Storm-driven continental shelf seiches and associated hazards

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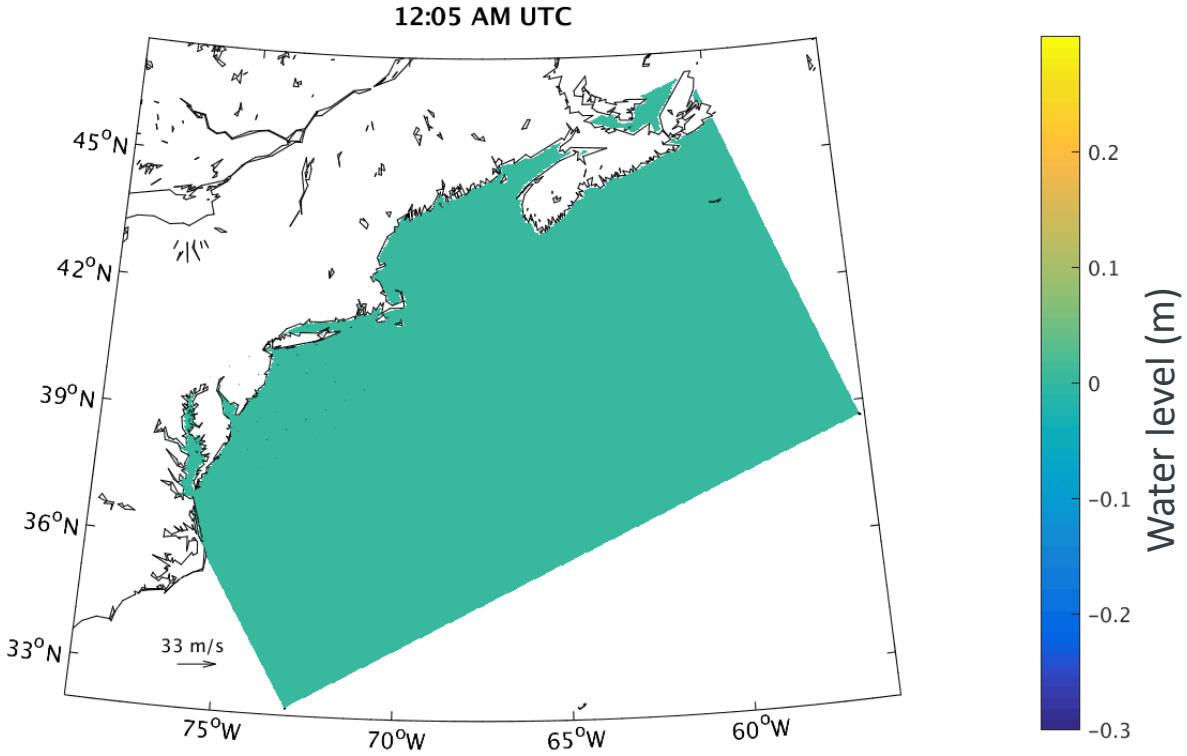
Coastal Trapped Waves? or Continental Shelf Seiches?

What do you see in this animation?

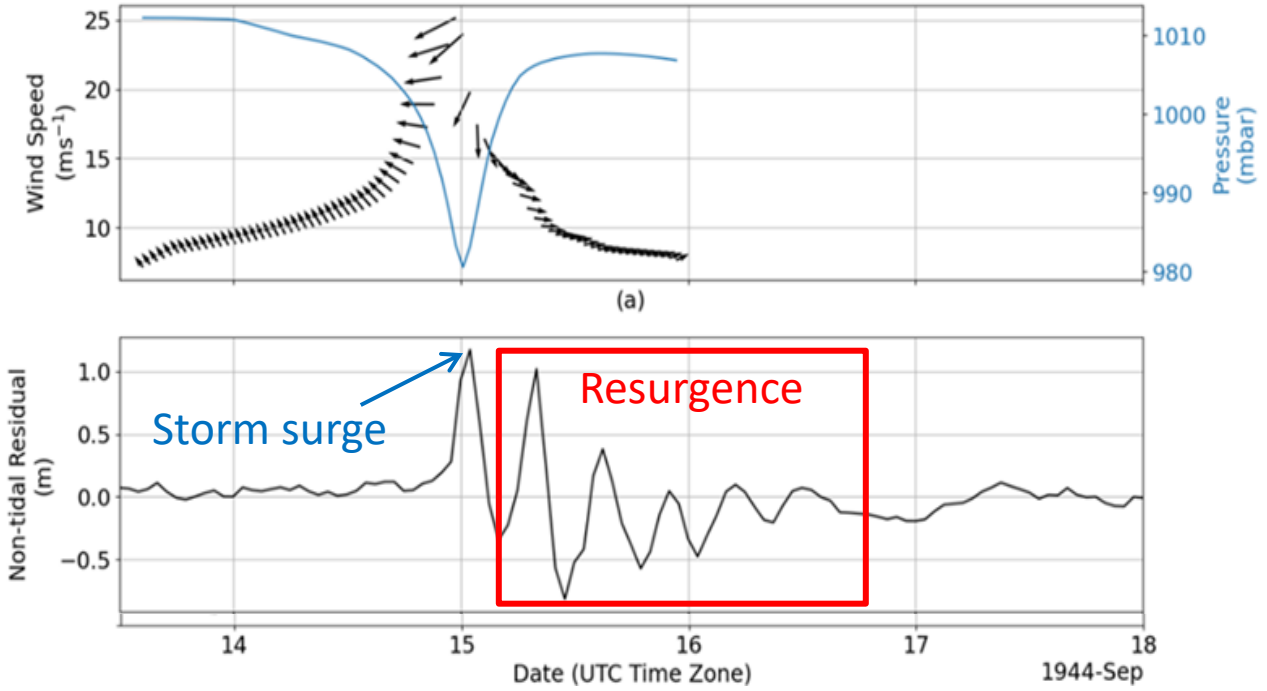
- Model simulation of the US East Coast
- Idealized wind blows 24h at 20 m/s.



Introduction

- A resurgence is a periodic recurrence of high water levels after a storm surge subsides.
- Munk et al. (1956) identified New York Bight as a location for hurricane-induced resurgence events and identified them as Edge Waves
- Resurgences are dangerous because they tend to catch one unaware, coming after the storm has subsided (Redfield & Miller, 1957).
- A resurgence, if it peaks at high (low) tide, could cause flooding (ship grounding) or other hazards (e.g. dangerous or erosive currents)

From Trinh et al. (submitted)

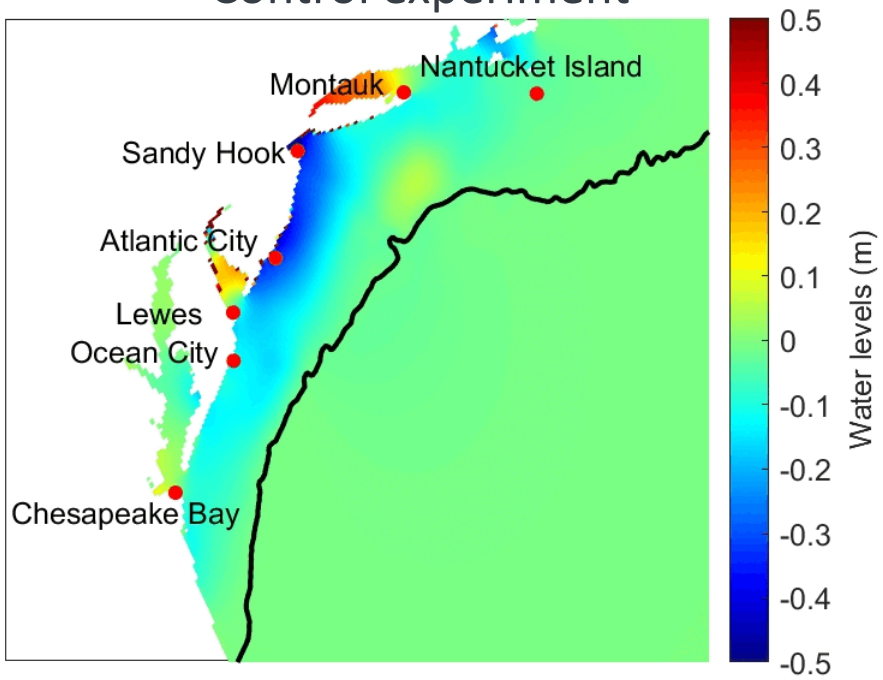


Storm Surge Modeling with Idealized Wind

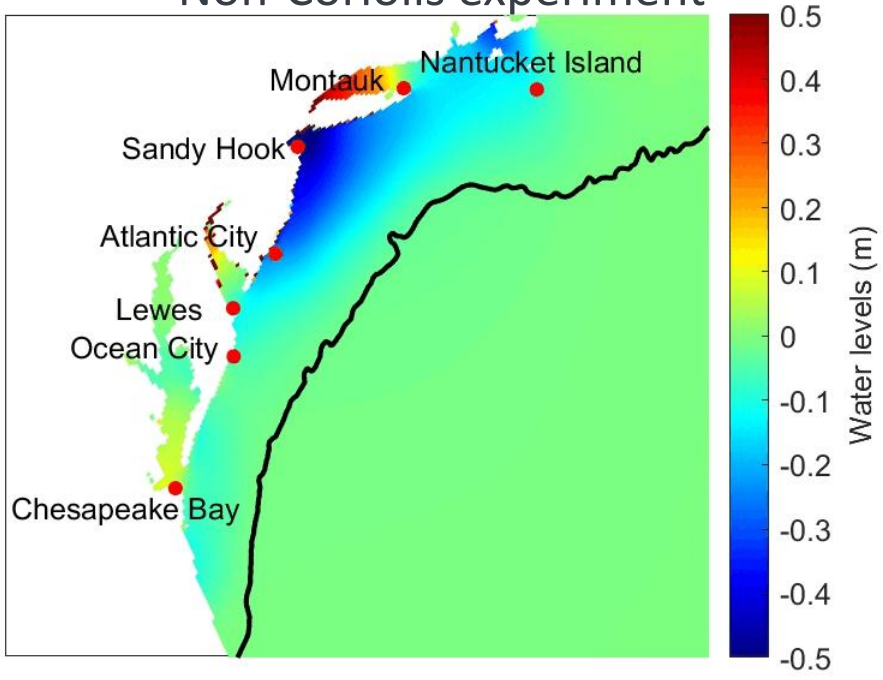
Trinh et al., submitted -- "Revisiting the mechanism and assessing historical resurgences after hurricane storm surges in New York Bight", submitted to ***Continental Shelf Research***.

- The sECOM model is applied in 5-day simulations with idealized wind forcing.
- Northwest Atlantic domain with ~5 km resolution, 300 x 300 grid, constant T and S.
- Forcing: No tides; One-day southeast 20 m s^{-1} wind, then wind is abruptly reduced to zero.

Control experiment

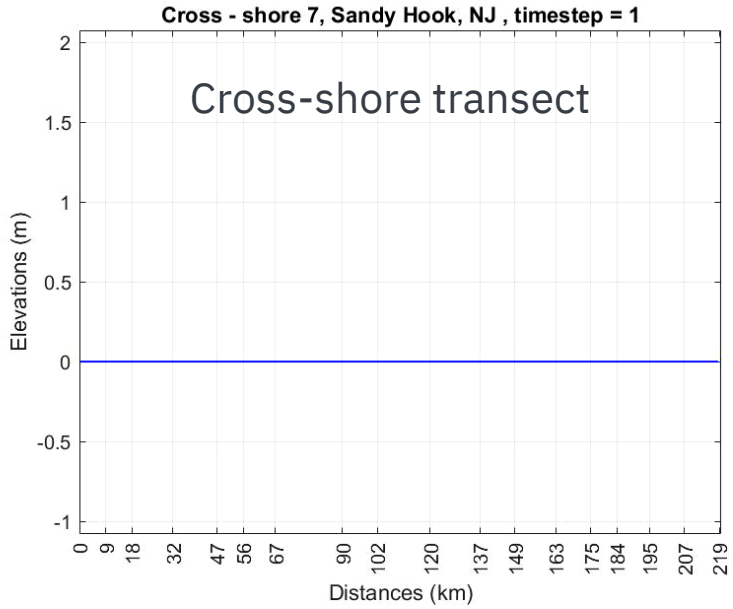


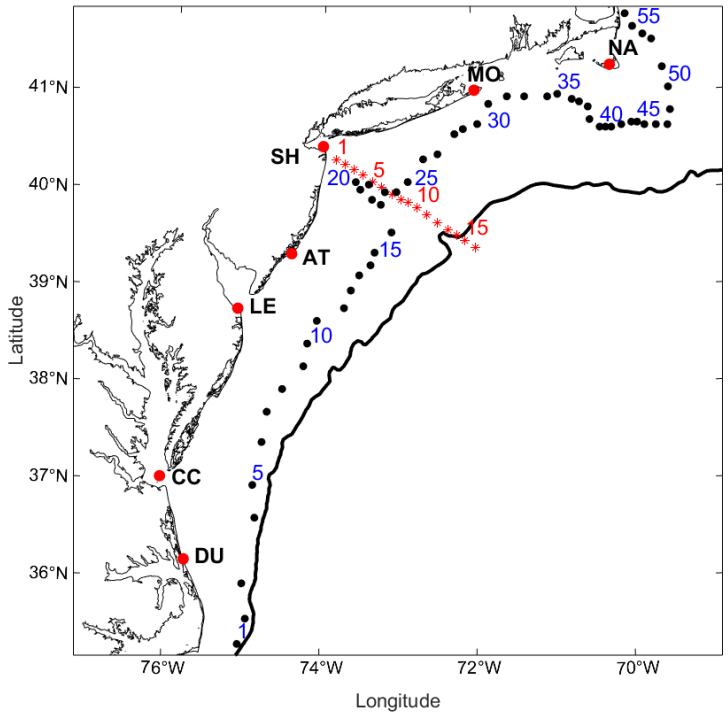
Non-Coriolis experiment

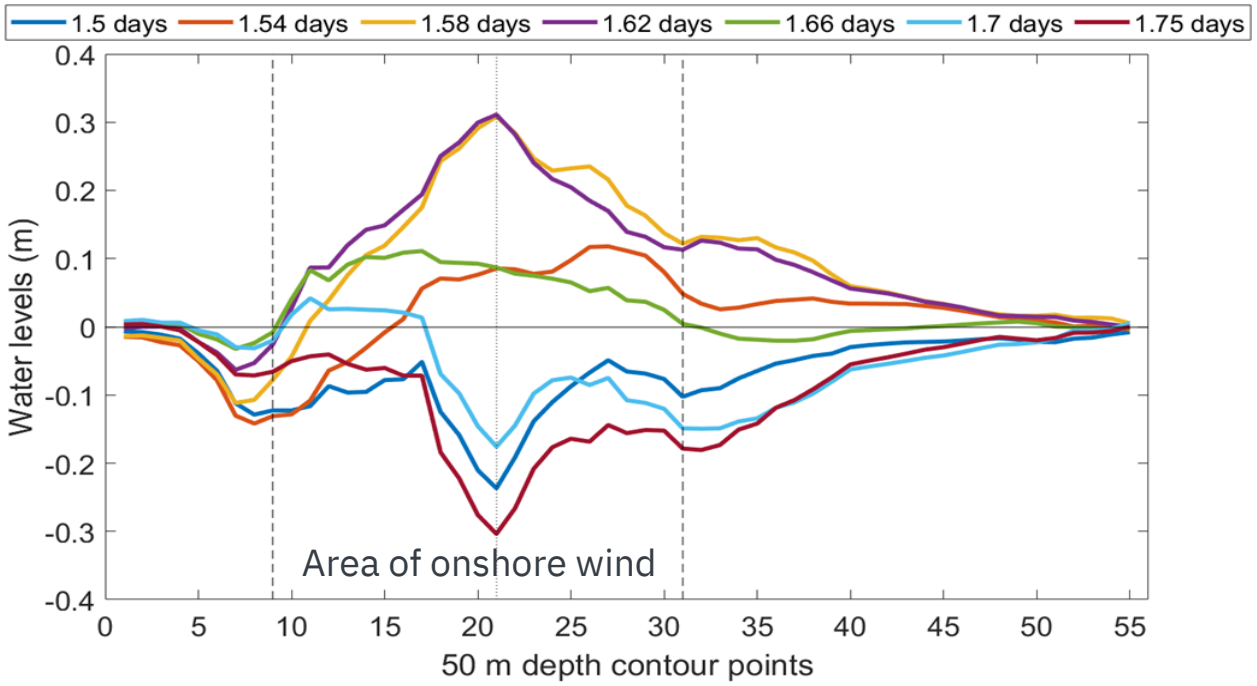


Results

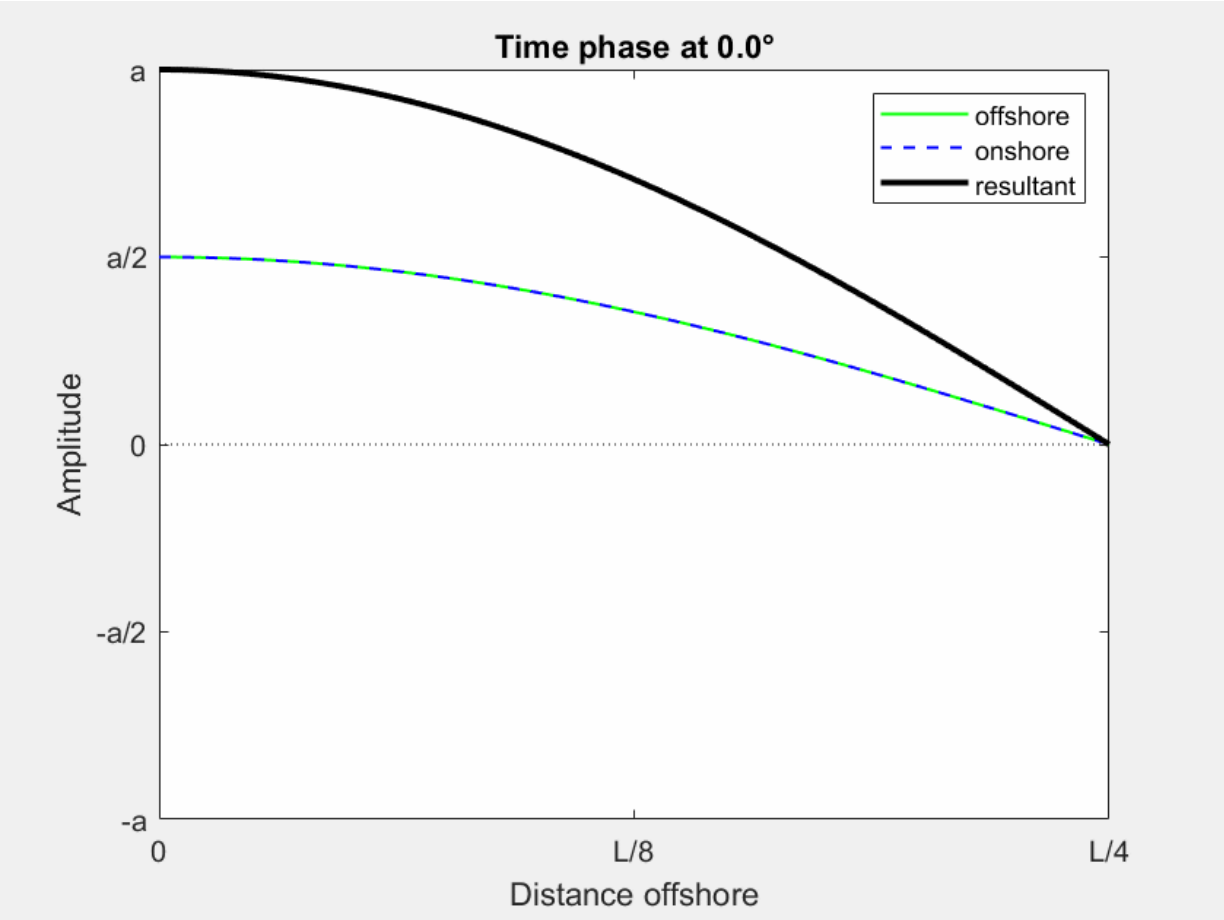
- Water level oscillations from idealized wind modeling along the cross-shore and alongshore transects indicate a **localized standing wave**.
- Predominant mechanism: continental shelf seiche, with energy trapped and amplified in the NYB by the convergent coastline
- Secondary mechanism: Energy is leaked down-coast by Kelvin waves.







Mechanics of an Idealized Shelf Seiche



Here, a sinusoidal cross-shelf wave form is assumed.

L is the seiche wavelength and L/4 corresponds to the continental shelf width

Perfect coastal reflection at X = 0

Negative reflection at X = L/4 (e.g. Battjes and Labuer, 2014)

However, real-world seiches do not have exactly 180-degree phase shift reflection and a period L/sqrt(gh)

Trinh et al., 2025, submitted to *Continental Shelf Research*

Part II: East and Gulf Coast Seiches and Associated Hazards

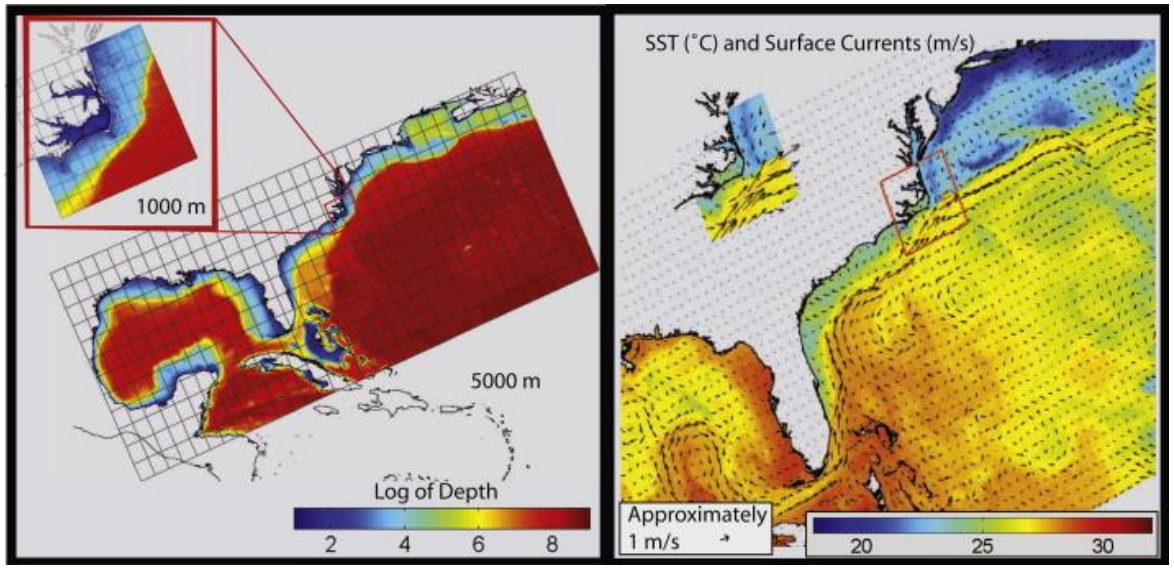
- Resurgences have recently caused minor flooding at New York Harbor when coinciding with high tides (Ayyad et al. 2020)
- According to the literature, shelf seiches have been observed on the Texas shelf (Hope et al., 2013), Argentina (Mysak, 1980), and Western Australia (Pattiaratchi et al. 2022).

➢ **Objectives:**

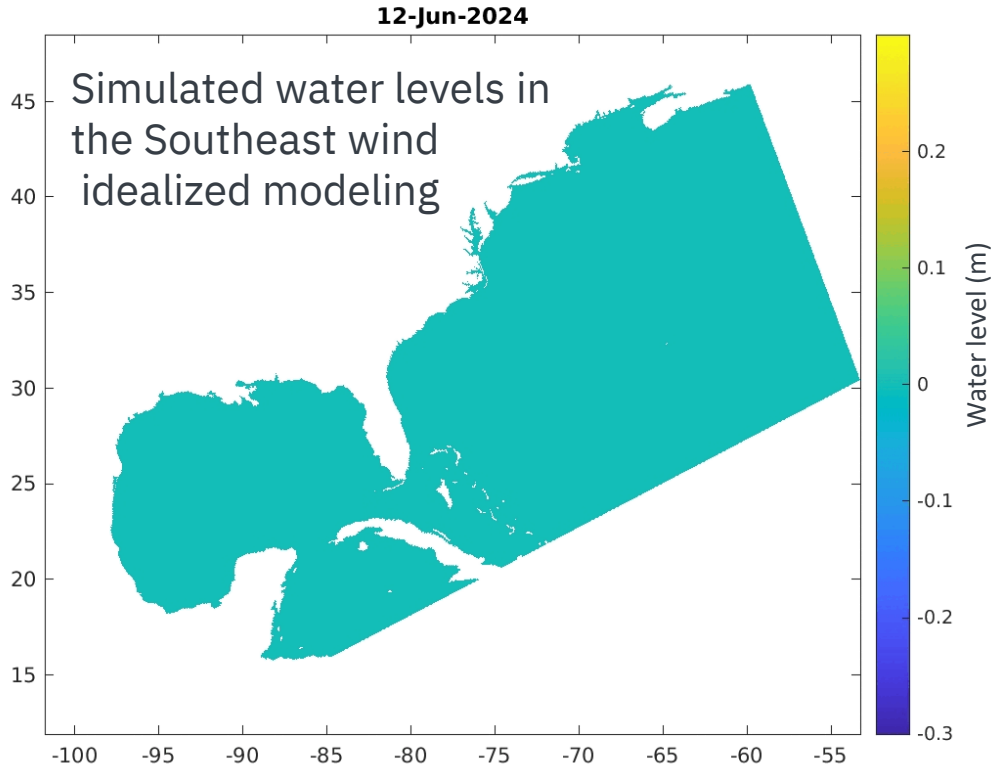
- Estimate the intrinsic period of the shelf along the US East and Gulf Coast using wavelet analysis of model data from idealized wind events
- Apply this knowledge of shelf period with wavelet **analysis of historical tide gauge** observations **objectively detect** resurgence events
- Quantify the number of historical floods and blowout tides (low waters)
- Estimate the probability of resurgence events of different magnitudes and different resulting hazards (floods, blowout tides, erosive currents)

Methods: Idealized Wind Modeling for the U.S. Gulf and East Coasts

- More detailed 3D ROMS modeling within the COAWST framework (model applied with assistance from John Warner, US Geological Survey) with 16 depth layers
- Model grid covers the US East and Gulf Coasts at a resolution of 5 km (Warner et al., 2010)
- Idealized 6h wind events, applied for 8 wind directions: N, NE, E, SE, S, SW, W, NW

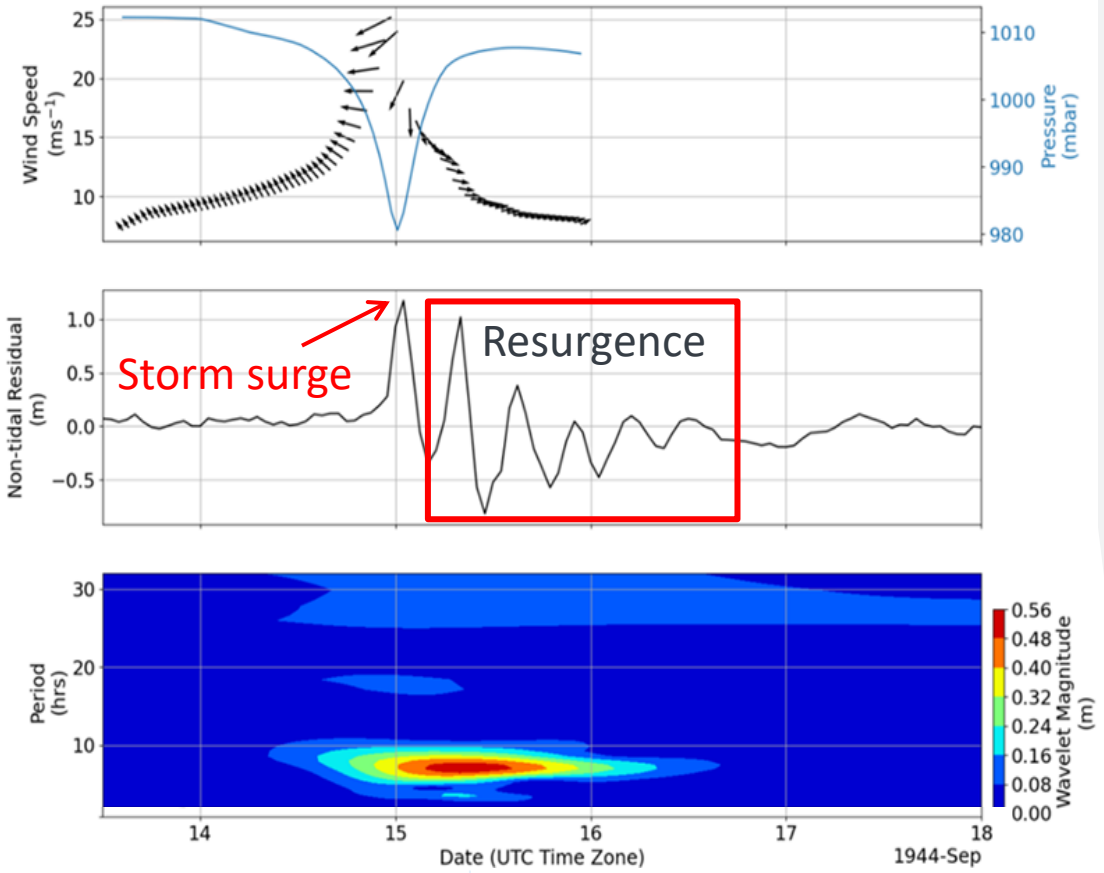


1/10 cell edges shown for clarity (Warner et al., 2010)



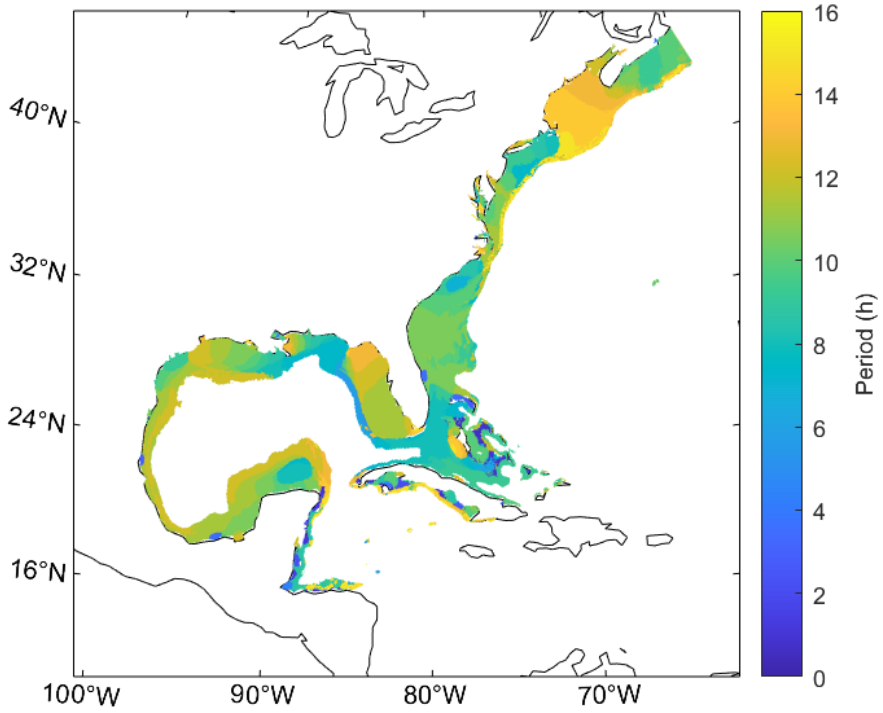
Methods: Wavelet Analysis for Seiche Detection

- Continuous wavelet transform
- Morse wavelet
- For each wind direction, determine the locations with large wavelet magnitudes
- Record the corresponding periods
- Applied at all grid cells with depth <1000m



Results: Potential Resurgence Locations and Periods

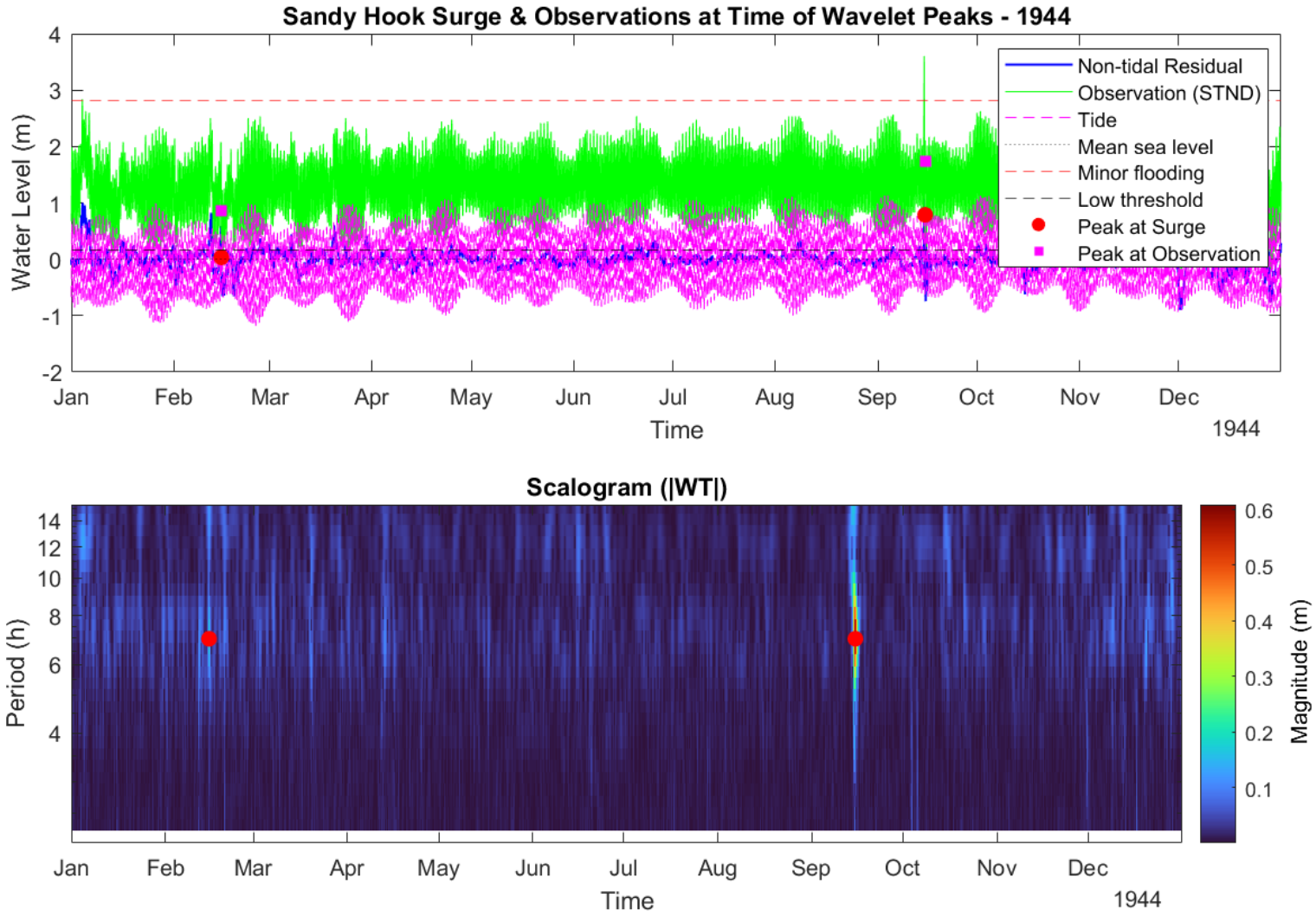
- The Bay of Fundy, Long Sound Island and the west coast of Florida have seiche periods of 12-13 hours – tidal resonance
- (not shown) Onshore and offshore wind can be a key factor to excite a resurgence on the coast
- The range of periods discovered with these experiments guides an analysis of historical tide gauge observations to seek resurgence events



Periods corresponding to their maximum amplitudes

Method: Historical observation analysis

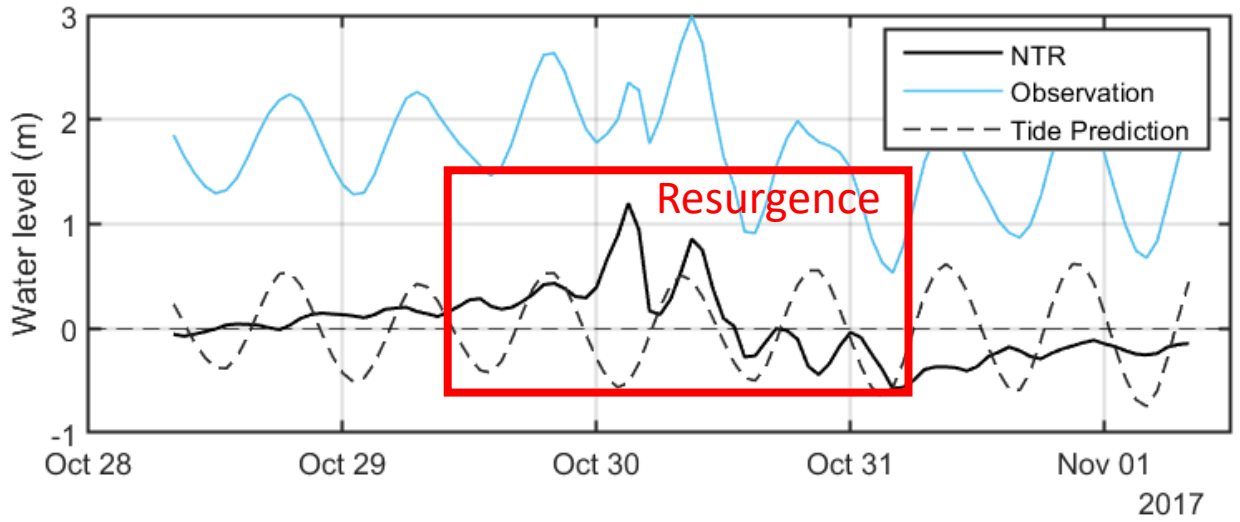
- Analyze observed water levels, up to more than 100 years at some stations
- Apply automatic detection with wavelet analysis of NTR to find where and when resurgence occurs
- Quantify resurgence characteristics
- Assess coastal hazards



Preliminary Results: Floods, low waters, probabilities

Location	Shelf Seiche Detections	Flooding Events	Low-Water Events	Flooding Probability	Low-Water Probability
Sandy Hook, NJ	154	8	21	0.052 (5.2%)	0.136 (13.6%)
Atlantic City, NJ	71	6	9	0.085 (8.5%)	0.127 (12.7%)
Boston, MA	81	2	-	0.025 (2.5%)	-
Cedar Key, FL	44	0	23	(*)	0.523 (52.3%)
Galveston Bay, TX	5	0	-	(*)	-
Texas Point, TX	6	0	-	(*)	-

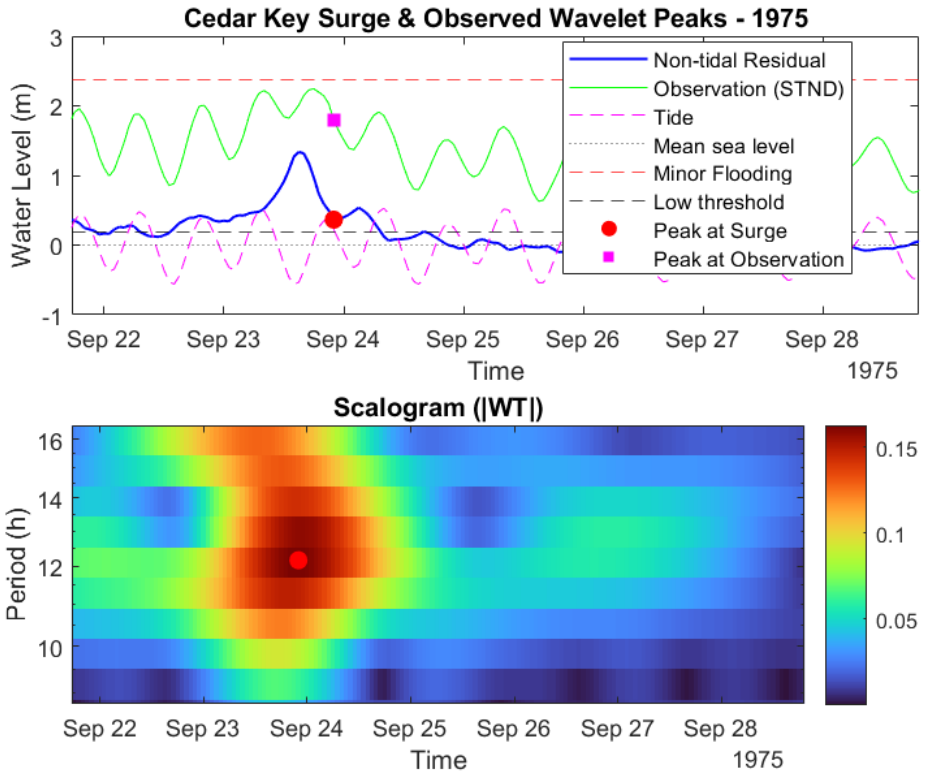
* Zero floods but potential cases where tide-surge interaction (or storm surge) and seiches could not be separated with current methods



Resurgence at Sandy Hook during an Extratropical Cyclone, 2017

Challenges and Future work

- Resurgence is an impulse-driven process and difficult to separate and quantify apart from the storm surge
- Resurgences can have a period similar to tide-surge interactions. Thus, it is difficult to separate their effects
  - We are experimenting with asymmetric wavelets to seek to separate these signals
- We will next use idealized geometry shelf modeling to assess what controls the seiche period and what controls trapping of seiche energy



Conclusions

Conclusions from Trinh et al. (submitted) include:

- New York Bight is a hotspot for “resurgence”
- Resurgence trough-to-crest heights were up to 1.5 m, and historical floods are identified
- Idealized modelling demonstrates that the predominant mechanism at NYB is a shelf seiche

Part II preliminary conclusions include:

- We have mapped the intrinsic period of the US East and Gulf Coast continental shelf
- Seiches have caused flooding after both extratropical and tropical cyclones
- Tide-surge interaction can be difficult to separate from seiches at locations of tidal resonance, and we are working on improving our detection methods

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THANK YOU

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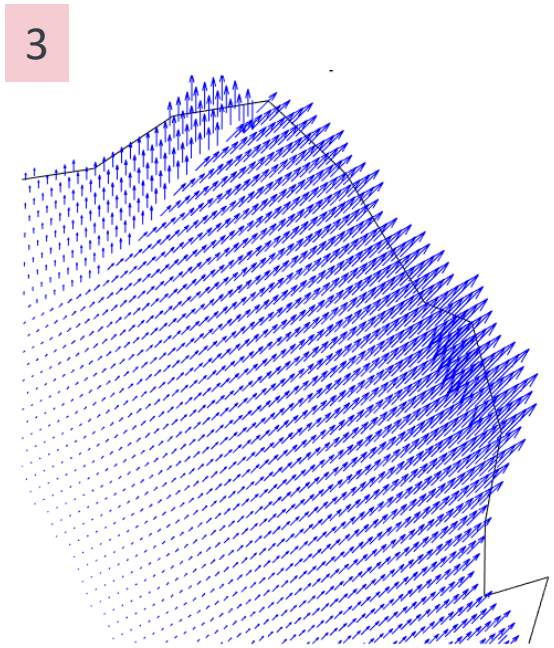
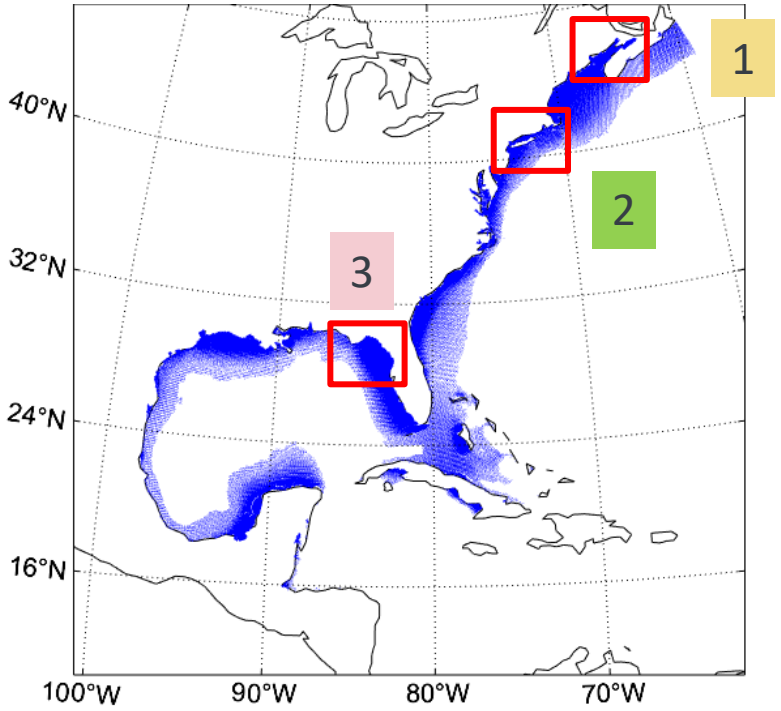
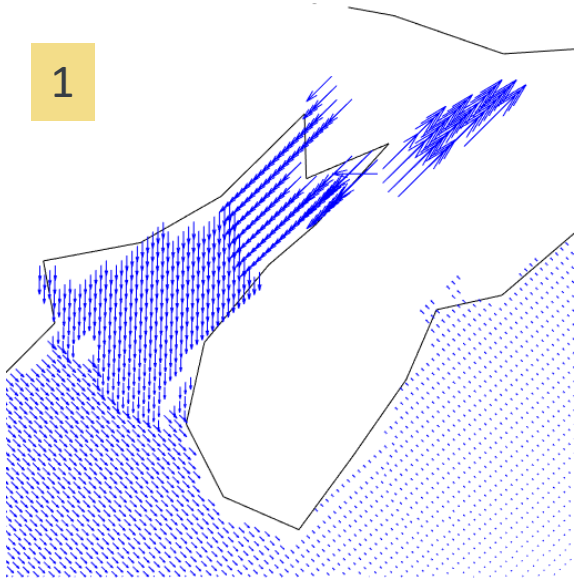
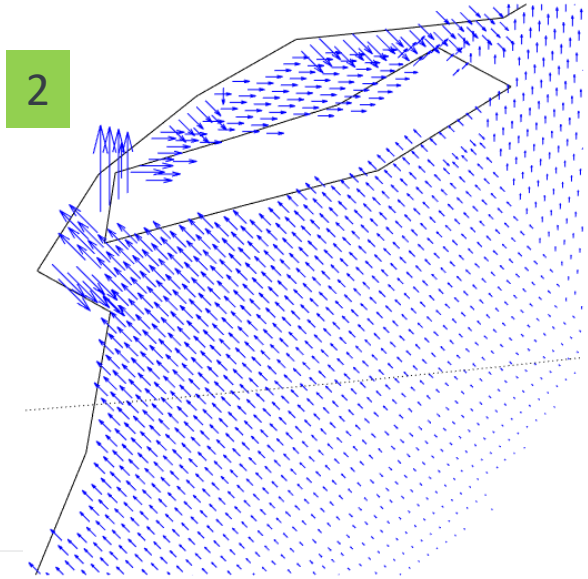
Corresponding Wind Direction with Maximum Resurgence Amplitudes

- The Bay of Fundy and Long Sound Island, and the west coast of Florida, the western Gulf of America, have periods of semidiurnal tide.
- Along the East Coast and the Gulf of America have potential continental shelf seiches.
- Onshore and offshore wind can be a key factor to excite a resurgence on the coast

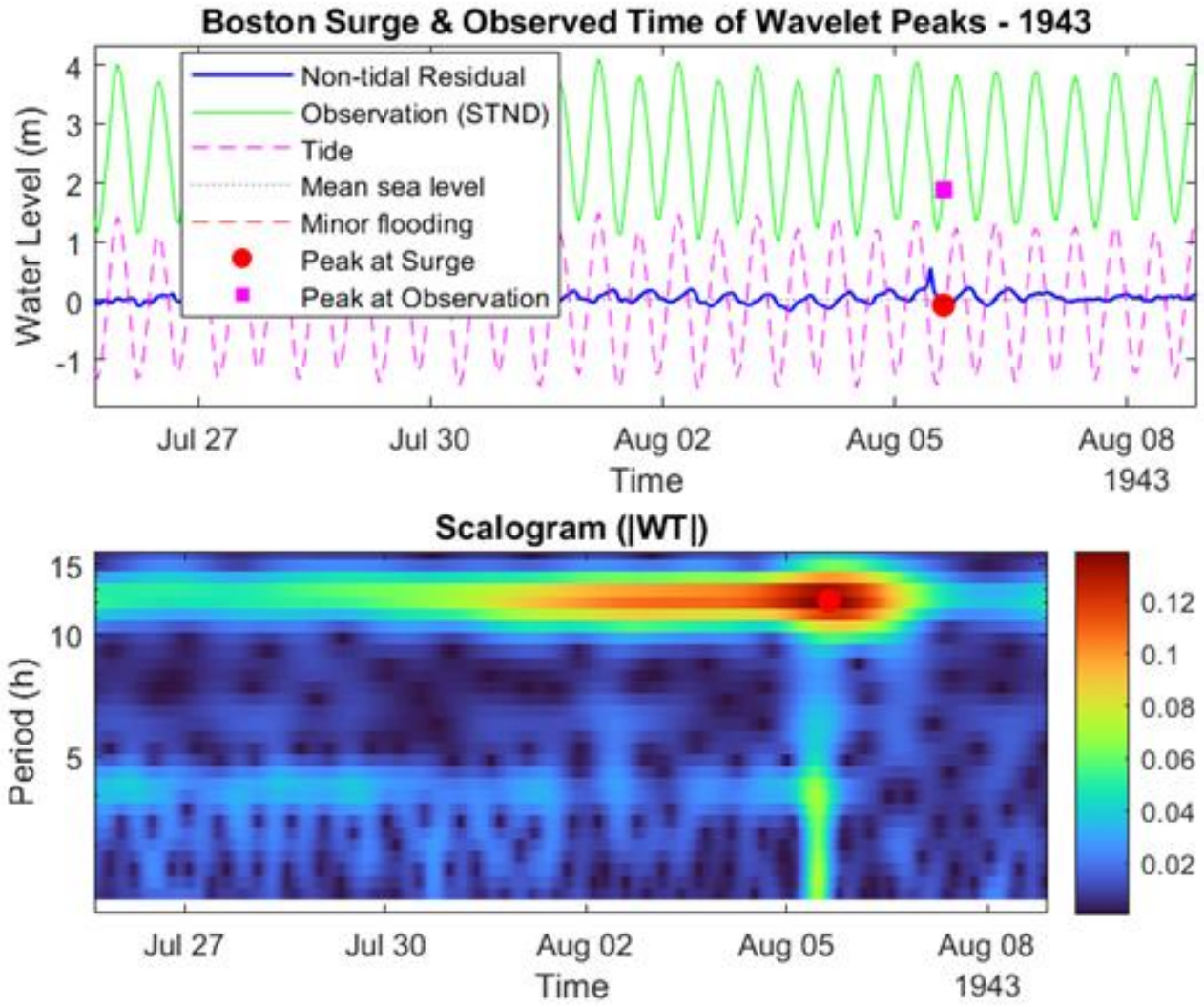








Challenges


Boston Surge & Observed Time of Wavelet Peaks - 1943
Non-tidal Residual
Observation (STND)
Tide
Mean sea level
Minor flooding
Peak at Surge
Peak at Observation
Water Level (m)
4
3
2
1
0
-1
Jul 27
Jul 30
Aug 02
Aug 05
Aug 08
1943
Time
Scalogram (|WT|)
Period (h)
15
10
5
0.12
0.1
0.08
0.06
0.04
0.02
Jul 27
Jul 30
Aug 02
Aug 05
Aug 08
1943
Time