Improved Shallow-Water Wave Modeling

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Outline

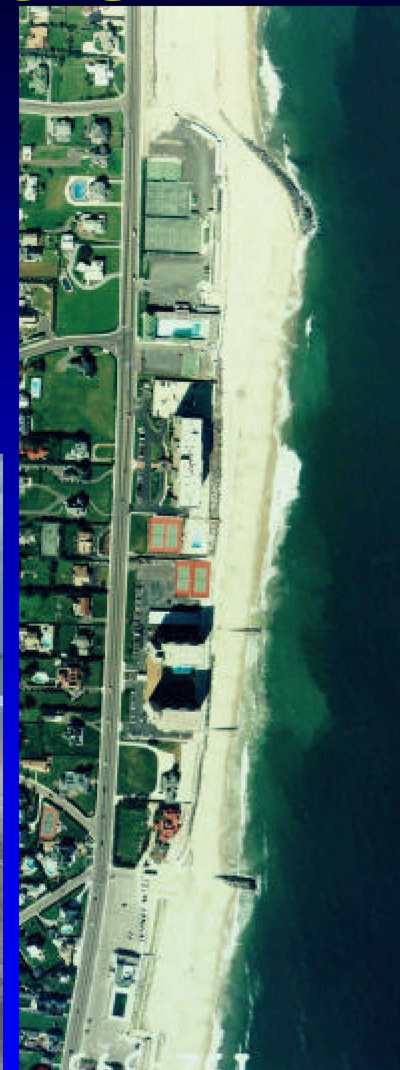
- Introduction
- Half-Plane STWAVE
- Full-Plane STWAVE
- Enhancements
  - Bottom interaction
  - Diffraction/Reflection
  - 3G Source Terms
- Summary

Global vs. Coastal

- Correct Deepwater Physics
- No Regional/Local Tuning
- Correct Shallow-water Physics

Nearshore Transformation

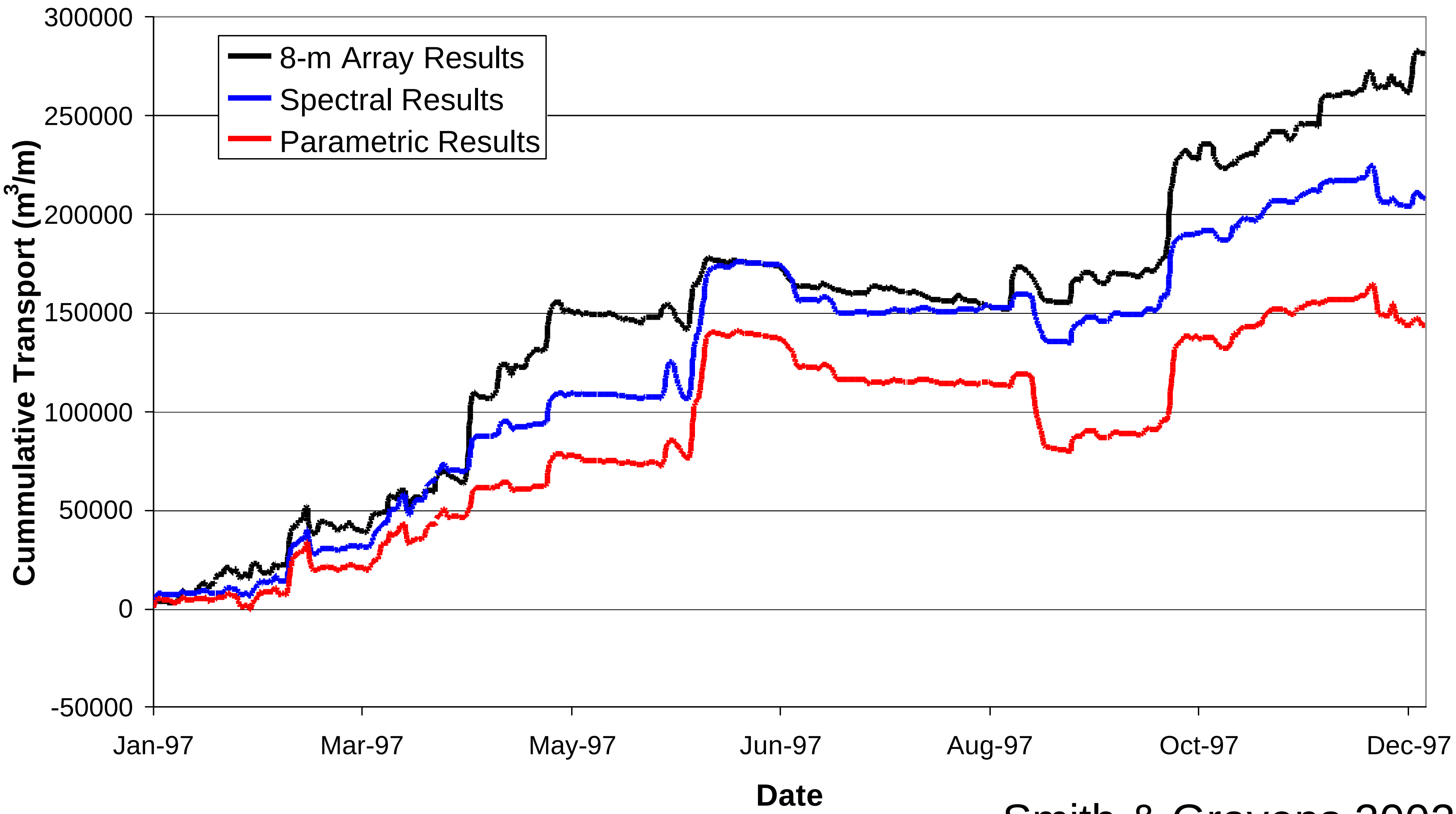
- Sediment Transport
- Coastal Flooding and Storm Damage
- Navigation and Harbor/Jetty Design



Nearshore Transformation

- Past
  - Distribution: H, T, θ
  - Climate statistics (lookup tables)
  - Refraction, shoaling, and breaking
- Present/Future
  - Directional spectra
    - Smith & Gravens (2002)
    - ~50% error reduction
  - Full time histories
    - Interaction w/ currents & water levels
    - Update bathymetry
    - Complex spectra
  - Advanced transformation processes

Longshore Transport Estimates



Smith & Gravens 2002

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Advanced Processes

- Wave-current interaction
- Wind input
- Wave-wave interactions
- Whitecapping
- Wave-bottom interaction
- Diffraction
- Reflection
- Transmission
- Wave asymmetry

How good are present formulations in shallow water?

How many times do we need to change models for a single application?

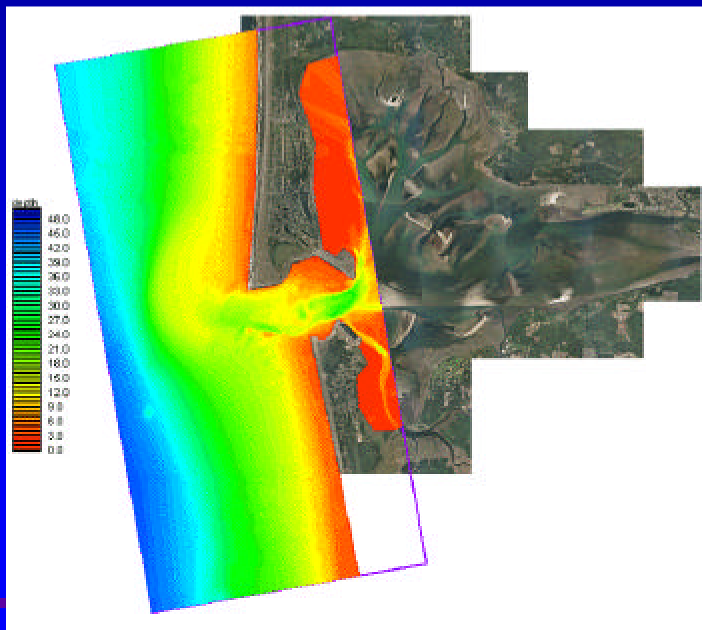
Modeling Requirements

- Grid Flexibility
- Efficiency
- Ease of Application
- Robustness

No Model Tweaking

Half-Plane STWAVE

- Steady-State, Phase-Averaged
- Linear Refraction and Shoaling
- Depth and Steepness-Limited Breaking
- Linear Wave-Current Interaction
- 2G Wave Generation
- Half Plane
- Resio (1988a,b)
- Smith et al. (2001, 2002)
- Windows Interface (SMS)



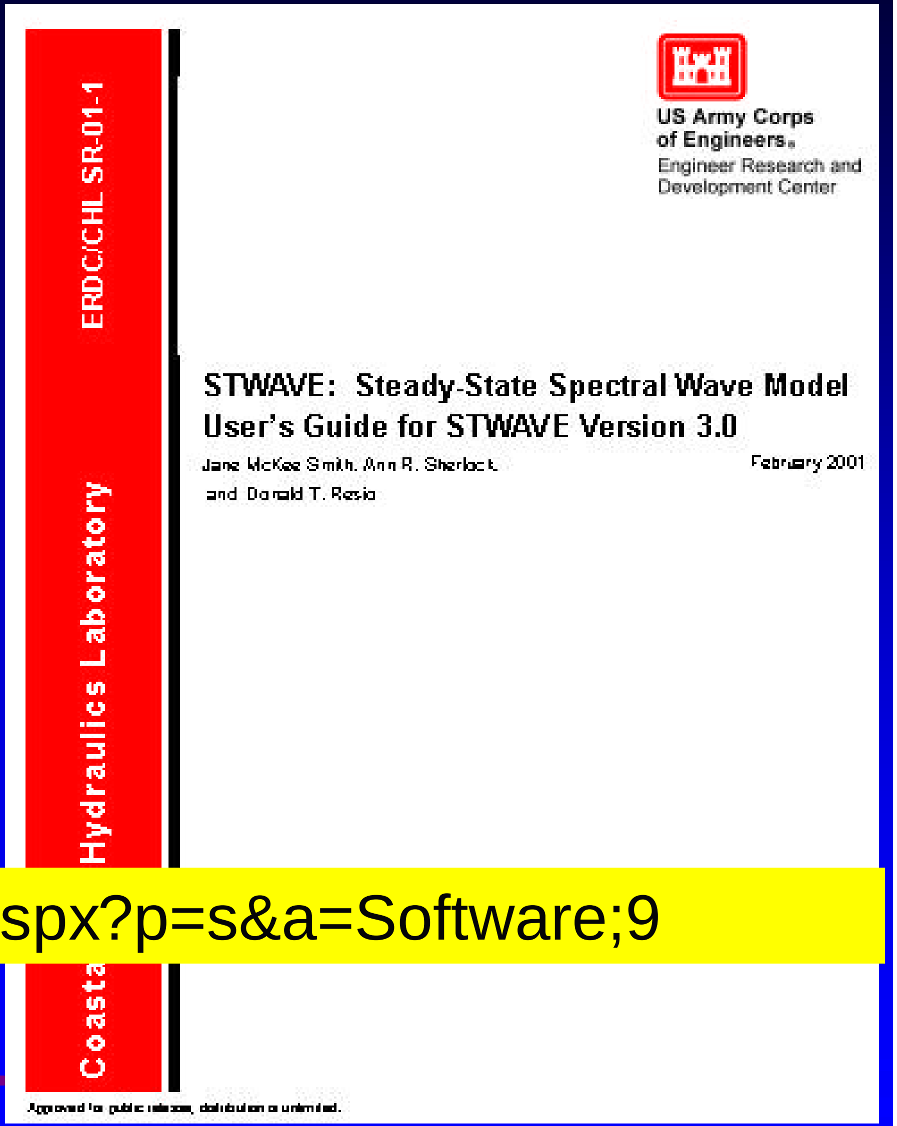
Documentation on Web

- PDF User's Guide
- Latest executable
- Sample files
- Sample applications

  Willapa Bay

  Grays Harbor

  Ponce Inlet


ERDC/CHL SR-01-1

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US Army Corps of Engineers.
Engineer Research and Development Center

STWAVE: Steady-State Spectral Wave Model User's Guide for STWAVE Version 3.0

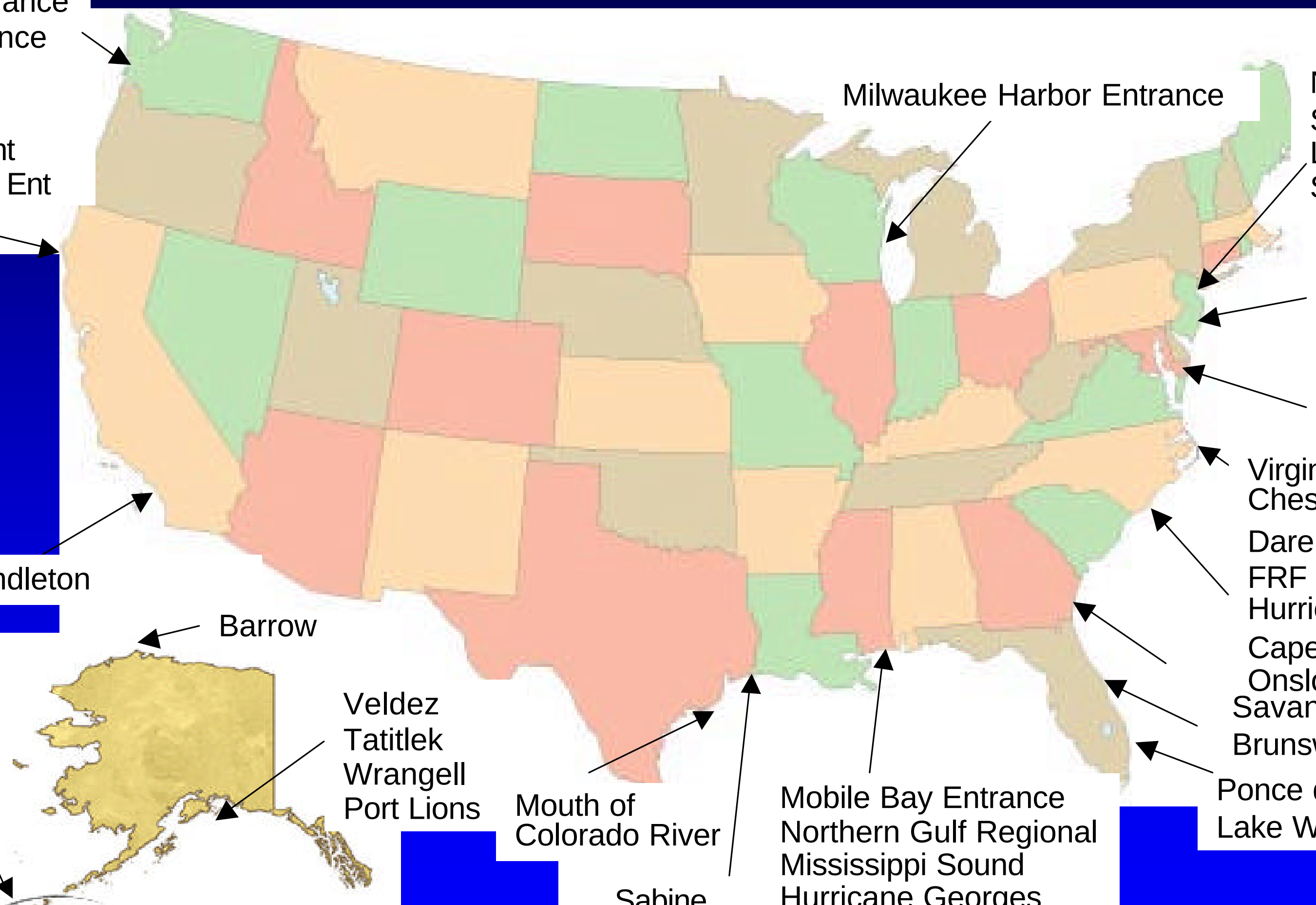
Jane McKee Smith, Ann R. Sherlock, and Donald T. Resio

February 2001

Approved for public release; distribution is unlimited.

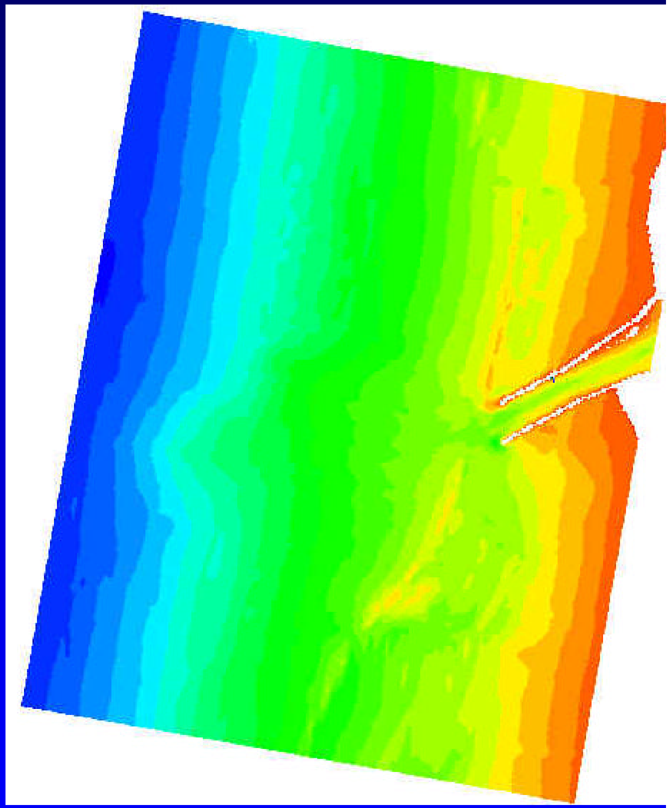
http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;9

Recent Corps STWAVE Applications



STWAVE (Half Plane) Advantages

- Substantially lower memory requirements
- Faster computational speed
- No tuning
- Benchmarked
- Robust
  - Widely used & tested
  - Parametric
- Minimal open boundary impact
- Automated nesting
- Interface (SMS) for input & output



STWAVE (Half Plane) Disadvantages

- Oblique energy is lost (> 60 deg to x-axis)
- 2G physics – missing details
- Steady state
- Simplified diffraction
- Processes neglected
  - Transmission
  - Reflection
  - Bottom interactions
- Square grid cells, fixed angle bands

Full-Plane STWAVE

- **Step 1:**

  Full-plane, 2G, Steady-state Model
- **Step 2:**

  Bottom Interaction, Diffraction, and Reflection
- **Step 3:**

  3G, Nonsteady, and 3-Wave Interactions

Full-Plane STWAVE

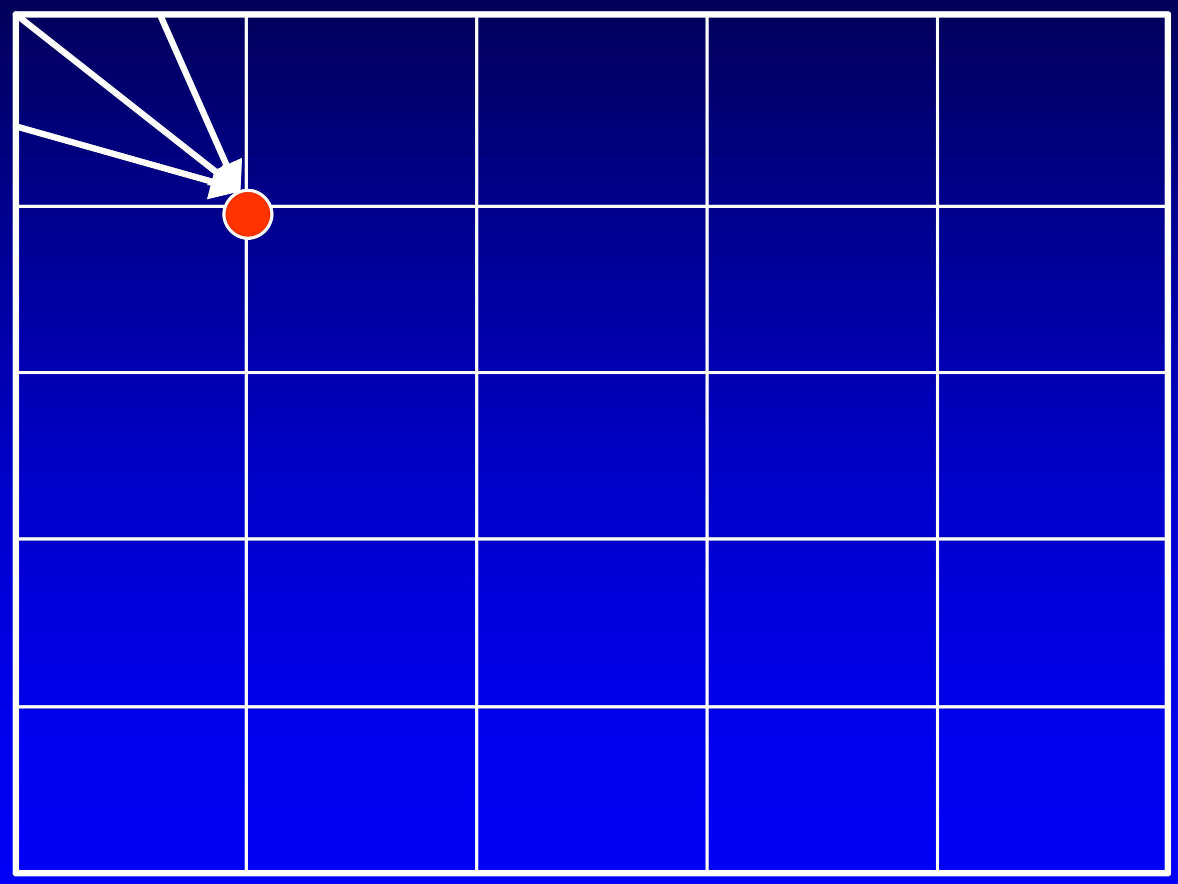
- **Conservation of spectral action balance**

$$(C_{ga})_x \frac{\partial}{\partial x} \frac{C_a C_{ga} \cos(m-a) E(f,a)}{w_r} +$$
$$(C_{ga})_y \frac{\partial}{\partial y} \frac{C_a C_{ga} \cos(m-a) E(f,a)}{w_r} = \sum \frac{S}{w_r}$$

- **Back-traced wave rays**

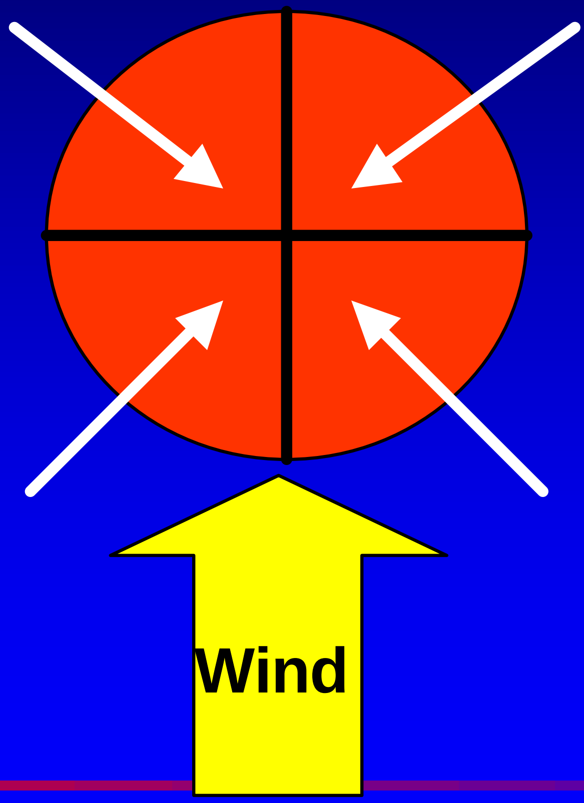
Full-Plane STWAVE

- Solved in 4 Quadrants



Full-Plane STWAVE

- Solved in 4 quadrants, alternate sweeps
- Iteration required for complex bathymetry



Full-Plane STWAVE

- **Sources Terms**

$$F_{in} = l \frac{r_a}{r_w} 0.85 C_p \frac{u_*}{g}$$

$$(f_p)_{i+1} = \left[(f_p)_i^{-3.33} + \frac{2.5\Delta x}{g\cos(a)} \left(\frac{u_*}{g} \right)^{1.33} \right]^{-0.3}$$

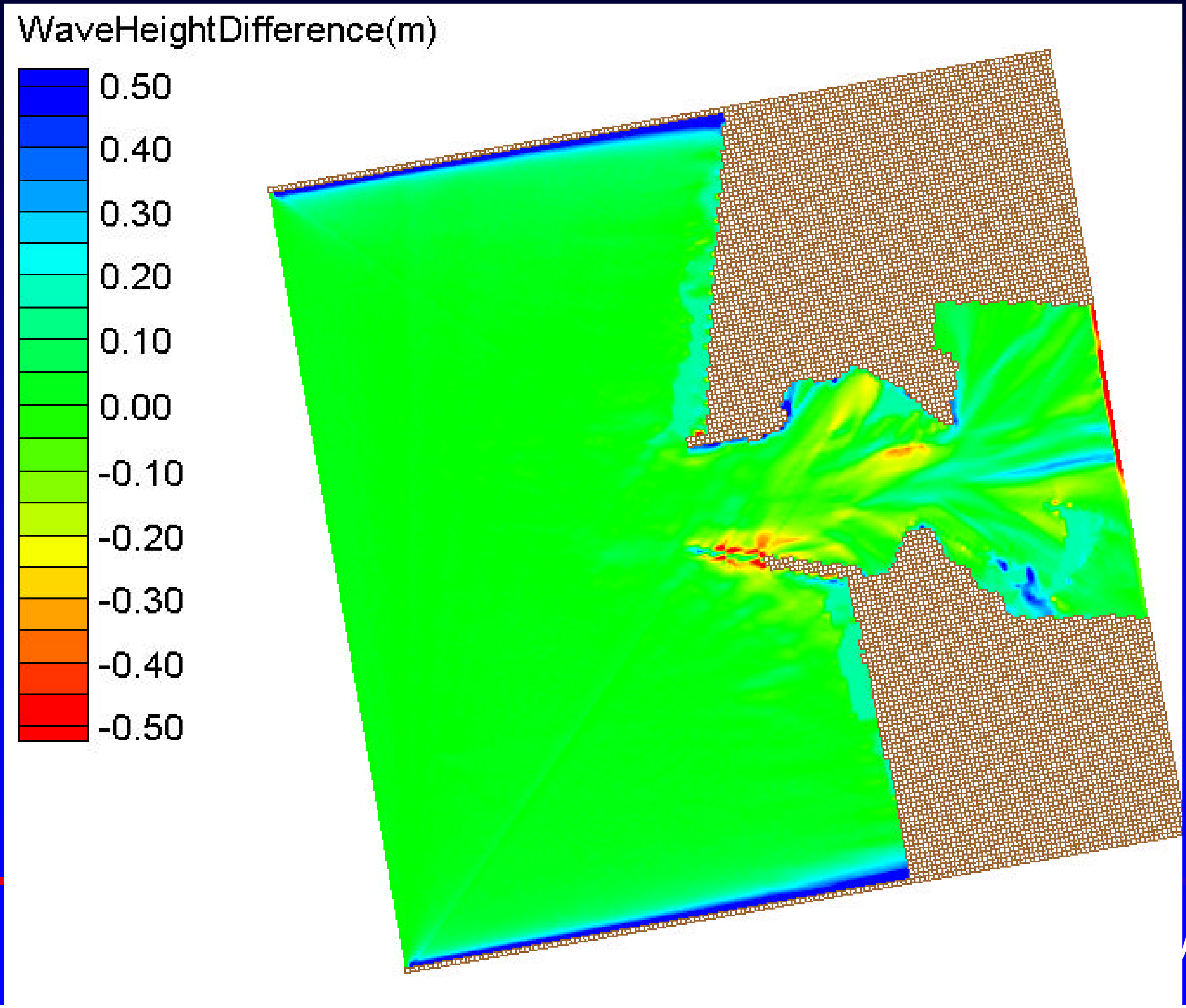
$$\Gamma_E = \frac{e g^{\frac{1}{2}} E_{tot}^{3} k_p^{\frac{9}{2}}}{\tanh^{\frac{3}{4}}(k_p h)}$$

$$H_{mo_{\max}} = 0.1 L \tanh kh$$

Full-Plane STWAVE

- dx and dy not required to be equal, dq arbitrary
- TMA spectral generated included (H, T, q input allowed)
- Refraction and shoaling precomputed for efficiency (redo for tide or current variations)

Full-Plane STWAVE



Diffraction and Reflection

- Diffusion operator in STWAVE + directional spread sufficient in most cases
- More rigor required for surface-piercing structures

Diffraction – Mild Slope Equation

$$\frac{1}{a}\left\{\nabla a+\frac{1}{CC_g}\nabla a\cdot\nabla(CC_g)\right\}+k^2-\nabla r\cdot\nabla r=0$$

$$\nabla\cdot(a^2CC_g\nabla r)=0$$

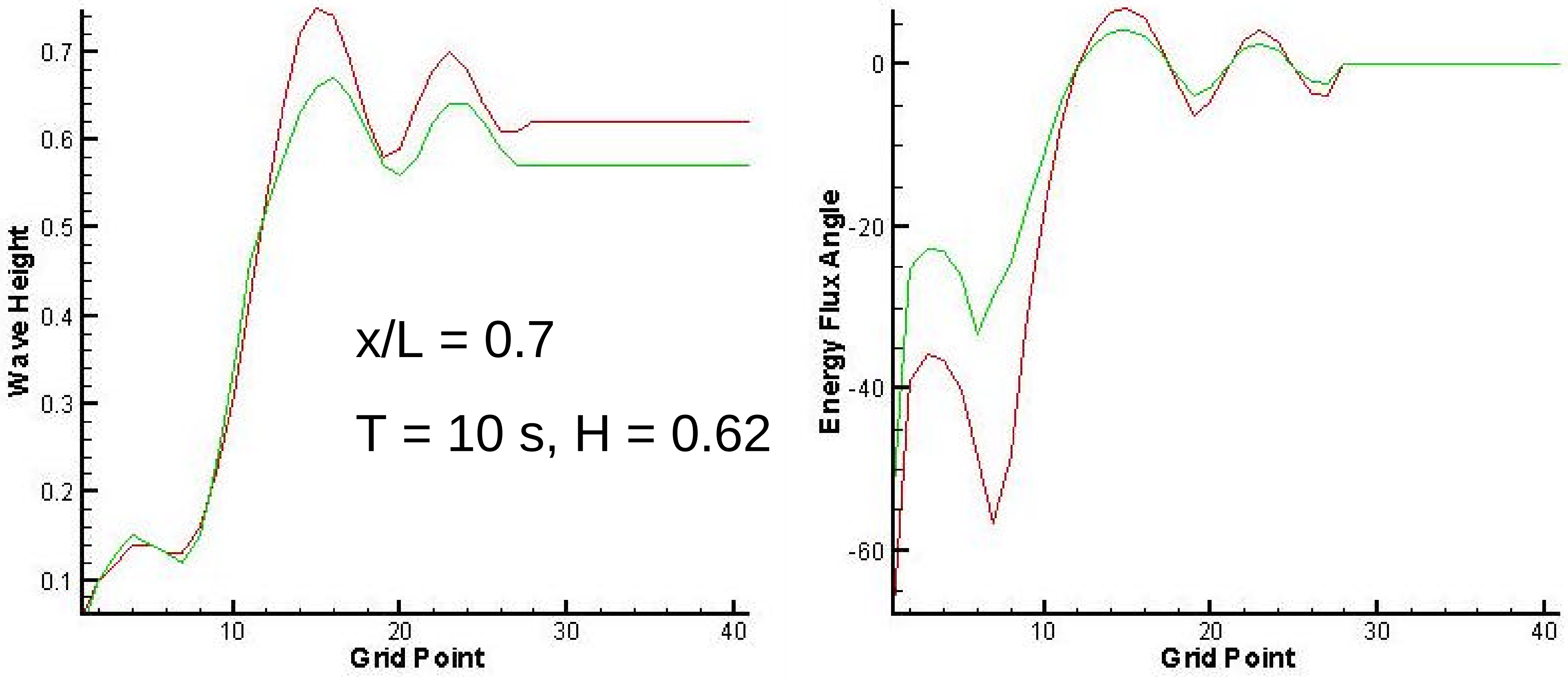
Requires high spatial resolution (L/8)

Solution is phase dependent

Diffraction

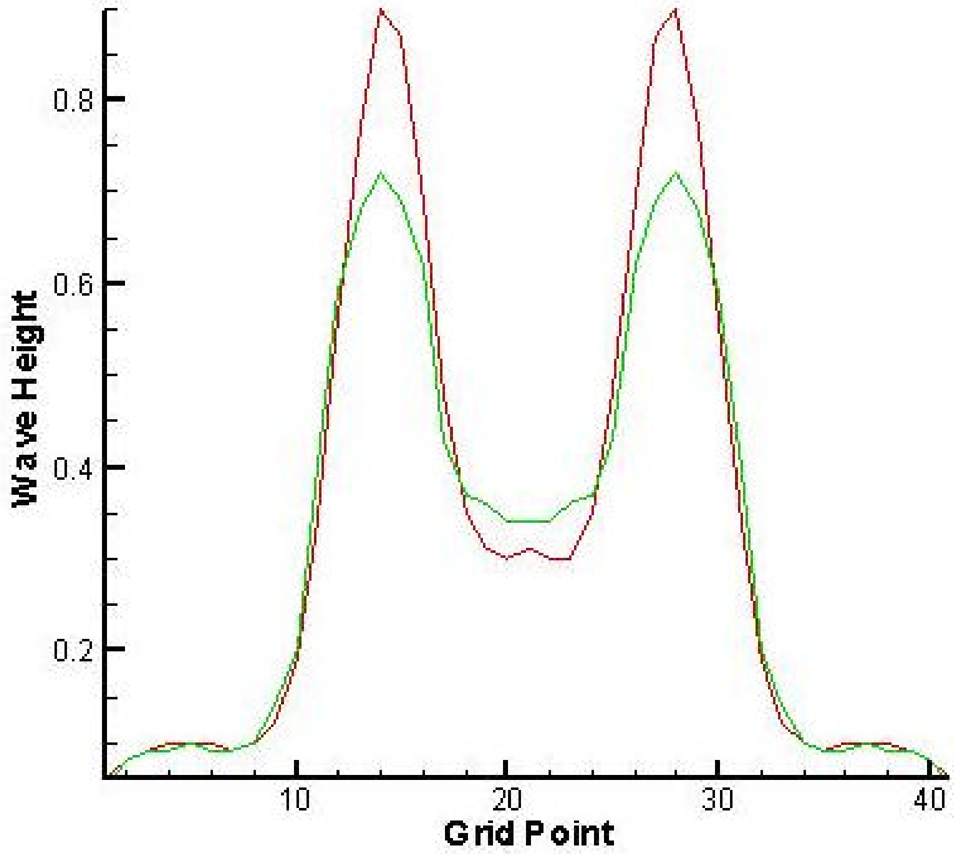
- Behind structure, diffraction dominates
- Solve diffraction based on geometry
  - Complex amplitude solved as integral along the boundary (Huyghens-Kirchoff integral)
  - Integrals (summations) pre-computed
  - Solution not restricted by grid resolution
- Add refraction, shoaling, and source terms

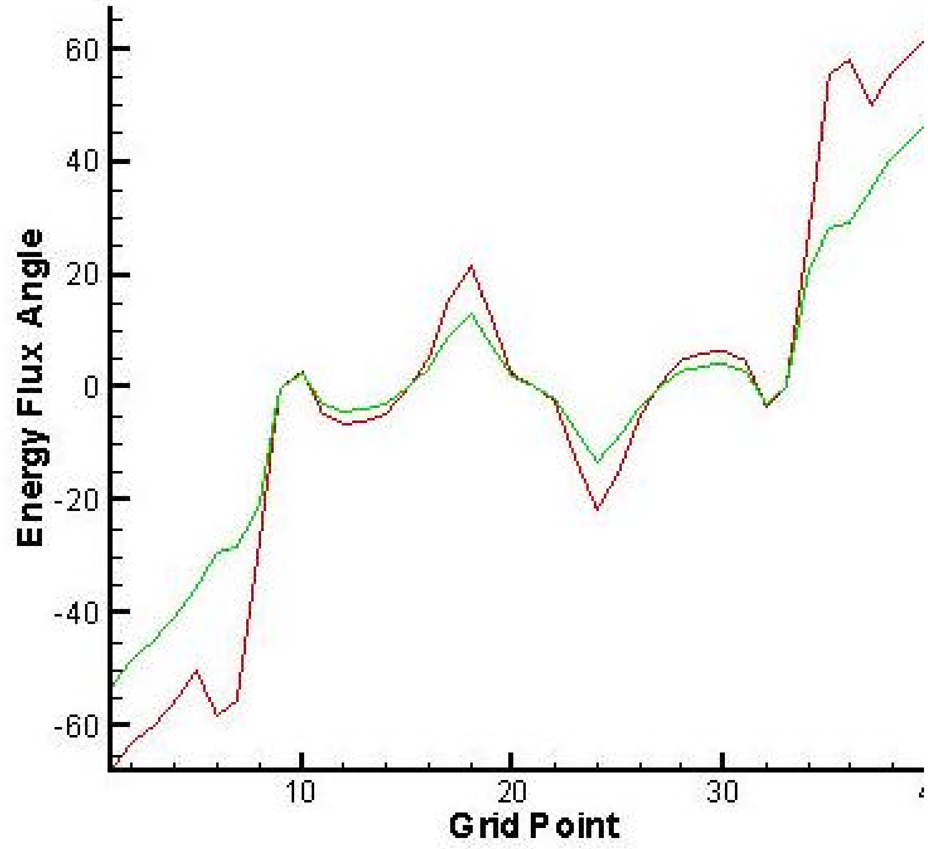
One-Arm Breakwater



Red is diffraction Only, Green is w/ refraction, shoaling and breaking

Two-Gap Breakwater





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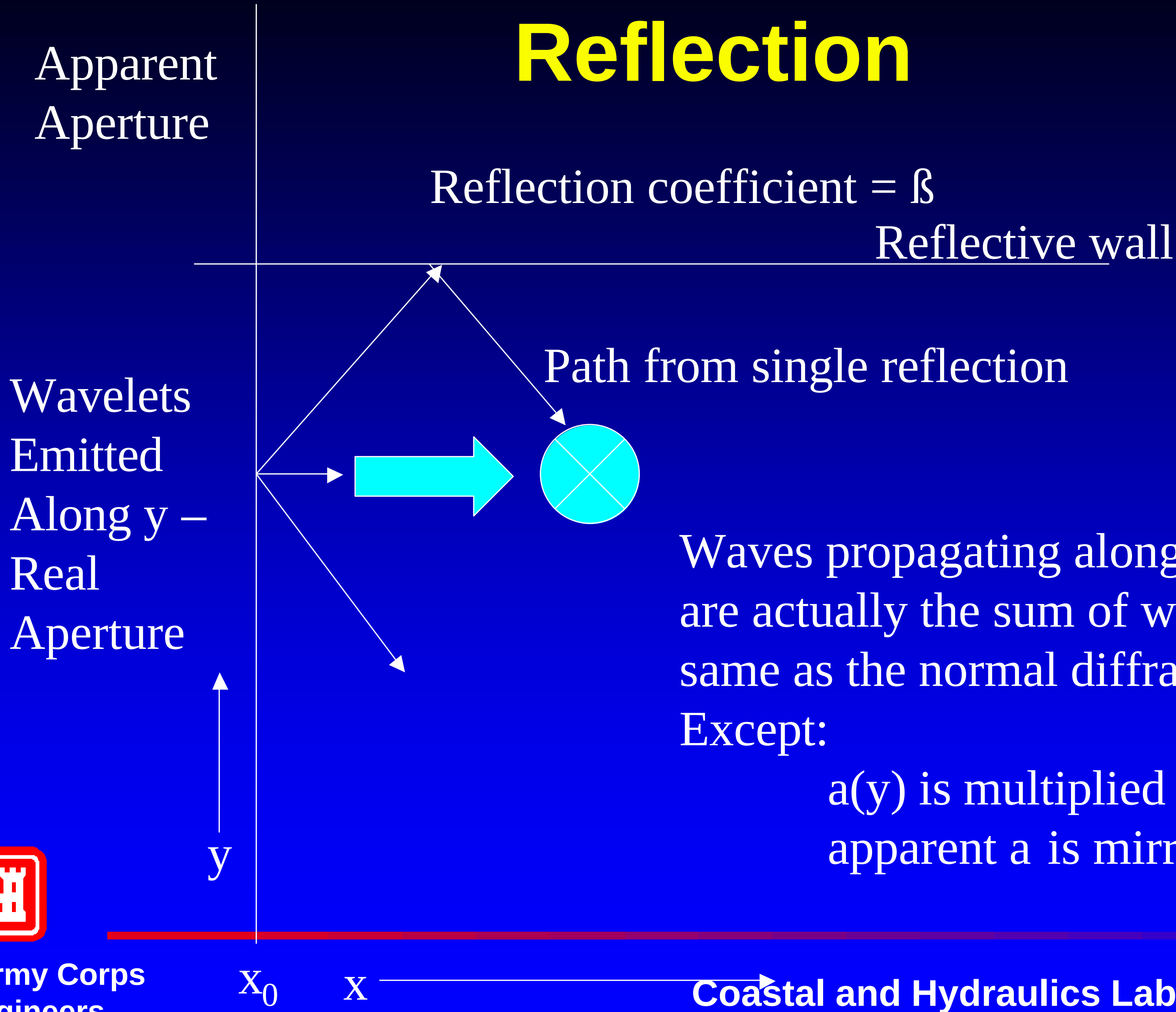
Reflection

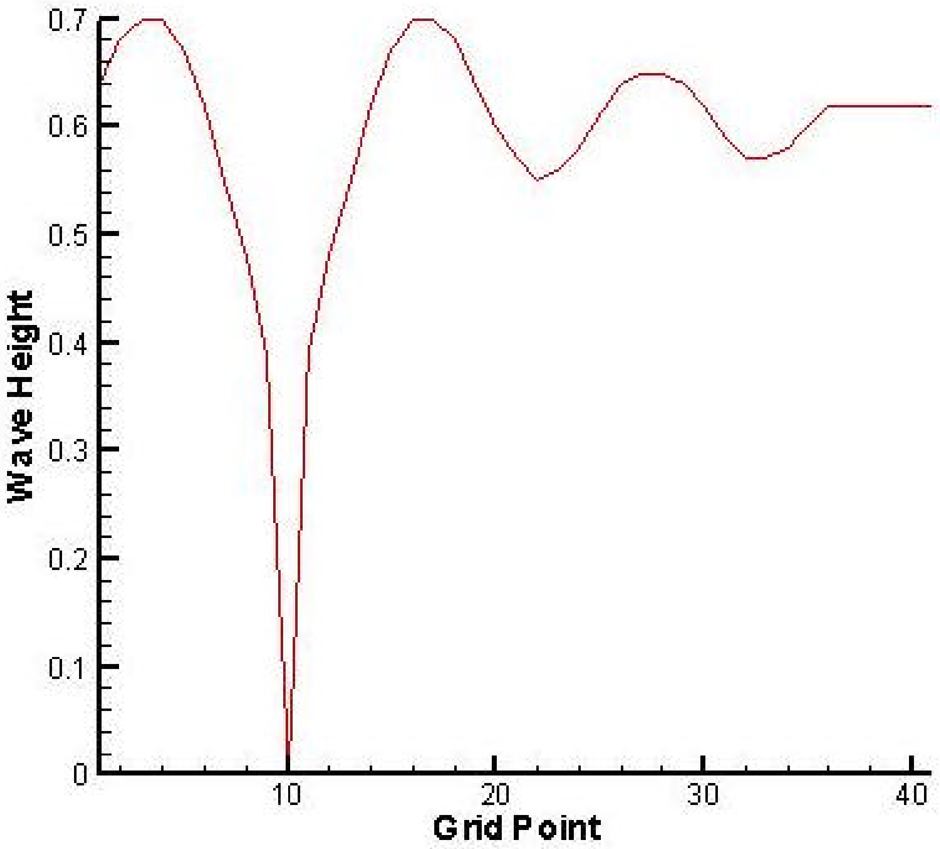


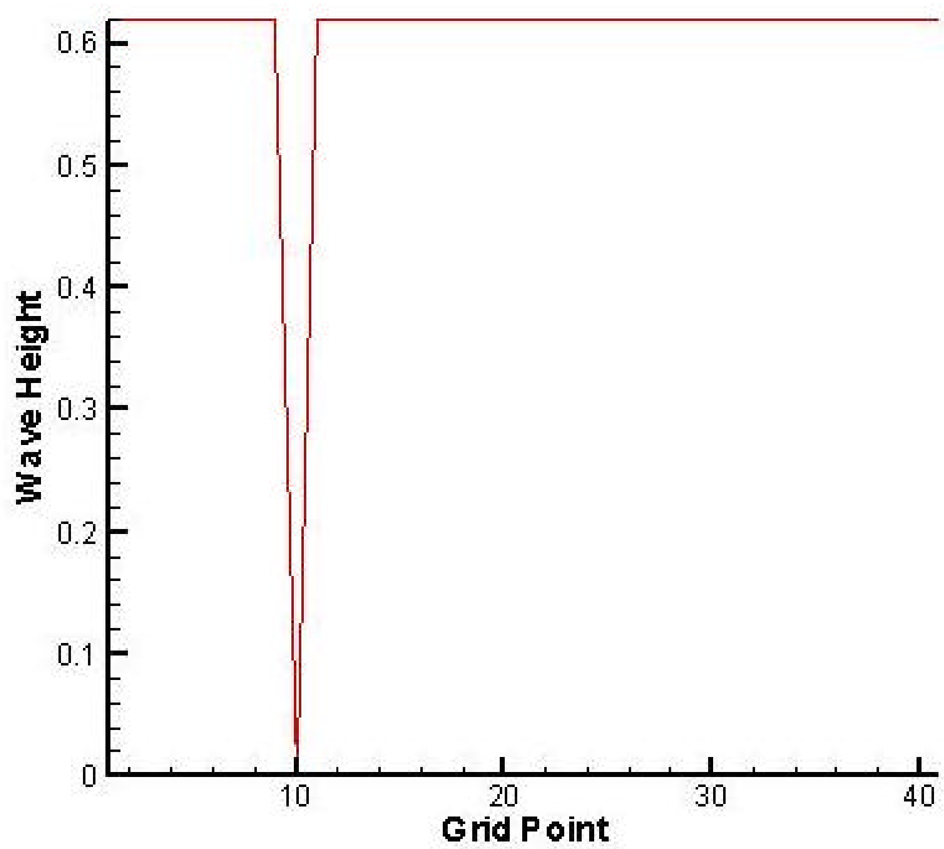
Waves propagating along “wall”
are actually the sum of wavelets -
same as the normal diffraction solution
Except:

a(y) is multiplied by ß

apparent a is mirror image

Absorbing and Reflecting Wall



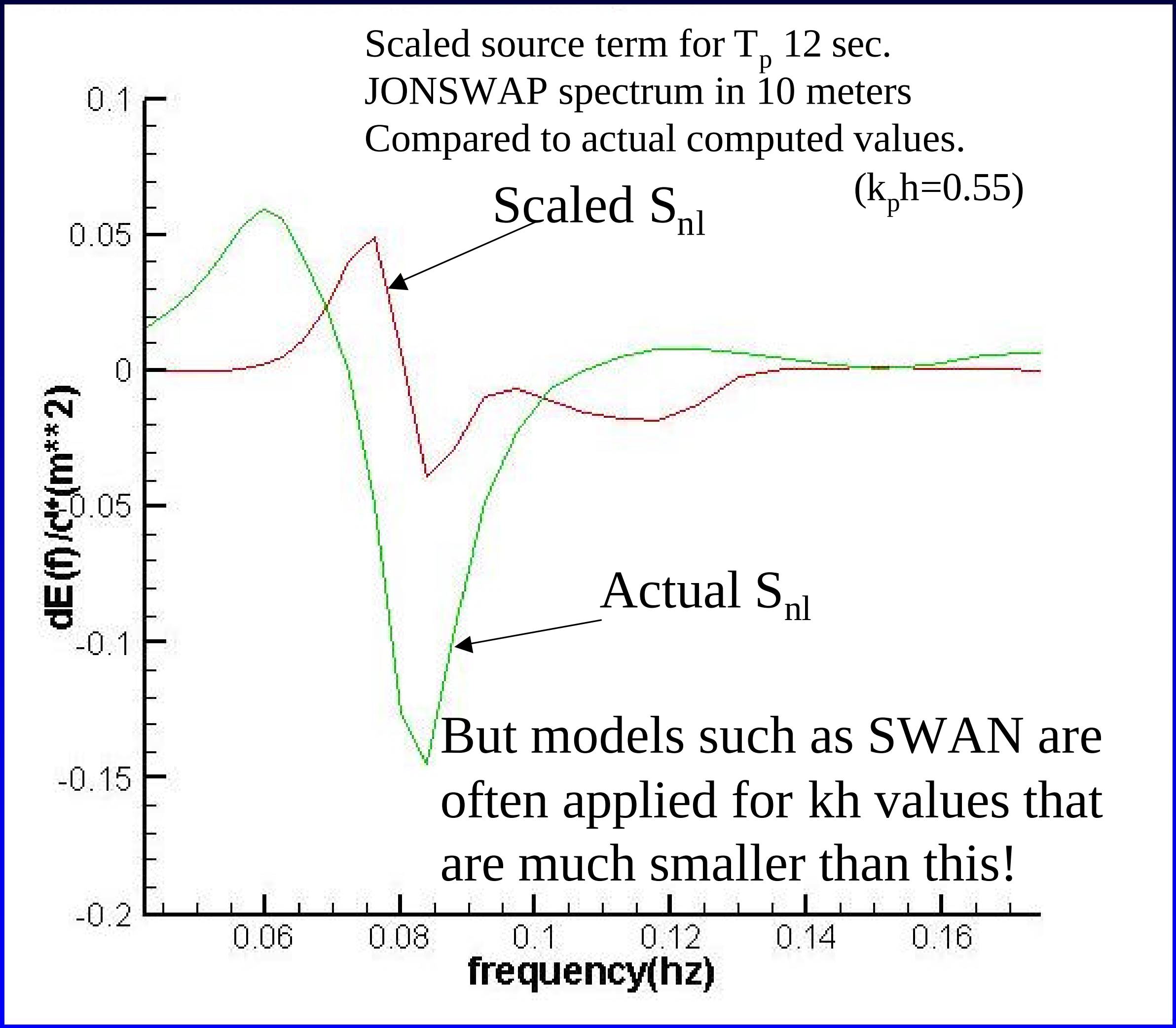


3G Source Terms

- DIA limitation in coastal regions:
  - Complex spectral shapes
  - Heterich & Hasselmann (1980) scaling $k_p h > 1$

  (e.g., 10-sec wave in 20 m depth)

3G Source Terms



Summary

- **Sophisticated Nearshore Modeling Requires:**
  - Advanced physics
  - Improved efficiency and flexibility
- **On-going Effort with STWAVE**
  - Wind input function
  - High-frequency breaking
  - Arbitrary-depth wave-wave interactions
  - Incorporation of 3-wave interactions
  - Benchmarking