CMS: A Coastal Modeling System for Inlets and Navigation Projects

Emphasis on practical coastal modeling

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COAA2010
Taipei
Outline

- Introduction of Coastal Modeling System (CMS)
- GUI and Interface by Surface-water Modeling System (SMS)
- Idealized and Laboratory Examples
- Real-world Examples
- Summary
Coastal Modeling System (CMS)

- CMS-Wave
  - Diffraction, Reflection, Run-up, Setup, Overtopping, Wave generation, Structures
  - Current, Water Level, Morphology Change
  - Wave Height, Direction, Period, Dissipation, Radiation Stresses

- CMS-Flow
  - Hydrodynamics
    - Waves, Tide, Wind, River, Current
  - Wave Info
  - Sediment Transport
  - Other Processes
    - Weirs, Culverts
  - Morphology
    - Morphologic Constraints

- CMS-PTM
  - Lagrangian Particle Tracking Model

- 3 main models:
  - CMS-Flow
  - CMS-Wave
  - CMS-PTM

- 3 main models:
  - CMS-Flow
  - CMS-Wave
  - CMS-PTM

- Physics-based to simulate complete coastal processes

- Integrated and user-friendly system in SMS

Unstructured grid, several sediment transport formulas, fast, channel sedimentation, inlet shoals
CMS Models

• **CMS-Flow**: a 3D time-dependent hydrodynamic and sediment transport model for simulating circulation, salinity & sediment transport forced by tides, wind, atmospheric pressure, river inflow, waves using implicit numerical scheme on quad-tree grid

• **CMS-Wave**: a steady-state, half-plane spectral wave transformation model based on wave-action balance diffraction equation on a non-uniform Cartesian grid

• **CMS-PTM**: a particle tracking model to calculate the paths & mobility of sediment (cohesive and non-cohesive particles in a Lagrangian approach
West Coast/Pacific
Mouth of Columbia River, WA/OR
Seattle, WA (CMS-Wave)
Grays Harbor, WA
Willapa Bay Toke Point, WA (NWS)
Willapa Bay Center, WA
Noyo, CA
Humboldt, CA
Ocean Beach, CA
Dana Point, CA
Pelekeane, HI
Cold Bay, AK
Ketchikan, AK (CMS-Wave)

Great Lakes
Cleveland Harbor, OH
New Buffalo, MI
Lake Erie
Ontario Beach, Rochester, NY

Gulf
Bahia Grande, TX
Mouth of Colorado River, TX
Matagorda Ship Channel, TX
Baffin Bay, TX
Corpus Christi Bay, TX
Houston-Galveston, TX
Sabine Pass, TX

Gulf (cont)
Port of S. LA, Bonne Carie, LA
White Ditch, Plaquemines Parish, LA
Pensacola Pass, FL
Eglin-Ft. Walton Beach, FL
New Pass, FL (SAJ)
Big Sarasota Pass, FL (SAJ)
Sarasota Bay (SAJ)
Blind Pass, FL
Johns Pass, FL
Tampa Bay, FL
Venice Inlet, FL
Gordon Pass, FL
Longboat Pass, FL
Wiggins Pass, FL
Gasparilla Island, FL
Anna Maria Island, FL
Cape Sable Canal, FL
Key West Federal Navigation Channel (SAJ)

Atlantic (cont)
Rooster Island, MD
Ponce Inlet, FL
St. Augustine, Del. Bay, DE
Point Lookout, NY
Shark River Inlet, NJ
Hereford Inlet, NJ
Pleasant Bay, MA
Lake Montauk, NY
Askaroken, NY
Shinnecock Inlet, NY
Moriches Inlet, NY
East Harbor, MA (NAE)
Rhode Island (RSM) (NAE)
Great Egg Inlet, (NAP)

International
NW Australia
Veracruz, Mexico
Grand Cayman Is., Bahamas
Bardawil Lagoon, Egypt
Nanaimo, British Columbia, Canada (CMS-Wave)
Papua New Guinea (CMS-Wave)
Equatorial Guinea, Africa (CMS-Wave)

CMS Licenses
CANADA 4
CHINA 5
COLOMBIA 1
GERMANY 1
GUATAMALA 1
INDIA 1
INDONESIA 1
ITALY 1
JAPAN 1
JORANDA 4
ROMANIA 2
S. KOREA 6
SPAIN 5
TAIWAN ROC 1
U.K. 4
USA 30
VENEZUELA 1
VIETNAM 2
TOTAL 71
Surface-water Modeling System (SMS)

A Complete Modeling Interface
Build a CMS simulation from start to finish

Toolbars
Project Explorer
Edit Fields
Display
Modules
Help/Status
CMS-Flow Key Features

- **Grid option**
  - Non-uniform Cartesian grid: Easy to setup
  - Telescoping (quadtree) grid: Efficient, flexible

- **Solver option**
  - Implicit: Tidal flow, long-term morphology change, ~ 10 to 15 min time step
  - Explicit: Flooding, breaching, super-critical flow, ~ 1 sec time step

- **Parallel Processing**
CMS Telescoping (Quad-tree) Grid

Telescoping Grid

Nowcast and forecast
Wind, waves, tide, and current, Humboldt Bay Entrance, CA
Collaboration with NWS (NOAA)

Total 57 k cells
Cell size: 12.5 m – 1.6 km

Humboldt Bay, CA
CMS-Flow: Channel Infilling
Non-Equilibrium Sediment Transport

Galappatti and Vreugdenhil (1985)

Test 01

Initial Bathymetry
Measured 15 hr
Computed 15 hr
Computed 7.5 hr

Waves parallel to flow

Van Rijn (1985)

Waves perpendicular to flow

Galappatti and Vreugdenhil (1985)

Van Rijn and Havinga (1995)
Extreme Wetting/Drying

- Remediation, restoration project
- 1:1500 slope
- Circulation dominated by wind

Laquna Madre, TX
Bahia Grande
Wind Generated Circulation in Bahia Grande, TX

30-day simulation
CMS-Wave Key Features

- Shoaling, refraction, diffraction, reflection
- Bottom friction
- White capping
- Wave breaking (4 options)
- Wind generation
- Wave-current & wave-wave interactions
- Transmission, run-up & overtopping
- Infra-gravity wave
- Muddy bottom
- Non-uniform Cartesian grid with nesting capability
- Optional “Fast Mode”
Wave-Action Balance Equation with Diffraction (Mase, 2001)

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

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.
Wave Diffraction and Reflection

Animation by SMS
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 water elevation

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

Transmission coefficients $k_t$

$H_i = 1 \text{ m}, \ T_p = 6 \text{ sec (monochromatic wave)}$

$h = 10 \text{ m}, \ d = 5 \text{ m}, \ B = 80 \text{ m}$

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

Rita Hurricane
0400 UTC, 24 September 2005

Matagorda Bay, TX

Hurricane Rita
0400 UTC, 24 September 2005
Wave Dissipation over Muddy Coast

\[ S_{\text{mud}} = -4v_{\text{turb}} k^2 E \]

Lamb (1932)
Nonlinear Wave-Wave Interaction

Based on Jenkins and Phillips (2001)

\[ E = \frac{\alpha g^2}{\sigma^5} \exp(-0.74 \frac{\sigma_0^4}{\sigma^4}) \gamma^\alpha \]

\[ \gamma = 5 \]
Infra-gravity Waves

Incident Wave:
2 m, 15 sec
from NE

with infra-gravity wave

without infra-gravity wave

Humboldt Bay
CA
Coupling CMS-Flow & CMS-Wave

Jetty Breaching Simulation

Matagorda Ship Channel, TX

CMS-Flow

Morphological Change

South Jetty Breaching

CMS-Wave
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
Application: Testing of New Orleans Levees with Surge and Waves

ERDC/CHL TR-08-10 by Hughes (2008)
Calculated Levee Overtopping
Storm Surge = 1.3 m, $H_s$ = 2.3 m, $T_p$ = 14 sec

Coupled CMS-Flow & CMS-Wave
ADCIRC & CMS Simulations

Total 400 x 240 cells
Cells: 40 m x 30 m to 200 m x 200 m

Grays Harbor, WA

BUILDING STRONG®
ADCIRC & CMS Calculated Current Fields
13 October – 12 November 1999

ADCIRC (Wind, Tides)  CMS (Wind, Tides, Waves)
Flow and Wave Overtopping Rate Calculation

- Strait of Juan De Fuca
- Wave run-up calculation
- 191 overtopping output locations
- Elwha, WA
Boundary Condition (30-hr Simulation)

Water Level (30-hr input)

Constant Incident Wave:
2.3 m, 16.7 sec, WNW
Calculated Wave and Water Level @ 30-hr Simulation

Calc. wave field by CMS

CMS-Wave standalone

Calc. water level field by CMS

Shoreline
Calculated Flow Rate (m²/sec) Along 191 Locations

CMS-Wave standalone

Calc. wave field
Hurricane Isabel Simulation
17-21 Sep 2003

CMS Domain: Lower Chesapeake Bay
~ 20 x 24 km

Total Cells: ~ 530,000 (rectilinear grid)

Cell Size: 10 ~ 300 m

Water Surface Elevation Forcing:
ADCIRC regional simulation

Wind: PBL Model
CMS Simulation

Calculated Water Surface Elevation
(Mean Sea Level + 2 m Sea Level Rise):
CMS Simulation

Calculated Wave Height (2 m Sea Level Rise):
Dredged Material Discharge – clay particles (Noyo Bay, CA)
Summary

- CMS is developed for practical applications to simulate the full coastal processes emphasizing wave-structure-land interactions.

- It provides a powerful engineering tool on desk-top computers with both accuracy and run-time efficiency through the use of SMS interface.

- CMS-PTM shows path and mobility of sediment particles driven by hydrodynamics flow, waves, and interacted with sediment properties.

- Future capabilities include spherical coordinate for flow, full-plane for wave, shoreline change, and a advanced data analysis module.
CMS Documentation

- CIRP CMS
- CIRP Wiki

http://cirp.usace.army.mil/

http://cirp.usace.army.mil/wiki/
Questions?

“Sediment Impoundment Basin” on weir jetty, Rudy Inlet, VA