Shock-Capturing Boussinesq-type Model for Fringing Reef Environment

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Outline

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

$$\mathrm{U}_t + \mathrm{F}(\mathrm{U})_x + \mathrm{G}(\mathrm{U})_y + \mathrm{S}(\mathrm{U}) = 0$$

$$\mathrm{F} = \begin{bmatrix} Hu \\ Hu^2 + \frac{1}{2}g\eta^2 + g\eta h \\ Huv \end{bmatrix} \quad \mathrm{G} = \begin{bmatrix} Hv \\ Hvu \\ Hv^2 + \frac{1}{2}g\eta^2 + g\eta h \end{bmatrix} \quad \mathrm{S} = \begin{bmatrix} \psi_C \\ -g\eta h_x - H_t\psi_P + u\psi_C + \tau_1 \\ -g\eta h_y - H_t\psi_Q + v\psi_C + \tau_2 \end{bmatrix}$$

Nonlinear Shallow-Water Equations

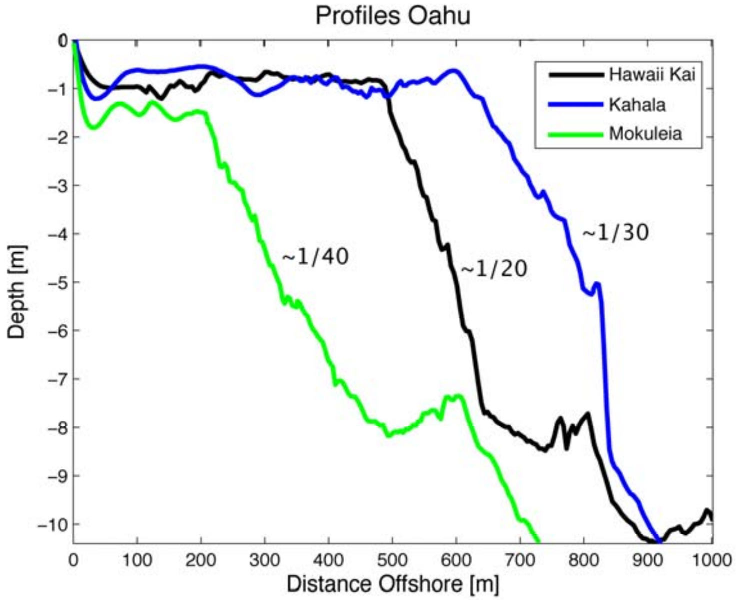
Dispersion terms only containing spatial derivatives

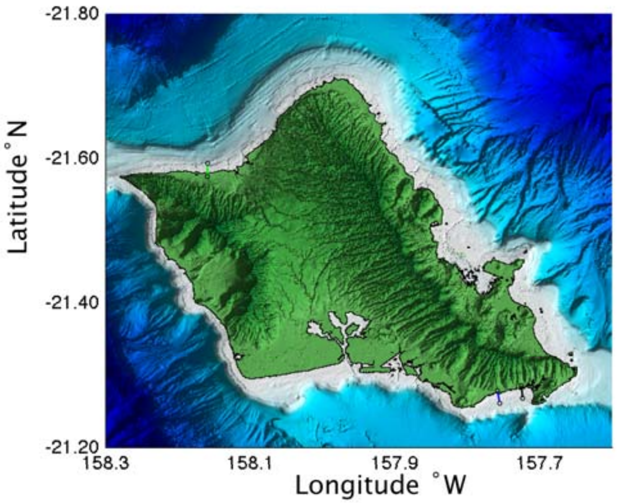
$$\left.\begin{aligned} P &= Hu + Hz_\alpha\left[0.5z_\alpha\left(u_{xx} + v_{xy}\right) + (hu)_{xx} + (hv)_{xy}\right] \\ Q &= Hv + Hz_\alpha\left[0.5z_\alpha\left(v_{yy} + u_{xy}\right) + (hv)_{yy} + (hu)_{xy}\right] \end{aligned}\right\}$$

Flow velocity from series of one-dimensional systems of equations

2. Validation

Idealized fringing reefs in 2D

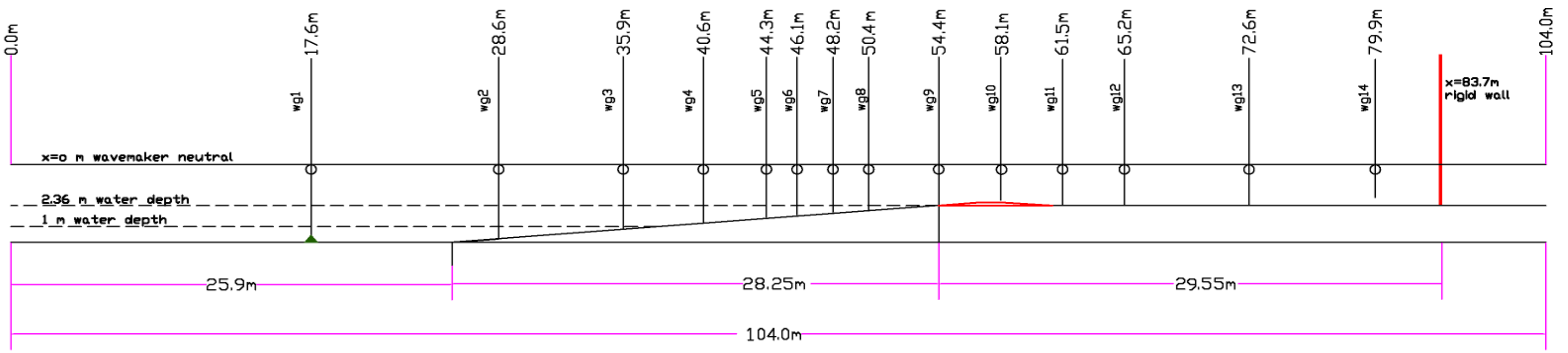




Extended reef flat with crest
Intermediate to steep fore-reef slope

Laboratory Facility

Large Wave Flume,
Oregon State University



b)

Large Wave Flume

Wave height: **0.75** m

Water depth: **2.50** m

A/h: **0.3**

Reef slope: 1:12

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

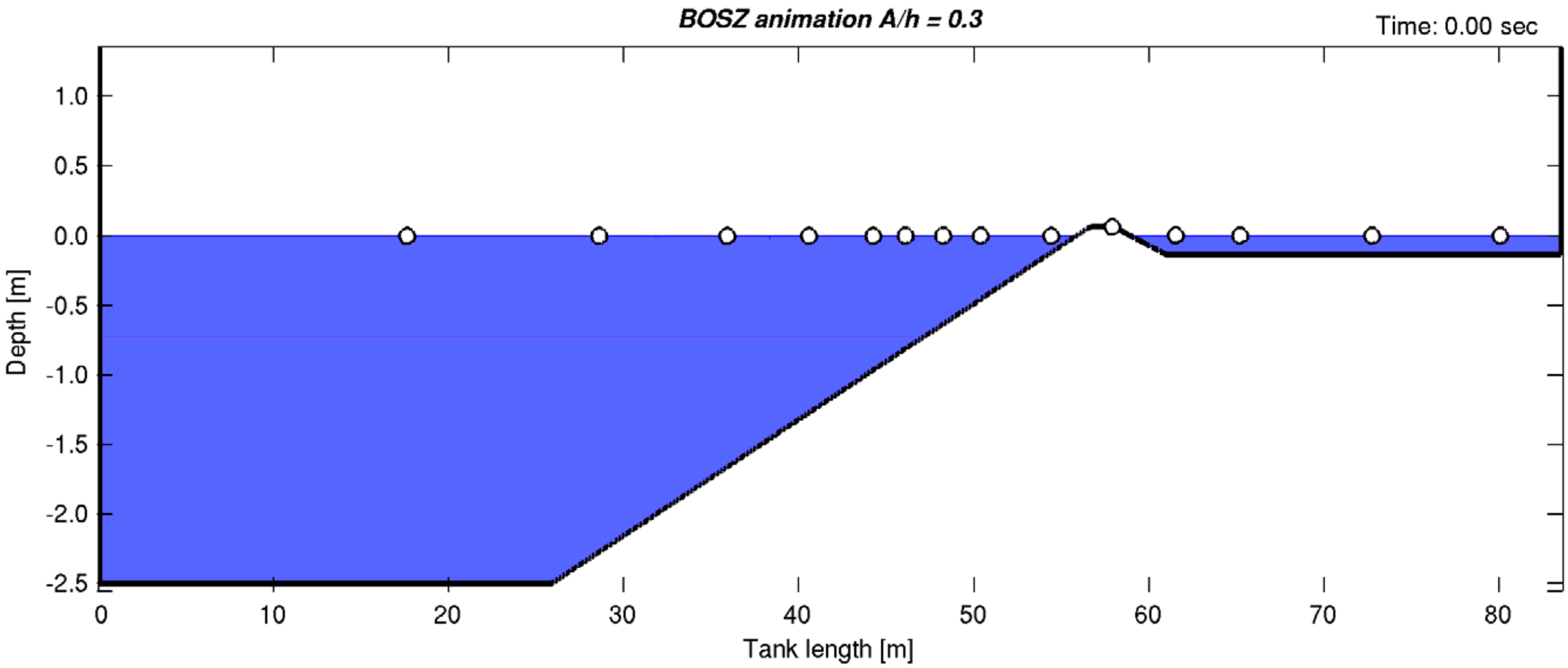
BOSZ - free surface, 2D reef

Large Wave Flume
Wave height: **0.75** m
Water depth: **2.50** m
A/h: **0.3**
Reef slope: 1:12

BOSZ setup

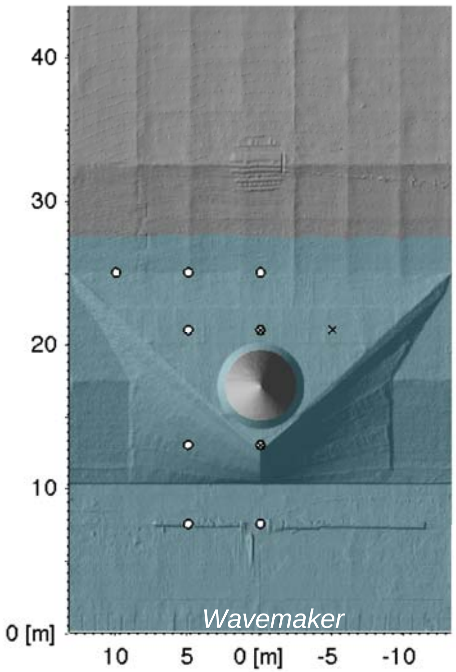
Δx : 0.1 m
C_r : 0.5
n : 0.014 $s/m^{1/3}$

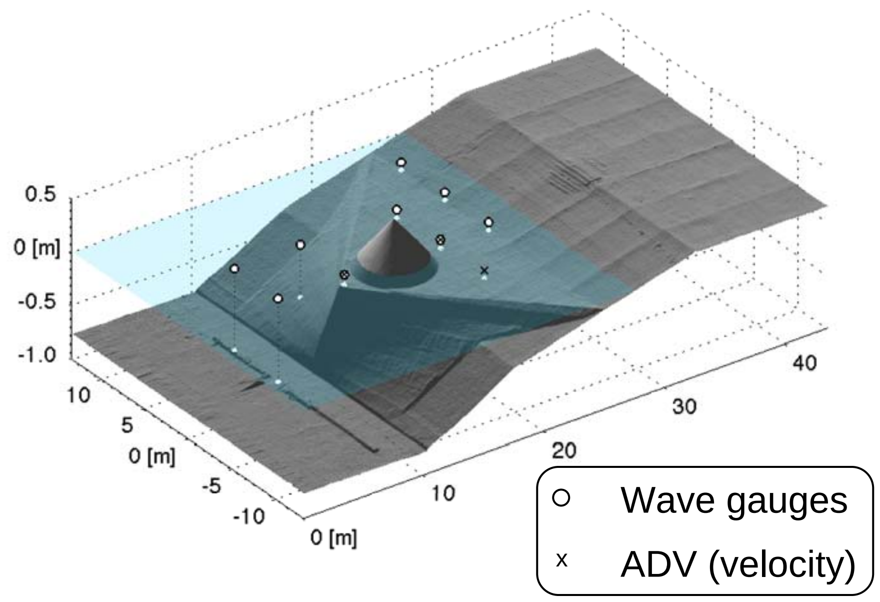
BOSZ
OSU data



BOSZ - validation, 3D reef with cone

Top view





Laboratory Facility

Tsunami Wave Basin,
Oregon State University

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

Experiment conducted by Dr. Patrick Lynett

BOSZ - free surface, 2D reef

Large Wave Flume

Wave height: **0.39** m

Water depth: **0.78** m

A/h: **0.5**

BOSZ setup

Δx : 0.1 m

C_r : 0.5

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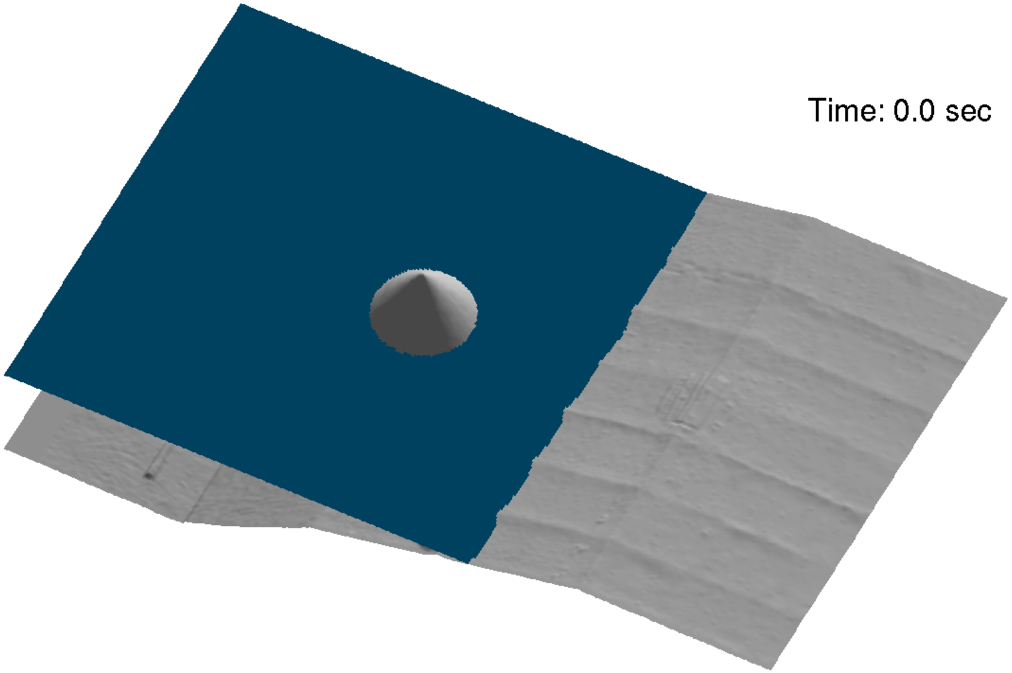
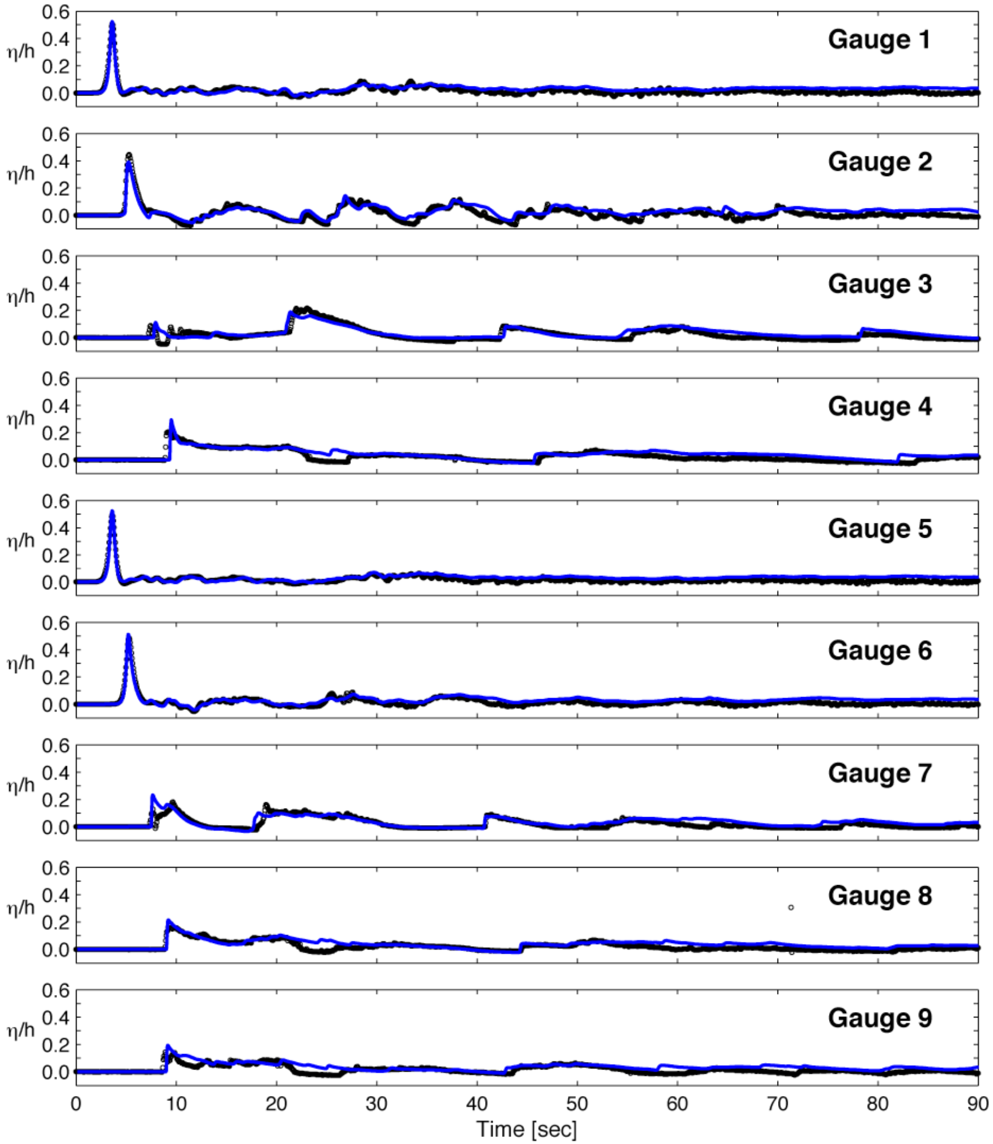
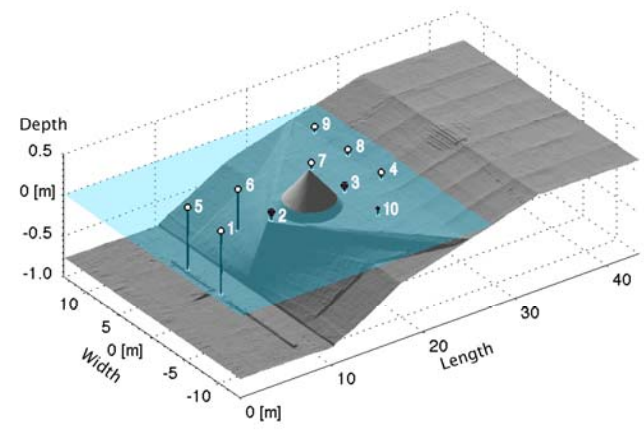


BOSZ - free surface, 3D reef

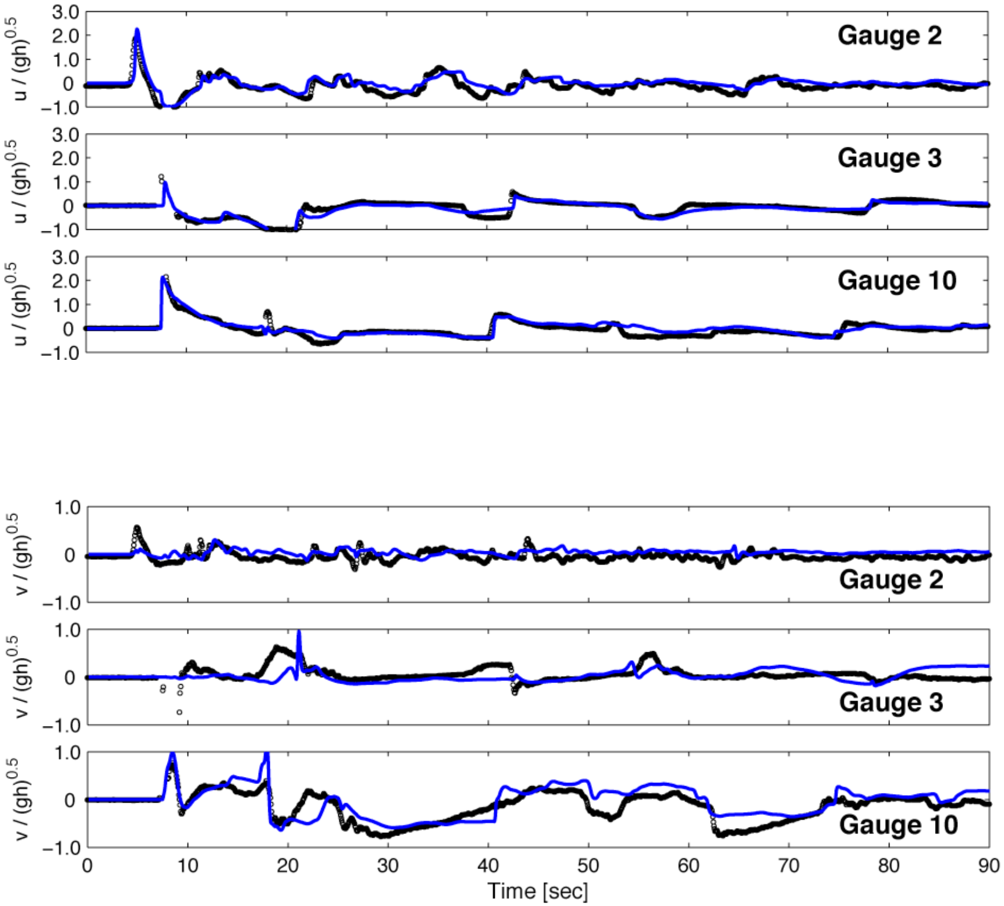


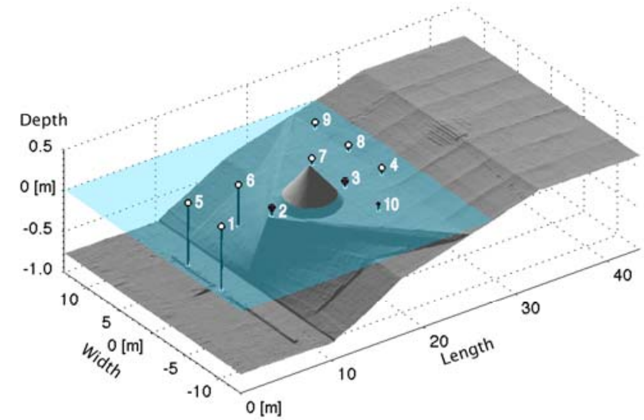


BOSZ

OSU data

BOSZ - velocity, 3D reef



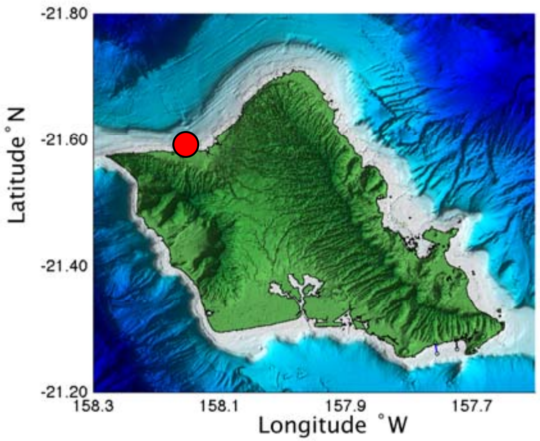


BOSZ

OSU data

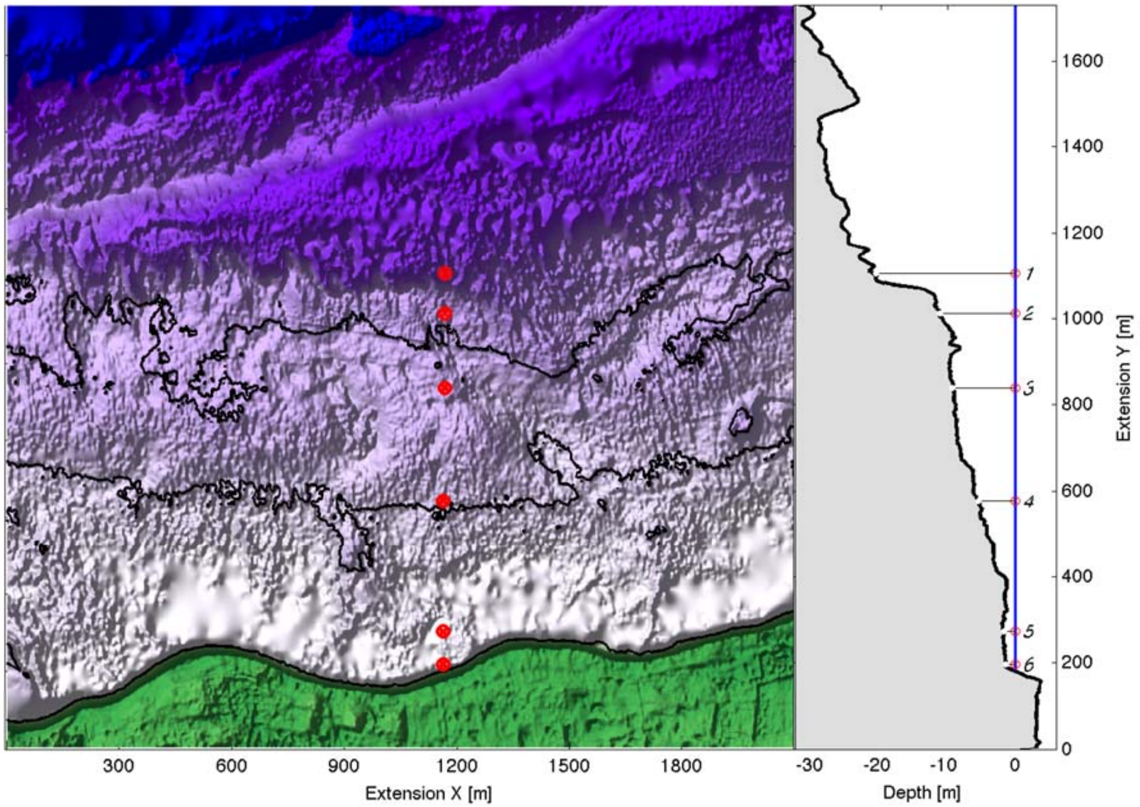
2. Application

Mokuleia, Oahu, HI



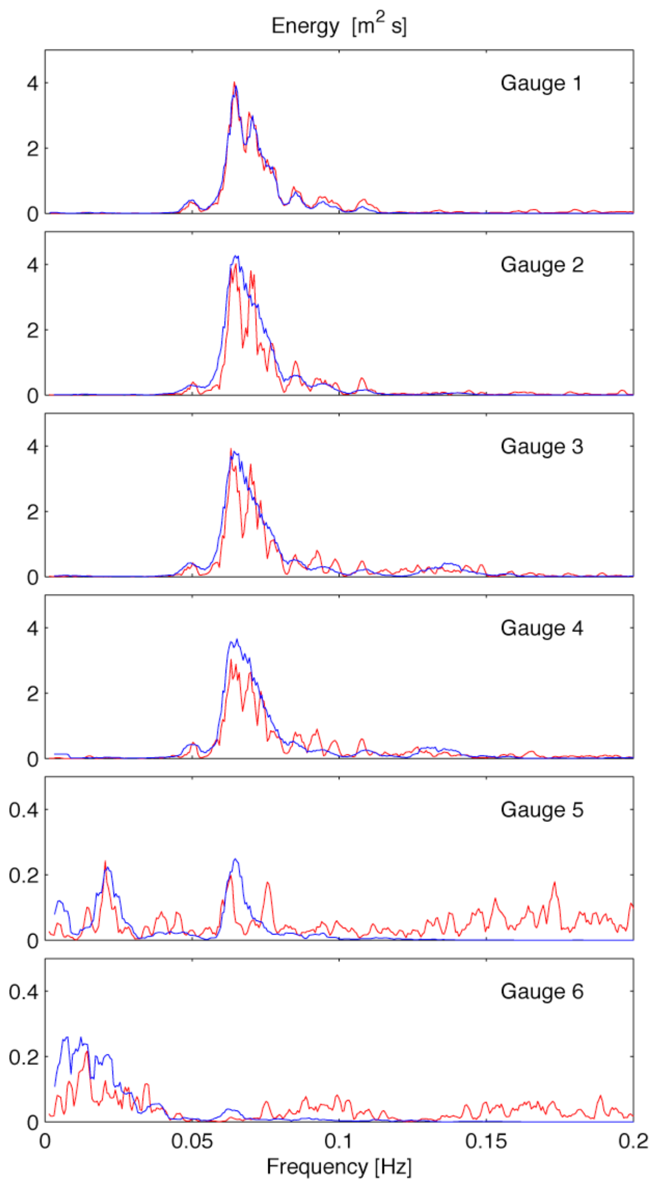
Experiment conducted by
Dr. Mark Merrifield &
Dr. Janet Becker, UH OCN

Mokuleia, bathymetry

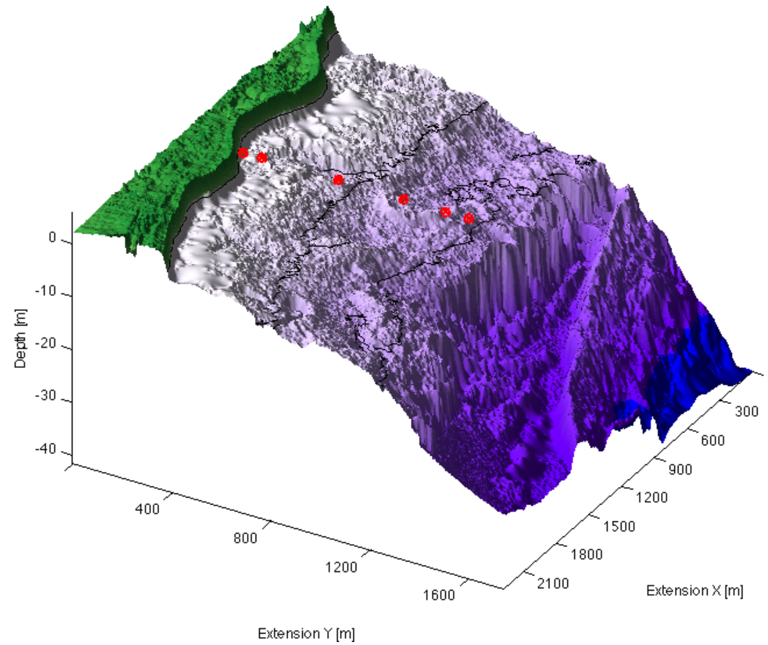


- Nearshore reef with lagoon
- Steep reef slope
- Highly irregular bathymetry
- Energetic breaking waves

BOSZ - free surface, Mokuleia



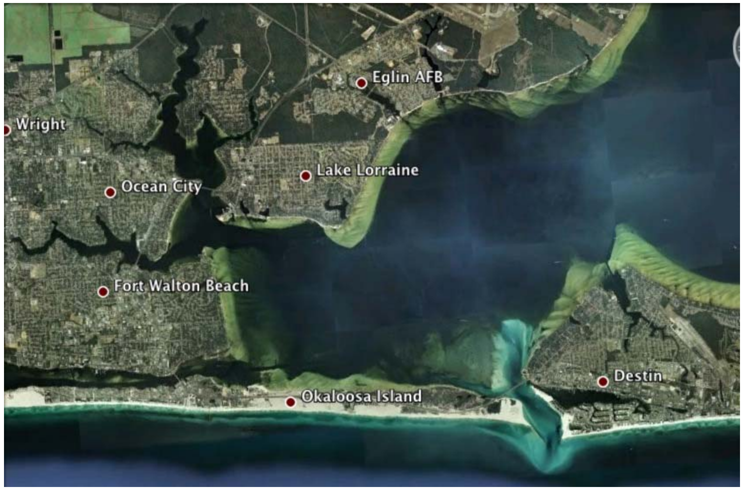
Typical North Swell
Hs: **1.0** m
Tp: **15** s
Grid: **3.5** m
Small directional spreading



BOSZ
field data

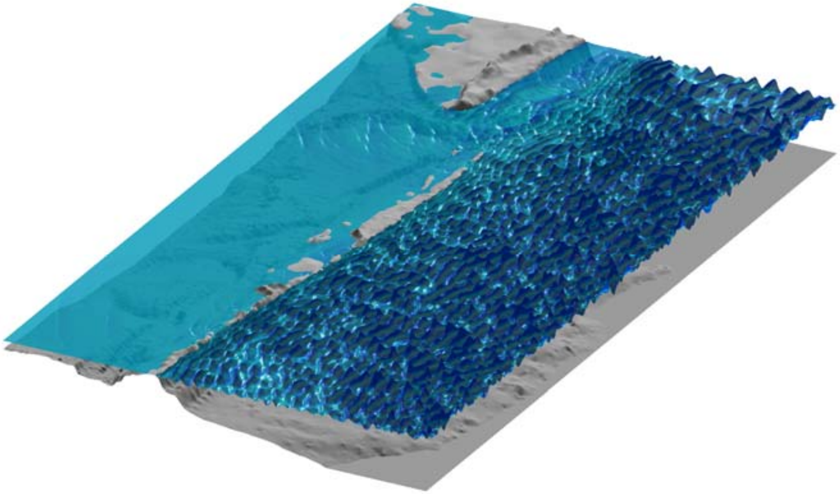
<u>Wave input:</u>
Spectrum from field data

Hurricane Ivan, Okaloosa, FL



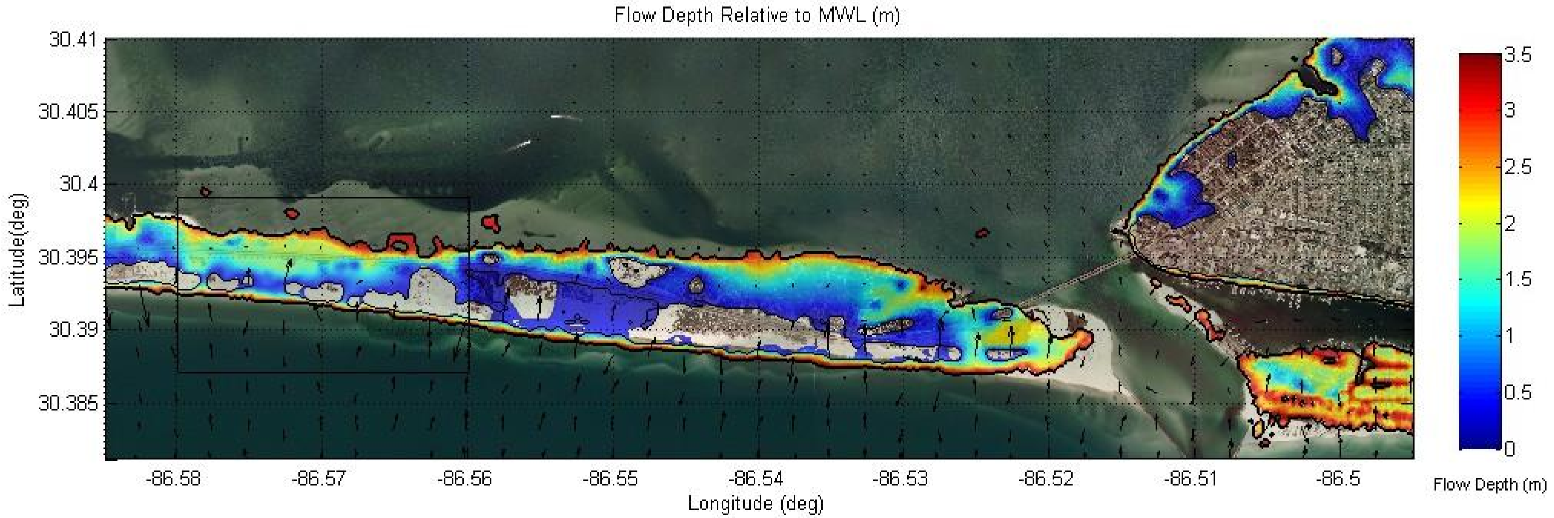
Hurricane Ivan
Hs: **6.3** m
Tp: **12.6** s
Grid: **5** m
Large directional spreading

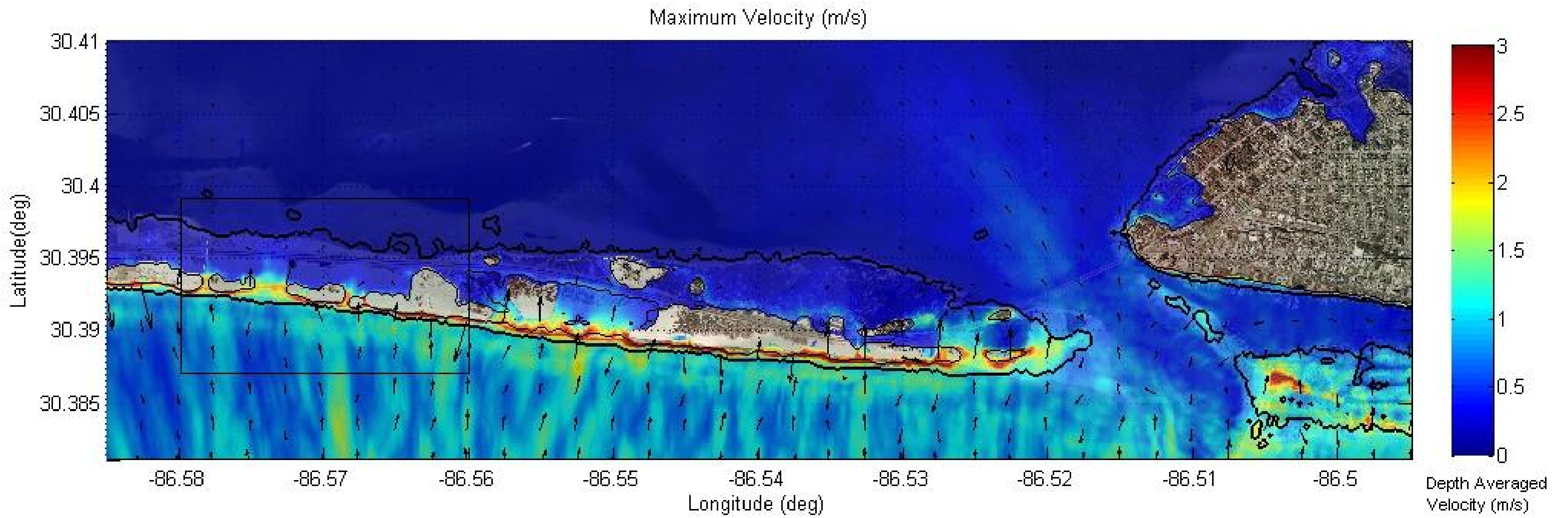
- Gentle sedimentary coast
- Barrier island, lagoon system
- Steep short period waves
- Energetic breaking waves



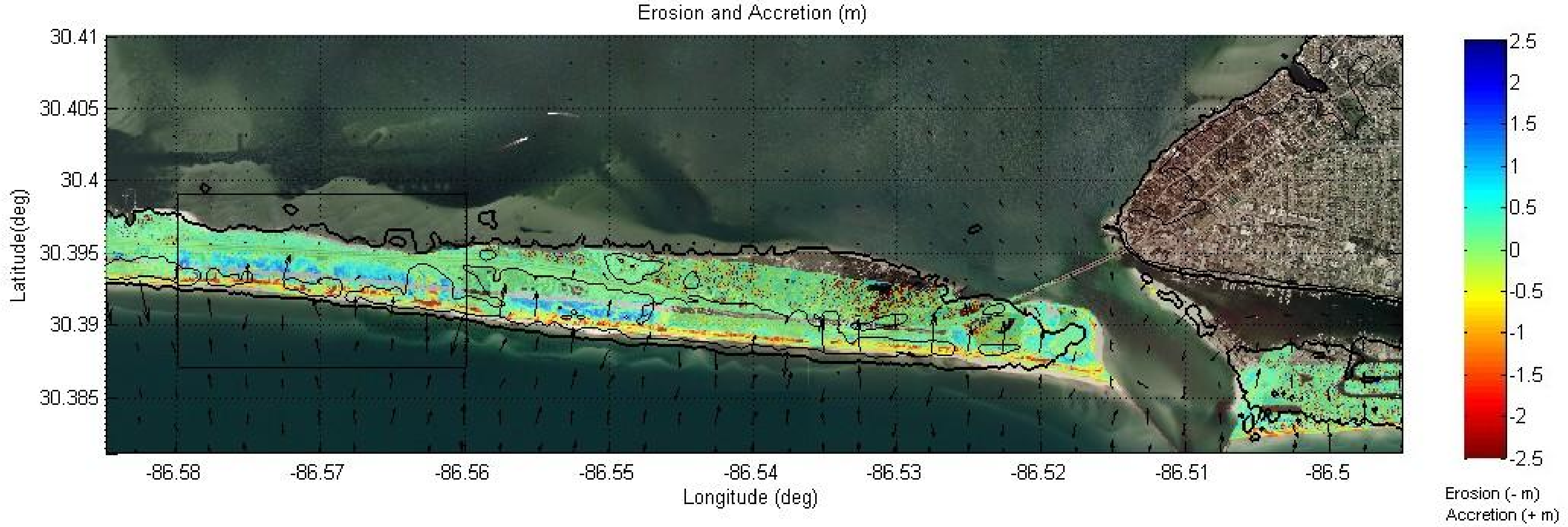
Wave input:
SWAN spectrum

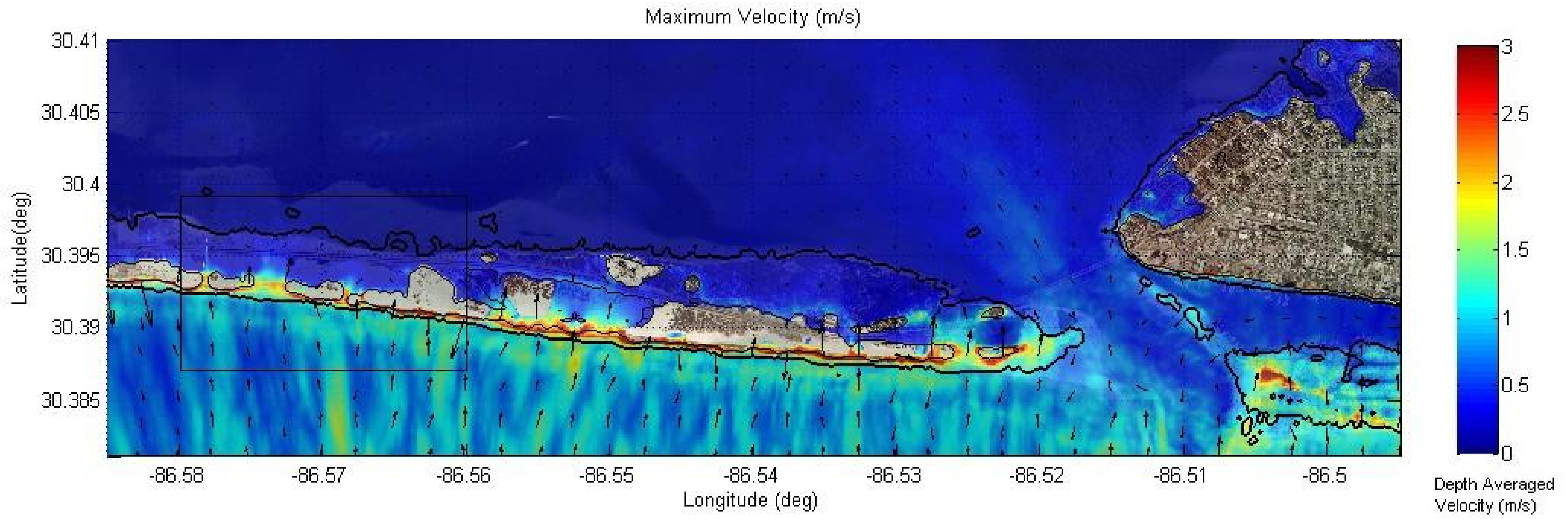
BOSZ - flow depth, velocity, Hurricane Ivan





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:

Roeber, V., Cheung, K.F., Kobayashi, M.H., (2010). Shock-capturing Boussinesq-type model for nearshore wave processes. Coastal Engineering, 57, 407-423.

Roeber, V., Cheung, K. F., (2011). Boussinesq-type model for energetic breaking waves in fringing reef environment. Coastal Engineering, in review.

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