National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

NASA Sea Level Change Portal

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109-8099, U.S.A.

Sea Level Change Portal Team

Carmen Boening (PI/JPL)

JPL Team
Hugh (Pat) Brennan, Daniel Delany, Kevin Gill, Frank Greguska, Ben Hamlington, Thomas Huang, Nga Quach, Holly Shaftel, and Victor Zlotnicki

MooreBoeck Team
Andera Boeck, Bergen Moore, and Justin Moore

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NASA Sea Level Change Portal – https://sealevel.nasa.gov

Goals for the NASA Sea Level Change Portal

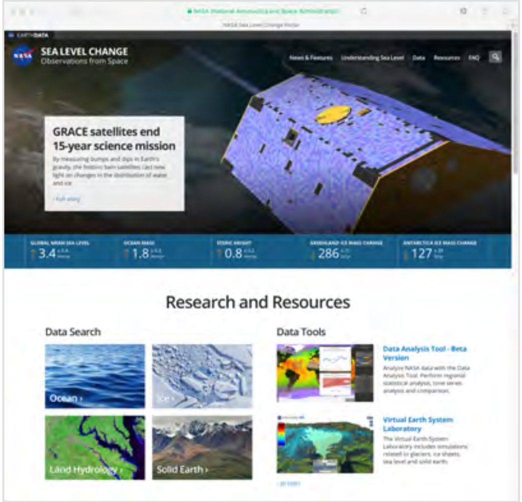
- Provide scientists and the public with a “one-stop” source
- Provide current sea level change information and data
- Provide interactive tools for analyzing and viewing regional data
- Provide virtual dashboard for sea level indicators
- Provide latest news, quarterly report, and publications
- Provide ongoing updates through a suite of editorial products

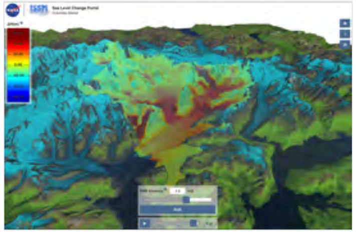
Requires

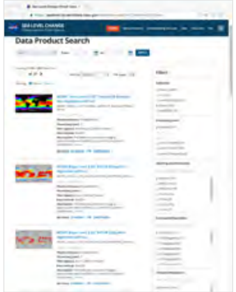
- Interdisciplinary collaboration
- Connect disciplines and evaluate dependencies

Sea Level Change Portal facilitates

- Easy interdisciplinary data comparison
- Access to latest news and information
- Collaboration (data and information exchange)







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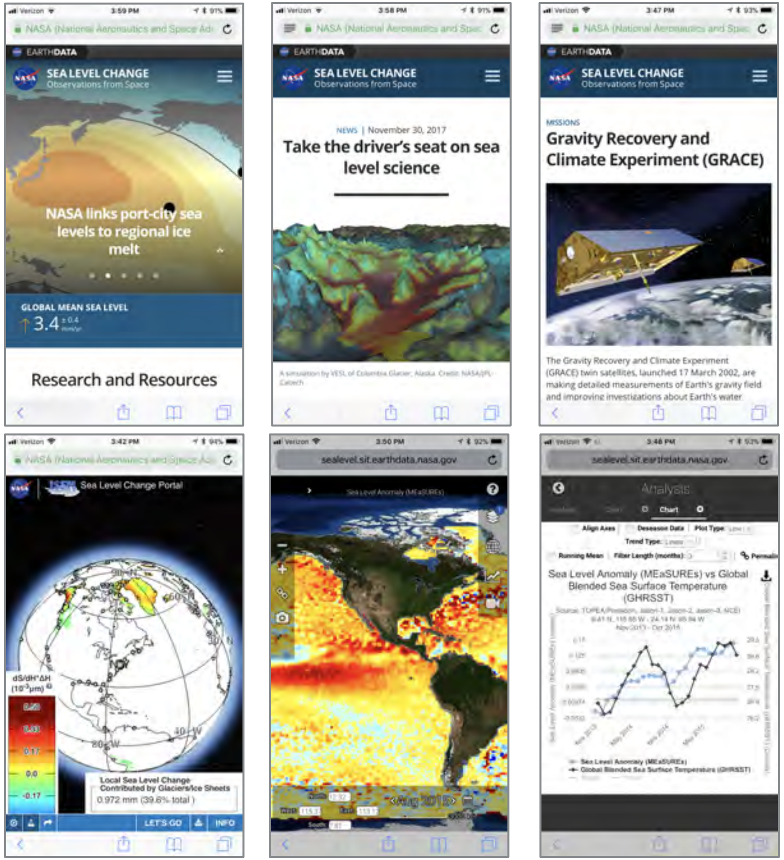
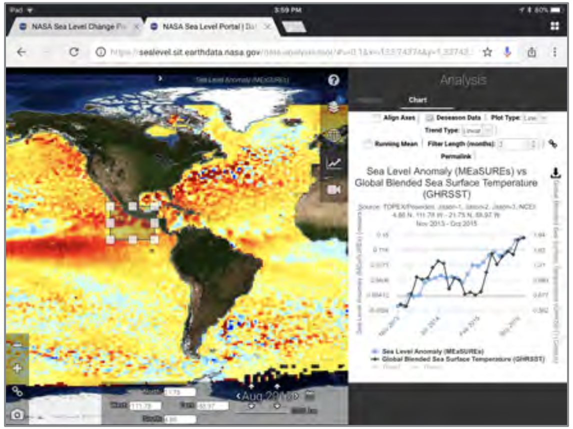
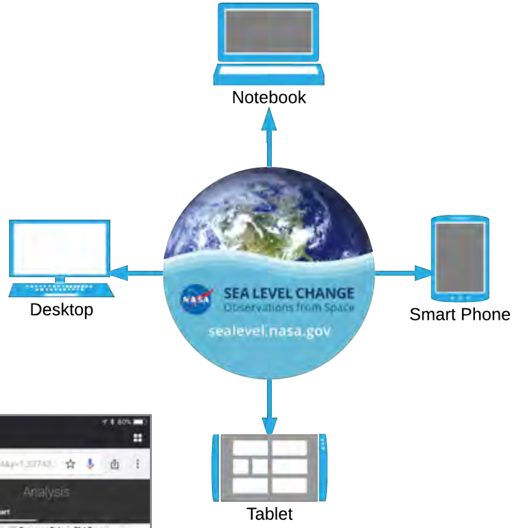
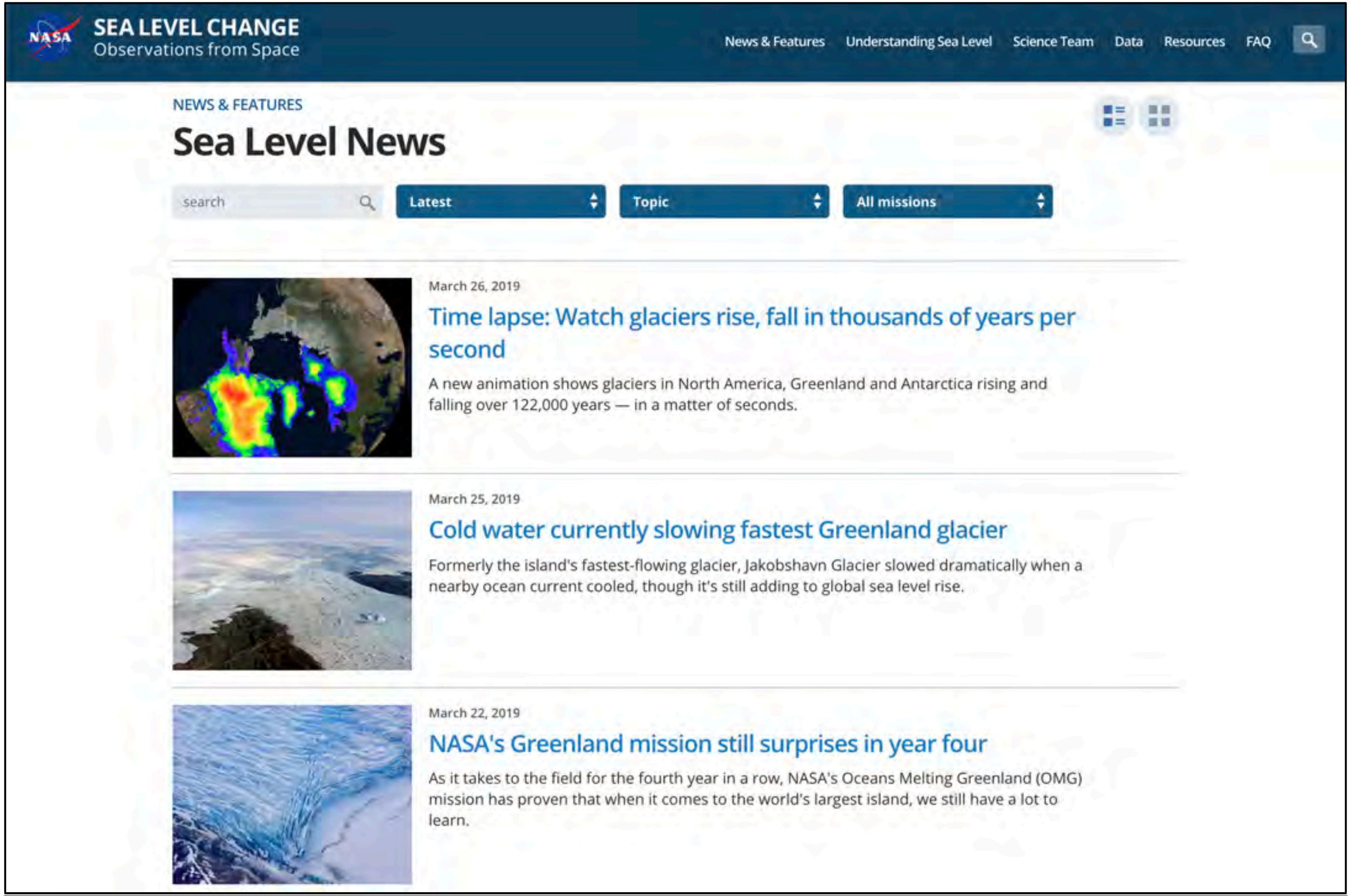
Mobile Friendly





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News & Features
Understanding Sea Level
Science Team
Data
Resources
FAQ
NEWS & FEATURES
Sea Level News
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All missions
March 26, 2019
Time lapse: Watch glaciers rise, fall in thousands of years per second
A new animation shows glaciers in North America, Greenland and Antarctica rising and falling over 122,000 years — in a matter of seconds.
March 25, 2019
Cold water currently slowing fastest Greenland glacier
Formerly the island's fastest-flowing glacier, Jakobshavn Glacier slowed dramatically when a nearby ocean current cooled, though it's still adding to global sea level rise.
March 22, 2019
NASA's Greenland mission still surprises in year four
As it takes to the field for the fourth year in a row, NASA's Oceans Melting Greenland (OMG) mission has proven that when it comes to the world's largest island, we still have a lot to learn.

SEA LEVEL CHANGE
Observations from Space

News & Features | Understanding Sea Level | Science Team | Data | Resources | FAQ

Global Mean Sea Level

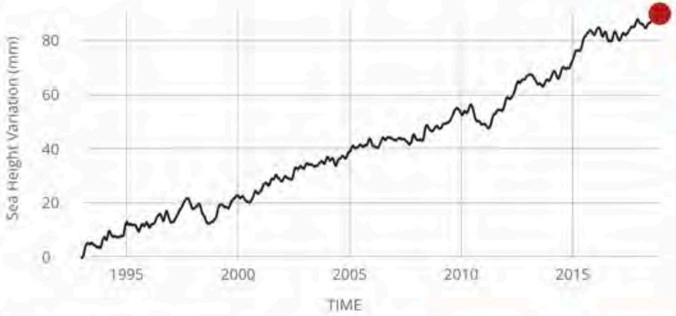
This dataset contains the Global Mean Sea Level (GMSL) generated from the Integrated Multi-Mission Ocean Altimeter Data for Climate Research (GMSL dataset). The GMSL is a 1-dimensional time series of globally averaged Sea Surface Height Anomalies (SSHA) from TOPEX/Poseidon, Jason-1 and OSTM/Jason-2. It starts in September 1992 to present, with a lag of up to 4 months. All biases and cross-calibrations have been applied to the data so SSHA are consistent between satellites. Data are reported as changes relative to January 1, 1993 and are 2-month averages. Glacial Isostatic Adjustment (GIA) has been applied. These data are available in ASCII format. Reference: Beckley et al., 2017.

Data shown are latest available, given time needed to allow for processing.

SATELLITE DATA: 1993 - PRESENT

Data source: Satellite sea level observations. Credit: GSFC/PO.DAAC

RATE OF CHANGE
↑ 3.3
(± 0.4) mm/yr

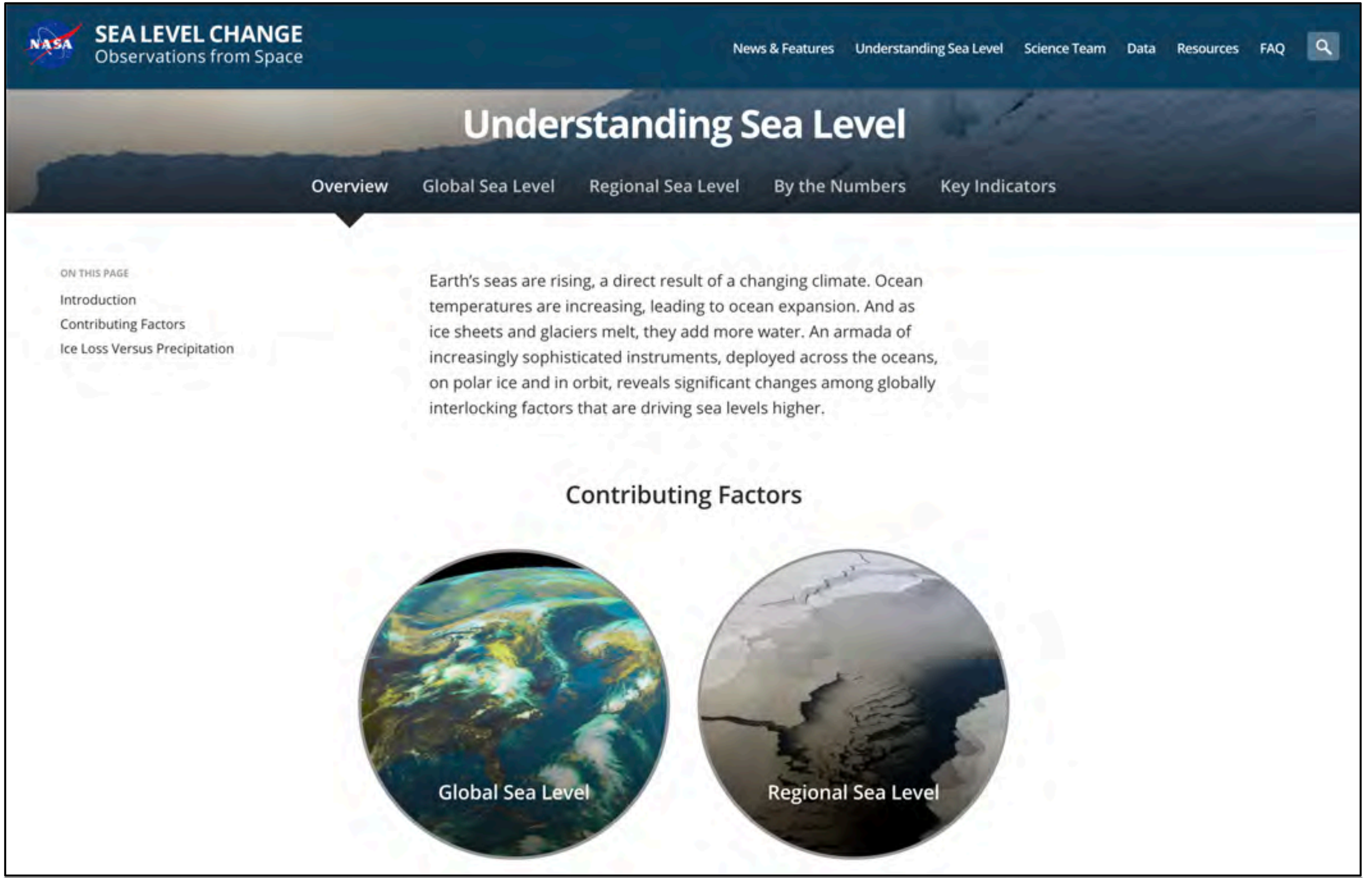


Click+drag to zoom

Get Data: FTP | Snapshot: PNG

Missions

Satellite Altimetry (TOPEX/Poseidon, Jason I+II)



NASA Sea Level Change Portal

SEA LEVEL CHANGE
Observations from Space

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UNDERSTANDING SEA LEVEL

By the Numbers

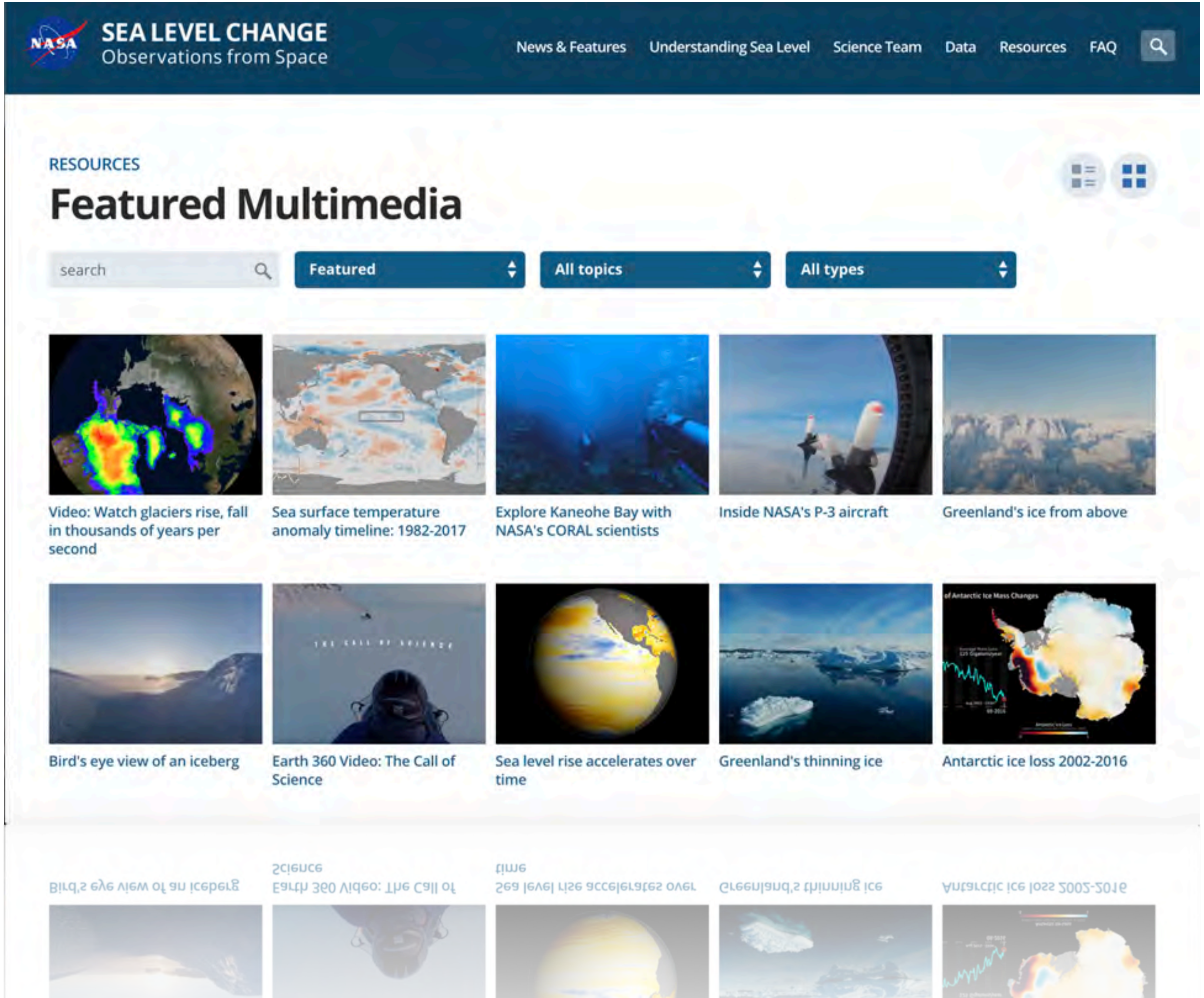
Estimates for sea level rates for different time periods. Find numbers and respective references for citation.

Total Sea Level

PERIOD	ESTIMATE (mm/yr)	UNCERTAINTY (+- mm/yr)	REFERENCE	MEASUREMENT / FORECAST MODEL
1993 - 2017	3.1	0.4	Cazenave et al., 2018	Satellite altimetry
1901 - 1990	1.1 to 1.9	0.3	Dangendorf et al., 2017	Tide gauge reconstruction
1993 - 2010	2.8 to 3.1	0.7 to 1.4	Cazenave et al., 2018	Tide gauge reconstruction

Steric Sea Level

PERIOD	ESTIMATE (mm/yr)	UNCERTAINTY (+- mm/yr)	REFERENCE	MEASUREMENT / FORECAST MODEL
1955 - 2010	0.5	0.1	Levitus et al., 2008	XBT/CTD (upper 2000 m)
1950 - 2003	0.5	0.1	Domingues et al., 2008	XBT/CTD (upper 700 m)
1993 - 2016	1.3	0.4	Cazenave et al., 2018	XBT/CTD/Argo Floats (Full Depth)
2005 - 2016	1.3	0.4	Cazenave et al., 2018	XBT/CTD/Argo Floats (Full Depth)
1992 - 2005	0.11	0.1	Purkey and Johnson, 2010	Deep hydrographic sections (below 2000 m)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All topics
All types
Video: Watch glaciers rise, fall in thousands of years per second
Sea surface temperature anomaly timeline: 1982-2017
Explore Kaneohe Bay with NASA's CORAL scientists
Inside NASA's P-3 aircraft
Greenland's ice from above
Bird's eye view of an iceberg
Earth 360 Video: The Call of Science
Sea level rise accelerates over time
Greenland's thinning ice
Antarctic ice loss 2002-2016

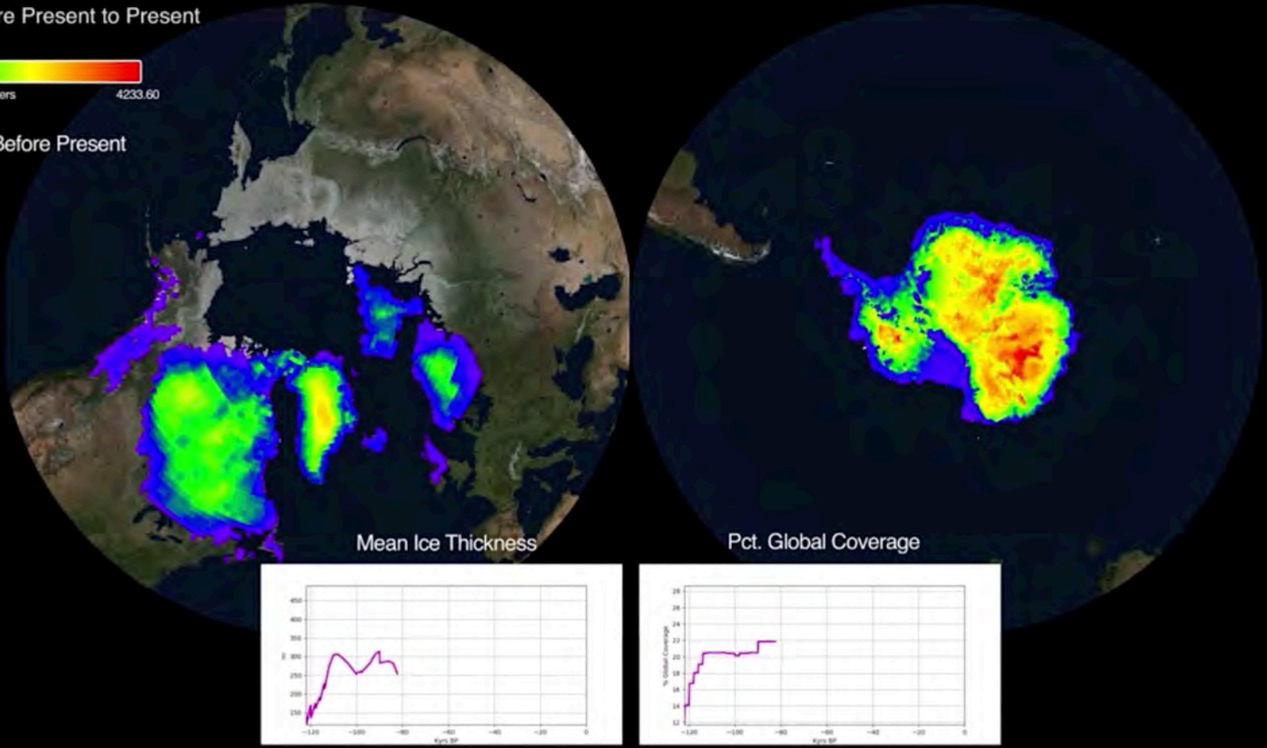
Vertical Ice Thickness in Postglacial Rebound Model ICE-6G_C/D (VM5a)

Jet Propulsion Laboratory
California Institute of Technology

122,000 Years Before Present to Present

0.00 meters 4233.60

82,000 Years Before Present



Sea Level Anomaly Estimate based on Altimeter Data

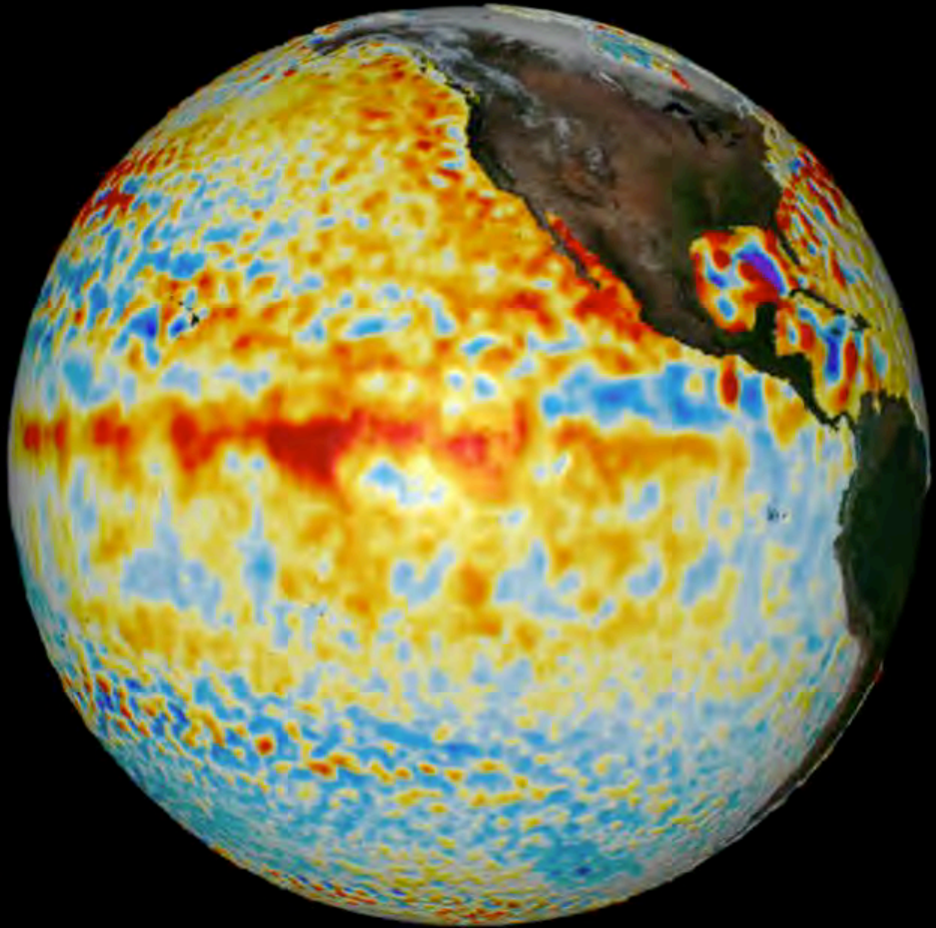
October 02, 1992

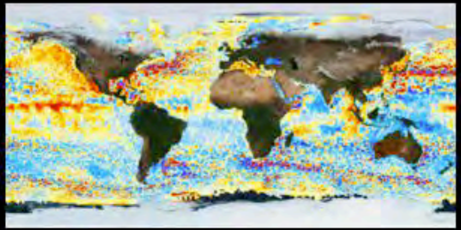
October 1992 - November 2015

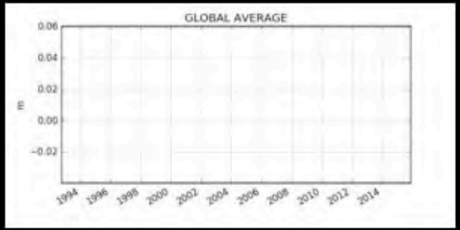
-0.3 0 0.3
meters

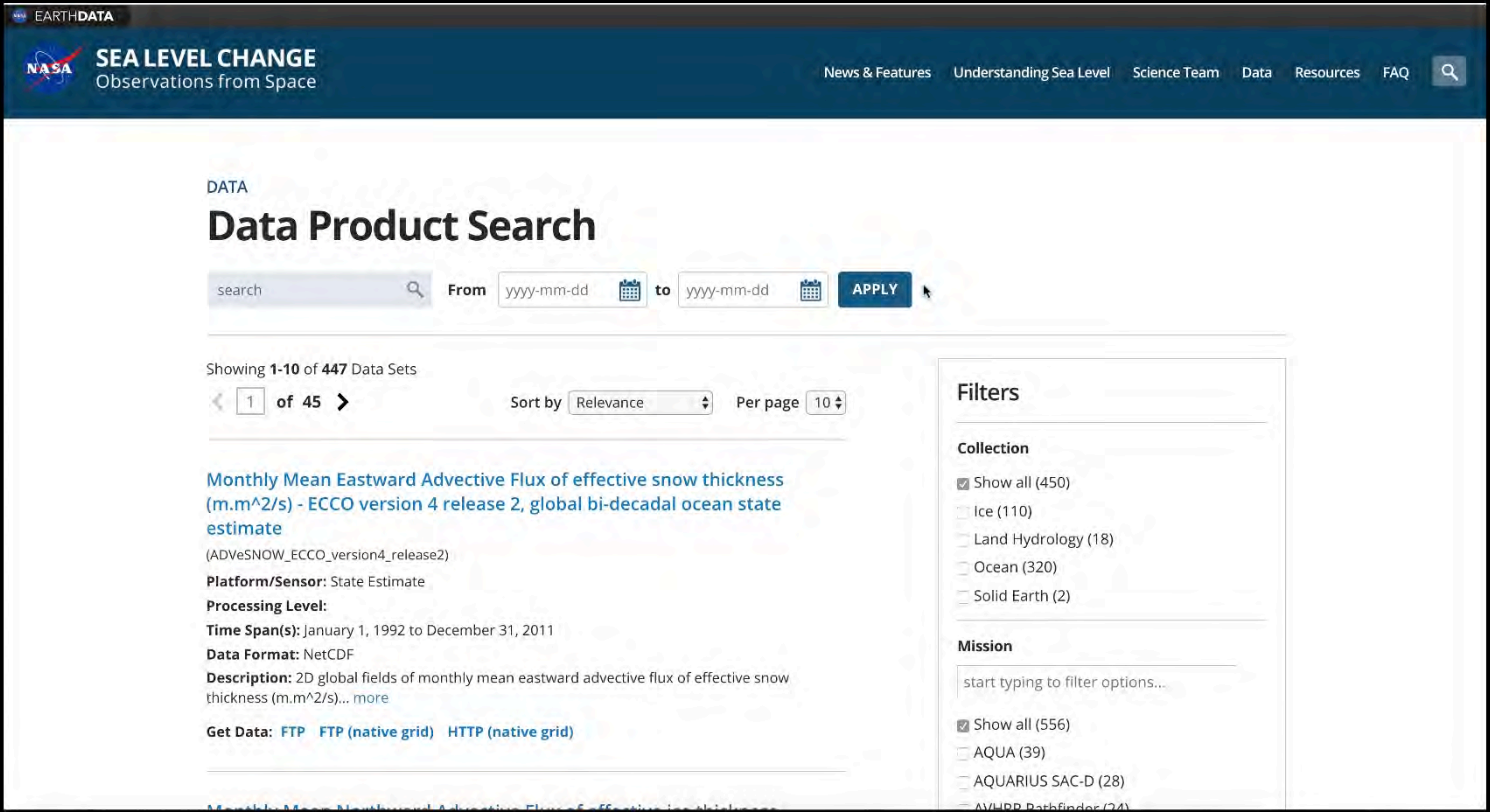
Sea level anomaly grids based on two simultaneous altimeters using Kriging technique, which gives best linear prediction based upon prior knowledge of covariance.

Version JPL 1603

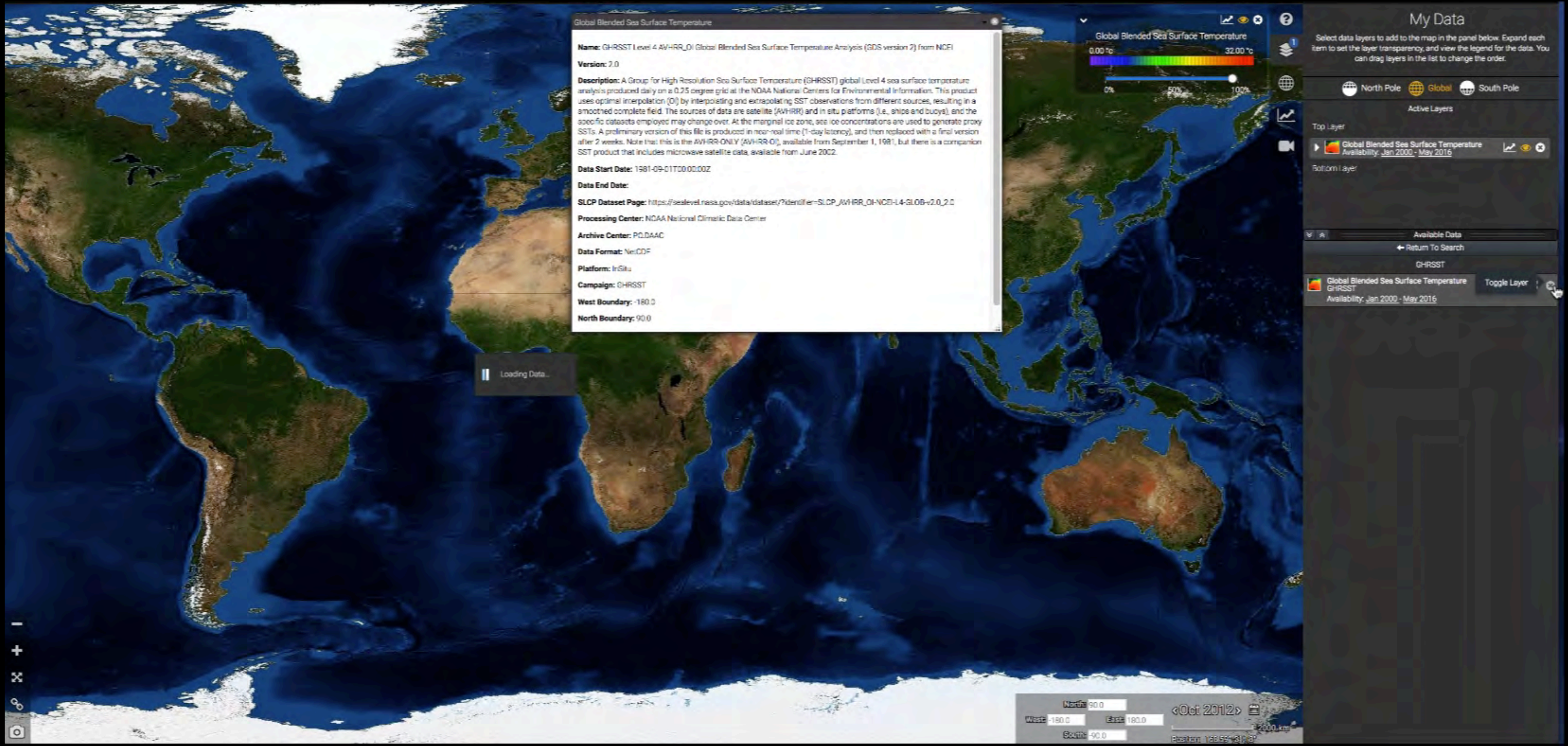








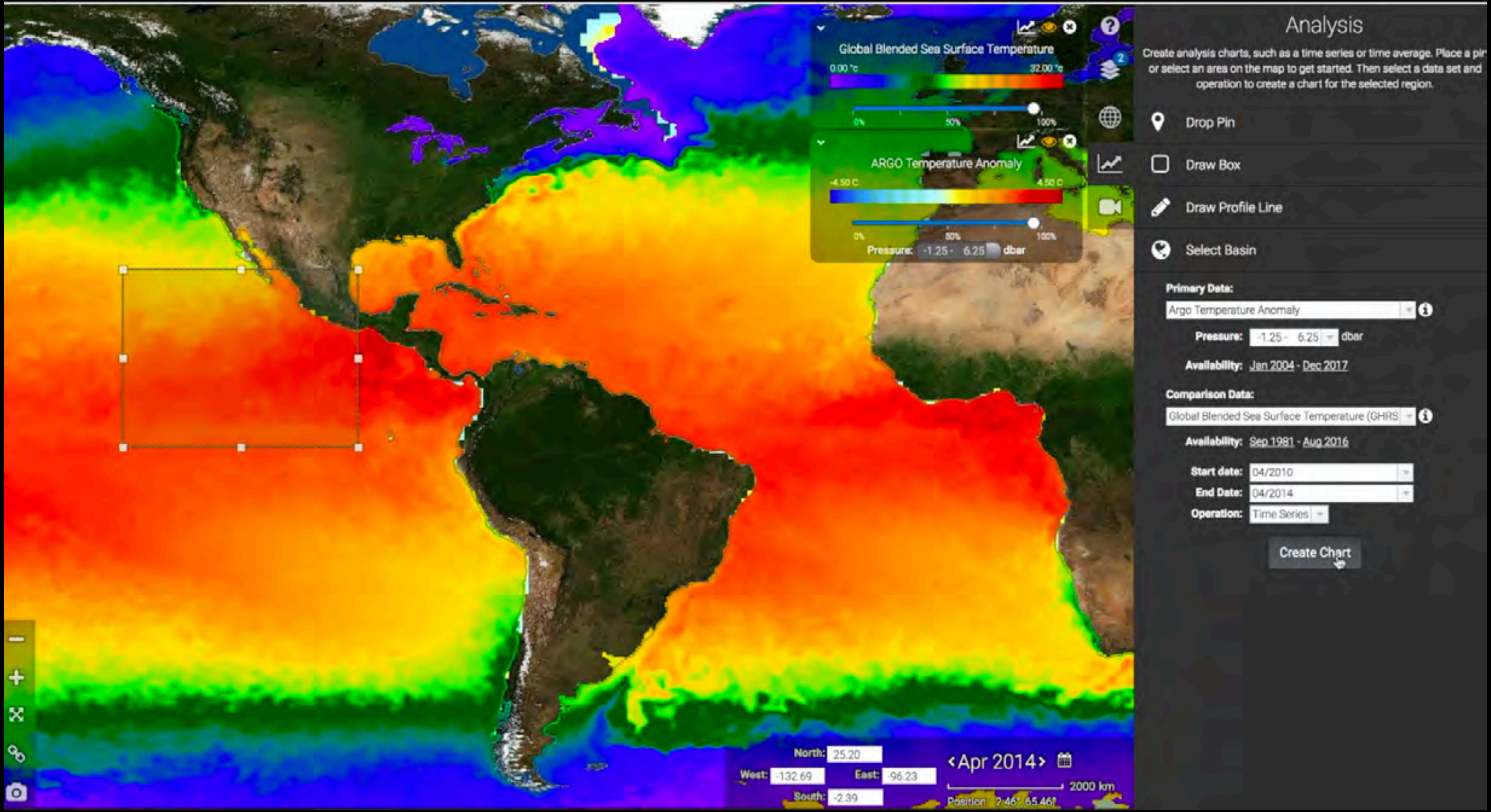
Data Search and Access



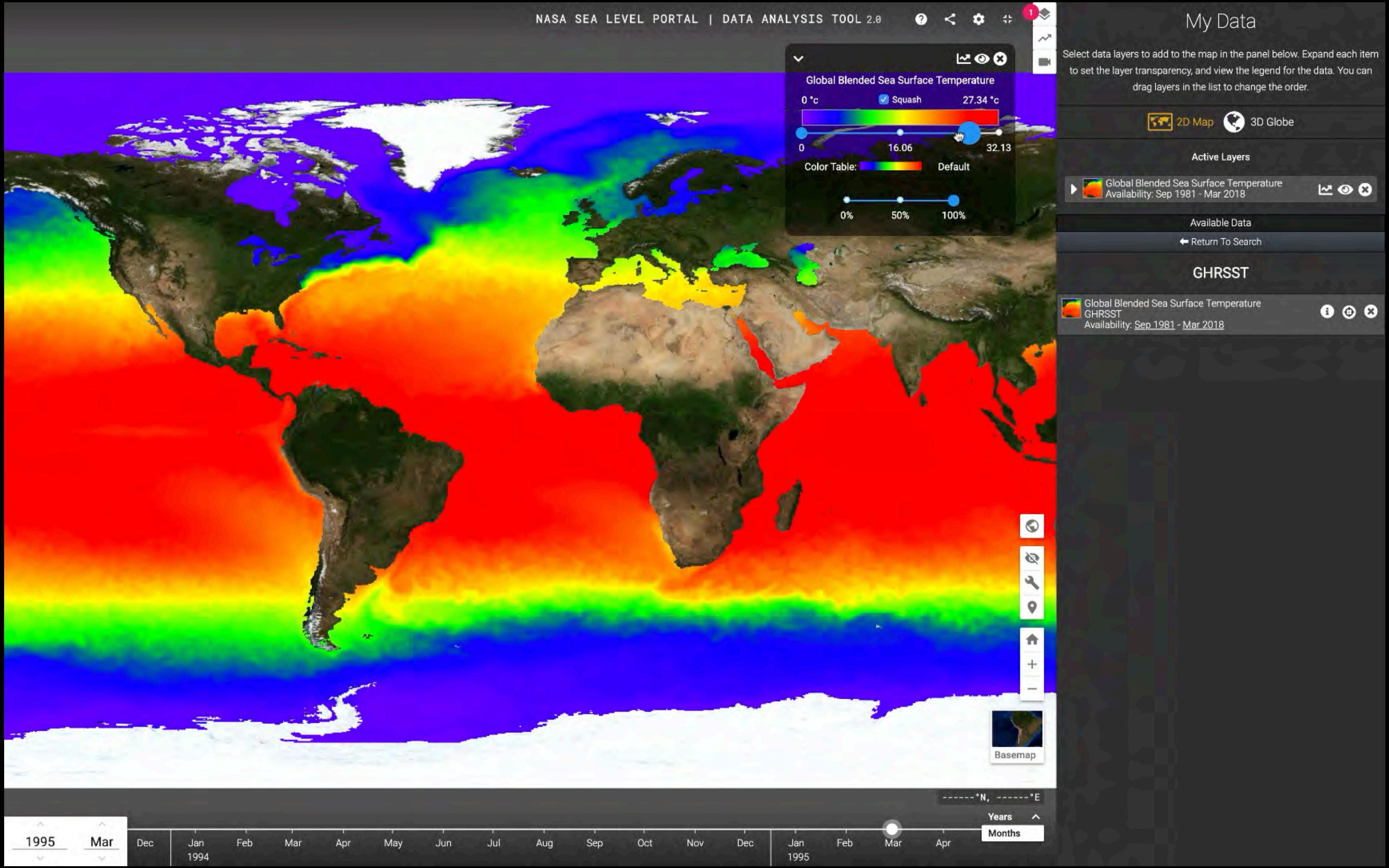
https://sealevel.nasa.gov/data-analysis-tool/


Verizon
2:25 PM
50%
NASA (National Aeronautics and Space Adn
North: 90.0
West: -180.0
East: 180.0
South: -90.0
Feb 2018
3000 km

Analyze Hydrological Basins



Compare In Situ Measurement against Observation

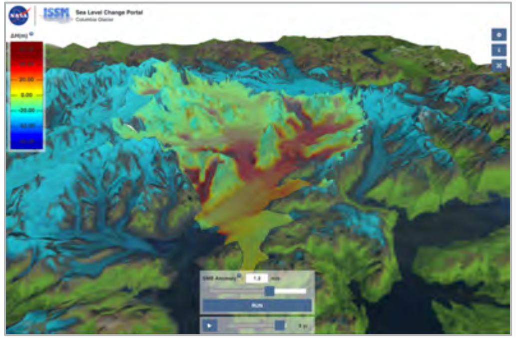


NASA SEA LEVEL PORTAL | DATA ANALYSIS TOOL 2.0
Global Blended Sea Surface Temperature
0 °c
Squash
27.34 °c
0
16.06
32.13
Color Table:
Default
0%
50%
100%
My Data
Select data layers to add to the map in the panel below. Expand each item to set the layer transparency, and view the legend for the data. You can drag layers in the list to change the order.
2D Map
3D Globe
Active Layers
Global Blended Sea Surface Temperature
Availability: Sep 1981 - Mar 2018
Available Data
Return To Search
GHRSST
Global Blended Sea Surface Temperature
GHRSST
Availability: Sep 1981 - Mar 2018
Basemap
Years
Months
1995
Mar
Dec
Jan 1994
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan 1995
Feb
Mar
Apr

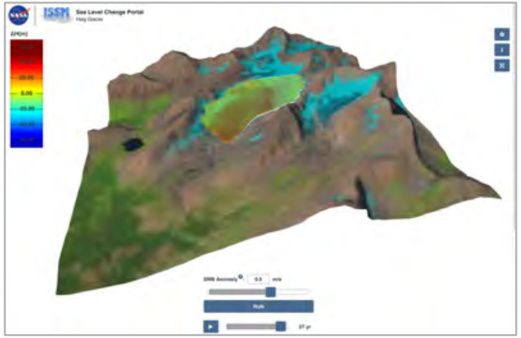
Virtual Earth System Laboratory (VESL) – PI: Eric Larour

Suite of Interactive Simulation Tools for Glaciers, Ice Sheets, Sea Level, and Solid Earth

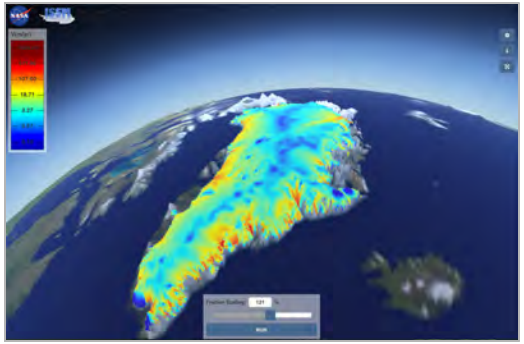
Simulation Service on Amazon Cloud



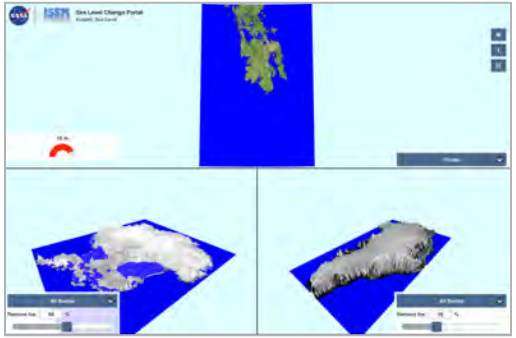
Columbia Glacier



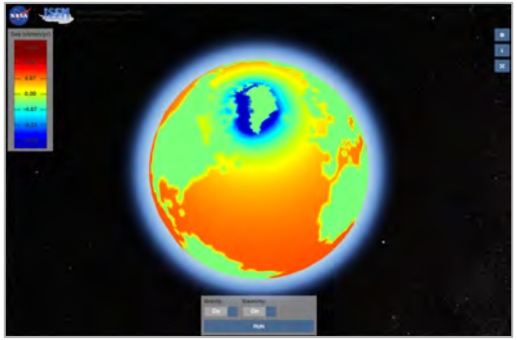
Haig Glacier



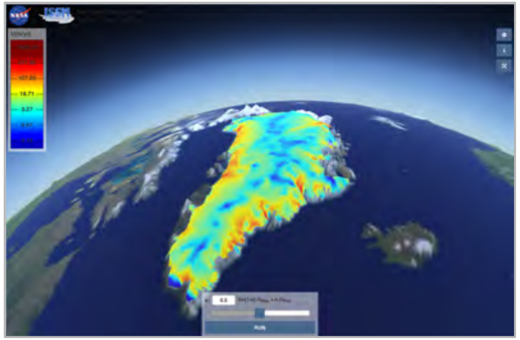
Greenland Basal Friction



Eustatic Sea Level

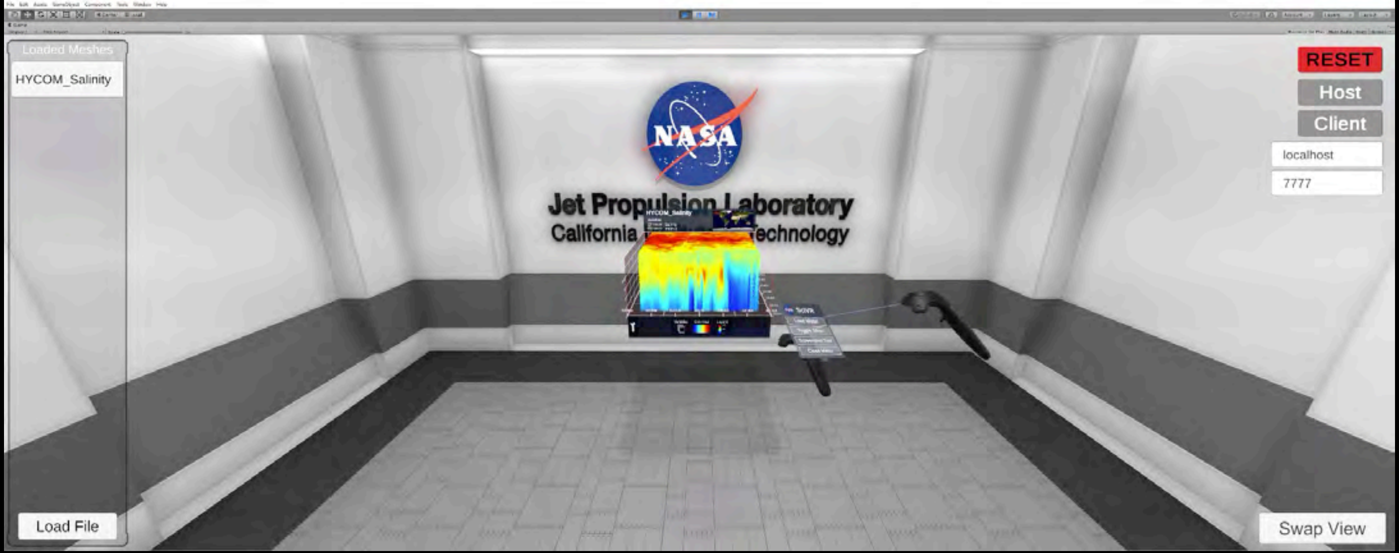


Local Sea Level



Greenland Steady-State-Friction

Typhoon Trami from RainCube and TEMPEST-D



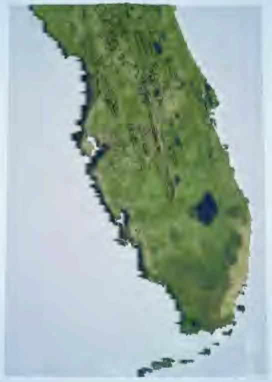
Ocean Salinity form HYCOM | Columbia Glacier from ISSM

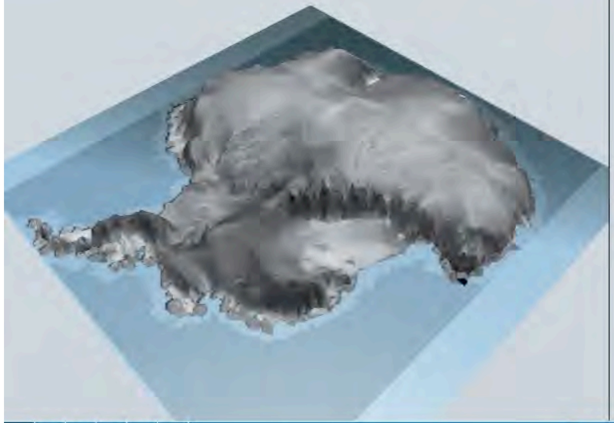
Virtual Earth System Laborato ✕ | Coastline Retreat From Sea-Le ✕ | +

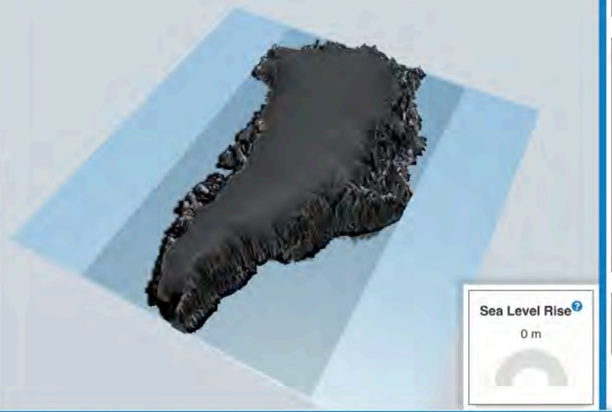
NASA (National Aeronautics and Space Administration) [US] | https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/

Sea Level Change Portal

VESL Coastline Retreat From Sea-Level Rise Simulation







Info

LET'S GO!

Introduction

This simulation explores the impact of collapsing polar ice sheets (Greenland and Antarctica) and their impact on global mean sea level rise, along with shrinkage in livable area around the world. Here, we look at US coastal areas, and how shoreline would retreat if Greenland and Antarctica were to dramatically decrease in volume.

More info...

How to Run the Simulation

Remove a certain amount of ice (relative percentage of the overall mass) from Antarctica and/or Greenland using the corresponding sliders (in the "Controls" drawer pane). The ice can be removed from all basins or from a specific basin by using the select menu. The resulting shrinkage of the ice sheets will be displayed in the initial frame, along with shoreline retreat and global mean sea level rise. Specific US coastal areas can be selected using the "Region" select menu.

Note that when viewing this page in portrait orientation, the Antarctica and Greenland panels can be displayed using the Glacier Region buttons after clicking **LET'S GO**.

Legend

	Toggle Results pane
	Toggle fullscreen mode
	Zoom in
	Zoom out
	Share simulation
?	Toggle tutorial
LET'S GO	Toggle Controls pane
INFO	Toggle Info pane

Feedback

If you have any questions or feedback, please send us an email.

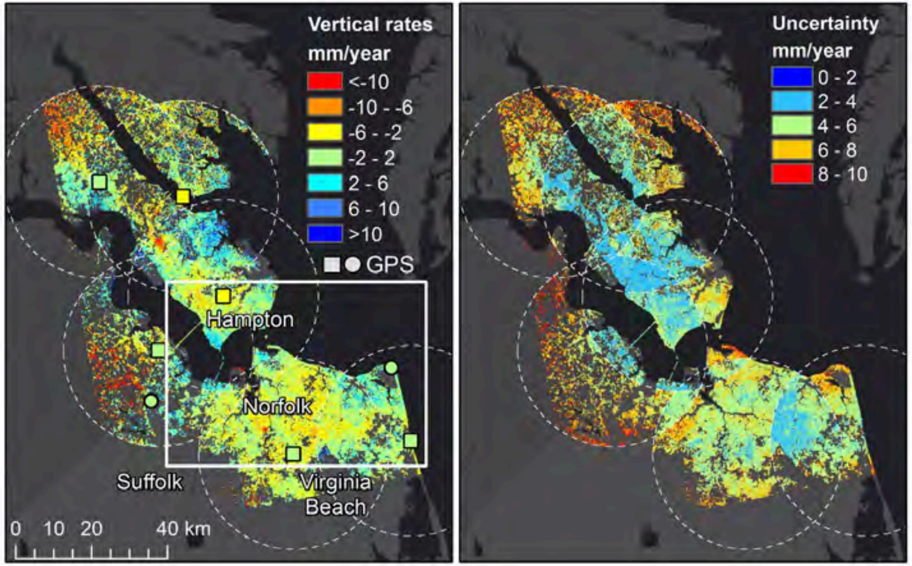
LET'S GO!

https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/#

LET'S GO | INFO

High Resolution Subsidence Measurements from InSAR

- Using InSAR analysis, we can provide high-spatial resolution subsidence estimates over large coastal regions.
- As part of the ARIA project at JPL (aria.jpl.nasa.gov), a standard product and open-source tools are being developed that allow for time series generation of vertical land motion along the U.S. coastlines → can be used for ongoing monitoring of subsidence at high resolutions.



CASE-study 1: Norfolk, Virginia

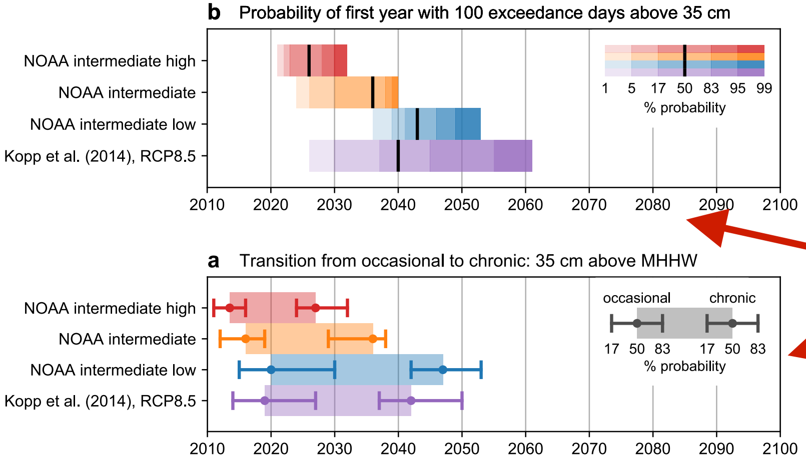
Dataset : Space-borne ALOS (L-band)
Time Span: Sept 2007 – Feb 2011
Number of Acq.: 12 Acquisitions
Spatial Resolution: 30 m
Number of GPS: 8 stations

Probabilistic projections of minor flooding frequency (PI: P. Thompson)

Probabilistic projections of flooding days per year:

- Projections of mean sea level (Kopp et al. 2014; NOAA scenarios) +
- Deterministic tidal predictions +
- Statistical model that better accounts for overdispersion of events/year compared to Poisson

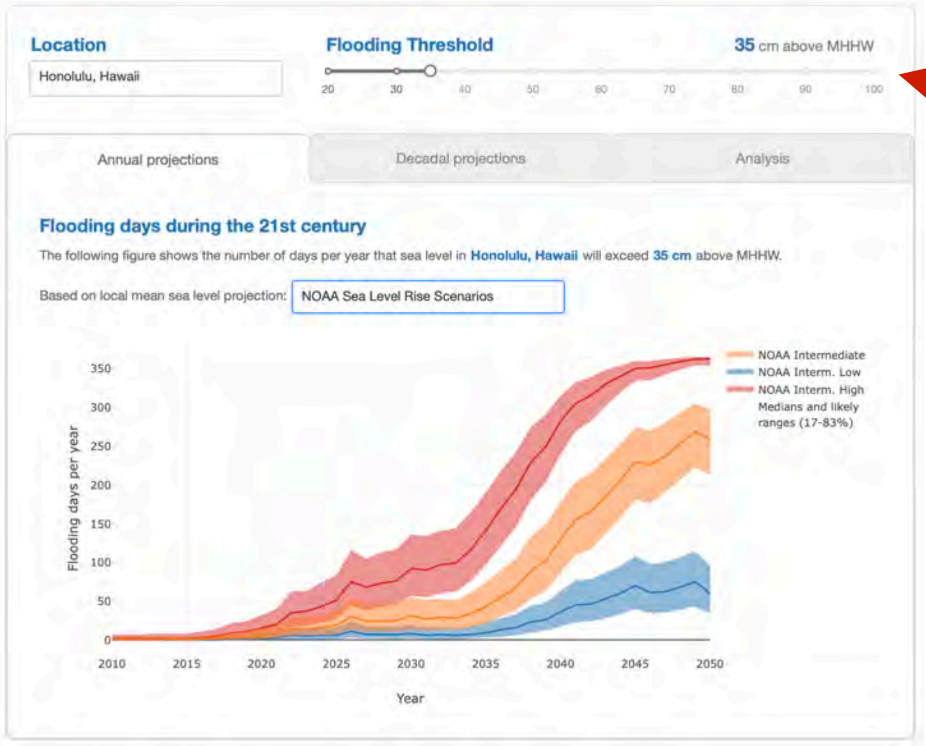
Developed for Honolulu (Thompson et al., 2019, in review)**, but extended to other locations.**



- Captures **decadal inflections** in the number of flooding days per year due to **long-period tidal modulation** (e.g., 18.6 year cycle).
- **Probabilistic framework** allows for ancillary calculations, such as:
  - Probability of first year with N exceedances
  - Identifying the onset and period of transition from occasional to chronic exceedance

Probabilistic projections of minor flooding frequency (PI: P. Thompson)

A **prototype web tool** has been developed to present these same projections (plus additional info) for **all U.S. locations** with sufficient tide gauge data (calculations complete).



The results can be **generalized for any flood threshold**, making the tool useful for a wide range of areas or thresholds in a given location.

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N-SLCT Budget Tool – Translating Science/Data into Information

Motivation:

- **Local numbers are different from regional numbers are different from global numbers – why and how do they relate to one another?**

Opportunity:

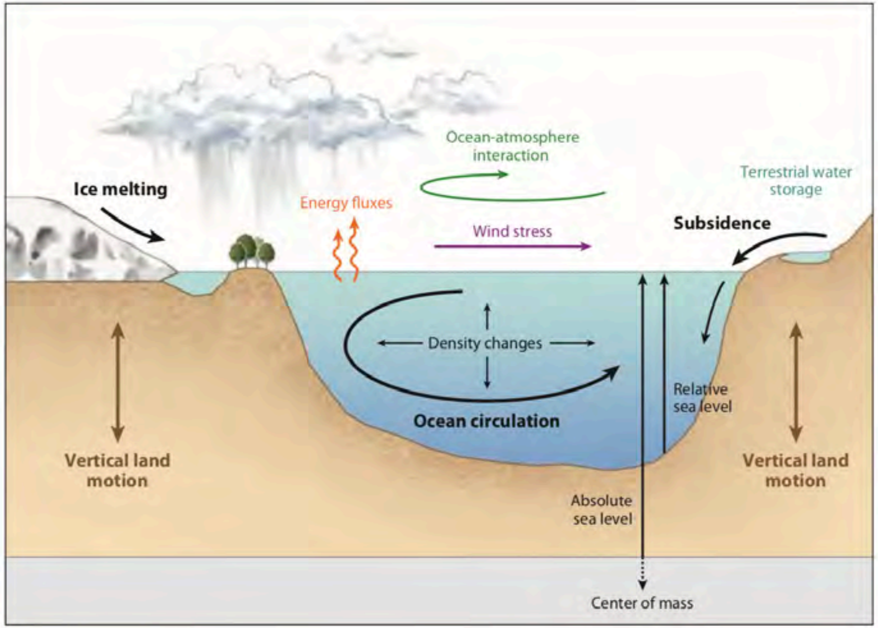
- **NASA has a vast amount of global and regional data on (almost) all contributions to SLC**

Challenge:

- **Translating data into information:**
  - **How much contribution from ice melt, ocean heat, vertical land motion, ocean circulation, water storage …?**
  - **What is important for the future at the local/state/ country level?**

Solution:

- **Tool to synthesize NASA data and information informing about current and future rates and contribution at the state-scale level**



(Stammer et al., 2013)

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40K followers
@sealevelNASA

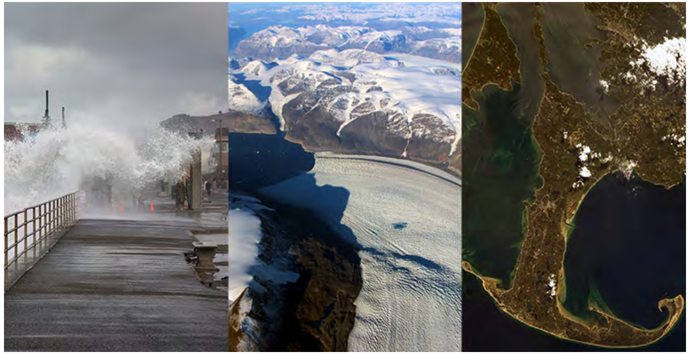
37K followers
@NASASeaLevel

2017 - 2020 NASA-Sea Level Change Team

- Team Lead: Ben Hamlington, NASA Jet Propulsion Laboratory (JPL), Pasadena, California
- Selected investigations:
  - Identifying, quantifying, and projecting decadal sea level change, Benjamin Hamlington, Old Dominion University Research Foundation
  - Understanding current and projected sea level change with multi-satellite observations, modeling and climate system assimilation, Sophie Nowicki, NASA Goddard Space Flight Center, Greenbelt, Maryland
  - Understanding and predicting coastal sea level variability around the United States, Manoochehr Shirzaei, Arizona State University, Tempe
  - Using satellite measurements to improve regional estimates of the impacts of sea level change, Robert Nerem, University Of Colorado, Boulder
  - Global interconnections of cryosphere and solid Earth, sea-level change and ice mass balance, Erik Ivins, NASA Jet Propulsion Laboratory (JPL), Pasadena, California
  - A NASA web portal for sea level change, Carmen Boening, JPL
  - 21st century regional sea level projections due to land ice mass losses and geodynamic adjustments using 3-D Earth models, Regine Hock, University Of Alaska, Fairbanks
  - Quantifying and reducing uncertainty in future global and local sea-level estimates: linking physics, observations, and risk analysis to inform climate adaptation, Isabella Velicogna, University Of California, Irvine

New NASA-Sea Level Change Team and team leader announced

https://sealevel.nasa.gov/news-features/sea-level-news



Left: Higher Pacific sea levels increase coastal flooding risks. Credit: Flickr user Alan Grinberg, "Coming Ashore!", CC BY-NC-ND 2.0.
Middle: One of many Greenland glaciers losing mass and contributing to sea level rise. Credit: NASA/OIB.
Right: Part of Massachusetts, a victim of nuisance flooding brought about by sea level rise. Astronaut photo ID: ISS028-E-9967.

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NASA Sea Level Change Team
Introduction and Overview of Workshop

Ben Hamlington
NASA Sea Level Change Team Lead
Jet Propulsion Laboratory
California Institute of Technology

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

NASA Sea Level Change Team - Brief History

- 1st iteration of NASA Sea Level Change Science Team (N-SLCT) was formed in 2014.
    - Focus on fostering the interdisciplinary research required to improve the accuracy and spatial resolution of current and future sea level change estimates.
- The team was re-competed in 2016, and we are currently on the second iteration of the team.
    - Eight total teams funded for three years, 70+ PIs, Co-Is, Collaborators.
    - Current team lead is Ben Hamlington (JPL).

NASA Sea Level Change Team: 2017-2020

- Two areas of focus for the current team:

First Focus Area - Science: Advance the understanding of regional sea level change through interdisciplinary research.

- **Characterizing current changes in sea level: Global and regional sea level projections that extrapolate from satellite and contemporary observations**
- **Characterizing underlying processes and improving predictions of regional variations in sea level.**
- **Improving knowledge of ice mass change that specifically improves estimates of current and future sea level rise**
- **Integrating these results into better forecasts of sea level rise.**

Required the formation of interdisciplinary proposing teams, with each team addressing one or more of the above areas.

NASA Sea Level Change Team: 2017-2020

Second Focus Area - Outreach: Provide ”useful information” regarding ongoing and future regional sea level change.

- What is “useful” sea level information?
  - Clear need to engage those translating science into action across a range of applications → organized a workshop as part of the annual team meeting in March, 2019 in Annapolis.
  - Addressed two important questions for the day:

    (1) Are there areas where sea level scientists may think they are being useful, but are actually largely following their own curiosity?

    (2) Are there areas that would be useful that sea-level scientists aren’t giving enough attention to?
- An important part of this outreach effort – both to the broader public and other scientists - is the web portal (sealevel.nasa.gov), that was created as part of the N-SLCT.

NOAA Sea Level Rise Observations and Science supporting Decision Making


USCLIVAR Workshop
Sea Level Hotspots from Florida to Maine
April 24, 2019

William Sweet
NOAA CO-OPS Oceanographer

NOAA Nat'l Ocean Service Product/Service Heading

1. Problem Recognition: Sea Level Rise (SLR)

    (or erosion if on Tangier Island)

1. Defining: Societal impact thresholds
2. Monitoring: Weather!
3. Tracking: Changes in trends, patterns
4. Projecting: Seasonal to century (S2C)
5. Mapping: 1D, 2D…3D

Problem Recognition

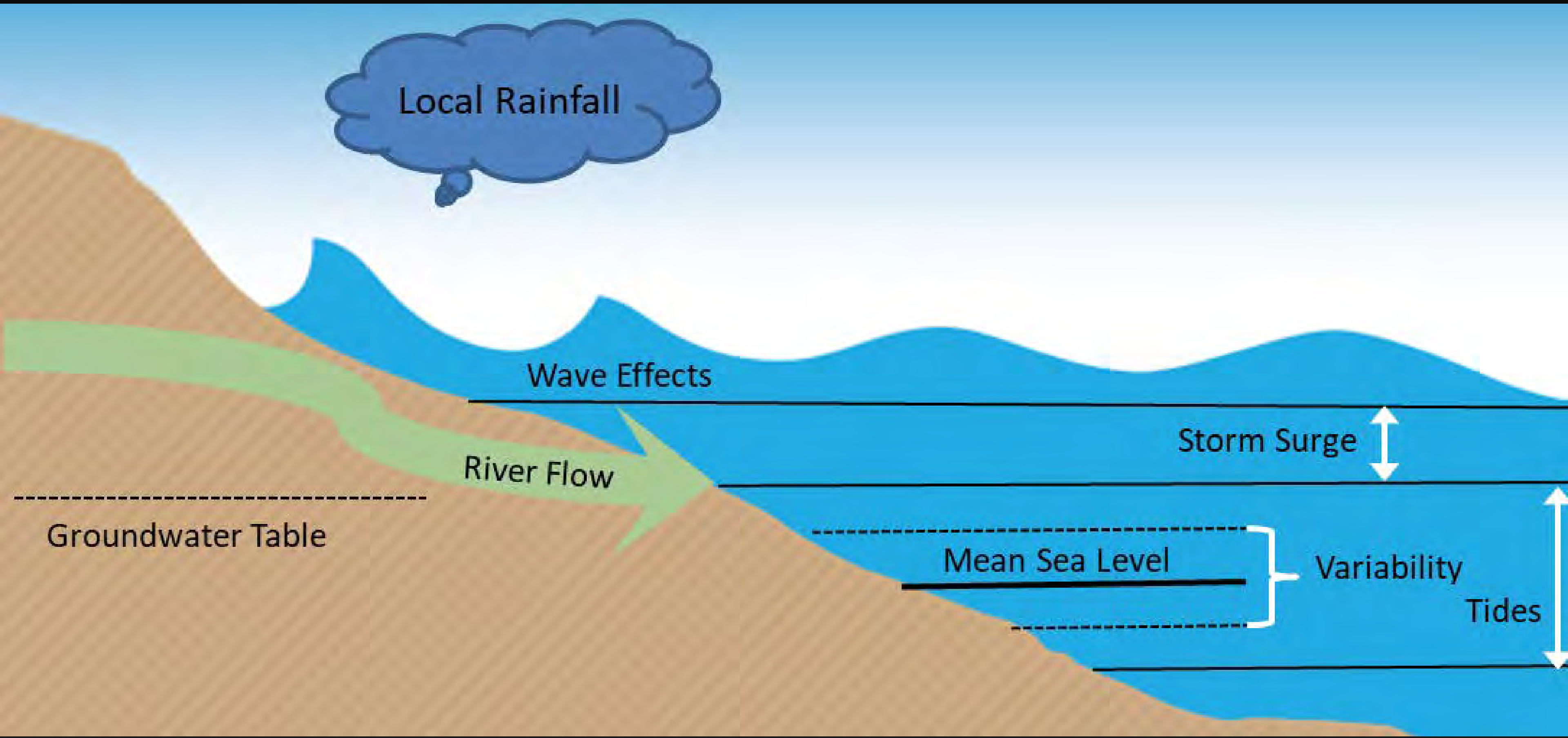
Sea level rise (SLR) flooding now happening in East Coast towns

Annapolis, MD

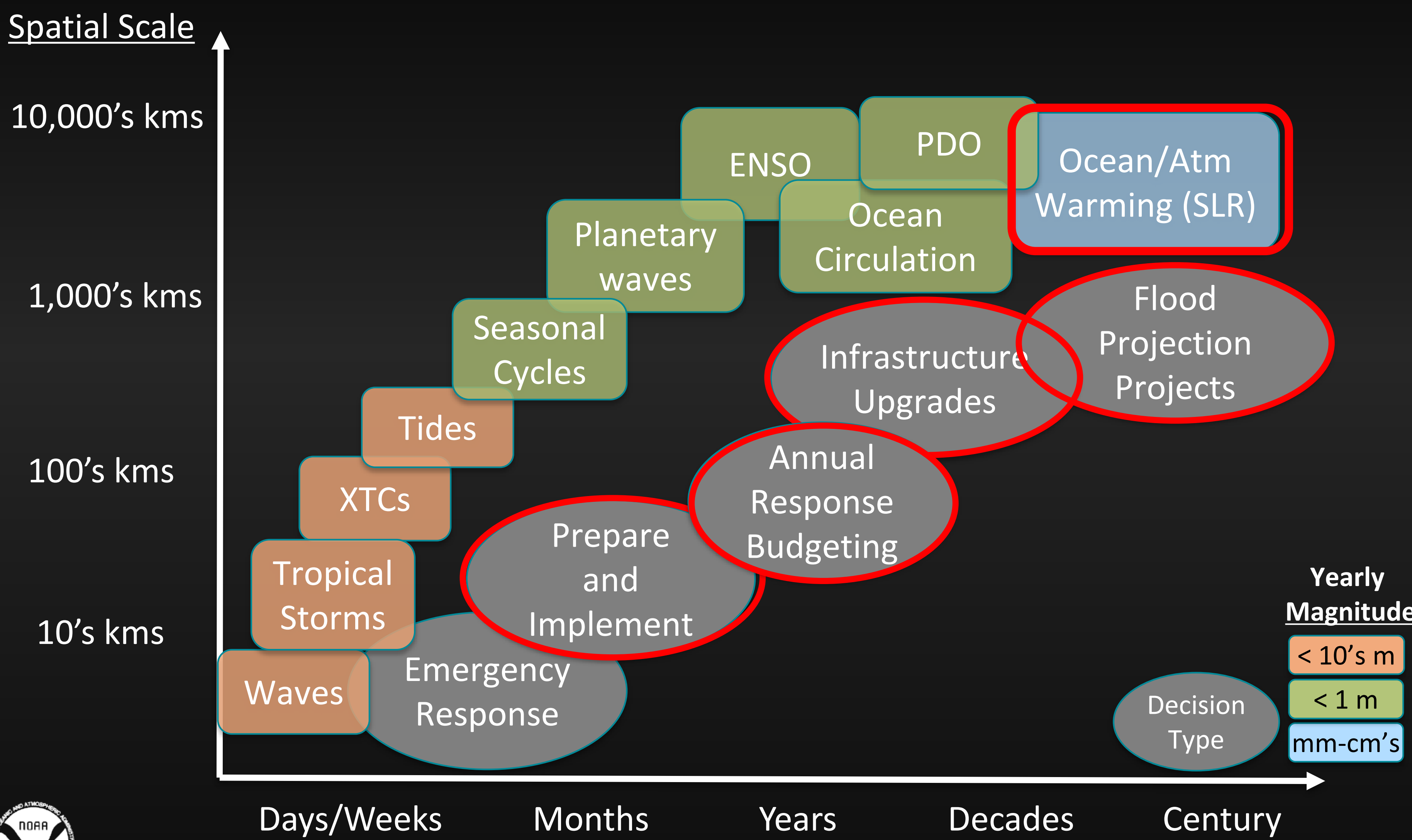
Charleston, SC

Norfolk, VA

Sea Level Rise is a Key Driver Changing Flood Risk



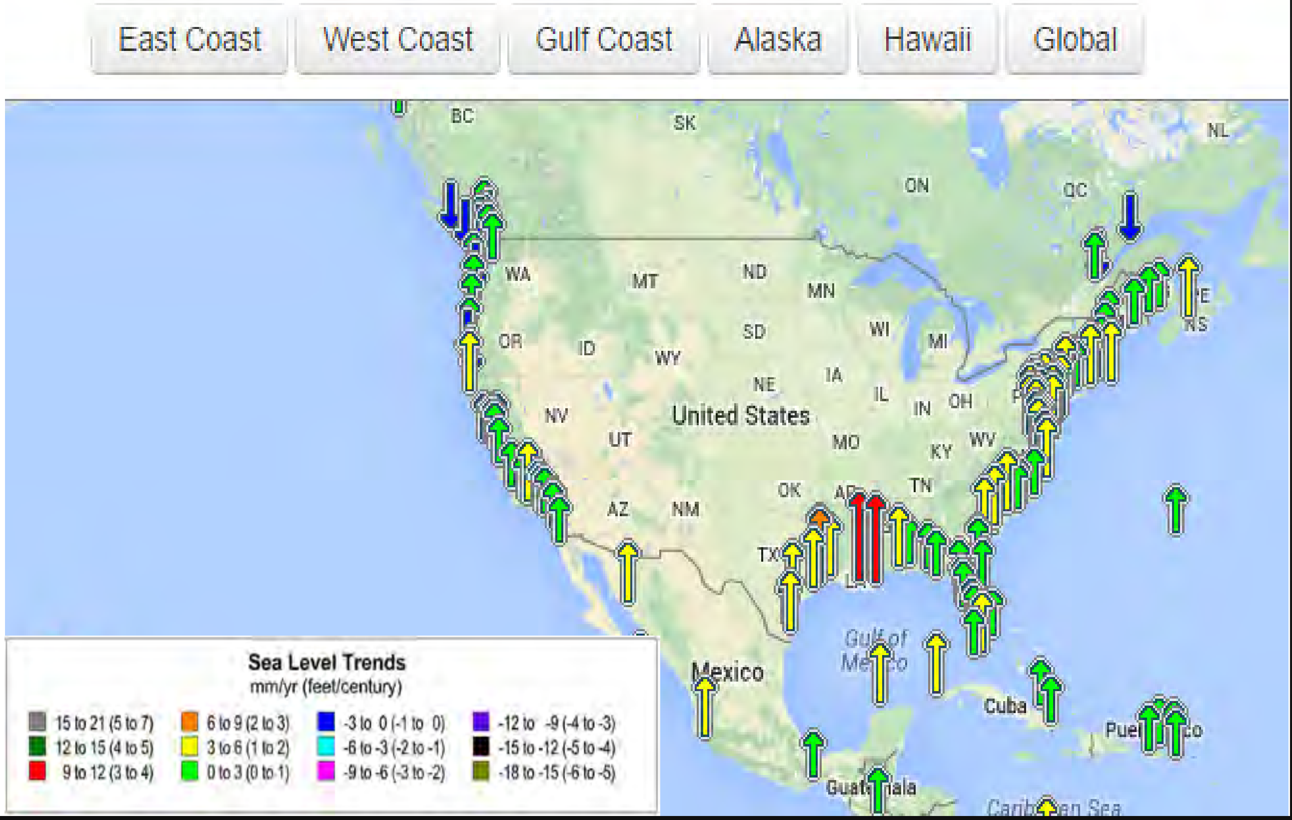
Ocean and Atmospheric Warming (SLR) complicates Decision Making



NOAA Tide Gauges Measuring Relative SLR

Tide gauges measure changes in relative sea levels

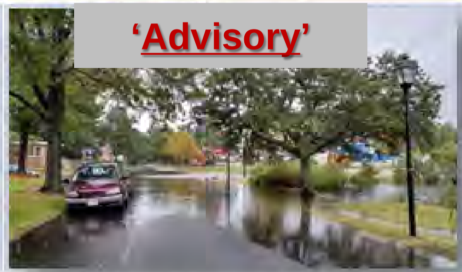
Relative Sea Level Trends
(tidesandcurrents.noaa.gov/sltrends)



Defining Societal Impacts: In-your-face-Weather!!

Coastal Flooding Thresholds

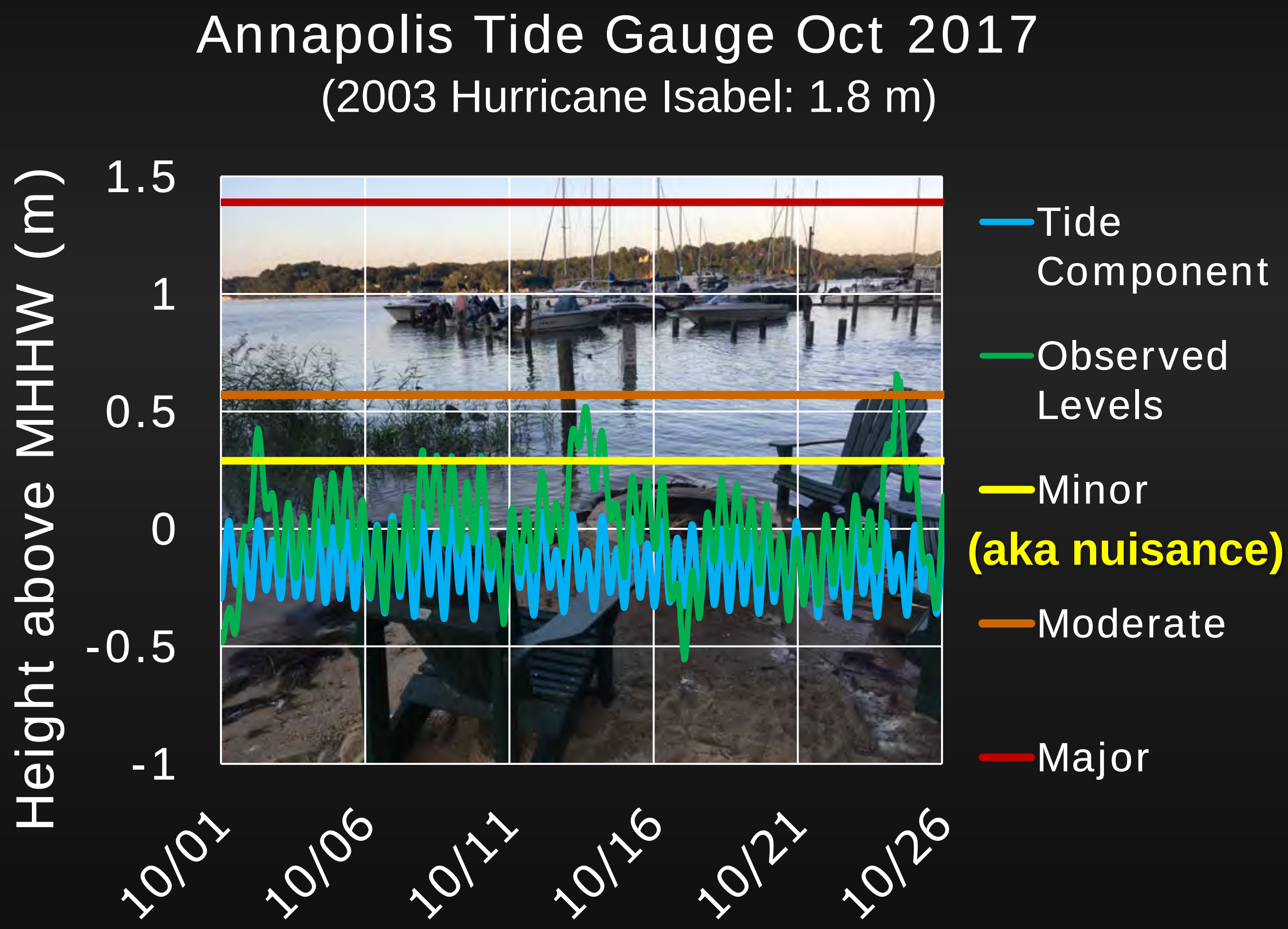
National Weather Service Wakefield, Virginia

	Minor	Moderate	Major
Picture			
Hazard	➢ **Shallow flooding** in the most vulnerable locations near the waterfront and shoreline resulting in a **low threat of property damage.** ➢ **Up to 1 foot of inundation** in shoreline and vulnerable areas.	➢ **Widespread flooding** of vulnerable areas will result in an **elevated threat of property damage.** ➢ **1 to 2 feet of inundation** primarily in shoreline and vulnerable areas.	➢ **Severe flooding** will cause extensive inundation and flooding of numerous roads and buildings resulting in a **significant threat to property and life**. ➢ **2 to 3 feet or more of inundation.**
Impact	➢ A few shoreline and vulnerable roadways and adjacent properties will experience shallow flooding. ➢ Minor beach erosion with possible erosion to the front of vulnerable dune structures.	➢ Inundation of roads and low lying property near the waterfront. ➢ Flooding will extend along tidal rivers and creeks resulting in some road closures, flooding of vehicles, and some property. ➢ Severe beach erosion and considerable erosion of dunes, especially during long duration events.	➢ Numerous roads will be impassable, with many unprotected cars submerged. ➢ Evacuations will be necessary for the most vulnerable areas. ➢ Flood waters may extend well inland. ➢ Substantial coastal damage and severe erosion of dunes.

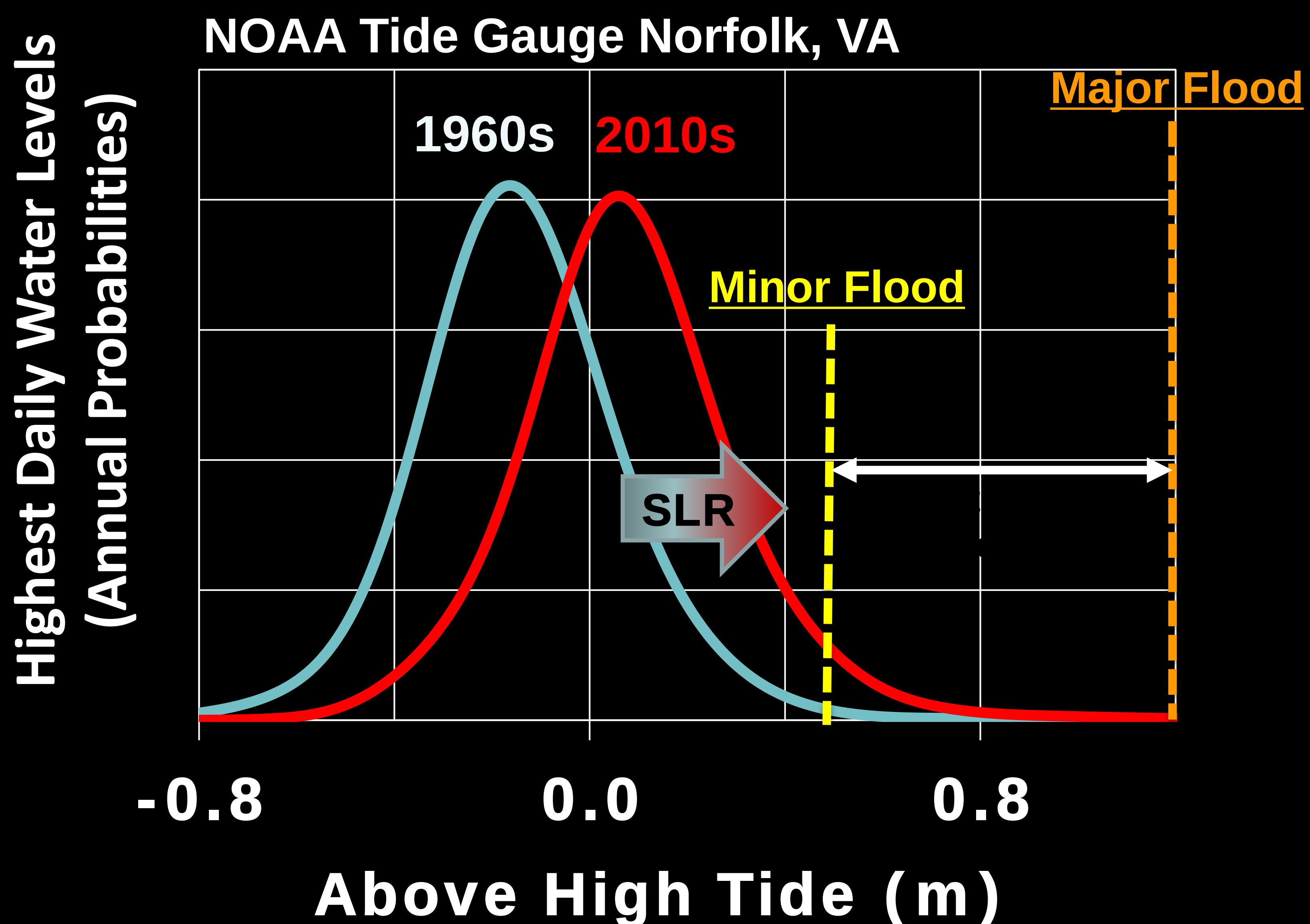
High tide (minor, nuisance) flooding used now by NOAA

NOAA Tide Gauges Monitoring for Coastal Flooding

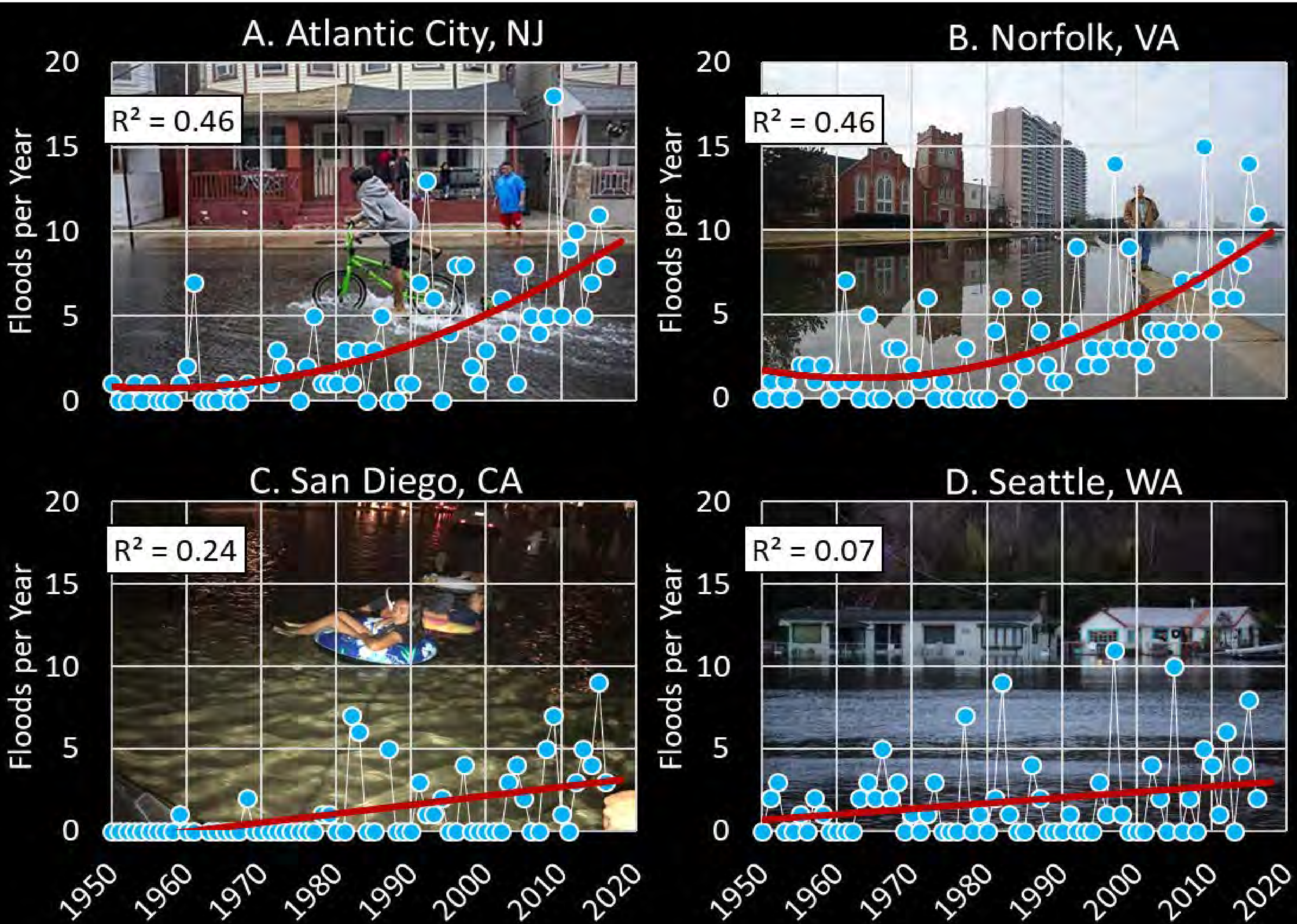
Tide gauges monitor for coastal flooding with severities defined by NOAA NWS thresholds



Tracking Change: Goodbye Freeboard, Hello Flooding

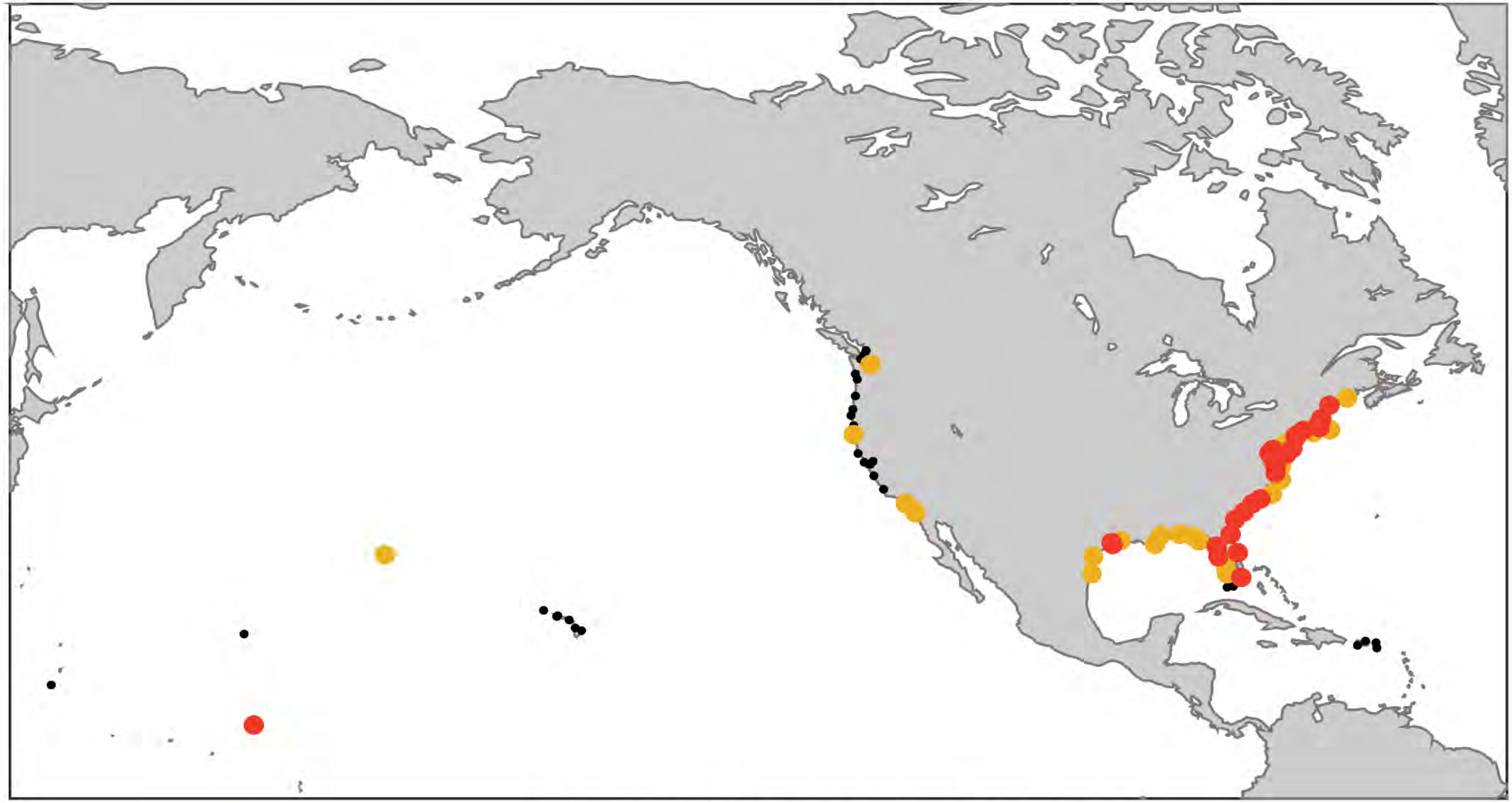


Tracking Changes in High Tide Flood Frequencies



Sweet et al. (2018)

Trend Changes in High Tide Flood Frequencies



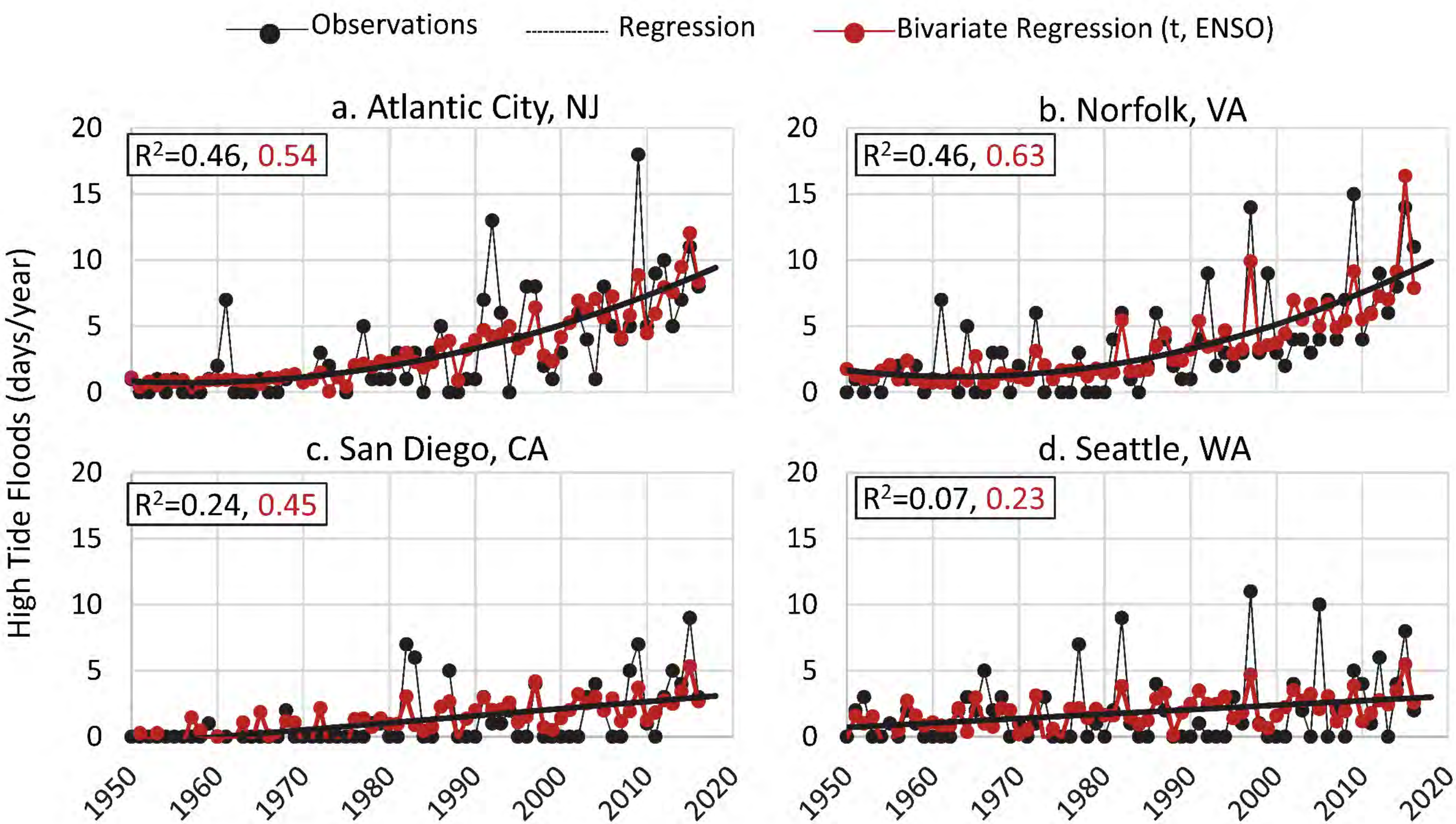
Trend Characterization

Increasing

Accelerating

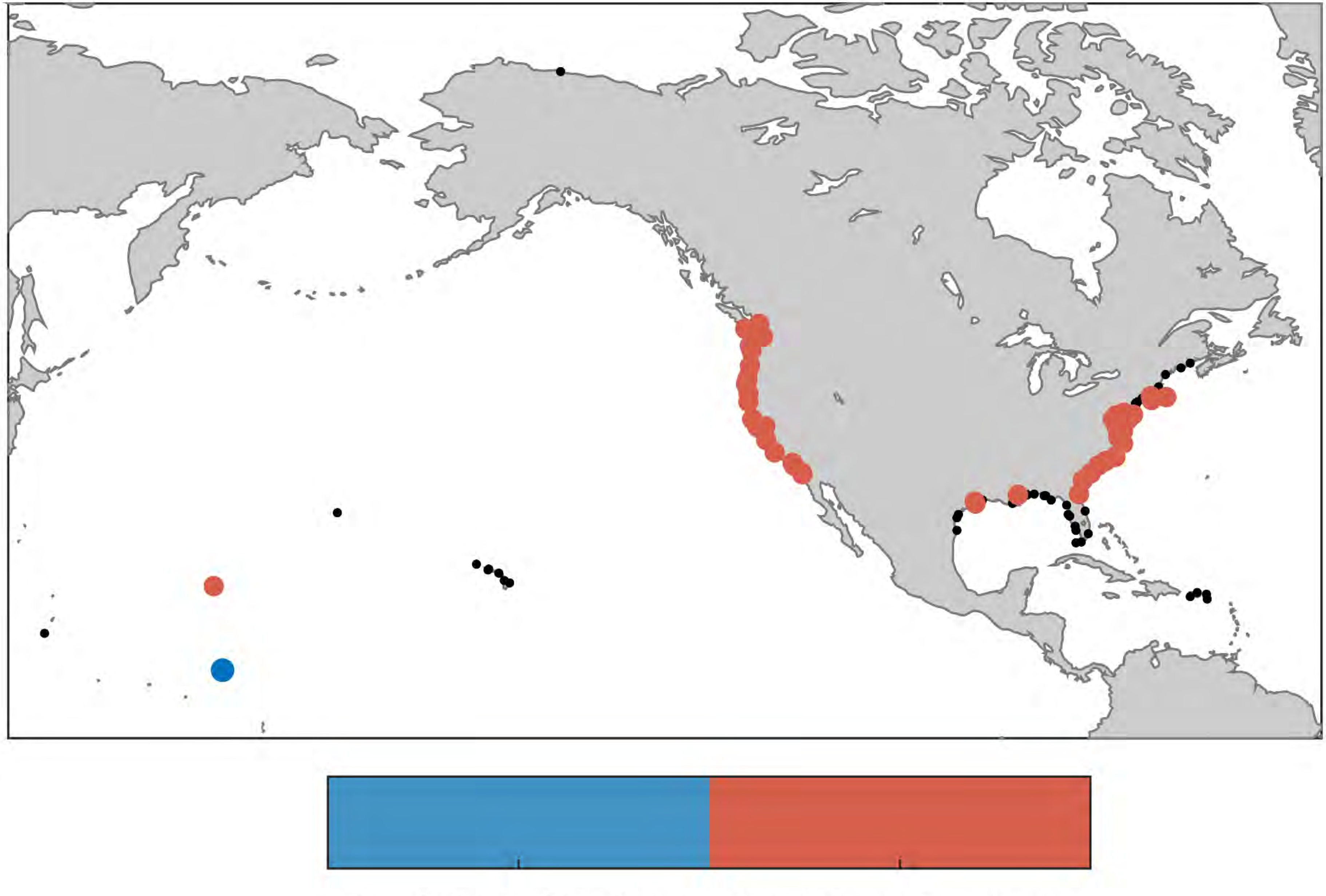
Sweet et al. (2018)

High Tide Flooding: Trends + El Nino



Sweet et al. (2018)

High Tide Flood Frequencies and El Nino/La Nina



Sweet et al. (2018)

Seasonal Outlook of (~King) High Tides

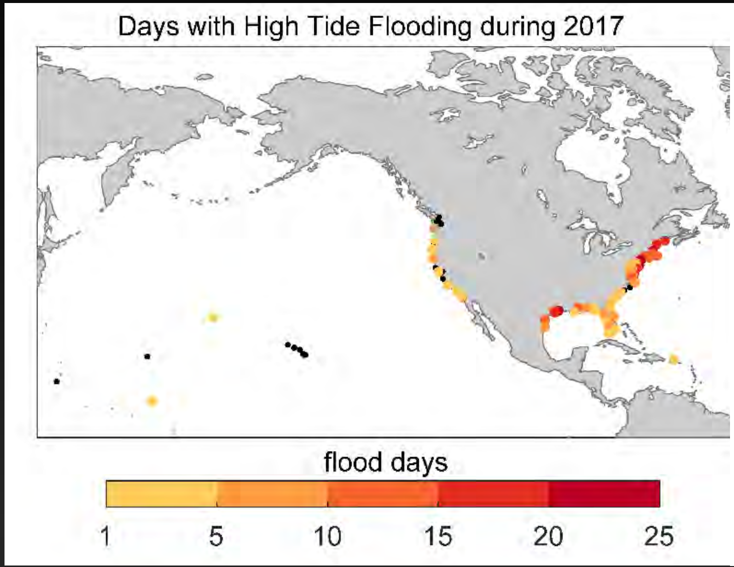
https://oceanservice.noaa.gov/news/high-tide-bulletin/

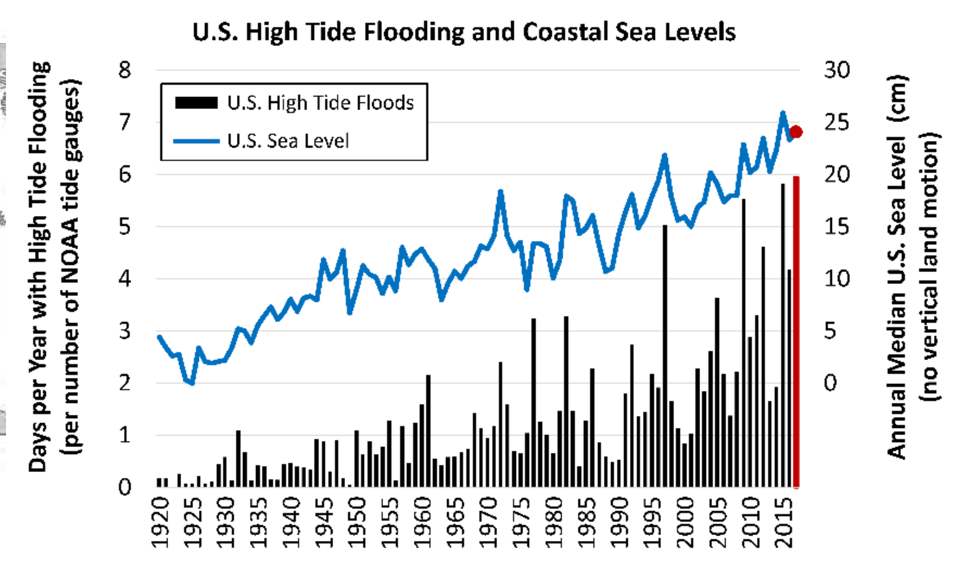
High Tide Bulletin

- Alerts of seasonally high (deterministic) spring tides
- Warns of possible impacts considering where tide/weather dominate high water formations
- Hope to expand this product with ensemble of mean/variance based estimates (e.g., Widlansky et al)

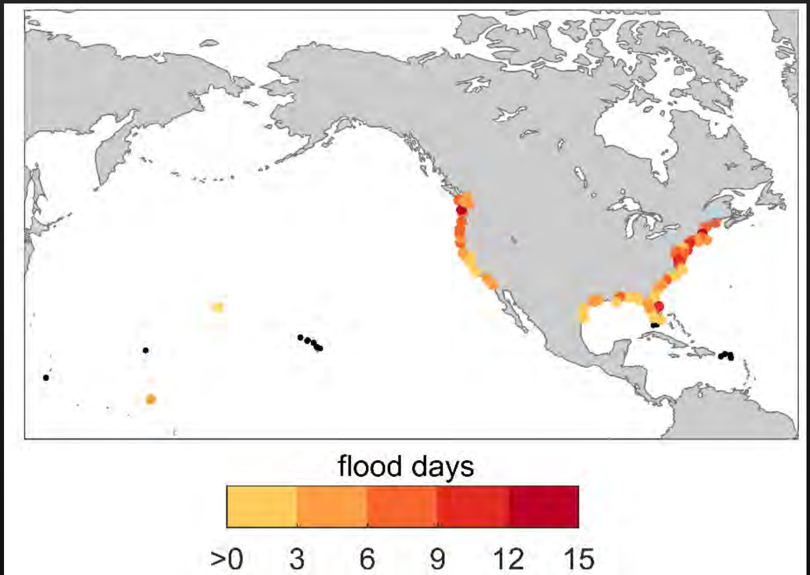
Annual Recap/Outlooks of High Tide Flooding

2017 Recap



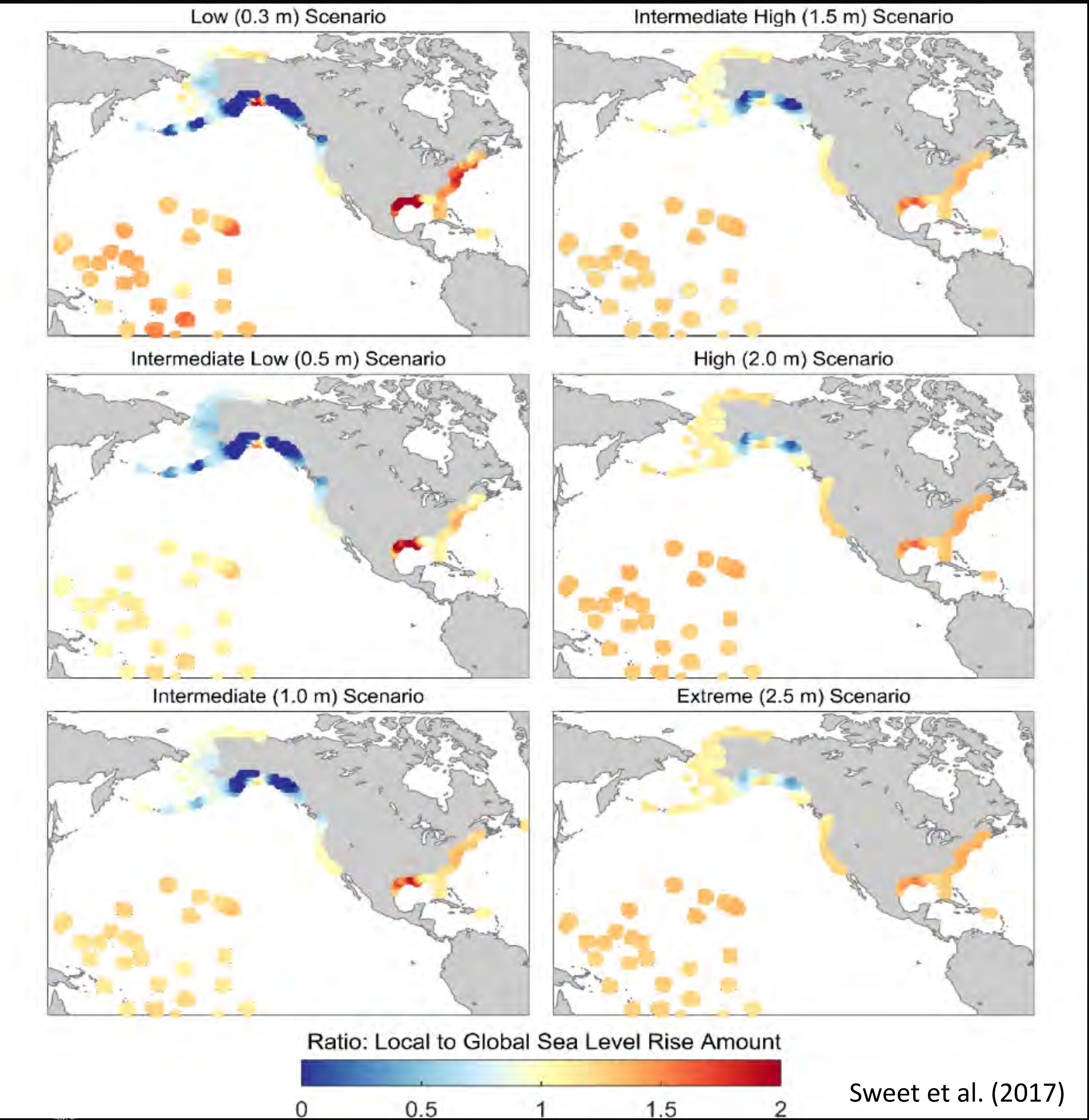


2018 Outlook (May '18 – Apr '19)



https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook

Projections of Global SLR Scenarios (1-degree gridded)



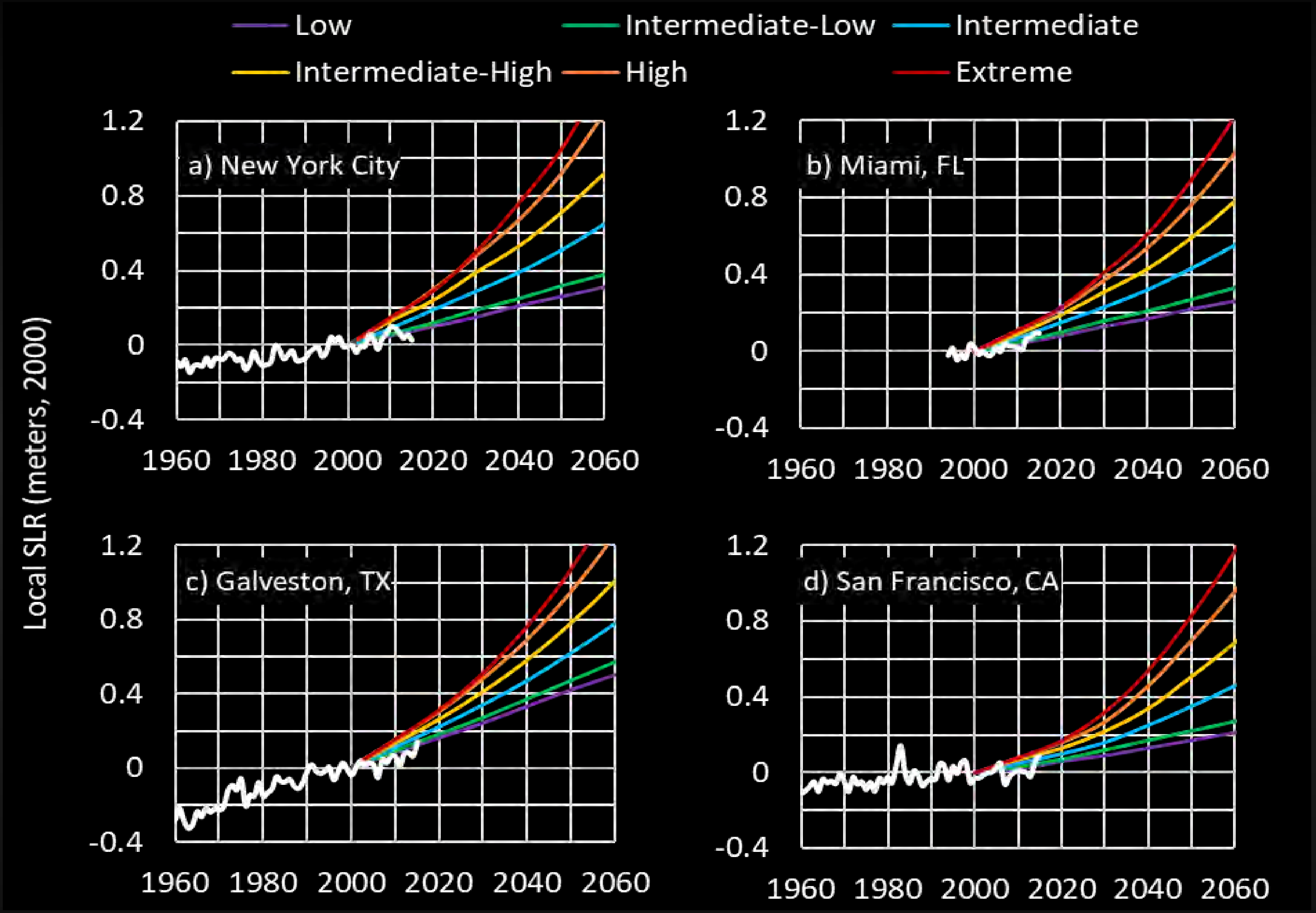
Sweet et al. (2017)

<u>Includes changes in:</u>

- Ocean circulation
- Earth's gravitational field & rotation
- Vertical land motion

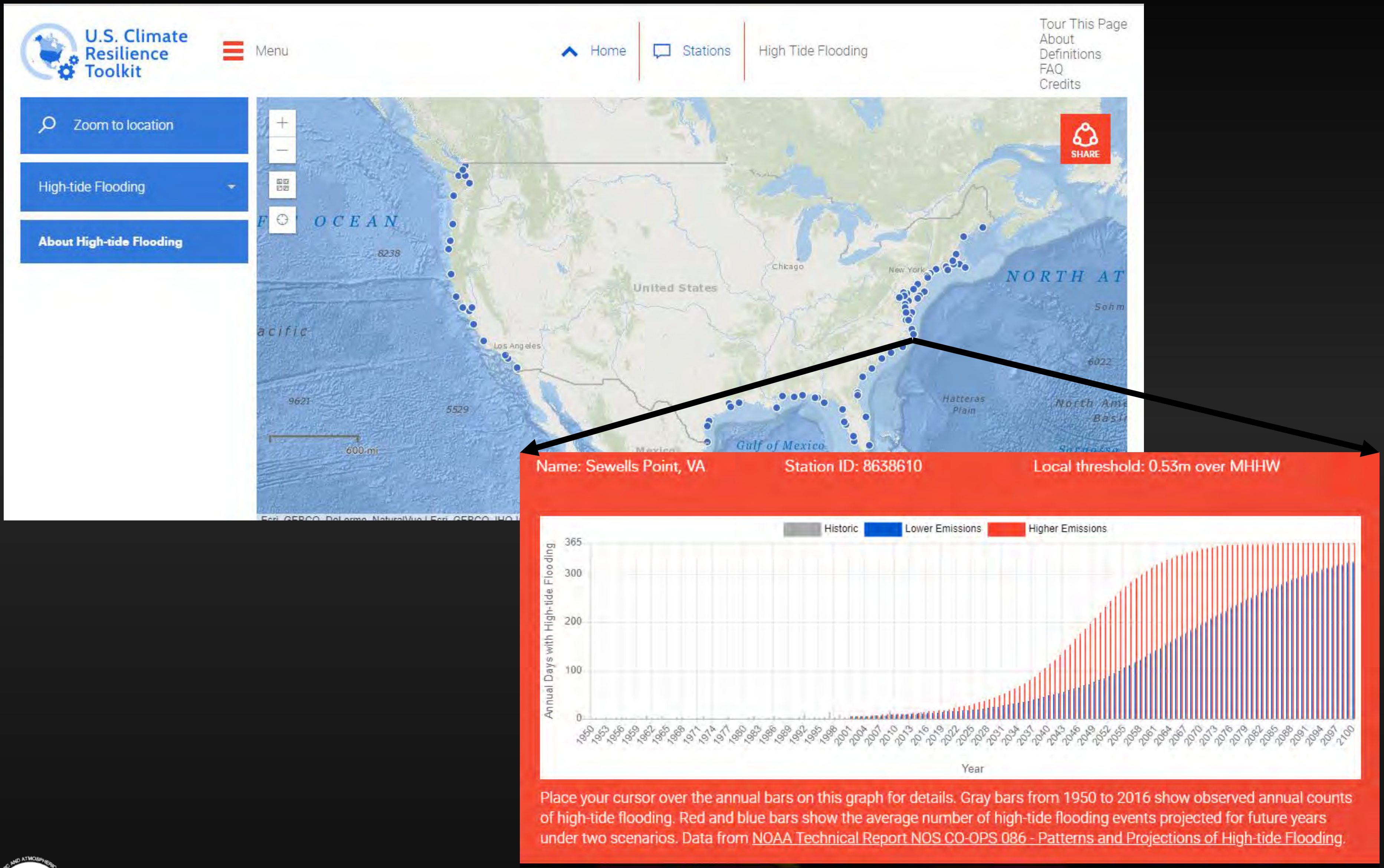
Year 2100 shown but decadal values through 2200 provided

SLR Tracking and Rise Projections



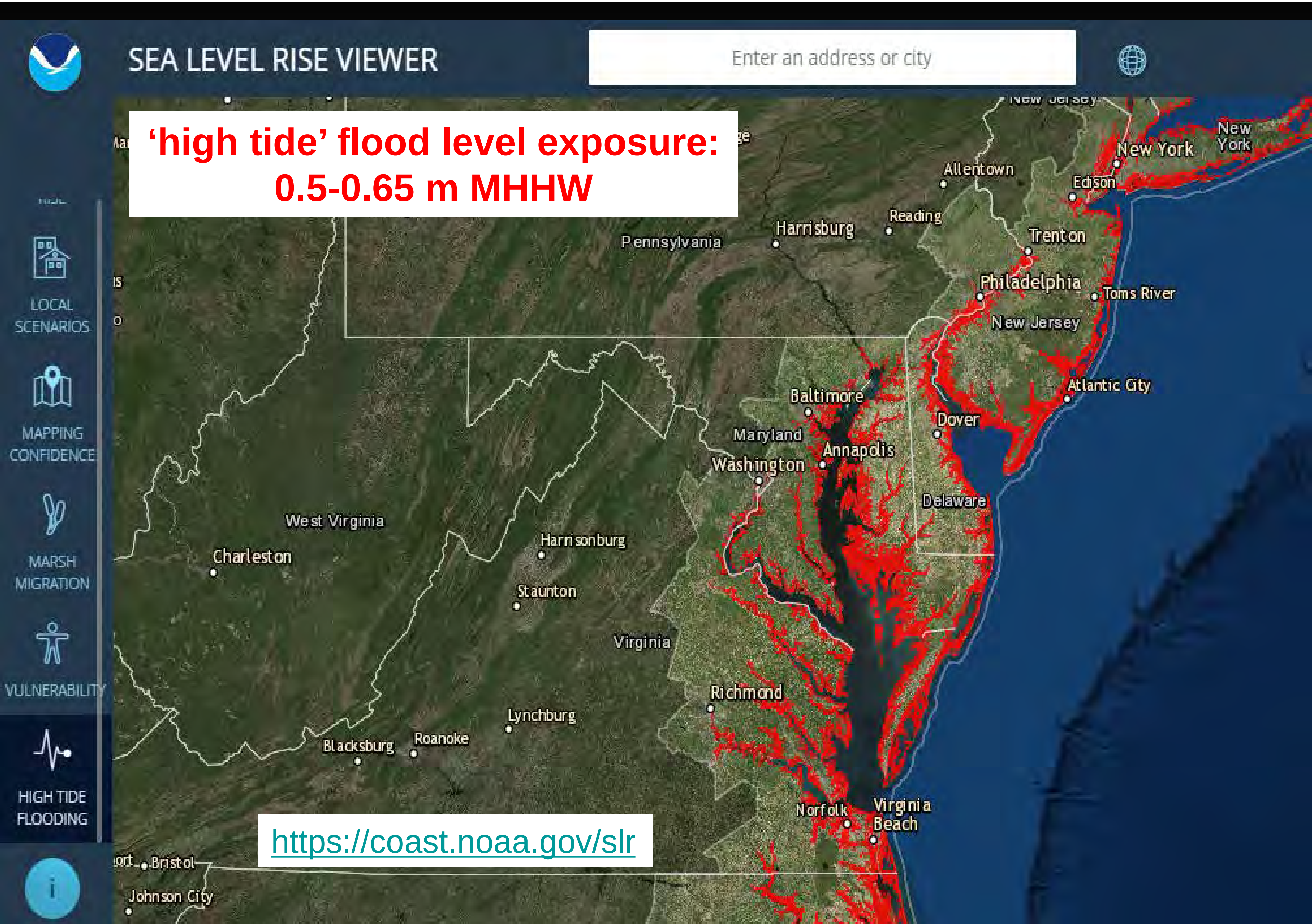
https://tidesandcurrents.noaa.gov/sltrends

Projecting Changes in High Tide Flooding



https://crt-climate-explorer.nemac.org/

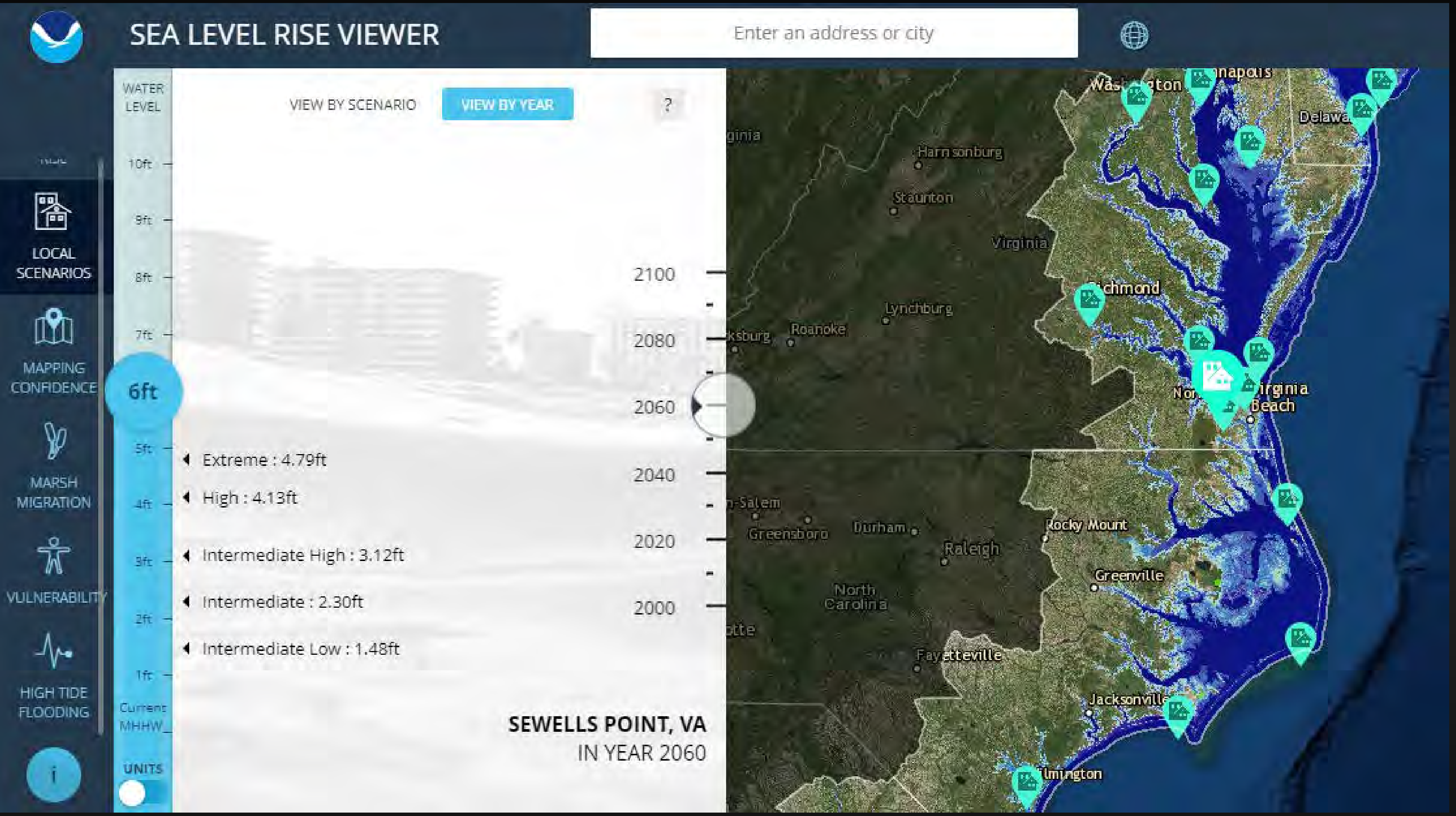
Mapping of Land Exposed to High Tide Flood Frequencies



‘high tide’ flood level exposure: 0.5-0.65 m MHHW

https://coast.noaa.gov/slr

Mapping of Land Exposed to MHHW under SLR Projections



https://coast.noaa.gov/slr