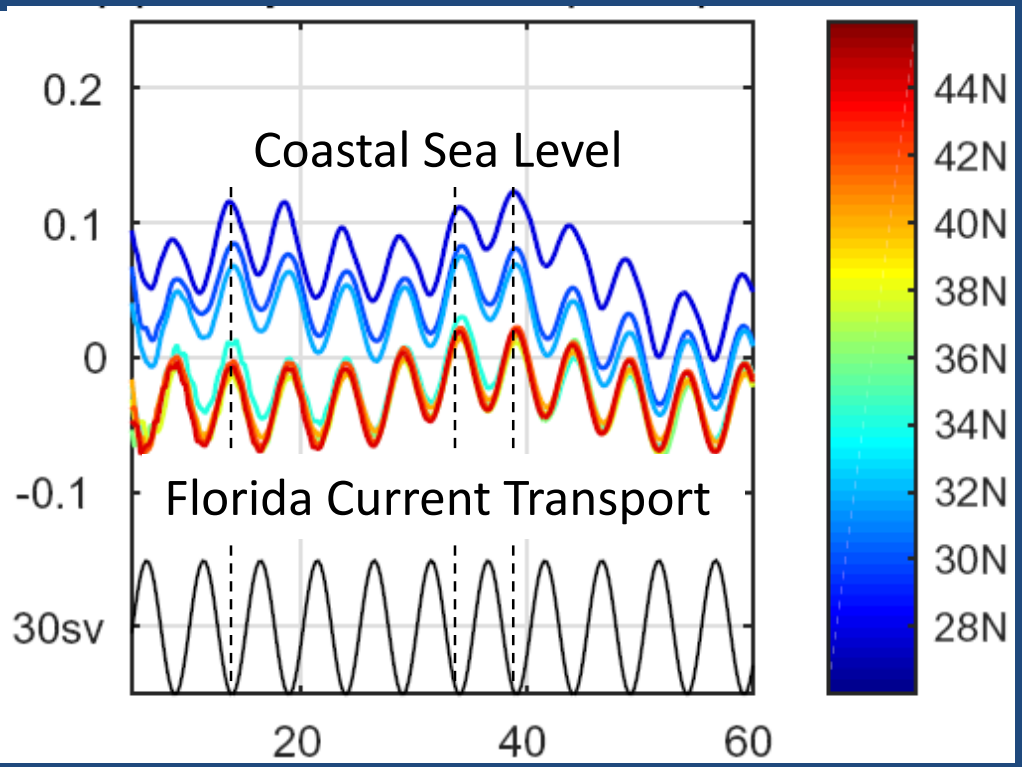
VS.



Gulf Stream-driven
(transport ±10 sv)

[coherent response due to barotropic waves]





How can large-scale variations in the ocean offshore can impact coastal sea level?
One of the mechanism is the generation of **Coastal Trapped Waves (CTW)**

On Coastal Trapped Waves: Analysis and Numerical Calculation by Inverse Iteration

JOHN M. HUTHNANCE

Department of Oceanography, University of Liverpool, Liverpool, England L69 3BX

(Manuscript received 4 April 1977, in final form 7 October 1977)

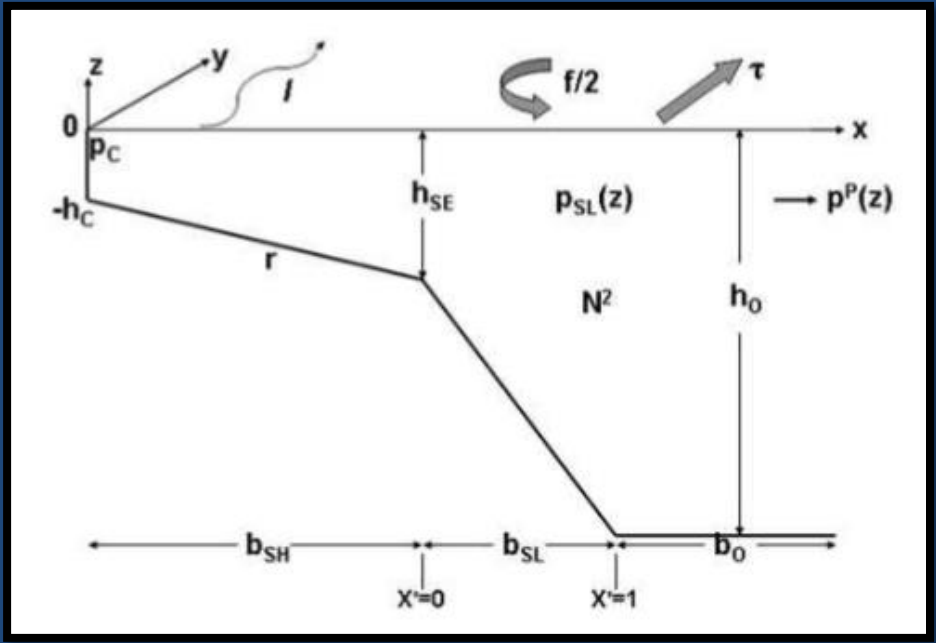
JPO (1978)

Ocean-to-shelf signal transmission: A parameter study

John M. Huthnance

Proudman Oceanographic Laboratory, Liverpool, UK

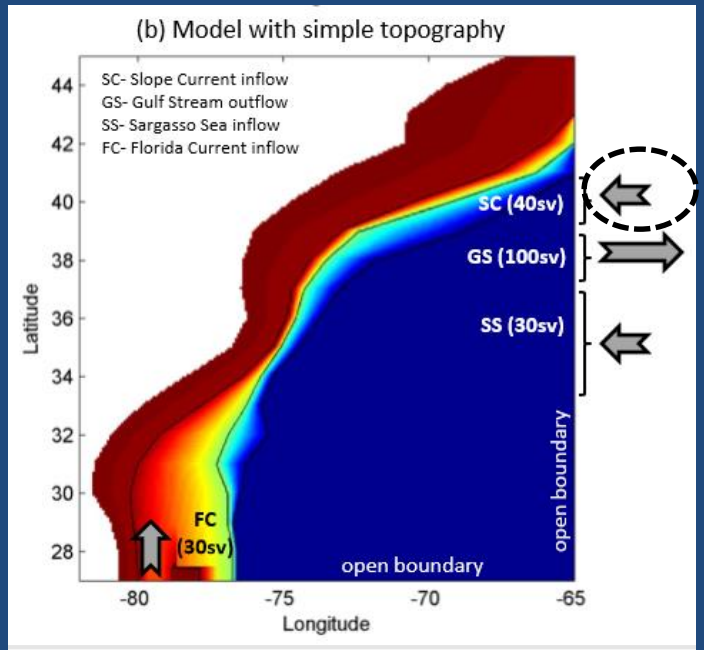
JGR (2004)

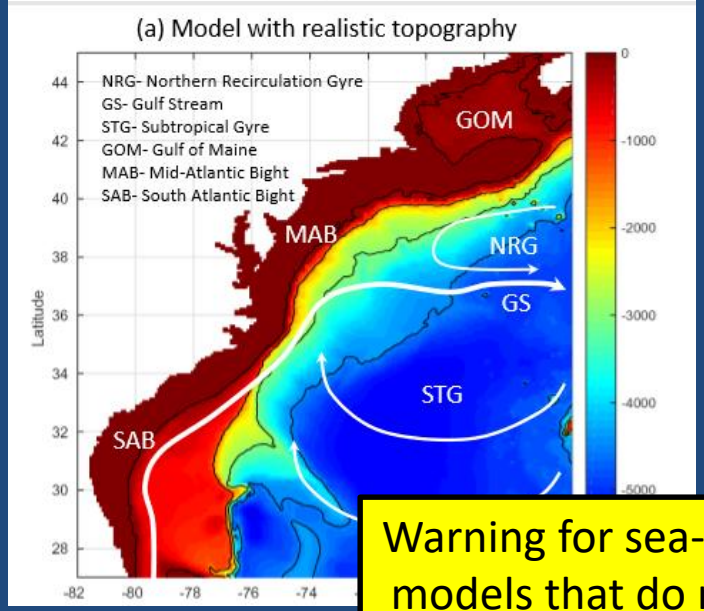


Simple models show that CTW depend on:

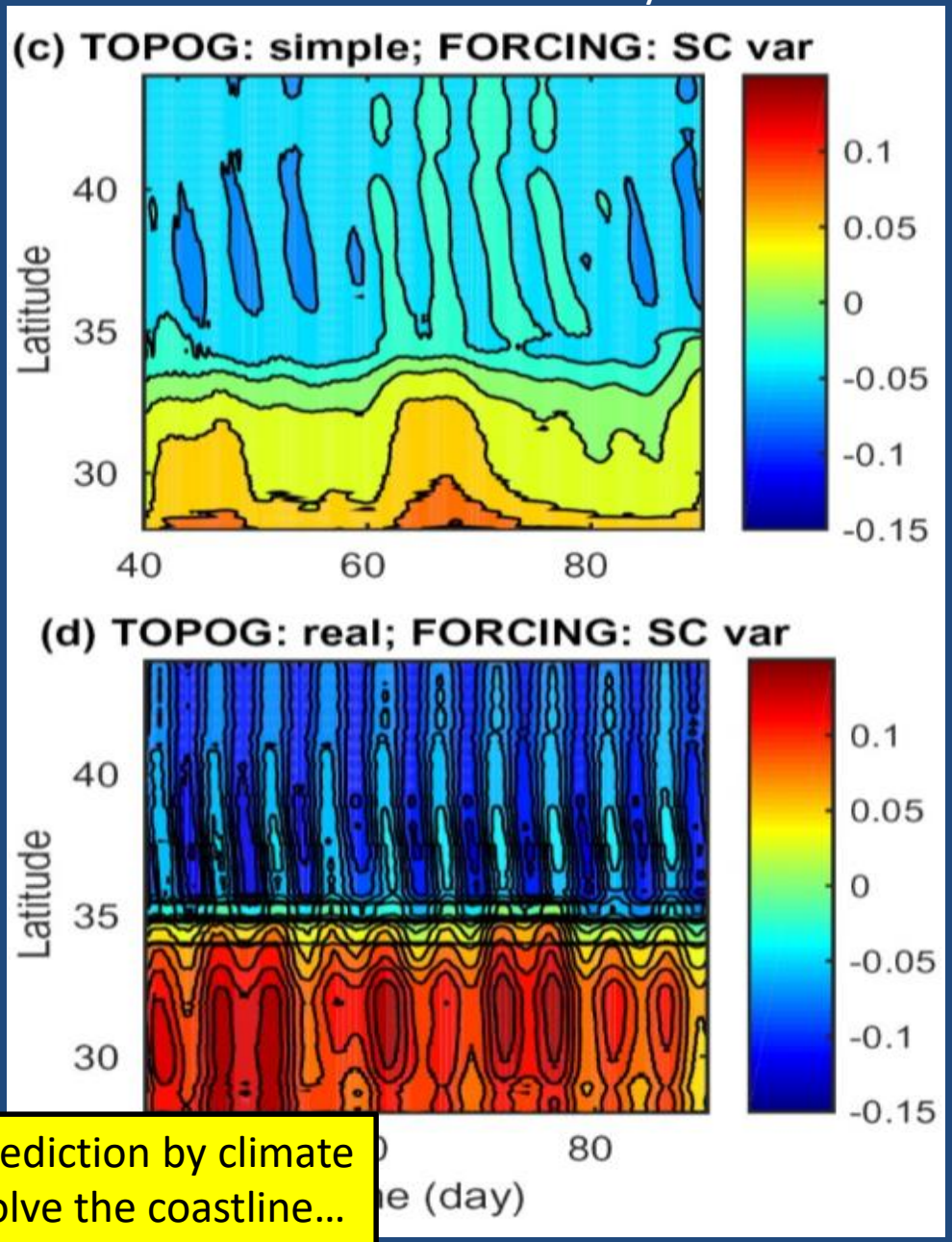
- Length and time-scale of forcing
- Frequency of forcing
- Shape of continental shelf and slope
- Shape of coastline

Impact of topography on **coastal-trapped-waves** (forcing: Slope Current variations)



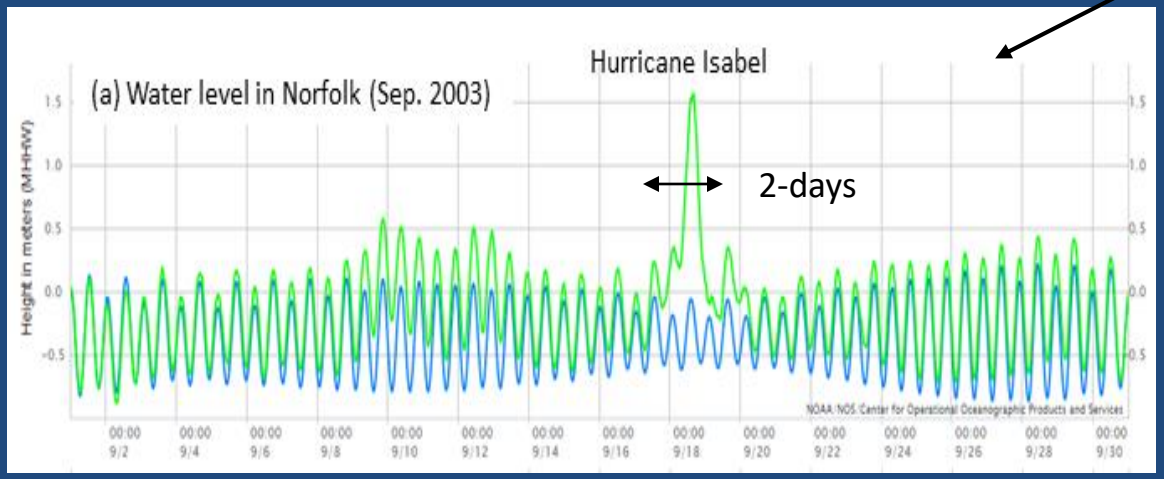


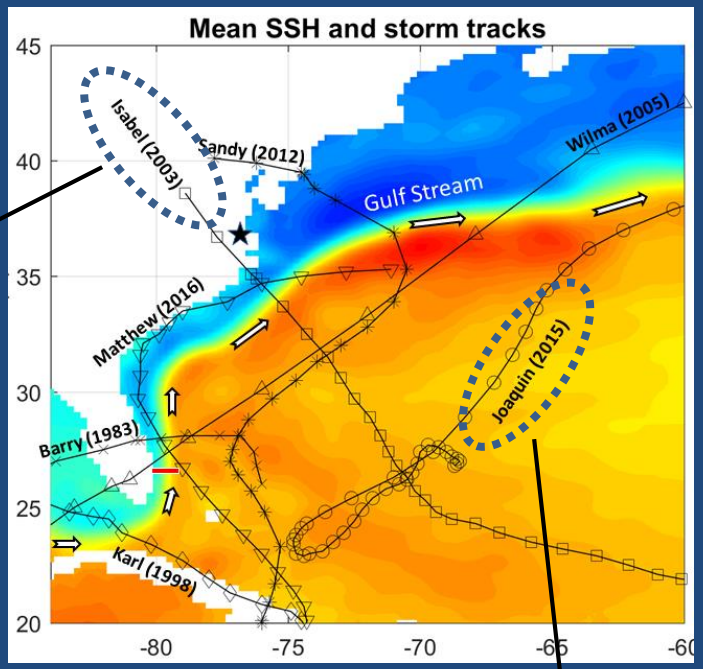
Coastal SL anomaly



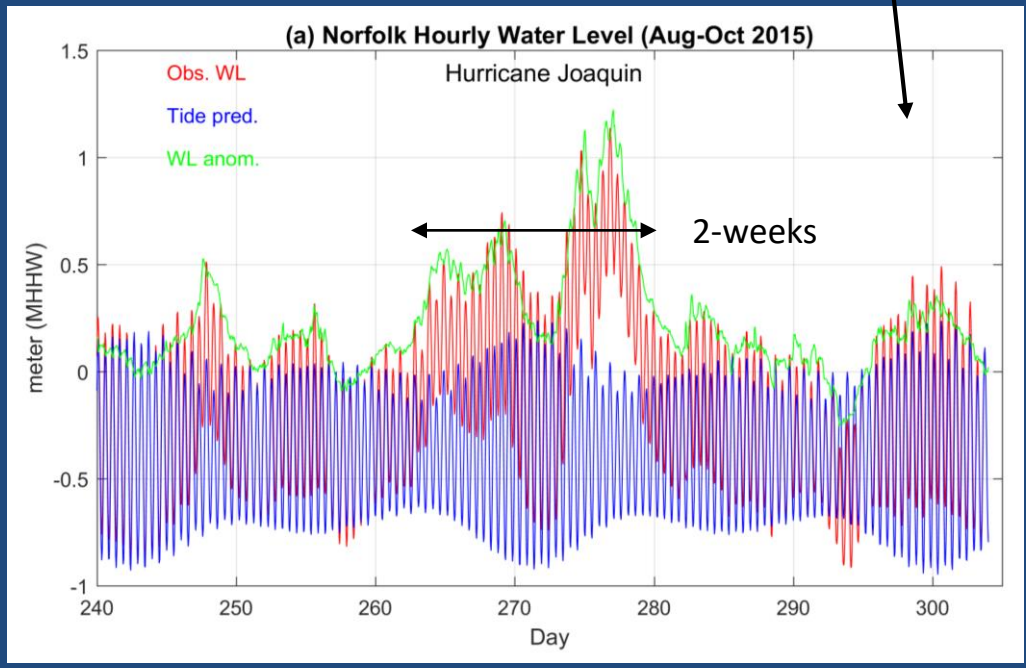
Warning for sea-level prediction by climate models that do not resolve the coastline…

Impact of tropical storms and hurricanes



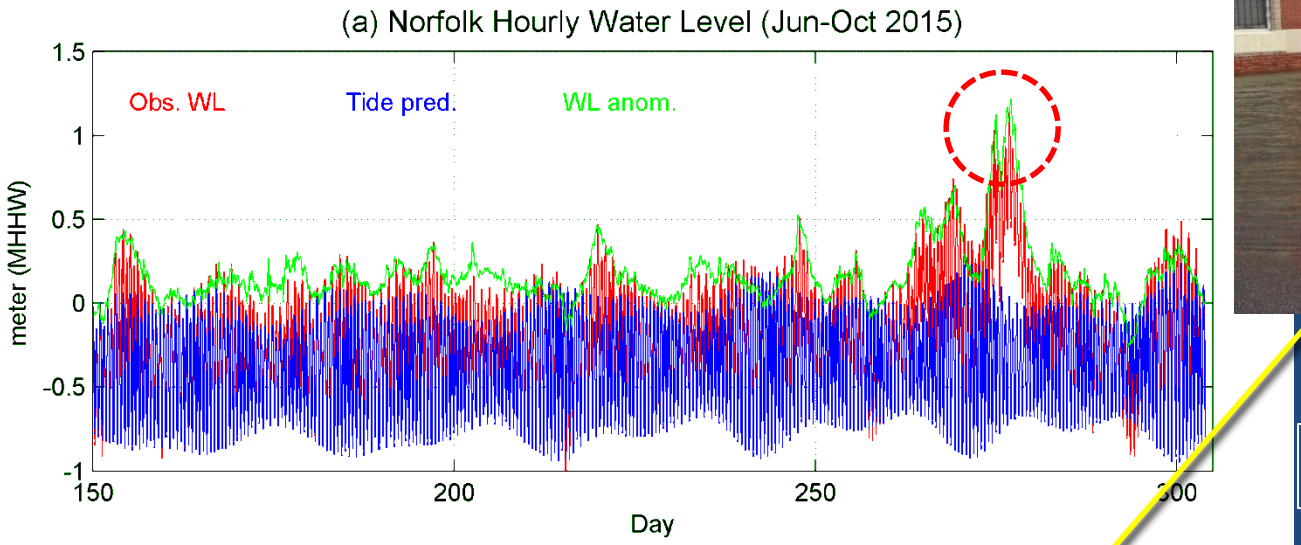


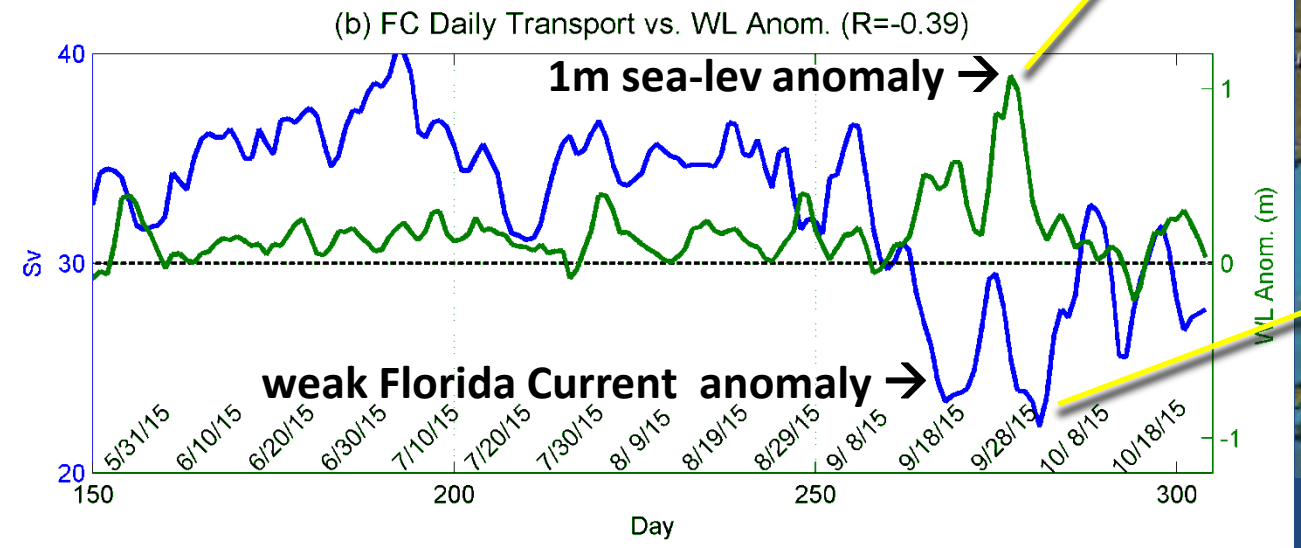
- Hurricane Isabel (2003) made landfall & caused 1.5 m storm surge that lasted a few hours (2nd largest in history)
- During Hurricane Joaquin (2015) that stayed offshore high water and flooding lasted for almost 2-weeks!
- Why?



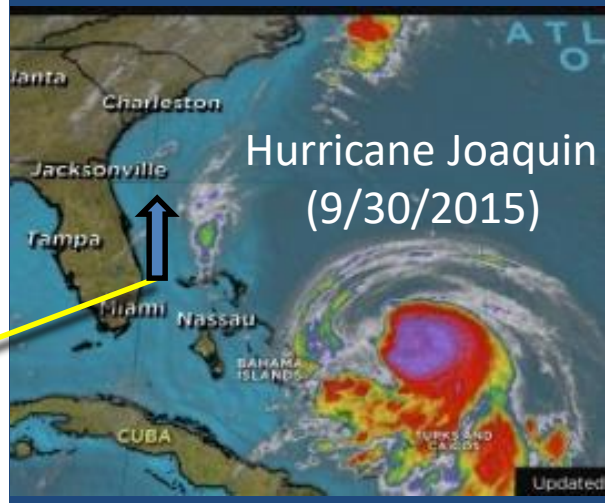
Sep-Oct 2015: severe flooding on the southeast US coast: a combination of Hurricane Joaquin and weakening Gulf Stream

"Clear-Day Flooding" in Norfolk, VA



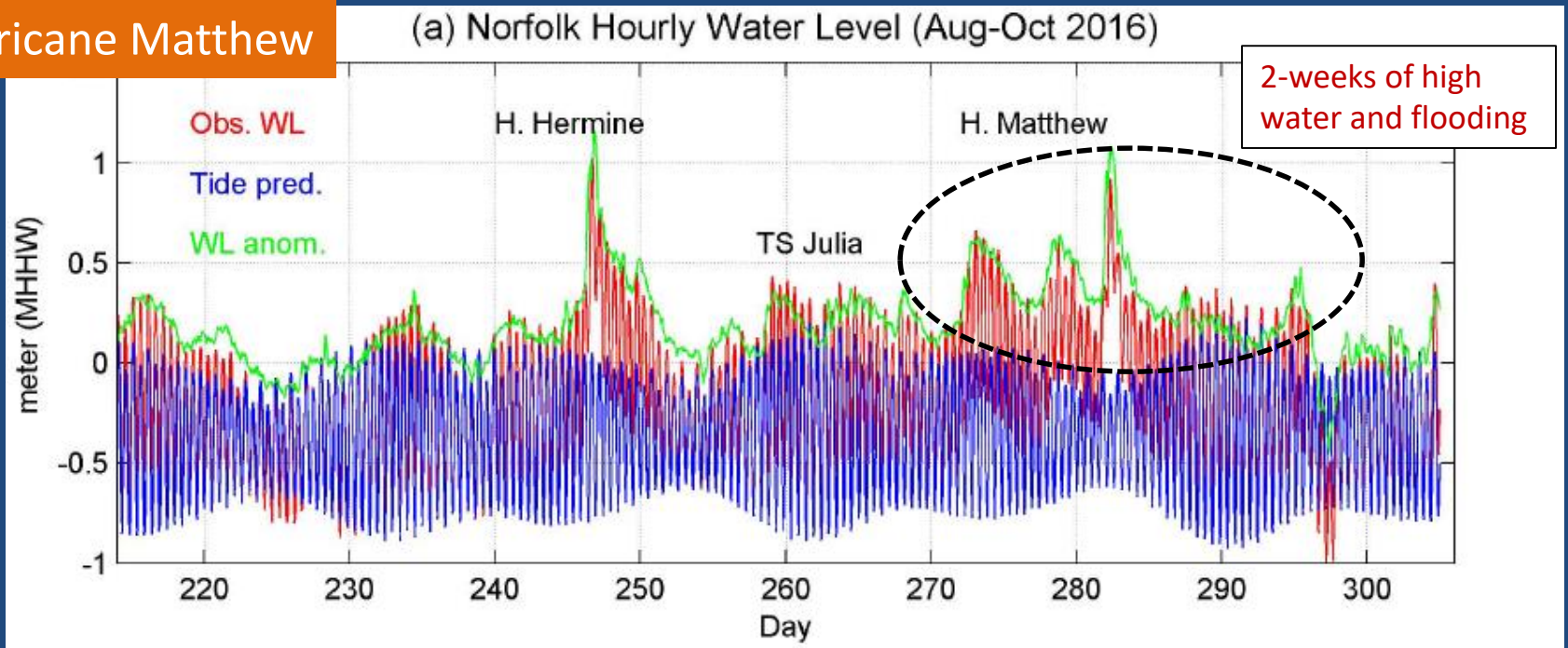


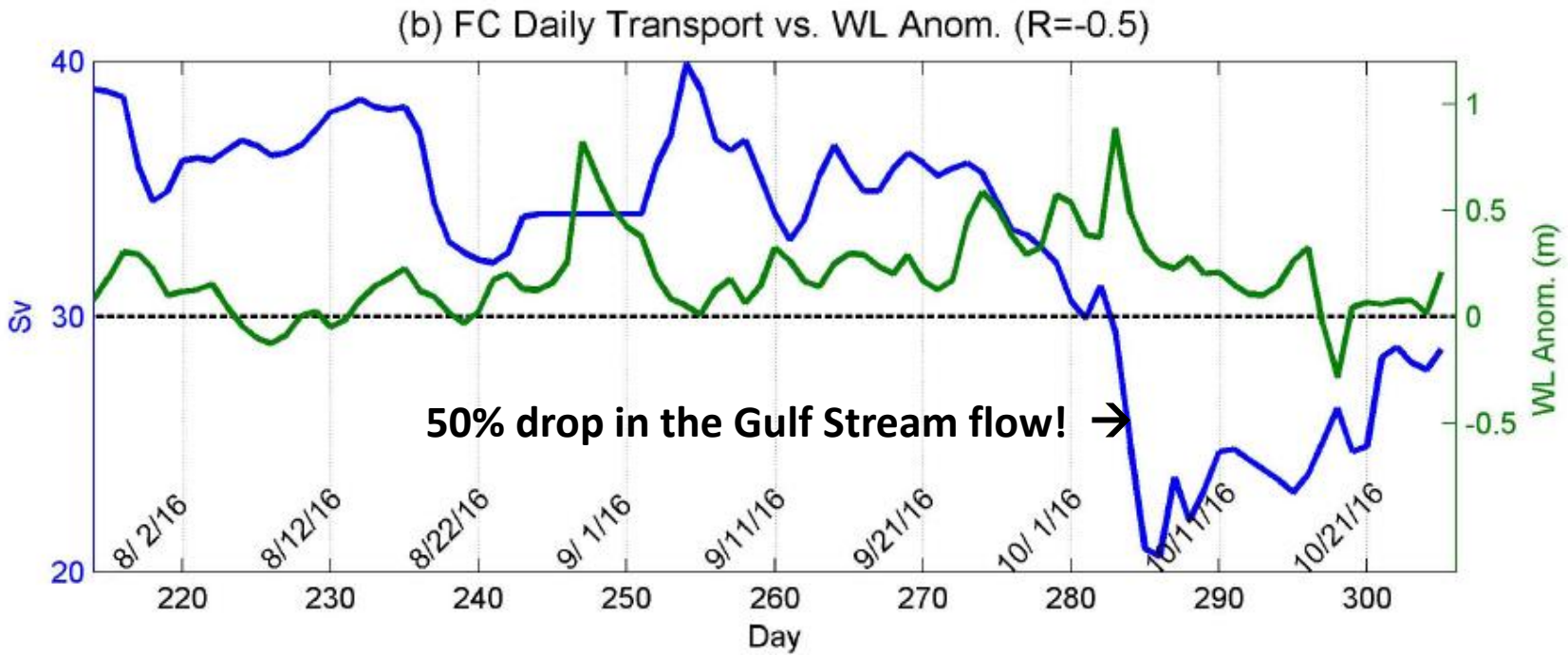
Hurr .→ GS → coastal SL



Hurricane Joaquin (9/30/2015)

Hurricane Matthew





Study air-sea-coast interactions during hurricanes in two steps:

1. Analyze NOAA's operational coupled hurricane model (HWRF-POM)

2. Sensitivity experiments with ocean only model:

- No surface forcing
- HF only
- WIND only — from HWRF-POM
- HF+WIND
- Gulf Stream — from FC transport

→ Hurricane Matthew is used as a case study

Description and Analysis of the Ocean Component of NOAA's Operational Hurricane Weather Research and Forecasting Model (HWRF)

RICHARD M. YABLONSKY, ISAAC GINIS, AND BIJU THOMAS

Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island

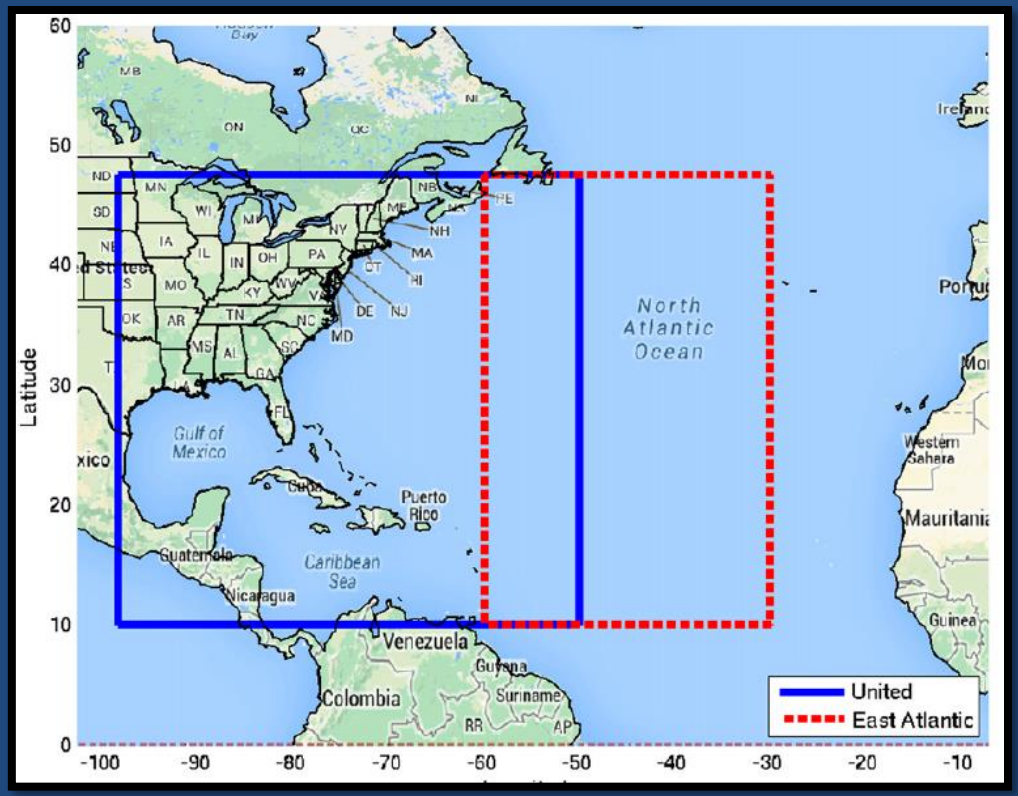
VIJAY TALLAPRAGADA AND DMITRY SHEININ

NOAA/NWS/NCEP/Environmental Modeling Center, College Park, Maryland

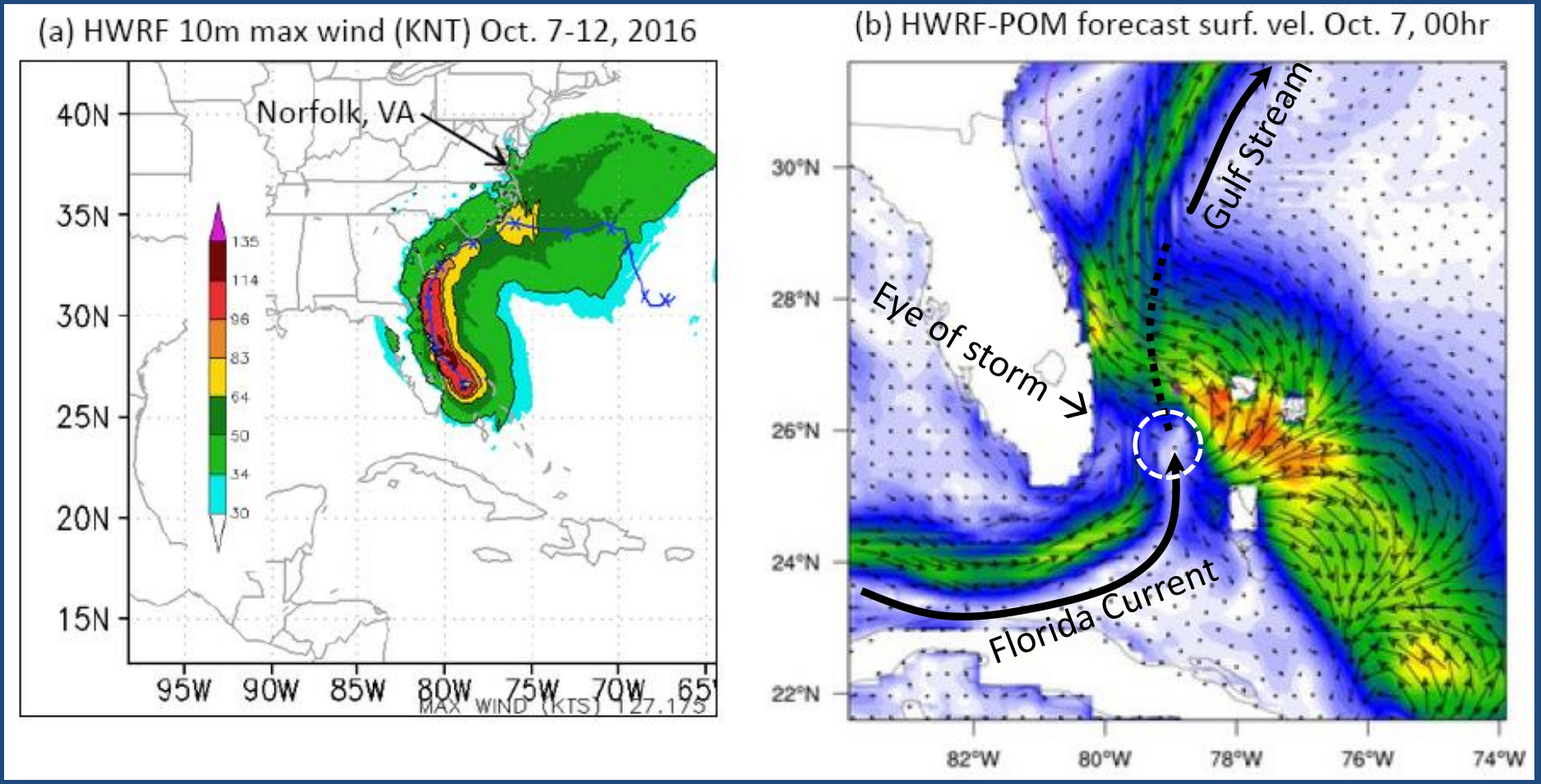
LIGIA BERNARDET

NOAA/ESRL/Global Systems Division, and CIRES, University of Colorado Boulder, Boulder, Colorado

(Manuscript received 28 March 2014, in final form 5 September 2014)

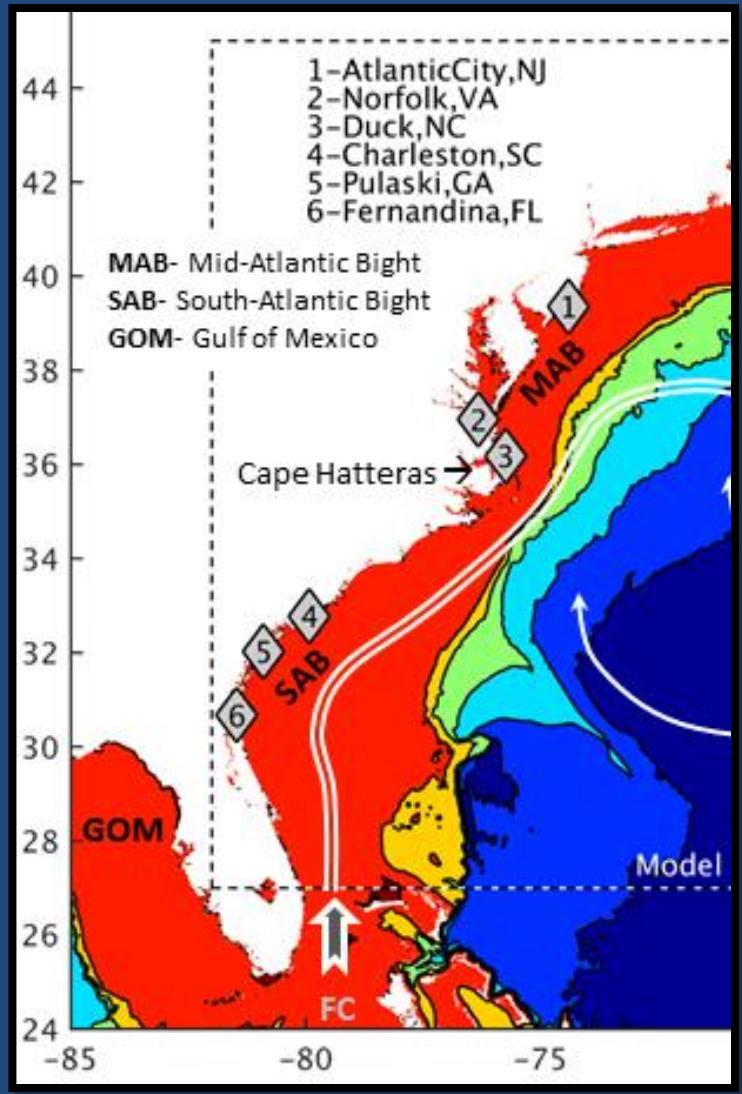


Hurricane Matthew (2016) did not reach the Mid-Atlantic coast, but nevertheless caused severe flooding there, why?
Surface currents in the coupled model show that the hurricane disrupts the flow of the Gulf Stream



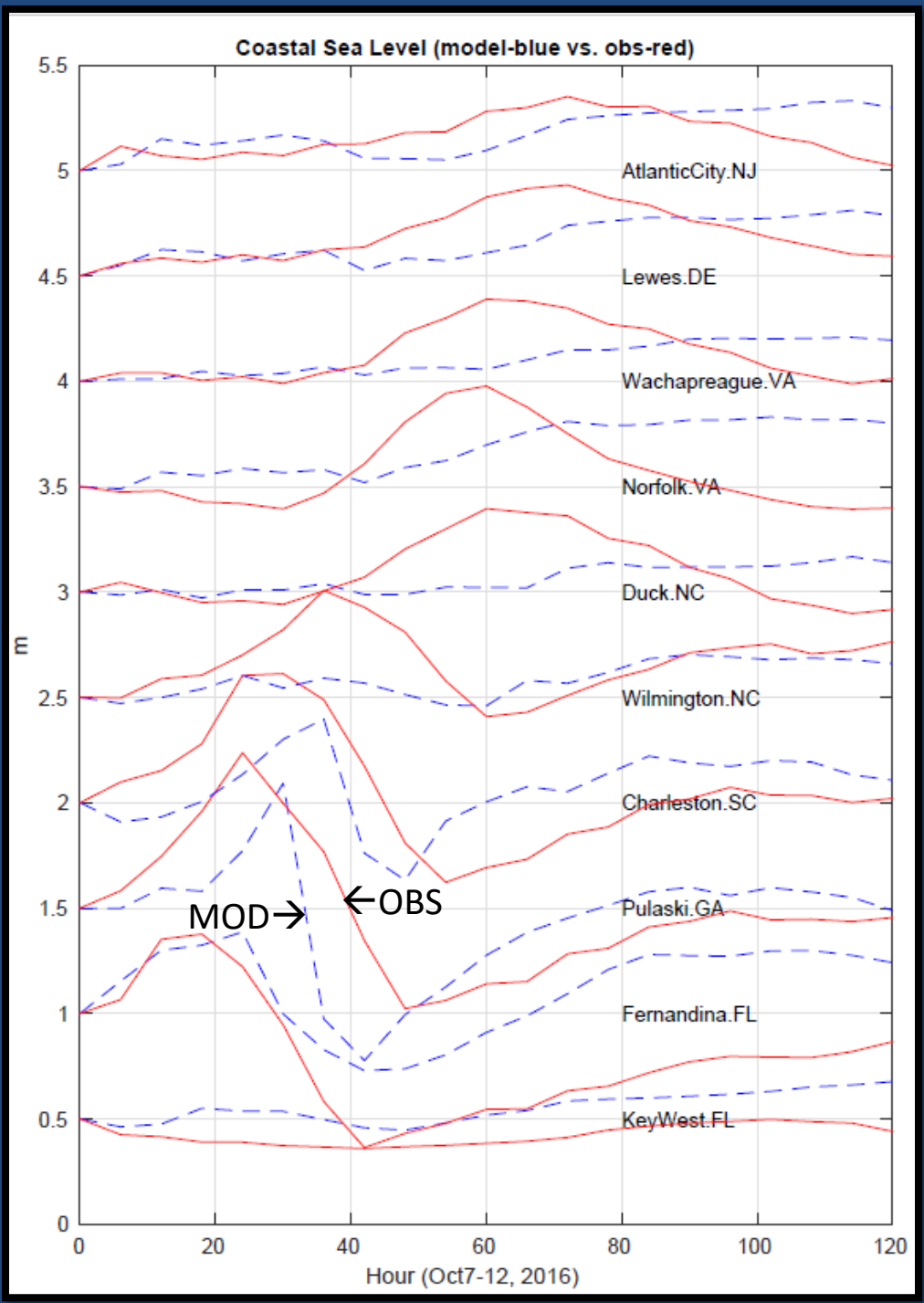
Ezer (2018)

The **coupled HWRF-POM** model has some skill in predicting coastal sea level, but storm surge was not simulated very well in the MAB (the model was not intended to be a coastal ocean model…)

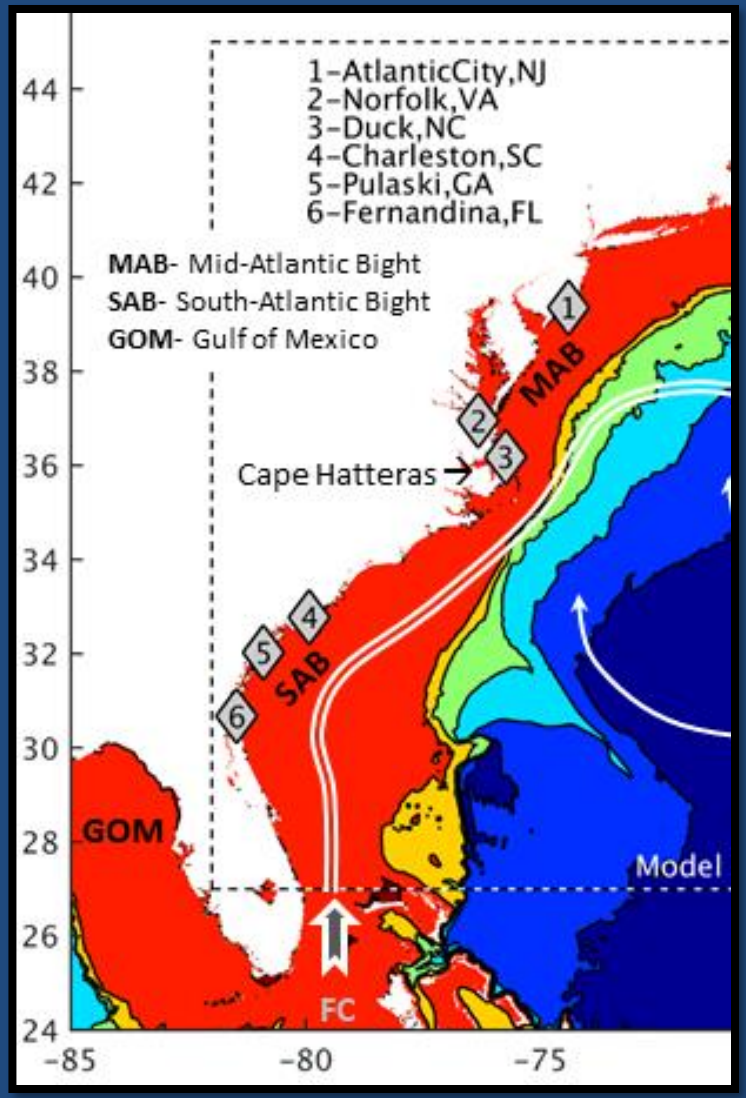


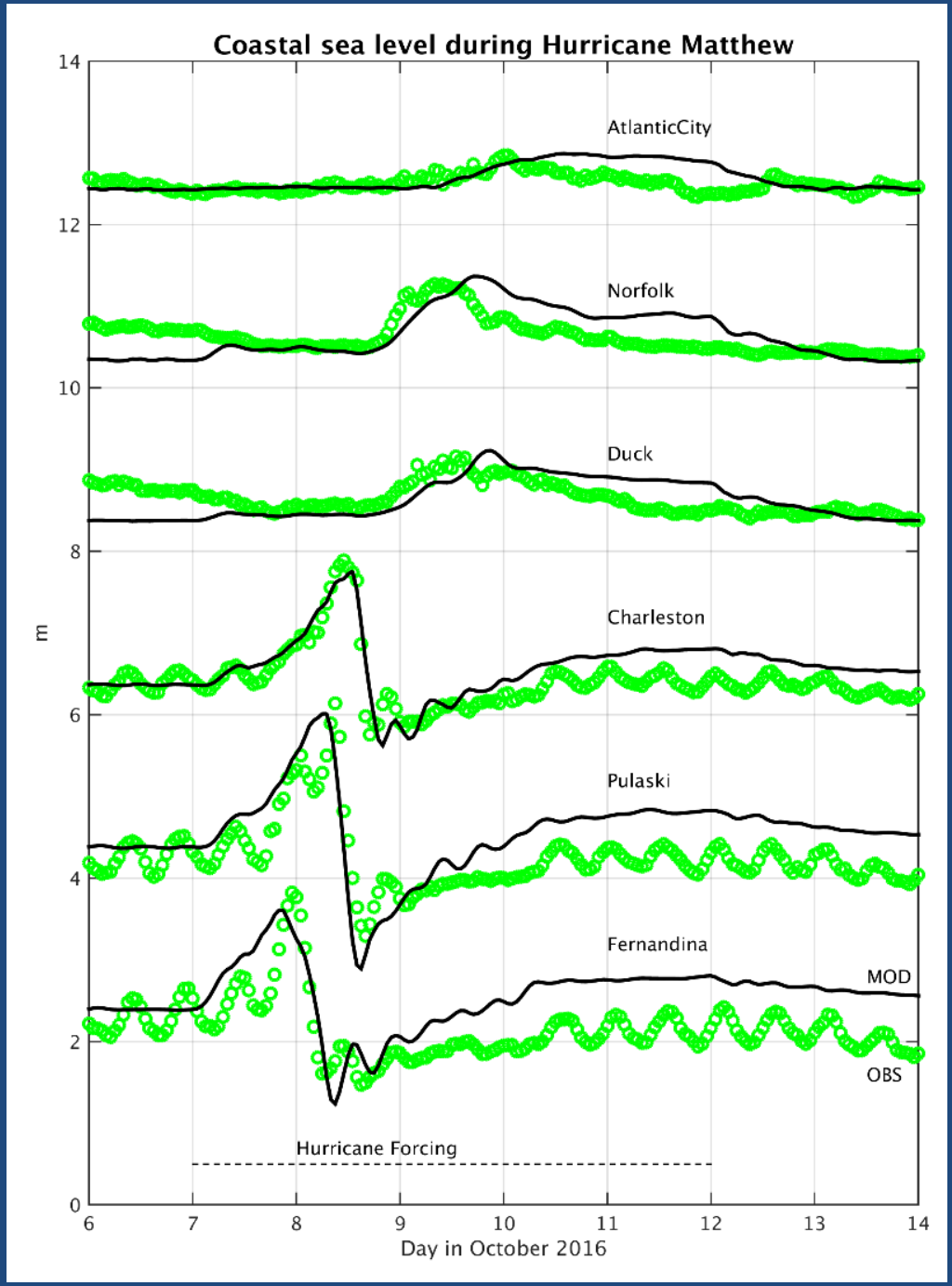
MAB

SAB

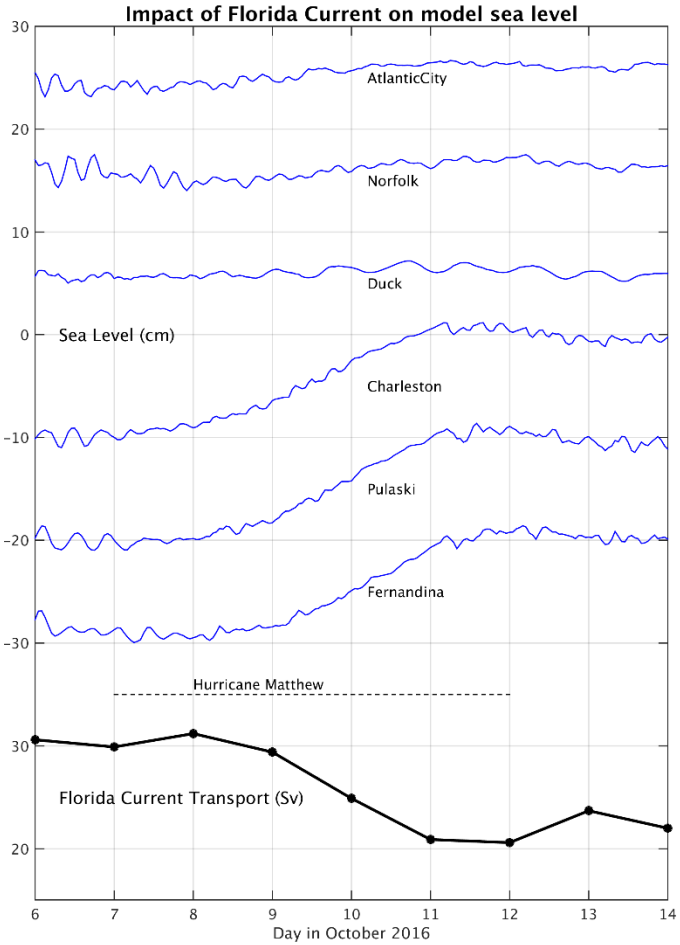


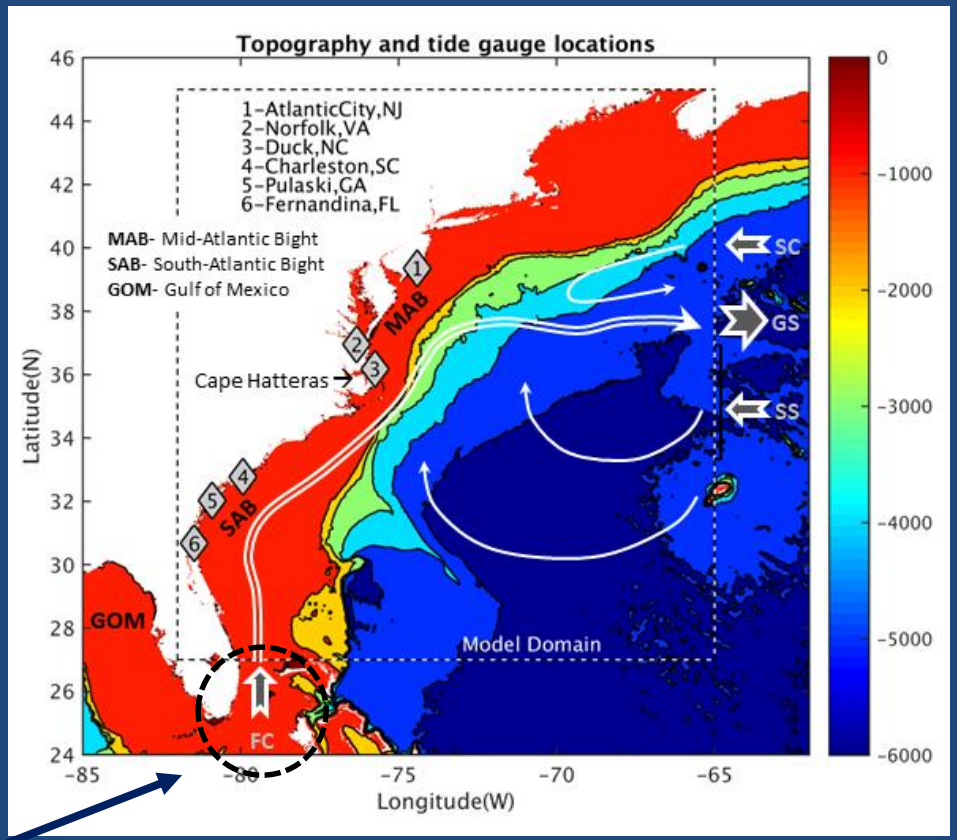
On the other hand, **ocean only POM** (1/12deg) forced by wind from the coupled model has better skill in predicting storm surge



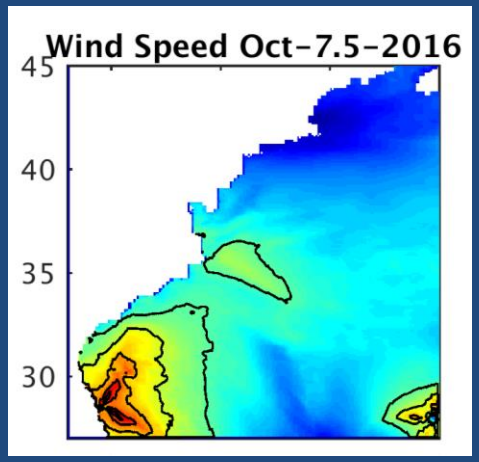


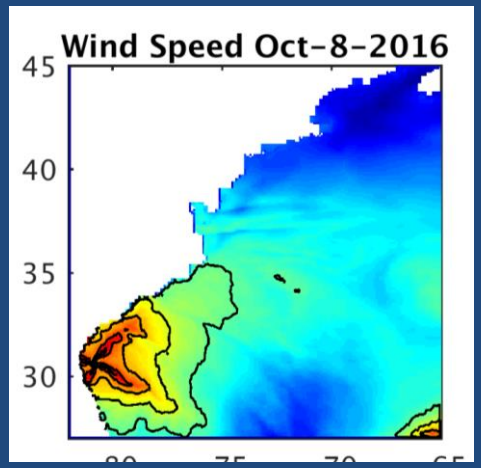
We can also use the numerical model to simulate the contribution of the Gulf Stream by forcing the model with the Florida Current observations during the storm (but no wind)

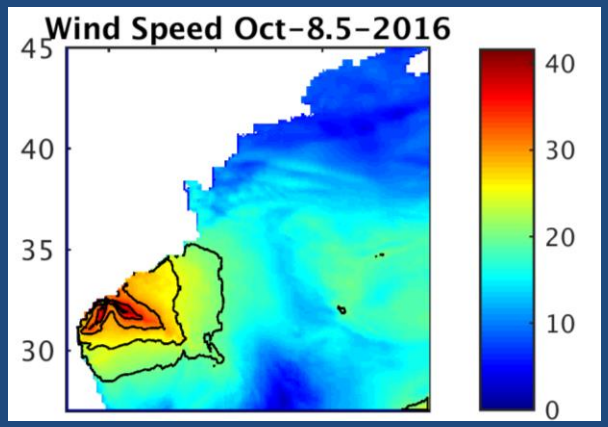


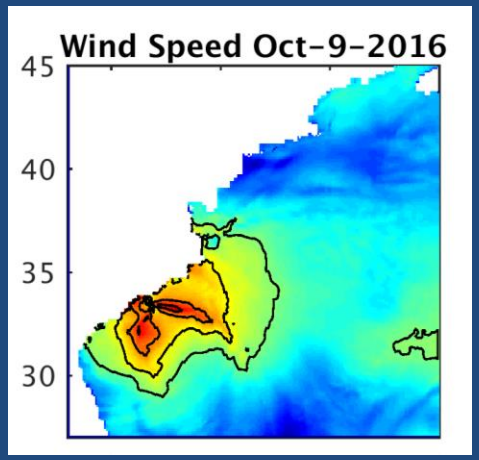


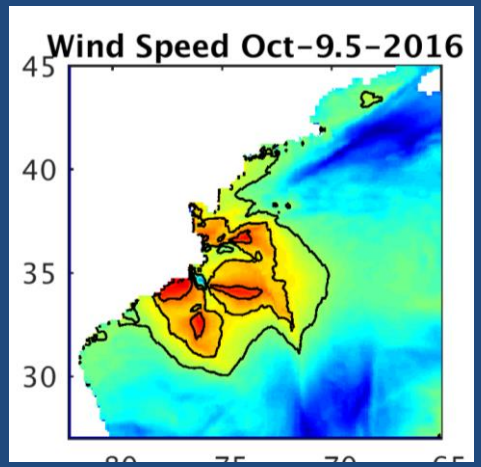
Conclusion: indirect impact of a hurricane on sea level can last several days after the hurricane disappeared

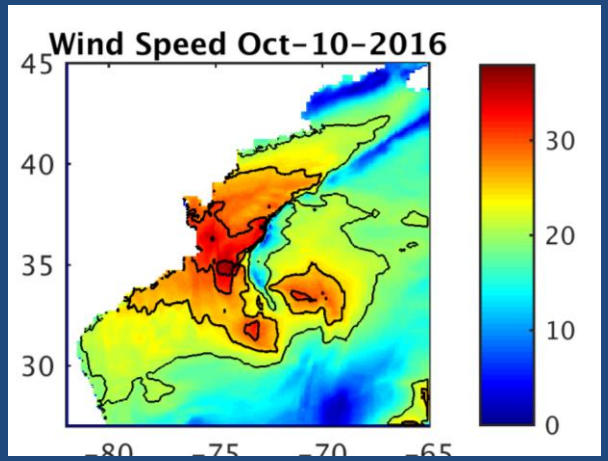

Wind Speed Oct-7.5-2016
45
40
35
30

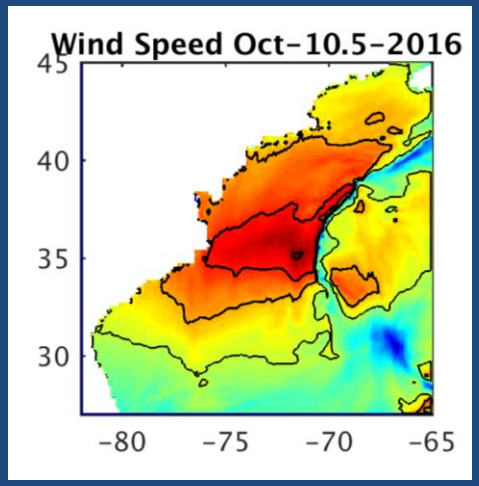

Wind Speed Oct-8-2016
45
40
35
30

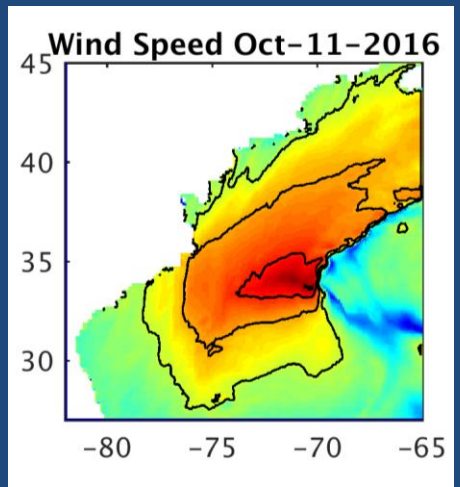

Wind Speed Oct-8.5-2016
45
40
35
30
40
30
20
10
0

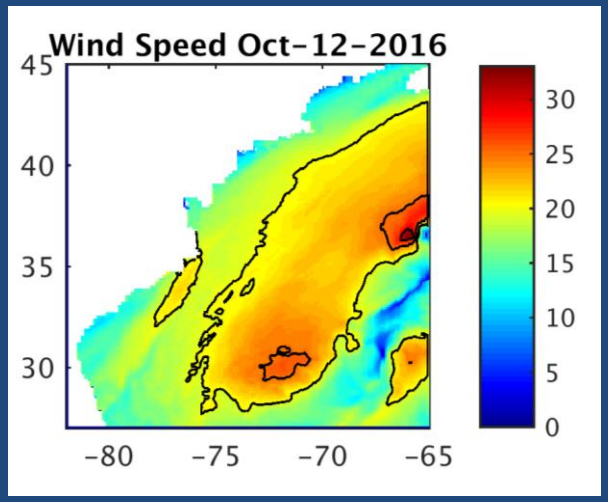

Wind Speed Oct-9-2016
45
40
35
30


Wind Speed Oct-9.5-2016
45
40
35
30

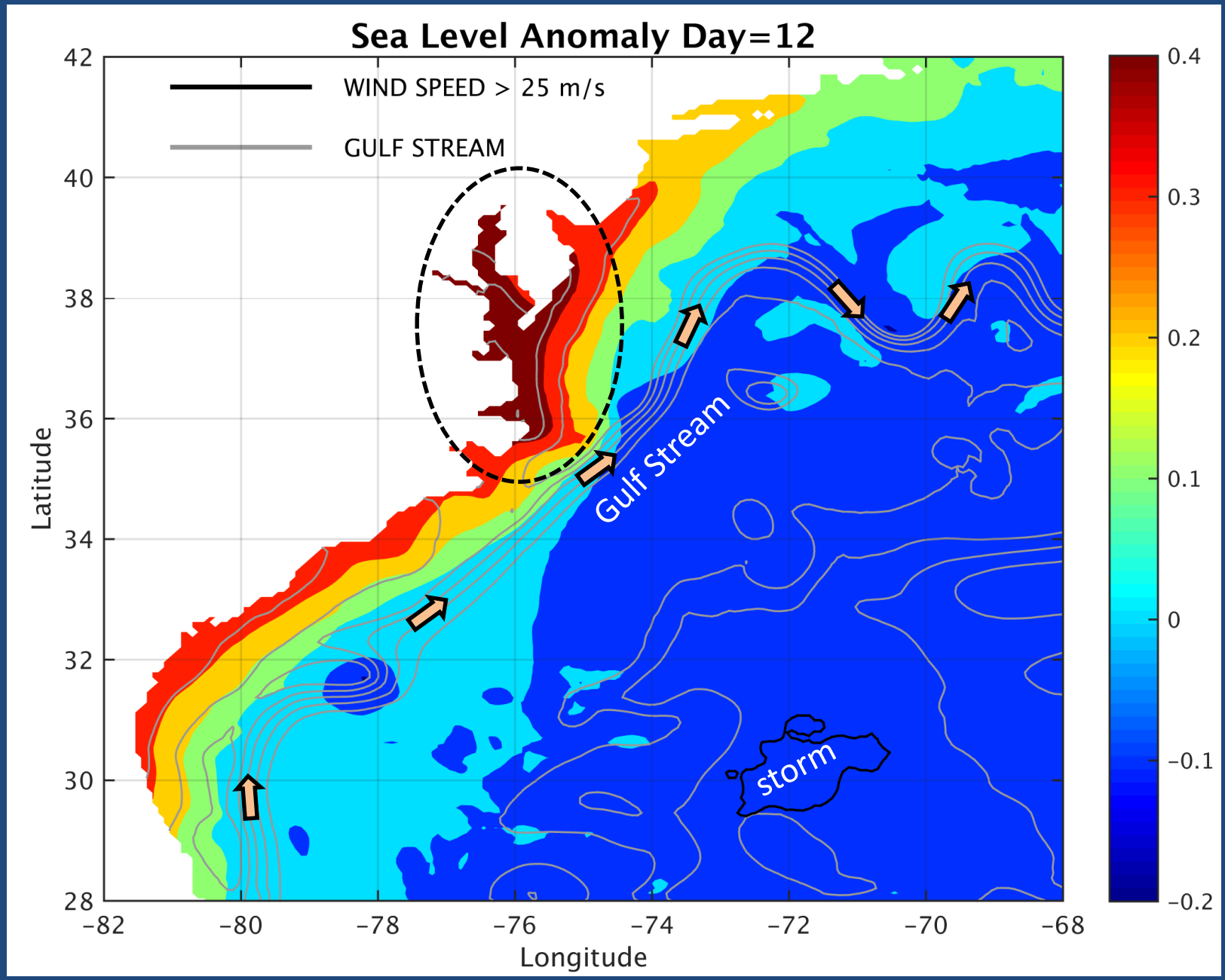

Wind Speed Oct-10-2016
45
40
35
30
30
20
10
0

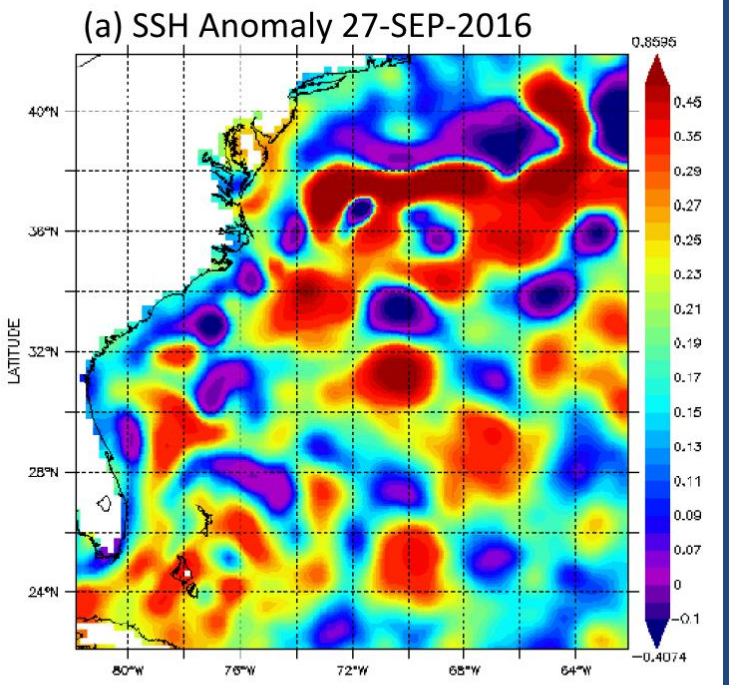

Wind Speed Oct-10.5-2016
45
40
35
30
-80
-75
-70
-65

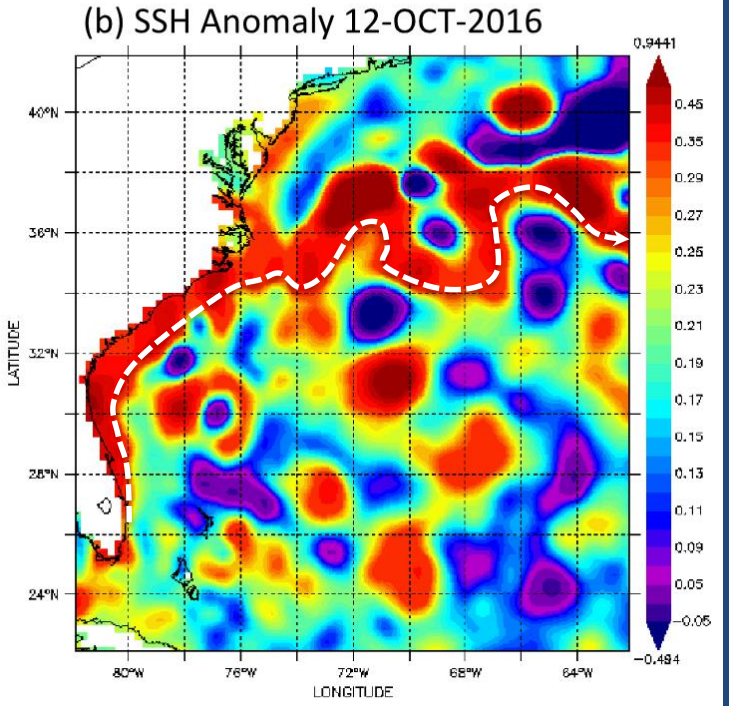

Wind Speed Oct-11-2016
45
40
35
30
-80
-75
-70
-65


Wind Speed Oct-12-2016
45
40
35
30
-80
-75
-70
-65
30
25
20
15
10
5
0

Several days after Hurricane Matthew disappeared, coastal sea level remained high (especially in the **Chesapeake Bay** and north of the Gulf stream)







Altimeter data confirm model results

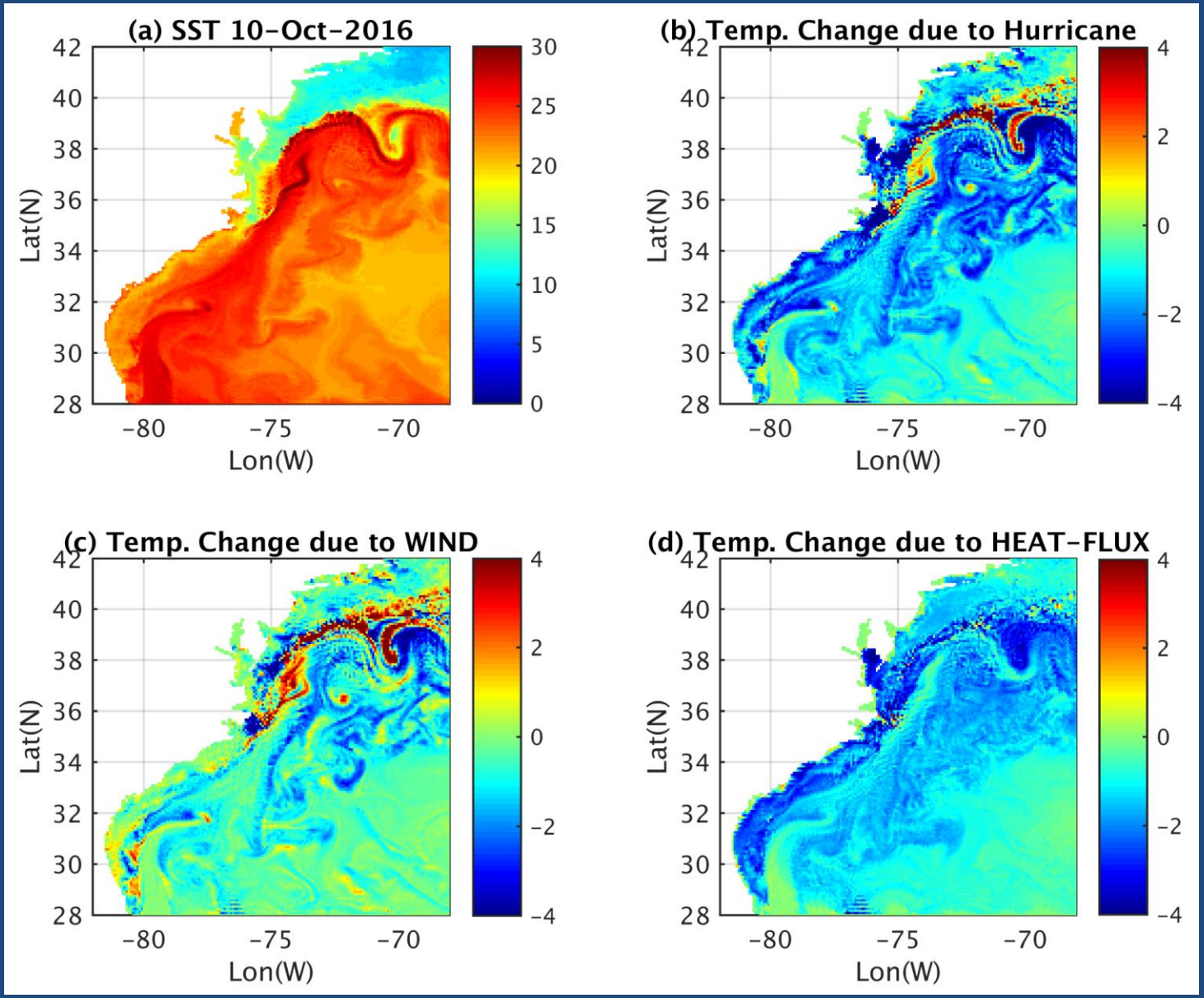
~ a week before Hurricane Matthew:

typical meso-scale eddies

~ a week after Hurricane Matthew:

- Gulf Stream remained weaker along most of its path
- coastal sea level remained high along most of the U.S. coast

Sensitivity model simulations show how the surface forcing impact temperature changes during the Hurricane (up to 4°C cooling)

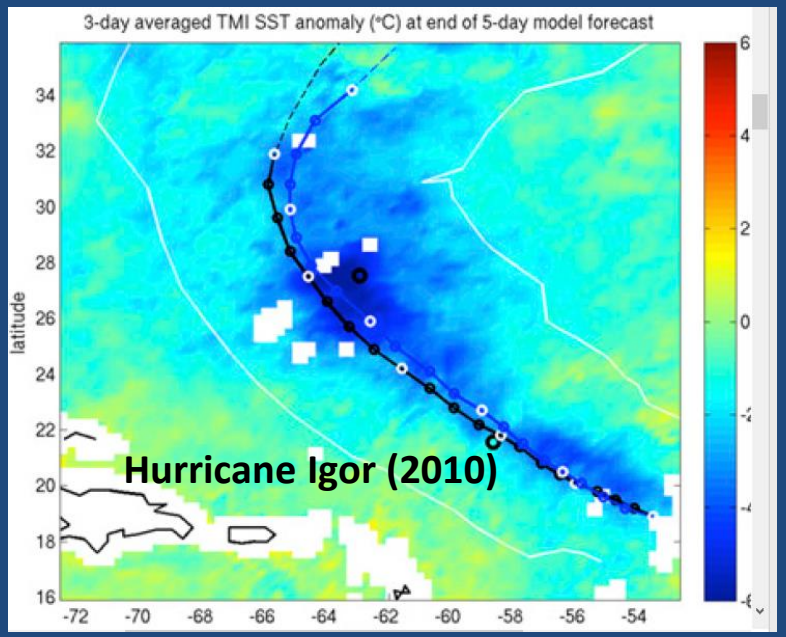


forcing: WIND+HF

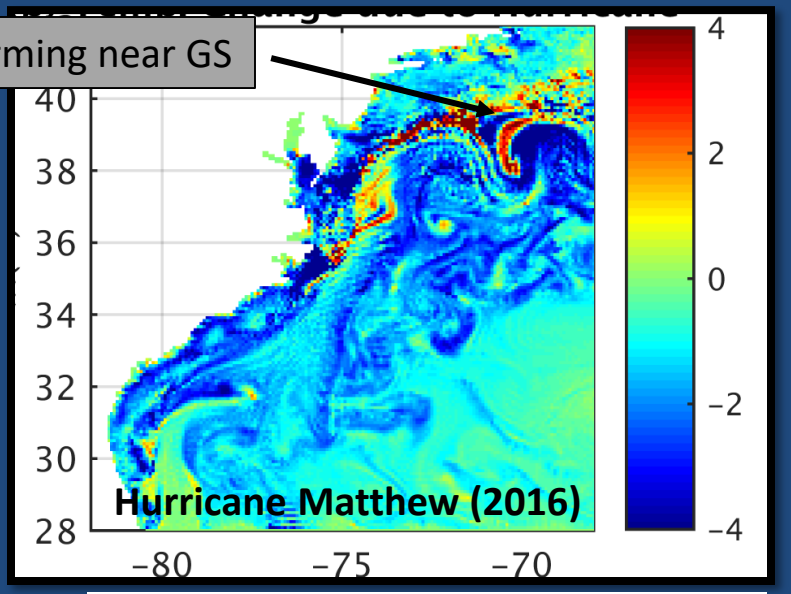
forcing: only WIND

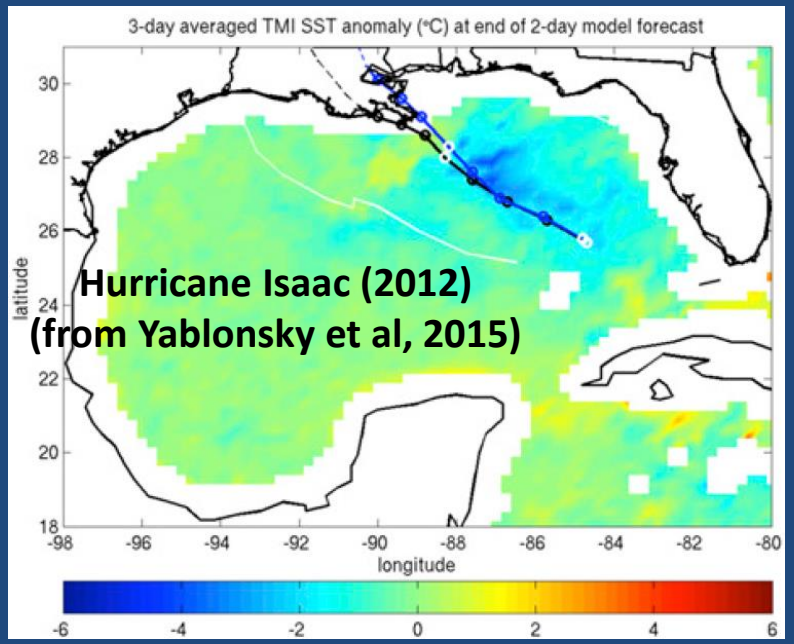
forcing: only HF

Note that due to the interaction of Hurricane Matthew with the Gulf Stream, the pattern of cooling is different than typical impact of hurricanes

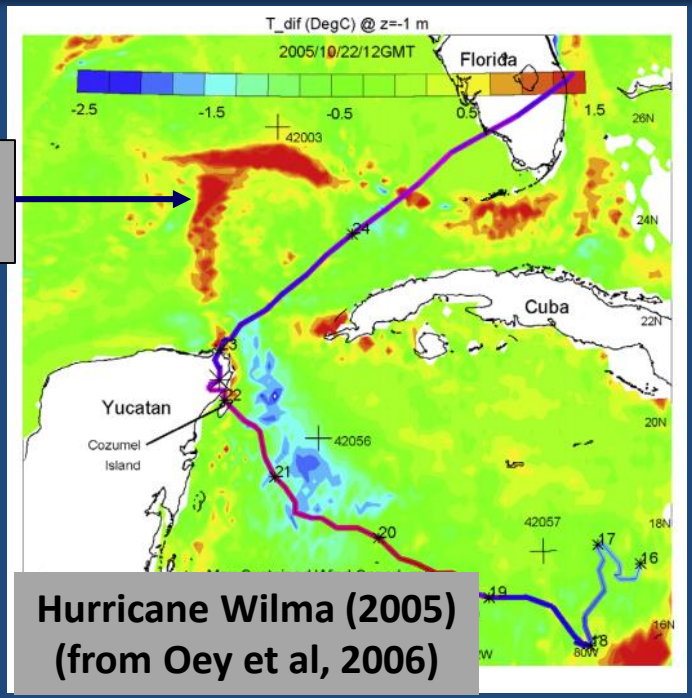


warming near GS

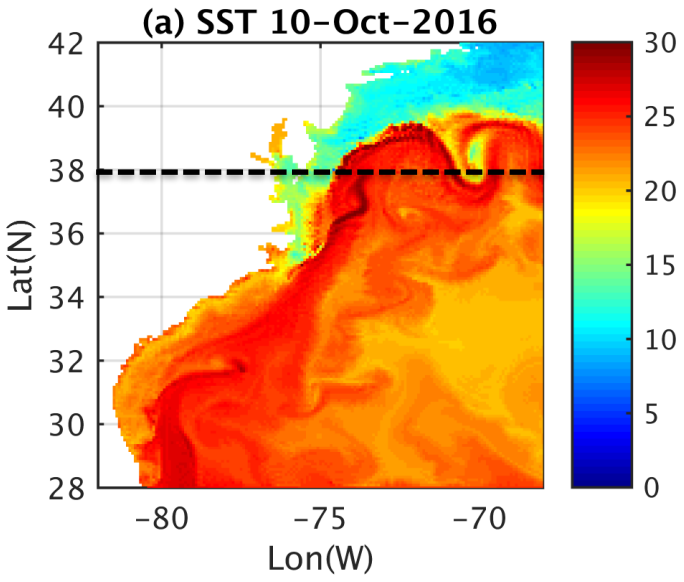


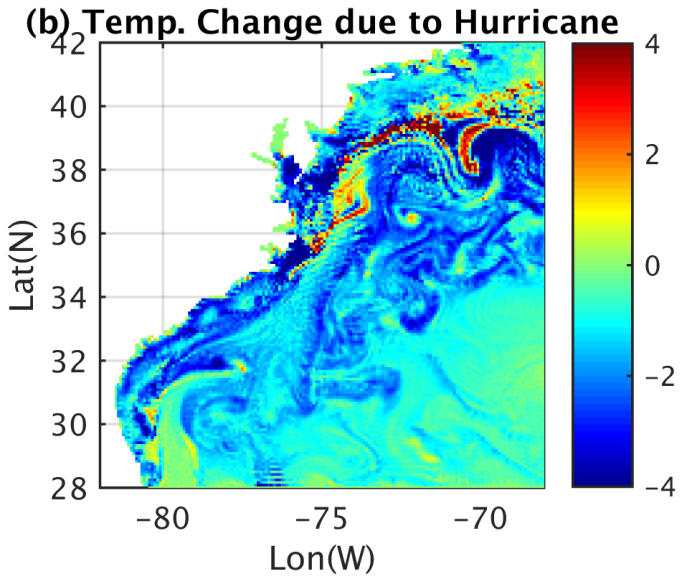


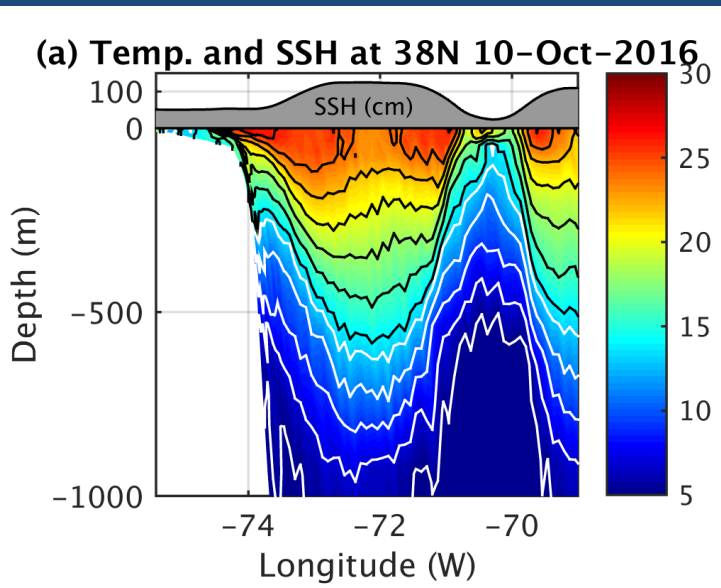
warming of the Loop Current

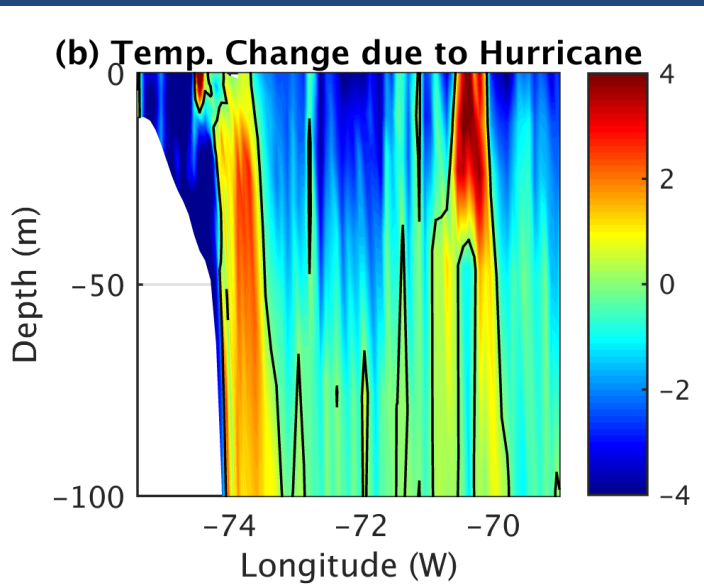


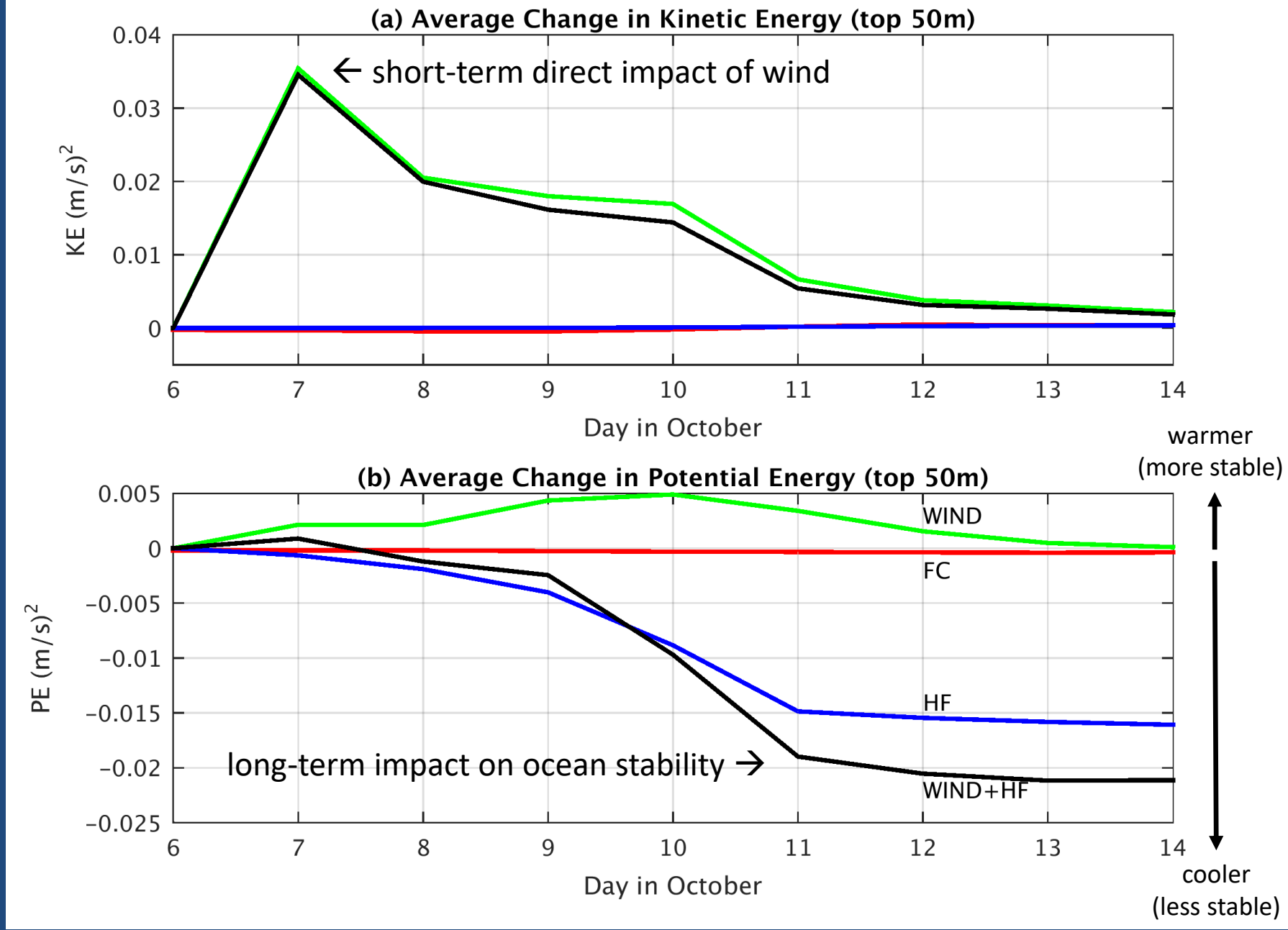
The interaction between the hurricane's winds and the Gulf Stream flow results in cooling (and warming!) near fronts and eddies









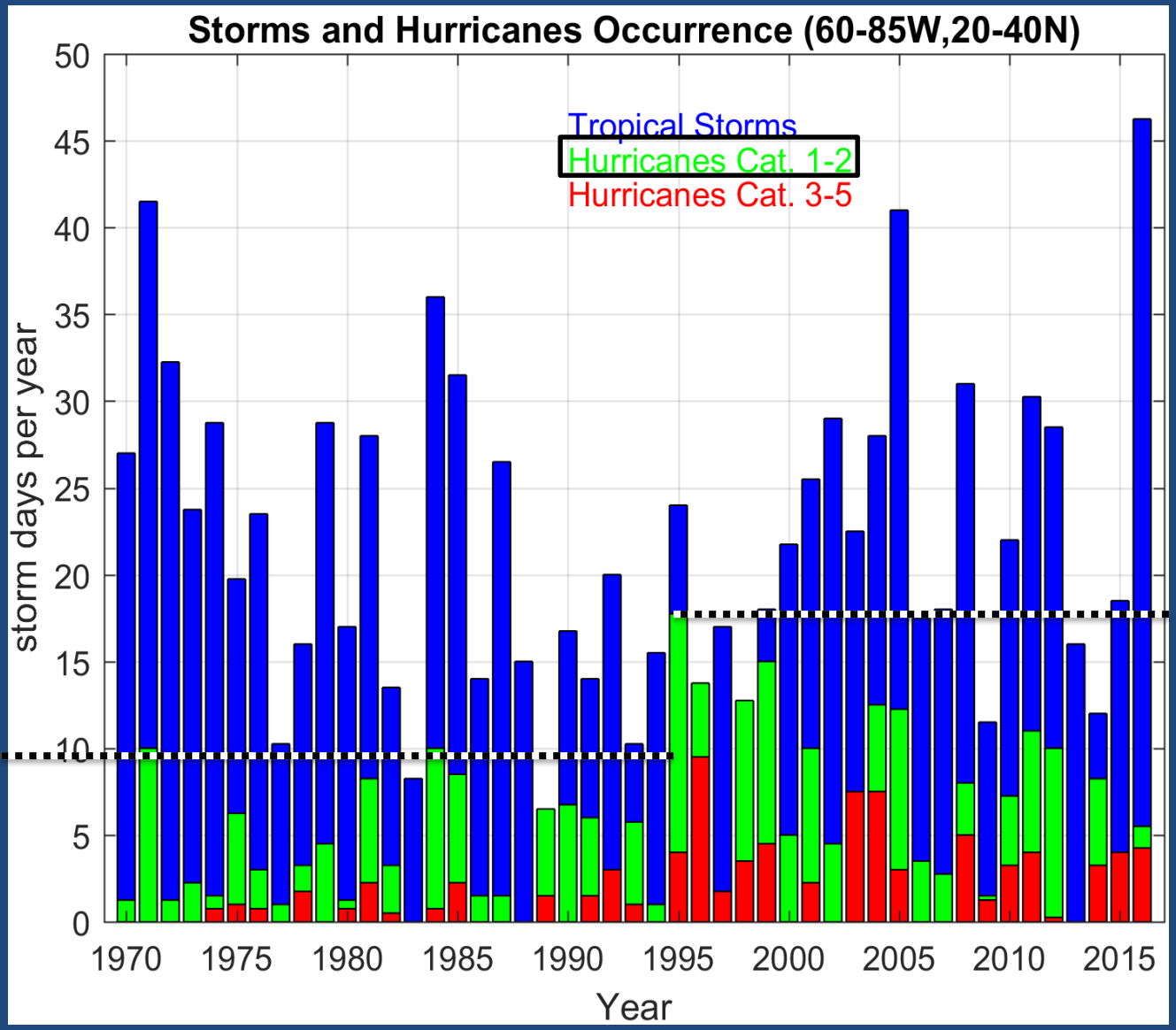

(a) Average Change in Kinetic Energy (top 50m)
← short-term direct impact of wind
KE (m/s)^2
0.04
0.03
0.02
0.01
0
6
7
8
9
10
11
12
13
14
Day in October
(b) Average Change in Potential Energy (top 50m)
PE (m/s)^2
0.005
0
−0.005
−0.01
−0.015
−0.02
−0.025
WIND
FC
HF
WIND+HF
long-term impact on ocean stability →
Day in October
warmer
(more stable)
cooler
(less stable)

Questions:

- With warming climate, are Atlantic storms (tropical storms and hurricanes) getting stronger, more frequent, or last longer?

- Do storms have a lasting impact on ocean circulation (e.g., the Gulf Stream)

A shift in the pattern of hurricanes since the 1990s?
More days with storms- do they last longer due to warmer waters?



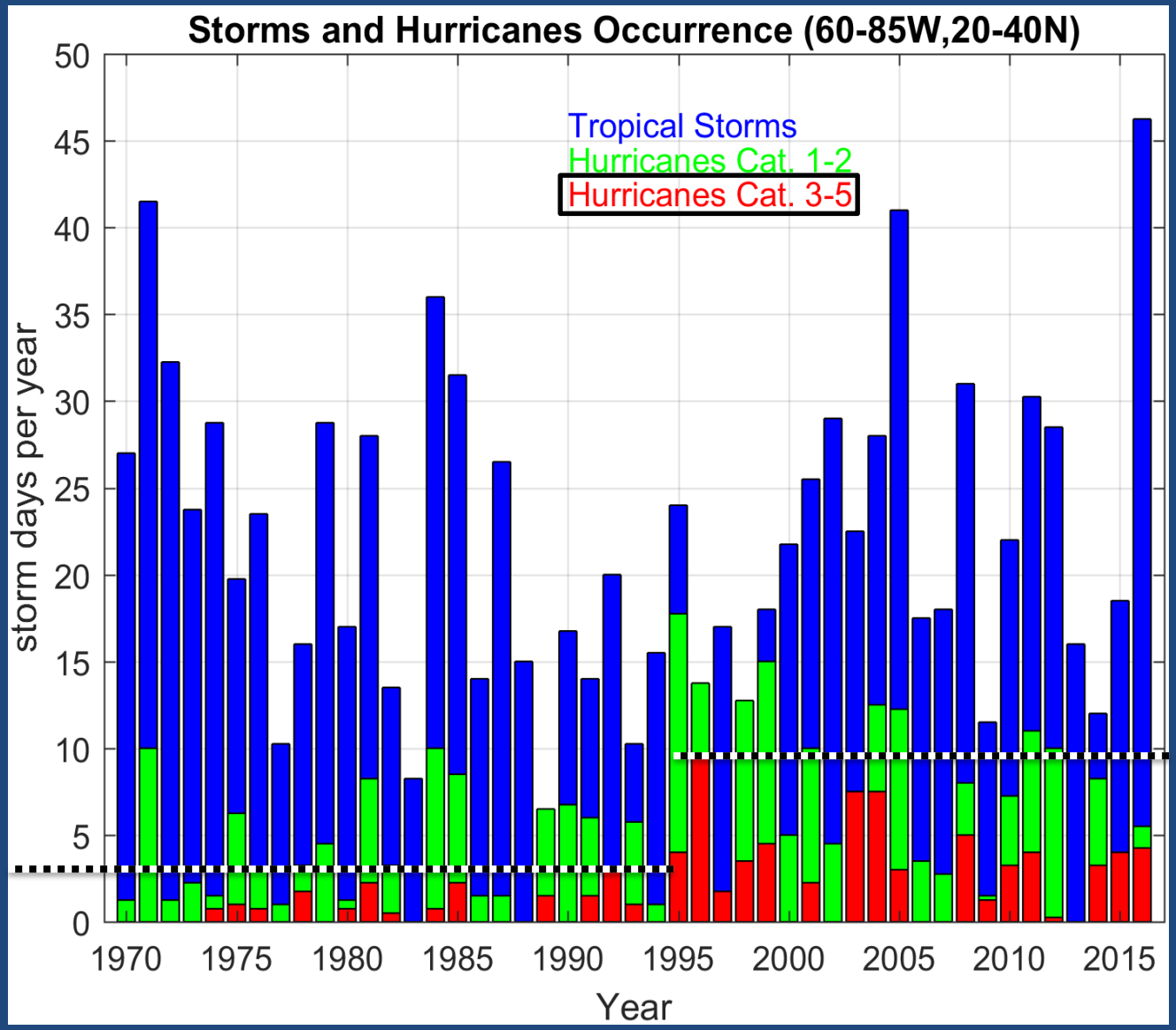
max storm days before 1990s

Hur. Cat. 1-2

max storm days after 1990s

Hur. Cat. 1-2

A shift in the pattern of hurricanes since the 1990s?
More days with storms- do they last longer due to warmer waters?



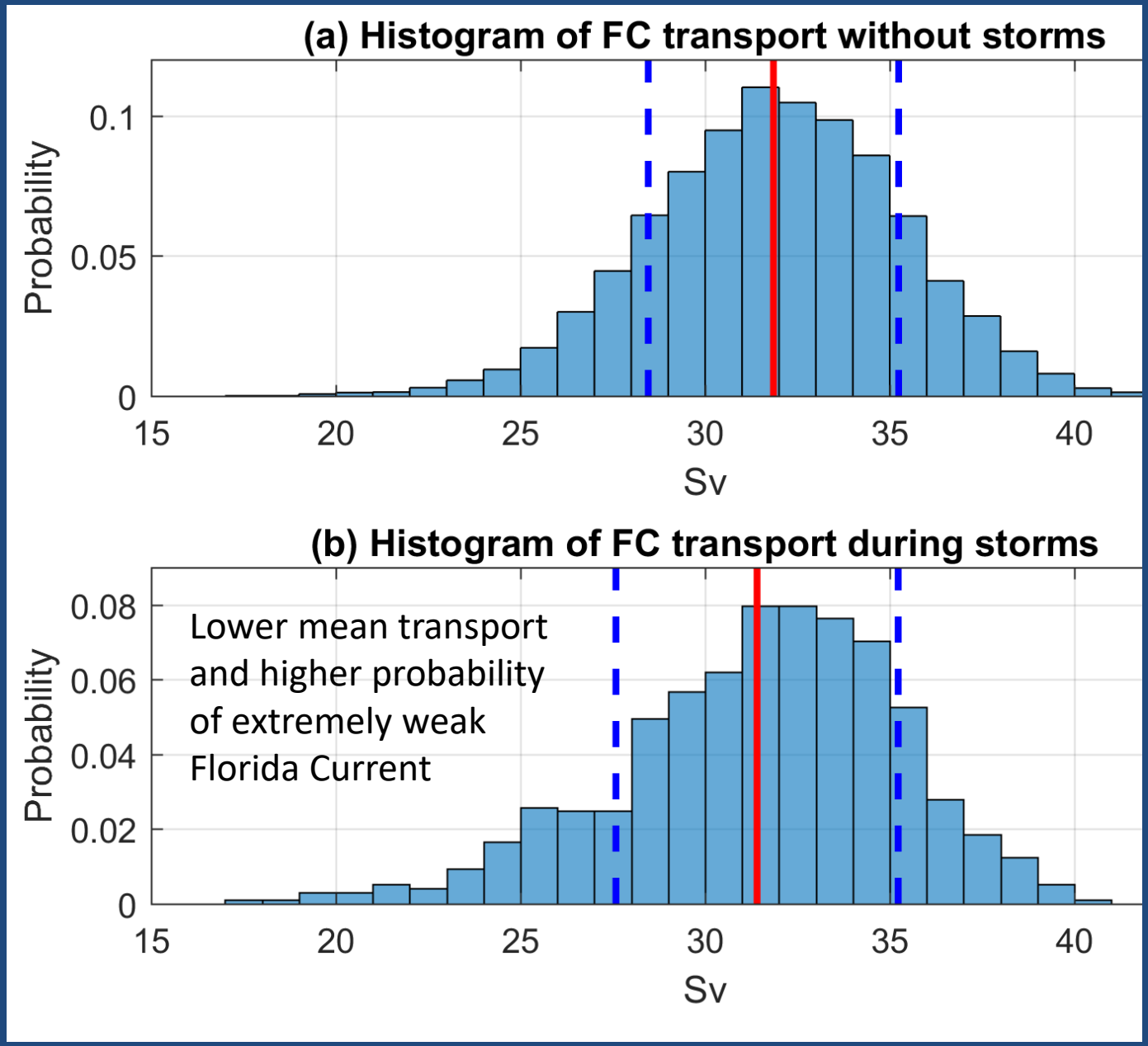
max storm days before 1990s

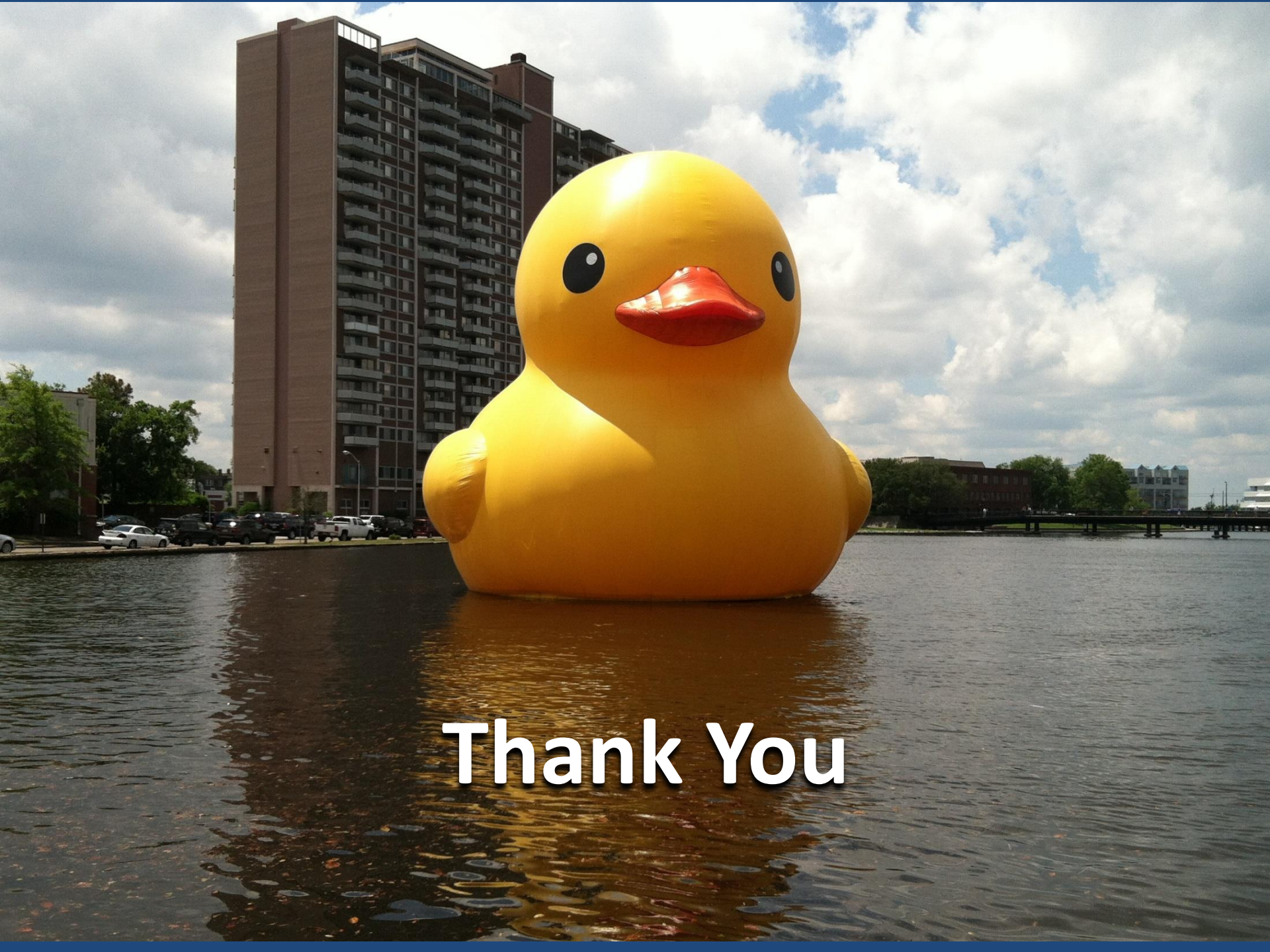
Hur. Cat. 3-5

max storm days after 1990s

Hur. Cat. 3-5

Potential lasting impact of tropical storms and hurricanes on the FC: Lower mean transport and larger probability of extremely weak FC.




Thank You