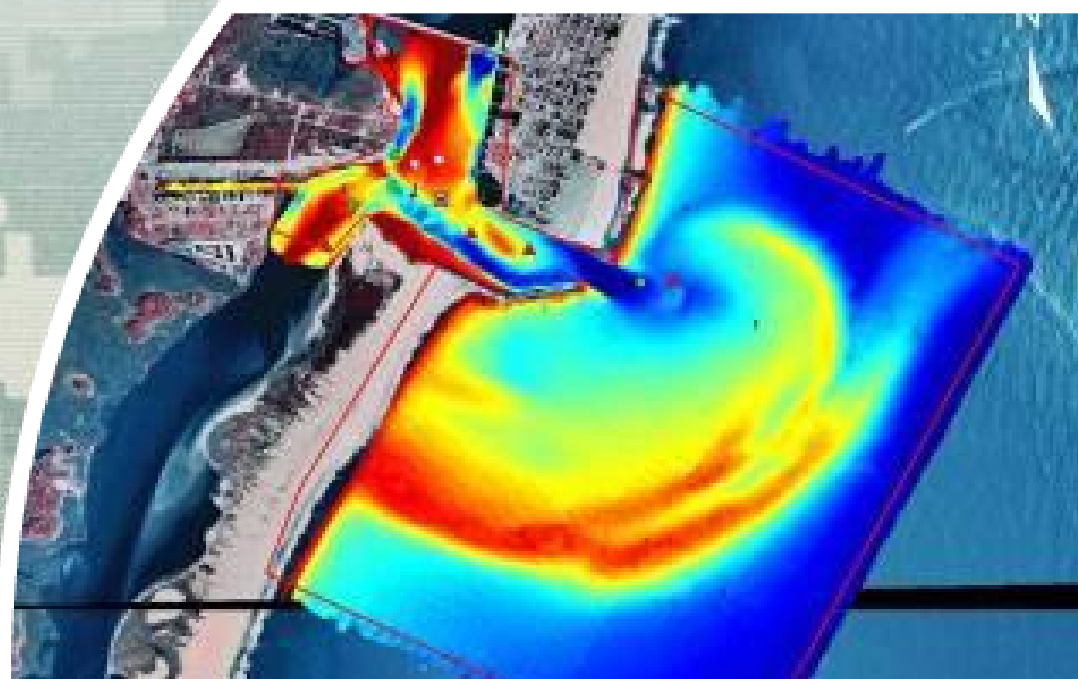
CMS-Wave Background and Capabilities

Developed for coastal and inlet applications

Lihwa Lin, PH.D

Research Hydraulic Engineer

U.S. Army Engineer Research and Development Center



US Army Corps of Engineers

BUILDING STRONG®

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

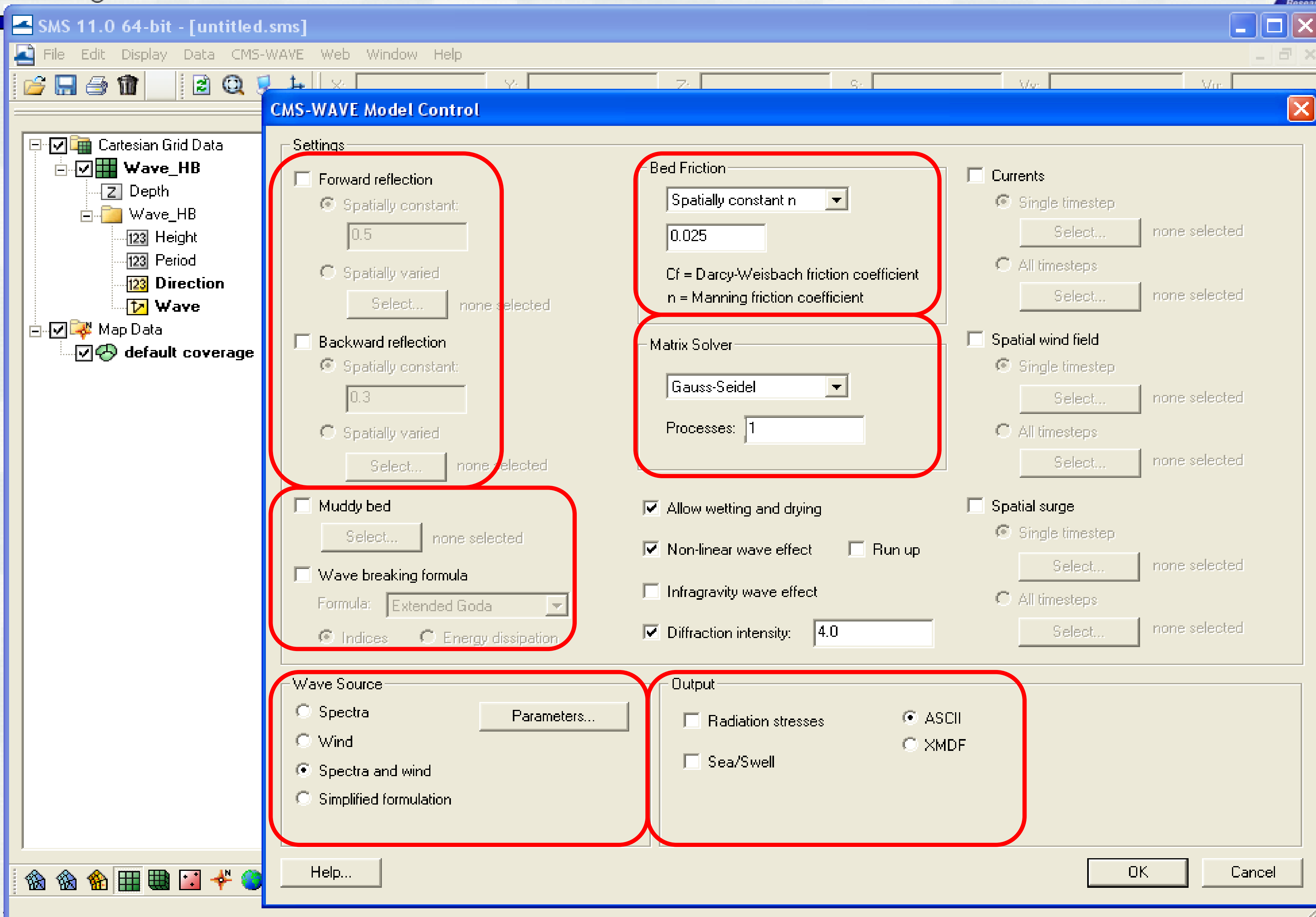
2. Capabilities

- 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
Structures	**Diffraction**	**Theory**	**Smoothing**
Structures	**Reflection**	**Represented**	**None**
Structures	**Transmission**	**Formulas**	**None**
Structures	**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

CMS-Wave SMS 11.0 Interface



3. Governing Equation

Wave-Action Balance Equation with Diffraction

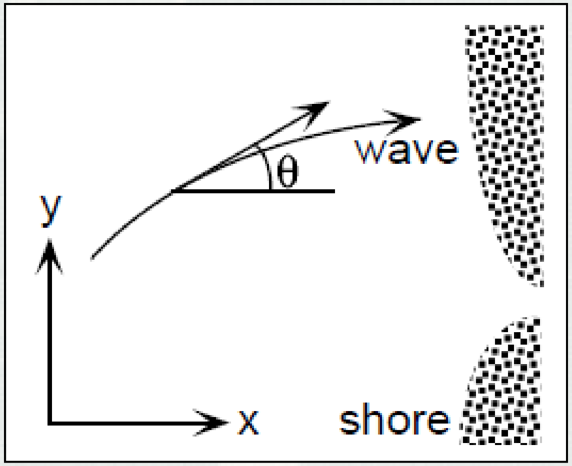
Diffraction intensity factor

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

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

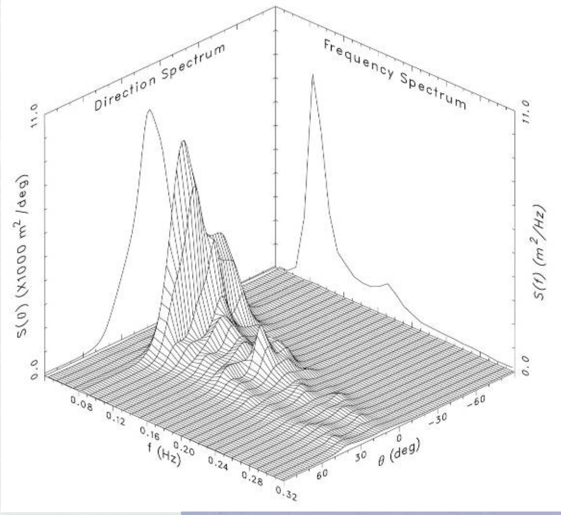
and $E = E(\sigma,\theta)$, wave directional spectrum.

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



4. Incident Wave Spectrum

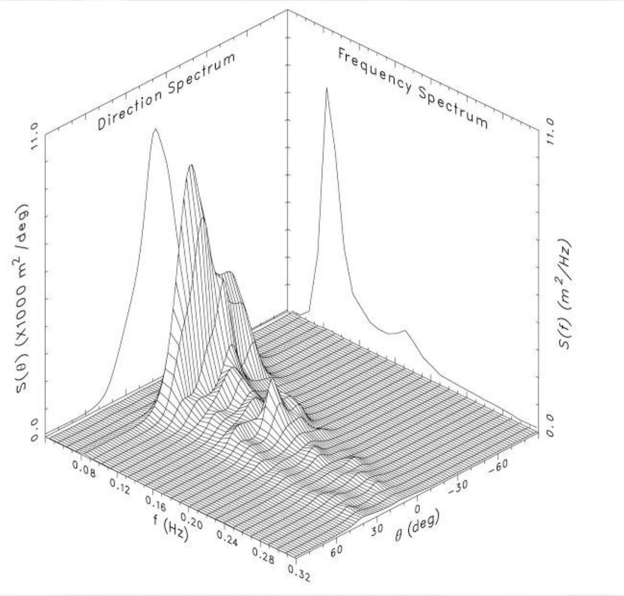
- NDBC/NOAA Ocean Buoys
- CDIP Coastal Buoys
- Project specific measurements (ADCP)
- Theoretical spectra (SMS)



Theoretical Spectrum

A single input spectrum applied along the seaward boundary,

e.g., a JONSWAP type:



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

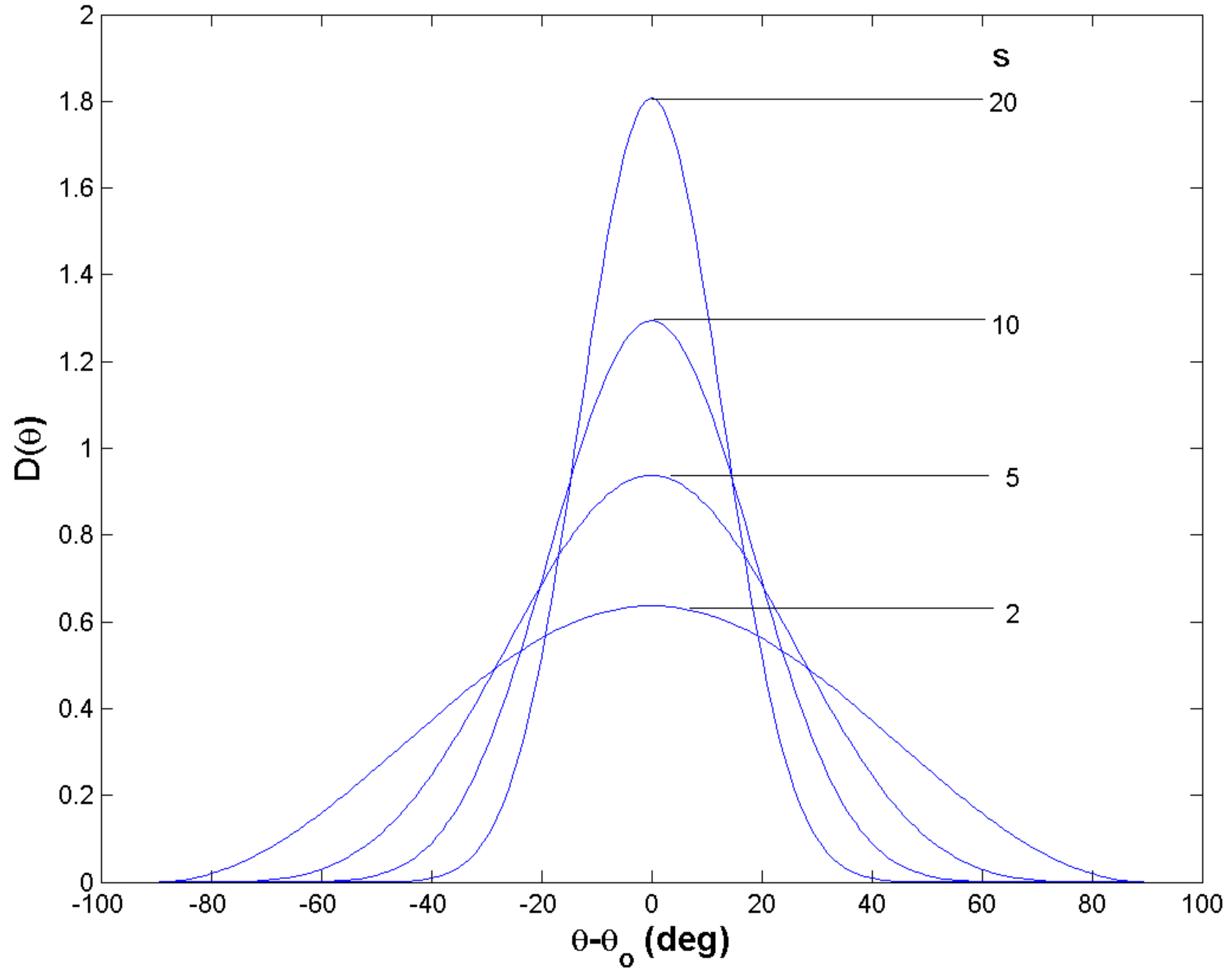
where

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

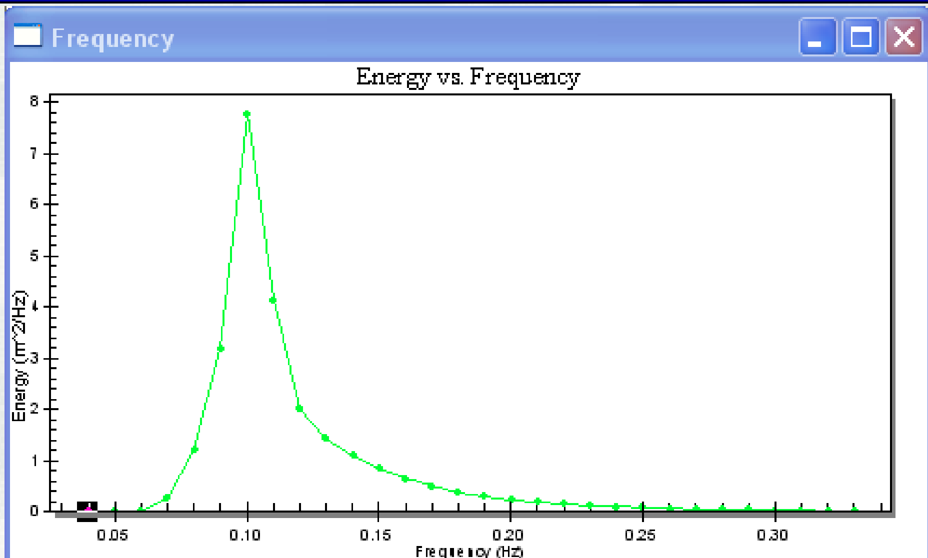
for $|\theta - \theta_o| < \pi/2$

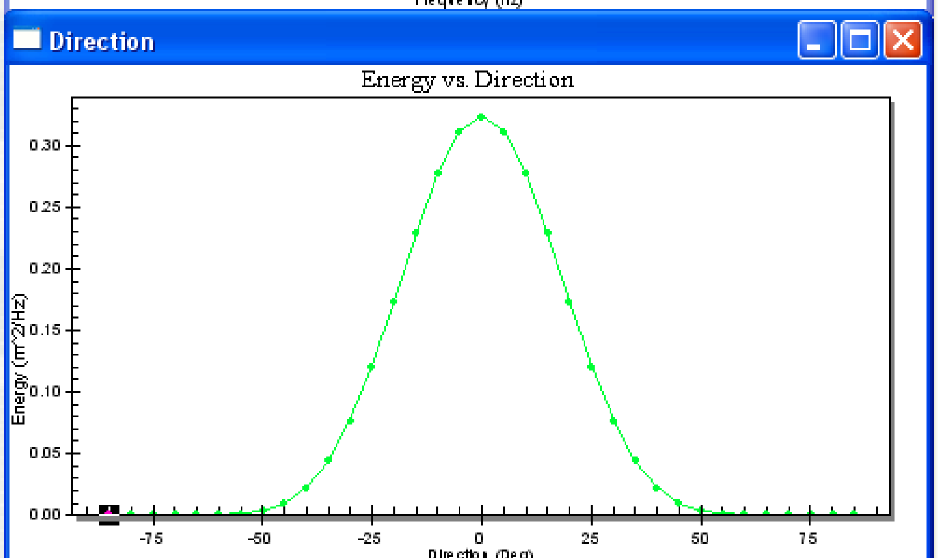
and s is the directional spreading parameter.

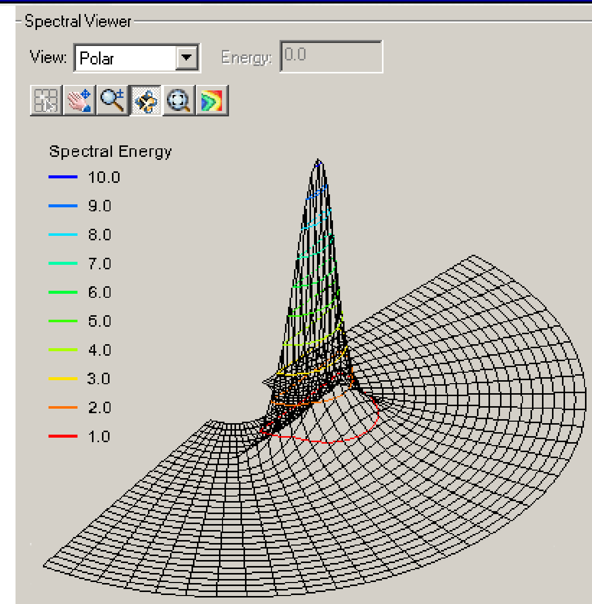
Idealized Directional Distribution

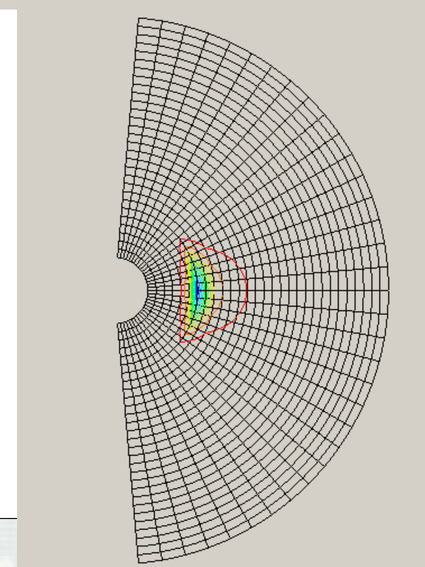


SMS10.1 Wave Spectrum Display









5. Wave-Current Interaction

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

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

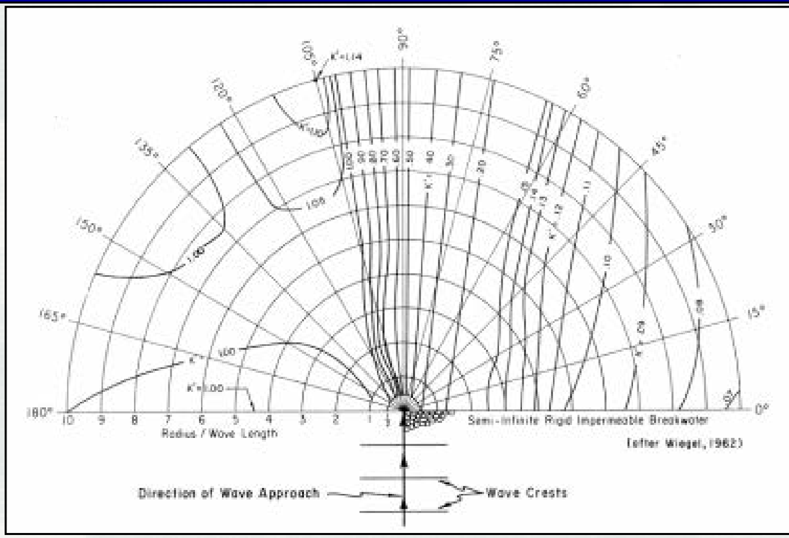
- Computing wave radiation stresses:

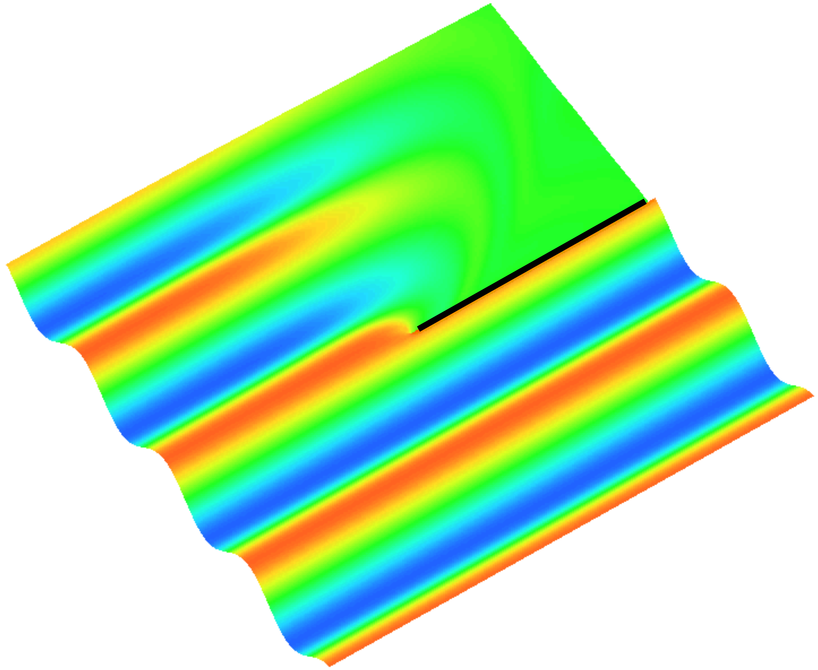
$$S_{xx} = E[n(\cos^2\theta + 1) - \frac{1}{2}],$$

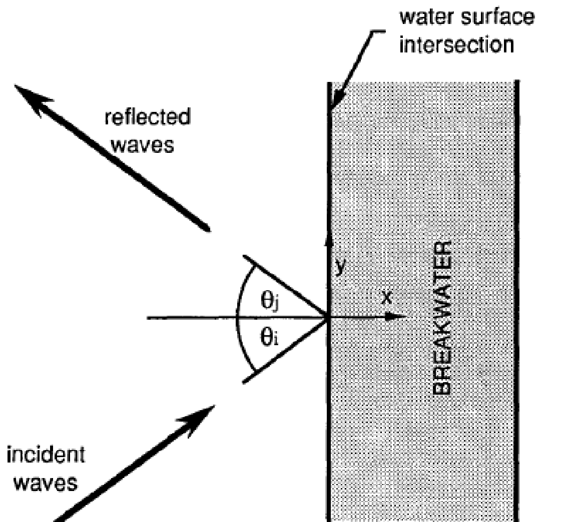
$$S_{yy} = E[n(\sin^2\theta + 1) - \frac{1}{2}],$$

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

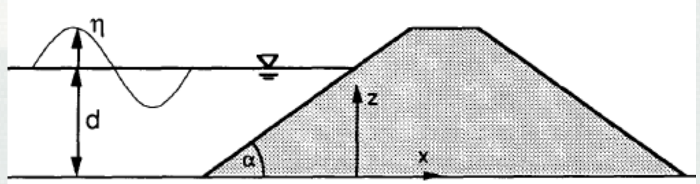
6. Jetty Breakwater Wave Diffraction and Reflection





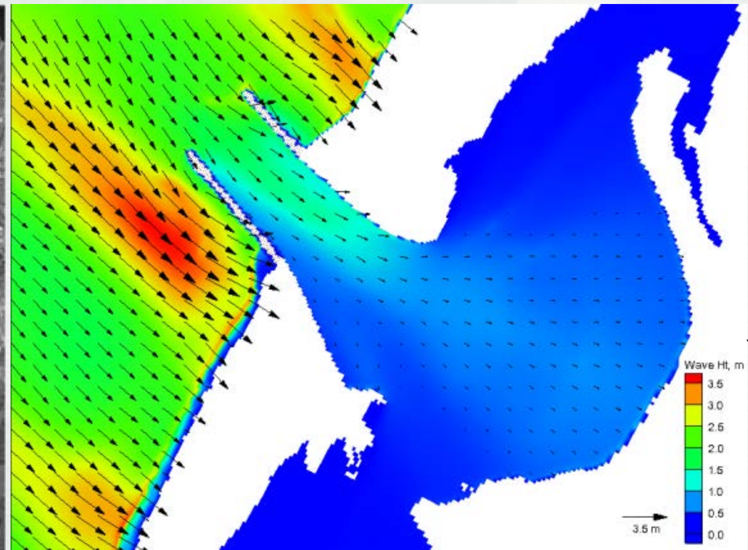


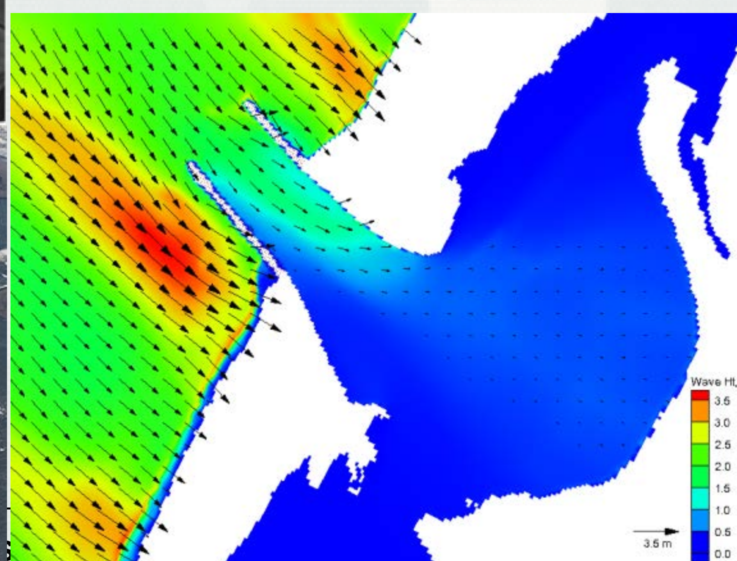
(a) Plan



(b) Elevation

Infra-gravity Waves at *Humboldt Bay, CA*



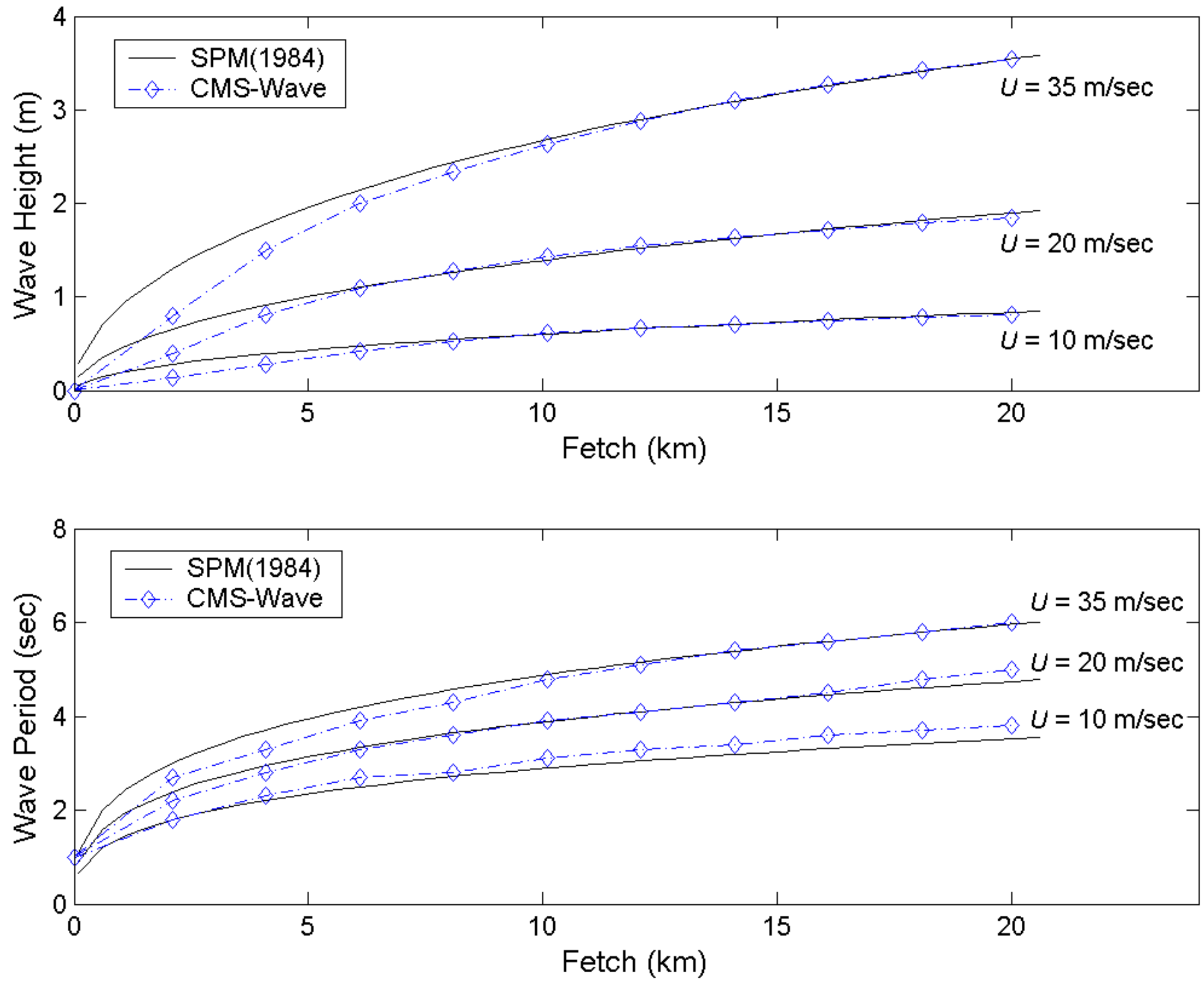


Incident wave:
2 m, 15 sec
from NE

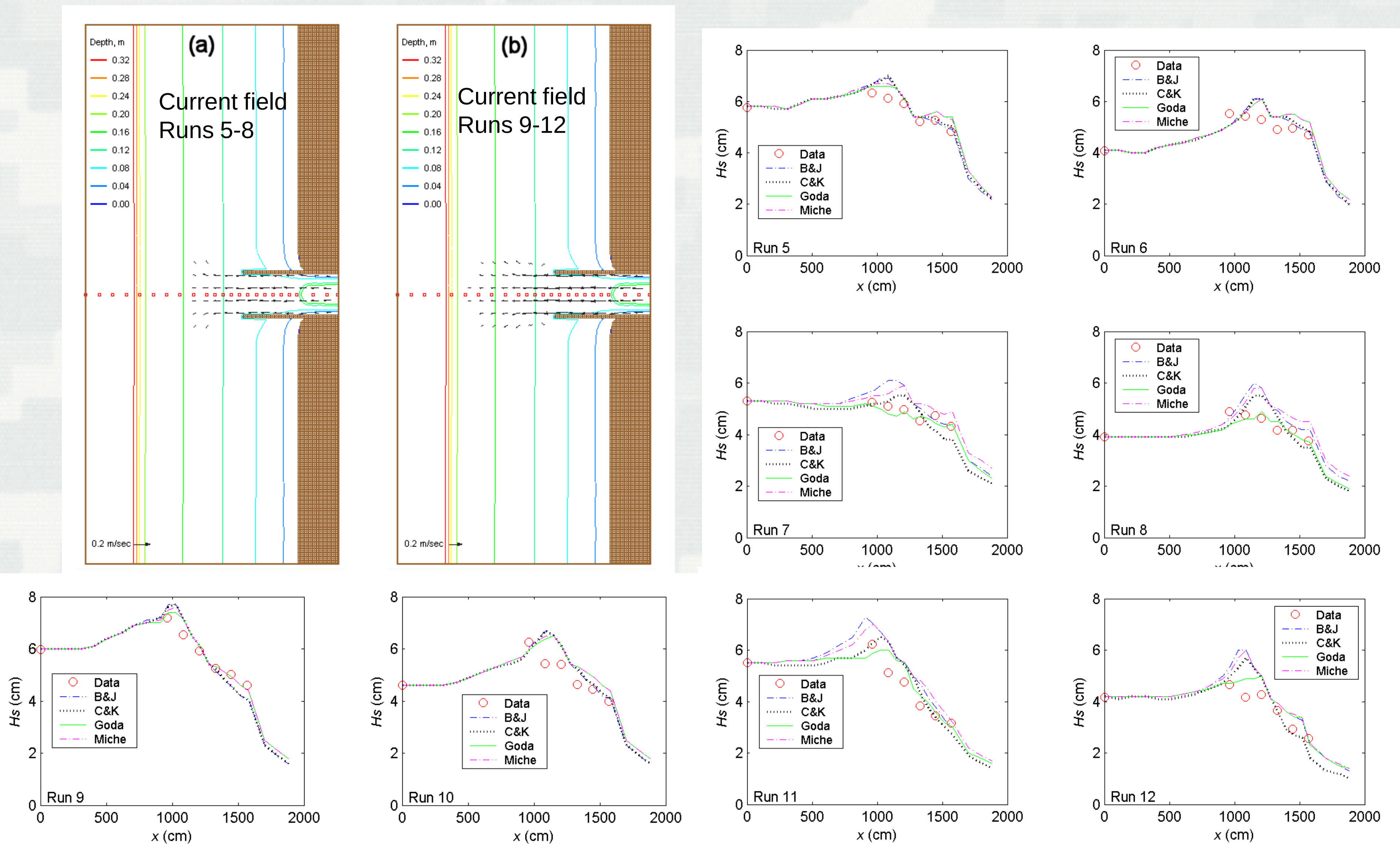
with infra-gravity wave

without infra-gravity wave

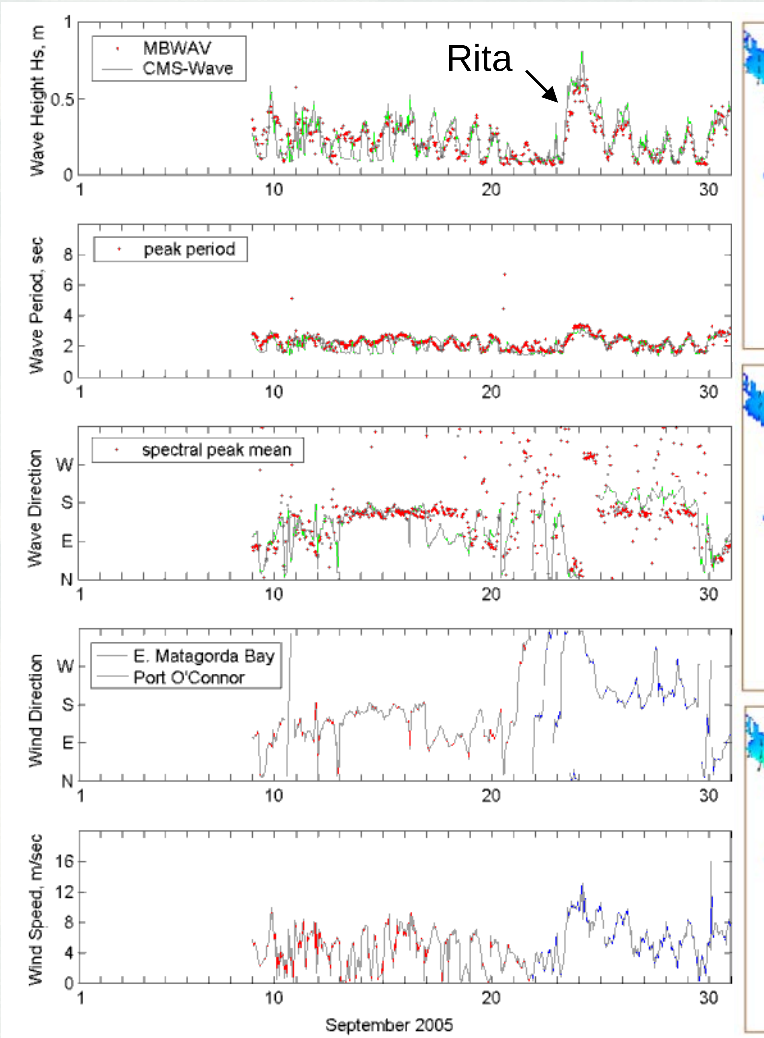
7. Wind-Wave Generation

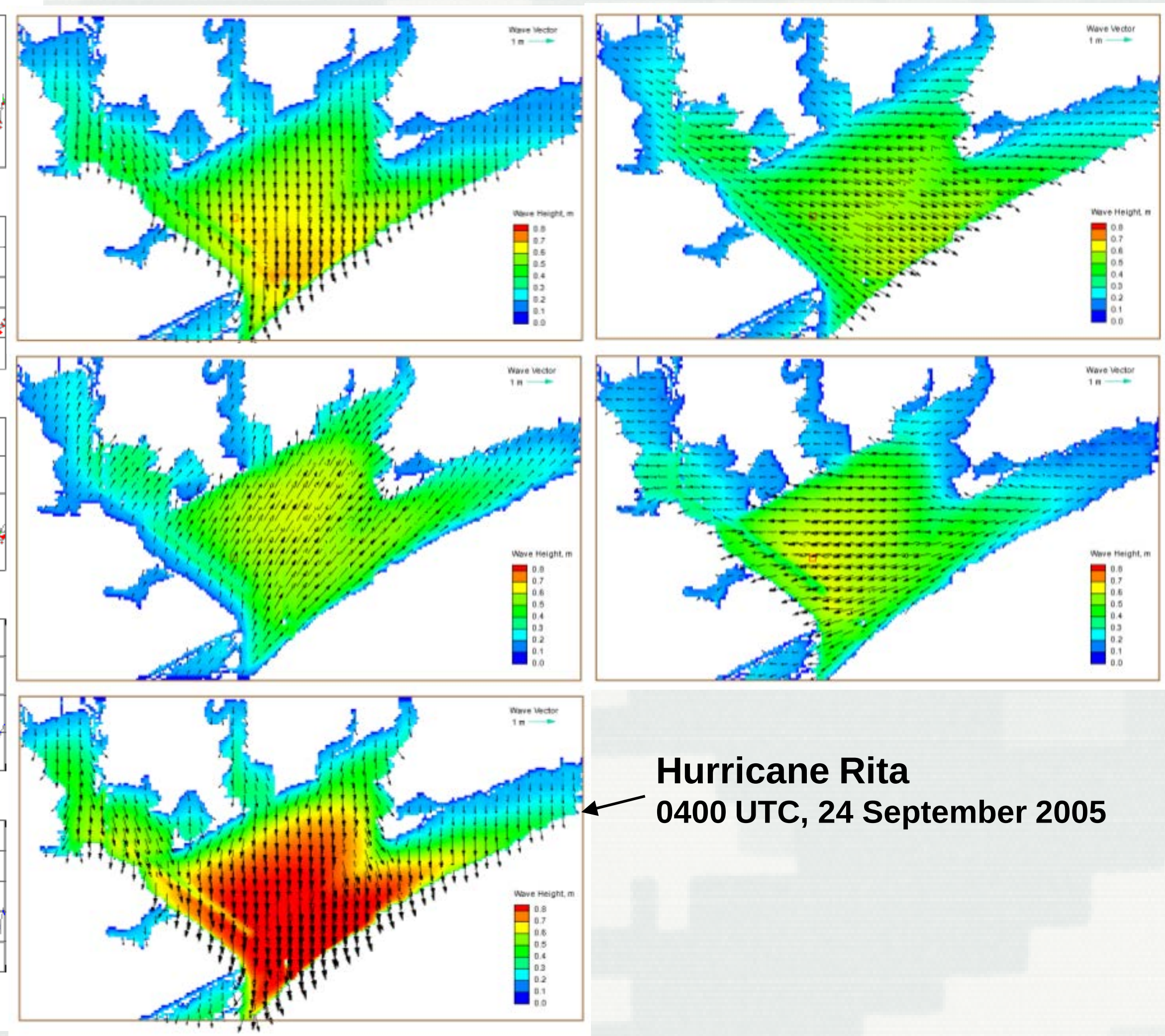


Wave Breaking Formulas



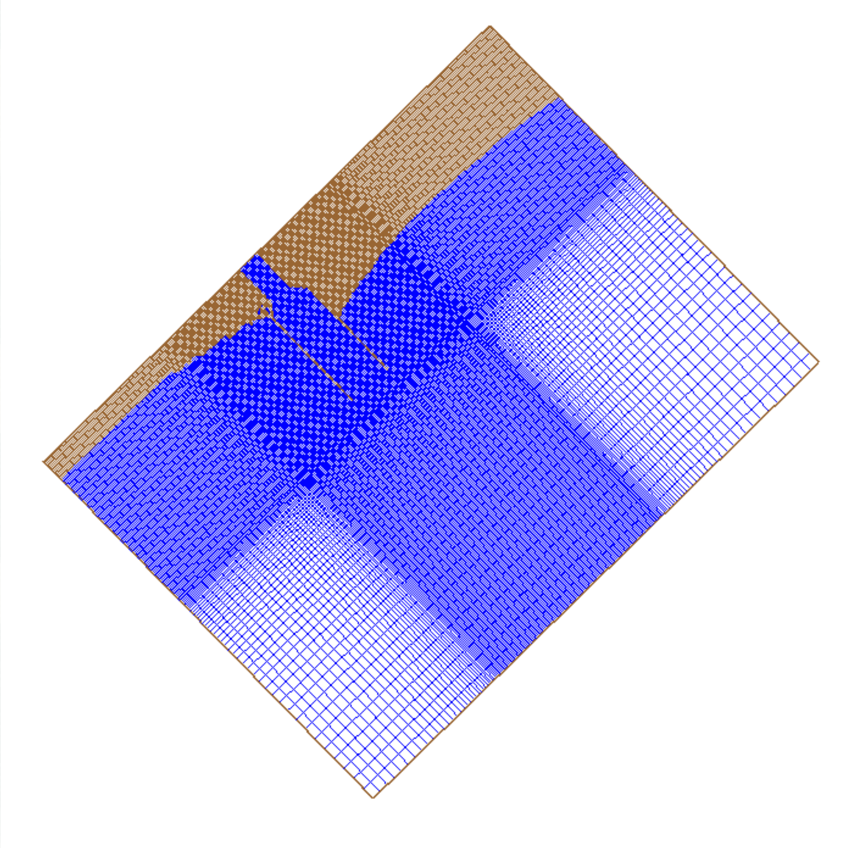
Wave Generation in *Matagorda Bay, TX*



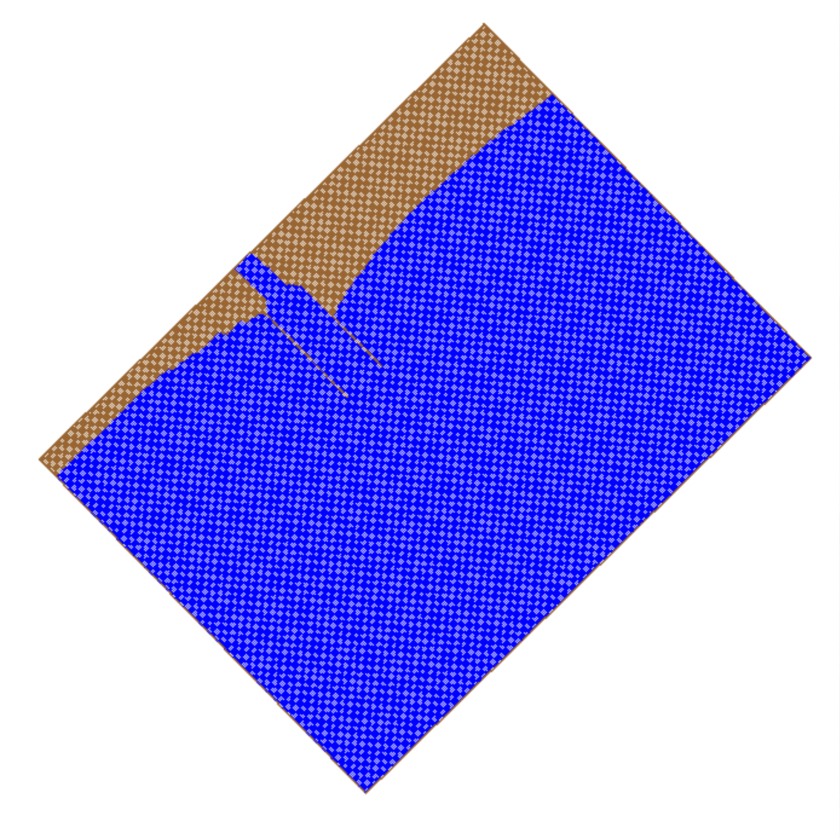


Hurricane Rita
0400 UTC, 24 September 2005

Variable Rectangular-Cell Grids

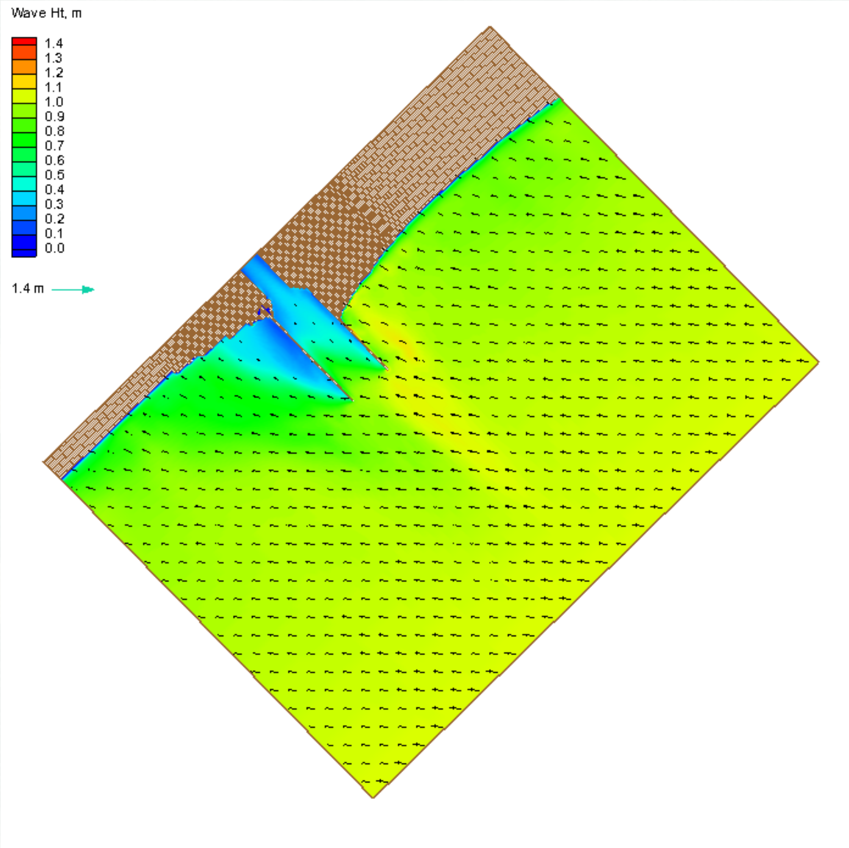


Variable-rectangular cells
Total 223 x 172 cells

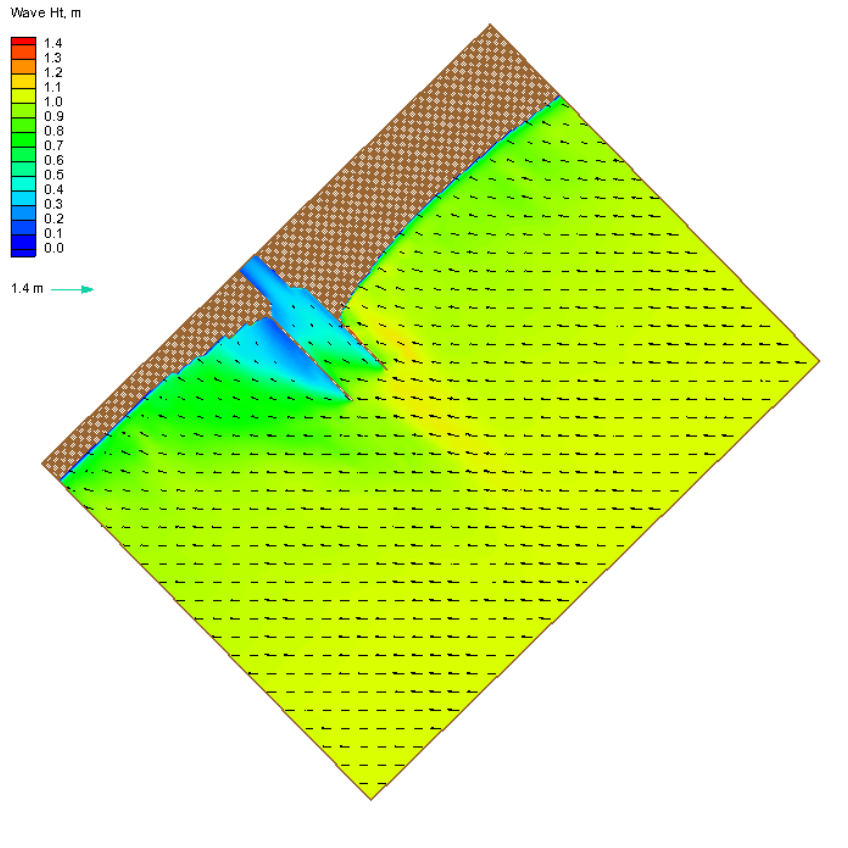


Square (20 m x 20 m) cells
Total 316 x 426 cells

CMS-Wave on Variable Grids

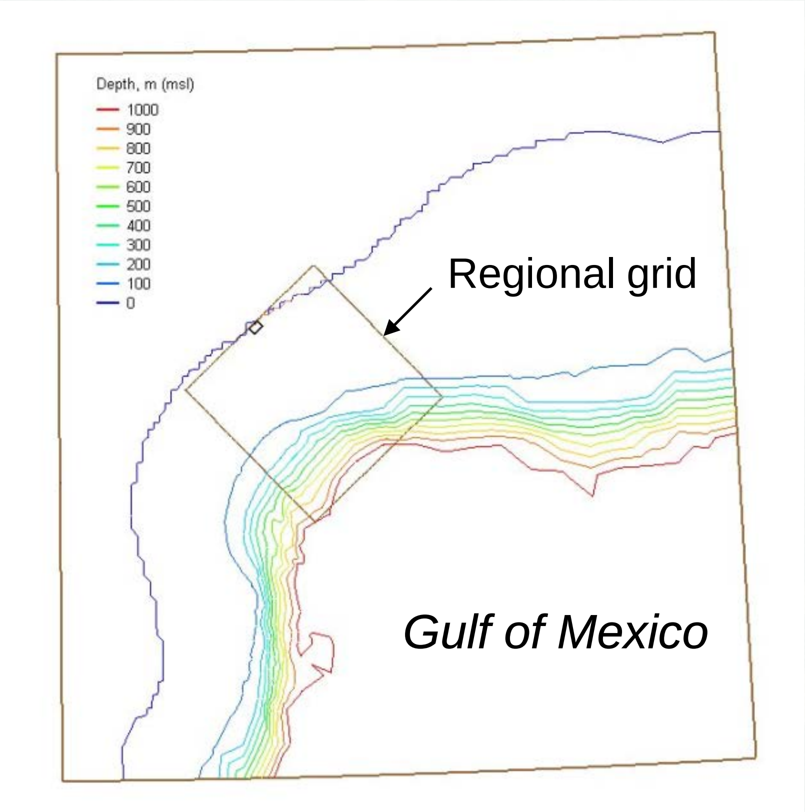


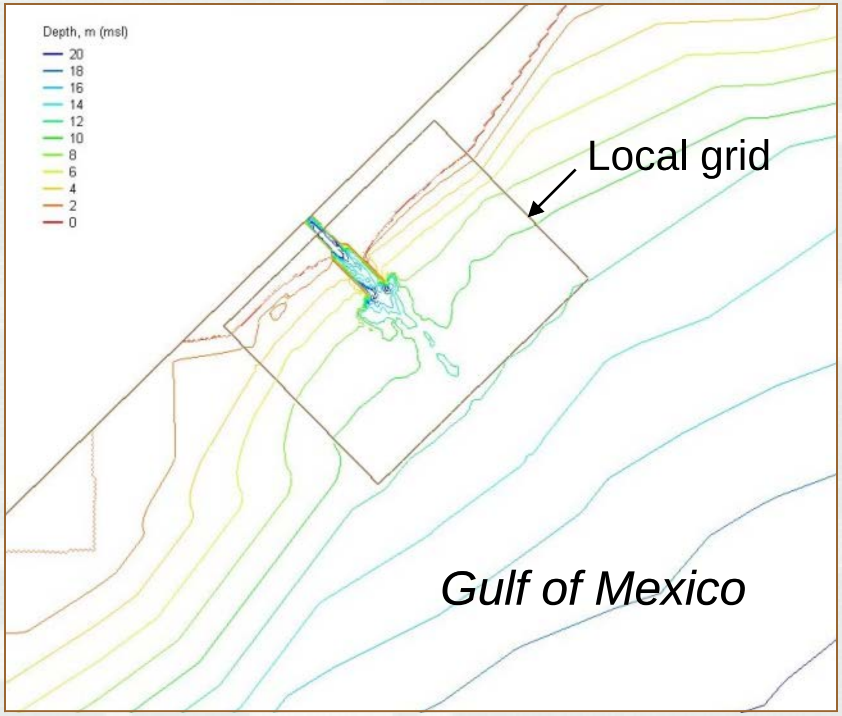
Variable-rectangular cells
Total 223 x 172 cells



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

Grid Nesting

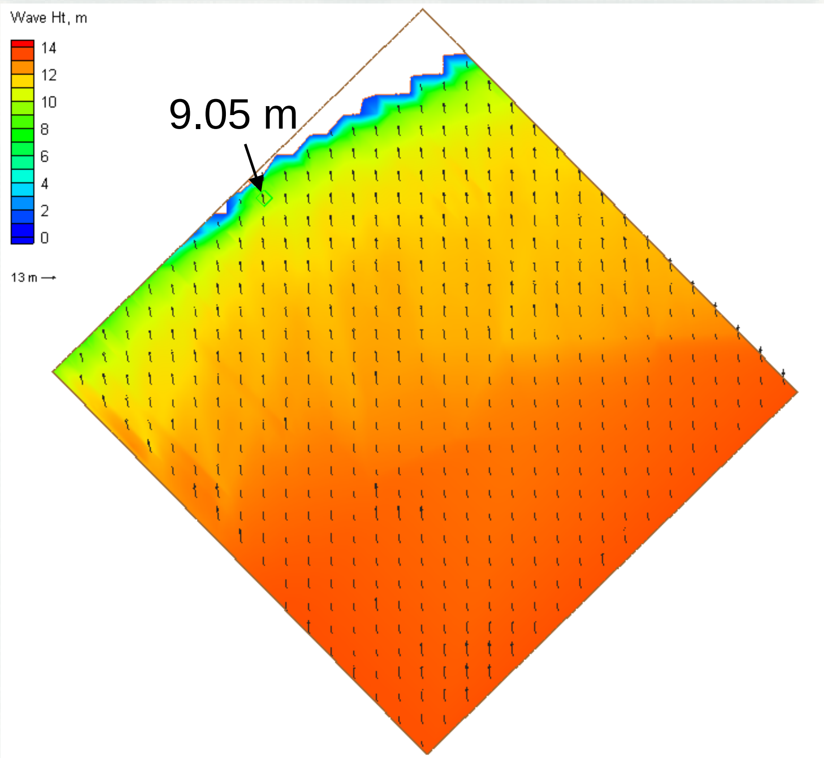




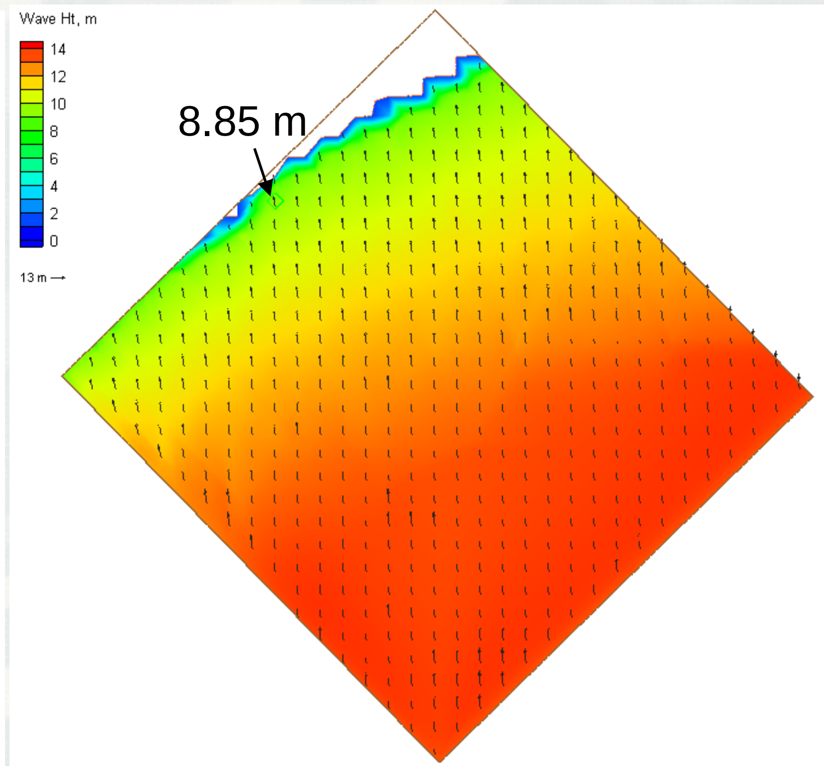
Regional Wave Generation

Incident Waves: 12.9 m, 13.8 sec, from S

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

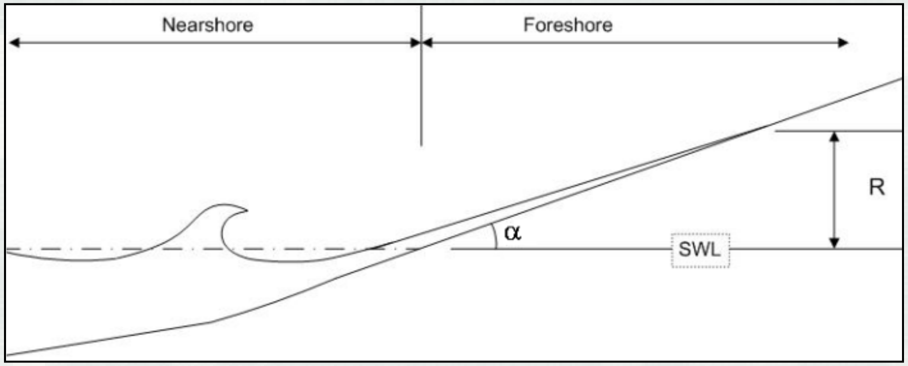


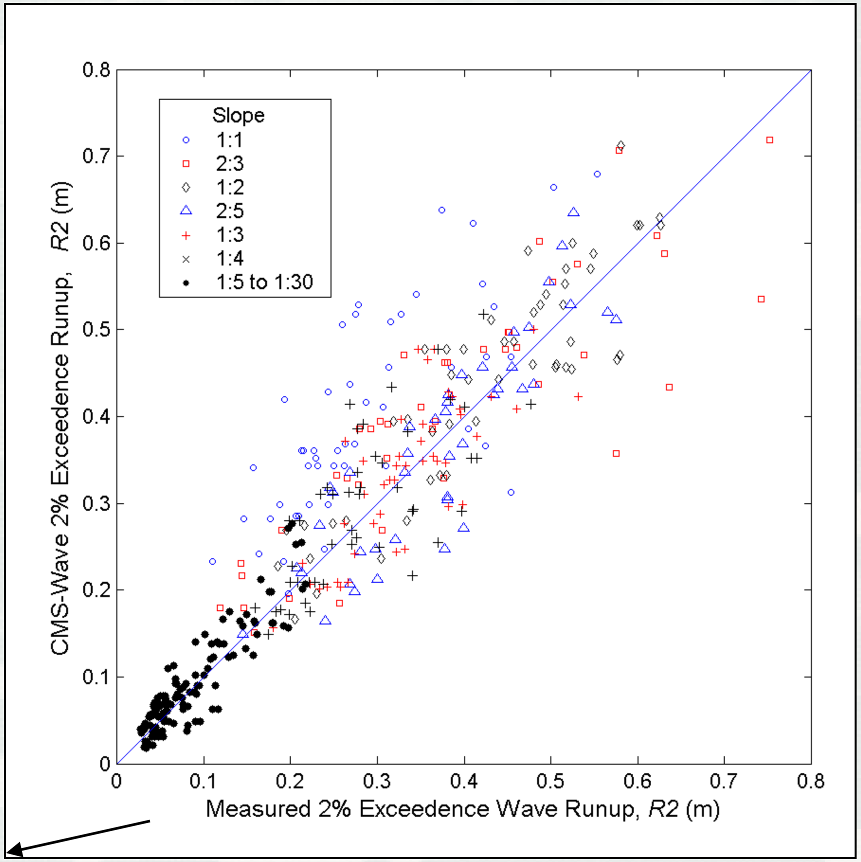
Without wind



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

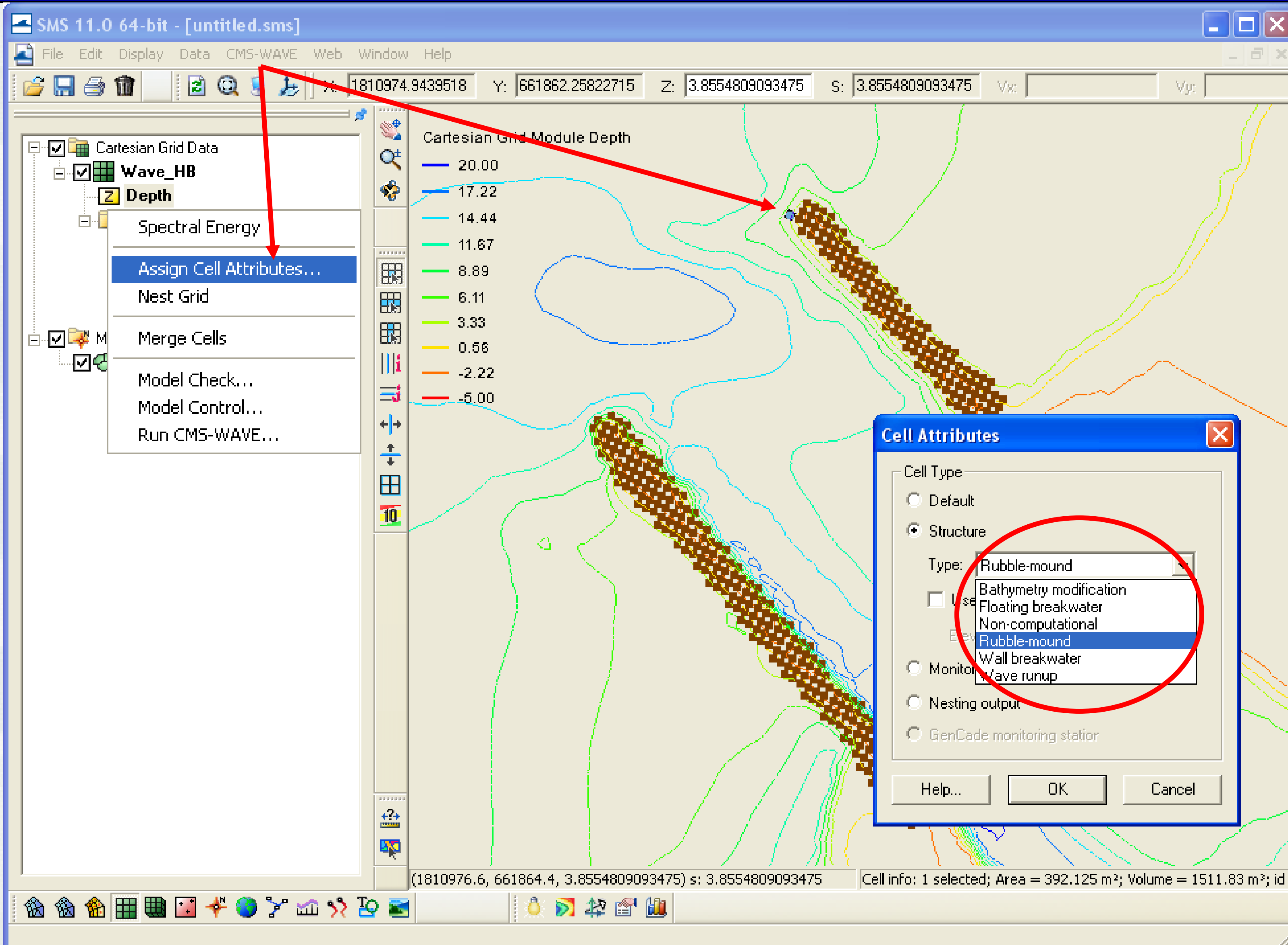
Max setup (Guza and Thornton, 1981): $\eta_{\max} = 0.17 H_0$

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 SMS11.0



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):

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

Composite or rubble-mound breakwater:

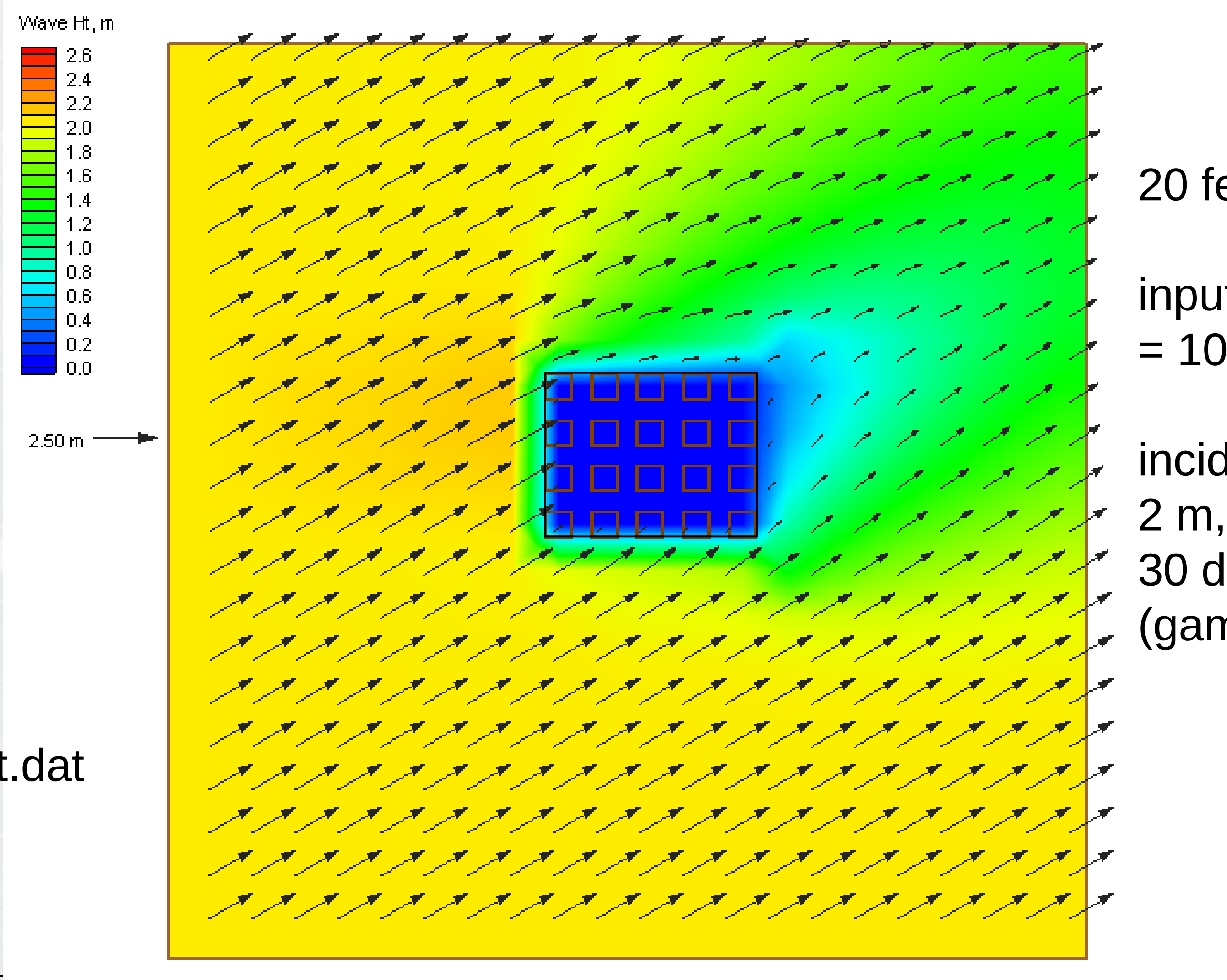
$$K_t = 0.3\ (1.1 - \frac{h_c}{H_s}), \quad \text{for} \quad 0 \le \frac{h_c}{H_s} \le 0.75$$

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

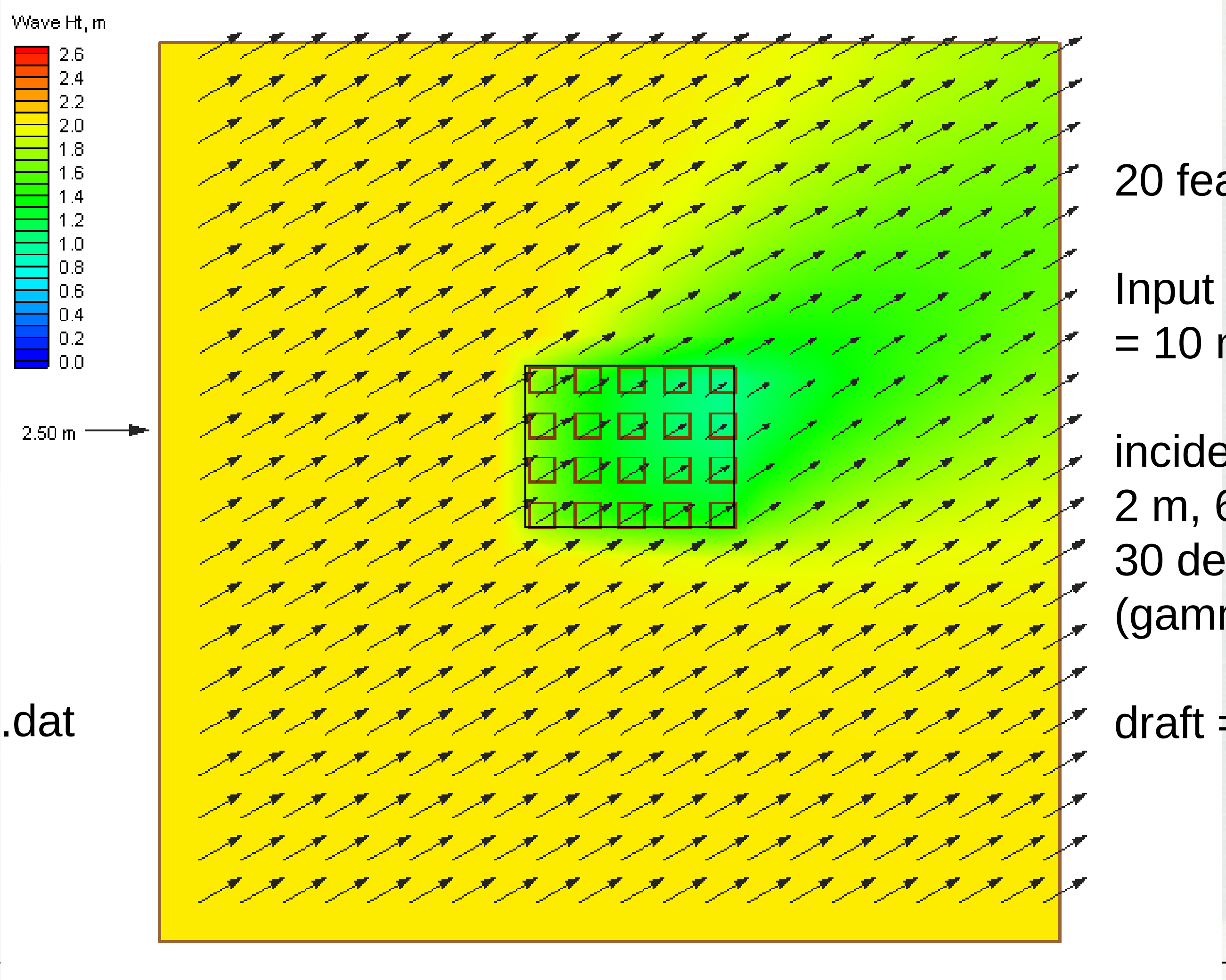
input depth
= 10 m

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

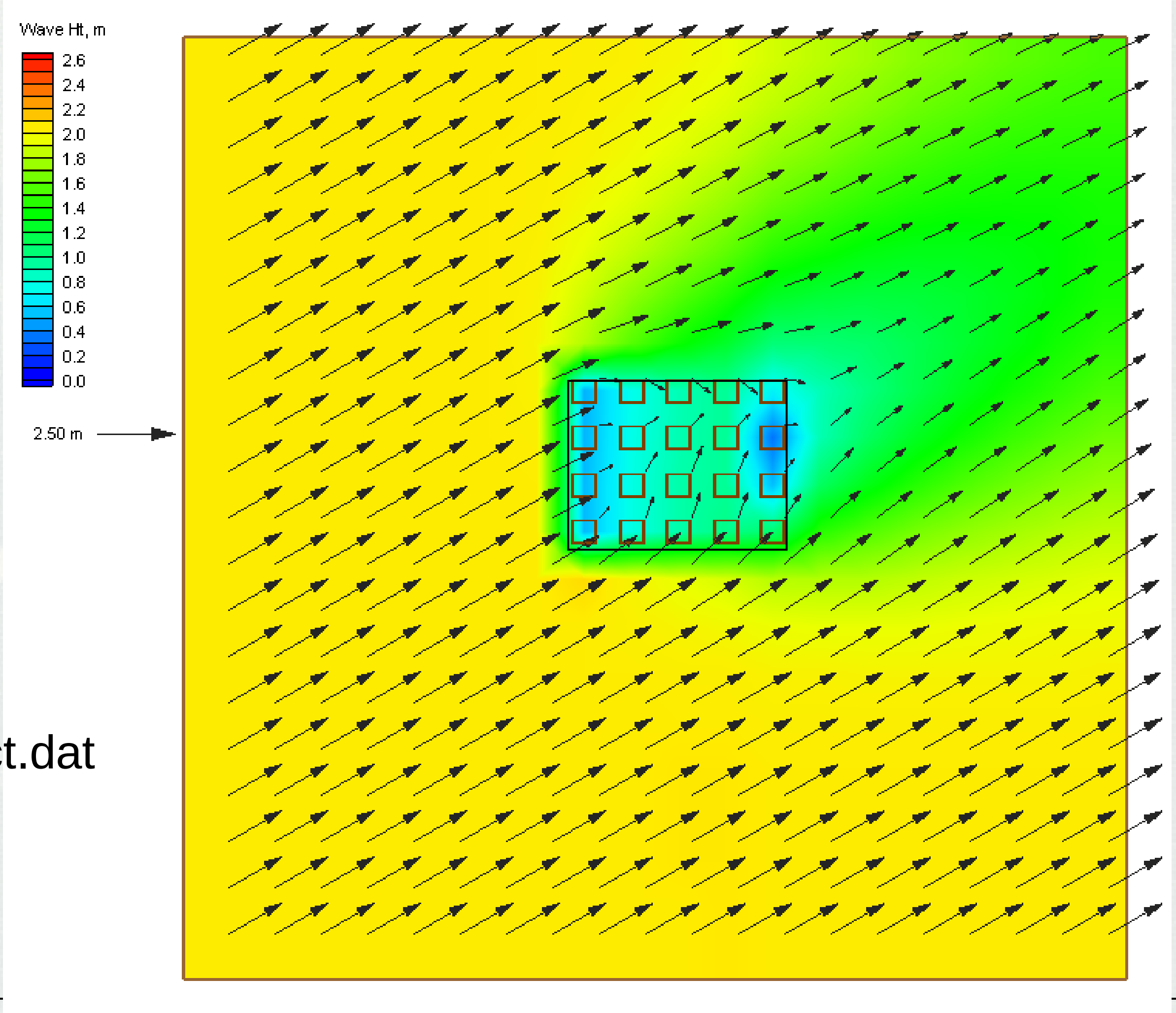
incident wave: 2 m, 6 sec, 30 deg oblique (gamma = 4)

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

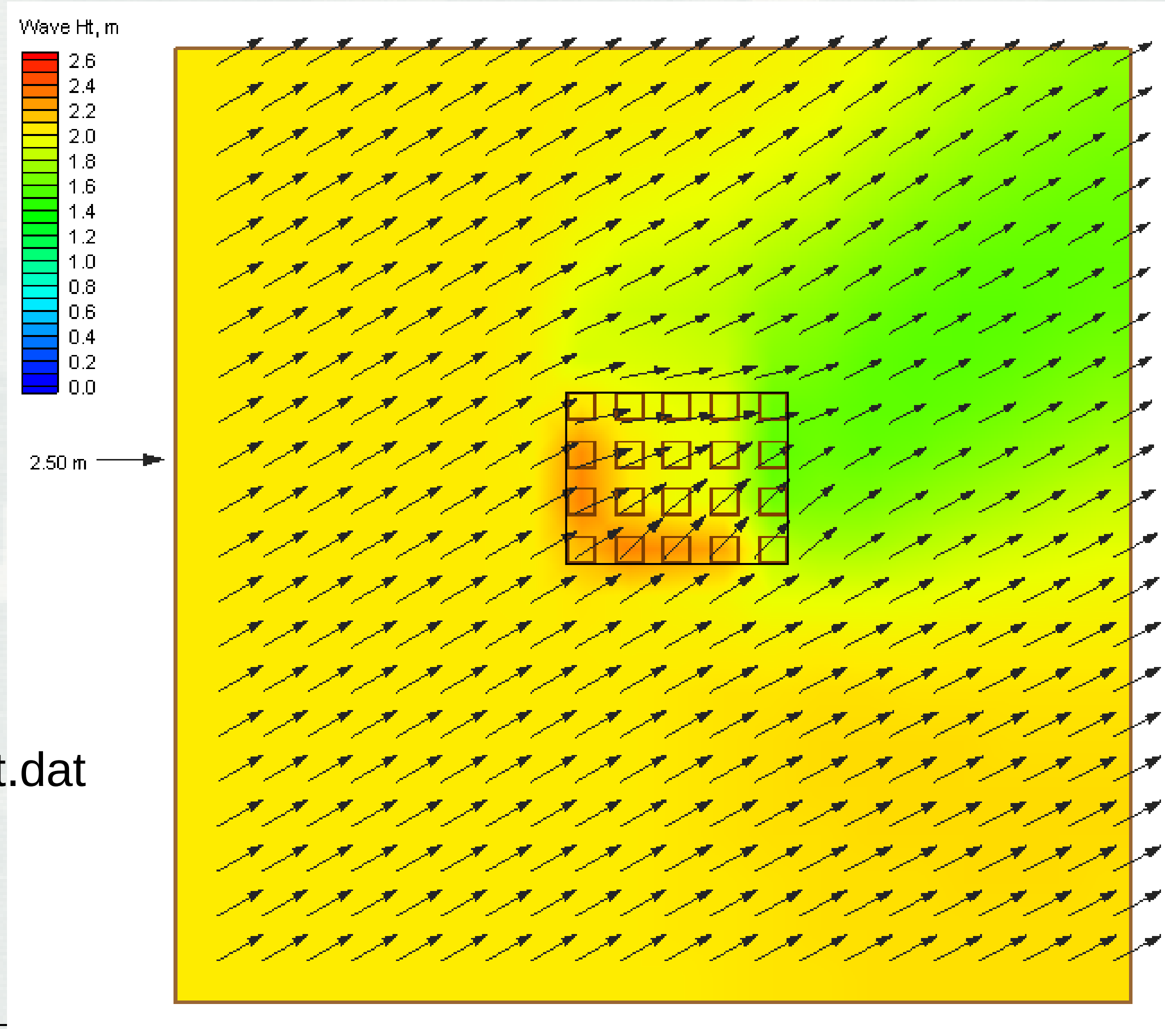
incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)

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



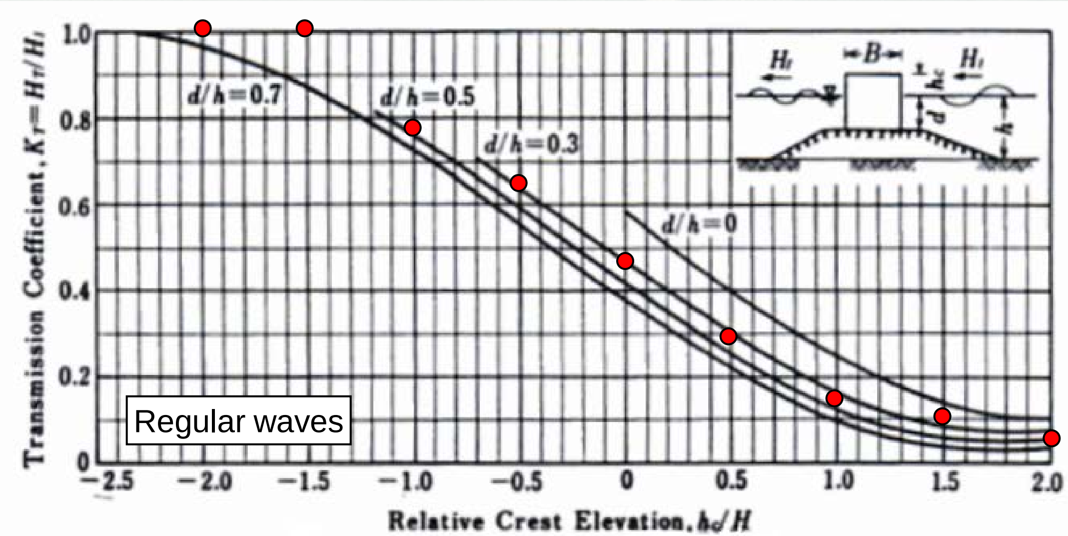
20 feature cells

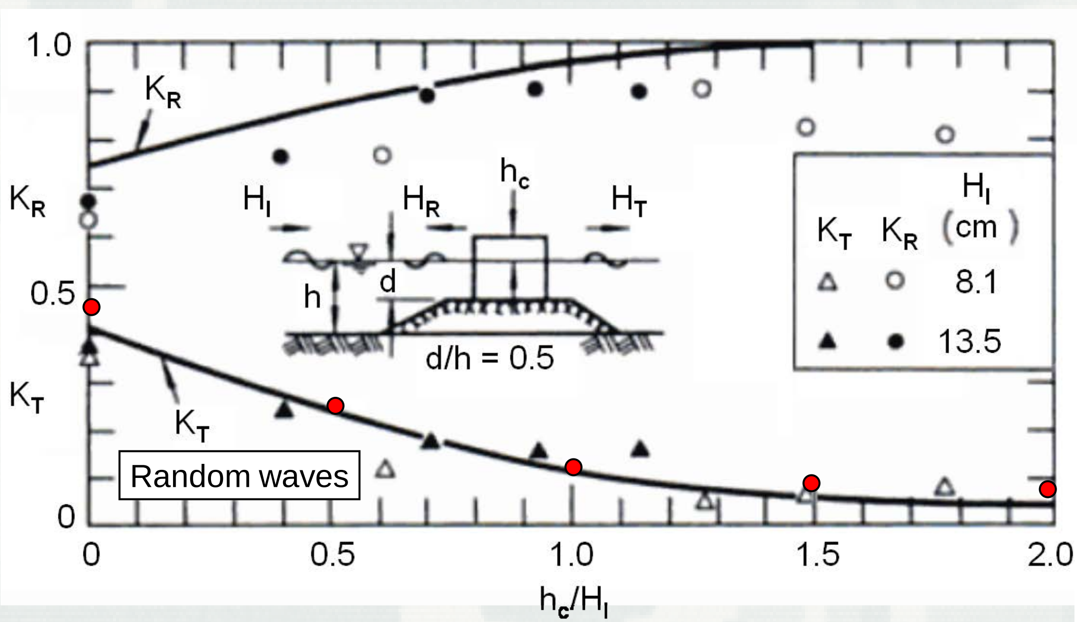
input depth = 10 m

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

platform elev. = -2 m (mwl)

Wave Transmission Experiment (Goda, 2000)





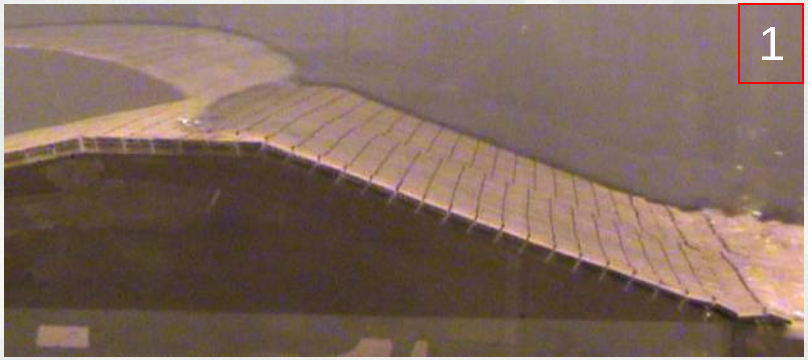
Transmission coefficients k_t

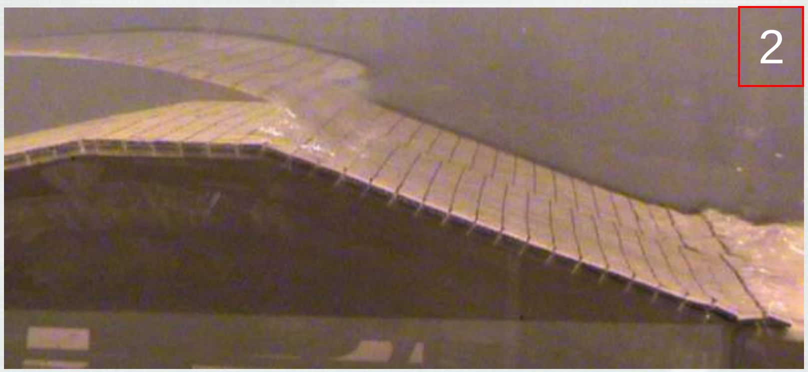
H_i = 1 m, *Tp* = 6 sec (monochromatic wave)

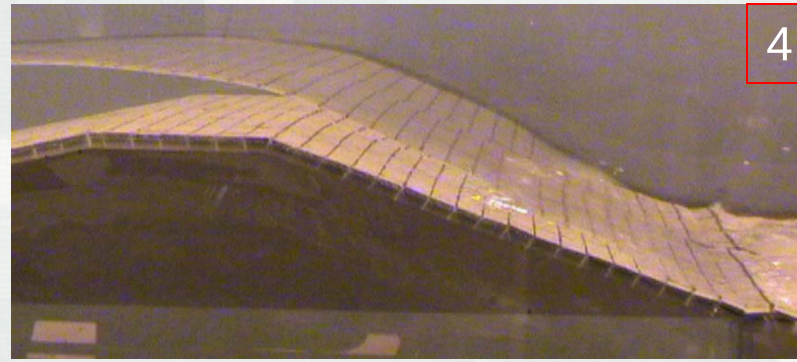
h = 10 m, *d* = 5 m, *B* = 80 m

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)

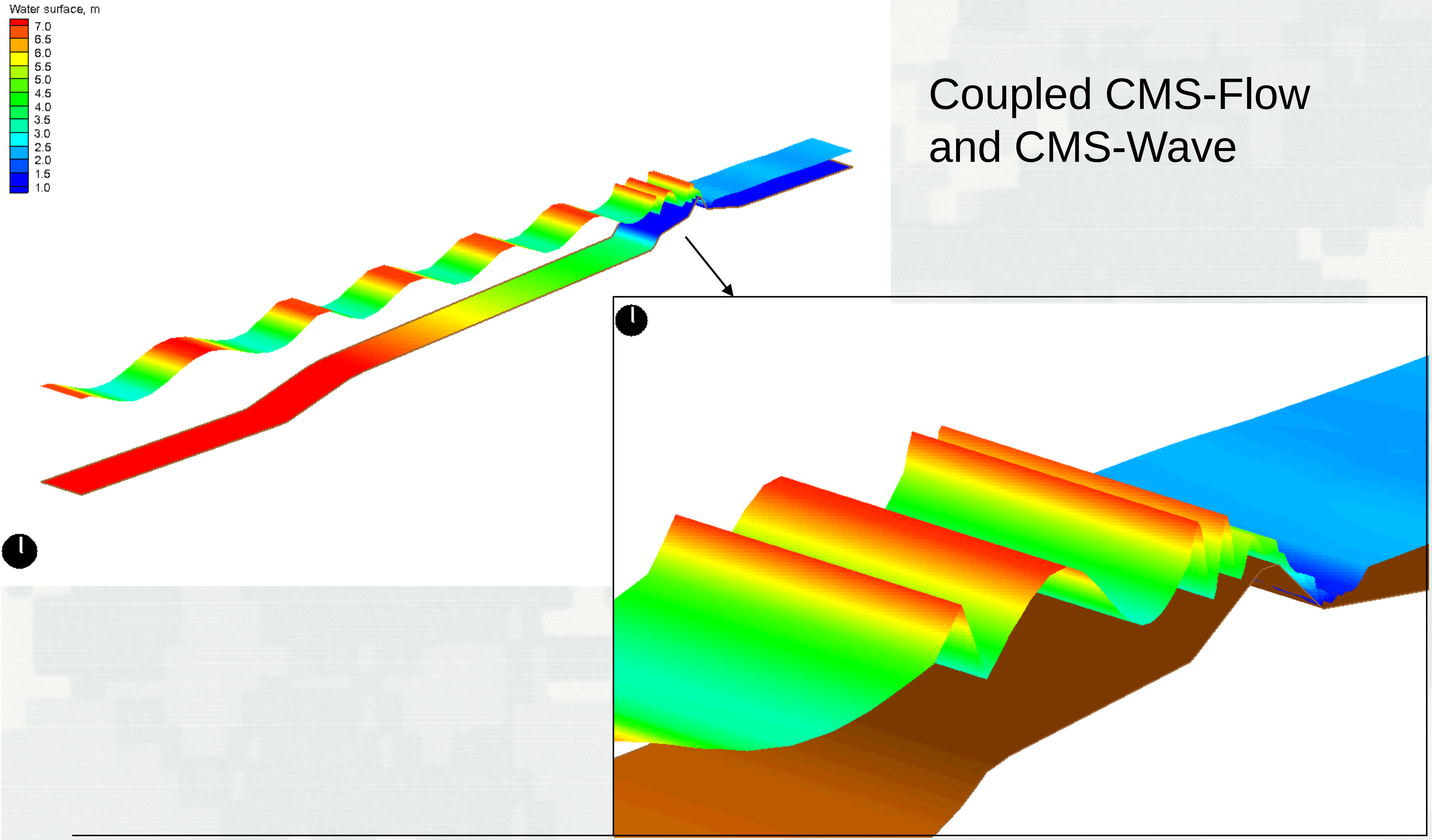






ERDC/CHL TR-08-10
by Hughes (2008)

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):

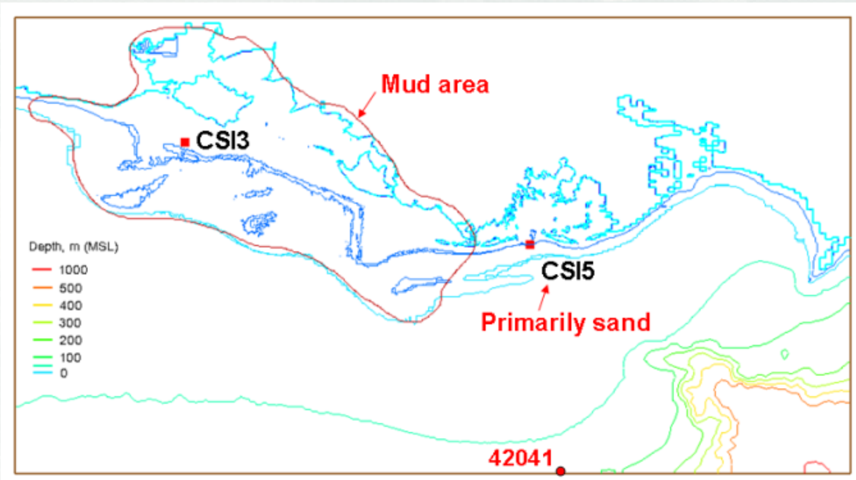
$$S_{dp} = -4(\nu_k + \nu_t)k^2 E$$

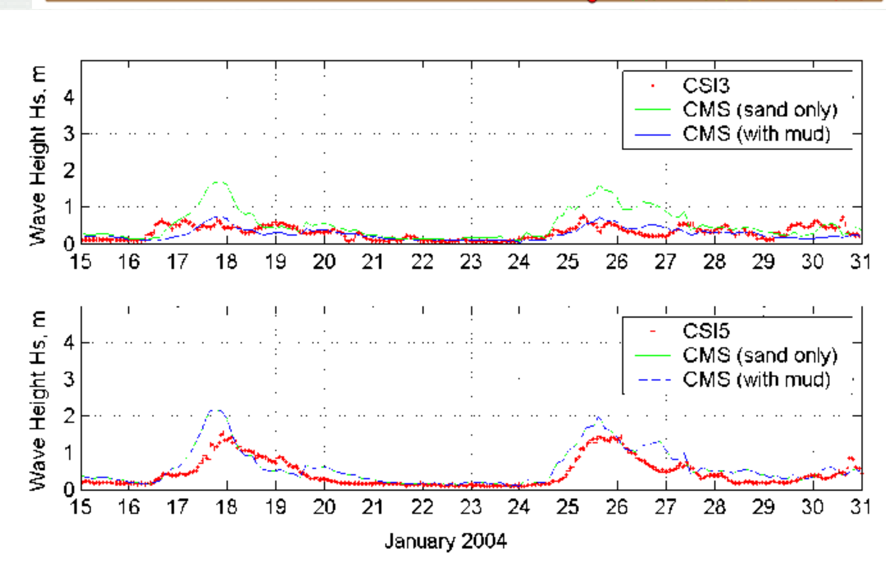
where ν_k is the kinematic viscosity of sea water,

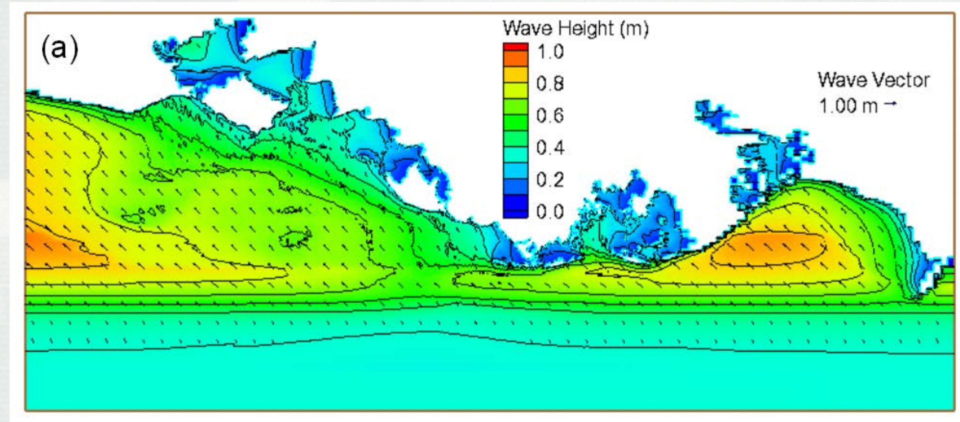
and ν_t is the turbulent eddy viscosity:

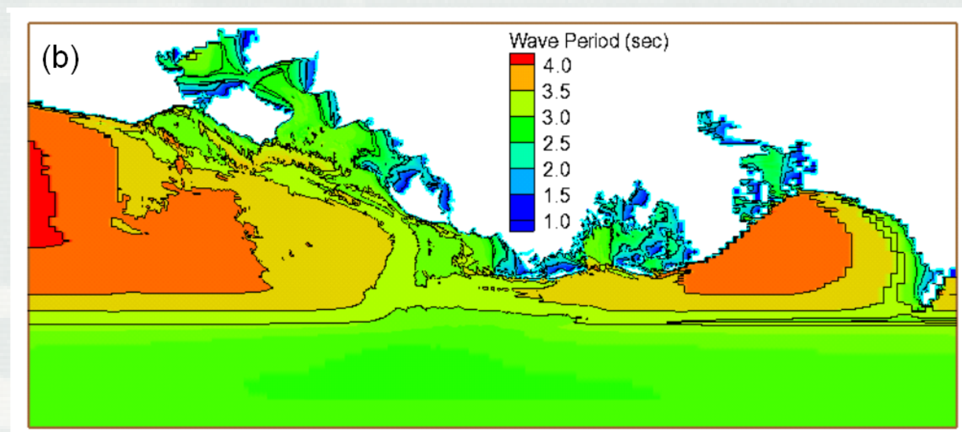
$$\nu_t = \nu_{t,breaking} \frac{H_s}{h}$$

Louisiana Muddy Coast Simulation





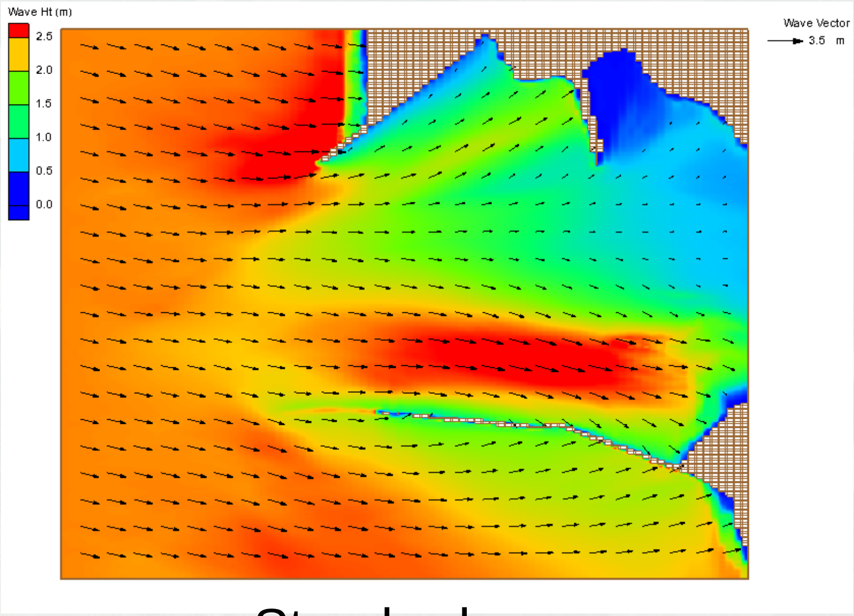




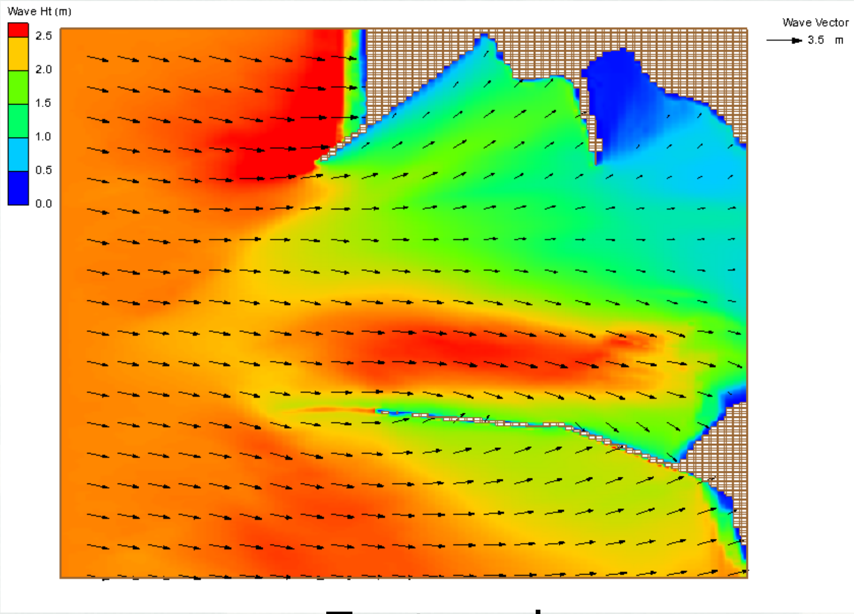
CMS-Wave Fast Mode
(Simplified Formulation)

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

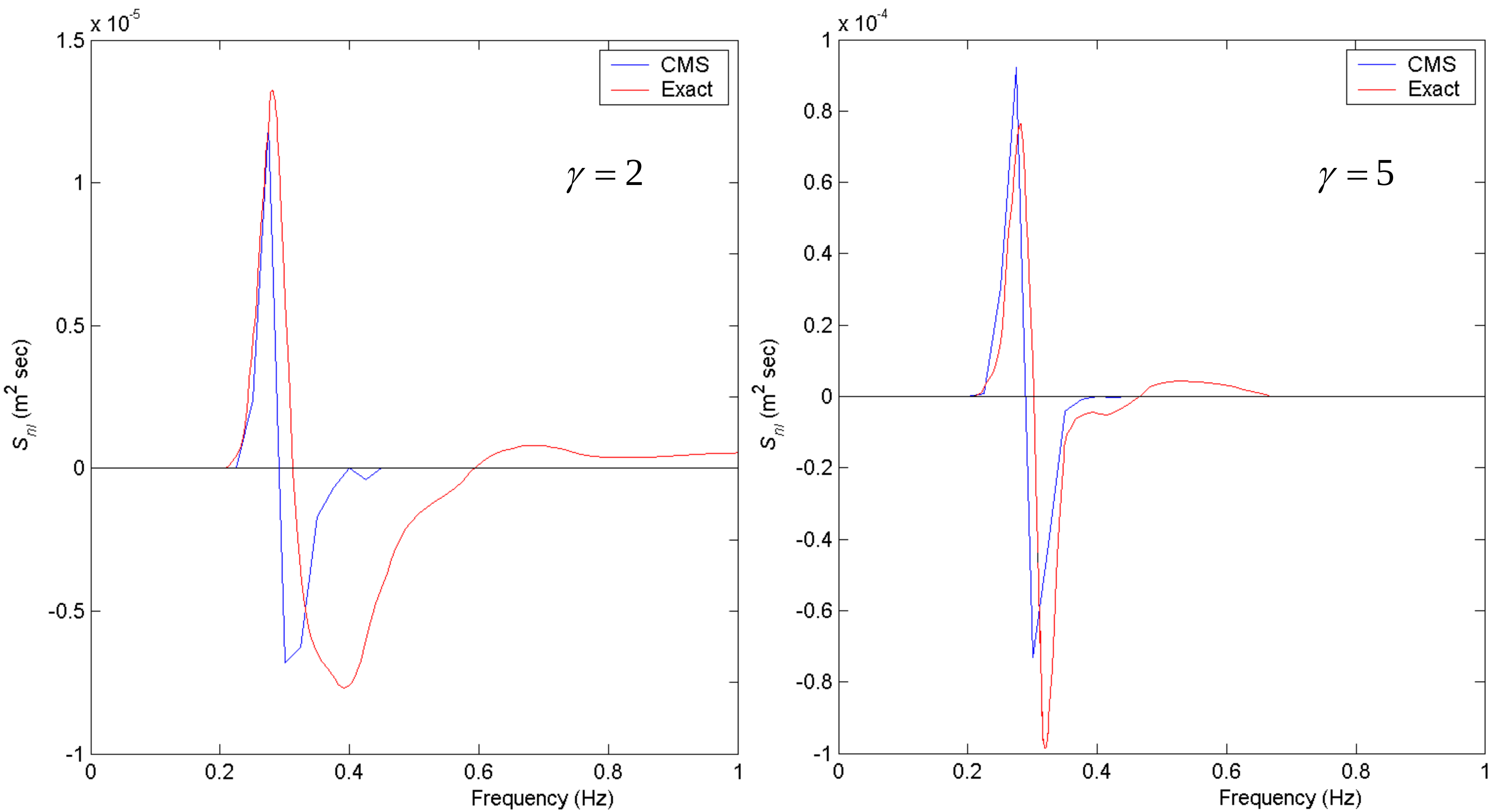
where S_{nl} is the nonlinear wave-wave interaction term

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

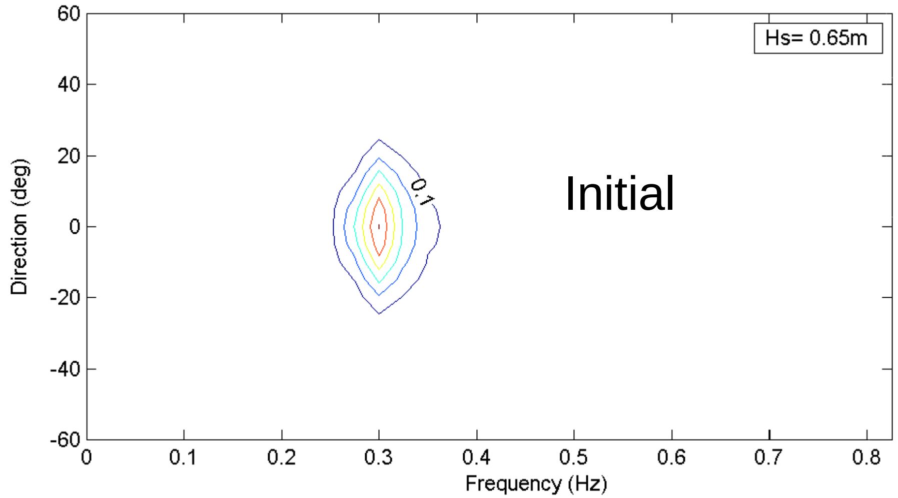
where $$a = \frac{1}{2n^2}[1 + (2n-1)^2 \cosh 2kh] - 1, \quad b = \frac{a}{n\sigma}$$

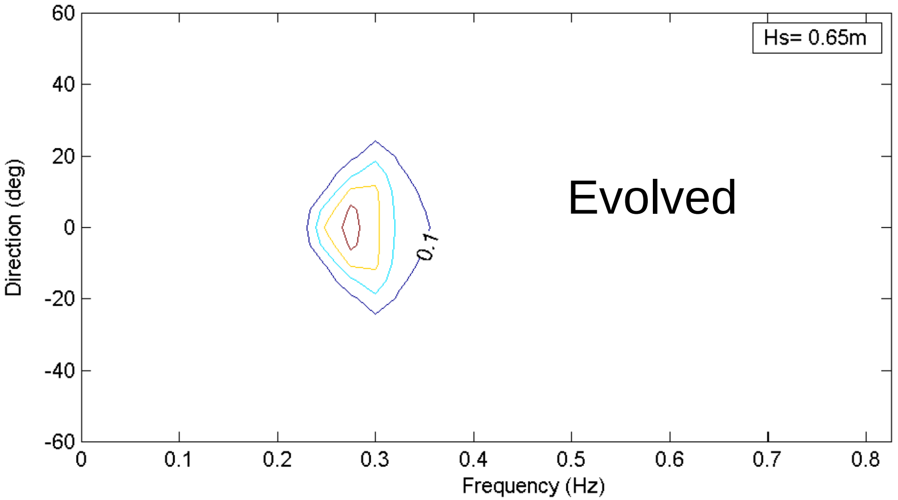
and $$B = k^3 \sigma^5 \frac{n^4}{(2\pi)^2 g}[(\frac{\sigma_o}{\sigma})^4 E]^3$$

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

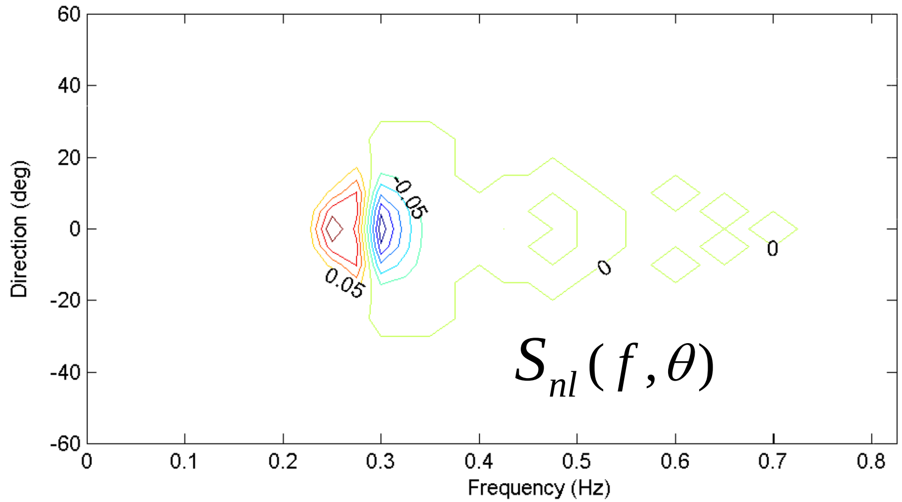


Spectral Evolution and $S_{nl}(f,\theta)$

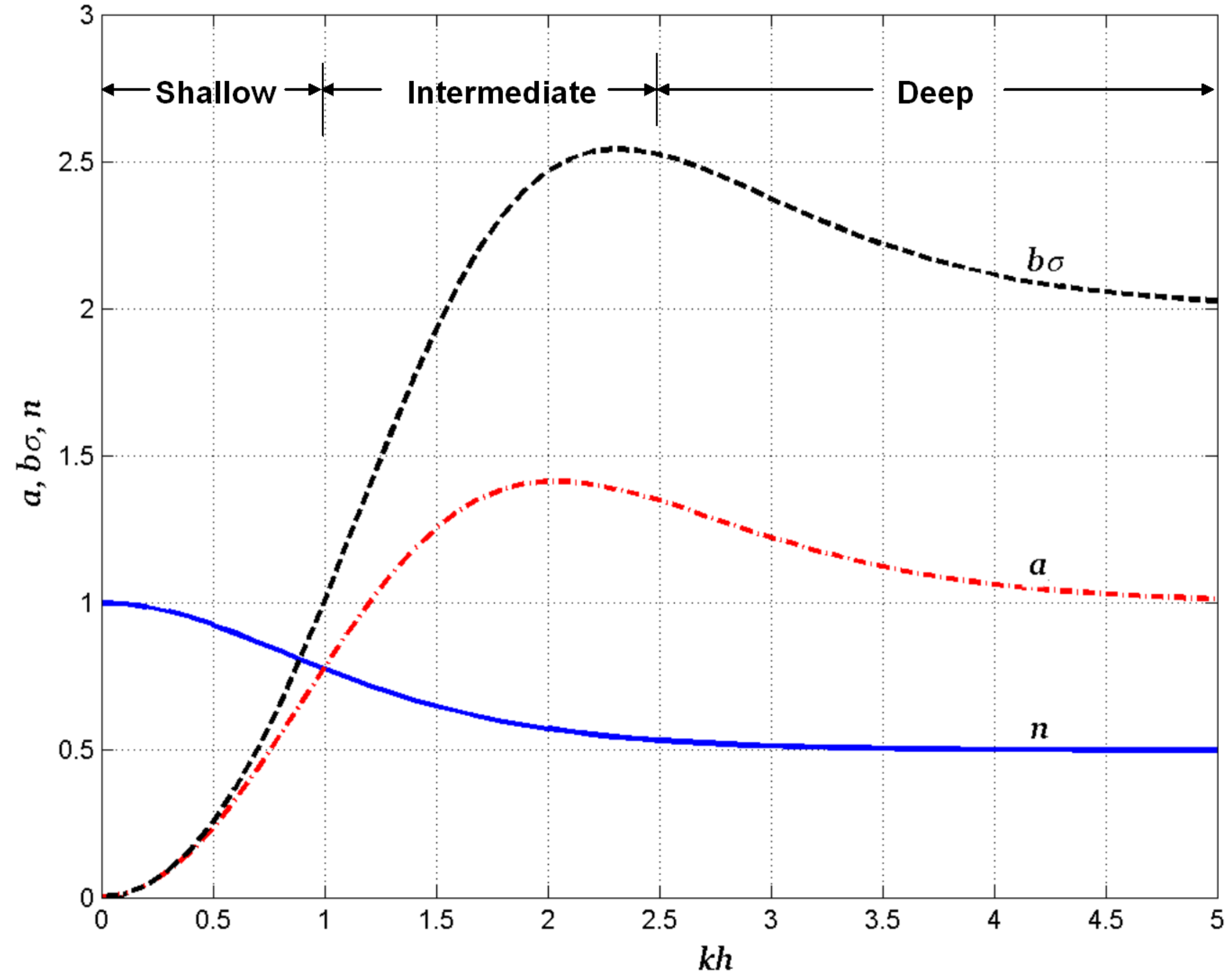




$\gamma = 5$

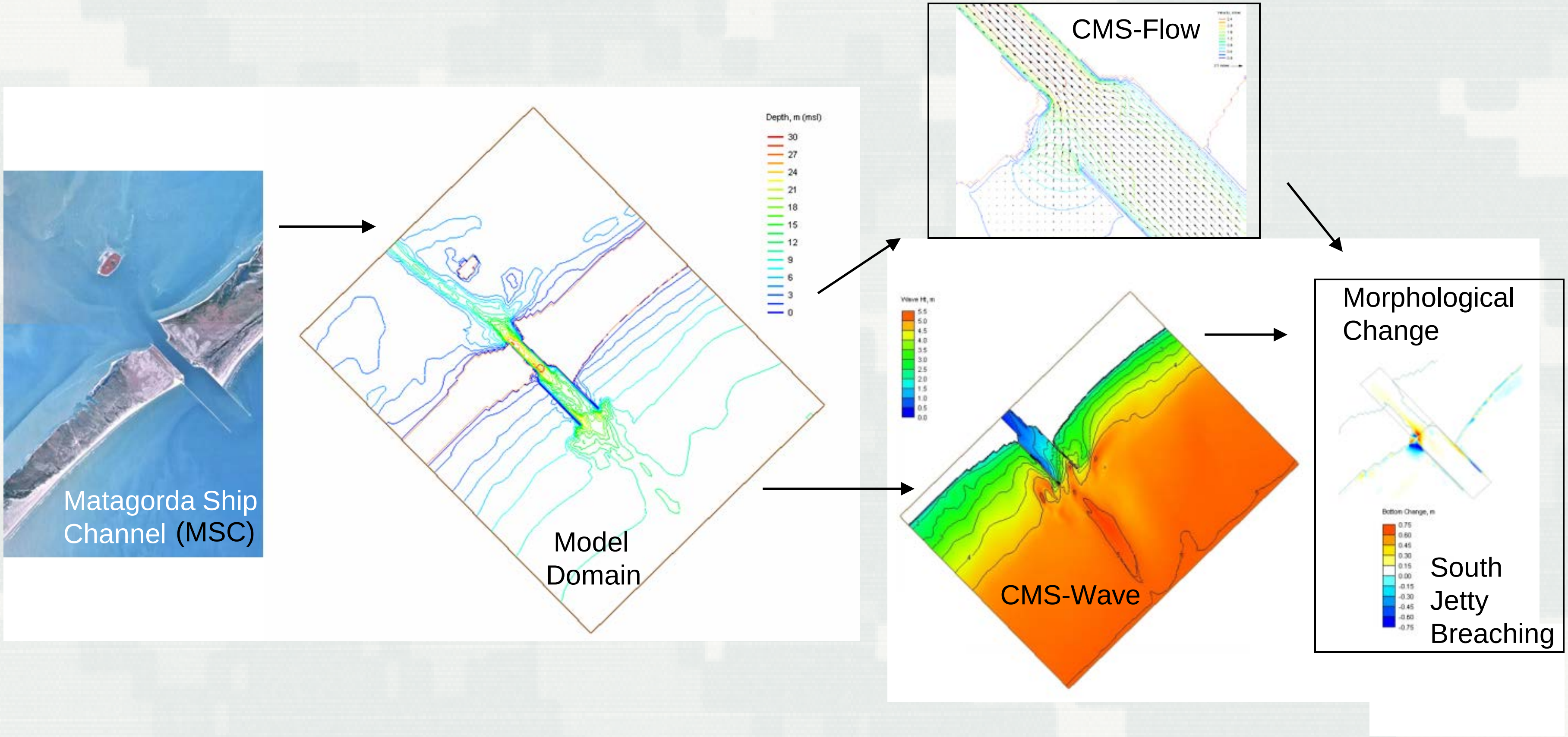


Nonlinear Wave Effect

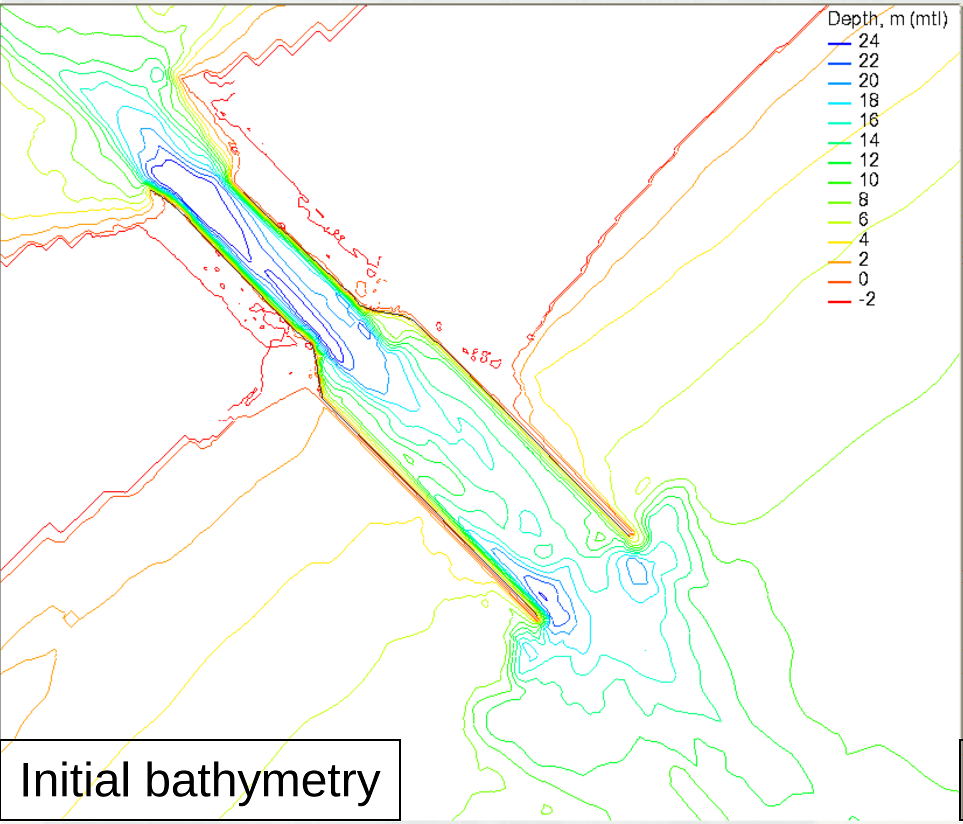


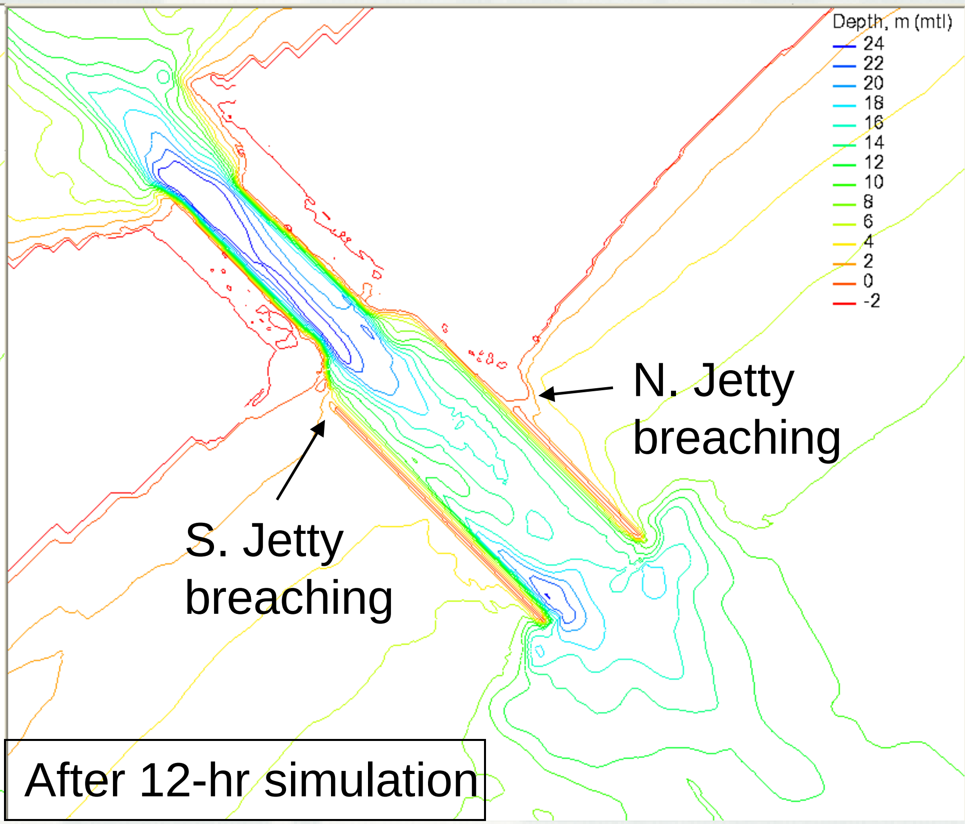
9. Coupling with CMS-Flow

Breaching at Jetty, Simulation at Matagorda Ship Channel, TX



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

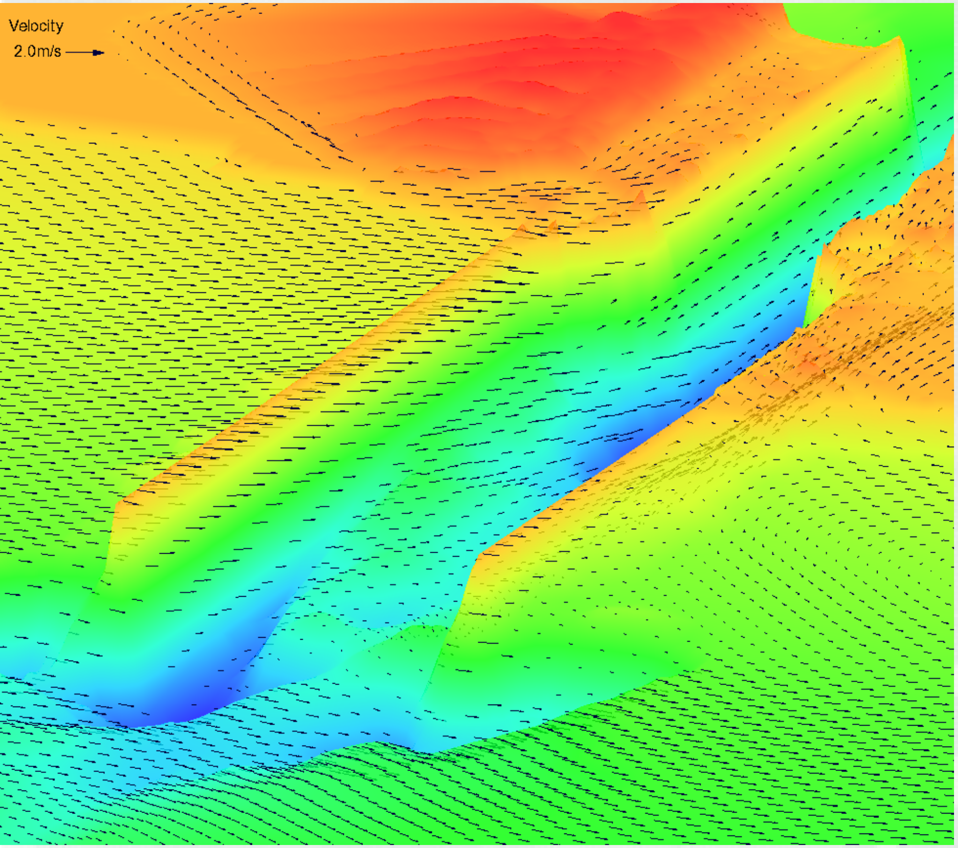




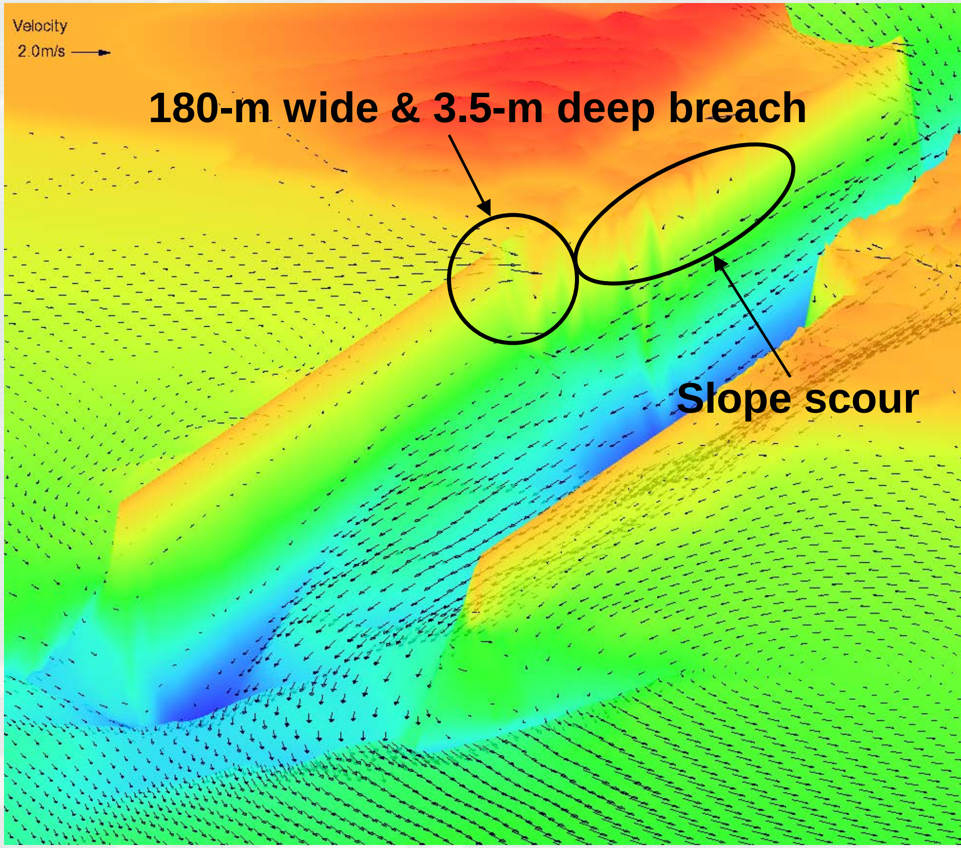
- Peak storm surge level reaches 3.5 m between Hrs 4 and 8
- Incident offshore wave is 7.6 m, 14.3 sec, from south

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

Storm surge over the initial bathymetry

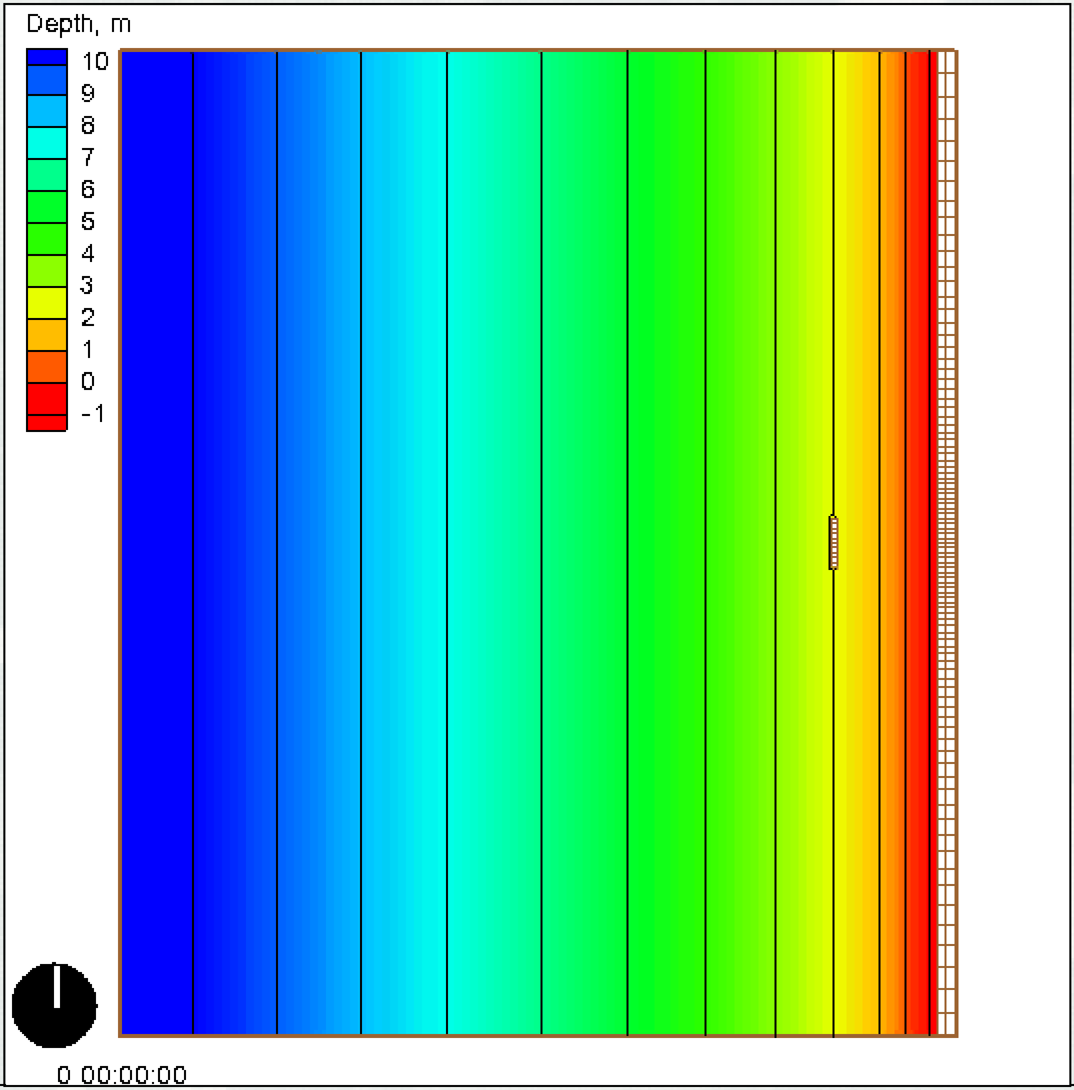


South Jetty breach in 12-hr simulation



- 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

- 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**