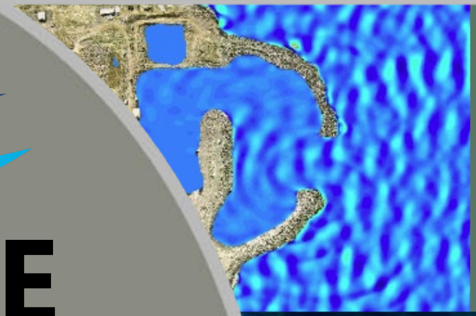
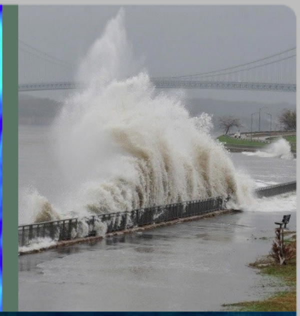
U.S.ARMY

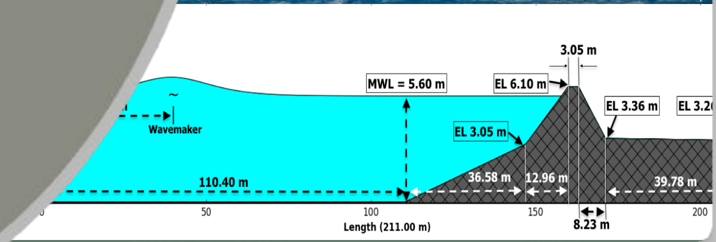
FUNWAVE

CIRP TECH DISCUSSION:

BRIDGING THE SHALLOW-TO-DEEP WATER WAVE GAP







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Coastal and Hydraulics Laboratory
U.S. Army Engineer R&D Center

US Army Corps of Engineers

ERDC
Engineer Research and Development Center

FUNWAVE

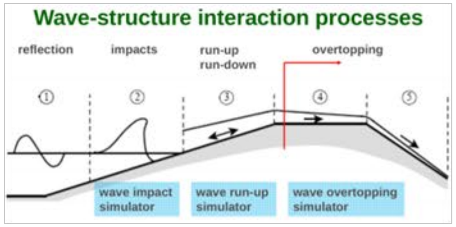
FUNWAVE is a nearshore shallow-to-intermediate water phase-resolving Boussinesq-type numerical wave model that resolves many processes such as:

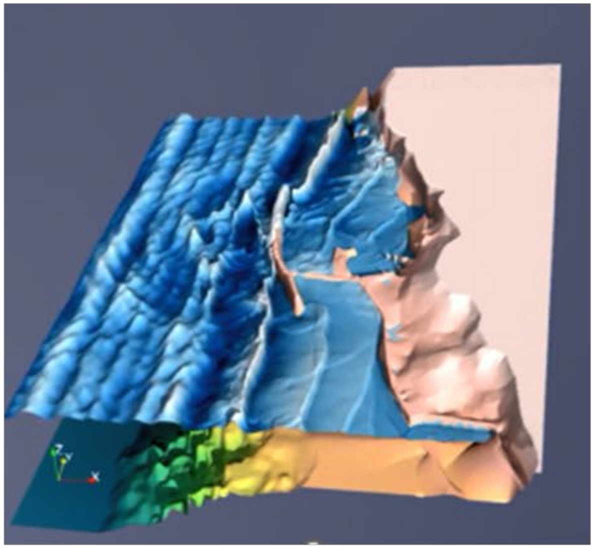
- ✓ nearshore wave propagation & transformation, including refraction, **diffraction** & nonlinear shoaling (Littoral Entry Operations)
- ✓ bottom friction & wave-induced current, nonlinear wave-wave & wave-current interactions
- ✓ wave breaking with **runup** & **overtopping of structures** (Flooding threats)
- ✓ **harbor resonance** and **infragravity (IG) waves** (Important for understanding austere ports of entry)
- ✓ **vessel-generated waves** & related sediment transport with morphology change
- ✓ landslide-generated tsunamis (regional and global ocean basin)
- ✓ (IMPROVED FY21) multi-grid nesting (MGN) with flexible grids for refined **two-way** coupled grids
- ✓ (NEW FY21) **- VER 2.0 -** High Performance Computing (HPC) Portal web-based access with GUI

* **underline/bold** not available in phase-averaged models!

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.

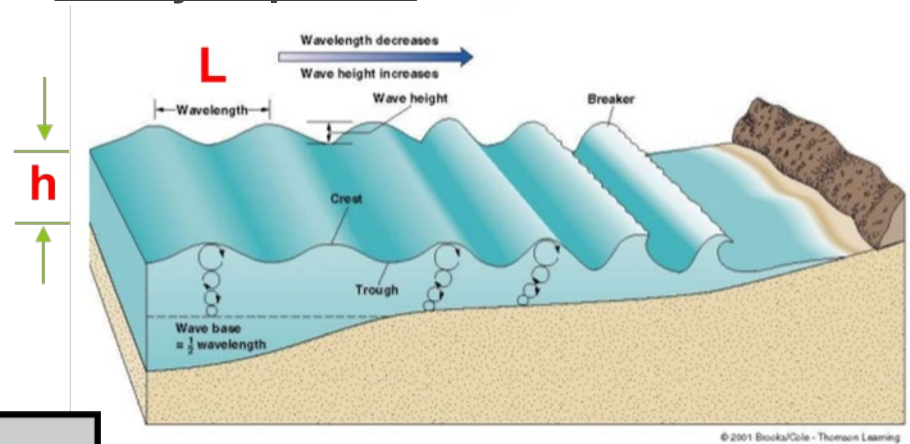




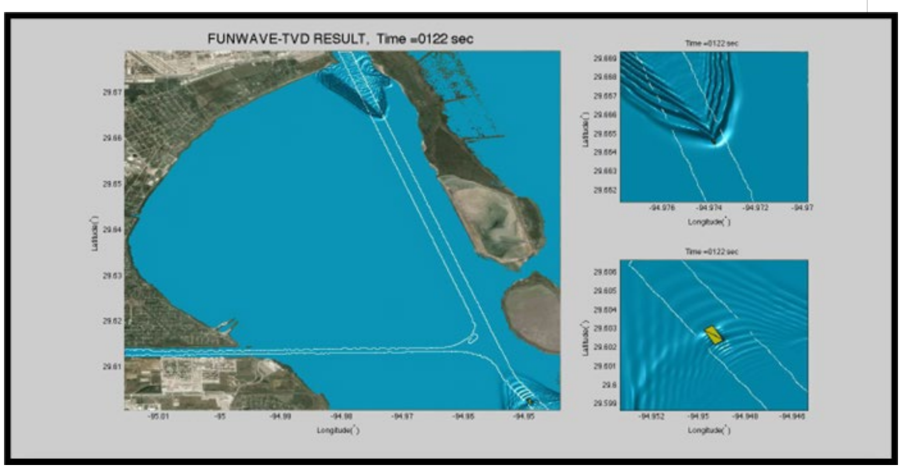
Motivation for current extensions

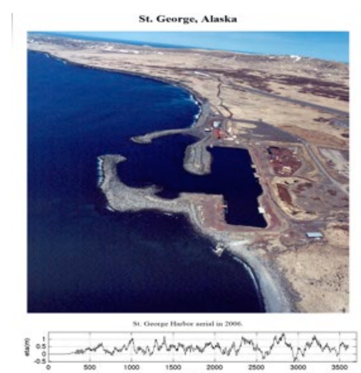
- **FUNWAVE is being applied to increasing more complex domains, with larger (space) and longer (time) simulations needing to adjust to variable water level.**

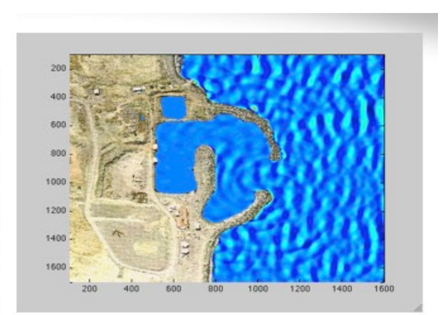
- **2nd Order (h / L) Boussinesq models are weakly dispersive**
  (Waves need to feel the bottom)



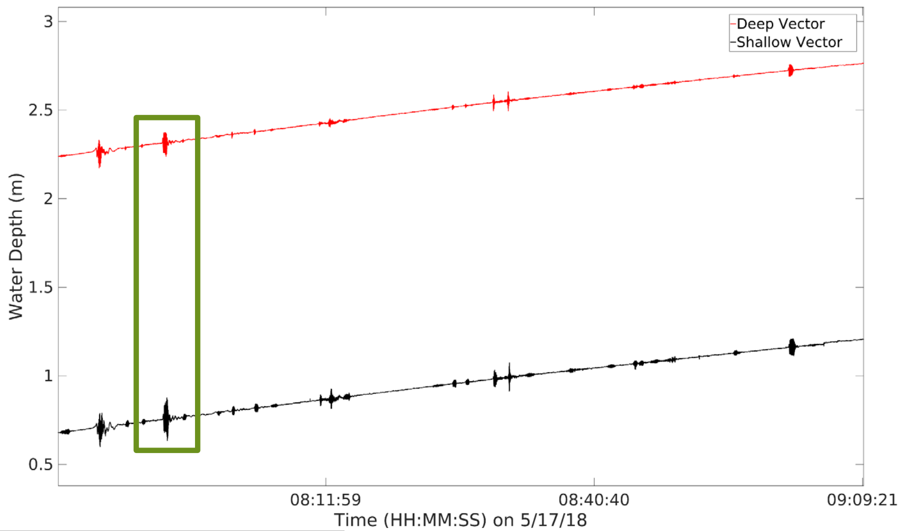
- **Need for surge/tidal forcing & tidal currents interacting with wind and vessel-generated waves at inlets [depth-limited wave breaking & sediment transport – erosion].**

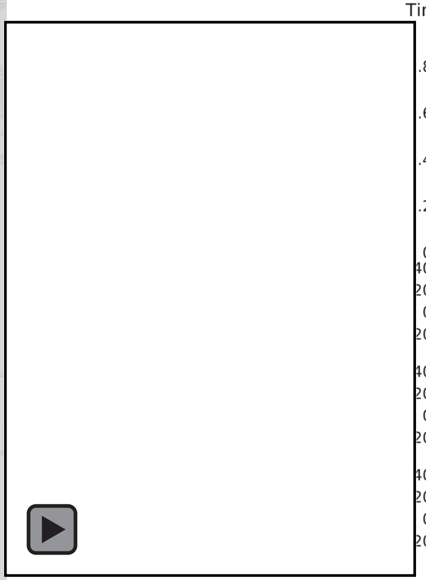


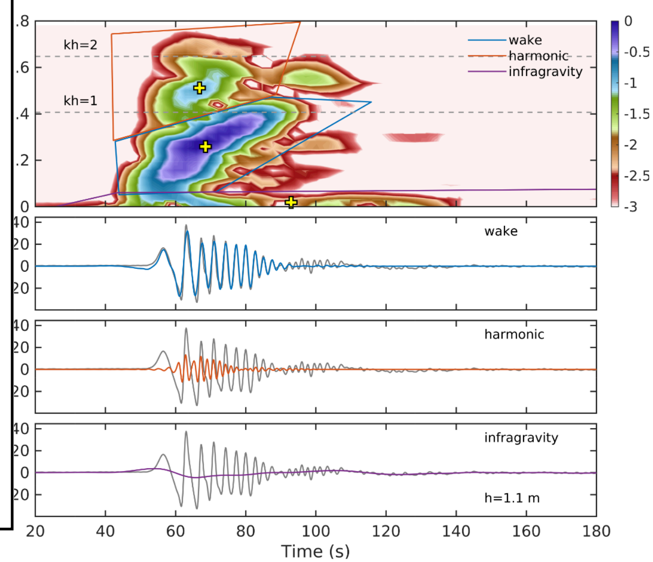


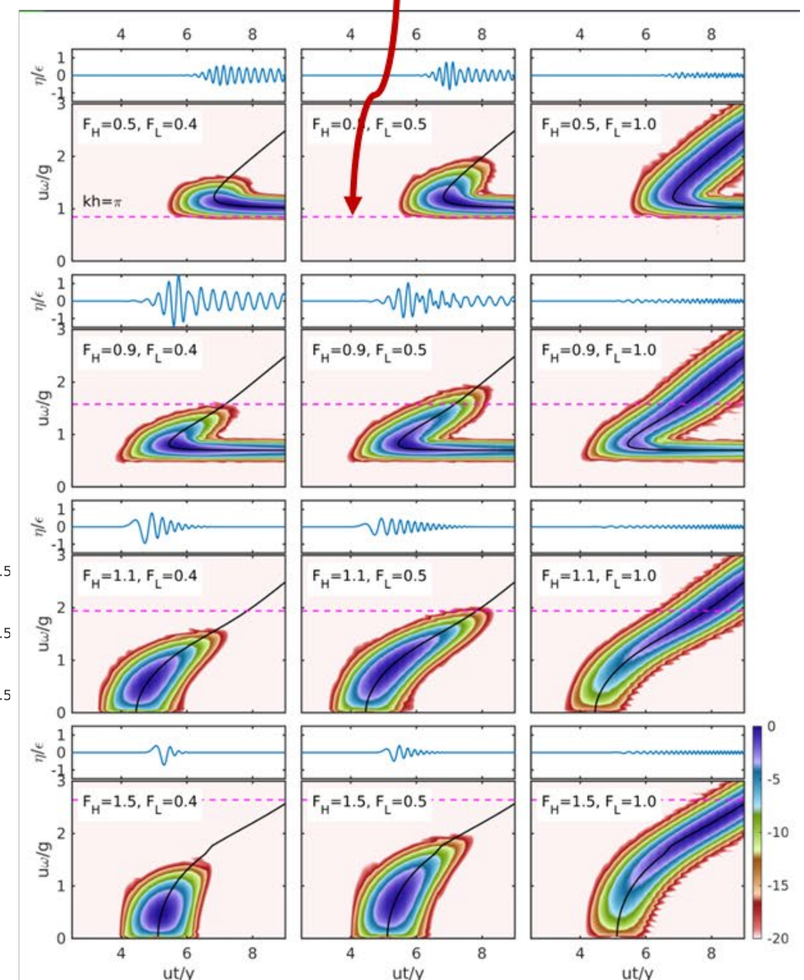


Vessel-Generated Waves in Confined Channels $(kh < \pi)$





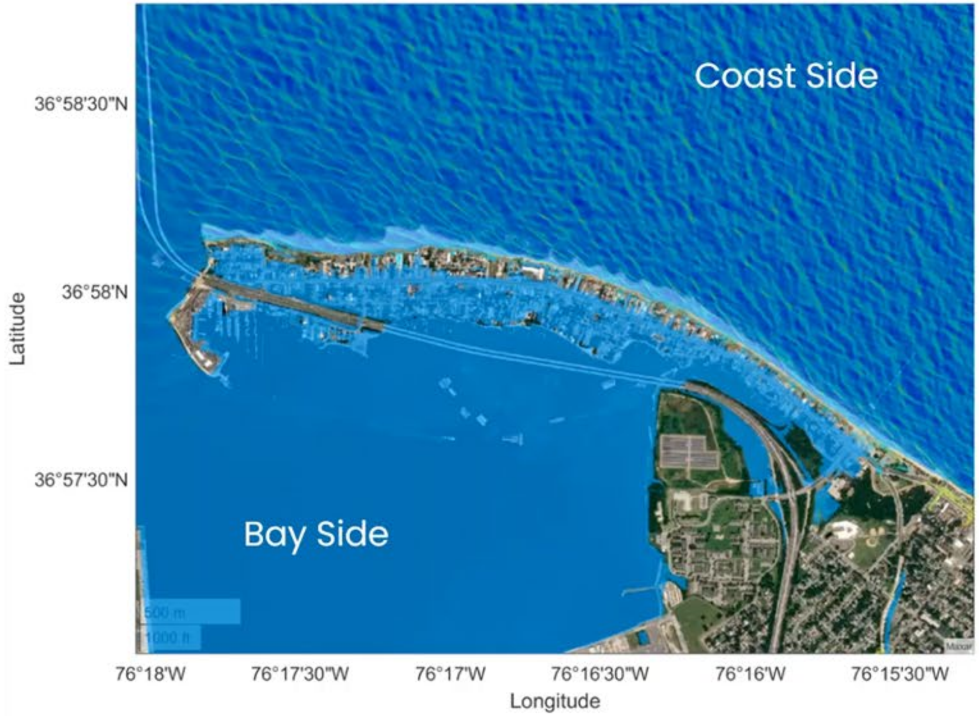


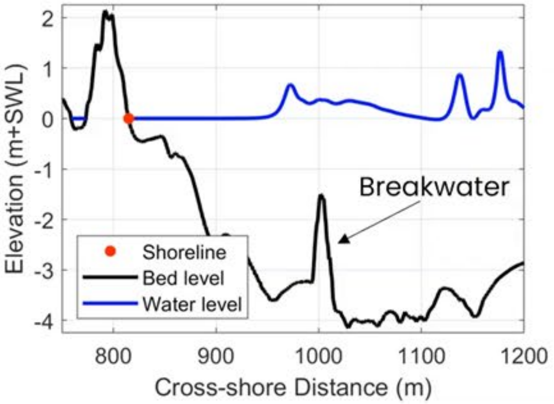


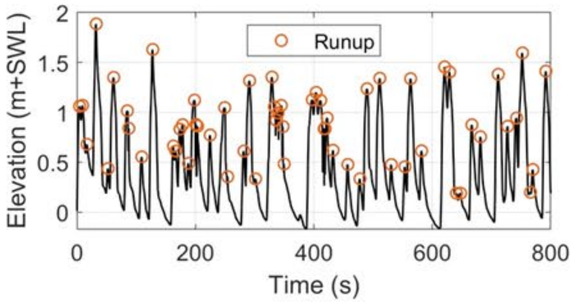
(1) Tidal and Surge forcing

Simulation of wave impact on coastal inundation using the tidal and surge forcing condition (Hurricane Irene at Norfolk)

FUNWAVE: But what about wave runup?



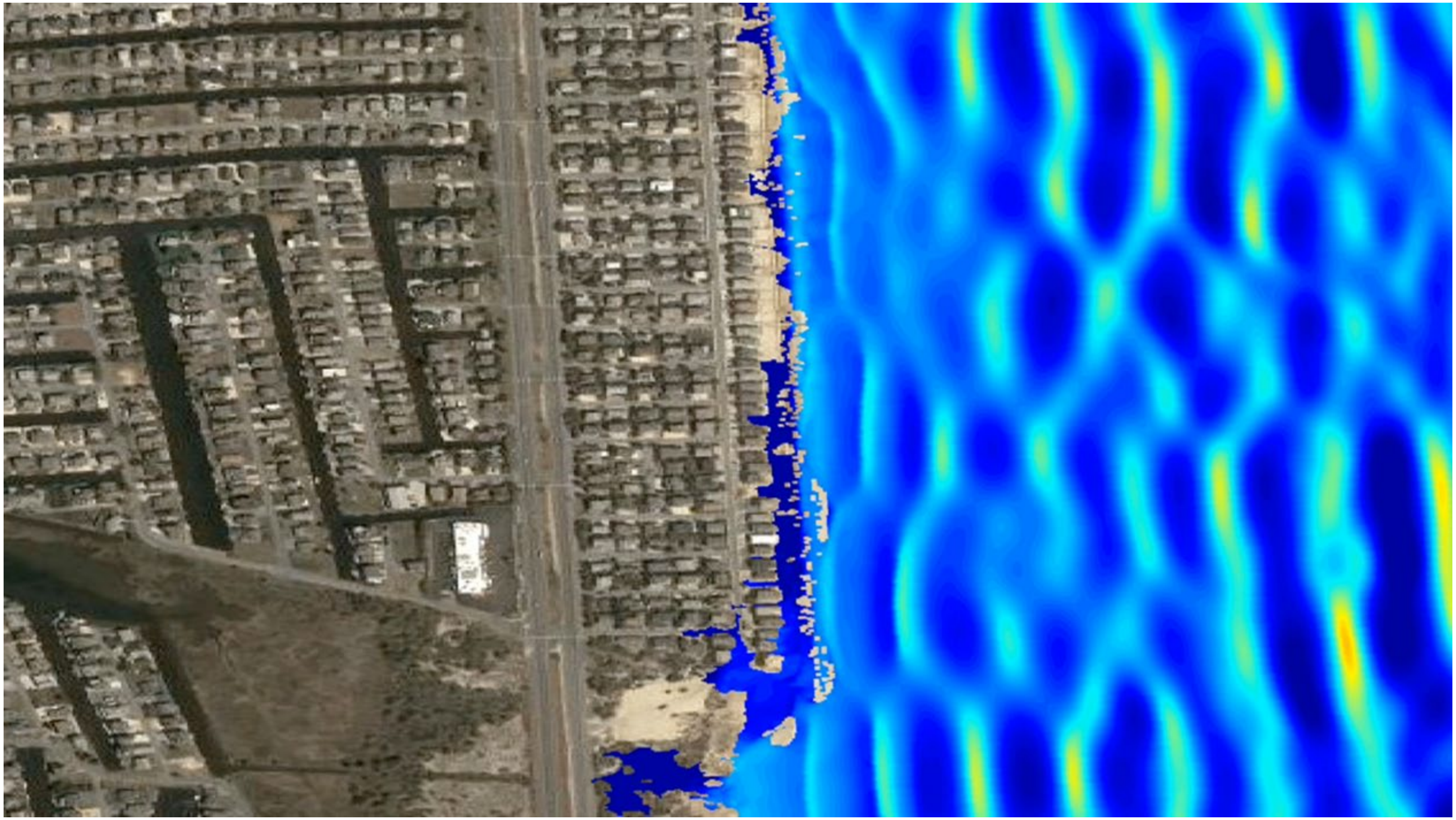




Tidal and Surge forcing

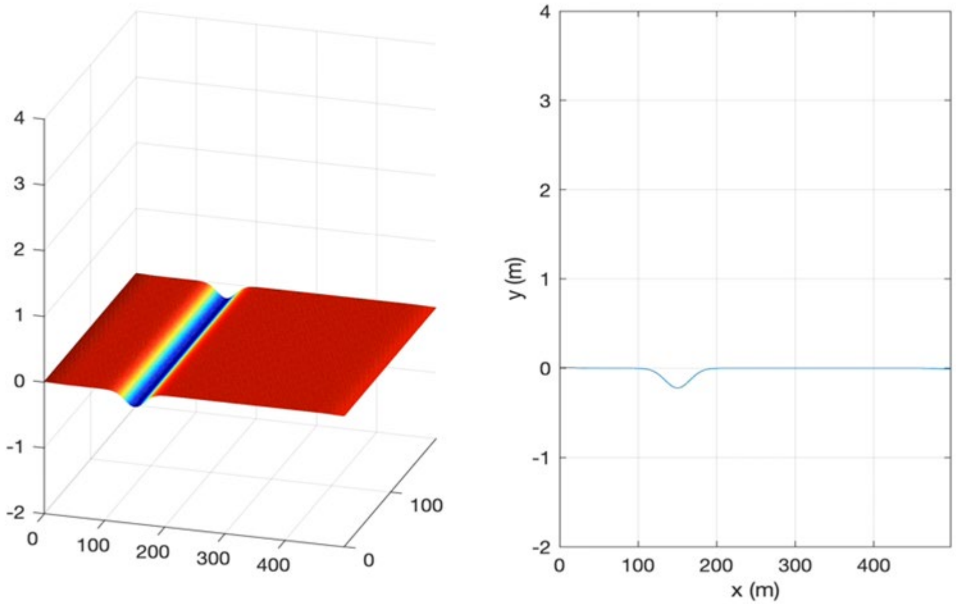
- **Modeling coastal inundation using the <u>tidal and surge forcing condition</u>**

100-year storm at South Bethany Beach. Boundary condition from Hanson et al. (2013), ERDC/CHL TR-11-1



Tidal and Surge Forcing

- **Initial implementation of tidal and surge forcing in the current version of FUNWAVE-TVD.**
- **The forcing condition will be further developed in the fully-dispersive model based on the same theory and numerical techniques**



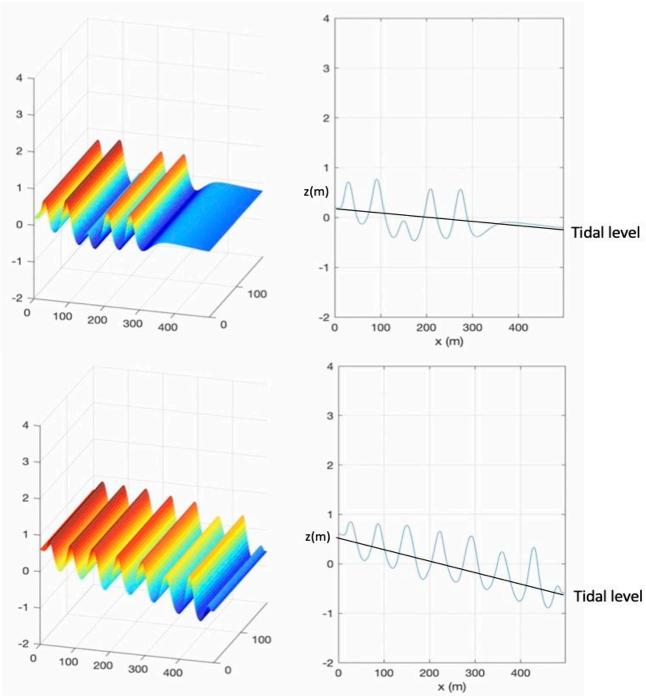
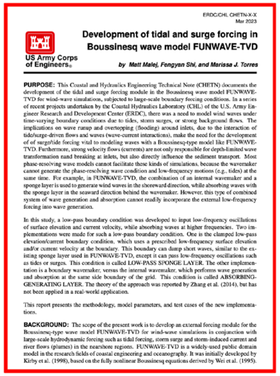


Figure 2. Case: /tide abs 2bc data/. Demonstration of 2D (left) and 1D (right) section views of surface elevation at time = 30.0 (top) and 90.0 (bottom) sec, respectively. Black solid lines denote tidal levels.



ERDC/CHL CHETN-X-X
Mar 2023

US Army Corps of Engineers®

Development of tidal and surge forcing in Boussinesq wave model FUNWAVE-TVD

by Matt Malej, Fengyan Shi, and Marissa J. Torres

PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) documents the development of the tidal and surge forcing module in the Boussinesq wave model FUNWAVE-TVD for wind-wave simulations, subjected to large-scale boundary forcing conditions. In a series of recent projects undertaken by the Coastal Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC), there was a need to model wind waves under time-varying boundary conditions due to tides, storm surges, or strong background flows. The implications on wave runup and overtopping (flooding) around inlets, due to the interaction of tide/surge-driven flows and waves (wave-current interactions), make the need for the development of of surge/tide forcing vital to modeling waves with a Boussinesq-type model like FUNWAVE-TVD. Furthermore, strong velocity flows (currents) are not only responsible for depth-limited wave transformation nand breaking at inlets, but also directly influence the sediment transport. Most phase-resolving wave models cannot facilitate these kinds of simulations, because the wavemaker cannot generate the phase-resolving wave condition and low-frequency motions (e.g., tides) at the same time. For example, in FUNWAVE-TVD, the combination of an internal wavemaker and a sponge layer is used to generate wind waves in the shoreward direction, while absorbing waves with the sponge layer in the seaward direction behind the wavemaker. However, this type of combined system of wave generation and absorption cannot readily incorporate the external low-frequency forcing into wave generation.

In this study, a low-pass boundary condition was developed to input low-frequency oscillations of surface elevation and current velocity, while absorbing waves at higher frequencies. Two implementations were made for such a low-pass boundary condition. One is the clamped low-pass elevation/current boundary condition, which uses a prescribed low-frequency surface elevation and/or current velocity at the boundary. This boundary can damp short waves, similar to the existing sponge layer used in FUNWAVE-TVD, except it can pass low-frequency oscillations such as tides or surges. This condition is called LOW-PASS SPONGE LAYER. The other implementation is a boundary wavemaker, versus the internal wavemaker, which performs wave generation and absorption at the same side boundary of the grid. This condition is called ABSORBING-GENERATING LAYER. The theory of the approach was reported by Zhang et al. (2014), but has not been applied in a real-world application.

This report presents the methodology, model parameters, and test cases of the new implementations.

BACKGROUND: The scope of the present work is to develop an external forcing module for the Boussinesq-type wave model FUNWAVE-TVD for wind-wave simulations in conjunction with large-scale hydrodynamic forcing such as tidal forcing, storm surge and storm-induced current and river flows (plumes) in the nearshore regions. FUNWAVE-TVD is a widely-used public domain model in the research fields of coastal engineering and oceanography. It was initially developed by Kirby et al. (1998), based on the fully nonlinear Boussinesq equations derived by Wei et al. (1995).

Malej et al., 2023, (in review)
ERDC/CHL CHETN

Tidal and Surge Module – Forcing (Type 1)

TYPE 1: ABSORBING (LOW-PASS) SPONGE B.C.

```
TIDAL_BC_ABS = T
TideBcType = CONSTANT
TideWest_ETA = 1.0
TideEast_ETA = 1.0
```

Or time-varying BC for long (surge/tidal) forcing

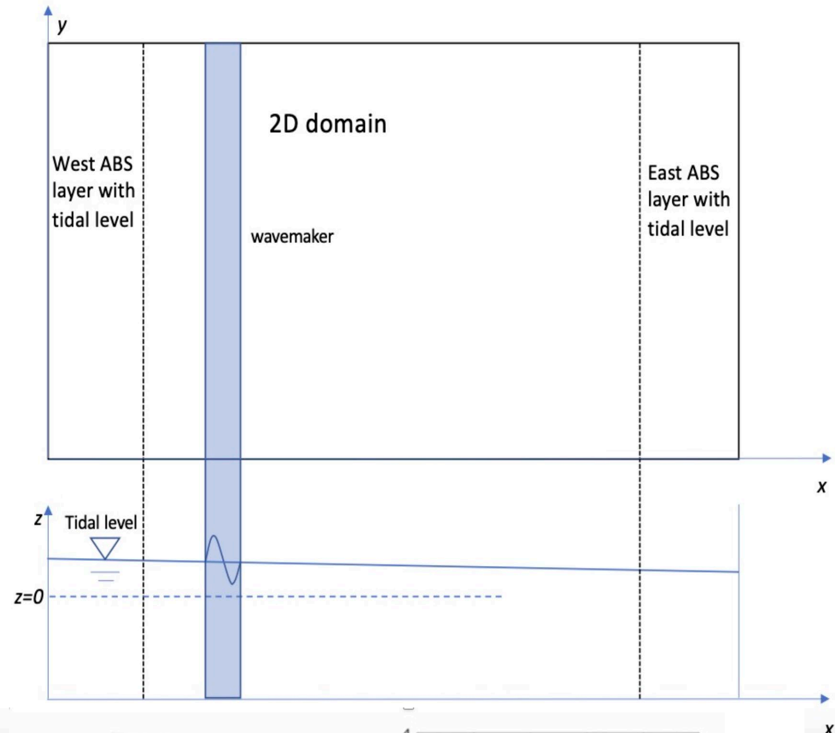
```
TIDAL_BC_ABS = T
TideBcType = DATA
TideWestFileName = tide_data_west.txt
TideEastFileName = tide_data_east.txt
```

tide_data_west.txt

```
tide data (time, eta, u, v)
0.0    0.0   0.0   0.0
20.0   0.2   0.0   0.0
30.0   0.3   0.0   0.0
100.0  1.0   0.0   0.0
1000.0 1.0   0.0   0.0
```

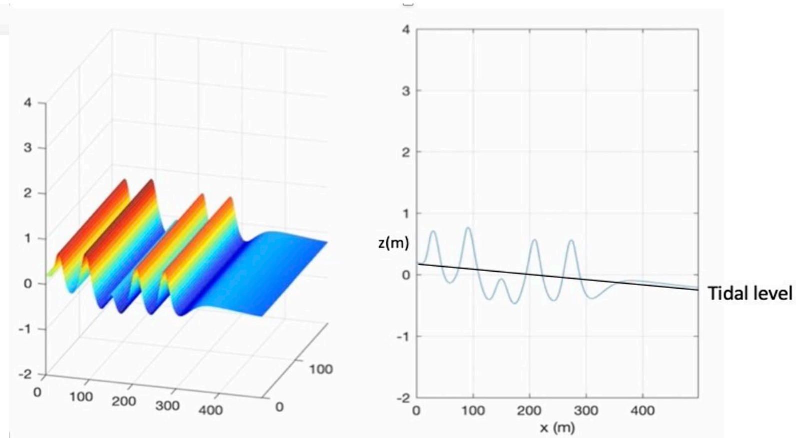
tide_data_east.txt

```
tide data (time, eta, u, v)
0.0    0.0   0.0   0.0
20.0   -0.2  0.0   0.0
30.0   -0.3  0.0   0.0
100.0  -1.0  0.0   0.0
1000.0 -1.0  0.0   0.0
```



requiring an interval wavemaker for short-waves.

```
WAVEMAKER = WK_REG
DEP_WK = 8.0
Xc_WK = 150.0
Yc_WK = 0.0
Tperiod = 8.0
AMP_WK = 0.5
Theta_WK = 0.0
Delta_WK = 3.0
```



Tidal and Surge Module – Forcing (Type 2)

TYPE 2: ABSORBING-GENERATING B.C.

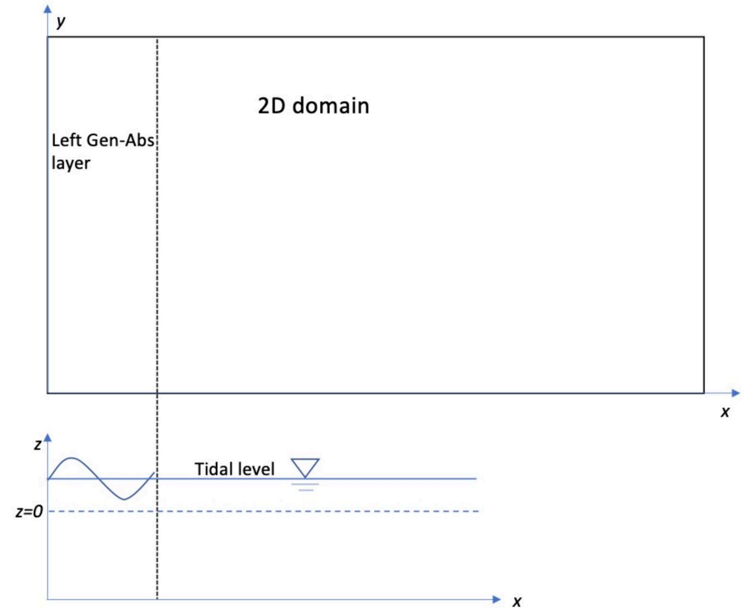
```
WAVEMAKER = ABSORBING_GENERATING
WAVE_DATA_TYPE = DATA
WaveCompFile = wave_data.txt
...
TIDAL_BC_GEN_ABS = T
TideBcType = DATA
TideWestFileName = tide_data_west.txt
```

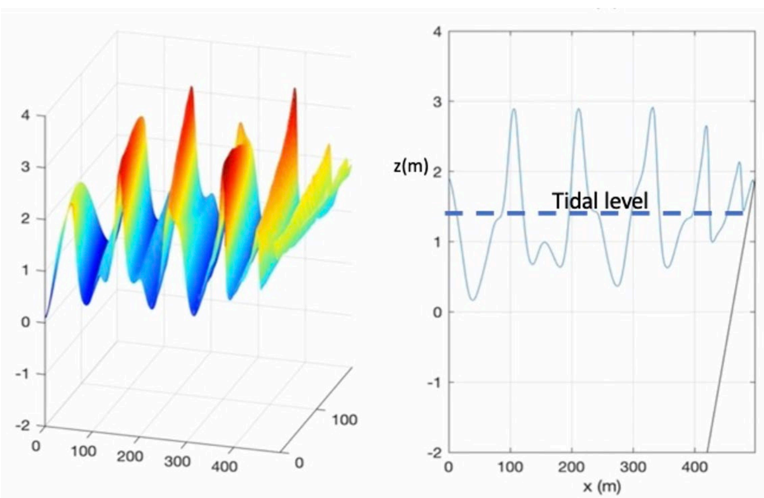
wave_data.txt

```
1 1
0.1
0.1
30.0
1.0
```

tide_data_west.txt

```
tide data (time, eta, u, v)
0.0    0.0   0.0   0.0
20.0   0.2   0.0   0.0
30.0   0.3   0.0   0.0
100.0  1.0   0.0   0.0
1000.0 1.0   0.0   0.0
```





FUNWAVE

MODEL WIKI

FUNWAVE Documentation » DEFINITIONS OF PARAMETERS » Parameters for Central Module »

Quick search

Go

Tide and Surge Boundary Conditions

SPECIFICATION OF TIDE AND SURGE OPEN BOUNDARY CONDITIONS

- `TIDAL_BC_ABS`: logical parameter for tidal absorbing boundary conditions, T – tide and surge at open boundaries, F – no tide or surge.
- `TIDAL_BC_GEN_ABS`: logical parameter for the combined tidal and absorbing-generating boundary conditions, T – ture, F – false.
- `TideBcType`: string parameter for data types. Default: TideBcType = CONSTANT
- `TideWest_ETA`: constant eta value at the WEST boundary.
- `TideWest_U`: constant u value at the WEST boundary, defalut: 0.0.
- `TideWest_V`: constant v value at the WEST boundary, defalut: 0.0.
- `TideEast_ETA`: constant eta value at the EAST boundary.
- `TideEast_U`: constant u value at the EAST boundary, defalut: 0.0.
- `TideEast_V`: constant v value at the EAST boundary, defalut: 0.0.
- `TideSouth_ETA`: constant eta value at the SOUTH boundary.
- `TideSouth_U`: constant u value at the SOUTH boundary, defalut: 0.0.
- `TideSouth_V`: constant v value at the SOUTH boundary, defalut: 0.0.
- `TideNorth_ETA`: constant eta value at the NORTH boundary.
- `TideNorth_U`: constant u value at the NORTH boundary, defalut: 0.0.

Current development work…

- Quality control of input (robust UI)
- Efficient I/O system for massively parallel machines
- Processor distribution for MPI, especially for multi-grid nesting
- Pre- and Post-processing packages tying to different frameworks and I/O standards

- Extension to deeper ("more dispersive/shorter waves") water
- Varying water level throughout a simulation
- Seamless coupling to other models (e.g., CSTORM framework)
- …