Evolution of Ocean Surface Waves Across a Muddy Continental Shelf

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Objective

General Objective
To improve understanding and operational modeling capability of ocean wave evolution across a muddy continental shelf.

Modeling

Array design

Verification/validation

Field experiment
Objective Field Experiment

Augment detailed fluid-mud layer measurements [Trowbridge/Traykovsky/Kineke] and nearshore wave measurements [Elgar/Raubenheimer] with large-scale array of wave and bottom (fluid-mud) measurements across the shelf to obtain (for the first time) a comprehensive set of field observations of waves over a muddy shelf.
Array plan

Experiment site

Elgar/Raubenheimer Array

Platforms (Trowbridge/ Kineke/ Traykovski)

Pressure Velocity Bottom Tripods

Directional Waverider Buoys

24 6 8 10 15 m

29.25 to 29.50

92.75 to 92.50

10 km
Array plan

Experiment site

25 km Linear array

2D array MURI tower

Wave boundary condition
Tripod instrument clusters

Spider

Mounting rack
Tripod instrument clusters

- Nortek Aquadopp acoustic Doppler current profiler
- Nortek Vector acoustic Doppler velocimeter
- Benthos dual acoustic releases
- Spider
- Mounting rack

1.5 m
Tripod instrument clusters

- Acoustic Release
- Locating hemisphere
- Release cord
Open Questions: Fluid/mud layer depth?
Strength of consolidated mud?
Open Questions: Mount ABS device to spider to detect bottom/mud dynamics?
Observations provide e.g.:
  • Surface elevation time series
    • Mean current profiles
  • Frequency-directional wave spectra
    • Time series lutocline dynamics
Objective Wave Modeling

To develop modeling capability for random ocean wave evolution over natural muddy bottom topography on the scale of the continental shelf.
Wave Modeling

Direct Interaction

e.g. Gade ’58;
Dalrymple & Liu ’78
McPherson ’80
Mei & Liu ’87
Ng 2000

Nonlinear quadratic surface/interface coupling

e.g. Hill & Foda ‘96
Hill & Foda ’99
Jamali et al. ‘03

Surface waves

Water

Mud

Interfacial waves
Wave Modeling

- Direct Interaction
- Nonlinear quadratic surface/interface coupling
- Existing Deterministic Model
Wave Modeling

Surface elevation decomposed in multi-frequency angular spectrum

$$\eta = \sum_{\lambda, \omega} A^\lambda_{\omega}(x,t) \exp[i(\lambda y - \omega t)]$$

See also: Dalrymple et al. 1989, JFM ; Suh et al. 1990, JFM

$$\frac{D}{Dt} A^\lambda_{\omega}(x,t) = \Gamma\{hA\} + \Gamma\{AA\} + \Gamma\{AAA\}$$

Existing Deterministic Model

Quadratic nonlinear interactions

Cubic nonlinear interactions

Topography scattering

Janssen et al. 2006 JFM
\[ \frac{D}{Dt} A_{\omega}^2(x,t) = \Gamma\{hA\} + \Gamma\{AA\} + \Gamma\{AAA\} \]

Janssen et al. 2006 JFM
Group-scale evolution, cubic nonlinearities

Wave-scale evolution, quadratic nonlinearities

Wave modeling

deep

shallow
Wave modeling

Dissipation

Nonlinear evolution

Deep

Dissipation

? (question mark)

Shallow

Mud

Sand
\[
\frac{D}{Dt} A_1^1(x,t) = \Gamma\{DA\} + \Gamma\{hA\} + \Gamma\{AA\} + \Gamma\{AAA\}
\]

- **Mud damping/dispersion**
- **Topography scattering**
- **Quadratic nonlinear interactions**
- **Cubic nonlinear interactions**

**Surface waves**

**Water**

**Mud**

**Direct Interaction**

Ng (2000)
Direct Interaction
Ng (2000) Coast Engn

Observations
De Wit (1995)
Ng (2000)
Damping & shallow-water harmonics

\[ x = 2\text{km} \]

\[ x = 4\text{km} \]
Inhomogeneous mud patches:

damping + nonlinear refraction/diffraction

Direction of wave propagation
Inhomogeneous mud patches:

damping + nonlinear refraction/diffraction
Stochastic Modeling Approach

Janssen et al. 2006 JFM

Existing deterministic spectral model → Deterministic model → Mud physics
Stochastic Modeling Approach

Existing deterministic spectral model

Deterministic model

Mud physics

Janssen et al. 2006 JFM
Stochastic Modeling Approach

Existing deterministic spectral model

Deterministic model

Issues Stochastic Modeling
- Spatial inhomogeneity
- Non-Gaussianity
- Parametrized physics

See e.g. Janssen 2003, JPO

Large-scale operational wave model

Janssen et al. 2006 JFM
Wave Modeling

Stochastic Modeling Approach

- Existing deterministic spectral model
- Deterministic model
- Monte Carlo
- Closure
- Phase-coupled stochastic wave modeling
- Parameterization
- Large-scale operational wave model

Janssen et al. 2006 JFM
Phase-coupled stochastic modeling

Deterministic evolution equation

\[
\frac{d}{dx} A_{\omega_1}^{\lambda_1}(x, t) = \Gamma_{\lambda_1} \left\{ D(y) A_{\omega_1}^{\lambda_2} \right\} + \text{Nonlinear interactions}
\]

Topography scattering

Stochastic evolution equation

\[
\frac{d}{dx} E_{12}^{12} = \Gamma_{\lambda_1} \left\{ D(y) E_{12}^{32} \right\} + \left( \Gamma_{\lambda_2} \left\{ D(y) E_{12}^{31} \right\} \right)^* + \text{Nonlinear interactions}
\]

Topography scattering

Form evolution equation for statistical moments

\[
E_{12}^{12} = \left\langle A_{\omega_1}^{\lambda_1} A_{\omega_1}^{\lambda_2} \right\rangle^*
\]
Phase-coupled stochastic modeling

Cross-spectrum, measure of correlation between non-collinear components \((\omega_1, \lambda_1)\) and \((\omega_1, \lambda_2)\).

\[ \frac{d}{dx} E_{12}^{12} = \left( \Gamma_{\lambda_1} \left\{ D(y) E_{1}^{32} \right\} \right) + \left( \Gamma_{\lambda_2} \left\{ D(y) E_{1}^{31} \right\} \right)^* \]

Form evolution equation for statistical moments

\[ E_{12}^{12} = \left\langle A_{\omega_1}^{\lambda_1} \left( A_{\omega_1}^{\lambda_2} \right)^* \right\rangle \]
Phase-coupled stochastic modeling

Narrow-band swell

SWAN

Phase-coupled

relative wave height

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Wave Modeling

Deterministic model
Particularly suited for:
• meso-scale applications
• study of nonlinear evolution

Phase-coupled stochastic wave modeling
Particularly suited for:
• meso-scale applications
• non-homogeneous and non-Gaussian wave fields
• wind generation whitecap dissipation

Large-scale operational wave model
Particularly suited for:
• large-scale applications
• wind generation and whitecap dissipation