ODU Climate Change and Sea Level Rise Initiative

http://www.odu.edu/ao/research/ccslri/

US.AMOC/UK.RAPID Meeting, Baltimore, MD, July 16-19, 2013

On the impact of the AMOC on sea level rise: new evidence that a slowdown of the Gulf Stream is responsible for accelerating sea level rise along the U.S. mid-Atlantic coast

Tal Ezer

Center for Coastal Physical Oceanography (CCPO)

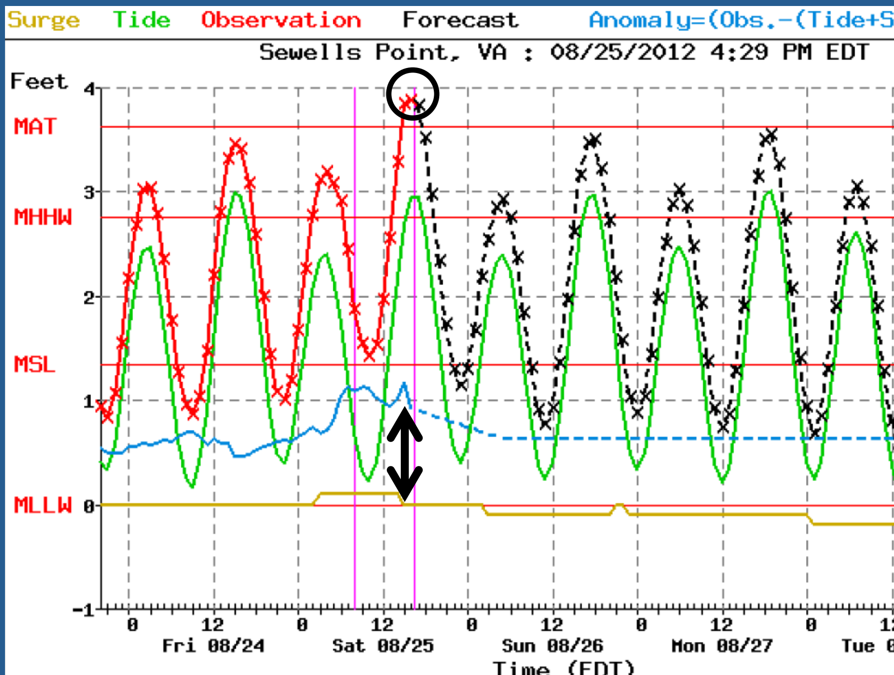
Old Dominion University, **Norfolk***, **Virginia, USA**

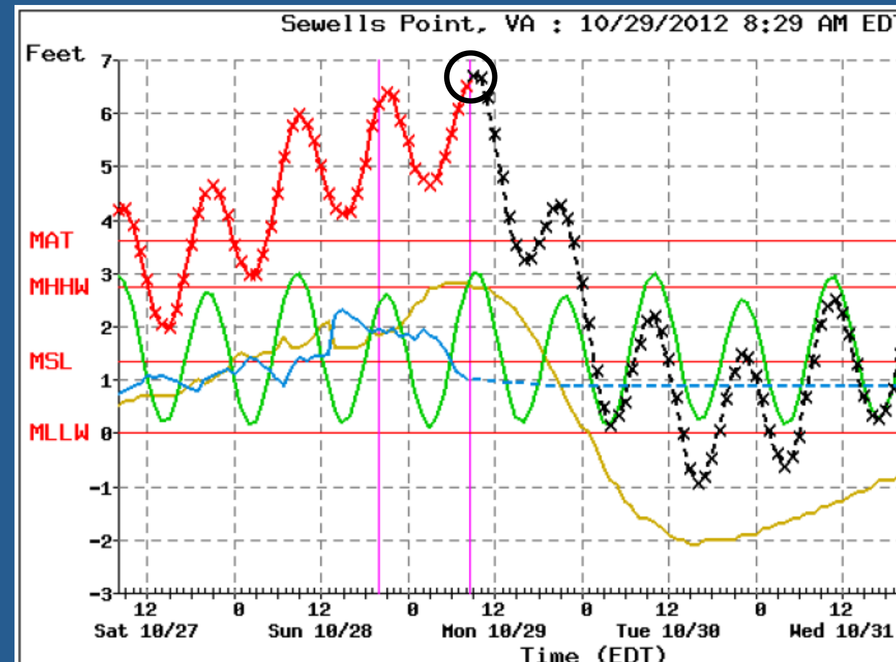
* "Norfolk has been ranked second only to New Orleans among U.S. coastal cities threatened by flooding"

Floods in Norfolk, Virginia

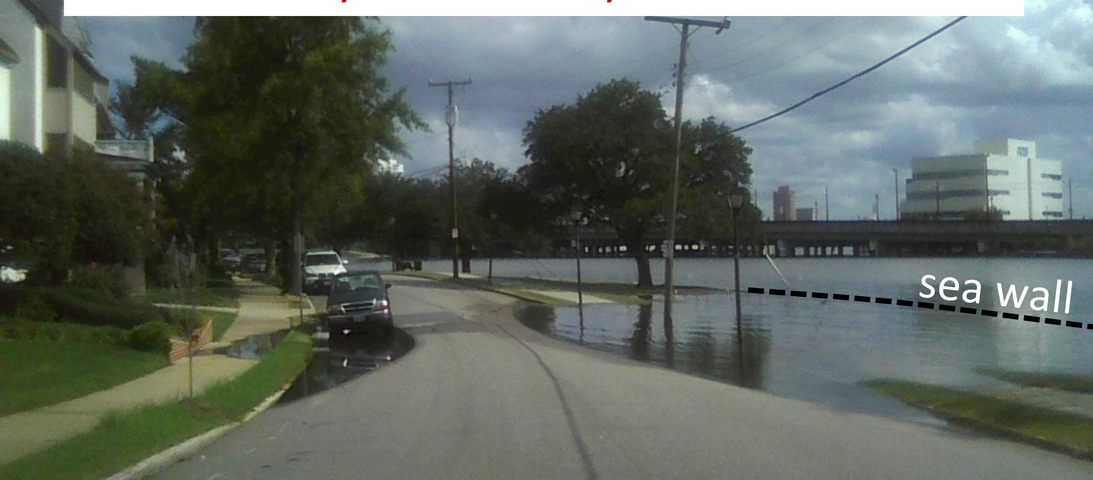
Minor flood: high tide (~4ft; 8-25-2012)

Major flood: Hurricane Sandy (~7ft; 10-29-2012)

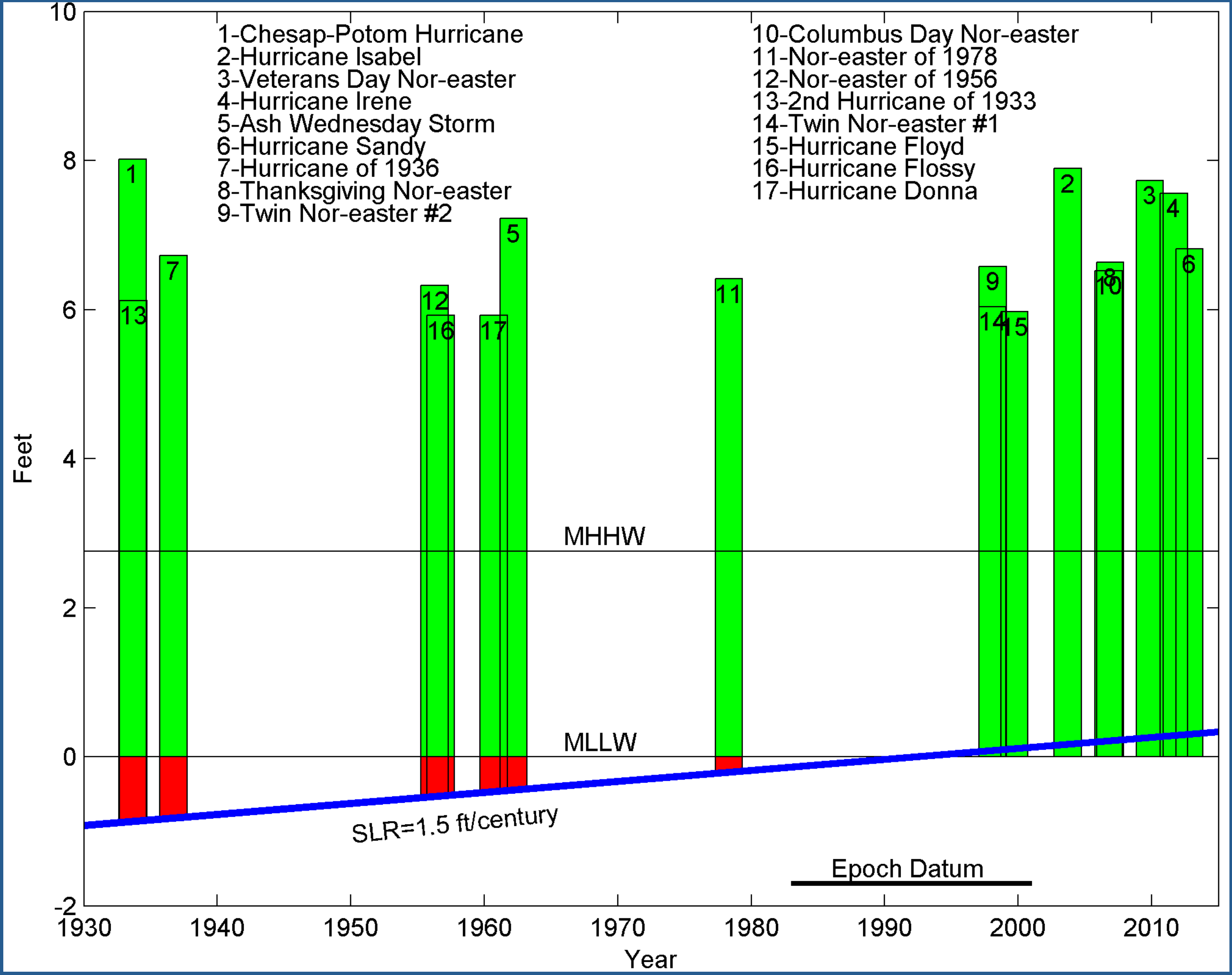


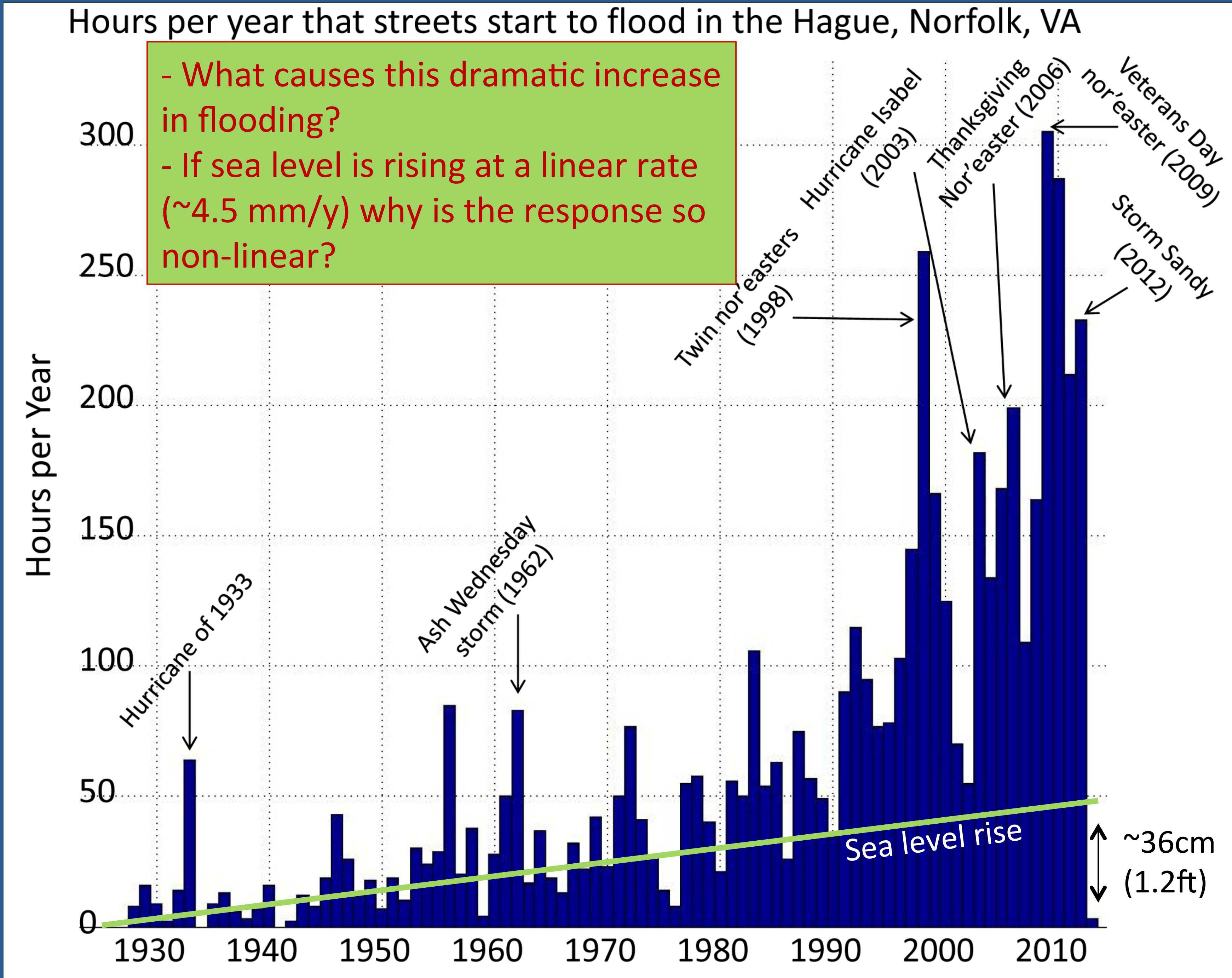


Storm surge+tide prediction underestimated water level by 1 foot! Why?

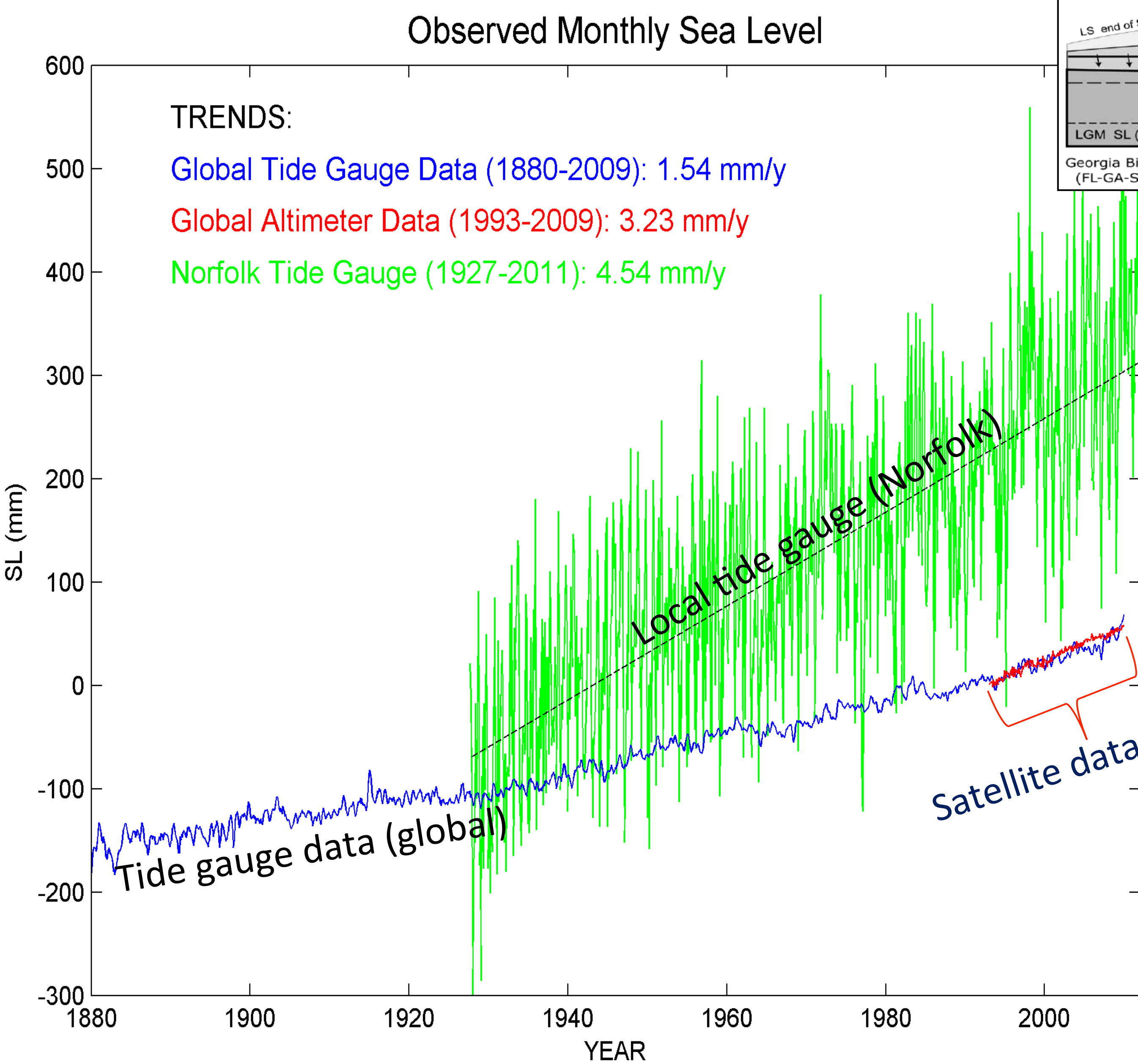


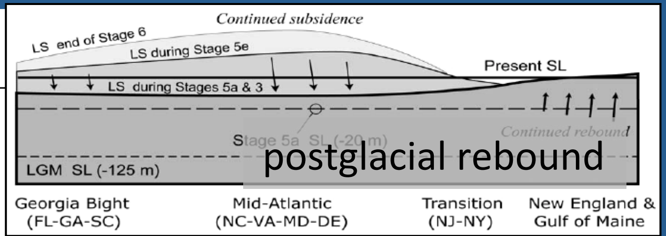
Top storm surges in Norfolk, VA

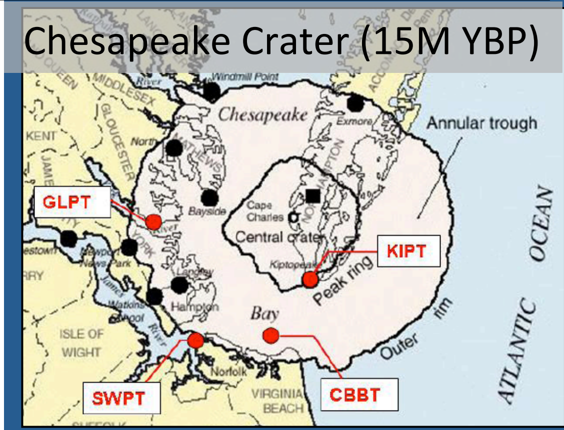



Hours per year that streets start to flood in the Hague, Norfolk, VA
- What causes this dramatic increase in flooding?
- If sea level is rising at a linear rate (~4.5 mm/y) why is the response so non-linear?
Hours per Year
300
250
200
150
100
50
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
Hurricane of 1933
Ash Wednesday storm (1962)
Twin nor'easters (1998)
Hurricane Isabel (2003)
Thanksgiving Nor'easter (2006)
Veterans Day nor'easter (2009)
Storm Sandy (2012)
Sea level rise
~36cm (1.2ft)

Mean SLR in Norfolk is ~50% higher than global SLR from altimeter data and ~200% higher than global SLR from tide gauge data



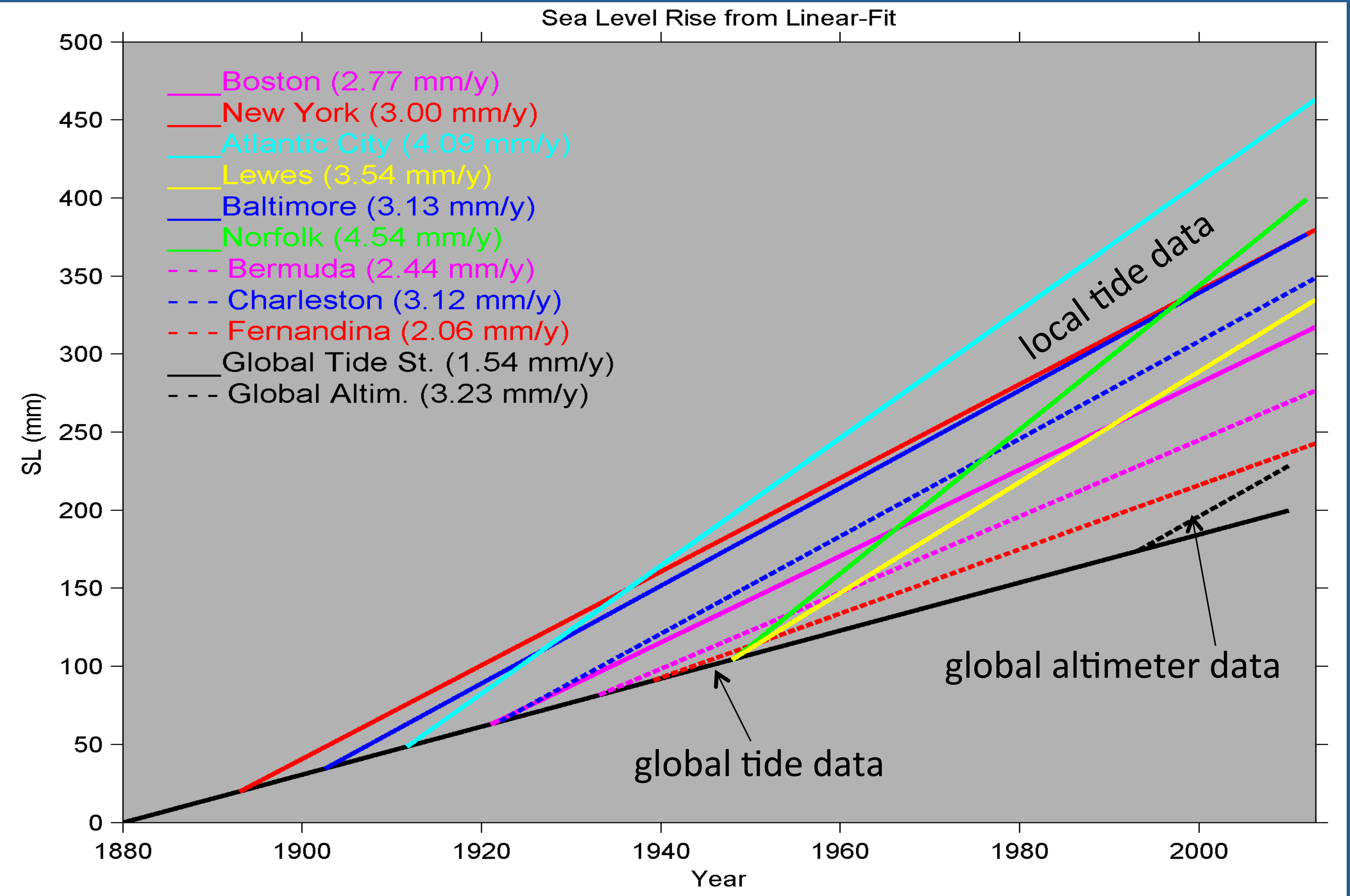




Until recently, land subsidence was blamed for the high local SLR (Boon et al 2010)

But this may be only part of the story…

- **Why is local SLR along the US East coast different than global SLR?**
- **Is linear SLR rates accurately represent the underlying dynamics?**

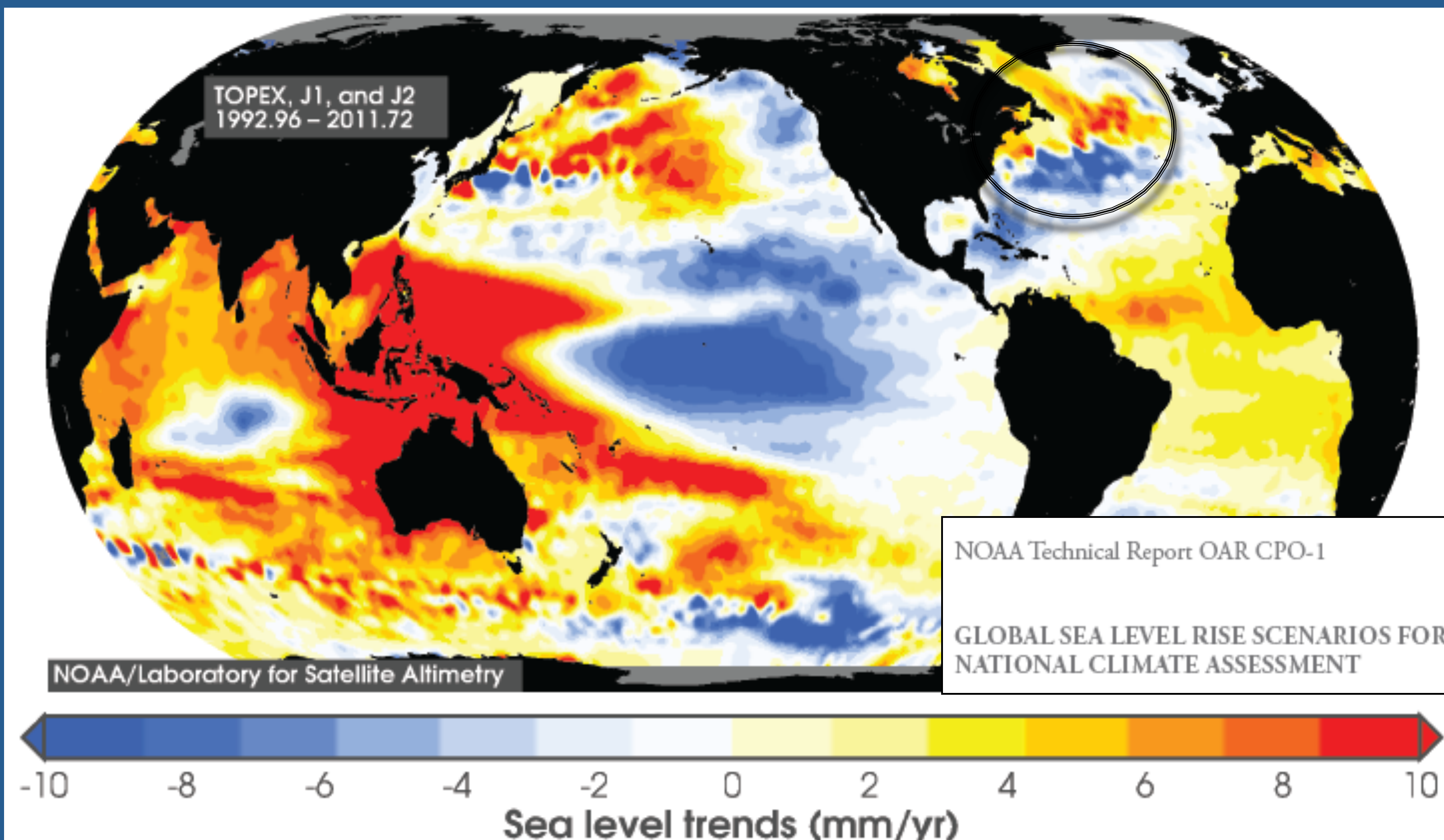


Global vs. Local Sea Level Rise:

thermal expansion
melting ice sheets & glaciers
volume change

Local (relative) SLR =

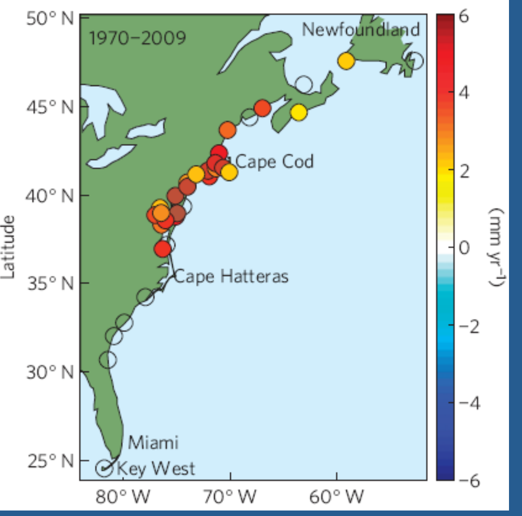
Global SLR ± Land Subsidence/Uplift ± Ocean Dynamics



NOAA Technical Report OAR CPO-1

GLOBAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES NATIONAL CLIMATE ASSESSMENT

Three separate studies published within months in 2012 all indicate a **"hotspot of accelerated SLR"** in the mid-Atlantic coast



nature climate change

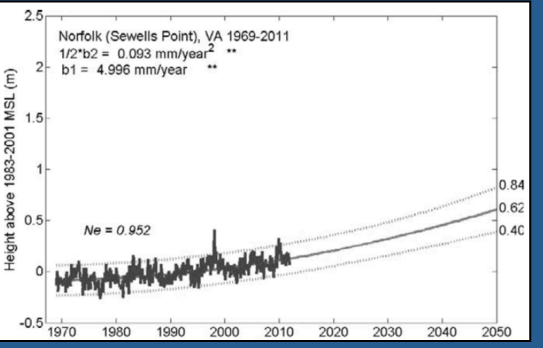
LETTERS

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



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
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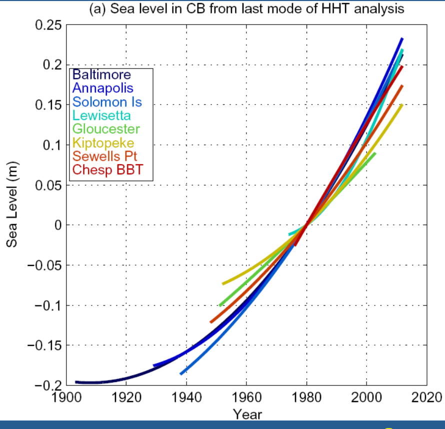
boon@vims.edu

COASTAL EDUCATION & RESEARCH FOUNDATION, INC. CERF

www.cerf-jcr.org

J. Coastal Res. 2012

VIMS



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

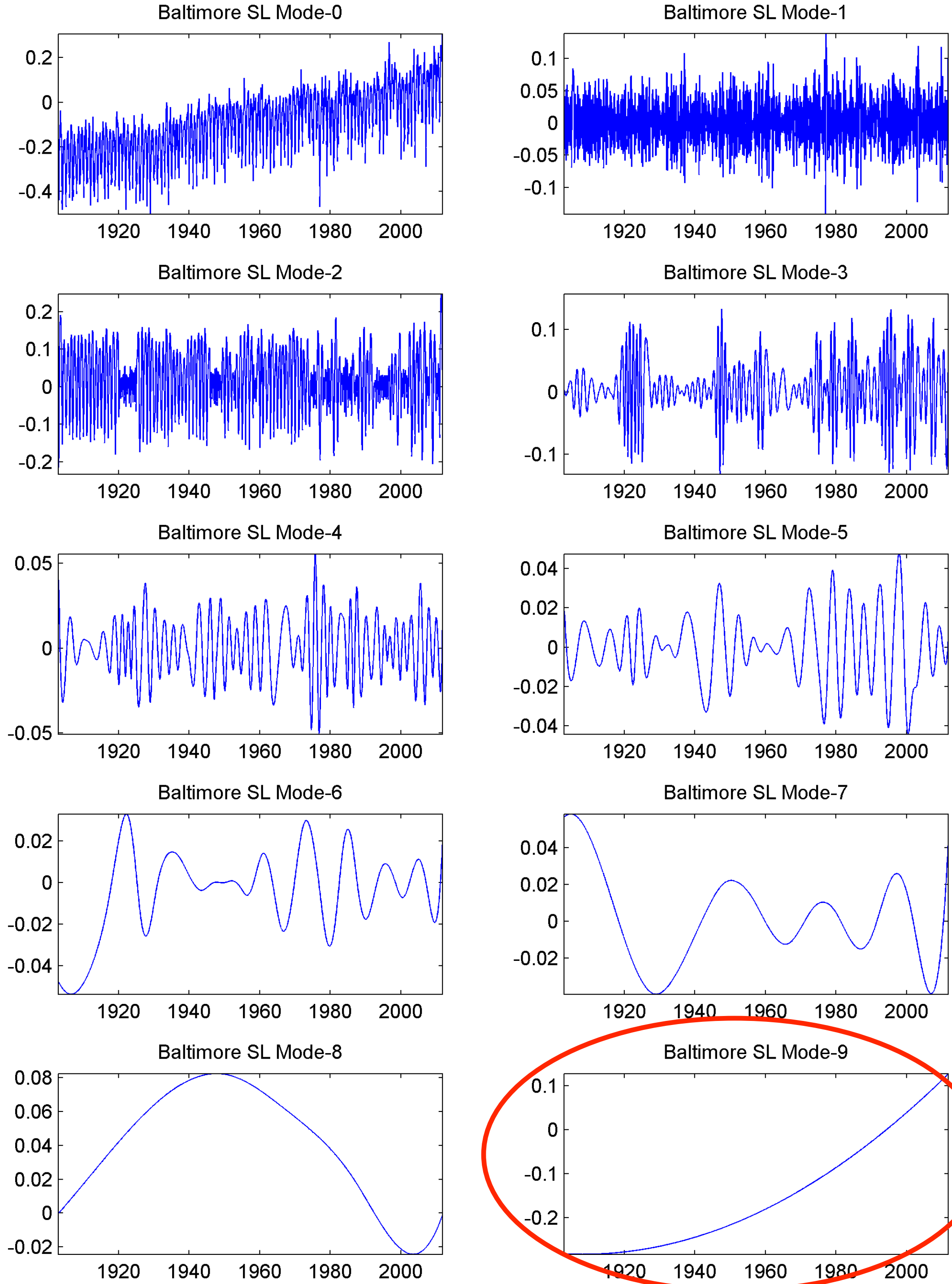
Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach for analyzing sea level data

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

ODU

Empirical Mode Decomposition Hilbert-Huang Transformation, **EMD/HHT** [Huang et al., 1998]

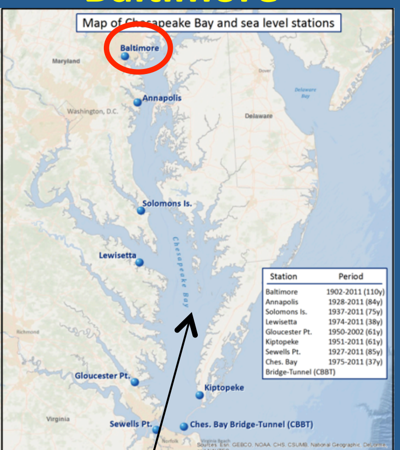
Original SL data →



Example of EMD analysis for **Baltimore**: separating the SL record into oscillating modes and a trend

$$\eta(t) = \overbrace{\sum_{i=1}^{N} c_i(t)}^{\text{intrinsic mode functions (IMF)}} + \overbrace{r(t)}^{\text{mean trend}}$$

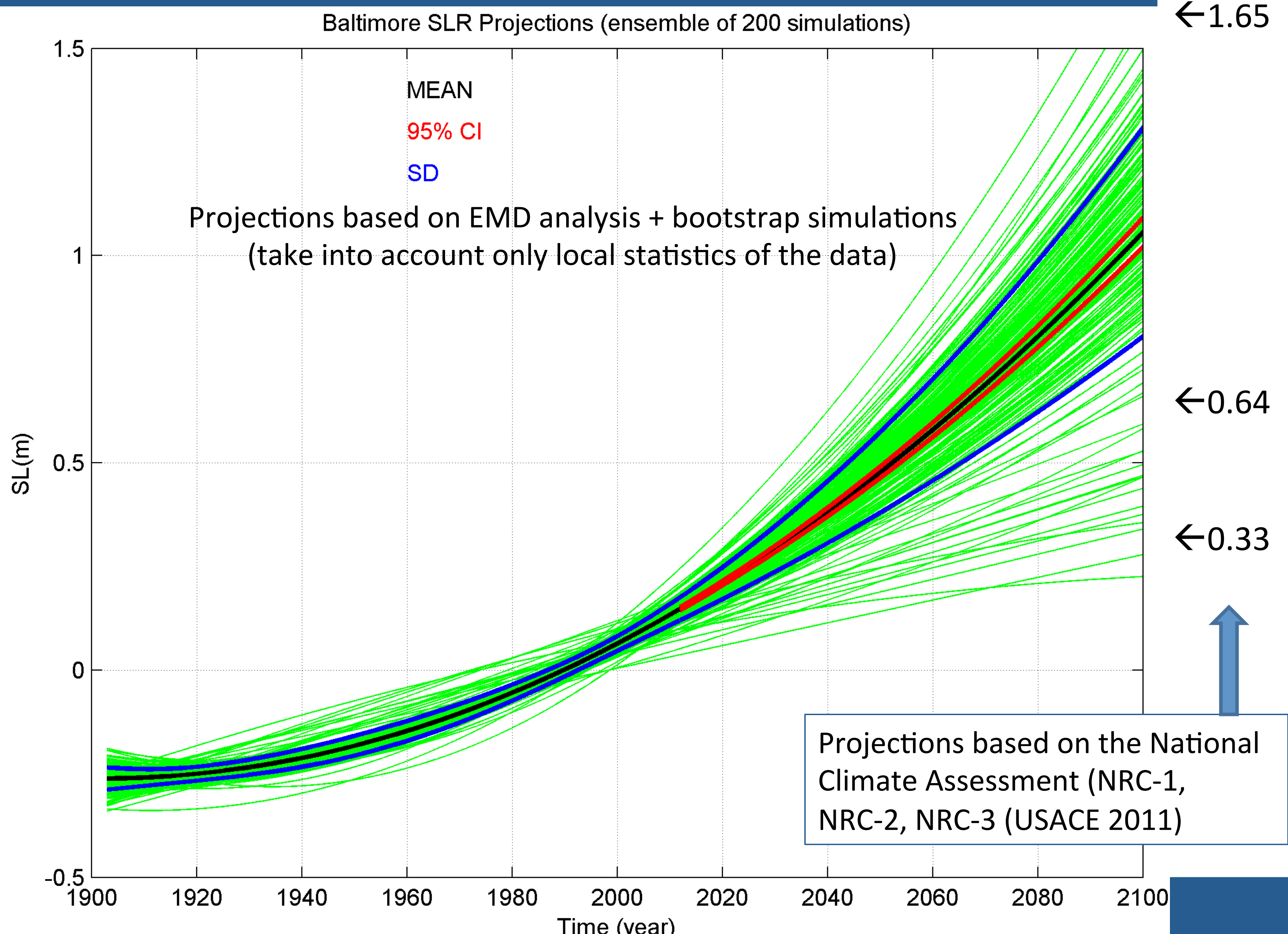
Baltimore

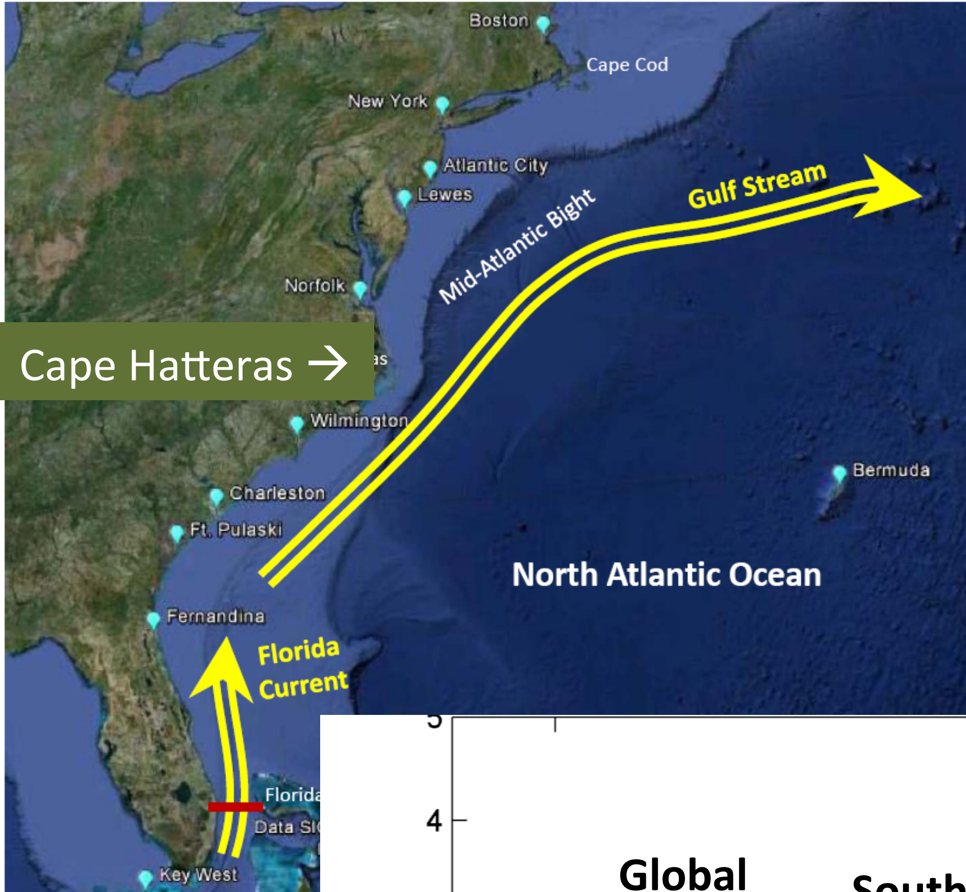


Chesapeake Bay

Decadal & multi-decadal cycles are separated from the trend →

←SL Trend (non-linear acceleration)


Baltimore SLR Projections (ensemble of 200 simulations)
MEAN
95% CI
SD
Projections based on EMD analysis + bootstrap simulations
(take into account only local statistics of the data)
SL(m)
Time (year)
1.5
1
0.5
0
-0.5
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
←1.65
←0.64
←0.33
Projections based on the National Climate Assessment (NRC-1, NRC-2, NRC-3 (USACE 2011)

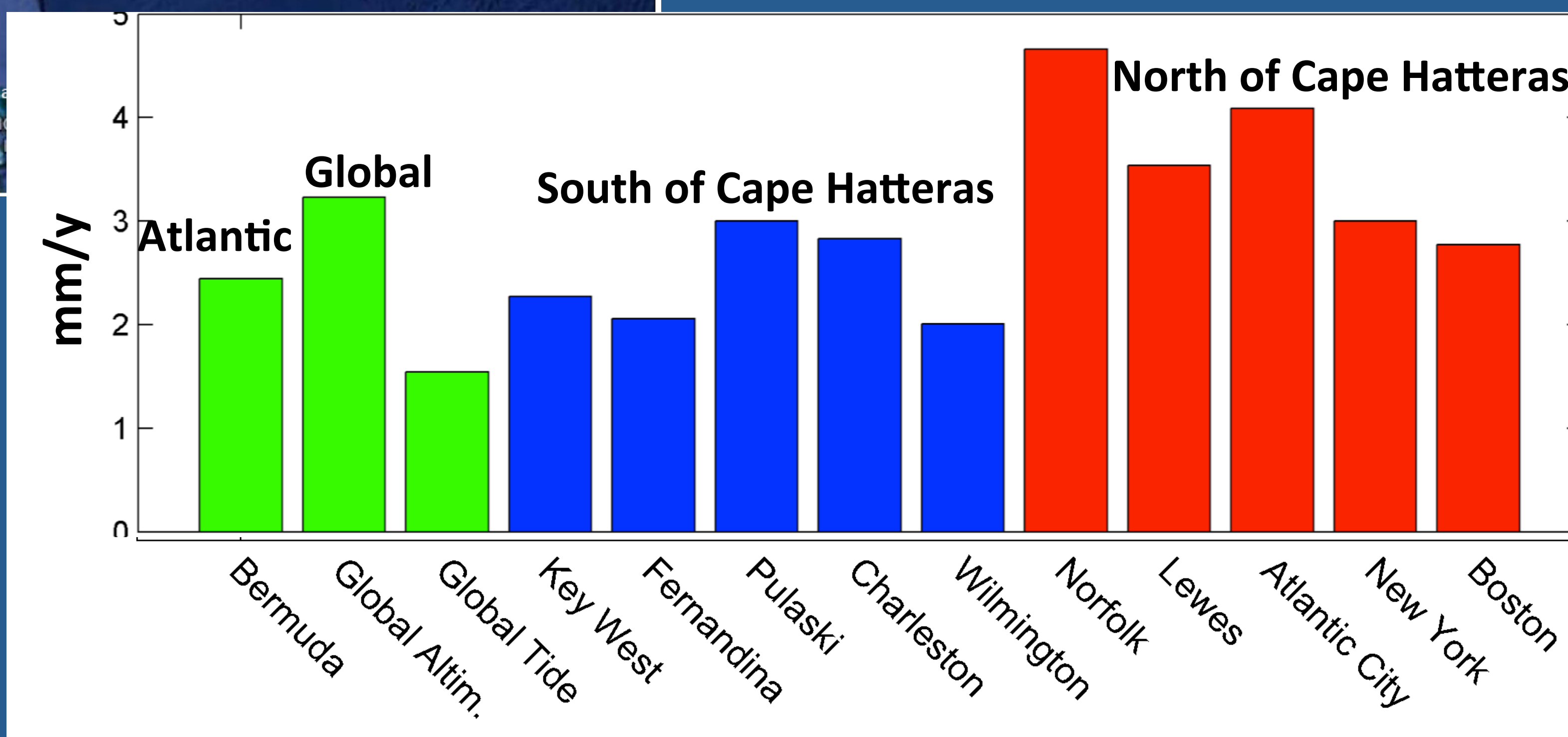


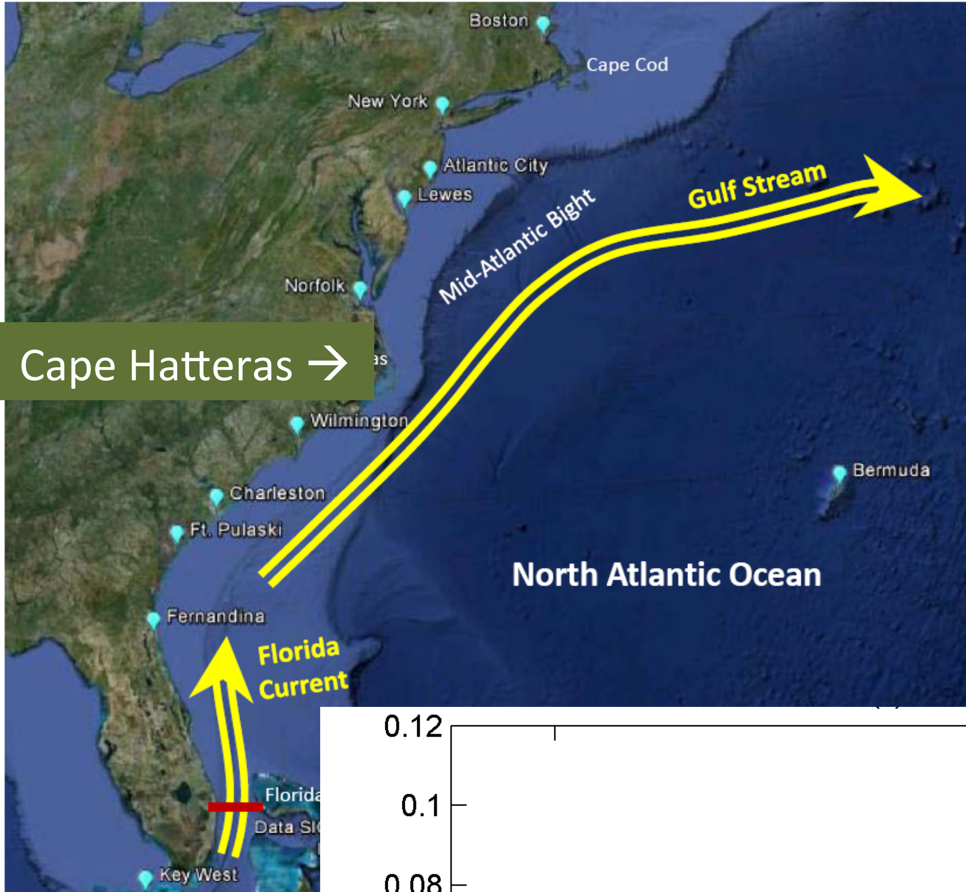
Mean Sea Level Rise Rates (from linear regression)

linear local land subsidence

+

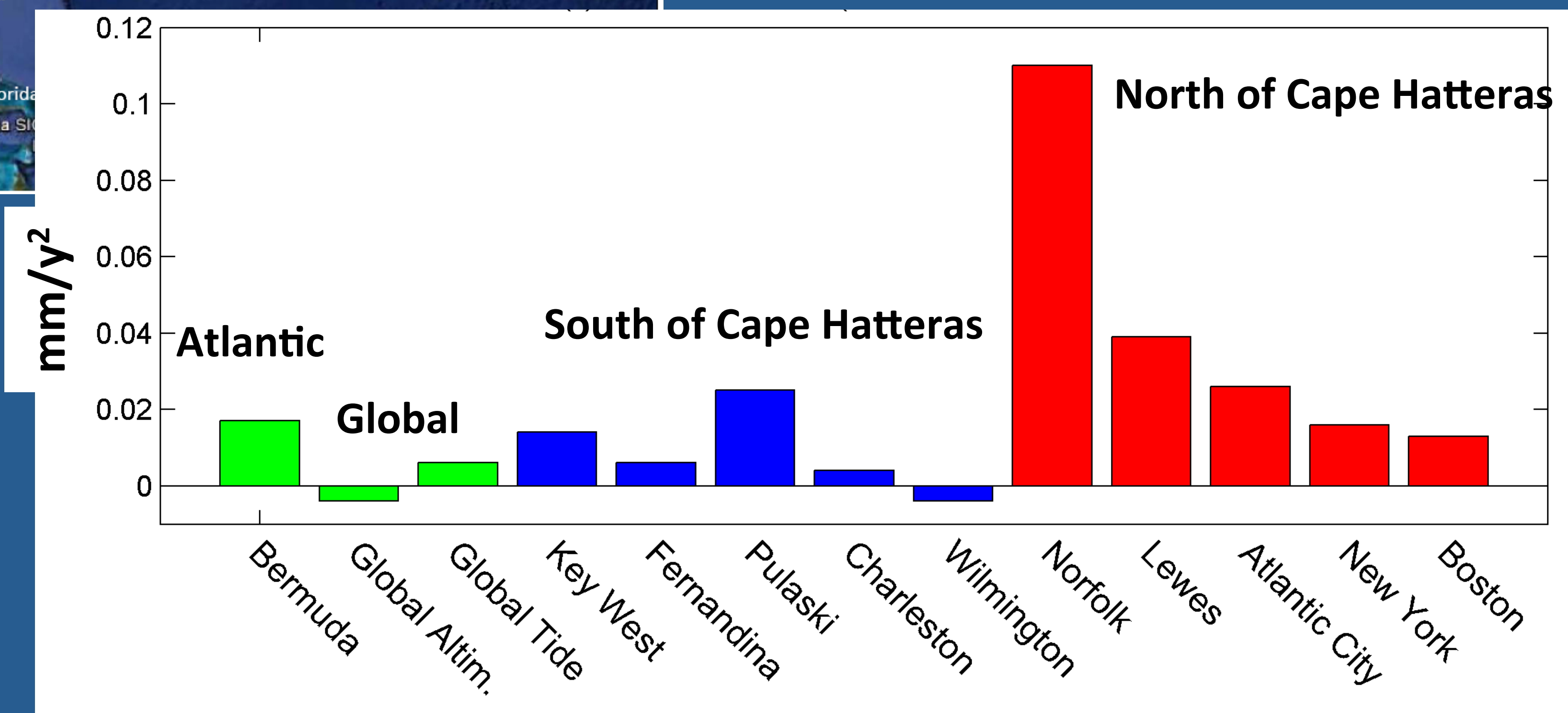
linear global SLR





Sea Level Rise Acceleration (from EMD analysis)

eliminates the long-term geological land movement and oceanic multi-decadal variations



Why is SLR accelerating north of CH? Does the Gulf Stream play a role?

We proposed that weakening Gulf Stream is contributing to sea level rise.

Gulf Stream's induced sea level rise and variability along the U.S. mid-Atlantic coast

Tal Ezer[1,*], Larry P. Atkinson[1], William B. Corlett[1,2], Jose L. Blanco[1,3]

Article first published online: 6 FEB 2013

DOI: 10.1002/jgrc.20091

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Issue

Journal of Geophysical Research: Oceans

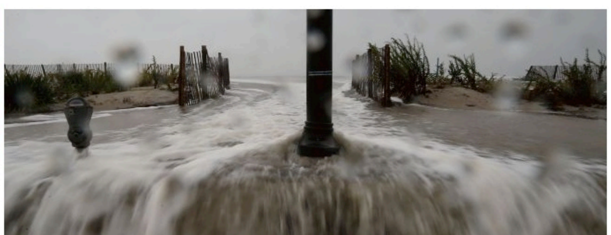
…the most viewed paper in JGR-Oceans during March-May 2013

~50 environmental/science web sites reported on this paper

News

East Coast Faces Rising Seas from Slowing Gulf Stream

Michael D. Lemonick, Climate Central | Published: Feb 18, 2013, 11:41 AM EST



The Weather Channel

East Coast Sea Level Rise Tied to Slowing of Gulf Stream

By Tom Yulsman | February 14, 2013 9:09 pm

DISCOVER

THE MAGAZINE OF SCIENCE, TECHNOLOGY, AND THE FUTURE

CLIMATE CENTRAL

East Coast Faces Rising Seas From Slowing Gulf Stream

WAMC NORTHEAST PUBLIC RADIO

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Academic Minute 5:00 AM FRI JULY 5, 2013

Dr. Tal Ezer, Old Dominion University – Uneven Sea Level Rise

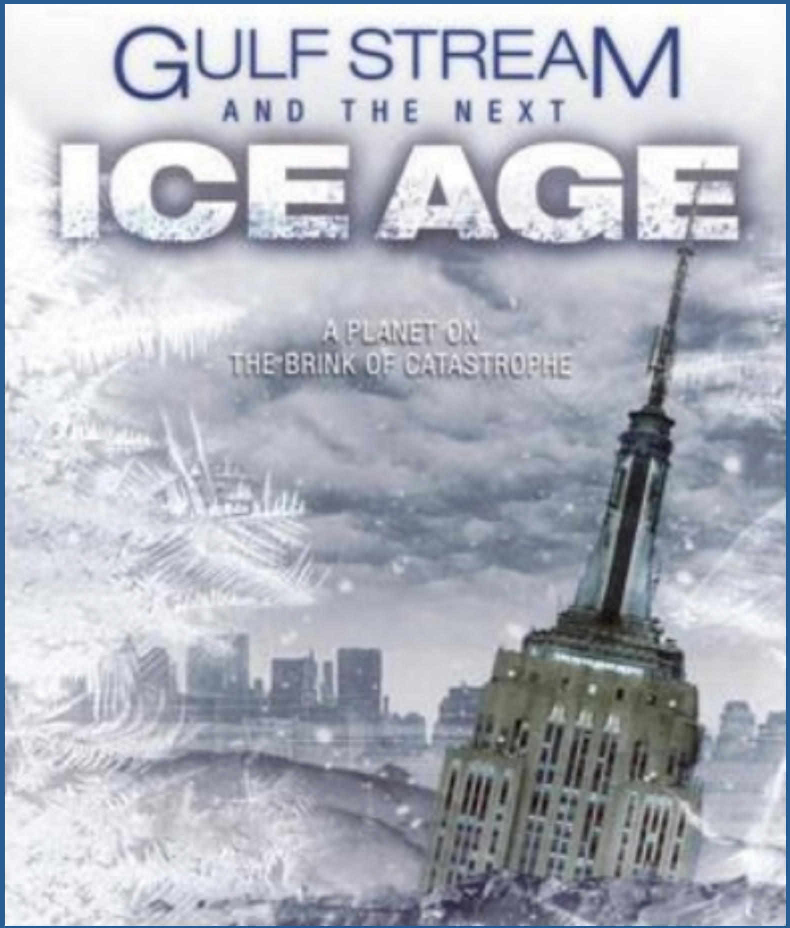
The Gulf Stream Stalled, Sea Level Rose & the East Coast Flooded in November 2012

FISHERYNATION.COM

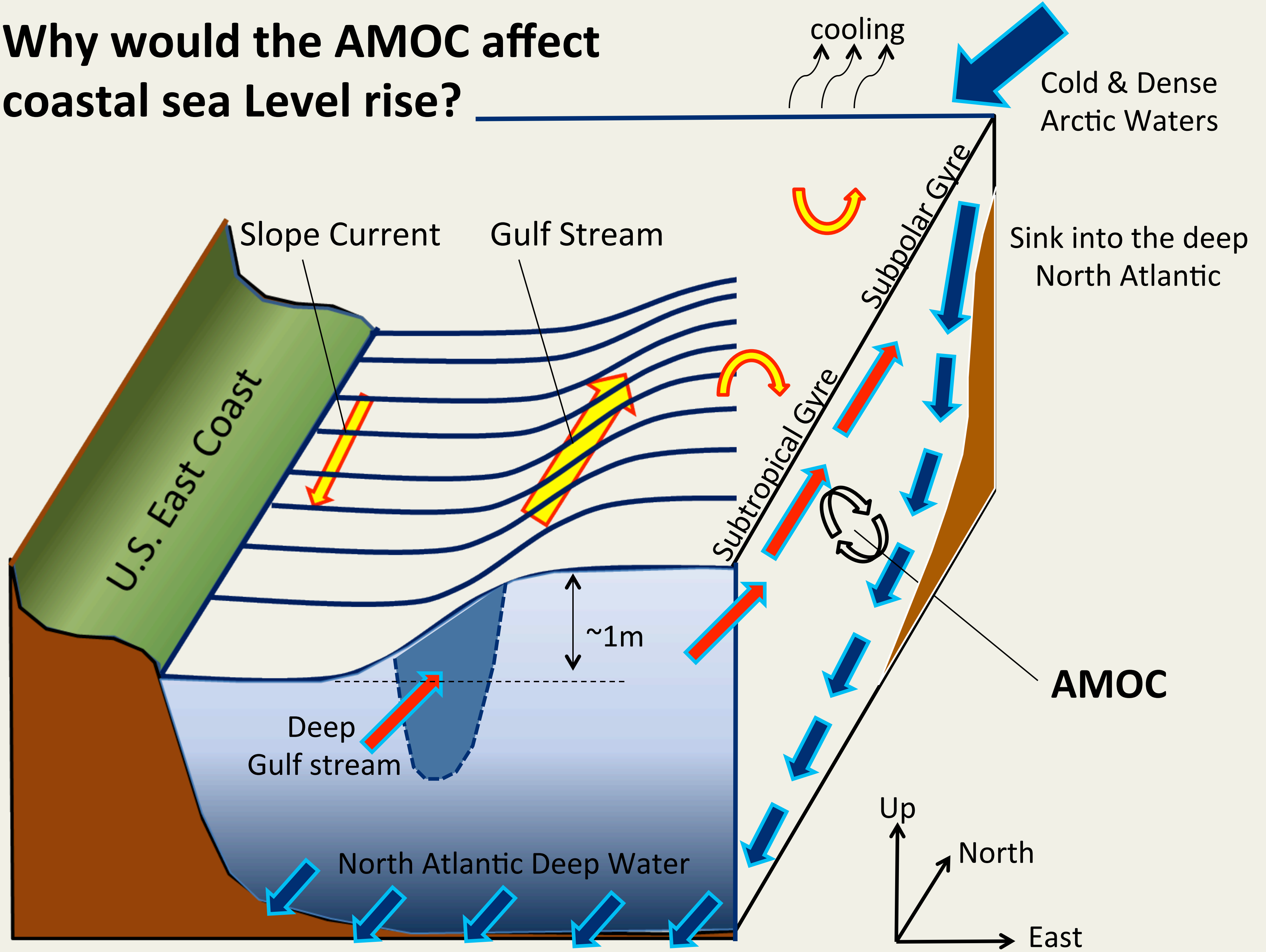
RISK & INSURANCE

The fascination of the public with possible Gulf Stream slowdown is partly due to science fiction movies …. but,

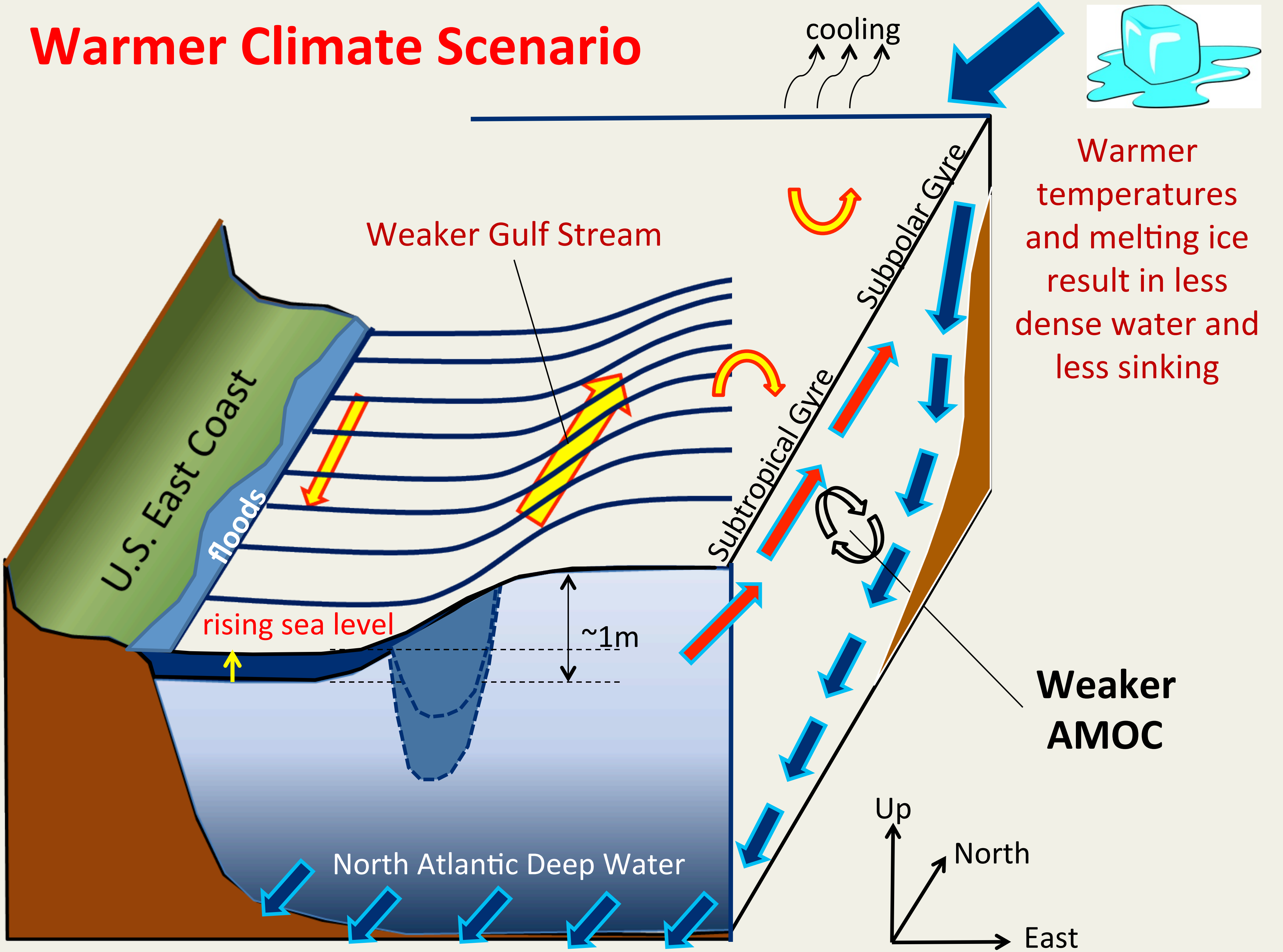
- does the Gulf Stream really slowing down?
- and if so, what are the impacts?

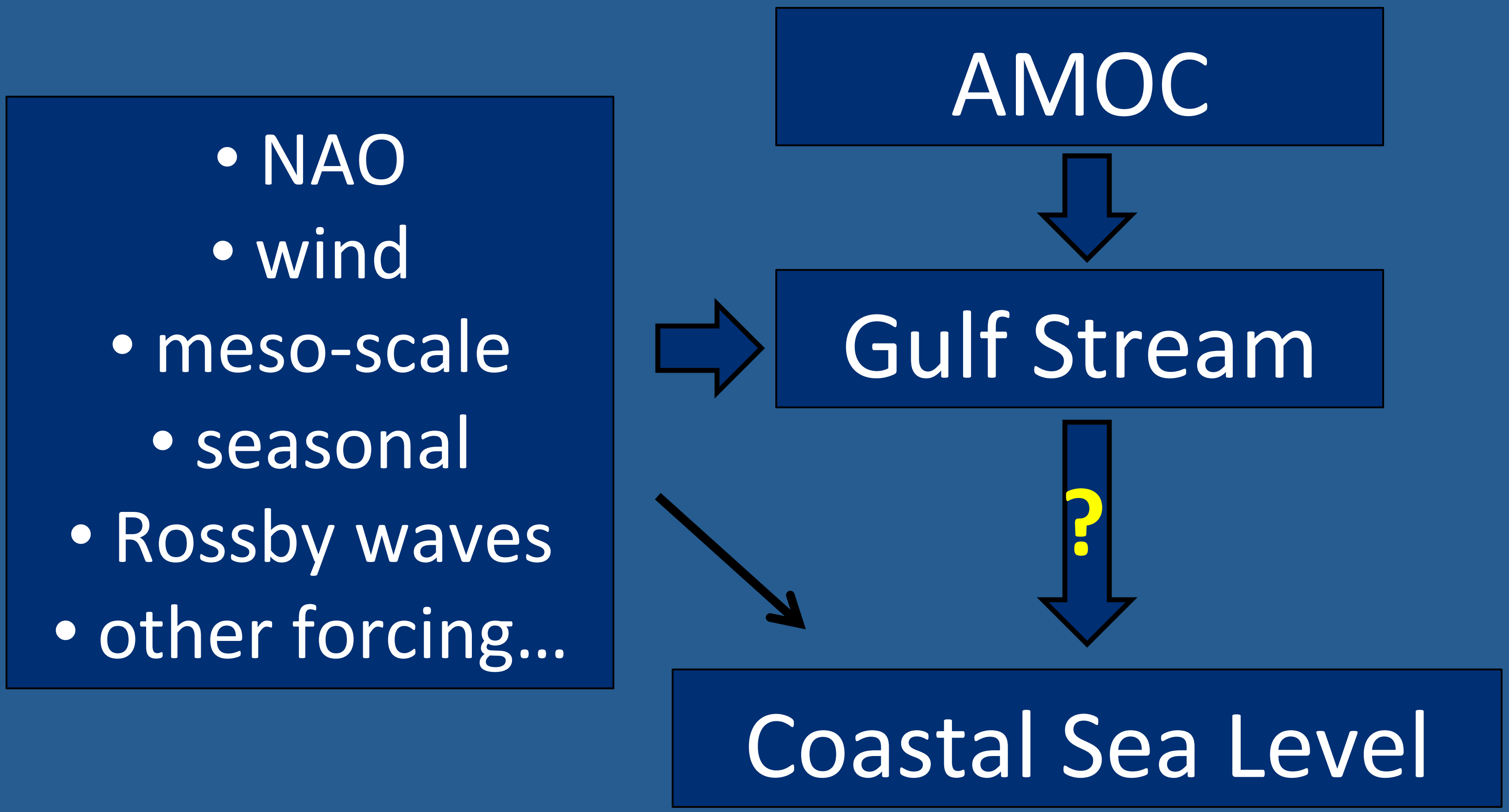


Why would the AMOC affect coastal sea Level rise?



Warmer Climate Scenario

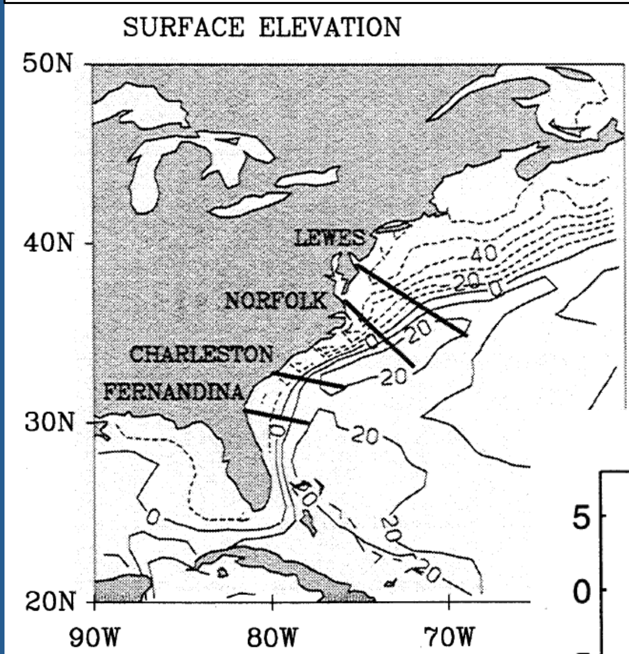




Is there evidence?

- Numerical Models
- Observations

Ezer, T. (2001): Can long-term variability in the Gulf Stream transport be inferred from sea level?, Geophys. Res. Let., 28(6), 1031-1034.



Model results:

changes in the Gulf Stream transport

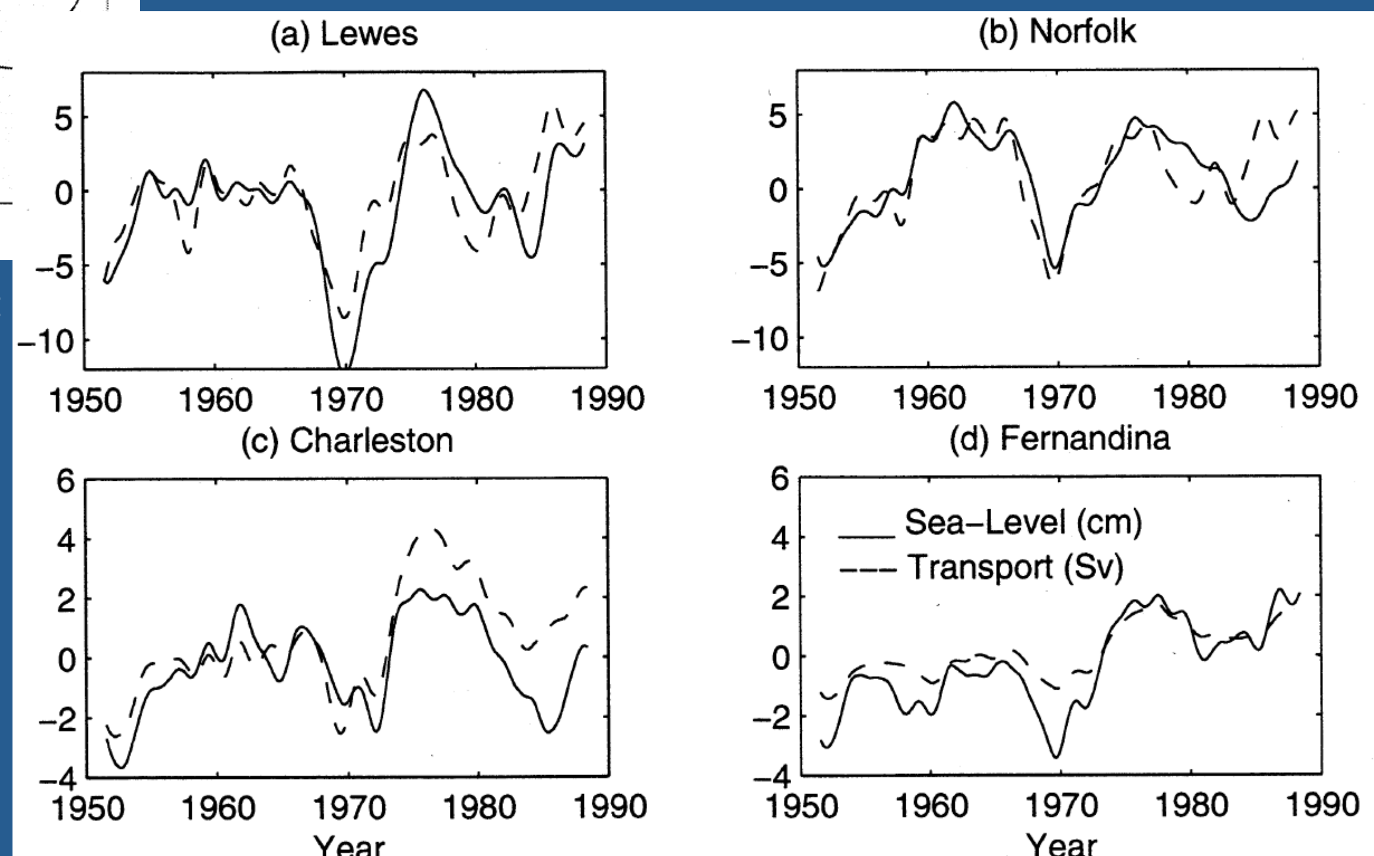
→ changes in the sea level across Gulf Stream

→ changes in coastal sea level

Decadal var. in sea level:

~10-15 cm
north of Cape Hatteras

~2-5 cm
south of Cape Hatteras

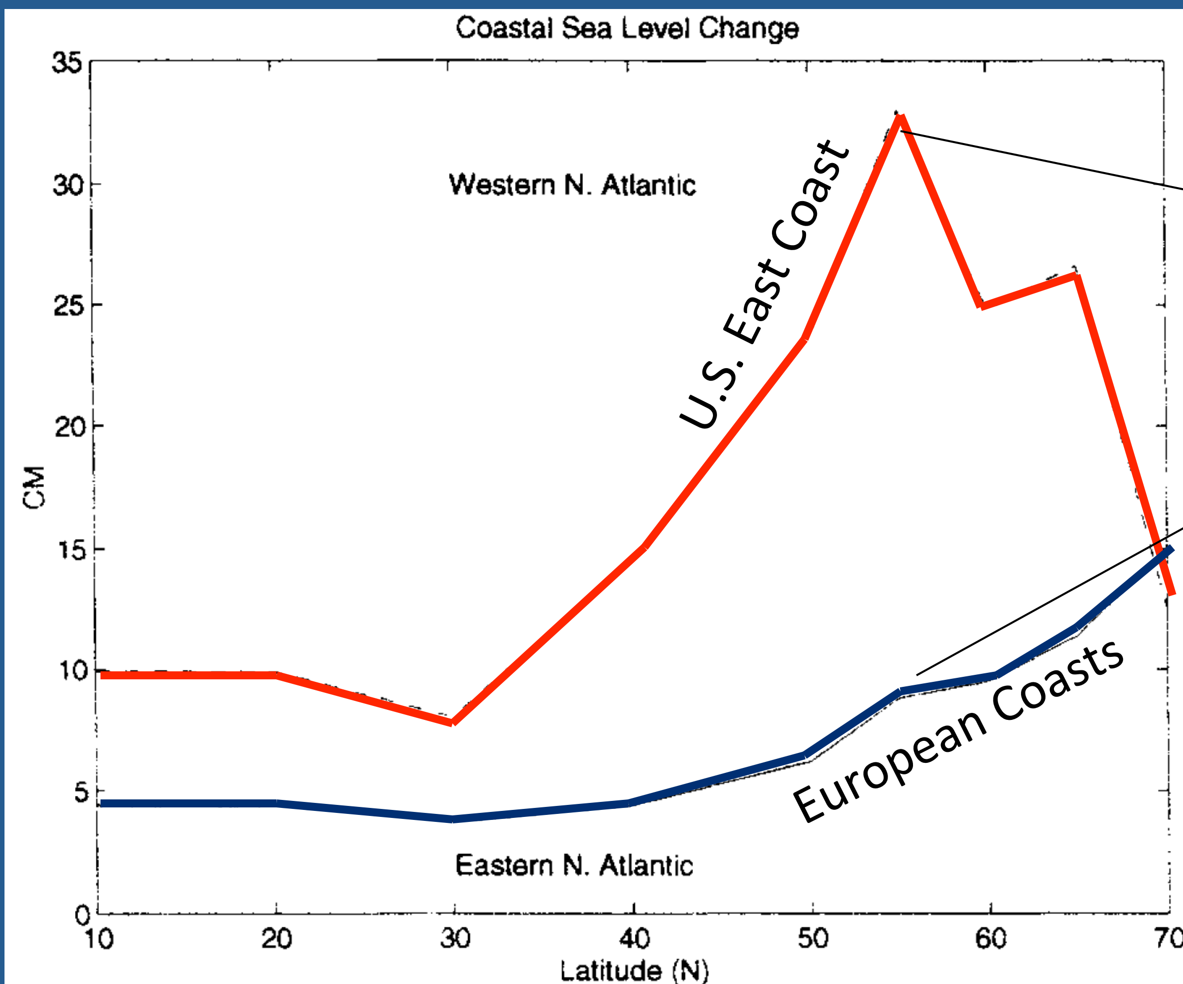


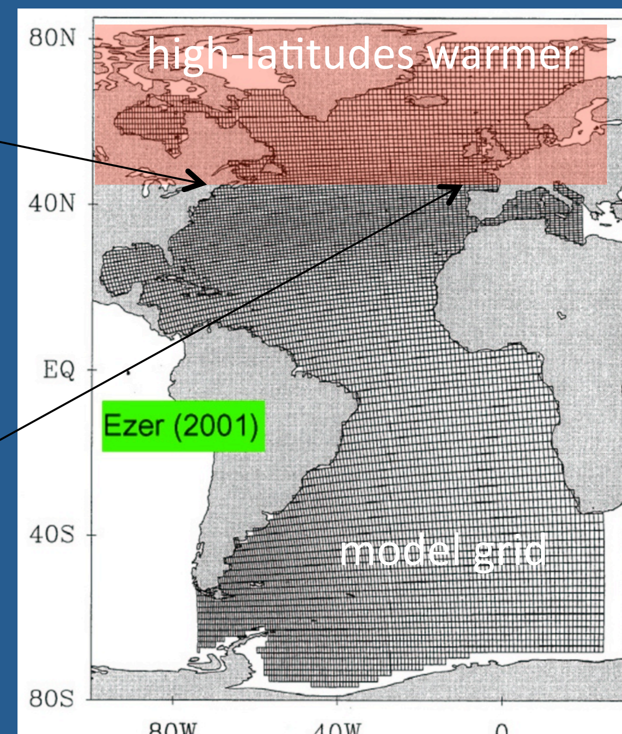
Ezer, T. (2001): On the response of the Atlantic Ocean to climatic changes in high latitudes. In: The Oceans and Rapid Climate Change. Geophys. Monogr. Ser., 126, AGU

Model experiment: warmer surface temperature in high latitude

Results: 2-3 times larger sea level rise along the western Atlantic (US east coast) than along the eastern Atlantic (European coast)

Why? ocean circulation changes in warmer climate





LETTERS
PUBLISHED ONLINE: 15 MARCH 2009 | DOI: 10.1038/NGEO462
nature geoscience

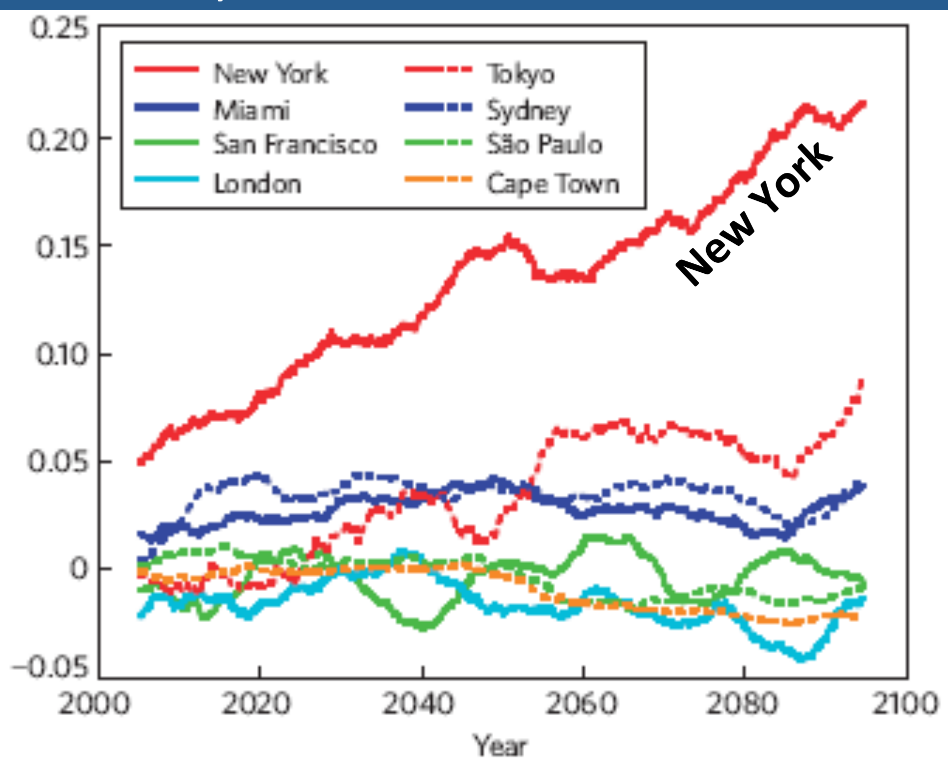
Yin et al. (2009)

Model projections of rapid sea-level rise on the northeast coast of the United States

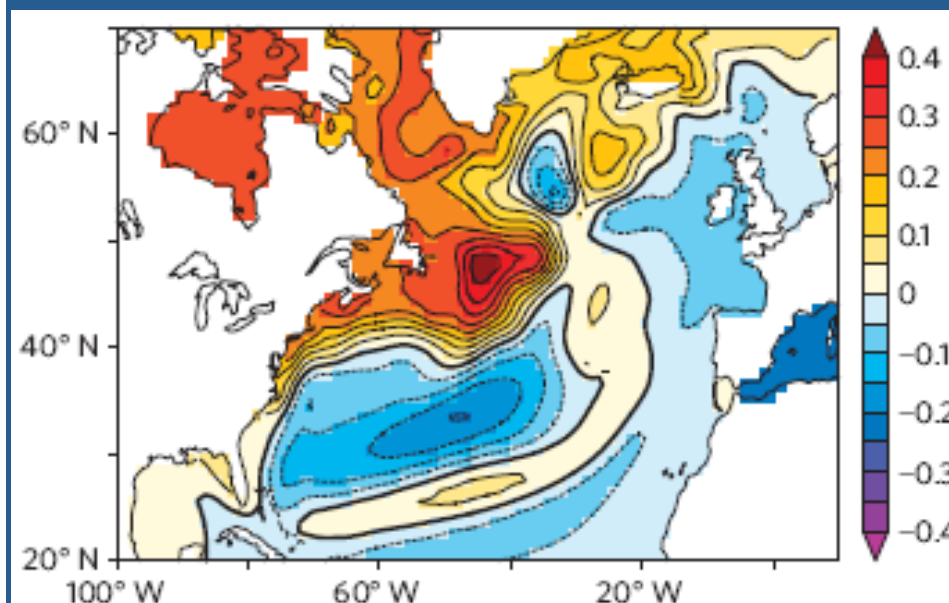
Jianjun Yin[1]*, Michael E. Schlesinger[2] and Ronald J. Stouffer[3]

Here we analyse climate projections from a set of state-of-the-art climate models for such regional changes, and find a rapid dynamical rise in sea level on the northeast coast of the United States during the twenty-first century.

Dynamic Sea Level Rise



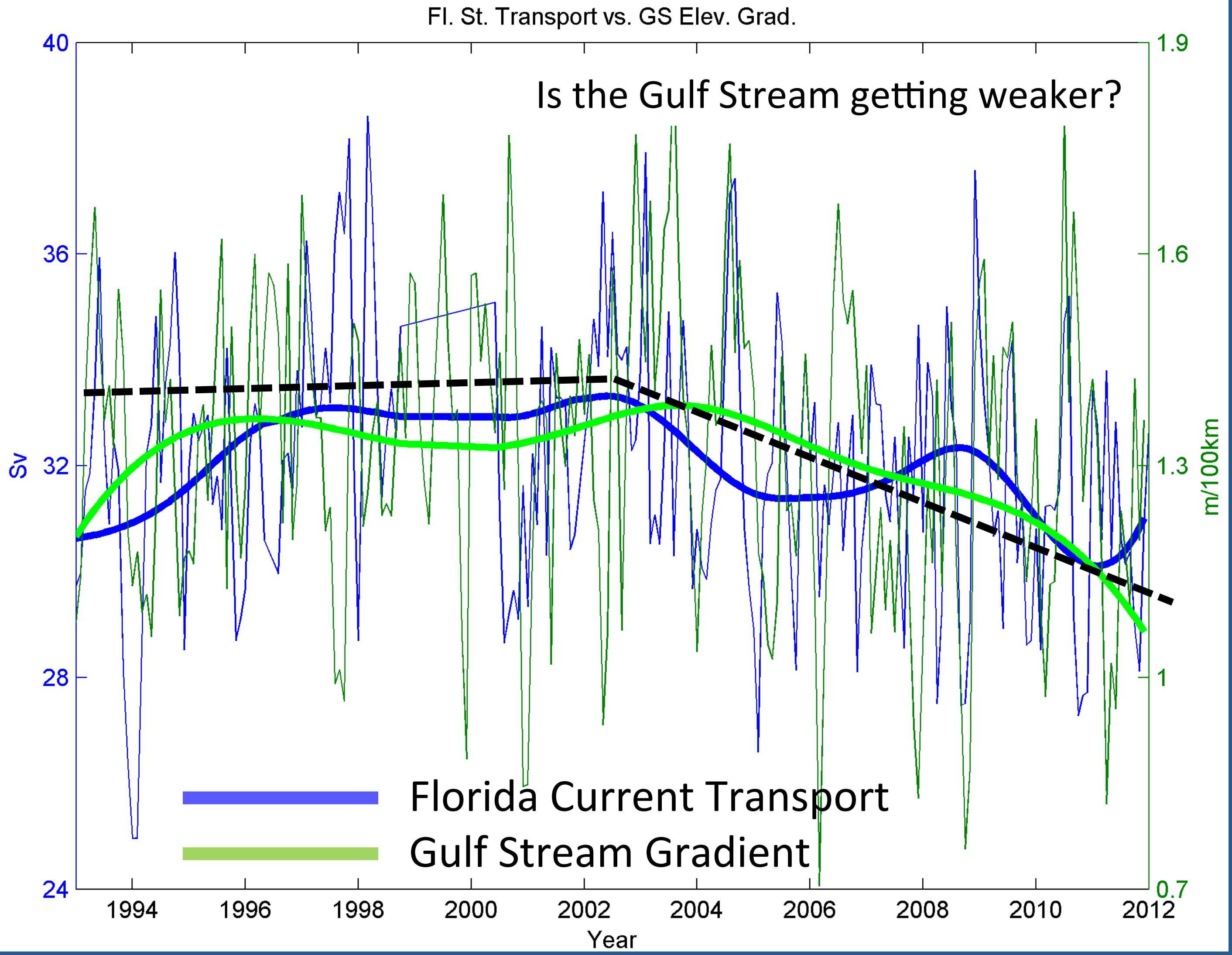
Projected SLR anomalies from 2000 to 2100

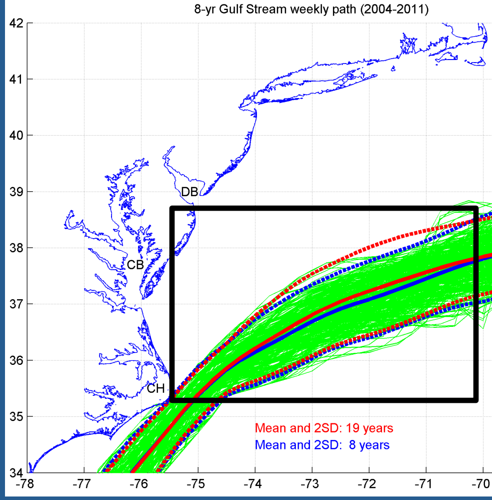


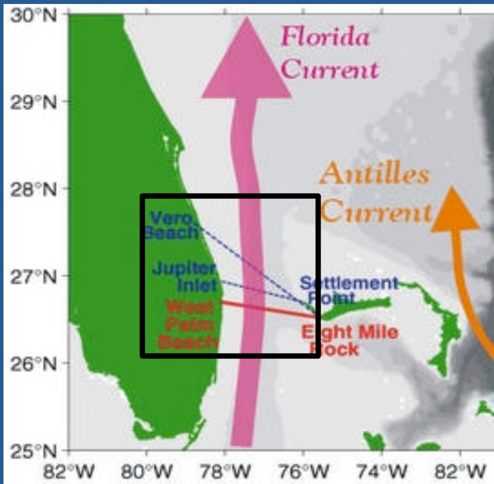
Gulf Stream – Florida Current Correlations

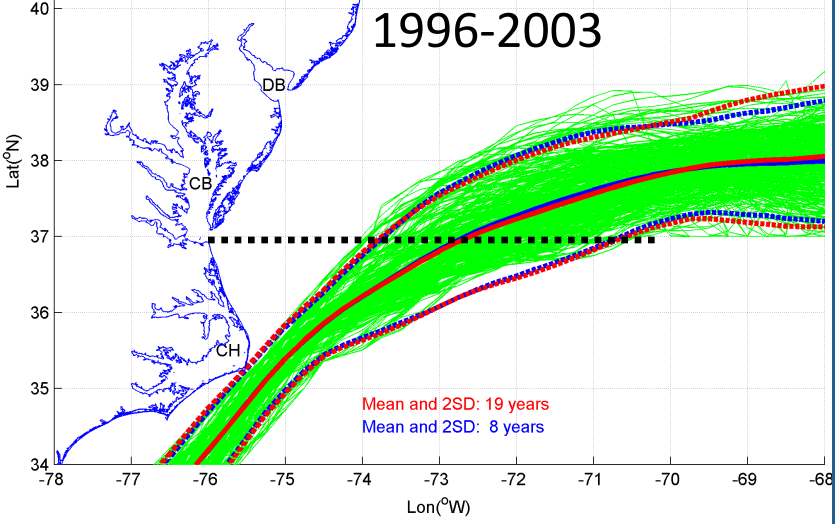
Monthly data: R=0.13 (95%)

Low-freq. modes: R=0.72 (99.9%)

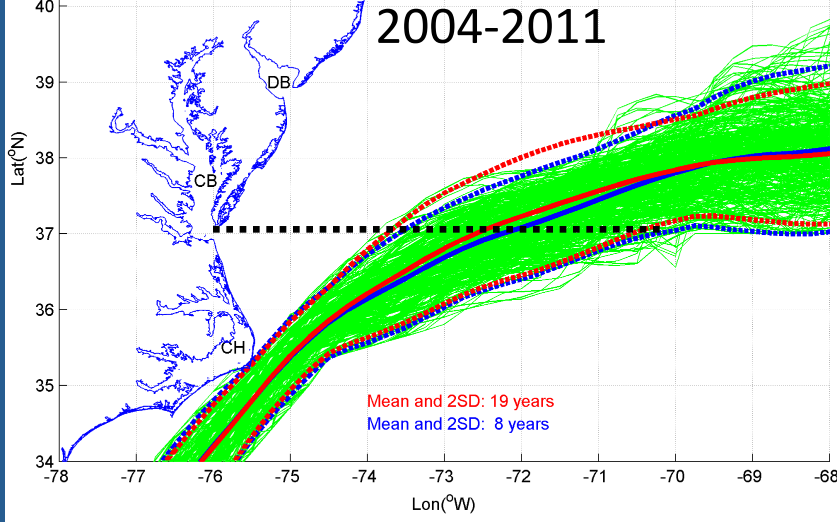






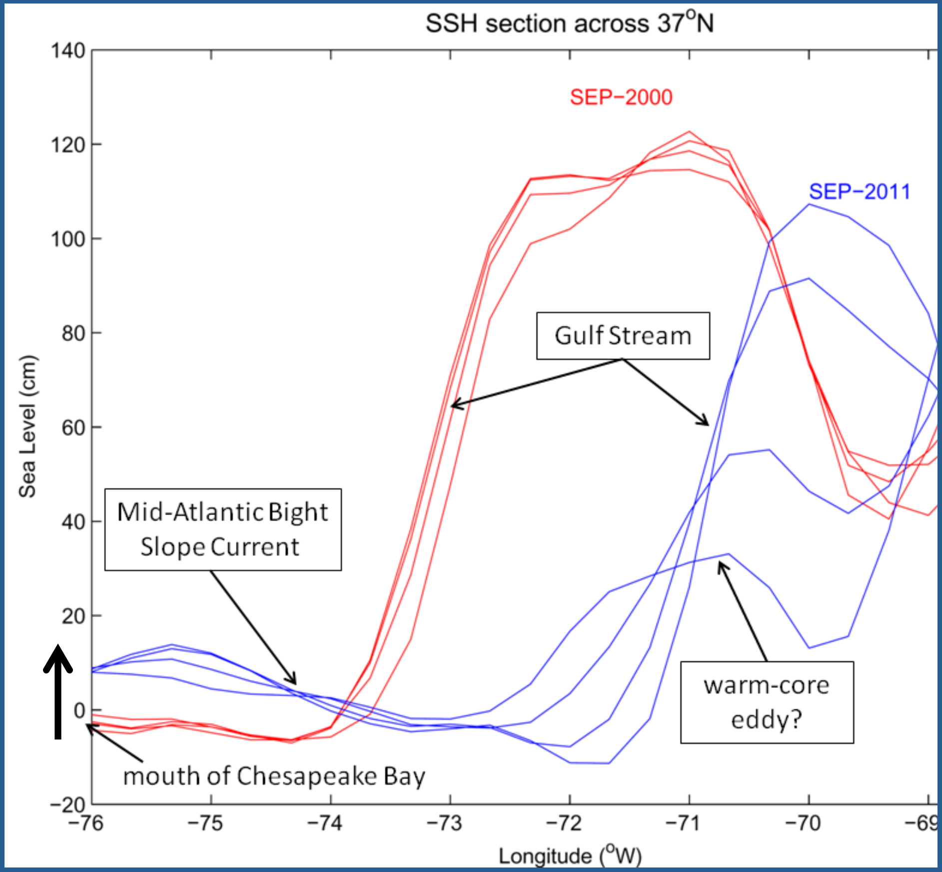


Weakly Gulf Stream path from satellite altimeter data

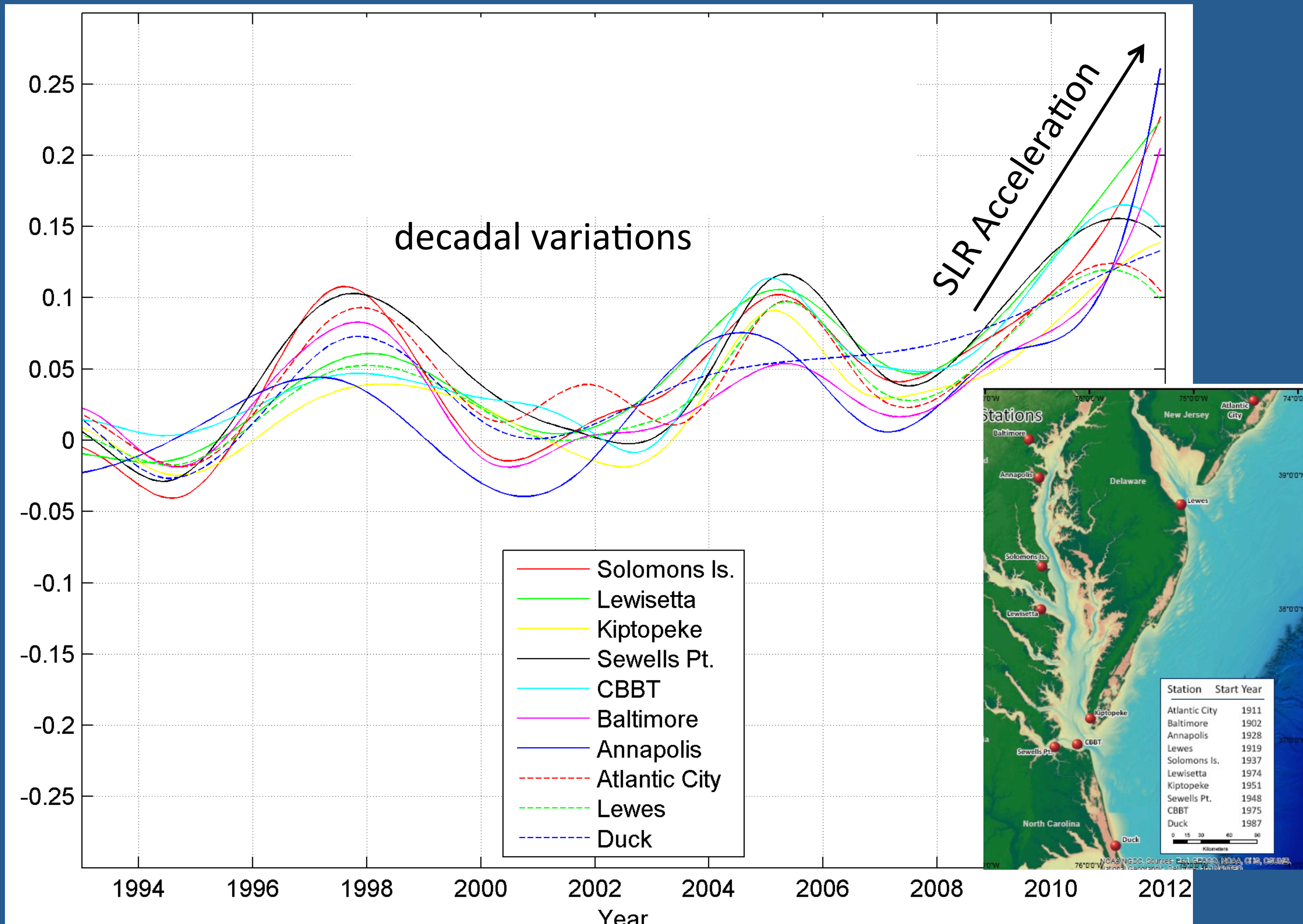


There is evidence that in recent years the Gulf Stream is weakening and potentially shifting offshore

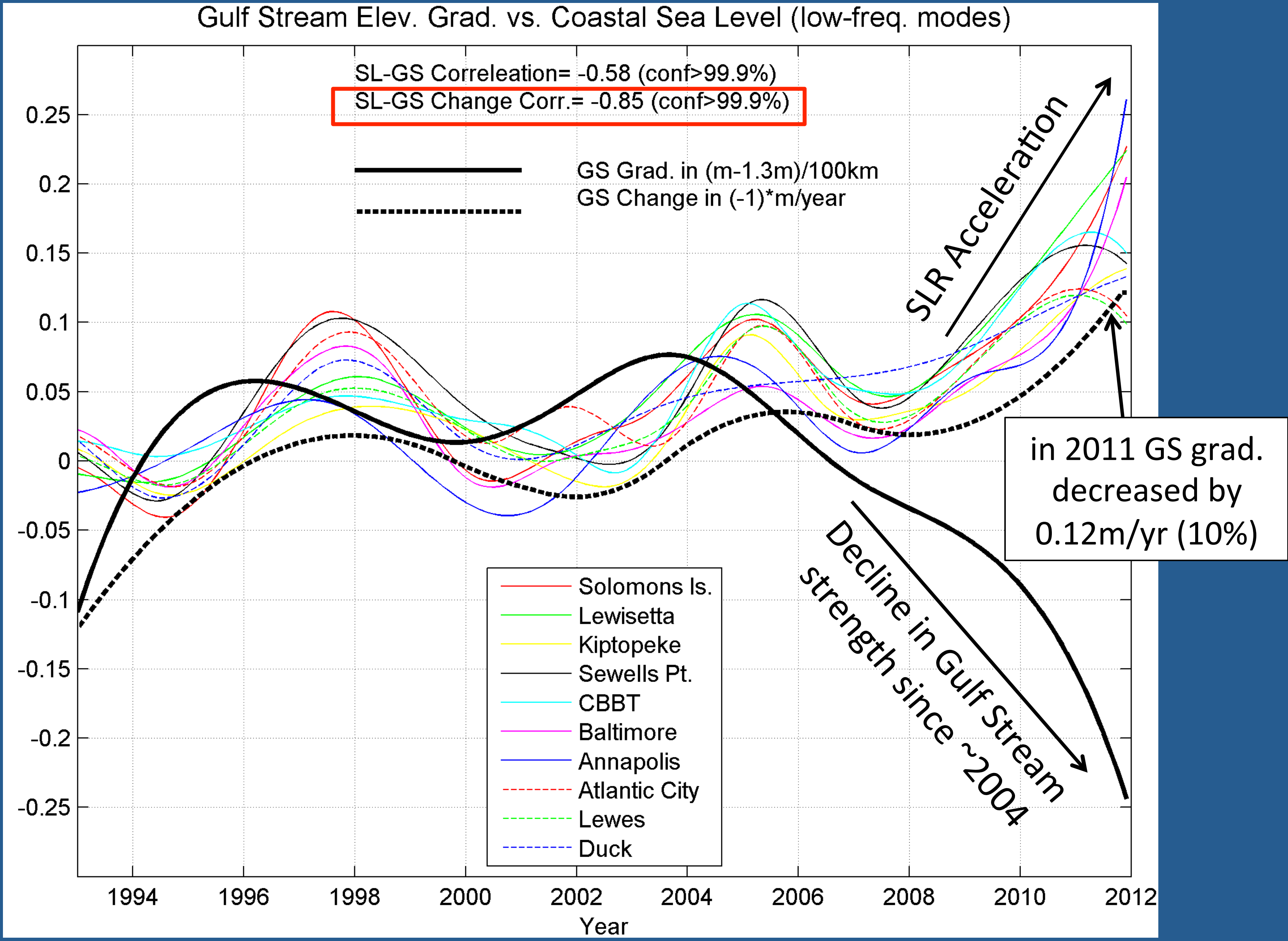
Change of 12 cm over 10 years →
(Six times the global sea level rise!)



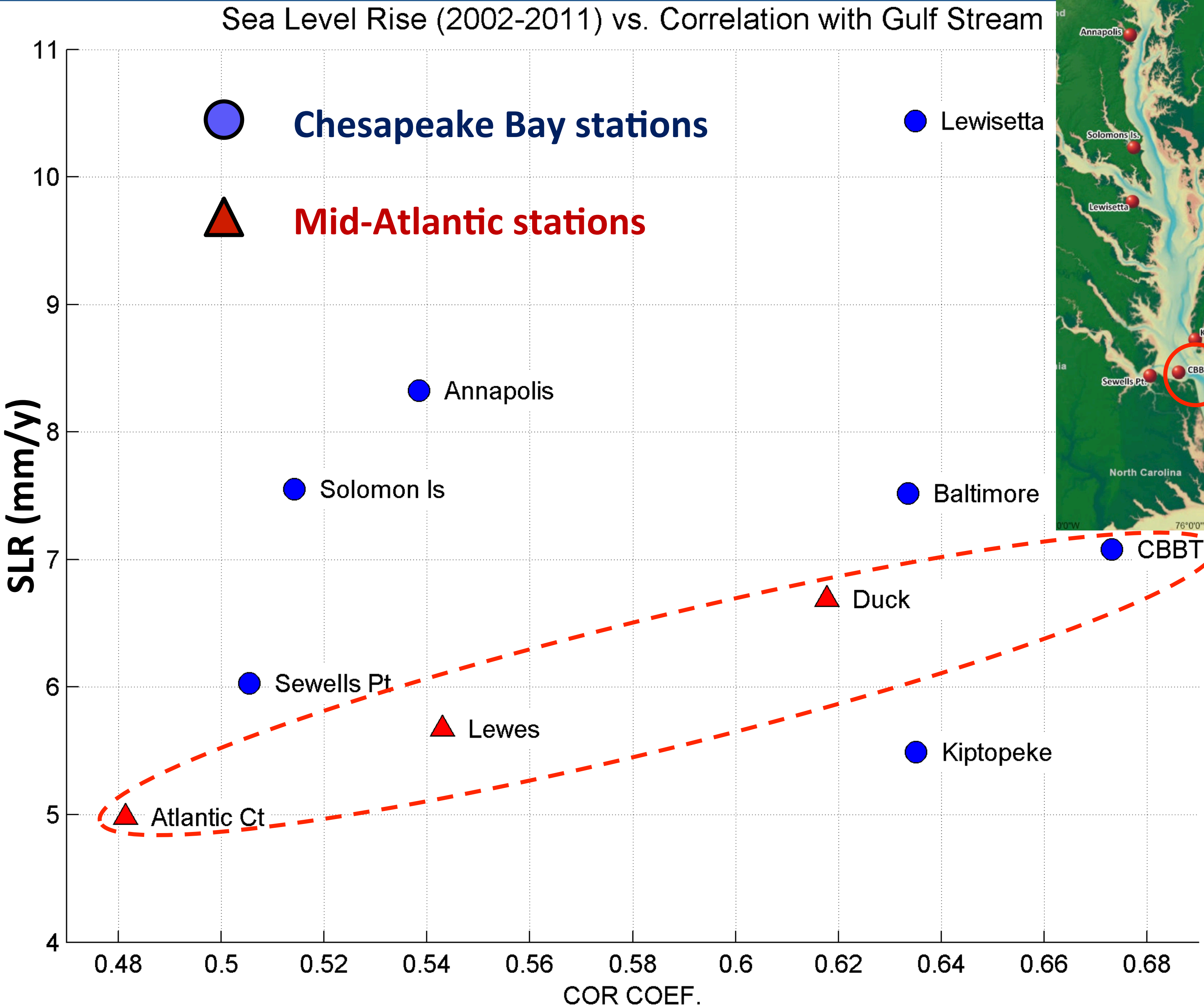
EMD/HHT Analysis (last 3-modes):
All sea level records show similar patterns



All sea level records are highly correlated with the Gulf Stream strength

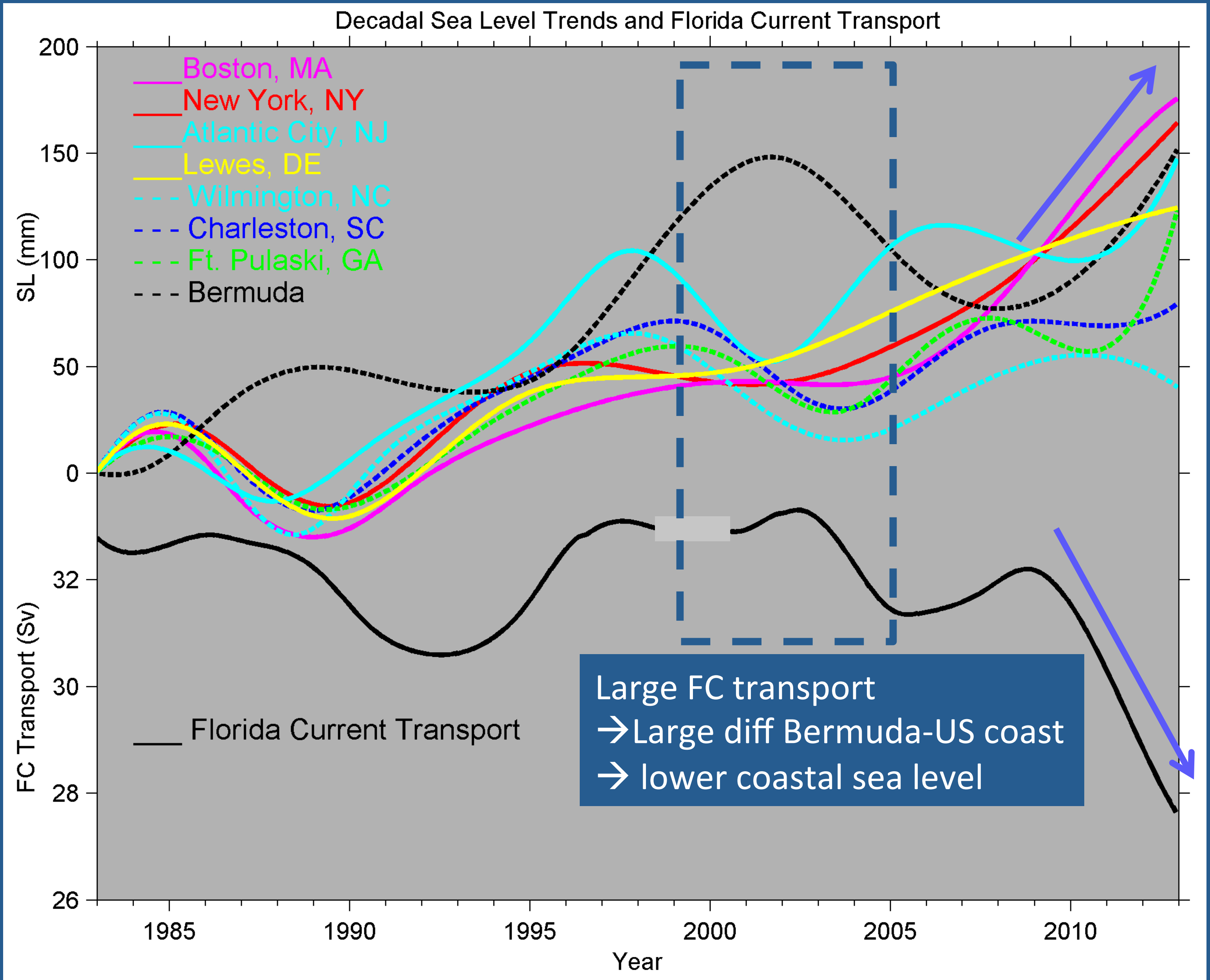


SLR rates of last decade & GS variability



GS-SL ← Corr.

Gulf Stream influence on decadal variability in sea level (note: Bermuda SL in opposite phase to US East coast)



Conclusions

• Variations in coastal sea level records in the Mid-Atlantic region were found to be highly correlated with variations in the Gulf Stream on time scales ranging from a few months to decades

• There is evidence that weakening of the Gulf Stream since ~2004 may be the cause of recent sea level rise acceleration in the region

• The proposed mechanism:

Climate warming and freshening of surface waters in polar regions
→ slow-down of Atlantic Meridional Overturning Circulation (AMOC)
→ decrease Florida Current and Gulf Stream transports
→ decrease surface gradients across the Gulf Stream
→ increase coastal sea level along the Mid-Atlantic region

Practical implication: SLR projections must take into account climatic changes in ocean dynamics

Sea Level Rise Projections for Maryland

Sea level along Maryland's shorelines could rise 2 feet by 2050

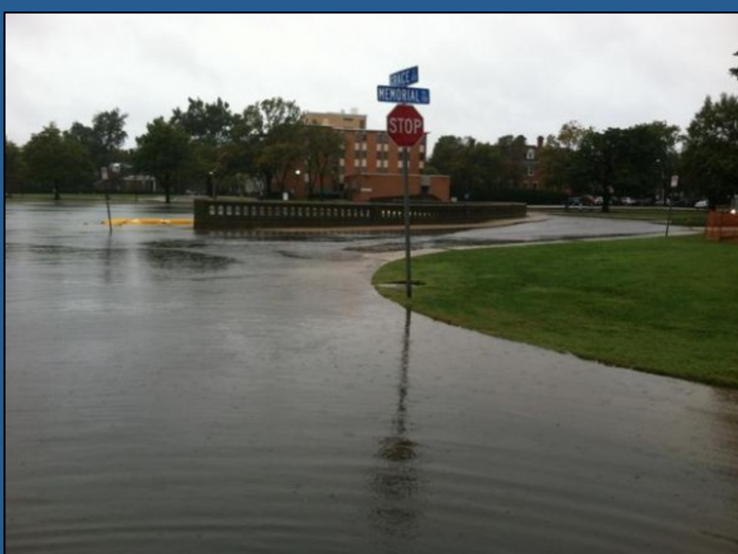
A new report on sea level rise recommends that the State of Maryland should plan for a rise in sea level of as much as 2 feet by 2050. Led by the University of Maryland Center for Environmental Science, the report was prepared by a panel of scientific experts in response to Governor Martin O'Malley's Executive Order on Climate Change and "Coast Smart" Construction. The projections are based on an assessment of the latest climate change science and federal guidelines.

Updating Maryland's **Sea-level Rise Projections**

Scientific and Technical Working Group
Maryland Climate Change Commission

June 26, 2013

A slowing Gulf Stream: The working group described several other factors that explain why Maryland can expect its coastal sea level to rise by more than the global average. One is a slowing in the flow of the Gulf Stream current, which travels north from Florida along the East Coast and then east across the Atlantic Ocean. Scientists have collected evidence that indicates a decline in the current's speed since 2004.



Thank You

Norfolk flooding during Hurricane Sandy, Oct. 2012