CMS-Wave Background and Capabilities

Developed for coastal and inlet applications

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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

<table>
<thead>
<tr>
<th>Capability</th>
<th>CMS-Wave</th>
<th>STWAVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum transformation</td>
<td>Directional</td>
<td>Directional</td>
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<tr>
<td>Refraction &amp; shoaling</td>
<td>Represented</td>
<td>Represented</td>
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<tr>
<td>Depth-limited wave breaking</td>
<td>Choice among four formulas</td>
<td>One formula</td>
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<tr>
<td><strong>Diffraction</strong></td>
<td>Theory</td>
<td>Smoothing</td>
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<tr>
<td><strong>Reflection</strong></td>
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<tr>
<td><strong>Transmission</strong></td>
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<td>Run-up and setup</td>
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<td>None</td>
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<tr>
<td>Wave-current interaction</td>
<td>Theory</td>
<td>Theory</td>
</tr>
<tr>
<td>Wave-wave interaction</td>
<td>Theory</td>
<td>Semi-empirical</td>
</tr>
<tr>
<td>Wind input</td>
<td>Theory</td>
<td>Semi-empirical</td>
</tr>
<tr>
<td>White capping</td>
<td>Theory</td>
<td>Semi-empirical</td>
</tr>
<tr>
<td>Bottom friction</td>
<td>Theory</td>
<td>Theory</td>
</tr>
</tbody>
</table>

## Structures

Coastal Modeling System Basics Webinar 5
CMS-Wave SMS 11.0 Interface

- Settings:
  - Forward reflection
  - Backward reflection
  - Muddy bed
  - Wave breaking formula

- Bed Friction:
  - Spatially constant: n
  - Spatially varied: none selected

- Matrix Solver:
  - Gauss-Seidel
  - Processes: 1

- Currents:
  - Single timestep
  - All timesteps

- Spatial wind field:
  - Single timestep
  - All timesteps

- Spatial surge:
  - Single timestep
  - All timesteps

- Wave Source:
  - Spectra
  - Wind
  - Spectra and wind
  - Simplified formulation

- Output:
  - Radiation stresses
  - Sea/Swell
  - ASCII
  - XMDF
3. Governing Equation

Wave-Action Balance Equation with Diffraction

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

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

Energy vs. Frequency

Energy vs. Direction
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
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 Height (m)

- **SPM(1984)**
- **CMS-Wave**

Fetch (km)

- $U = 35$ m/sec
- $U = 20$ m/sec
- $U = 10$ m/sec

Wave Period (sec)

- **SPM(1984)**
- **CMS-Wave**

Fetch (km)
Wave Breaking Formulas
Wave Generation in Matagorda Bay, TX

Rita

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 grid
- Local grid

Gulf of Mexico
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)
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 $R2 = \text{wave setup} + 2\% \text{ exceedance of swash level}$

Wave setup:

$$\frac{\partial \eta}{\partial x} = -\frac{1}{\rho gh} \left( \frac{\partial S}{\partial x} + \frac{\partial S}{\partial y} \right), \quad \frac{\partial \eta}{\partial y} = -\frac{1}{\rho gh} \left( \frac{\partial S}{\partial x} + \frac{\partial S}{\partial y} \right)$$

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

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

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
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):

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

Composite or rubble-mound breakwater:

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

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

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

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
Idealized Floating Breakwater

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

struct.dat
Idealized Platform

- 20 feature cells
- Input depth = 10 m
- Incident wave: 2 m, 6 sec, 30 deg oblique (gamma = 4)
- Platform elev. = 1 m (mwl)

struct.dat
Submerged Platform

20 feature cells

input depth = 10 m

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

platform elev. = -2 m (mwl)

struct.dat
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

<table>
<thead>
<tr>
<th>$h_c$ (m)</th>
<th>CMS-Wave</th>
<th>Equations</th>
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<tbody>
<tr>
<td></td>
<td>Vertical wall</td>
<td>Rubble mound</td>
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<tr>
<td>-2.0</td>
<td>1.02</td>
<td>1.02</td>
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<td>-1.5</td>
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<td>1.0</td>
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<tr>
<td>1.5</td>
<td>0.10</td>
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<tr>
<td>2.0</td>
<td>0.07</td>
<td>0.018</td>
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</table>
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

Coupled CMS-Flow and CMS-Wave
## Calculated Wave Overtopping Rate

<table>
<thead>
<tr>
<th>Case number</th>
<th>Surge level (m)</th>
<th>Wave height (m)</th>
<th>Wave peak period (sec)</th>
<th>Overtopping rate (m²/sec)</th>
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<tbody>
<tr>
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<td>Measured</td>
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<td>R128</td>
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<td>2.31</td>
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</table>

* Calibration  □ With wave overtopping
Wave dissipation by damping (Lamb, 1932):

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

where \( \nu_k \) is the kinematic viscosity of sea water, and \( \nu_t \) is the turbulent eddy viscosity:

\[ \nu_t = \nu_{t,\text{breaking}} \frac{H_s}{h} \]
Louisiana Muddy Coast Simulation

![Muddy Coast Simulation Diagram]

**Graphs:**
- Graph (a) showing wave height (m) with colors ranging from 0.0 to 1.0.
- Graph (b) showing wave period (sec) with colors ranging from 1.0 to 4.0.

**Legend:**
- **CSI3**
- **CMS (sand only)**
- **CMS (with mud)**

**Color Shading:**
- Coarse green</doc>
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
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
\[
B = k^3 \sigma^5 \frac{n^4}{(2\pi)^2 g} \left[ \left( \frac{\sigma_0}{\sigma} \right)^4 E \right]^3
\]
Exact and Calculated $S_{nl}(f)$

\[ \gamma = 2 \]

\[ \gamma = 5 \]
Spectral Evolution and $S_{nl}(f, \theta)$

$\gamma = 5$

Initial

Evolved
Nonlinear Wave Effect

The graph illustrates the variation of parameters \(a\), \(b\), \(\sigma\), and \(n\) with \(kh\) across different water depth regimes: Shallow, Intermediate, and Deep.
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

Coastal Modeling System Basics Webinar
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


**CMS-Wave**  
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