2024 Coastal Inundation Community of Practice Workshop

SECTION A

November 13, 2024

8:30 am to 3:30 pm

American Society of Adaptation Professionals

Sea Grant

Lightning Talks:

Inundation Modeling

Road Flooding in Coastal Connecticut,
Jim O'Donnell,
Connecticut Institute for Resilience & Climate Adaptation (CIRCA)

NOAA's National Water Model (NWM),
Trey Flowers & Brian Cosgrove,
NOAA NWS Office of Water Prediction

Tsunami Inundation Modeling & Forecasting,
Ernesto Guerrero-Fernandez & Yong Wei,
NOAA Pacific Marine Environmental Laboratory (PMEL) & University of Washington

The Role of Marsh Area and Volume in Coastal Flood Protection

James O'Donnell[1,2], Alejandro Cifuentes-Lorenzen[1,2], and Michael M. Whitney[1],
[1]Department of Marine Sciences, University of Connecticut, Groton, CT 06340
[2]Connecticut Institute for Resilience and Climate Adaptation, University. of Connecticut, Groton, CT 06340

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CONNECTICUT ENERGY ENVIRONMENT

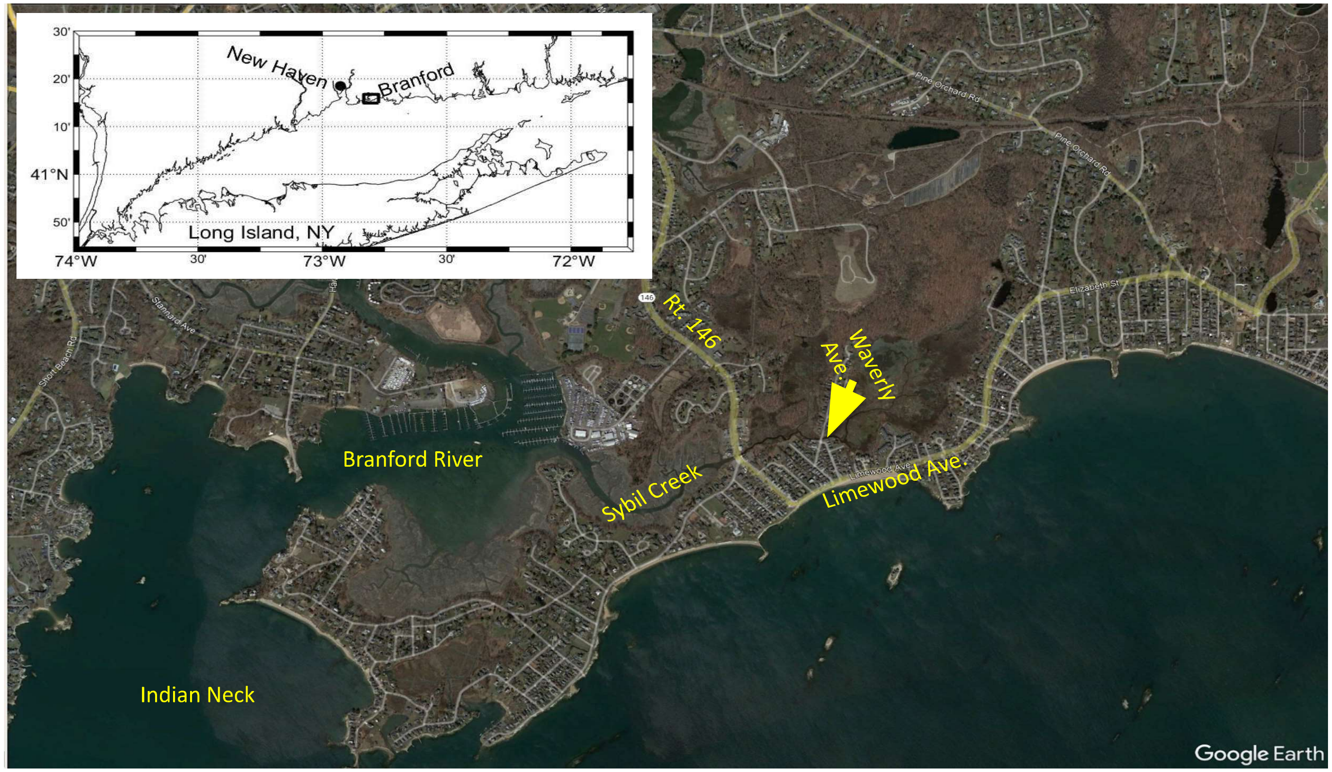
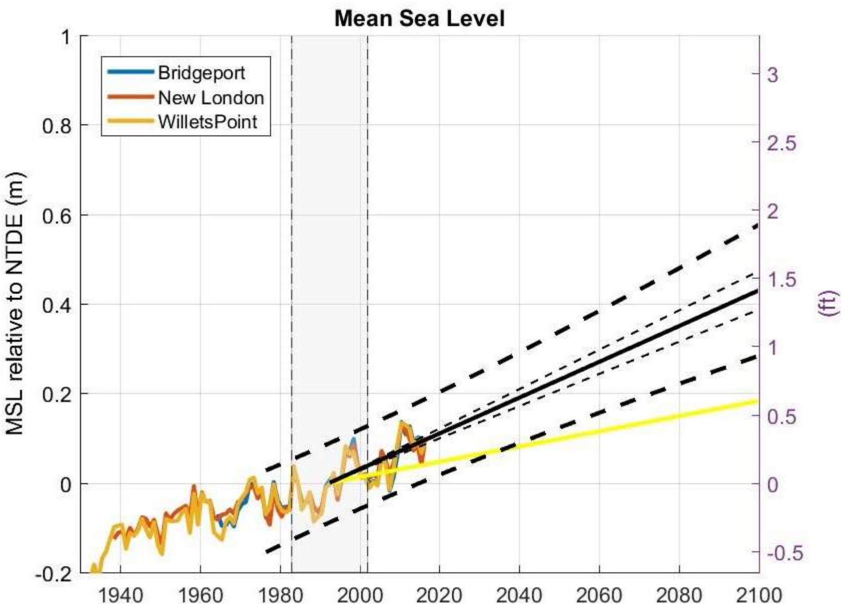


Figure 2. The inset map on the upper left shows the coastline of Long Island Sound and the location of Branford,CT. The small rectangle identifies the area shown in the GoogleEarth© the aerial photograph. The road highlighted in yellow is Rt 146.

Summary of Results



Year	Mean (m)	Upper 95% (m)	NOAA (m)	Mean (ft)	Upper 95% (ft)	NOAA (ft)
2020	0.15	0.25	0.06	0.5	0.81	0.21
2030	0.19	0.29	0.08	0.63	0.96	0.27
2040	0.23	0.34	0.10	0.76	1.11	0.32
2050	0.27	0.39	0.12	0.89	1.27	0.38
2070	0.31	0.43	0.13	1.02	1.42	0.43
2080	0.35	0.48	0.15	1.15	1.58	0.49
2090	0.39	0.53	0.17	1.29	1.74	0.55
2100	0.43	0.58	0.18	1.42	1.9	0.60

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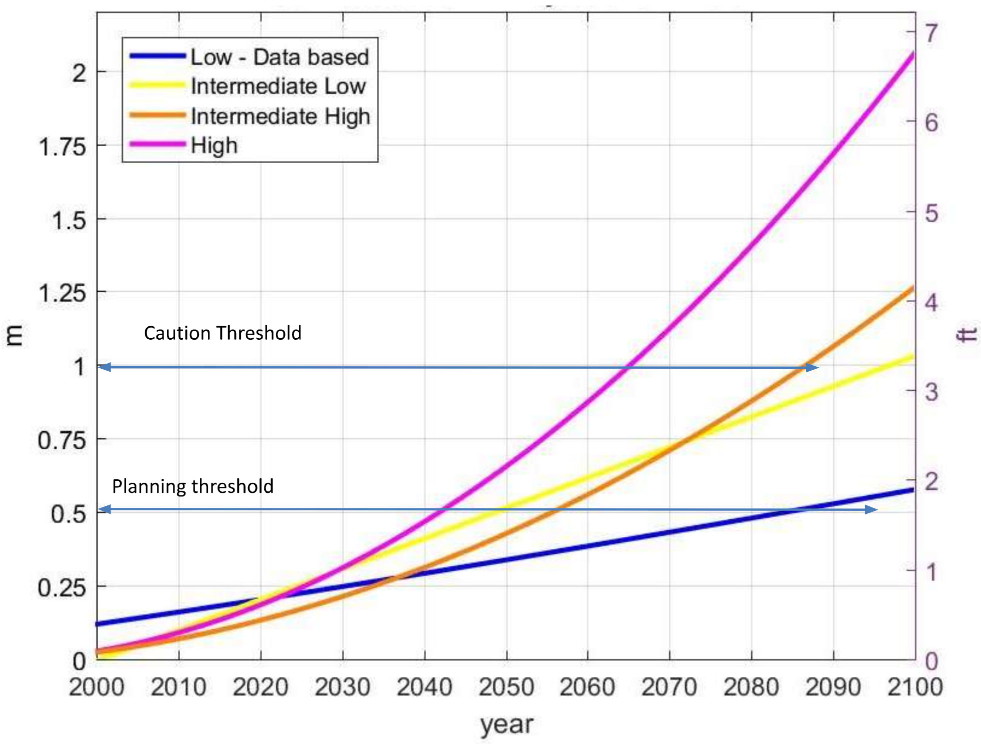

1. The glacial history of CT has created broad areas of flat, sandy-gravel coastal plains (relic deltas).

2. The northwest Atlantic will likely experience more sea level rise than the rest of the oceans and the uncertainty in predictions is among the largest as well.

3. CT should plan for UP TO 50 cm (20 inches) increase by 2050.

4. That is the consensus of prediction of the upper bound in global models at 2050. At 2100 that a a conservative estimate.

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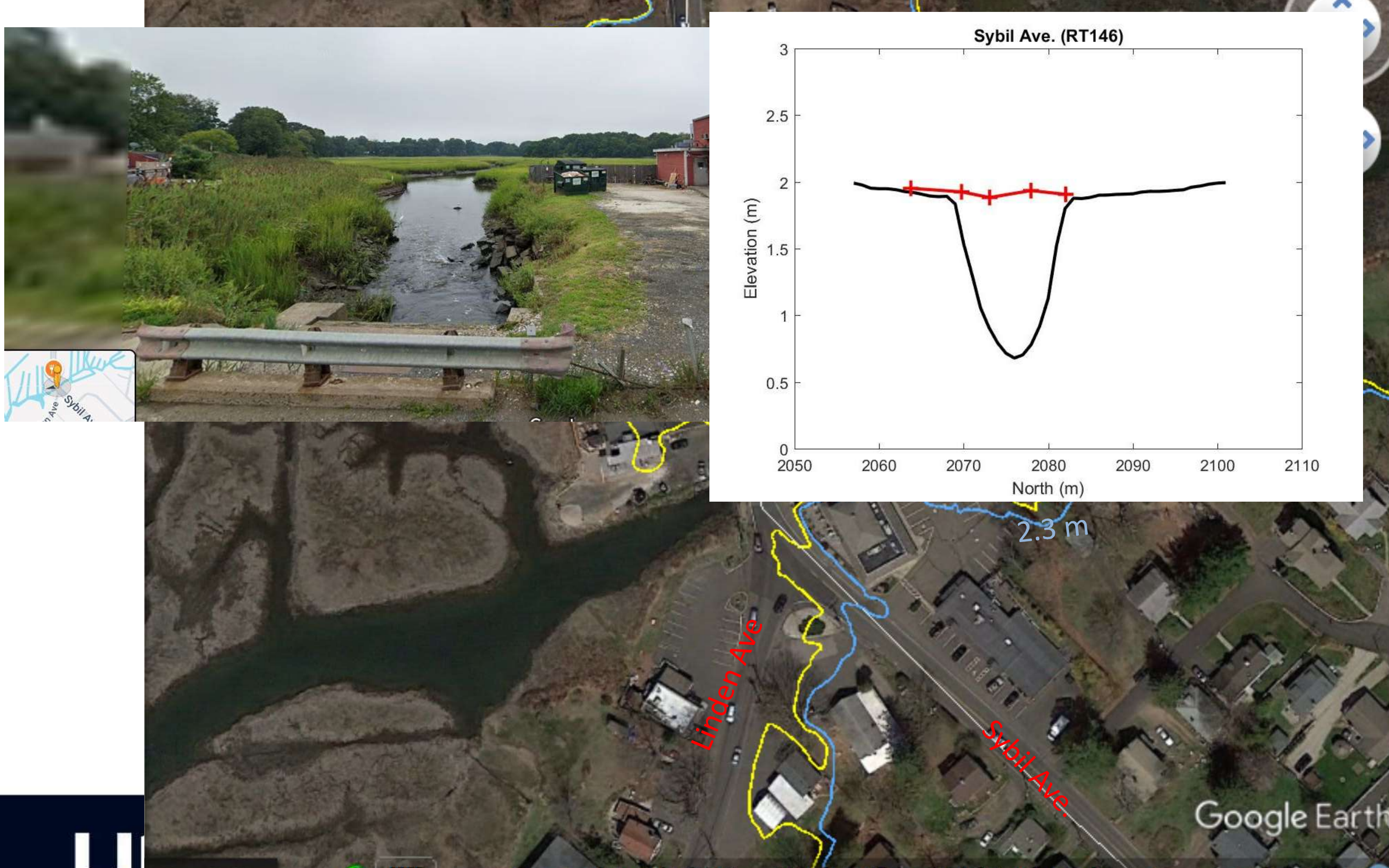
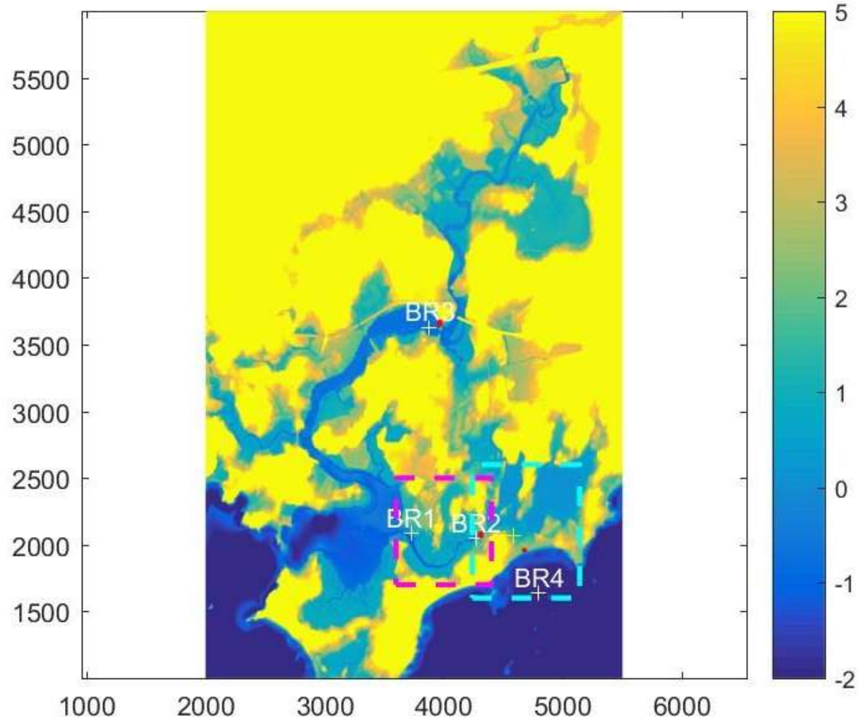

Sybil Ave. (RT146)
Elevation (m)
North (m)
0
0.5
1
1.5
2
2.5
3
2050
2060
2070
2080
2090
2100
2110
2.3 m
Linden Ave
Sybil Ave.
Google Earth



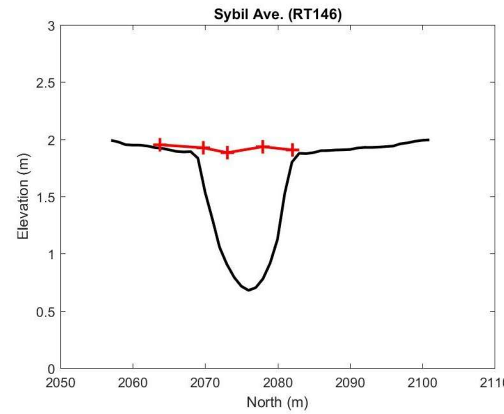
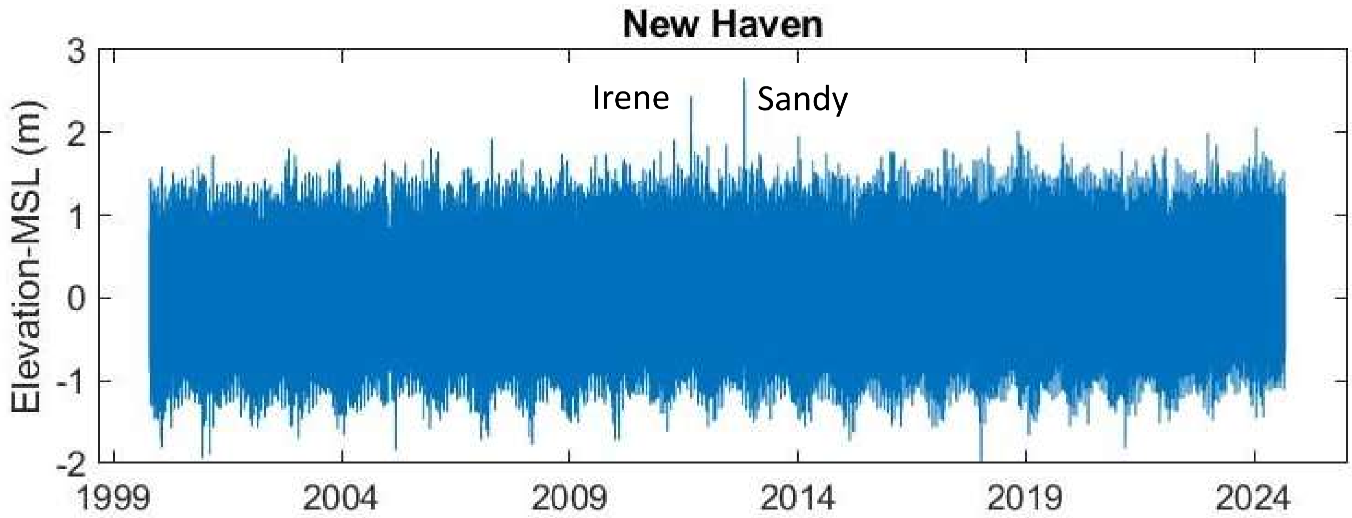
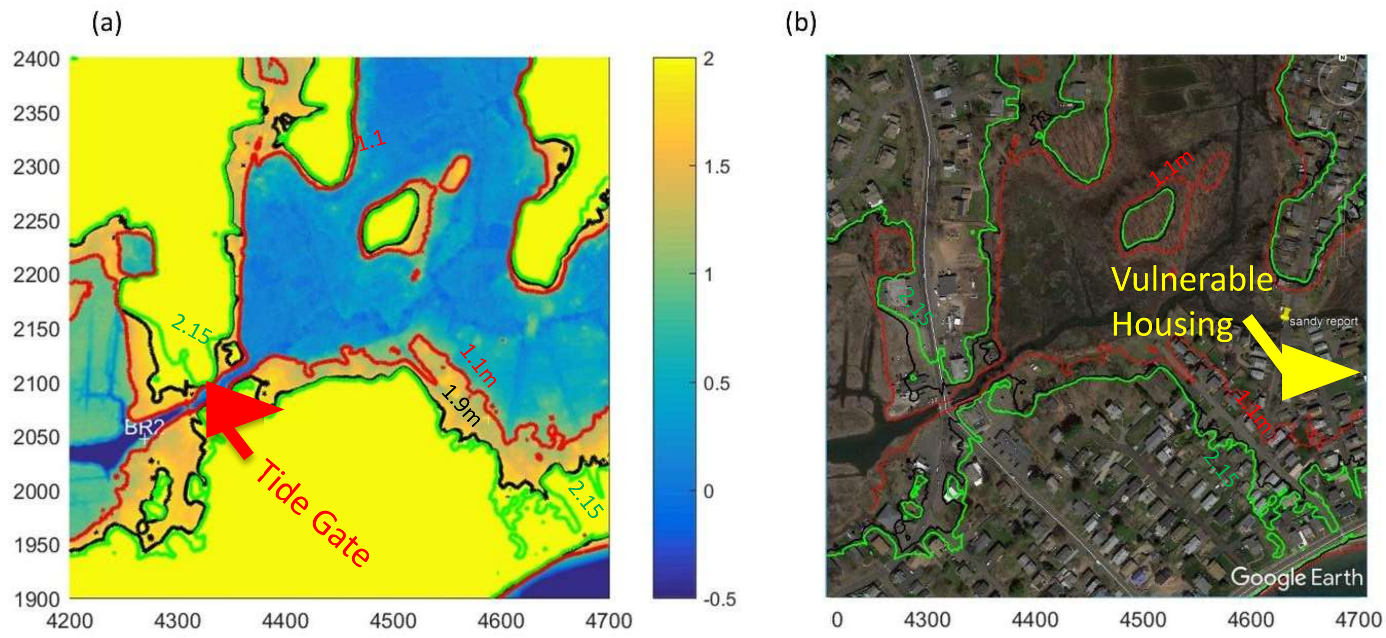


Figure 46. The black line shows elevation estimates along Sybil Avenue from the LIDAR shown in Figure 45, and the red + symbols and line shows measurements by RTK GPS at the locations shown by the red points in Figure 45.

Figure 44. The topography and bathymetry of Branford, CT. The color codes are shown on the right. The square defined by the dashed magenta line surrounds the junction of Sybil and Linden Avenue and defines the area shown in higher resolution in Figure 45. The white + symbols show the location of moored instruments. The area surrounded by the cyan square is discussed in the next section.


New Haven
Elevation-MSL (m)
3
2
1
0
-1
-2
1999
2004
2009
2014
2019
2024
Irene
Sandy

Black line shows the 1.9 m contour – The level of the Linden-Sybil Ave.
Green line shows the 2.15 m contour – The Level of Limewood Ave.
Red line shows the 1.1 m contour - The maximum water level in Sybil Creek Marsh.



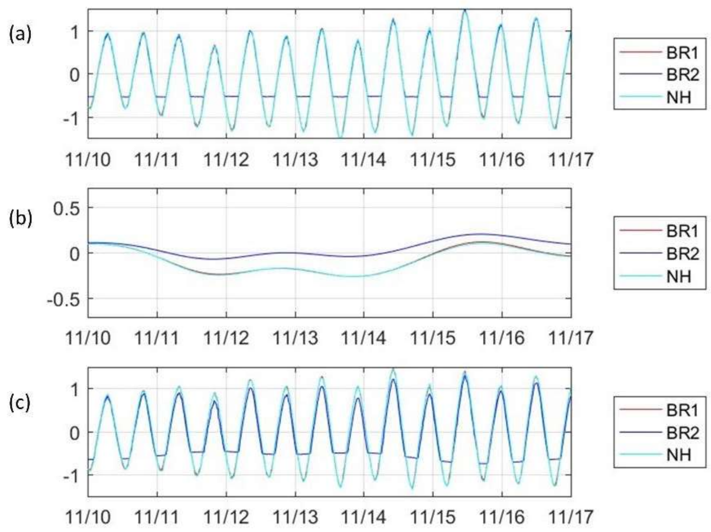


Figure 48. The same data as in Figure 4 but for a 7 day interval in November 2016.

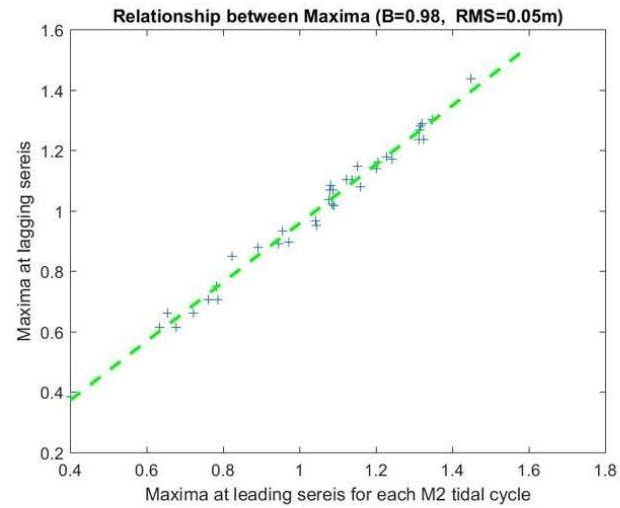
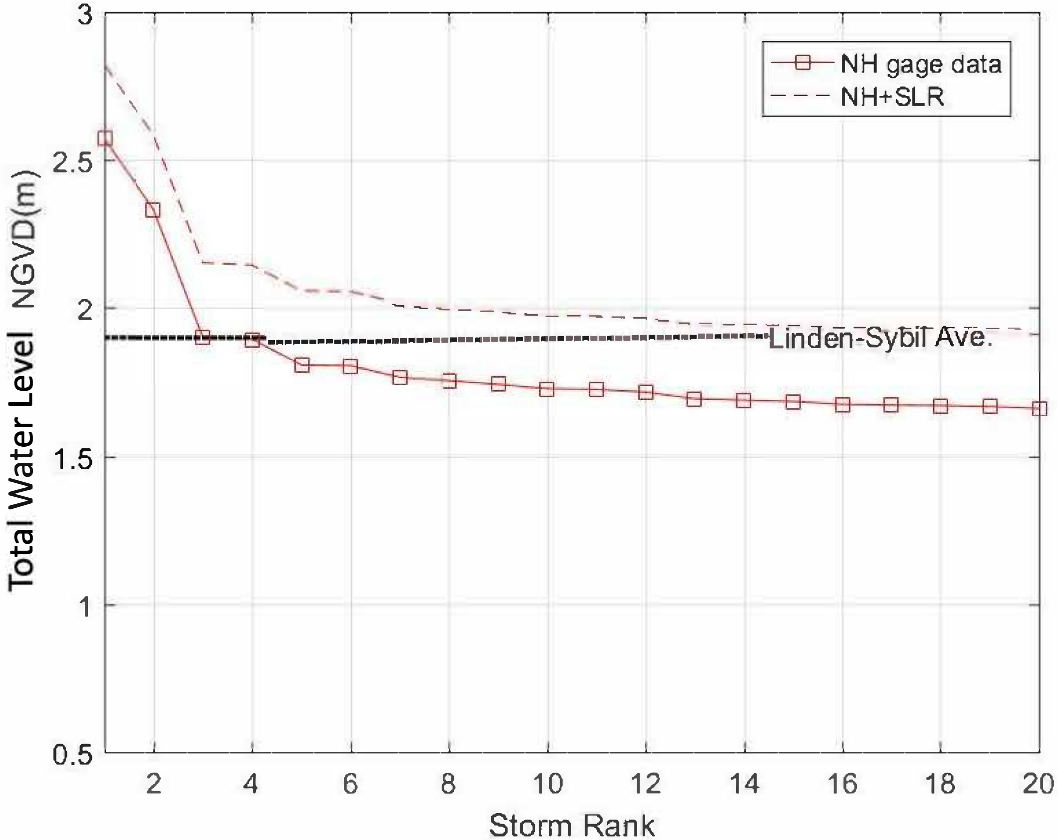


Figure 49. The correlation between the magnitude of the peaks observed in the New Haven (horizontal axis) and BR2 (vertical axis) series shown in Figure 4 (a).



- The 1.9 m level has been reached or exceeded 4 times since 1999.
- An increase in MSL of 0.25 m would cause the road to be flooded 20 times (i.e. a factor of 5 increase in flood risk).

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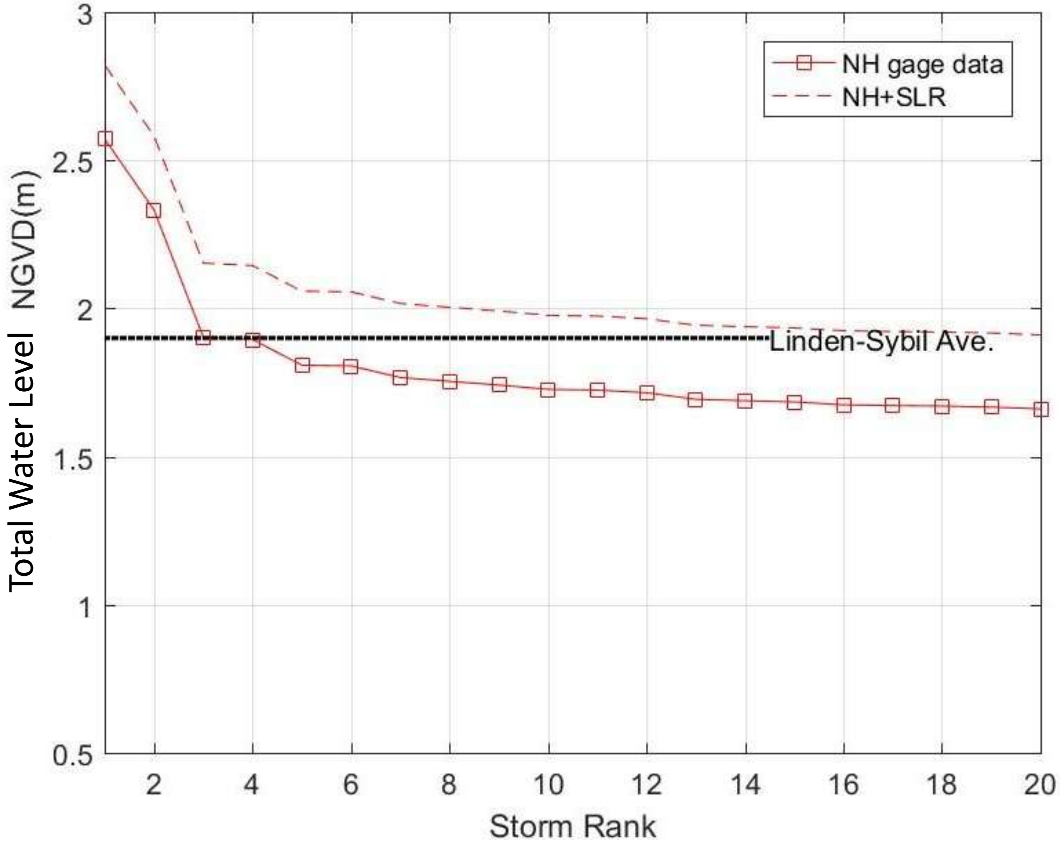


- The 1.9 m level has been reached or exceeded 4 times since 1999.
- An increase in MSL of 0.25 m would cause the road to be flooded 20 times (i.e. a factor of 5 increase in flood risk).

Figure 50. The red squares show the levels of the 20 highest water levels observed at New Haven since January 1999. The dashed black line shows the level 1.9 m, which is the elevation of the road surface at the bridge across Sybil Creek. The dashed line is the levels that the water levels would have reached of the means sea level was 0.25 m higher.


Waverly
Sybil Ave.
Limewood
Google Earth
Tour Guide
1992
Imagery Date: 4/20/2016
41°15'45.97" N 72°48'03.26" W elev 0 m eye alt 451 m

The volume of water in the basin is written a V_1. The conservation of mass can be written following

Roman et al. (1995) where $Q_{1,2}$ is the volume flux past/over the bridge as

$$\frac{d}{dt}V_1 = R + Q_{1,2} + Q_{SO}$$

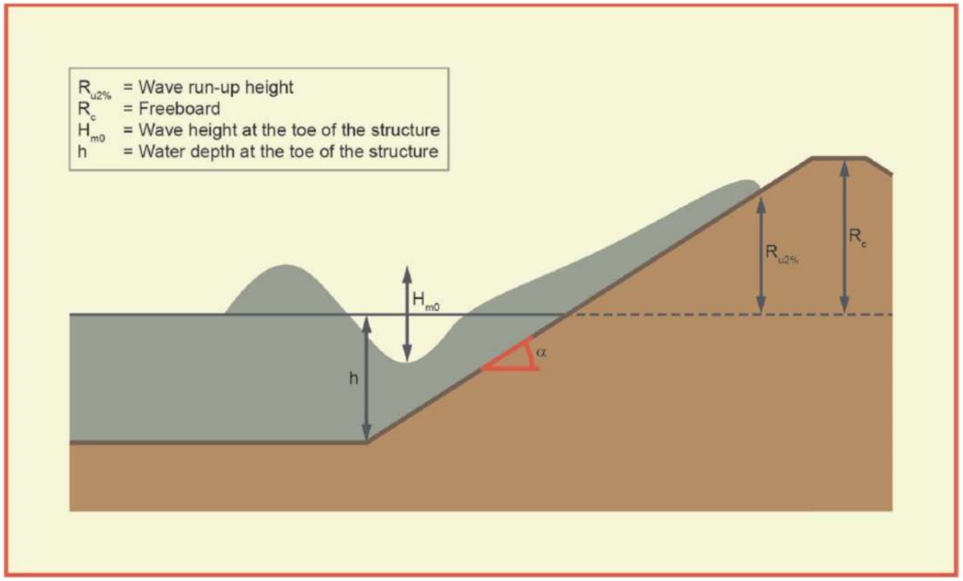
where R is the freshwater inflow from tributaries and

$$Q_{1,2} = -\frac{C_{12}^{5/3}}{n\,P^{2/3}} \frac{(|\eta_1 - \eta_0|)^{1/2}}{L_d} \frac{(\eta_1 - \eta_0)}{|\eta_1 - \eta_0|}$$

Note $Q_{1,2} < 0$ when $\eta_1 > \eta_0$.

where $C_{1,2}(\eta_1, \eta_0) = (\frac{\eta_1+\eta_0}{2} + H)\,W$ is the cross-sectional area of the inflow; H represents the mean water depth and W the width of the opening, and $P(\eta_1, \eta_0) = \frac{\eta_1+\eta_0}{2} + W,$ is the wetted perimeter, and L_D is the length of the constriction.

The Manning coefficient n is an empirical constant. Chow (1959) reported a range of values for steady flow in canals and rivers as $n = 0.012 - 0.150$.



$$Q_{so} = \sqrt{gH_0^3}\, a\, exp\left\{-\left\{b\,\frac{R_c}{H_0}\right\}^c\right\}$$

Schematic of an idealized coastal dyke or embankment defined in the EurOtop II report (Van der Meer et al., 2016).

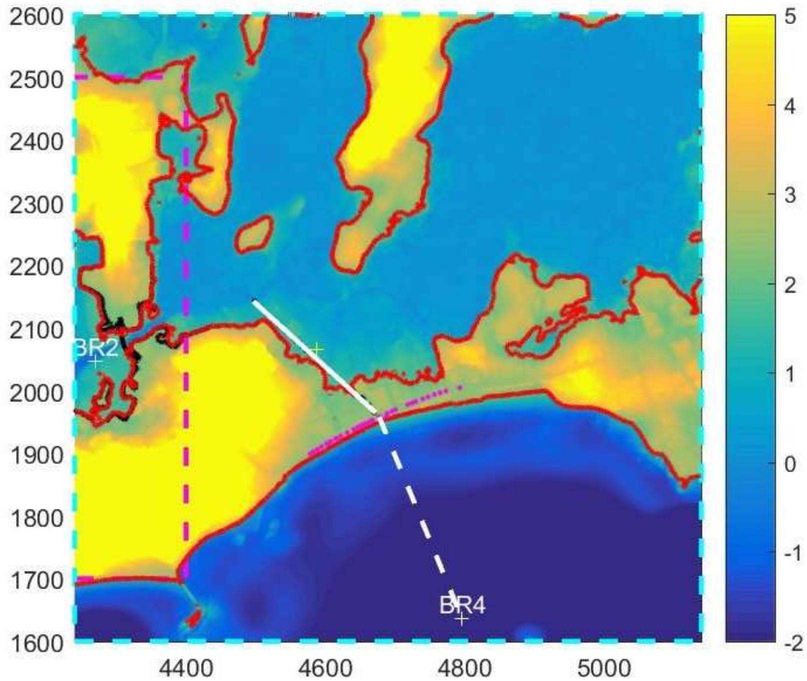


Figure 52. Topography of the Limewood Avenue –Waverly Road area. The color scale show the elevation in the range -2 to 5 m using the color scale on the right. The location of the water level and wave sensors at BR 4 is shown by the white + symbol. The magenta points lie on Limewood Avenue and the solid white line shows Waverly Road.

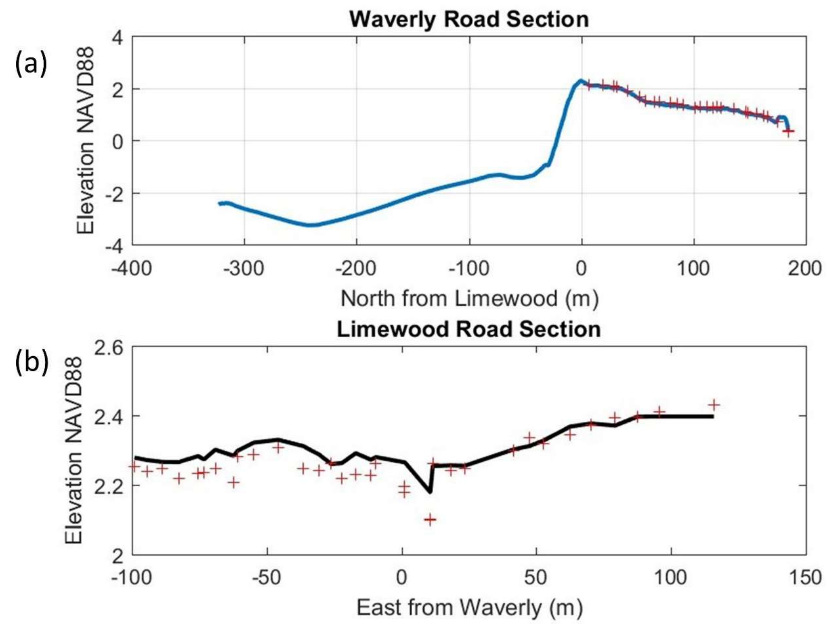
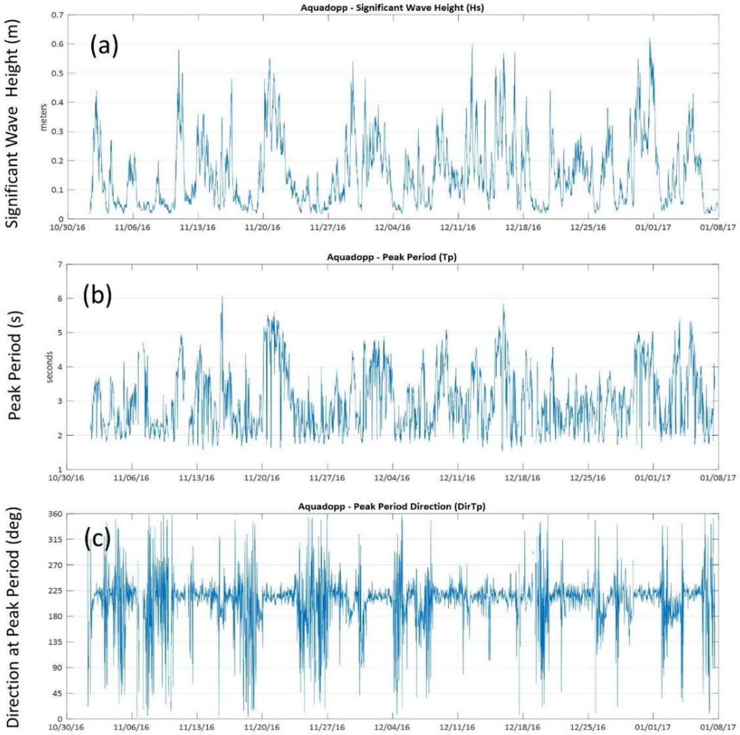
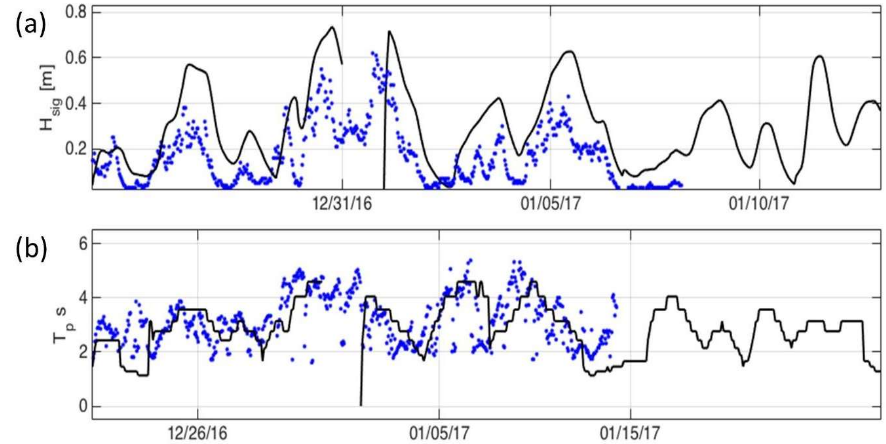


Figure 53. (a) The variation of water depth and land elevation along the dashed white line from BR4 to Limewood Avenue, and along the solid while line that shows Waverly Road in Figure 52. (b) The variation of elevation along Limewood Avenue. The zero of both graphs is at the junction of Limewood and Waverly. The red + symbols show measurements by RTKGPS



Wave observations at BR4 from October 30, 2016 to January 8th, 2017. (a) shows the significant wave height (m), (b) the peak wave periods (s) and (c) shows the direction (degs.) the waves at the peak period were traveling from.



Simulation of the (a) significant wave height at BR4 and (b) the peak wave period.

Wind Wave Growth and Dissipation in a Narrow, Fetch-Limited Estuary: Long Island Sound

by Amin Ilia *, Alejandro Cifuentes-Lorenzen, Grant McCardell and James O'Donnell

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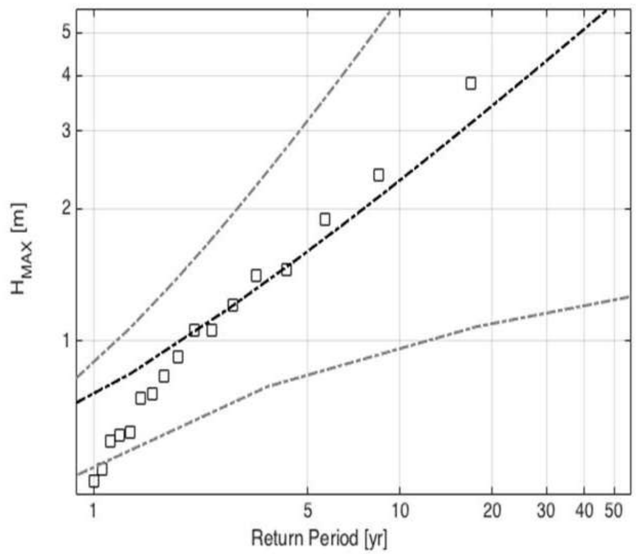
* Author to whom correspondence should be addressed.

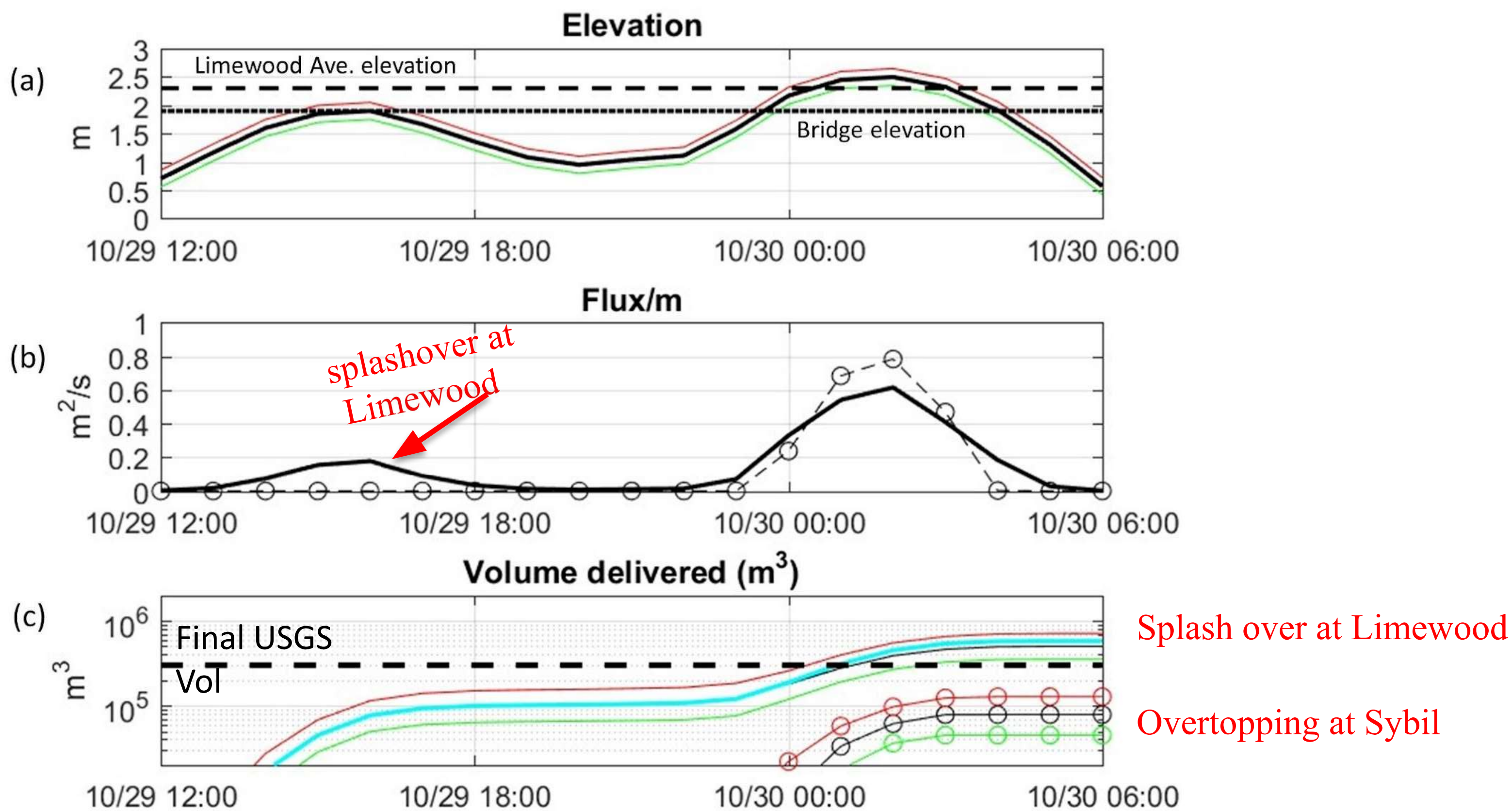
J. Mar. Sci. Eng. **2023**, *11*(8), 1579; **https://doi.org/10.3390/jmse11081579**



Return period of significant wave heights Branford, CT. The dashed black line corresponds to the best-fit GEV function and the grey dashed lines mark the 95% confidence interval. The black squares show the maximum significant wave height (m) in the simulations at the site.

Table 2. Results of the simulations of significant wave height, H_s and dominant period T_p near Branford, CT.

Year	[m]	T_p [s]
1985	3.84	8.83
1954	2.38	9.67
2012	1.89	7.37
2011	1.45	6.73
2017	1.41	6.75
2008	1.31	4.68
2014	1.21	5.92
2006	1.06	5.12
1991	0.93	4.61
2015	0.76	5.61
1978	0.75	5.61
2013	0.62	4.27
2007	0.61	4.05
2005	0.59	4.05
2016	0.51	2.26
2003	0.48	4.05
2009	0.41	3.56
2011	0.37	4.68


Elevation
(a)
m
Limewood Ave. elevation
Bridge elevation
10/29 12:00
10/29 18:00
10/30 00:00
10/30 06:00
Flux/m
(b)
m^2/s
splashover at Limewood
Volume delivered (m^3)
(c)
m^3
Final USGS Vol
Splash over at Limewood
Overtopping at Sybil

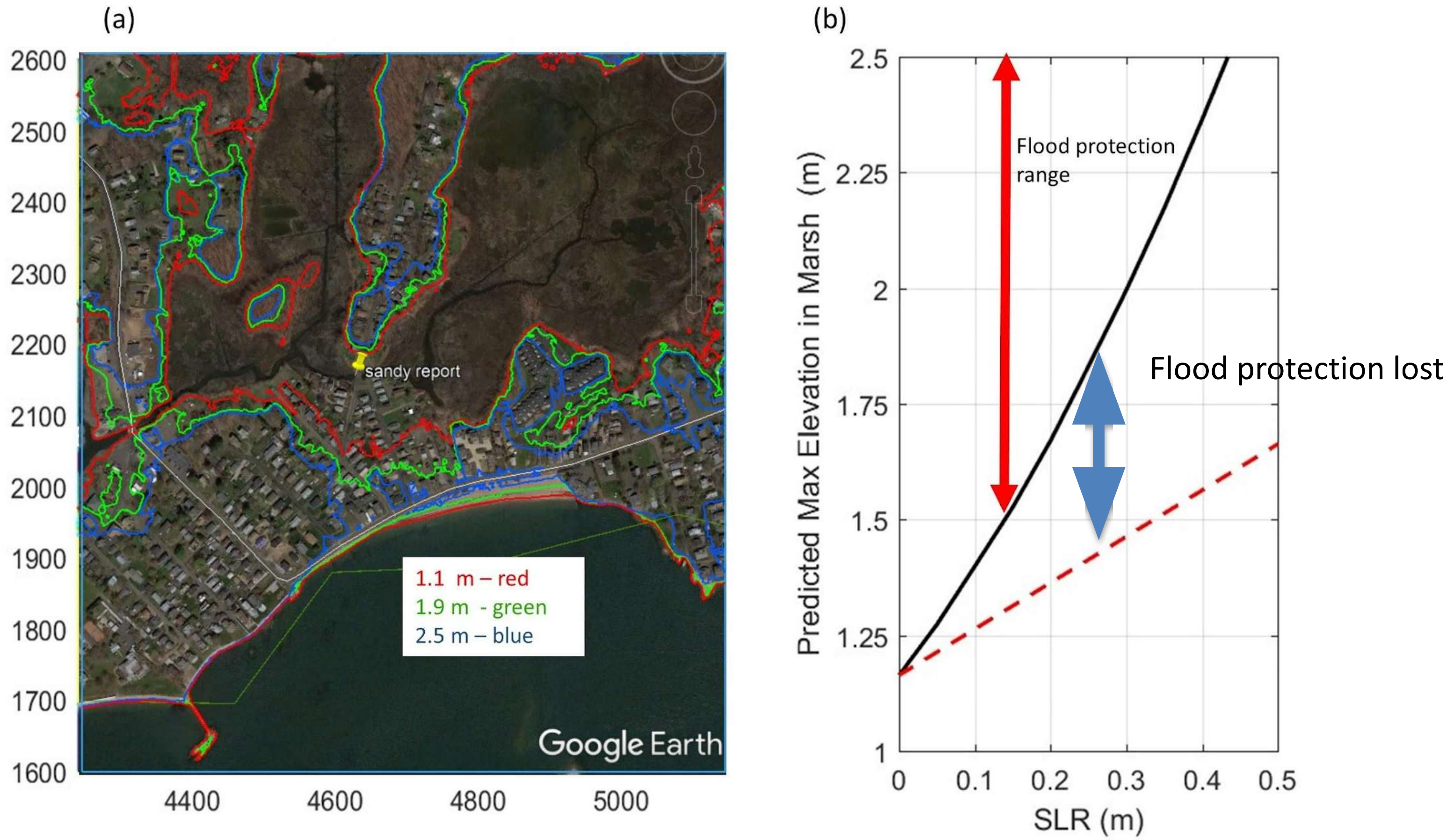


Figure 62. (a) A GoogleEarth map of the coastal area near Limewood Avenue. The white line show the location of RT 146 and the red, green and blue lines show the 1.1 m 1.9, and 2.5 m elevation contours. (b) The black solid line shows the elevation in the marsh that corresponds to the maximum predicted volume transported into the marsh. The red dashed line shows the change in sea level in the marsh if it was just do to sea level rise.

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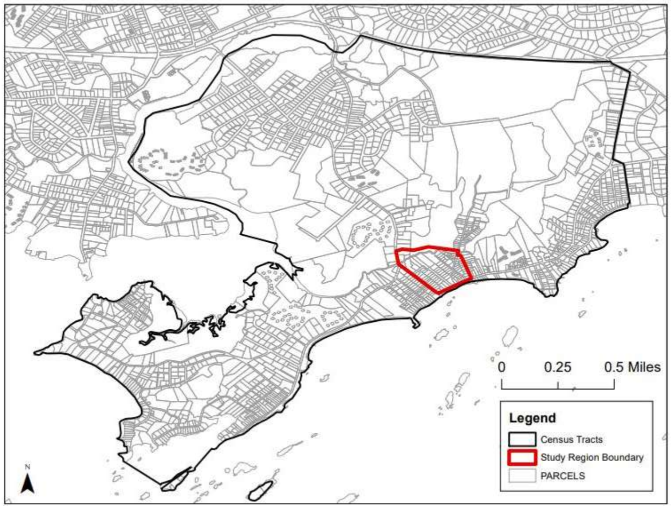

The area considered at-risk in HAZUS doesn't conform with the contours.

SUMMARY

To assess the future risk of flooding we built a simple basin model that resolves the critical details of flooding pathways and represents the flux from the ocean using well-established hydraulic models.

We estimate the over-topping flux from Limewood Avenue and the flow over Sybil Creek Avenue into the marsh during Sandy and find that the predicted high-water level in the marsh was similar to that observed by the USGS survey.

Most of the water in the marsh resulted from splashover.

Even though the fluxes were high, the large area of the marsh contained the flood volume below the 1.1 m level avoiding flooding in many residences.

At a 0.25 m higher mean sea level, simulations show that the flood protection value was lost and a Sandy-like event would cause flooding around the marsh to 1.9m.

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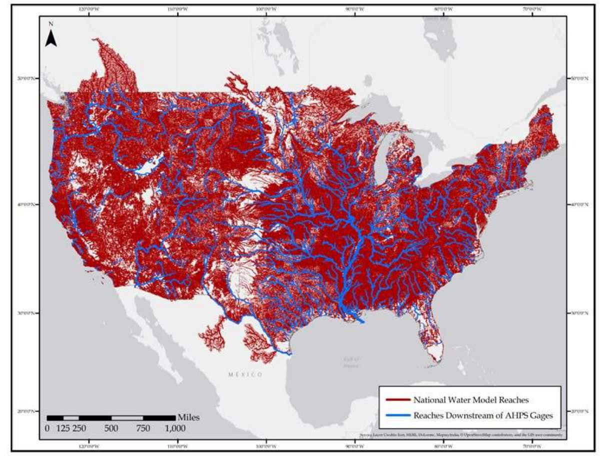
OWP | OFFICE OF WATER PREDICTION

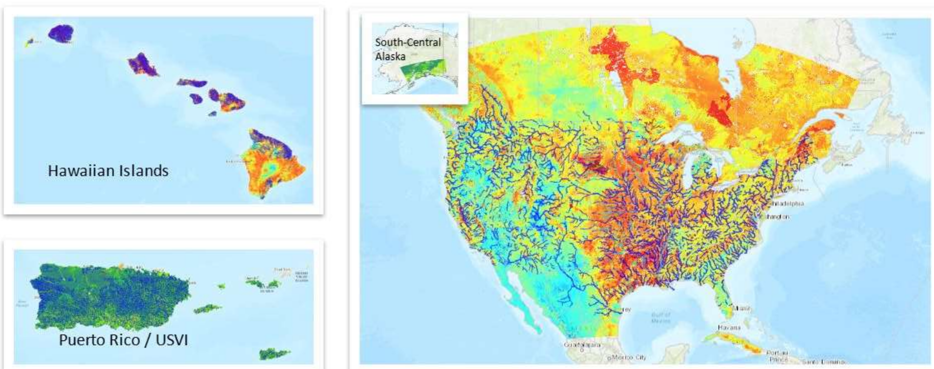
NOAA’s National Water Model

Brian Cosgrove and Trey Flowers
NOAA/NWS Office of Water Prediction

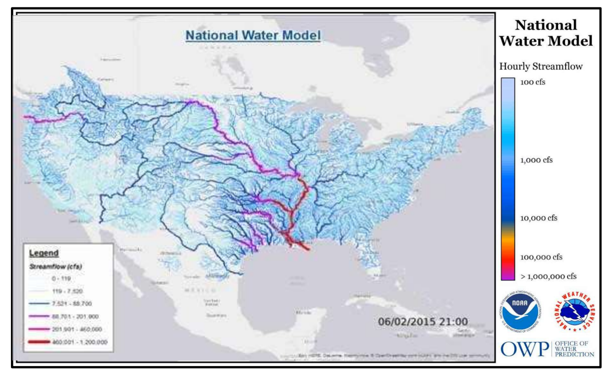
National Water Model Overview

- The NWM provides both complementary and first-time hydrologic guidance to users
- The NWM continues to advance water prediction at an accelerated pace, addressing the nationwide coastal total water level prediction challenge with improved services for ⅓ of the Nation's population

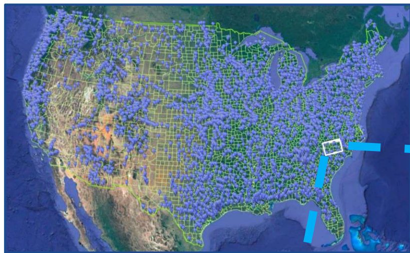




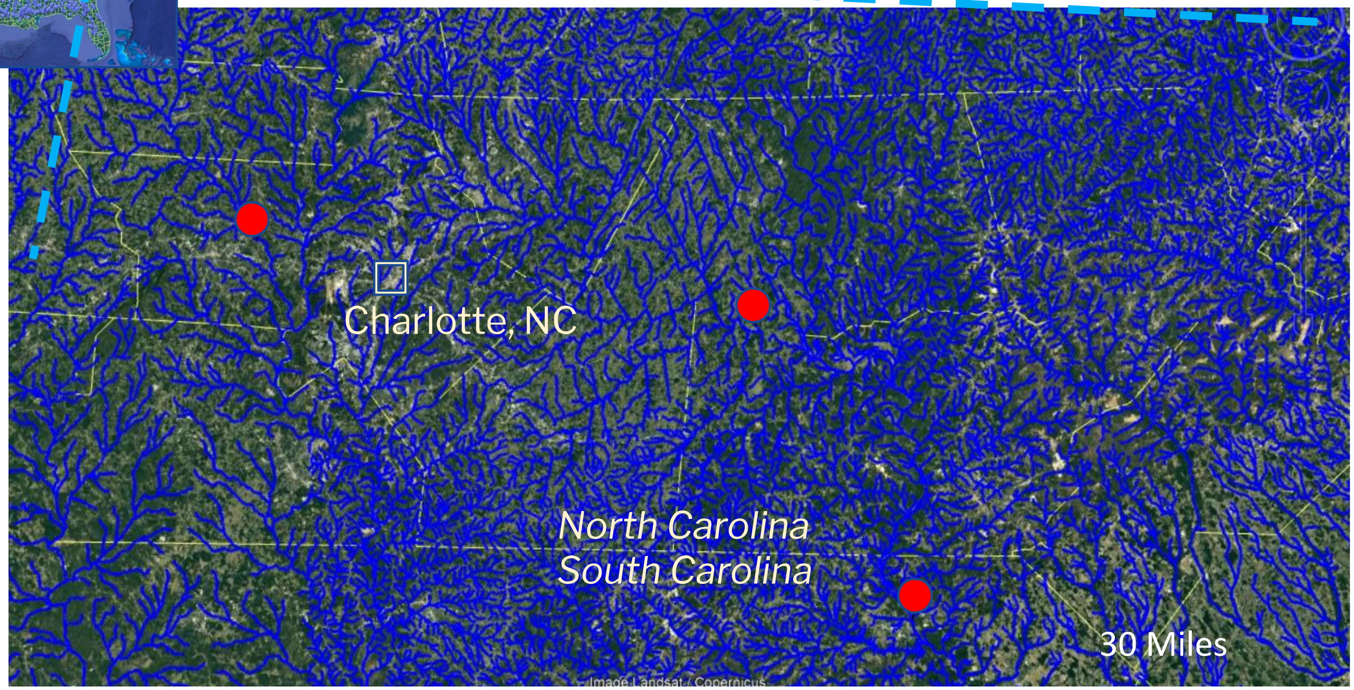
NWM Domain



NWM: Fills in Gaps in Spatial Coverage

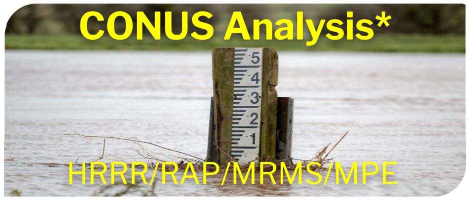


Coverage example over the Carolinas



- Population > 3 million in this region, much of which is more than 30 miles away from the nearest RFC forecast point (circles at right)
- NWM complements existing RFC forecasts by providing guidance over a very dense set of stream reaches (blue at right)

NWM: Fills in Gaps in Temporal Coverage



Lookback Range 3-28 hrs

Including open loop (non-DA) members

18 Hour Forecast

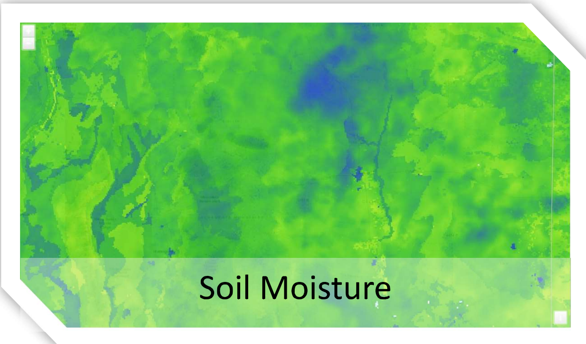
~10 Day Ens Forecast

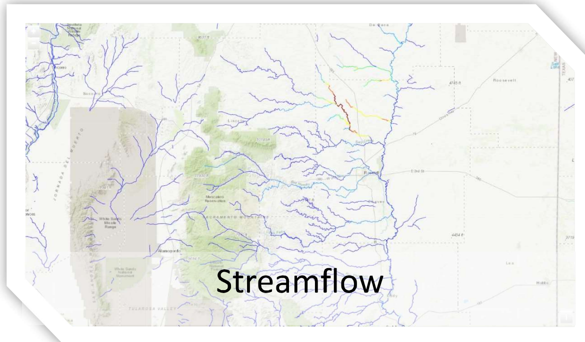
Including open loop (non-DA) member

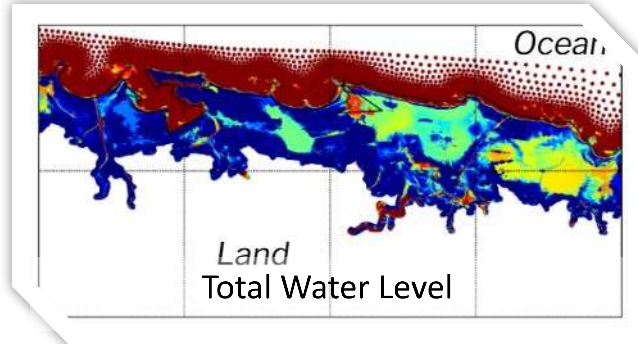
30 Day Ensemble Forecast

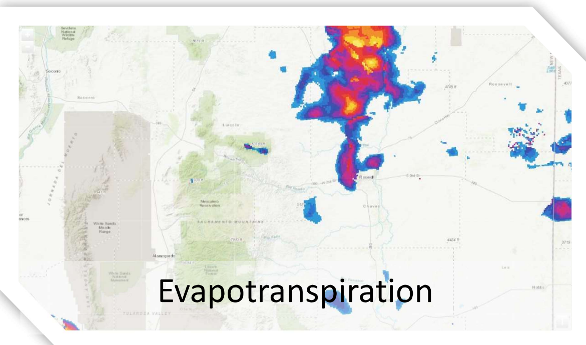
NWM: Fills in Gaps in Types of Guidance

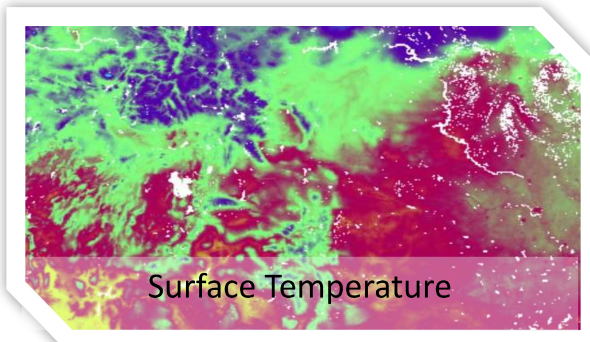
Select NWM Output Fields

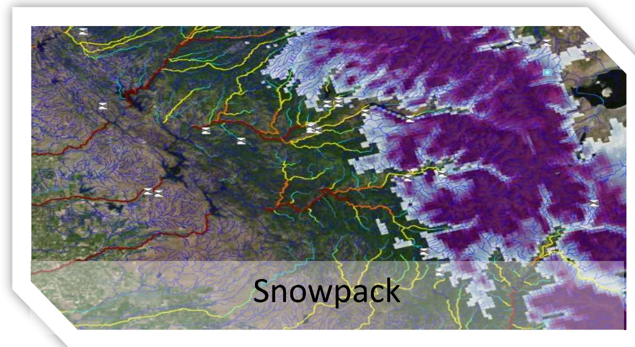






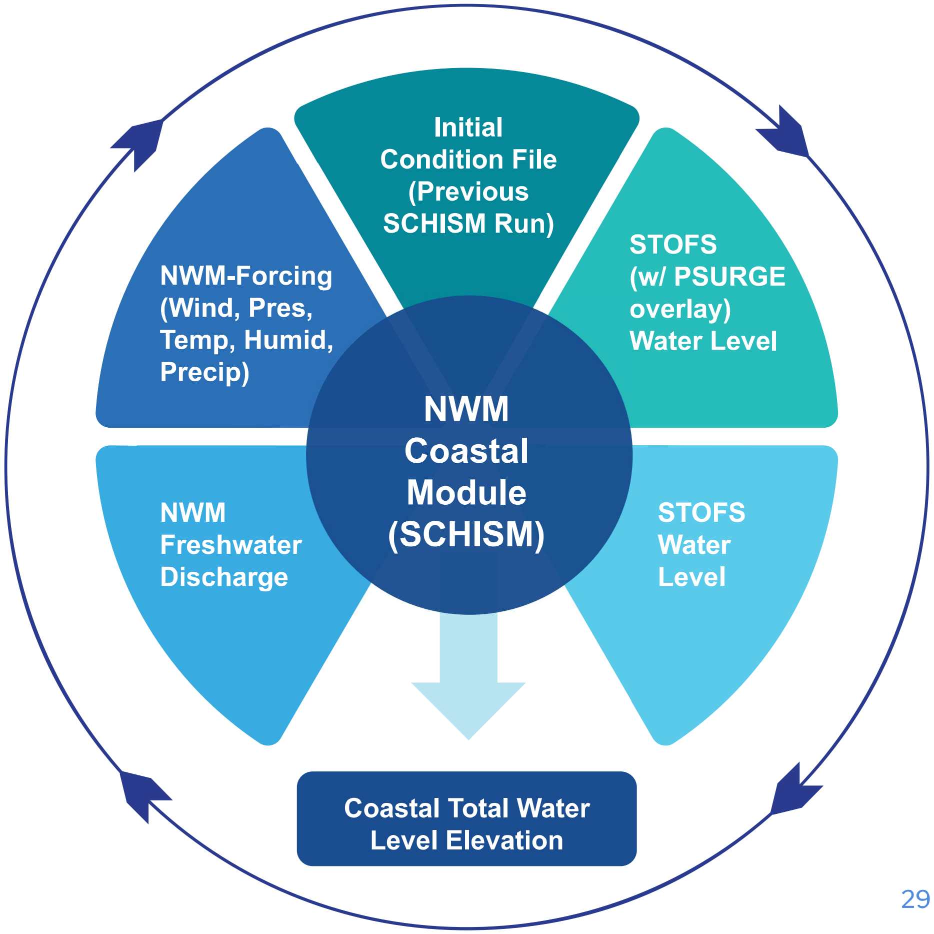






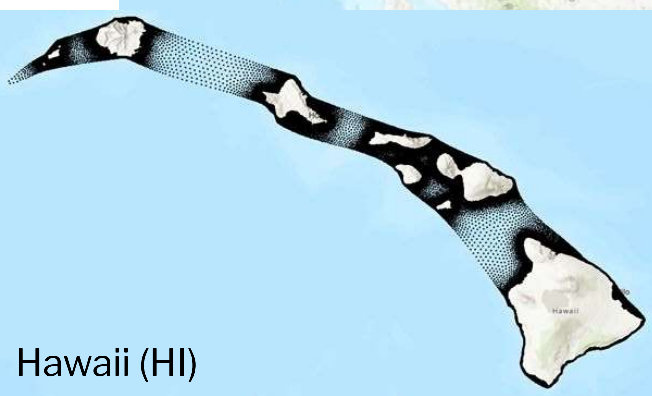
NWM Total Water Level Coastal Modeling Capability

- With version 3.0, NWM TWL guidance complements existing regional forecasts over *CONUS, Hawaii, and PR/VI domains*
- This new freshwater-estuary-ocean coupling leverages the NWM, SCHISM, STOFS & P-Surge, executes in both Analysis and Forecast modes.
  - NWM provides regridded HRRR/GFS-based atmospheric forcing and freshwater streamflow
  - STOFS provides water level as a base layer
  - P-Surge water levels are overlaid on the STOFS data when/where available



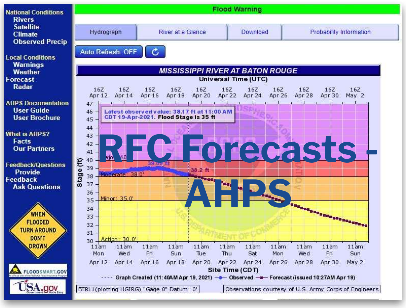
NWM v3.0 Coastal Modeling Domain Coverage

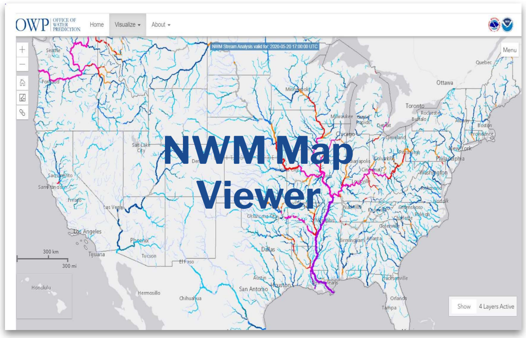
TWL output is masked to a 5 meter bathymetric depth offshore, and extends to 10 meter topographic height inland

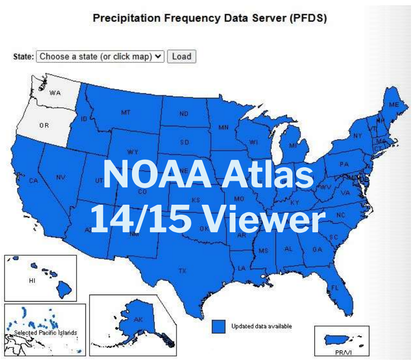


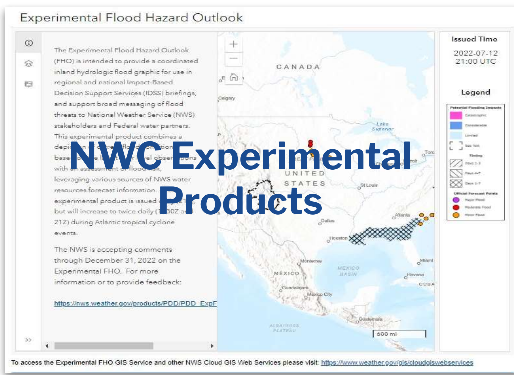
<u>Average Resolution</u>
Atlantic: 75 m
Pacific: 50 m
PR-VI and HI: 30 m

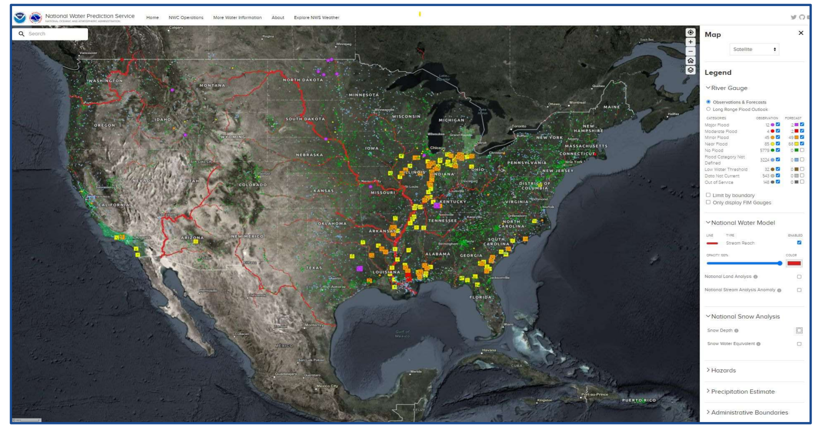
Data is only as useful as the method of dissemination: Integration of OWP's web presence into the National Water Prediction Service (NWPS)







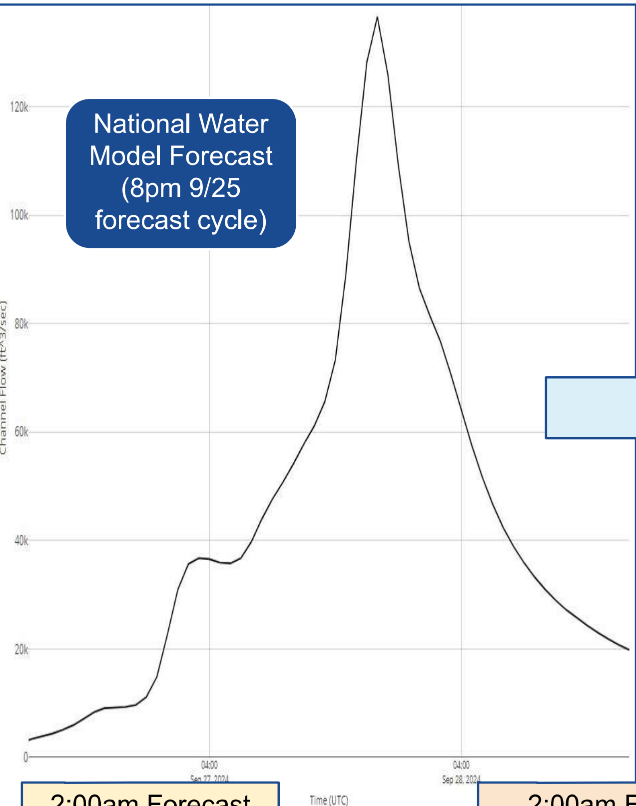


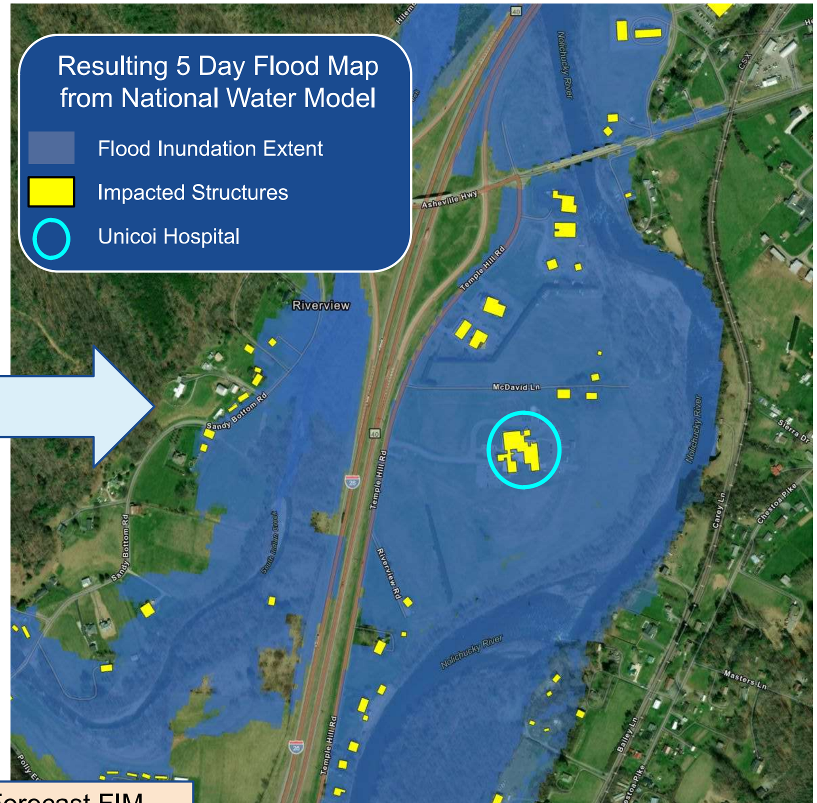


National Water Prediction Service
http://water.noaa.gov/
Putting Water on a Map

Additionally: Big Data providers host real-time and retrospective NWM data

Inland NWM FIM: Filing in the Gaps with Guidance at Ungauged Locations
Unicoi Hospital High Water Rescue along the Nolichucky River near Erwin, TN



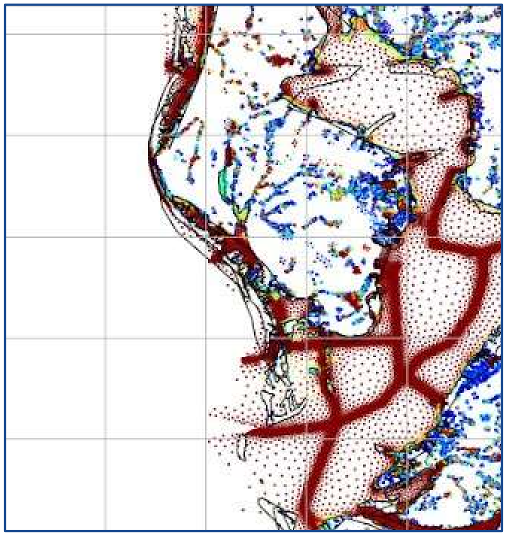


2:00am Forecast FIM Shows Hospital Cut Off

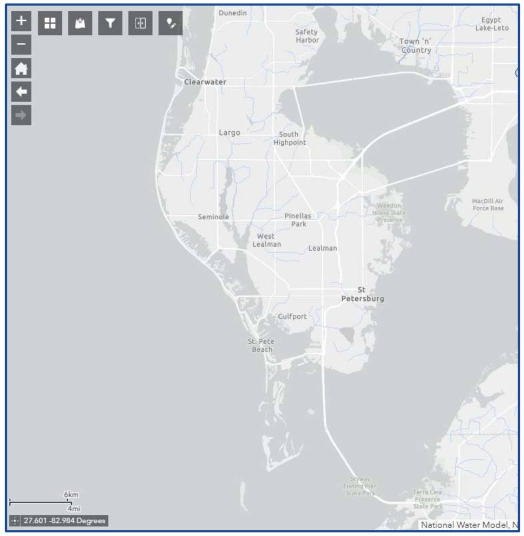
2:00am Forecast FIM Shows Hospital Inundated (shown above)

9/25	12:00 am	9/26	12:00 pm	9/26	12:00 am	9/27

Forthcoming Product: Coastal Flood Inundation Mapping



NWM Coastal Module Total Water Level Elevation Output



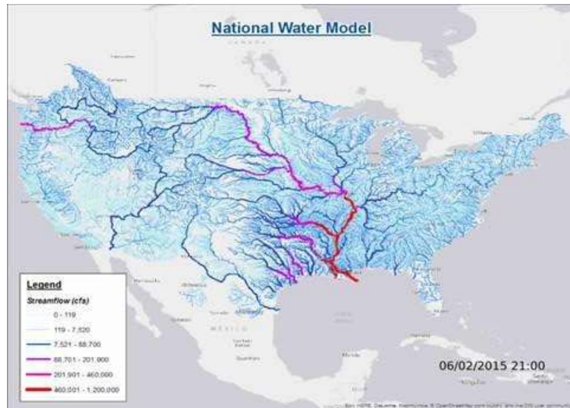
Digital Elevation Model (DEM)

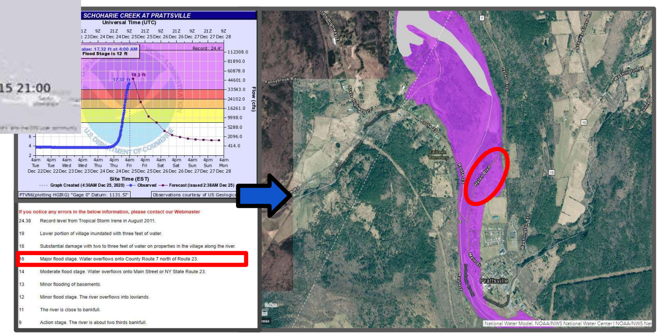
NWM-Based Coastal TWL Depth and Extent Map

- Based on NWM coastal output and DEM processing, Coastal FIM will provide extent and depth information
- Will be available to the public via NWPS by completion of FIM rollout across country (2026)

Closing Thoughts

- The NWM provides hydrologic data at times and locations where there previously was none
- This information is publicly available through NWPS at http://water.noaa.gov





Tsunami Inundation Modeling and Forecasting

Ernesto G. Fernández[1,2], Yong Wei[1,2]

Christopher Moore, Vasily Titov, Natalia Sannikova, Clint Pells, Carrie Garrison-Laney, Diego Arcas, Laura Nesteckyte, Jaeda Woodruff

1. NOAA Center for Tsunami Research (NCTR), Pacific Marine Environmental Laboratory (PMEL), NOAA
2. Cooperative Institute for Climate, Ocean, and Ecosystem Studies (CICOES), University of Washington

Outline:

- Short-term hazard assessment
  - Short-term Inundation Forecast of Tsunamis (SIFT)
  - Forecasting of tsunamis generated by non-seismic sources

- Long-term capabilities
  - Probabilistic Tsunami Hazard Assessment (PTHA)
  - Morphological evolution and influence on tsunami waves
  - Tsunami inundation mapping

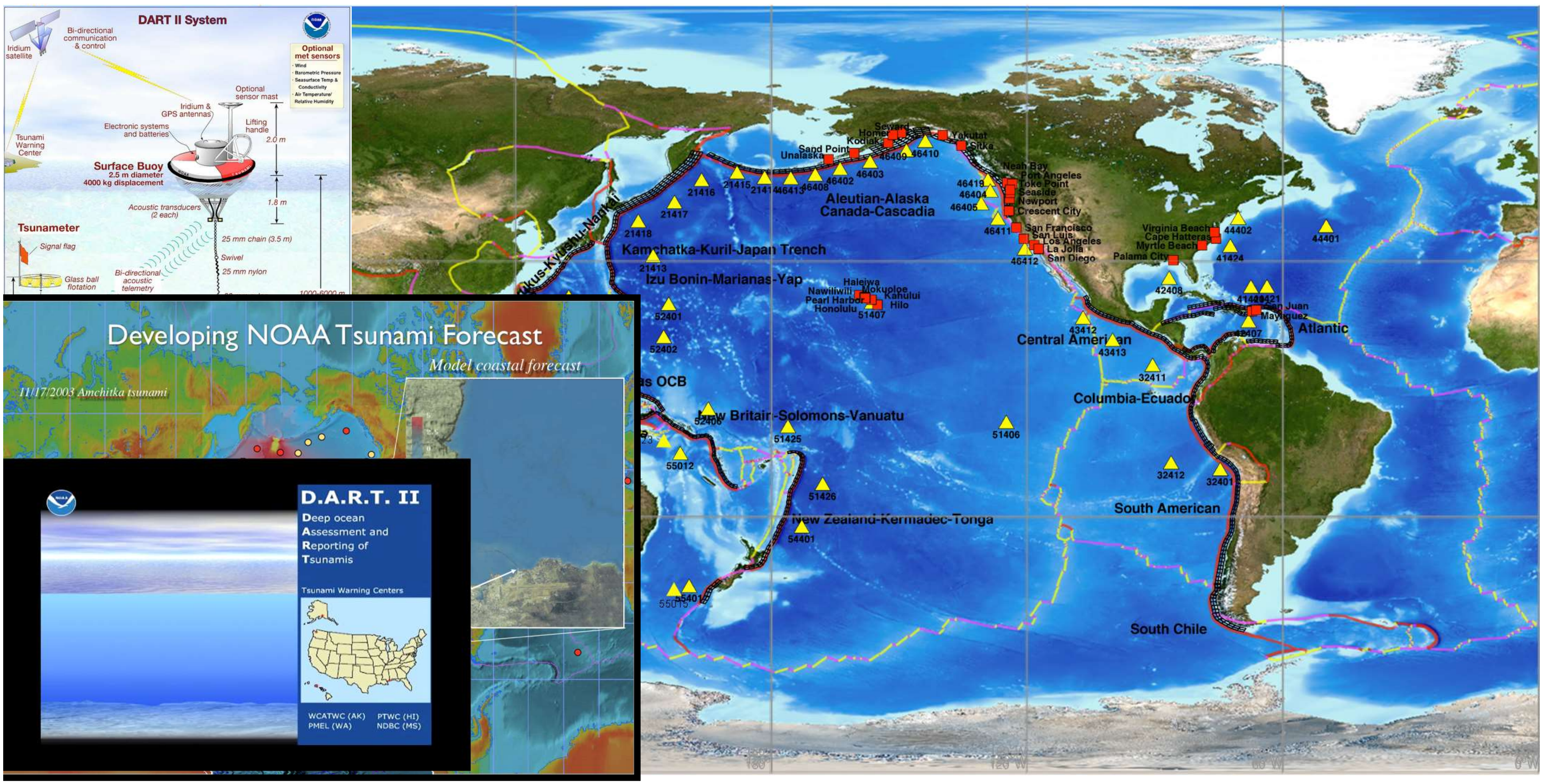
- NCTR's current research lines: storm surge, meteotsunami, sediment evolution

NOAA’s Short-term Tsunami Forecast Methodology

Detection
Tsunameter

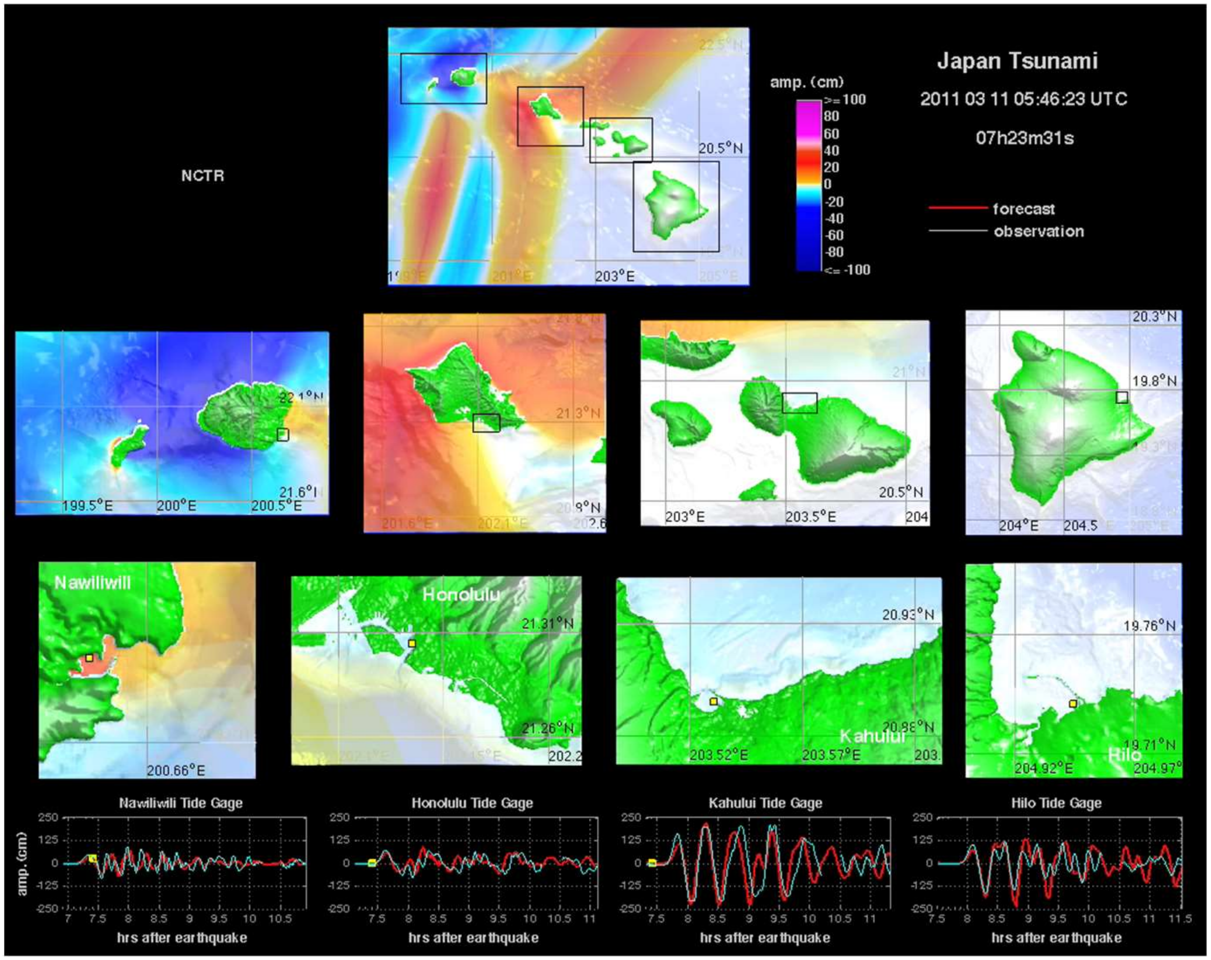
Inversion
Prop. Database

Inun. forecast
Forecast Models



Real-time SIFT forecast of the 2011 Japan tsunami inundation at U.S. harbors

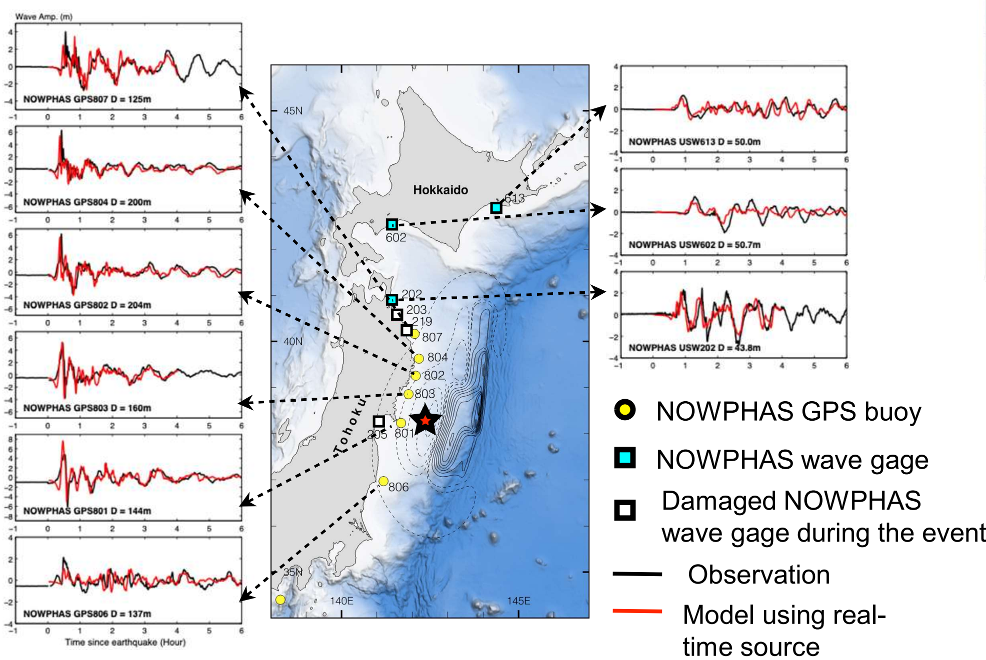
- Accurate flooding forecast obtained ~ 6 hours before tsunami entered the Hawaiian Islands
- Forecast accuracy of max tsunami amplitudes is ~70% at 32 tide gauges along U.S. coastline.

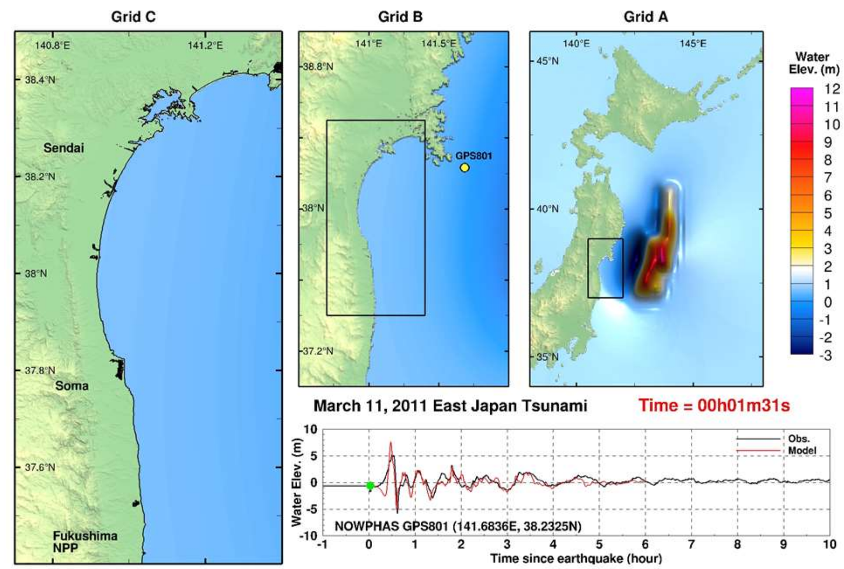


Model-forecasted 2011 Japan tsunami propagation and inundation in the Hawaiian Island chain.

Model forecast benchmarking in the near field

Model forecast was made ~ 1.5 hours after the earthquake using the tsunami source constrained from two DART measurements





Along Japan's east coast:

- Measured inundation: 533 km2
- Modeled inundation: 610 km2
- Modeling accuracy: 85.6%

Recent major enhancements of SIFT

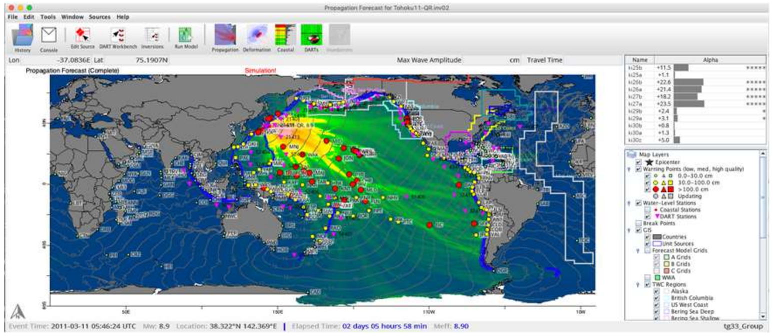
Challenges	Enhancements
Latency of DART detection	Rapid detection using DART 4G (4th generation)
Not rapid enough for near-field forecasting	Early detection based on Global Navigational Satellite System (GNSS) network
Earthquake/tsunami sources are limited by the existing database	Arbitrary tsunami sources: on-the-fly computation of sources characteristics, wave propagation and inundation
Forecasting improvements	Global tsunami propagation database, auto inversion, tidal level.

Empowered by Graphic Processing Unit (GPU) computation

Short-term tsunami hazard assessment tools

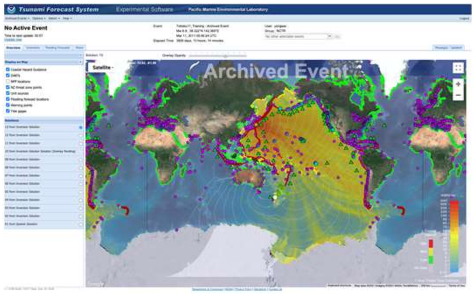
1.SIFT (Short-term Inundation Forecast of Tsunamis):

- Operational forecast tool at both NOAA Tsunami Warning Centers
- A Graphic User Interface integrating source inversion, data assimilation, propagation and inundation forecast.



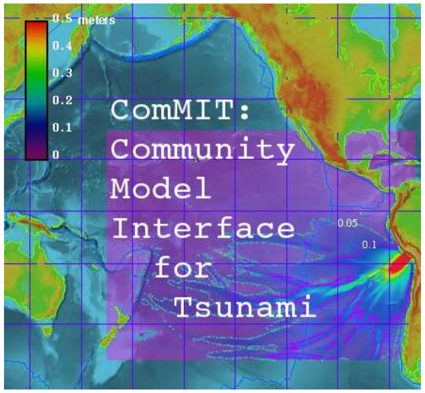
2. T-Web (Tsunami Web)

- Adopts majority of SIFT functions
- Tool for research & operational testing
- Produces graphical forecast results
- Aims at international collaborations



3. ComMIT – Community Model Interface for Tsunamis

- Short- and long-term hazard modeling tool supporting Tweb
- A community modeling tool applied globally for coastal tsunami inundation forecast



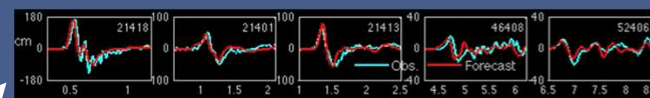
Developing NOAA's Next-Generation Tsunami Forecast - Common Analytic System (CAS)

- Provides comprehensive and consistent forecast and alerting guidance in support of joint NOAA Tsunami Warning operations
- 5 Functional Areas (FA)

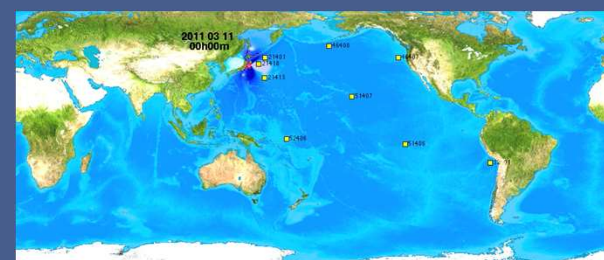
NWS Advanced Weather Interactive Processing Systems (AWIPS) Tsunami Operations Messaging System (ATOMS)

Communications with ATOMS

FA1. Background Layer: *System health monitoring*

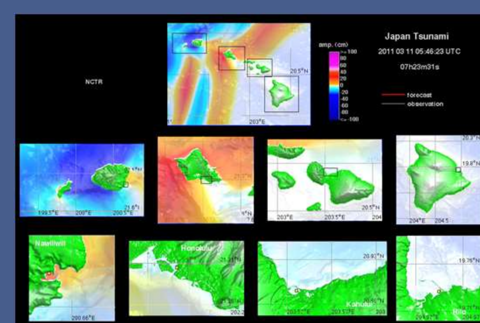


FA2. Common Data Layer: *assimilation of all available data*



FA3. Common Assessment Layer: assess initial threats and subsequent forecast

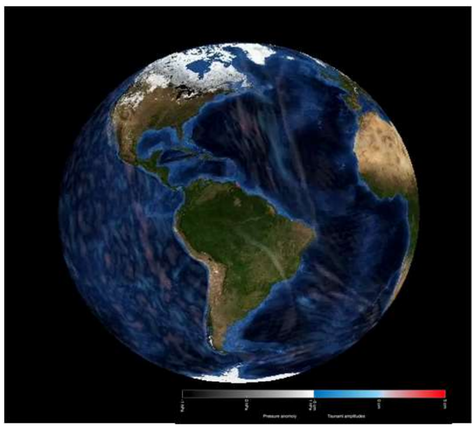
FA4. Common Forecast Layer: provide continuous flooding forecasts



FA5. Common Monitoring Layer: refine forecast and identify model/data discrepancies

Enhance Forecasting Capability for Non-Seismic Tsunamis

Data from atmospheric and weather observations, combined with real-time coastal and deep water tsunami detection, could provide necessary input for models to forecast coastal amplitudes before coastal impact of a non-seismic tsunami.



+

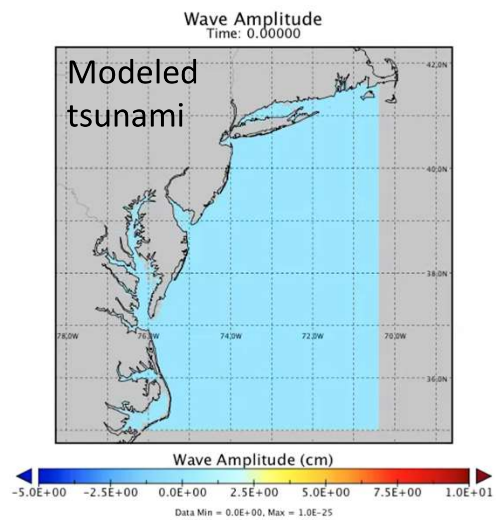
Active phase before eruption

After eruption

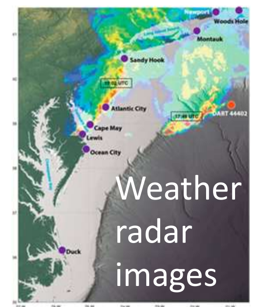
Complex origins of Jan 15, 2022 Tonga volcanic tsunami:

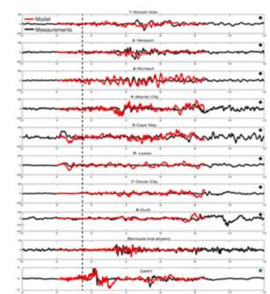
Left (above): Global tsunami impact from air-pressure waves

Right (above): Volcanic caldera collapse that resulted in severe inundation impact in the near field of Tonga



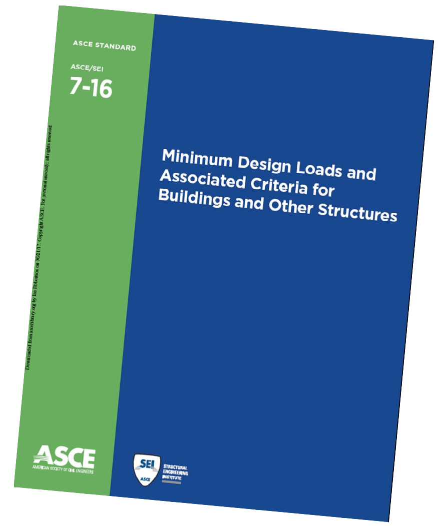
Meteotsunami: June 13, 2013 "derecho" along the U.S. East Coast



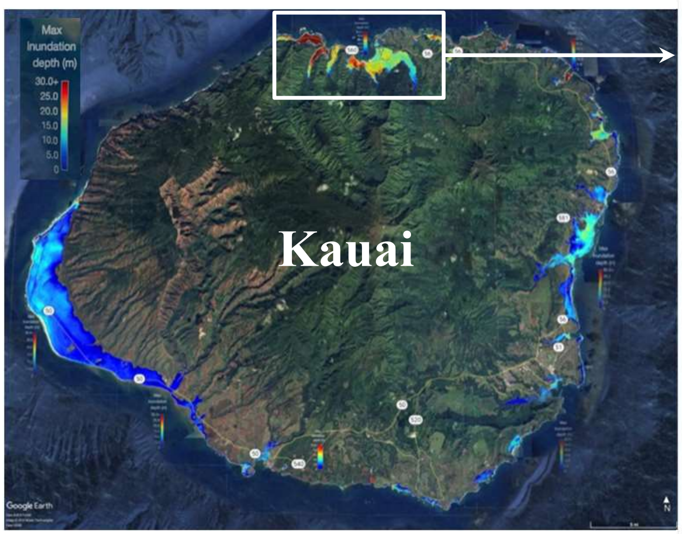


Model (red) Vs. Observations (black)

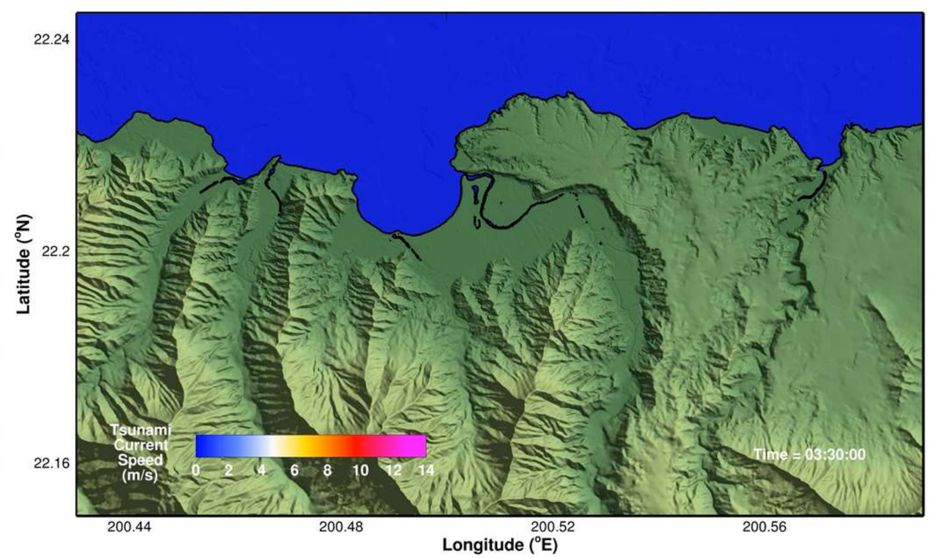
Probabilistic Tsunami Hazard Assessment



- Collaborating with American Society of Civil Engineers (ASCE) to develop the world's first probability-based tsunami design provisions
- Building-resilient studies supported by federal, state and coastal communities: Dept. of State, Navy, Hawaii State (examples below), OSU



High-resolution (10 m) Tsunami Design Zone maps across the Island of Kauai



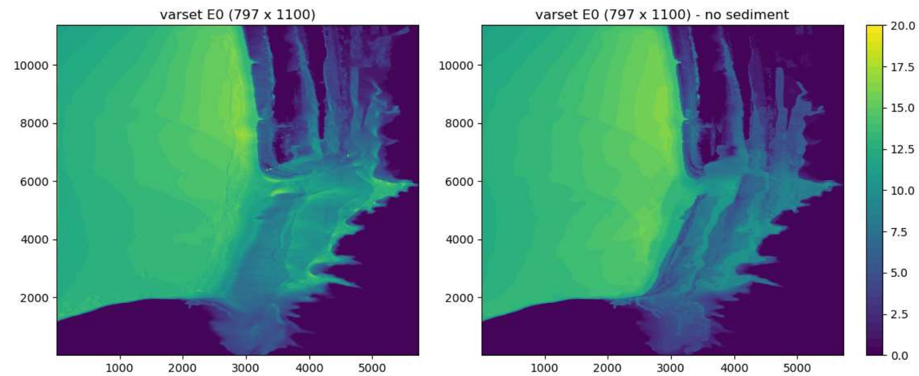
Hanalei, Kauai: Tsunami current speed produced by a 2,500-yr Aleutian-Trench earthquake

Project supported by Bipartisan Infrastructure Law (BIL)

Morphological evolution and influence on tsunami waves

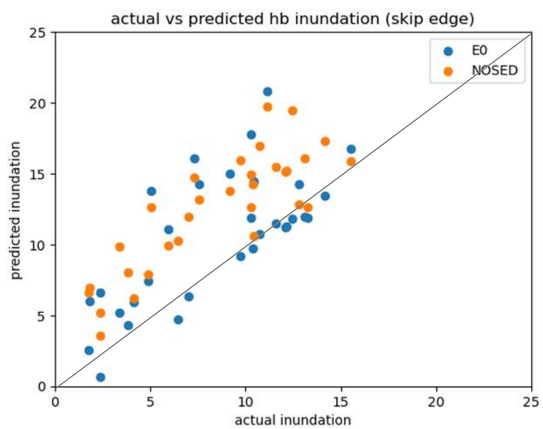
Developed a depth-averaged shallow-water model with the following characteristics:

- Able to accurately simulate coastal inundation due to tsunami waves.
- Able to incorporate sediment erosion/deposition effects.
- One submitted paper currently under review and two more in preparation.

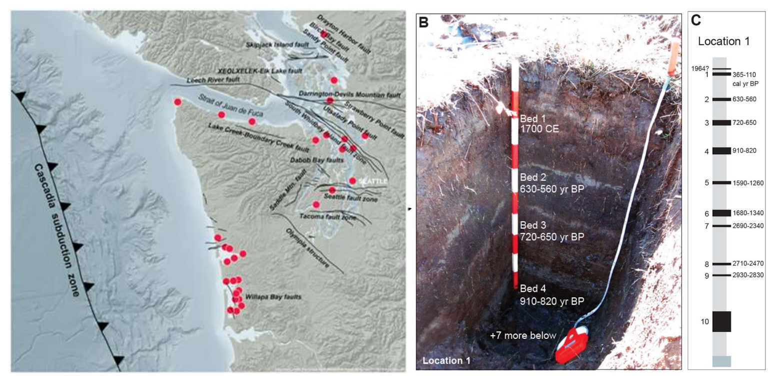


Total tsunami comparison with and without sediment for Seaside (OR). Total inundation is larger with sediment in most occasions, but not always.

Left: with sediment evolution
right: without sediment.



Left: Inundation with and without sediment compared with survey data. Taking sediment into account improves the forecast

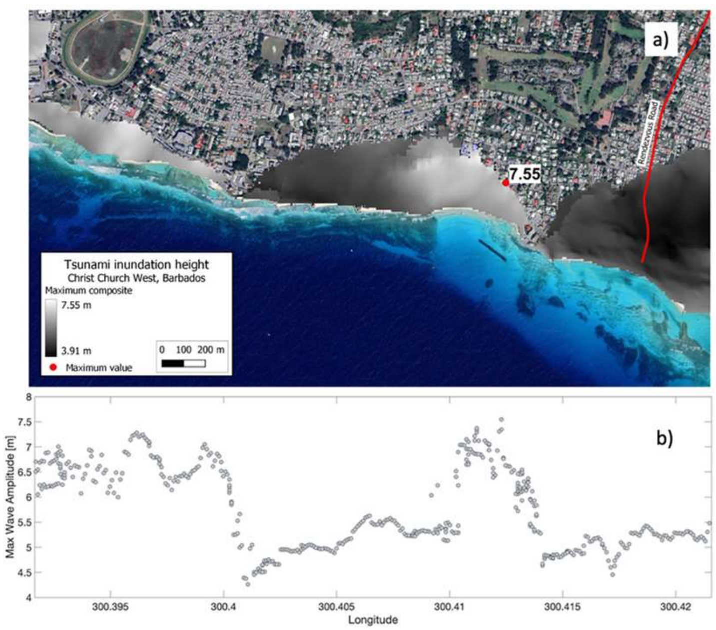


Above: CICOES funded project to compare tsunami records in Discovery Bay, WA, with model results.

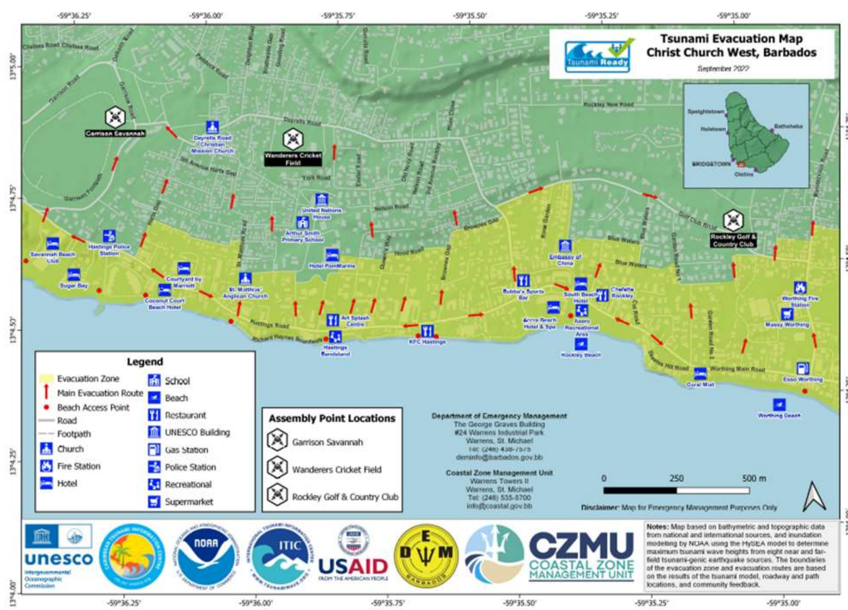
Supported by the International Tsunami Information Center under the UNESCO IOC Tsunami Ready Recognition Programme:

Empowering communities to be prepared for the next tsunami through proactive efforts in hazard assessment, preparedness, and response through the estimation of maximum flooding from tsunamis

Finished locations: Barbados, Majuro (The Republic of Marshall Islands), Chuuk, Yap, Pohnpei (The Federated States of Micronesia), Fiji Islands and Cayman Islands, Palau
Upcoming locations: Anguila, Antigua and Barbuda



Southwestern Barbados area of Christ Church West along the coastline (Google Earth) with maximum composite inundation and tsunami inundation height (a), composite maximum wave heights distribution along the coastline (b)



Tsunami evacuation map, Christ Church West, Barbados

NSF Large-Scale CoPe

The Cascadia Coastlines and People Hazards Research Hub (2021-2026)

COASTLINES AND PEOPLE

- Cascadia CoPes Hub is a multi-organizational collaborative NSF research hub - "*informing and enabling integrated hazard assessment, mitigation, and adaption through targeted scientific advances in collaboration with coastal communities*"
- CICOES/NCTR is a co-PI of the NSF-supported CoPe research hub
- CICOES/NCTR collaborates with other researchers across the hub on tectonic geohazard sources and integrated probabilistic modeling, with particular focus on tsunami debris forecasting and vulnerability assessment

Oregon State University | HUMBOLDT STATE UNIVERSITY | Sea Grant Washington | Georgia Tech | UNIVERSITY of WASHINGTON | William D. Ruckelshaus Center

Swinomish Indian Tribal Community | ASU Arizona State University | University of Oregon | Sea Grant Oregon | USGS science for a changing world

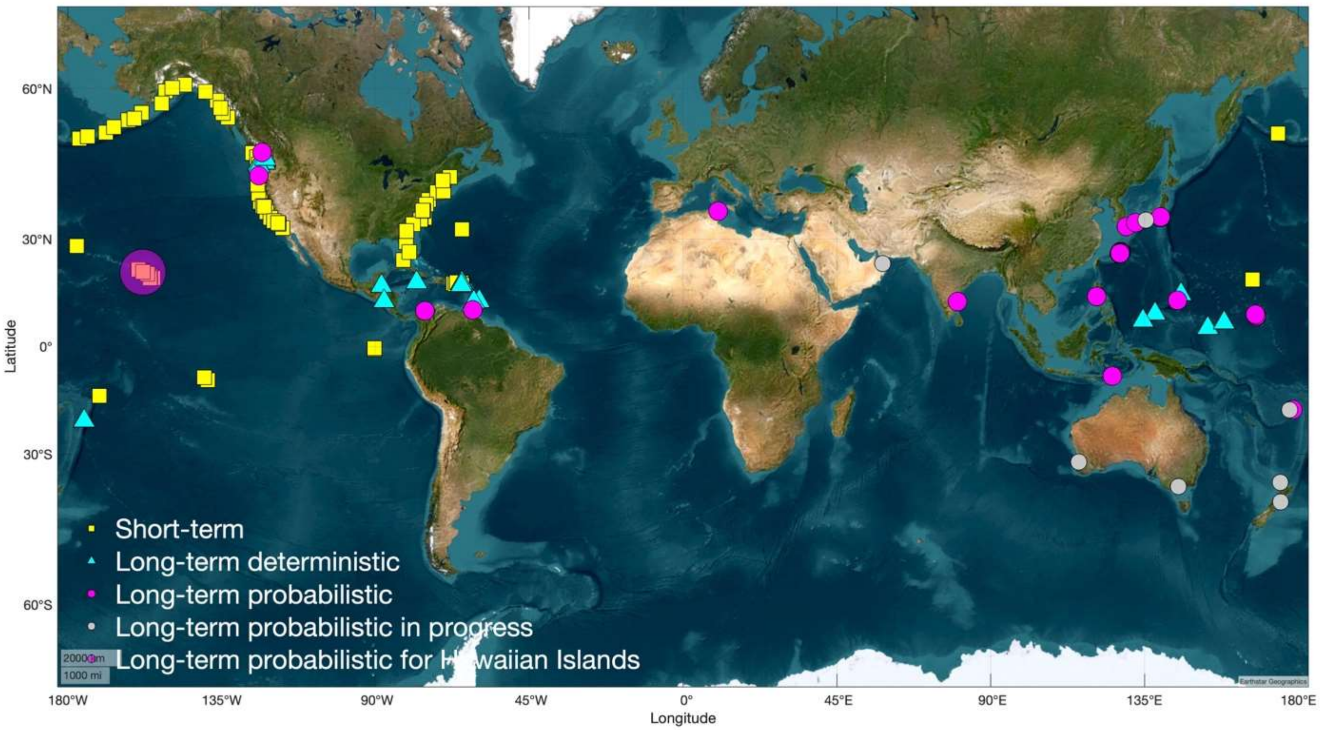
https://cascadiacopeshub.org/

Take-Away Points

- Unique role of PMEL/NCTR & UW/CICOES in applied tsunami research
- Highly collaborative/leveraged cross-NOAA research activities engaging a wide range of federal, state, and local partners to serve communities, governments, and businesses.
- Compelling future cutting-edge research directions and needs:
  - ❑ Enhancement and capability building of early detection system
    DART 4G array and GNSS network; AI-assisted warning and forecast system; Community-based design of effective tsunami information dissemination.
  - ❑ Advance tsunami research, observation, and forecasting in the context of Climate Change:
    Tsunami-tide-weather coupling; Intensified tsunami flooding due to sea level rise, rainfall and river flooding, and other extreme weather events; Sediment transport; Source investigation.
  - ❑ Improve probabilistic tsunami hazard assessment for coastal building resilience
  - ❑ Attract, train, and support the next-generation tsunami scientists

Short- and Long-Term Tsunami Hazard Assessments

- Short-term hazard assessments support NOAA's mission to issue real-time tsunami warnings that includes the flooding forecast capability based on DART data assimilation.
- A long-term tsunami hazard assessment is the application of modeling technology to identify the potential impact of tsunamis to coastal communities at risk using a deterministic approach or a probabilistic approach



Left: Location coverage of NCTR's short-term and long-term tsunami inundation hazard assessments.