PRACTICAL WAVE RESPONSE GUIDANCE OVER EMERGENT AND SUBMERGED COASTAL STRUCTURES USING FUNWAVE-TVD

INLET ENGINEERING TOOLS

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19 APR 2024

COASTAL INLETS RESEARCH PROGRAM

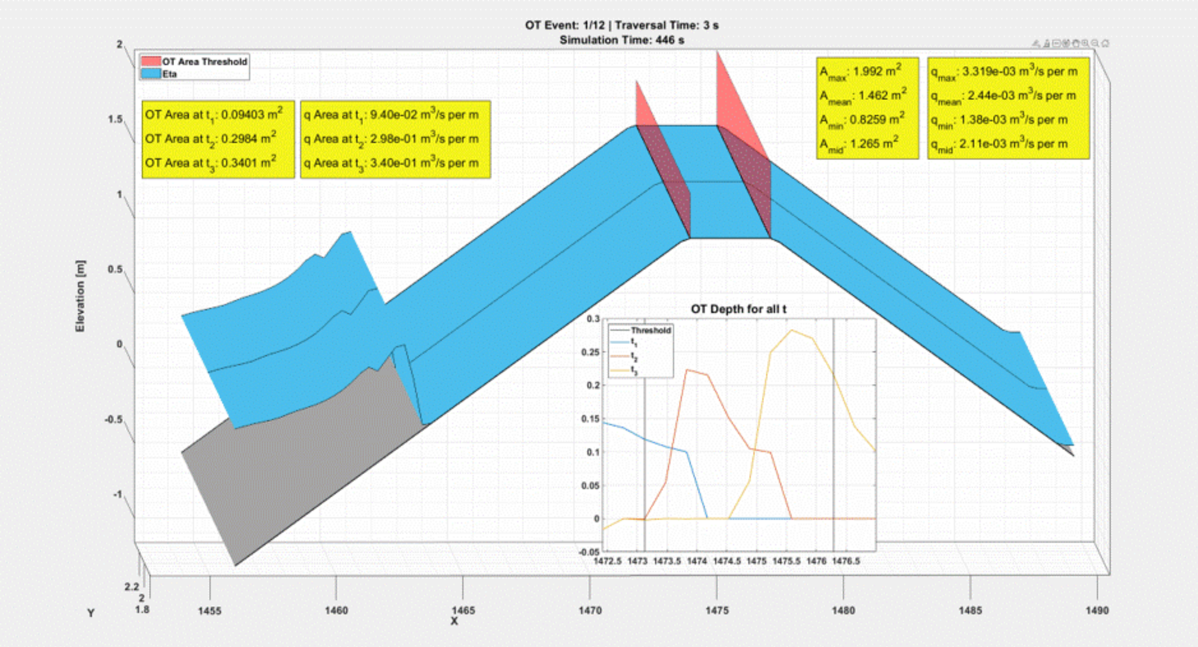
FY23 IN PROGRESS REVIEW

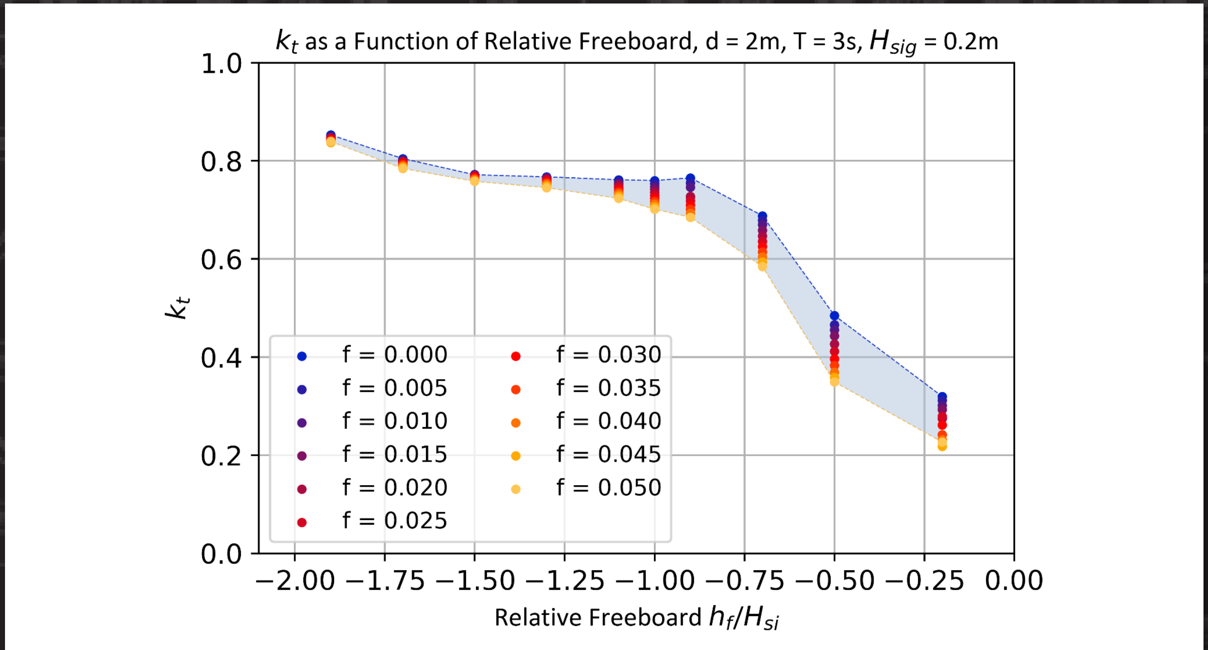
U.S. ARMY

US Army Corps of Engineers®

ERDC

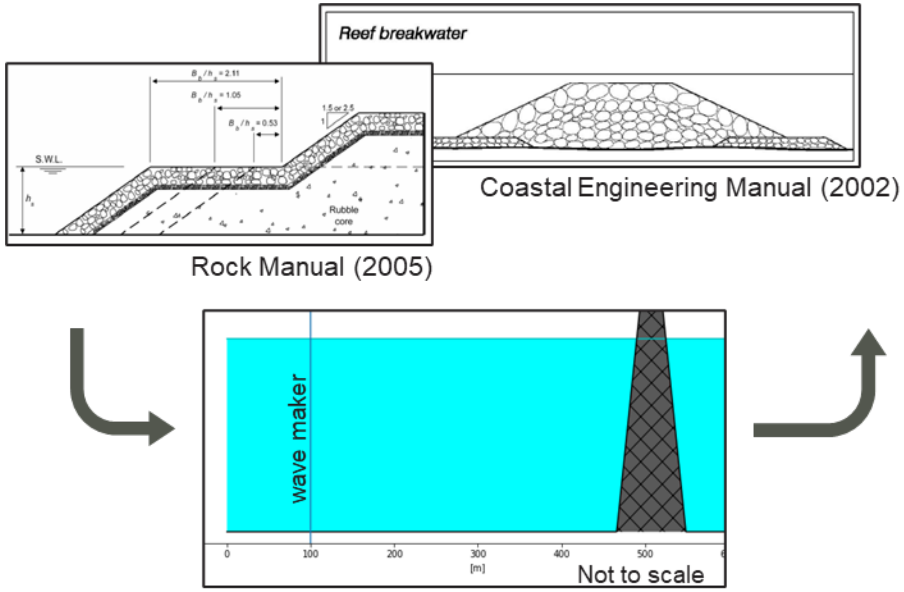
CIRP





PROBLEM STATEMENT

- Coastal structures (e.g., breakwaters and jetties) are vital for navigation, shore protection, and beach stabilization
- There is rarely enough time, money, and resources to execute screening of structure design alternatives or robust assessment of wave-structure interactions
- Connect coastal engineering applications to the phase-resolving, nearshore numerical wave modeling environment & make numerical wave modeling more accessible to practitioners



Statements of Need:

- SoN-1664 (2022) “Enhanced user guidance and support tools for FUNWAVE-TVD, a Boussinesq-type numerical wave model”
- SoN-1370 (2020) “Testing and evaluation of USACE coastal numerical models”
- SoN-1278 (2020) “Boussinesq modeling of wave transformation and interaction with permeable and submerged structures”

FY23 was Year 2 of 3

CAPABILITY AND STRATEGIC IMPACT

- Improved understanding of how to represent coastal structure design properties in FUNWAVE-TVD for increased reliability and accuracy in environmental assessments of coastal structures.
- Enhanced accessibility and usability of FUNWAVE-TVD for users of all levels to save time, money, and resources on SMART planning initiatives
  - Case studies, NNBF, Inland Nav
- Help the Nation stay resilient to coastal storms and floods by providing tools and resources to coastal practitioners.

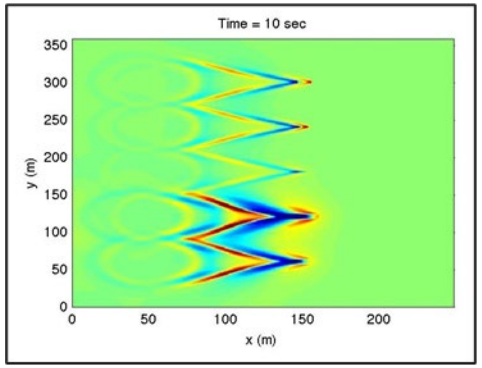
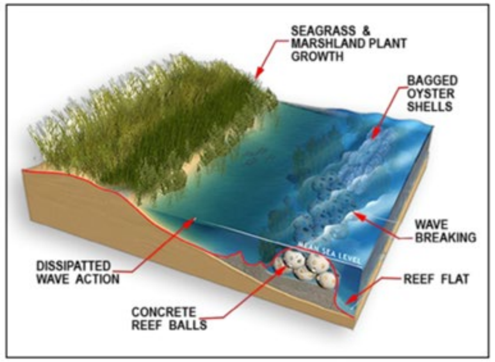


Figure 1. Examples of Coastal Natural and Nature-Based Features



Source: U.S. Army Corps of Engineers, Engineering With Nature, "Natural and Nature-Based Features," at https://ewn.el.erdc.dren.mil/nnbf.html.

PROJECT OBJECTIVES

Wave Response	Dimension	Wave Climate	Structure Properties
Overtopping	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Emergent Smooth / Rough Impermeable
Runup	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Emergent Smooth / Rough Impermeable
Transmission (over structure)	1D	Regular Irregular	Submerged Smooth / Rough Impermeable / permeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Submerged Smooth / Rough Impermeable / permeable
Reflection	1D	Regular Irregular	Emergent Smooth / Rough Impermeable
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Submerged Smooth / Rough Impermeable / permeable

215 (h, T) reg.
160 (h, T) irreg.
5 wave heights
5 wave dir.
5 struct. slopes
5-9 struct. heights
3-5 crest widths
5-10 fric. values
5-9 sponge widths
5-10 sponge strengths
.
.
.

10M+ simulations per wave response!

PROJECT OBJECTIVES (CONT)

Wave Response	Dimension	Wave Climate	Structure Properties	% Complete	Exp. Completion
Runup & Overtopping	1D	Regular Irregular	Emergent Smooth / Rough Impermeable	20%	~~30 SEP 2023 (FY24)~~ **31 DEC 2024 (FY25)**
Reflection	2D	Regular (normal, oblique) Irregular (normal, oblique)	Emergent Smooth / Rough Impermeable	0%	TBD
Transmission (over structure)	1D	Regular Irregular	Submerged Smooth / Rough Impermeable / permeable	30%	~~30 SEP 2023 (FY23)~~ **31 DEC 2024 (FY25)**
	2D	Regular (normal, oblique) Irregular (normal, oblique)	Submerged Smooth / Rough Impermeable / permeable	0%	TBD

- Collapse total number of simulations and group wave responses where possible
  - Each simulation set up for wave reflection analysis
  - Identify where to reduce test suite for meaningful results requiring less resources
  - Isolate runup-only and overtopping events

YEAR-OVER-YEAR

YEAR 1
APR FY22 – FEB FY23
Completed

YEAR 2
FEB FY23 – FEB FY24
Recently concluded

YEAR 3
OCT FY25 – SEP FY25
Upcoming

Project schedule by MONTH FY

APR 22 | JUL 22 | OCT 23 | JAN 23 | APR 23 | JUL 23 | OCT 24 | JAN 24 | // | OCT 25 | JAN 25 | APR 25 | JUL 25

Year 1

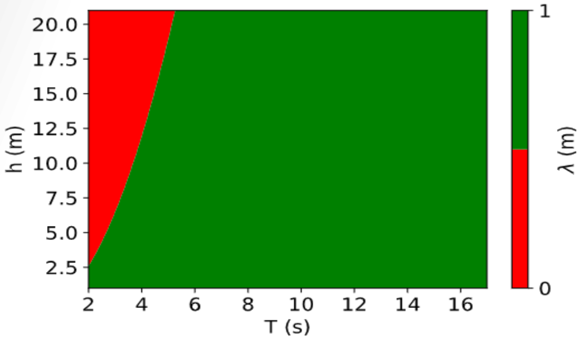
- Completed pre-processing guidance on range of validity and spatial resolution checks
- Identified test cases to verify post-processing script development
- Enhanced usability and accessibility of DoD HPC Portal application

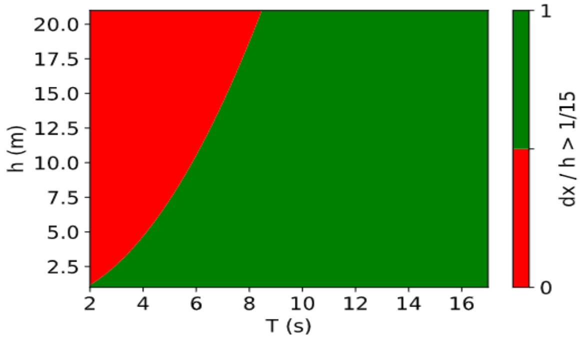
Year 2

- Transitioned pre-processing guidance on range of validity and spatial resolution checks to DoD HPC Portal application
- Completed initial validation of post-processing scripts with test cases
- Developed preliminary guidance on implementing structures in FUNWAVE

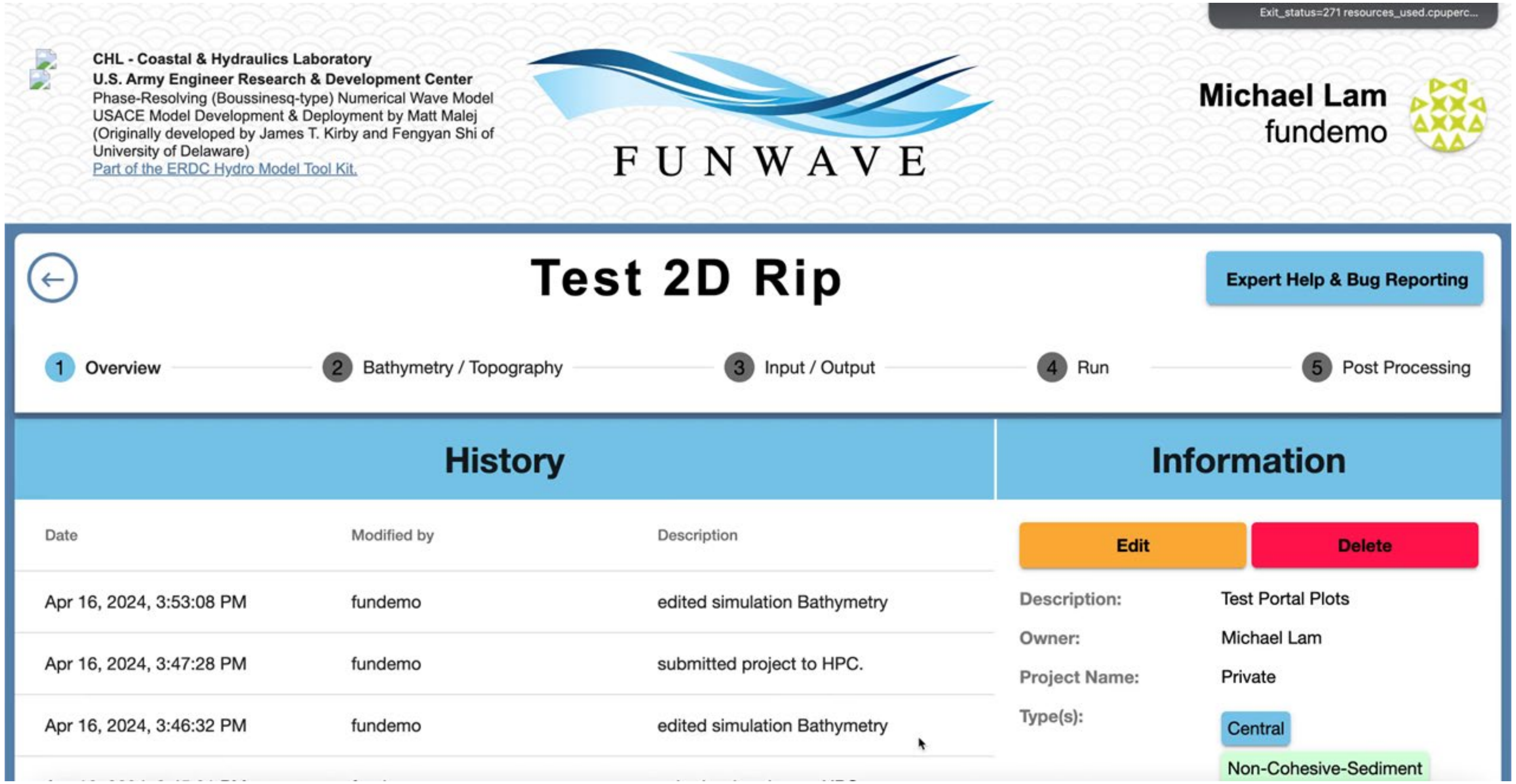
DOD HPC PORTAL APPLICATION

λ > 2h





DX / h > 1 / 15



*Partially supported by HH&C SET program

WAVE RUNUP

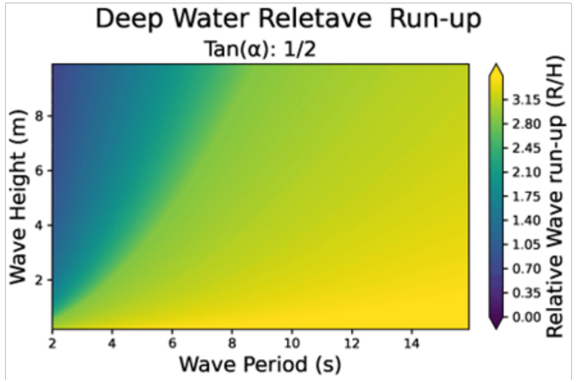
- Comparing results with EurOtop
  - Reframed relative runup (R/H) in terms of depth-limited wavelength
  - Goal: recreate heatmap from FUNWAVE results and compare
  - Initial results require further analysis

$$\frac{R_{u2\%}}{H_{m0}} = 1.65\gamma_b\gamma_f\gamma_\beta\xi_{m-1,0}$$

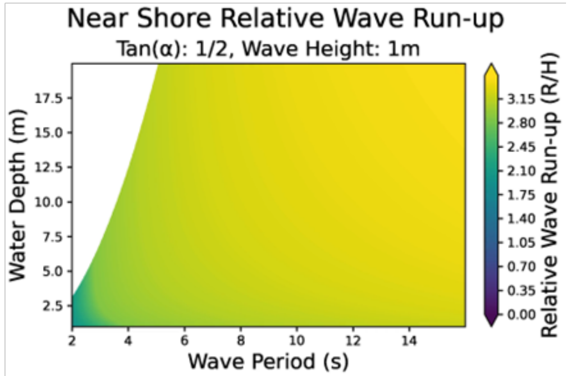
$$\xi = \frac{\tan\alpha}{\sqrt{H/L}}$$

	Wavelength (L)
(DW) $h/L < 1/2$	$\frac{gT^2}{2\pi}$
(IW) $1/20 < h/L < 1/2$	$\frac{gT^2}{2\pi}\tanh\left(\frac{2\pi h}{L}\right)$

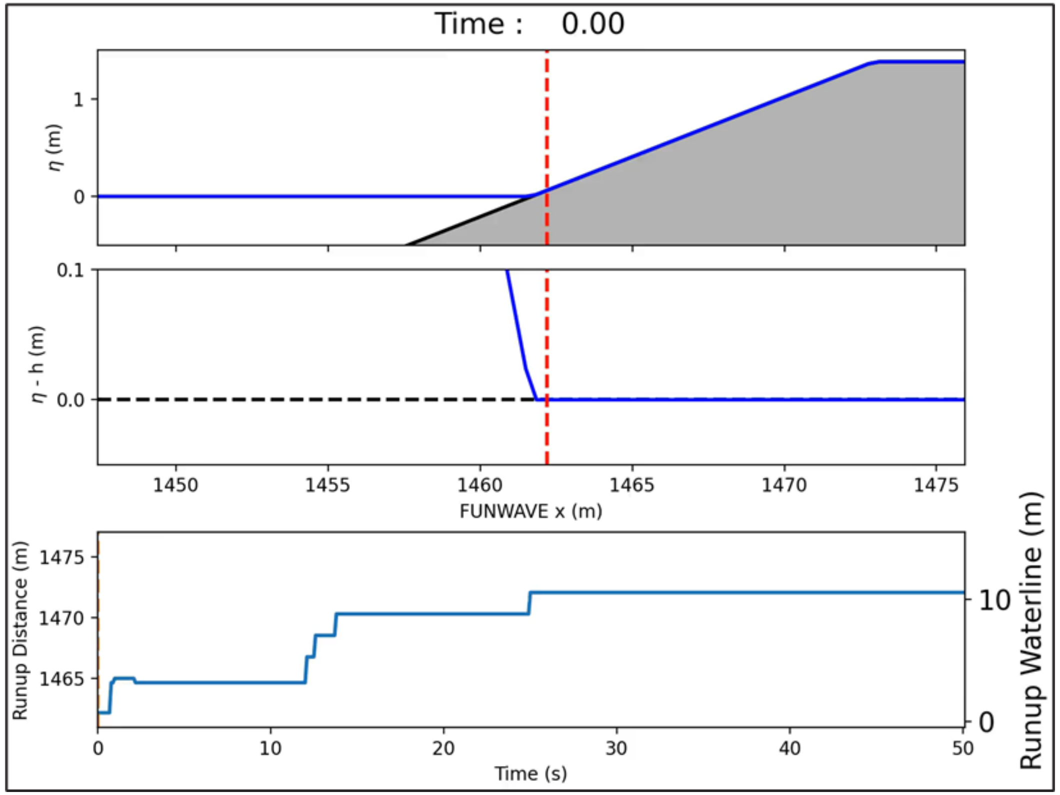
EurOtop (2018)
w/ DW wavelength



w/ IW wavelength

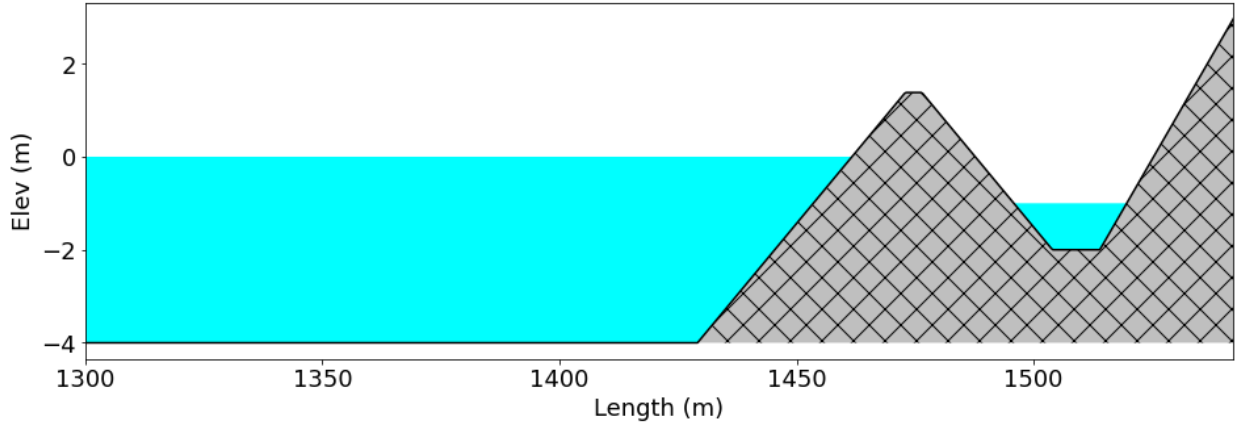


Example of tracking the water line on slope in post-processing; not capturing initial runup line until overtopping occurs



WAVE OVERTOPPING

- Self-validating test case for wave overtopping – check computed volume with bucket volume change
- Careful consideration when computing area over crest versus volume flux
- Initial results show FUNWAVE estimates fall within empirical equation confidence limit



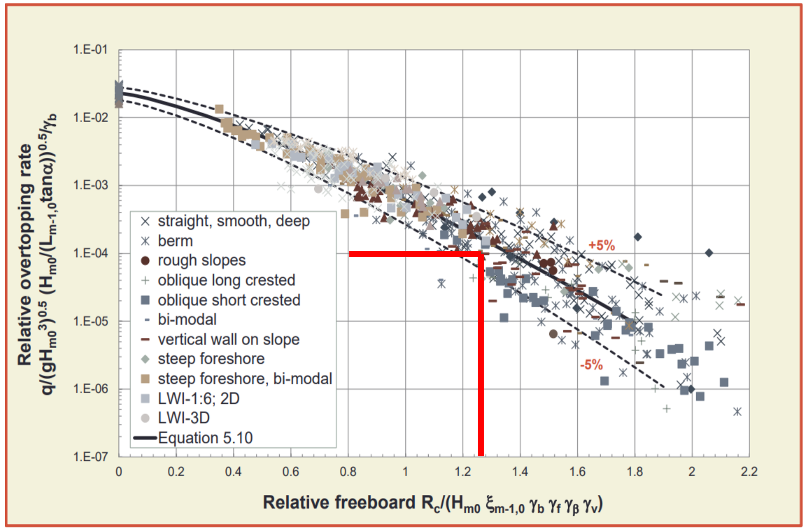
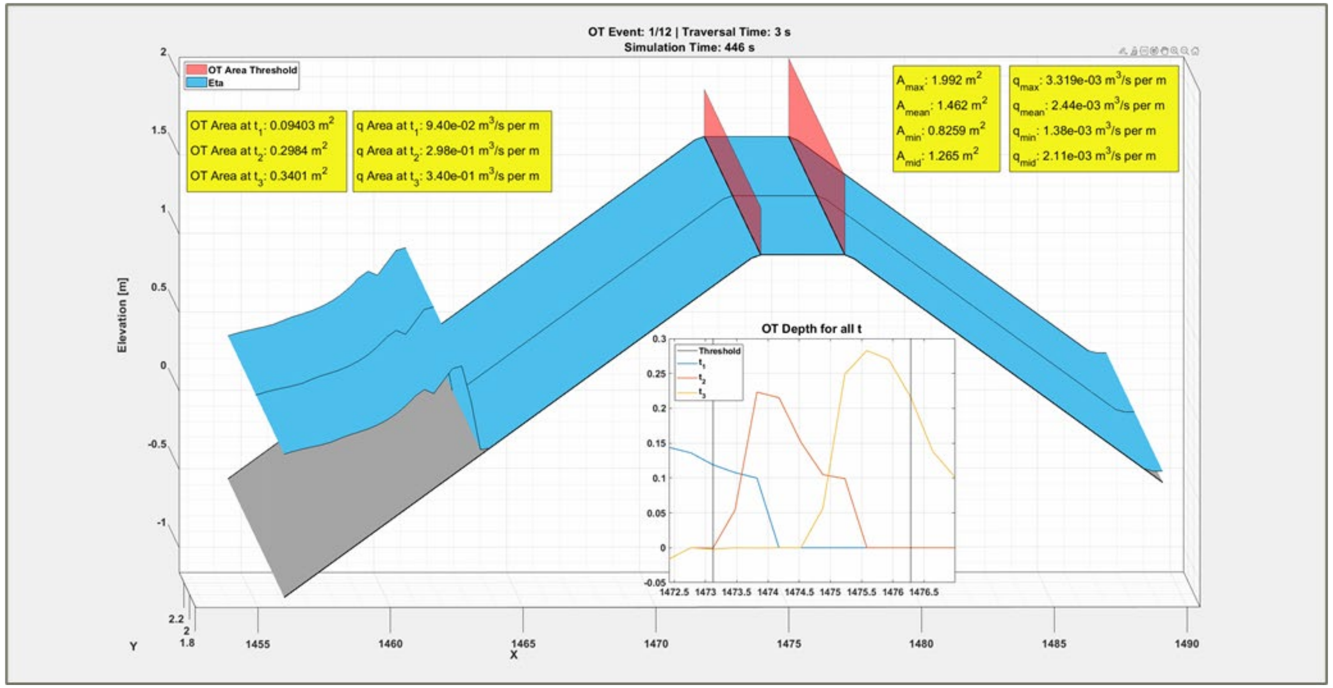
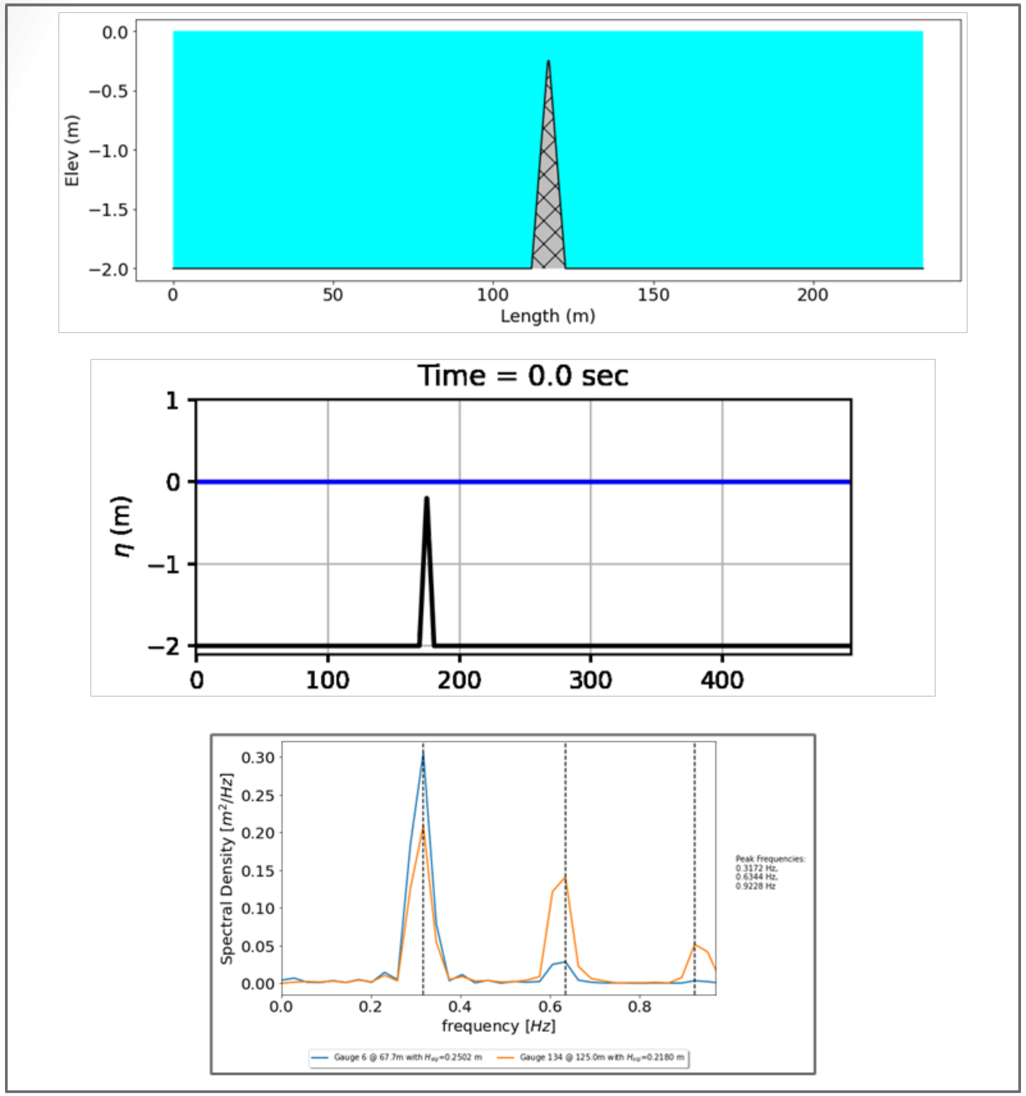


Figure 5.12: Wave overtopping data for breaking waves and overtopping Equation 5.10 with 5% under and upper exceedance limits (= 90%-confidence band)

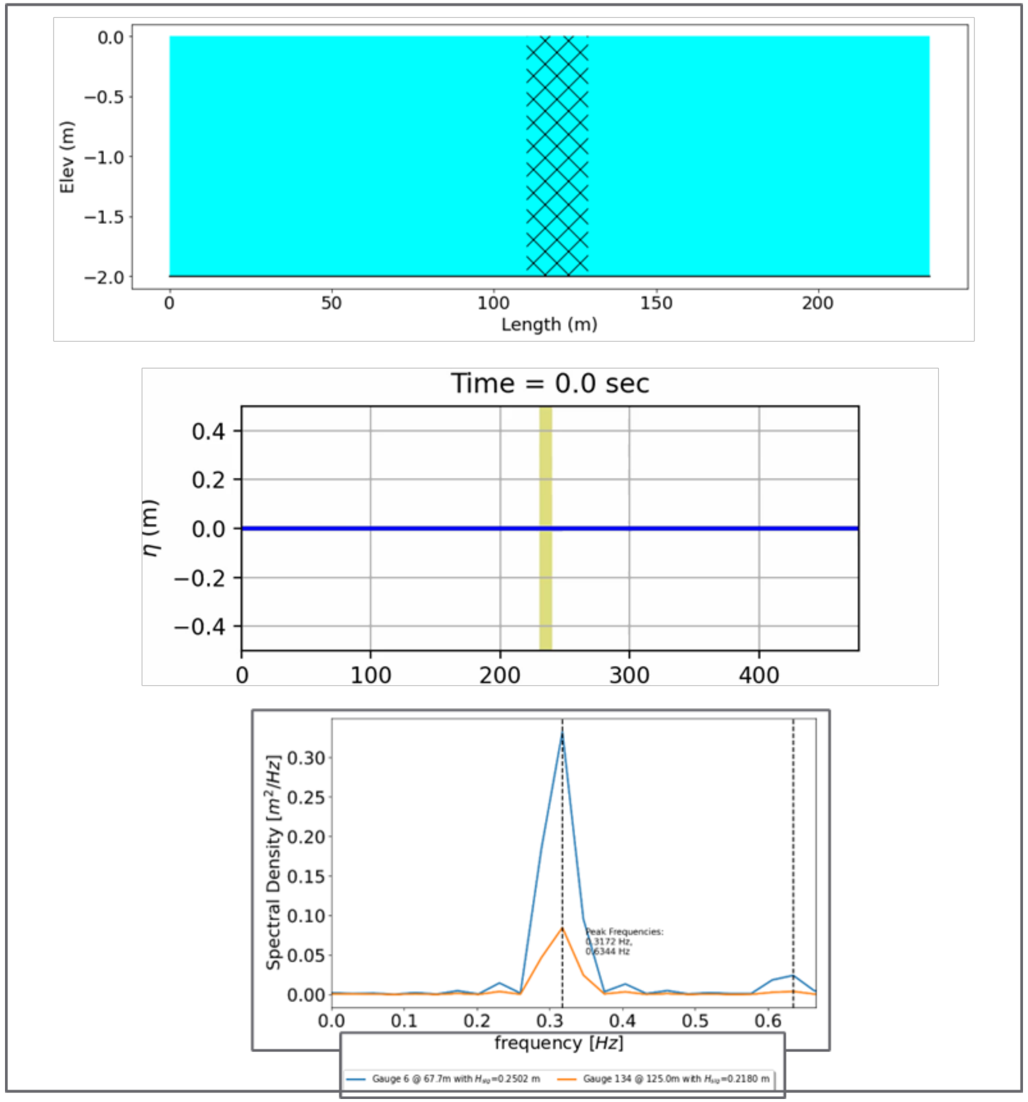


WAVE TRANSMISSION

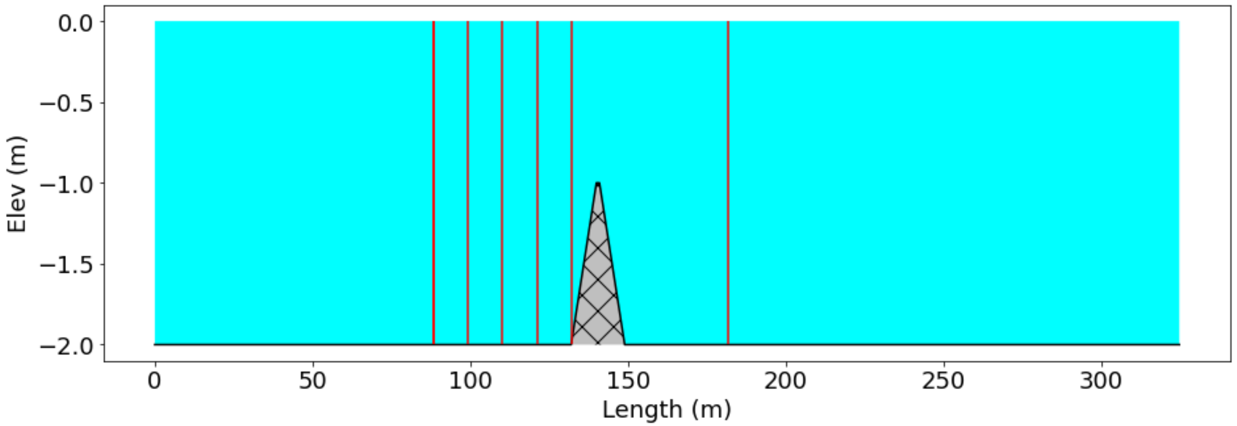
Modify bathymetry



Internal sponge layer

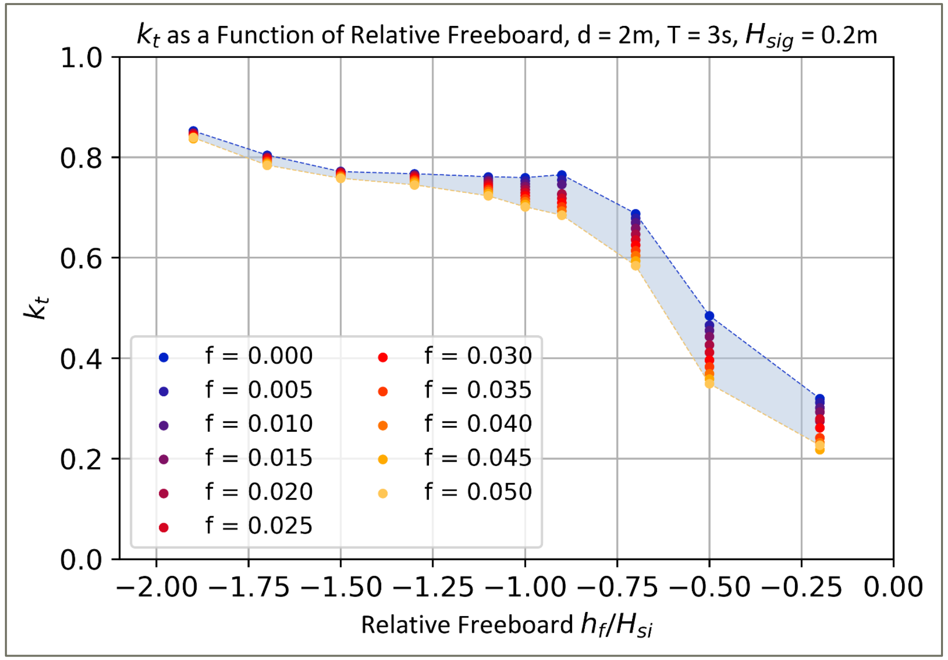


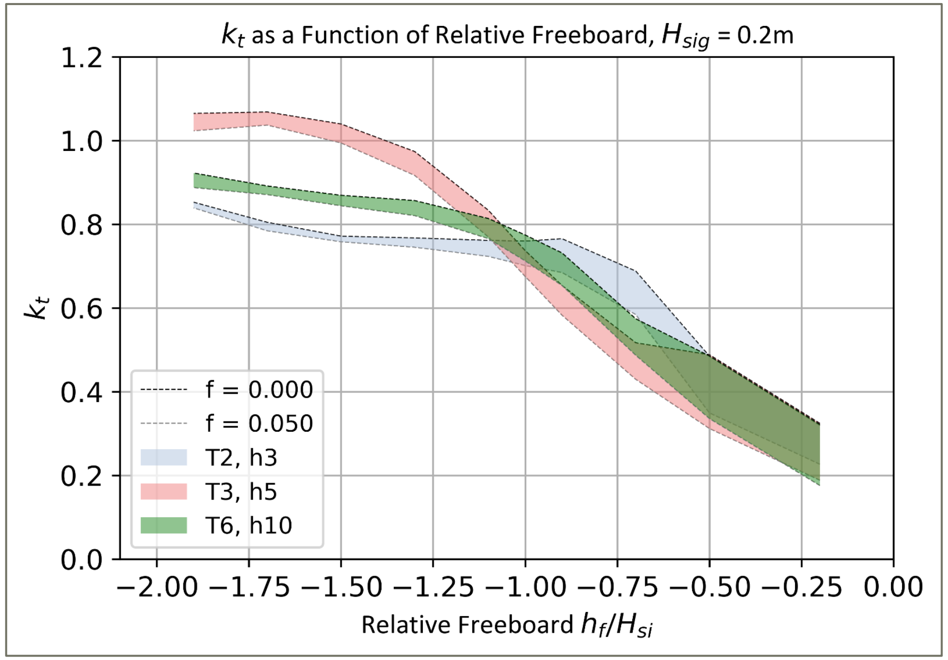
WAVE TRANSMISSION (CONT)



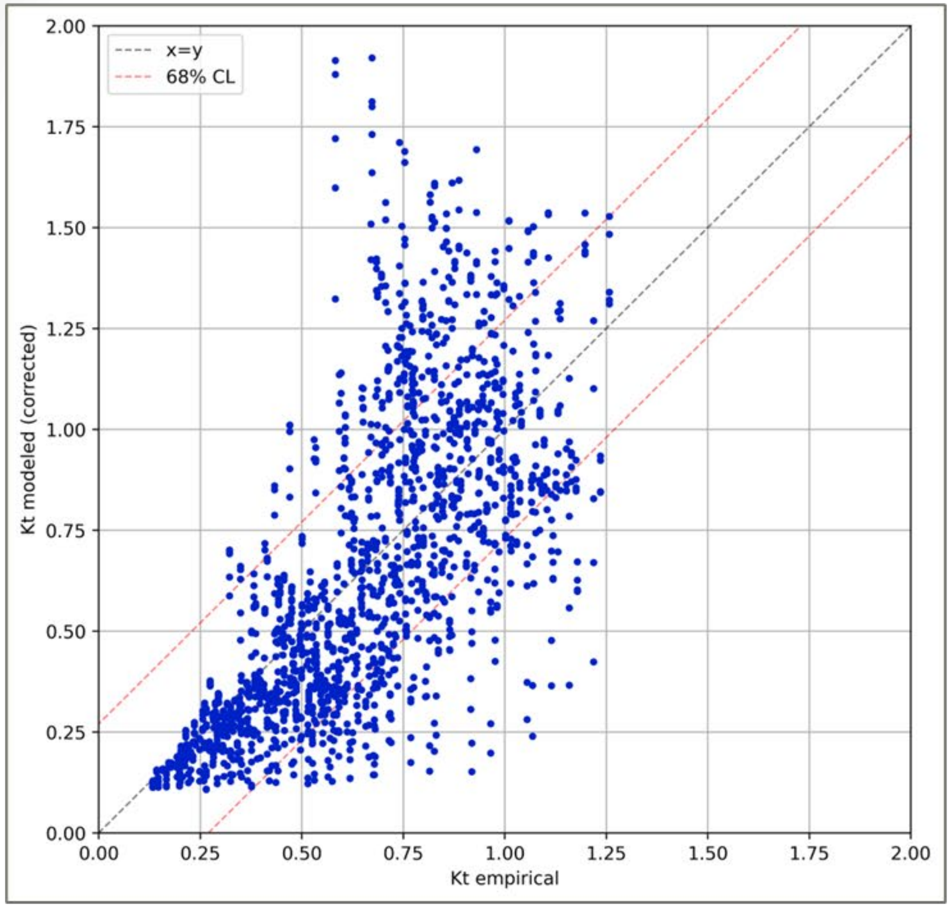
Subset wave conditions

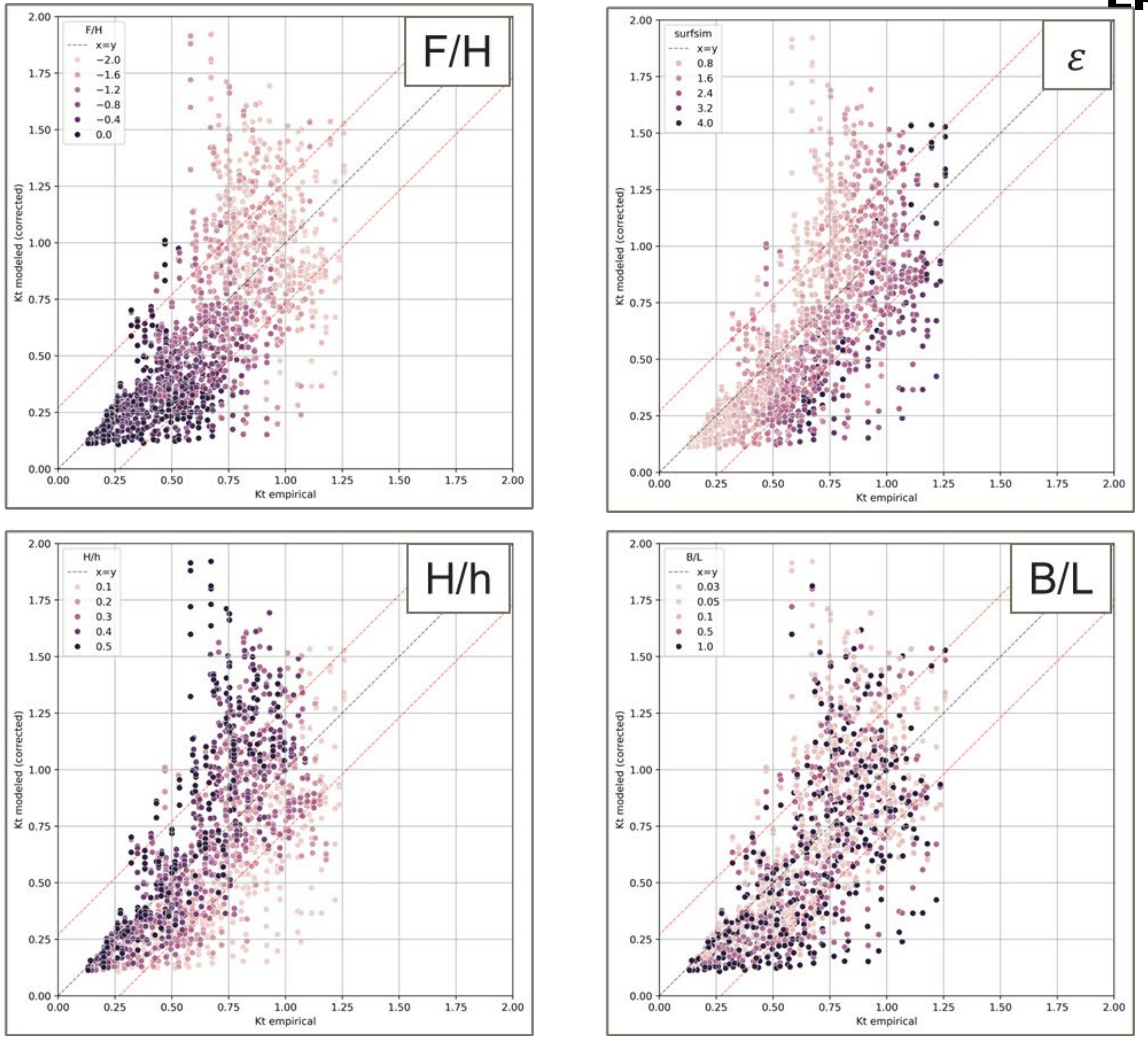
- T = 3, 5, 6 s
- h = 2, 4, 10 m
- m = 1:2, 1:3, 1:5, 1:8
- H/h = 0.1, 0.2, 0.3, 0.4, 0.5
- F/H = -2.0, -1.8, -1.5, -1.0, -0.5, -0.2, 0.0
- B/L = 0.03, 0.05, 0.1, 0.5, 1.0





WAVE TRANSMISSION (CONT.)





FUNWAVE WORKSHOPS

Northeastern University
July 2023

Detroit District
August 2023

Buffalo District
November 2023

*Primarily supported by HH&C SET Program

SUMMARY

FY23 Major Advancements in Capability

- Transition pre-processing tools to DoD HPC Portal application
- Wave response post-processing scripts available on GitHub in FUNWAVE Python Toolbox
- Simulation checklist on FUNWAVE Wiki & other updates
- Troubleshooting guidance and recommendations

FY23 Major Products & Collaborations

- ERDC TN on troubleshooting guidance (exp. APR 24)
- ERDC TR on FUNWAVE Testbed (exp. APR 24)
- CIRP TD on wave transmission (12 SEP 23)
- ASBPA conference presentation (OCT 23)
- 3 PDT presentations/discussions
- ORISE student transitioned to SSEP
- Storyboard
- FUNWAVE Wiki updates
- New District partners: Buffalo, New England

FY25 Products & Advancements

- Transition post-processing tools and interactive visualization to DoD HPC Portal application
- ERDC TR on wave transmission, overtopping, and runup results
- Potential JP on effect of nonlinearities on wave energy propagation in FUNWAVE
- FUNWAVE Workshops (JUL 24) and tech discussions (TBD)
- ASBPA, AGU Oceans, or other conference presentation