CMS-Wave Background and Capabilities

Developed for coastal and inlet applications

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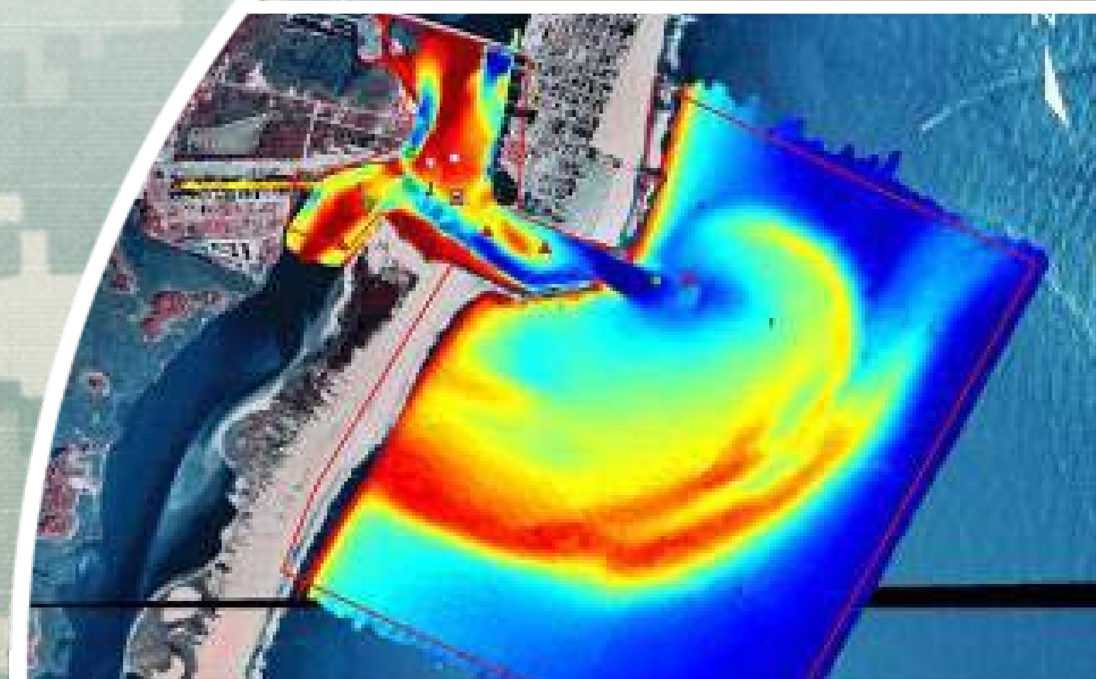
1 Dec 2009



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Outline

- Overview of CMS-Wave
- Capability
- Governing equations
- Incident wave spectrum
- Wave-current interaction
- Diffraction and reflection
- Wind input and wave dissipation
- Wave run-up, overtopping, & new features
- Coupled operation and future development
- Conclusions

1. Overview of CMS-Wave

- Steady-state (time-independent), half-plane, two-dimensional spectral transformation solved by finite-difference, forward-marching implicit scheme
- PC-based efficient model, stand-alone or coupled to CMS-Flow, a circulation and sediment transport model, through the SMS interface
- Emphasis on wave-structure-land interactions for practical coastal engineering projects

2. Capabilities

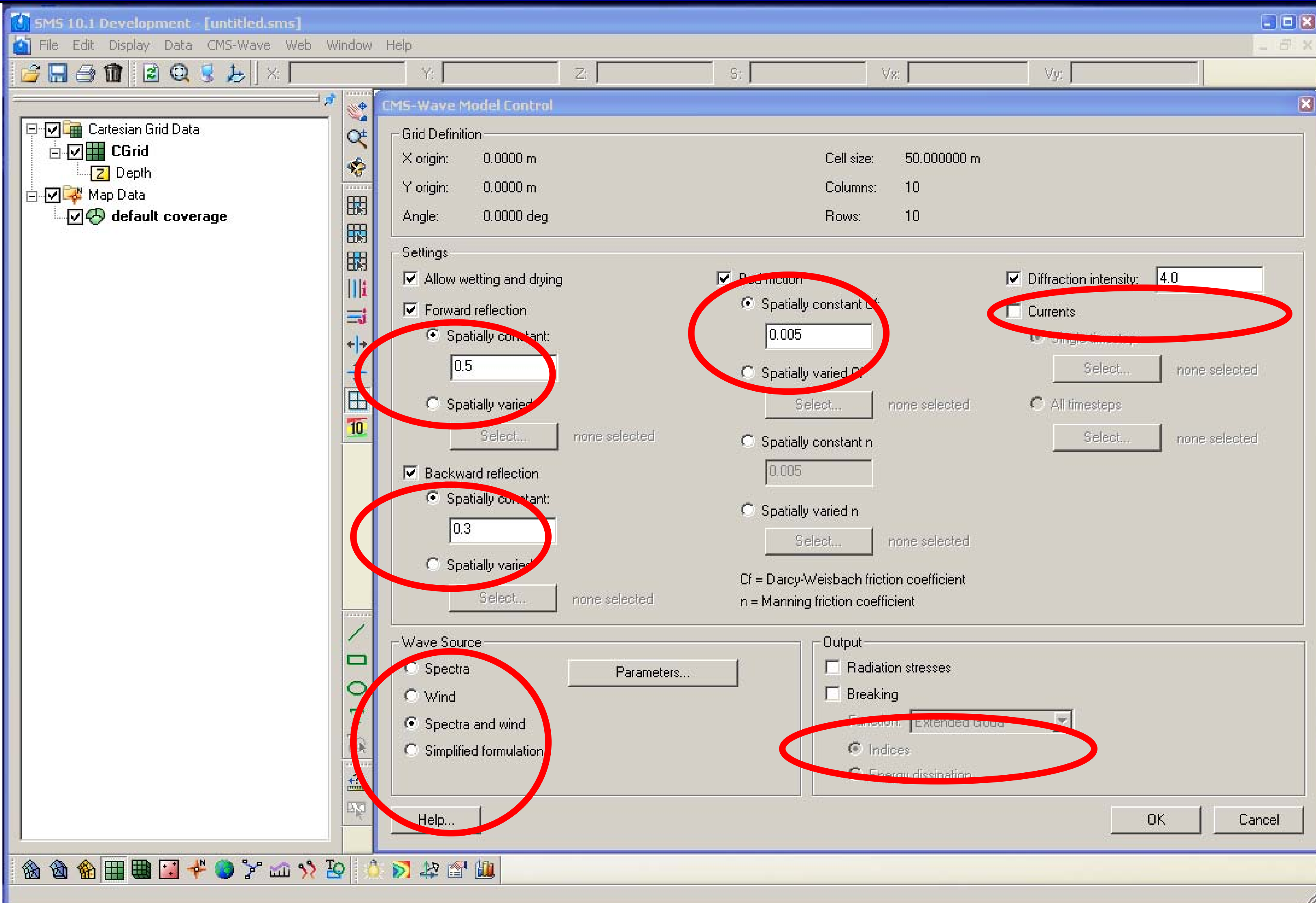
- Wave diffraction, reflection (forward & backward), breaking, bottom friction dissipation
- Wind input, wave-current interaction
- Wave transmission at structures
- Wave run-up, overtopping, overland flow
- Variable grids with nesting
- Nonlinear wave-wave interaction & infra-gravity waves
- “Fast mode” for quick calculations & prelim runs

CMS-Wave and STWAVE

CMS-Wave and STWAVE (half-plane) Comparison		
Capability	**CMS-Wave**	**STWAVE**
Spectrum transformation	Directional	Directional
Refraction & shoaling	Represented	Represented
Depth-limited wave breaking	Choice among four formulas	One formula
Roller	Represented	None
Diffraction	**Theory**	**Smoothing**
Reflection	**Represented**	**None**
Transmission	**Formulas**	**None**
Run-up and setup	**Theory**	**None**
Wave-current interaction	Theory	Theory
Wave-wave interaction	Theory	Semi-empirical
Wind input	Theory	Semi-empirical
White capping	Theory	Semi-empirical
Bottom friction	Theory	Theory

Structures (Diffraction, Reflection, Transmission, Run-up and setup)

CMS-Wave SMS 10.1 Interface



3. Governing Equation

Wave-Action Balance Equation with Diffraction

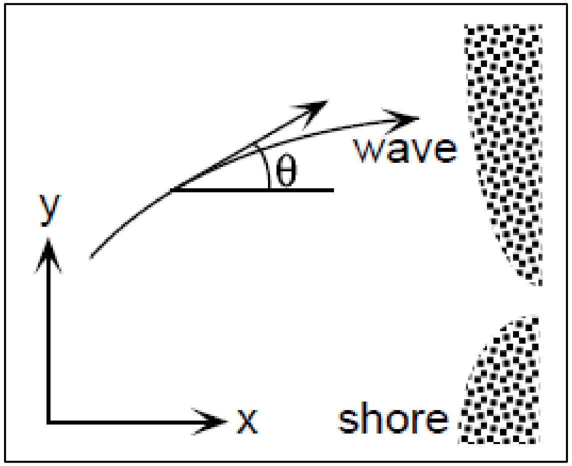
Diffraction intensity factor

$$\frac{\partial[(c_{gx}+u)A]}{\partial x}+\frac{\partial[(c_{gy}+v)A]}{\partial y}+\frac{\partial[c_{g\theta}A]}{\partial\theta}=\frac{\kappa}{2\sigma}\{(cc_g\cos^2\theta A_y)_y-\frac{1}{2}cc_g\cos^2\theta A_{yy}\}+S_{in}+S_{dp}$$

where $A = E/\sigma$, wave-action spectrum

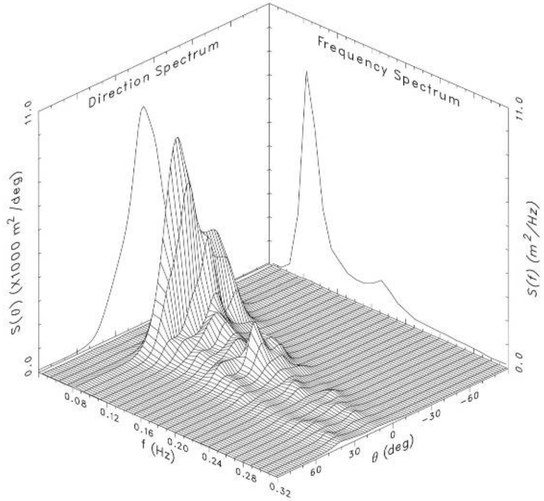
and $E = E(\sigma,\theta)$, wave directional spectrum.

Note: *x* is normal to the offshore boundary; *y* is parallel to the offshore boundary



4. Incident Wave Spectrum

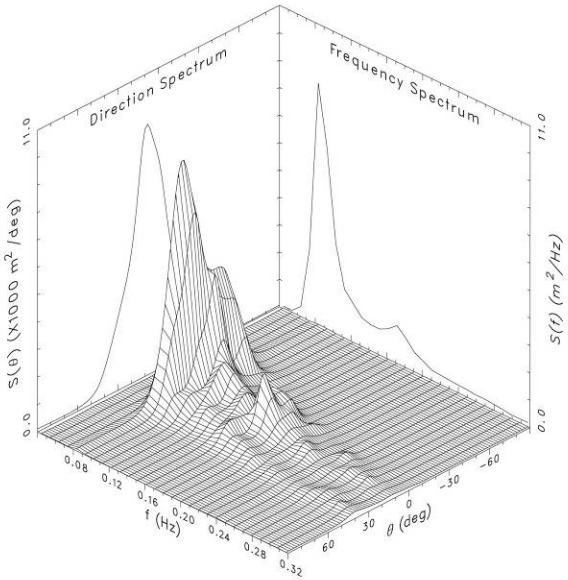
- NDBC/NOAA Ocean Buoys
- CDIP Coastal Buoys
- Project specific measurements (ADCP)
- Theoretical spectra (SMS)



Theoretical Spectrum

A single input spectrum applied along the seaward boundary,

e.g., a JONSWAP type:



$$E = \frac{\alpha g^2}{\sigma^5}\exp(-0.74\frac{\sigma_0^4}{\sigma^4})\gamma^a D(\sigma,\theta)$$

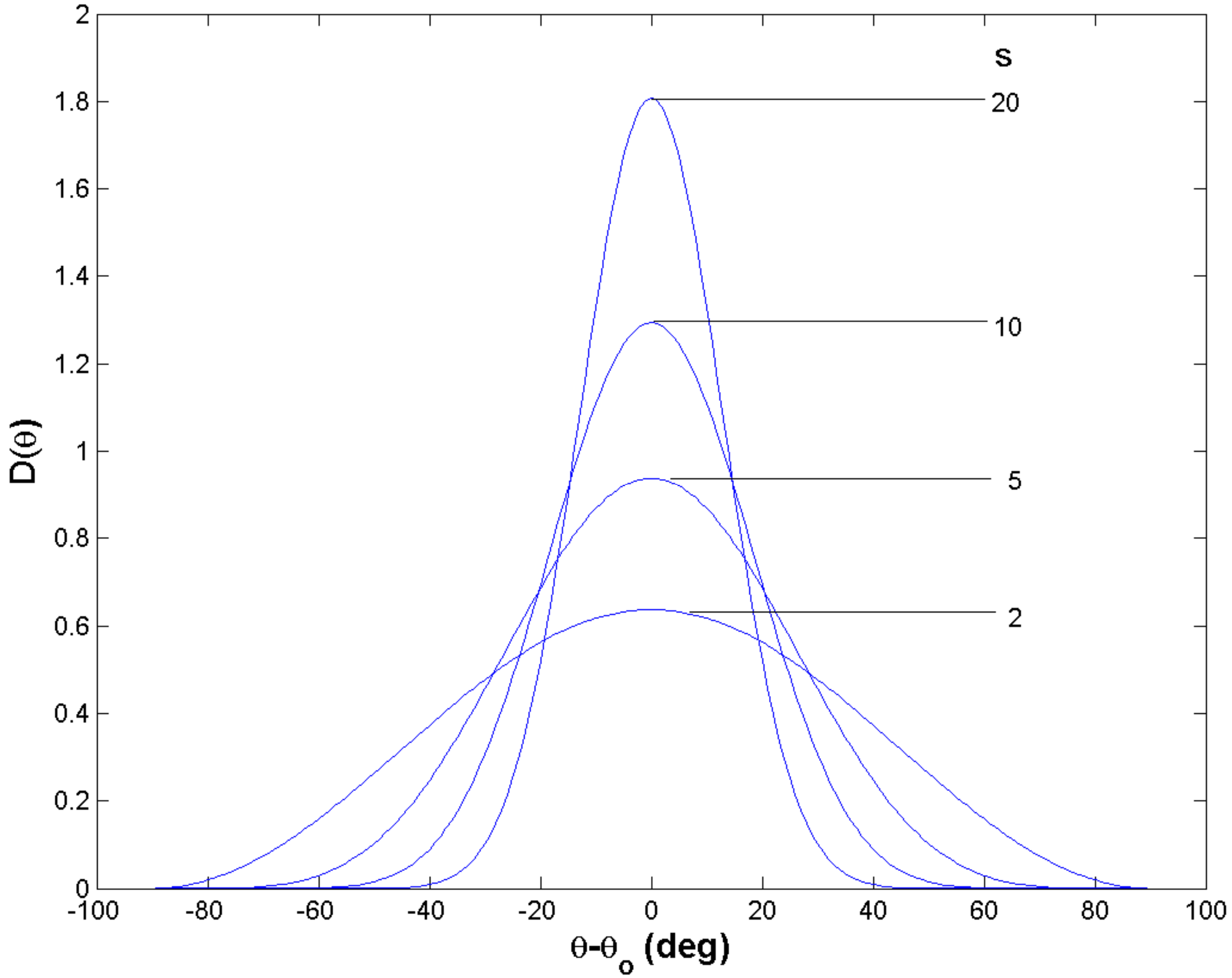
where

$$D(\theta) = \frac{2^s}{\pi}\frac{\Gamma(s/2+1)}{\Gamma(s+1)}\cos^s(\theta-\theta_o)$$

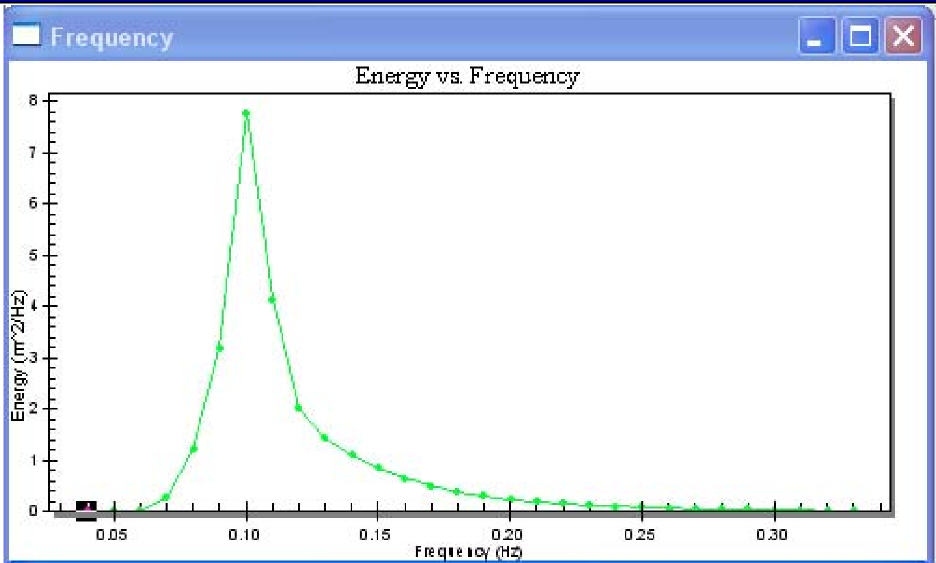
for $|\theta-\theta_o| < \pi/2$

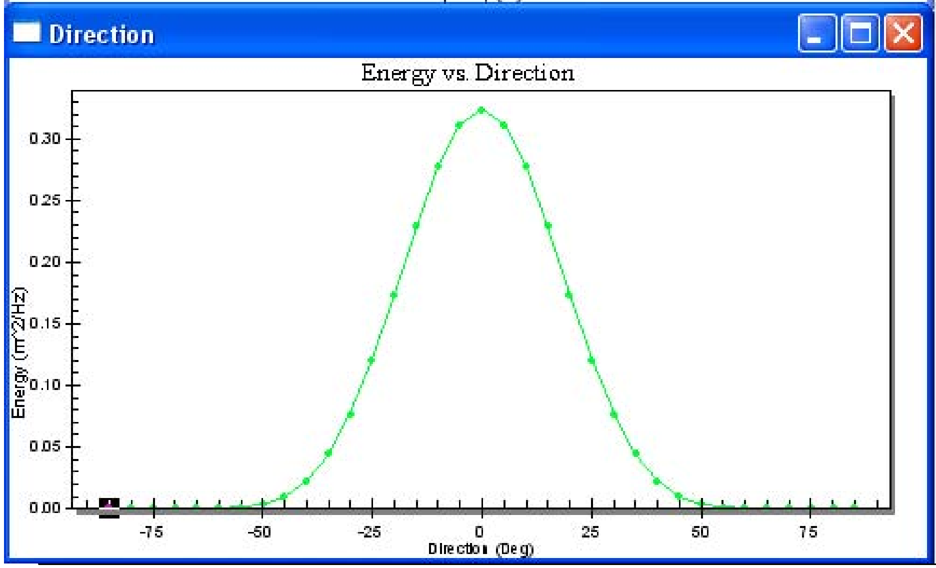
and s is the directional spreading parameter.

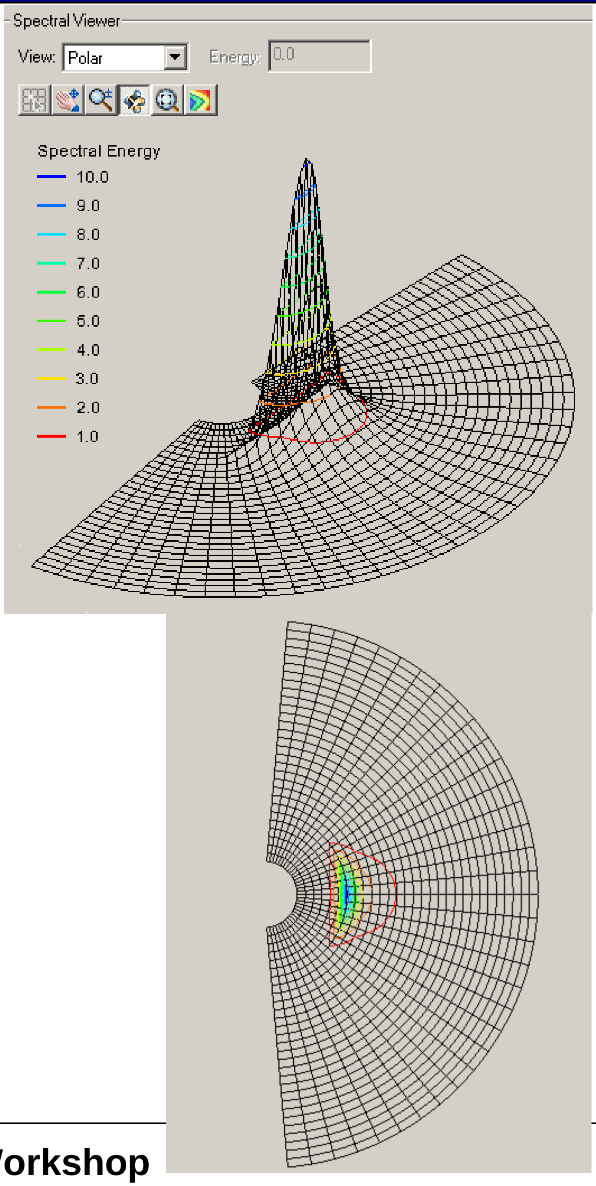
Idealized Directional Distribution



SMS10.1 Wave Spectrum Display







5. Wave-Current Interaction

- Solving for wave number *k* in dispersion equation with a current:

$$\sigma = \sqrt{gk \tanh kh} + ku \cos\theta + kv \sin\theta$$

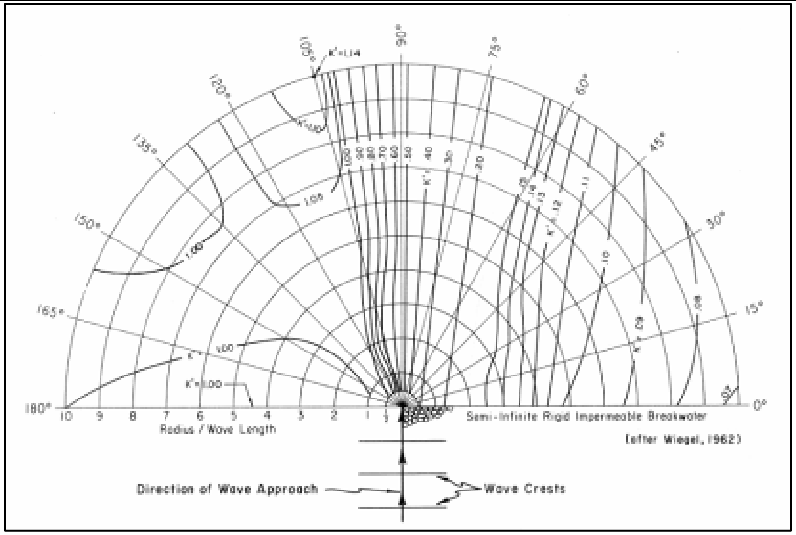
- Computing wave radiation stresses:

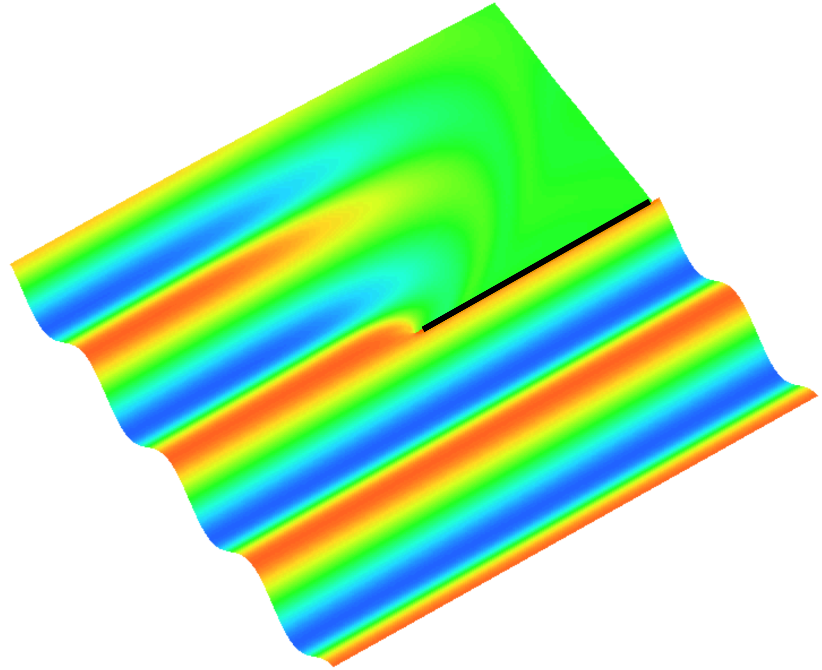
$$S_{xx} = E[n(\cos^2\theta + 1) - \frac{1}{2}],$$

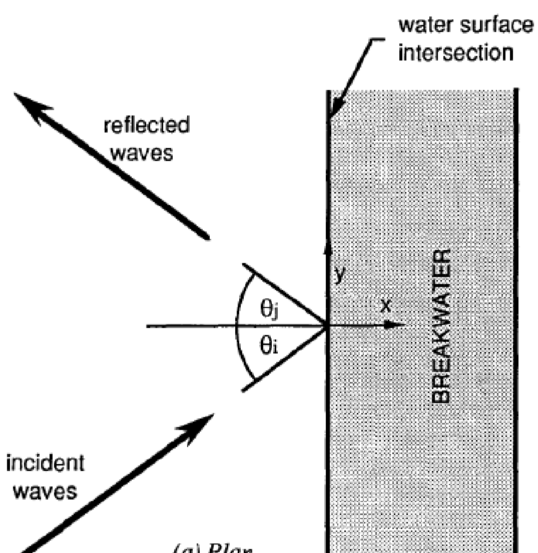
$$S_{yy} = E[n(\sin^2\theta + 1) - \frac{1}{2}],$$

$$S_{xy} = E\frac{n}{2}\sin 2\theta, \quad \text{where} \quad n = \frac{1}{2} + \frac{kh}{\sinh 2kh}$$

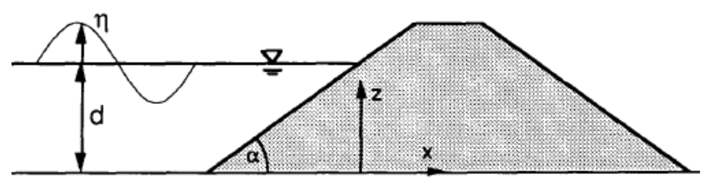
6. Jetty Breakwater Wave Diffraction and Reflection





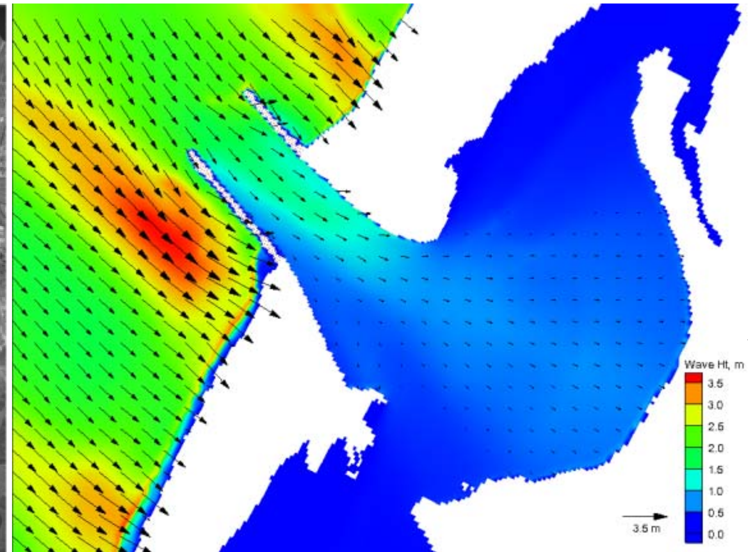


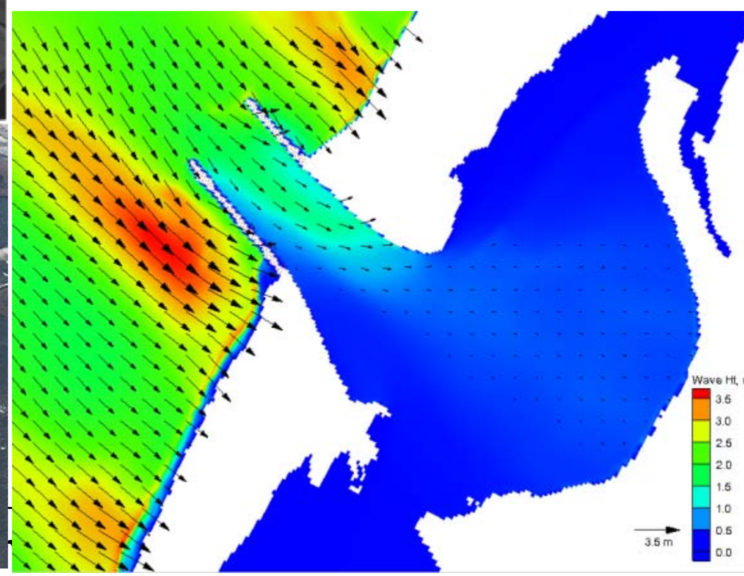
(a) Plan



(b) Elevation

Infra-gravity Waves at *Humboldt Bay, CA*



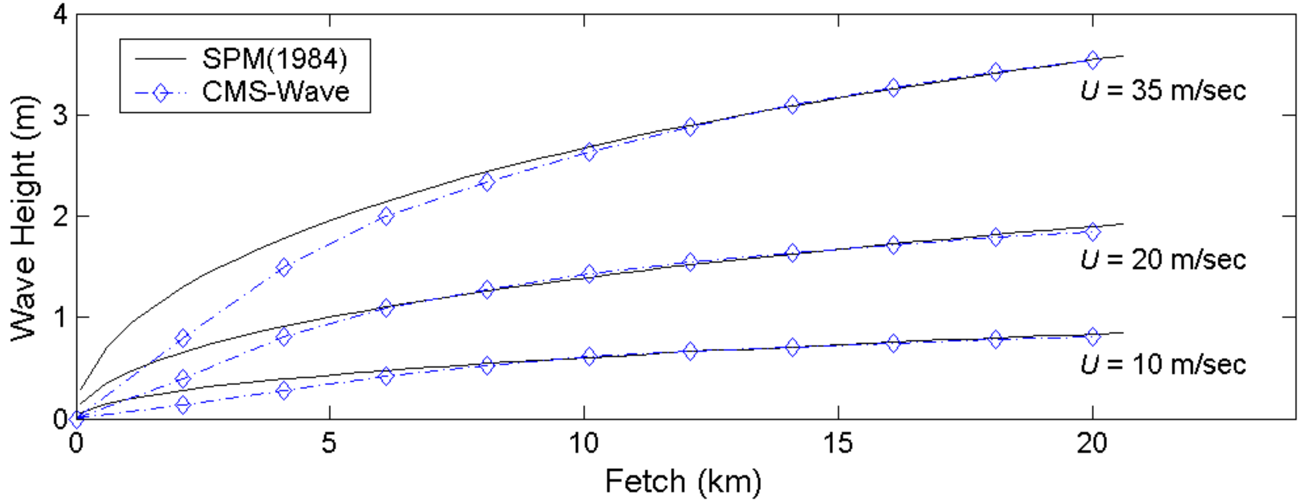


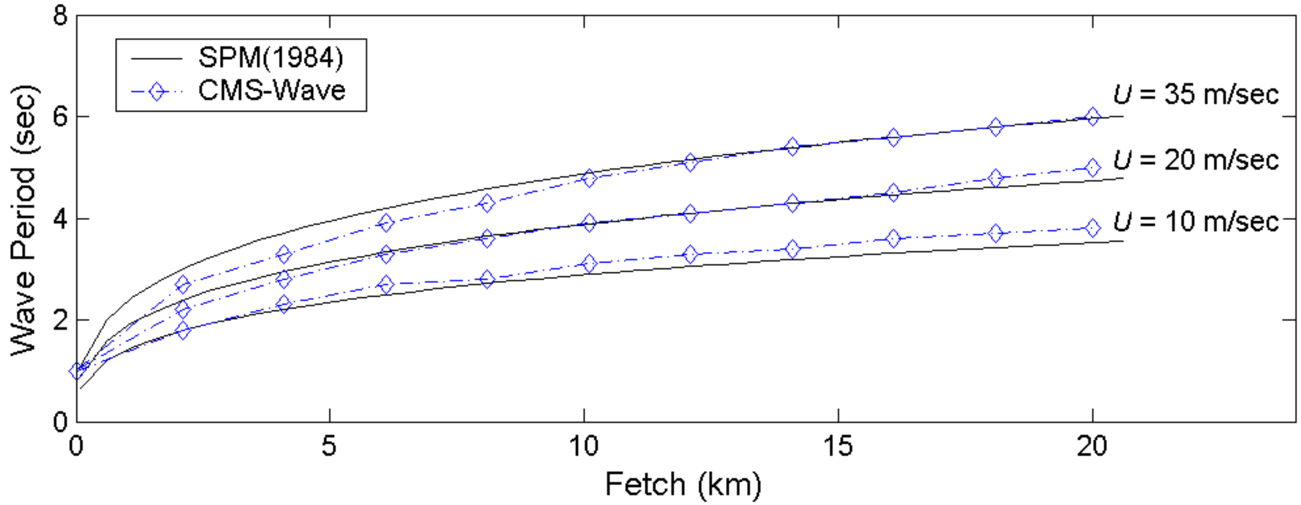
Incident wave:
2 m, 15 sec
from NE

with infra-gravity wave

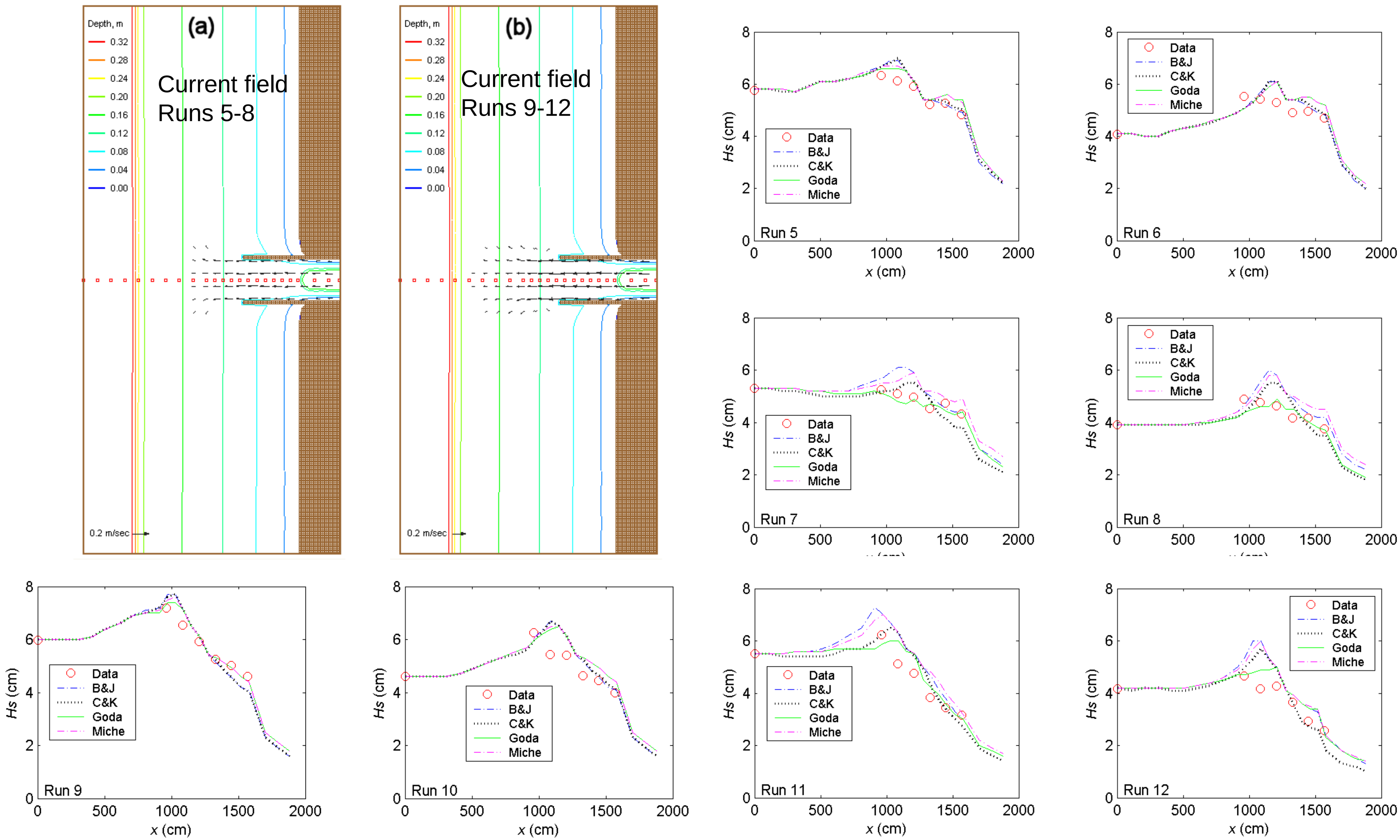
without infra-gravity wave

7. Wind-Wave Generation

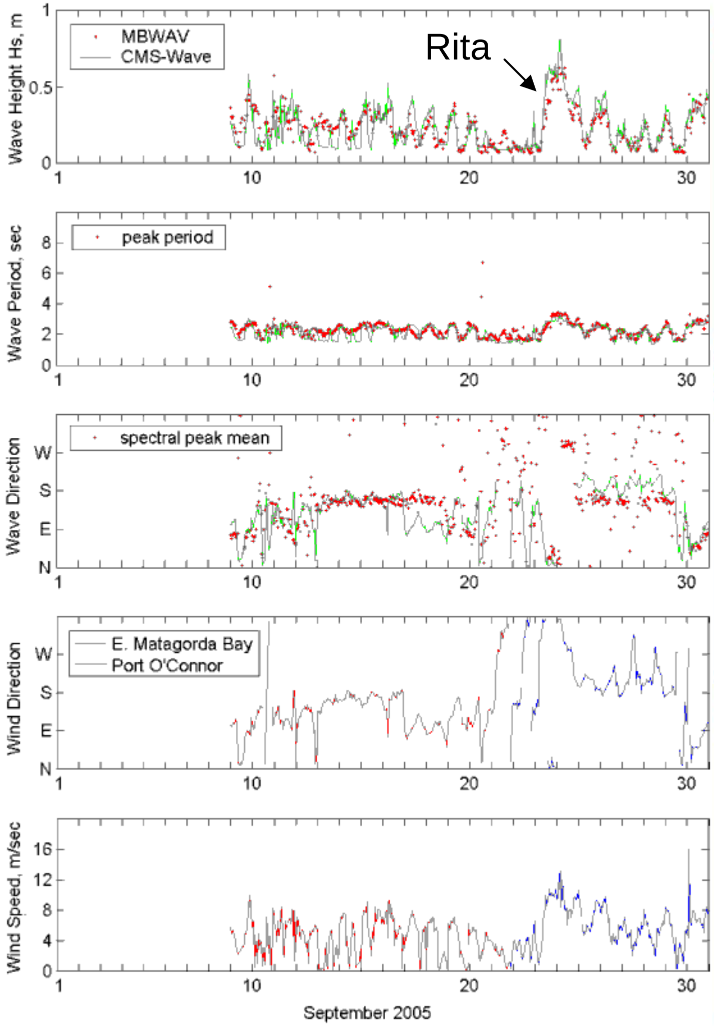


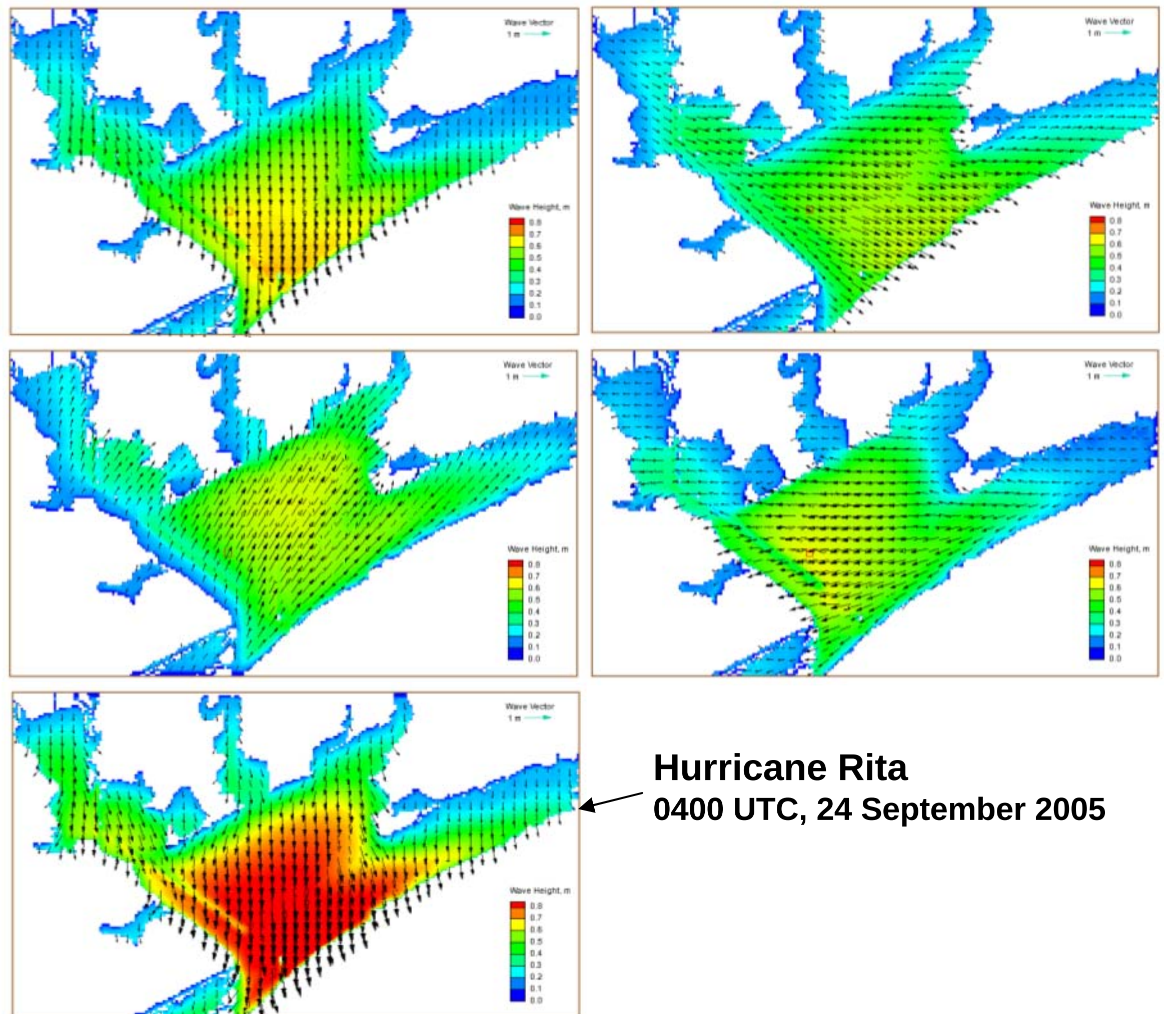


Wave Breaking Formulas

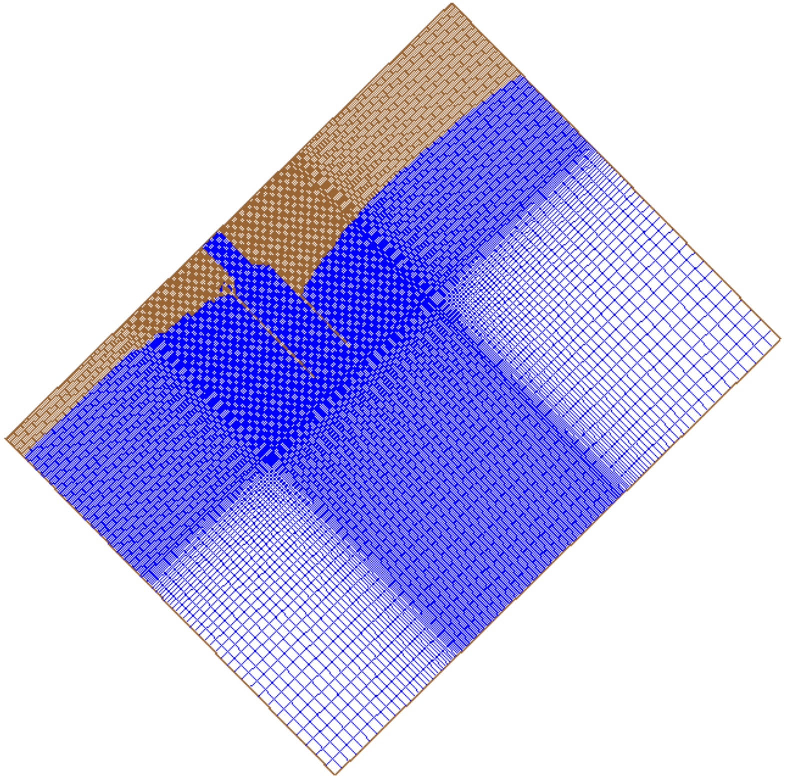


Wave Generation in *Matagorda Bay, TX*

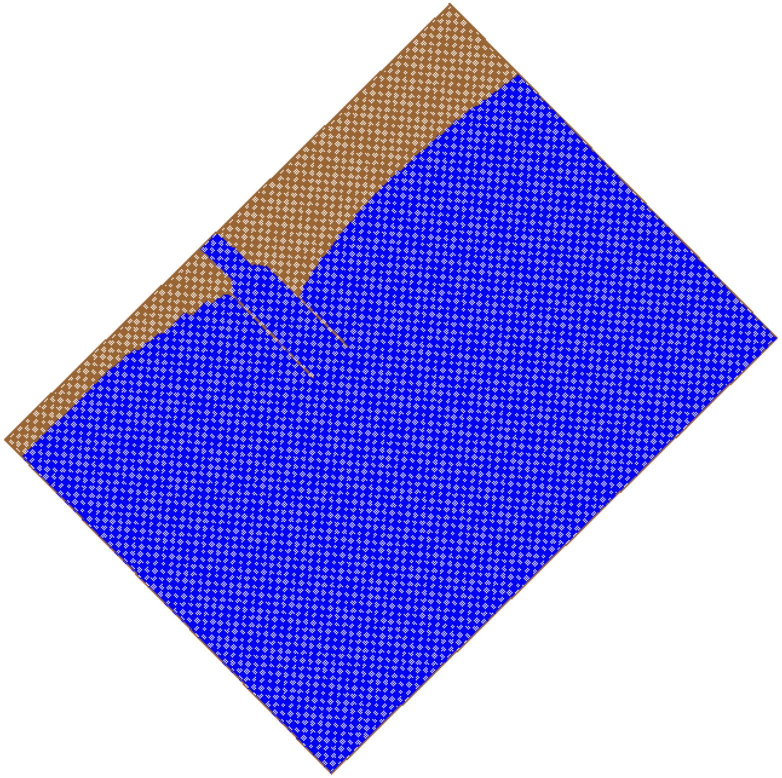




Variable Rectangular-Cell Grids

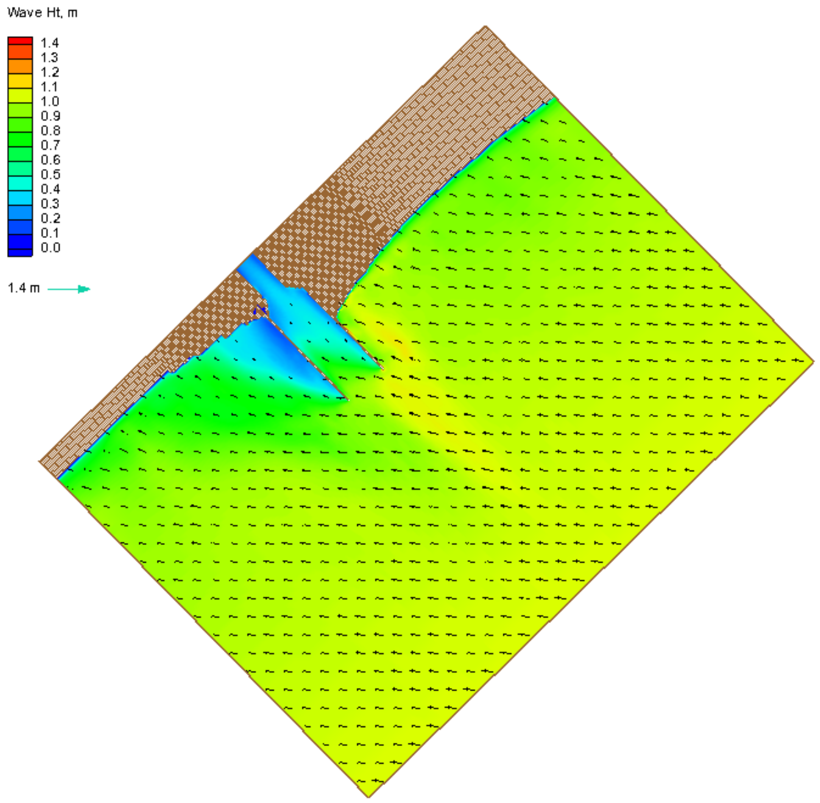


Variable-rectangular cells
Total 223 x 172 cells

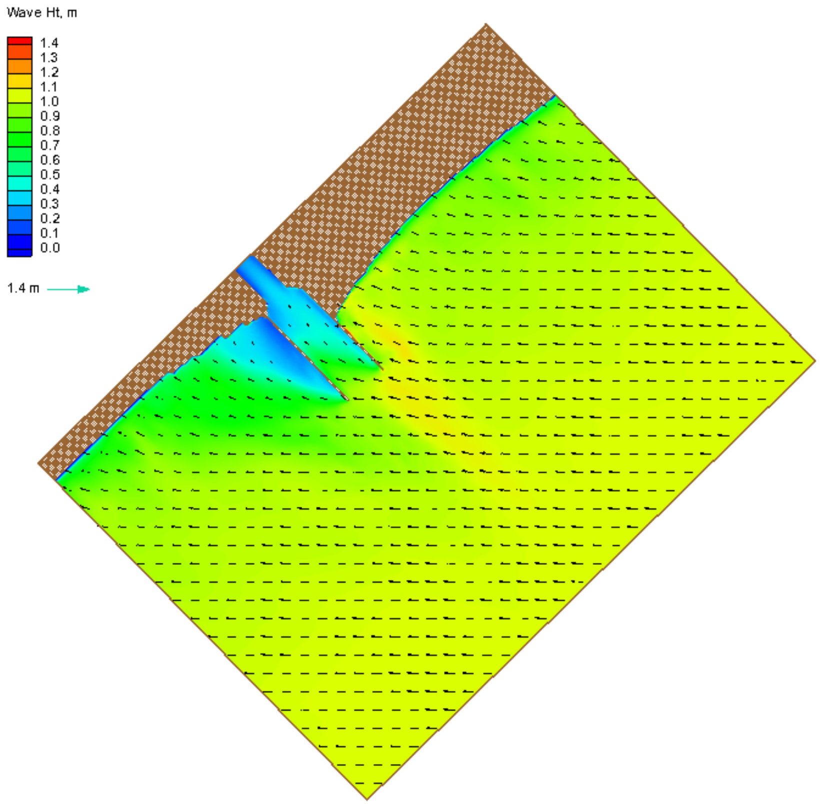


Square (20 m x 20 m) cells
Total 316 x 426 cells

CMS-Wave on Variable Grids

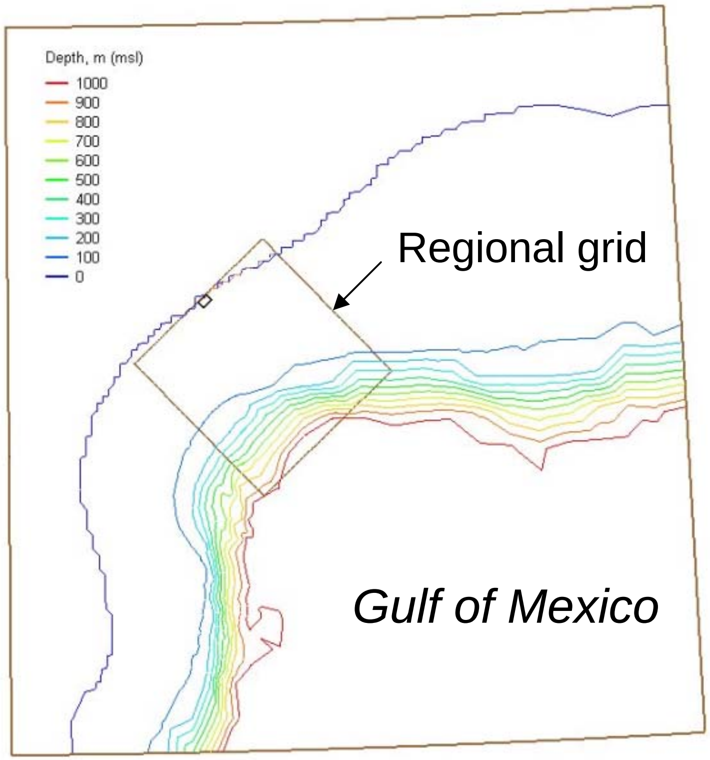


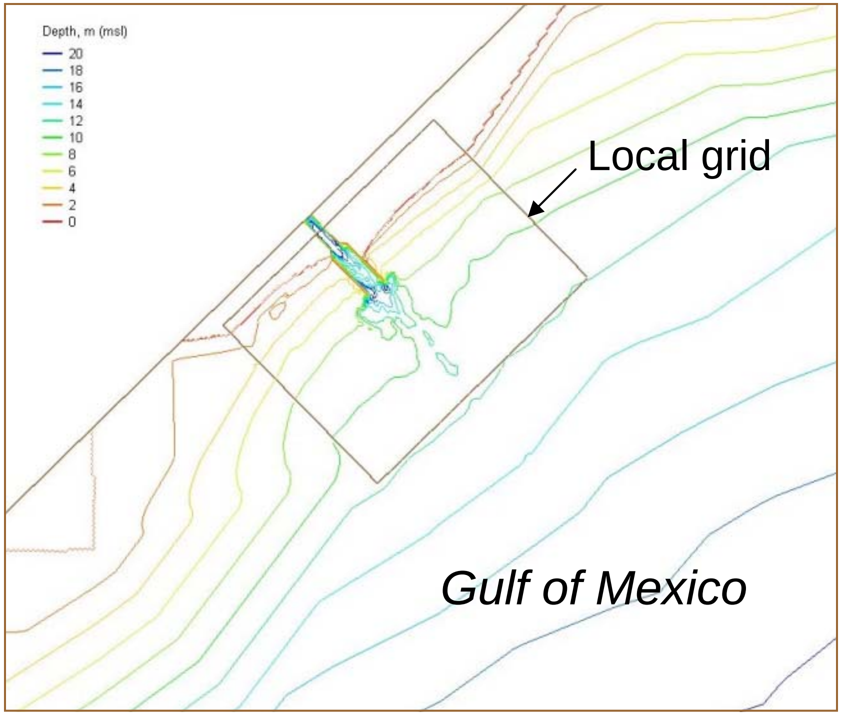
Variable-rectangular cells
Total 223 x 172 cells



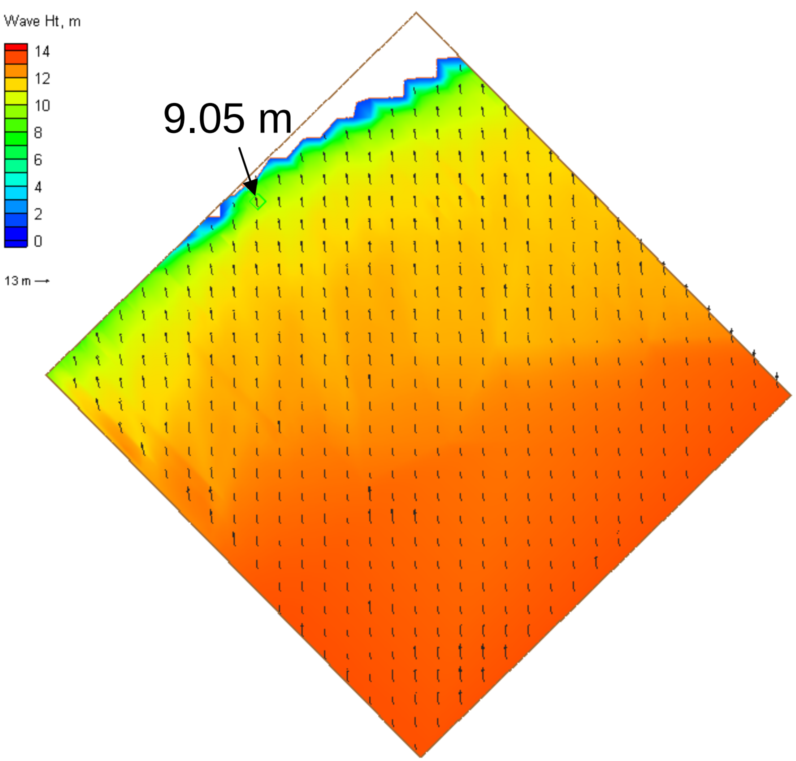
Square (20 m x 20 m) cells
Total 316 x 426 cells

Grid Nesting

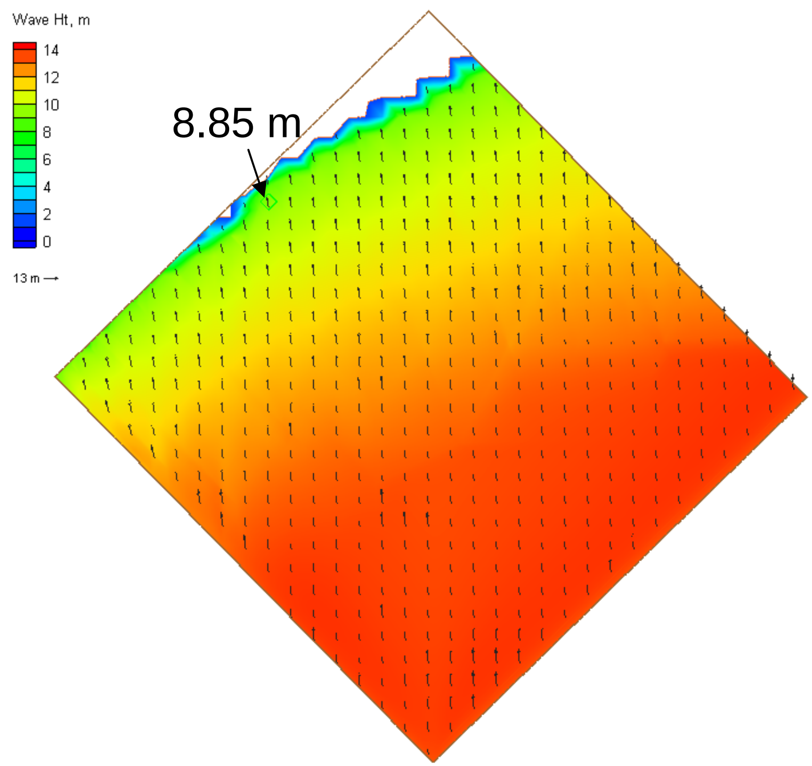




Max Surge: 3.5 m (Return Period = 50 yrs)

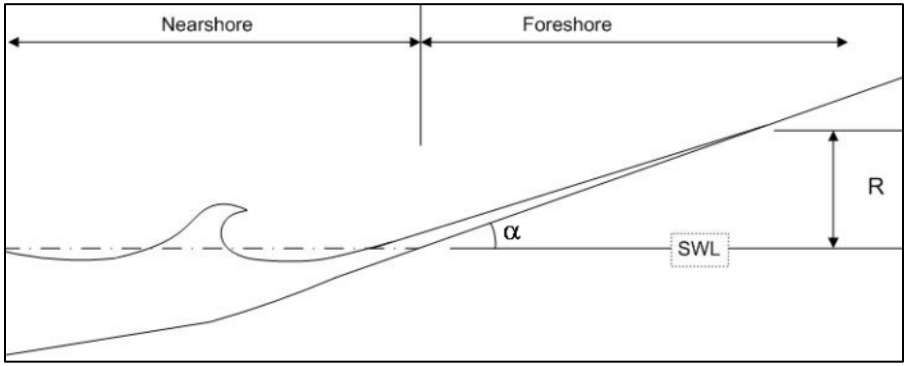


Without wind



With wind (27 m/sec, from S)

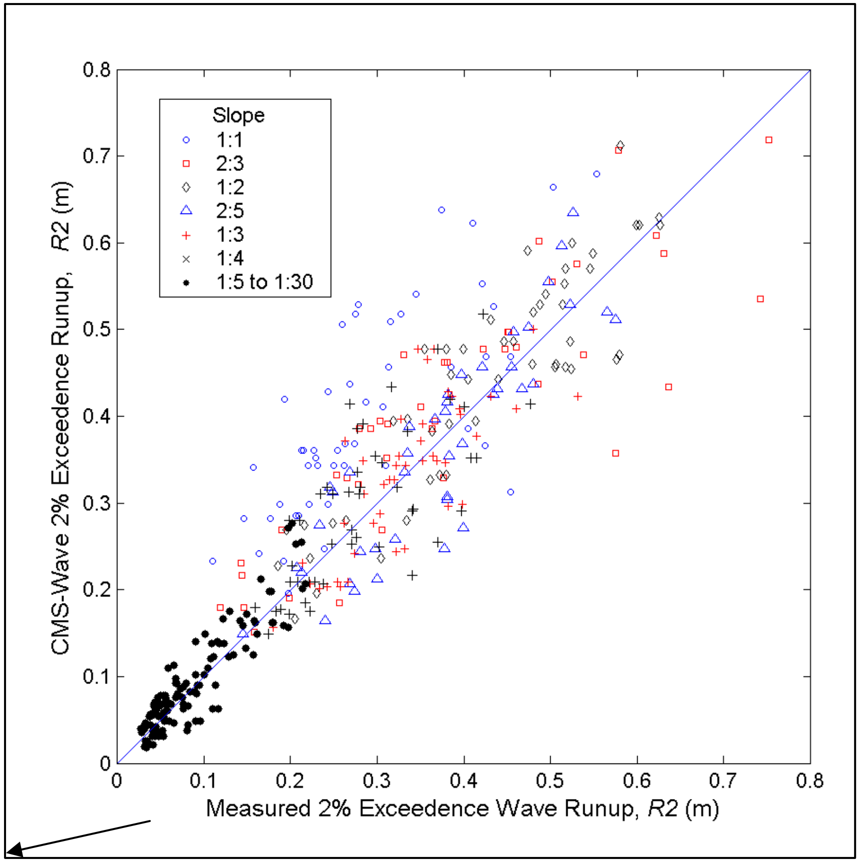
8. Wave Run-up



Wave run-up: rush of waves up a slope or structure

Two-percent run-up, *R2* : the vertical up-rush level exceeded by 2-percent of the larger run-up height

Ahrens & Titus (1981), Mase & Iwagaki (1984) ~ 400 laboratory experiments



Wave Run-up Calculation

Total run-up *R2* = wave setup + 2% exceedance of swash level

Wave setup: $\frac{\partial \eta}{\partial x} = -\frac{1}{\rho g h}(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y})$, $\frac{\partial \eta}{\partial y} = -\frac{1}{\rho g h}(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y})$

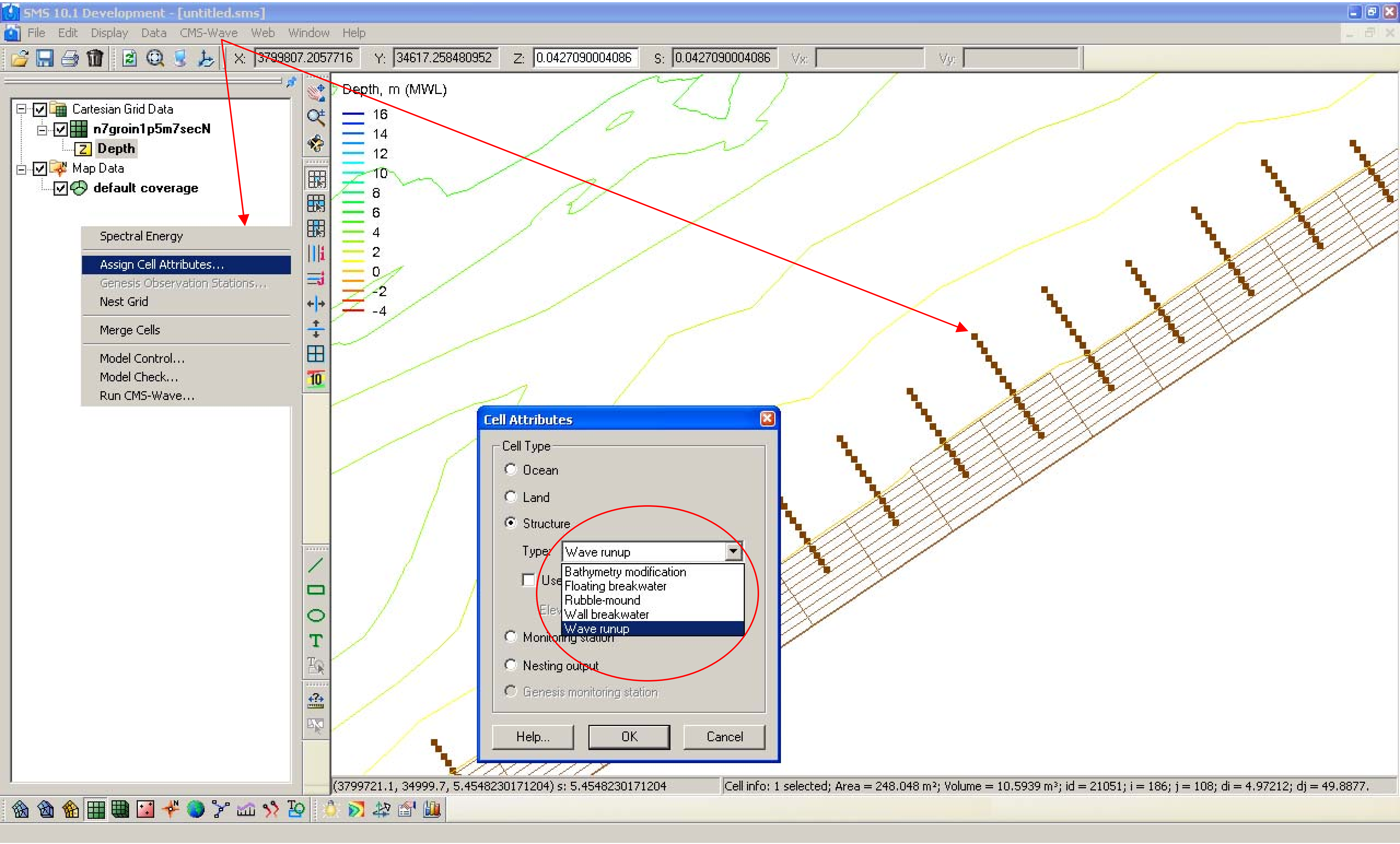
Max setup (Guza and Thornton, 1981): $\eta_{\max} = 0.17 H_0$

Total runup *R2* (2% exceedance) = 2 $\eta_{\max}$ (Komar, 1998)

Max water level = max of ($\eta + H_s / 2$, *R2*)

* Wave setup and max water level field are saved in setup.wav

Specify Feature Cells in SMS10.1



Floating Breakwater

An analytical formula of the transmission coefficient for a rectangle floating breakwater of width *B* and Draft *D* (Macagno 1953):

$$K_t = \left[1 + \left(\frac{kB \sinh \frac{kh}{2\pi}}{2 \cosh k(h-D)} \right)^2 \right]^{-\frac{1}{2}}$$

Bottom-Mound Breakwater

Vertical wall breakwater (Kondo and Sato, 1985):

$$K_t = 0.3 \ (1.5 - \frac{h_c}{H_s}), \qquad \text{for} \quad 0 \le \frac{h_c}{H_s} \le 1.25$$

Composite or rubble-mound breakwater:

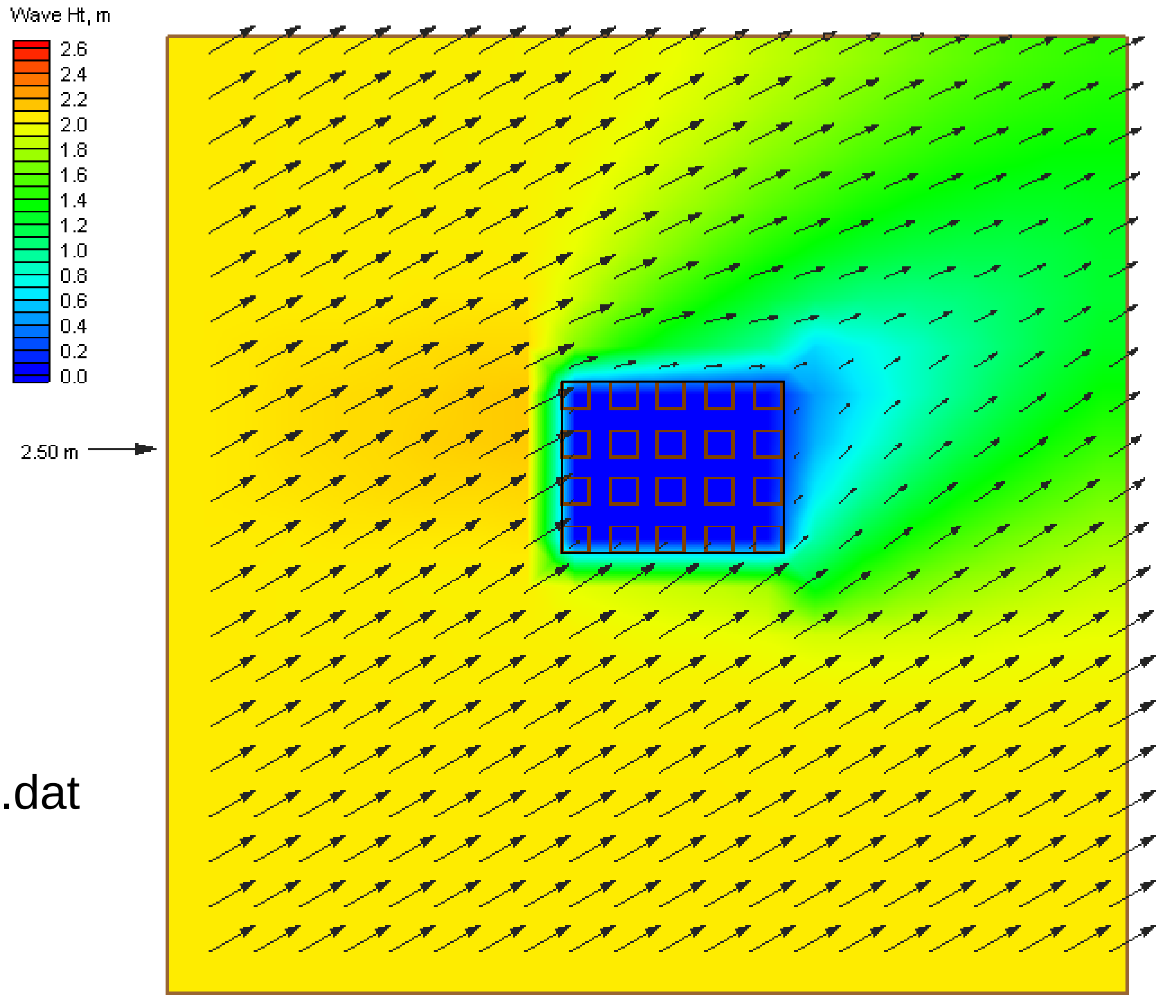
$$K_t = 0.3 \ (1.1 - \frac{h_c}{H_s}), \qquad \text{for} \quad 0 \le \frac{h_c}{H_s} \le 0.75$$

where h_c is the crest height (above mean water level) and H_s is the incident wave height.

Idealized Island Example

20
9 10
10 10
11 10
12 10
13 10
9 11
10 11
11 11
12 11
13 11
9 15
10 15
11 15
12 15
13 15
9 16
10 16
11 16
12 16
13 16

struct.dat



20 feature cells

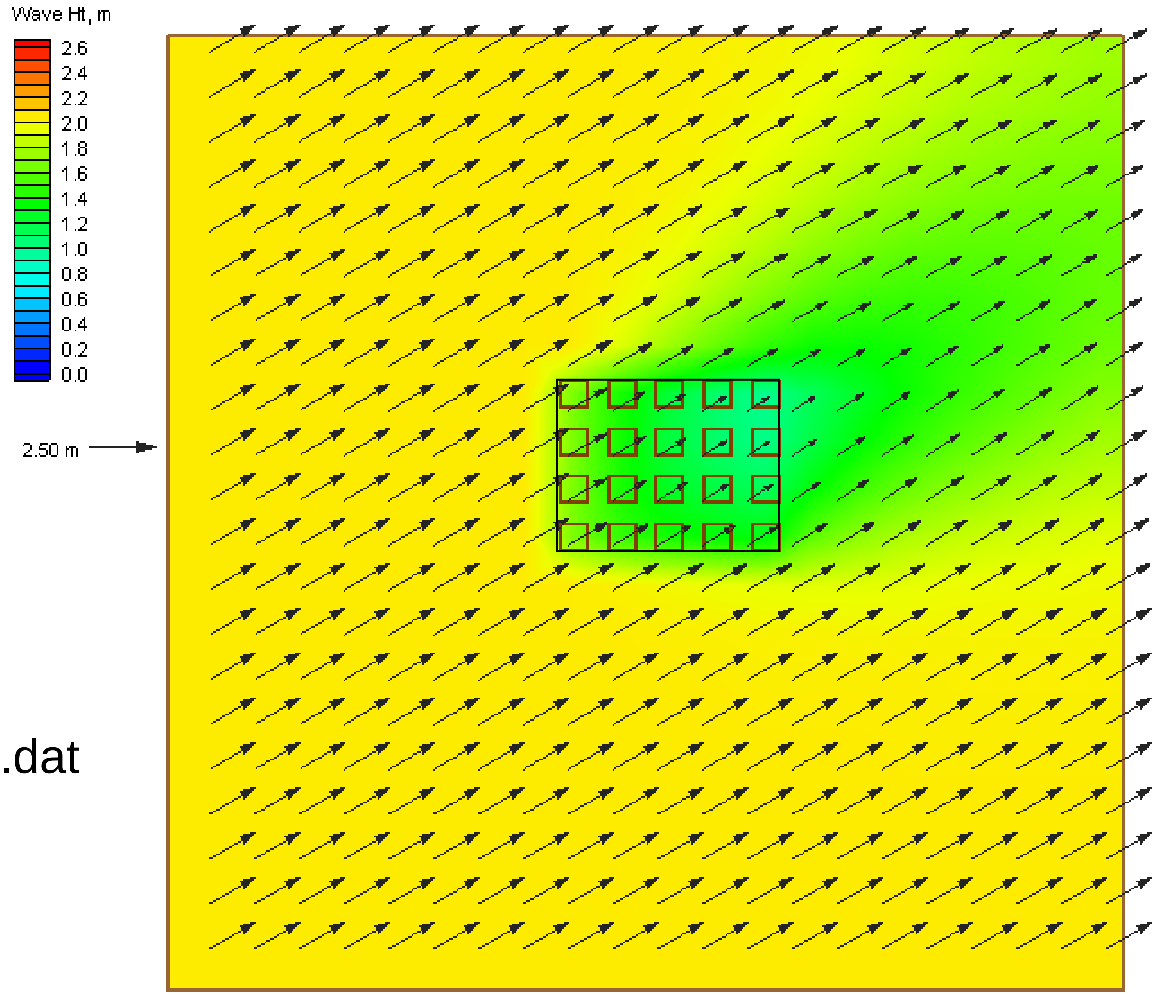
input depth = 10 m

incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)

Idealized Floating Breakwater

```
20
 9 10 3 2
10 10 3 2
11 10 3 2
12 10 3 2
13 10 3 2
 9 11 3 2
10 11 3 2
11 11 3 2
12 11 3 2
13 11 3 2
 9 15 3 2
10 15 3 2
11 15 3 2
12 15 3 2
13 15 3 2
 9 16 3 2
10 16 3 2
11 16 3 2
12 16 3 2
13 16 3 2
```

struct.dat



20 feature cells

Input depth
= 10 m

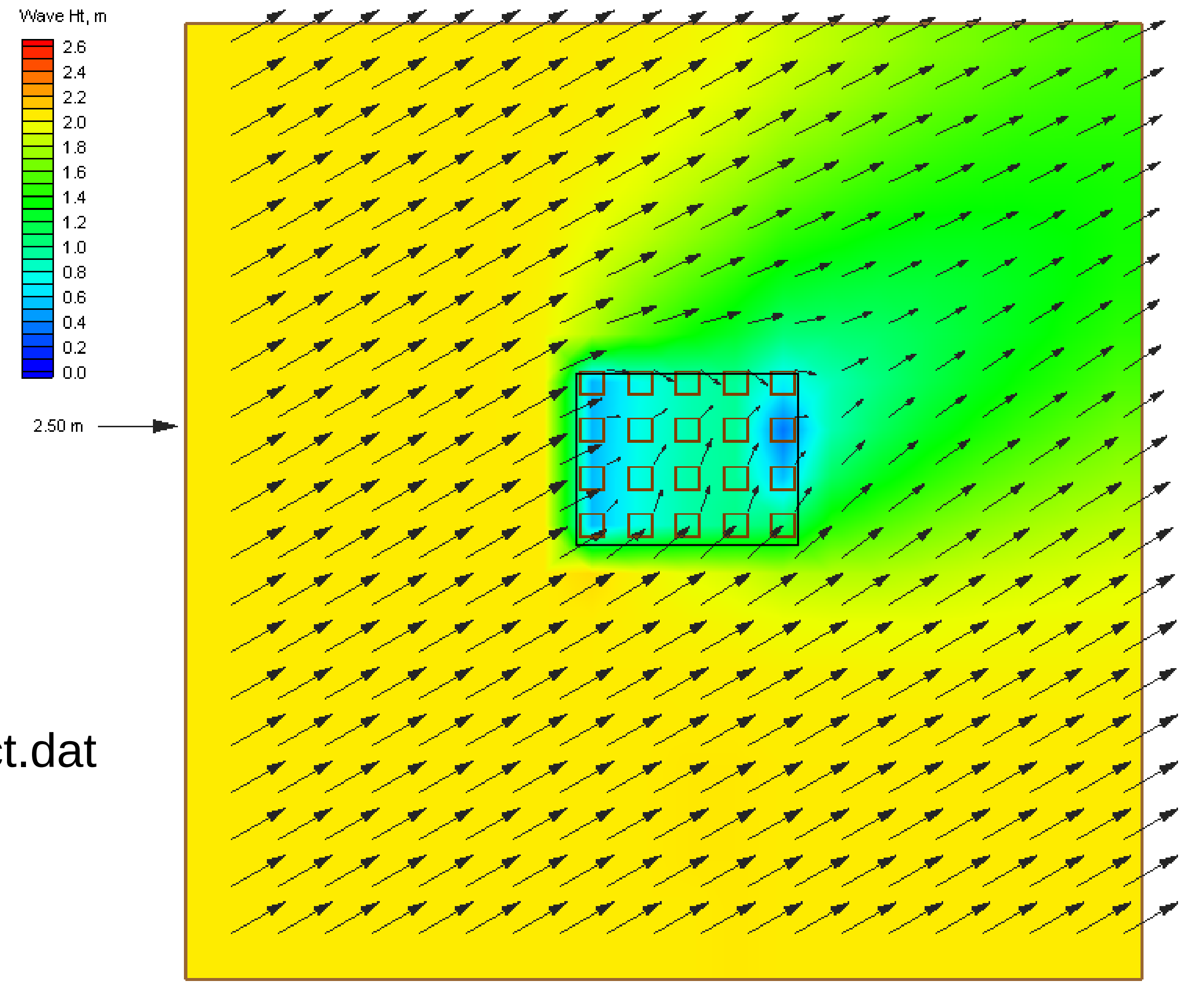
incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)

draft = 2 m

Idealized Platform

20
9 10 4 1
10 10 4 1
11 10 4 1
12 10 4 1
13 10 4 1
9 11 4 1
10 11 4 1
11 11 4 1
12 11 4 1
13 11 4 1
9 15 4 1
10 15 4 1
11 15 4 1
12 15 4 1
13 15 4 1
9 16 4 1
10 16 4 1
11 16 4 1
12 16 4 1
13 16 4 1

struct.dat



20 feature cells

input depth
= 10 m

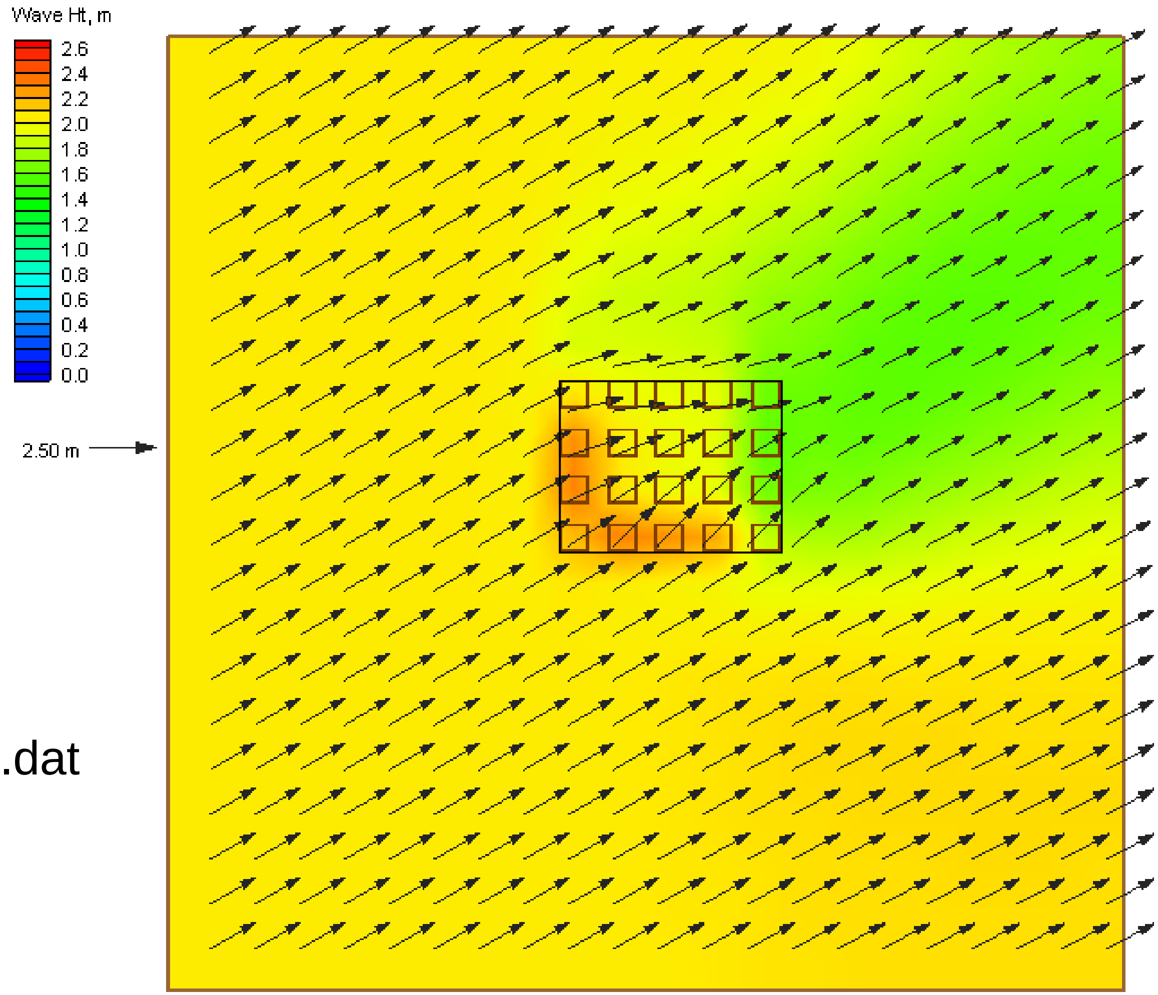
incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)

platform elev.
= 1 m (mwl)

Submerged Platform

```
20
 9 10 4 -2
10 10 4 -2
11 10 4 -2
12 10 4 -2
13 10 4 -2
 9 11 4 -2
10 11 4 -2
11 11 4 -2
12 11 4 -2
13 11 4 -2
 9 15 4 -2
10 15 4 -2
11 15 4 -2
12 15 4 -2
13 15 4 -2
 9 16 4 -2
10 16 4 -2
11 16 4 -2
12 16 4 -2
13 16 4 -2
```

struct.dat



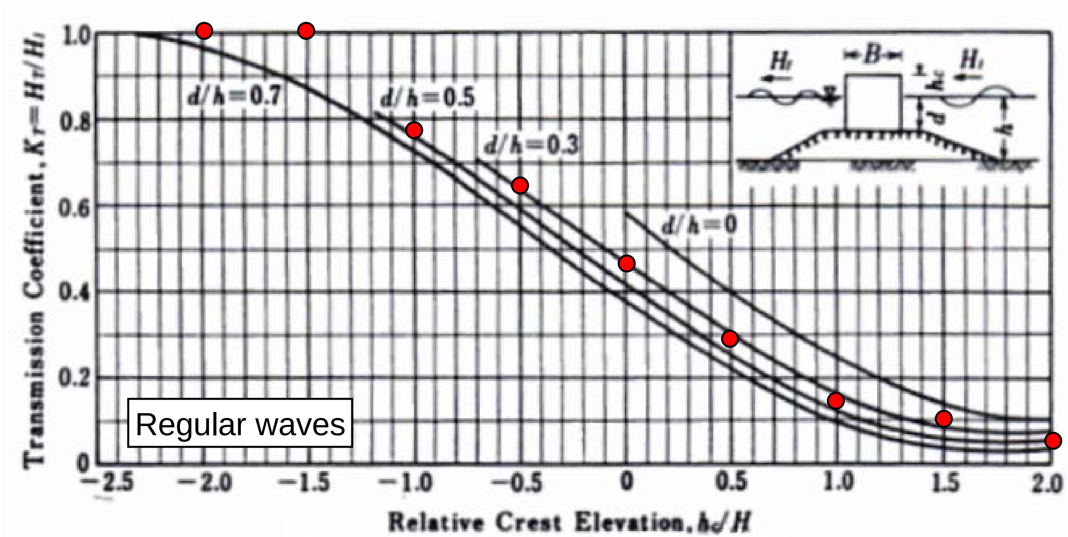
20 feature cells

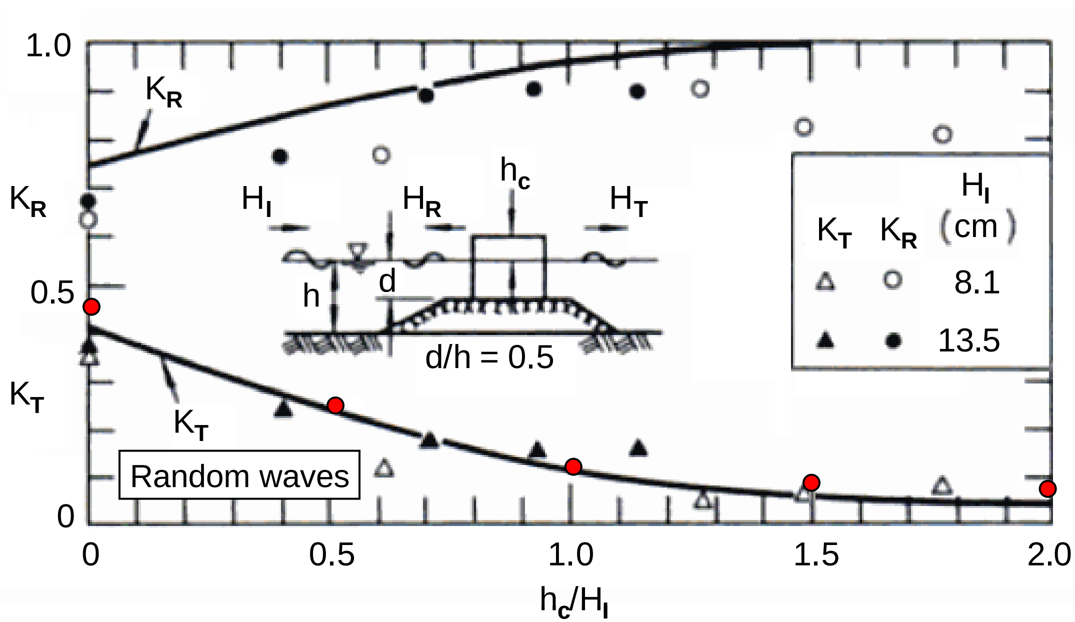
input depth = 10 m

incident wave: 2 m, 6 sec, 30 deg oblique (gamma = 4)

platform elev. = -2 m (mwl)

Wave Transmission Experiment (Goda, 2000)



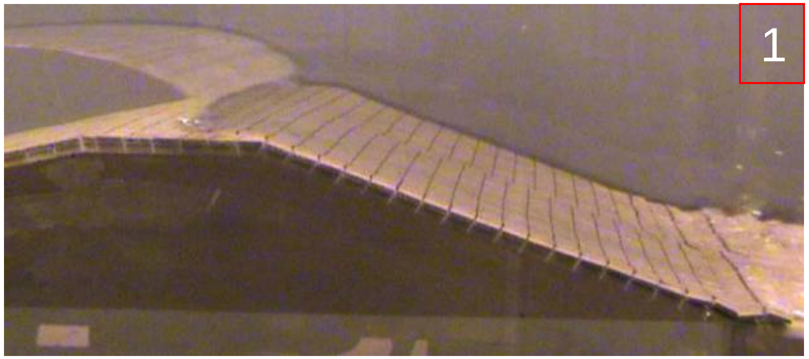


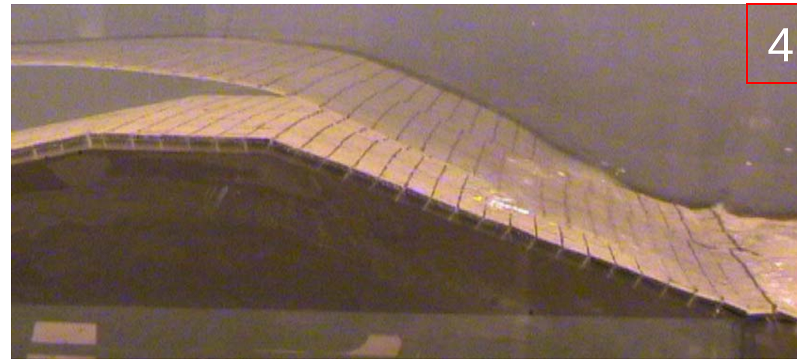
Transmission coefficients k_t

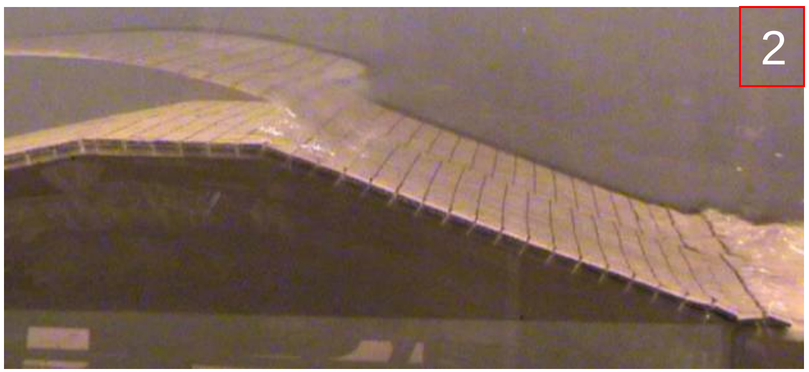
H_i = 1 m, *Tp* = 6 sec (monochromatic wave)
h = 10 m, *d* = 5 m, *B* = 80 m

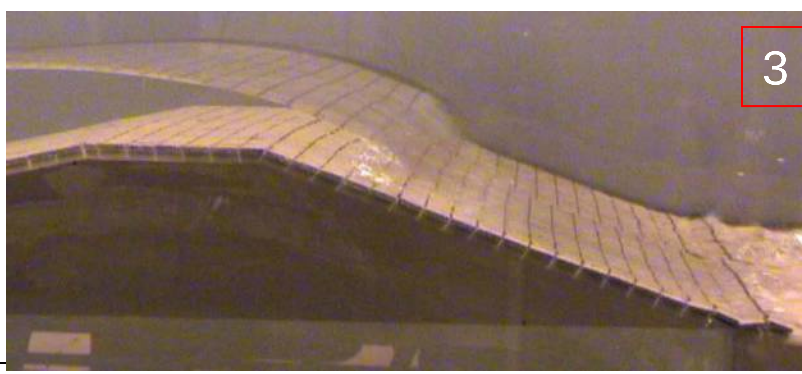
h_c (m)	CMS-Wave		Equations	
	Vertical wall ●	Rubble mound	Vertical wall	Rubble mound
-2.0	1.02	1.02		
-1.5	1.03	1.03		
-1.0	0.78	0.78		
-0.5	0.63	0.63		
0.0	0.46	0.34	0.45	0.33
0.5	0.27	0.18	0.30	0.18
1.0	0.15	0.04	0.15	0.03
1.5	0.10	0.024		
2.0	0.07	0.018		

Wave overtopping: Surge level = 0.81 m (3 ft)
Hs = 0.88 m, *Tp* = 10.1 sec (Hughes, 2008)





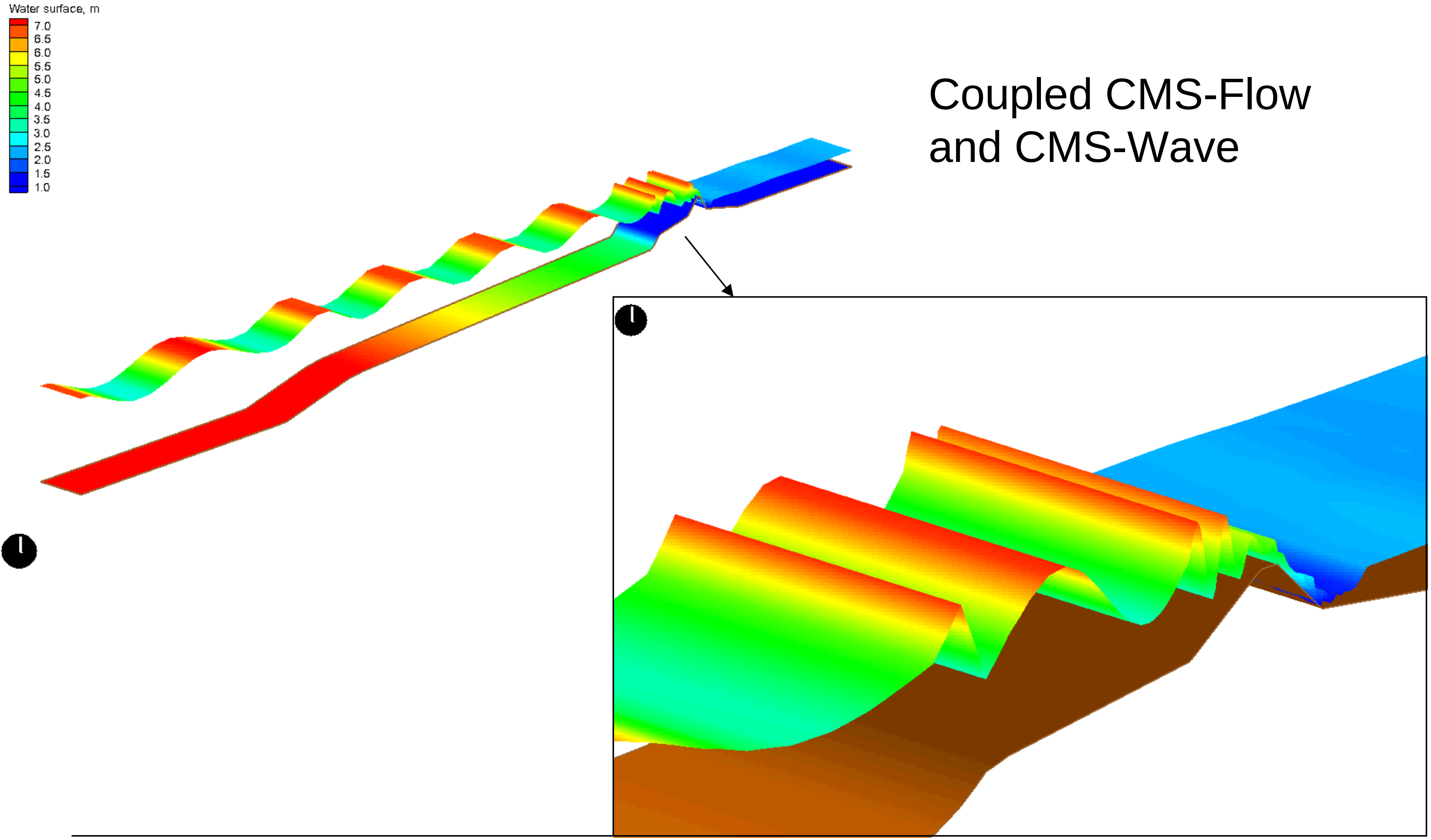




ERDC/CHL TR-08-10
by Hughes (2008)

Calculated Wave Overtopping R127
Surge level =1.3 m, *Hs* =2.3 m, *Tp* =14 sec

Coupled CMS-Flow and CMS-Wave



Calculated Wave Overtopping Rate

Case number	Surge level (m)	Wave height (m)	Wave peak period (sec)	Overtopping rate (m^2/sec)		
				Measured	CMS-Flow	CMS-Wave
R128	0.29			0.27	0.28*	
	0.29	0.82	6.1	0.38	0.38	0.39
R109	0.29			0.26	0.28*	
	0.29	2.48	13.7	0.70	0.85	0.92
R121	1.3			2.55	2.57*	
	1.3	2.30	6.1	2.67	2.93	2.76
R127	1.3			2.54	2.57*	
	1.3	2.31	14.4	2.84	2.98	2.81

* Calibration ☐ With wave overtopping

Muddy Bottom

Wave dissipation by damping (Lamb, 1932):

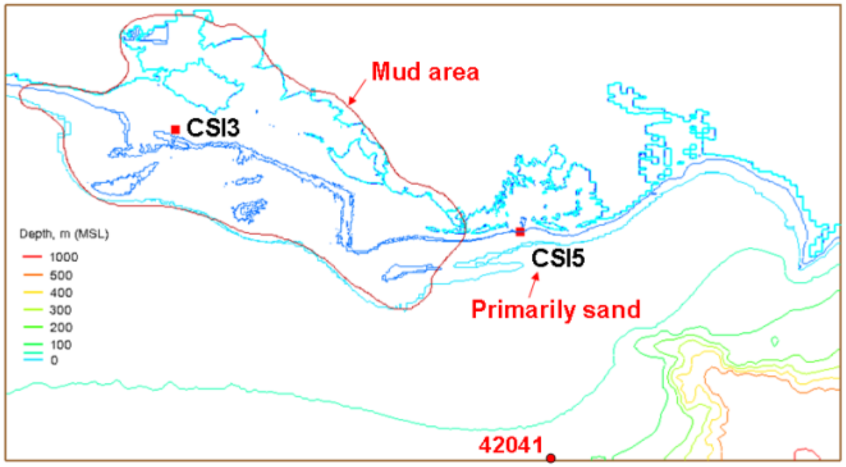
$$S_{dp} = -4(\nu_k + \nu_t)k^2 E$$

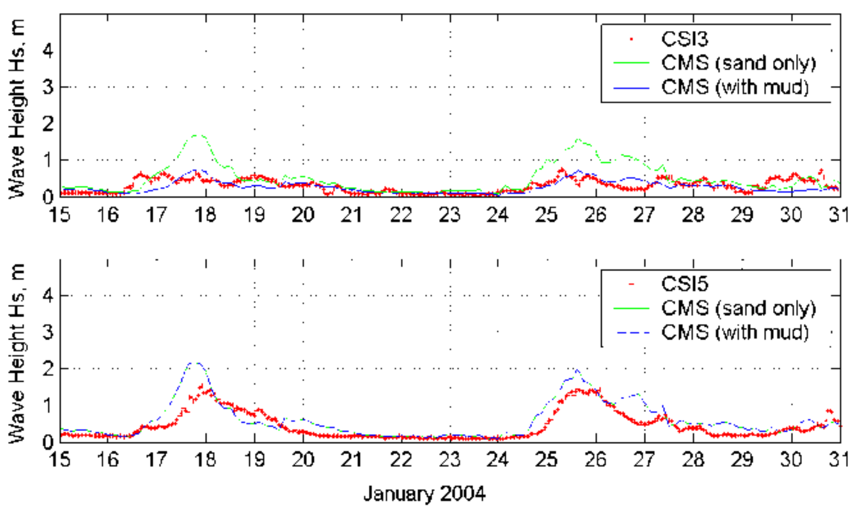
where ν_k is the kinematic viscosity of sea water,

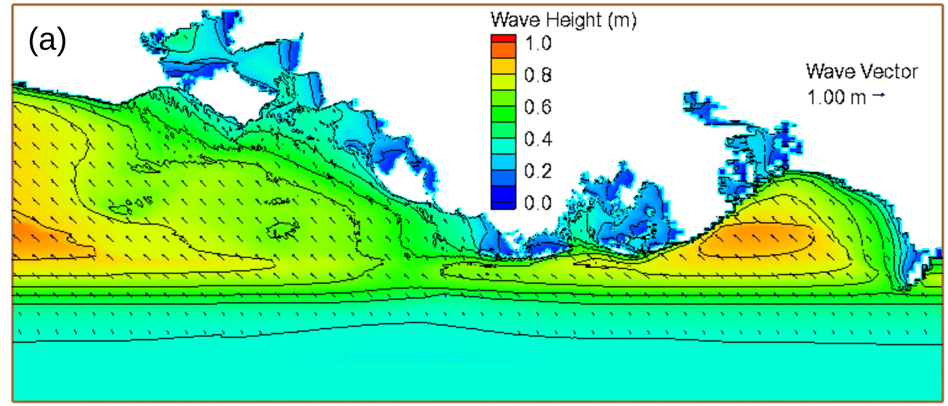
and ν_t is the turbulent eddy viscosity:

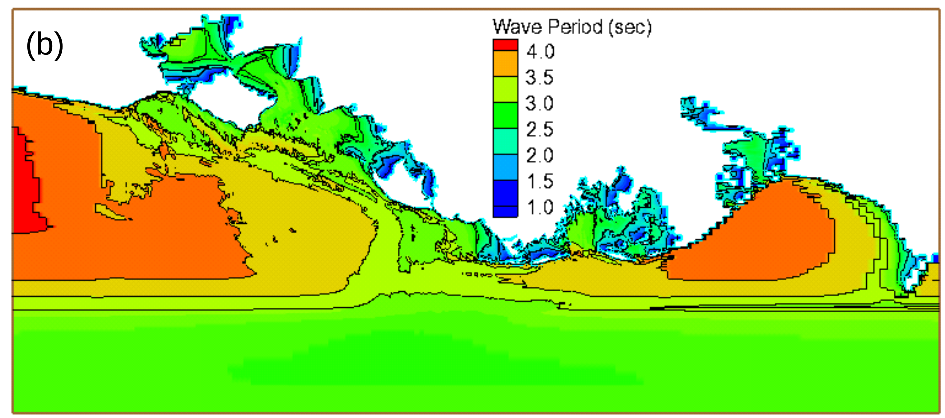
$$\nu_t = \nu_{t,breaking} \frac{H_s}{h}$$

Louisiana Muddy Coast Simulation





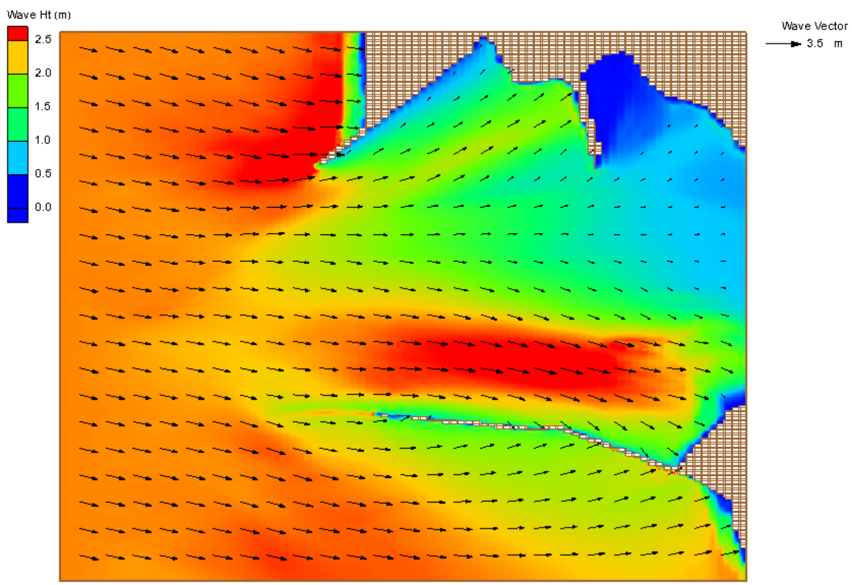




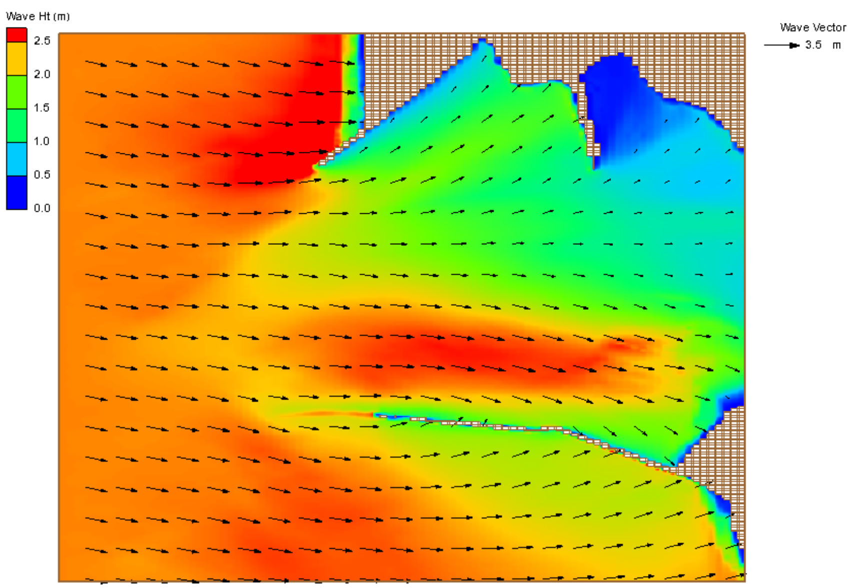
CMS-Wave Fast Mode

- Fast mode uses 5 to 7 directional bins with spectral calculations (Standard runs with 35 directional bins)

- Ideal for quick applications, prelim runs, time-pressing project



Standard run



Fast mode

Nonlinear Wave-Wave Interaction

Governing Equation: $$\frac{DA}{Dt} = S_{\text{diffraction}} + S_{in} + S_{dp} + S_{nl}$$

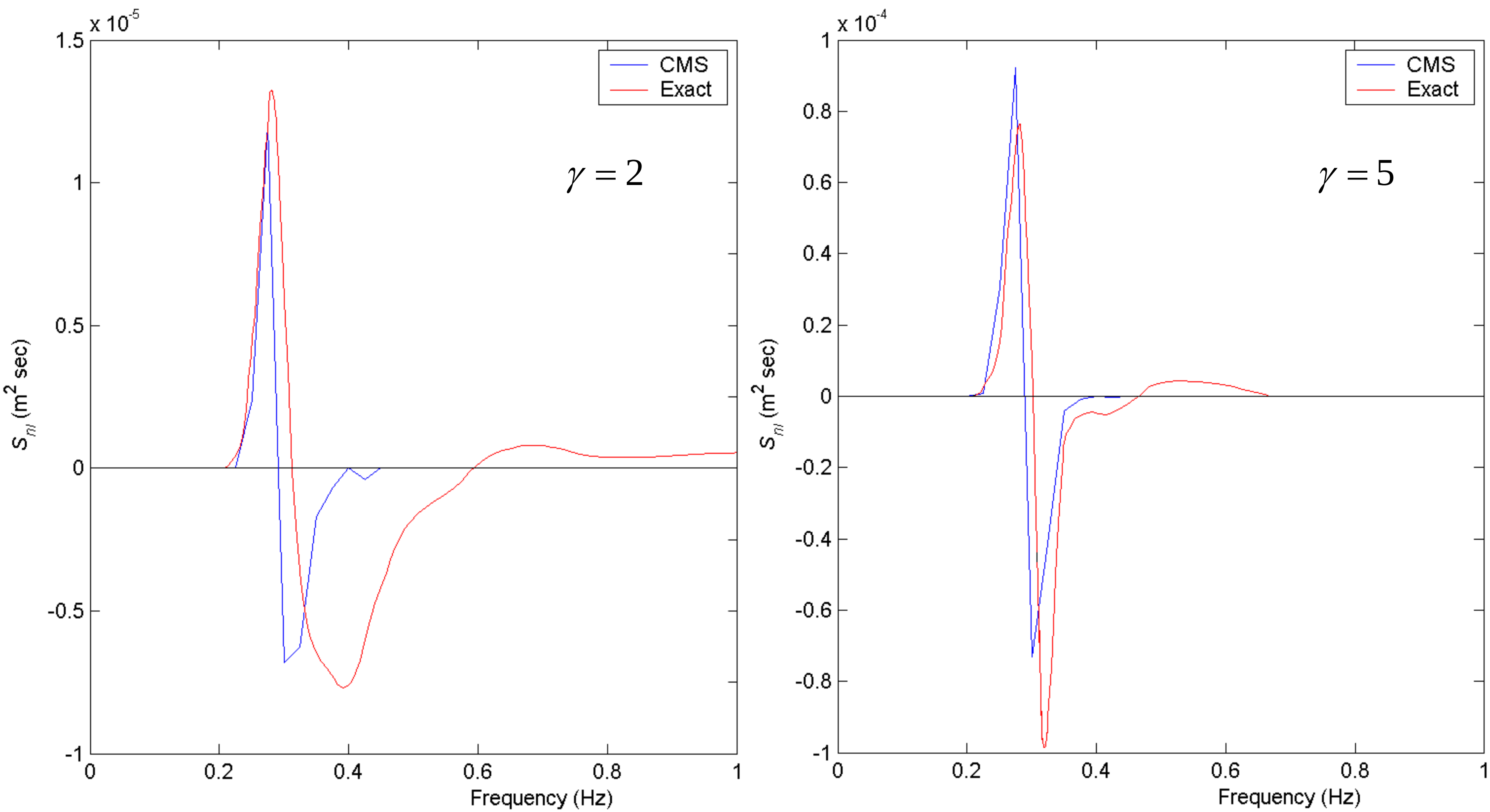
where S_{nl} is the nonlinear wave-wave interaction term

Anisotropic S_{nl}: $$S_{nl} = a(\sigma)\frac{\partial B}{\partial \sigma} + b(\sigma)\frac{\partial^2 B}{\partial \theta^2}$$ (Jenkins & Phillips, 2001)

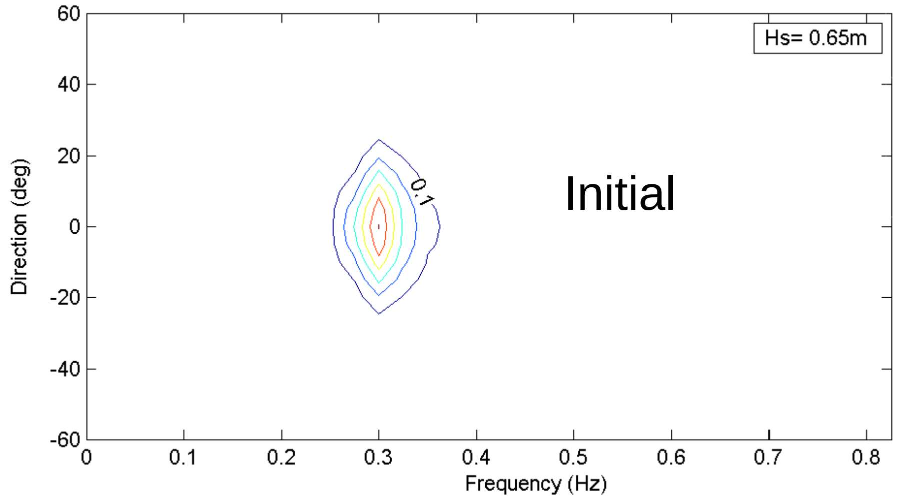
where $$a = \frac{1}{2n^2}[1 + (2n-1)^2 \cosh 2kh] - 1, \quad b = \frac{a}{n\sigma}$$

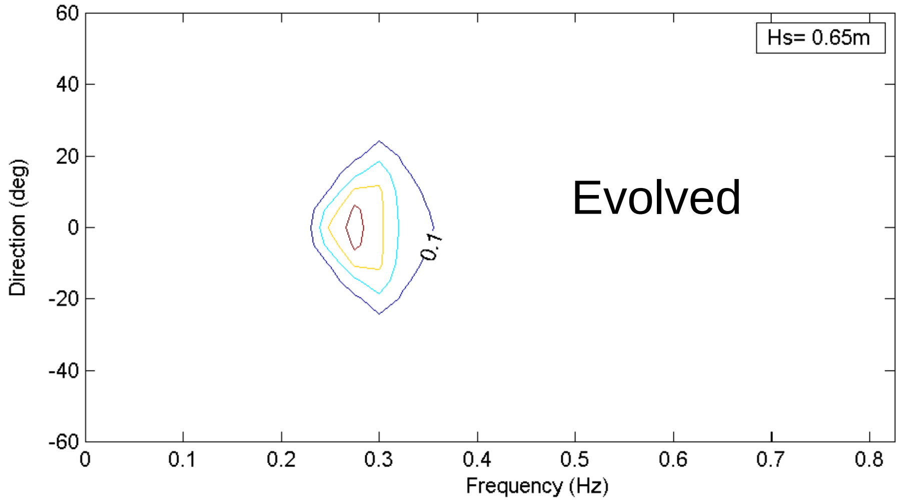
and $$B = k^3 \sigma^5 \frac{n^4}{(2\pi)^2 g}[(\frac{\sigma_o}{\sigma})^4 E]^3$$

Exact and Calculated $S_{nl}(f)$

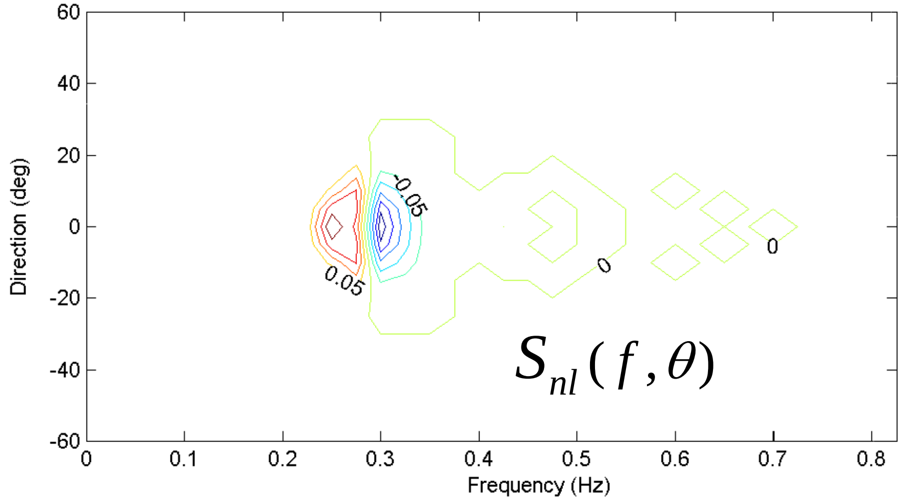


Spectral Evolution and $S_{nl}(f,\theta)$



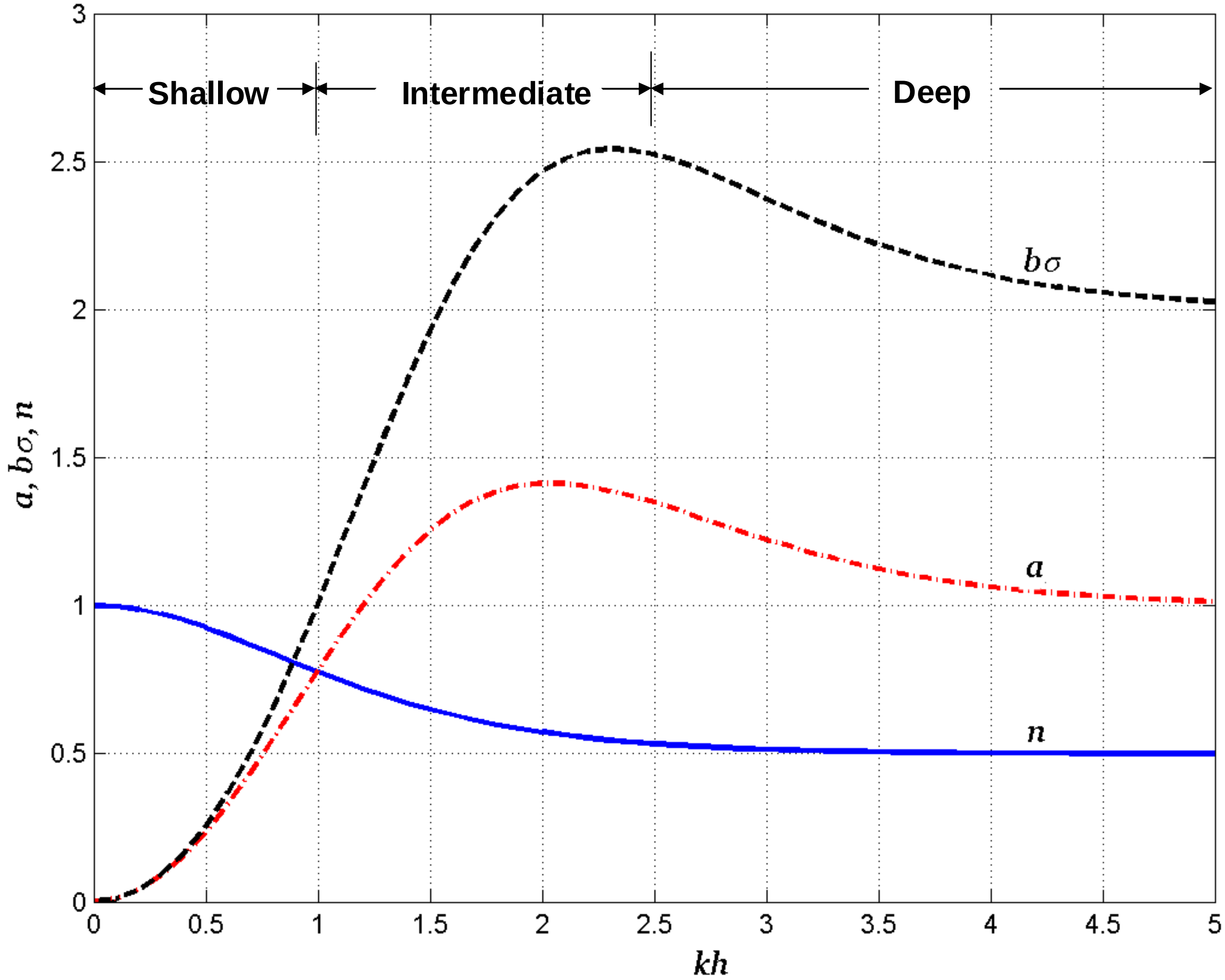


$$\gamma = 5$$

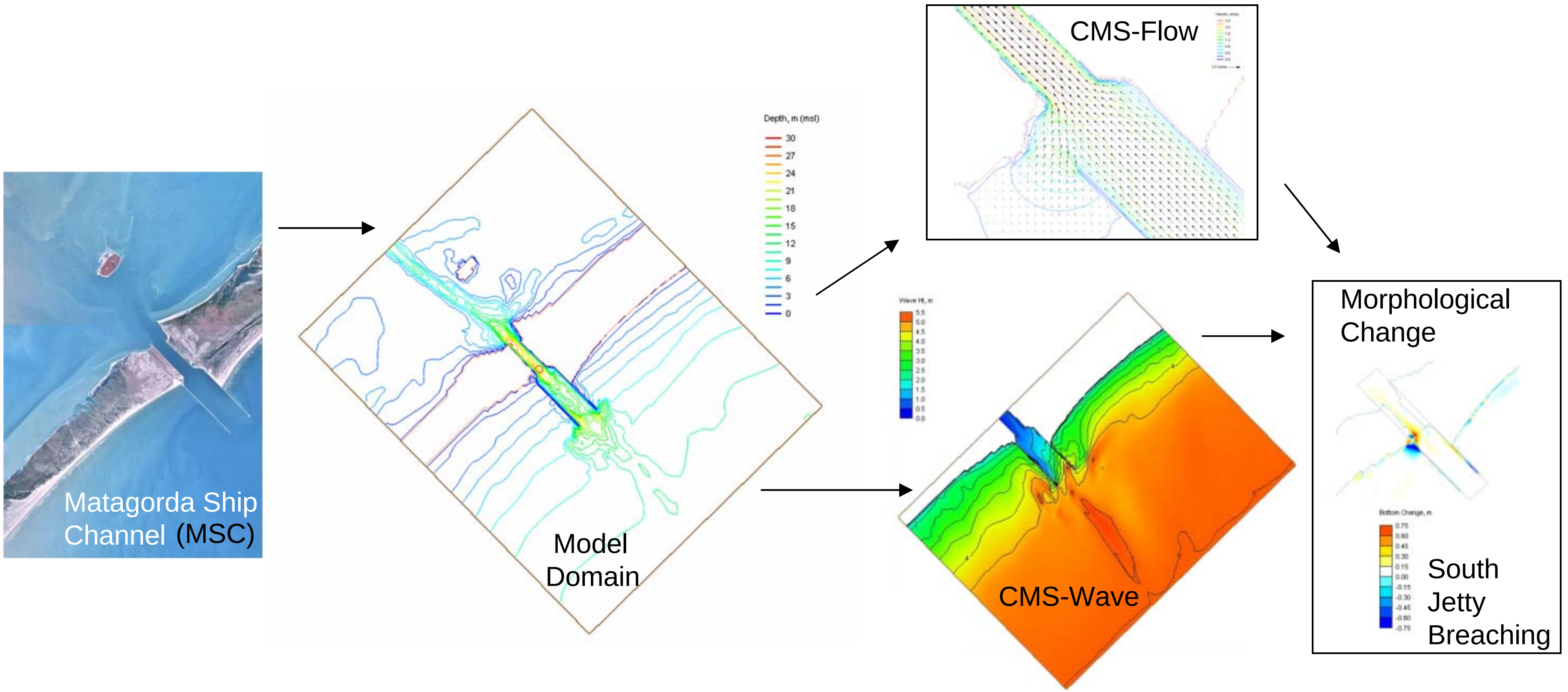


$S_{nl}(f,\theta)$

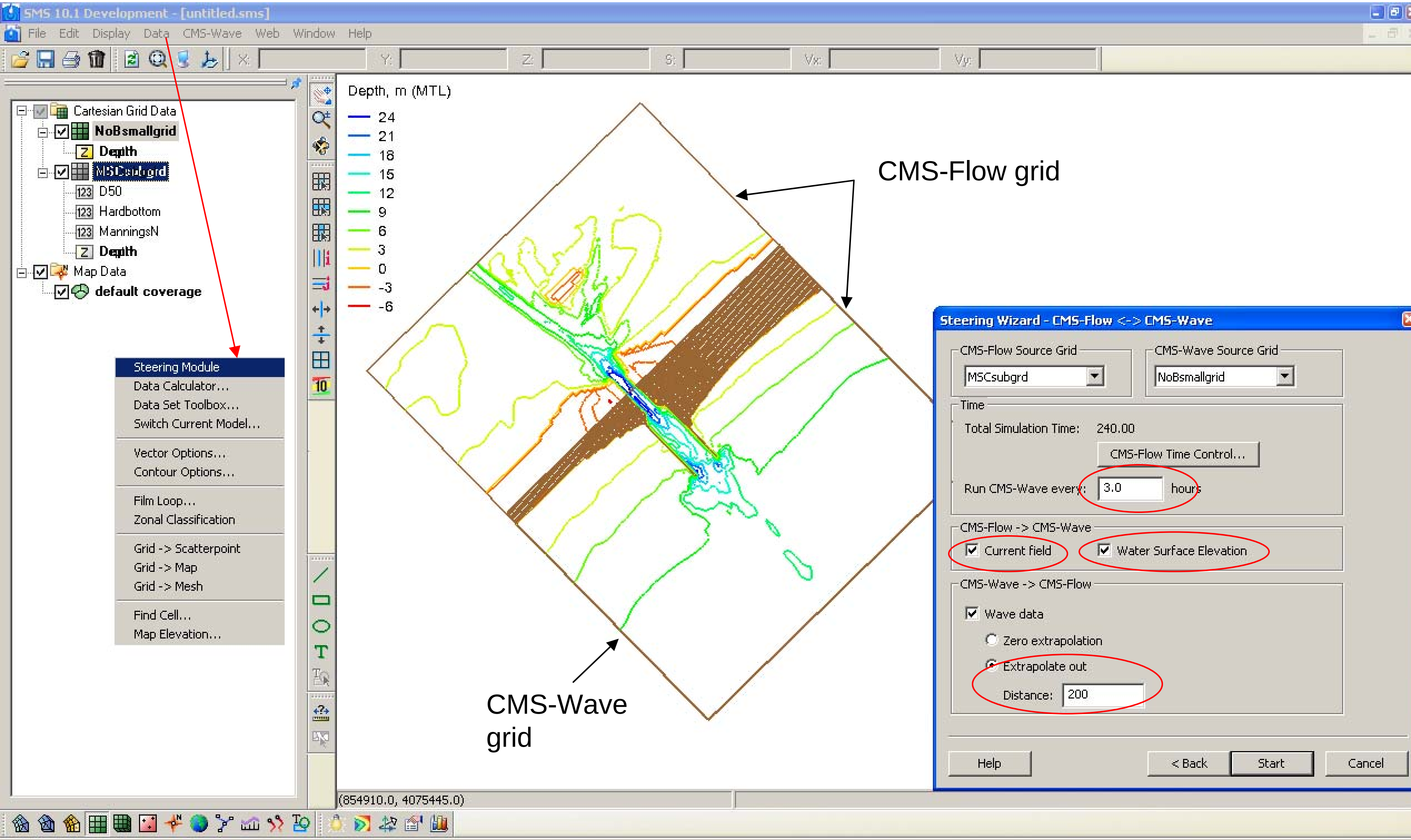
Nonlinear Wave Effect



Breaching at Jetty, Simulation at Matagorda Ship Channel, TX

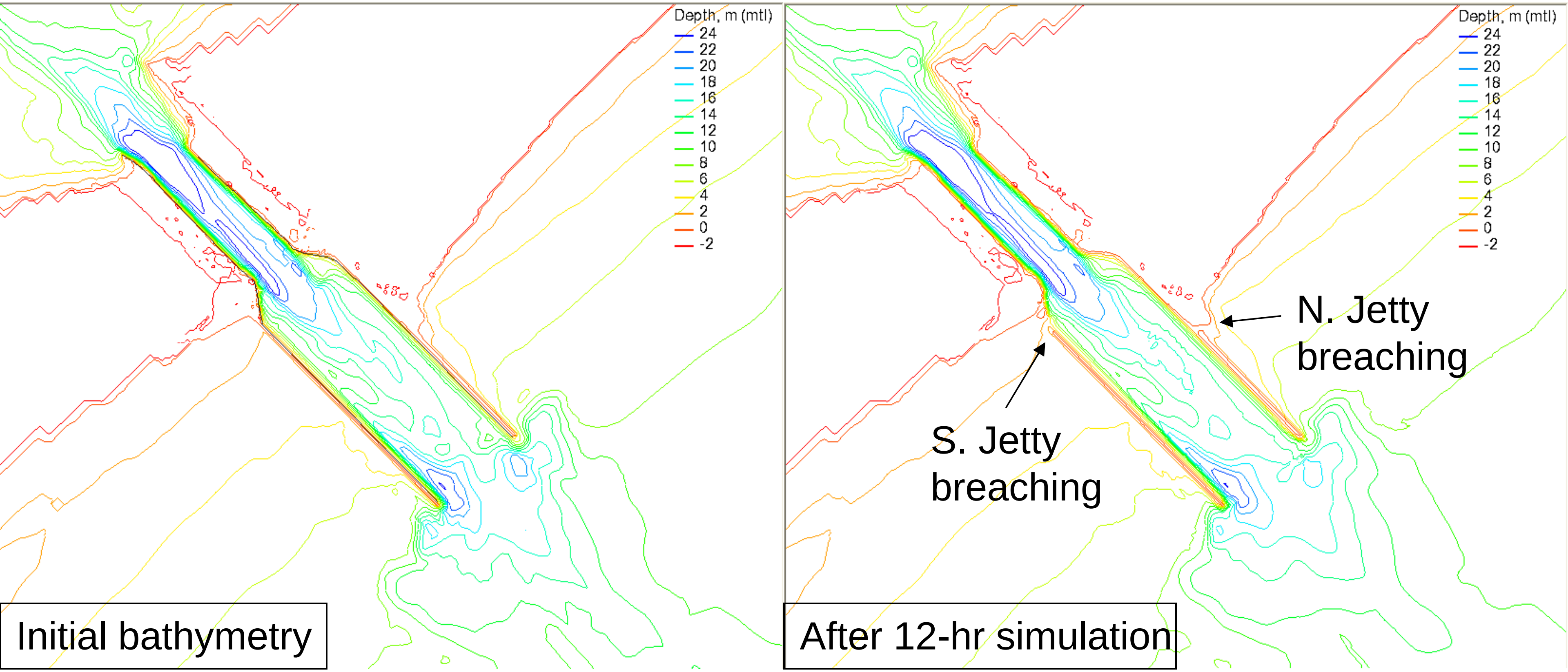


Sample CMS Steering SMS 10.1 Interface



MSC Jetty Wave Run-up & Breaching

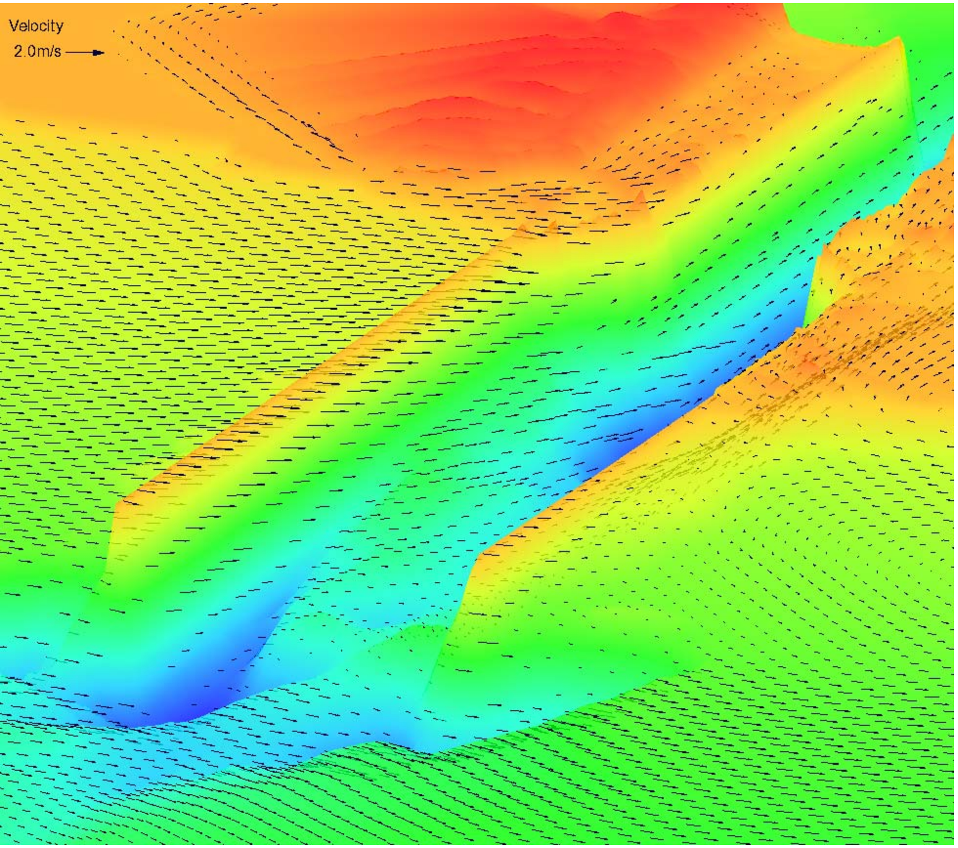
Cat 3 Hurricane (50-Yr Life-Cycle)



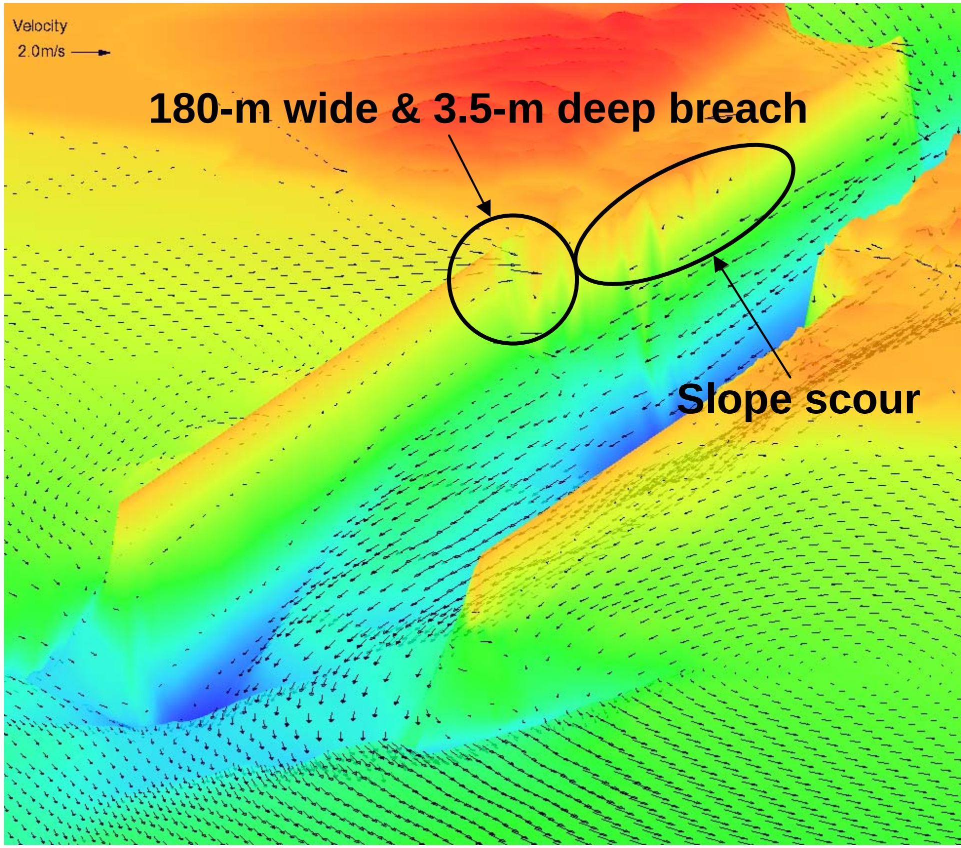
- Peak storm surge level reaches 3.5 m between Hrs 4 and 8
- Incident offshore wave is 7.6 m, 14.3 sec, from south

MSC Jetty Wave Run-up & Breaching
Cat 3 Hurricane (50-Yr Life-Cycle)

Storm surge over the initial bathymetry

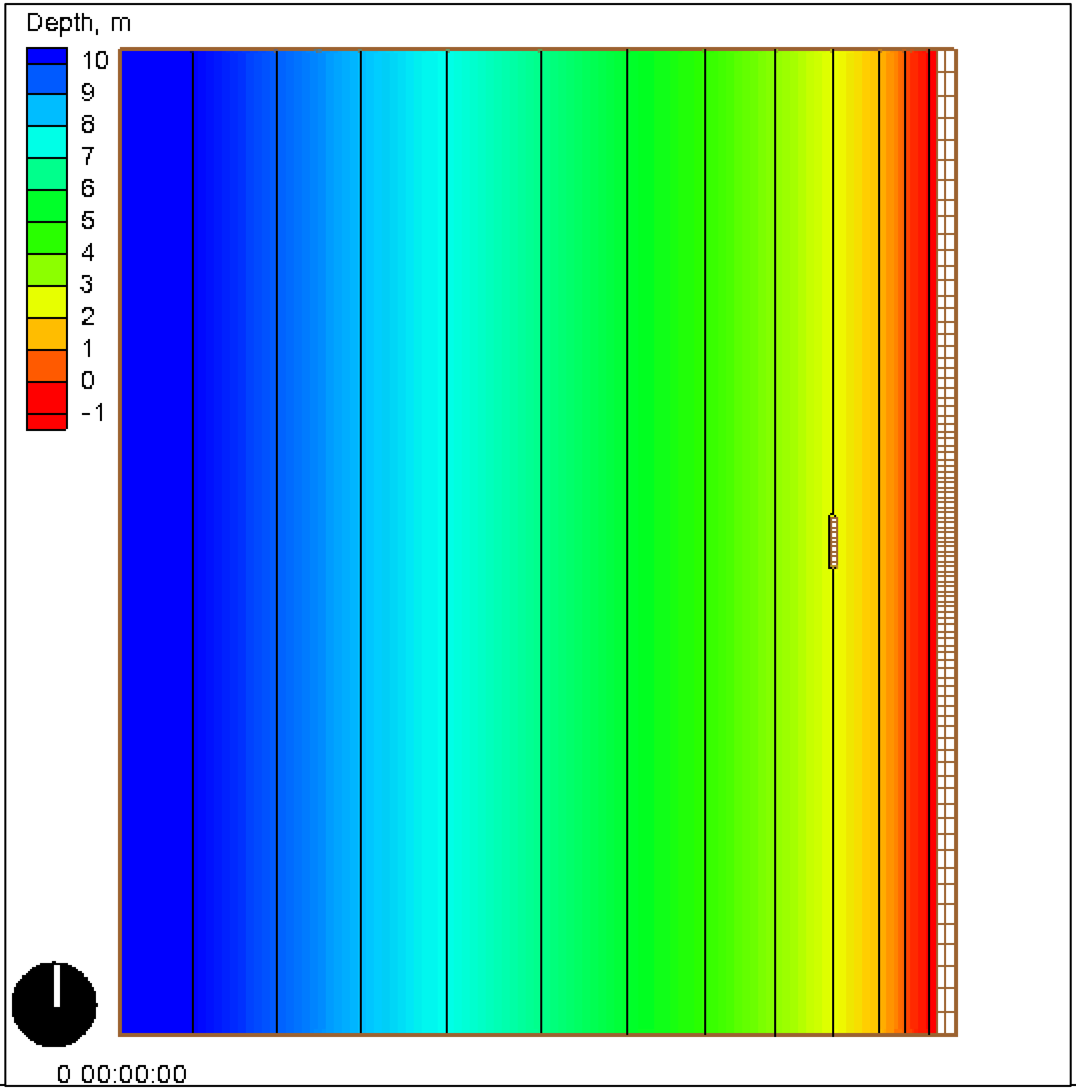


South Jetty breach in 12-hr simulation



- Peak storm surge level reaches 3.5 m between Hrs 4 and 8
- Incident offshore wave is 7.6 m, 14.3 sec, from south

Calculated 30-day Morphology Change
Tombolo Development



CMS
Steering Interval
= 4 hr

Grain Size
= 0.18 mm

Hydro time step
= 0.25 sec

Transport and
morphology
calc time step
= 9 sec

10. Future Development

- Permeable breakwaters
- Binary (XMDF) input/output
- Telescoping grids
- Dynamic memory
- Full-plane transformation

Conclusions

- CMS-Wave designed for wave-structure-land interactions for inlet and nearshore applications
- Coastal inlet-specific processes represented
- Emphasis on computational speed and SMS integration for PC users
- Coupled to CMS-Flow for sediment transport and morphology change

References & Contacts

1. Lin, L., H. Mase, F. Yamada, and Z. Demirbilek. 2006. Wave-Action Balance Equation Diffraction (WABED) Model: Tests of Wave Diffraction and Reflection at Inlets. ERDC/CHL CHETN-III-73.

2. Zheng, J., H. Mase, Z. Demirbilek, and L. Lin. 2008. Implementation and evaluation of alternative wave breaking formulas in a coastal spectral wave mode. *Ocean Engineering*. Vol. 35., pp.1090-1101.

3. Lin, L., Z. Demirbilek, H. Mase, J. Zheng., and F. Yamada. 2008. CMS-Wave: A Nearshore Spectral Wave Processes Model for Coastal Inlets and Navigation Projects. ERDC/CHL TR-08-13.

CMS-Wave **Lihwa.Lin@usace.army.mil**

US Army Corps of Engineers

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Updated 14 November 2009

CMS | Inlet Reservoir Model | RMAP | SMS | SBAS | Other Products | CPT - Coming Soon

Coastal Modeling System (CMS)

The Coastal Modeling System is an integrated 2D numerical modeling system for simulating waves, current, water level, sediment transport, and morphology change at coastal inlets and entrances. Emphasis of the CMS is on navigation channel performance and sediment exchange between the inlet and adjacent beaches. A key objective of this work is to develop, test, and transfer the CMS to Corps Districts and industry for use on specific engineering studies. The models CMS-Flow and CMS-Wave are included and linked in the CMS through a Steering Module developed within the Surfacewater Modeling System (SMS) version 10.0 and higher.

Select a tab below for more information on a particular model.

CMS-Flow | CMS-Wave | Other Tools

Version Release (chronological, latest first)

CMS-Wave - 2.50 - September 2009

- **Interface** - Default version for SMS 10.1. Reduced functionality with SMS 10.0, but operational.
- **New Features (SMS interface development underway)**
  - Muddy coast / bed definition
  - Impermeable structures
  - Nonlinear wave-wave interation
  - Overtopping rate calculation
- **Coming Soon**
  - Infragravity waves **(presently in testing phase)**
  - Improved steering with CMS-Flow within the SMS interface
  - OpenMP Parallelization

CMS-Wave version 2.50 – Executable