Introduction to CMS-Wave

Lihwa Lin, ERDC CHL

Lihwa.Lin@usace.army.mil

Outline

1. Overview of CMS-Wave
2. Capability
3. Governing Equations
4. Incident Wave Spectrum
5. Wave-Current Interaction &
   Radiation Stress Calculation
6. Diffraction and Reflection
7. Wind Input Function
8. Wave Dissipation
9. Variable Rectangular-Cell Grid
10. Wave Run-up & Other New Features
11. CMS Steering Operation
12. Future Improvement

1. Overview of CMS-Wave

Objective: CMS-Wave is designed for accurate spectral transformation affecting operation and maintenance of coastal inlet navigation projects as well as the reliability assessment of shipping in inlets and harbors.

- Introduced to Coastal Modeling System (CMS) in 2005. Fully operational in Surface Modeling System (SMS)
- Based upon **WABED** (Wave-Action Balance Equation with Diffraction) developed by Mase (2001)
- Steady-state (time-dependent), half-plane, two-dimensional spectral transformation model using a finite-difference, forward-marching implicit scheme

Overview of CMS-Wave (Continue)

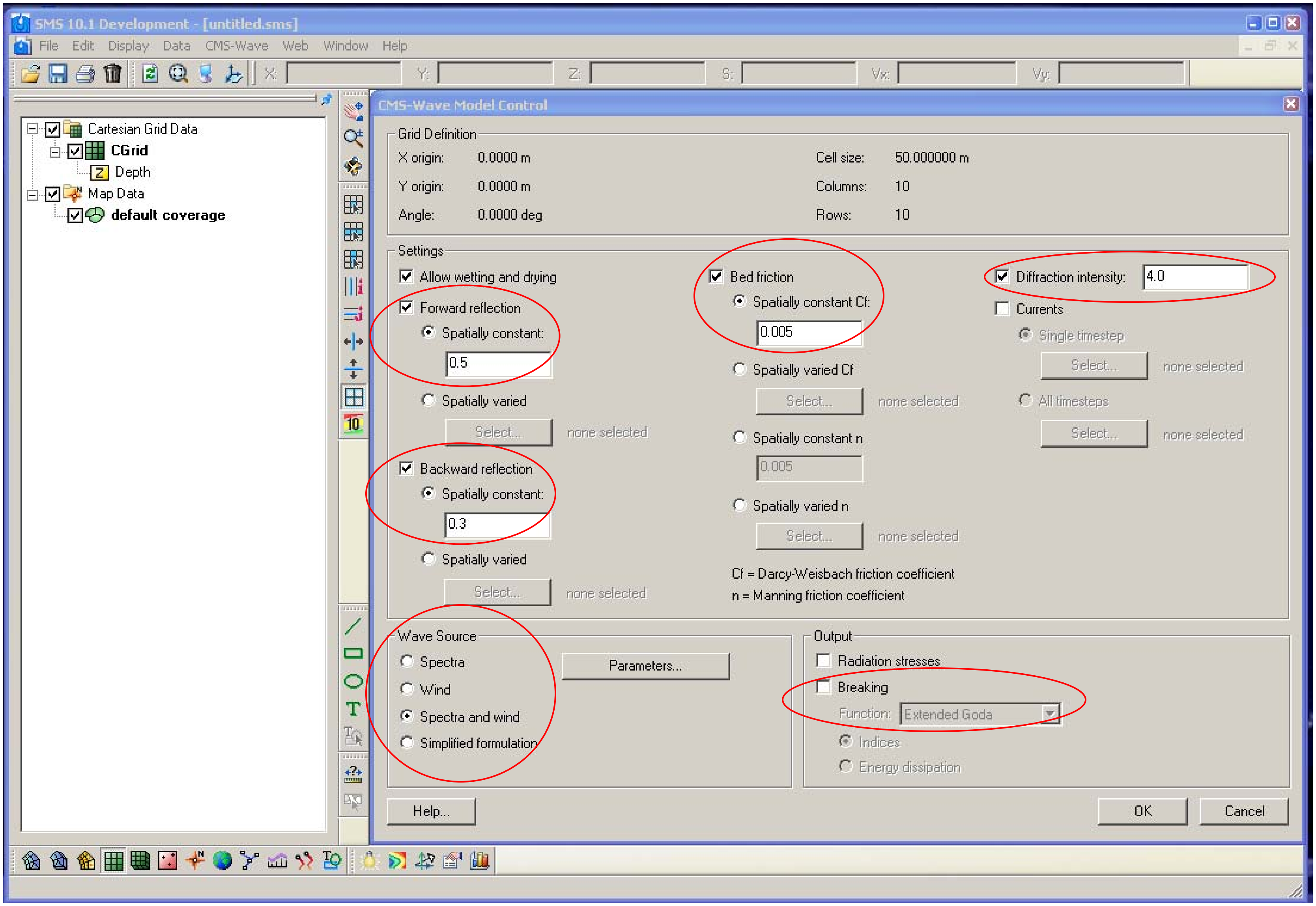
- Mathematically consistent treatment of wave refraction; diffraction, reflection, & transmission at structures; wave run-up, wave setup, shoaling, bottom friction, wind input, and wave-current interaction
- Can be operated standalone or coupled to CMS-Flow, a circulation and sediment transport model, through the SMS interface

2. CMS-Wave Capability

CMS-Wave and STWAVE (half-plane) Comparison, 31 Mar 09

	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

Sample CMS-Wave SMS 10.1 Interface



3. Governing Equation

Wave-Action Balance Equation with Diffraction

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

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

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

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

4. Incident Wave Spectrum

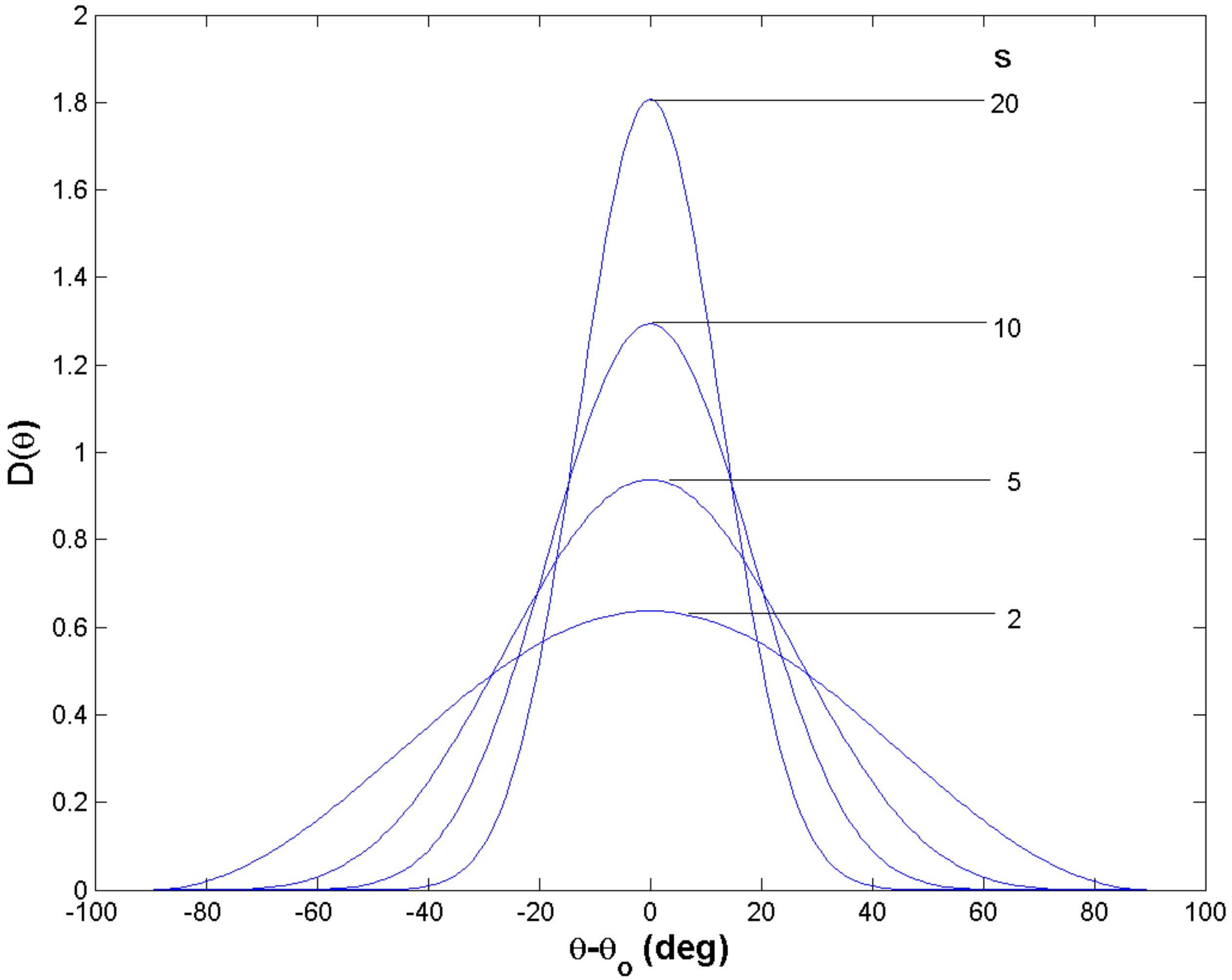
A single input spectrum applied along the seaward boundary, e.g., a JONSWAP type:

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

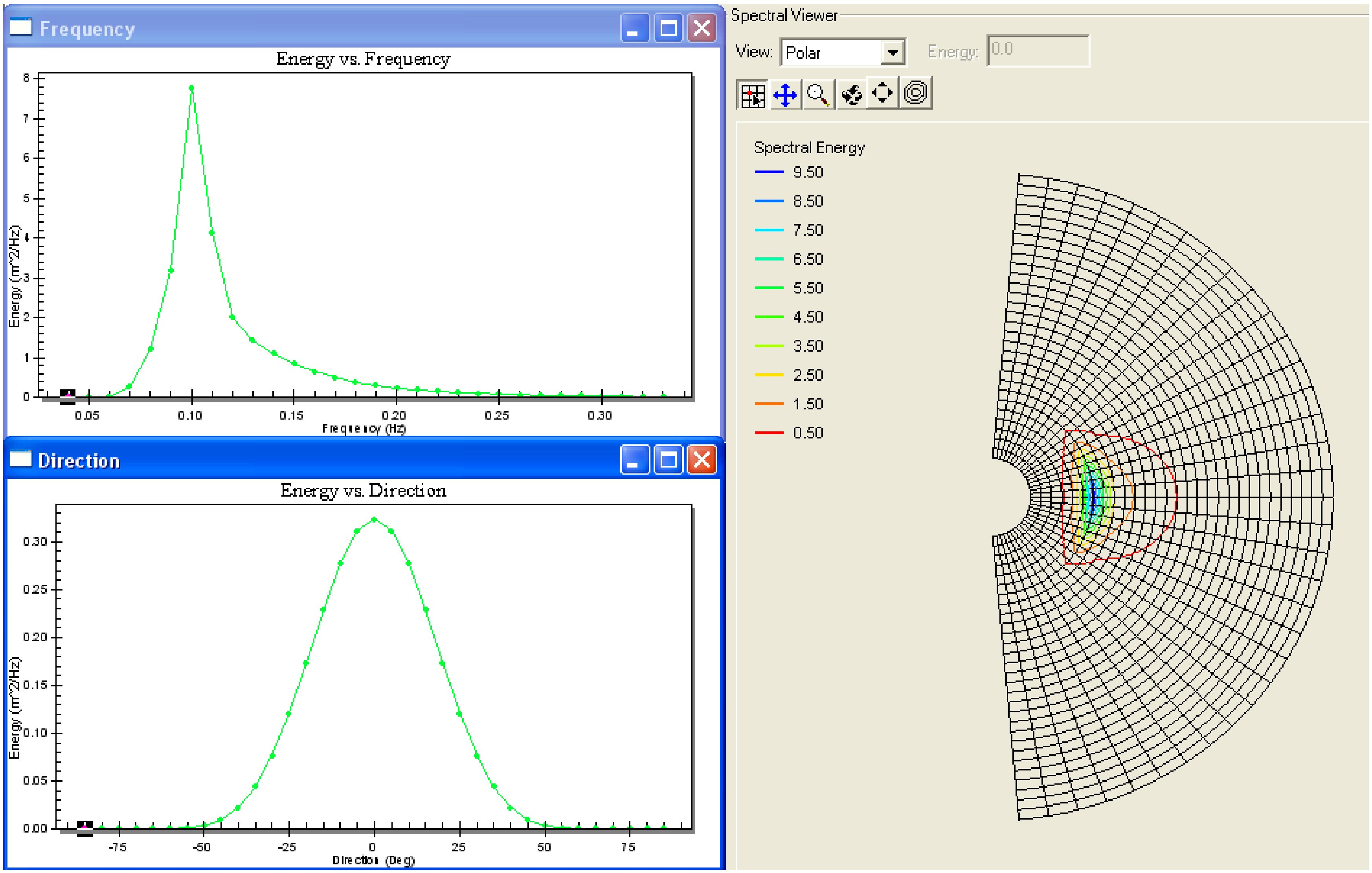
where $D(\theta) = \frac{2^s}{\pi} \frac{\Gamma(s/2+1)}{\Gamma(s+1)} \cos^s(\theta - \theta_o)$ for $|\theta - \theta_o| < \pi / 2$

and s is the directional spreading parameter.

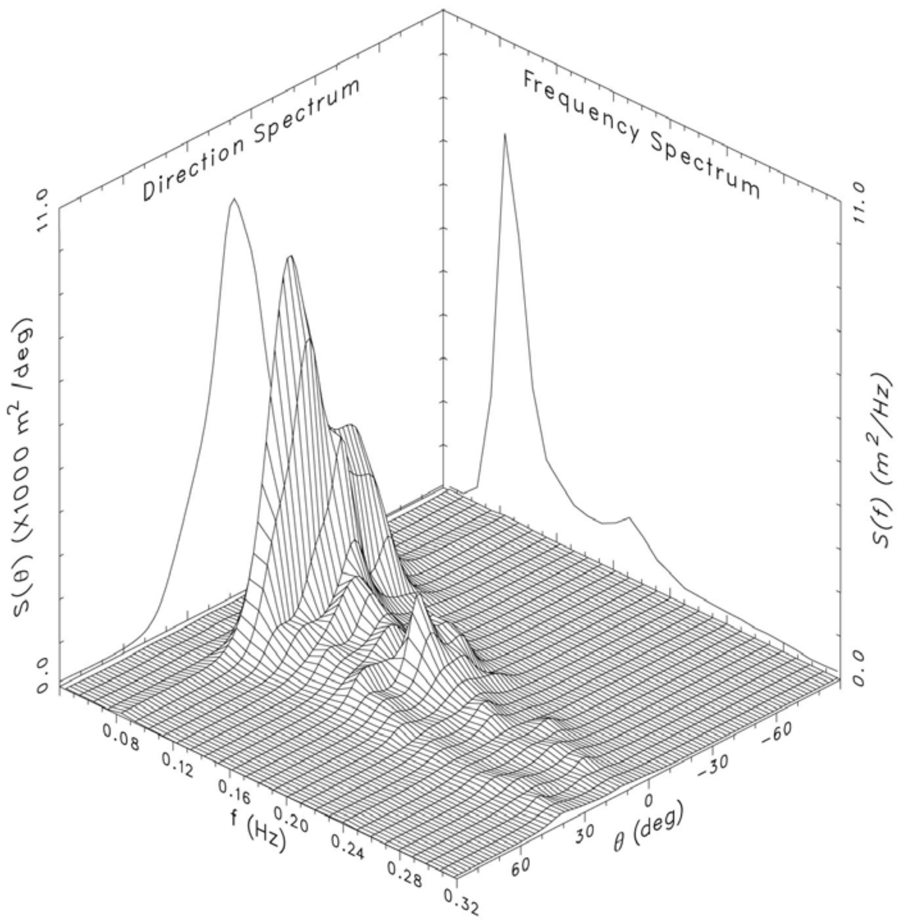
Idealized Directional Distribution

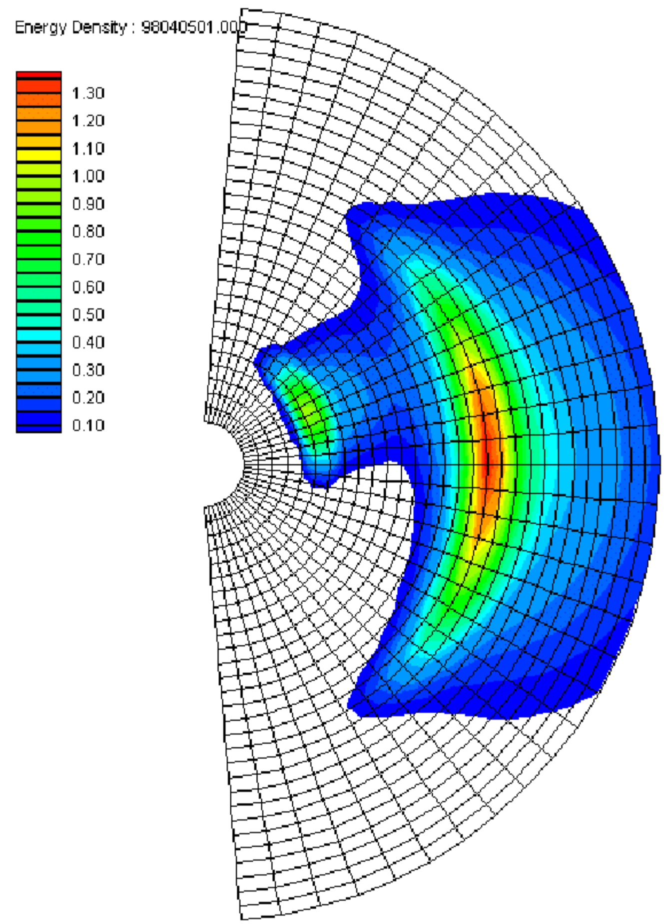


JONSWAP Spectrum
H = 2 m, T = 10 sec, S = 10



Input Measured Spectrum





5. Wave-Current Interaction & Radiation Stress Calculation

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

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

- Computing wave radiation stresses:

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

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

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

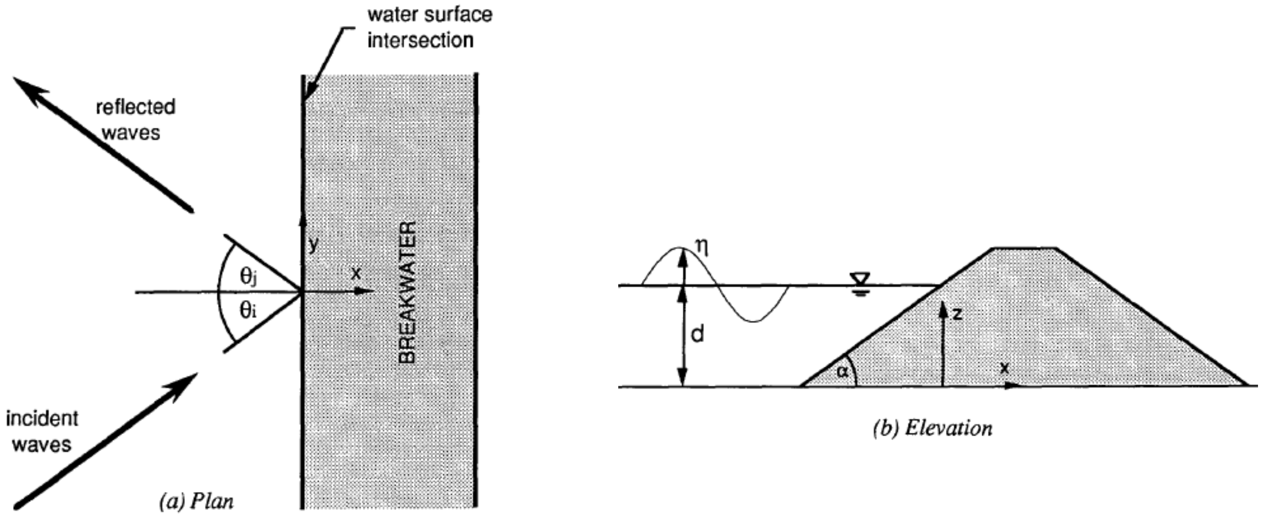
6. Diffraction and Reflection

- Diffraction included in the governing equation

Diffraction intensity factor

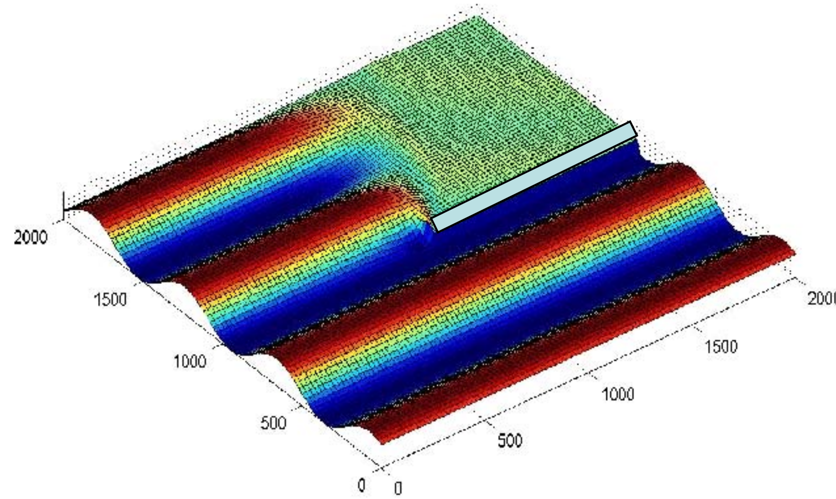
$$\frac{\partial[(c_{gx}+u)A]}{\partial x}+\frac{\partial[(c_{gy}+v)A]}{\partial y}+\frac{\partial[c_{g\theta}A]}{\partial\theta}=\frac{\kappa}{2\sigma}\{(cc_g\cos^2\theta A_y)_y-\frac{1}{2}cc_g\cos^2\theta A_{yy}\}+S_{in}+S_{dp}$$

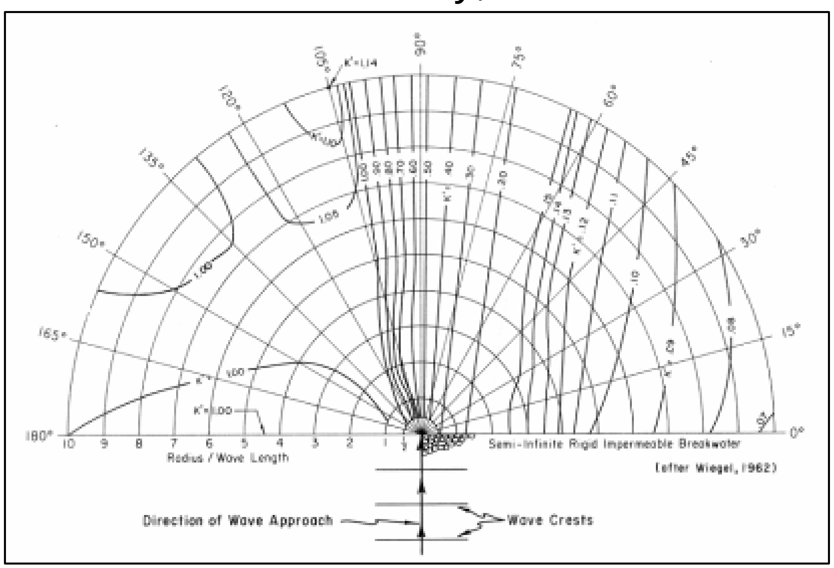
- Reflection computed as the mirror image of incident waves

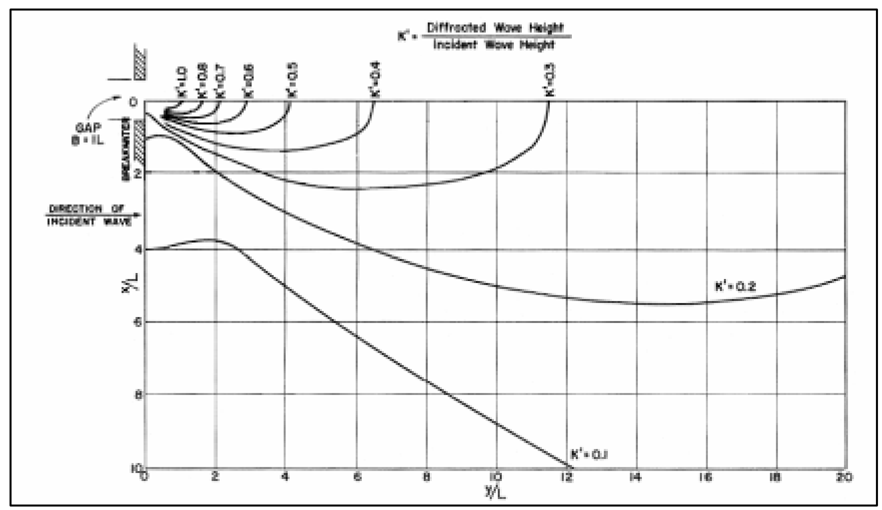


Jetty and Breakwater Wave Diffraction

Humboldt Bay, CA







7. Wind Input Function

$$S_{in} = \frac{a_1\sigma}{g} F_1(\vec{w} - \vec{c}_g) F_2(\frac{c_g}{w}) E^*_{PM}(\sigma)\Phi(\theta) + \frac{a_2\sigma}{g} F_1(\vec{w} - \vec{c}_g) F_2(\frac{c_g}{w}) F_3(\frac{c_g}{w}) E$$

where $F_1(\vec{w} - \vec{c}_g) = \begin{cases} w\cos(\theta_{wind} - \theta) - c_g(\sigma,\theta), & \text{if } c_g < w \\ 0, & c_g \geq w \end{cases}$

$$F_2(\frac{c_g}{w}) = \begin{cases} (\frac{c_g}{w})^{1.2}, \\ 1, \end{cases} \text{ and } F_3(\frac{c_g}{w}) = \begin{cases} \log_{10}[(\frac{c_g}{w})^{-1}], & \text{if } c_g < w \\ 0, & c_g \geq w \end{cases}$$

$$E^*_{PM}(\sigma) = \frac{g^2}{\sigma^5}\exp(-0.74\frac{\sigma_0^4}{\sigma^4}),\ \sigma_0 = g/w, \text{ and } \Phi(\theta) = \frac{8}{3\pi}\cos^4(\theta - \theta_{wind})$$

8. Wave Dissipation

- White capping

$$S_{dp} = -C_{ds}(ak)^{1.5}\frac{\sigma}{g}c_g(\sigma,\theta)F_4(\vec{w},\vec{u}_{current},\vec{c}_g)F_5(kh)E$$

where $F_4(\vec{w},\vec{u}_{current},\vec{c}_g) = \left|\frac{\upsilon + w}{\vec{w}+\vec{u}_{current}+\vec{c}_g}\right|$, $F_5(kh) = \frac{1}{\tanh kh}$

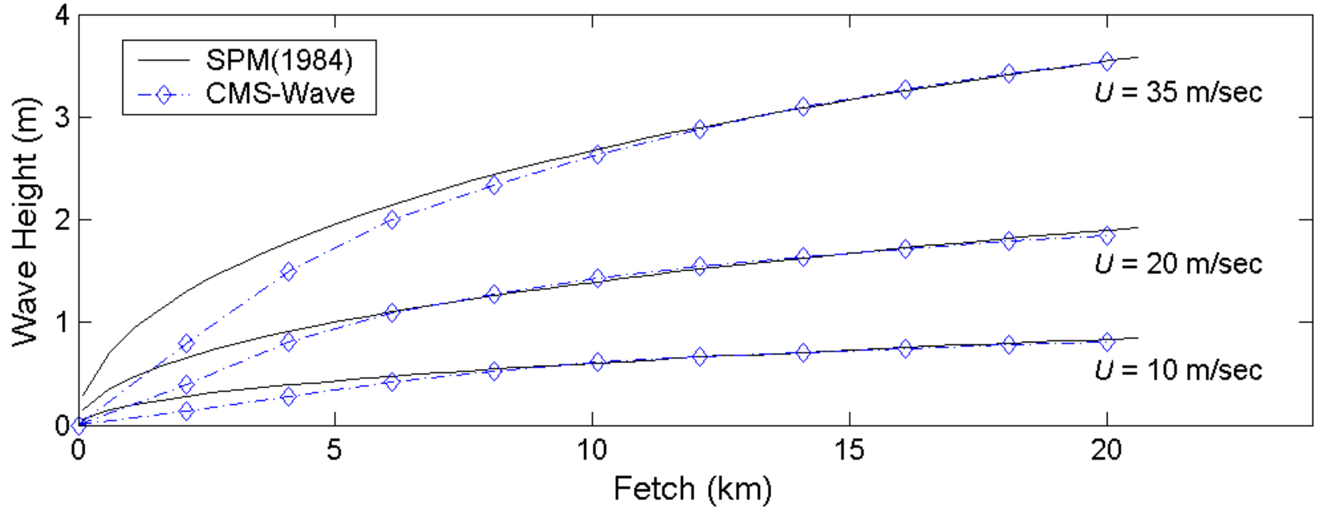
and $a = \sqrt{E(\sigma,\theta)\mathrm{d}\sigma\mathrm{d}\theta}$ is wavelet calculated for each grid cell

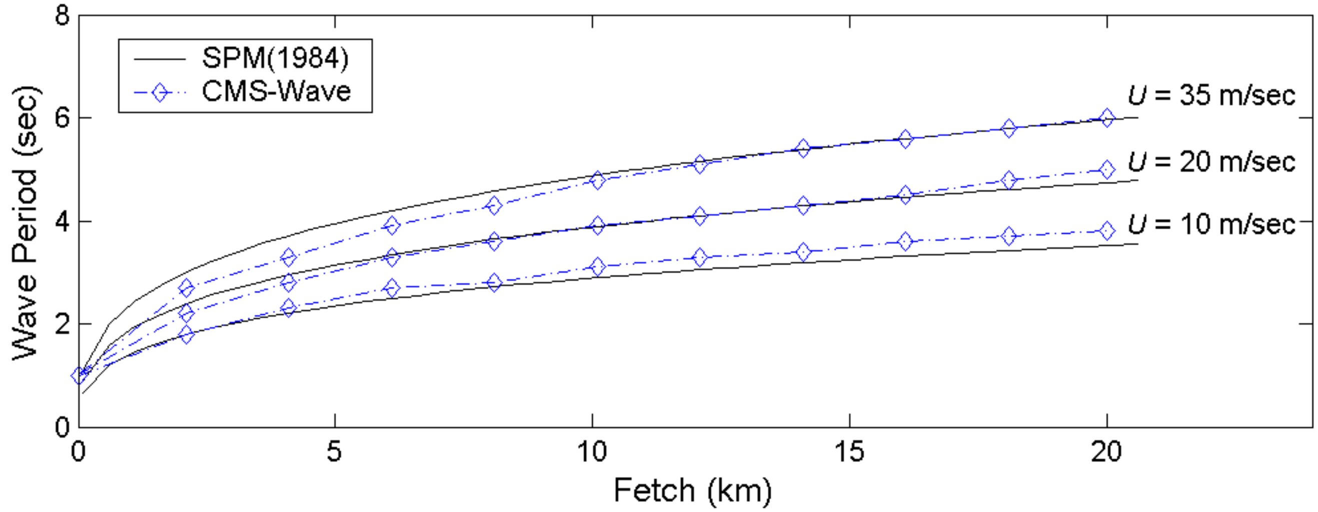
- Depth-limited Breaking

$$S_{dp} = -\varepsilon_b A$$

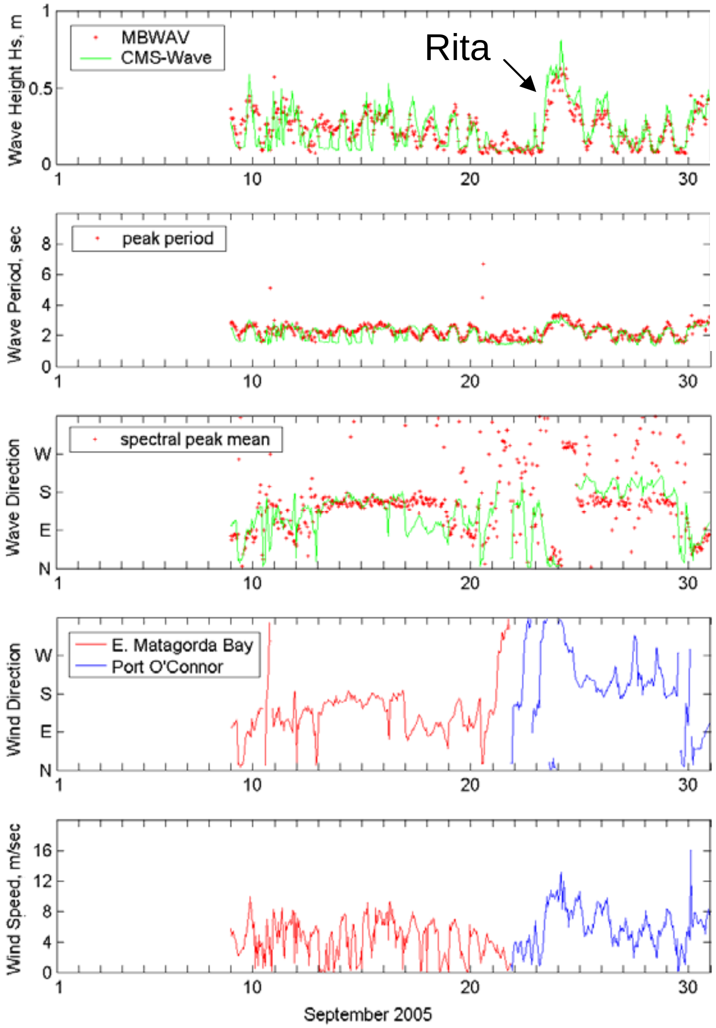
Can select from formulas of Goda (default), Miche, Battjes and Janssen, Chawla and Kirby

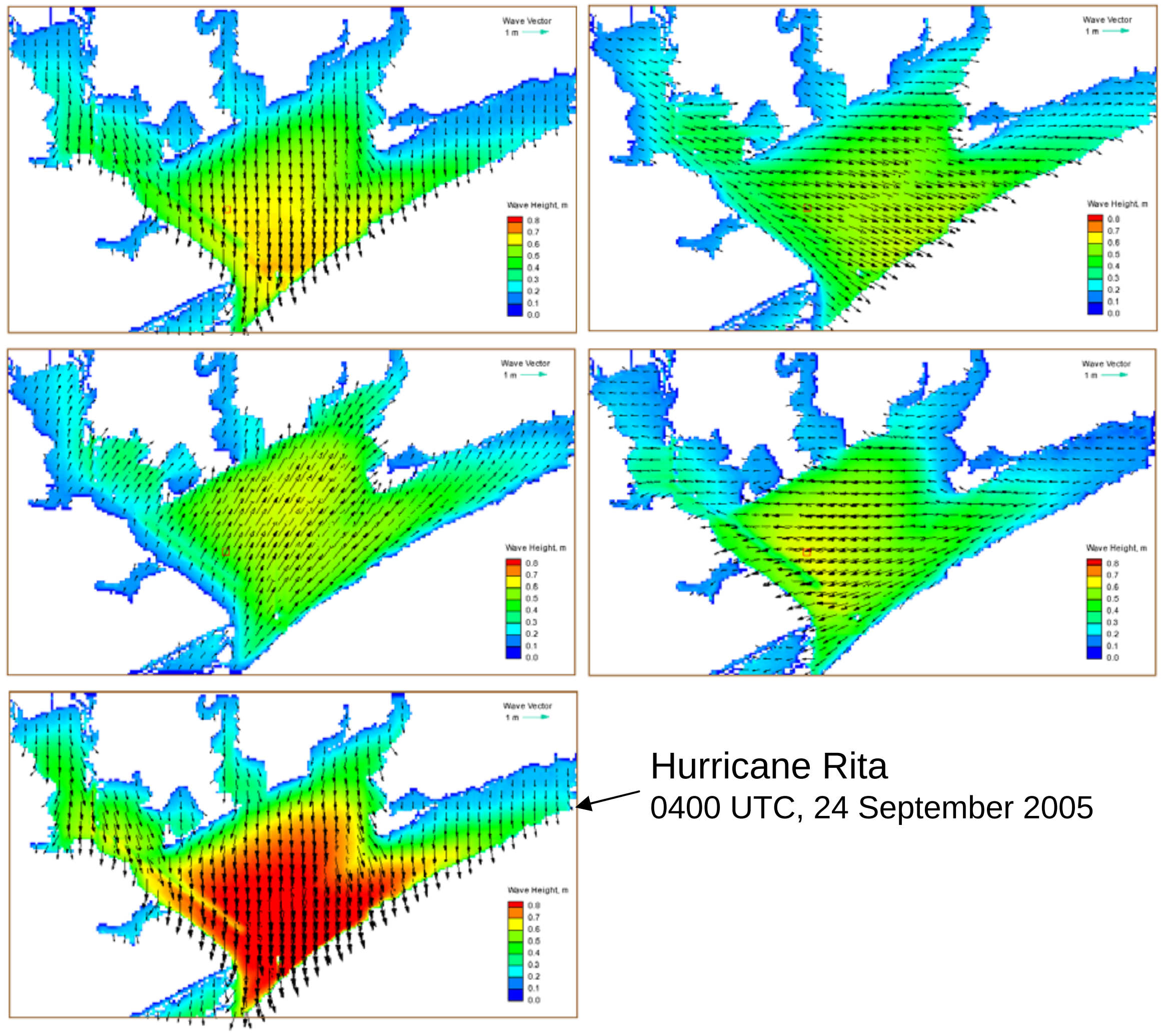
Fetch-limited Wind-wave Growth





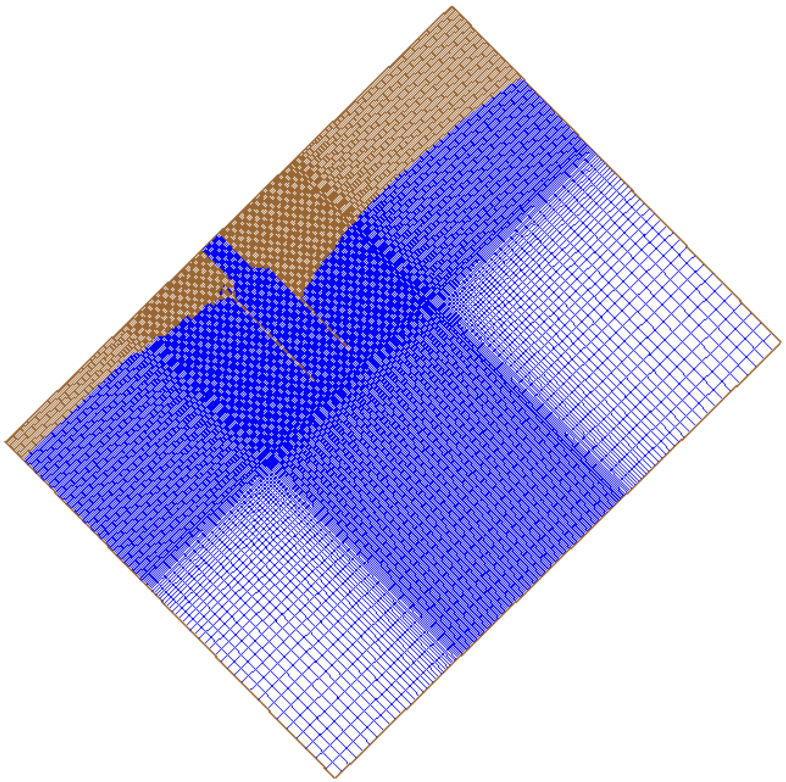
Wave Generation with Arbitrary Wind Direction
Matagorda Bay, TX



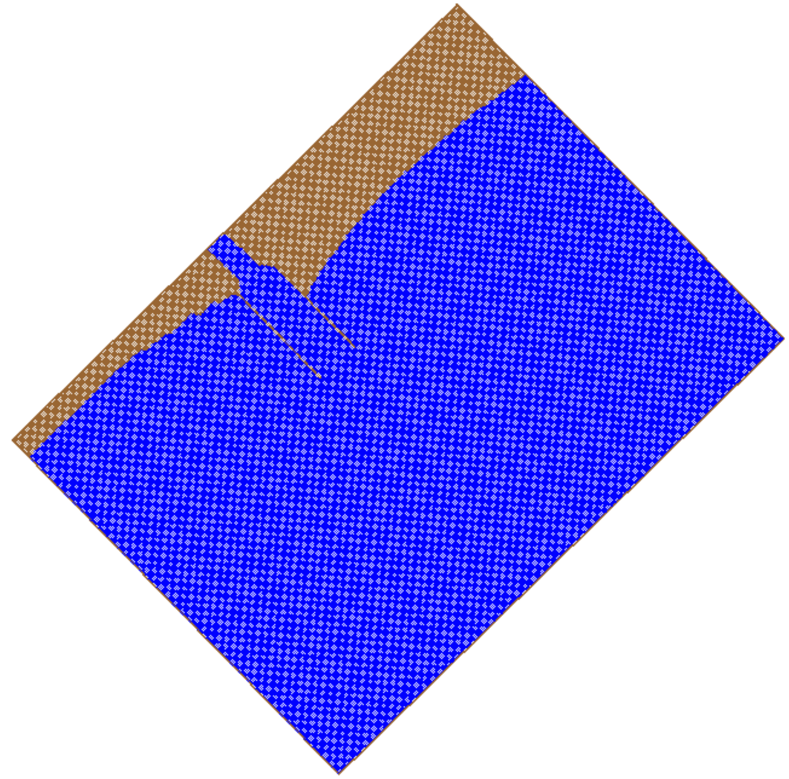


Hurricane Rita
0400 UTC, 24 September 2005

9. Variable Rectangular-Cell Grid (saves time)

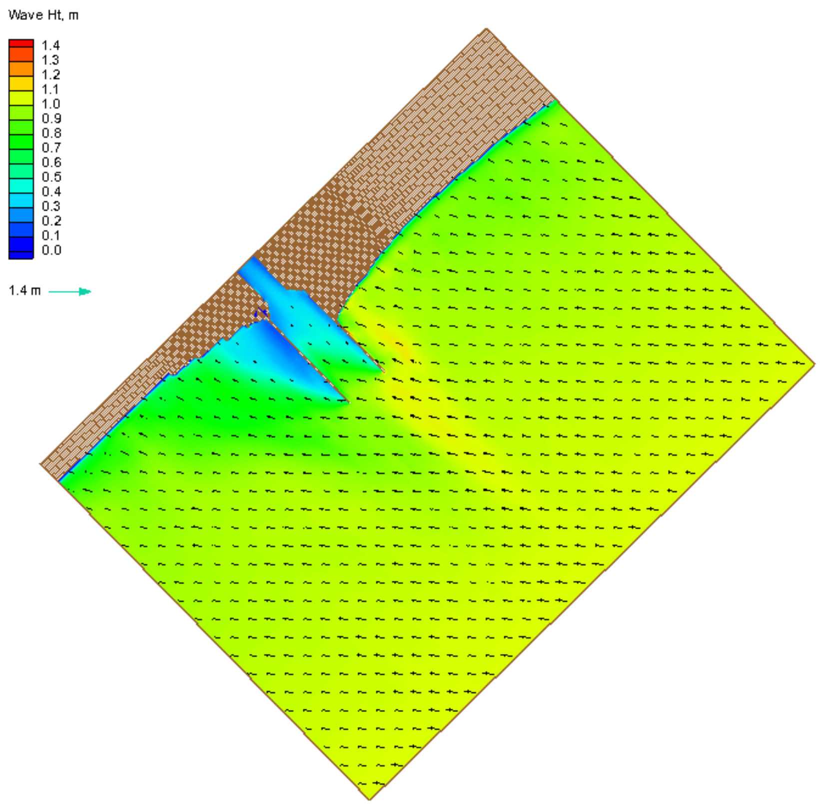


Variable-rectangular cells
Total 223 x 172 cells

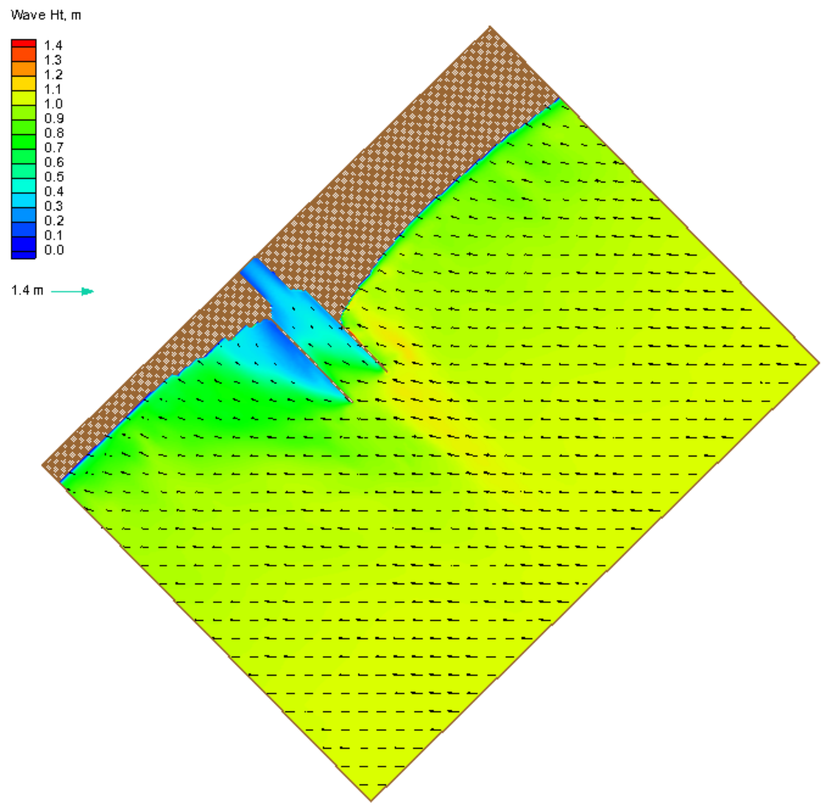


Square (20 m x 20 m) cells
Total 316 x 426 cells

CMS-Wave Simulation
Hs = 3 m, Tp = 6 sec, Surge = 2.9 m



Variable-rectangular cells
Total 223 x 172 cells



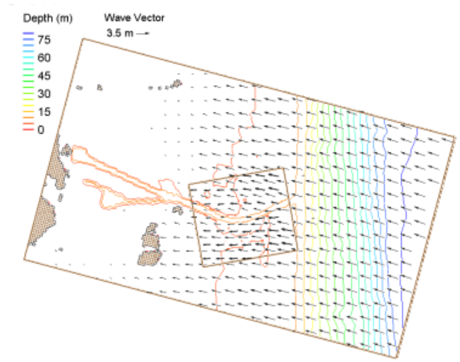
Square (20 m x 20 m) cells
Total 316 x 426 cells

10. Wave Run-up & Other New Features

A. Wave Run-up Calculation

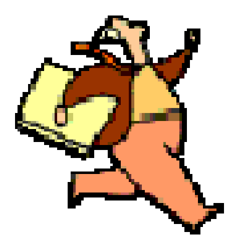
B. Four different wave-breaking formulas

C. Specify feature cells for wave run-up, setup wave transmission & overtopping structures.



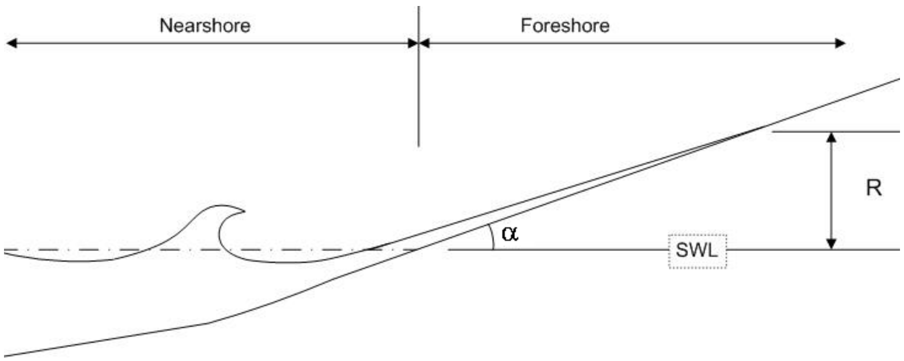
D. Muddy coast

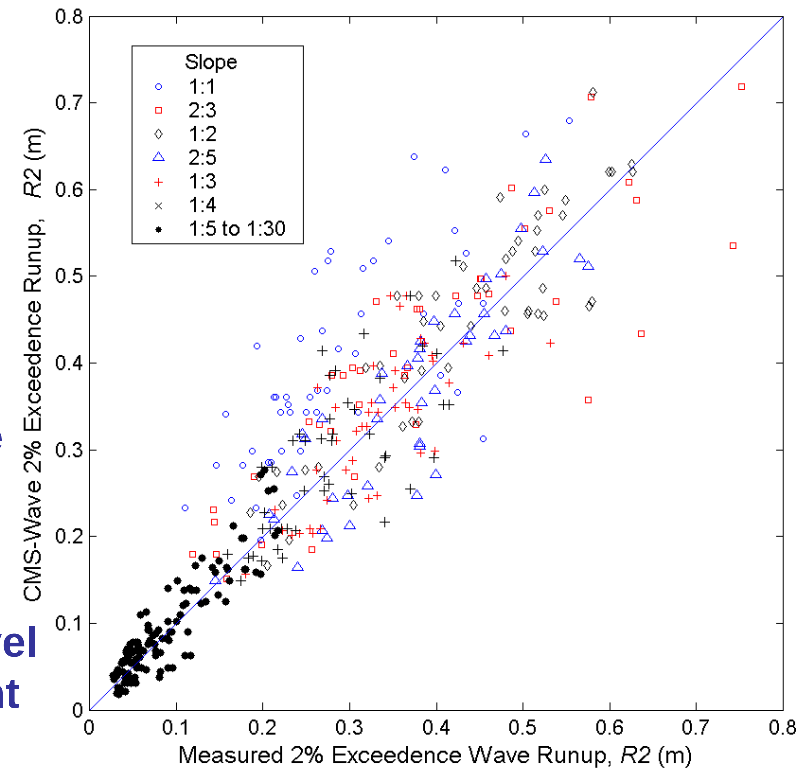
E. Grid nesting capability



F. “Fast mode” run capability

A. Wave Run-up Calculation





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

- **Mean run-up, *RM* : average run-up of all waves**
- **Two-percent run-up, *R2* : the vertical up-rush level exceeded by 2-percent of the larger run-up height**

Wave Run-up Calculation

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

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

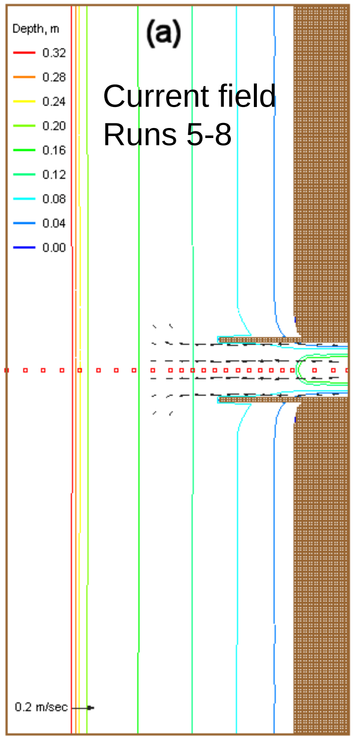
Max setup (Guza and Thornton, 1981): $\eta_{\max} = 0.17 H_0$

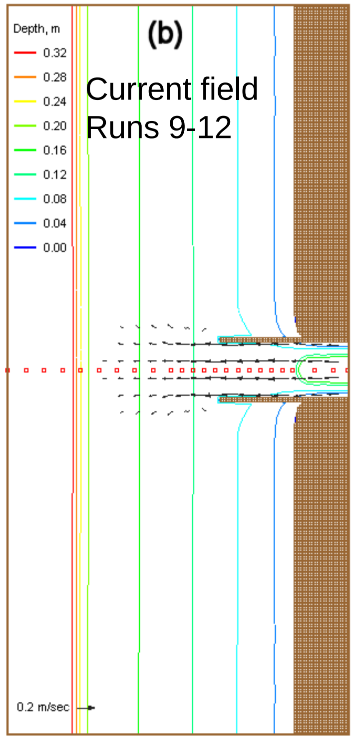
Total runup *R2* (2% exceedance) = 2 $\eta_{\max}$ (Komar, 1998)

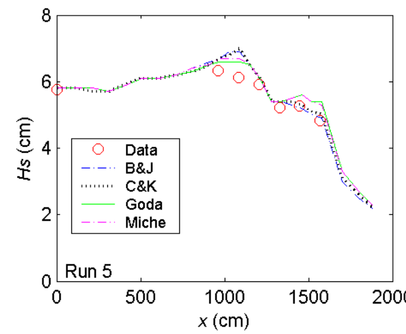
Max water level = max of ($\eta + H_s / 2$, *R2*)

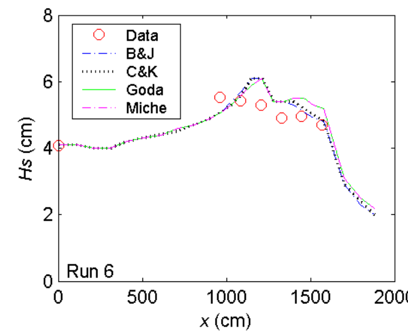
* Wave setup and max water level field are saved in setup.wav

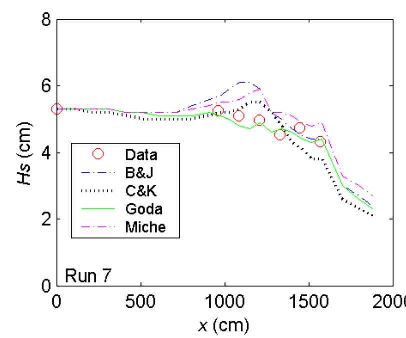
B. Four Different Wave-Breaking Formulas

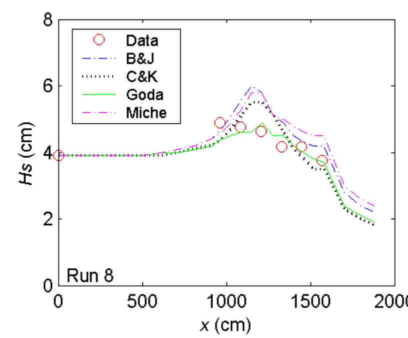


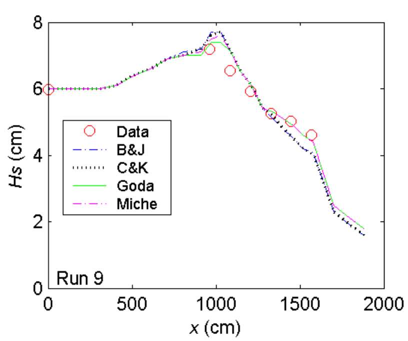


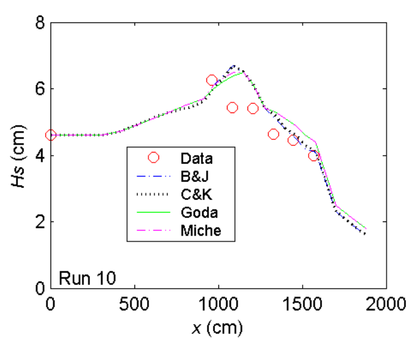


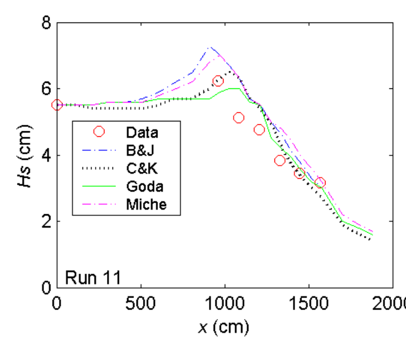


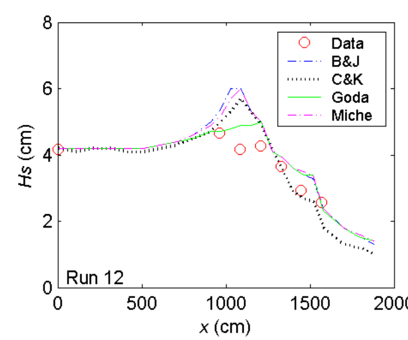




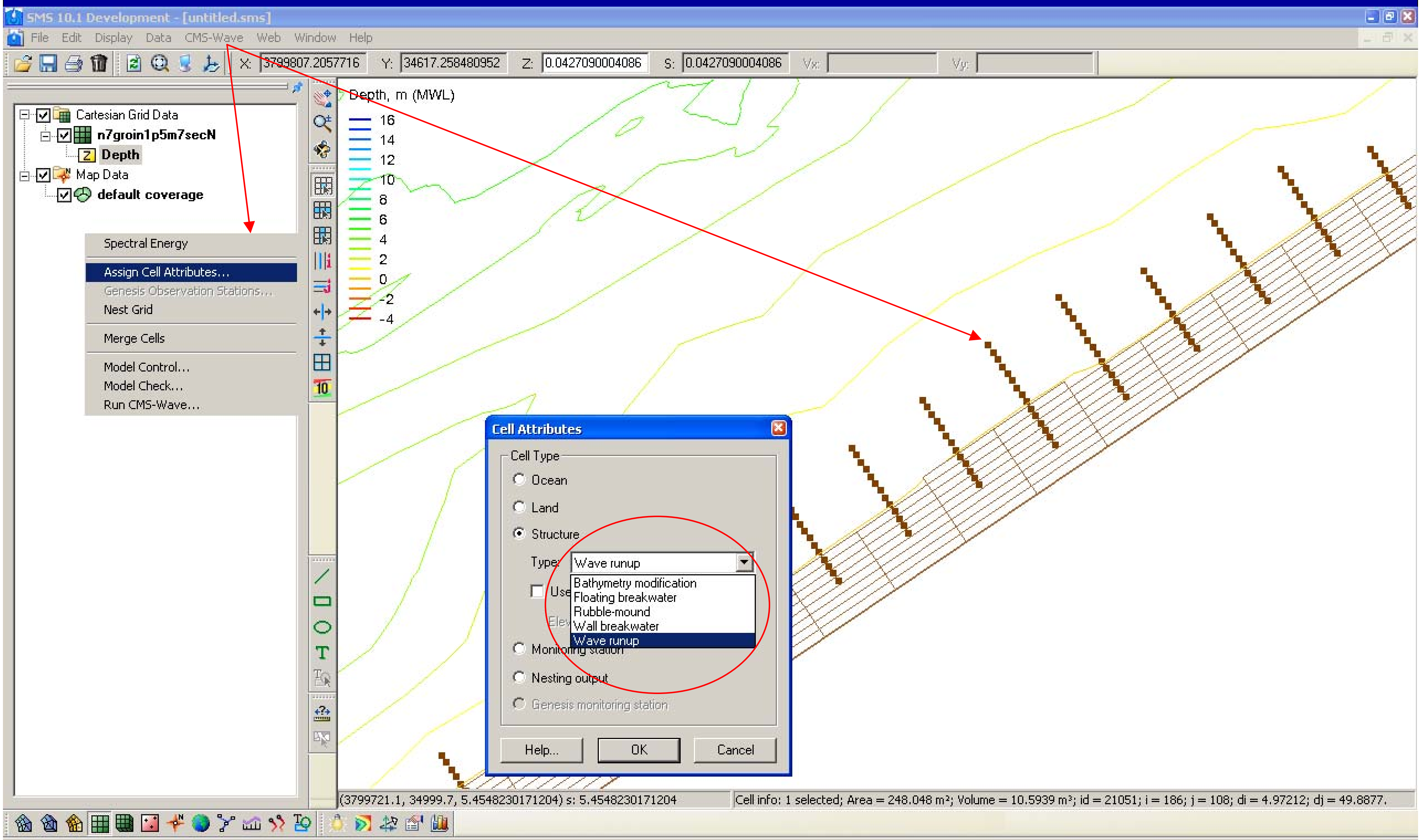








C. Specify Feature Cells in SMS10.1



Floating Breakwater

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

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

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:

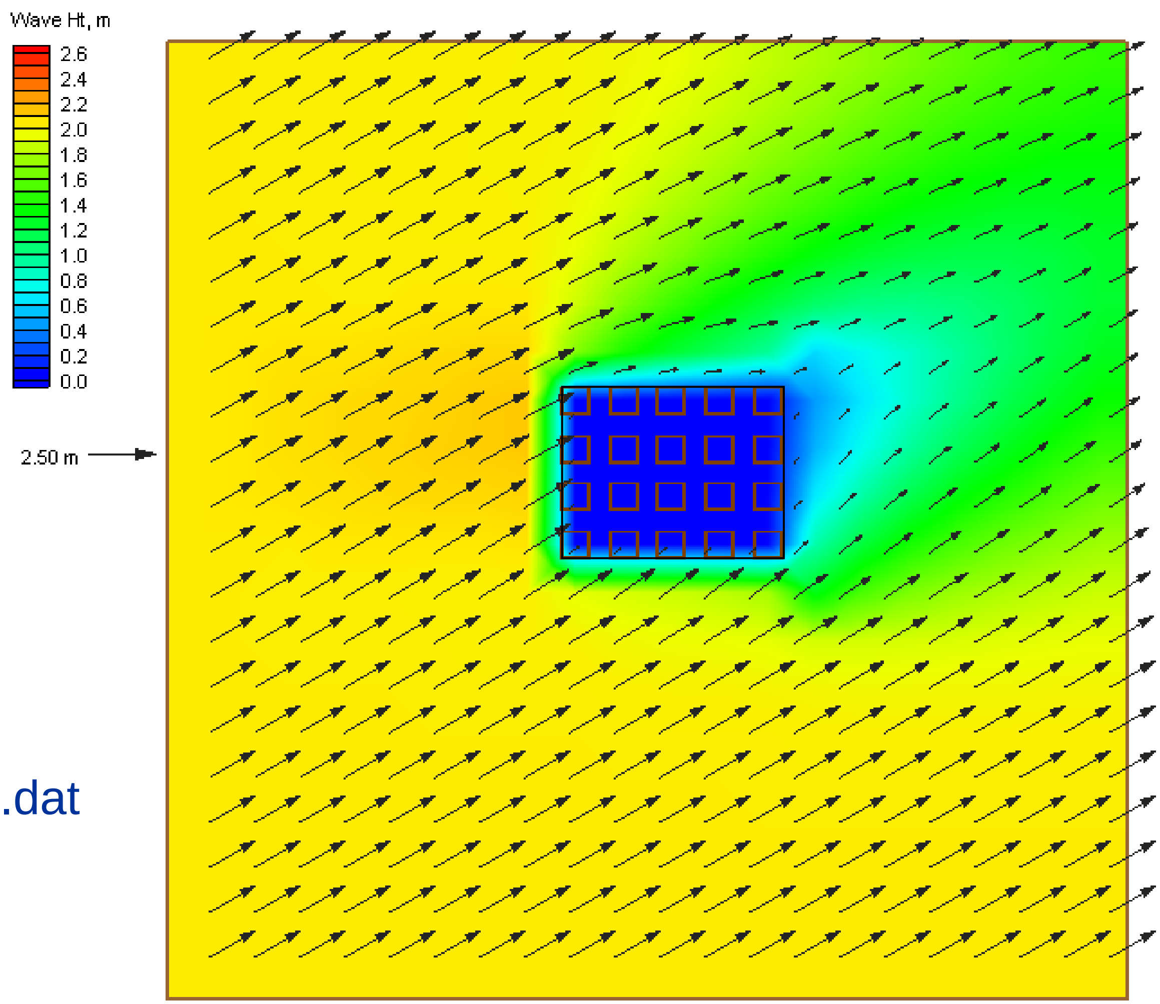
$$K_t = 0.3\ (1.1 - \frac{h_c}{H_s}), \quad \text{for} \quad 0 \le \frac{h_c}{H_s} \le 0.75$$

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

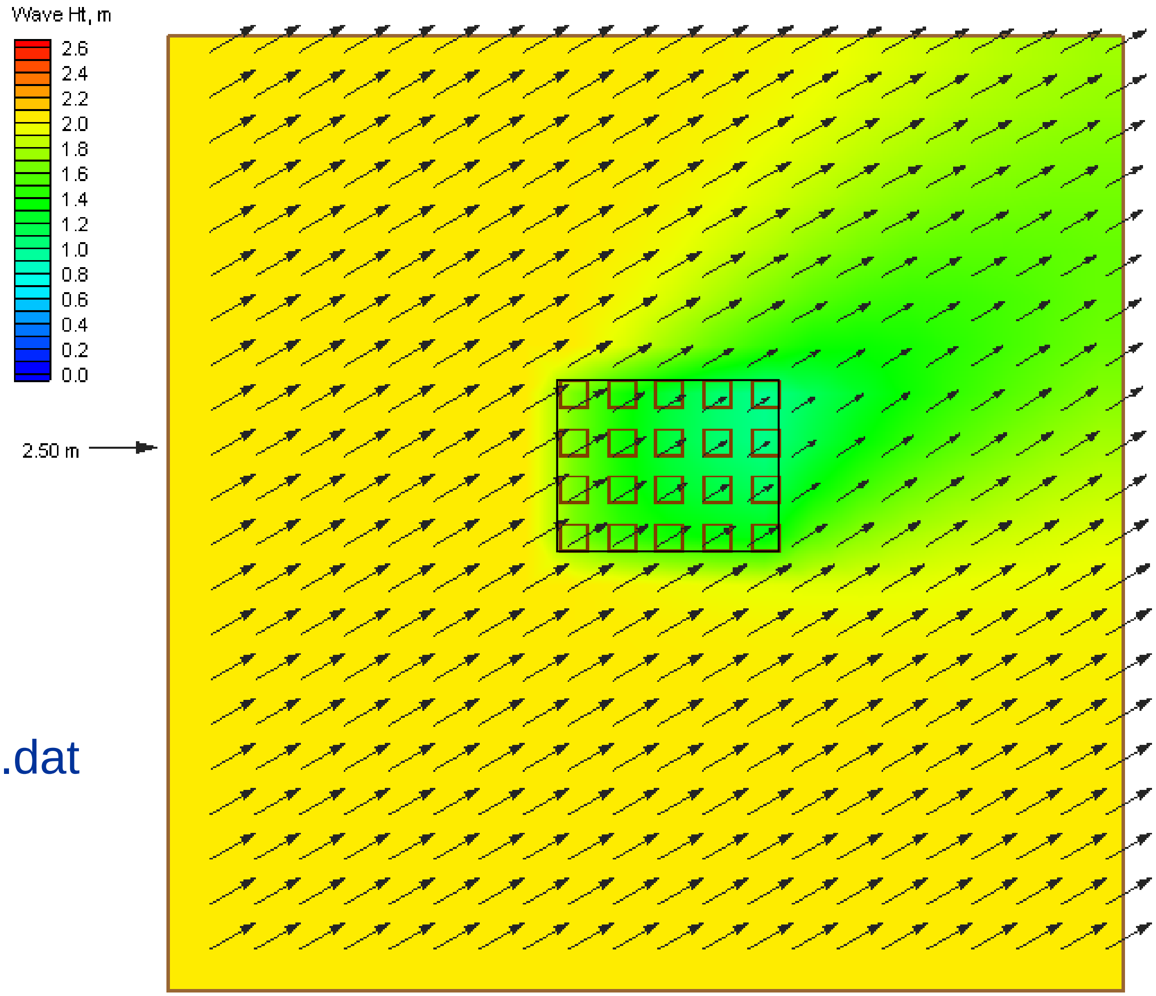
input depth
= 10 m

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

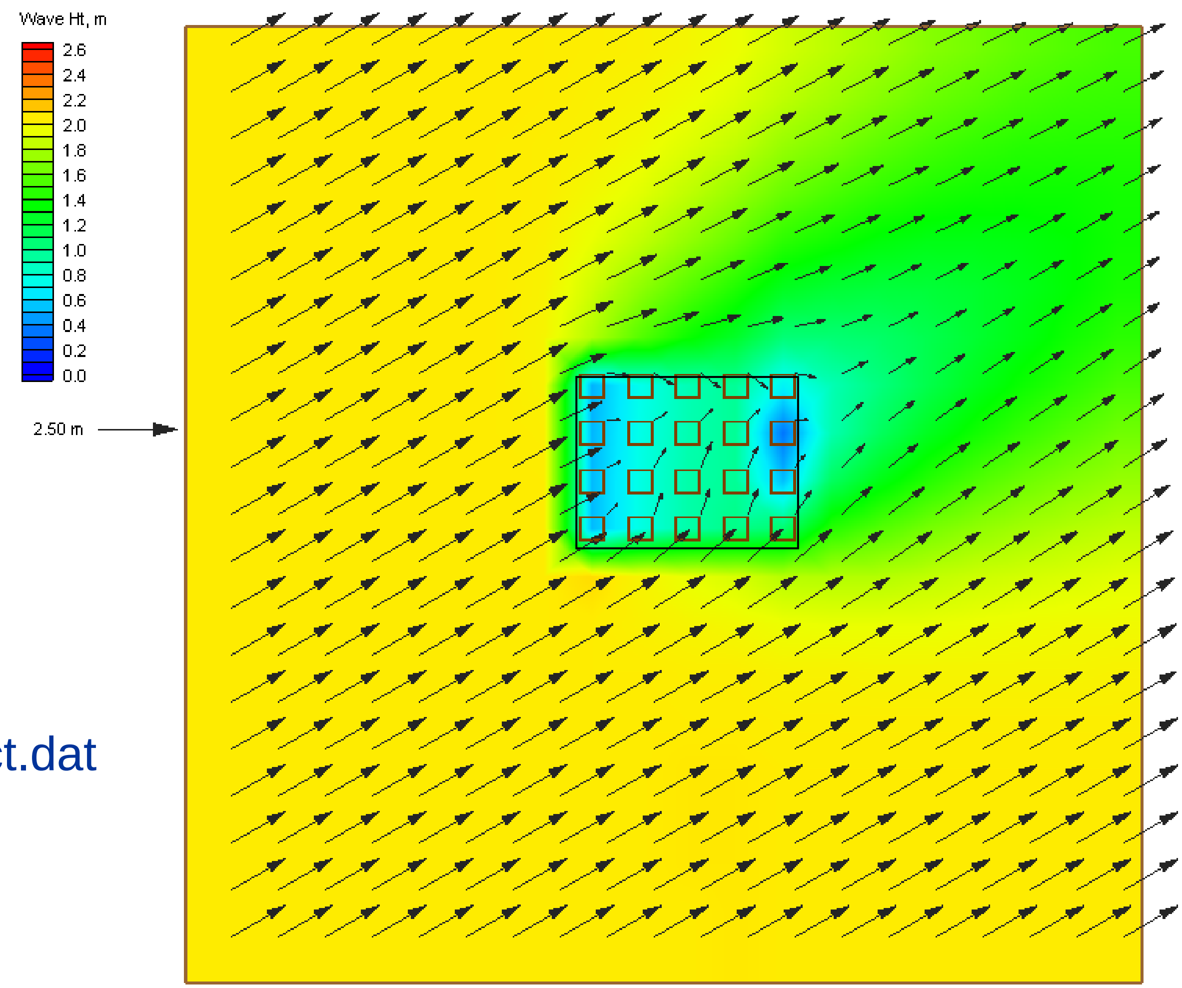
incident wave: 2 m, 6 sec, 30 deg oblique (gamma = 4)

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

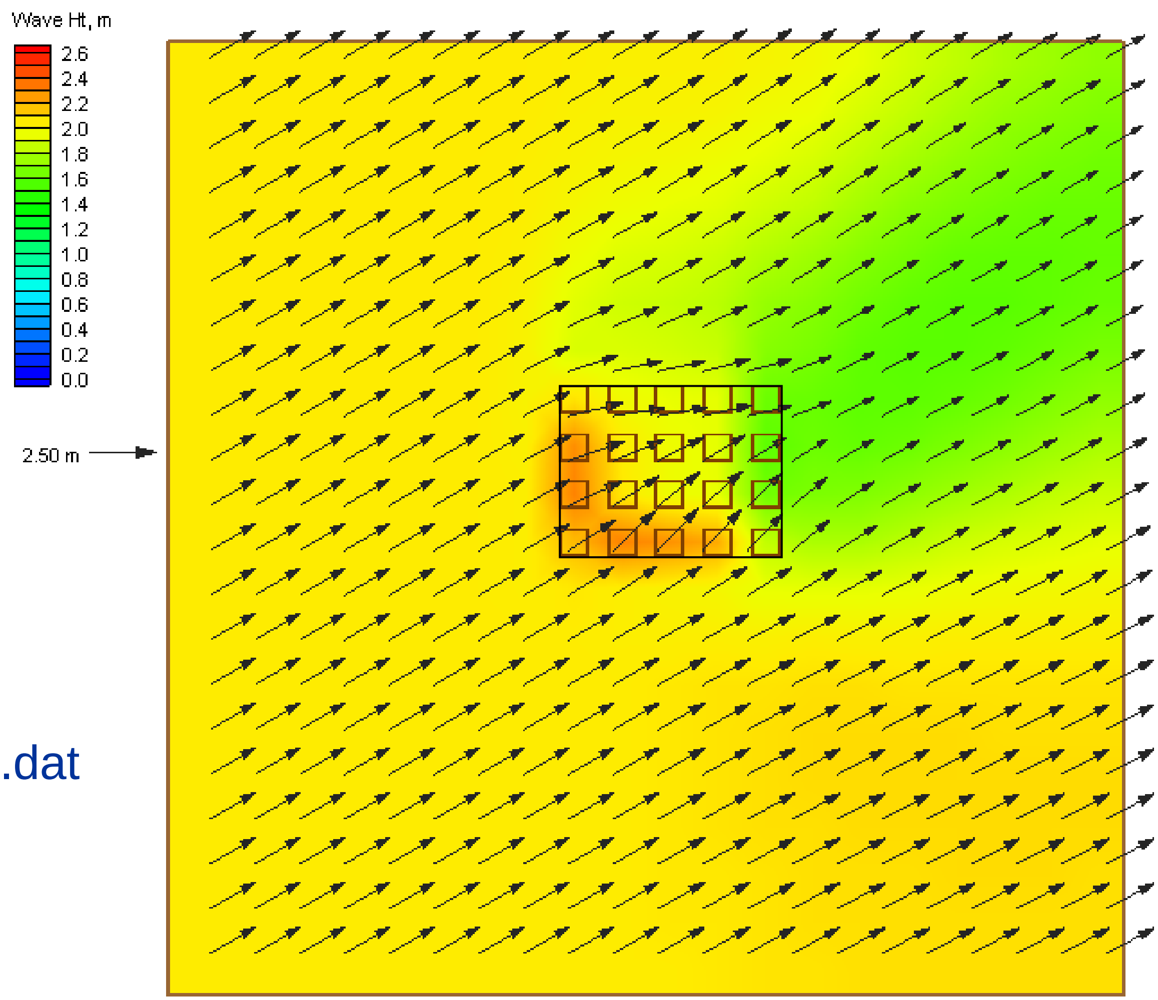
incident wave:
2 m, 6 sec,
30 deg oblique
(gamma = 4)

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)

D. Muddy Coast

Wave dissipation by damping (Lamb, 1932):

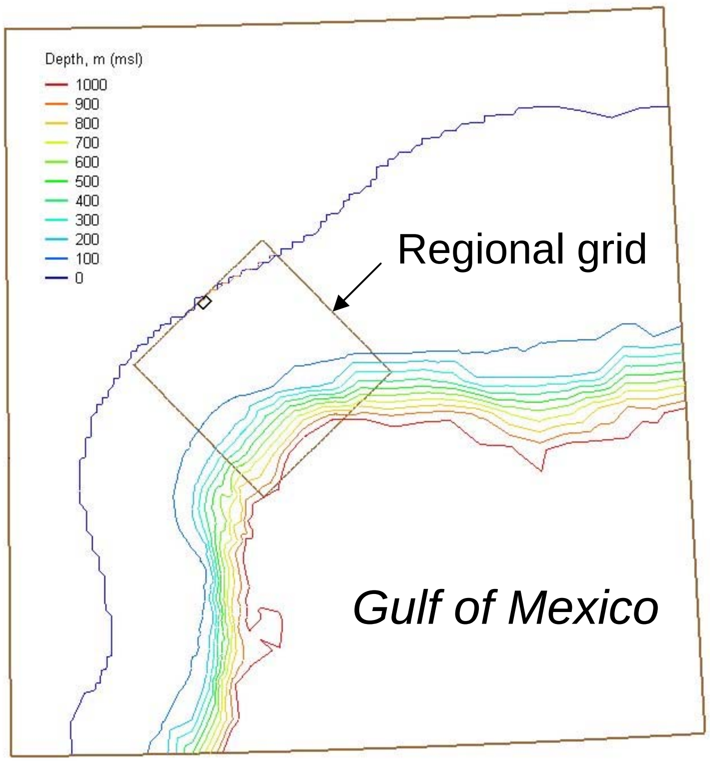
$$S_{dp} = -4(\nu_k + \nu_t)k^2 E$$

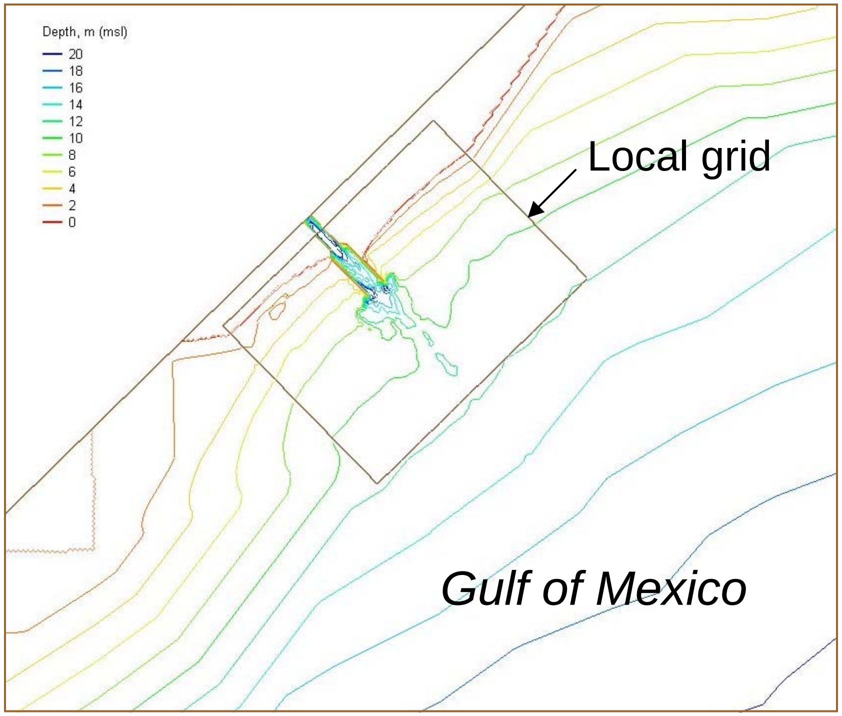
where ν_k is the kinematic viscosity of sea water,

and ν_t is the turbulent eddy viscosity:

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

E. CMS-Wave Grid Nesting

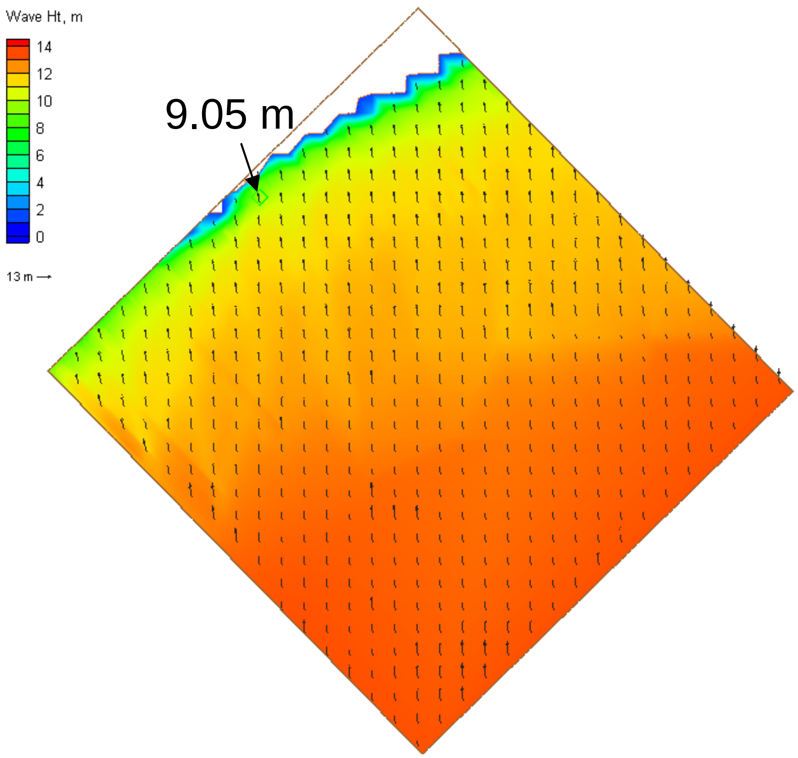




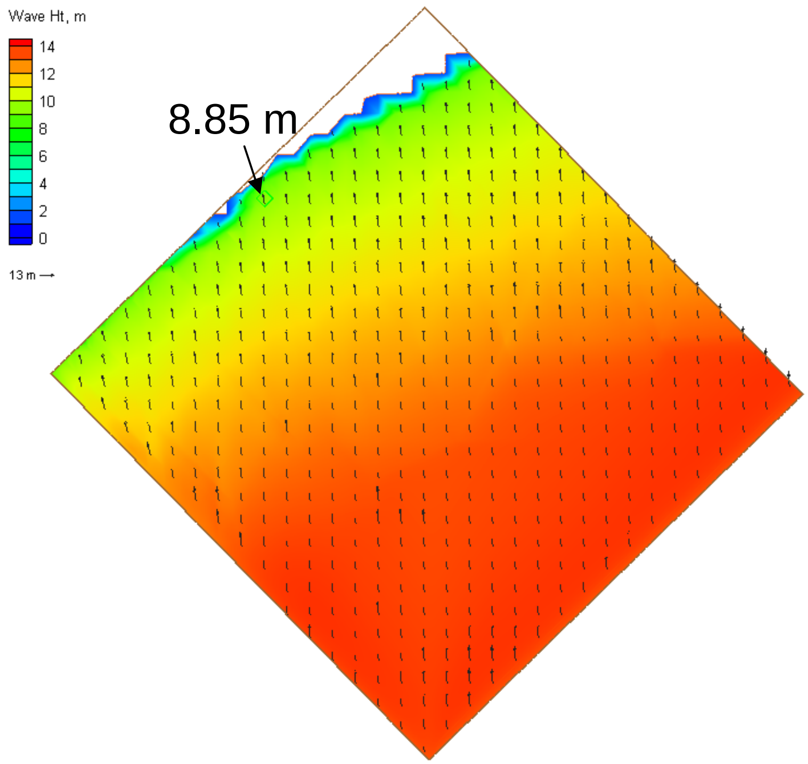
Regional Wave Generation

Incident Waves: 12.9 m, 13.8 sec, from S

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



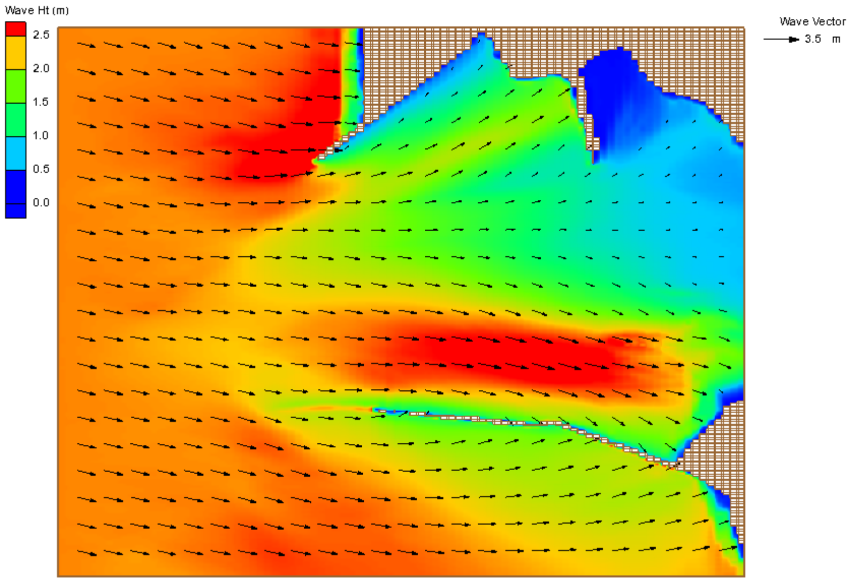
Without wind



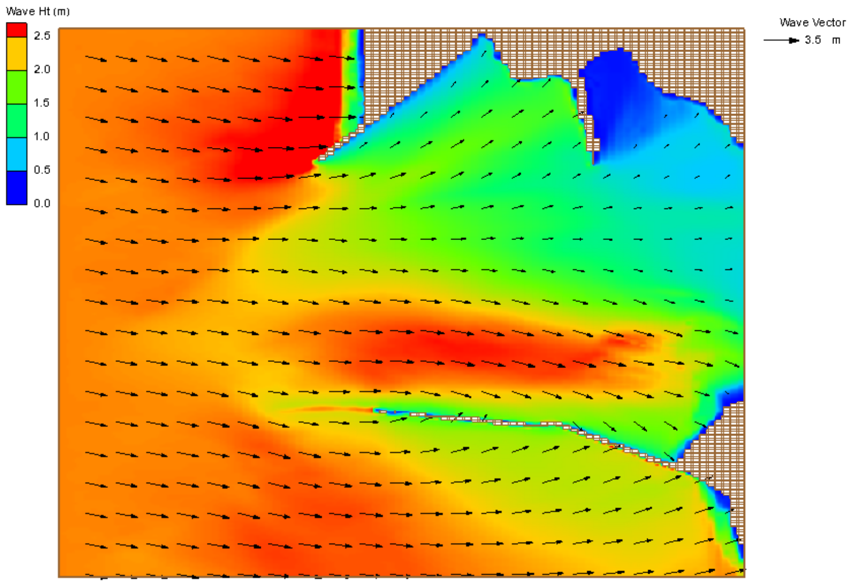
With wind (27 m/sec, from S)

F. CMS-Wave Fast Mode

- Use 5 to 7 directional bins in spectral calculations (Normal runs on 35 directional bins)
- Ideal for a quick application or time-pressing run

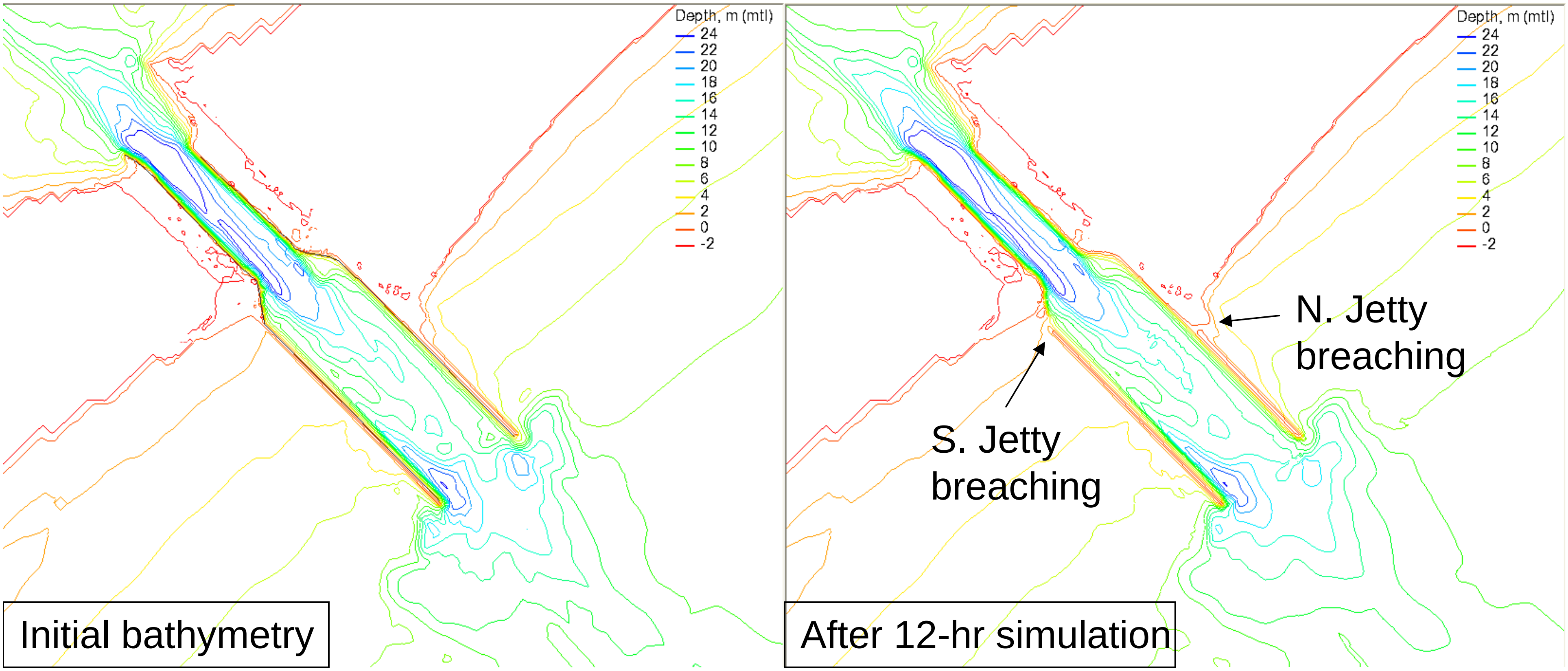


Normal run



Fast mode

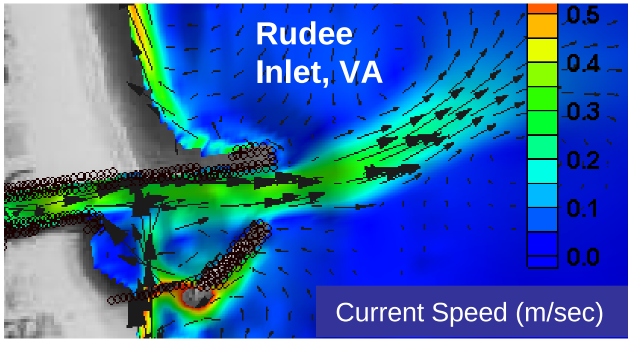
MSC Jetty Wave Run-up & Breaching
Cat 3 Hurricane (50-Yr Life-Cycle)



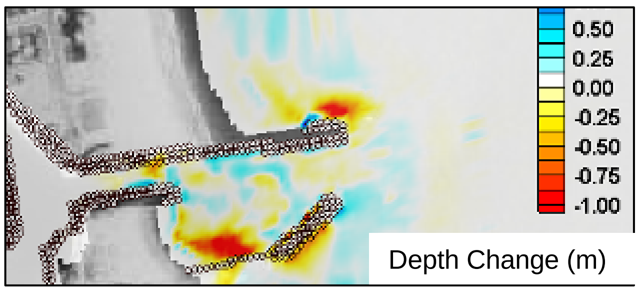
- Peak storm surge level reaches 3.5 m between Hrs 4 and 8
- Incident offshore wave is 7.6 m, 14.3 sec, from south direction

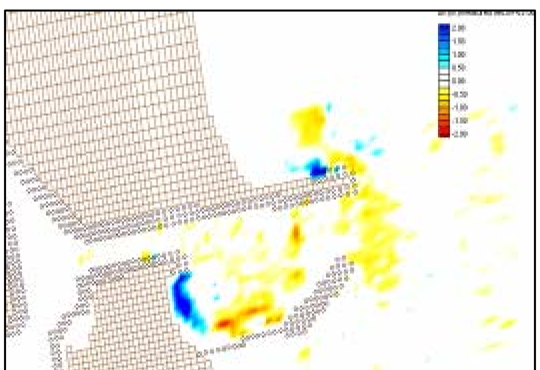
Sample CMS Steering Applications

Wave & Tide-driven current

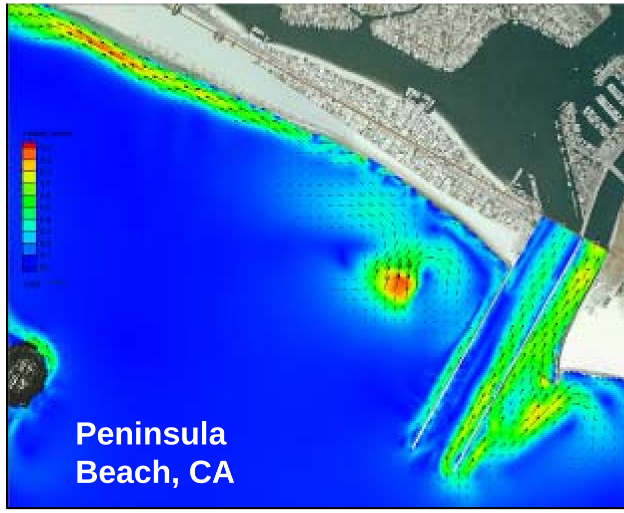


Morphology Change

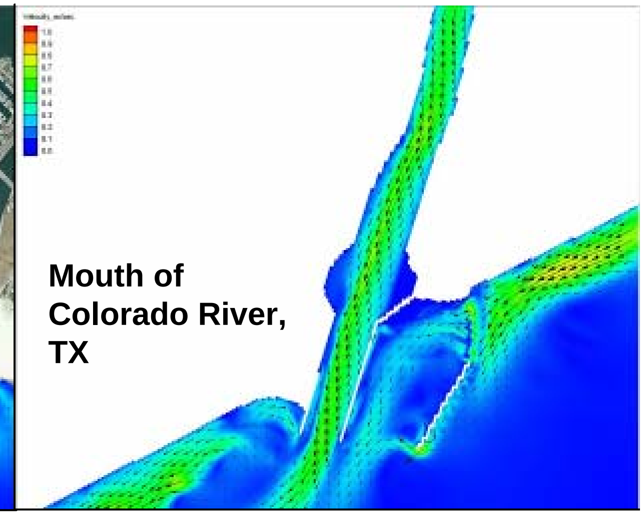


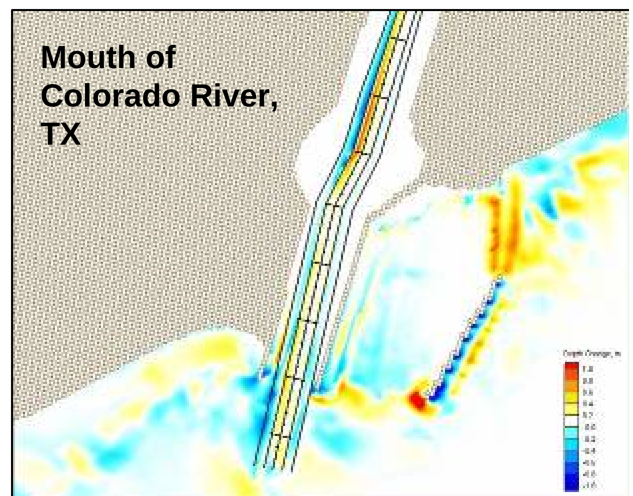


Wave-driven current



Wave & Tide-driven current





12. Future Improvement

Physics
- Non-linear wave-wave interaction

Speed increases
- Inline code: CMS-Wave & CMS-Flow
- XMDF (binary format) for CMS-Wave
- Implementation of Open MPI
- Unstructured and telescoping grids

Functionality
- Full-plane transformation

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**

http://cirp.wes.army.mil/cirp/cirp.html