Shock-Capturing Boussinesq-type Model for Fringing Reef Environment

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November 3, 2011
Hilton Waikoloa Village, Kona, Hawai`i
1. Numerical model: BOSZ
   ● Theoretical and Numerical Formulation

2. Model validation with laboratory data
   ● 2D experiments from Oregon State University
   ● 3D experiments from Oregon State University

3. Model applications
   ● PILOT project, Mokuleia, Oahu, HI
   ● Hurricane Ivan, Okaloosa, FL

4. Conclusions and Outlook
BOSZ
(Boussinesq model for Ocean and Surf Zones)

Governing Equations

- **Conservative Boussinesq-type equations**
  - Conservative form of Nwogu’s (1993) Boussinesq-type equations

Numerical Scheme

- **Explicit, Finite Volume scheme**
  - Runge-Kutta time integration, adaptive time step, iteration-free
  - Mass balance at moving boundary
  - 2D reconstruction technique, Riemann solver for wave breaking
  - Robust for energetic breaking waves over irregular bathymetry

- **Momentum Conservation**
  - Imbedded conservation laws for sub- and supercritical flows

- **Parallelization**
  - OpenMP parallelization for handling of large flow problems
1. BOSZ

Governing Equations

**Conservative Boussinesq-type equations**

Vector form

\[ U_t + F(U)_x + G(U)_y + S(U) = 0 \]

\[
F = \begin{bmatrix}
Hu & \frac{1}{2} g \eta^2 + g \eta h \\
Hu^2 + \frac{1}{2} g \eta^2 + g \eta h & Huv
\end{bmatrix}
\]

\[
G = \begin{bmatrix}
Hv \\
Hu \\
Hv^2 + \frac{1}{2} g \eta^2 + g \eta h
\end{bmatrix}
\]

\[
S = \begin{bmatrix}
\psi_C \\
-g \eta h_x - H_t \psi_P + u \psi_C + \tau_1 \\
-g \eta h_y - H_t \psi_Q + v \psi_C + \tau_2
\end{bmatrix}
\]

Nonlinear Shallow-Water Equations

Flow velocity from series of one-dimensional systems of equations

\[
P = Hu + Hz_a \left[ 0.5 z_a \left( u_{xx} + v_{xy} \right) + (hu)_{xx} + (hv)_{xy} \right]
\]

\[
Q = Hv + Hz_a \left[ 0.5 z_a \left( v_{yy} + u_{xy} \right) + (hv)_{yy} + (hu)_{xy} \right]
\]

Dispersion terms only containing spatial derivatives
2. Validation

Idealized fringing reefs in 2D

Extended reef flat with crest
Intermediate to steep fore-reef slope
Laboratory Facility
Large Wave Flume, Oregon State University
Large Wave Flume
Wave height: 0.75 m
Water depth: 2.50 m
$A/h: \quad 0.3$
Reef slope: 1:12

QuickTime™ and a
H.264 decompressor
are needed to see this picture.
**Large Wave Flume**
- Wave height: 0.75 m
- Water depth: 2.50 m
- $A/h$: 0.3
- Reef slope: 1:12

**BOSZ setup**
- $\Delta x$: 0.1 m
- $C_r$: 0.5
- $n$: 0.014 m$^{1/3}$/s

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**BOSZ animation** $A/h = 0.3$

- Time: 0.00 sec

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**BOSZ - free surface, 2D reef**

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- BOSZ
- OSU data

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BOSZ - validation, 3D reef with cone

Tsunami Wave Basin, Oregon State University

Wave height: 0.39 m
Water depth: 0.78 m
$A/h$: 0.5
3D reef with apex

Experiment conducted by Dr. Patrick Lynett
Large Wave Flume
Wave height: 0.39 m
Water depth: 0.78 m
$A/h$: 0.5

BOSZ setup
$\Delta x$: 0.1 m
$C_r$: 0.5
$n$: 0.014 s/m$^{1/3}$

BOSZ - free surface, 2D reef
BOSZ - free surface, 3D reef
BOSZ - velocity, 3D reef
2. Application

Mokuleia, Oahu, HI

Experiment conducted by Dr. Mark Merrifield & Dr. Janet Becker, UH OCN
Mokuleia, bathymetry

- Nearshore reef with lagoon
- Steep reef slope
- Highly irregular bathymetry
- Energetic breaking waves
BOSZ - free surface, Mokuleia

**Typical North Swell**
- Hs: 1.0 m
- Tp: 15 s
- Grid: 3.5 m
- Small directional spreading

Wave input:
Spectrum from field data
Hurricane Ivan, Okaloosa, FL

Hurricane Ivan
Hs: 6.3 m
Tp: 12.6 s
Grid: 5 m
Large directional spreading

- Gentle sedimentary coast
- Barrier island, lagoon system
- Steep short period waves
- Energetic breaking waves

Wave input:
SWAN spectrum
BOSZ - flow depth, velocity, Hurricane Ivan
BOSZ - erosion, velocity, Hurricane Ivan
4. Conclusions

1. Development of numerical model BOSZ
   ● Designed for - but not limited to - fringing reefs
   ● Robust and computationally efficient

2. Model validation
   ● Model combines shock-capturing and dispersive capabilities
   ● Works for energetic breaking waves with moving boundary

3. Model applications
   ● Wave transformation over reefs and continental coasts
   ● Coastal engineering tool for flood and hazard assessment

More information:


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