EXTENDING FUNWAVE:

TIDAL/SURGE FORCING & BRIDGING THE SHALLOW-TO-DEEP WATER GAP

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COASTAL INLETS RESEARCH PROGRAM

FY24 TECHNICAL DISCUSSION

U.S. ARMY

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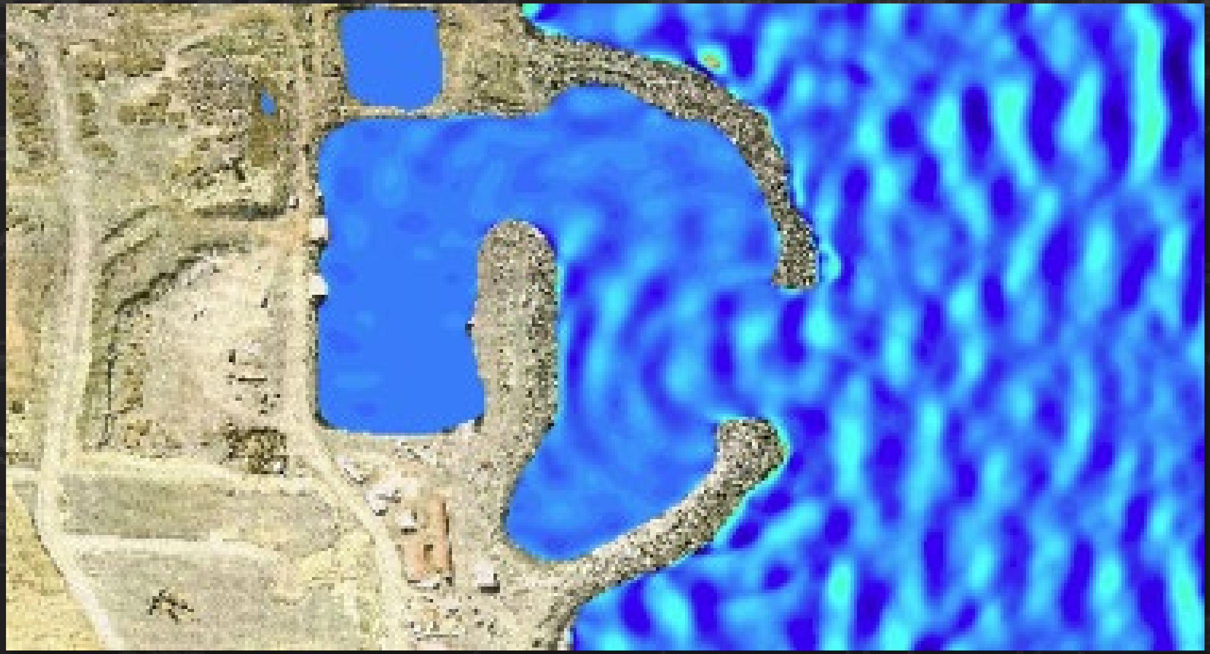
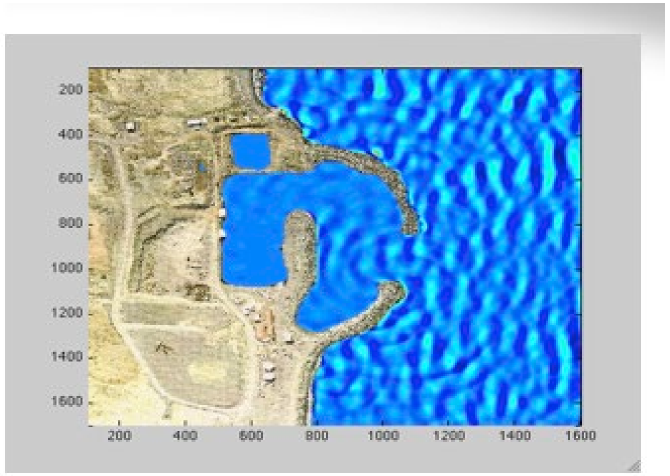
ERDC

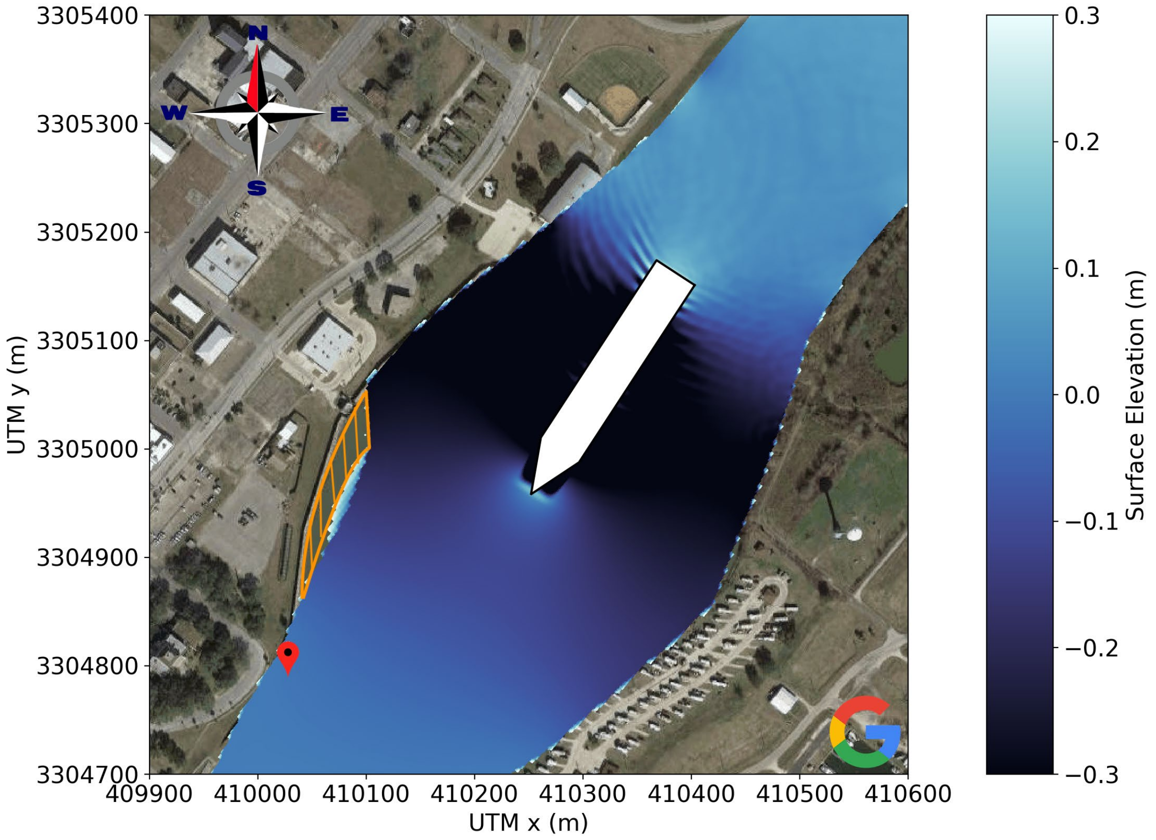
CIRP



OVERVIEW

- FUNWAVE Model
- Tidal/Surge Module
- Deepwater Module [Ongoing]





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

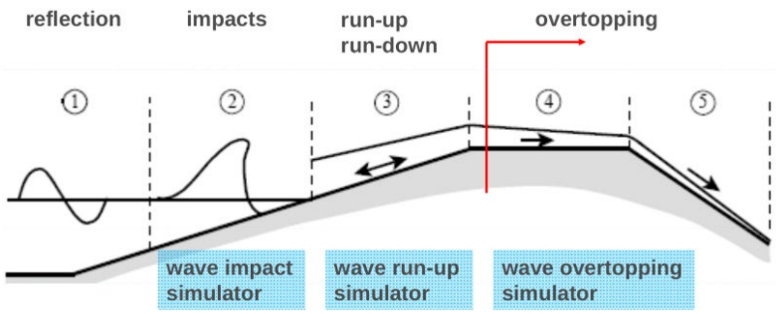
OPEN SOURCE SOFTWARE

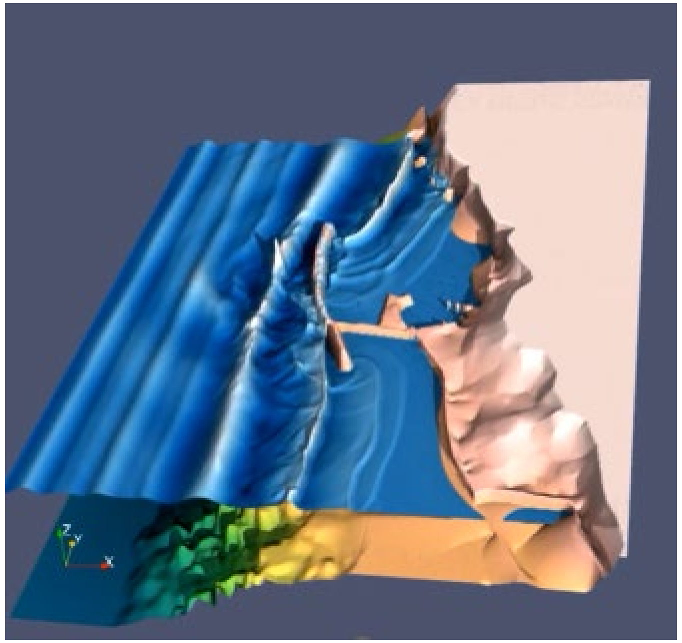
* **underline/bold** not available in phase-averaged models!
* (blue) military application

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



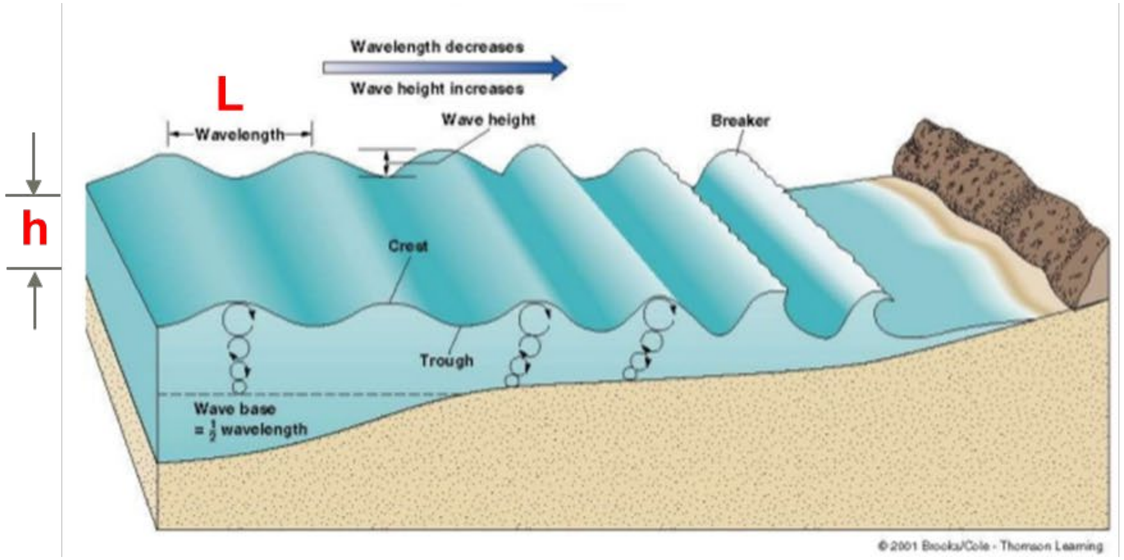


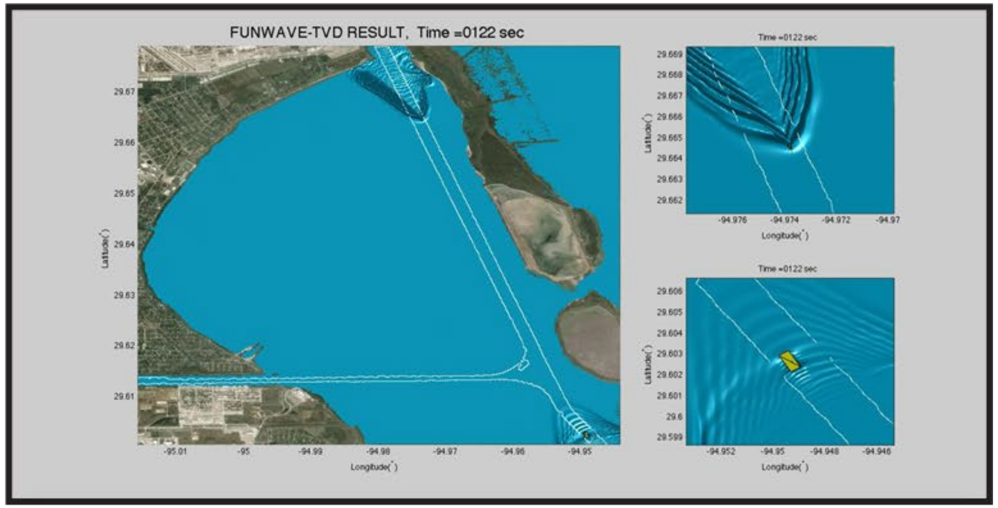
MOTIVATION

- A depth-averaged approach that removes z-dependence, i.e., $(x, y, z) \Rightarrow (x, y)$.
  - Computational less expensive
- 2nd Order, h/L, Boussinesq type model that is weakly dispersive, but fully non-linear
  - Waves feel the bottom, $h \lesssim L/2$, and move at slightly different speeds
- FUNWAVE applied to increasing more complex scenarios, including:
  - larger domains, pushing FUNWAVE into deeper waters; and
  - longer times, therefore tidal forces are relevant.

$$\frac{h}{L} \sim kh$$

$$k = \frac{2\pi}{L}$$

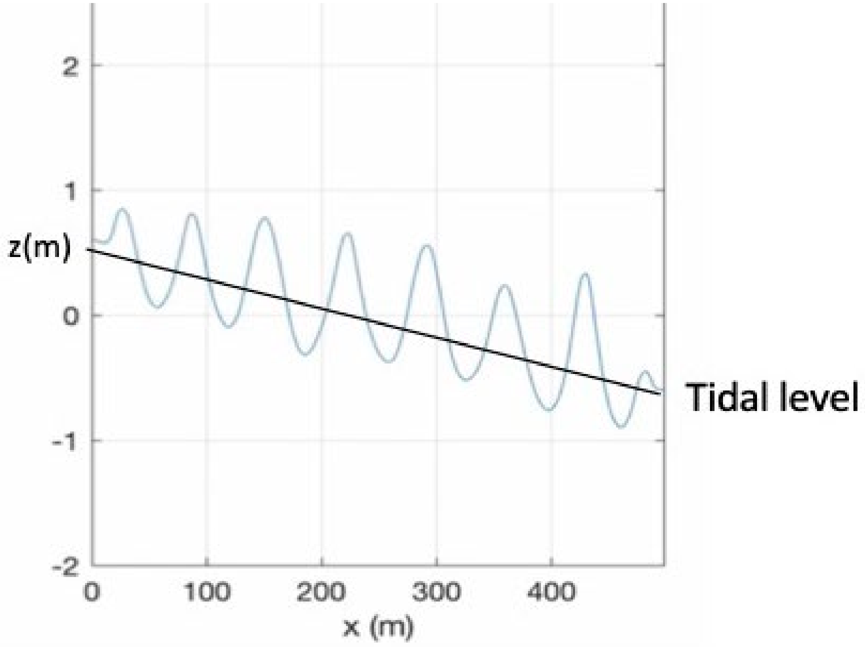


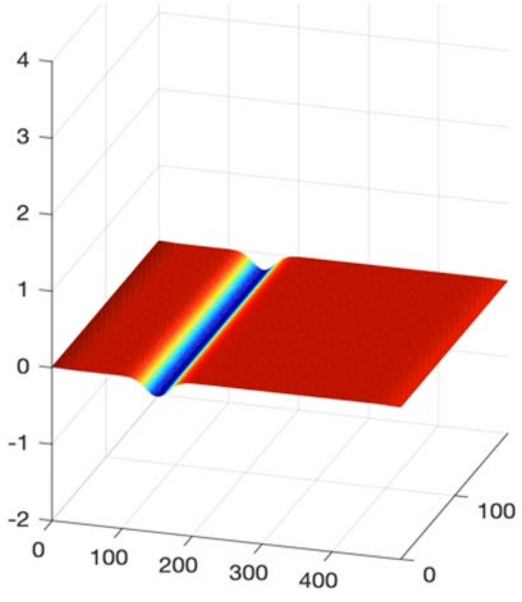


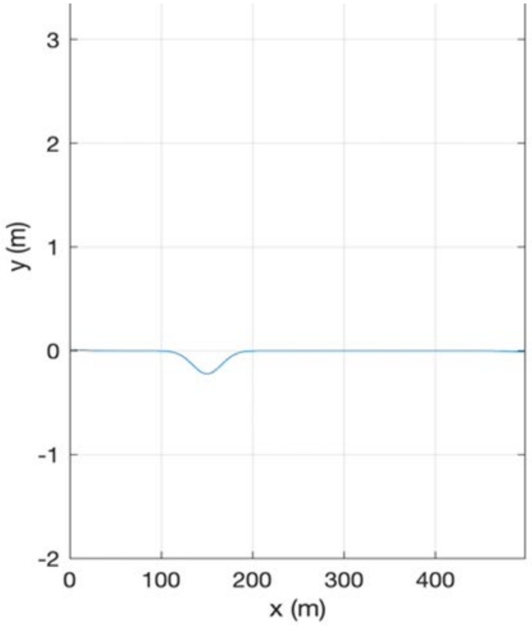
TIDAL FORCING METHOD 1

Absorbing Tidal Boundary Condition (BC)

- Analogous to the sponge layer implementation
- May be used on one or more boundaries
- Water level and velocity inputs, two types:
  constant or time-varying







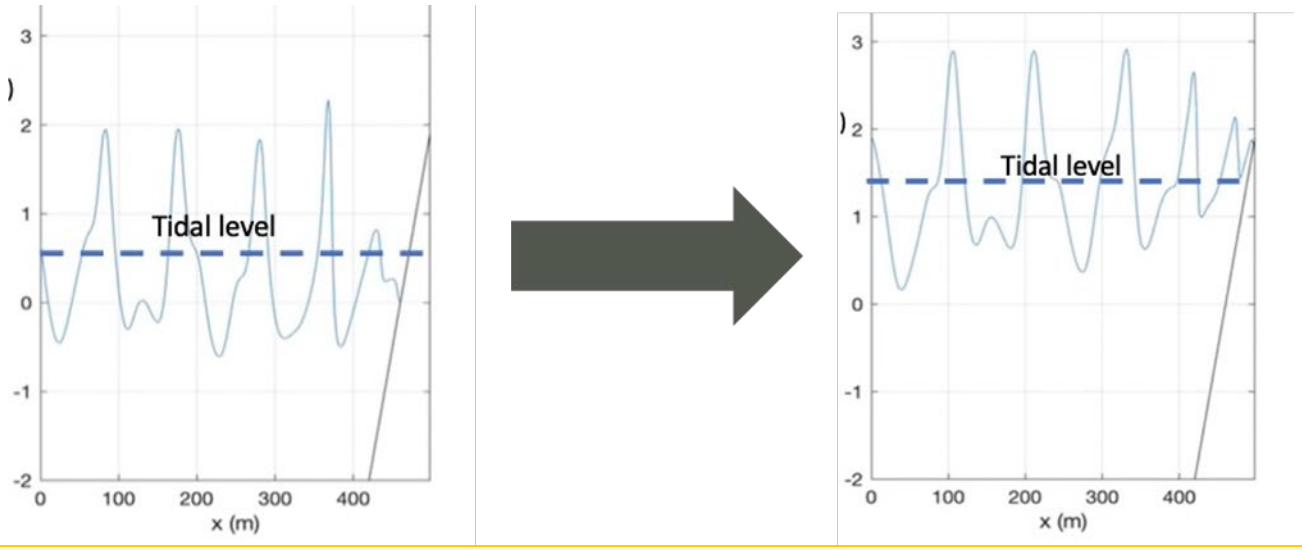
NOTES:
Wavemaker implemented separately

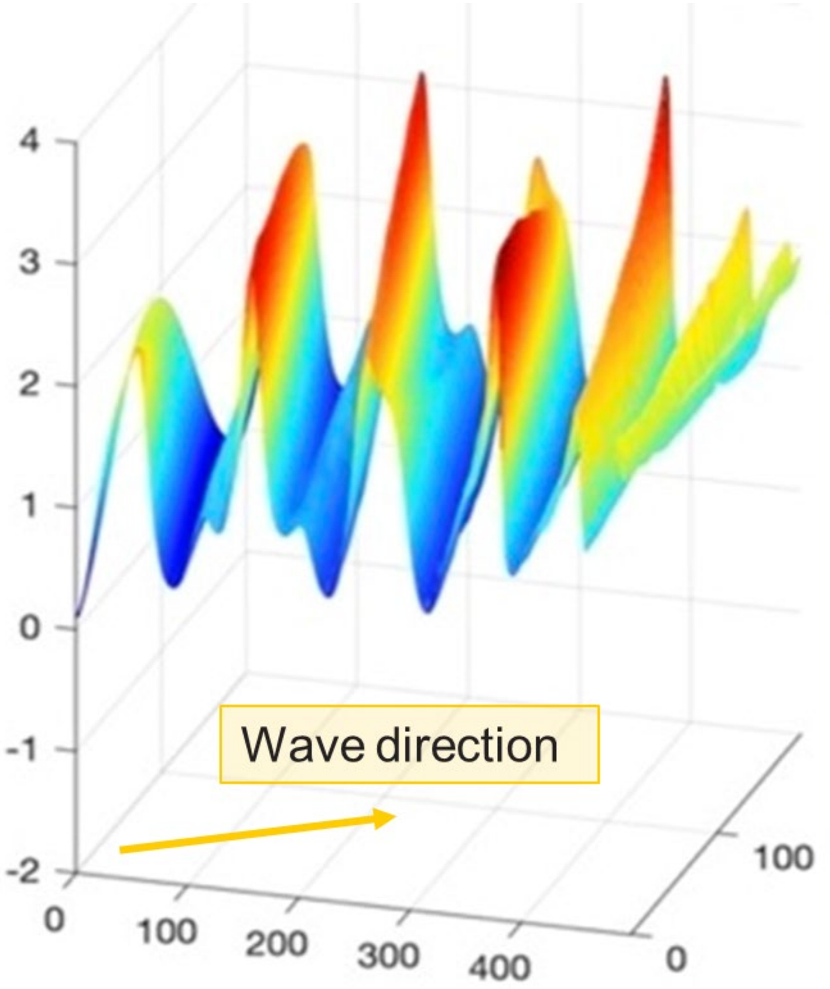
Either sponge layer or absorbing tidal BC at each boundary

TIDAL FORCING METHOD 2

Absorbing-Generating Tidal BC

- Combines absorbing BC with wavemaker
- Limited to the west boundary
- Simplifies coupling of wavemaker with tidal forcing



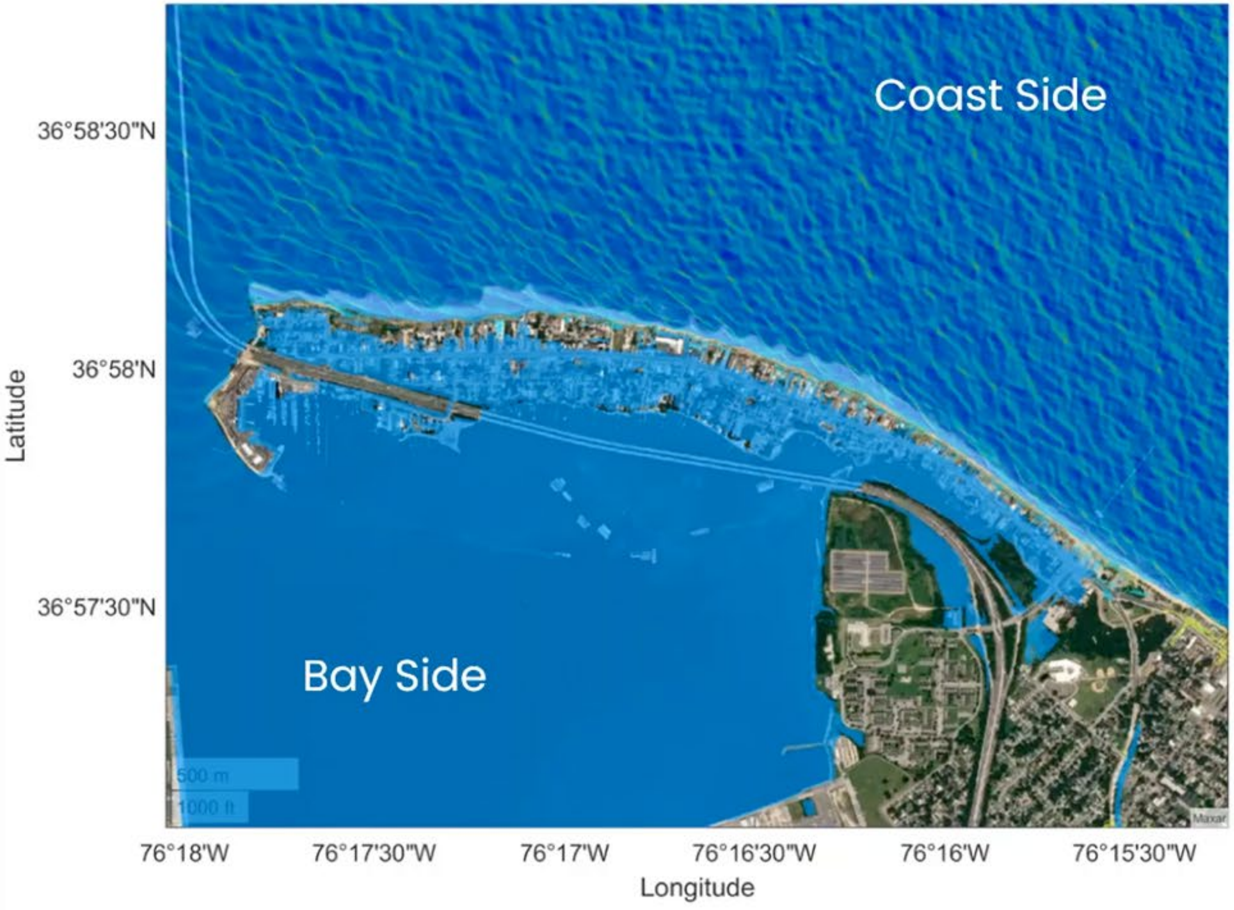


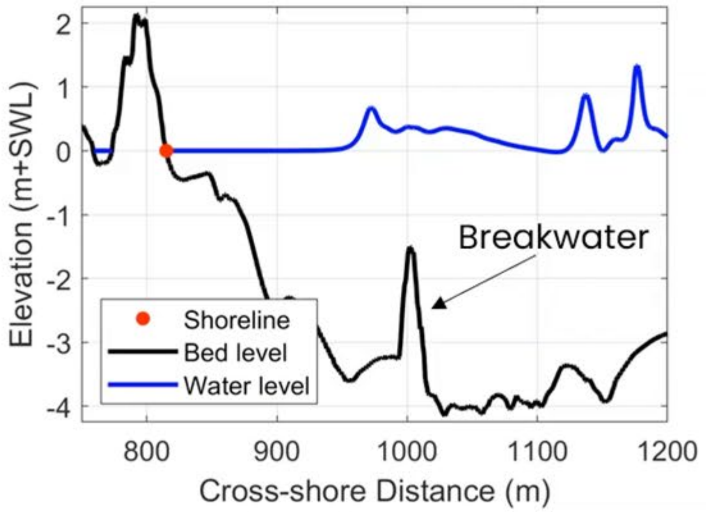
NOTE: This new wavemaker type is limited to JONSWAP, TMA, or spectral (FFT) inputs.

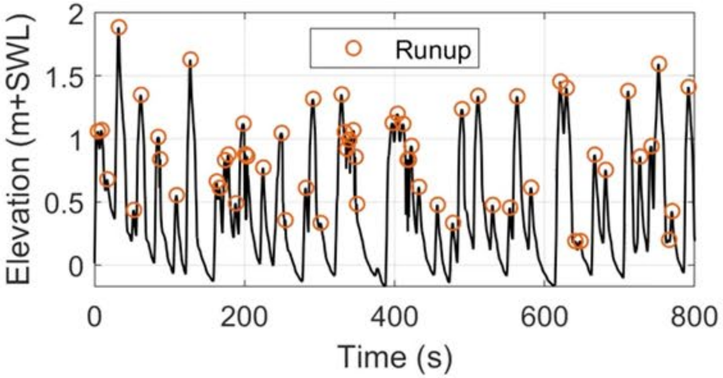
TIDAL FORCING EXAMPLE

ERDC

Hurricane Irene at Norfolk



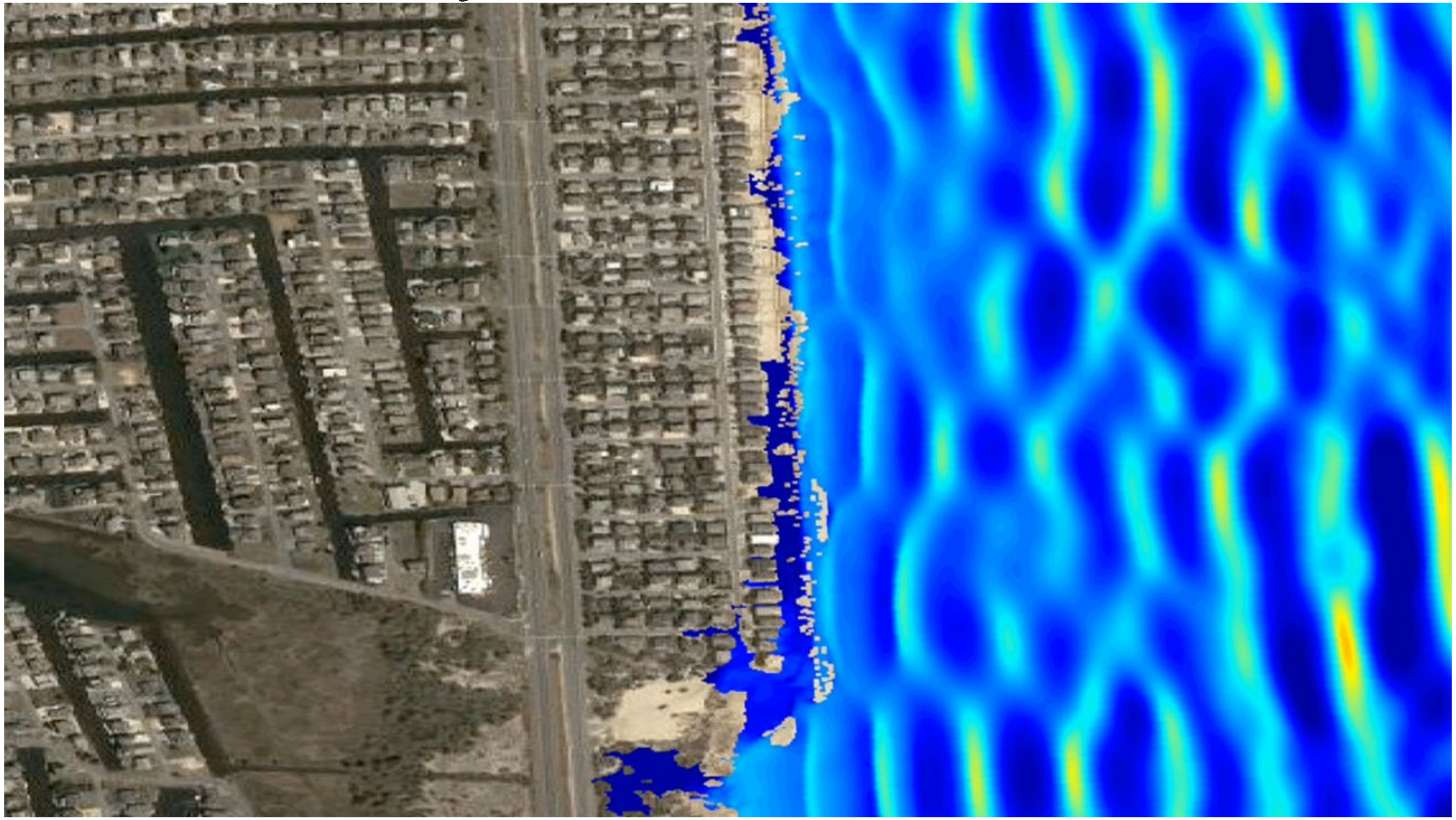




Joint work with Jack Puleo & Fengyan Shi at the University of Delaware

SURGE FORCING EXAMPLE

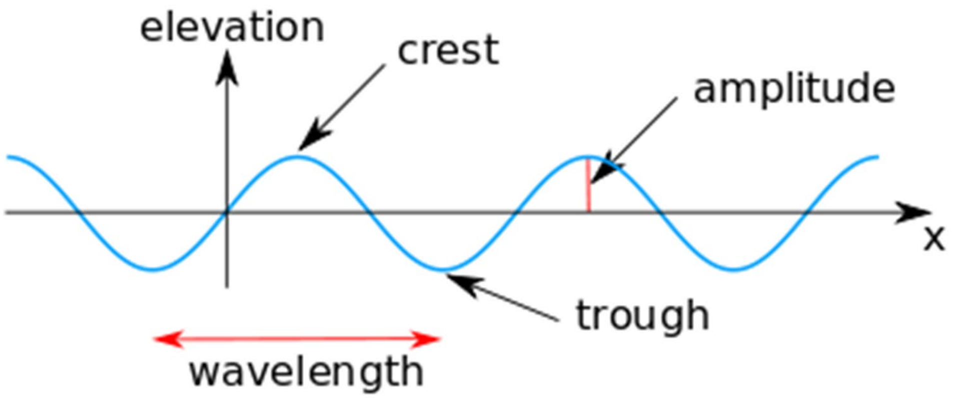
100-year storm at South Bethany Beach



Joint work with University of Delaware. Surge boundary condition from Hanson et al. (2013), ERDC/CHL TR-11-1

DEEP WATER EXTENSION

- FUNWAVE is limited to waves to 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.



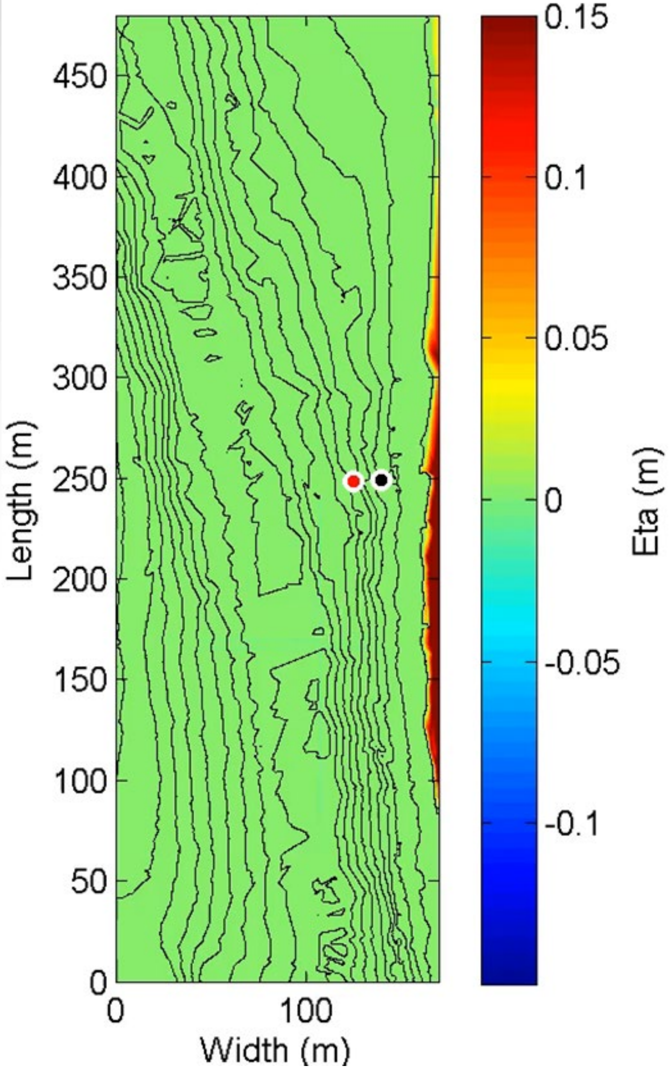
k – Wave Number

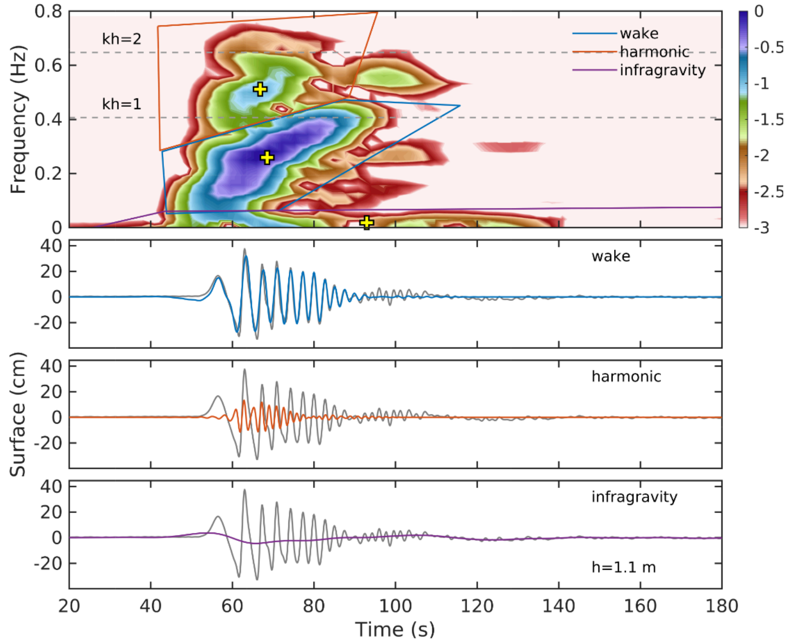
L – Wavelength

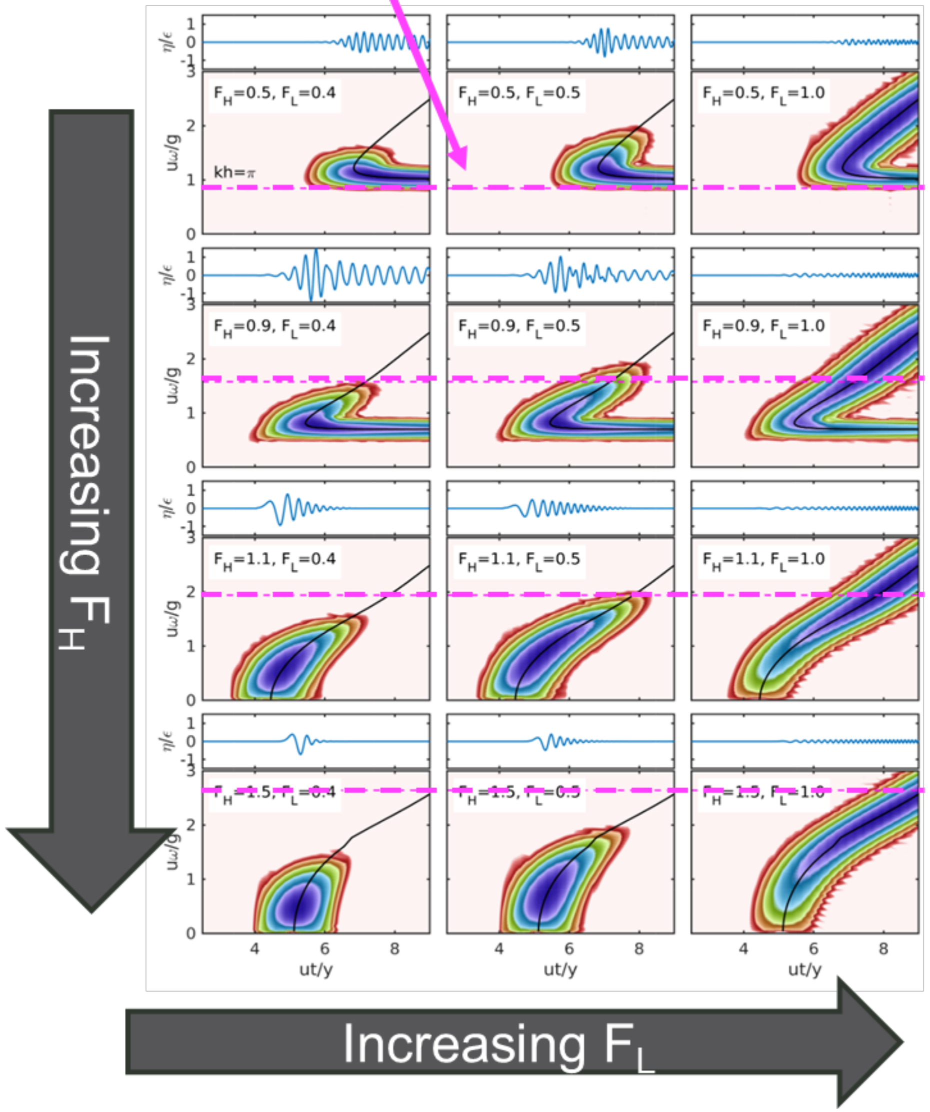
h – Depth

$$L = \frac{2\pi}{k}$$

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 H – depth

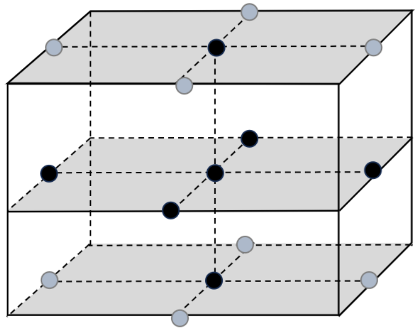
U – speed of vessel g – gravity

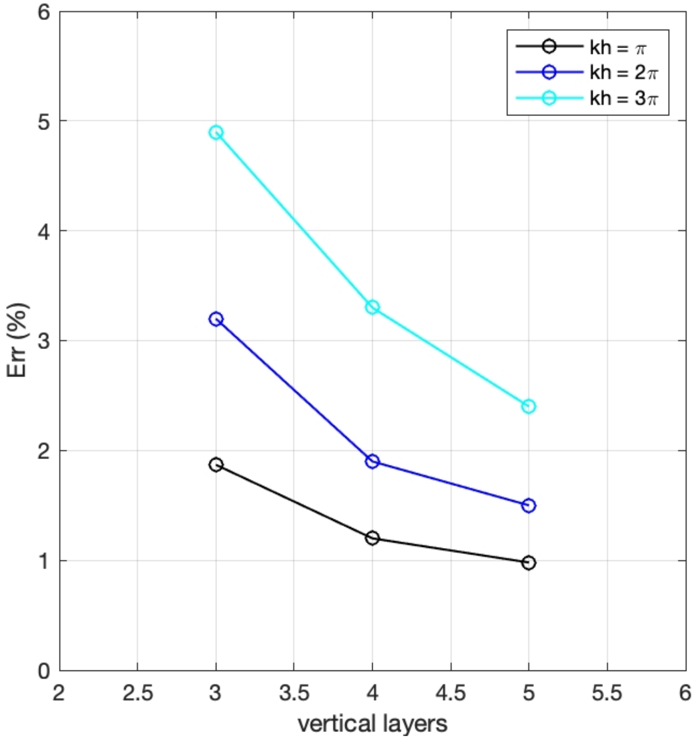
SURFACE FLOW APPROACH

IN DEVELOPMENT

- New non-hydrostatic phase that corrects the velocity field via a new dynamic pressure term.
- Solving for the dynamic pressure term requires solving Poisson's equation.
- For computational efficiency, a partially implicit scheme is implemented.
- Preliminary results show good agreement between the solution and the dispersion relationship.

NOTE: Layers are not added to the underlying FUNWAVE model or involved in the correction step, but rather, layers are introduced in solving the Possion’s equation to compute the dynamic pressure





SUMMARY & FUTURE WORK

- Publications
  - Technical Note: Tides Module (w/ editor)
  - Technical Report: FUNWAVE Test Bed (w/ editor) [contributed]
  - Journal of Ocean Engineering Article (peer-reviewed, needs minor changes)
    - *Modeling the optical signature induced by wave breaking using the Boussinesq-type*
  - Technical Note: Deepwater Module (work in progress)
- Test cases with the deep water module
  - Ship wakes
  - Wind waves
- Cross Collaboration with Engineering with Nature
  - Applying FUNWAVE tidal/surge forcing and sediment module to field data.

QUESTIONS?