Old Dominion University
ODU Digital Commons

July 29, 2016: The Latest in Sea Level Rise Science

Hampton Roads Sea Level Rise/Flooding Adaptation Forum

7-29-2016

# The Science of Sea Level Rise and the Impact of the Gulf Stream

Tal Ezer
*Old Dominion University*

Follow this and additional works at: http://digitalcommons.odu.edu/hraforum_13

 Part of the Climate Commons

Repository Citation
Ezer, Tal, "The Science of Sea Level Rise and the Impact of the Gulf Stream" (2016). *July 29, 2016: The Latest in Sea Level Rise Science.* Paper 6.
http://digitalcommons.odu.edu/hraforum_13/6

This Presentation is brought to you for free and open access by the Hampton Roads Sea Level Rise/Flooding Adaptation Forum at ODU Digital Commons. It has been accepted for inclusion in July 29, 2016: The Latest in Sea Level Rise Science by an authorized administrator of ODU Digital Commons. For more information, please contact digitalcommons@odu.edu.

ODU Climate Change and Sea Level Rise Initiative


Hampton Roads SLR & Adaptation Forum
Hampton VA, 7/29/16

# The science of sea level rise and the impact of the Gulf Stream

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

- what is happening?

  on the impact of sea level rise and flooding

- what we know?

  on the science of sea level rise

- what will happen next?

  projections of future sea level rise

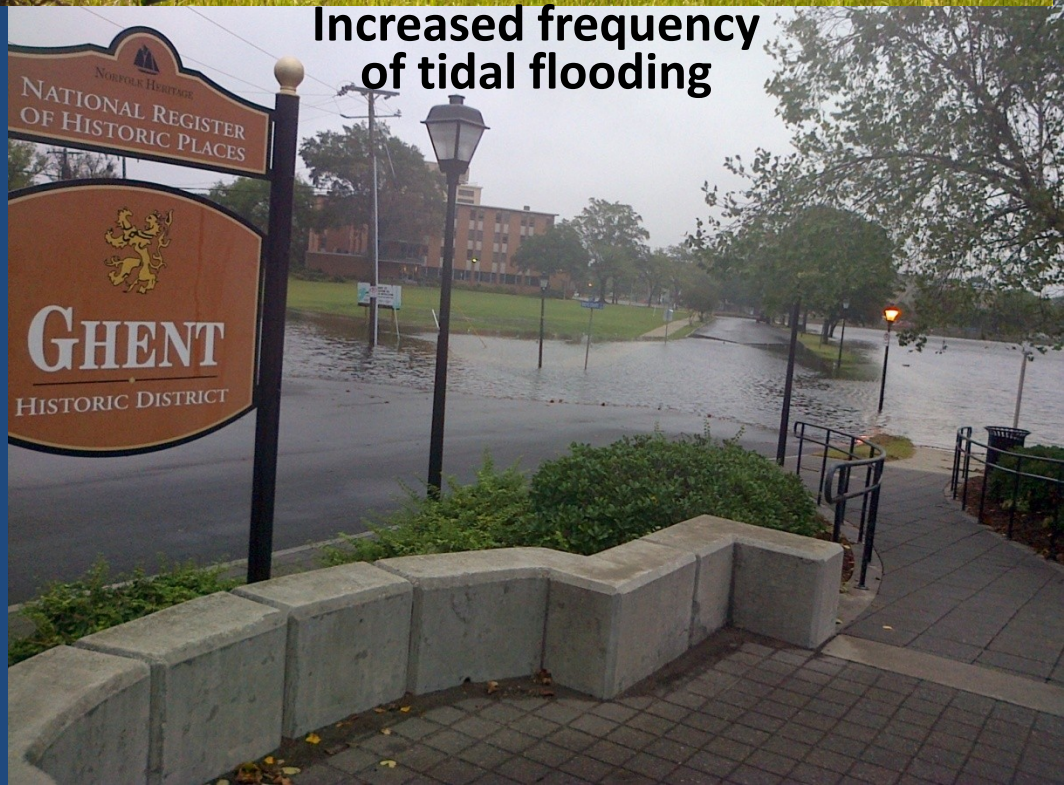
# Impacts of rising seas on the environment and coasts:

**Increased coastal erosion**

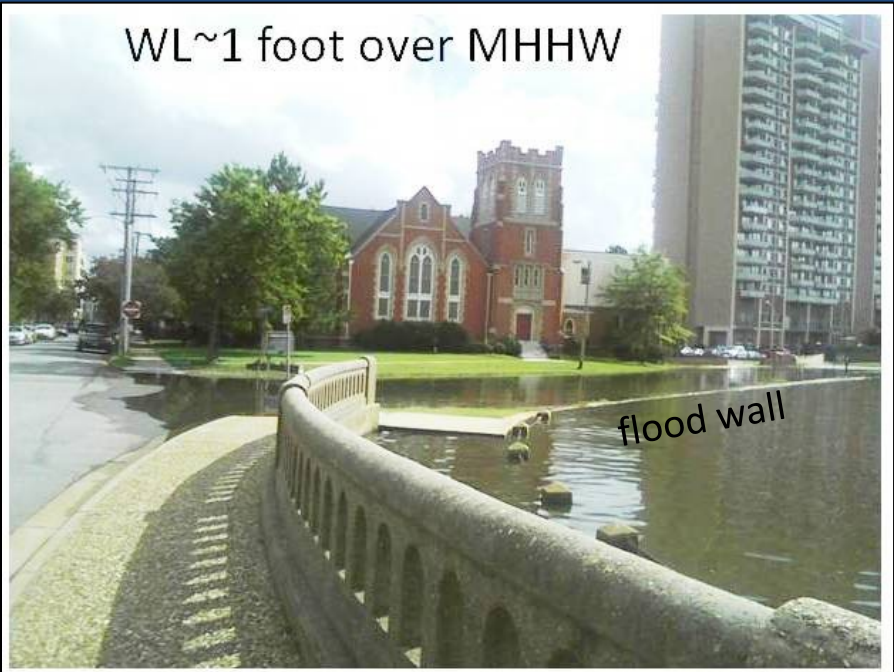
**Saltwater intrusion into Virginia's marshland**

**Increased damage from storm surges**


**Increased frequency of tidal flooding**



# What sea level rise looks like today: Historic Hague neighborhood of Norfolk, VA



Many complex and unpredictable factors can affect sea level rise and flooding…

Maps & Radar Severe Weather News & Blogs Photos & Video More Search Locations

Popular Cities | New York, NY 27.1 °F Clear | London, UK 46 °F Overcast | Chicago, IL 28.4 °F Mostly Cloudy | Boston, MA 26.6 °F Clear | Houston, TX 47.7 °F Overcast

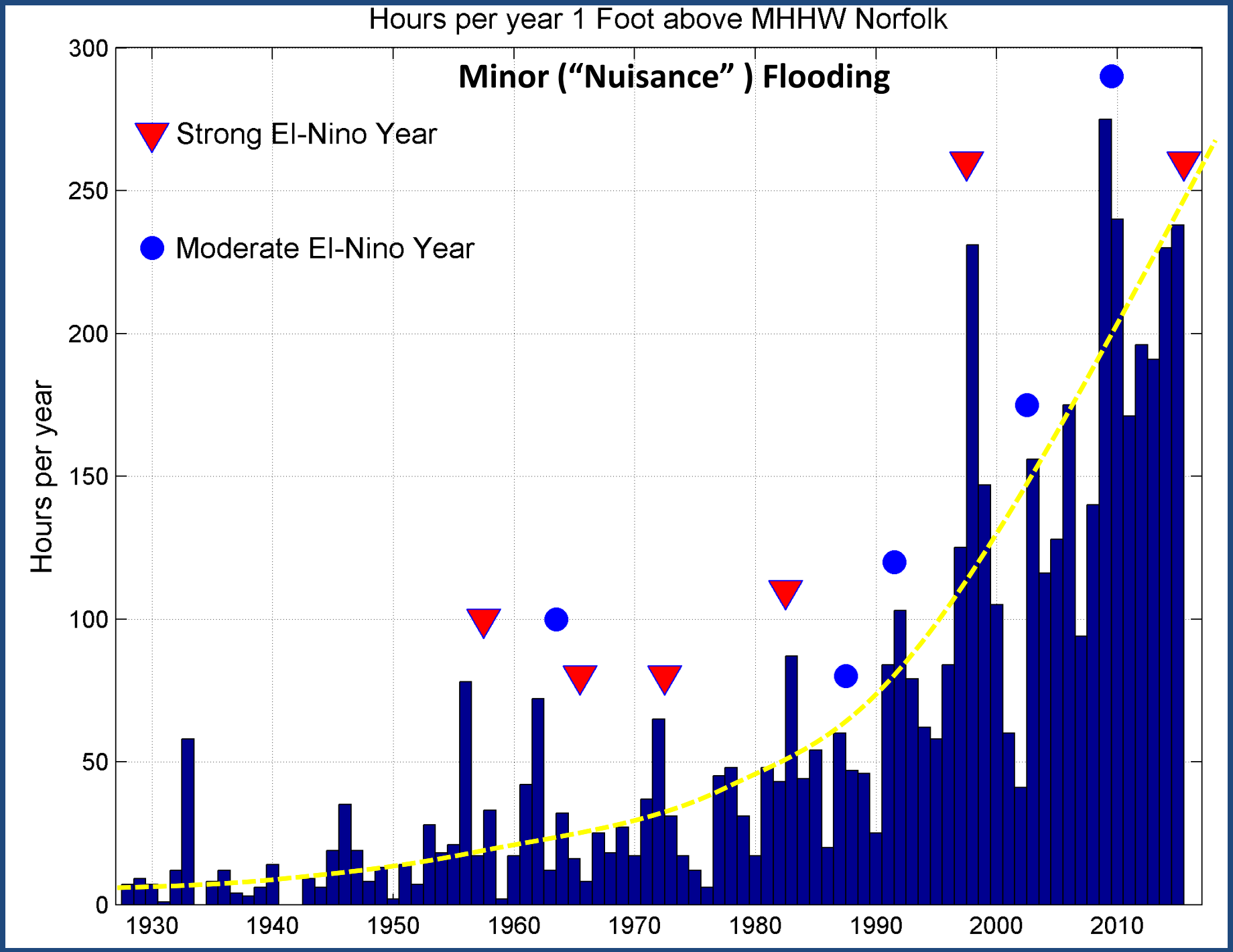
News & Blogs

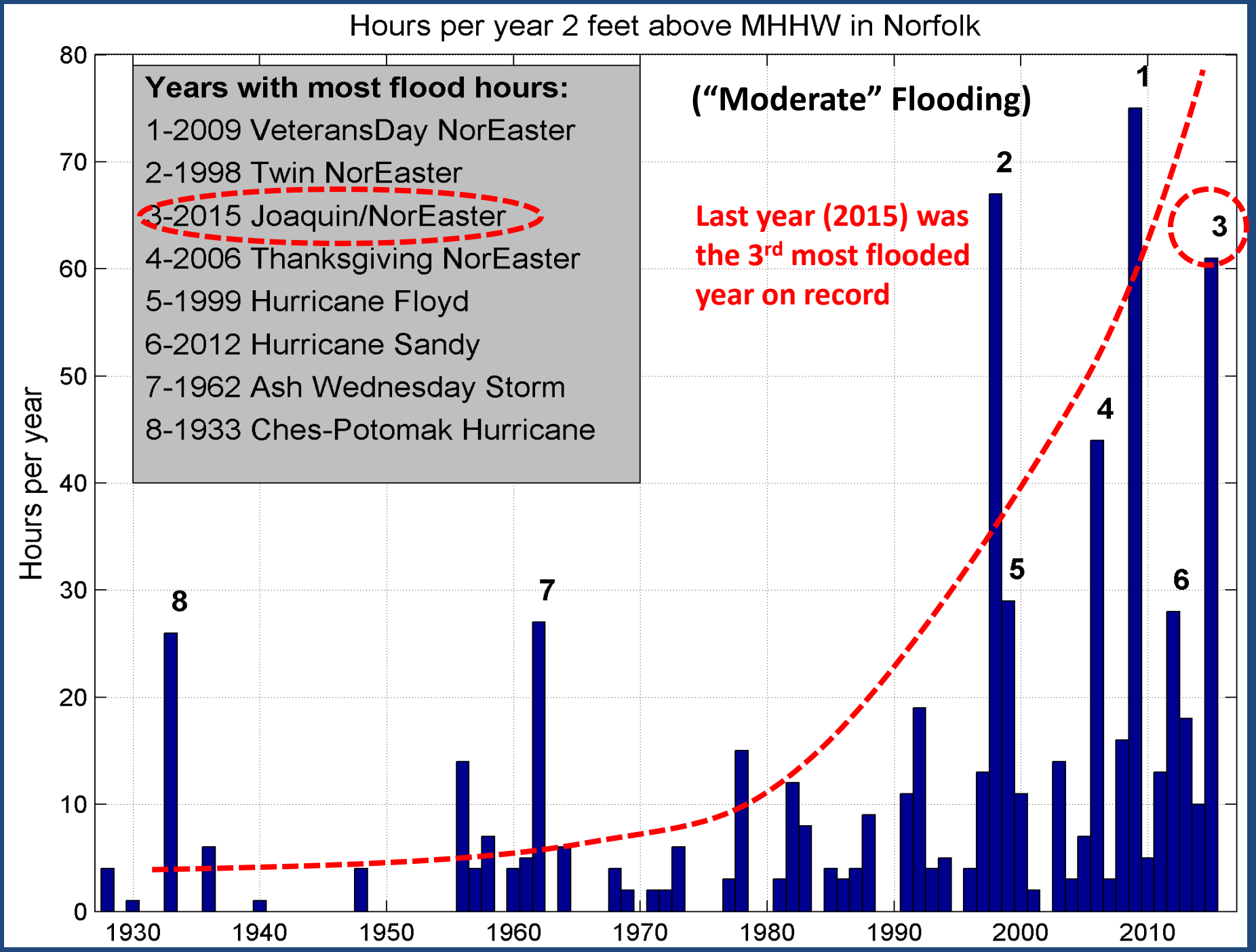
Dr. Jeff Masters | Weather Blogs | News Stories | Infographics | Posters | Sta

## El Niño Expected to Increase Nuisance Coastal Flooding in U.S.

By: Jeff Masters , 7:03 PM GMT on September 09, 2015

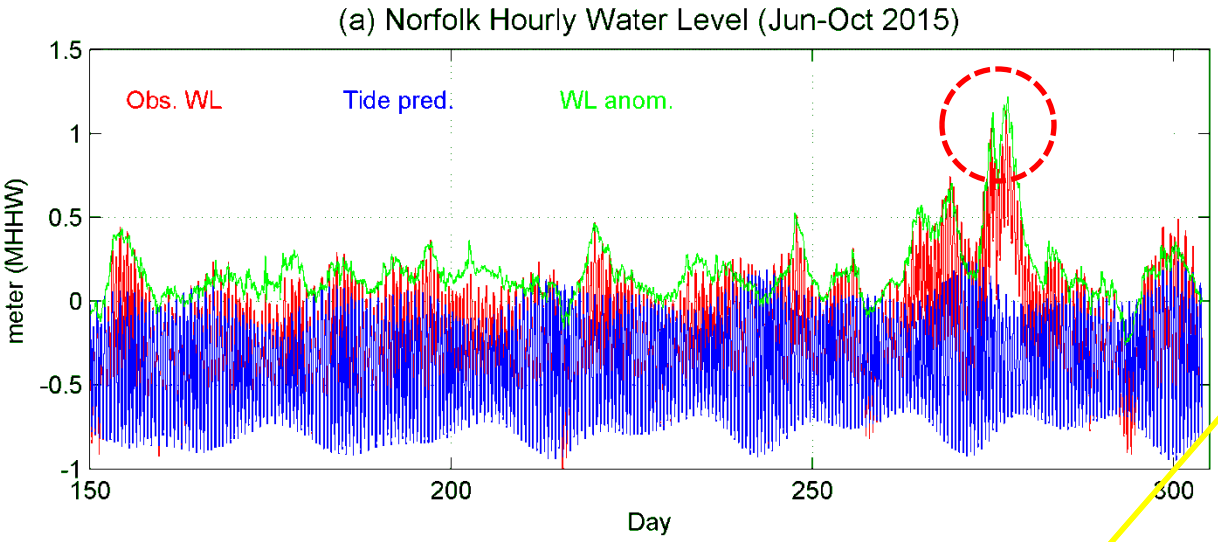
**Figure 1.** Nuisance street flooding in Norfolk, Virginia on October 9, 2013, during passage of a front at high tide. In the background: on the right side is a church built in 1902 and now for sale largely due to frequent flooding, and in the middle behind the trees is the Chrysler Museum of Art that just completed renovation that include improvements to reduce the potential damage from flooding. Image credit: Tal Ezer, Old Dominion University.

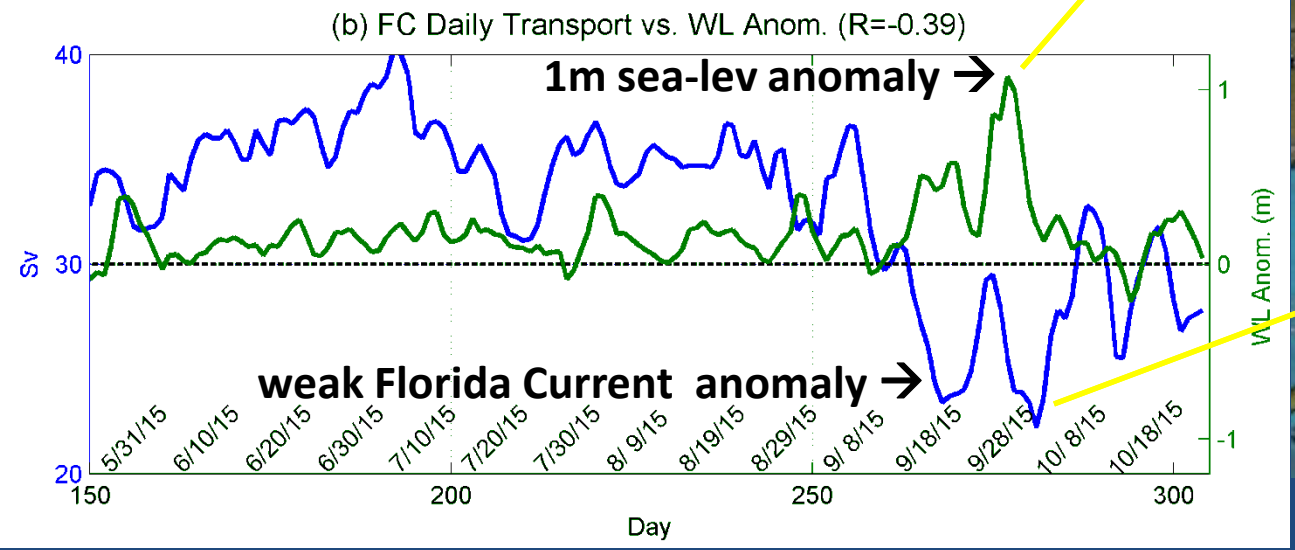

Hours per year 1 Foot above MHHW Norfolk
Minor ("Nuisance" ) Flooding
Strong El-Nino Year
Moderate El-Nino Year
Hours per year
300
250
200
150
100
50
0
1930
1940
1950
1960
1970
1980
1990
2000
2010


Hours per year 2 feet above MHHW in Norfolk
Years with most flood hours:
1-2009 VeteransDay NorEaster
2-1998 Twin NorEaster
3-2015 Joaquin/NorEaster
4-2006 Thanksgiving NorEaster
5-1999 Hurricane Floyd
6-2012 Hurricane Sandy
7-1962 Ash Wednesday Storm
8-1933 Ches-Potomak Hurricane
("Moderate" Flooding)
Last year (2015) was the 3rd most flooded year on record
Hours per year
0
10
20
30
40
50
60
70
80
1930
1940
1950
1960
1970
1980
1990
2000
2010
1
2
3
4
5
6
7
8

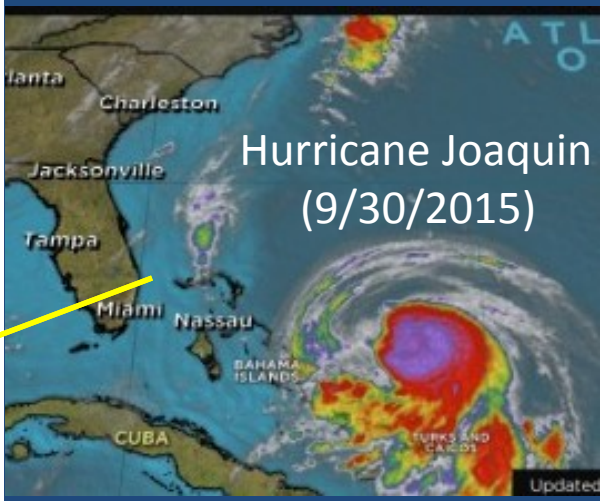
# Sep-Oct 2015: severe flooding on the southeast US coast: a combination of Hurricane Joaquin, Nor'easter and weakening Gulf Stream

Flooding in Norfolk, VA




Hurr .→ GS → coastal SL



Hurricane Joaquin (9/30/2015)

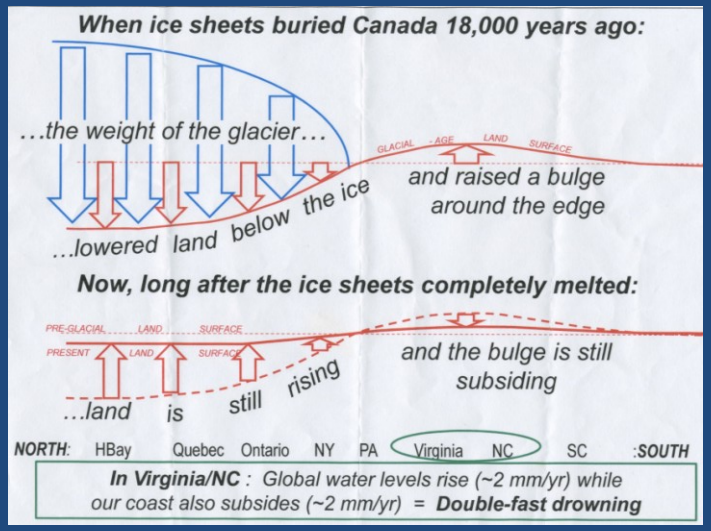
# Local sea level rise (SLR) is the result of several processes:

- Global Sea Rise

thermal expansion
melting ice sheets & glaciers
volume change

- Land Motion

Glacial Isostatic Adjustment (GIA), Groundwater extraction, hydrology, geology, etc.

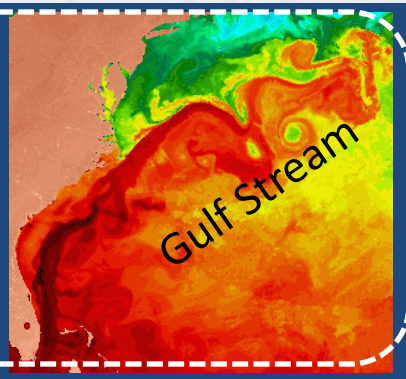



contribute to regional variations in SLR

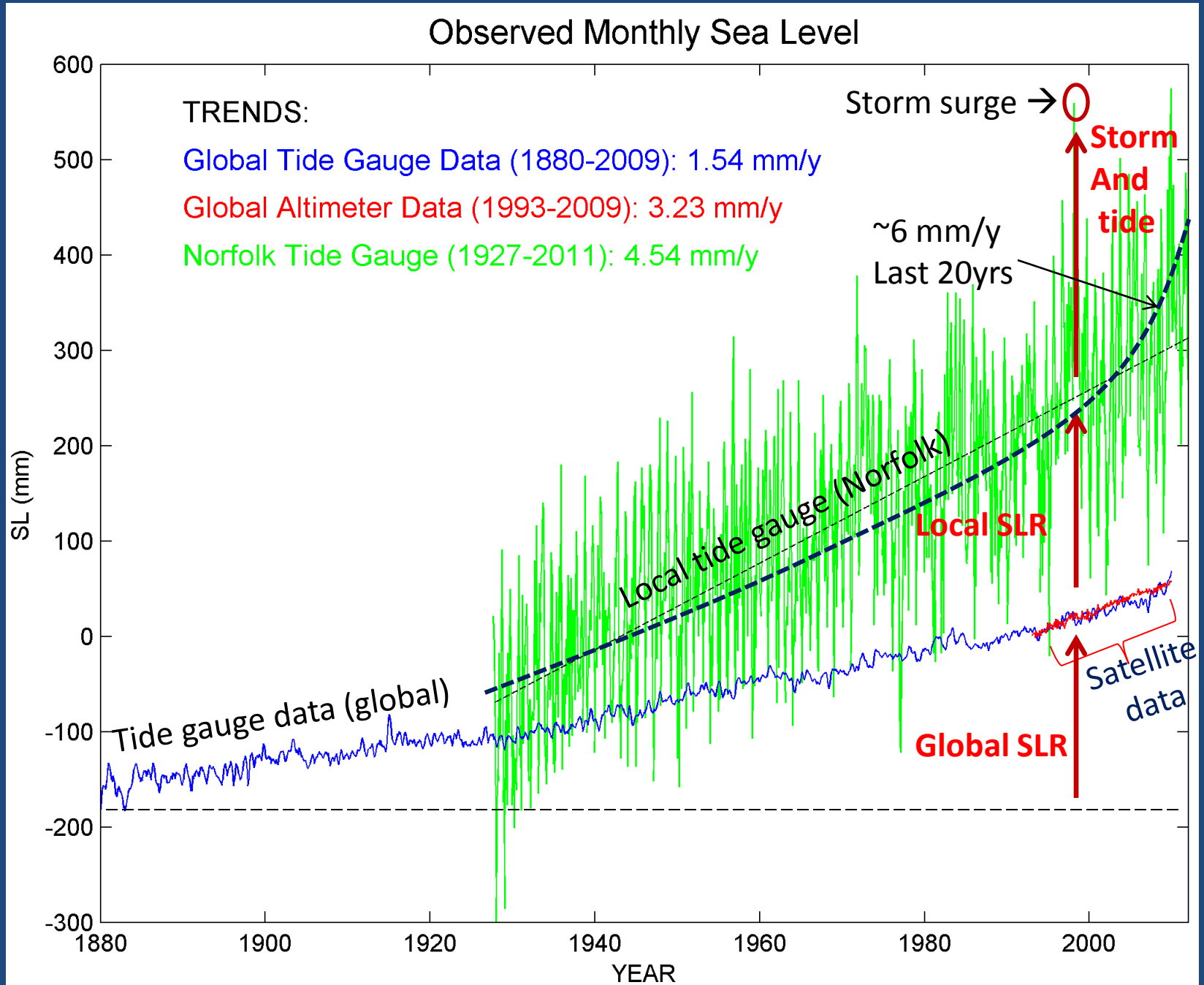
- Oceanic & Atmospheric Dynamics

Gulf Stream, Atlantic Meridional Overturning Circulation (AMOC), North Atlantic Oscillations (NAO), ENSO, etc.

least understood



# Local Sea Level Rise (SLR) – a combination of several factors

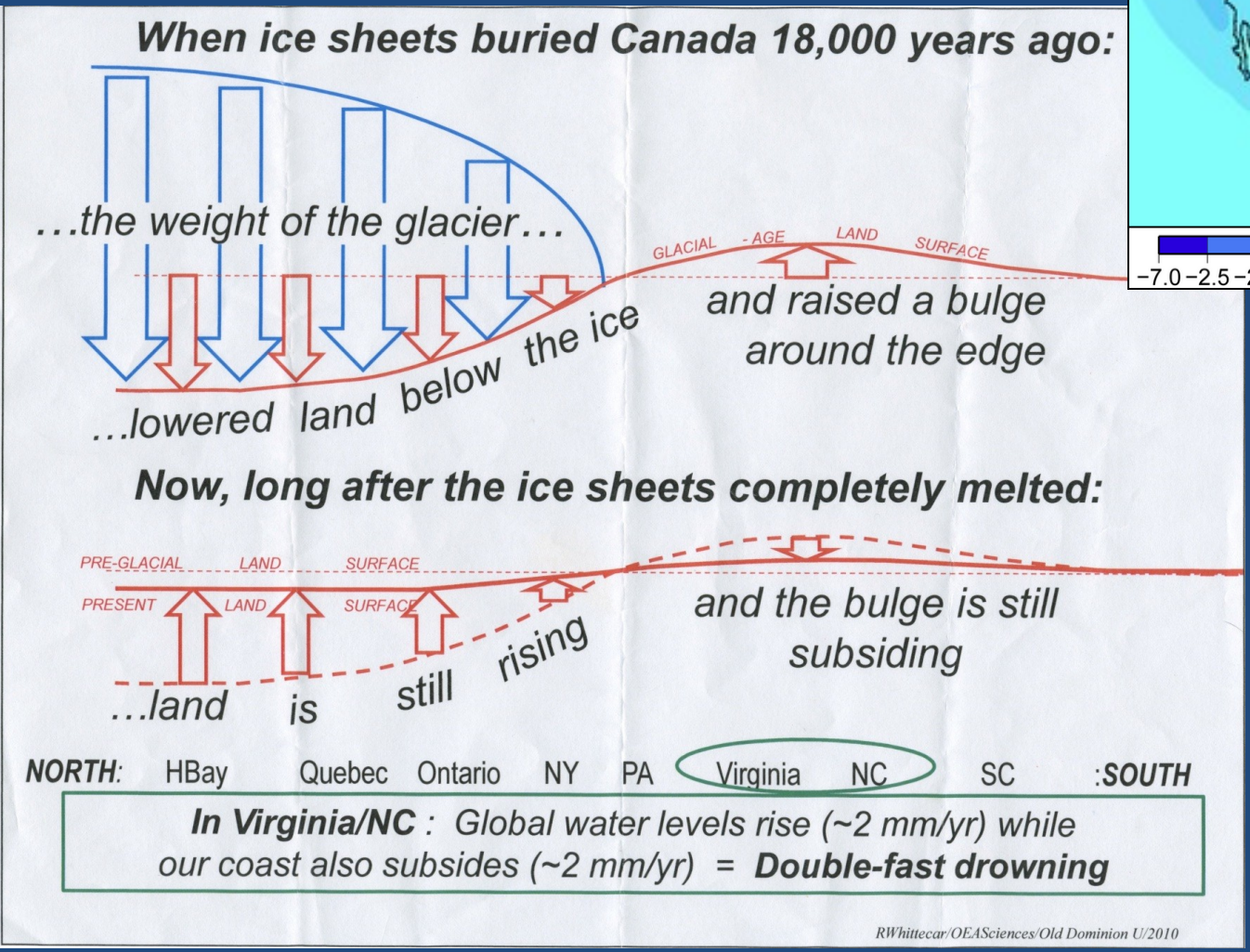


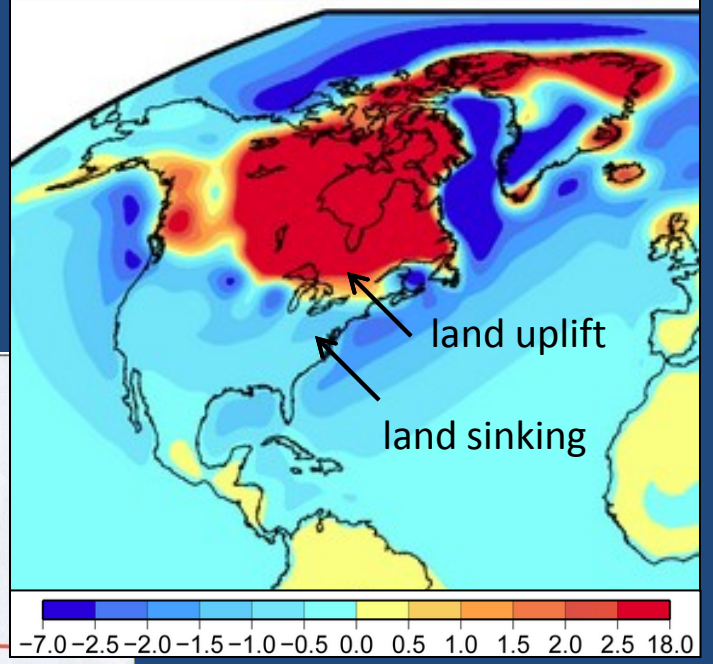

Impact from changes in ocean currents

land Subsidence (we are sinking…)

# Land **Subsidence:**

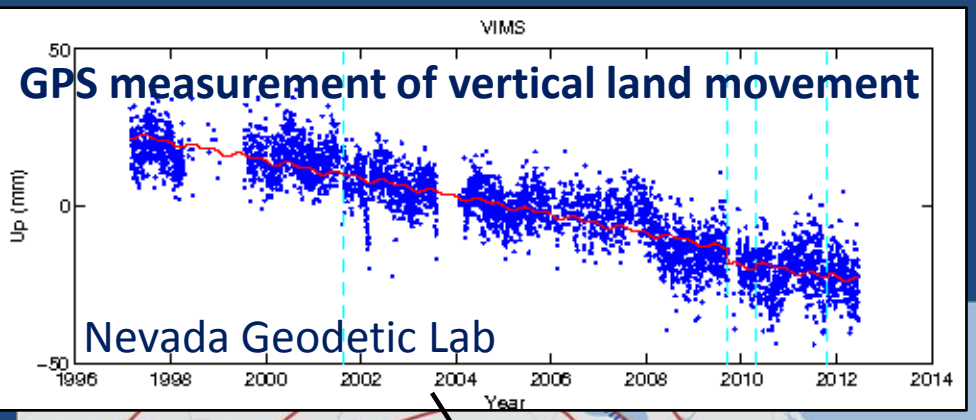
## Glacial Isostatic Adjustment (GIA): due to post glacial rebound the land is sinking (especially in VA, NC, MD)



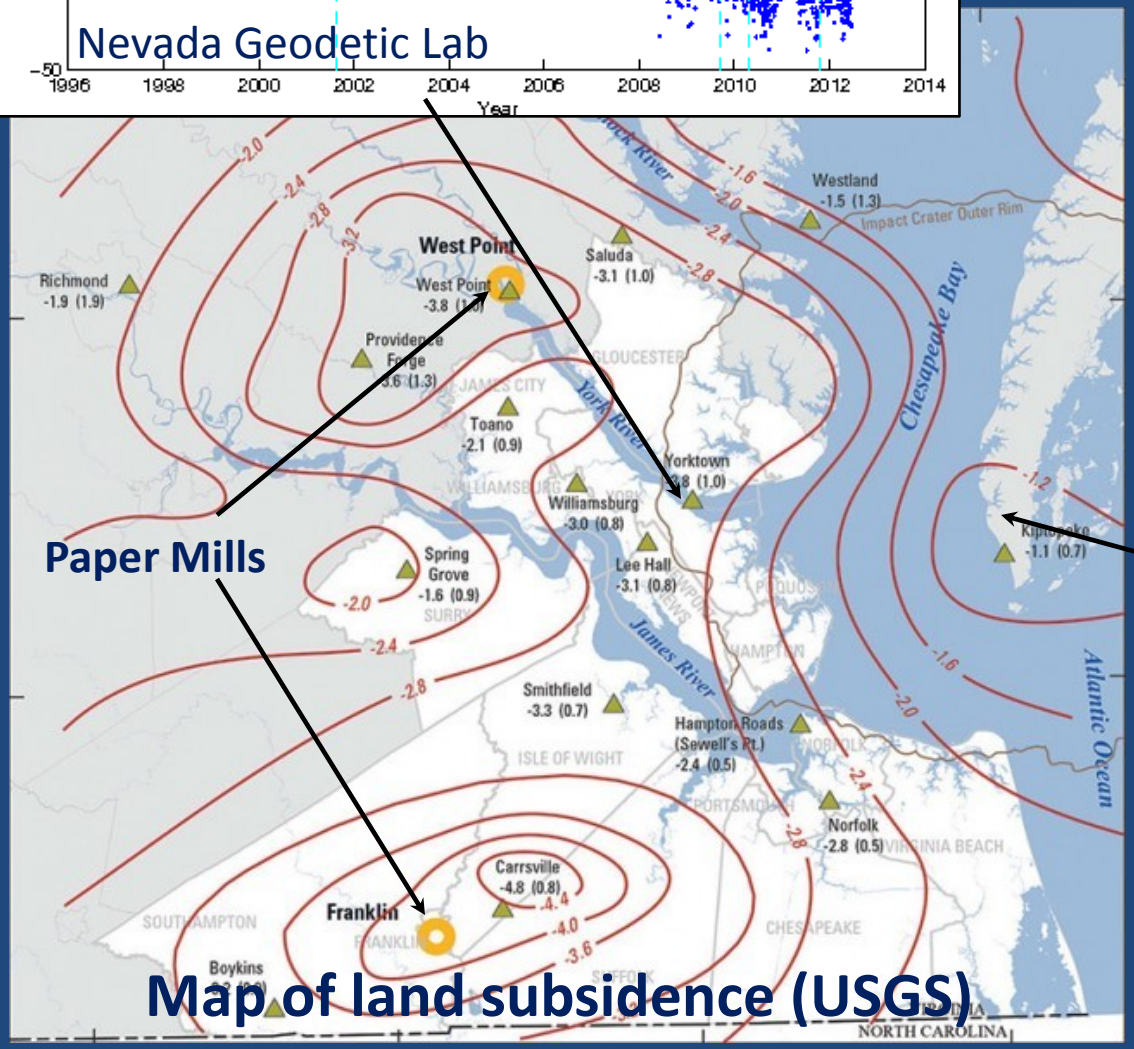



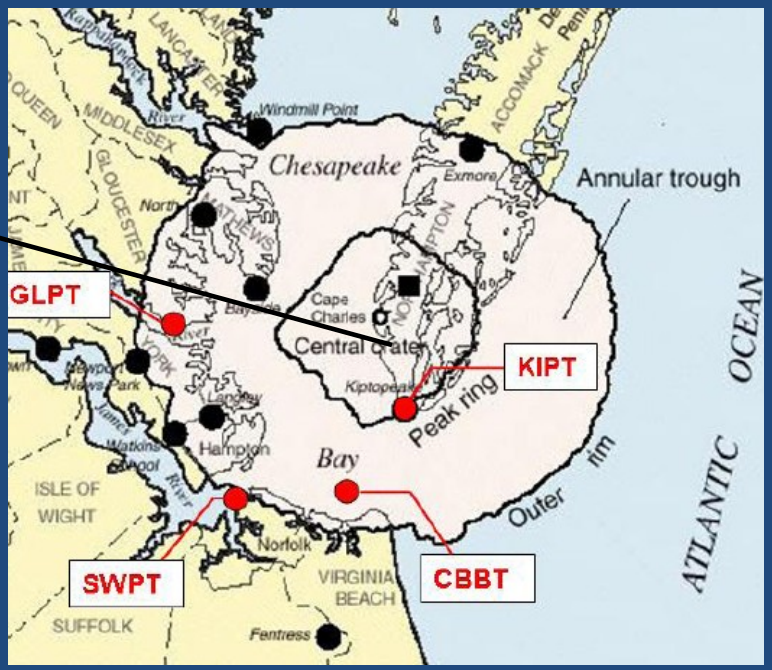

Other contributions to subsidence: sediment compactions, groundwater removal, etc. (Boon et al., 2010)

# While global sea level is rising, land is sinking (~1.5-3 mm/yr in VA)



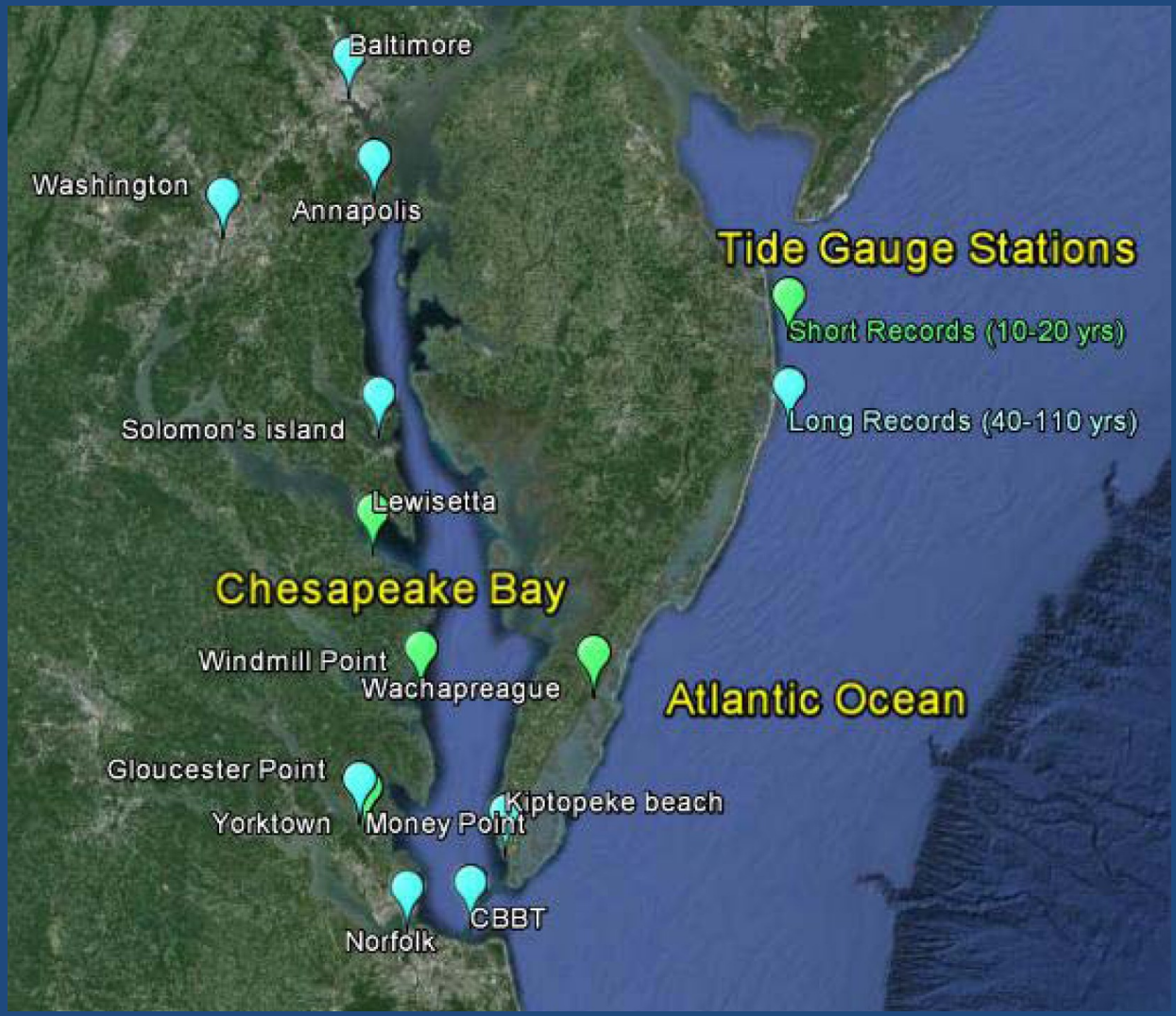

- Post glacial rebound
- Underground water extraction (West Point & Franklin paper mills)
- Other geological reasons (Chesapeake Impact Crater?)

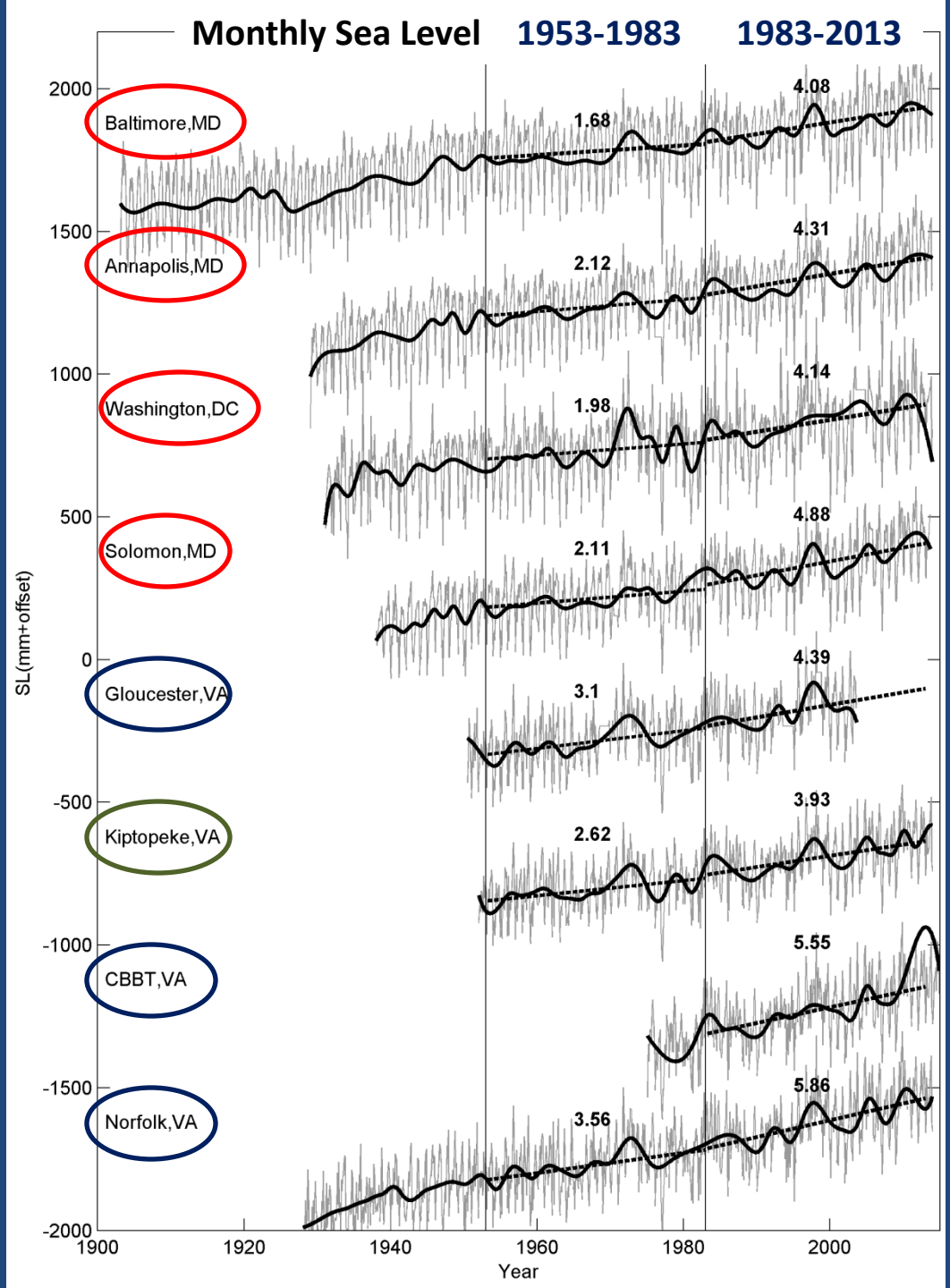


# Rates of sea level rise (SLR) around the Chesapeake Bay

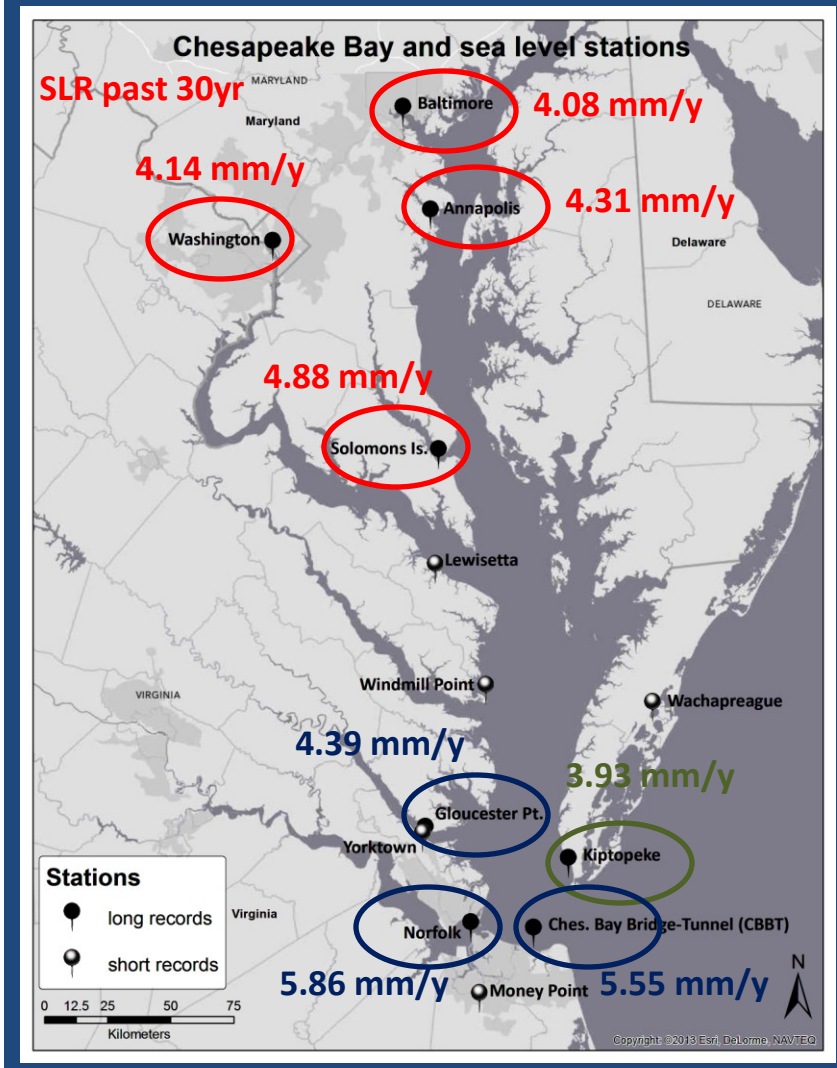
- What are the past trends?
- Are they constant or changing?
- What can they tell us about future SLR?





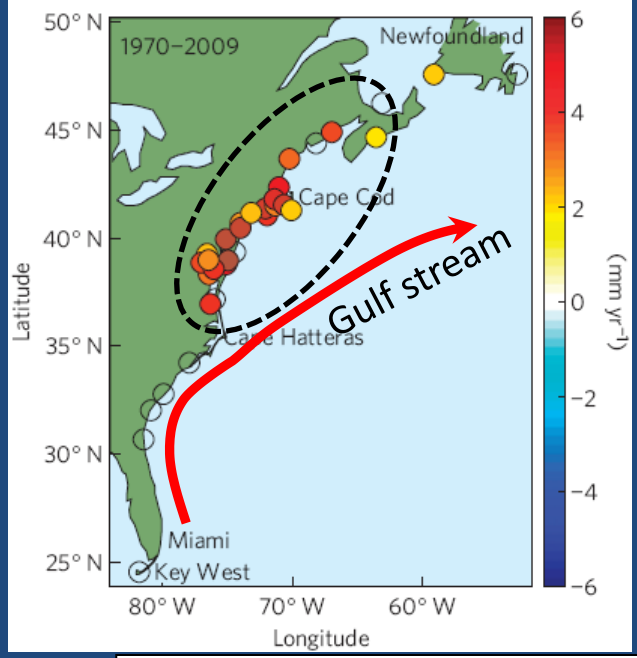

## Long (40-110 yrs) sea level records:

- increase SLR rate from ~**2.4 mm/y** (50s-80s) to ~**4.5 mm/y** (80s-today)
- higher SLR in lower CB, ~**5.3 mm/y**, than upper CB, ~**4.3 mm/y** and Eastern Shore Peninsula, **3.9 mm/y**



# 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

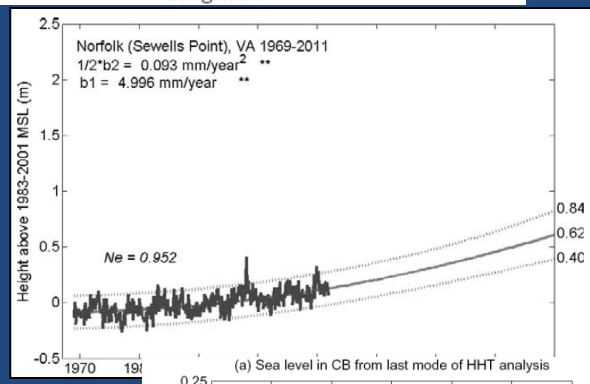
John D. Boon

Virginia Institute of Marine Science
College of William and Mary
P.O. Box 1346
Gloucester Point, VA 23062, U.S.A.
boon@vims.edu


www.cerf-jcr.org

**J. Coastal Res. 2012**

**VIMS**



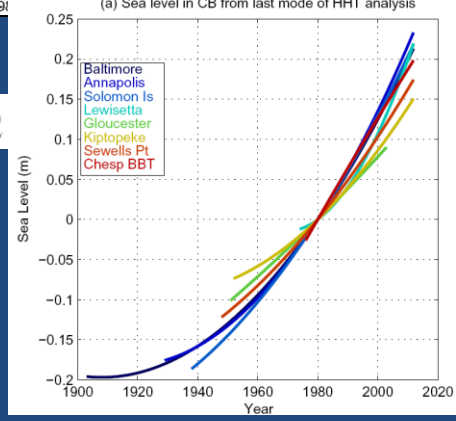

(Method: quadratic line fit)

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)

• The idea that the Gulf Stream can induce coastal sea level variations along the US coast on a range of time scales is not new…

**Fluctuations in Monthly Sea Level on Eastern U.S. Coast as Related to Dynamics of Western North Atlantic Ocean**

Montgomery, R.. *Journal of Marine Research* Volume: 1 Issue 2 (1938) ISSN: 0022-24
ISSN: 1543-9542

1938

JOURNAL OF GEOPHYSICAL RESEARCH
Oceans

JGR

**Fluctuations of monthly sea level as related to the intensity of the Gulf Stream from Key West to Norfolk**

John P. Blaha [observations; monthly-seasonal scales]

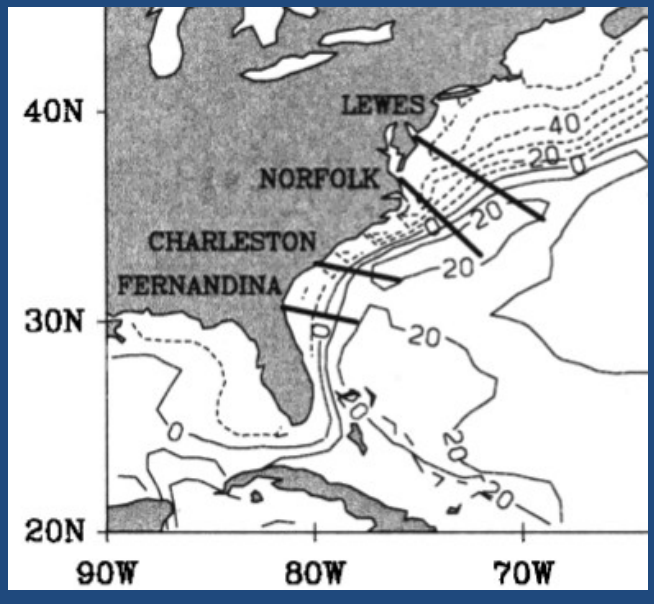
1984

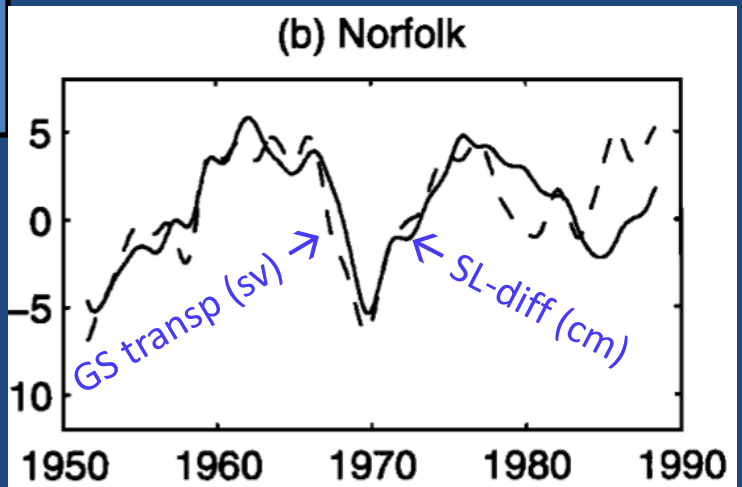
Geophysical Research Letters

**Can long-term variability in the Gulf Stream Transport be inferred from sea level?**

Tal Ezer [model; decadal time-scales]

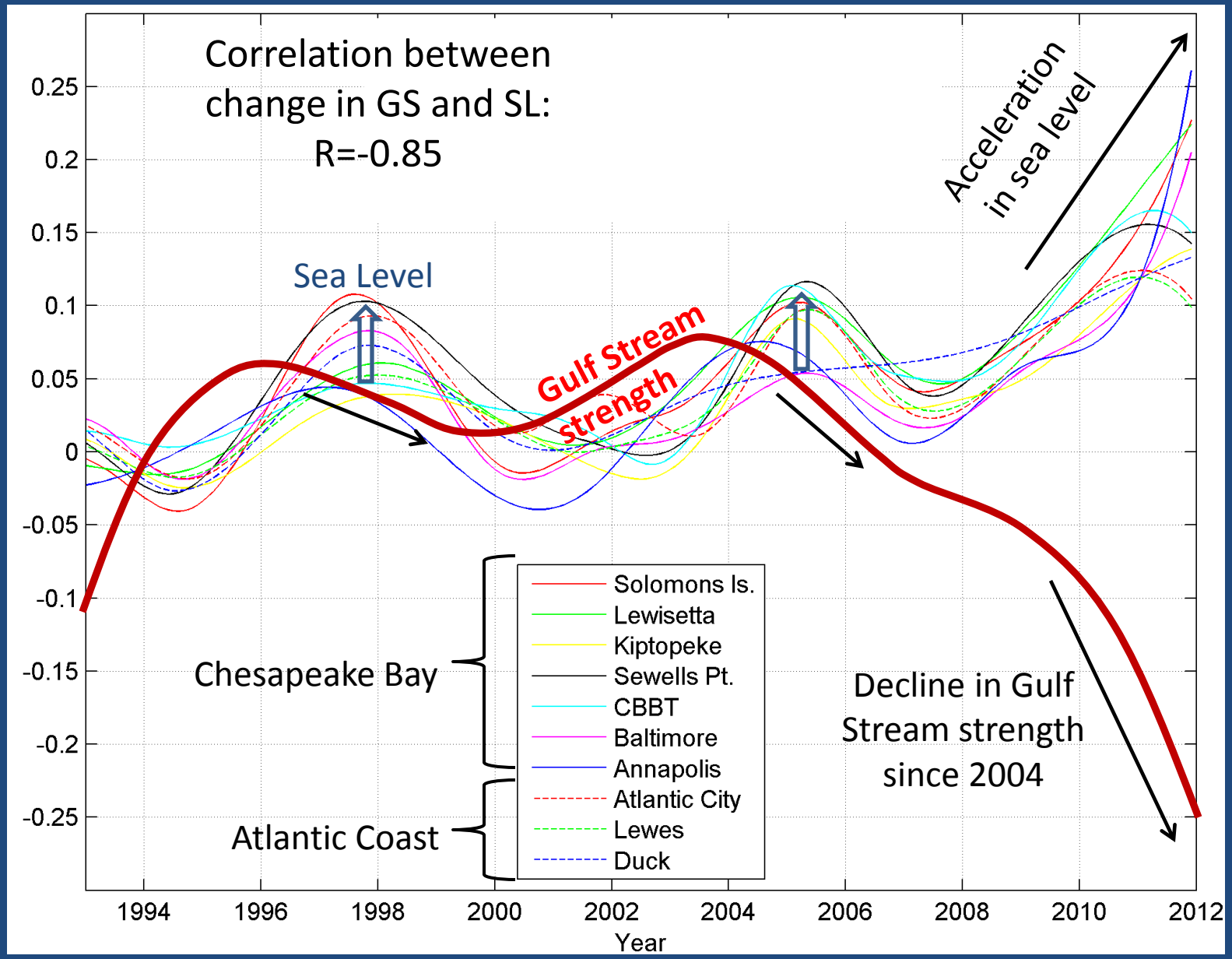
2001



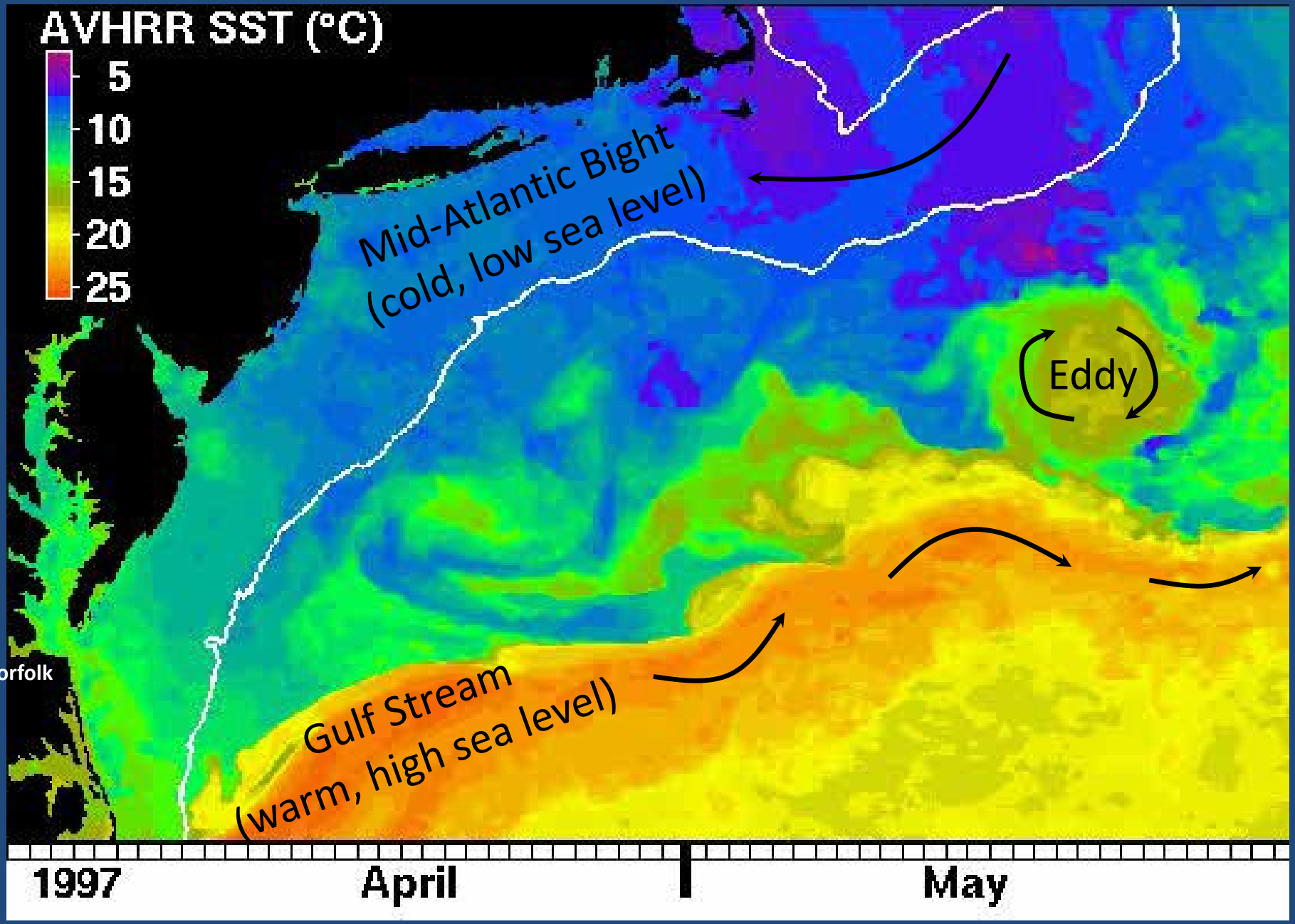



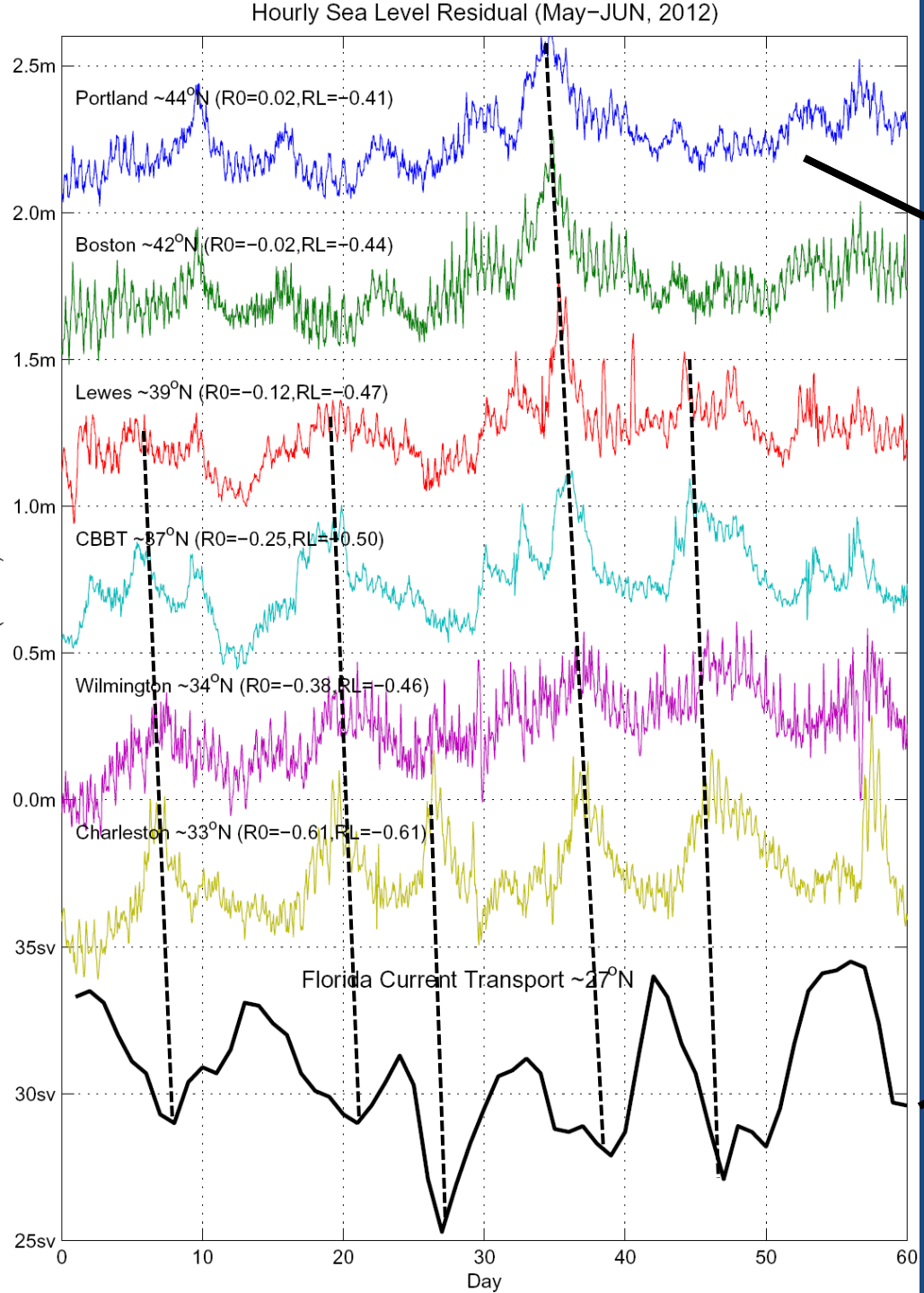
# Long-time scale variability (from Ezer et al., JGR, 2013)

## Why do stations in different locations show the same pattern?



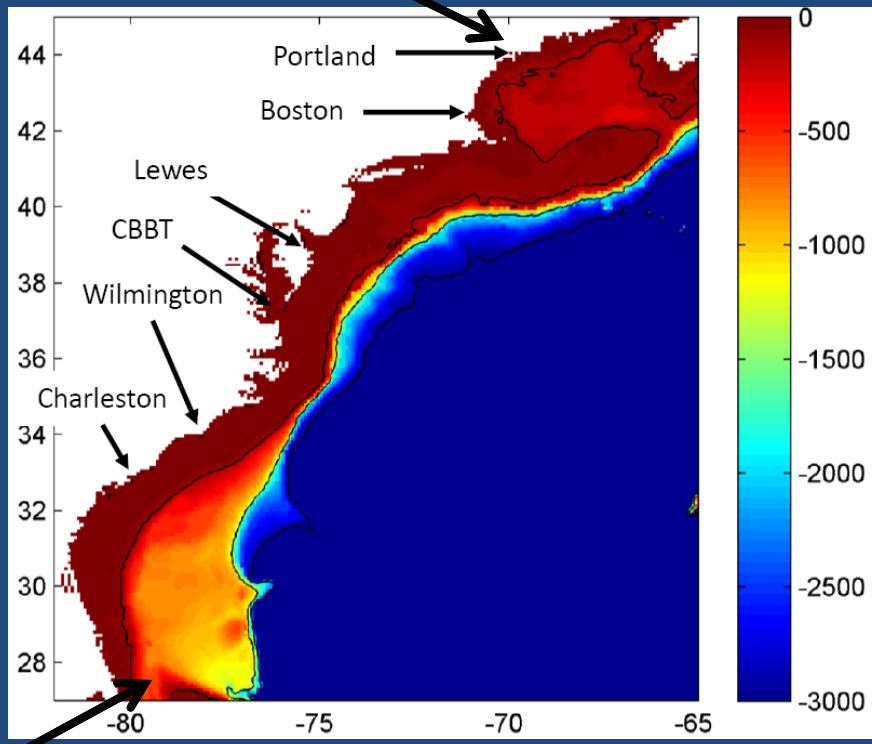
# The Gulf Stream is dynamic and unpredictable





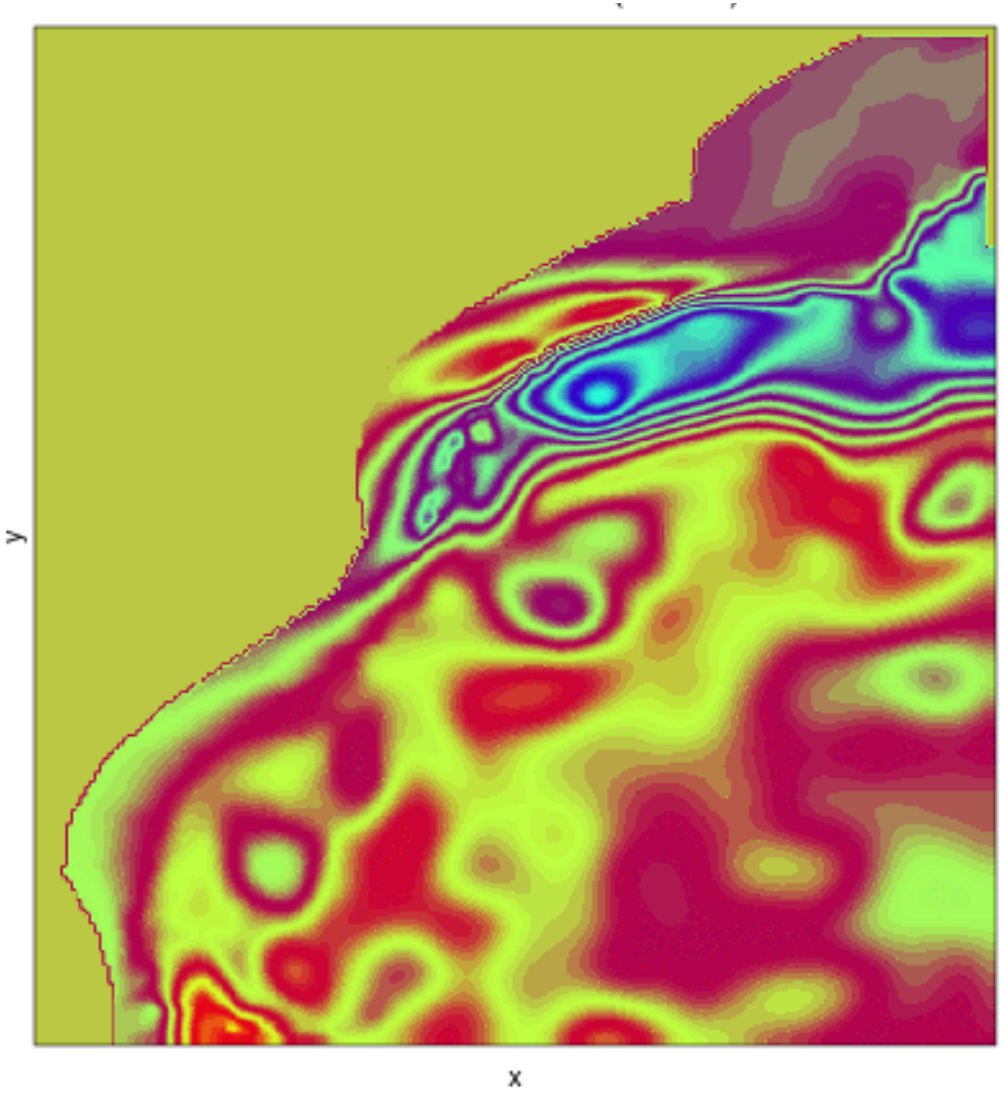

# Short-term fluctuations:

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

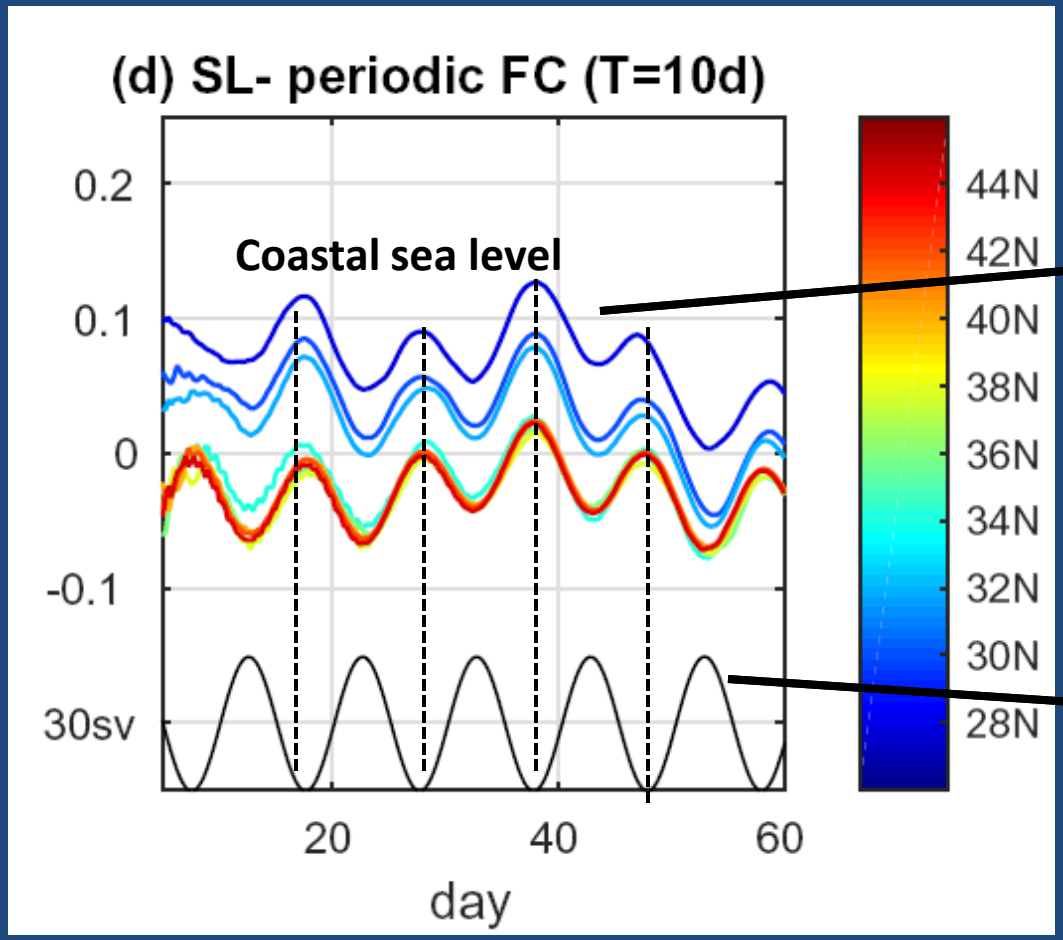


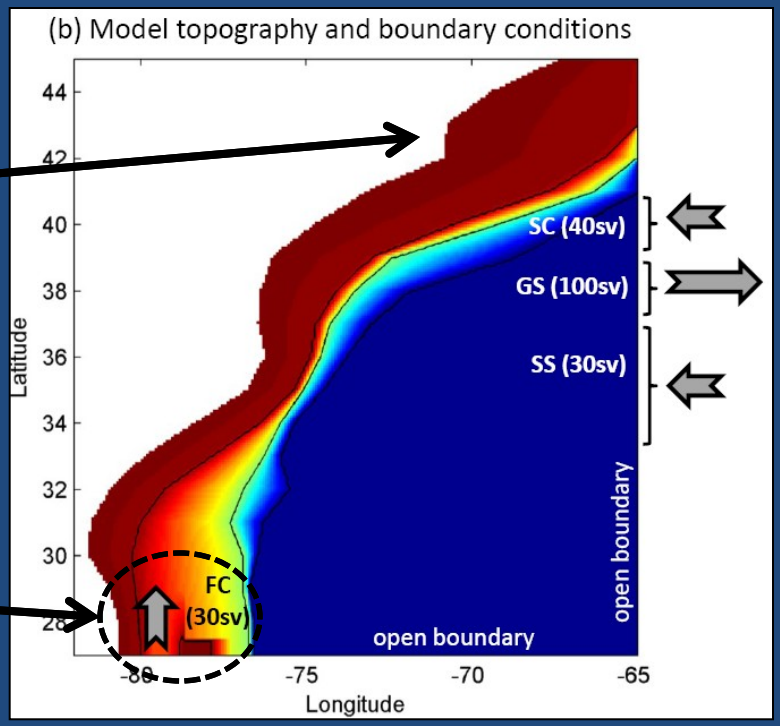

Florida Current Transport

Can fluctuations in the Gulf Stream really generate coastal sea level variations?, we can test this hypothesis with a computer model of the Gulf Stream (Ezer, 2016)



# The only forcing in the model is fluctuations in the Florida Current…
# … and in fact they do generate fluctuations in coastal sea level

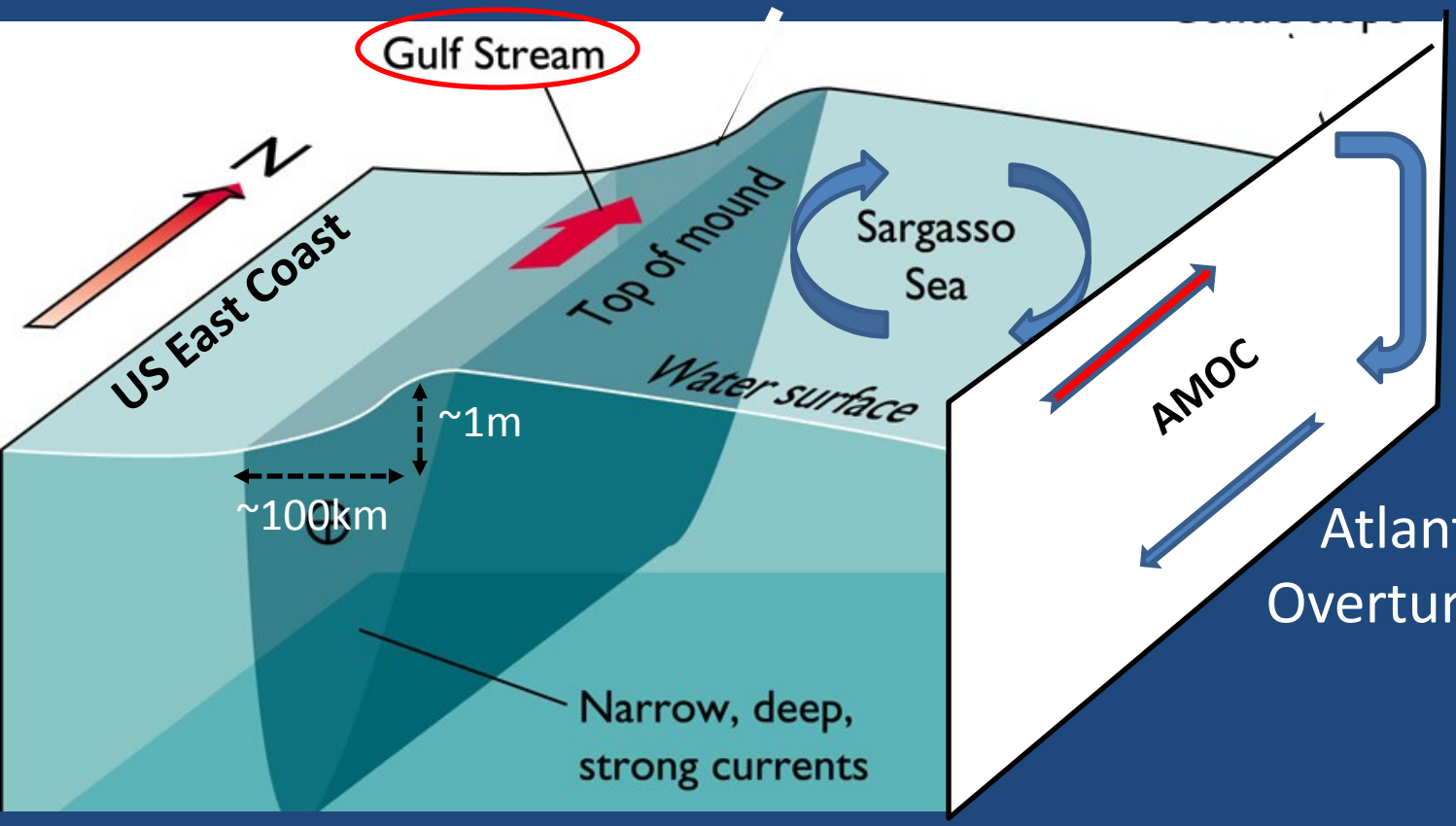



Florida Current Transport

# How can ocean dynamics affect coastal sea level?

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

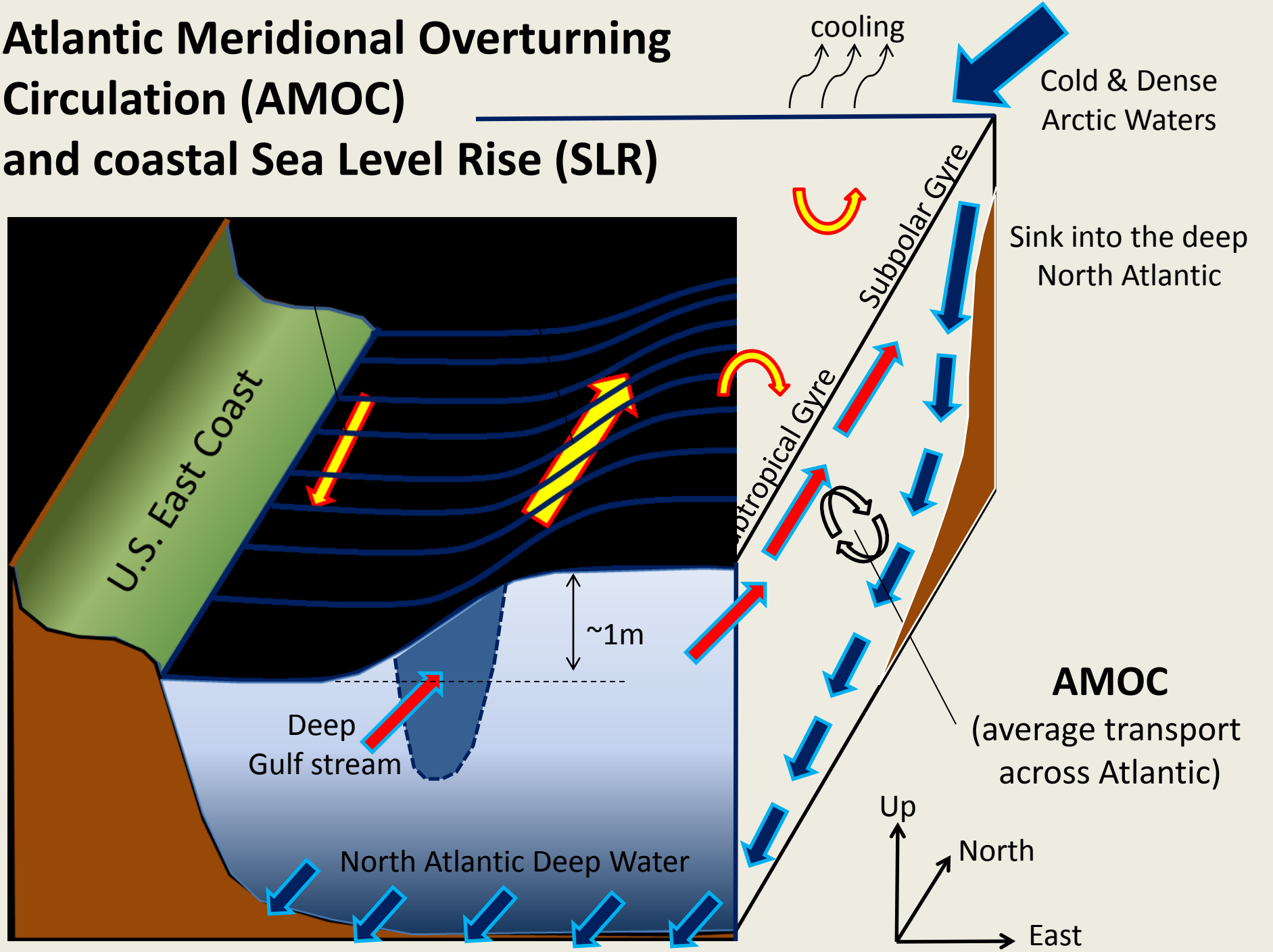



Atlantic Meridional Overturning Circulation (AMOC)

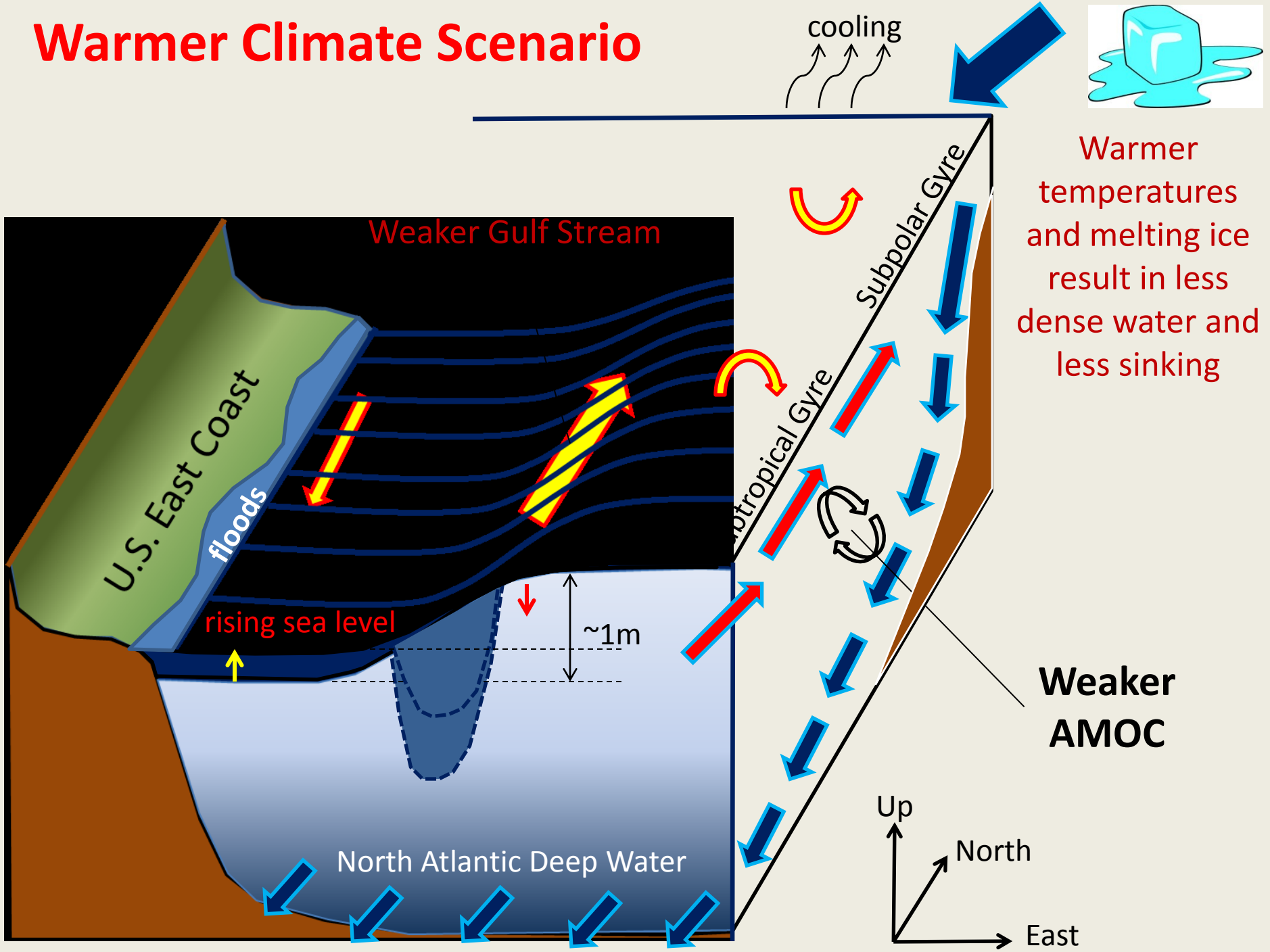
The Gulf Stream keeps sea level on the US East Coast ~1-1.5 m (3-5 feet) lower than water offshore → variations in GS strength or position will affect SL.

**In warmer climate the Atlantic Ocean circulation is expected to weaken**
**If the Gulf Stream slows down → sea level on the US coast could rise!!!**

# Atlantic Meridional Overturning Circulation (AMOC) and coastal Sea Level Rise (SLR)



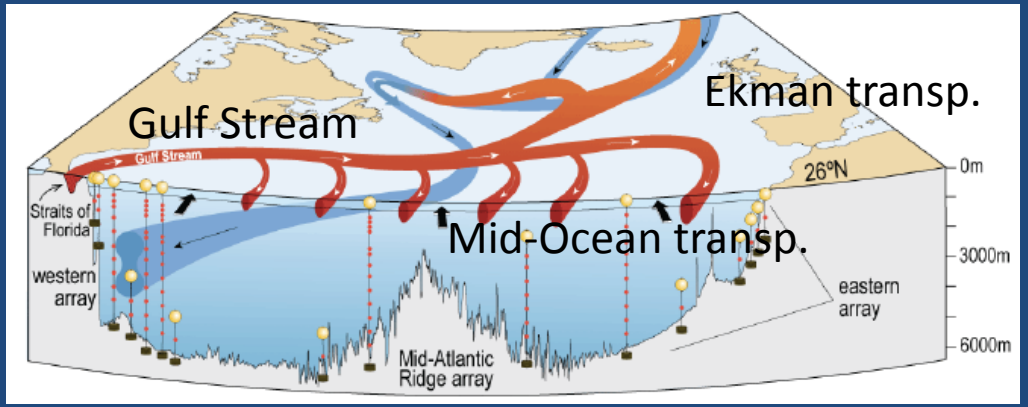
# Warmer Climate Scenario



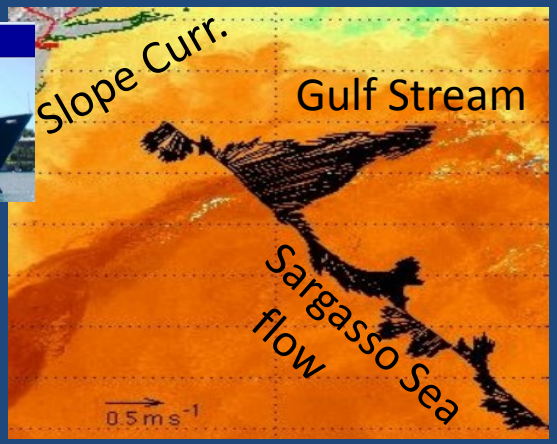
• Can we detect past climatic changes in the ocean?

• How can this information be used for future SLR projections?

• AMOC transport at 26°N from the RAPID project since 2004
(McCarthy et al, 2013) **~10yrs**

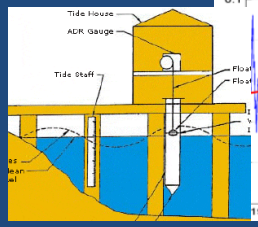


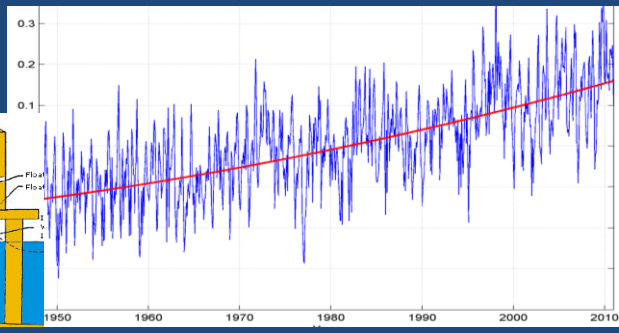

• Gulf Stream velocity from the Oleander project
(Rossby et al., 2010, 2014) **~20Yrs**


• Gulf Stream and sea level from altimeter data **~20Yrs**
(AVISO)

• Sea-Level data from tide gauges
(PSMSL) **~100yrs**



Ocean Sci. Discuss., 10, 1619–1645, 2013
www.ocean-sci-discuss.net/10/1619/2013/
doi:10.5194/osd-10-1619-2013
© Author(s) 2013. CC Attribution 3.0 License.

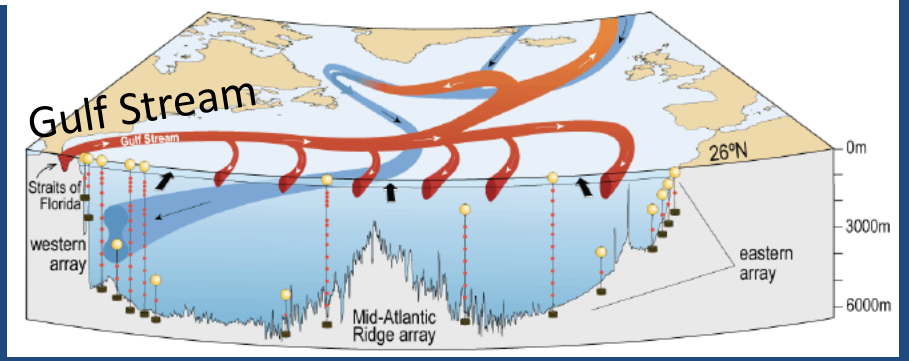
Ocean Science
Discussions
Open Access

This discussion paper is/has been under review for the journal Ocean Science (OS).
Please refer to the corresponding final paper in OS if available.

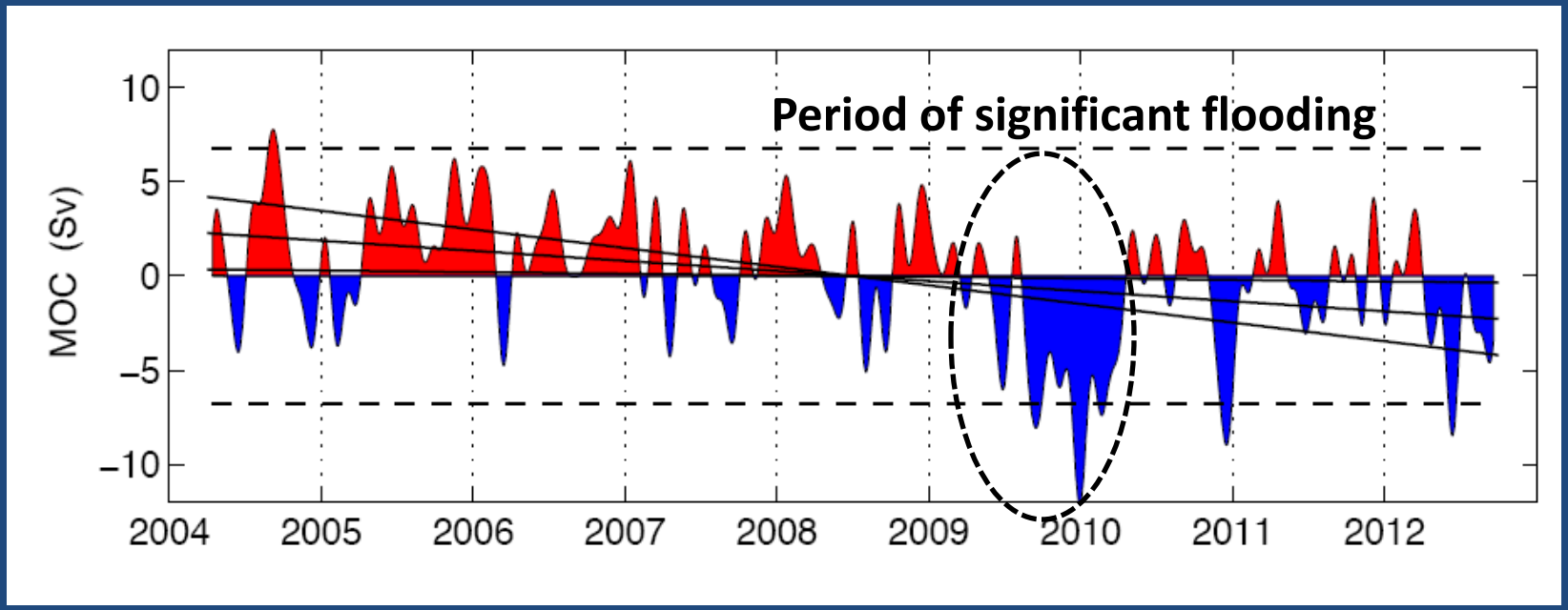
# Observed decline of the Atlantic Meridional Overturning Circulation 2004 to 2012

D. A. Smeed[1], G. McCarthy[1], S. A. Cunningham[2], E. Frajka-Williams[3], D. Rayner[1], W. E. Johns[4], C. S. Meinen[5], M. O. Baringer[5], B. I. Moat[1], A. Duchez[1], and H. L. Bryden[3]

## The 26° N RAPID-MOCHA-WBTS program



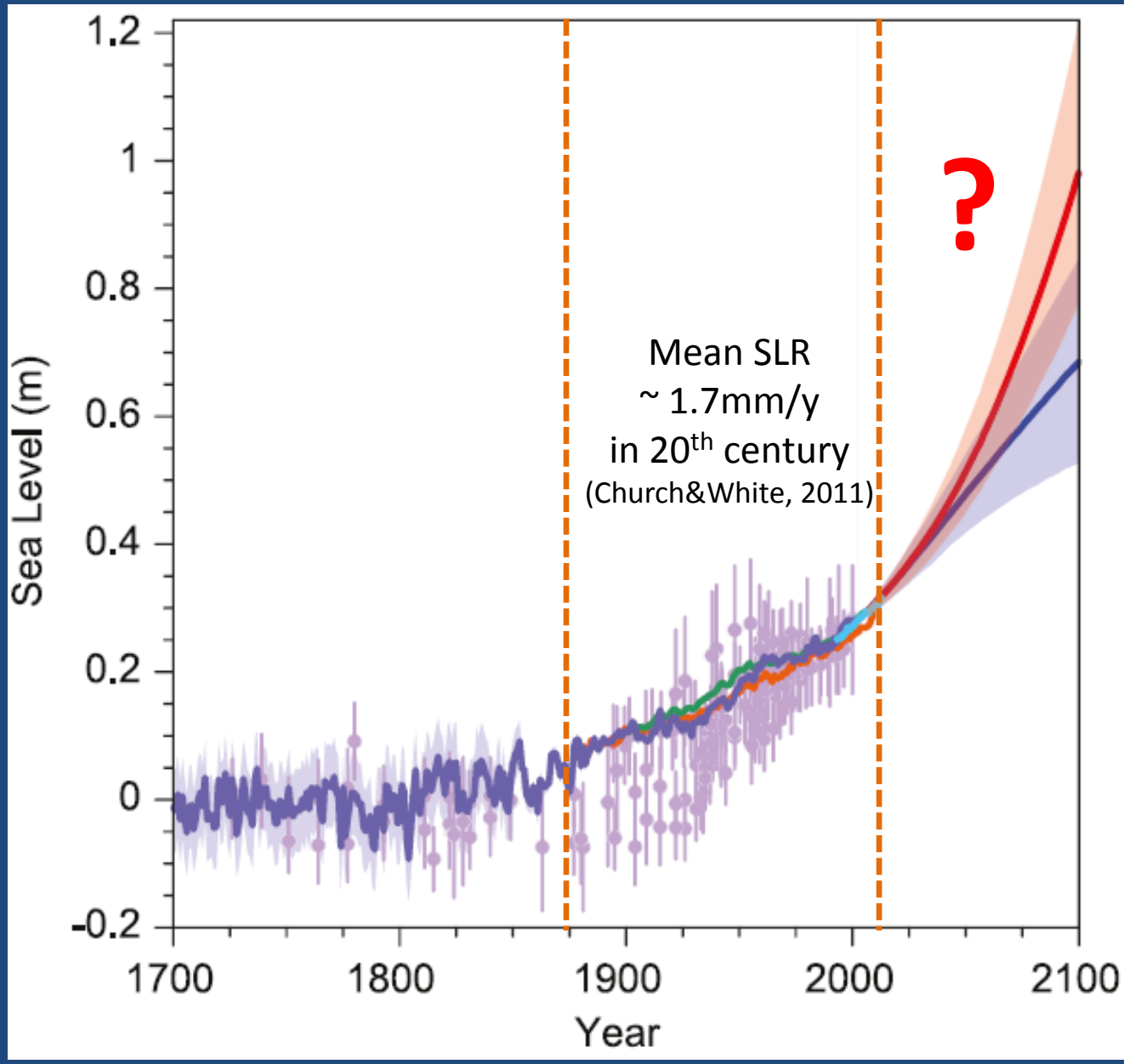

From April 2008 to March 2012 the AMOC was an average of 2.7 Sv weaker than in the first four years of observation (95 % confidence that the reduction is 0.3 Sv or more).



# Global-Mean Sea-Level Rise: past 300 years and next 100 years

Past sea level:
paleo-sea-level data, tide gauge data, satellite altimeter data.

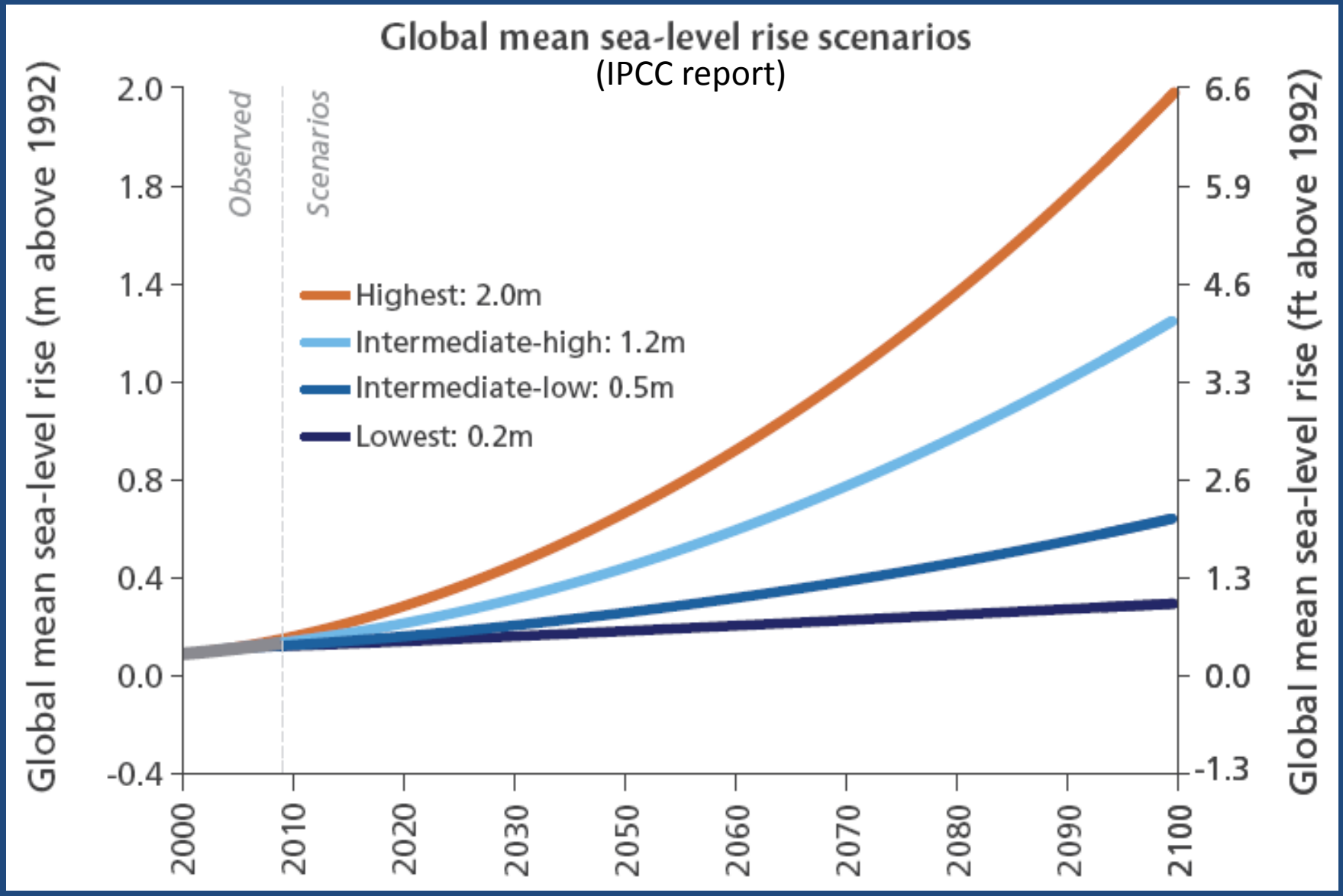
future estimates:
global climate models with different scenarios
RCP2.6 (blue) and
RCP8.5 (red)




Source: IPCC, 2013, AR5 WG1 (from Nicholls, 2013)

Projections of global sea level rise:

- too large range for practical local/regional planning
- neglect spatial variations due to land movements & ocean dynamics



# What is the projected SLR for particular location? Many use the USACE SLR Calculator…

corpsclimate.us/ccaceslcurves.cfm

Most Visited | Getting Started | Latest Headlines

RESPONSES TO CLIMATE CHANGE

US Army Corps of Engineers®

Home >> Climate Change Adaptation >> Comprehensive Evaluation of Projects with Respect to Sea-Level Change >> Sea Level Char

- Home
- Latest News
- Adaptation Policy
- Responses to Climate Change Program
- Climate Change Adaptation
- What is Adaptation?
- Info on Climate

## Climate Change Adaptation

### Comprehensive Evaluation of Projects with Respect to Sea-Level Change

Climate Change Adaptation Home | Coastal Risk Reduction and Resilience
Respect to Sea-Level Change | Update Drought Contingency Plans | Updat

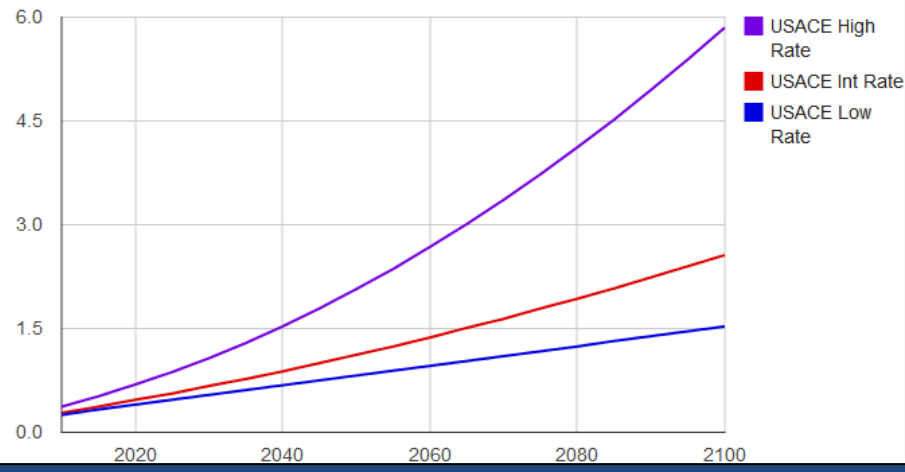
### Sea-Level Change Curve Calculator

$E(t)=(\text{Land Subsidence}) \times t + (\text{global SLR}) \times t + (\text{acceleration}) \times t^2$

- no probability
- local land subsidence not accurate
- global acceleration- no local dynamics

**USACE SLC Curves - Gauge VA, Sewells Point: 80 yrs**
**USACE Curves computed using criteria in EC 1165-2-212**

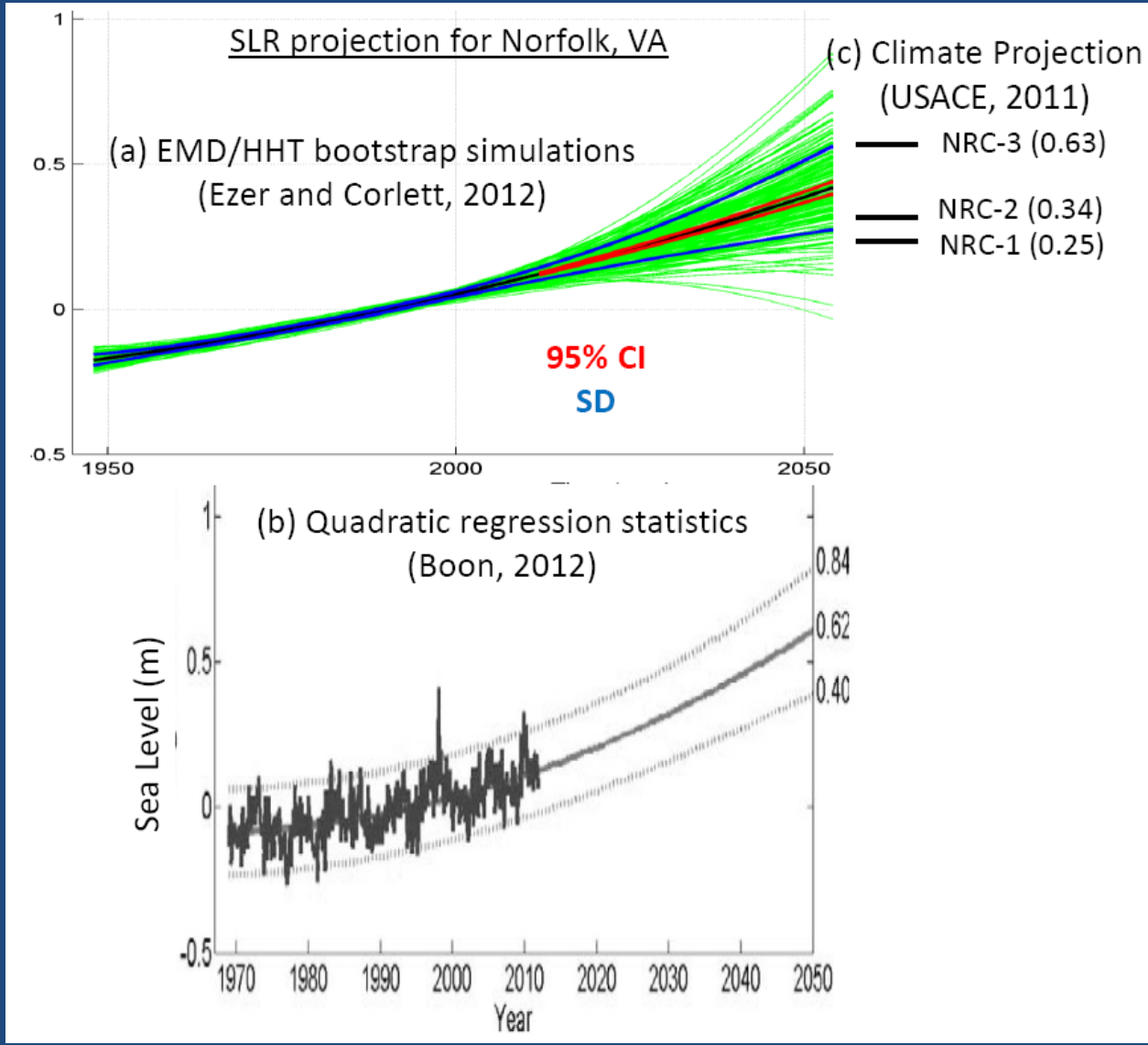
Projected SLR in Norfolk (ft)



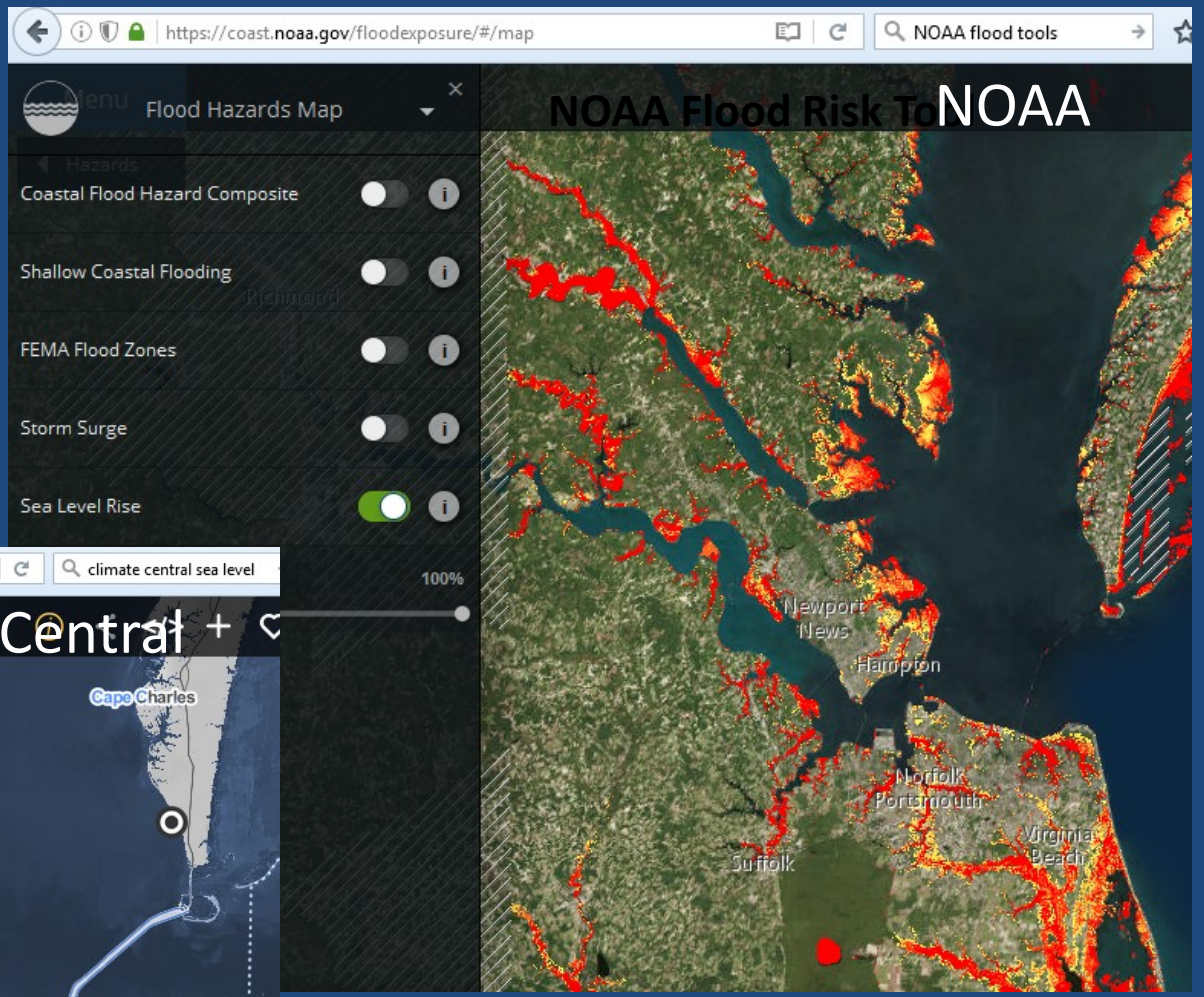
Projections based on statistics of past sea level data:

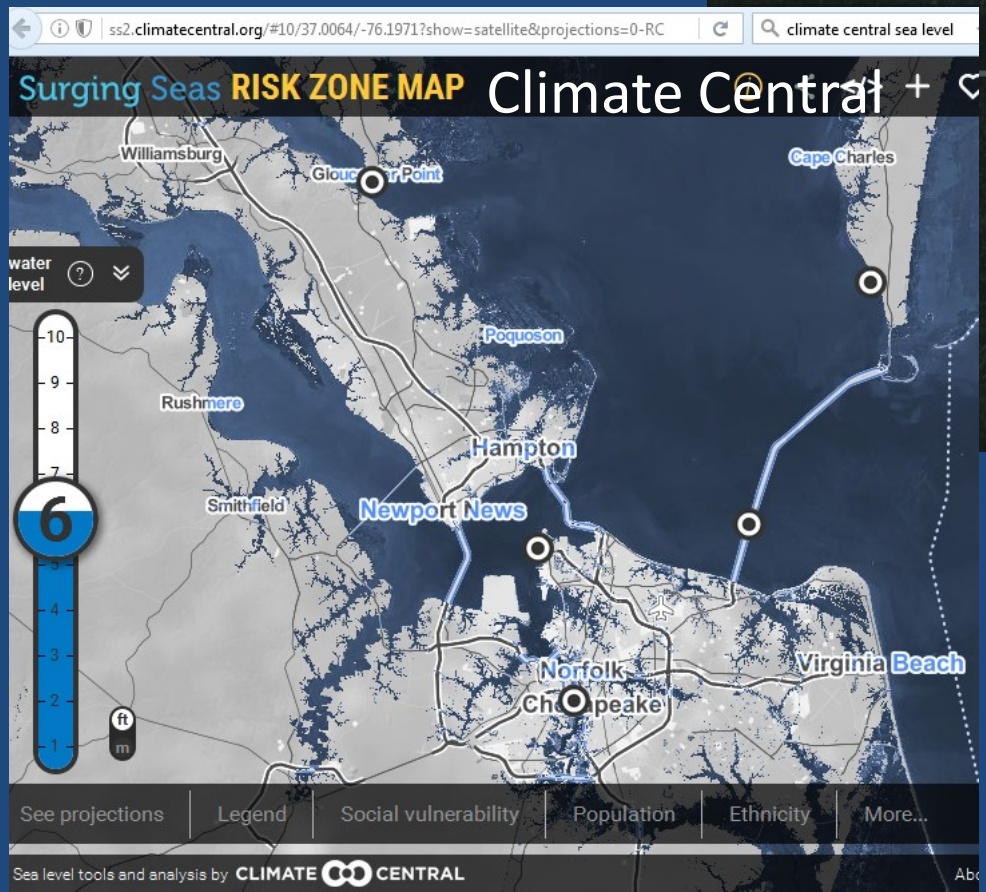
- May be useful for short-term horizon (~20-50 years?)
- Do not take into account potential long-term changes:

- abrupt Greenland ice-melt
- future CO2 emissions
- other unexpected climate change and feedbacks



# Tools to evaluate future flood risks and help planning for adaptation

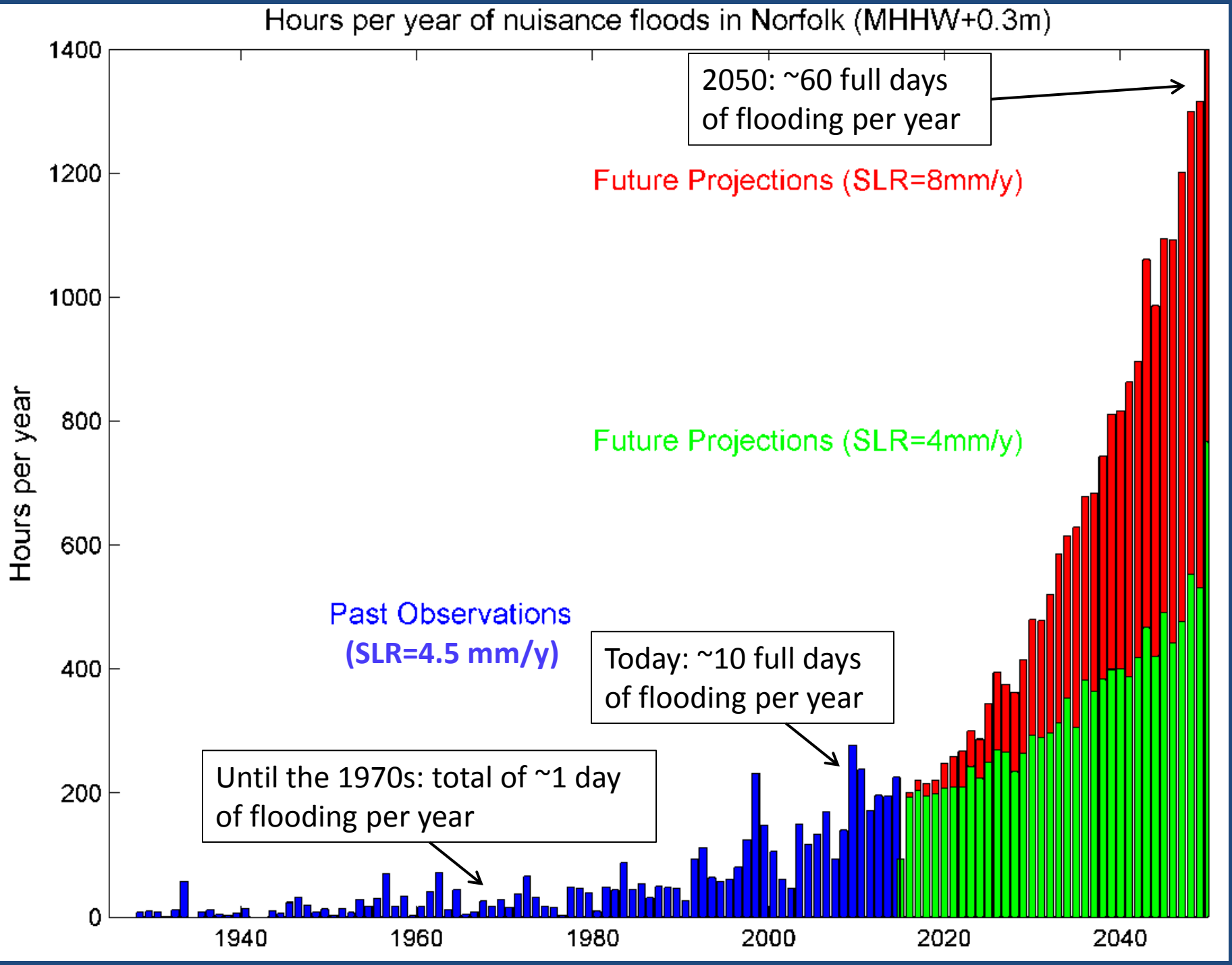


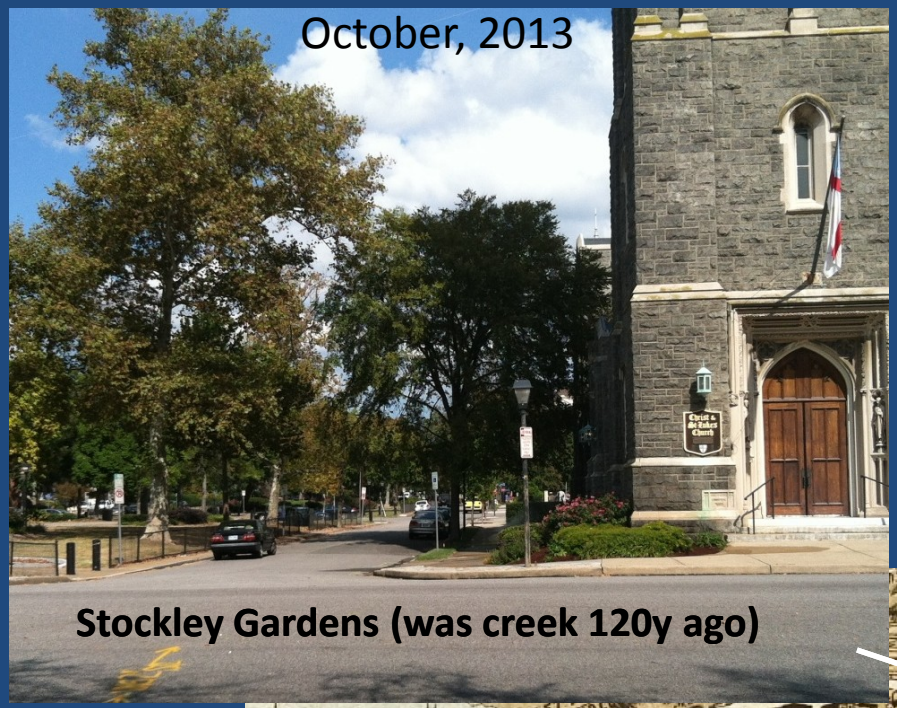
# Summary of contributions to SLR in the Chesapeake Bay region:

| SLR Process | Rate mm/y | Reference and notes |
|---|---|---|
| Subsidence – GIA | 0.6-1.8 mm/yr | USGS; Engelhart & Horton (2012); Miller et al. (2013) |
| Subsidence – Ground water pumping | 2-4.8 mm/yr (location dependent) | USGS; Eggleston & Pope (2013) |
| Subsidence – Impact crater | Probably small/unknown | USGS; Powars and Bruce (1999); Boon et al. (2010) |
| Ocean circulation | ±5-10 mm/yr (includes decadal variations) | Ezer (2013); Ezer et al. (2013) |
| Global scale thermal expansion and land ice melt | 1.7-3.2 mm/yr (larger recent rates) | Church and White (2011); Ezer (2013); many others. |

Future unknowns:
- Rapid Greenland ice sheet melt
- Gulf Stream slowdown

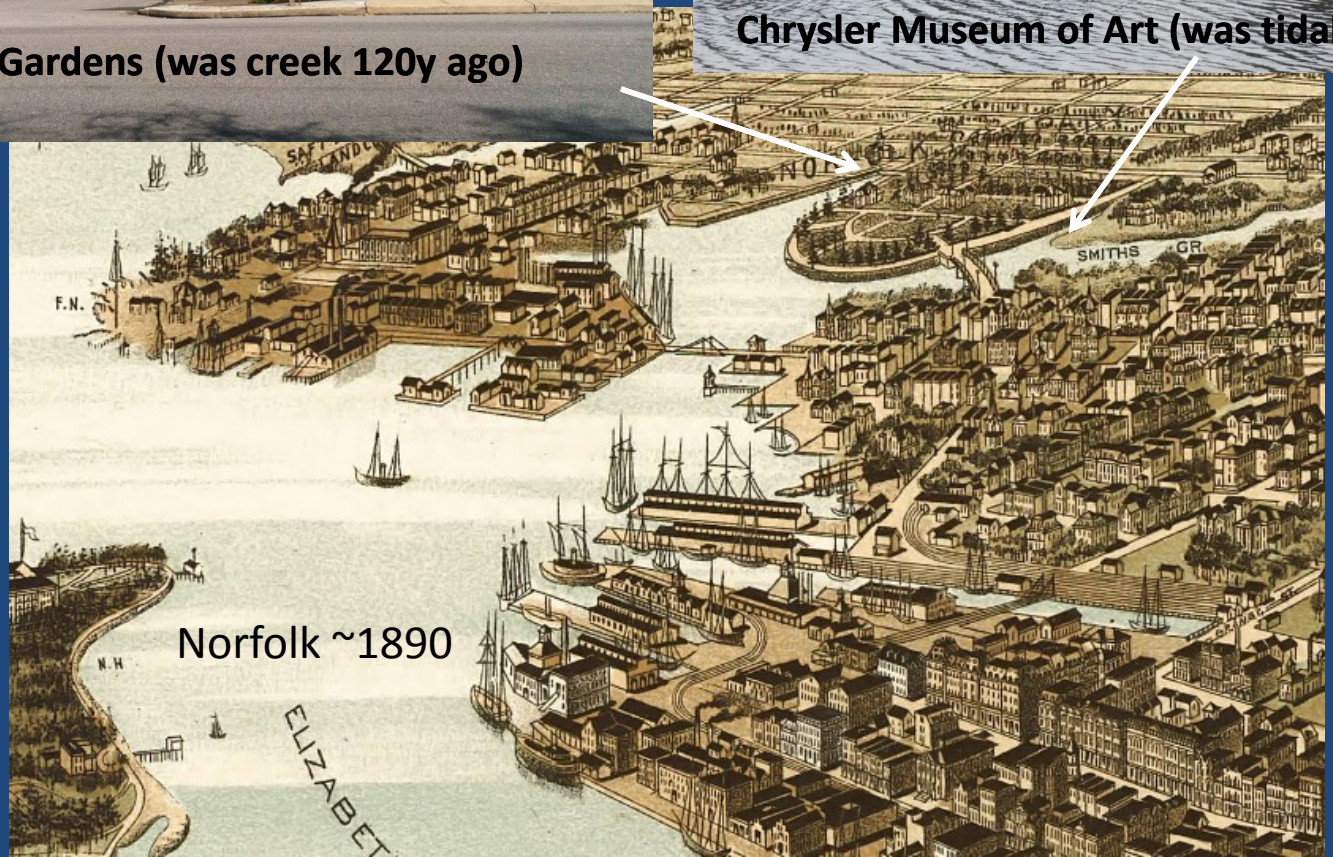

Hours per year of nuisance floods in Norfolk (MHHW+0.3m)
Hours per year
1400
1200
1000
800
600
400
200
0
1940
1960
1980
2000
2020
2040
2050: ~60 full days of flooding per year
Future Projections (SLR=8mm/y)
Future Projections (SLR=4mm/y)
Past Observations (SLR=4.5 mm/y)
Today: ~10 full days of flooding per year
Until the 1970s: total of ~1 day of flooding per year

# Impact of climate change on the Hampton Roads region




Stockley Gardens (was creek 120y ago)

Chrysler Museum of Art (was tidal flat 120y ago)




Norfolk ~1890

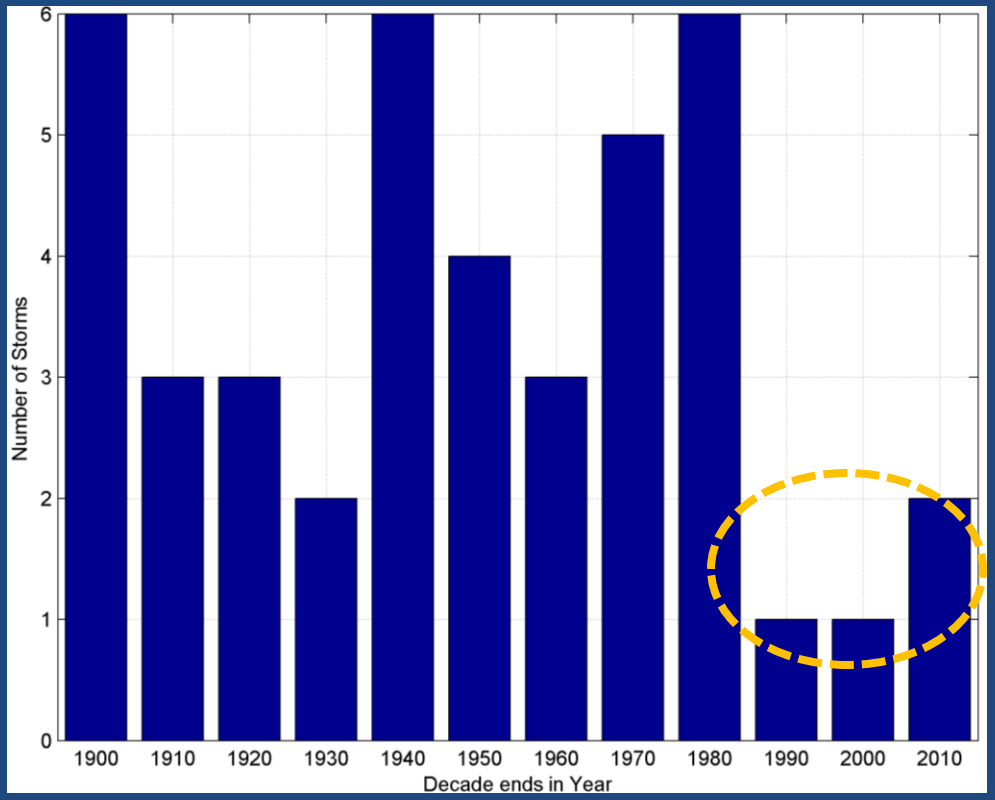
# Local impact of climate change in the Chesapeake Bay region

October, 2013

**… becomes very rare**

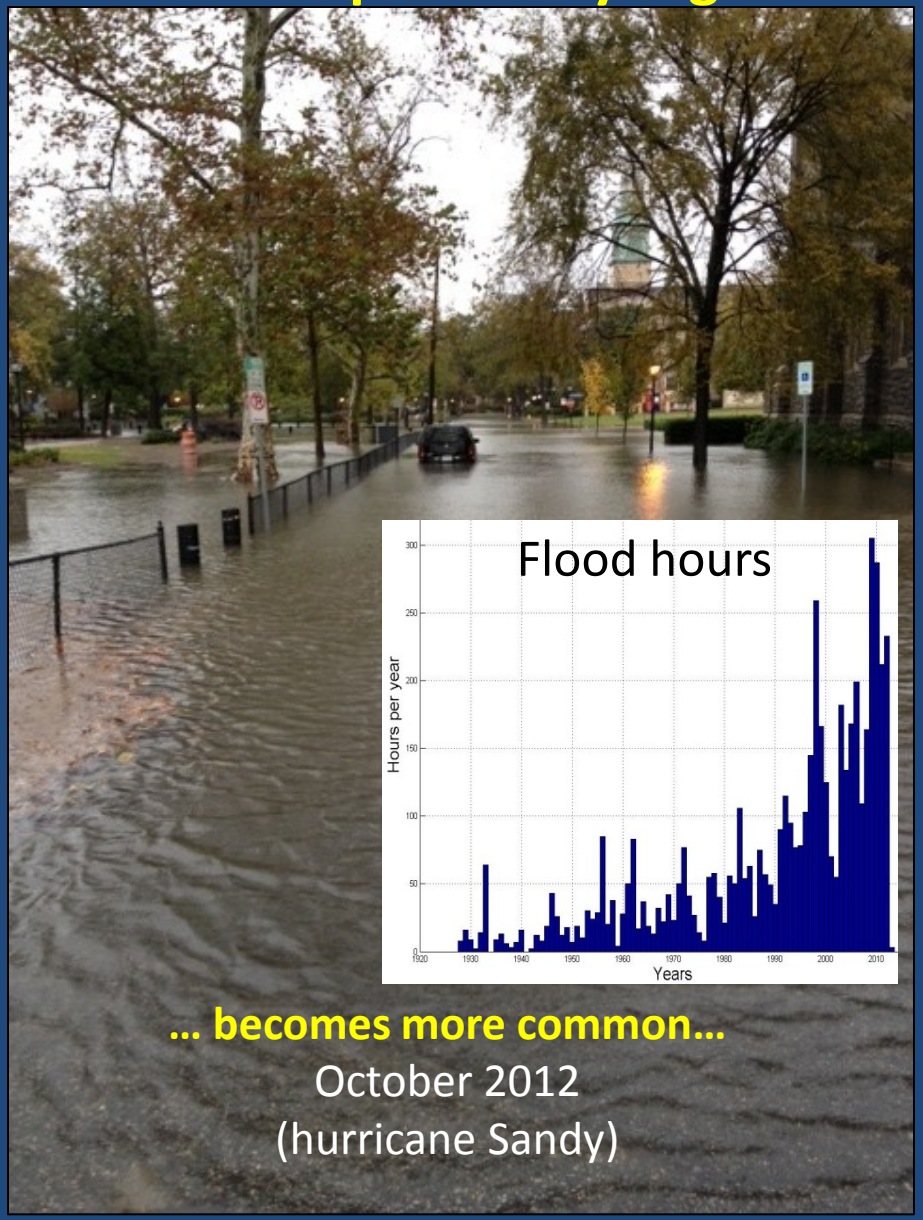
January, 2014

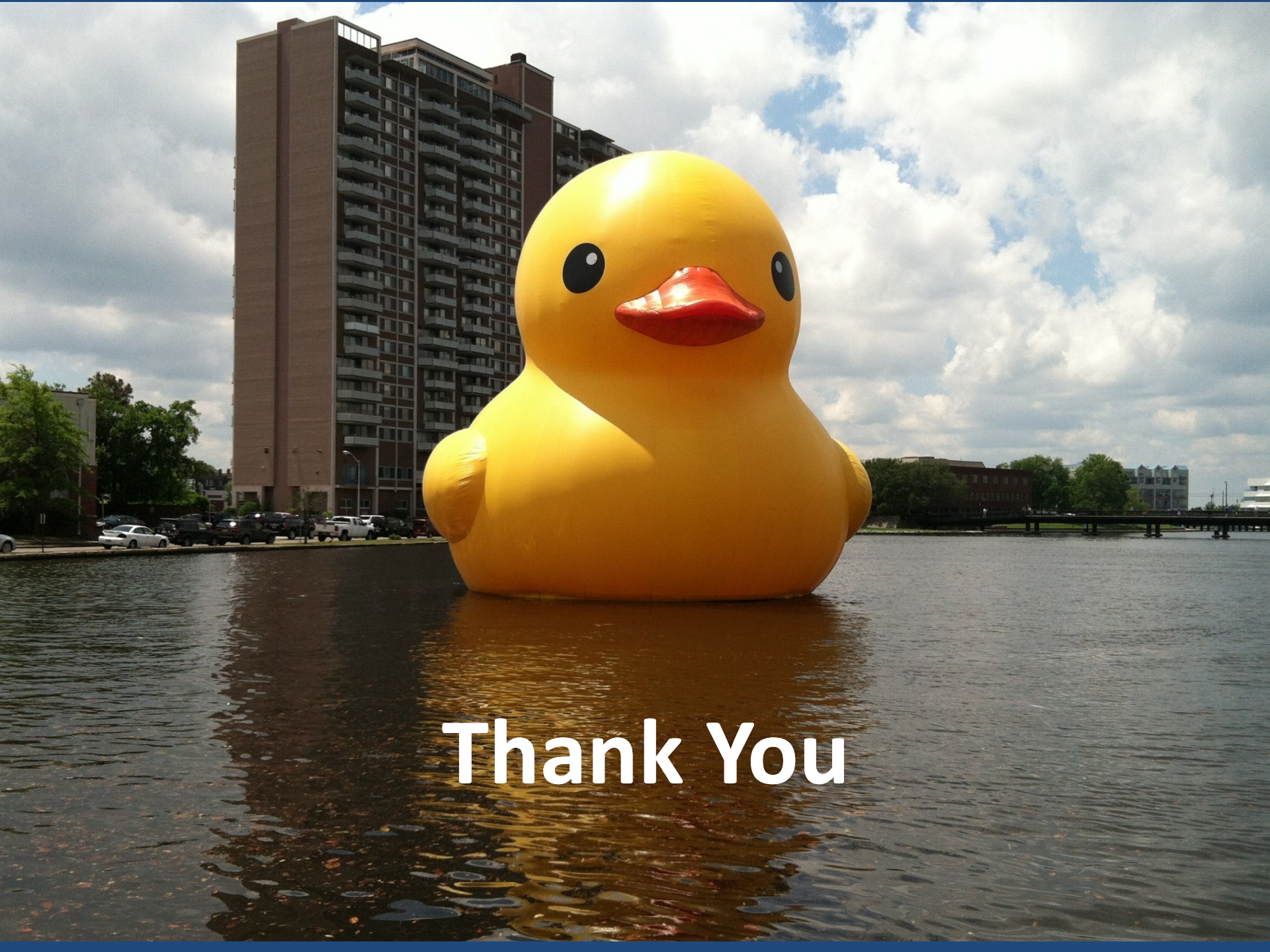
Number of big (>5 inch) snow storms per decade in Norfolk



# Local impact of climate change in the Chesapeake Bay region






Thank You