ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

ALONGSHORE VARIABILITY OF COASTAL MORPHODYNAMICS IN EASTERN LAKE ERIE DUE TO LOW FREQUENCY OSCILLATIONS OF LAKE LEVEL

Stony Brook University

Erdinc Sogut, PhD Student

Stony Brook University, Department of Civil Engineering, NY, USA

Stony Brook University

Ali Farhadzadeh, PhD, PE

Stony Brook University, Department of Civil Engineering, NY, USA

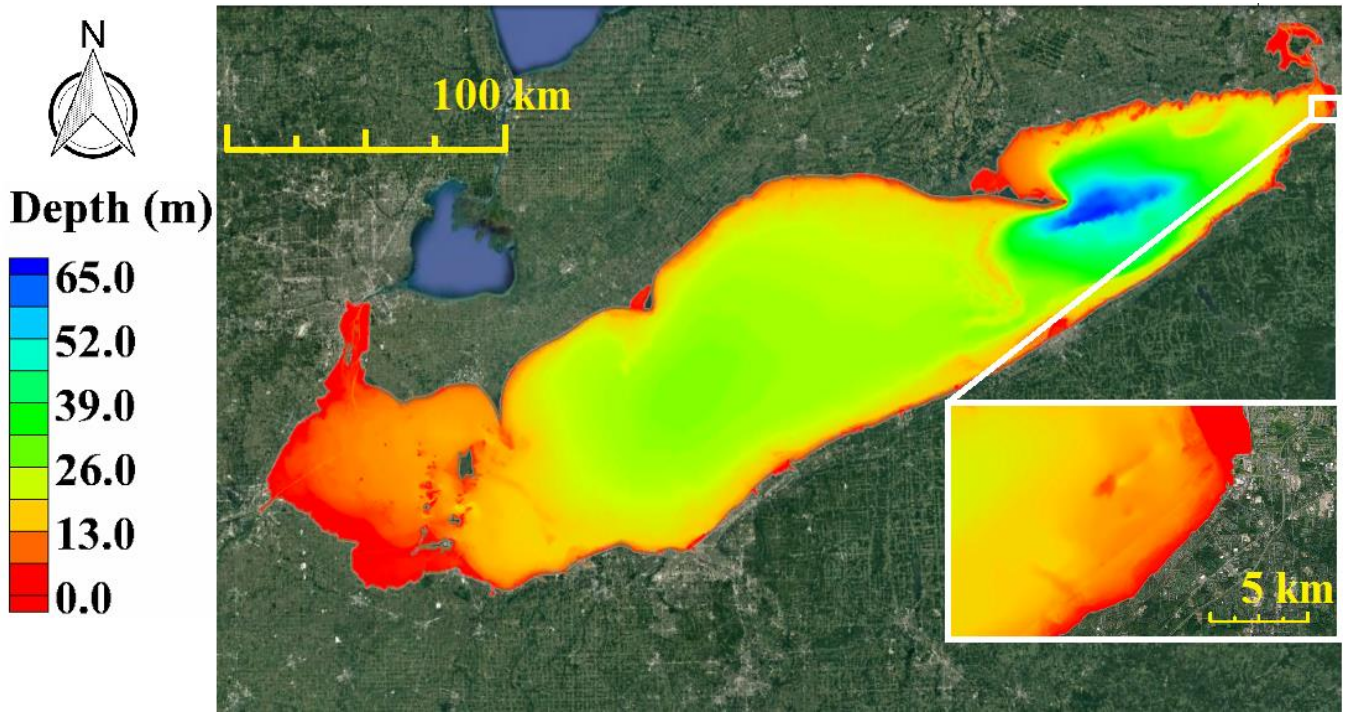



OUTLINE

- Introduction
- Seiche in Lake Erie
- Beach Morphology Response to Seiche
- Results & Discussions

Introduction

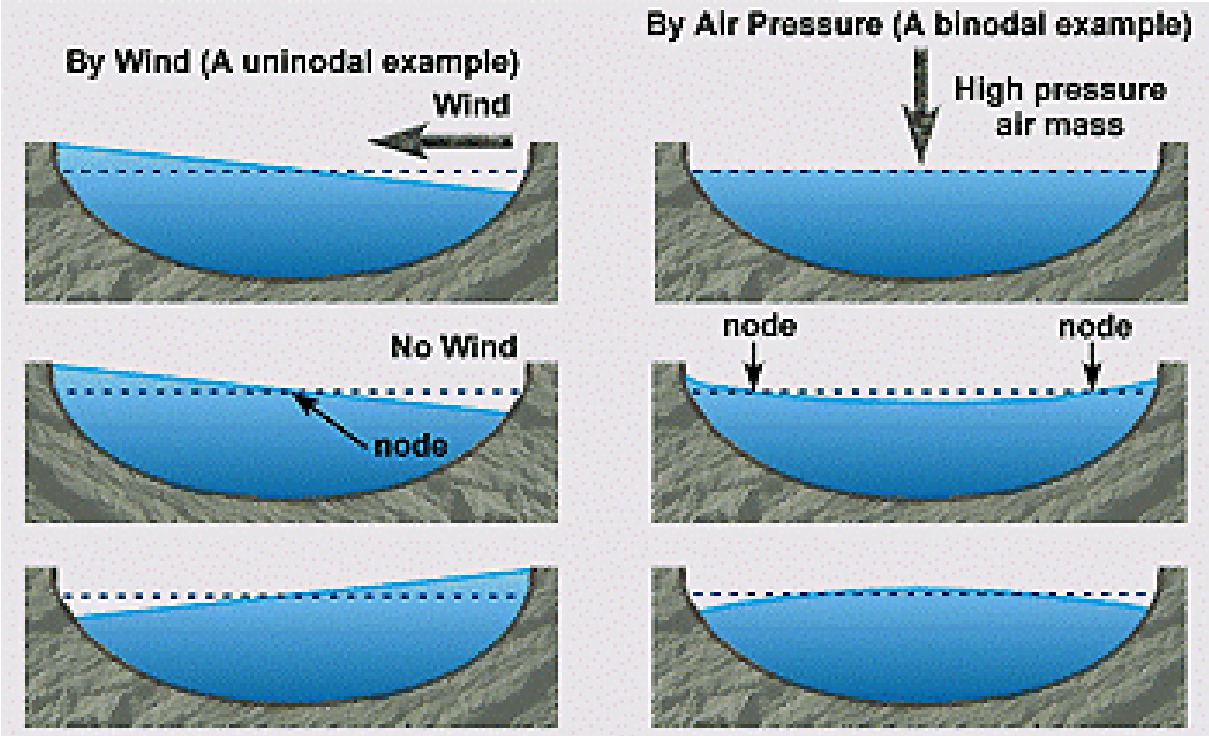
- Lake Erie has the fourth largest surface area, shallowest water depth and smallest volume among the five Great Lakes in North America.
- The lake is 390 km long and 90 km wide. The average depth and maximum depths are approximately 20 m and 64m (NOAA).
- The dominant wind direction over Lake Erie is southwest-northeast, along the lake's longitudinal axis.



Lake Erie Bathymetry and Study Area

Seiche in Lake Erie

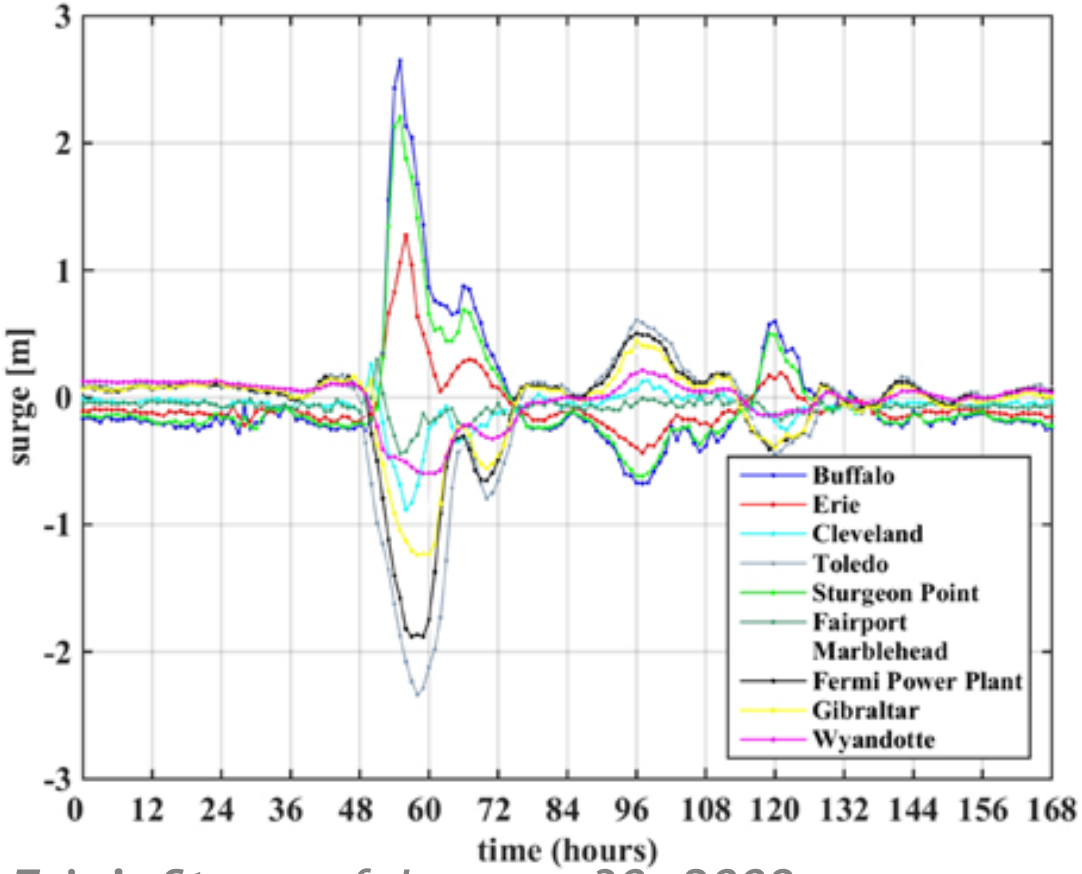
- High wind and moving pressure systems can result storm surges of up to 3 m on Eastern Lake Erie and significant drop in the water level at Western Lake Erie due to its shallow depth.
- Such a water level gradient can trigger unique post-storm free water-level fluctuations or seiches in Lake Erie.



Schematic Drawing of Seiche

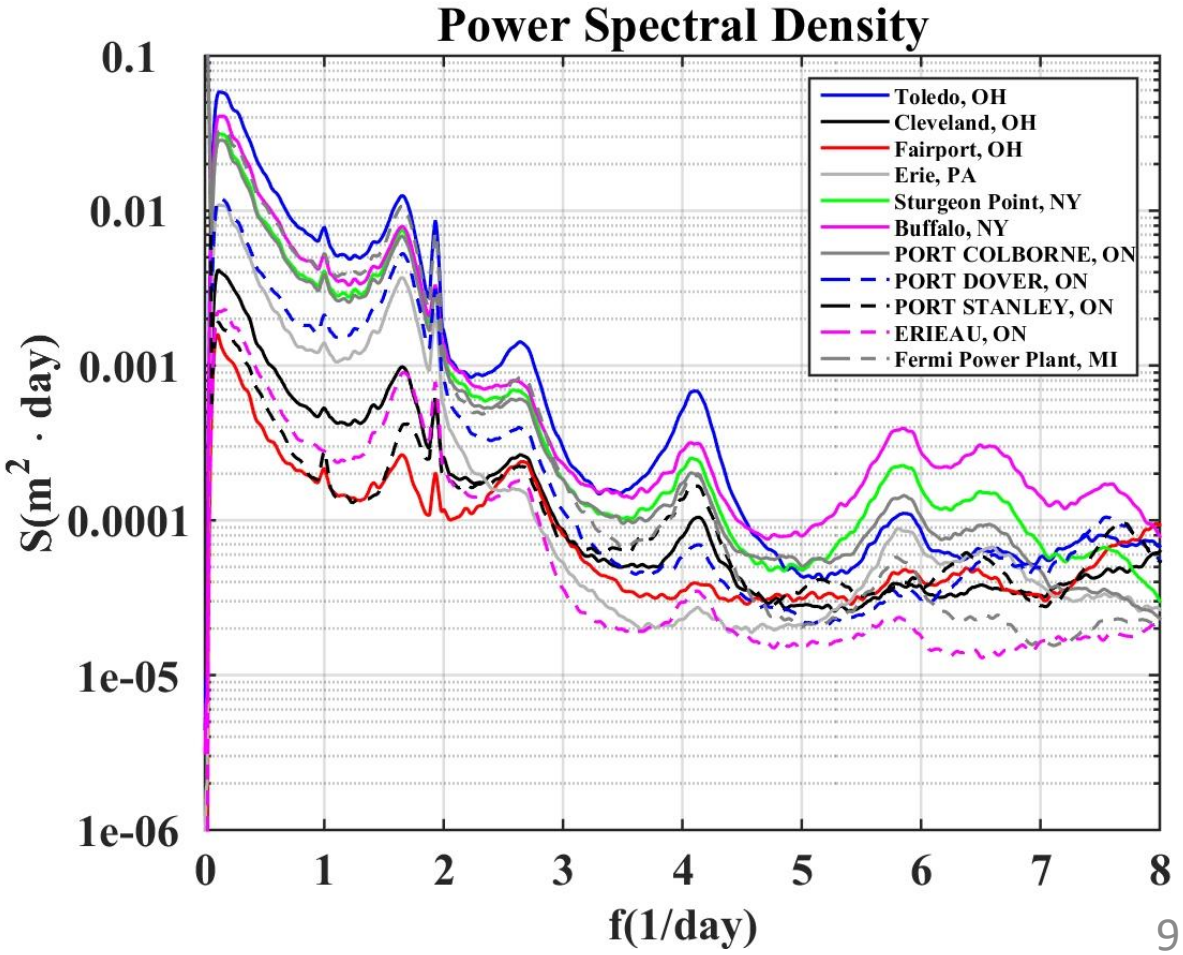
- Seiches are developed as standing waves in the lake travelling across the lake and rotating counterclockwise until their energy dissipates.
- A seiche event in 1844 was reported as “one of the greatest disasters in Buffalo’s recorded history.” It “occurred without warning, breaching the 14-foot seawall, flooding the waterfront, and drowning at least 78 people” (Buffalo Architecture and History 1865).

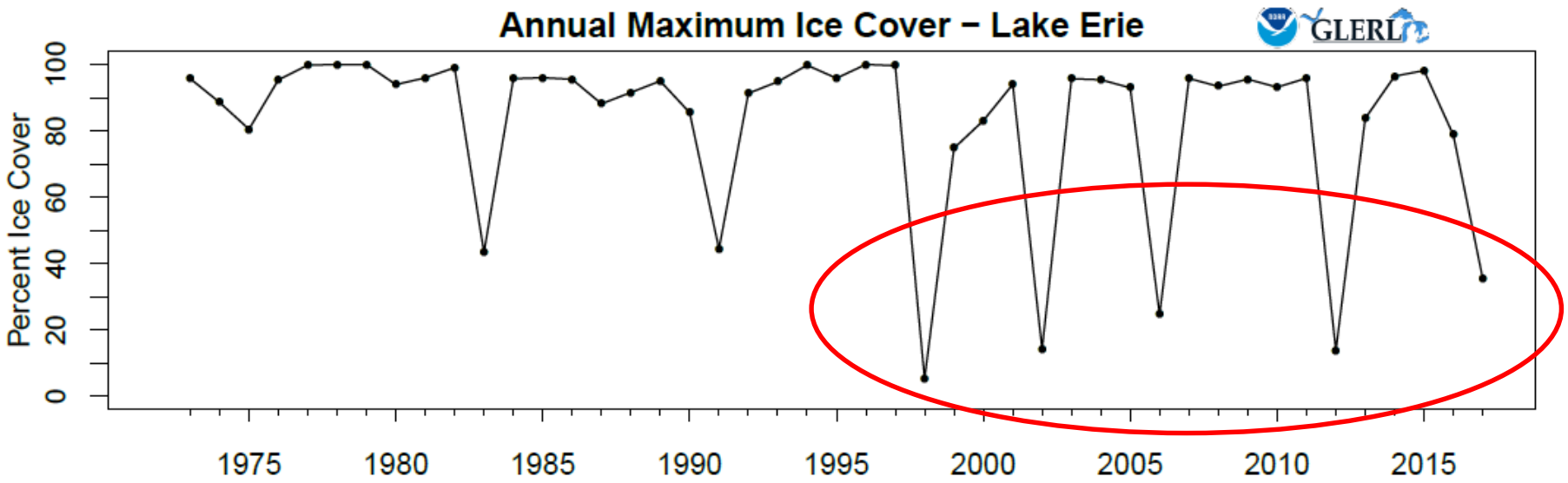
- Surge and seiche following an extreme event



Water level variations following Lake Erie's Storm of January 30, 2008

- Spectra of Lake Erie Long-term Water Level 1975-2015





Annual Maximum Ice Cover for Lake Erie (Ref: NOAA)

- Study shows surface ice tends to dampen low frequency motions in the lake
- We have been facing warmer winters lately, resulting in lower surface ice % and more seiching motions
- Question: What does this mean to our beaches?

Beach Morphology Response to Seiche

- A stretch of shoreline (≈ 2 km) near Buffalo where seiche is energetic is selected
- Coupled ADCIRC+SWAN model used to generate wave and surge fields for a 6-month period in 2012
- Morphodynamics models, CSHORE and XBeach are used to study seiche effects on shoreline

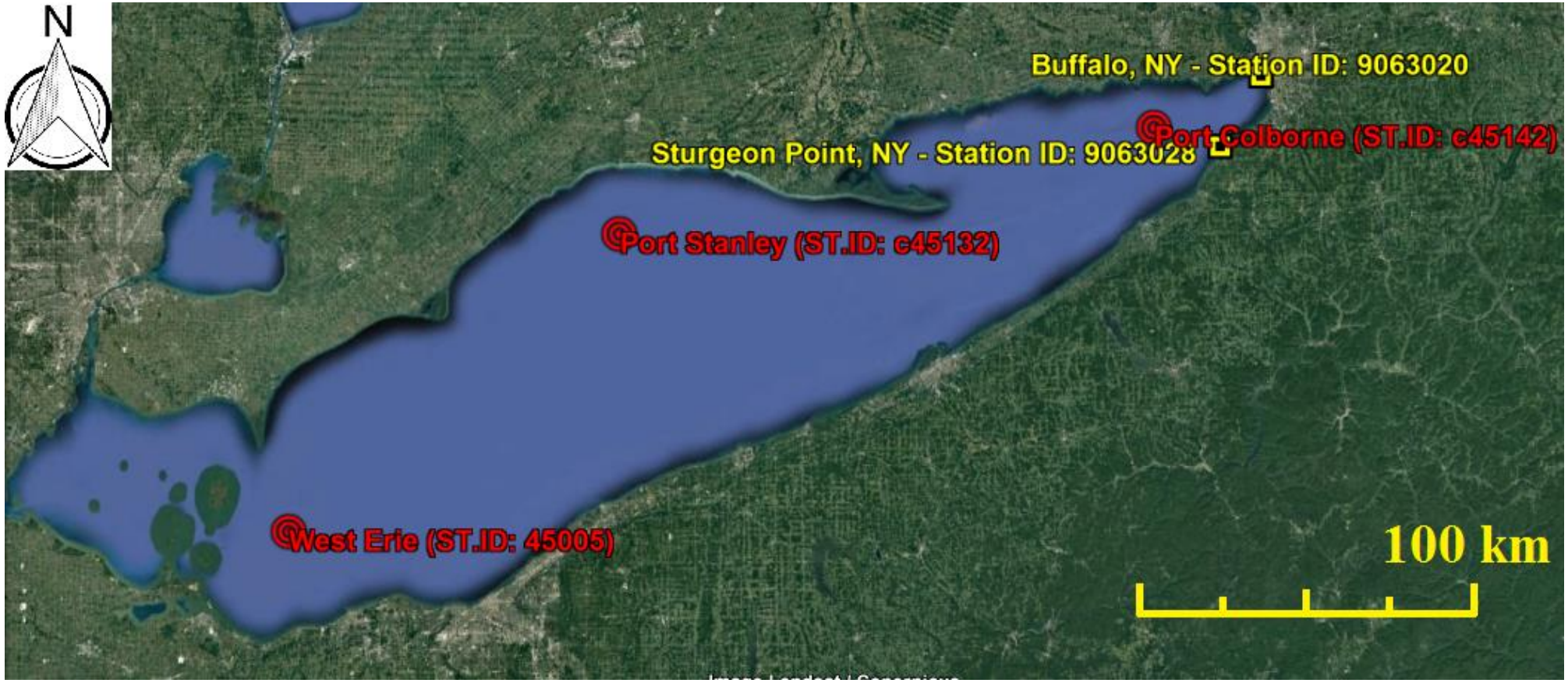
Morphodynamics Model Input

- Water Level and Wave Boundary Condition: Coupled ADCIRC+SWAN
  - *Wind and Pressure Data*
  - *Wind and Pressure Calibration/Validation*
  - *Water Level and Wave Data*
  - *Water Level and Wave Validation*
- Sediment Characteristics

Wind and Pressure Data

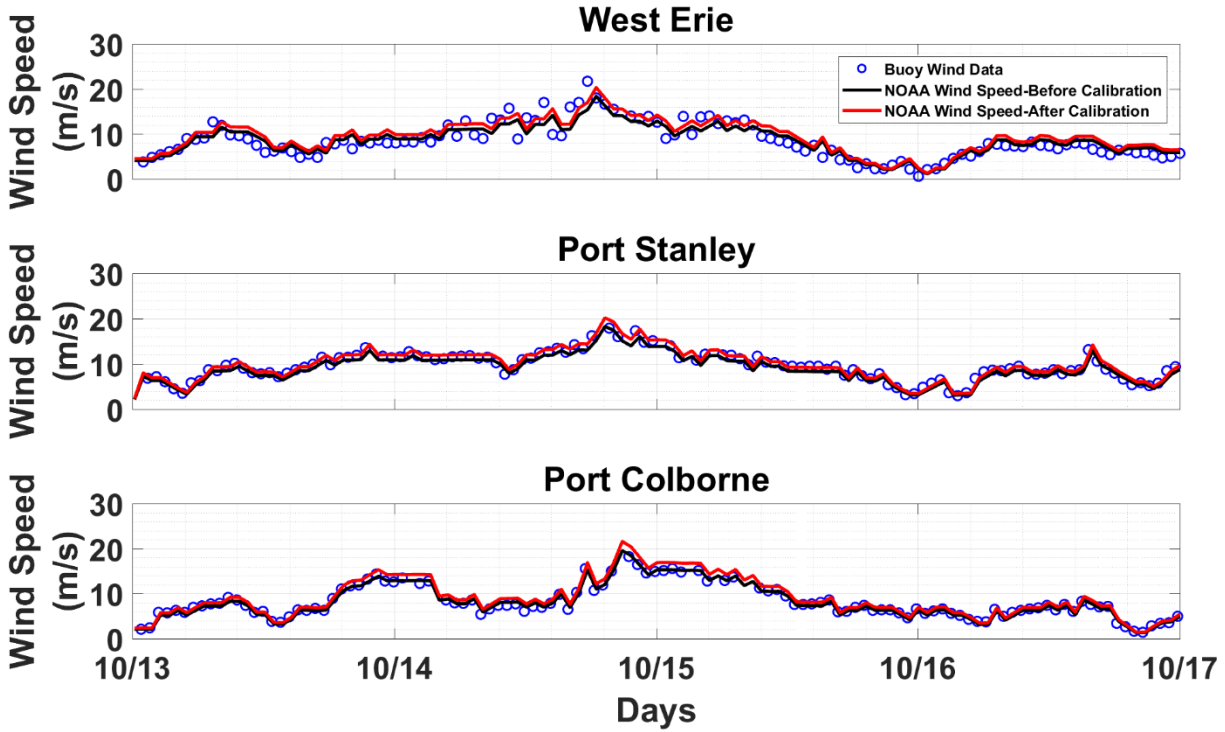
- Hourly wind data from NOAA GLCFS - Great Lakes Coastal Forecasting System (NOAA/GLERL GLCFS)
- Hourly pressure data from The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR)
- NOAA/GLERL GLCFS wind data and CFSR pressure data are refined to computational grid nodes of the coupled ADCIRC+SWAN model using the natural neighboring method.

Wind and Pressure Calibration/Validation

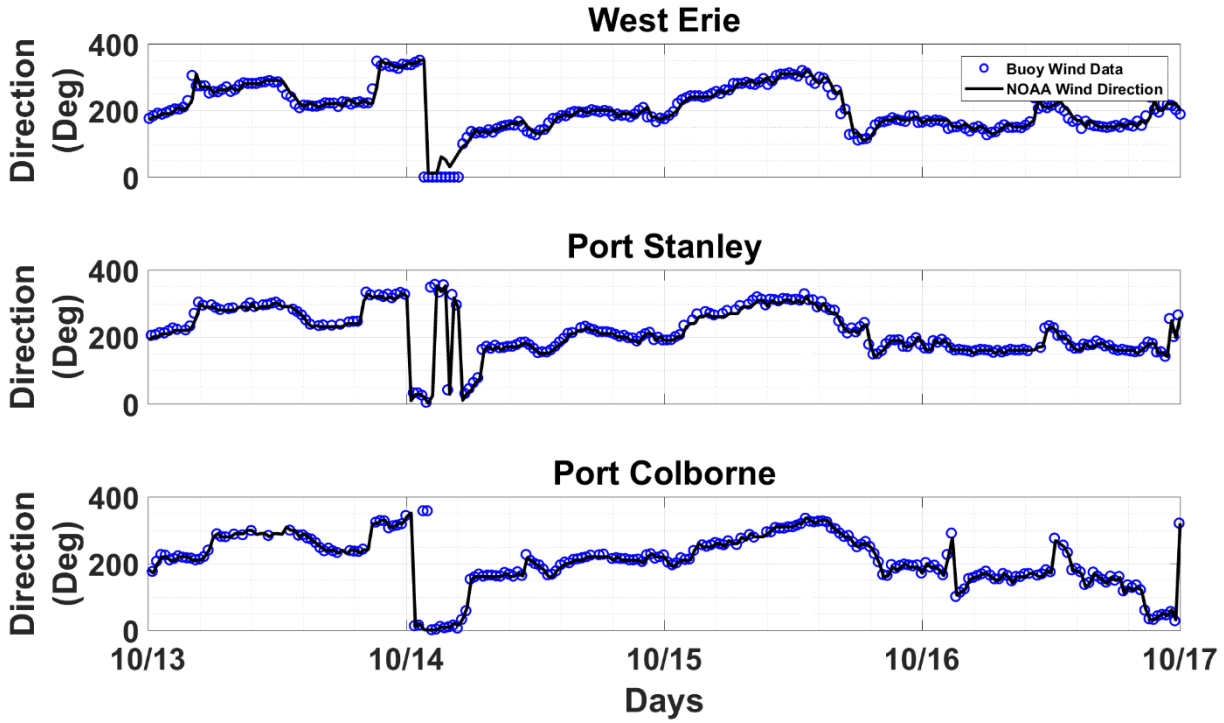


Locations of Water Level Stations and Wave Buoys in Lake Erie

Wind and Pressure Calibration/Validation

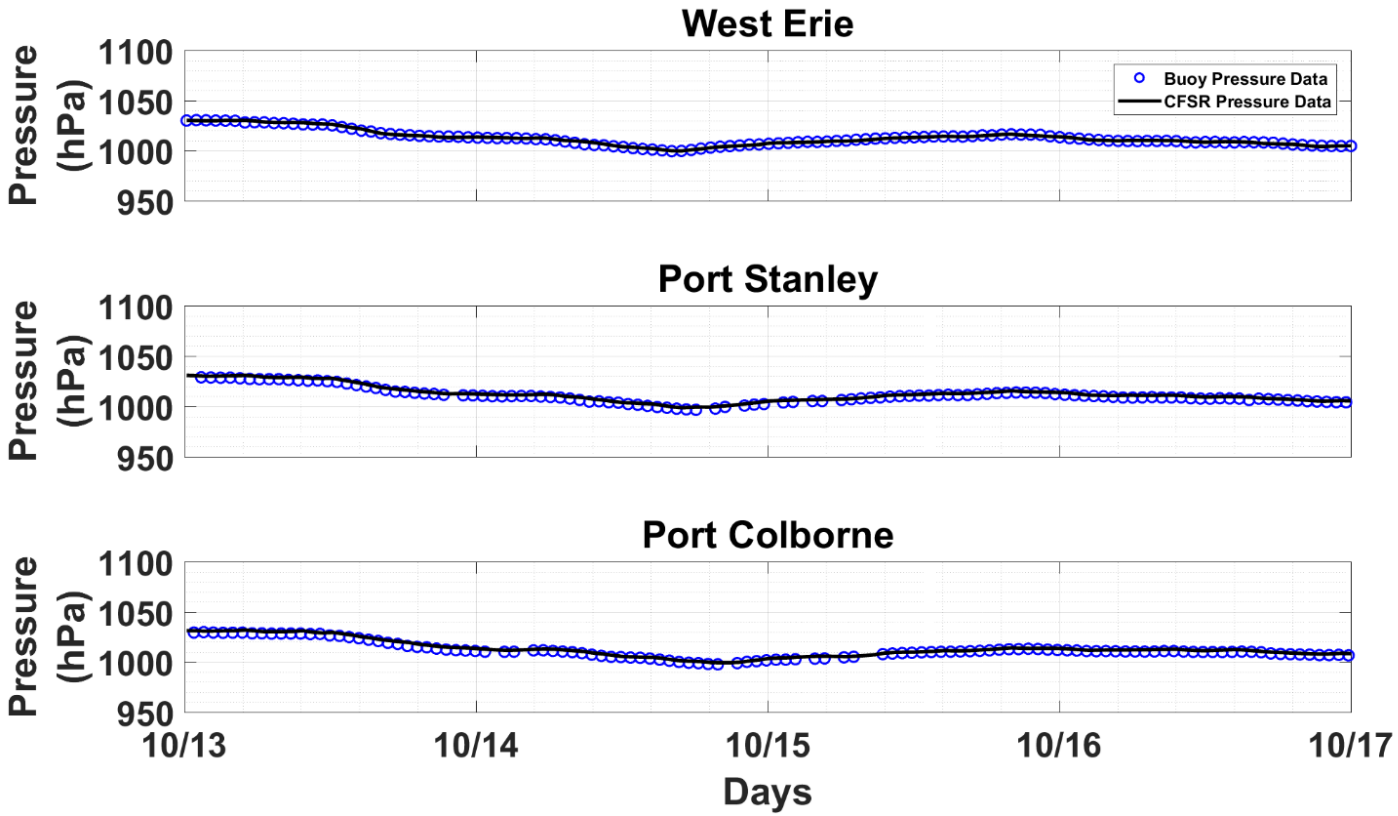


Wind Speed Comparison of October 15, 2012 Storm



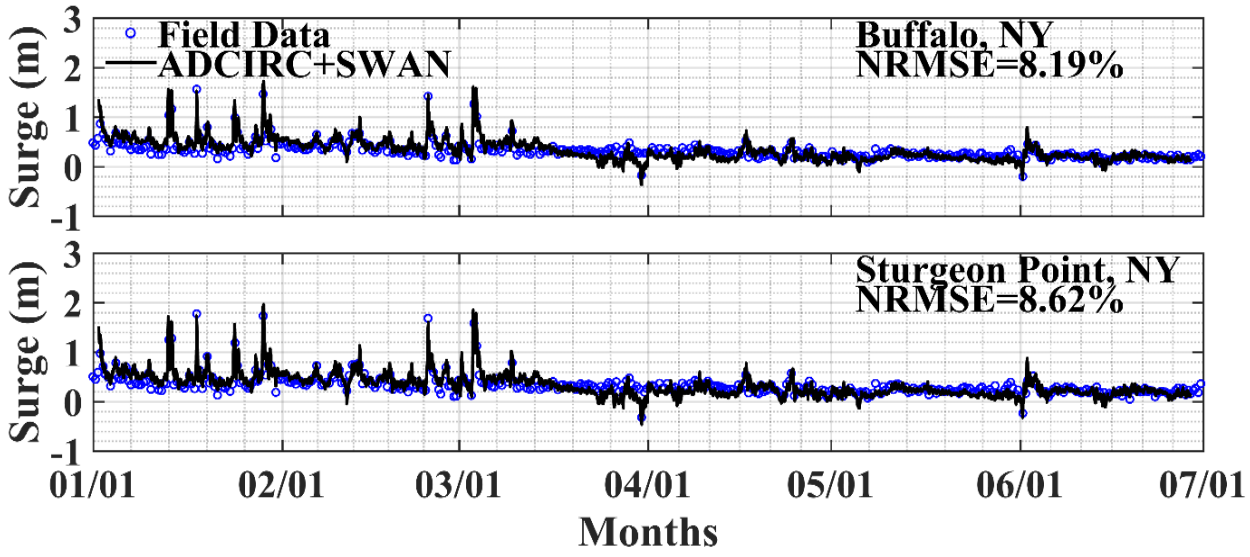
Wind Direction Comparison of October 15, 2012 Storm

Wind and Pressure Calibration/Validation

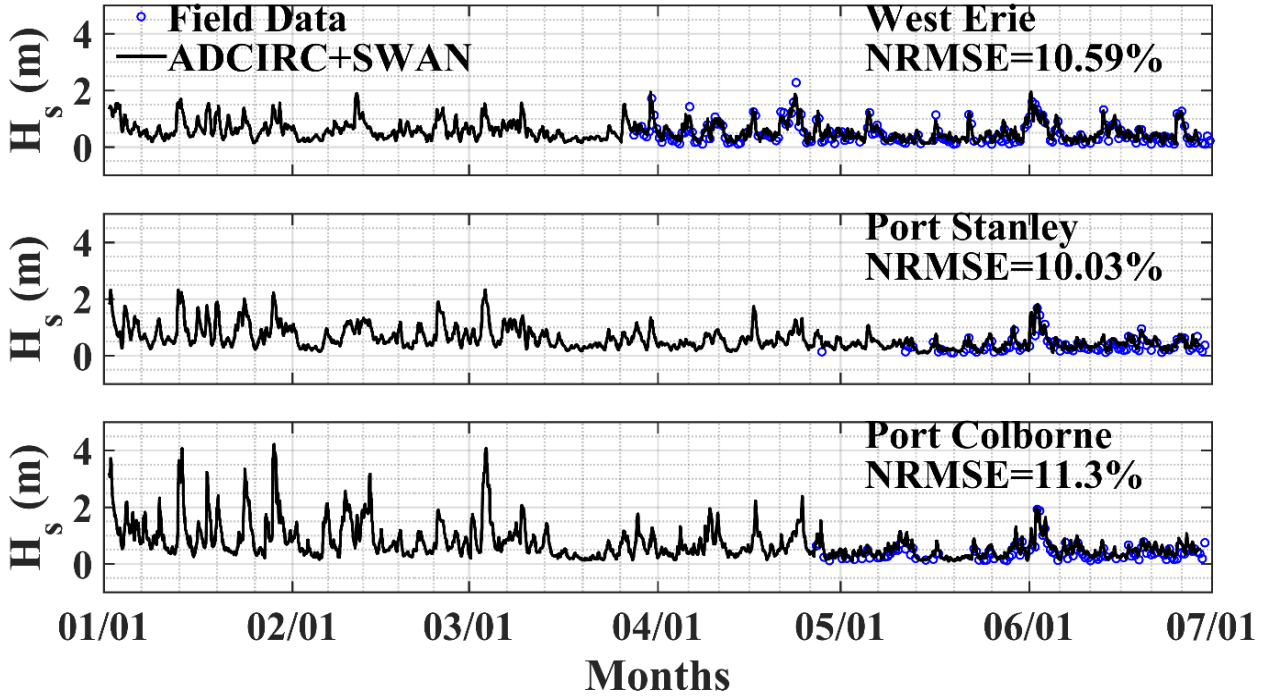


Pressure Comparison of October 15, 2012 Storm

Water Level and Wave Validation: Validation of Surge and Wave Height

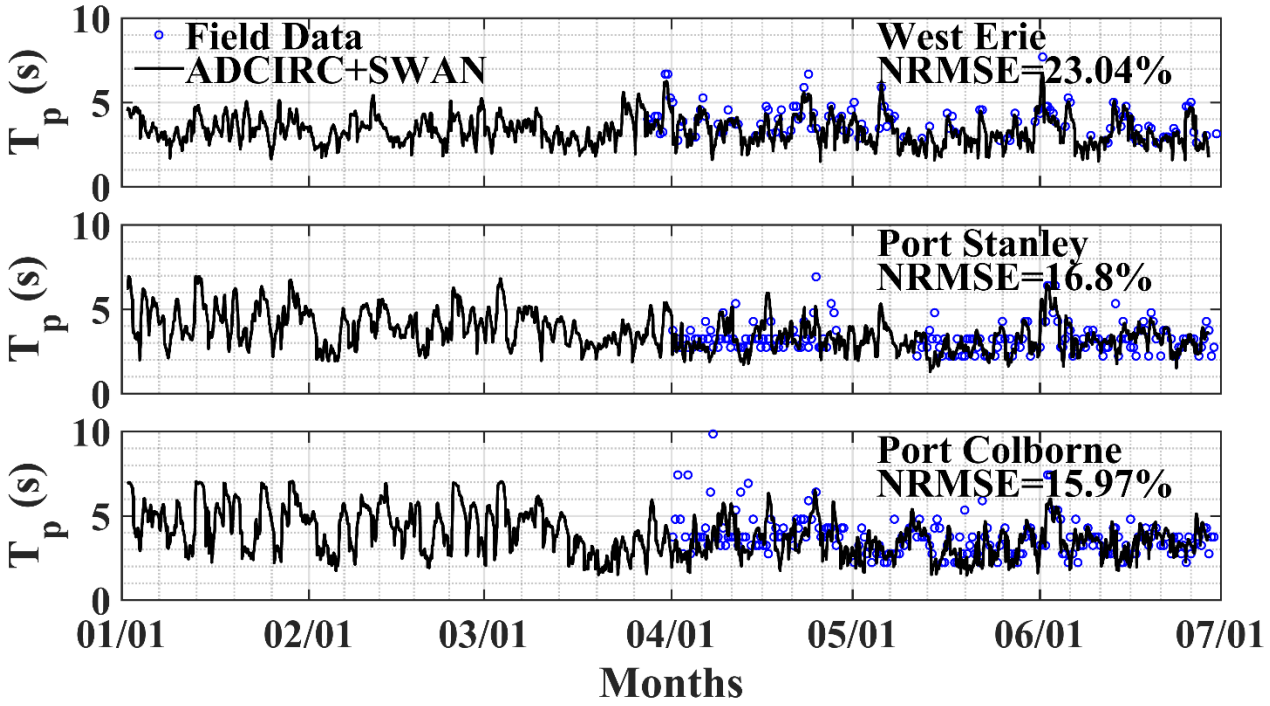


Surge

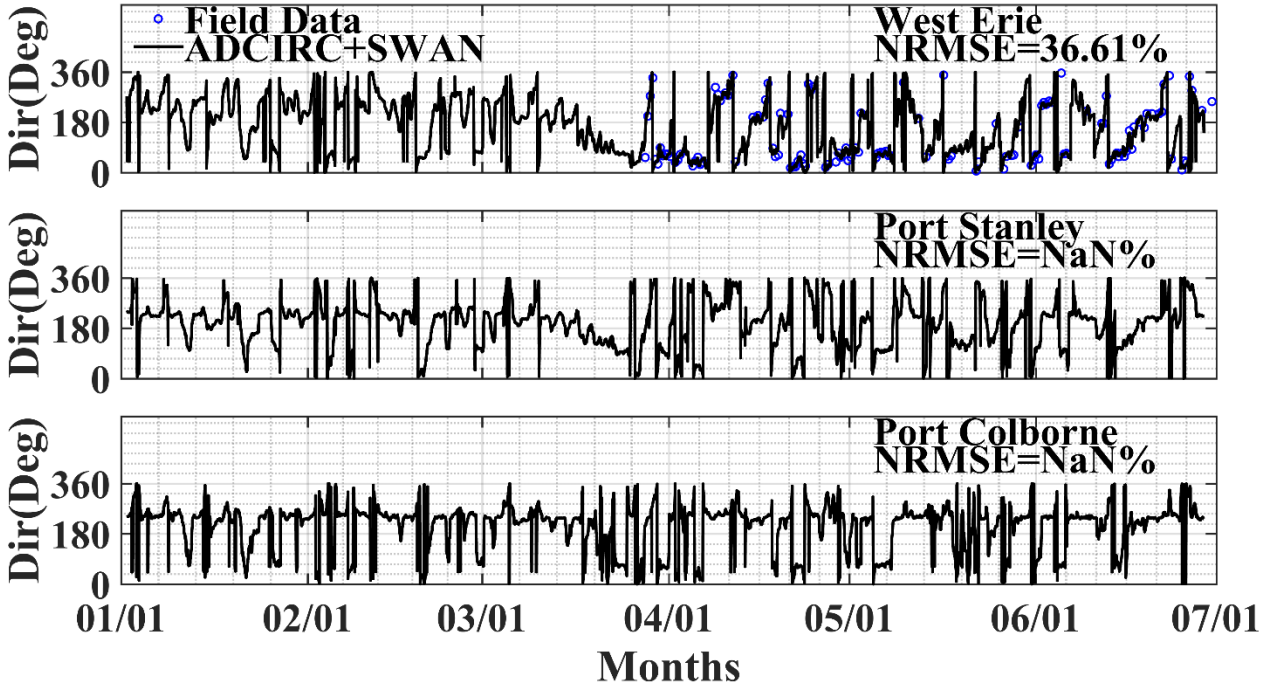


Wave Height

Water Level and Wave Validation: Validation of Wave Period and Wave Direction



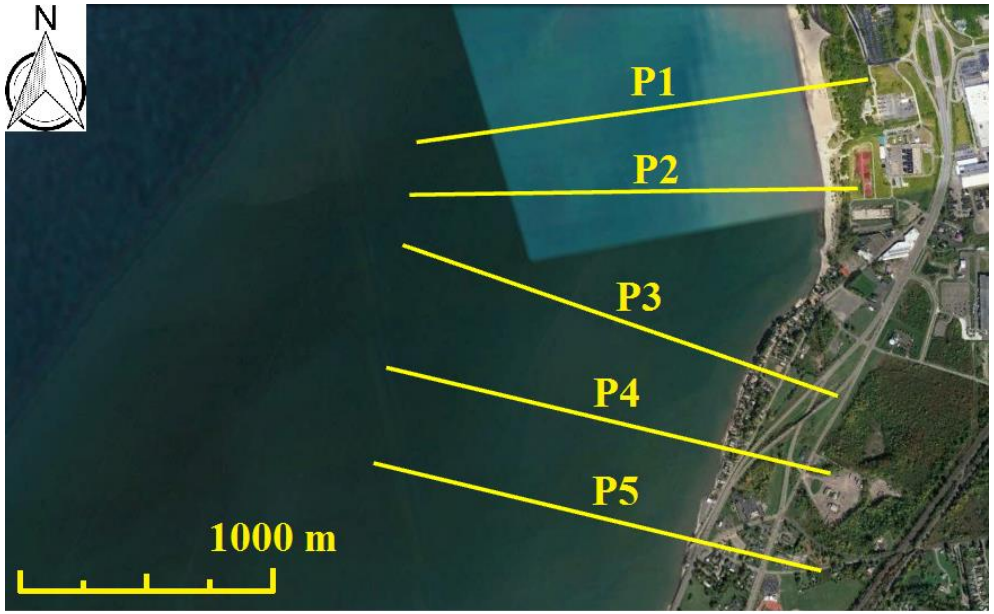
Wave Period



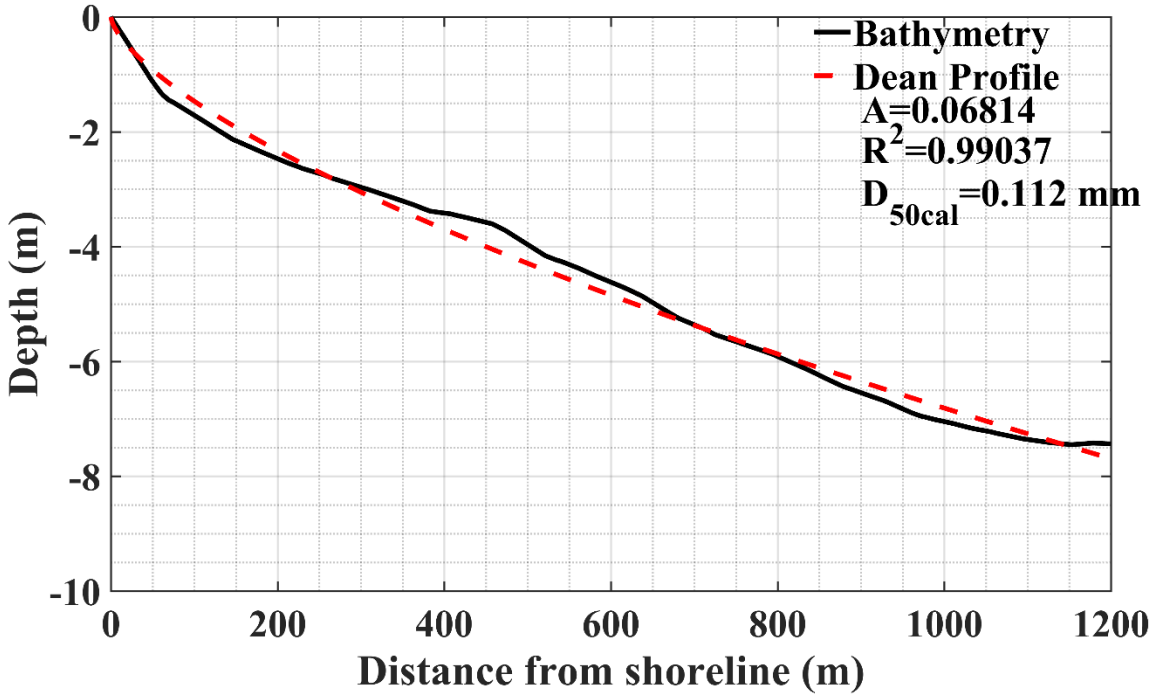
Wave Direction

Sediment Characteristics

- We were not able to identify detailed data on sediment characteristics for the study area
- Median grain size (D_{50}) estimated assuming equilibrium beach profile based on average of five cross-sectional profiles

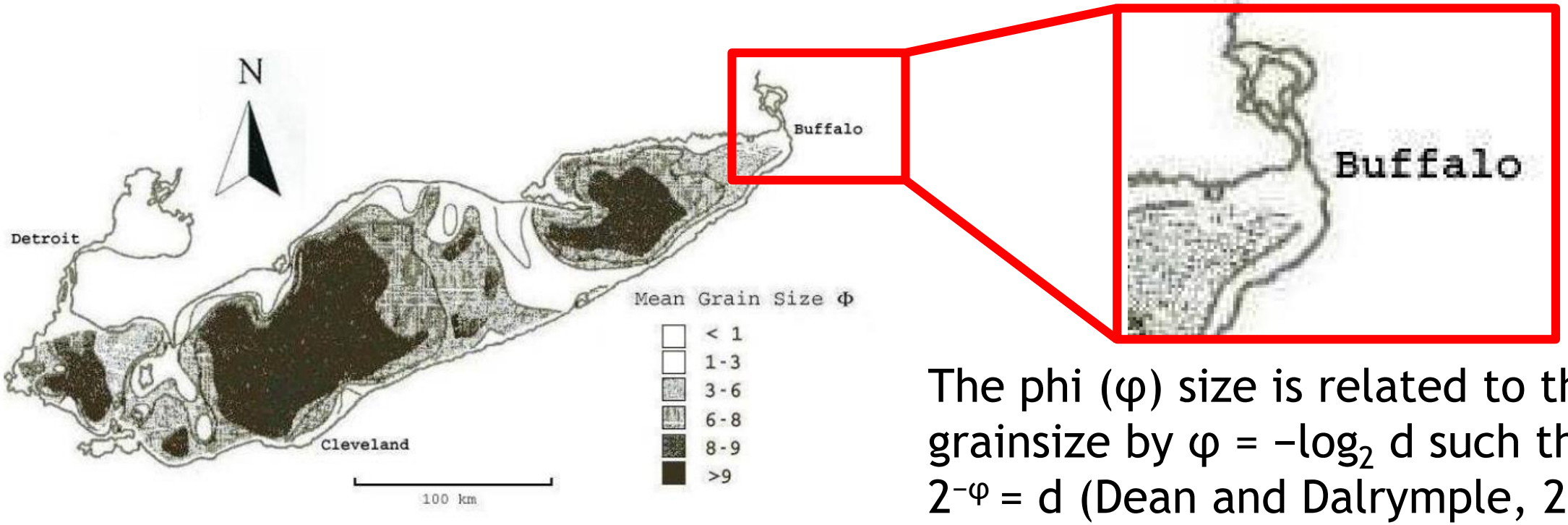


Locations of Cross-Sections



Equilibrium Beach Profile

- Using the Dean's equilibrium beach profile approach: D_{50} = 0.11mm (Fine sand)
- This was found consistent with Thomas et al. (1976) and Dusini (2005).



Lake Erie grain size in phi units (Thomas et al., 1976).

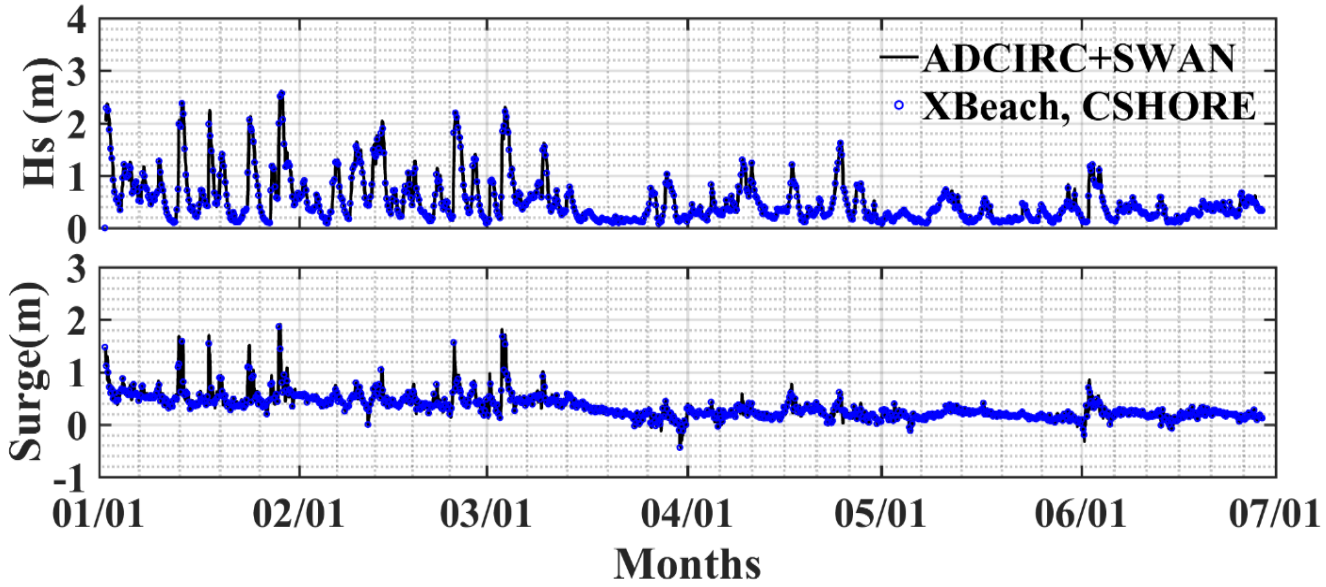
The phi (φ) size is related to the grainsize by $\varphi = -\log_2 d$ such that $2^{-\varphi} = d$ (Dean and Dalrymple, 2001). Then, 0.125mm< D_{50} <0.5mm according to Thomas et al.(1976).

Results

- Actual (Seiche-included) Water Level
  - *Eroded Area: Actual(Seiche-included) Water Level*
- Seiche-Free Water Level
  - *Seiche-Free Water Level Time-Series*
  - *Eroded Area: Seiche-Free Water Level*

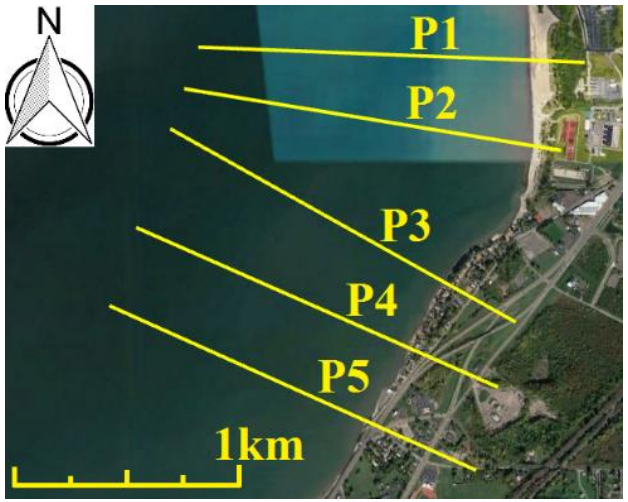
Actual (Seiche-included) Water Level

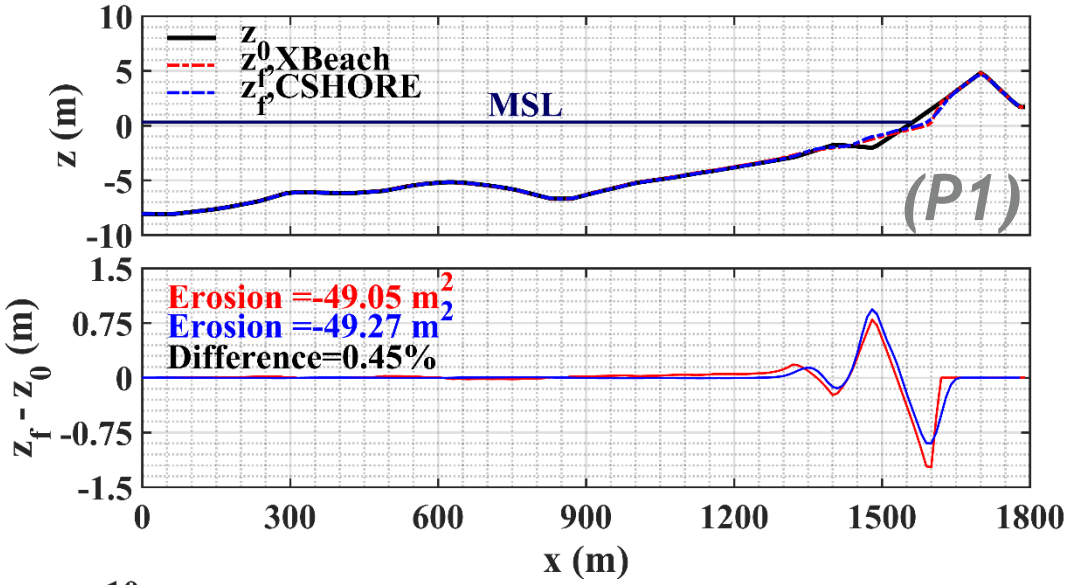
- Simulated water level and wave data obtained from coupled ADCIRC+SWAN model are enforced at the inlet boundaries of XBeach & CSHORE

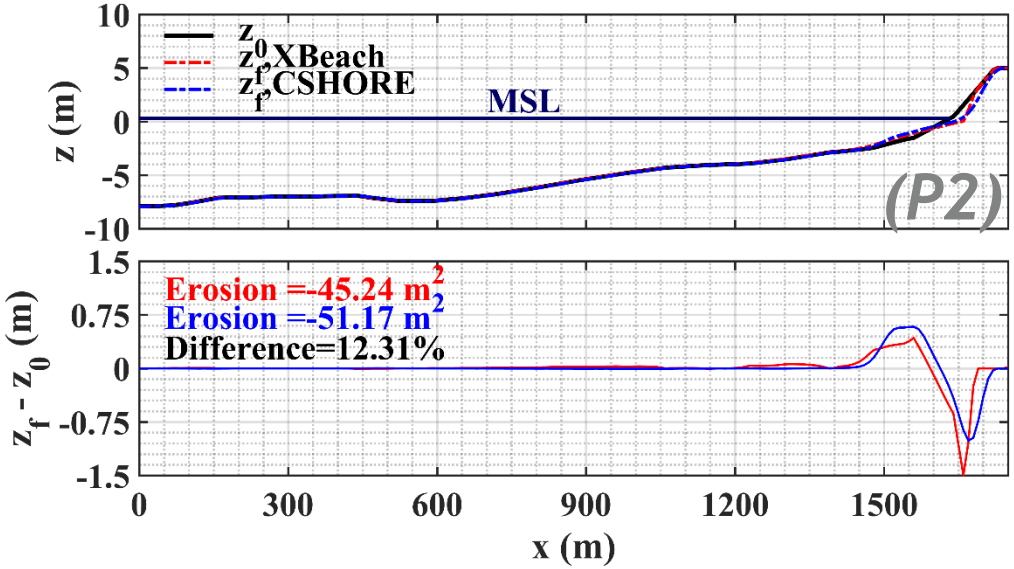


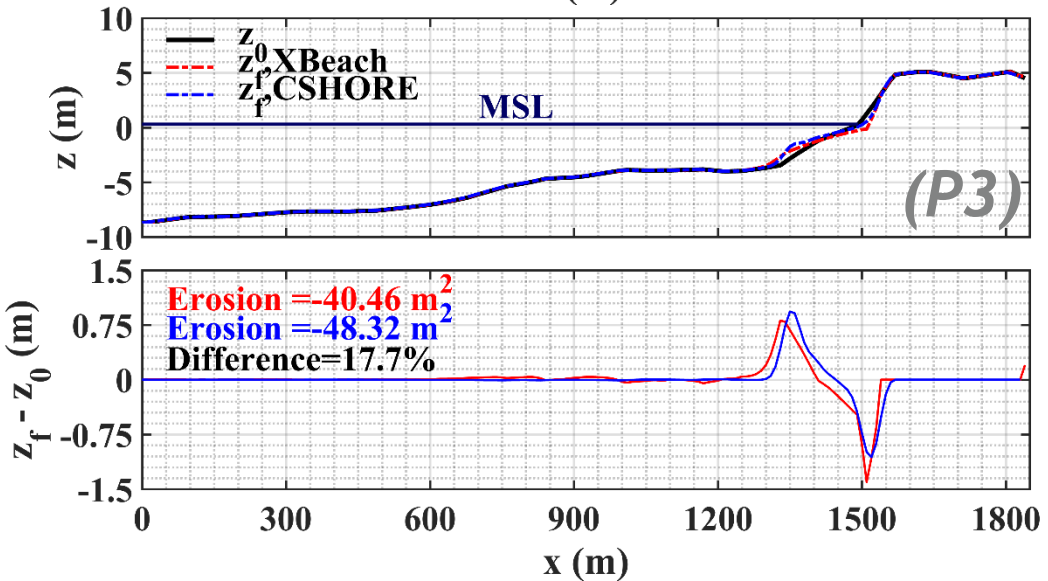
Water Level & Wave Height at Offshore Boundary of P1 to P5 in XBeach & CSHORE

Eroded Area: Actual(Seiche-included) Water Level

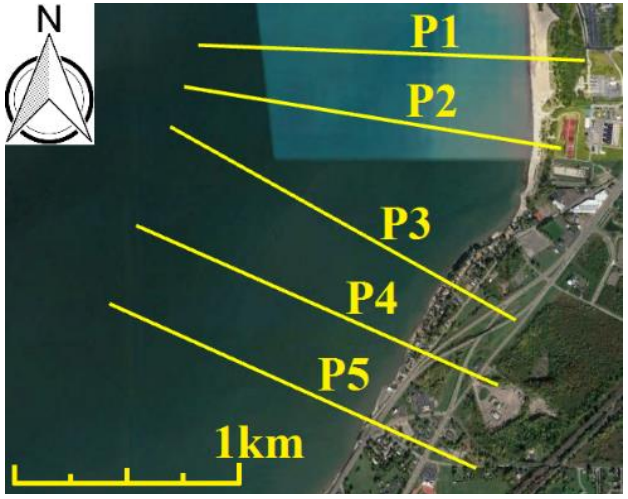


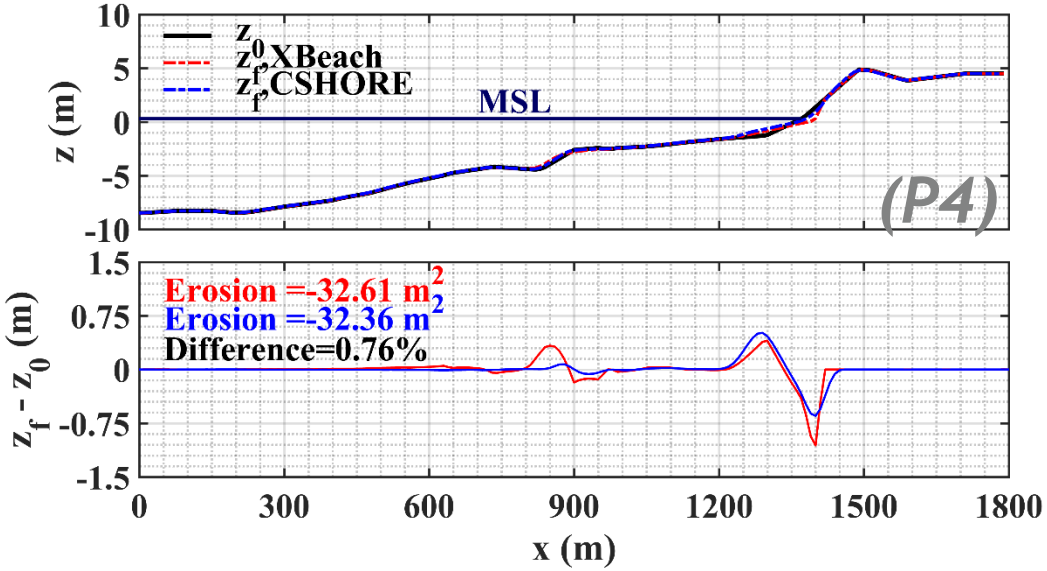


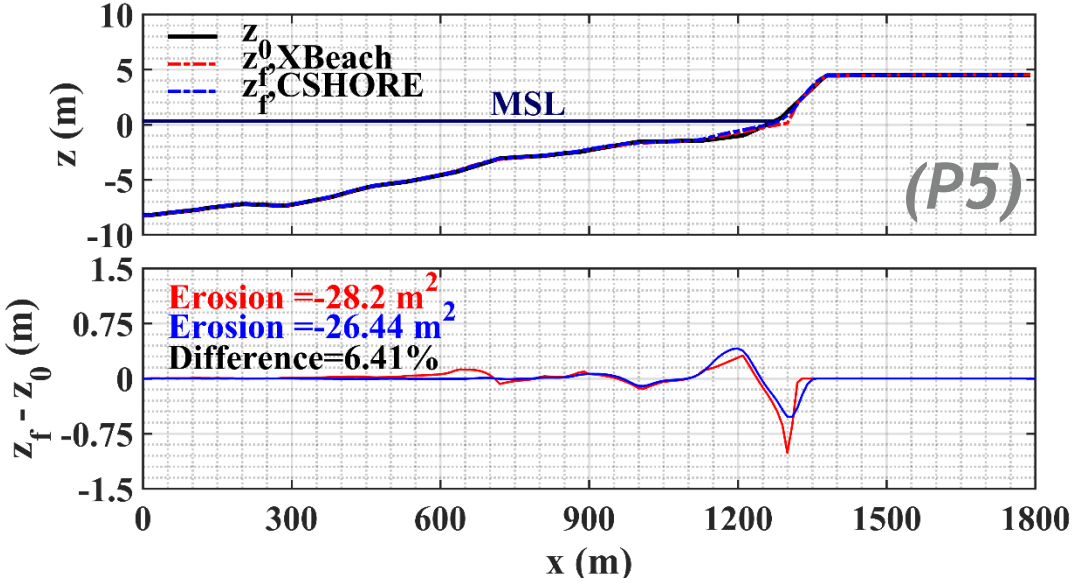




Eroded Area: Actual(Seiche-included) Water Level



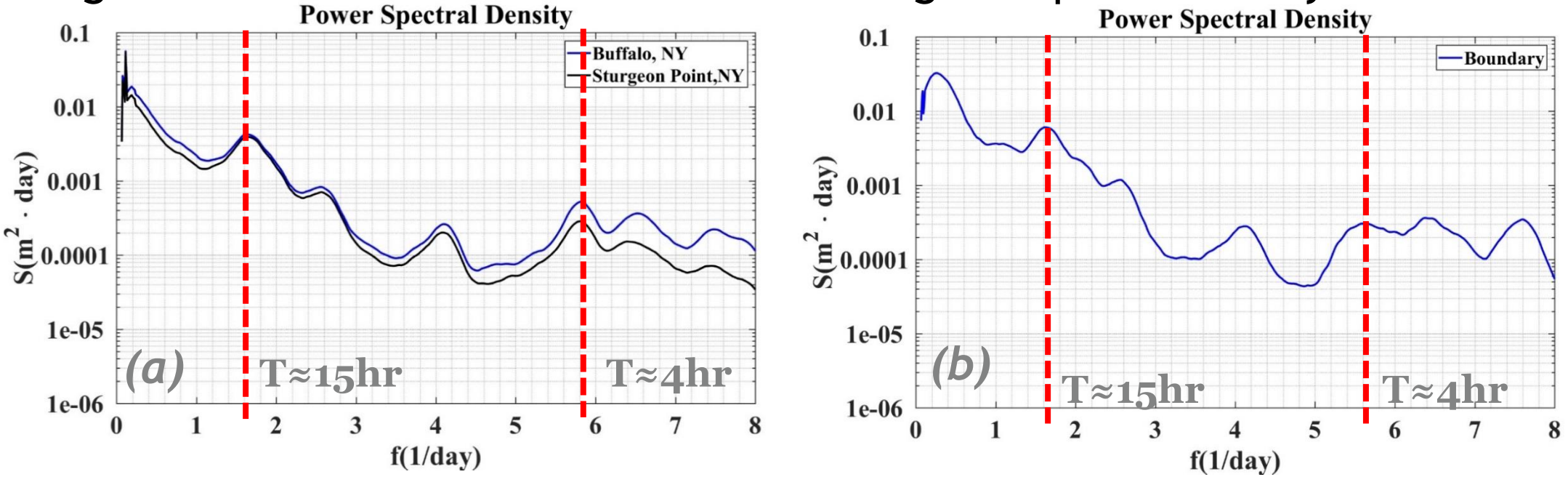




Profile	Eroded Area (m^2)		Difference
	XBeach	CSHORE	
P1	49.05	49.27	0.45%
P2	45.24	51.17	12.31%
P2	40.46	48.32	17.7%
P4	32.61	32.36	0.76%
P5	28.20	26.44	6.41%

Seiche-Free Water Level

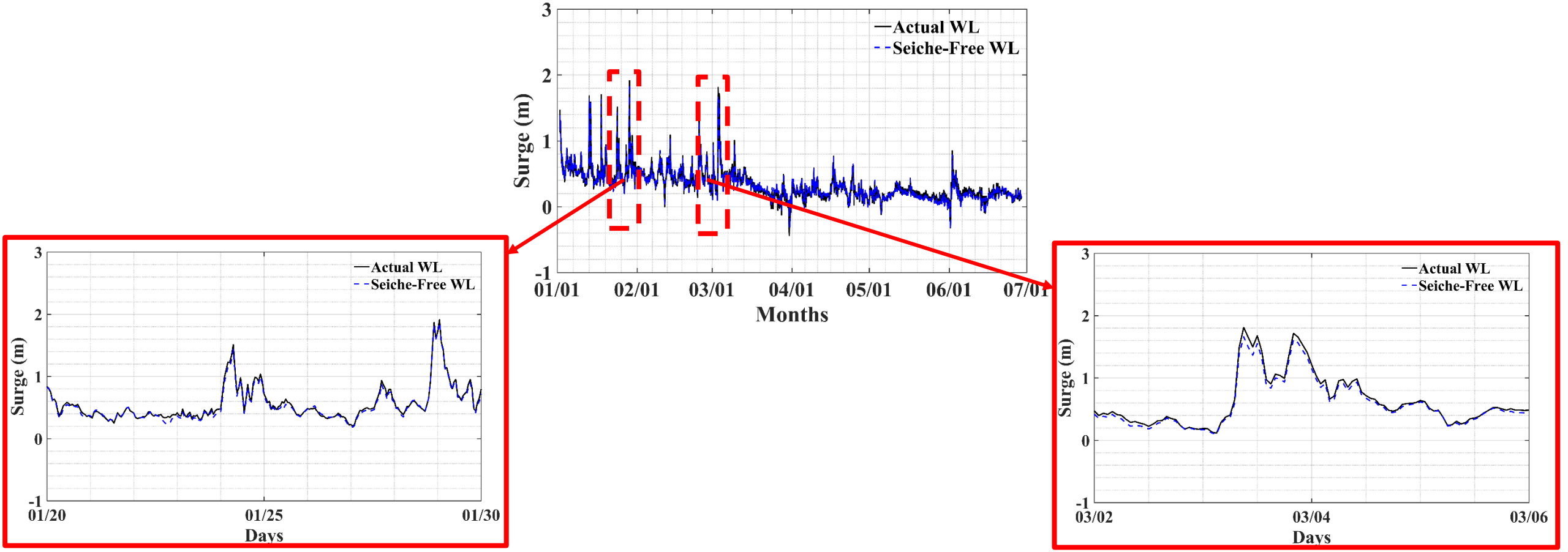
- Seiching modes of Lake Erie are identified using the spectral analysis method



Power Spectral Density (PSD) of hourly water level at a) Stations 9063020 & 9063028 b) Boundary of Profiles P1-P5 for selected time window.

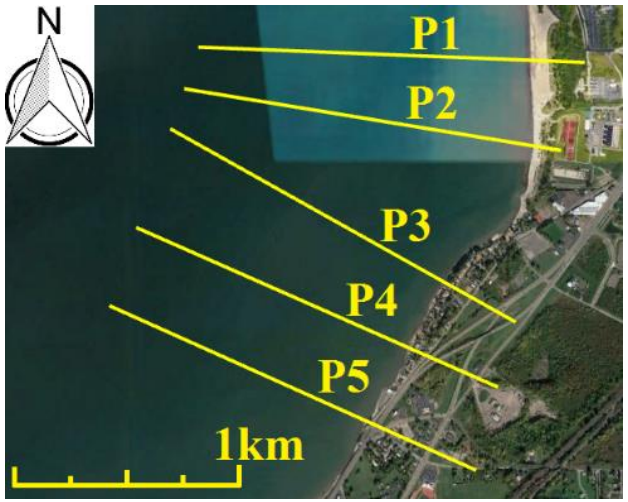
- The frequency band between the two vertical lines is associated with the oscillations at periods ranging between 4 to 15 hours (first four seiche modes)

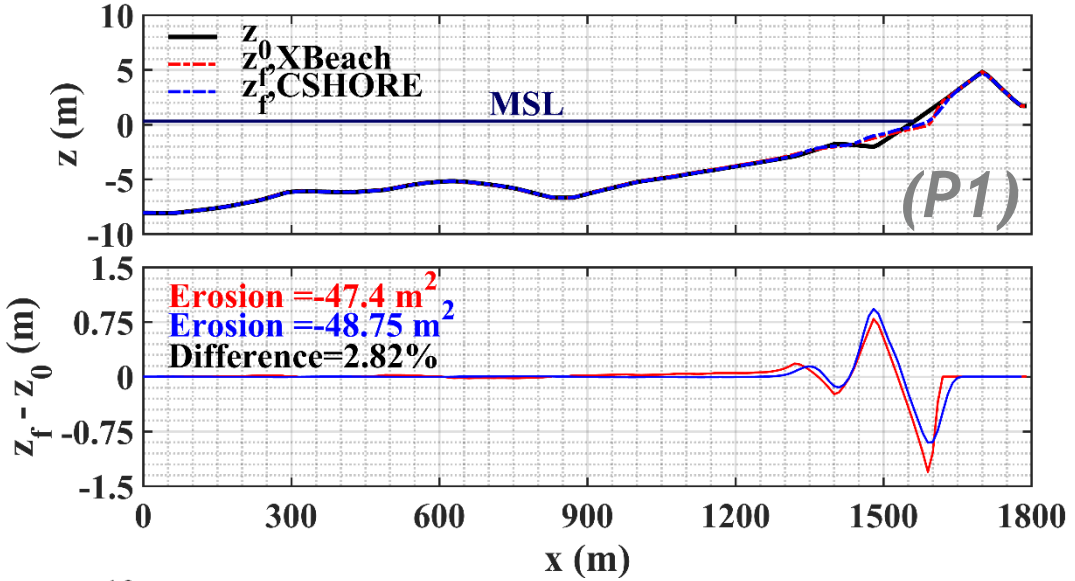
Seiche-Free Water Level Time-Series

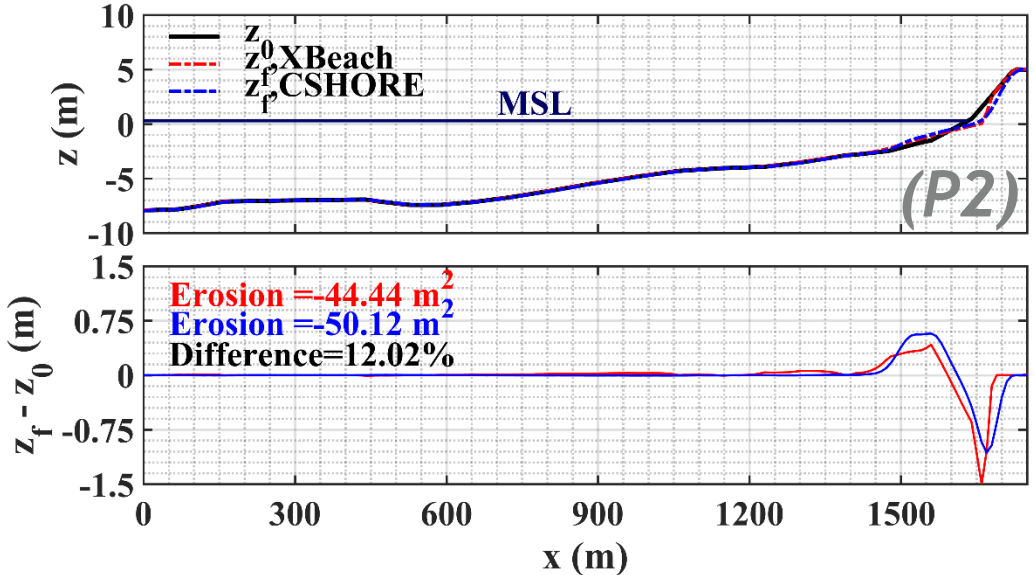


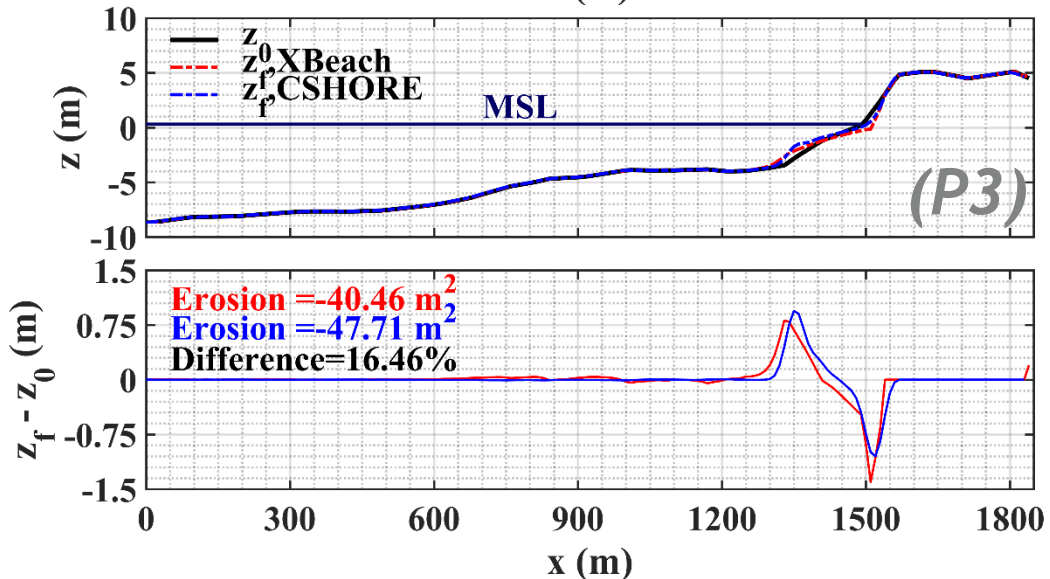
Seiche-Free Water Level Time-Series

Eroded Area: Seiche-Free Water Level

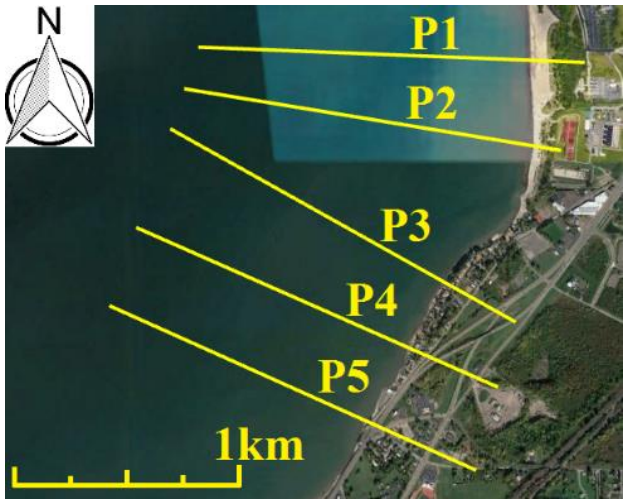


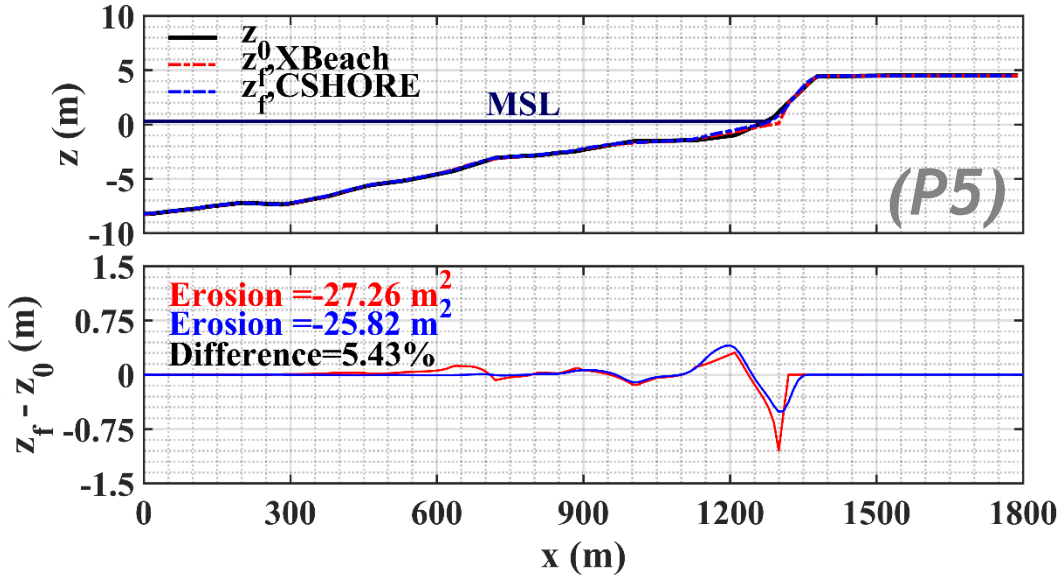


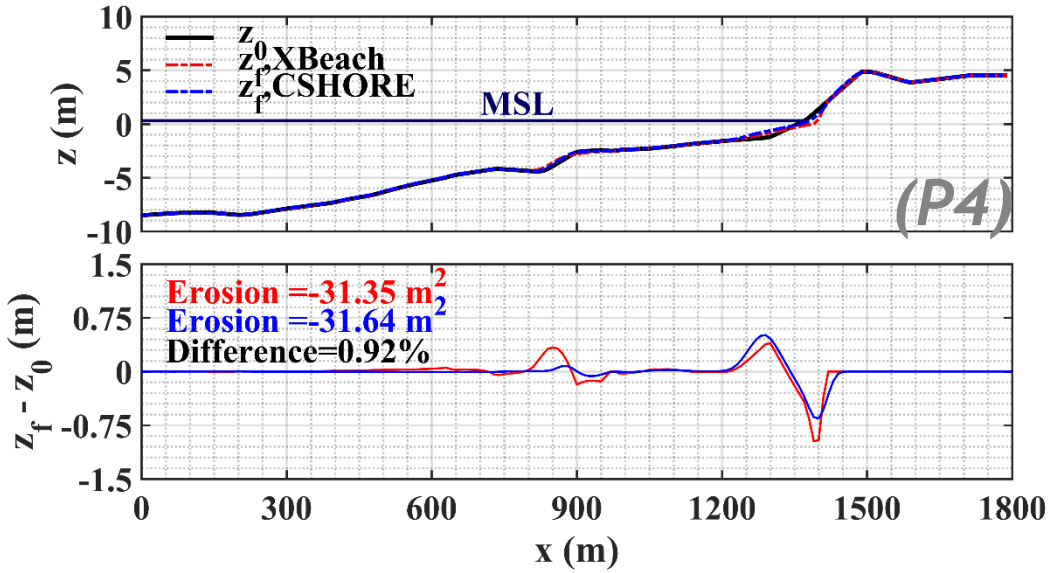




Eroded Area: Seiche-Free Water Level





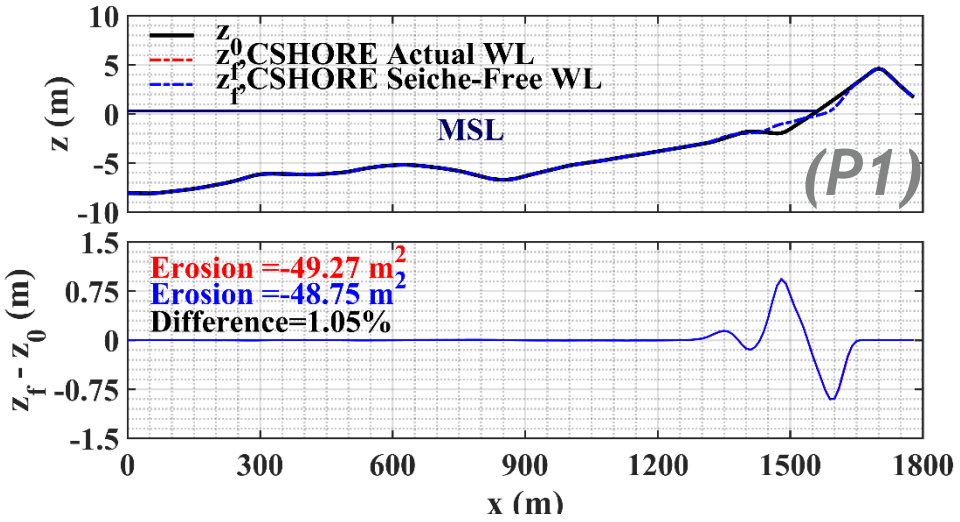


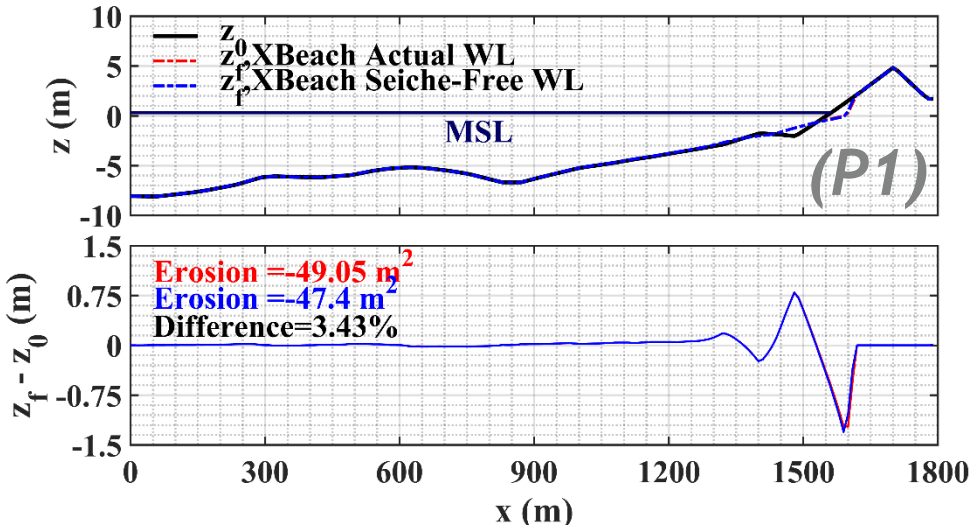
Profile	Eroded Area (m^2)		Difference
	XBeach	CSHORE	
P1	47.40	48.75	2.82%
P2	44.44	50.12	12.02%
P2	40.46	47.71	16.46%
P4	31.35	31.64	0.92%
P5	27.26	25.82	5.43%

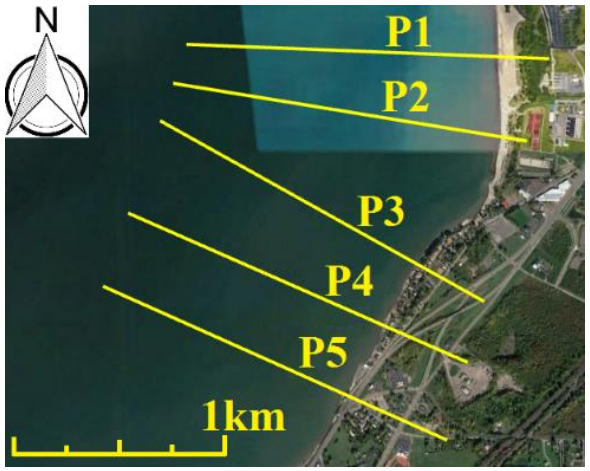
Discussions

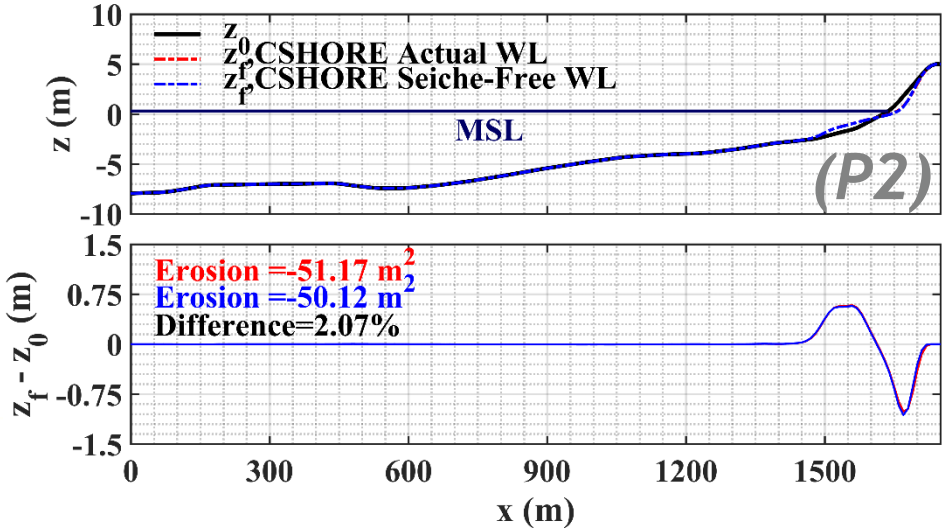
- Eroded Area: Actual (Seiche-Included) & Seiche-Free Water Levels
- Alongshore Variation of Beach Erosion
- What we learned?

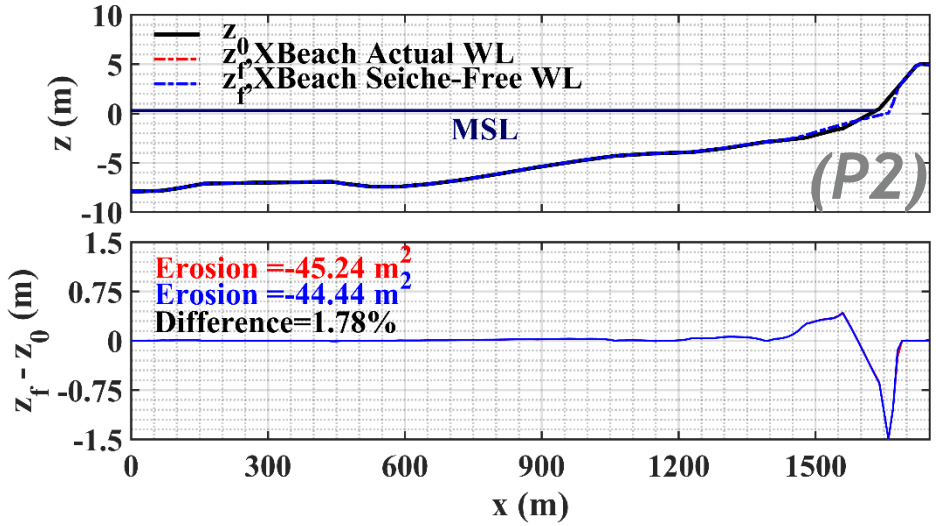
Eroded Area: Actual (Seiche-Included) & Seiche-Free Water Levels



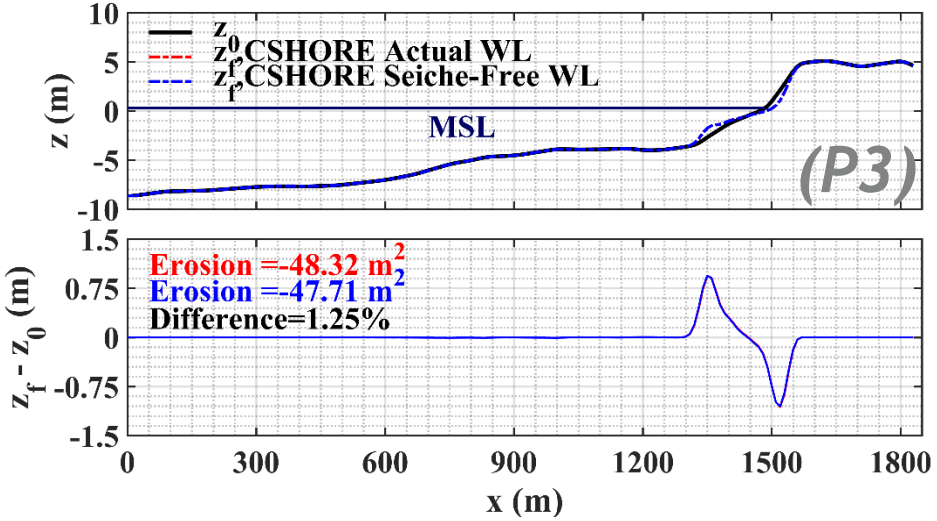


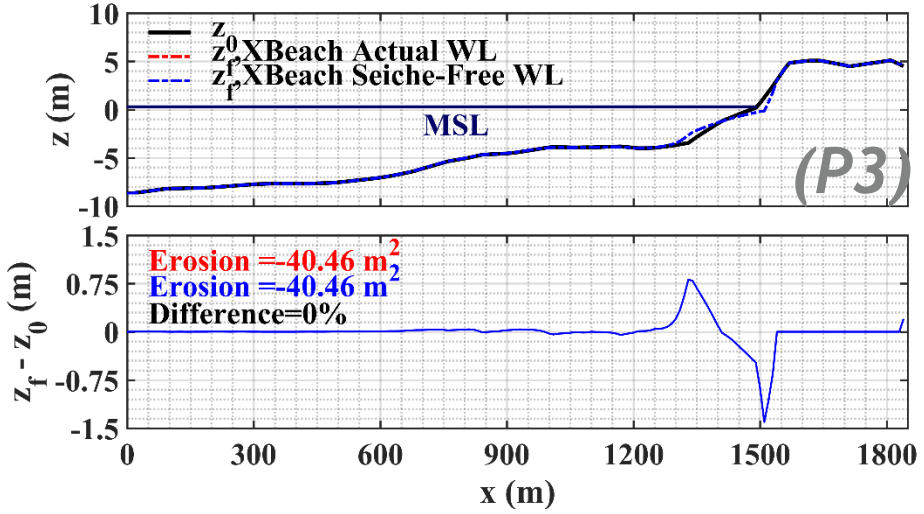


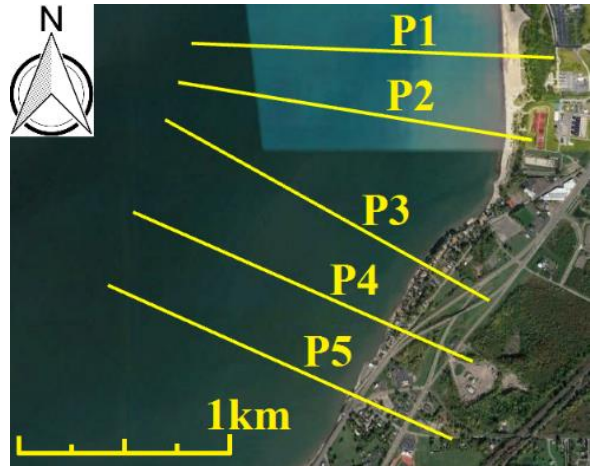


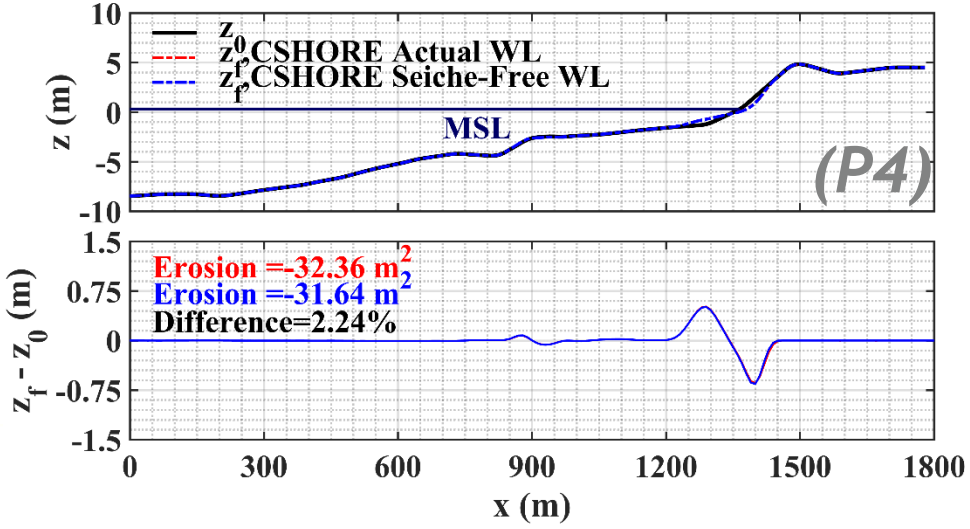


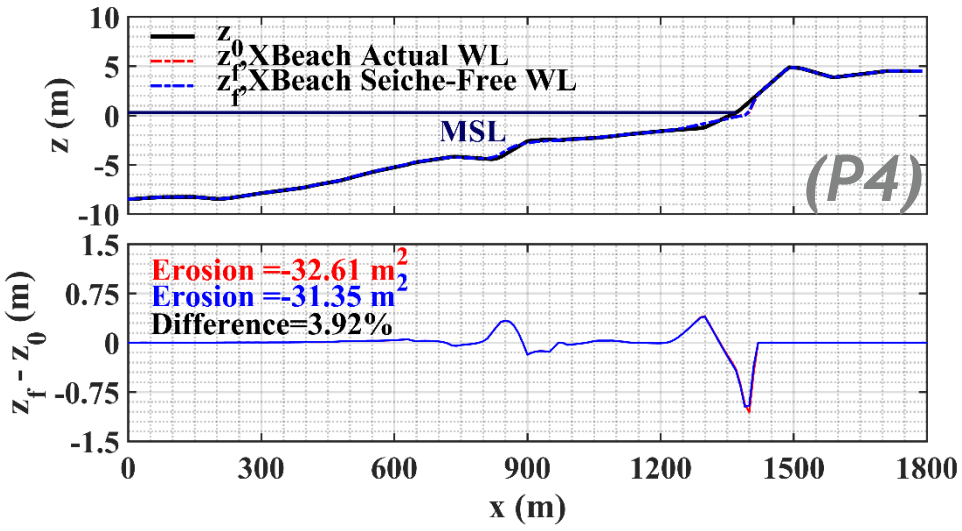
Eroded Area: Actual (Seiche-Included) & Seiche-Free Water Levels



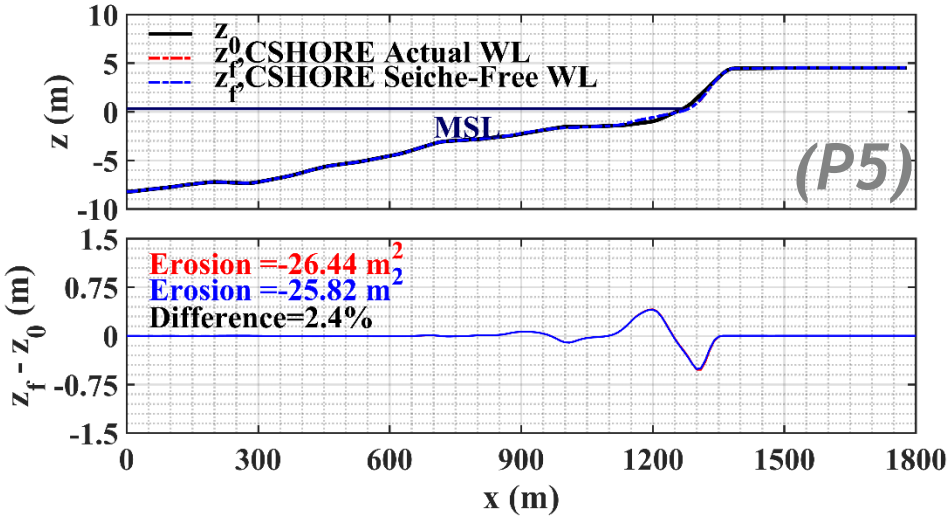


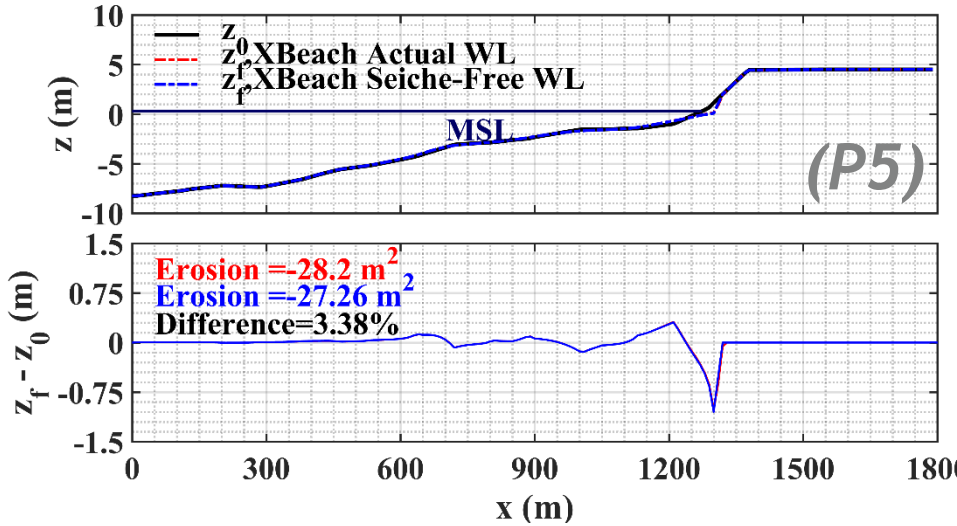


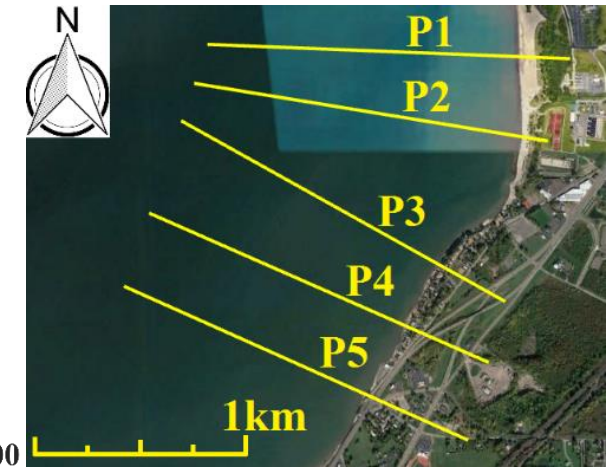




Eroded Area: Actual (Seiche-Included) & Seiche-Free Water Levels



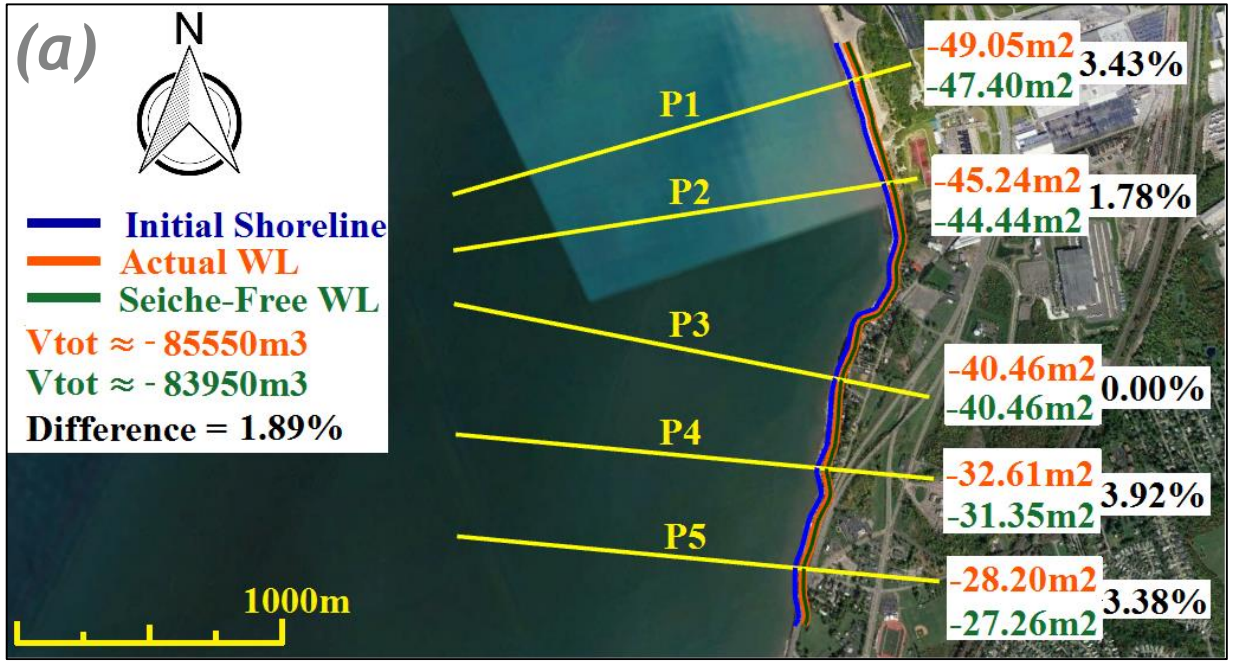


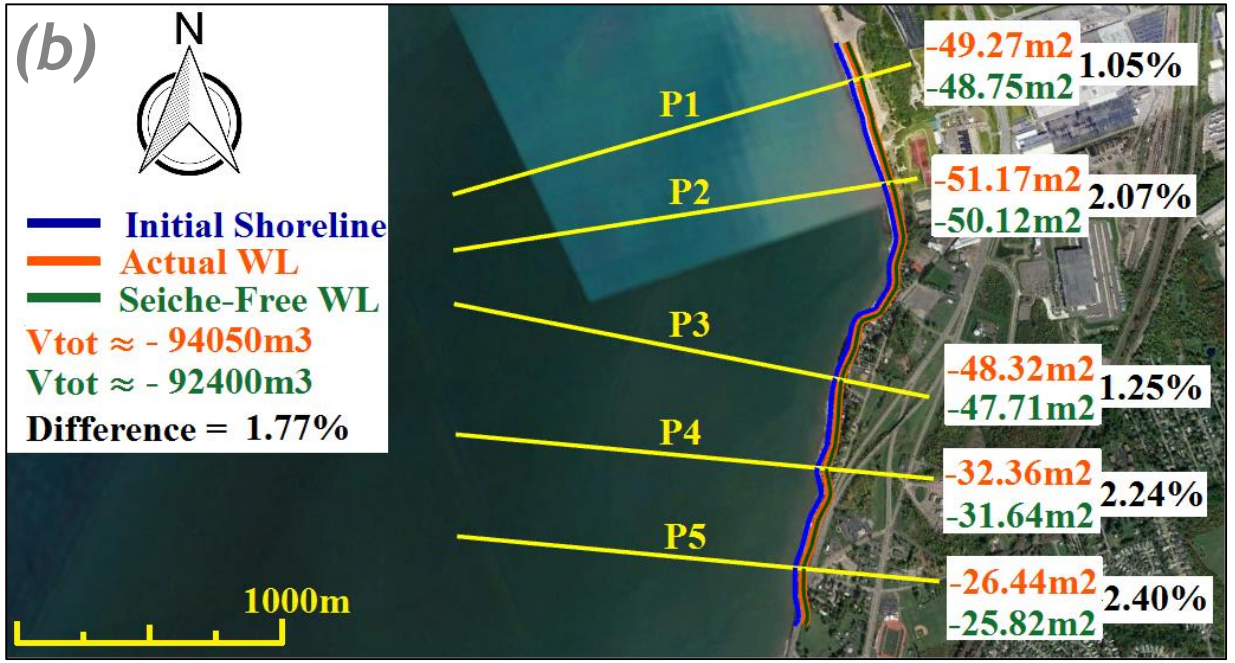


Actual (Seiche-included) and Seiche Free Water Level CSHORE and XBeach Simulations Results

Profile	CSHORE: Eroded Area (m^2)			XBeach: Eroded Area (m^2)		
	Actual WL	Seiche-Free WL	Difference	Actual WL	Seiche-Free WL	Difference
P1	49.27	48.75	1.05%	49.05	47.40	3.43%
P2	51.17	50.12	2.07%	45.24	44.44	1.78%
P2	48.32	47.71	1.25%	40.46	40.46	0.00%
P4	32.36	31.64	2.24%	32.61	31.35	3.92%
P5	26.44	25.82	2.40%	28.20	27.26	3.38%

Alongshore Variation of Beach Erosion





Total Erosion a) XBeach Actual and Seiche Free Water Level b) CSHORE Actual and Seiche Free Water Level

What we learned?

- The decrease in the ice cover may result in more energetic seiching motions and increased erosion of beaches because:
  - Low frequency oscillations in Lake Erie alters the width of surf zone by changing the location of the wave breaking.
  - Increased bottom shear stresses at low water levels can cause more erosion of the beach.
- Seiching motions in the Eastern Lake Erie appeared to contribute to 1-2% more erosion over a 6-month period.
- Further analyses and data collection are required

Thank You…

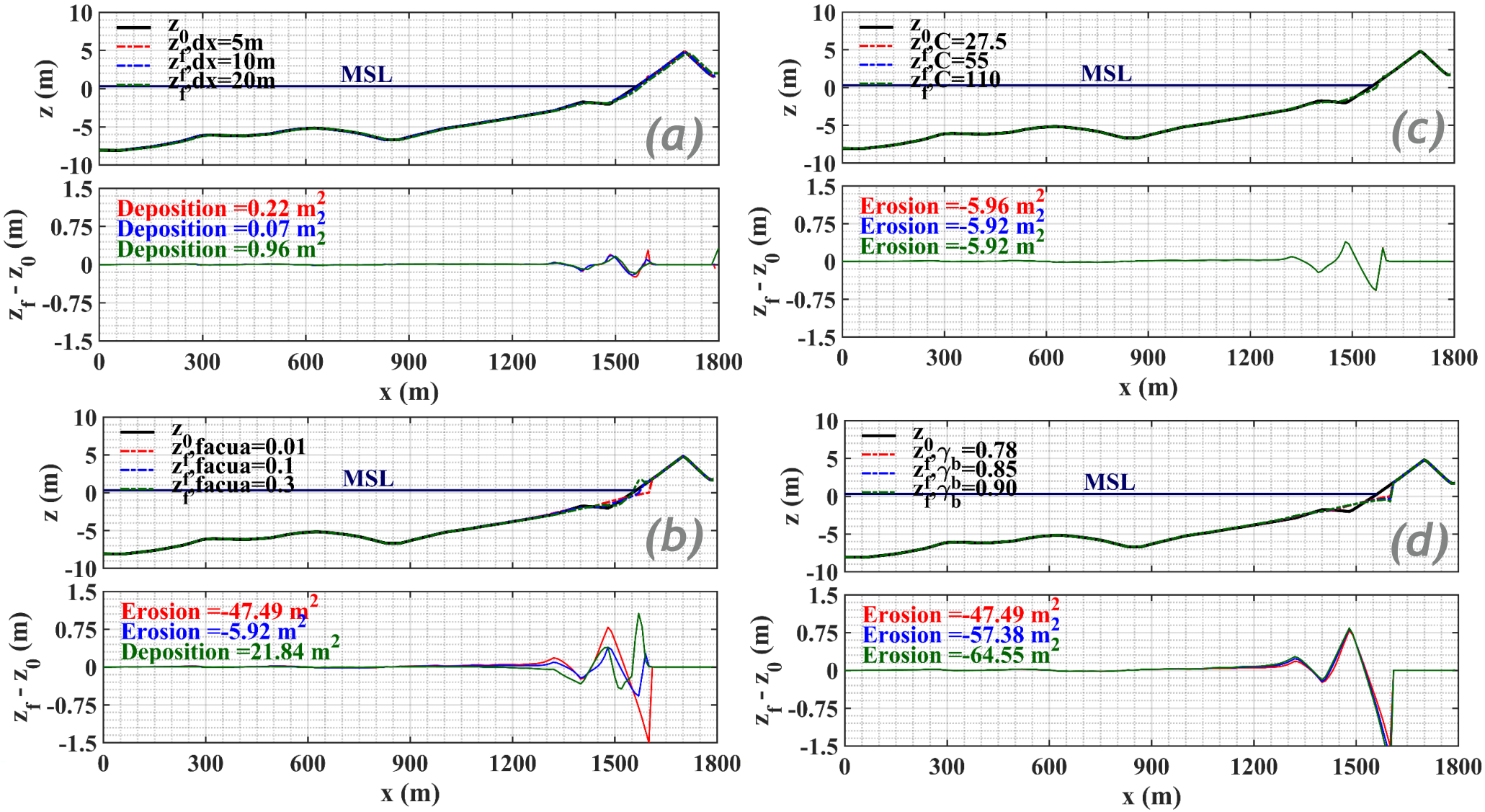
Erdinc Sogut
PhD Student
Department of Civil Engineering
Stony Brook University
erdinc.sogut@stonybrook.edu

REFERENCES

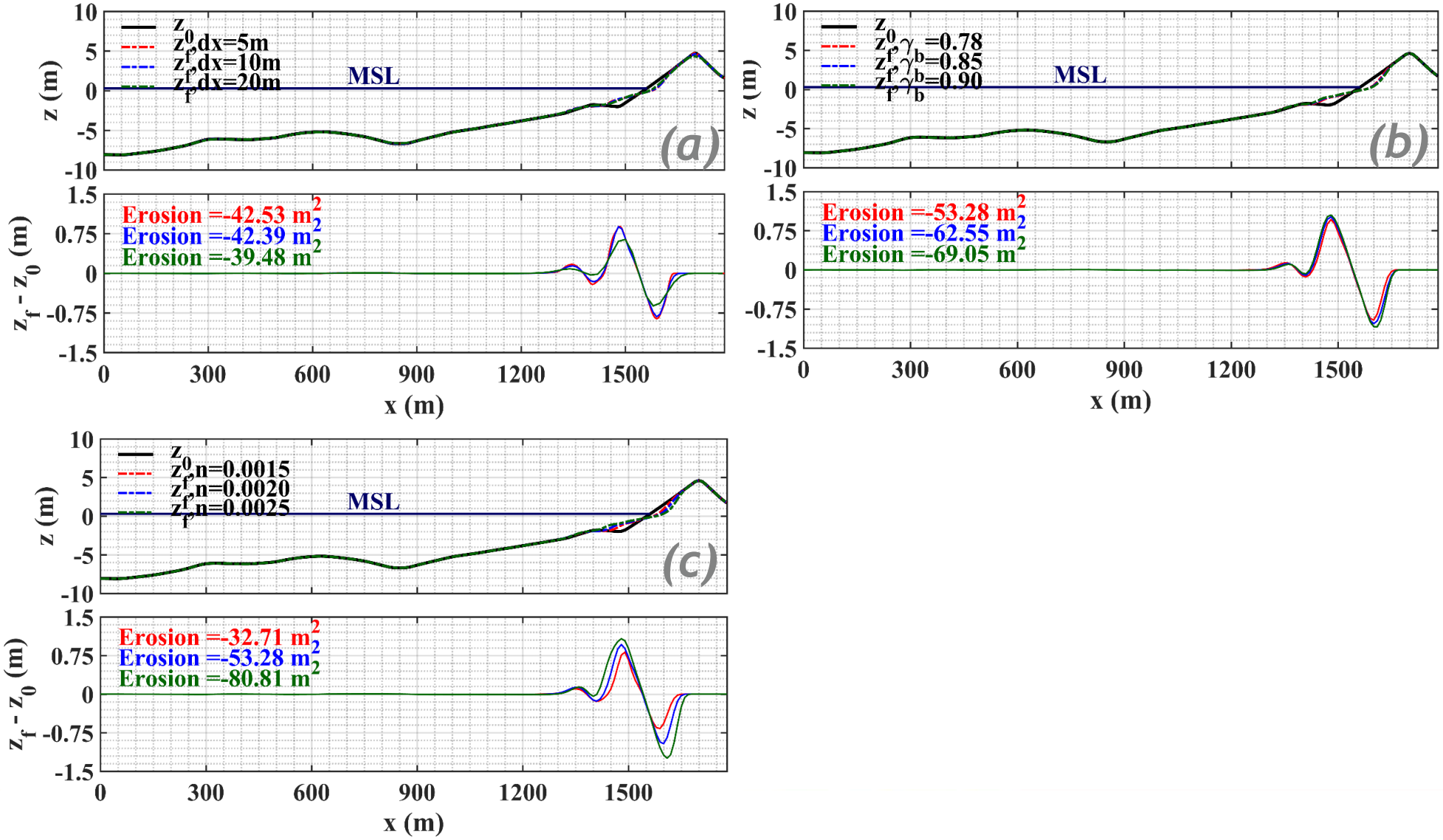
- Dean R. G., and Darlymple, R., A., (2004) Coastal Processes with Engineering Applications. Cambridge University Press.
- Dean, R. G., and Dalrymple, R. A. (1991). Water wave mechanics for engineers and scientists (Vol. 2). World Scientific Publishing Company.
- Dusini, D. S. (2005). The Effect of Lake Erie Water Level Variations on Sediment Resuspension. MSc Thesis, Ohio State University.
- Farhadzadeh (2017). "A study of Lake Erie seiche and low frequency water level fluctuations in the presence of surface ice", Ocean Engineering, Vol 135, 1 May 2017, Pages 117–136.
- Farhadzadeh, A., Ghazian A. M., and Bokuniewicz, H. (2018). "Contribution of Seiche to Beach Profile Evolution in Eastern Lake Erie", Shore and Beach (in press).
- Harter and Figlus (2017). "Numerical modeling of the morphodynamic response of a low-lying barrier island beach and foredune system inundated during Hurricane Ike using XBeach and CSHORE", Coastal Engineering, Volume 120, pp. 64-74.
- Kobayashi, and Farhadzadeh (2008). Cross-shore Numerical Model CSHORE for Waves, Currents, Sediment Transport and Beach Profile Evolution. Research Report No. CACR-08-01, Center for Applied Coastal Research, University of Delaware, Newark, Delaware.
- Roelvink, Reniers, van Dongeren, de Vries, Lescinski, and McCall (2010). XBeach Model Description and Manual. Unesco-IHE Institute for Water Education, Deltares and Delft University of Technology. Report June, 21 2010 version 6.
- Thomas, R., L., Jaquet, J., -M., Kemp, L., W. and Lewis, C., M., F. (1976). Surfical Sediments of Lake Erie. J. Fisheries Res. Board of Canada, 33:385–403.

Appendix-A: Beach Response to Low Frequency Lake Level Oscillations

Sensitivity Analysis of XBeach & CSHORE

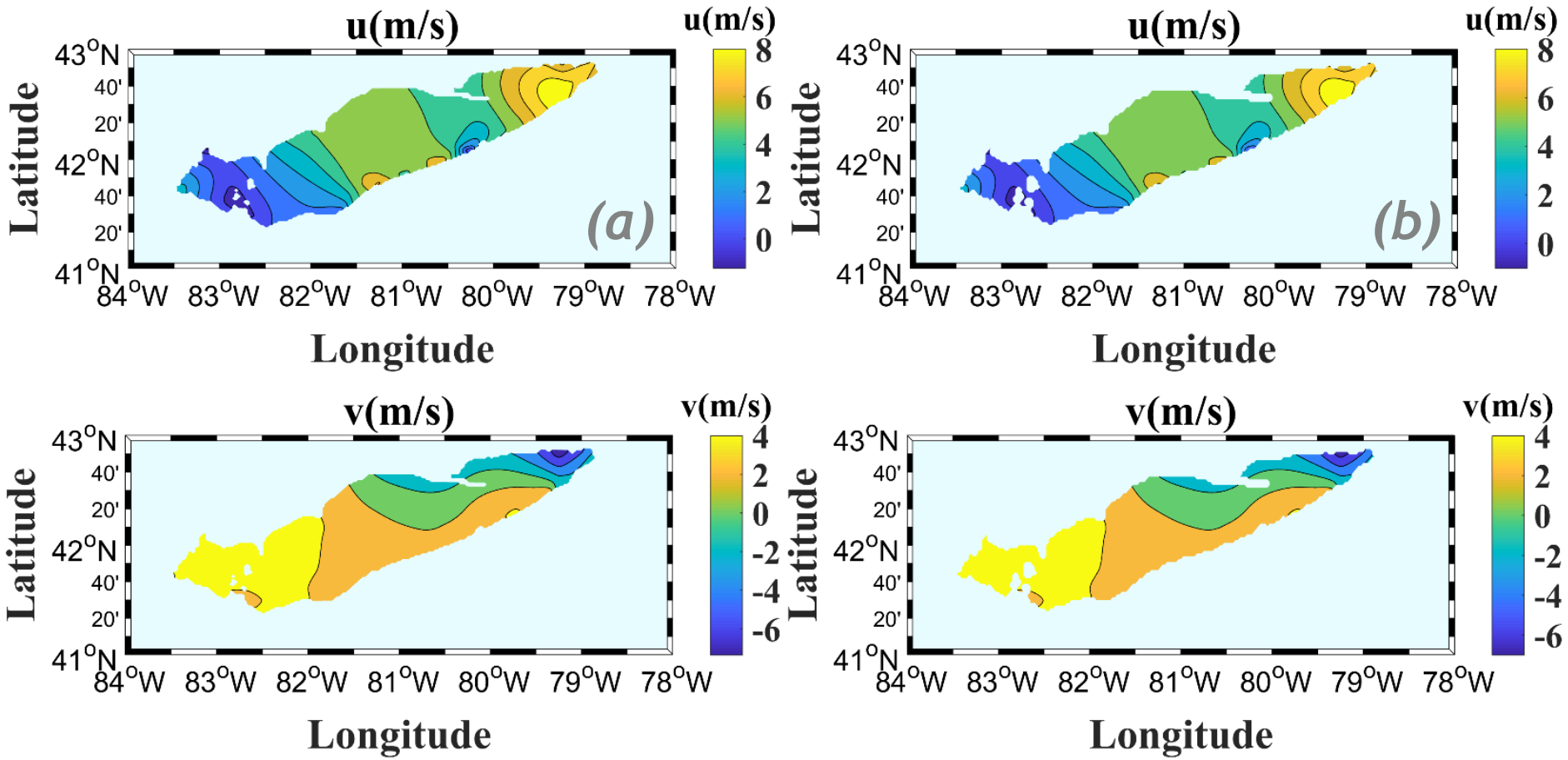


XBeach a) Grid b) Asymmetry & Skewness c) Bed Friction d) Breaker Index Sensitivity

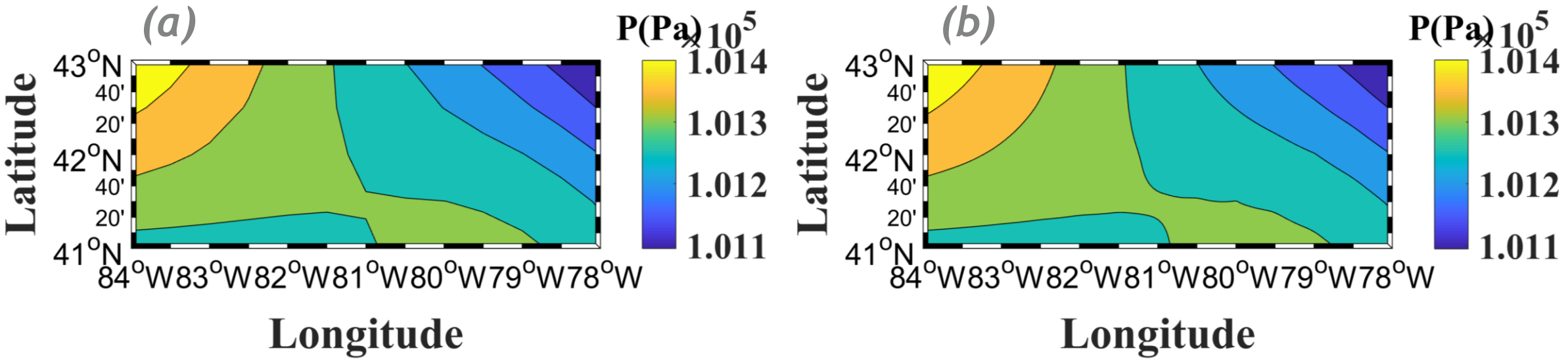


CSHORE a) Grid b) Breaker Index c) Bed Friction Sensitivity

Appendix-B: Wind and Pressure Fields



Wind Field a) NOAA/GLERL GLCFS Data b) Natural Neighboring Method



Pressure Field a) CFSR Data b) Natural Neighboring Method