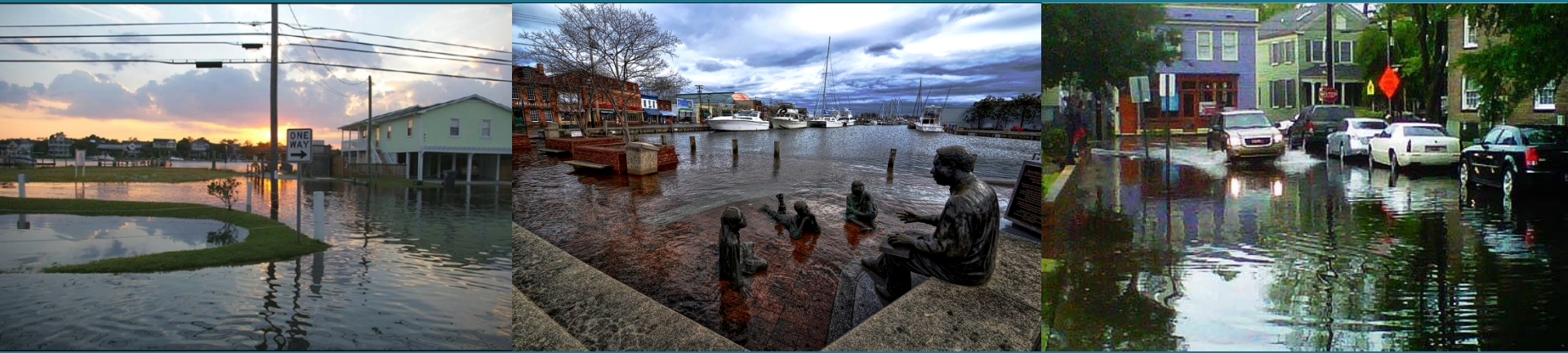


# From the Extreme to the Mean: Effects of Sea Level Rise on Coastal Flooding



**Integrating Coastal Flood Research, Modeling and Monitoring to  
Improve Coastal Resiliency in the Mid-Atlantic**

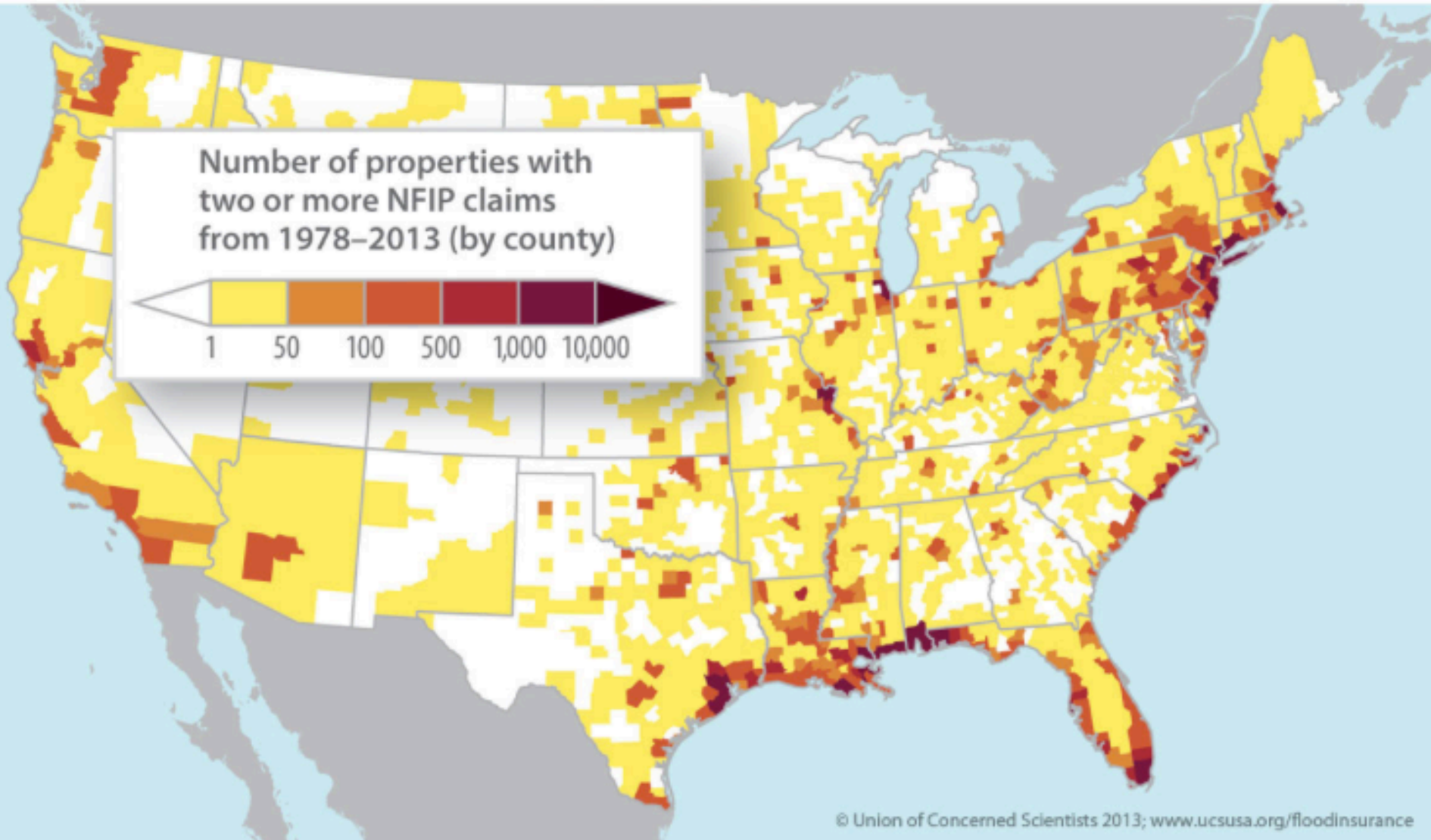
*September 16, 2015*

**Dr. William Sweet  
NOAA CO-OPS Oceanographer**

# Repetitive-Loss Properties by U.S. County

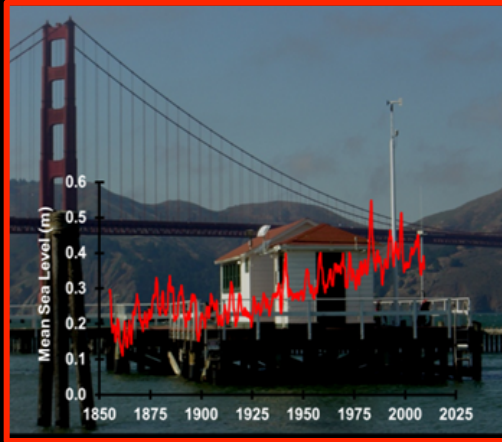
Number of properties with  
two or more NFIP claims  
from 1978–2013 (by county)

1 50 100 500 1,000 10,000

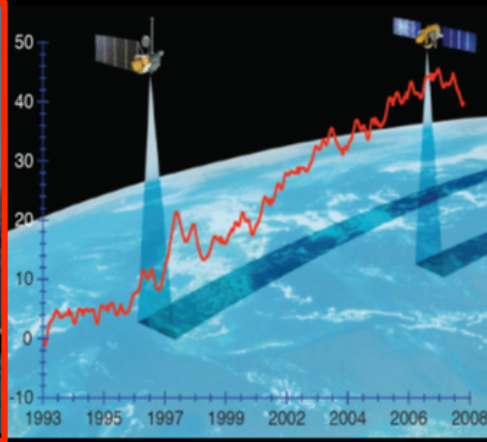


# Monitoring Global SLR and Relative Impacts from Tide Gauges

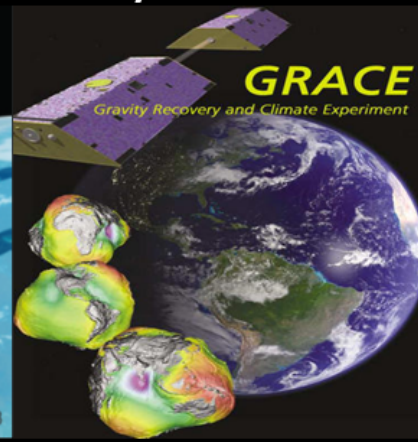
Water Level Stations



Satellite Altimeter



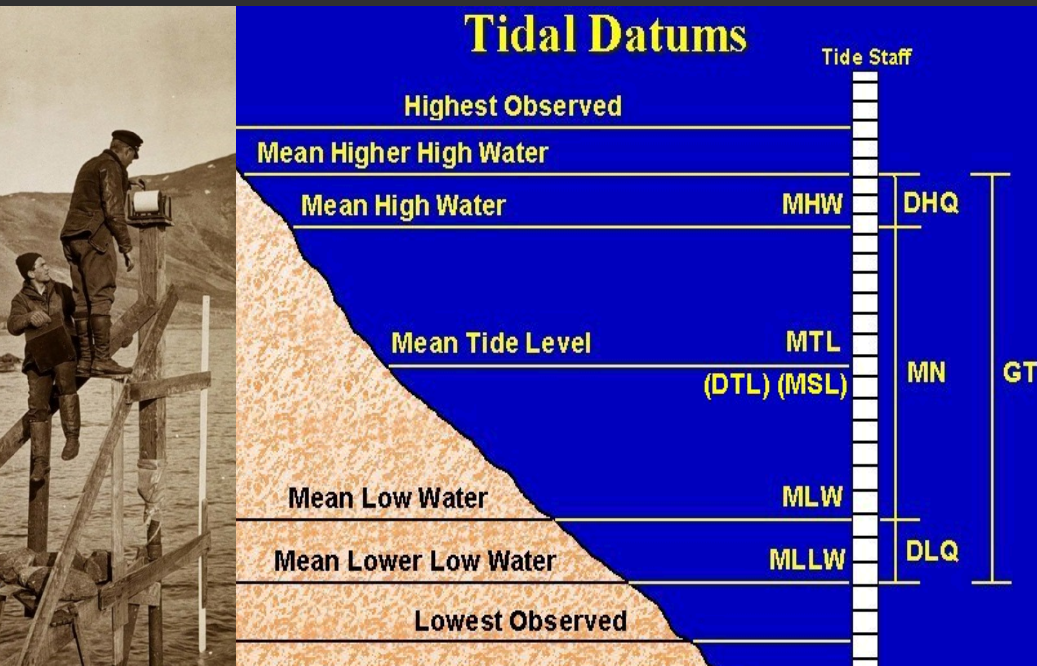
Gravity Measurements



ARGO Profilers



## NOAA tide gauges provide local coastal flood information



- Benchmark network and tidal-geodetic connection
- Relative SLR trends
- Vertical land motion
- Extremes and Impacts

# Relative Sea Level Rise (SLR<sub>rel</sub>)

## Sea Level Trends

East Coast

West Coast

Gulf Coast

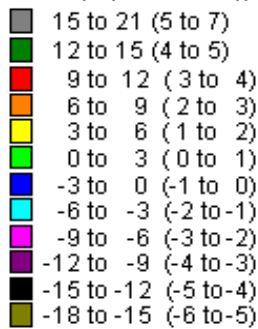
Alaska

Hawaii

Global

### Sea Level Trends

mm/yr (feet/century)



<http://tidesandcurrents.noaa.gov/sltrends>

- The seas are rising
- The land is sinking in many locations

[http://tidesandcurrents.noaa.gov/publications/Technical\\_Report\\_NOS\\_CO-OPS\\_065.pdf](http://tidesandcurrents.noaa.gov/publications/Technical_Report_NOS_CO-OPS_065.pdf)

# Thresholds of “Concern”

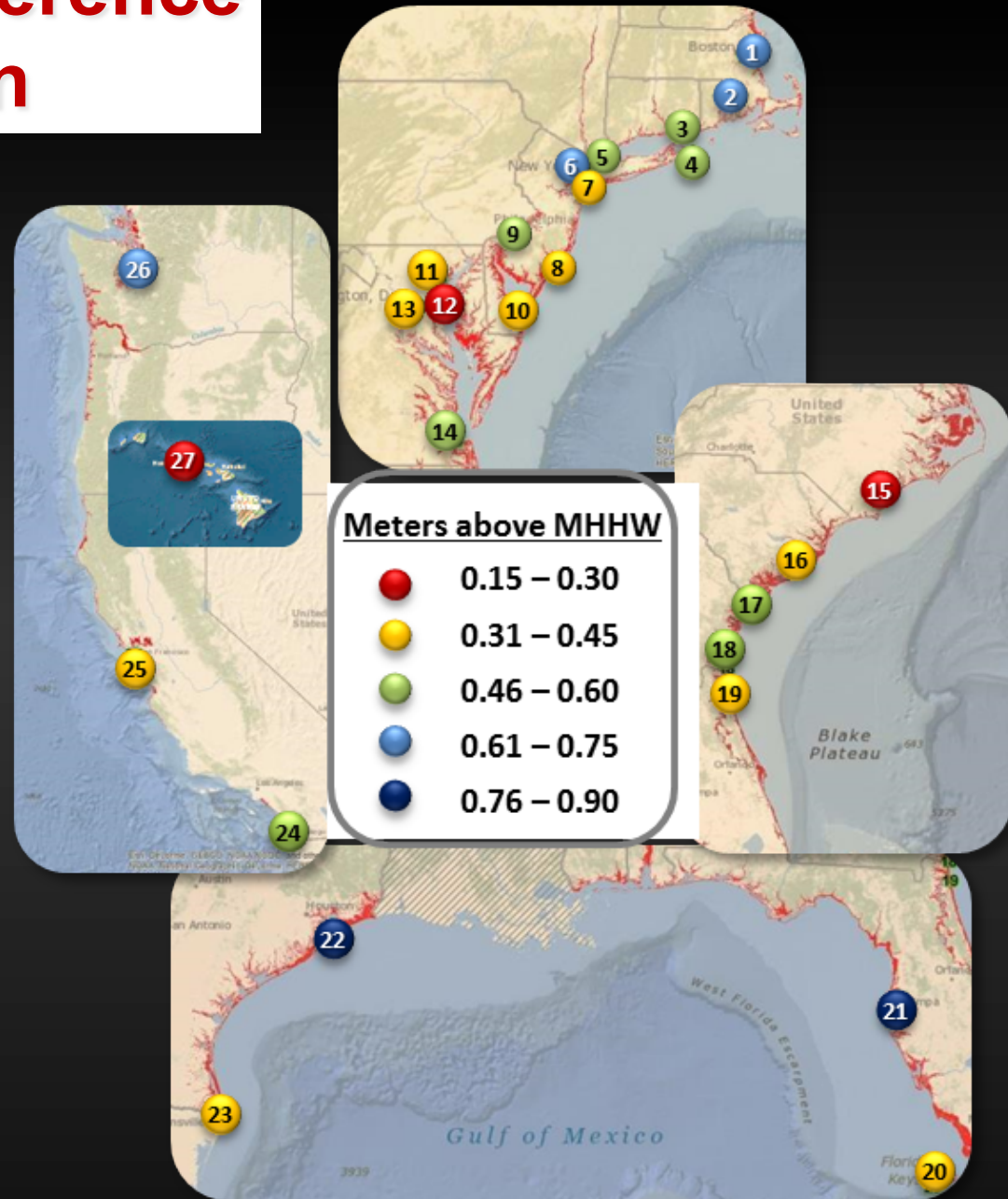
Exposure thresholds of systems to flooding at which functional degradation occurs...



# Today's Frame of reference ...looking down

Today's infrastructure:

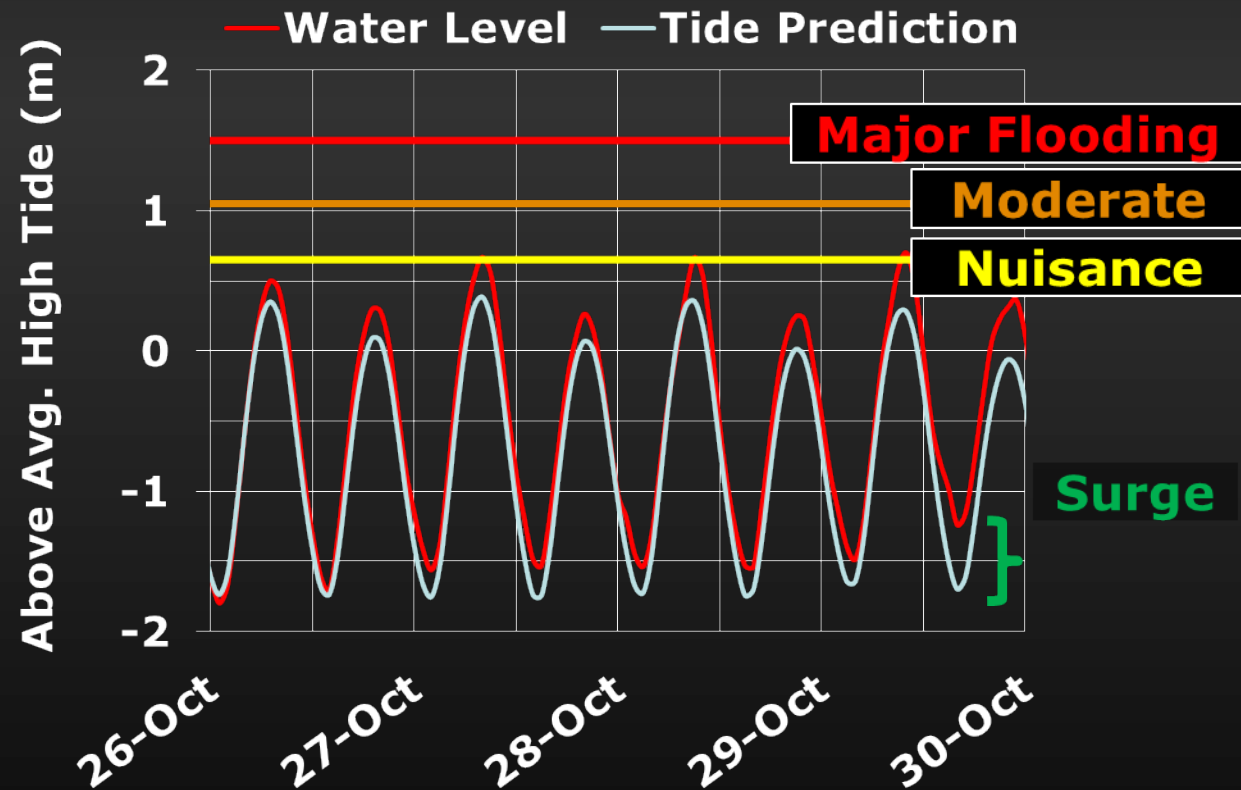
Vulnerable to minor  
nuisance flooding 1-2'  
above avg. highest tide



# NOAA Tide Gauges and Coastal Flooding

Tide gauges provide long records of high-water events whose impacts are defined by NOAA NWS

NOAA Tide Gauge Battery, NY: 2011



# What is "Nuisance" Tidal Flooding?

← → ↻ 🏠 [water.weather.gov/ahps2/index.php?wfo=phi](http://water.weather.gov/ahps2/index.php?wfo=phi)

📱 Apps 🎧 Ethiopian Music - A... 📄 North Atlantic Coast... 🌐 ERDDAP - Home Pa...

Local weather forecast by "City, ST"  
City, ST  Go

Adjacent Areas:  
📏 Zoom In 📏 Zoom Out

National Observations **WFO Observations**

Notice: New features, functions, and enhancements to AHPS pages as of 8/11/2015. [Click here for details](#)

Weather Forecast Office Philadelphia/Mount Holly, NJ Middle Atlantic River Forecast Center

River Observations River Forecasts Experimental Long-Range Flood Risk Precipitation Download Other Information

Auto Refresh: OFF

Print this map Permalink

843 total gauges 0 gauges in flood

Switch Basemap Reset View

- Forecast available
- Probability and forecasts available
- Observations only available
- Major Flooding
- Moderate Flooding
- Minor Flooding
- Near Flood Stage
- No Flooding
- Observations Are Not Current
- Out of Service
- Flood Category Not Defined
- At or Below Low Water Threshold

Last map update:  
09/10/2015 at 10:11:11 am EDT  
09/10/2015 at 14:11:11 UTC

[Disclaimer](#)

POWERED BY **esri**

Esri, DeLorme, FAO, USGS, NOAA, EPA, NPS

**FLOODSMART.GOV**  
U.S. National Flood Smart Program

**USA.gov**  
Government Made Easy

**NOAA**  
NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION  
U.S. DEPARTMENT OF COMMERCE

**USGS**  
U.S. GEOLOGICAL SURVEY  
SCIENCE FOR A CHANGING WORLD

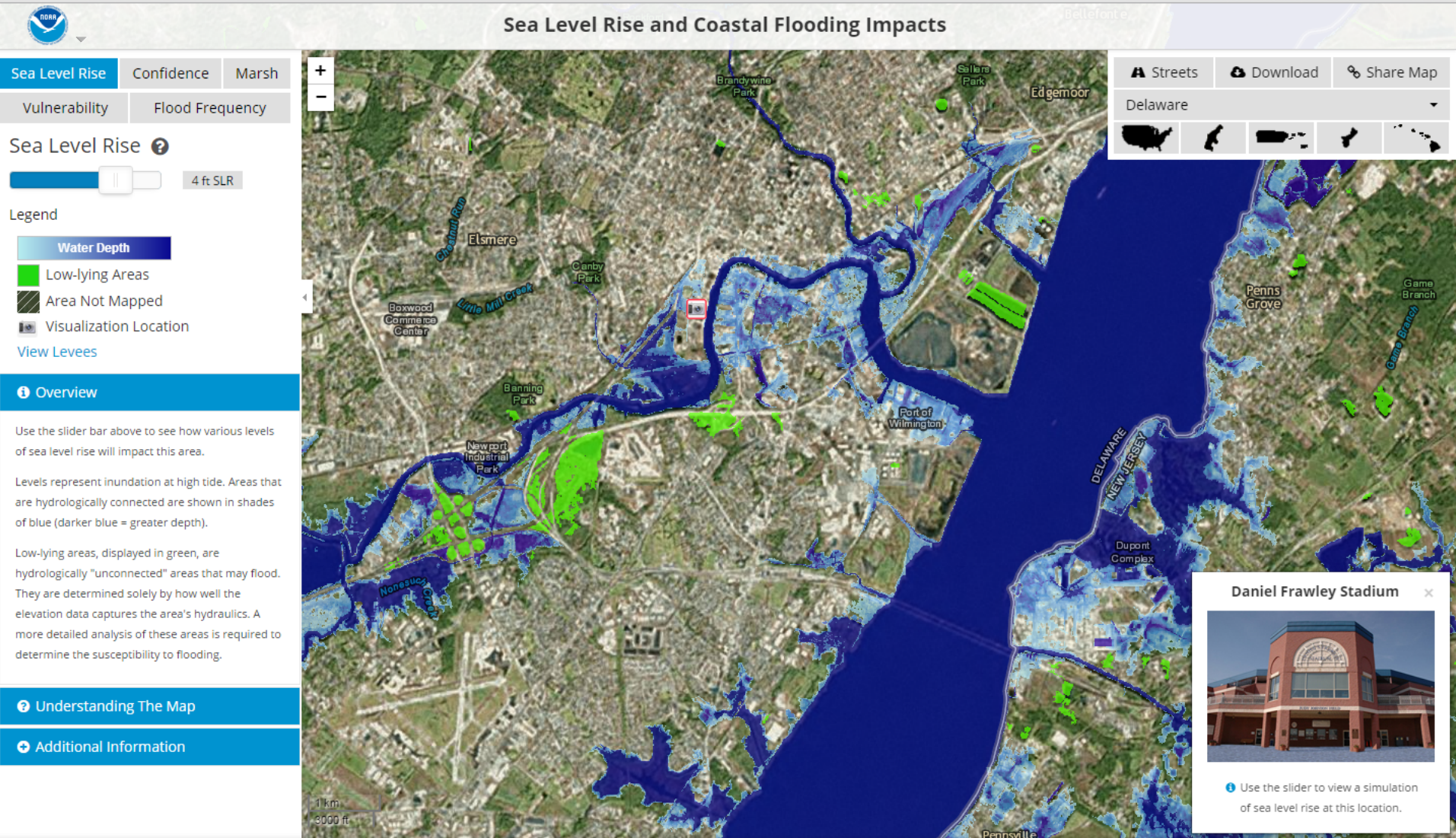
WHEN FLOODED TURN AROUND DON'T DROWN



# At Risk from Nuisance+ Level Flooding

## 4 feet above high tide (MHHW) in Wilmington, DE...~Sandy level

coast.noaa.gov/slr/



# What Does Nuisance Flooding Look Like?

(From: Picasa, King Tide in the NY-NJ Harbor Estuary)

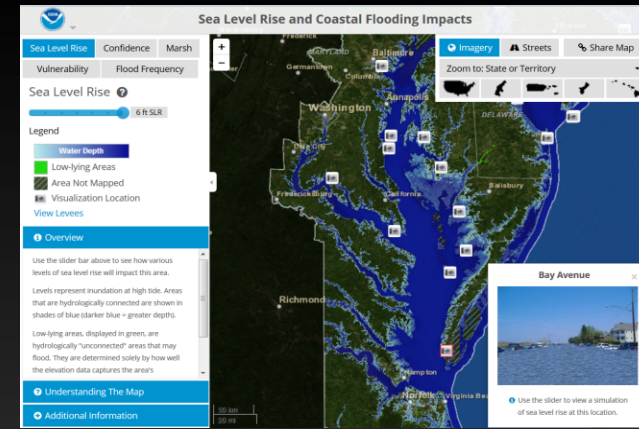


Hudson Line, Marble Hill, NYC

# What are the effects of SLR?

## 1. $SLR_{rel}$ increases perennial inundation

- difficult to sense “mean” changes  
... tides and storms dominate



## 2. Exacerbates extreme probabilities

- obscured by rarity of events

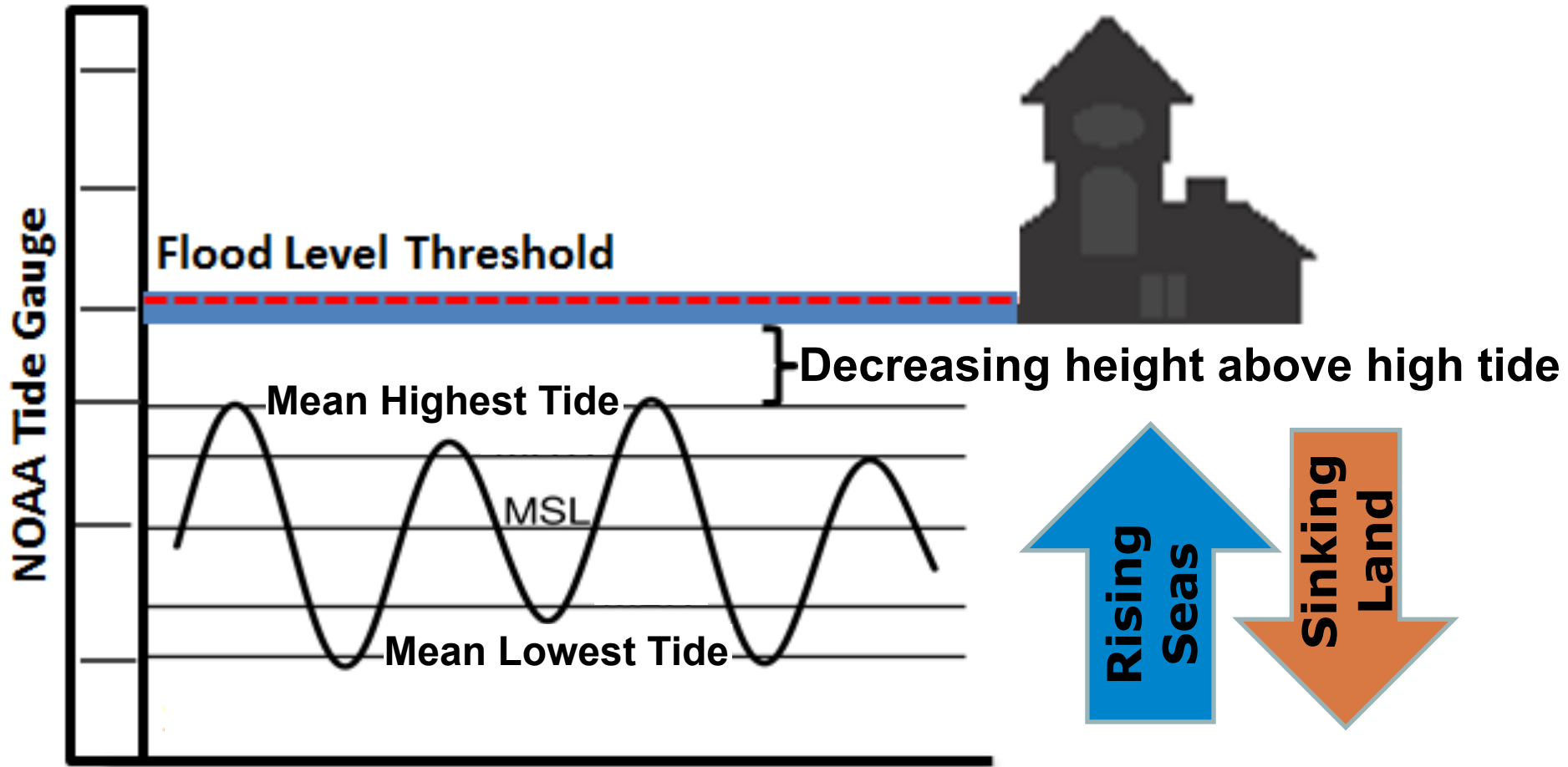


## 3. Exacerbates nuisance flooding

- more tangible indicator of climate change-related SLR



# Dylan's B-side hit: the tides...they are a changing

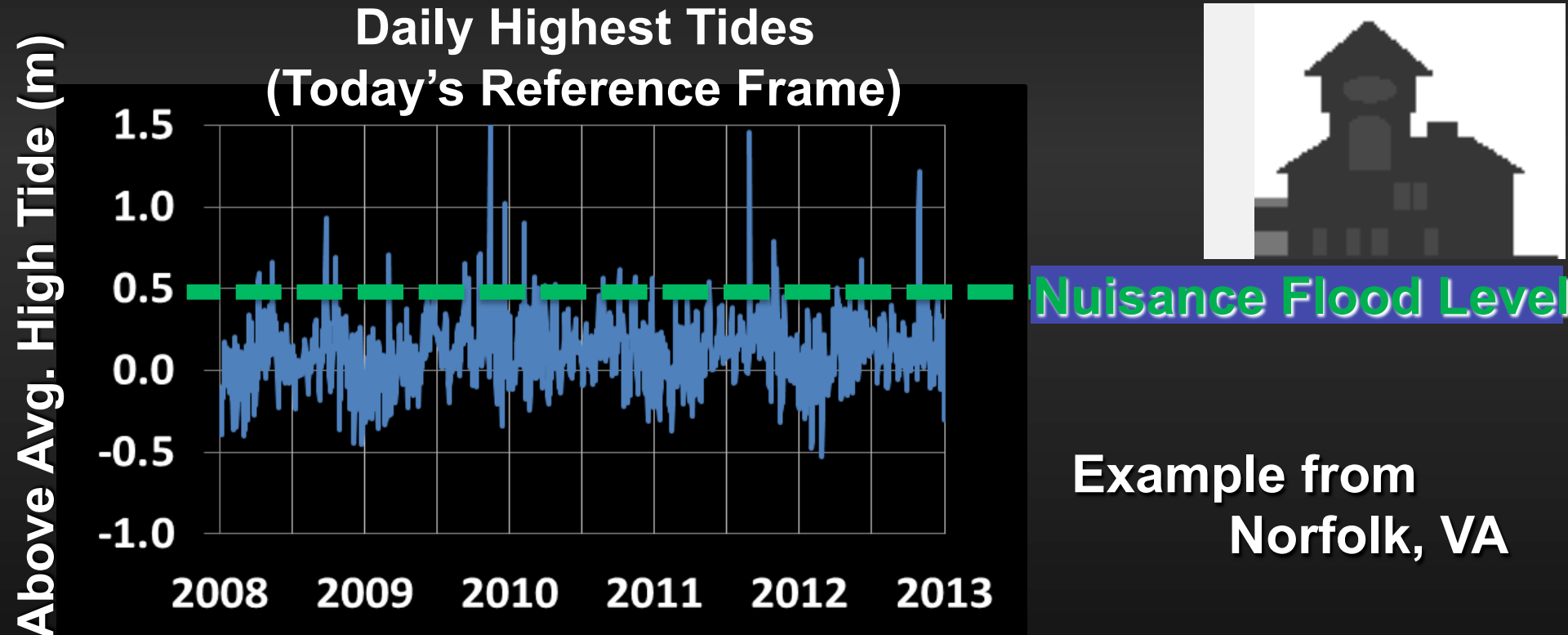


“Then” flooding occurred during big storms.

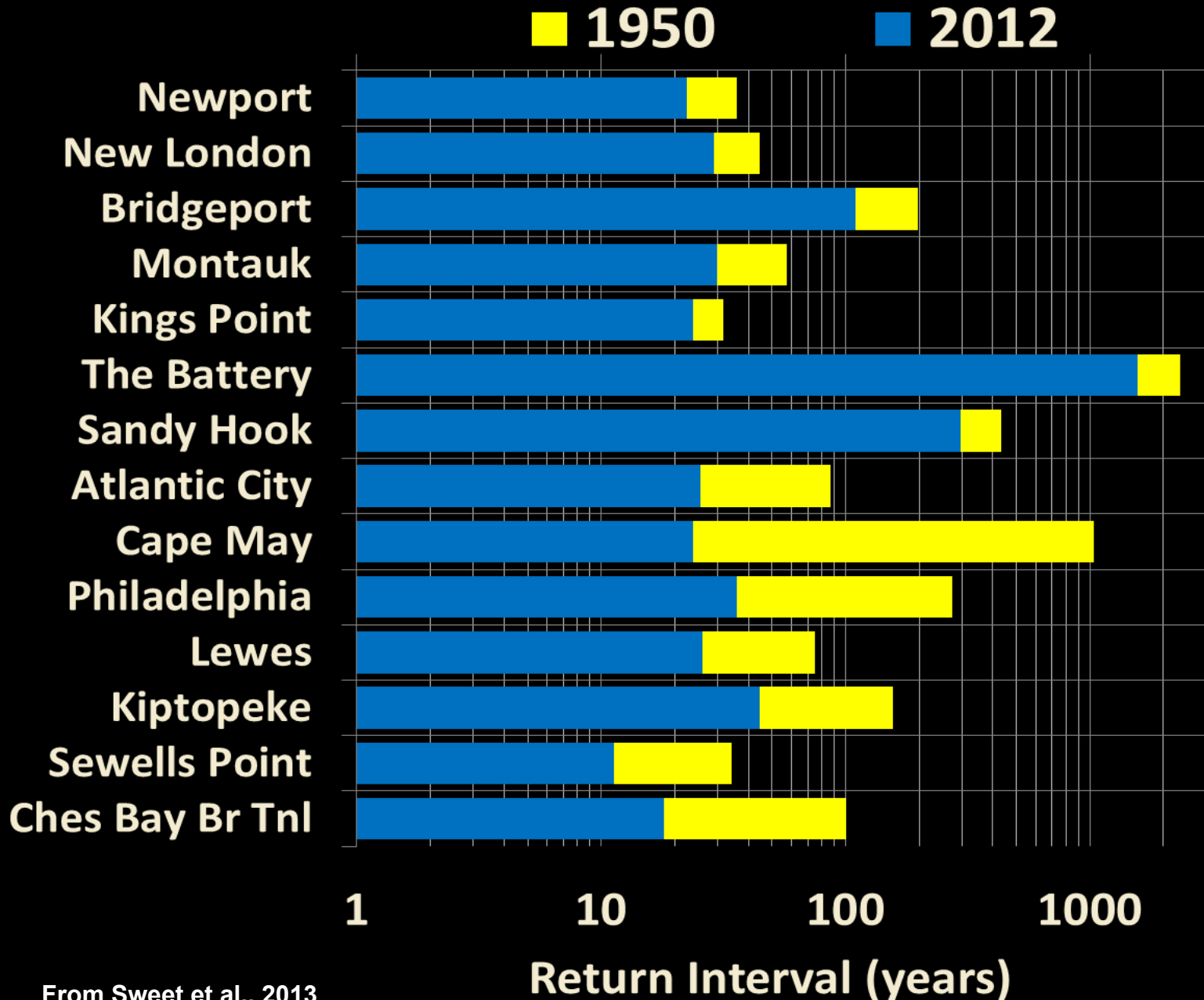
“Now” sunny-day nuisance urban flooding is common.

# NOAA Tide Gauges and Nuisance Coastal Flooding

Steady sea level rise ~ accelerated impacts (East & Gulf Coasts)



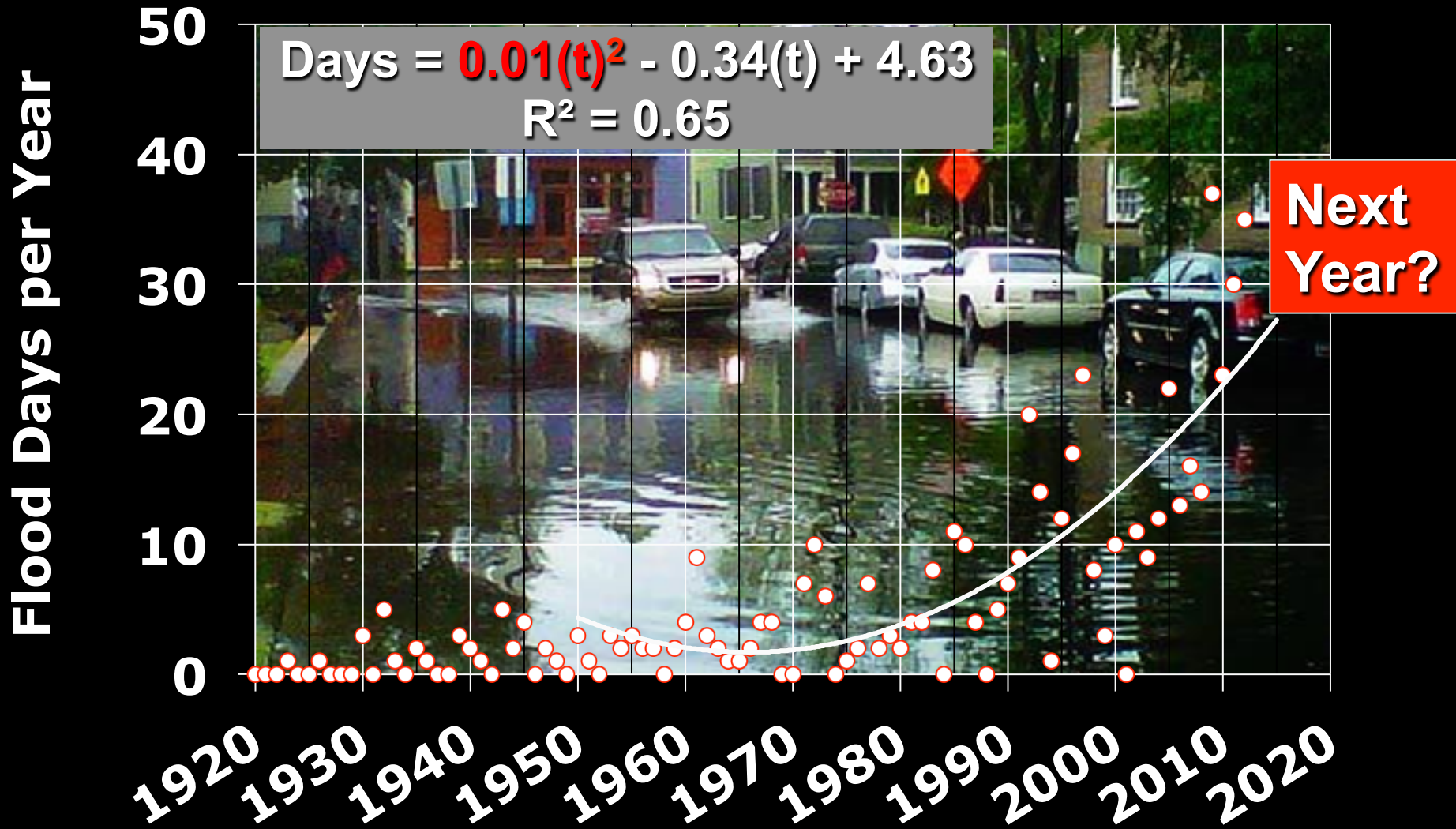
# General Nature of the Problem: Shifting Geometry



From Sweet et al., 2013

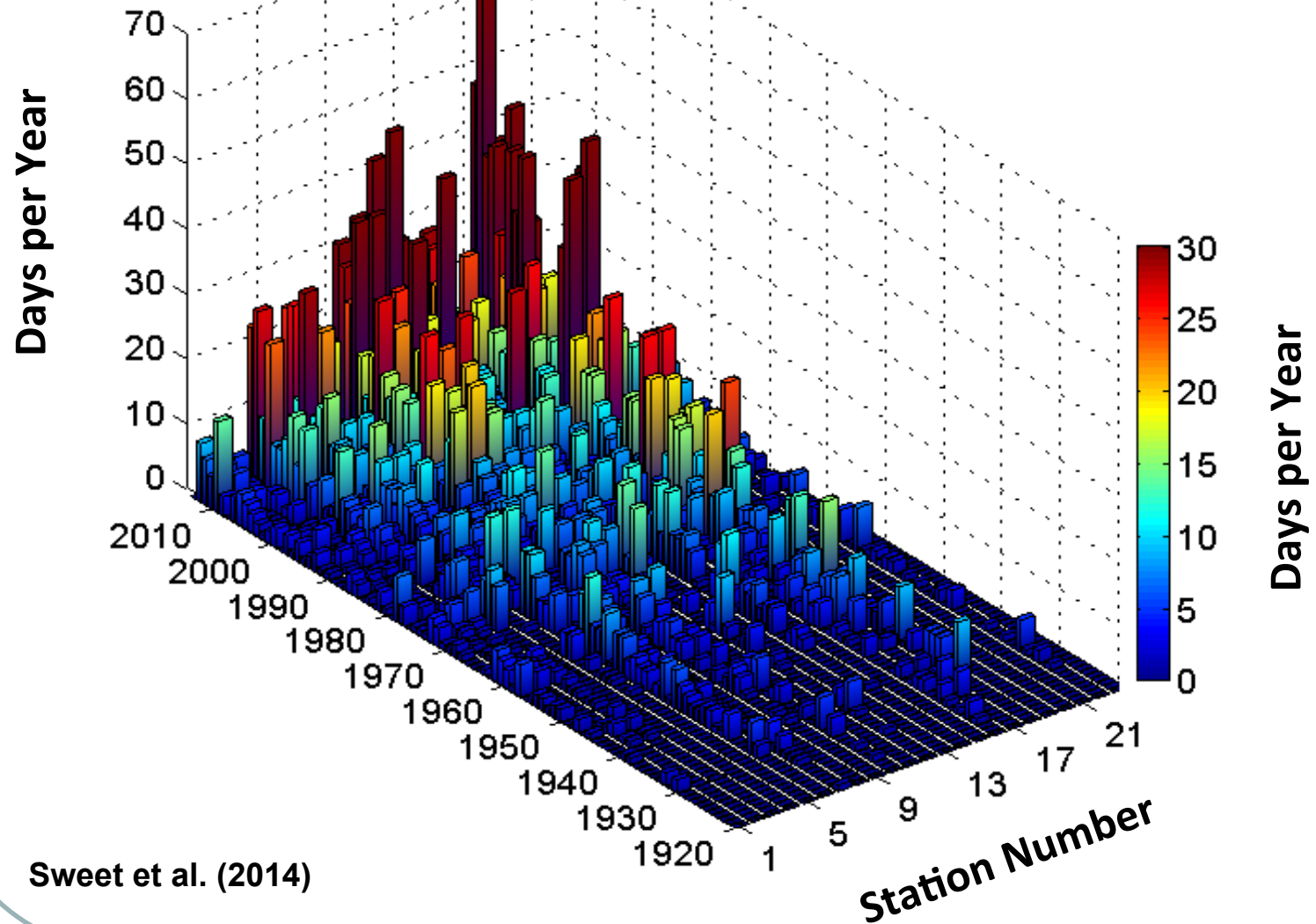
# Atlantic City, NJ: Days with Nuisance Level Flooding

## Accelerated Impacts



# Effects of Relative SLR

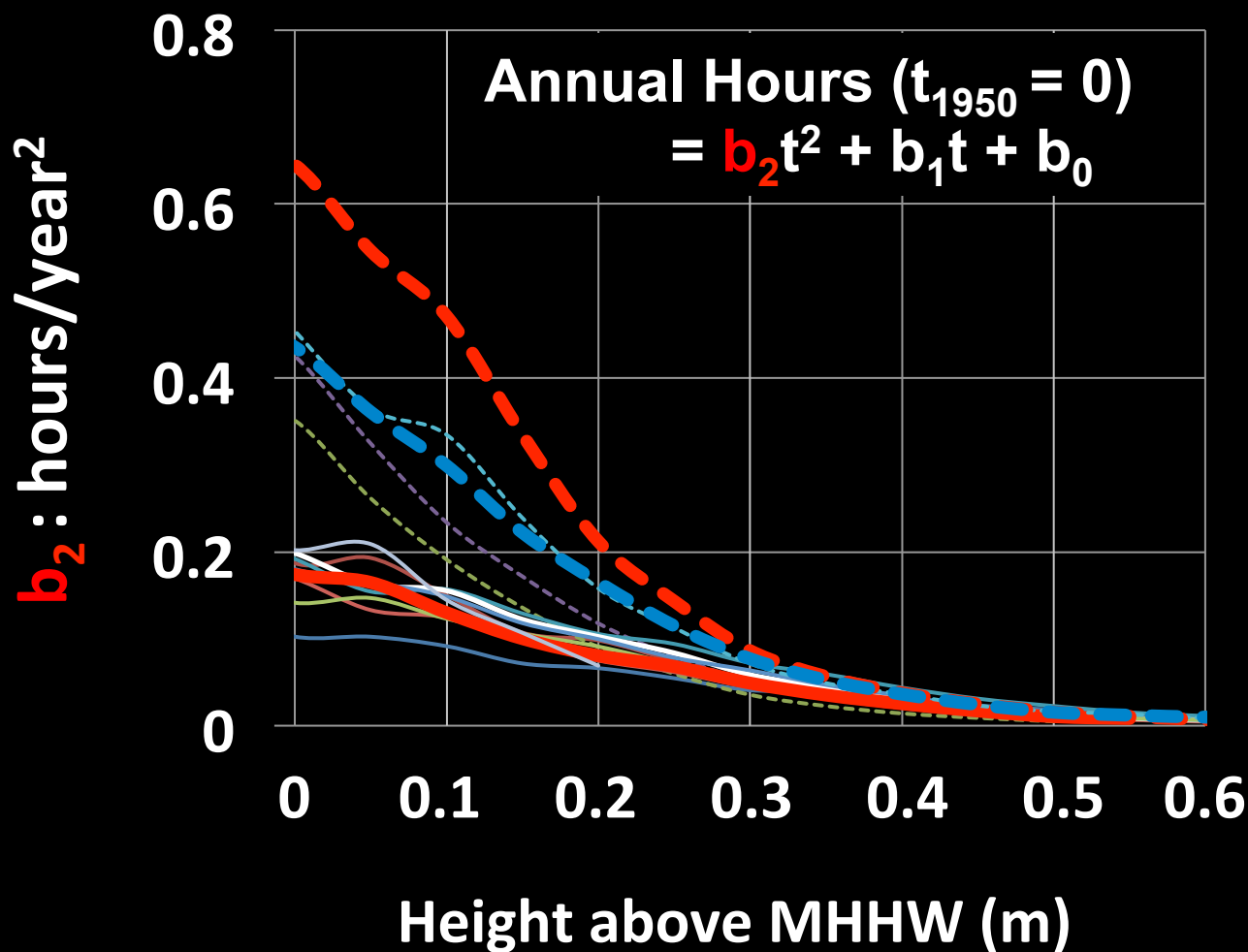
Boston, MA to  
Norfolk, VA





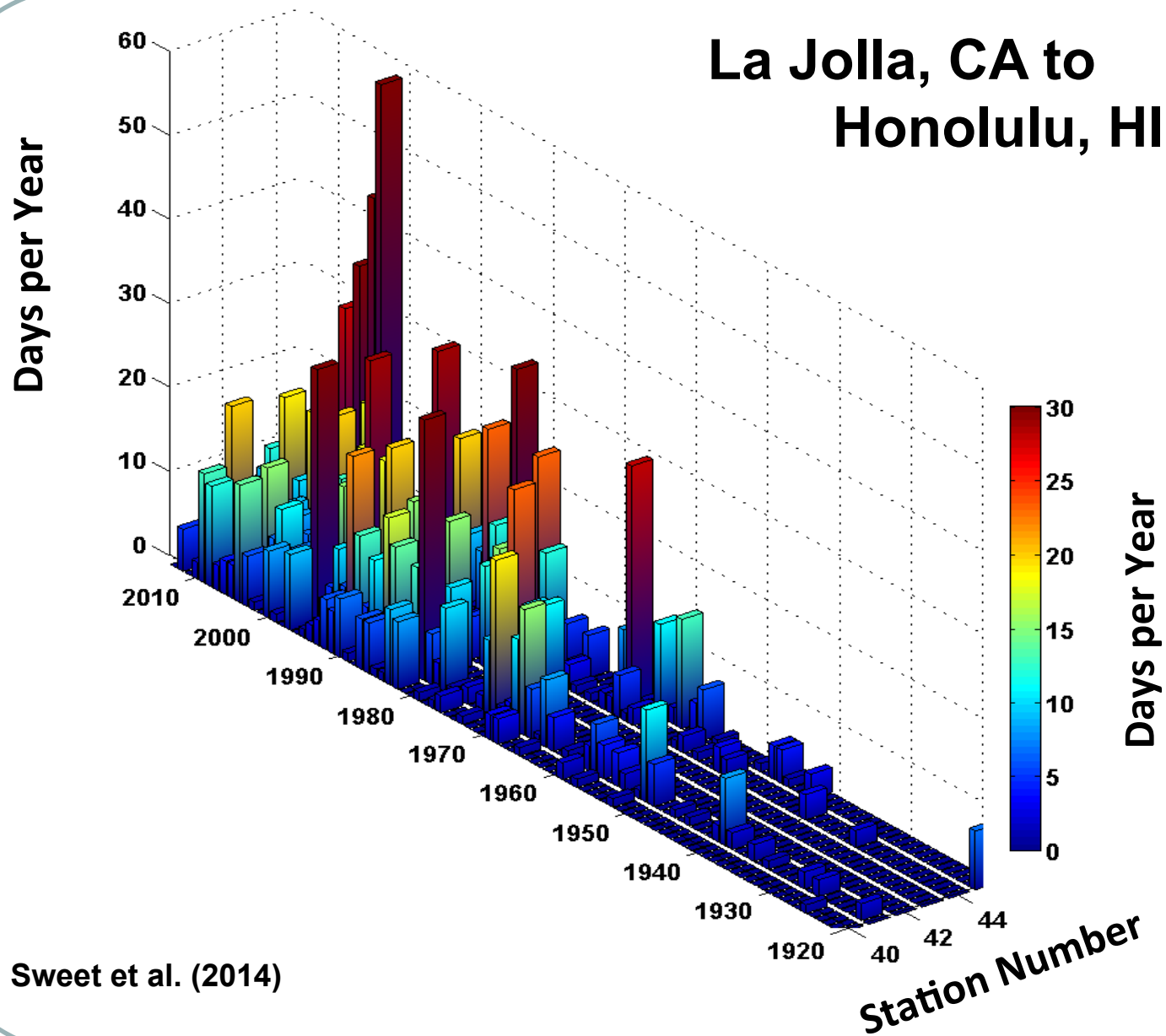
# Accelerated Flooding: SLR Rates & Tide Range

Acceleration Coefficient (1950-2013):  
Annual Duration above a threshold (hrs)



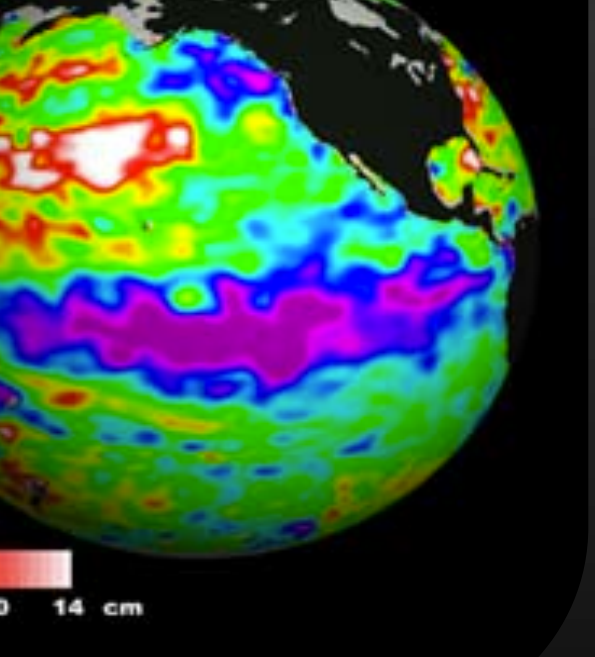
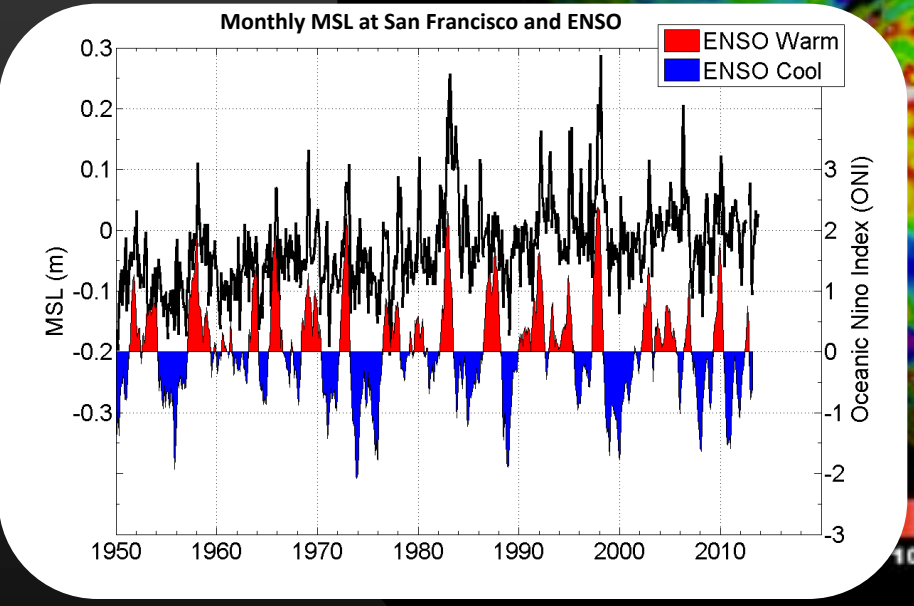
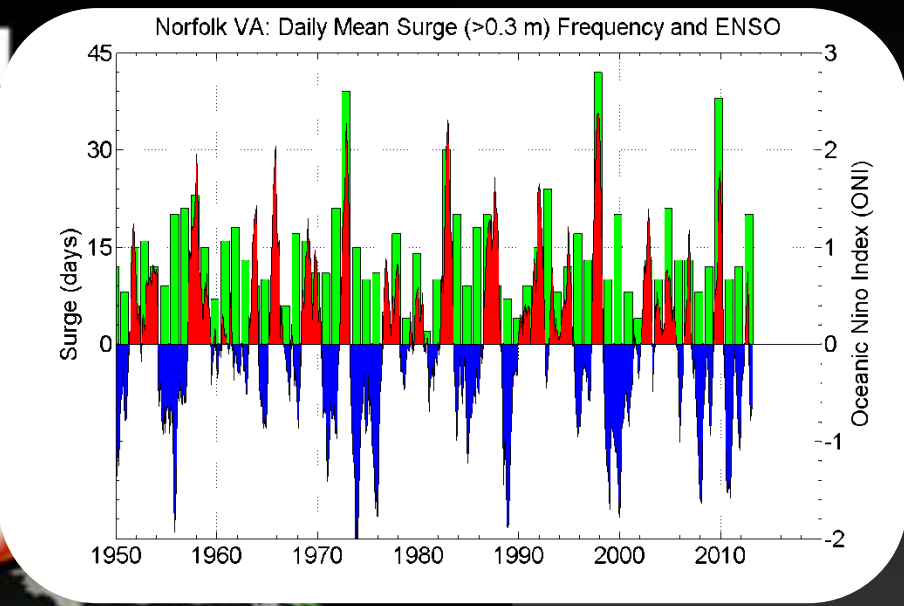
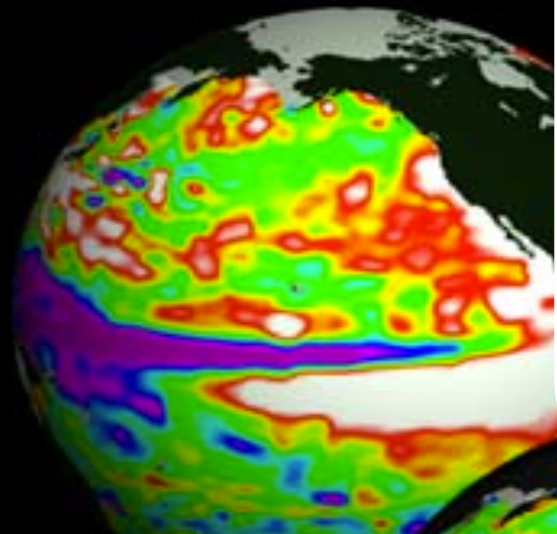
- Boston, MA
- Providence, RI
- - - New London
- - - Montauk, NY
- Kings Point, NY
- Battery, NY
- Sandy Hook, NJ
- Atlantic City, NJ
- Philadelphia, PA
- Lewes, DE
- - - Baltimore, MD
- - - Annapolis, MD
- Washington DC
- - - Sewells Point, VA

# Effects of Relative SLR



# East Coast: Higher storm surge frequency during El Nino

## El Niño / La Niña

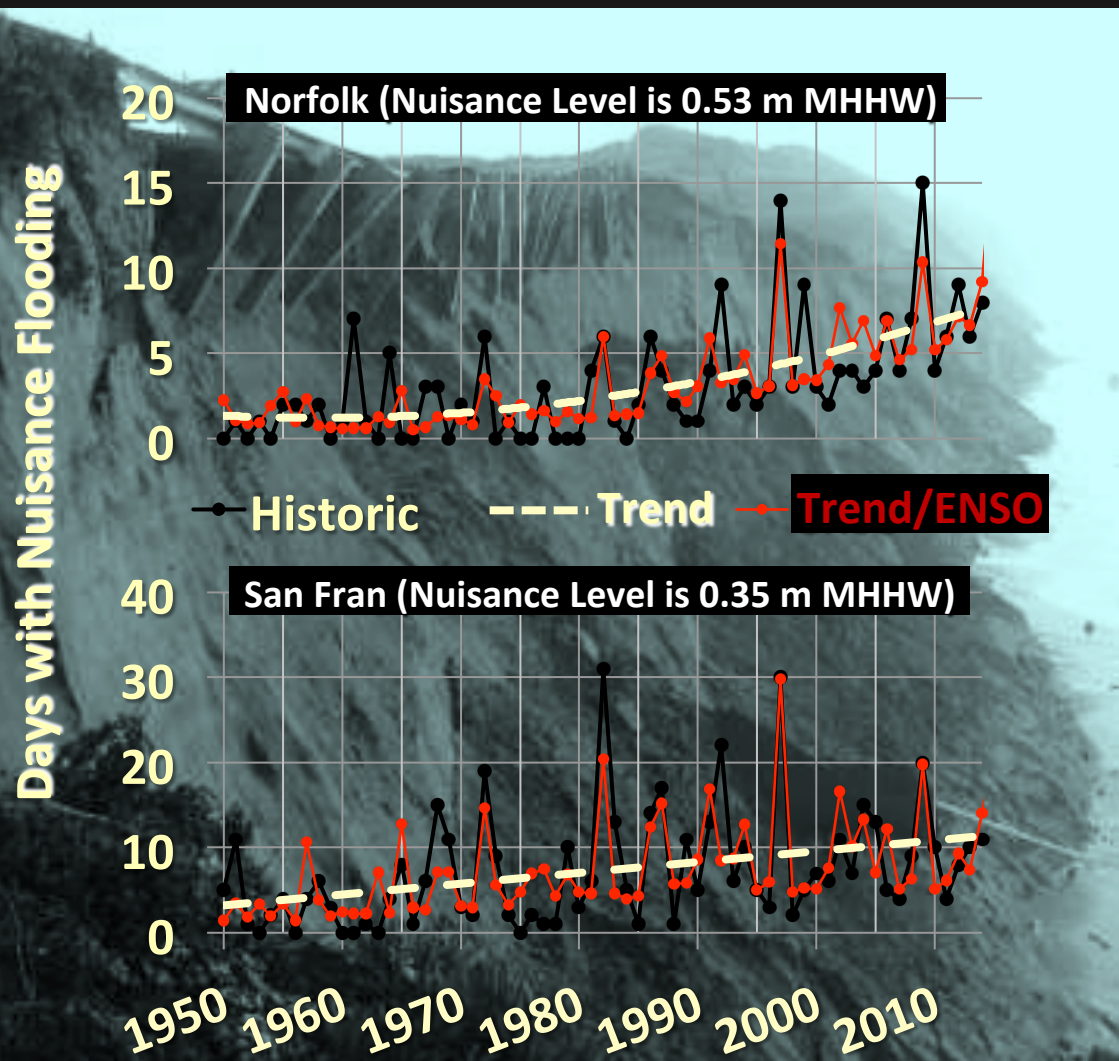


Sweet and Zervas (2011)

# West Coast: + (-) MSL anomalies during El Nino (La Nina)

# Climate Patterns and Nuisance Flooding

Yearly differences (from trend) in nuisance flood frequency are driven by El Nino Southern Oscillation (Sweet and Park, 2014)



Historical record is better characterized with an ENSO proxy



# RESILIENCE MEANS *BOUNCING BACK*

**Resiliency: community's ability to "bounce back" after an event, like a hurricane, coastal storm, or flooding...**

**but sea level rise is an on-going process, whose impacts are growing in severity.**





# RESILIENCE MEANS *BOUNCING BACK*

**SLR is a slow-motion disaster affecting public-serving systems, and resiliency will require continuous maintenance and mitigation over planning horizons.**

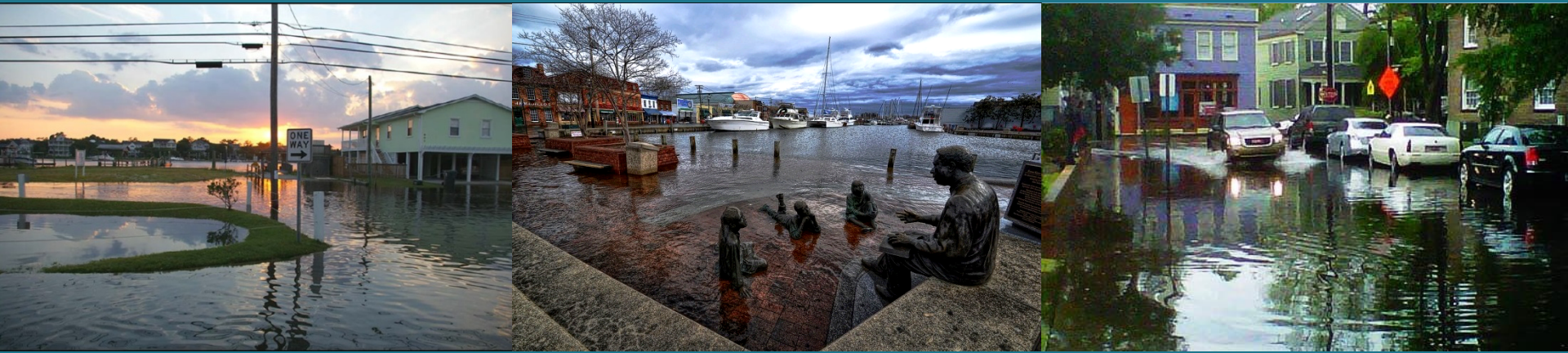
**Decade(s) of Tipping Point Crossing  
under 4 Projections (0.5, 0.6, 0.8, 1.2 m) of Global Sea Level Rise by 2100\***

Location	Nuisance Flood Level (meters above MHHW)	>30 days/year with Nuisance Flooding
Wilmington, NC	0.25	Past
Annapolis, MD	0.29	Past
Washington D.C.	0.31	Past
Lewes, DE	0.41	By 2020
Baltimore, MD	0.41	By 2020
Atlantic City, NJ	0.43	By 2020
Sandy Hook, NJ	0.45	By 2020
Kings Point, NY	0.52	By 2020
Philadelphia, PA	0.49	By 2030
Norfolk, VA	0.53	2021-2040
Boston, MA	0.68	2021-2040
Montauk, NY	0.60	2021-2050
The Battery, NY	0.65	2021-2050
New London, CT	0.60	2031-2060
Providence, RI	0.66	2031-2060

**30 days/year with nuisance flooding...**

**System tipping points – functional or economic – are dependent upon sensitivities to event magnitudes, frequencies or durations.**

# From the Extreme to the Mean: Effects of Sea Level Rise on Coastal Flooding



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