FUNWAVE:
BRIDGING THE SHALLOW-TO-DEEP WATER WAVE GAP

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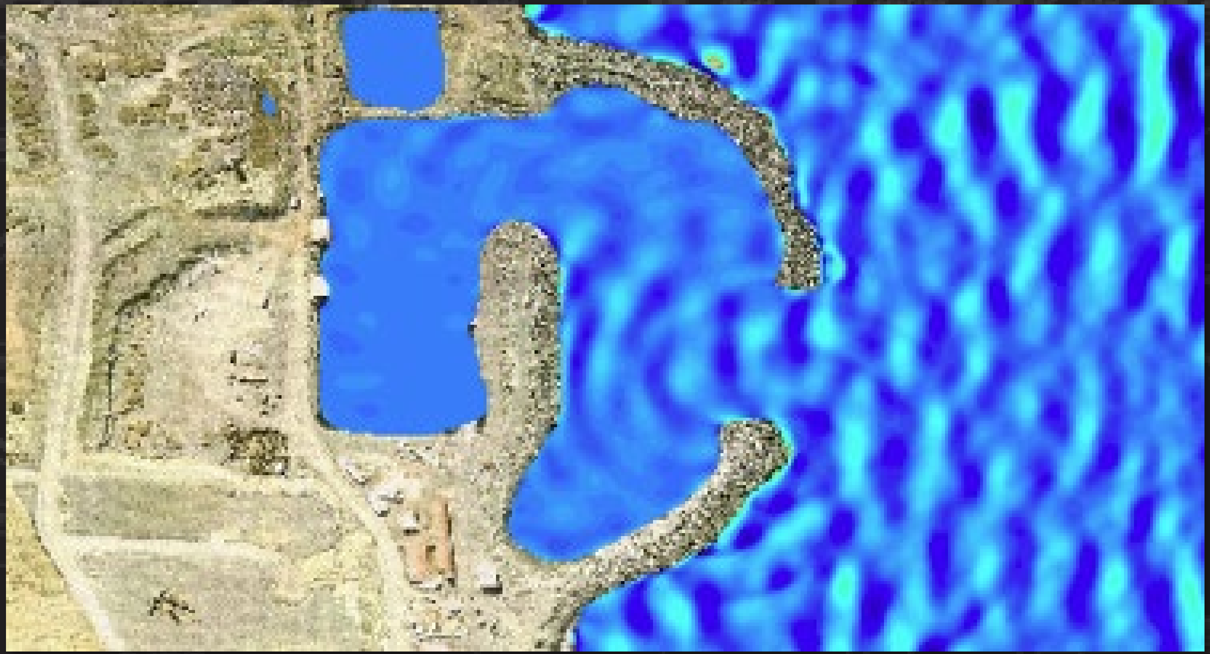

COASTAL INLETS RESEARCH PROGRAM
FY23 IN PROGRESS REVIEW

U.S. ARMY
US Army Corps of Engineers®
ERDC
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PROBLEM STATEMENT

- Boussinesq-type models have become popular in the last two decades, mainly due to two reasons:
  1. The growth of HPC resources has made the application of Boussinesq-type models more practical and
  2. A balance between computationally expensive high-fidelity models and less accurate but faster phase-averaged type models.
- Currently, there are <u>two</u> major limitations in practical applications of the FUNWAVE model:
  1. highly dispersive waves, common in intermediate to deep-water regions; and
  2. external forcing associated with variable water levels and large-scale processes, such as tides and storm surges.
- Common approaches to extend Boussinesq models from 2^{nd} to 4^{th} order in *kh* have been rendered computationally expensive and notoriously unstable.

Statement of Need: SON-N-1694 & SON-N-1754

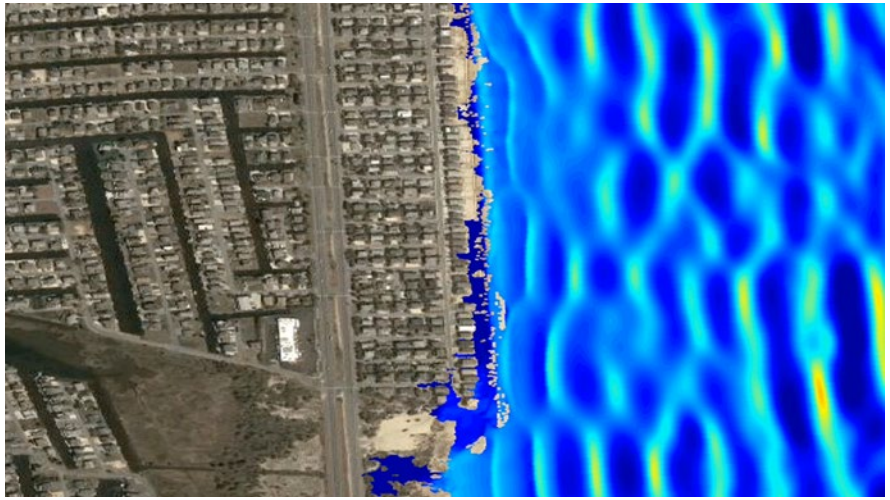
FY23 was Year 2 of 3

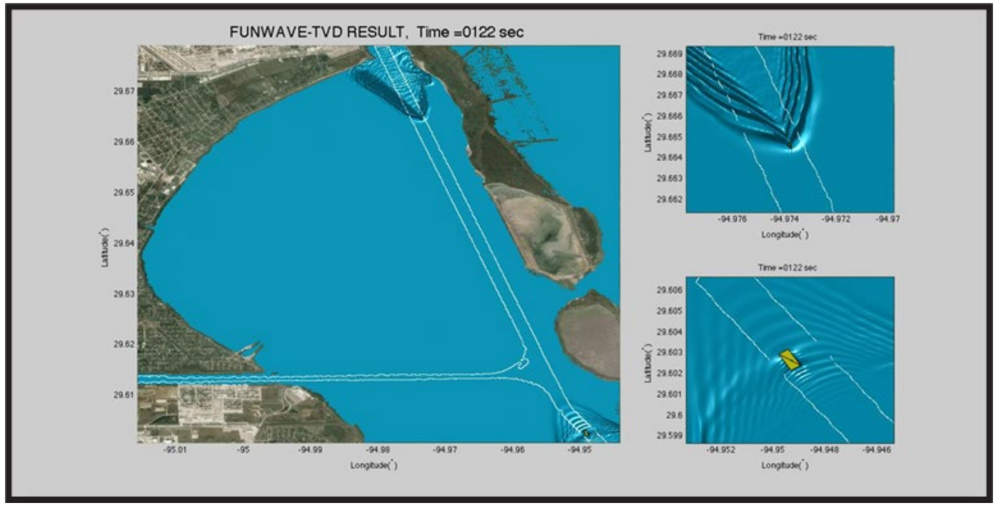
Year over year advancements to date

CAPABILITY AND STRATEGIC IMPACT

- The new modules/products will enhance the predictive capability of simulating surface waves, ship-wakes , and wave-induced processes, especially those involving wave interactions with shorelines in larger temporal and spatial domains. This will allow ERDC/CHL to remain state-of-the-art in wave modeling.

- Civil Works (CW) Strategic Focus Areas (SFA):
  - Improved model accuracy and efficiency in simulating event-scale hydrodynamics, such as hazardous waves, coastal flooding, and ship-wake-induced coastal erosion.





- Military Applications

FUNWAVE

FUNWAVE is a phase-resolving numerical wave model for shallow-to-intermediate water depths that resolves many physical wave processes in littoral regions, such as:

- ✓ nearshore wave propagation & transformation, including refraction, **diffraction** & nonlinear shoaling (Littoral Entry Operations)
- ✓ bottom friction & wave-induced current, nonlinear wave-wave & wave-current interactions
- ✓ wave breaking with **runup** & **overtopping of structures** (Flooding threats)
- ✓ **harbor resonance** and **infragravity (IG) waves** (Important for understanding austere ports of entry)
- ✓ **vessel-generated waves** & sediment transport with morphology change
- ✓ landslide-generated tsunamis (regional and global ocean basin)
- ✓ High-Performance Computing (HPC) Portal web-based access with GUI

DOD HPC DEPARTMENT OF DEFENSE HIGH PERFORMANCE COMPUTING PORTAL

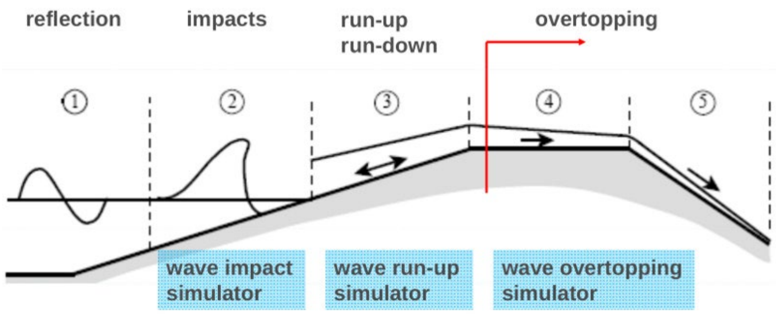
OPEN SOURCE SOFTWARE

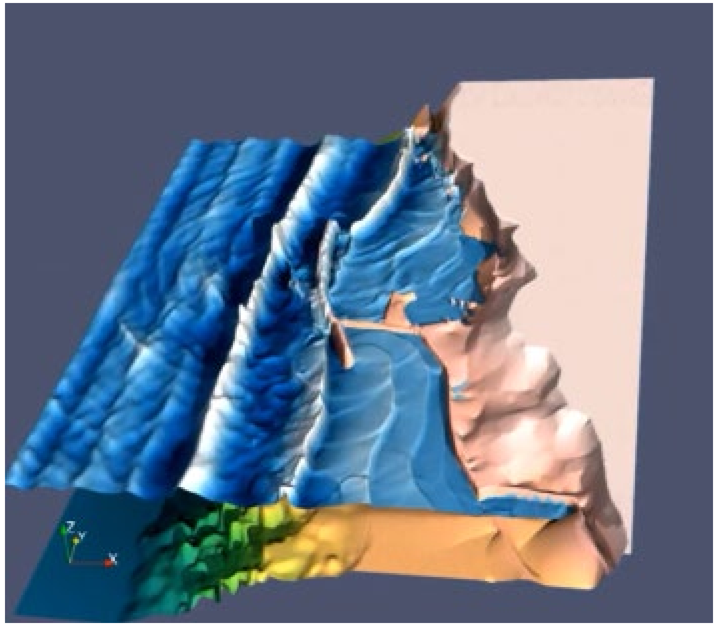
* **underline/bold** not available in phase-averaged models!
* (blue) military application

Model Access: FUNWAVE has a comprehensive Wiki page with source code access via a version-controlled online repository and an extensive suite of test cases at https://fengyanshi.github.io/build/html/index.html

Bridging the Gap: Utilize FUNWAVE to pre-calculate surfzone wave dynamics swash zone runup & overtopping to provide rapid surrogate modeling between high-fidelity N-S equation models and phase-averaged ones.

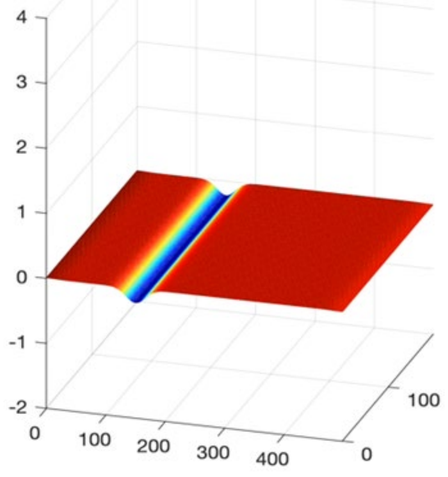
Wave-structure interaction processes

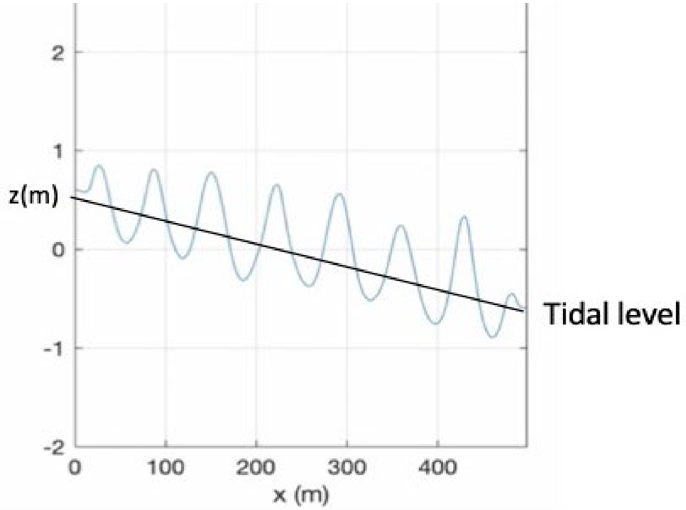


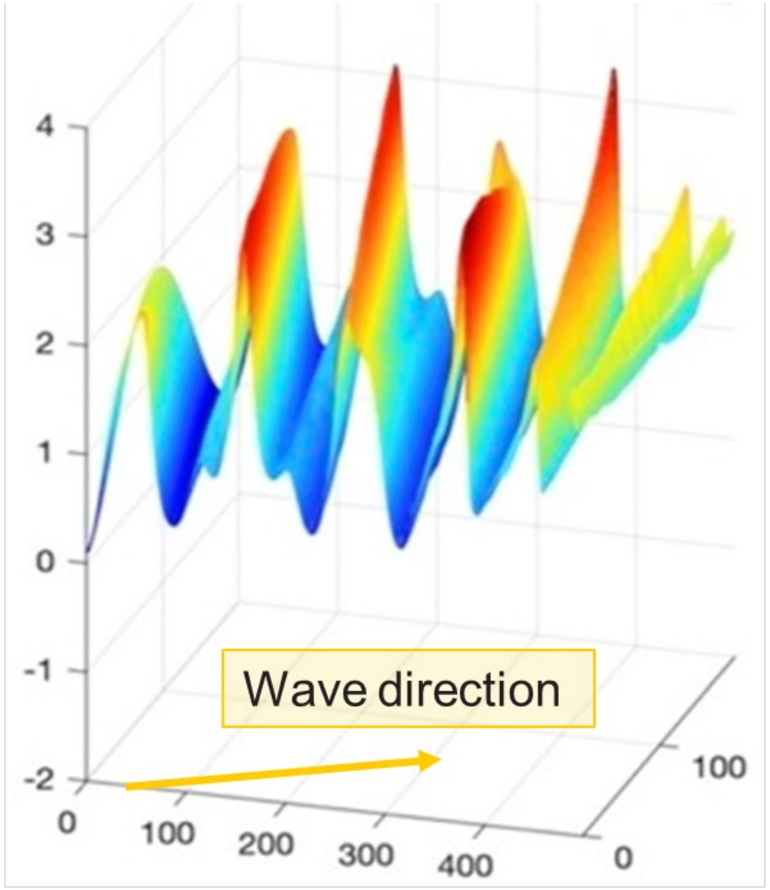


TIDAL FORCING

- Analogous to the sponge layer methodology
- Absorbing Tidal Boundary Condition (BC)
  - It can be applied at any boundary
- Absorbing-Generating Tidal BC:
  - Simplifies coupling of wavemaker and absorbing tidal BC
  - This can only be applied to the west boundary
  - A limited selection of wave maker types





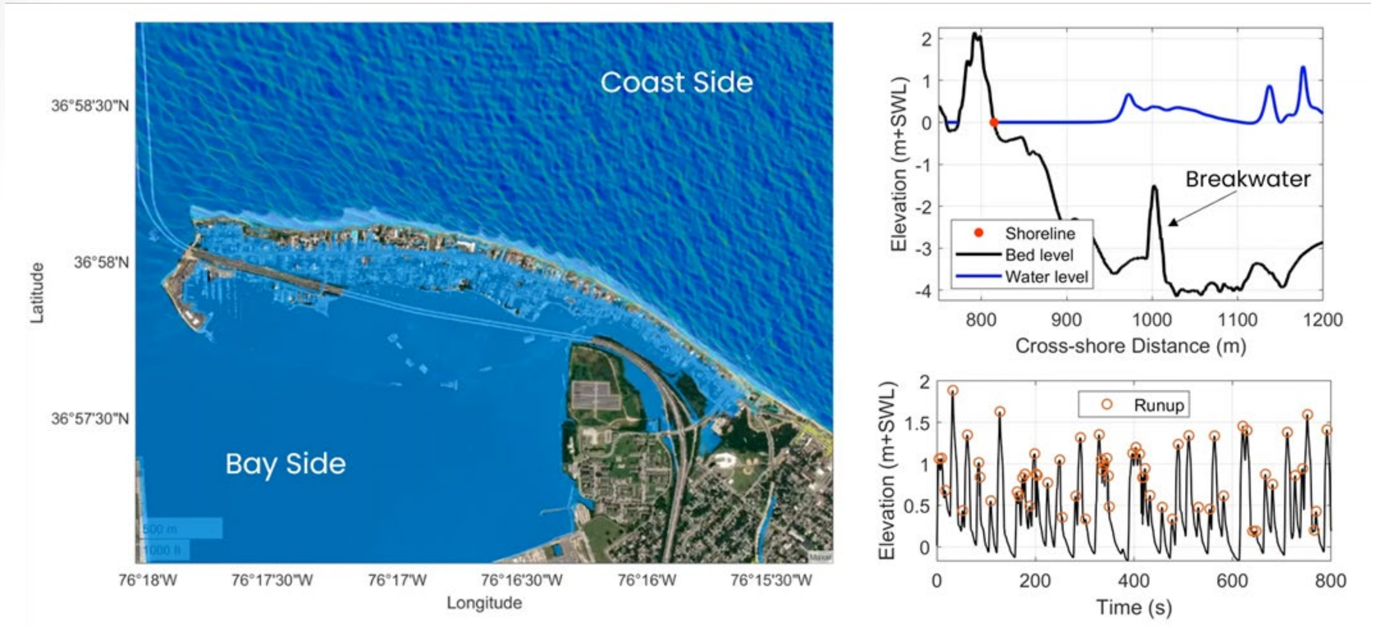


NOTE: Either sponge layer or absorbing tidal BC at each boundary

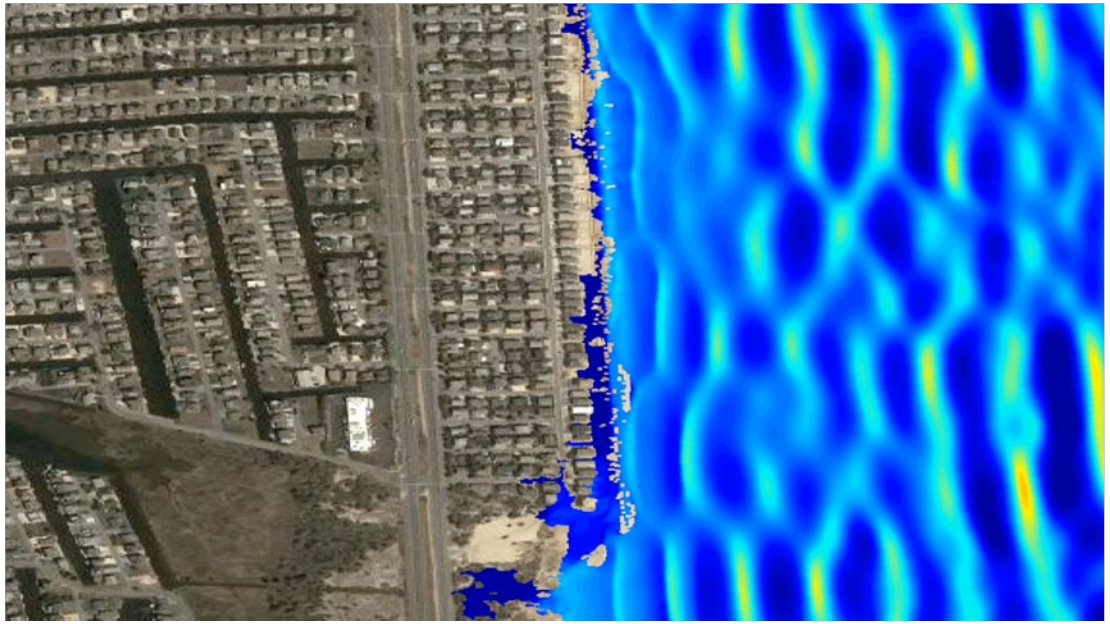
TIDAL/SURGE EXAMPLE

While called the tidal module, storm surge data may also be used as input.

(Tidal) Hurricane Irene at Norfolk



(Surge) 100-year storm at South Bethany Beach



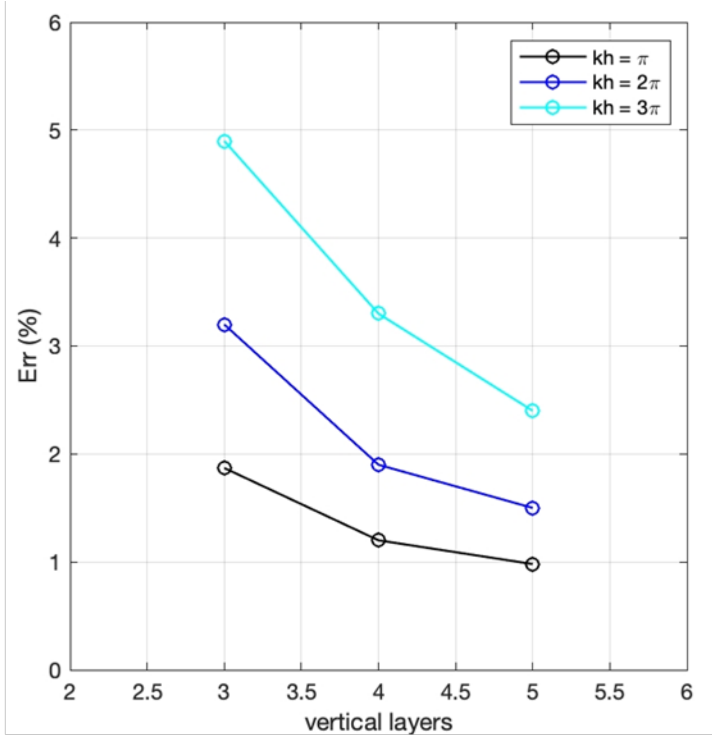
Joint work with University of Delaware

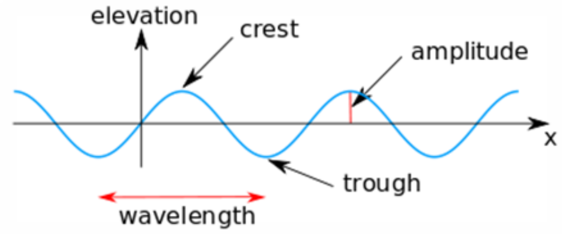
DEEP WATER EXTENSION

- FUNWAVE is limited to waves satisfying:

$$kh < \pi \Leftrightarrow h/L < 1/2.$$

  - Increasing kh barrier would allow:
    - Deeper waters (larger h), or
    - Shorter waves (smaller $L \Leftrightarrow$ larger k).
- 4th order (kh) Boussinesq type models are highly unstable.
- Based on surface flow techniques commonly used for non-hydrostatic models.



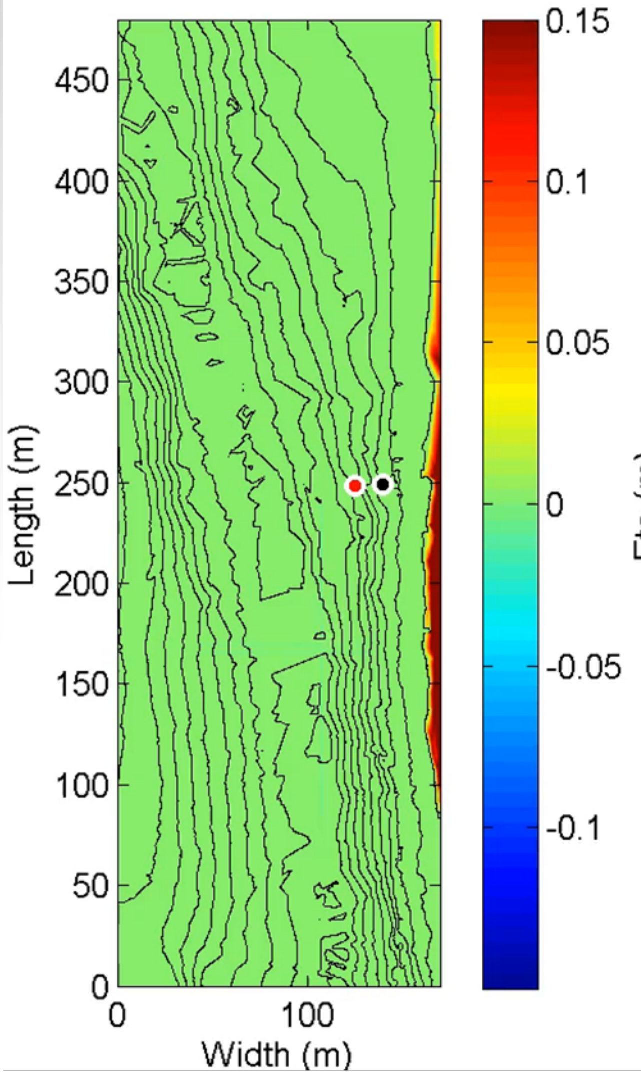


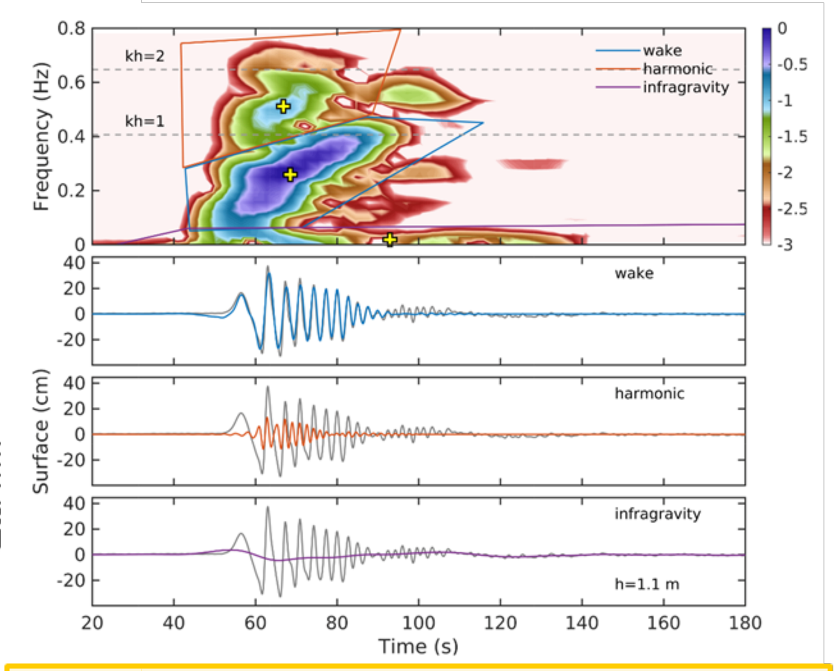
k – Wave Number

L – Wavelength $\quad L = \dfrac{2\pi}{k}$

h – Depth

VESSEL GENERATED WAVES ($kh < \pi$)





Froude Number: Which reference length?

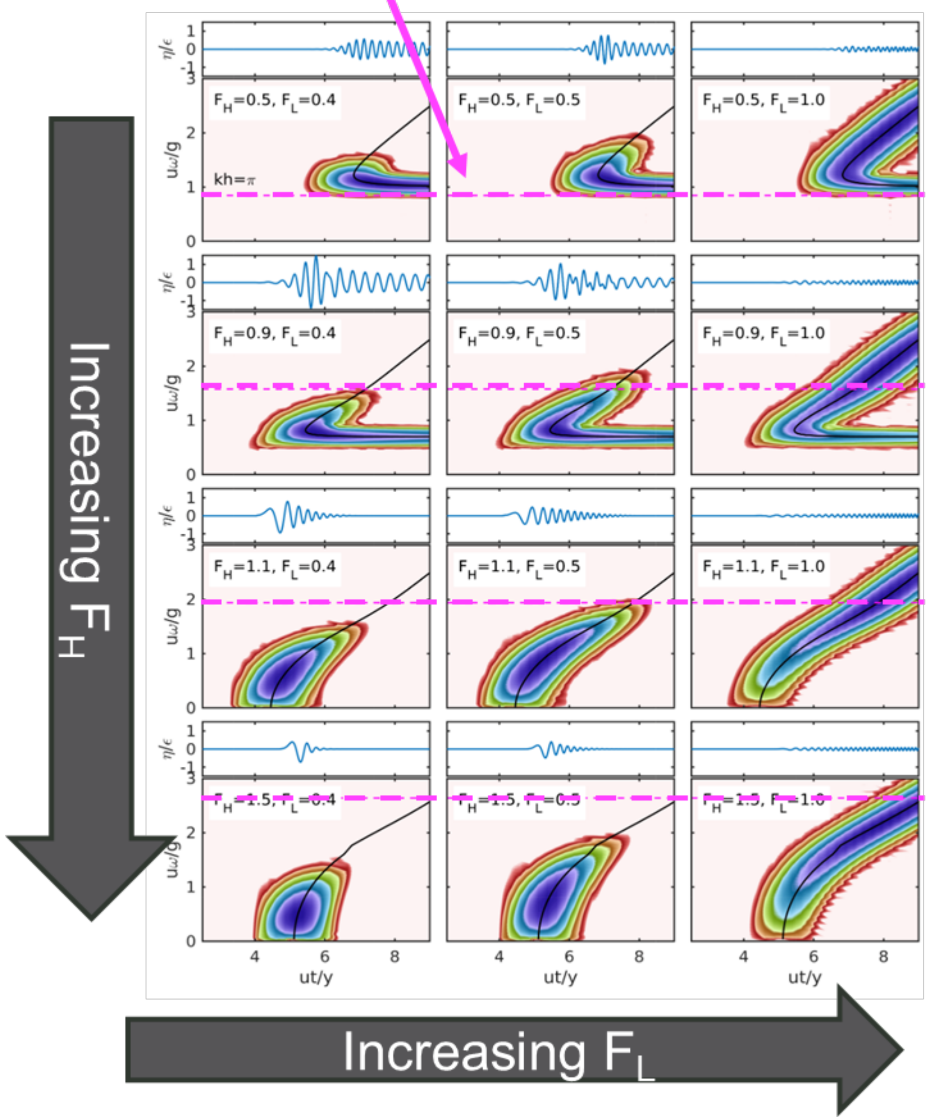
$$F_H = \frac{U}{\sqrt{gH}} \qquad F_L = \frac{U}{\sqrt{gL}}$$

L – length of vessel

U – speed of vessel

H – depth

g – gravity



SUMMARY

FY23 Major Advancements in Capability

Tide Module

- Available in the latest version of FUNWAVE
- Documentation available on Wiki and in the soon-to-be-released technical note

Deep Water Module

- The beta version of the code was completed
- Promising preliminary validation

FY23 Major Products & Collaborations

Publications

- Technical Note: Tide Module (w/ editor)
- Technical Report [Contributed]: FUNWAVE Test Bed (w/ editor)
- Journal of Ocean Engineering (peer-reviewed)
  - *Modeling the optical signature induced by wave breaking using the Boussinesq-type*

Collaborator

- Districts: LRB, NWP, LRE, SAJ, POH, SPL, and SWG.
- Academia: University of Florida, University of Delaware, Georgia Tech, University of Rhode Island

FY24 Products & Advancements

- Completion of deep-water module with the release of open-source code
- Technical Note/Report on deep water module with test cases
- Workshop/Mini-workshop on deep water module and tide module