

CMS-Wave Background and Capabilities

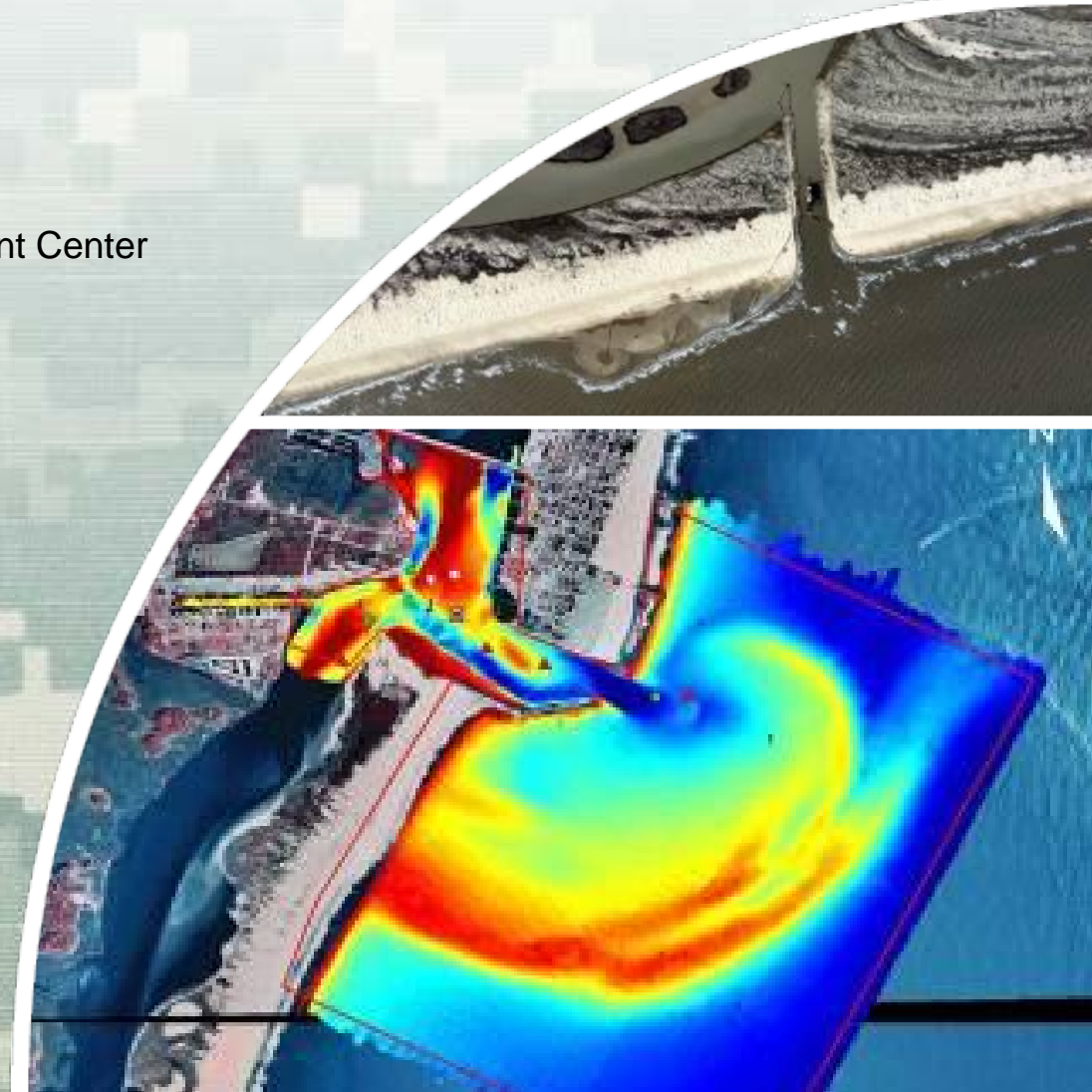
Developed for coastal and inlet applications



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Report Documentation Page

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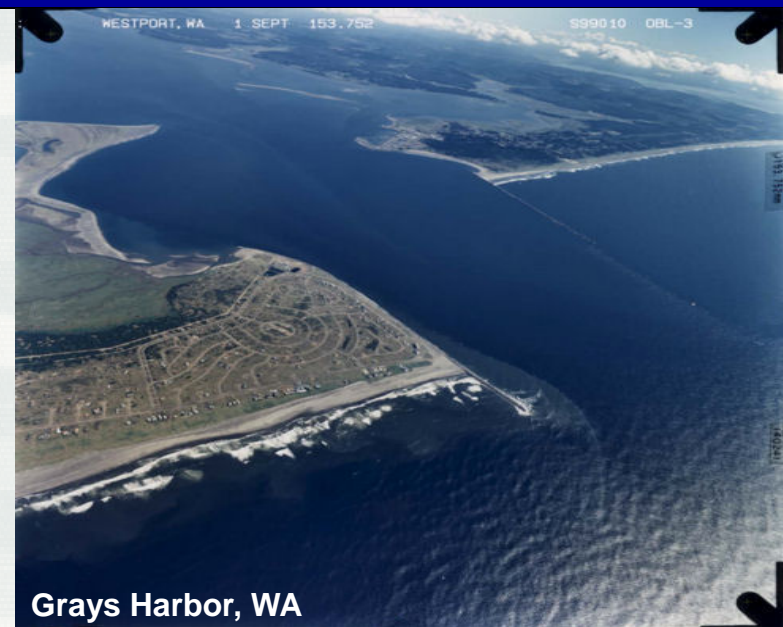
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Outline



- 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	
Structures {	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	

Wave-Action Balance Equation with Diffraction

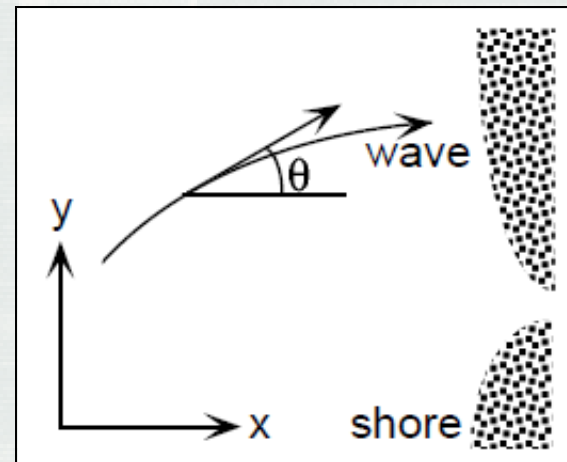
$$\frac{\partial[(c_{gx} + u)A]}{\partial x} + \frac{\partial[(c_{gy} + v)A]}{\partial y} + \frac{\partial[c_{g\theta}A]}{\partial \theta} = \frac{\kappa}{2\sigma} \left\{ (cc_g \cos^2 \theta A_y)_y - \frac{1}{2} cc_g \cos^2 \theta A_{yy} \right\} + S_{in} + S_{dp}$$

↙ Diffraction intensity factor

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

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

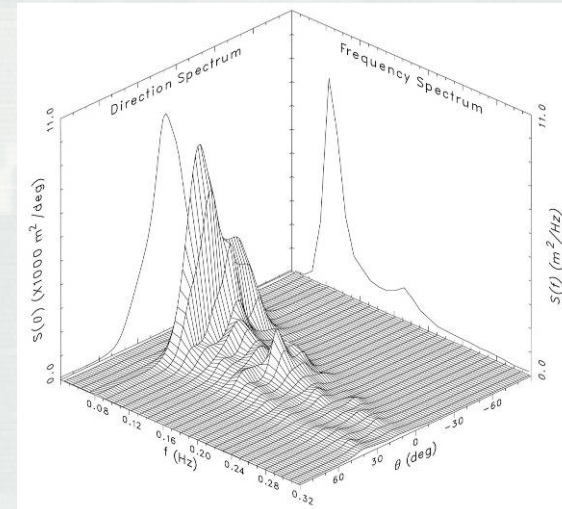
Note: x is normal to the offshore boundary;
 y is parallel to the offshore boundary





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:

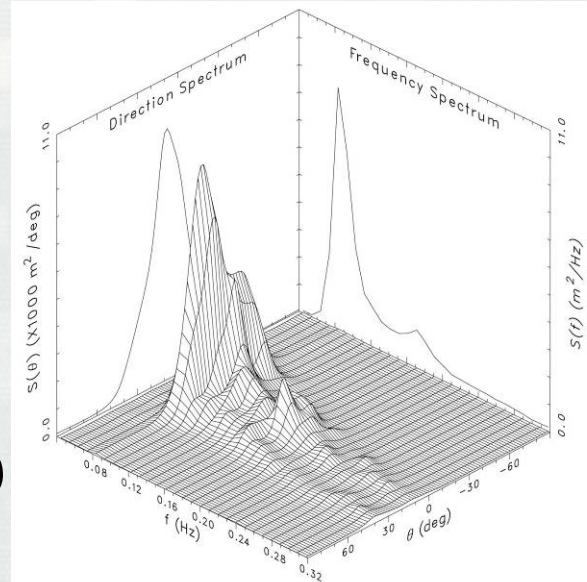
$$E = \frac{\alpha g^2}{\sigma^5} \exp(-0.74 \frac{\sigma_0^4}{\sigma^4}) \gamma^a D(\sigma, \theta)$$

where

$$D(\theta) = \frac{2^s}{\pi} \frac{\Gamma(s/2 + 1)}{\Gamma(s + 1)} \cos^s(\theta - \theta_0)$$

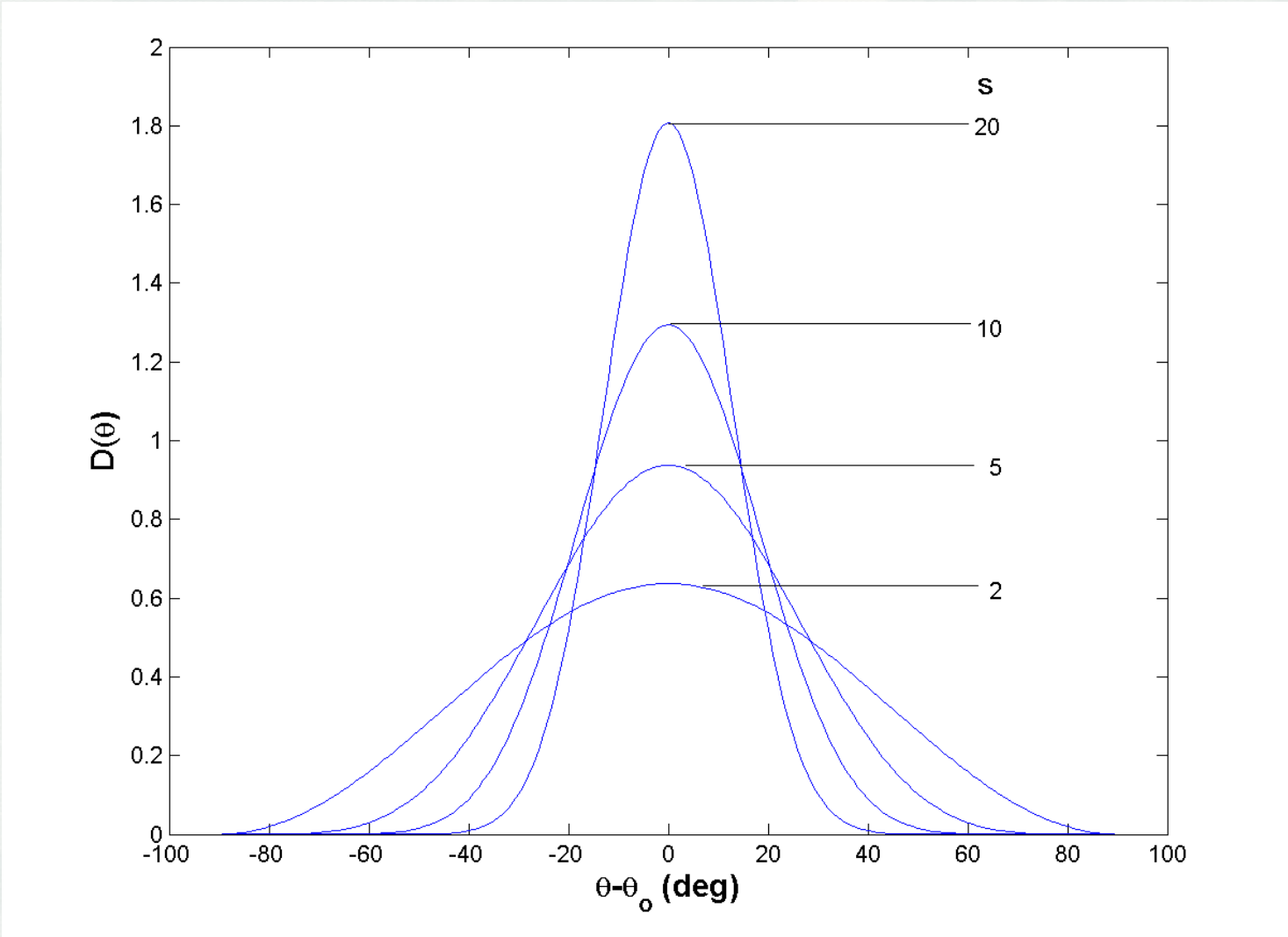
for $|\theta - \theta_0| < \pi/2$

and s is the directional spreading parameter.



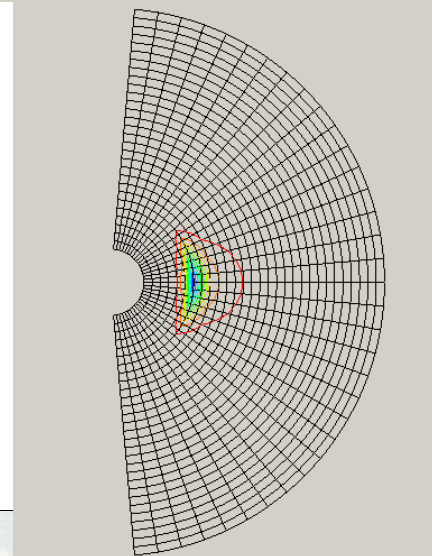
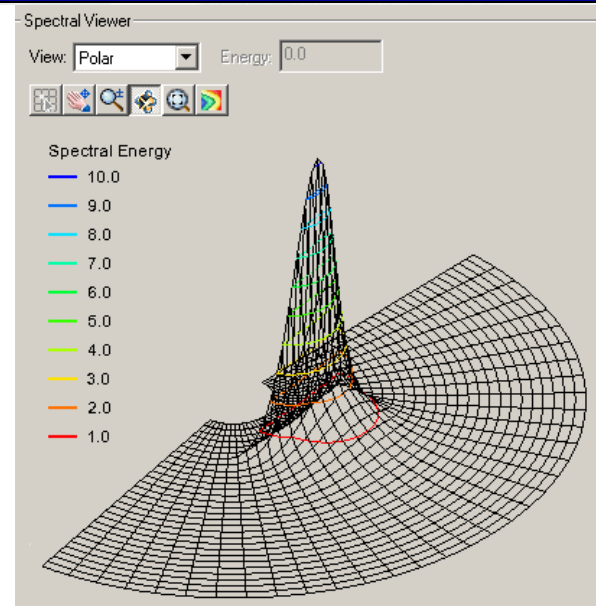
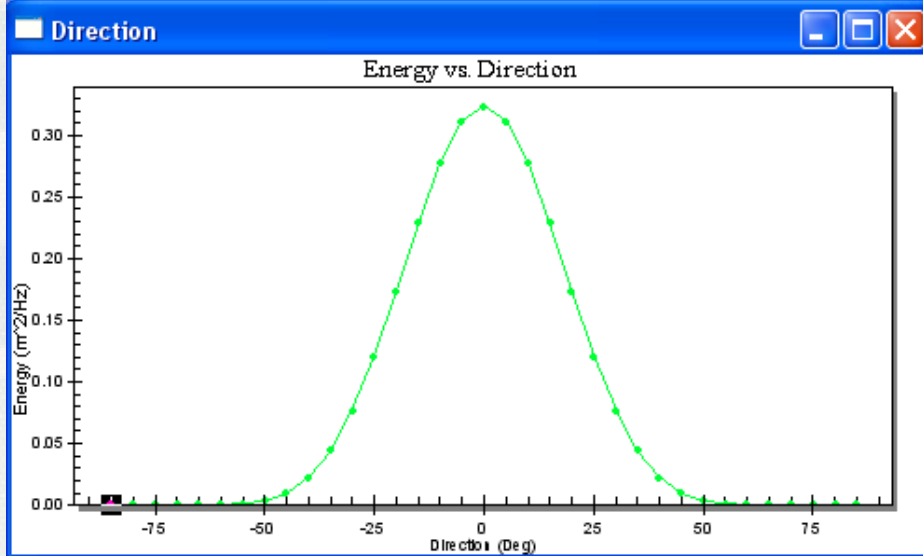
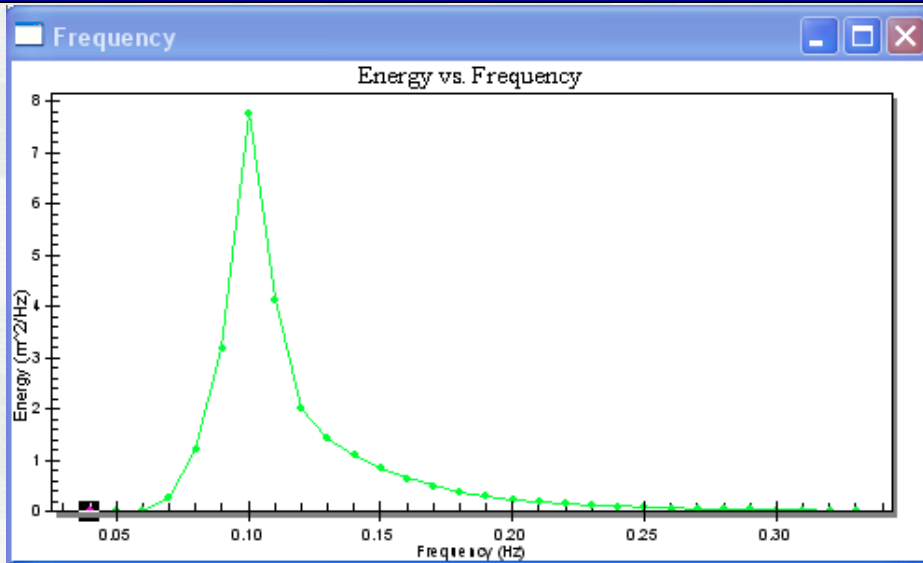


Idealized Directional Distribution





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:

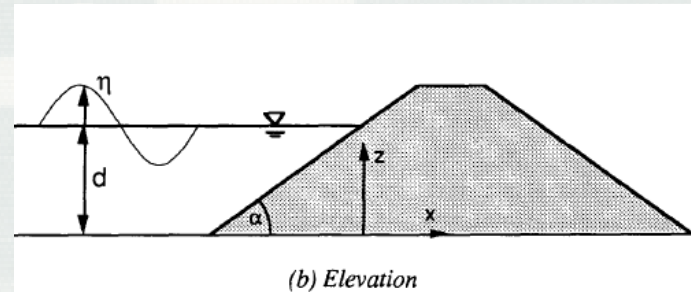
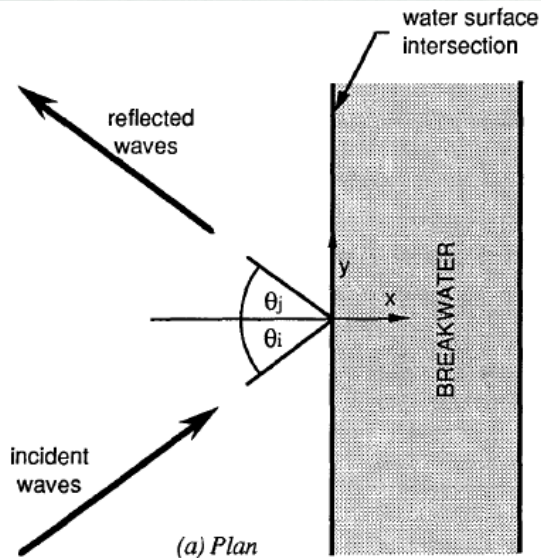
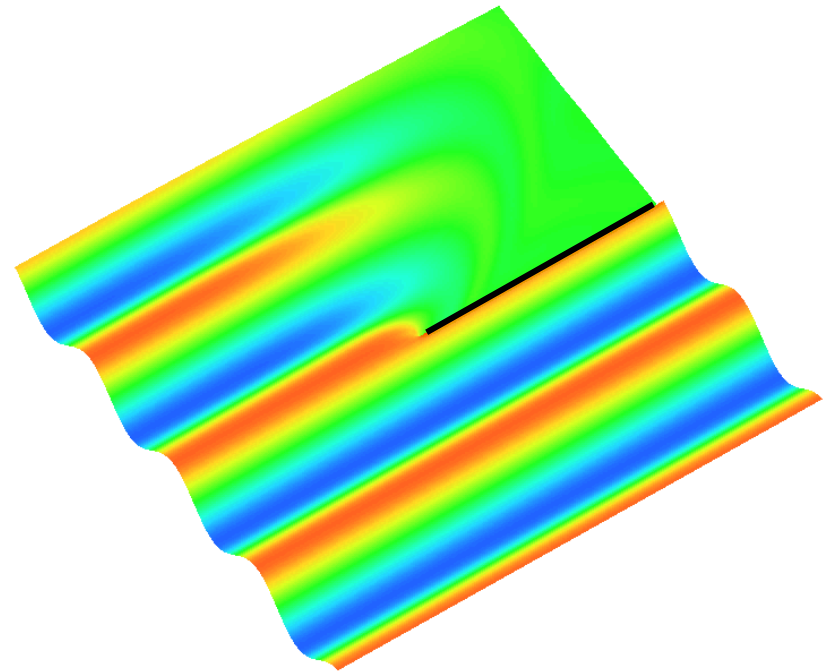
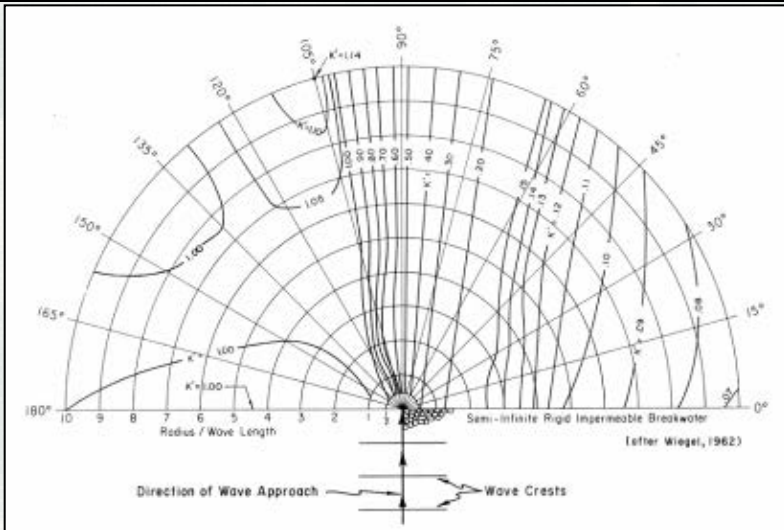
$$S_{xx} = E\left[n(\cos^2 \theta + 1) - \frac{1}{2}\right],$$

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

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

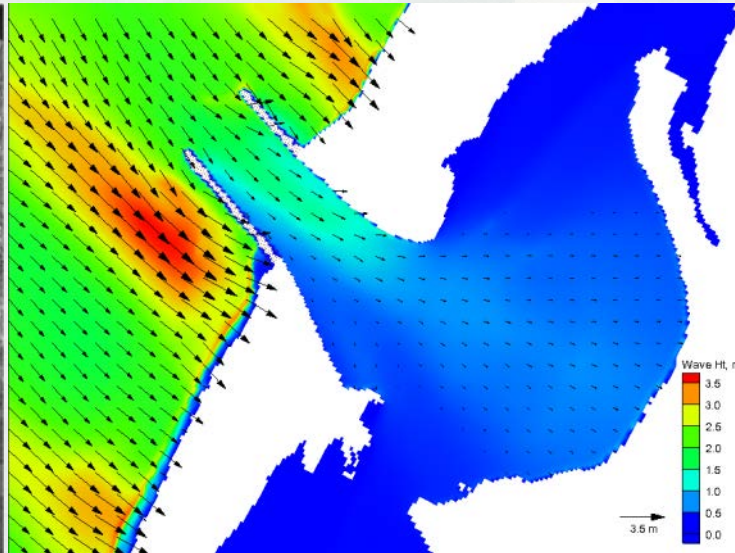


6. Jetty Breakwater Wave Diffraction and Reflection



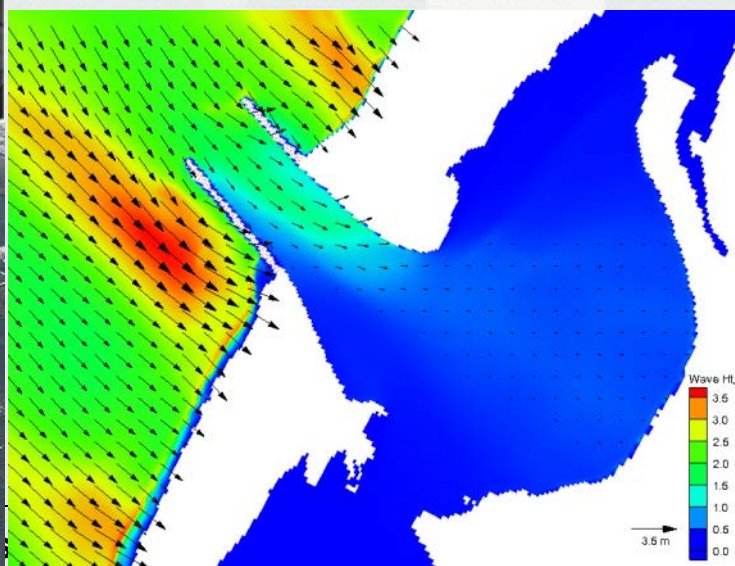


Infra-gravity Waves at *Humboldt Bay, CA*



Incident wave:
2 m, 15 sec
from NE

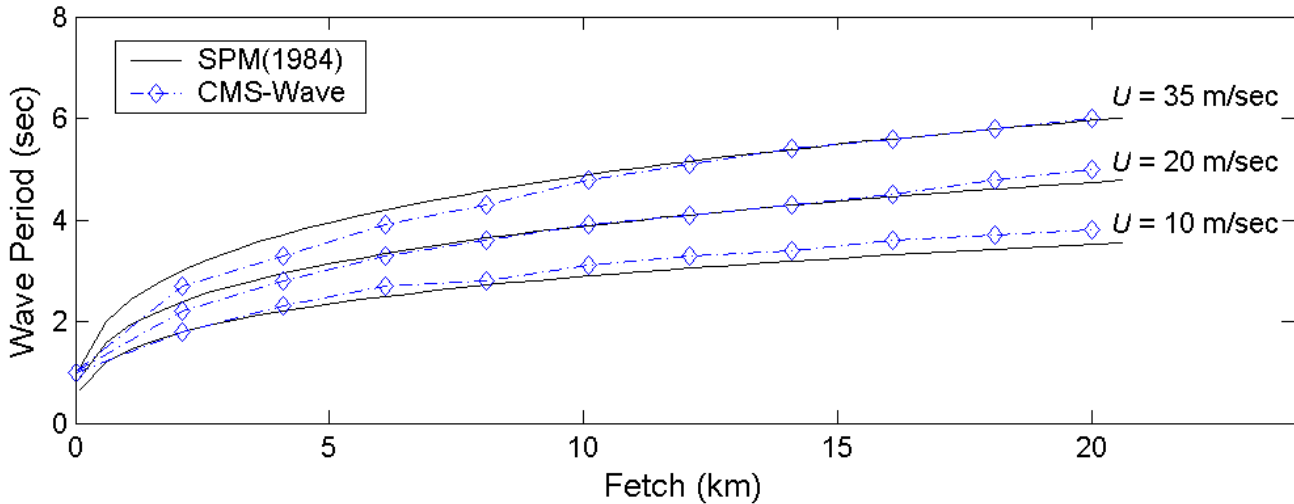
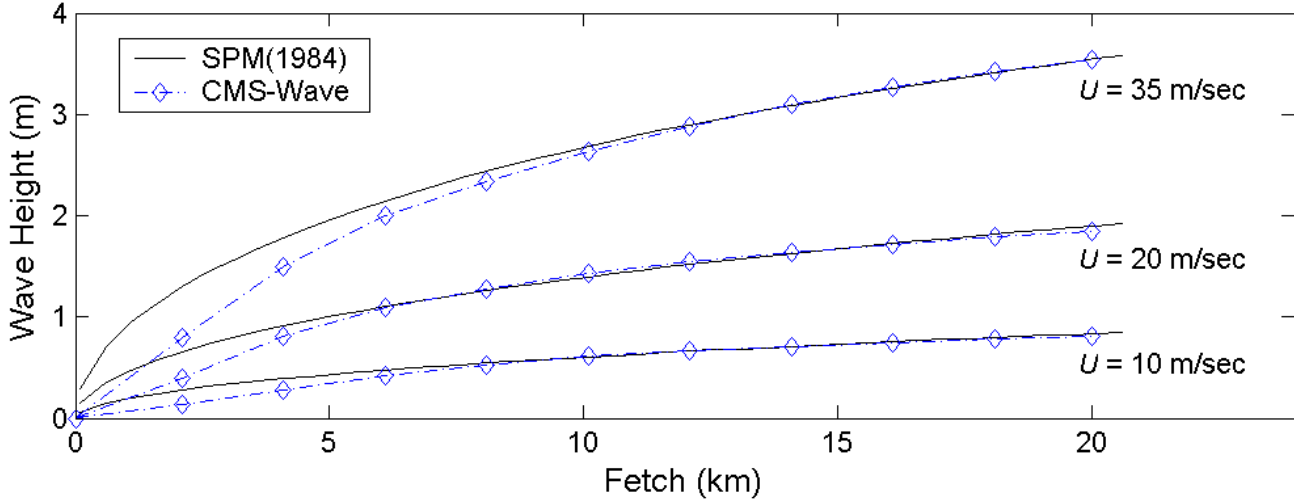
with infra-gravity wave



without infra-gravity wave



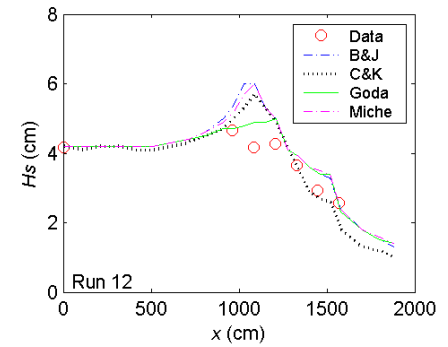
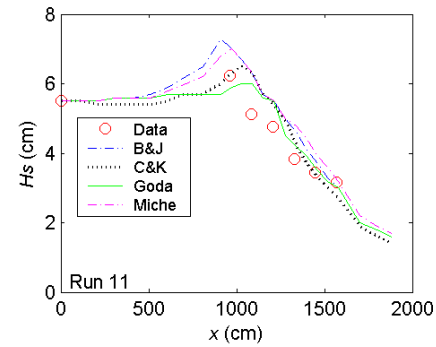
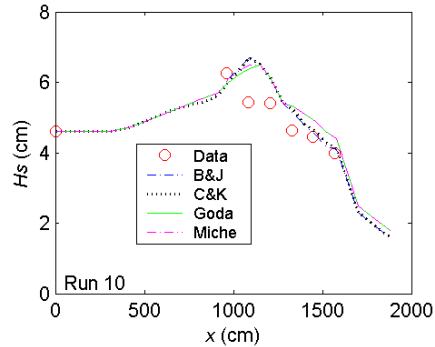
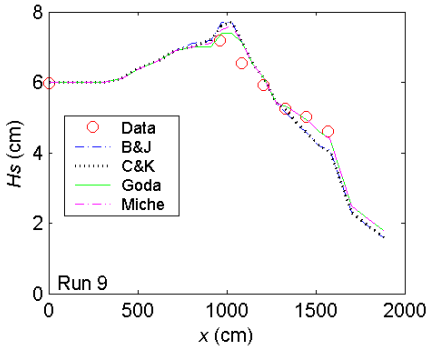
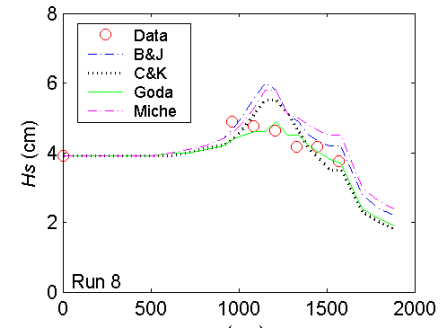
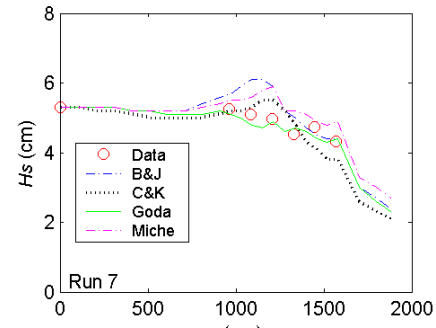
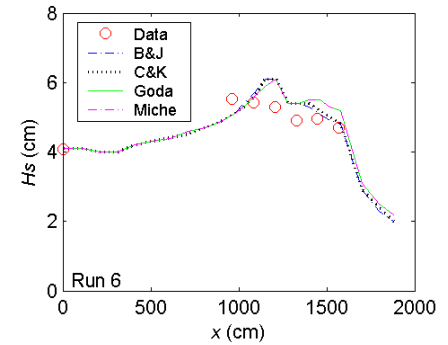
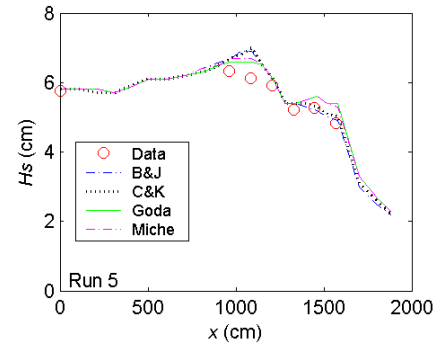
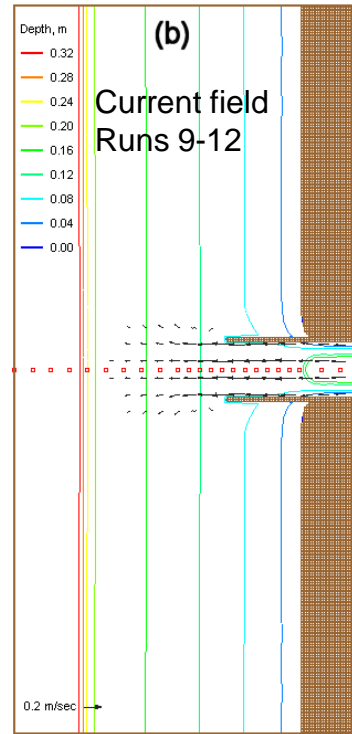
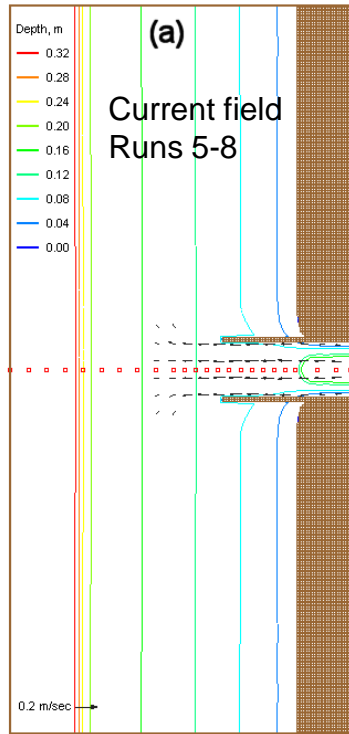
7. Wind-Wave Generation





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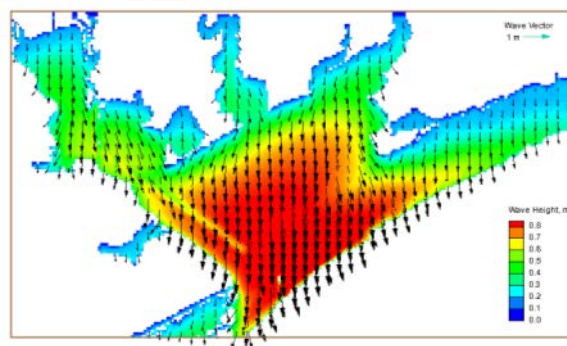
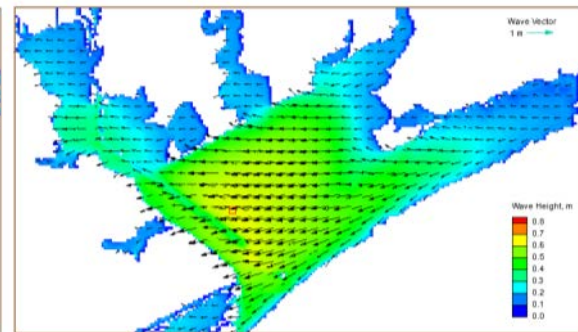
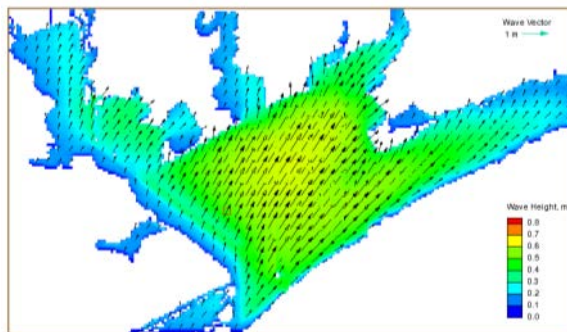
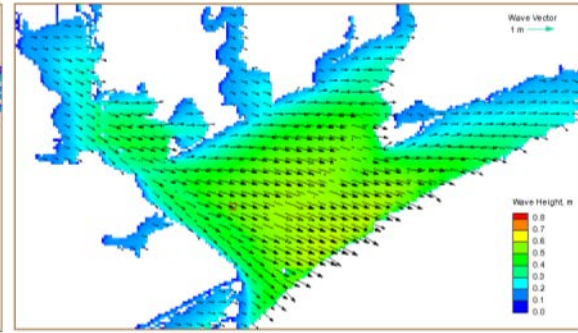
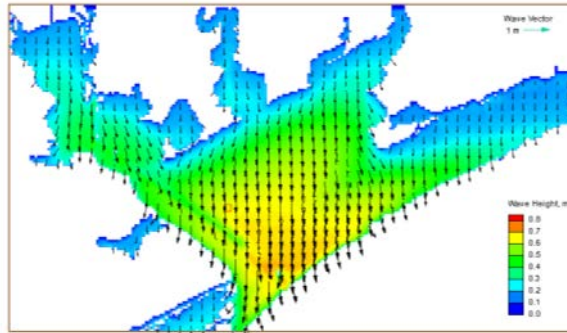
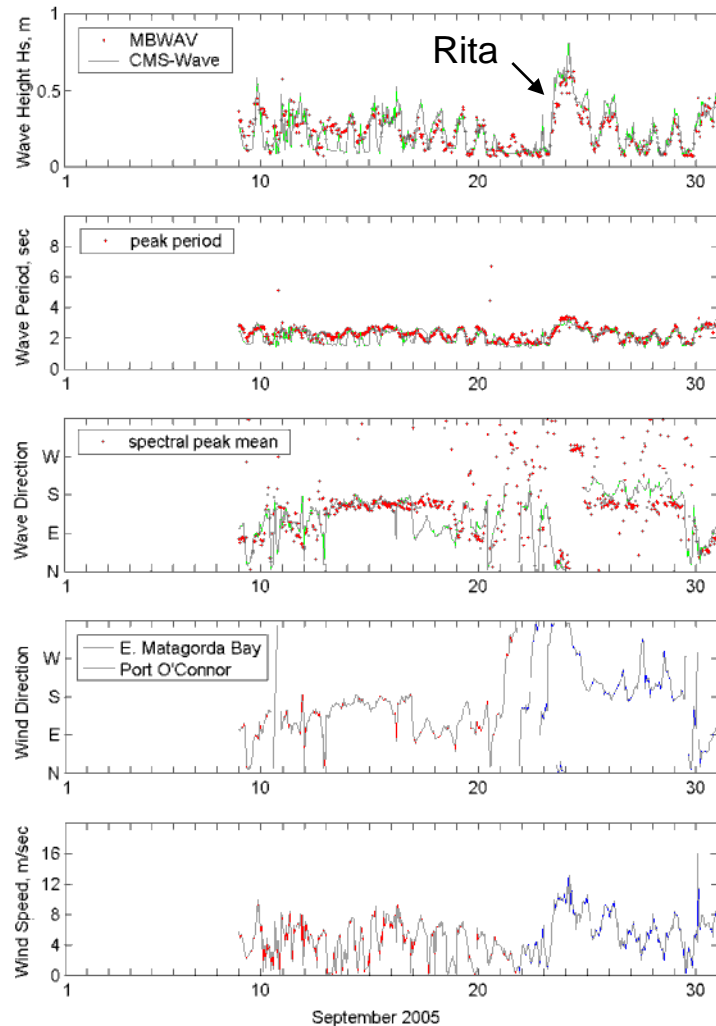
Wave Breaking Formulas





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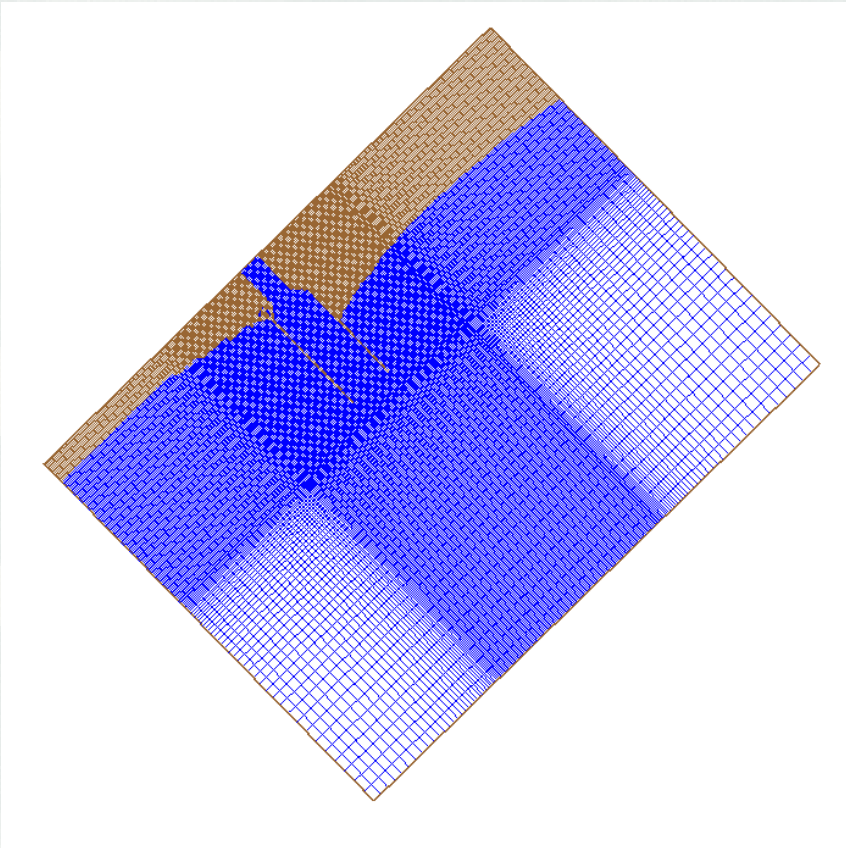
Wave Generation in *Matagorda Bay, TX*



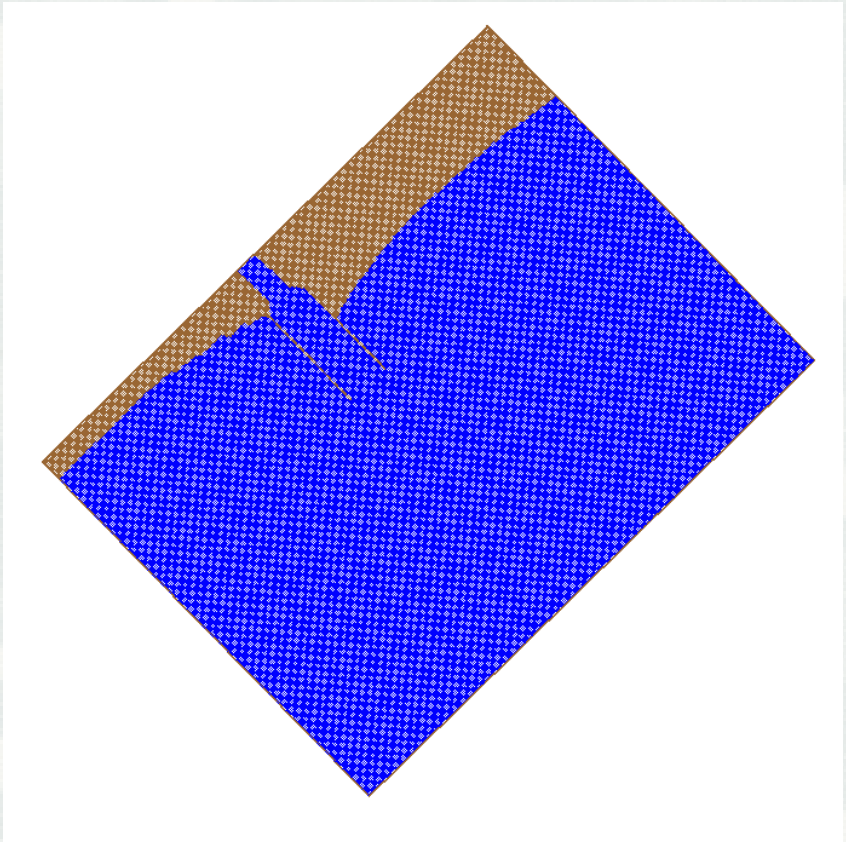
Hurricane Rita
0400 UTC, 24 September 2005



Variable Rectangular-Cell Grids



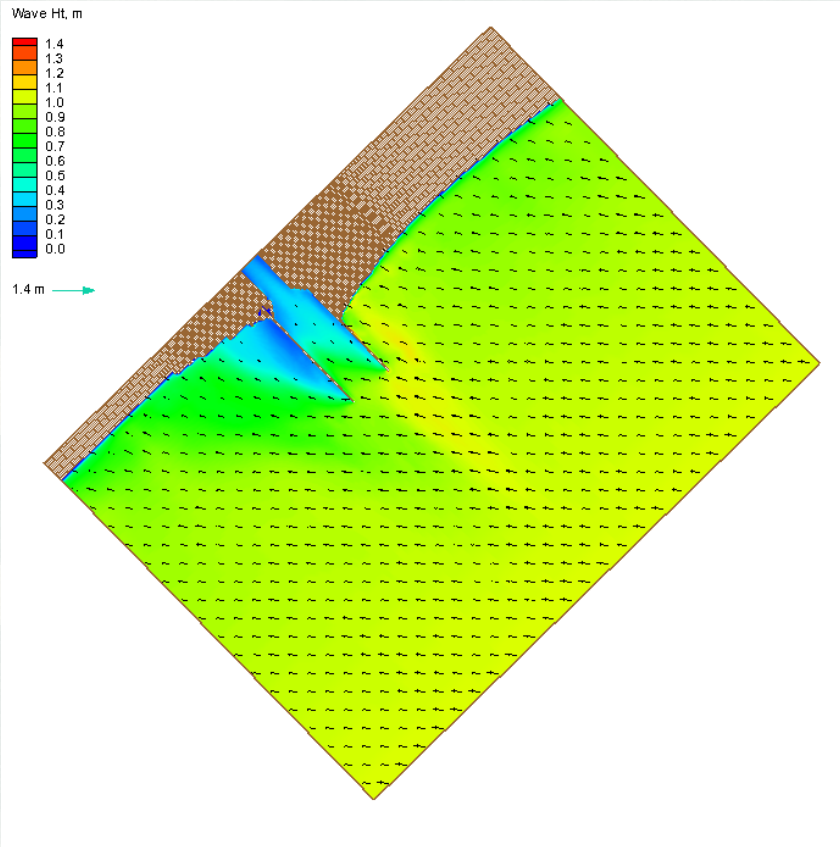
Variable-rectangular cells
Total 223 x 172 cells



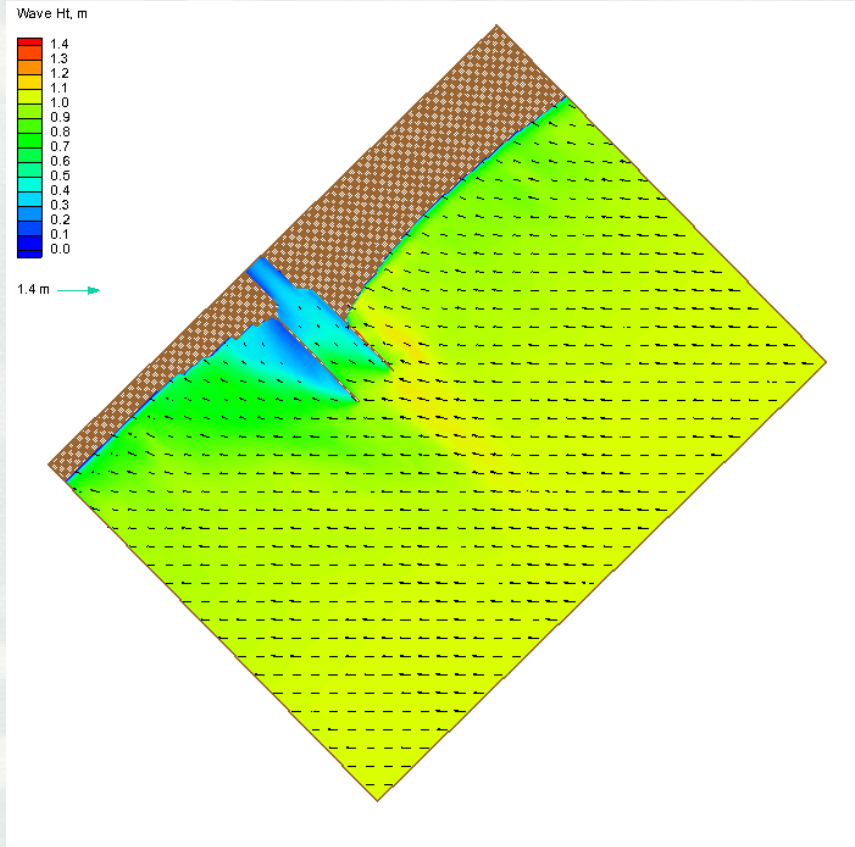
Square (20 m x 20 m) cells
Total 316 x 426 cells



CMS-Wave on Variable Grids



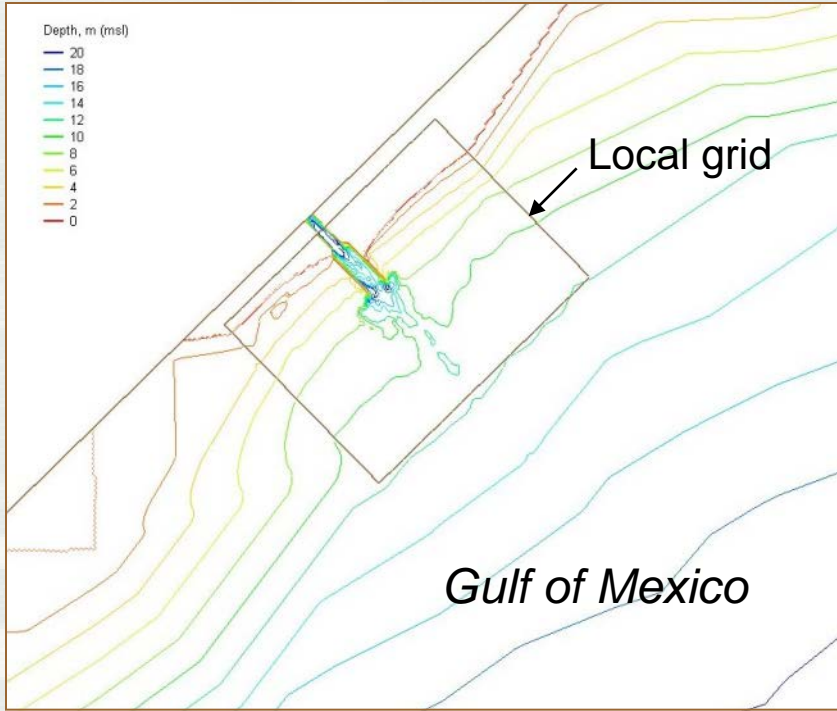
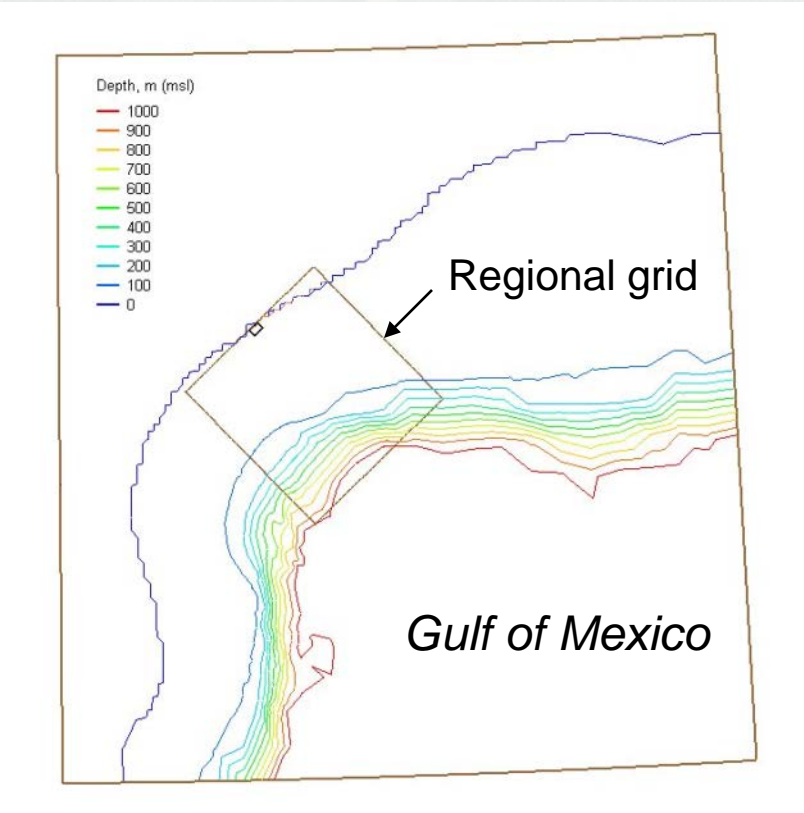
Variable-rectangular cells
Total 223 x 172 cells



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



Grid Nesting



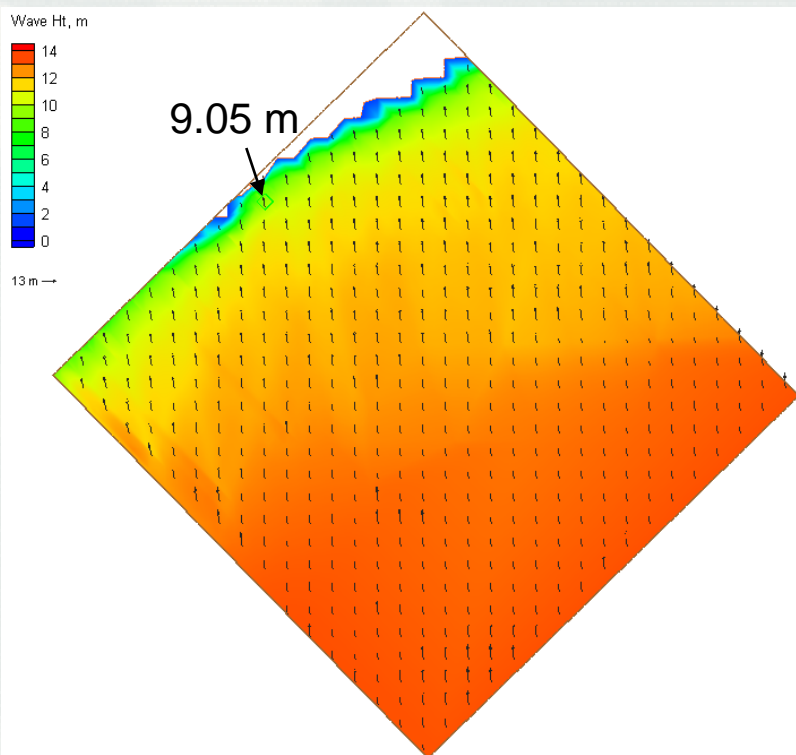


Regional Wave Generation

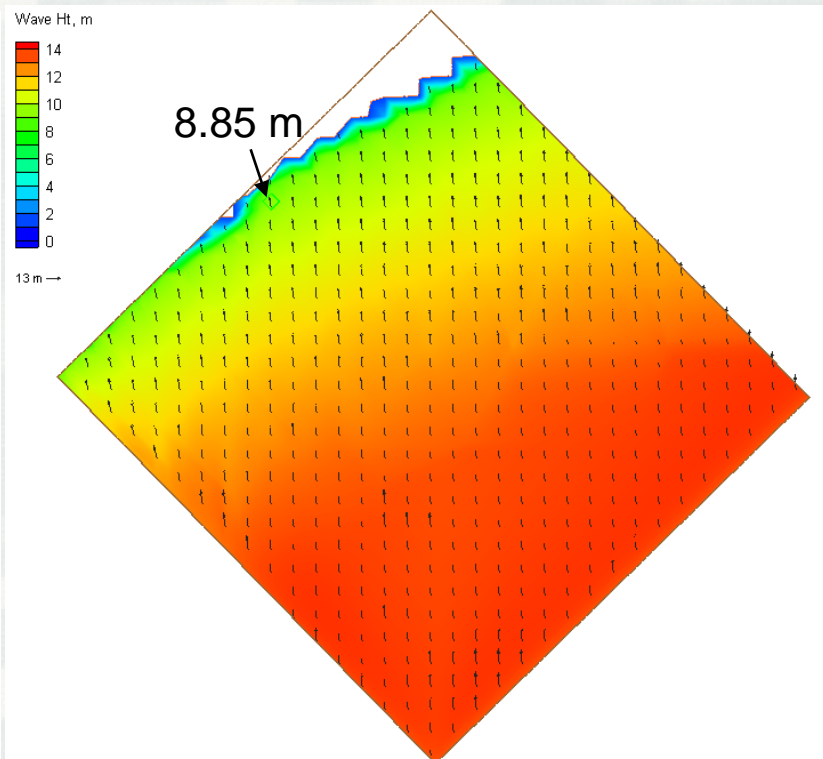
Incident Waves: 12.9 m, 13.8 sec, from S



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



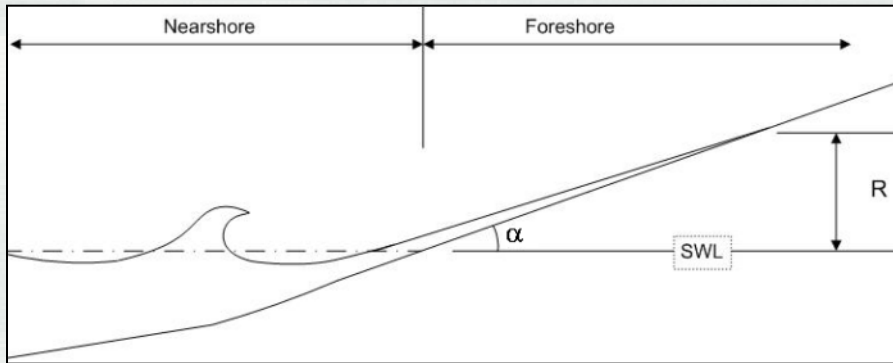
Without wind



With wind (27 m/sec, from S)



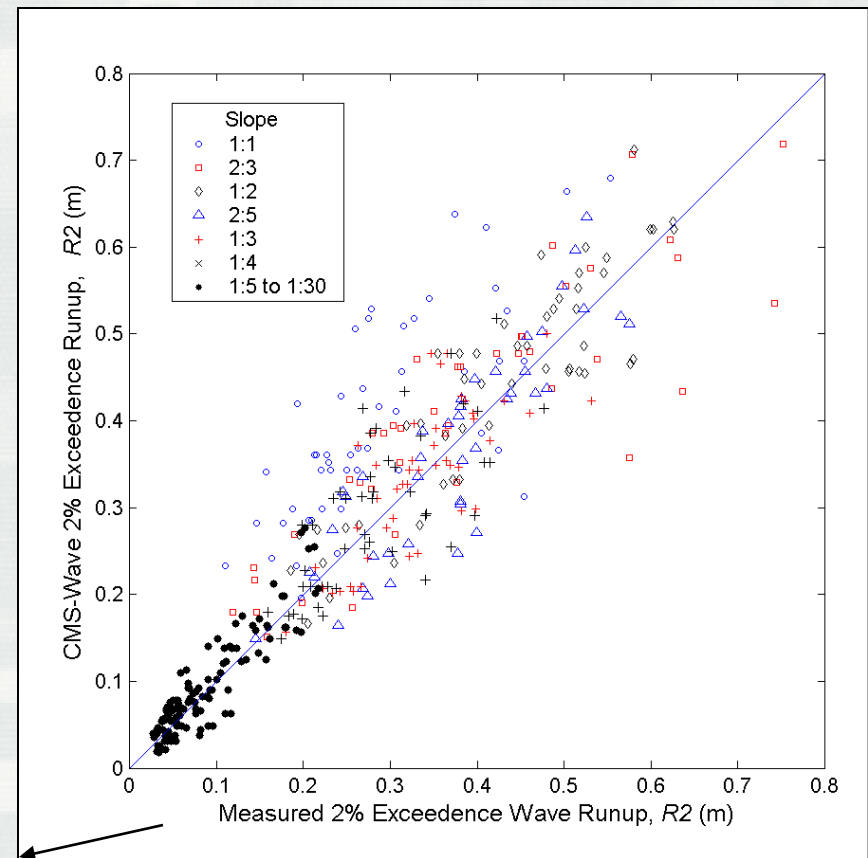
8. Wave Run-up



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

Two-percent run-up, R_2 : 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

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

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

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

$$\text{Max water level} = \max \left(\eta + H_s / 2, R2 \right)$$

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



Specify Feature Cells in SMS11.0

The screenshot displays the SMS 11.0 64-bit interface. The main window shows a bathymetric map with a grid of cells. A red arrow points from the 'Assign Cell Attributes...' option in the 'Depth' layer's context menu to a specific cell on the map. The 'Cell Attributes' dialog box is open, showing the 'Structure' radio button selected and the 'Type' dropdown menu set to 'Rubble-mound'. The 'Type' dropdown menu is circled in red, and the 'Rubble-mound' option is highlighted. The dialog box also includes options for 'Default', 'Monitoring', 'Nesting output', and 'GenCade monitoring station'. The status bar at the bottom indicates 'Cell info: 1 selected; Area = 392.125 m²; Volume = 1511.83 m³; id'.



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):

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

Composite or rubble-mound breakwater:

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

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

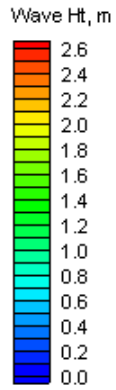


Idealized Island Example

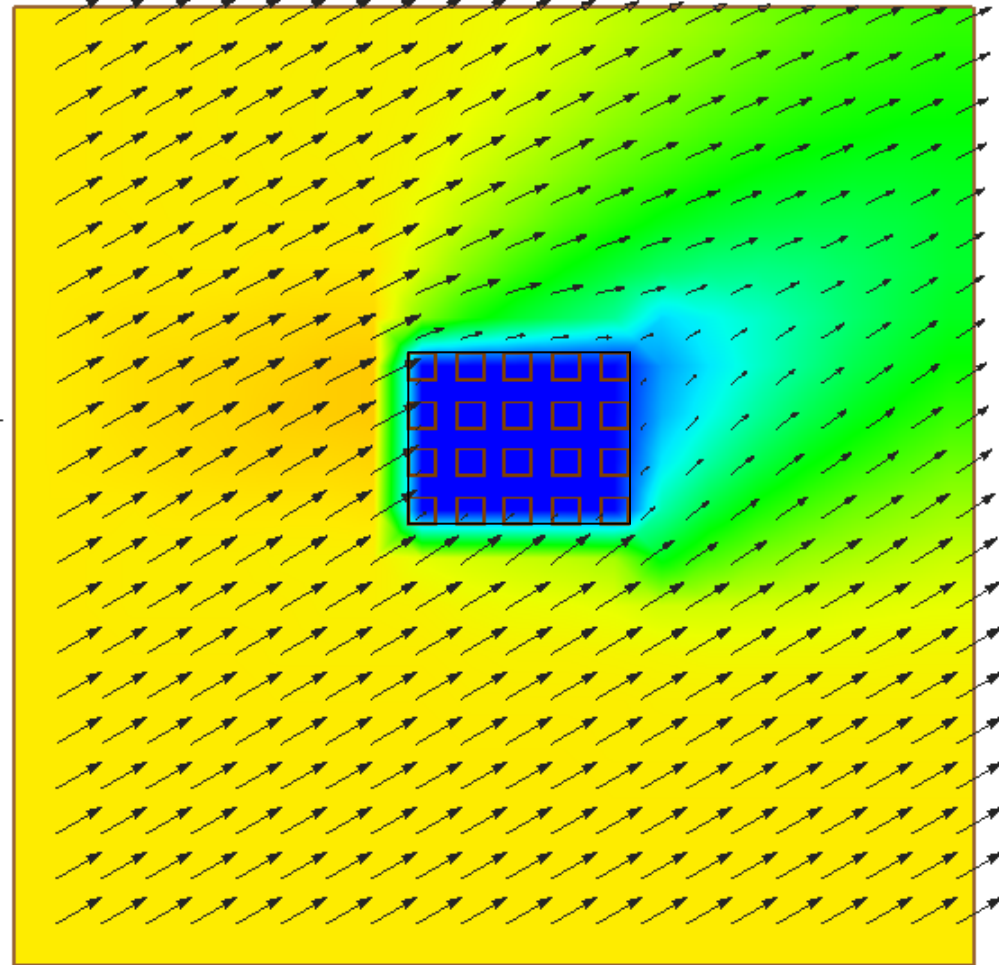


- 20
- 9 10
- 10 10
- 11 10
- 12 10
- 13 10
- 9 11
- 10 11
- 11 11
- 12 11
- 13 11
- 9 15
- 10 15
- 11 15
- 12 15
- 13 15
- 9 16
- 10 16
- 11 16
- 12 16
- 13 16

struct.dat



2.50 m →



20 feature cells

input depth = 10 m

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

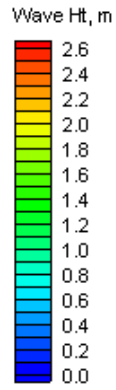


Idealized Floating Breakwater

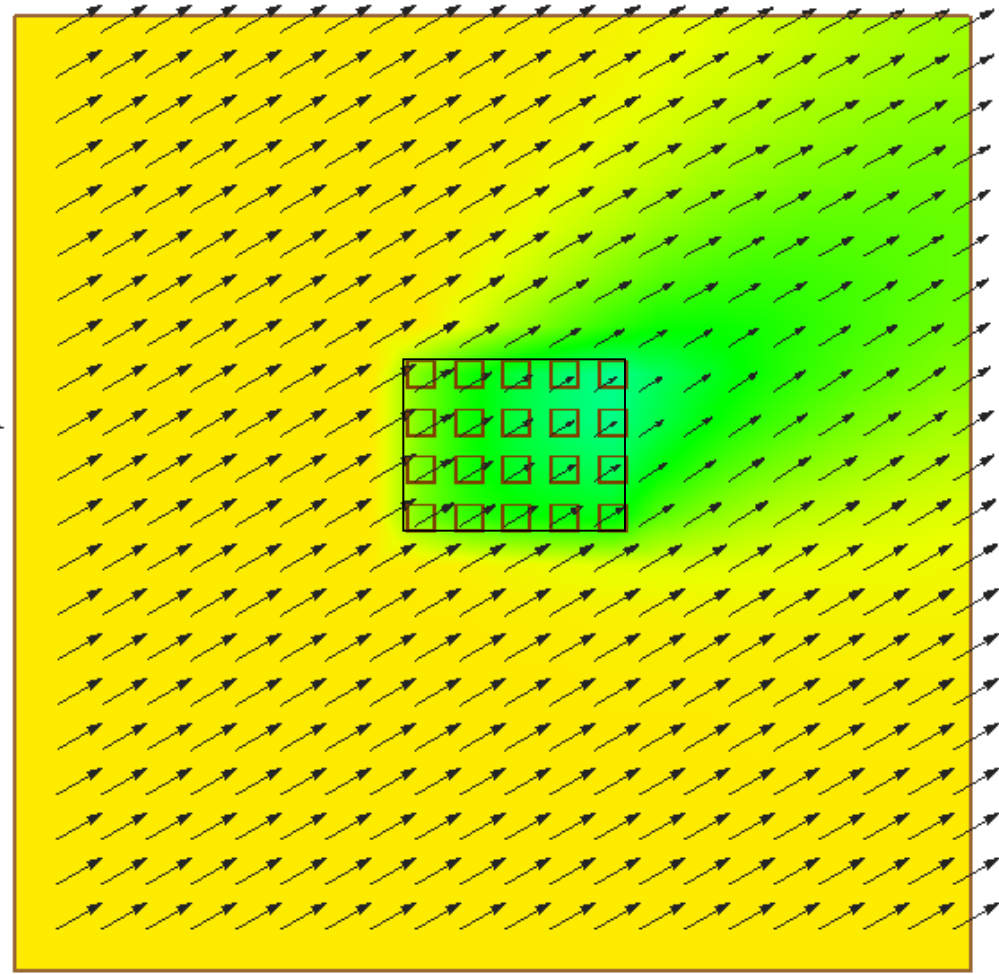


- 20
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- 12 10 3 2
- 13 10 3 2
- 9 11 3 2
- 10 11 3 2
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- 12 11 3 2
- 13 11 3 2
- 9 15 3 2
- 10 15 3 2
- 11 15 3 2
- 12 15 3 2
- 13 15 3 2
- 9 16 3 2
- 10 16 3 2
- 11 16 3 2
- 12 16 3 2
- 13 16 3 2

struct.dat



2.50 m →



- 20 feature cells
- Input depth = 10 m
- incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)
- draft = 2 m



Idealized Platform

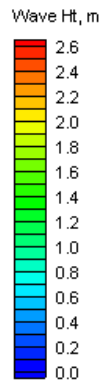


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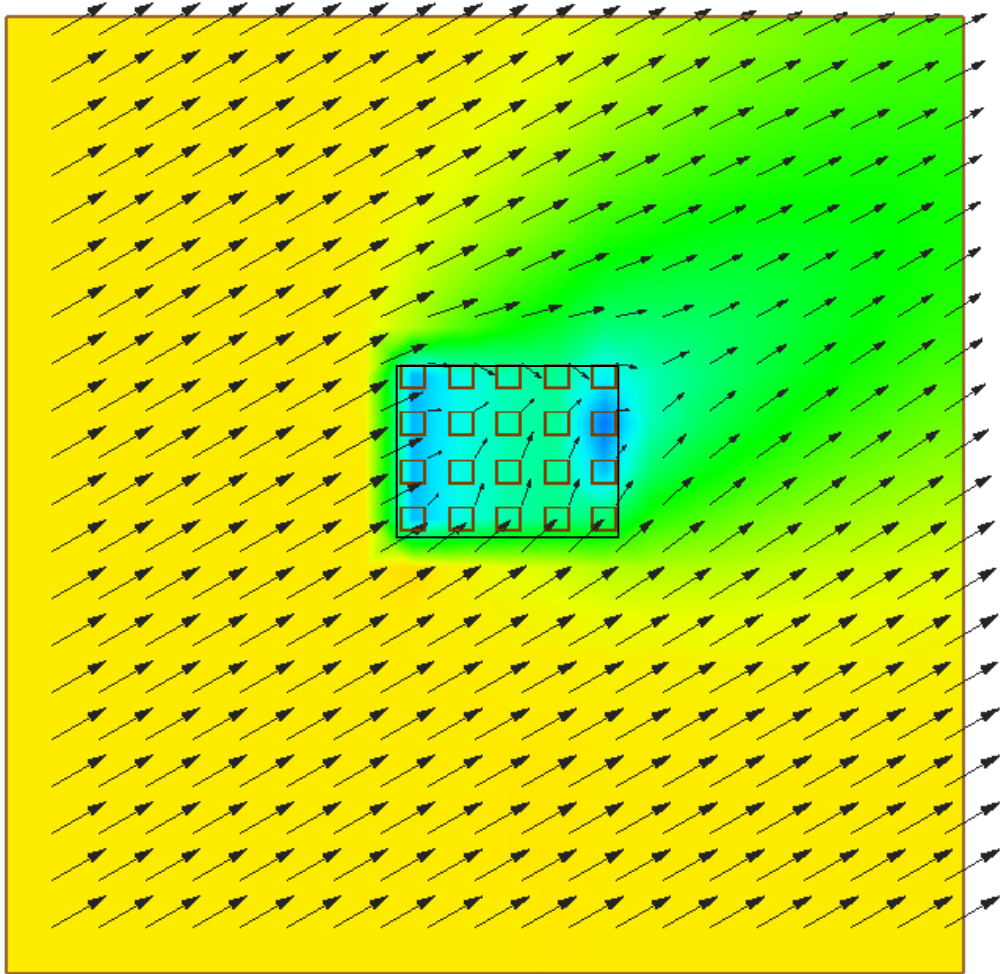
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 9 15 4 1
10 15 4 1
11 15 4 1
12 15 4 1
13 15 4 1
 9 16 4 1
10 16 4 1
11 16 4 1
12 16 4 1
13 16 4 1

```

struct.dat



2.50 m



20 feature cells

input depth = 10 m

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

platform elev. = 1 m (mwl)

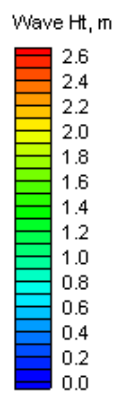


Submerged Platform

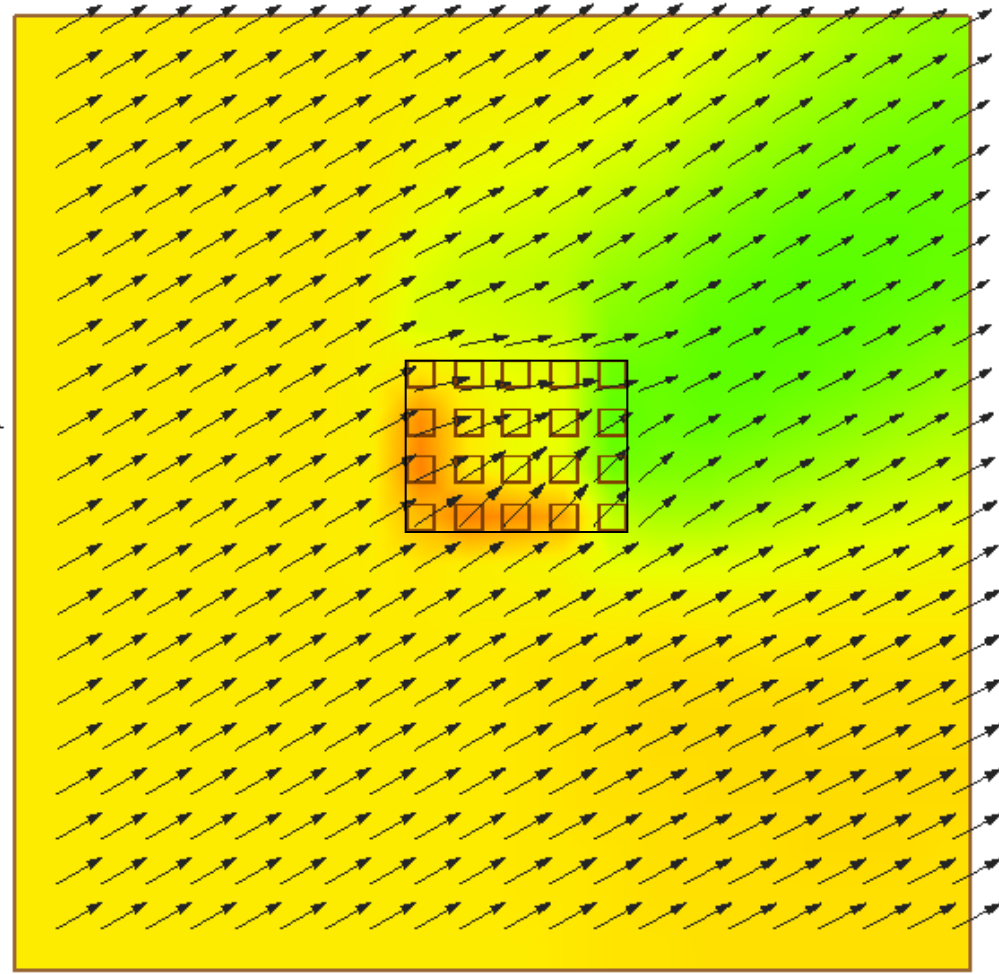


- 20
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- 10 10 4 -2
- 11 10 4 -2
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- 12 11 4 -2
- 13 11 4 -2
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struct.dat



2.50 m



20 feature cells

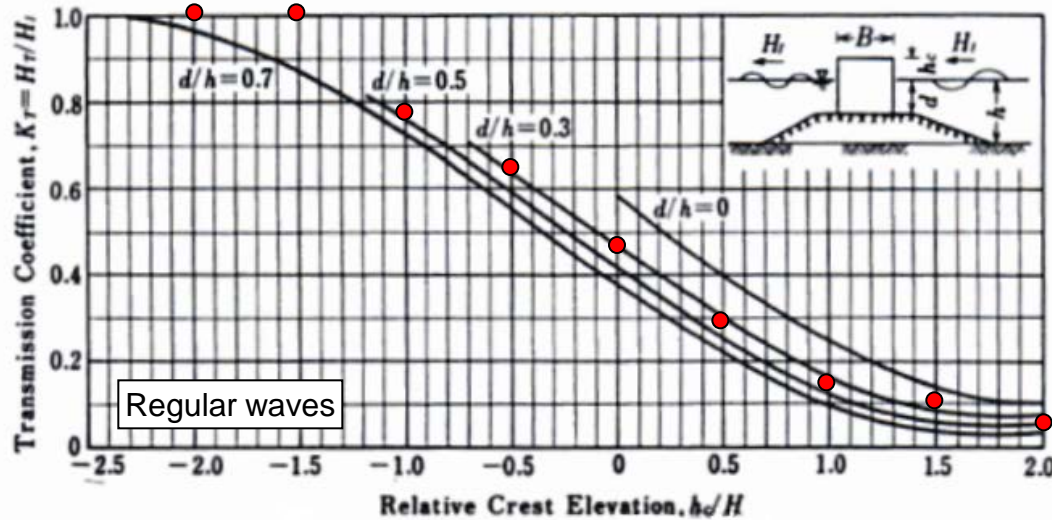
input depth = 10 m

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

platform elev. = -2 m (mwl)



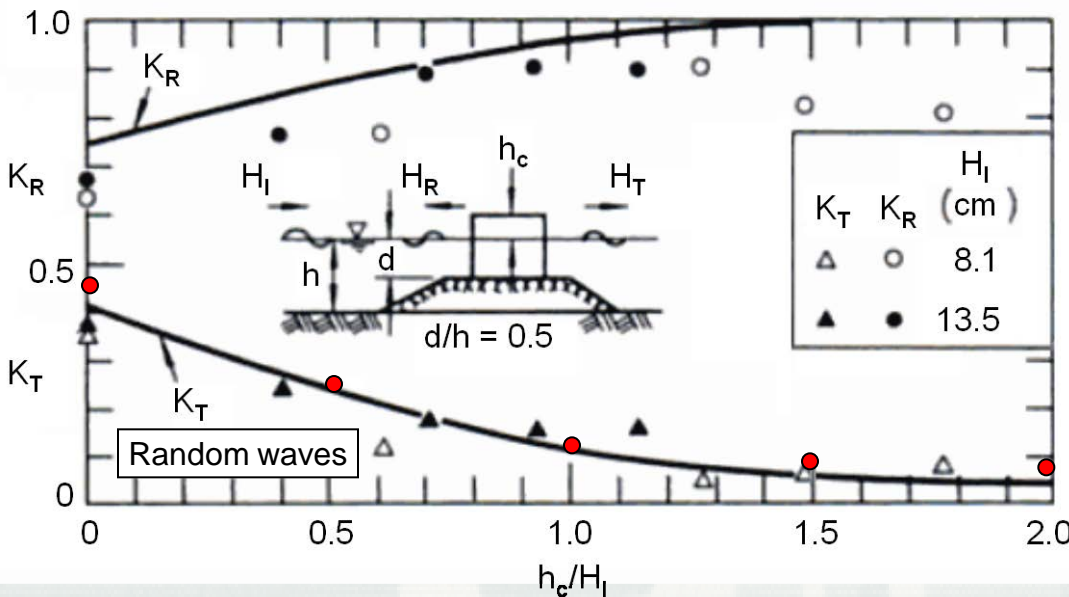
Wave Transmission Experiment (Goda, 2000)



Transmission coefficients k_t

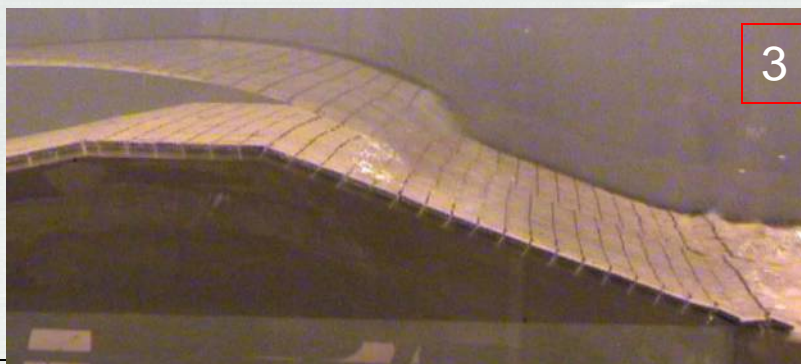
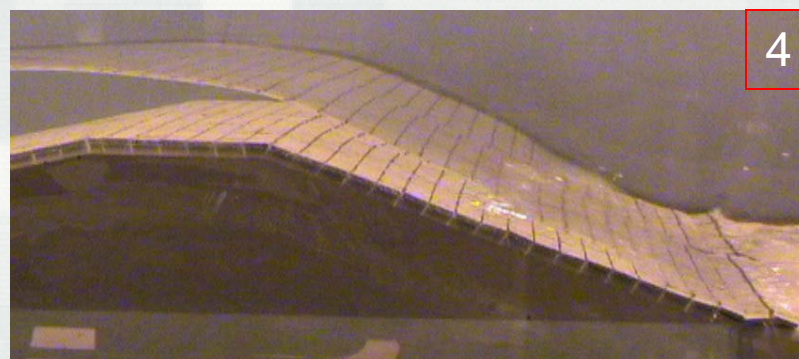
$H_i = 1$ m, $T_p = 6$ sec (monochromatic wave)
 $h = 10$ m, $d = 5$ m, $B = 80$ m

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)
 $H_s = 0.88$ m, $T_p = 10.1$ sec (Hughes, 2008)



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

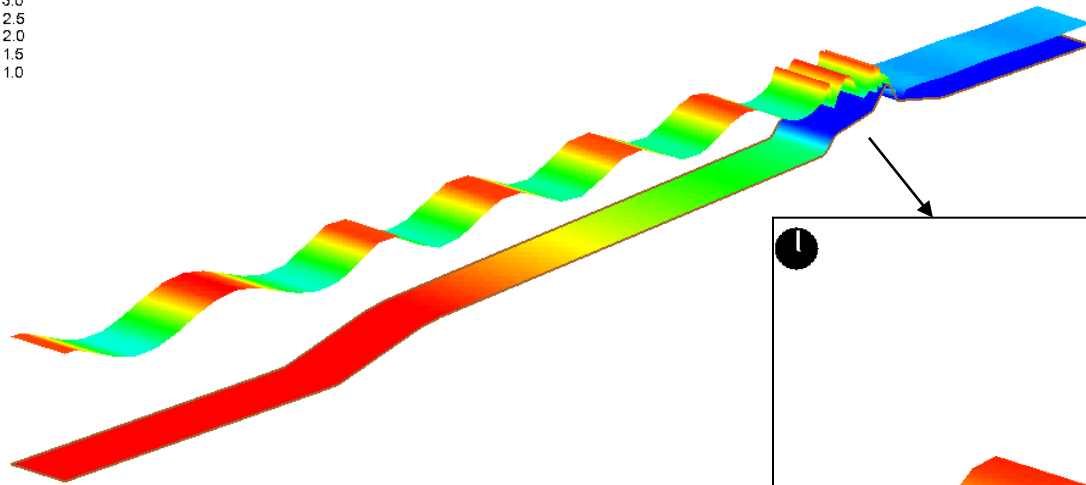
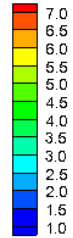


Calculated Wave Overtopping R127

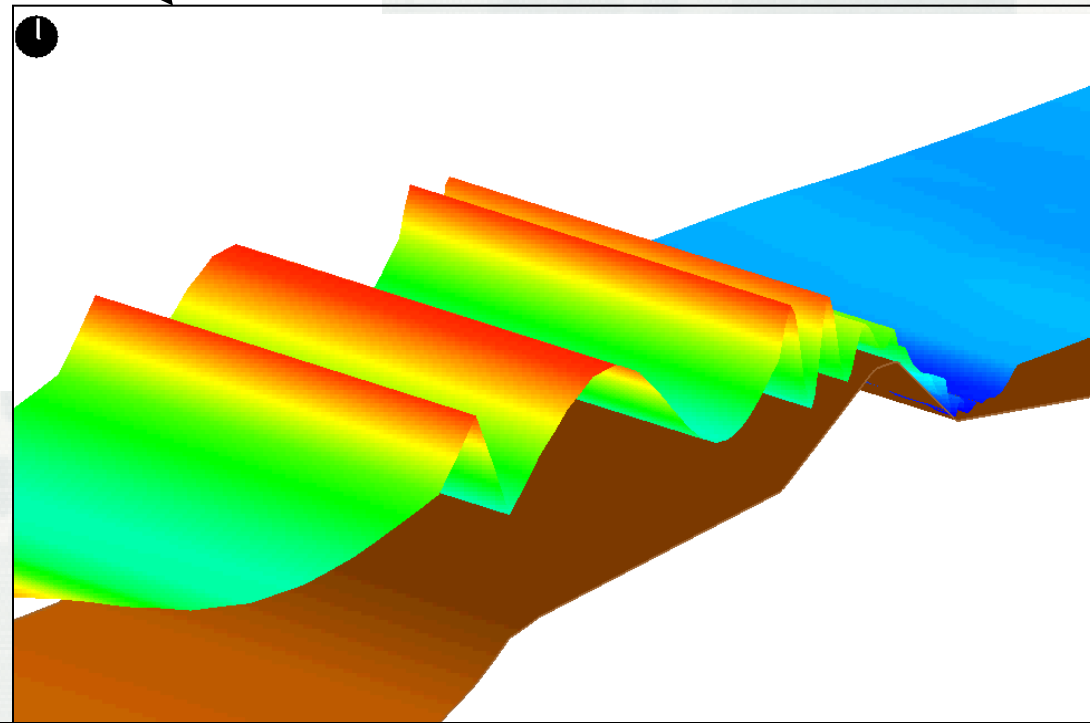
Surge level = 1.3 m, $H_s = 2.3$ m, $T_p = 14$ sec



Water surface, m



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):

$$S_{dp} = -4(v_k + v_t)k^2 E$$

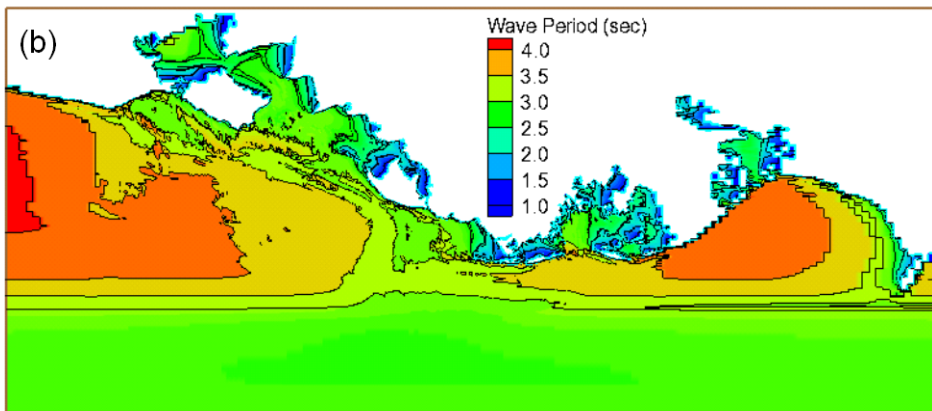
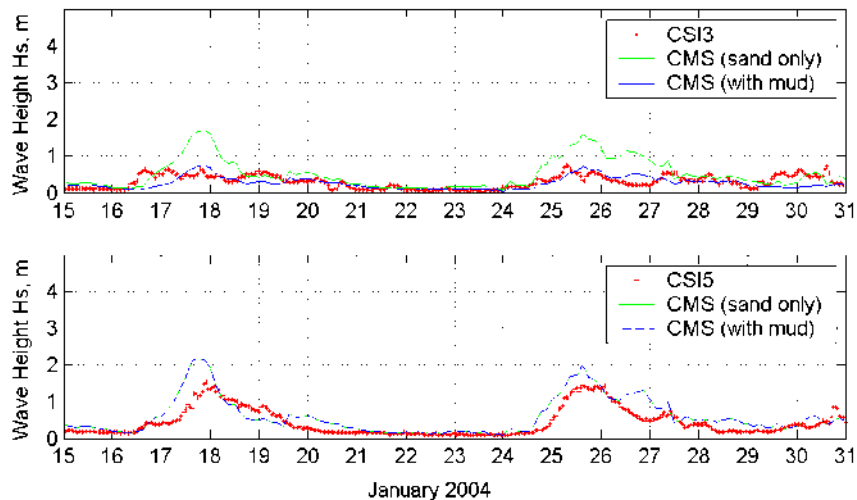
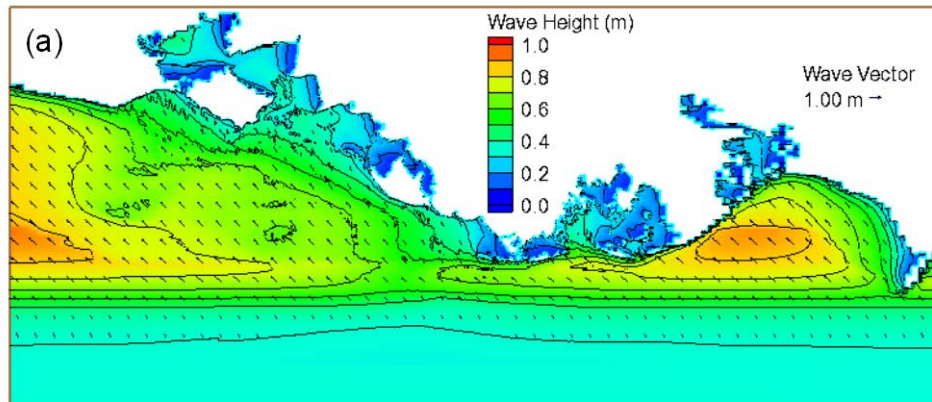
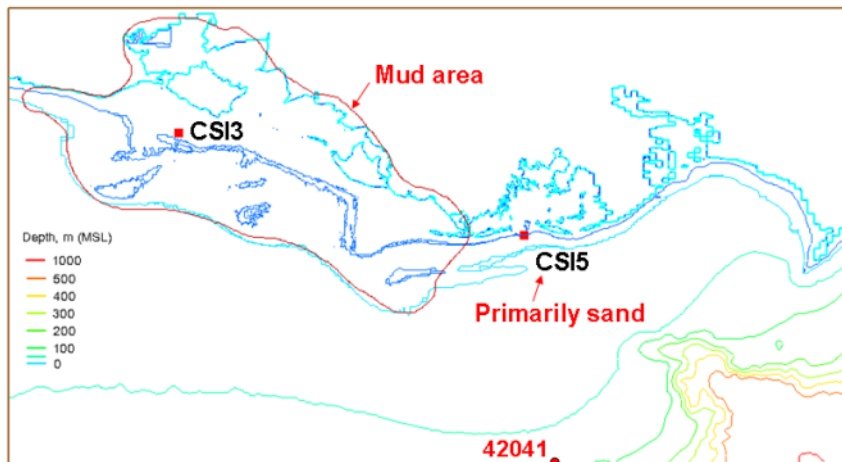
where v_k is the kinematic viscosity of sea water,

and v_t is the turbulent eddy viscosity:

$$v_t = v_{t,breaking} \frac{H_s}{h}$$



Louisiana Muddy Coast Simulation

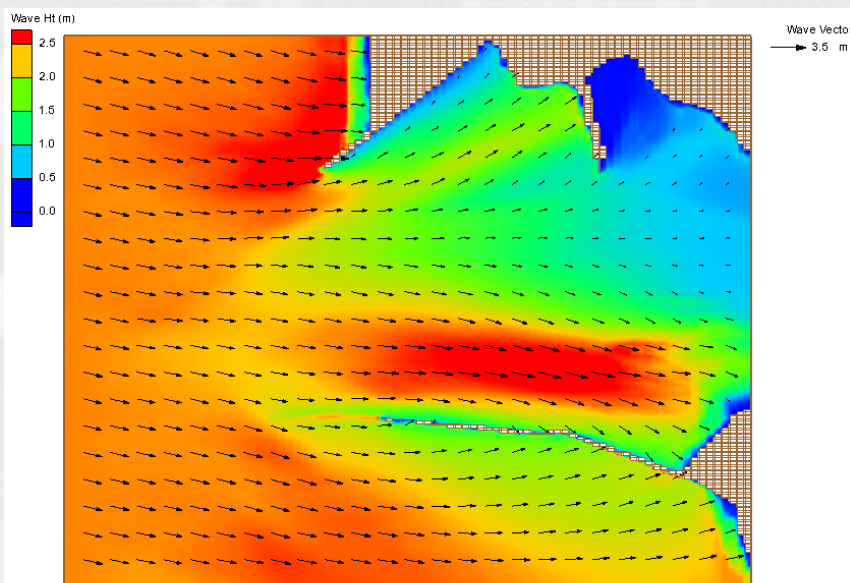




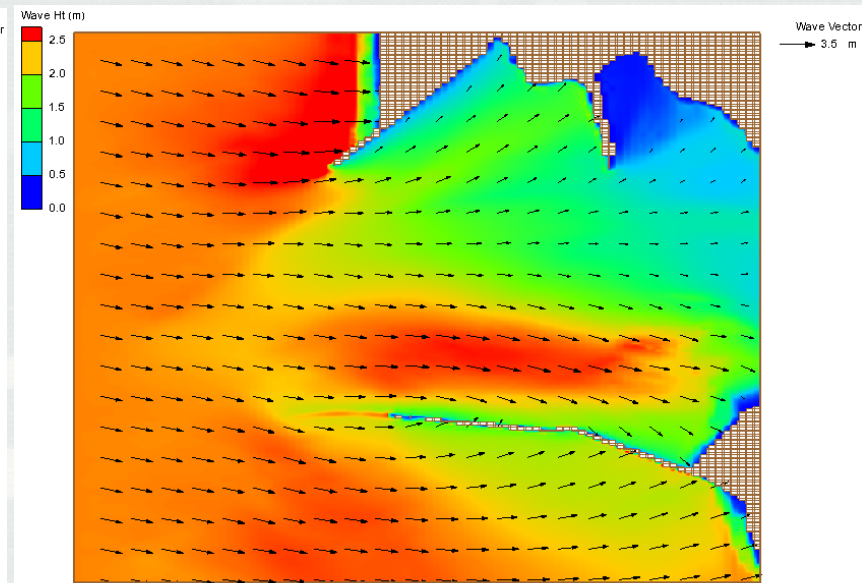
CMS-Wave Fast Mode (Simplified Formulation)



- 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

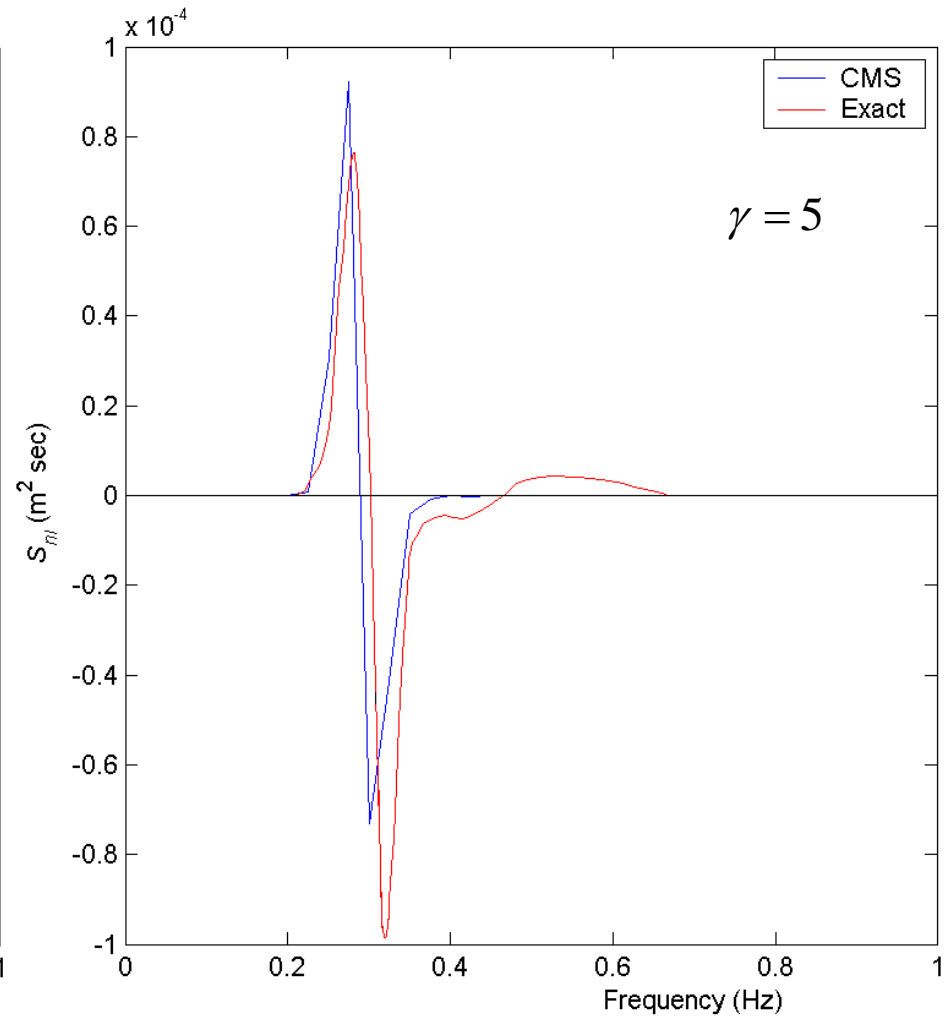
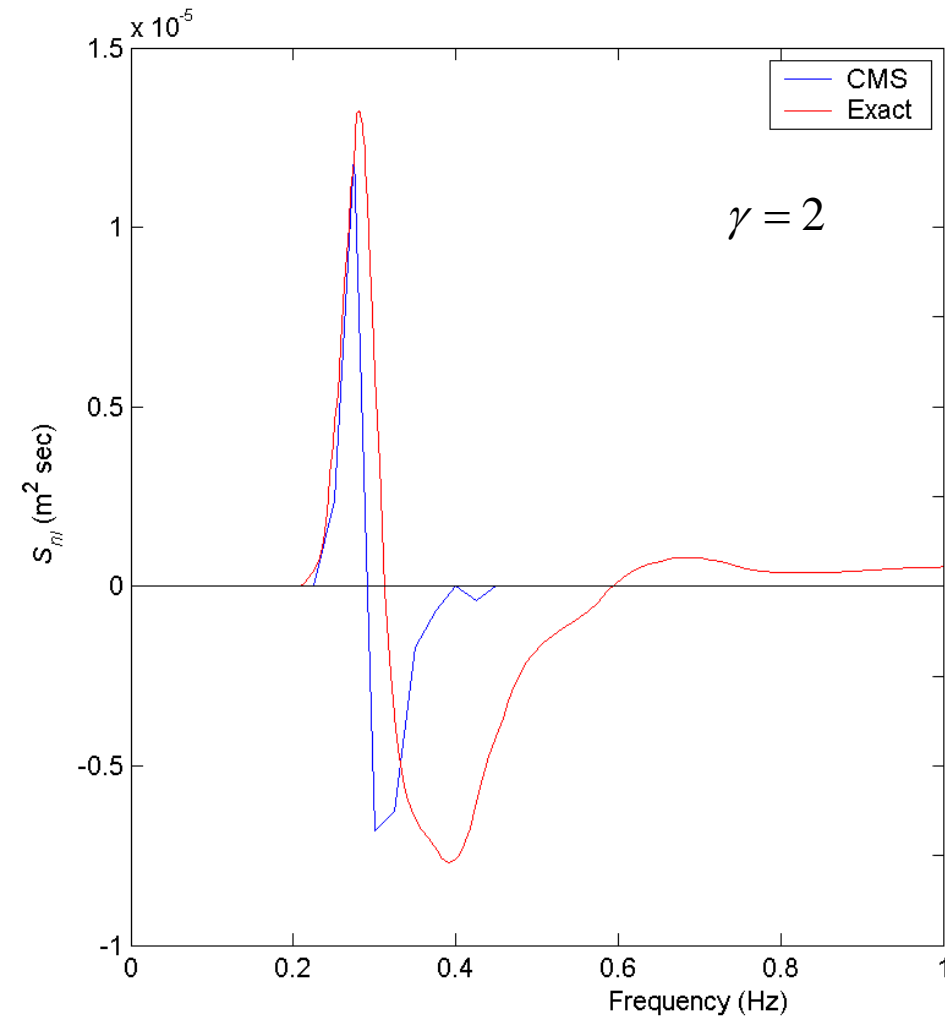
Anisotropic S_{nl} :
$$S_{nl} = a(\sigma) \frac{\partial B}{\partial \sigma} + b(\sigma) \frac{\partial^2 B}{\partial \theta^2} \quad (\text{Jenkins \& Phillips, 2001})$$

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

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

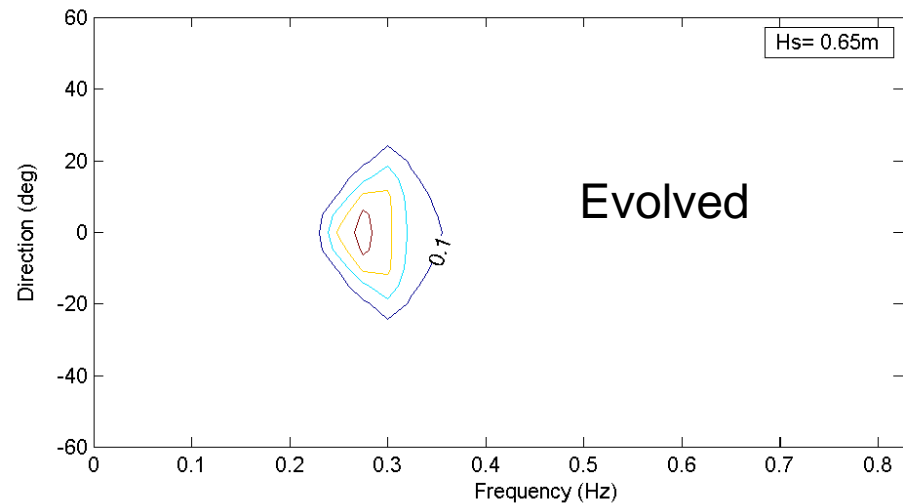
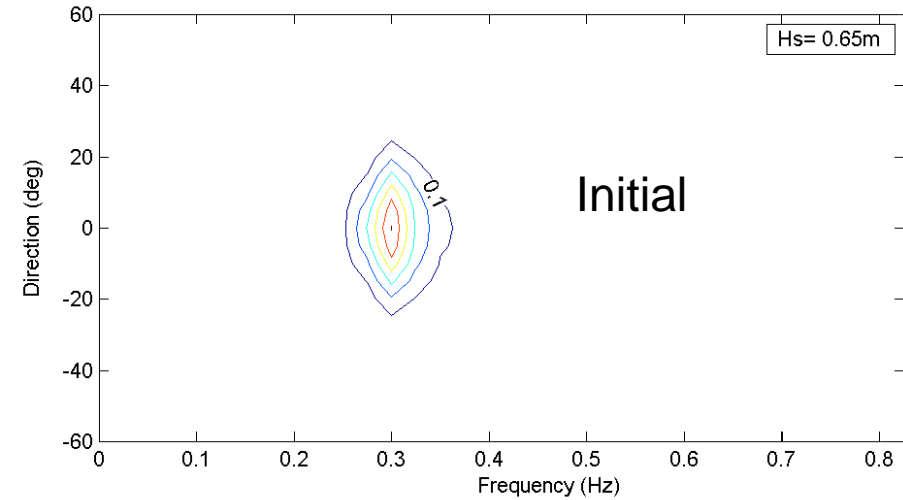


Exact and Calculated $S_{nl}(f)$

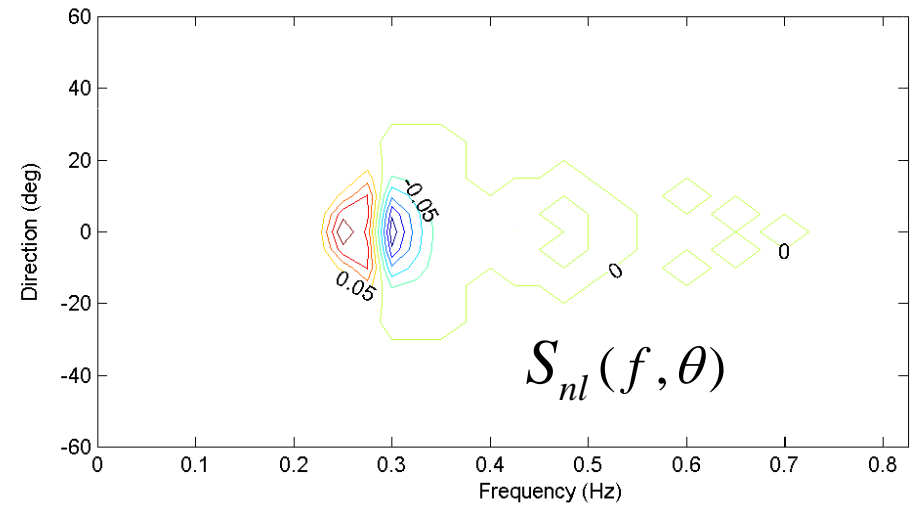




Spectral Evolution and $S_{nl}(f, \theta)$

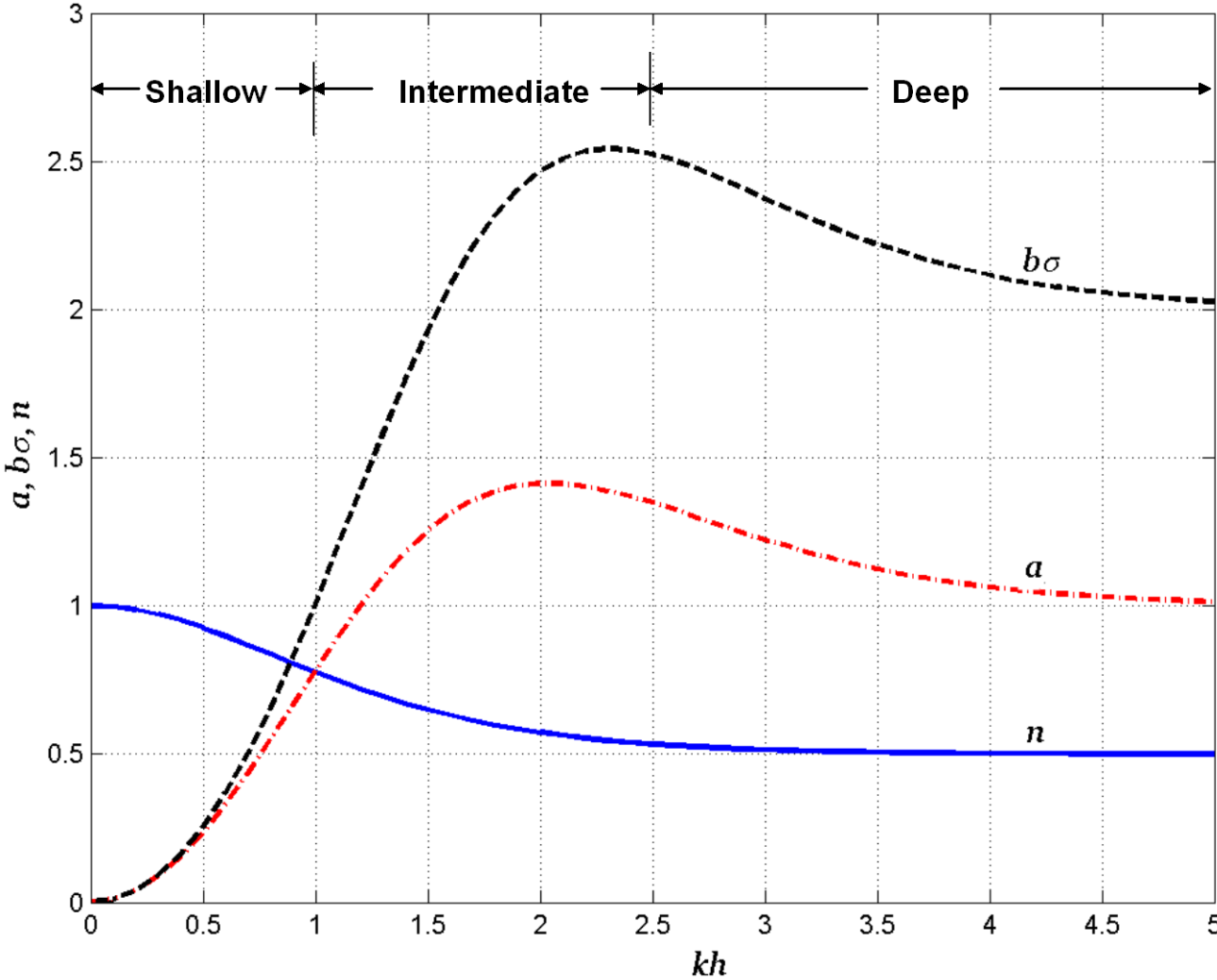


$$\gamma = 5$$





Nonlinear Wave Effect

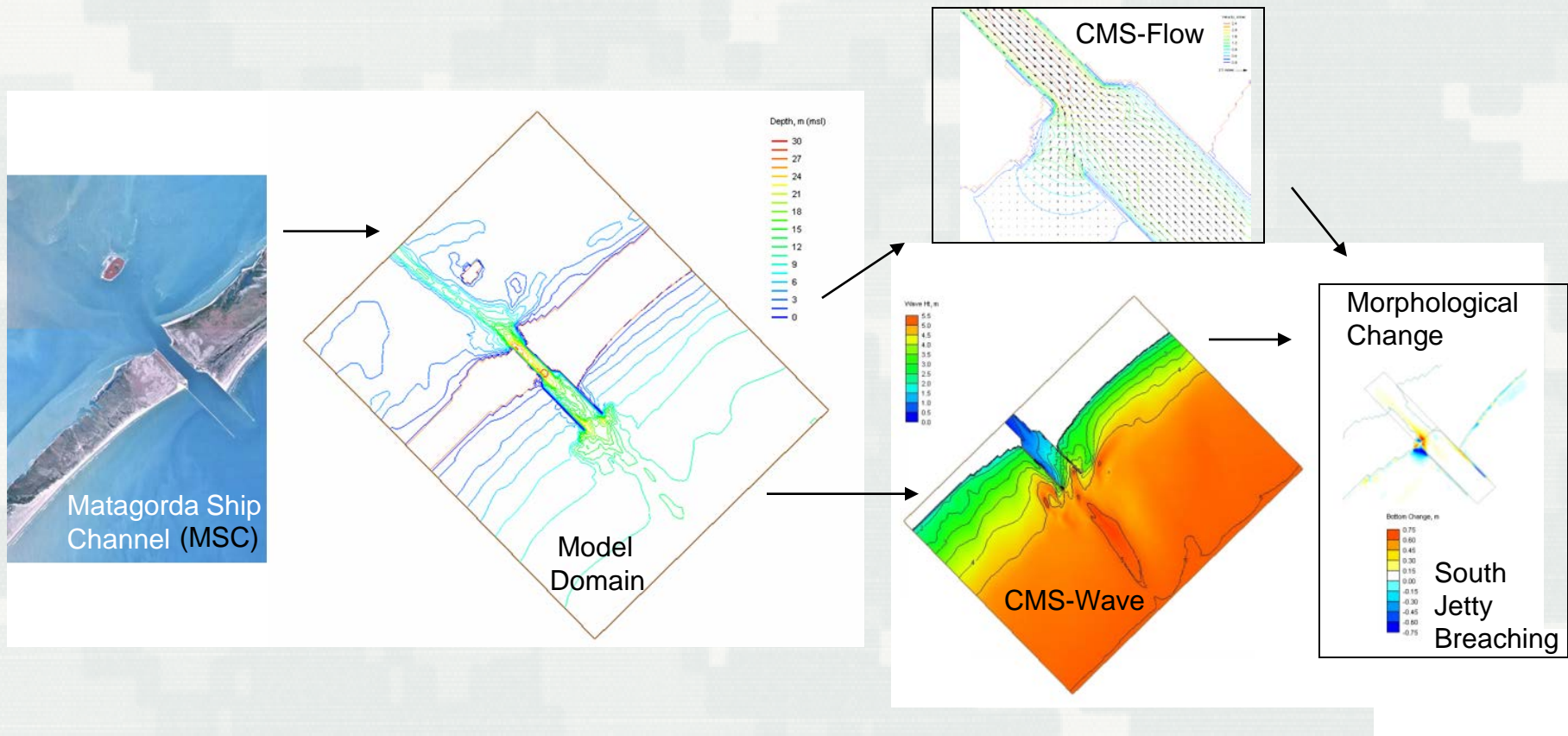




9. Coupling with CMS-Flow

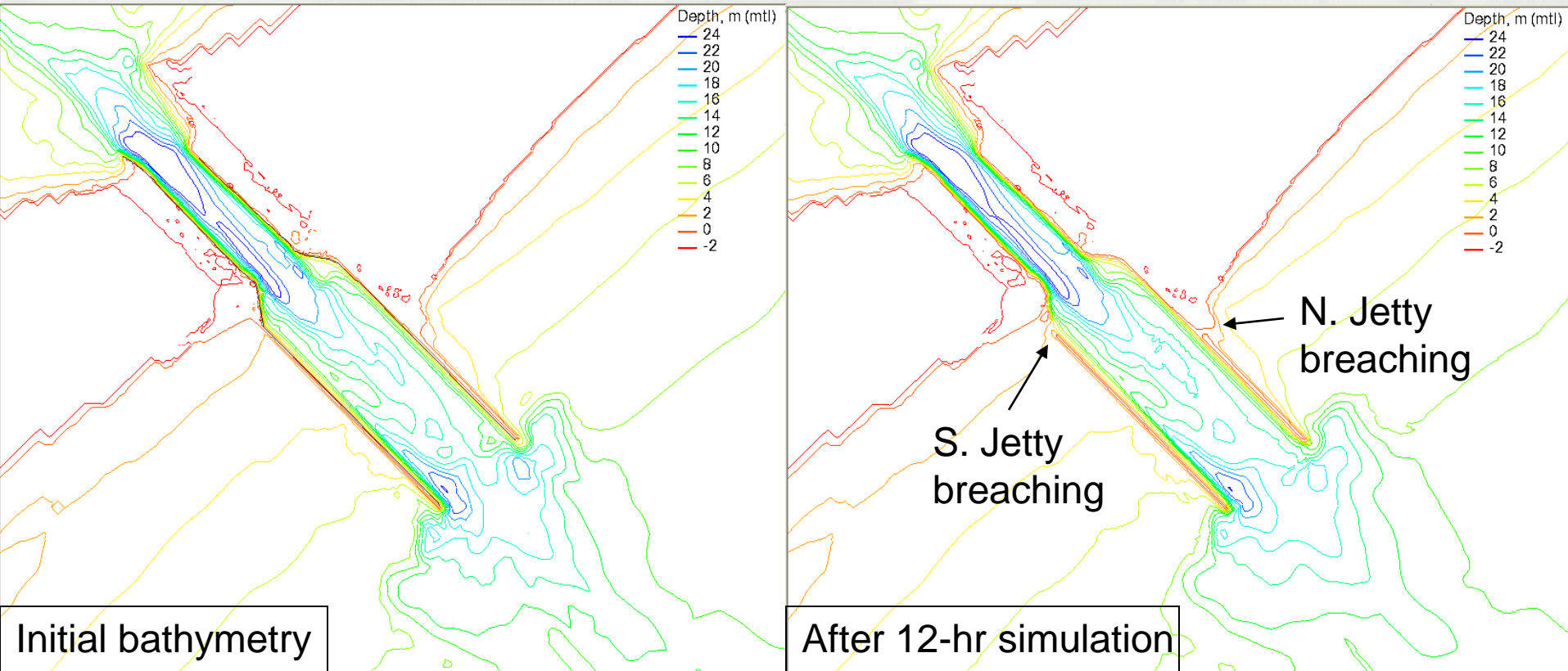


Breaching at Jetty, Simulation at Matagorda Ship Channel, TX





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



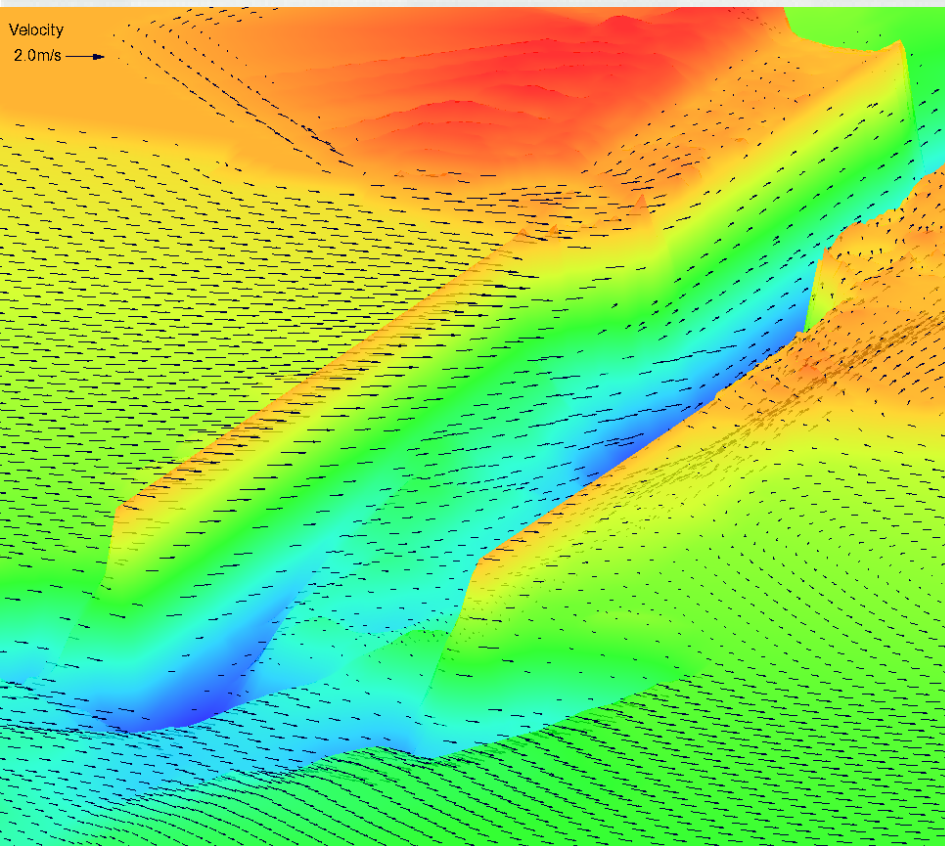
- Peak storm surge level reaches 3.5 m between Hrs 4 and 8
- Incident offshore wave is 7.6 m, 14.3 sec, from south



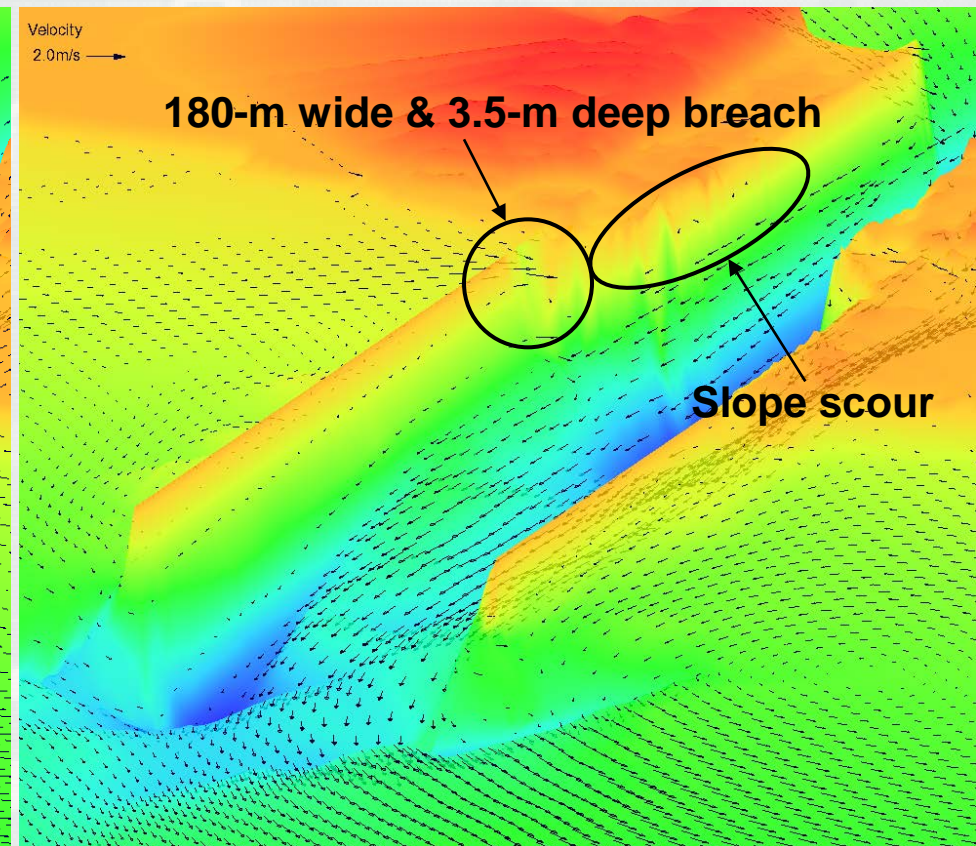
MSC Jetty Wave Run-up & Breaching *Cat 3 Hurricane (50-Yr Life-Cycle)*



Storm surge over the initial bathymetry

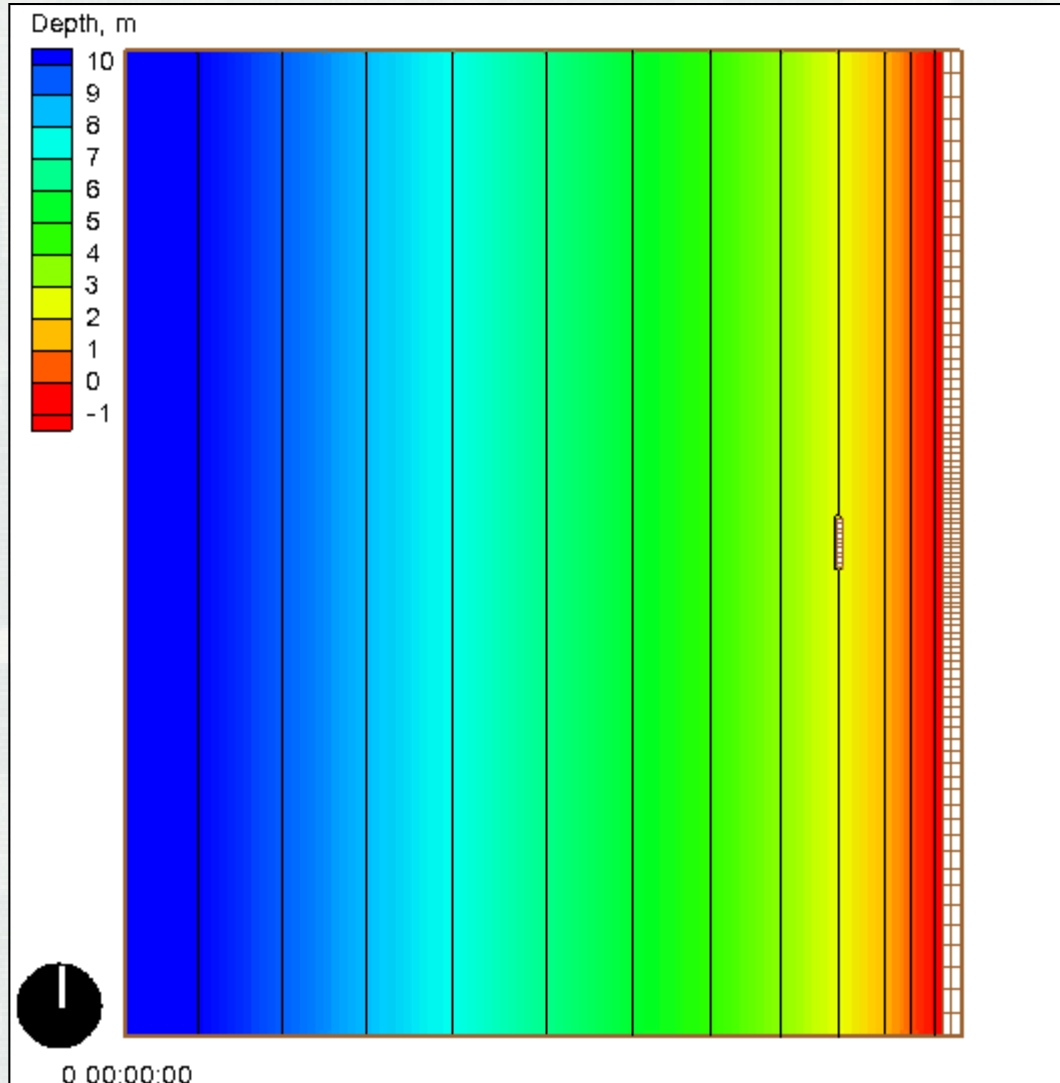


South Jetty breach in 12-hr simulation



- 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

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