



Coastal Inundation and High Tide Flooding Data and Resources

**Northeast Regional Climate Center
2024 Webinar Series**

John Callahan
NOAA National Ocean Service
Center for Operational Oceanographic Products & Services (CO-OPS)
Ocean Associates, Inc



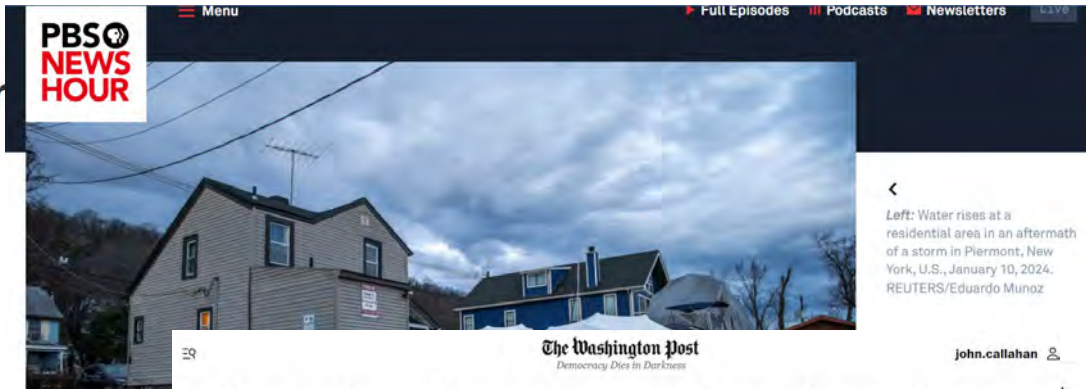
WEATHER

East Coast storm causes major flooding across the Northeast

DECEMBER 20, 2023 · 5:04 AM ET

HEARD ON MORNING EDITION

By Patty Wight // Maine Public



It's time for Northeast to prep for floods like those that hit this winter. Climate change is why

PATRICK WHITTLE Associated Press Feb 17, 2024 0



There are many processes that can lead to coastal flooding

Physical Process	Spatial Scale			Temporal Scale	Potential Magnitude (yearly)
	Global	Regional	Local		
Wind Waves Effects	—	—	X	seconds to minutes	<10 m
Tsunami	—	X	X	minutes to hours	<10's of m's
Storm Surge (e.g., tropical and extra-tropical storms)	—	X	X	minutes to days	<10 m
Tides	—	X	X	hours to years	<15 m
Ocean/Atmospheric Variability (e.g., ENSO response)	—	X	X	days to years	<0.5 m
Ocean Gyre and Over-turning Variability	—	X	X	years to decades	<0.5 m
Land Ice Melt/Discharge	X	X	X	years to centuries	mm's to cm's
Thermal Expansion	X	X	X	years to centuries	mm's to cm's
Vertical Land Motion	—	X	X	minutes to centuries	mm's to m's

Weather timescales, hard to predict

Tides, predictable long timescale

Climate, provide "favorable environment" for weather events



Regional major physical contributors to coastal flood events...

Waves, tides, ocean currents

Pacific tropical systems, tides, ocean currents, waves

Tides, wind fields, storm surge

Wind fields, storm surge, tropical systems

Storm surge, tropical systems

Atlantic and Gulf tropical systems







Impacts from flooding are a combination of elevated water levels AND thresholds!

Minor Threshold, shallow flooding, causes disruptions to daily life; can be damaging over time. Can have many “minor” causes.

Moderate – damaging

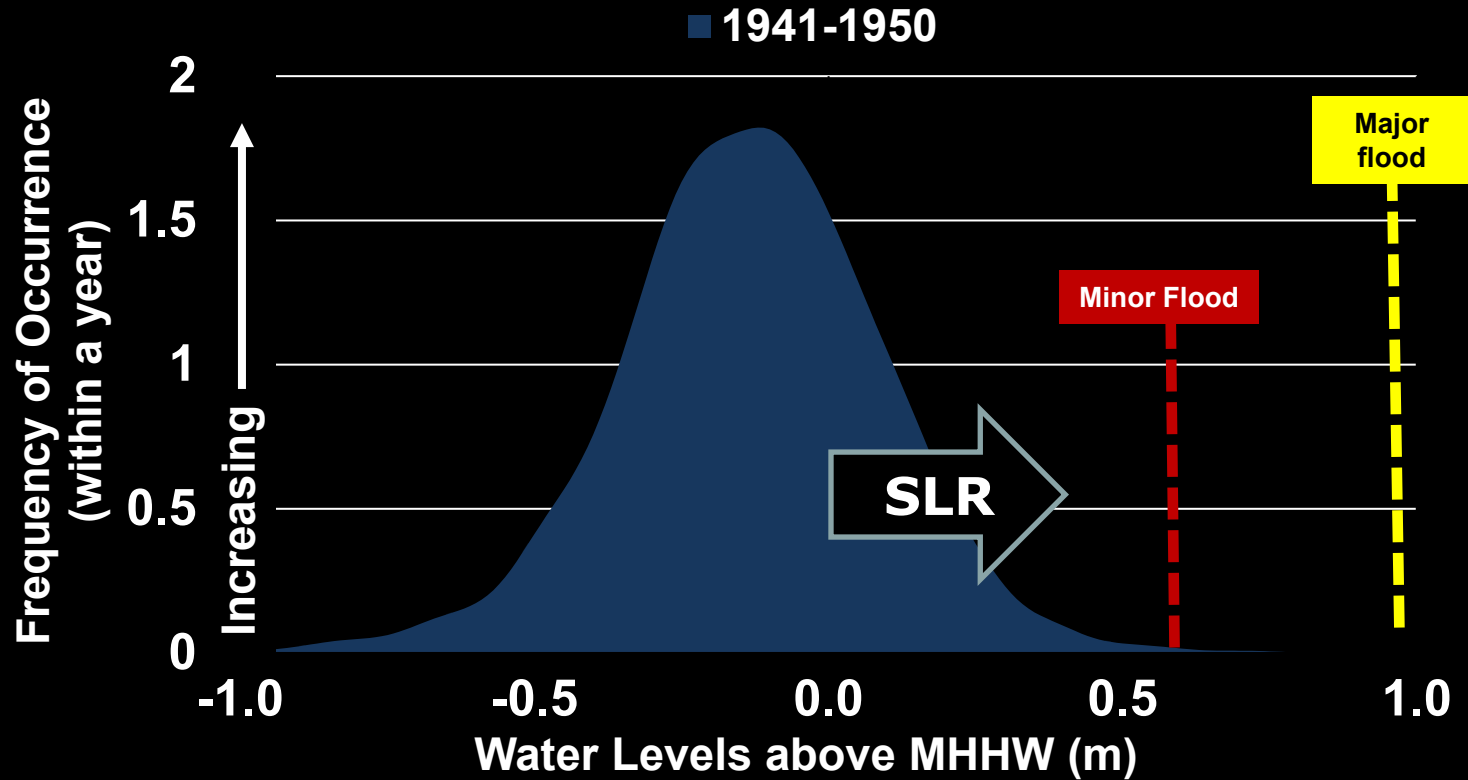
Major – destructive

Require coastal storm or strong meteorological influence.

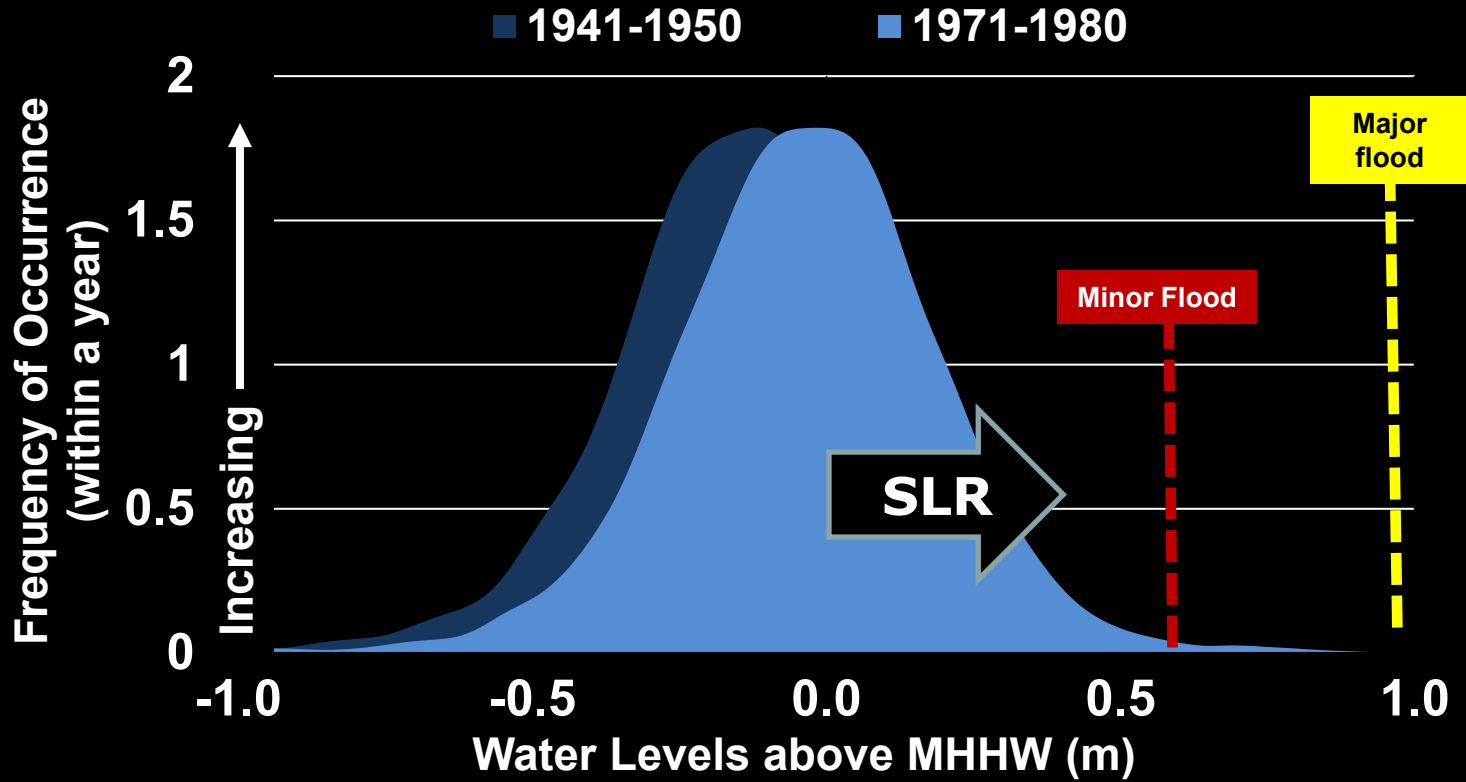
 <h1>Coastal Flooding Thresholds</h1> <p>National Weather Service Wakefield, Virginia</p>			
	Minor	Moderate	Major
Picture			
Hazard	<ul style="list-style-type: none"> ➤ Shallow flooding in the most vulnerable locations near the waterfront and shoreline resulting in a low threat of property damage. ➤ Up to 1 foot of inundation in shoreline and vulnerable areas. 	<ul style="list-style-type: none"> ➤ 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. 	<ul style="list-style-type: none"> ➤ 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	<ul style="list-style-type: none"> ➤ 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. 	<ul style="list-style-type: none"> ➤ 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. 	<ul style="list-style-type: none"> ➤ 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.



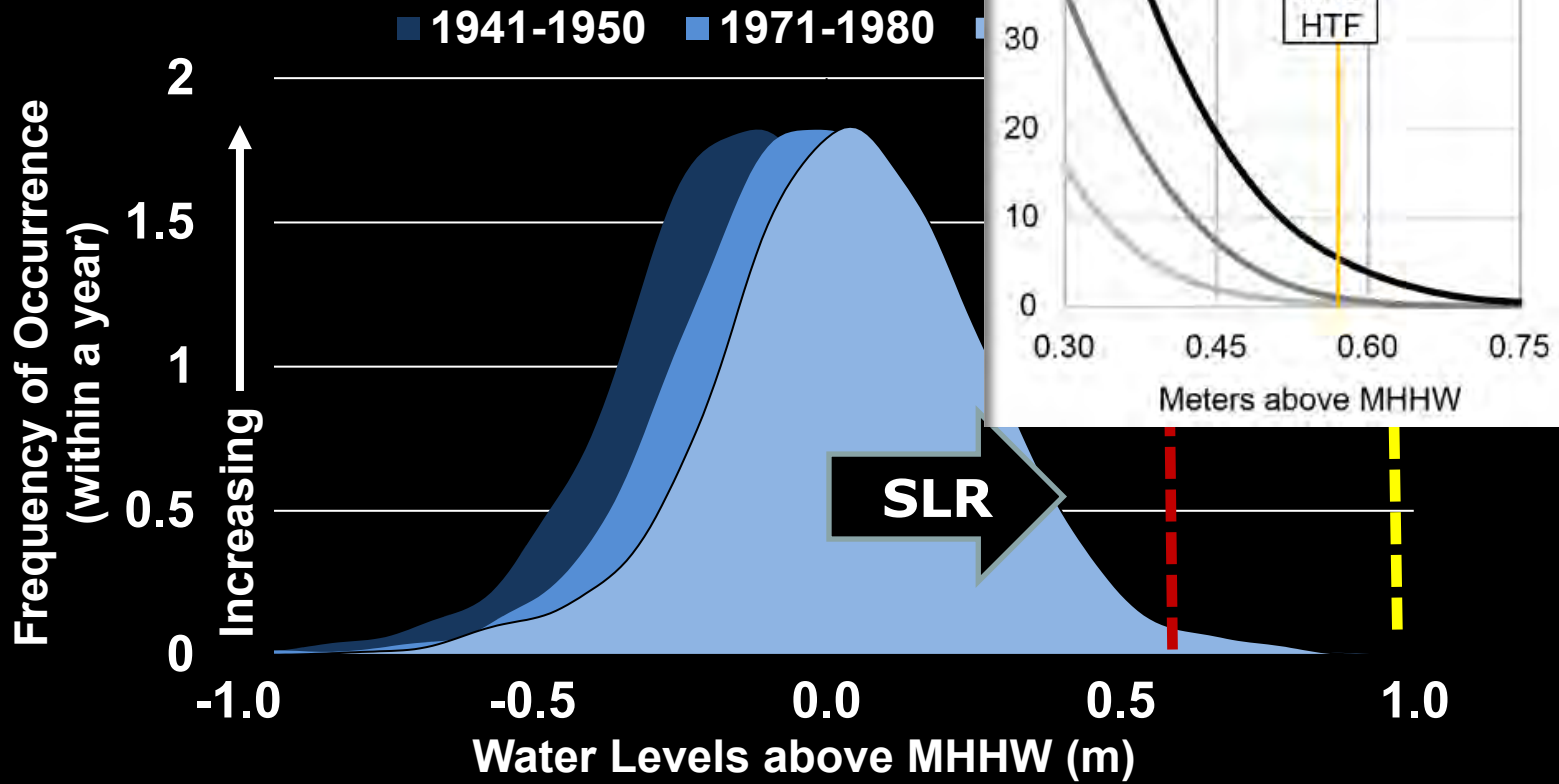
Daily Highest Water Levels at NOAA Tide Gauge NYC



Daily Highest Water Levels at NOAA Tide Gauge NYC

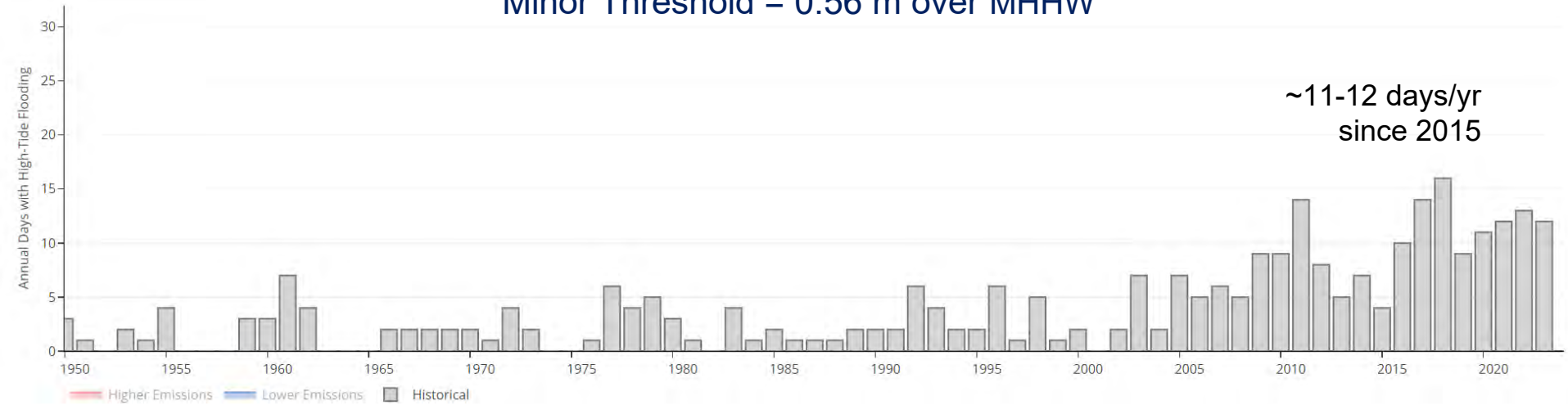


Daily Highest Water Levels at NO



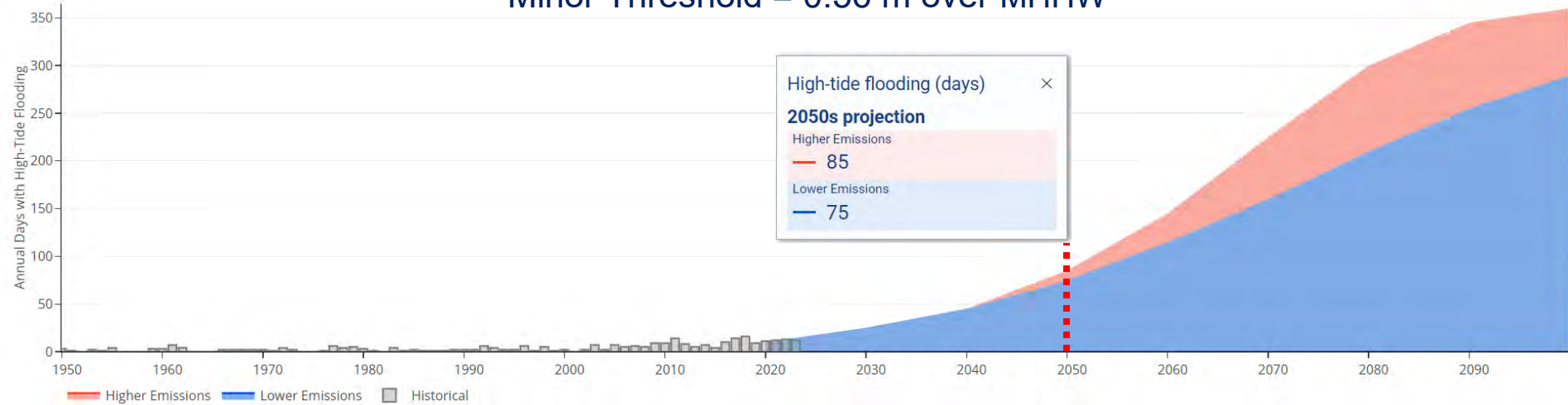
Coastal Flood Frequency at New York, The Battery

Minor Threshold = 0.56 m over MHHW



Coastal Flood Frequency at New York, The Battery

Minor Threshold = 0.56 m over MHHW



Coastal Inundation Resources

- Coastal inundation at Climate Timescales (CICT) Whitepaper
- 2022 US Interagency SLR Technical Report

- NOAA CO-OPS Products
 - SLR Trends and Projections (Means)
 - Annual Chance Return Levels (Extremes)
 - High Tide Flooding Frequency (In-Between)

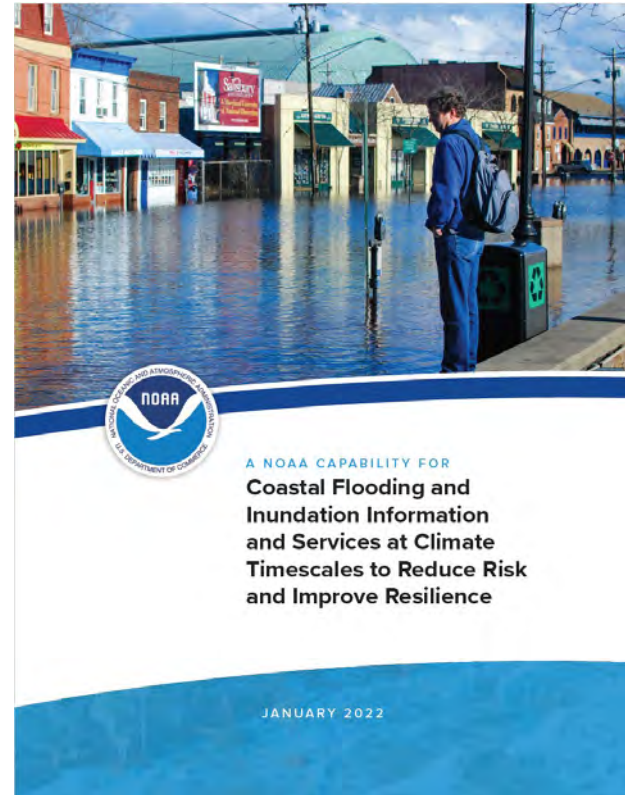
- ~~Real-time Monitoring and Model Guidance~~

- A few new products



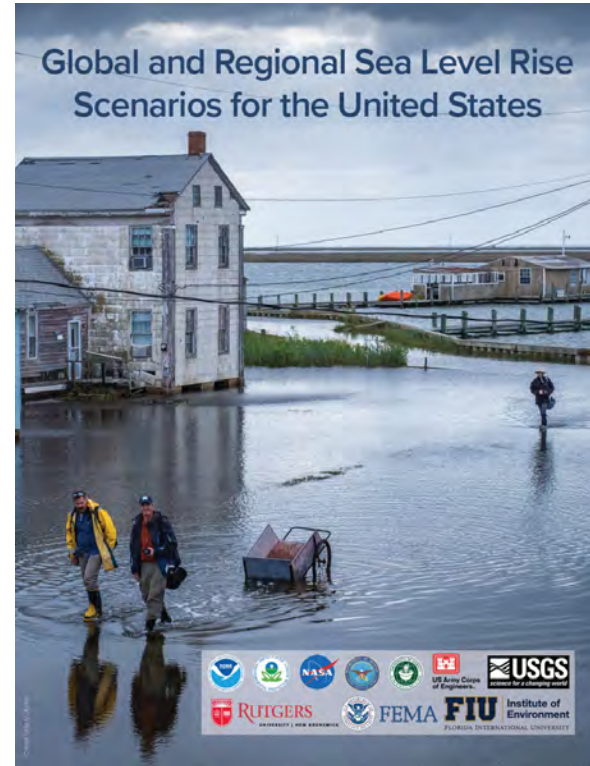
Coastal Inundation at Climate Timescales (2022)

- NOAA-led report,
A “whole-of-government” approach
- Describes an *enhanced federal capability* to provide authoritative data, products, and services that quantify and communicate the risk of **subseasonal-to-centennial** coastal flooding and inundation for the US and its territories.



US Interagency Task Force SLR Technical Report (2022)

- “Interagency” report, not NOAA only!
- Latest SLR projections, extremes, HTF, gridded and station based, etc...
- Basis for NCA5; beginning to be integrated across federal space products and services.



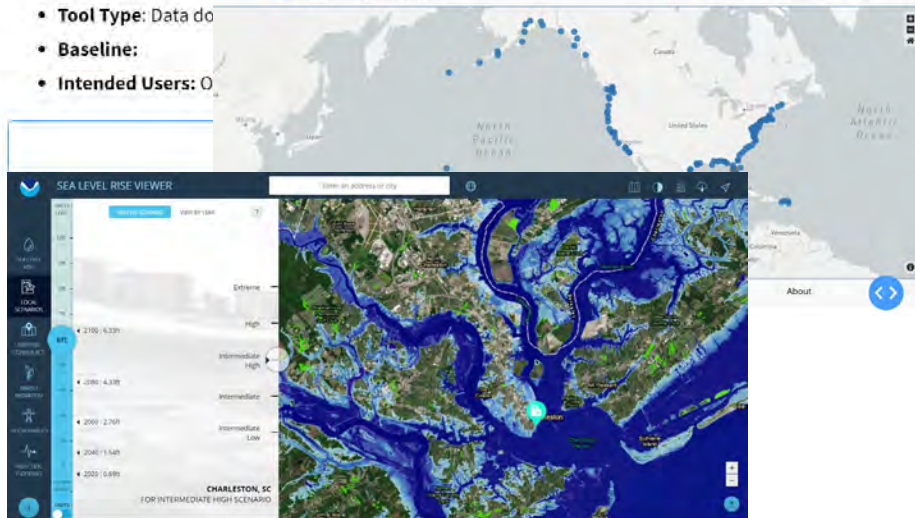
US Interagency Task Force SLR Technical Report (2022)

2022 Sea Level Rise Technical Report Data Files

These CSV files provide a way to directly download three datasets from the 2022 technical report.

- Available Data (Download Datasets Below)
 - 2022 Scenarios of Future Mean Sea Level
 - 2022 Extreme Water Levels (Tide Gauges)
 - 2022 Extreme
- Tool Type: Data do
- Baseline:
- Intended Users: O

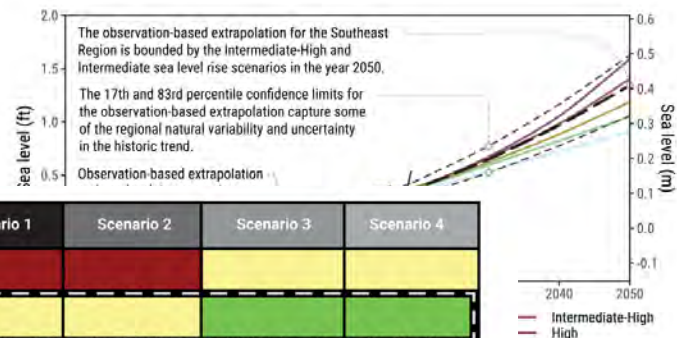
NASA Sea Level Change from Flooding Analysis Tool



APPLICATION GUIDE

for the

2022 Sea Level Rise Technical Report



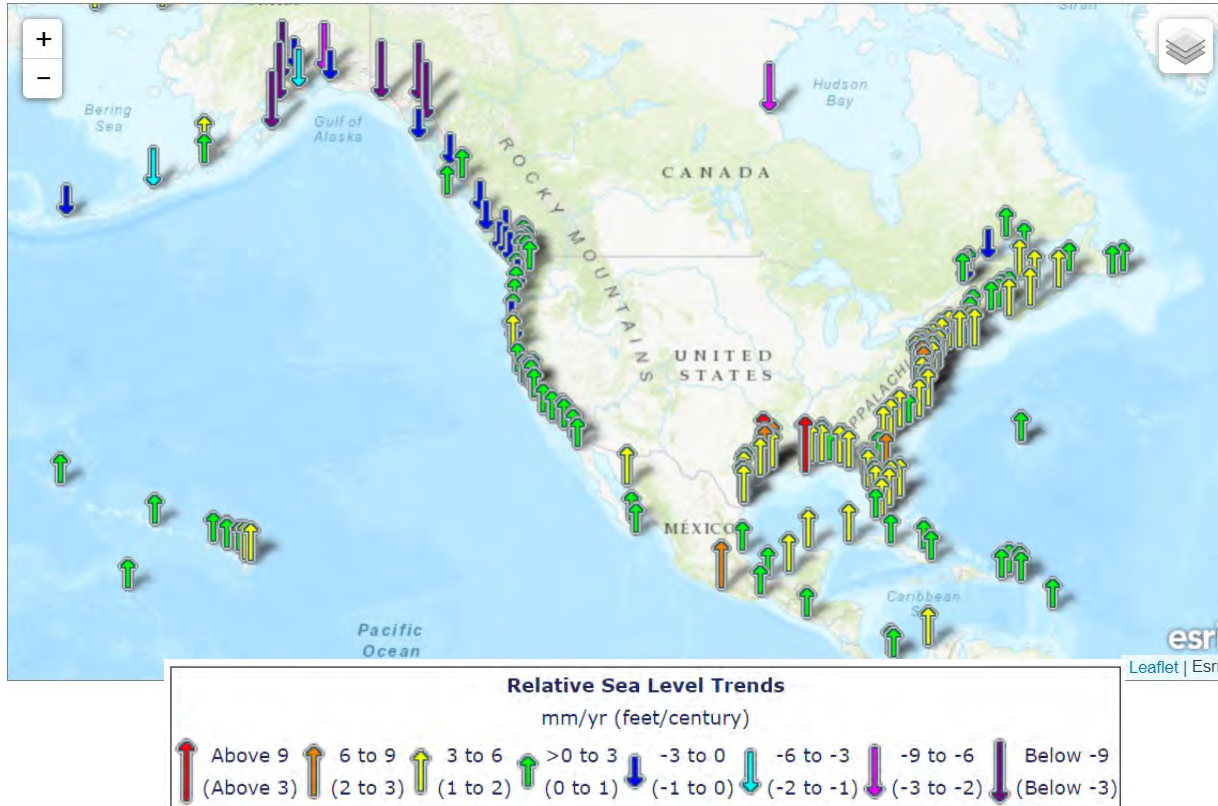
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Management Strategy 1	Red	Red	Yellow	Yellow
Management Strategy 2	Yellow	Yellow	Green	Green
Management Strategy 3	Red	Yellow	Yellow	Green

Intermediate-High
High

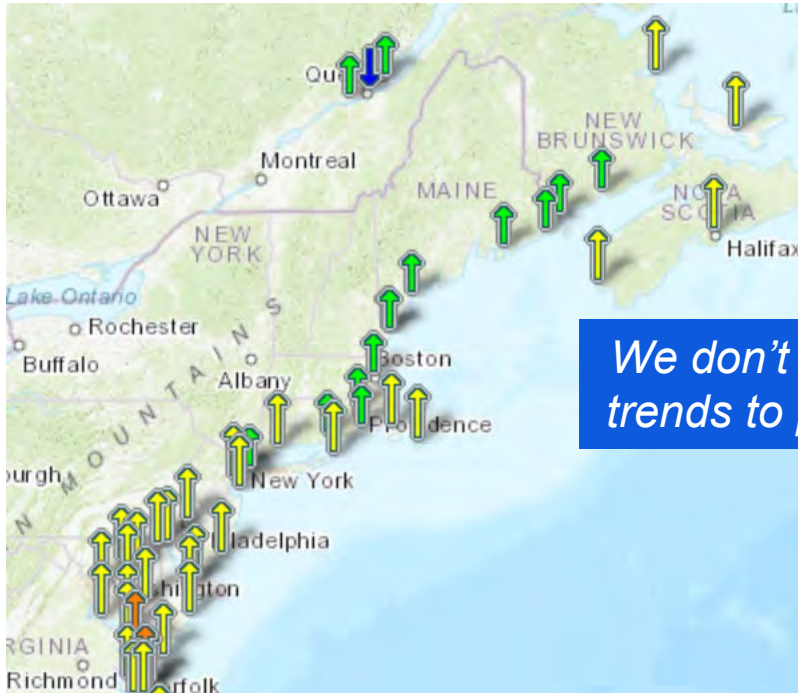
Figure 12. Conceptualization of scenario planning. Scenarios refer to various climate scenarios (e.g., high sea-level rise and low land-use change vs. low sea-level rise and low land-use change). Management strategies are different approaches for achieving a specific planning goal. The colors designate how well a management strategy meets a desired outcome (red = does not meet outcome, yellow = moderately meets the desired outcome, green = meets the desired outcome well). In this conceptualization, Management Strategy 2 would likely be the best investment (indicated by the dashed outline) because while it is not the best (green) under all scenarios, it supports the desired outcome to some level under all future conditions explored.



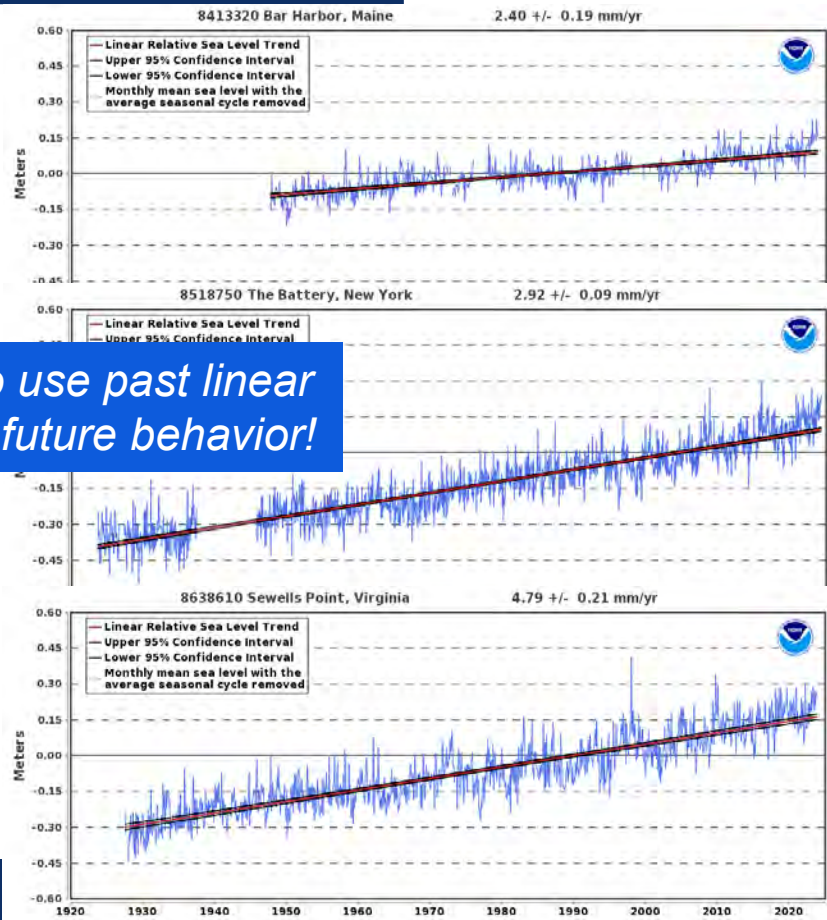
CO-OPS Mean Sea Level Trends



CO-OPS Mean Sea Level Trends

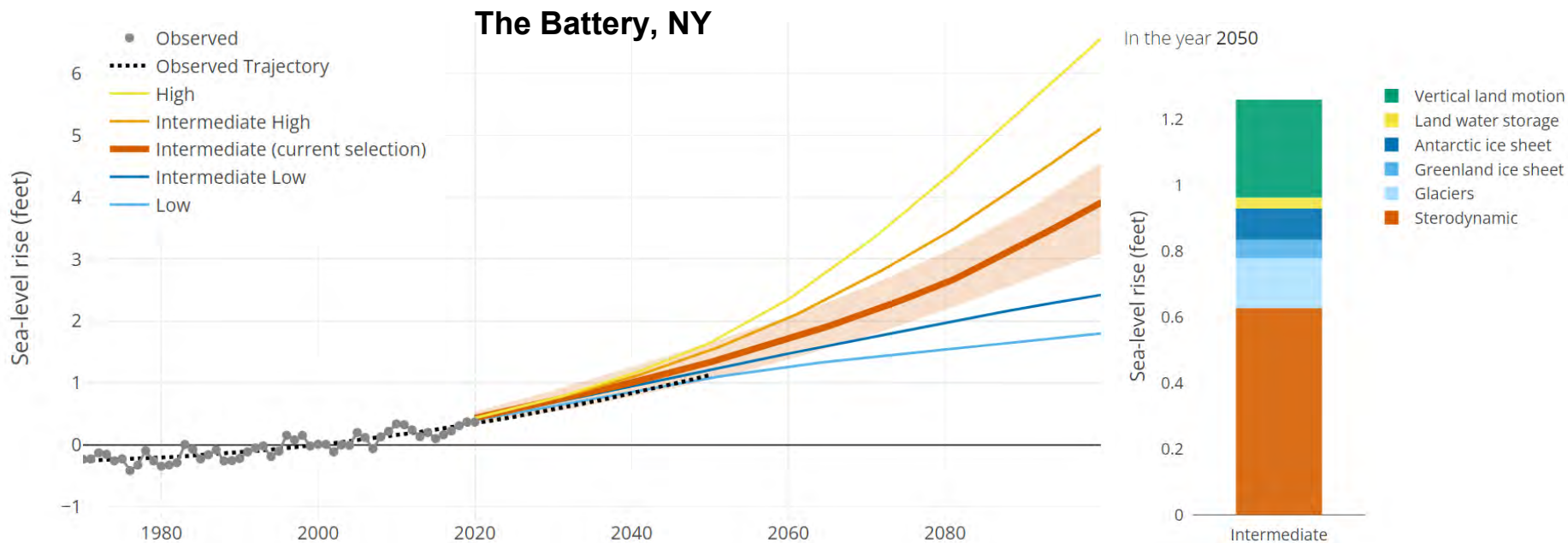


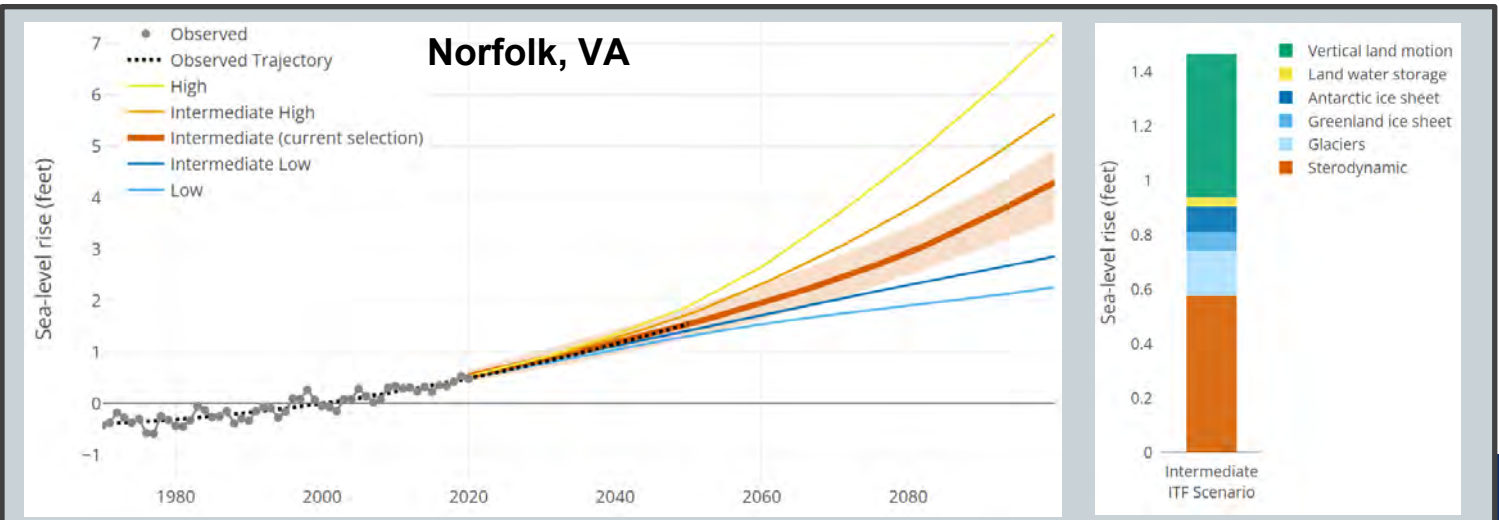
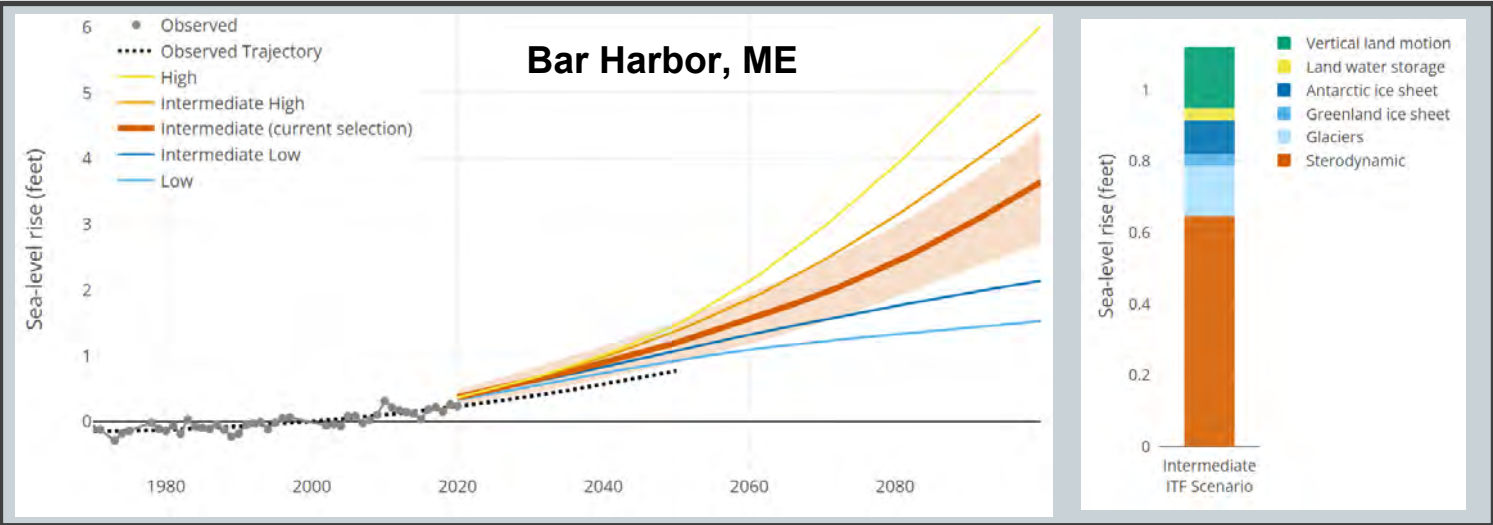
We don't want to use past linear trends to project future behavior!



ITF Mean Sea Level Trends and Projections

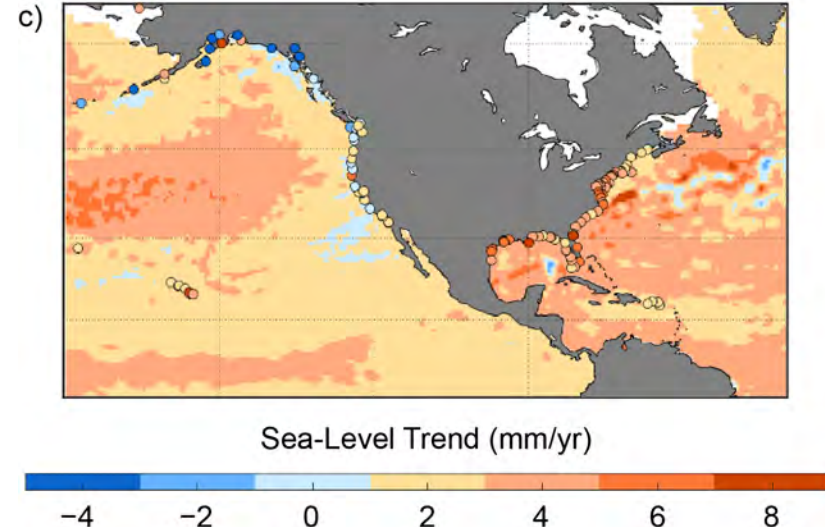
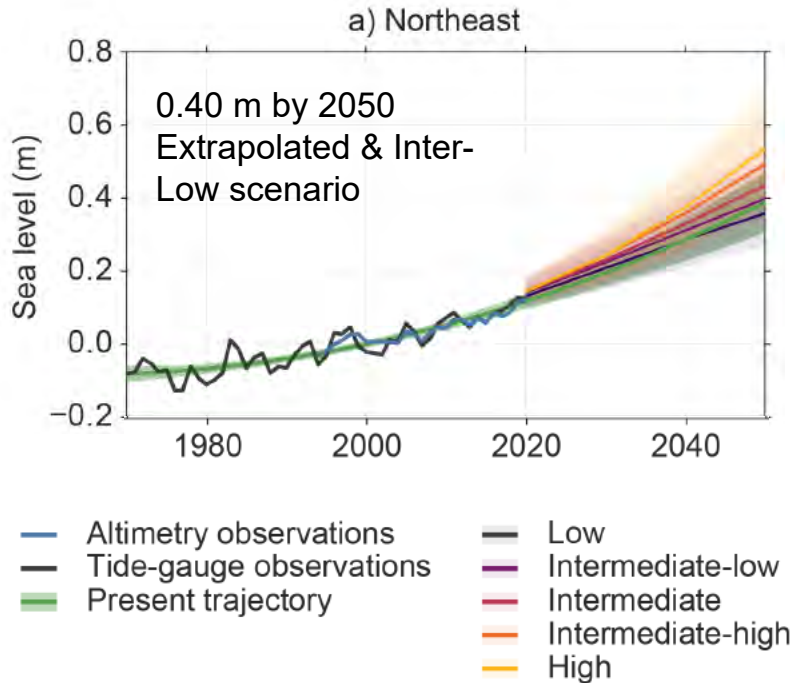
2022 ITF report includes model projections, process contributions, and “observed trajectories” over 1970 – 2020 extrapolated out to 2050, which could be linear or non-linear for each site.





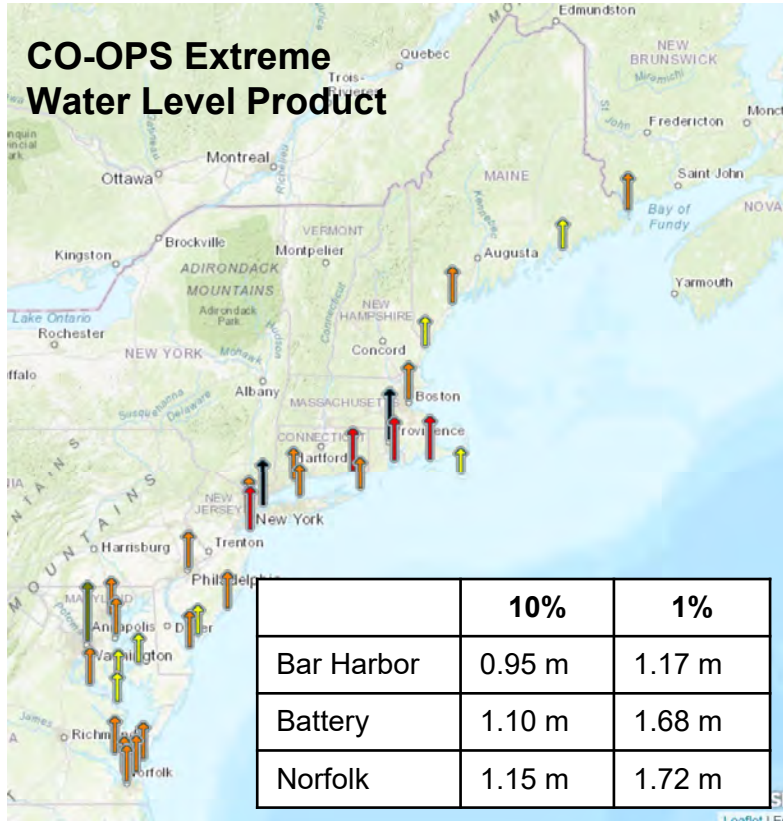
ITF Mean Sea Level Trends and Projections

2022 ITF report includes regional trajectories (ENSO, NAO, PDO climate modes removed) and 1-degree gridded model projections.

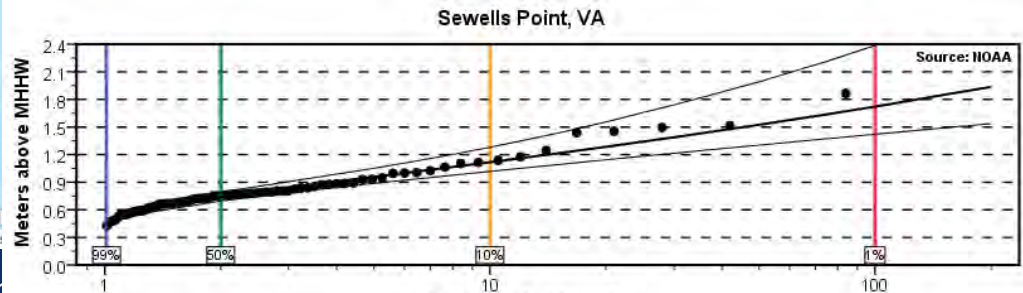
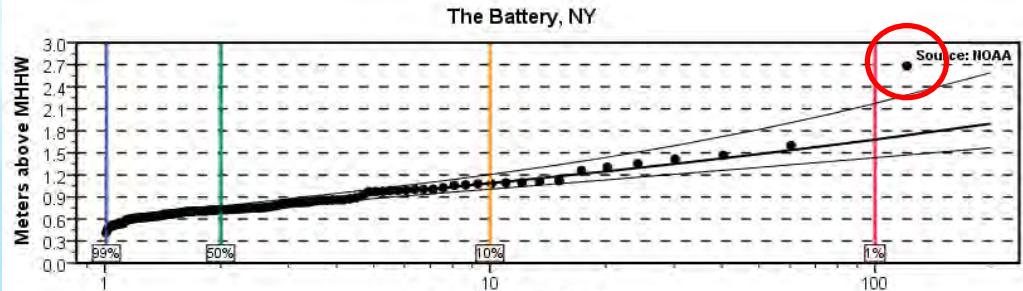
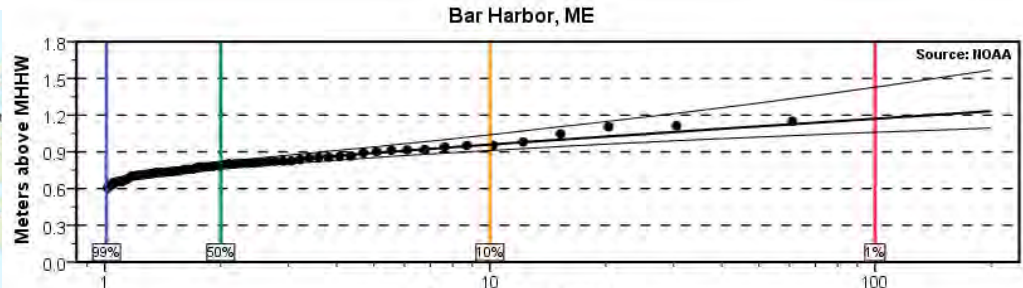


Extreme Sea Levels: Annual Chance Return Levels

CO-OPS Extreme Water Level Product

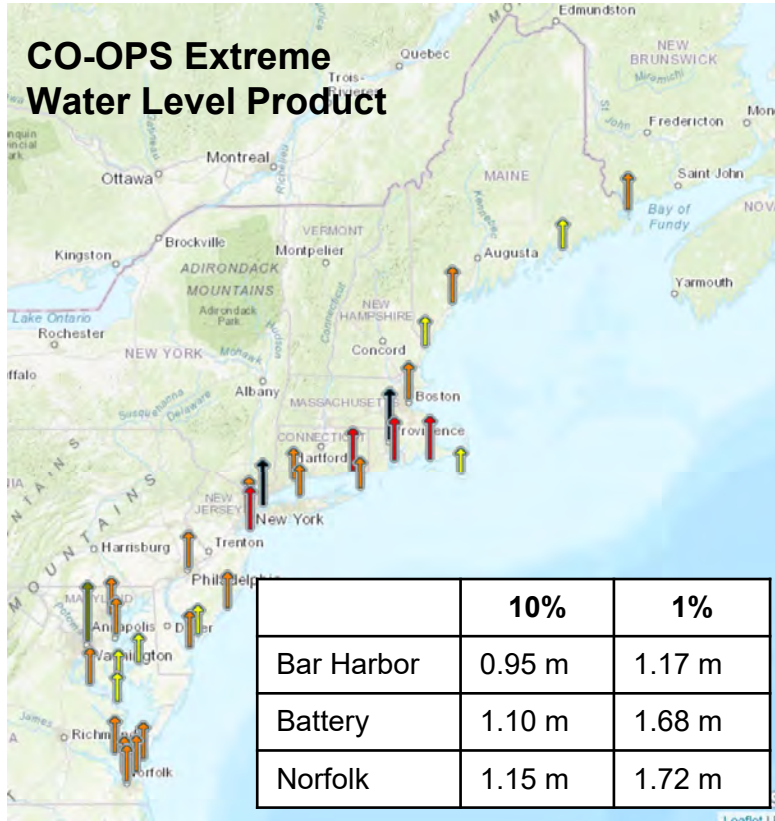


	10%	1%
Bar Harbor	0.95 m	1.17 m
Battery	1.10 m	1.68 m
Norfolk	1.15 m	1.72 m

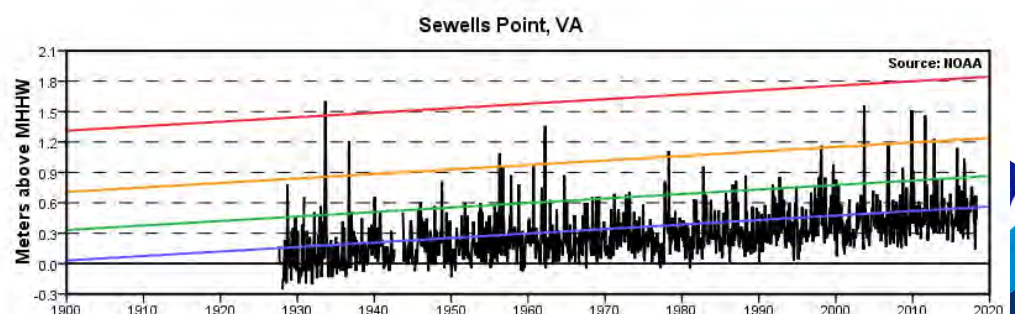
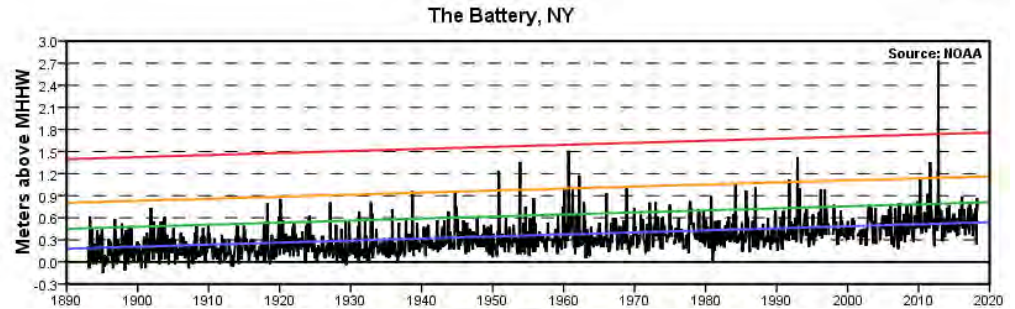
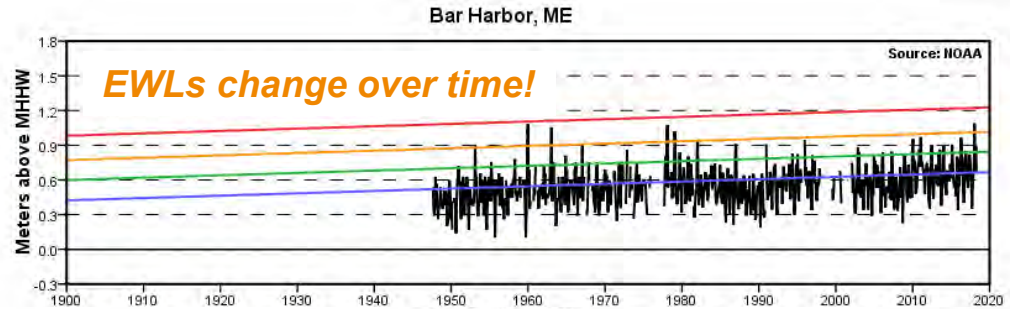


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CO-OPS Extreme Water Level Product

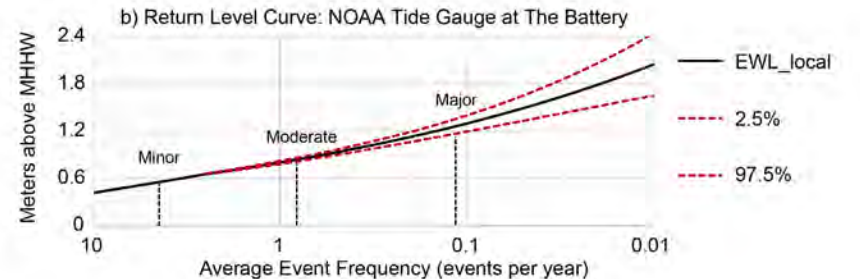
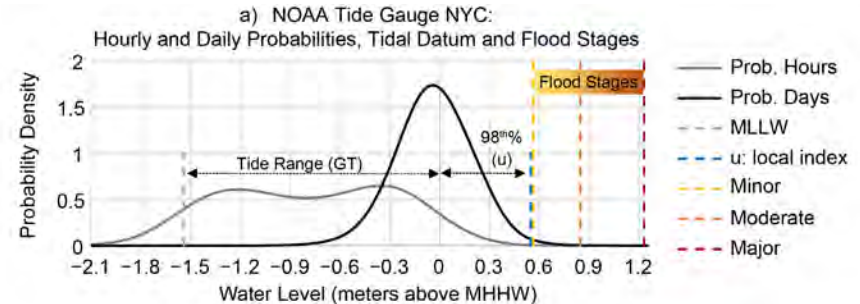


	10%	1%
Bar Harbor	0.95 m	1.17 m
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Extreme Sea Levels: Annual Chance Return Levels

- 2022 ITF report used a Regional Frequency Analysis (RFA) approach.
 - Combined data from multiple (3-10) tide gauges
 - More robust by extending records
- Based on 98th %tile of daily max (GPD/POT)
- 0.01 events/year to 10 events/year frequencies
- Usually RFA results in a bit higher EWLs from CO-OPS method



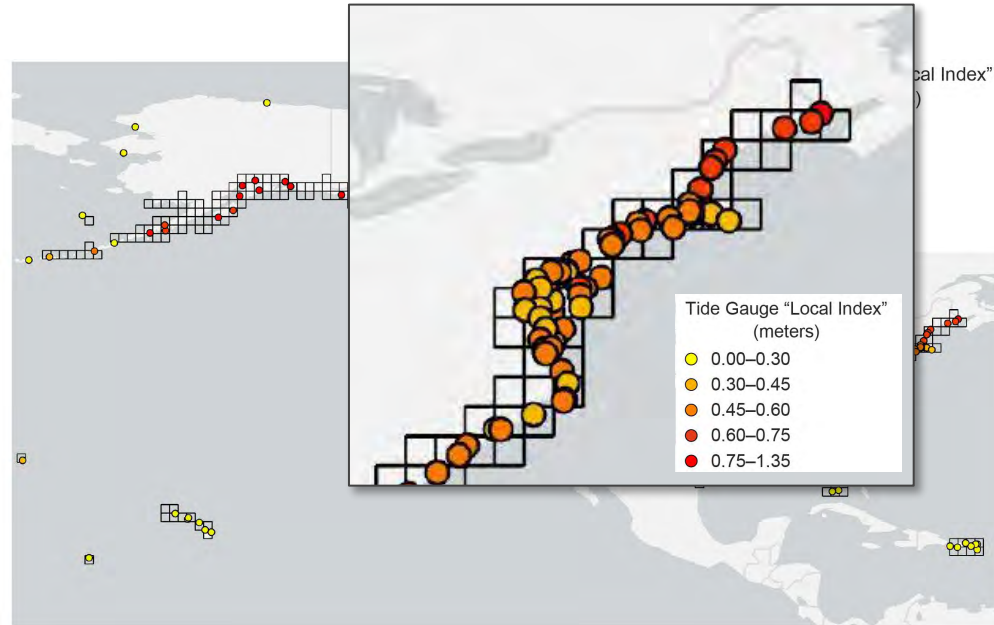
Extreme Sea Levels: Annual Chance Return Levels

- Gridded RFA allows for downscaling to short-term data sites:

$$EWL_{local} = EWL_{gridded} * u_{local} + u_{local}$$

where $u = 98^{th}$ %tile of daily max water level

- Takes advantage of nearby stations with long-term data records.

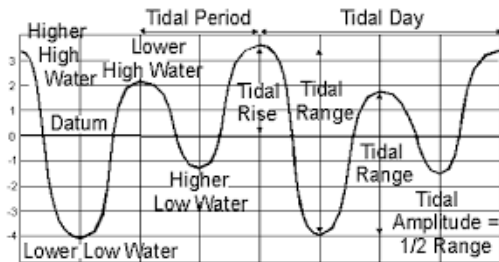


High Tide Flooding

High Tide Flooding (HTF) is defined as the overflow or excess accumulation of ocean water at high tide that covers low-lying areas. *Increasingly common* flood conditions due to SLR, sinking land, and the loss of natural barriers.

Referred to as nuisance, sunny day, or King Tide flooding.

Occurs whroughly about **1 to 2 feet above Mean Higher High Water (MHHW)**.



*Potomac River Flooding on King St
Alexandria, Virginia*







Impacts from flooding is a combination of elevated water levels AND thresholds!

Minor Threshold, shallow flooding, causes disruptions to daily life; can be damaging over time. Can have many “minor” causes.

Moderate – damaging

Major – destructive

Require coastal storm or strong meteorological influence.

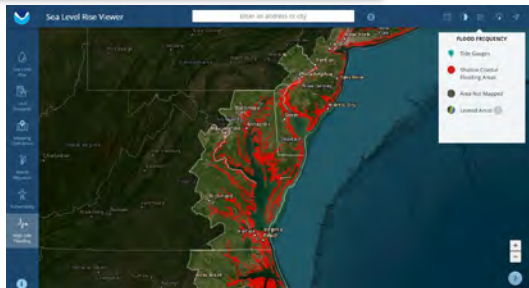
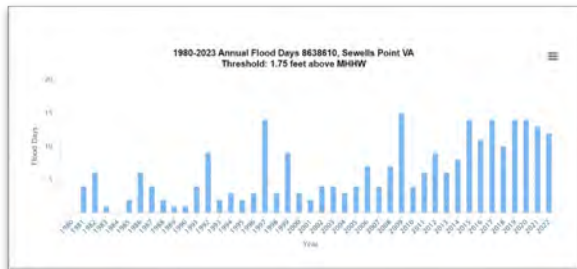
 <h1>Coastal Flooding Thresholds</h1> <p>National Weather Service Wakefield, Virginia</p>			
	Minor	Moderate	Major
Picture			
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Impact	<ul style="list-style-type: none"> ➤ A few shoreline and vulnerable roadways and adjacent properties will experience shallow flooding. ➤ Minor beach erosion with possible erosion to the front of vulnerable dune structures. 	<ul style="list-style-type: none"> ➤ 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. 	<ul style="list-style-type: none"> ➤ 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.



NOAA's Suite of High Tide Flooding Products

Past - Observations

Real-time Monitoring and Historical High Tide Flooding Statistics

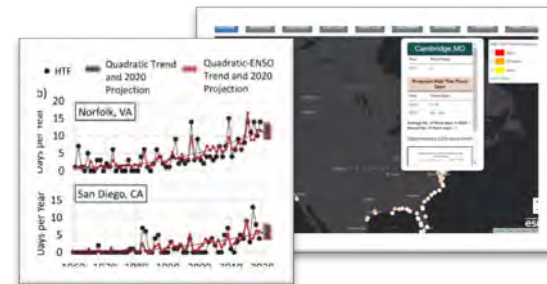


Future - Outlooks

Monthly HTF Outlook



Annual HTF Outlook



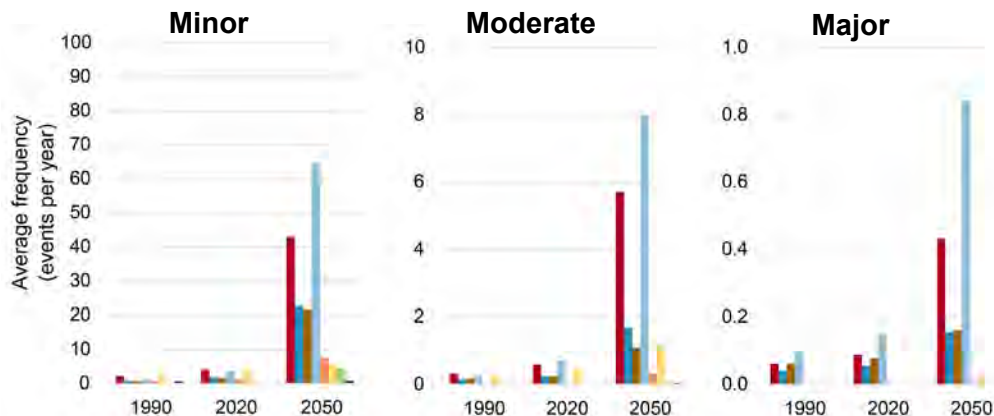
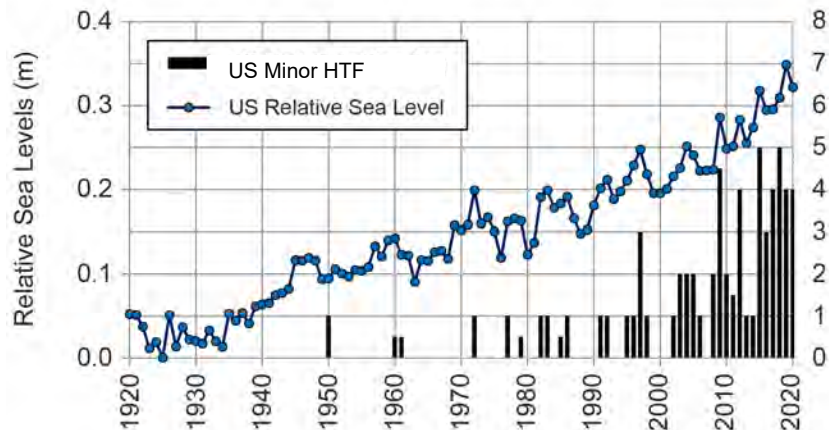
Decadal HTF Outlook



High Tide Flooding

- HTF will occur 5-10 times more often in 2050 than in 2020. Moderate/Major events will occur in 2050 as frequent as minor events do now.

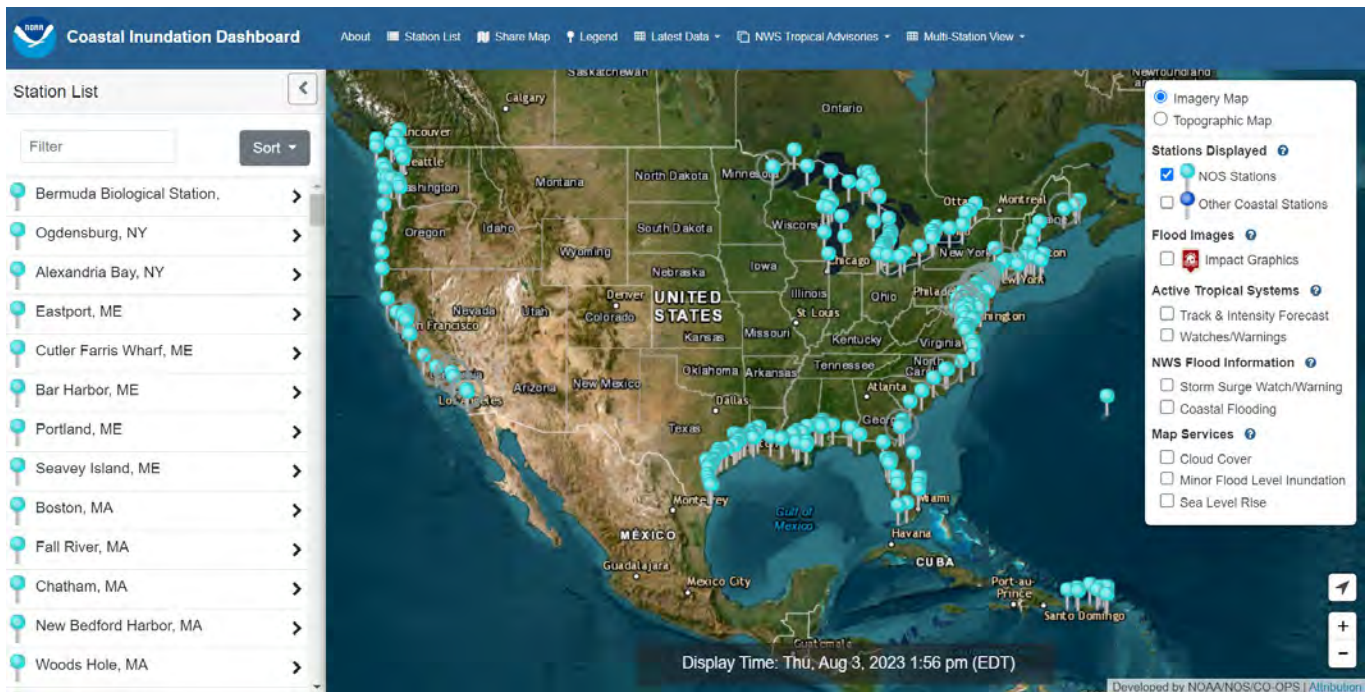
- Northeast and Western Gulf have highest frequency of HTF due to high rates of SLR.



Amount of Sea Level Rise from 1990–2020 and 2020–2050 Under the Intermediate Scenario



Coastal Inundation Dashboard and HTF



Real-time monitoring and historical data at water-level stations across the US.

Inundation History: water levels, HTF frequency, seasonal, extremes, projections...



Coastal Inundation Dashboard and HTF

Coastal Inundation Dashboard

Station List

- Ogdensburg, NY
- Alexandria Bay, NY
- Eastport, ME
- Cutler Farris Wharf, ME
- Bar Harbor, ME
- Portland, ME
- Seavey Island, ME
- Boston, MA
- Fall River, MA
- Chatham, MA
- New Bedford Harbor, MA
- Woods Hole, MA
- Nantucket Island, MA
- Newport, RI
- Conimicut Light, RI
- Providence, RI

Bar Harbor, ME (8413320)
Potential for high tide flooding on 3/9-3/14

NOAA/NOS/CO-OPS
Observed Water Levels at Bar Harbor, ME (8413320)
From 2024/02/27 00:00 LST:LDT to 2024/02/29 23:59 LST:LDT

Height in feet (MHHW)

Major Flooding
Substantial Flooding
Minor Flooding

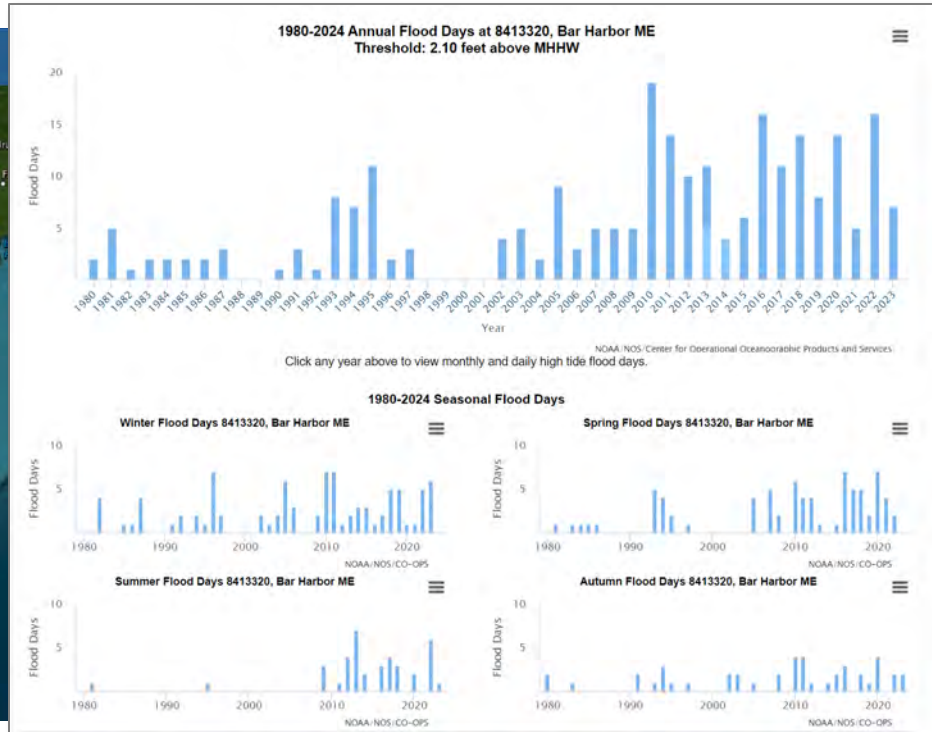
— Predictions — Observed — Forecast Guidance — Observed Water Level

Water Level Units:	Standard	Timezone:	LST:LDT	Datum:	MHHW
Present Water Level			2024-02-28 08:12 PM		-8.97
Latest Wind Speed (kts)			2024-02-28 08:06 PM		21.2
Latest Barometric Pressure (mb)			2024-02-29 08:06 PM		999.2
Next High Tide			2024-02-29 01:19 AM		-8.92
Highest Tomorrow			2024-02-29 00:54 AM		-8.03

* Flood levels displayed above have been established by the National Weather Service local Weather Forecast Office (WFO).

[Inundation History Page](#) [High Tide Flood Outlook](#) [Station Home Page](#)

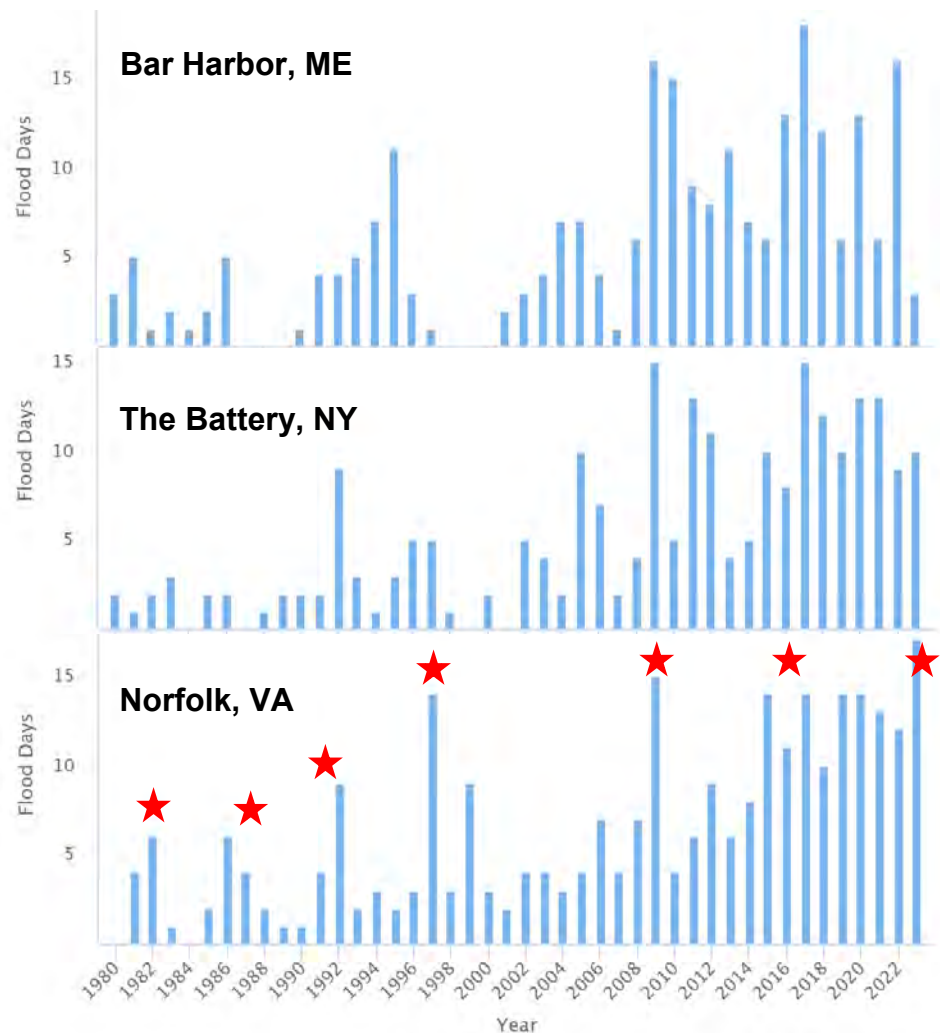
Display Time: Wed, Feb 28, 2024 8:18 pm (EST)



- High interannual variation in frequency of HTF days.

- Primary source of variation, particularly in more Mid-Atlantic stations, is ENSO

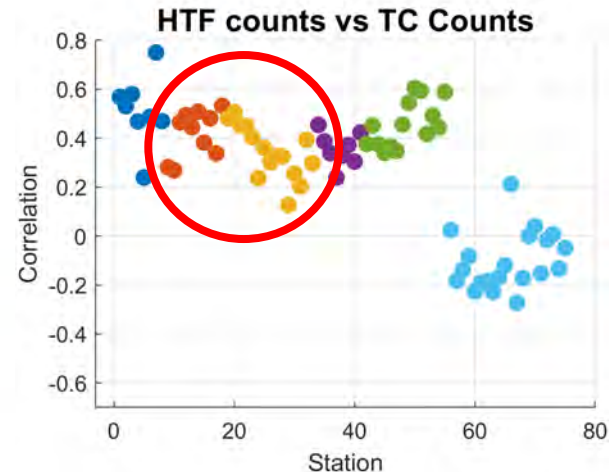
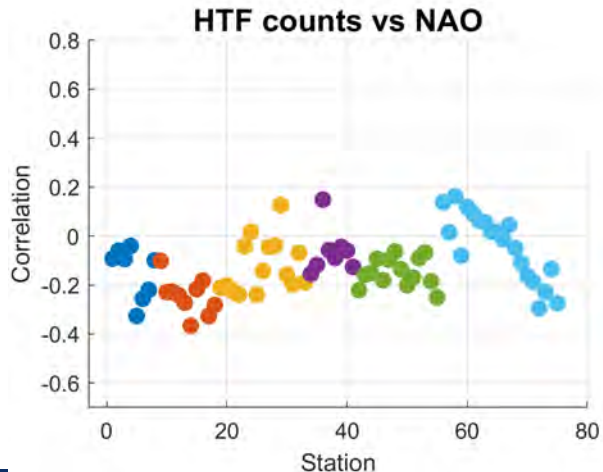
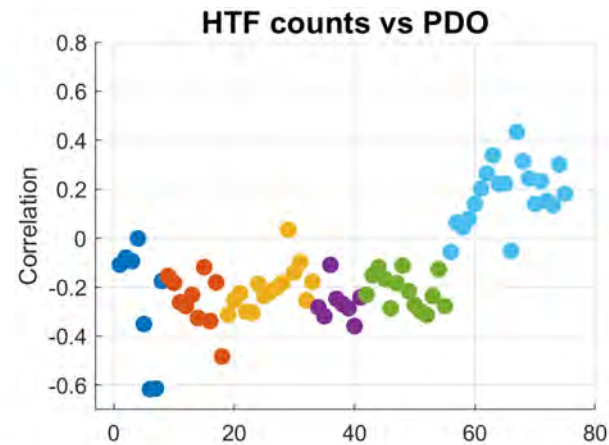
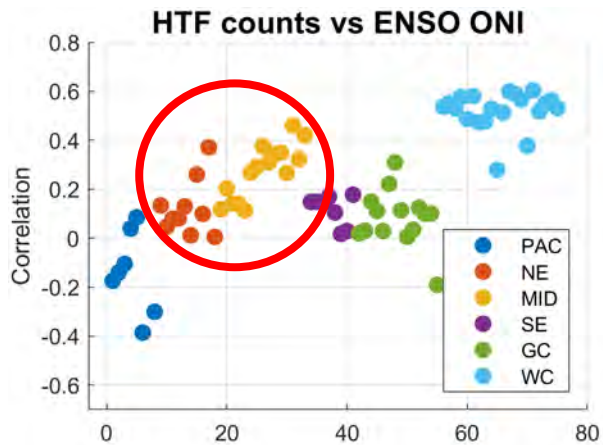
- 1982-83
- 1987-88
- 1991-92
- 1997-98
- 2009-10
- 2015-16
- 2023-24



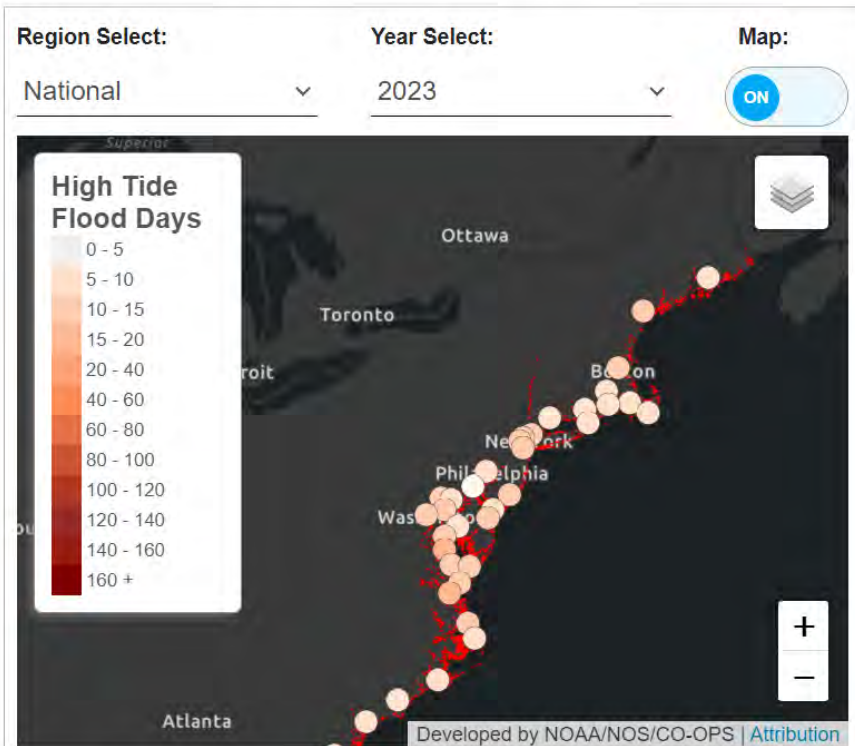
Pearson Correlation of HTF counts to climate

ENSO: MID and West Coast have positive correlation with ENSO. NE is mixed.

Tropical Cyclone counts: Mostly positive correlation, except WC.



Annual High Tide Flooding Outlook



A map showing the number of high tide flooding days at [National Water Level Observation Network](#) stations observed or projected for the selected year. Flooding thresholds are supplied by NOAA's Office for Coastal Management.

Region Station About

About the Annual Outlook

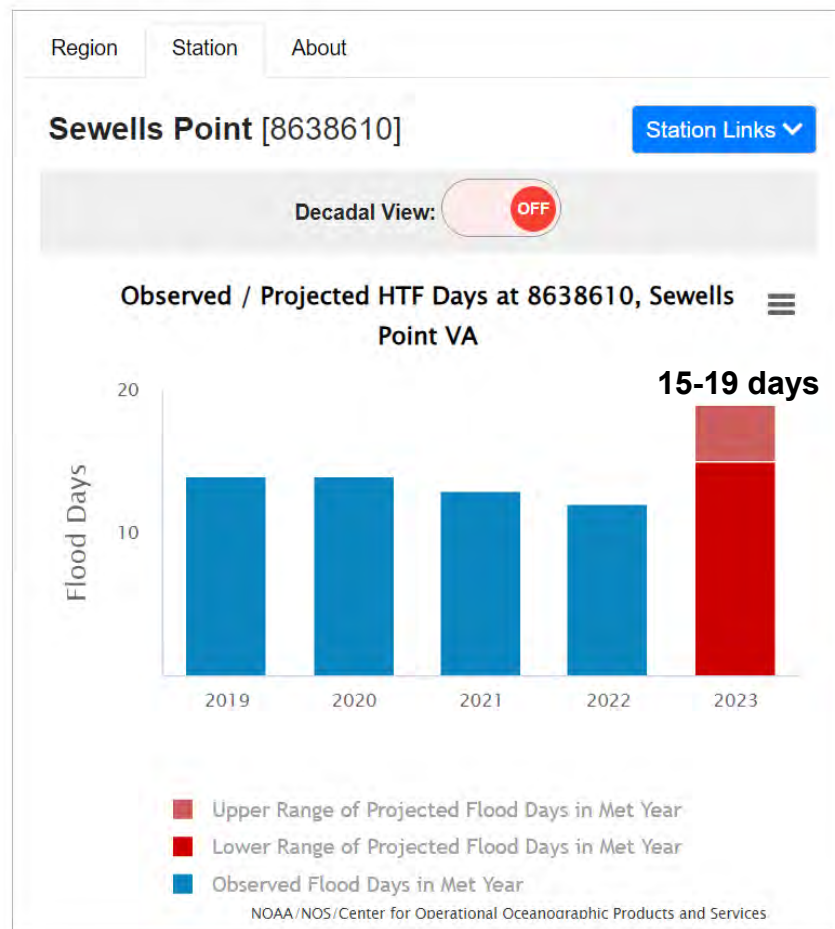
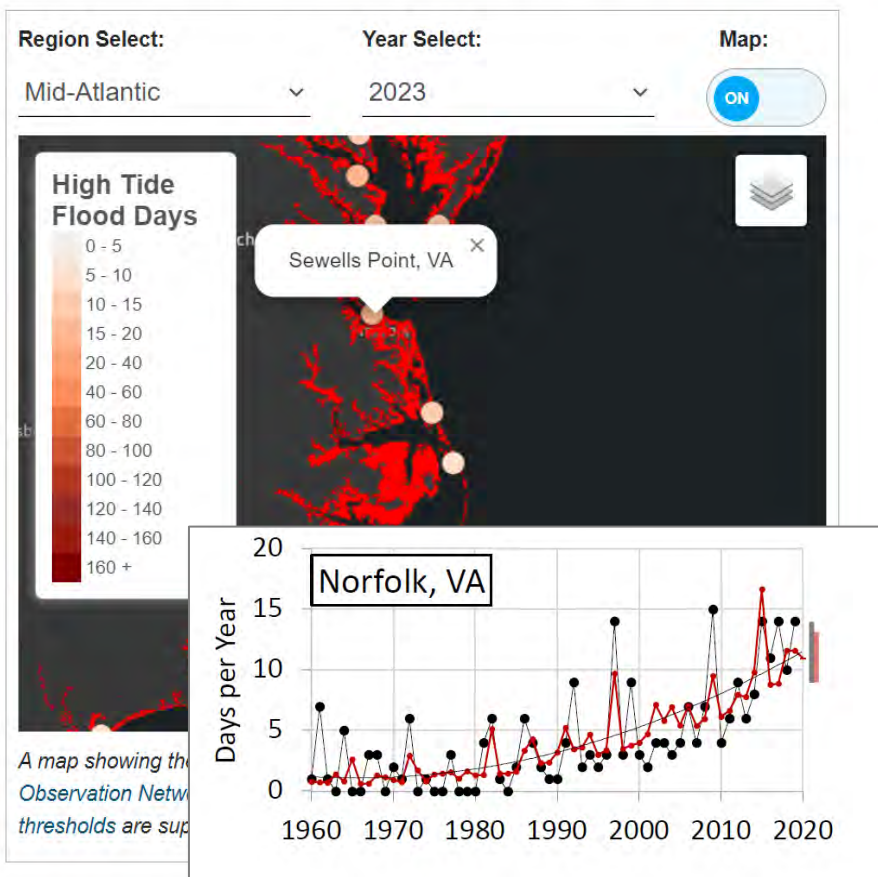
Above-normal tides can trigger high tide flooding, disrupting coastal communities. This flooding can occur on sunny days and in the absence of storms. More severe flooding may occur if high tides coincide with heavy rains, strong winds, or large waves. As sea levels continue to rise, our coastal communities will experience more frequent high tide flooding - a National average of 45 to 85 days per year by 2050. Predicting the frequency of high tide flooding in the future helps coastal communities plan for and mitigate flooding impacts.

The Annual High Tide Flooding Outlook provides the number of high tide flooding days predicted for the coming meteorological year (May to April). Data is supplemented with decadal projections for the year 2050, sea level rise scenarios, and high tide flood exposure maps to support long-term coastal planning. Summaries are provided for each region to account for geographical differences at the coast, and are accompanied by regional graphics to demonstrate potential high tide flooding impacts.

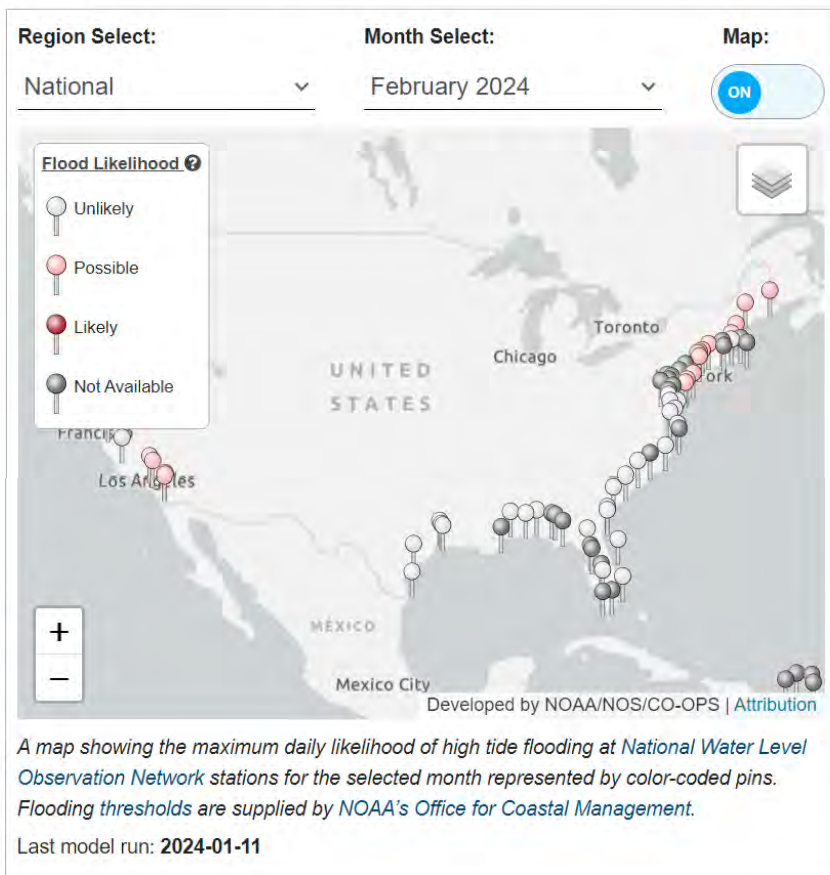
Using This Product

Begin by selecting a region and year from the drop down menu, or clicking a station on the map to see the number of observed and projected high tide flooding days. Click the region tab to learn more about regional drivers of higher water levels and potential high tide flooding impacts.

Annual High Tide Flooding Outlook



Monthly High Tide Flooding Outlook



Region | Station | About

About the Monthly Outlook

Above-normal tides can trigger high tide flooding, disrupting coastal communities. This flooding can occur on sunny days and in the absence of storms. More severe flooding may occur if high tides coincide with heavy rains, strong winds, or large waves. As sea levels continue to rise, our coastal communities will experience more frequent high tide flooding - about 45-85 days/year on average nationally by 2050. Predicting the likelihood of high tide flooding helps coastal communities plan for and mitigate impacts.

The Monthly High Tide Flooding Outlook shows when and where above-normal high tides and high tide flooding may be experienced. This model does not account for real-time weather conditions. In the event of severe weather, coastal flooding may still occur outside of dates identified in this product. To monitor water levels in real-time and track storms, visit our [Coastal Inundation Dashboard](#).

Using This Product

To get started, select a region from the drop-down menu or click a station pin on the map to see high tide flooding information for the selected month and year. Click the region tab to learn more about regional drivers and impacts of high tide flooding or the station tab to view daily flooding likelihoods.

- Map View:** Visualize where high tide flooding is predicted to occur at NOS water level stations in the selected month (default is the current month). Navigate the map by selecting a region from the drop-down menu or using the pan/zoom tools. Stations are represented by pins color-coded to show flooding likelihoods:
 - White - unlikely (0-5%)
 - Light red - possible (5-50%)



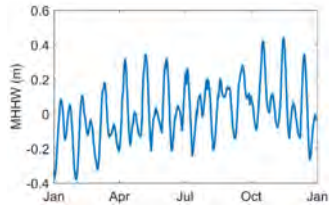
HTF Monthly Outlook

A novel statistical approach to predict seasonal high tide flooding

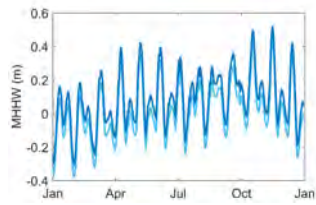


Gregory Dusek^{1*}, William V. Sweet¹, Matthew J. Widlansky², Philip R. Thompson^{2,3} and John J. Marra⁴

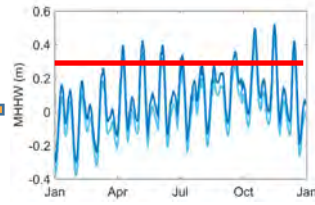
Daily likelihoods (probability of threshold exceedance) is computed for each day for the next 12 months.



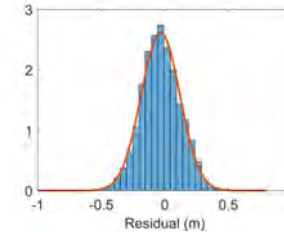
Tide Predictions



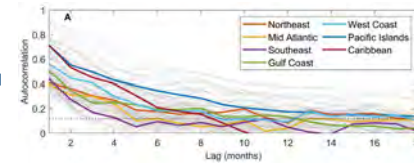
SLR



Relative to minor flood threshold



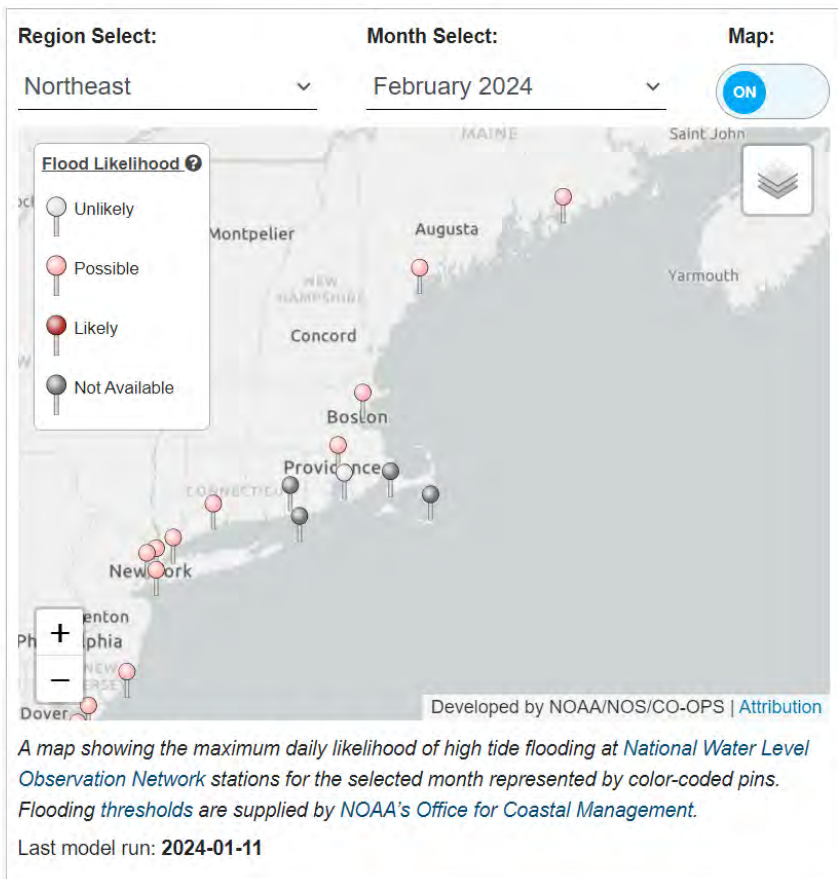
Monthly distribution of non-tidal residual



Previous month sea level anomaly



Monthly High Tide Flooding Outlook



Region Station About

Northeast

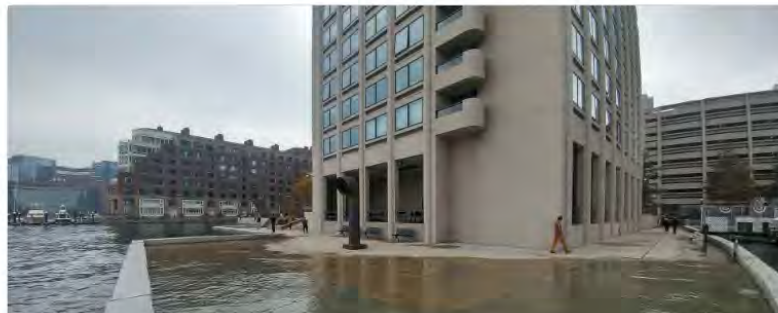
Why Will The Tide Be Higher Than Normal?

Expect higher tides on and around the dates of the new moon and full moon (known as spring tides). A new moon will occur on February 09, and a full moon will occur on February 24 (ET). Higher than normal high tides and lower than normal low tides will occur around the perigean spring tide, when the Moon is new and closest to Earth.

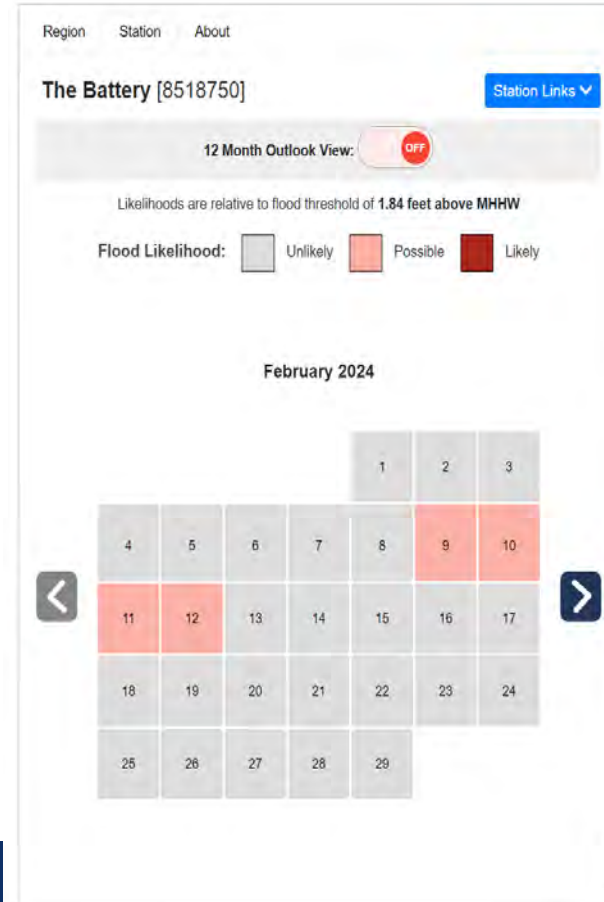
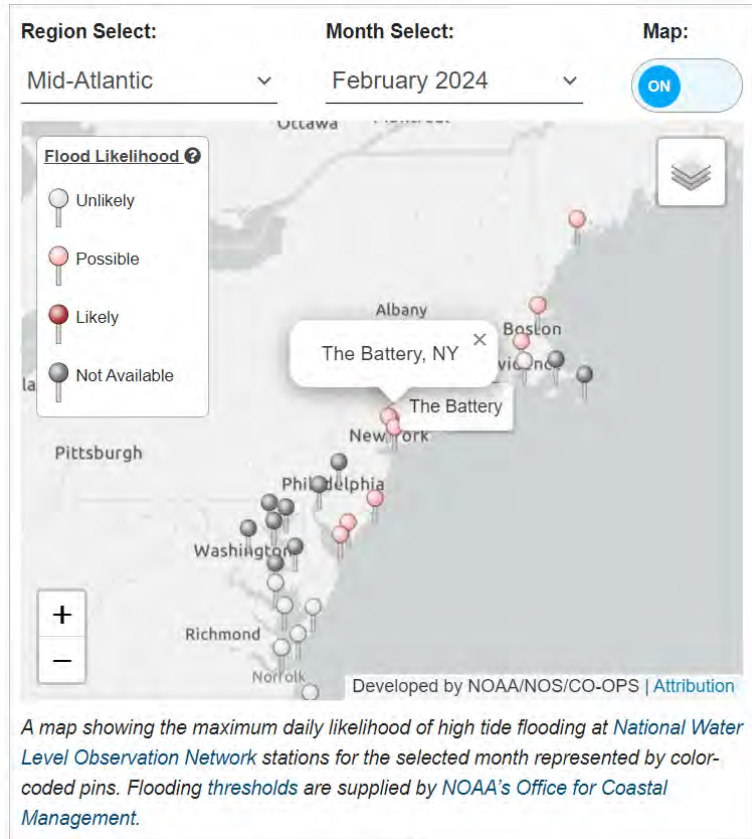
What kind of impact might I expect along the coast?

Low lying areas may flood, however high tides alone will likely not cause a significant impact on the coast in most areas unless accompanied by a storm or strong winds. Lower than normal low tides will also occur.

Visit the [NOAA Coastal Inundation Dashboard](#) for this region to view real-time water levels with forecasts out to 48 hours

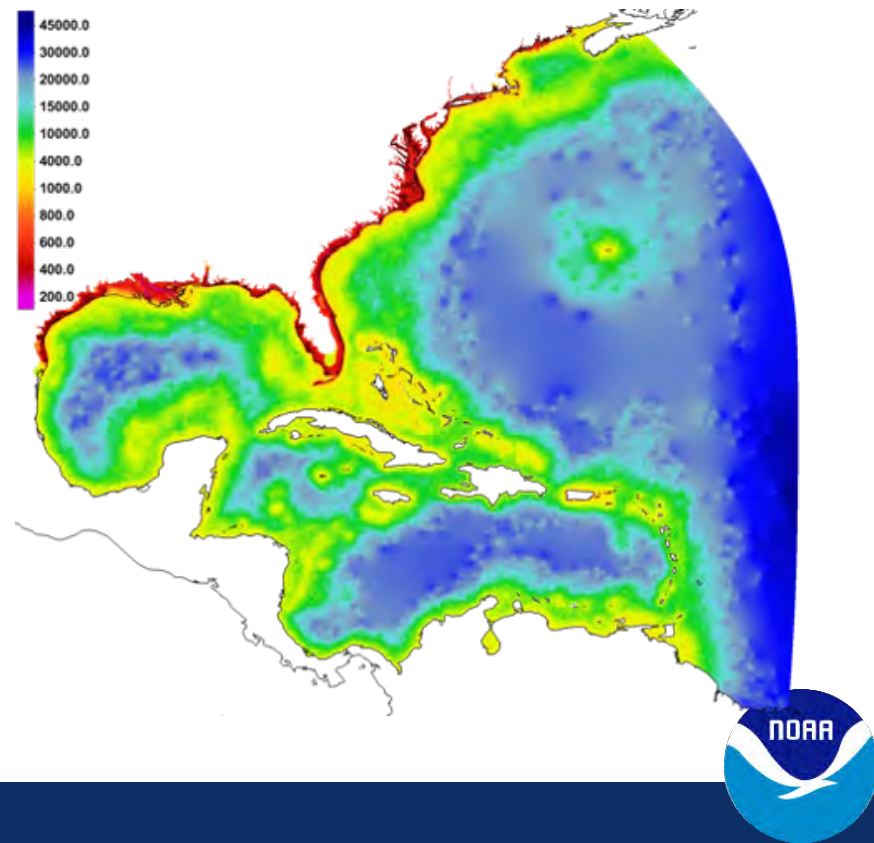


HTF Monthly Outlook

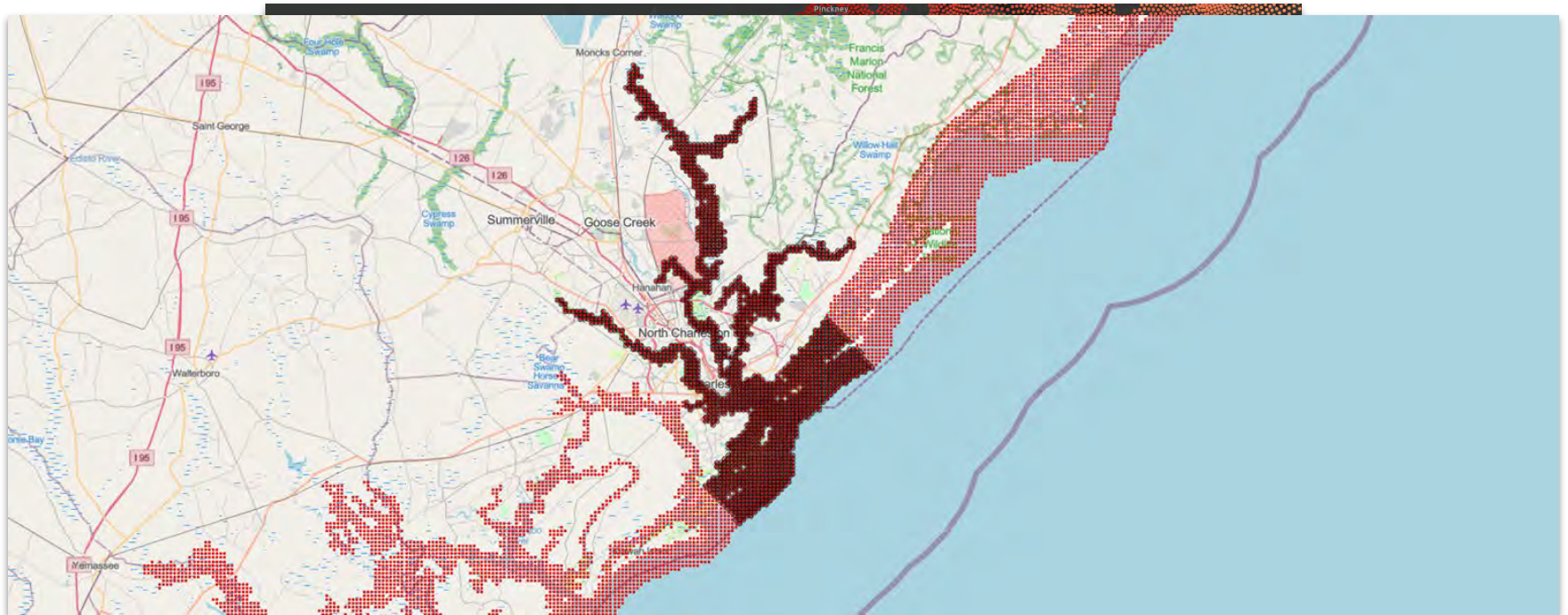


New Product: Coastal Ocean Reanalysis (CORA)

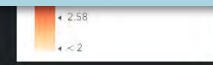
- Water level and wave reanalysis for 1979 – present (~43 years) every 500m along the entire US coastline.
- Forced by ERA5 (atmosphere) and coupled ADCIRC (surge+tides) and SWAN (waves) modeling.
- Data assimilation from NOAA tide gauges.
- US East and Gulf Coast version 1 complete.



New Product: Coastal Ocean Reanalysis (CORA)

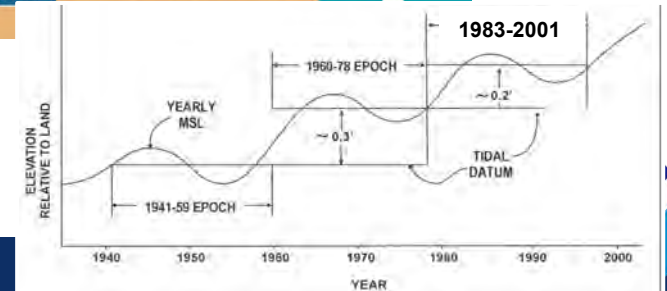
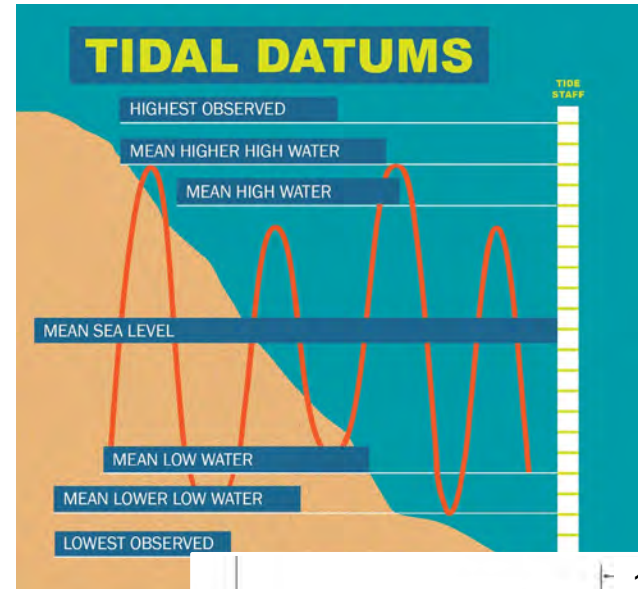


Southeast US
pilot region



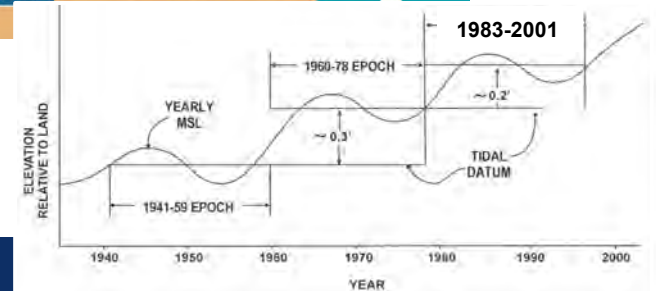
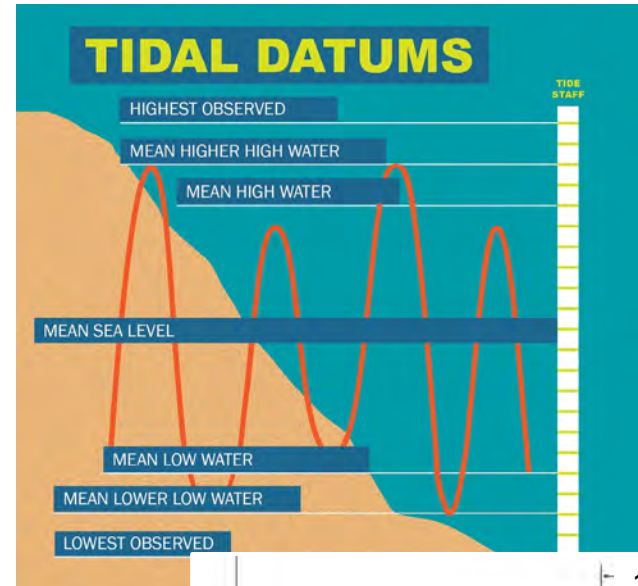
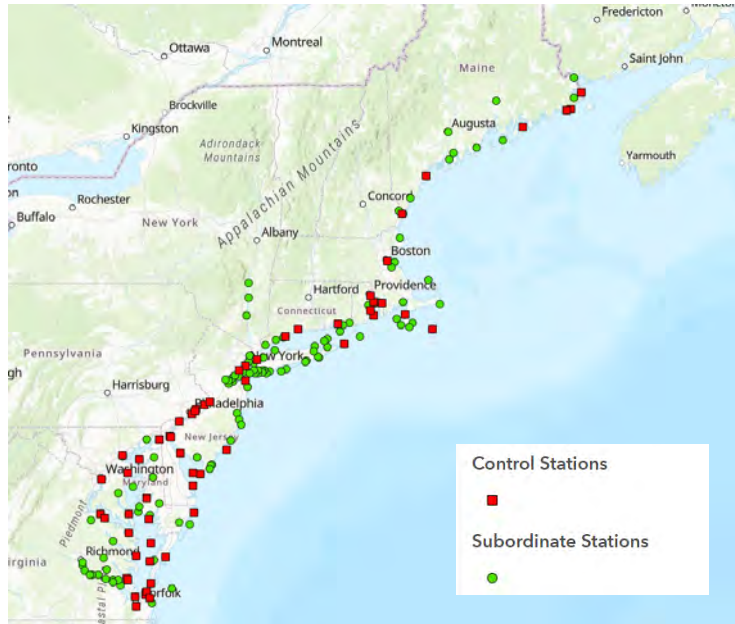
New Product: Tidal Datum Update

- National Tidal Datum Epoch (NTDE)
- Updating from 1983-2001 to 2002-2020
 - Increases at nearly all stations
- All products will need to take new datums into account:
 - Tidal predictions, navigation
 - Real-time water level monitoring
 - SLR projections
 - EWLs (above MHHW)
 - HTF thresholds
 - NWS warnings/advisories



New Product: Tidal Datum Update

- National Tidal Datum Epoch (NTDE)
- Updating from 1983-2001 to 2002-2020
 - Increases at nearly all stations



New-ish Product: CO-OPS APIs



TIDES &
CURRENTS

CO-OPS API URL Builder

This application builds a URL based off of inputed parameters that links to our various APIs. It can be used to make a link that returns data. Select one of the following to begin.

Data API

The Data API can be used to retrieve observations and predictions originating from CO-OPS stations based on date and time.

[Documentation](#)

MetaData API

The MetaData API (MDAPI) can be used to retrieve information about CO-OPS' stations. It can return information for a specific station, or multiple stations.

[Documentation](#)

Derived Product API

The Derived Product API (DPAPI) contains data that is derived from historical data.

[Documentation](#)



New-ish Product: CO-OPS APIs

Product Type: ? Sea Level Trends

Station: ?

Output Format:

Affiliation: ?

The URL on the right will automatically update based on the above fields

*Note that some fields are unavailable if left blank or unspecified.

*Some expand options are not available for certain requests

Products

- Top Ten Water Levels
- Yearly Inundation Statistics
- Extreme Water Levels
- Sea Level Trends**
- Sea Level Rise Projections
- Event Peak Water Levels

HTF (High Tide Flooding)

- HTF - Daily Flood Count
- HTF - Monthly Flood Count
- HTF - Seasonal Flood Count
- HTF - Annual Flood Count
- HTF - Met Year Flood Count
- HTF - Next Met Year Annual Outlook
- HTF - Decadal Projections Per Scenario
- HTF - Record Days and Typical HTF Days in 2000
- HTF - Daily Likelihoods
- HTF - Monthly Maximum Likelihoods

URL Generator Box

api.tidesandcurrents.noaa.gov/dpapi/product/sealvtrends.json?affil=us

Valid URL

Clear URL List Copy URL Submit URL

```
{
  "count": 1,
  "SeaLvlTrends": [
    {
      "stationId": "8518750",
      "stationName": "The Battery, NY",
      "affil": "US",
      "latitude": 40.700556,
      "longitude": -74.014167,
      "trend": 2.92,
      "trendError": 0.04,
      "units": "mm/yr",
      "startDate": "01/15/1856",
      "endDate": "12/15/2023"
    }
  ]
}
```

Web site owner: [Center for Operational Oceanographic Products and Services](#)
Questions or feedback? Contact us at co-ops.userservices@noaa.gov



Summary of Resources

- [Sea Level Trends](#)
- [Extreme Water Levels](#)
- [High Tide Flooding Annual Outlook](#)
- [High Tide Flooding Monthly Outlook](#)
- [CO-OPS API URL Generator](#)

- [Coastal Inundation at Climate Timescales Whitepaper](#)
- [2022 US Interagency SLR Technical Report](#)
- [NASA Flood Analysis Tool](#)
- [NOAA Sea Level Viewer](#)
- [NCA5 Coastal Effects Chapter](#)



Questions?

Thank you!

Contact:

john.callahan@noaa.gov



<https://tidesandcurrents.noaa.gov/>

