NONLINEAR WAVES OVER VEGETATION

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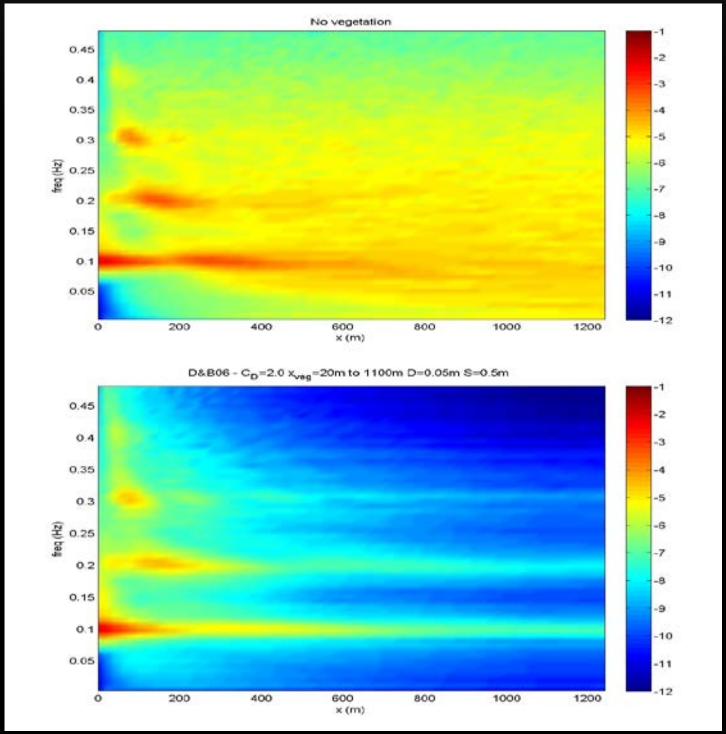
OUTLINE

- Preview of Conclusions and Future Work
- Motivation and Previous Work
- Nonlinear Wave Model
- Vegetation Models
- Comparison to Data
- Conclusions and Future Work



PREVIEW OF CONCLUSIONS AND FUTURE WORK

- A nonlinear wave model incorporating dissipation by vegetation was developed.
- Vegetation damping model: Kobayashi et al. (1993) with Mendez et al. (1999) expression for drag coefficient
- Compared to data from Anderson et al. (2013)
  - Good comparisons of bulk parameters (Hrms)
  - Interaction of nonlinearity and vegetation dissipation needs improvement

MOTIVATION AND PREVIOUS WORK

Wetlands

- Serve to balance water levels in coastal regions
- Help mitigate shoreline erosion

Predicting processes in wetlands

- Use wave models to predict waves in wetlands
- NOPP Focus – improve prediction in shallow areas

MOTIVATION AND PREVIOUS WORK

- Koehl (1984), Dalrymple (1984), Asano (1993), Kobayashi (1993), Dubi and Torum (1995) and Mendez (1999a) etc.
    - Analyzed influence of vegetation on wave damping
    - Identified mechanisms of wave and plant stem interaction.
- Dalrymple et al. (1984)
    - Wave height reduction for mono-chromatic waves over rigid cylinders
- Kobayashi et al. (1993)
    - Exponential wave-height decay for waves over rigid cylinders
- Mendez et al (1999)
    - Included effect of vegetation motion

MOTIVATION AND PREVIOUS WORK

Previous studies – linear wave propagation

- Focus on damping formulation

Nonlinear wave effects important in nearshore

- Velocity skewness contributes to sediment transport (Bailard 1981)
- Effect on velocity field surrounding vegetation (vegetation motion and damping)

NONLINEAR WAVE MODEL

Nonlinear triad interaction model of Kaihatu and Kirby (1995) with dissipation term (in 2D)

$$2i(kCC_g)_n A_{n,x} + i(kCC_g)_{nx} A_n - 2(kCC_g)_n(\bar{k}_n - k_n)A_n + \left[\left(CC_g\right)_n A_{ny}\right]_y + 2i(kCC_g)_n D_n A_n$$

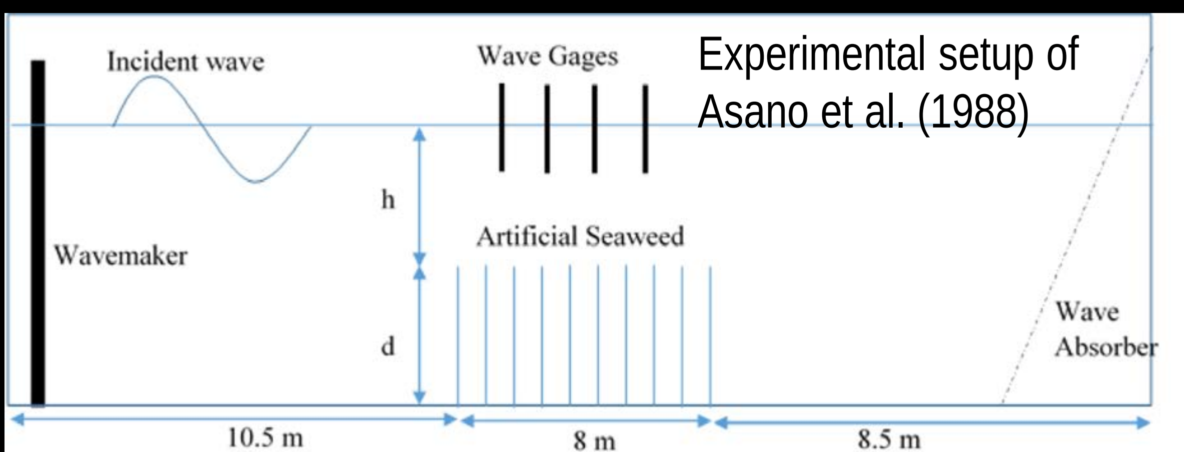
$$= \frac{1}{4}\left[\sum_{l=1}^{n-1} R A_l A_{n-l} e^{i\Theta_{l,n-l}} + 2\sum_{l=1}^{N-n} S A_l^* A_{n+l} e^{i\Theta_{n+l,-l}}\right]$$

- Triad nonlinear wave-wave interaction
- Full linear dispersion in transformation and nonlinear coupling
- Dissipation included (breaking, mud, and/or vegetation)

VEGETATION MODELS

- Energy dissipation term: Kobayashi et al. (1993)
  - Rigid cylinders with small diameter
  - Drag force: Morison's equation
  - Dissipation term:

$$\frac{\partial EC_g}{\partial x} = -D_d = -\frac{2}{3\pi}\rho C_D bN\left(\frac{k_r gH}{2\omega}\right)^3 \frac{\sinh^3 k_r d + 3\sinh k_r d}{3k_r \cosh^3 k_r (h+d)}$$



Experimental setup of Asano et al. (1988)

$$\eta = \frac{H_o}{2} e^{-k_i x} \cos(k_r x - \omega t)$$

b: plant cross-section area
N: stem density
C_D: drag coefficient

VEGETATION MODELS

Drag coefficient:

- Kobayashi et al. (1993)

$$C_D = \left(\frac{2200}{R_n}\right)^{2.4} + 0.08$$

- Mendez et al. (1999)
  - Accounts for vegetation motion

$$C_D = \left(\frac{4600}{R_n}\right)^{2.9} + 0.4$$

$$R_n = \frac{u(\omega)d}{\nu}$$

- Reynolds number depends on *u*
- Calculate *u* at stem head or depth integrated over stem for each frequency
- Mendez et al. (1999) worked best against Dubi and Torum (1995) data (*ASCE EMI Conf.*)

VEGETATION MODELS

Conversion from free surface to horizontal velocity (linear theory)

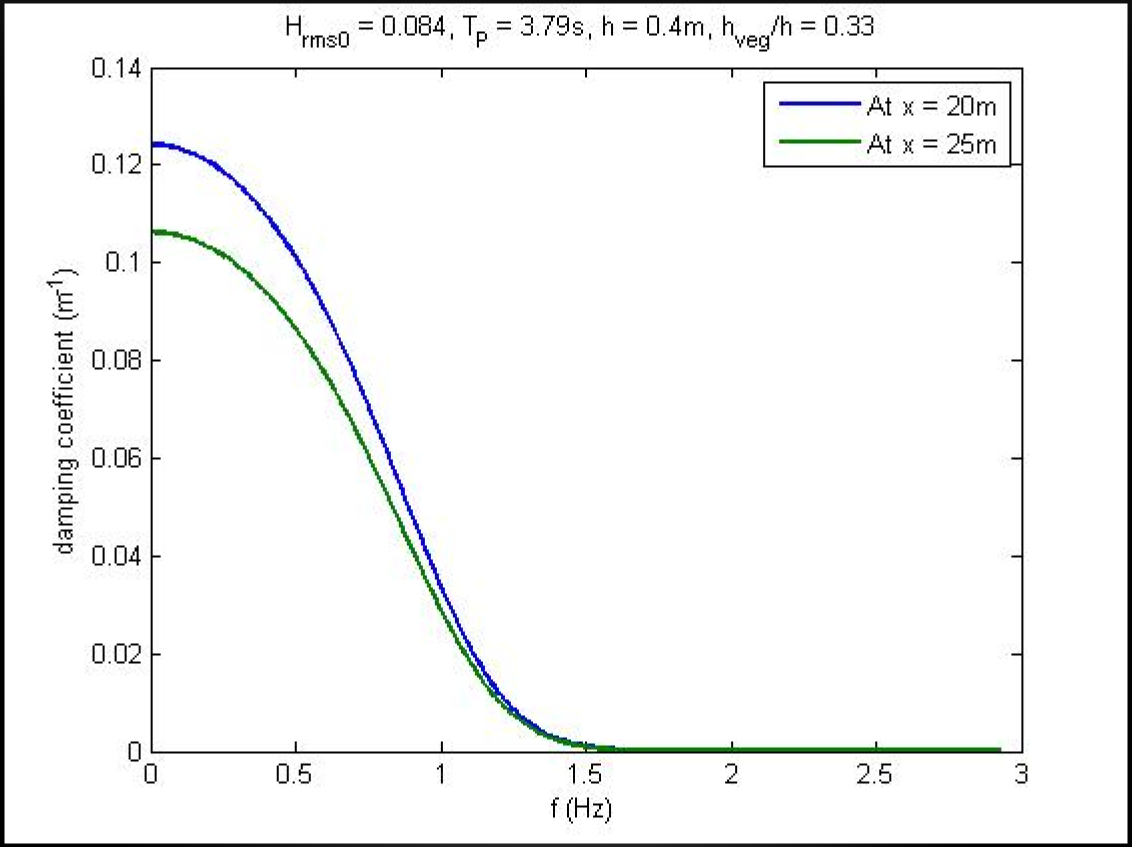
$$u = \left(\omega \frac{\cosh k(h+d+z)}{\sinh k(h+d)} \right) \eta$$

Conversion from free surface spectrum to velocity spectrum

$$S_{uu}(\omega_n) = \left(\omega_n \frac{\cosh k(h+d+z)}{\sinh k(h+d)} \right)^2 S_{\eta\eta}(\omega_n)$$

$$u(\omega) = \sqrt{2\Delta\omega S_{uu}(\omega)}$$

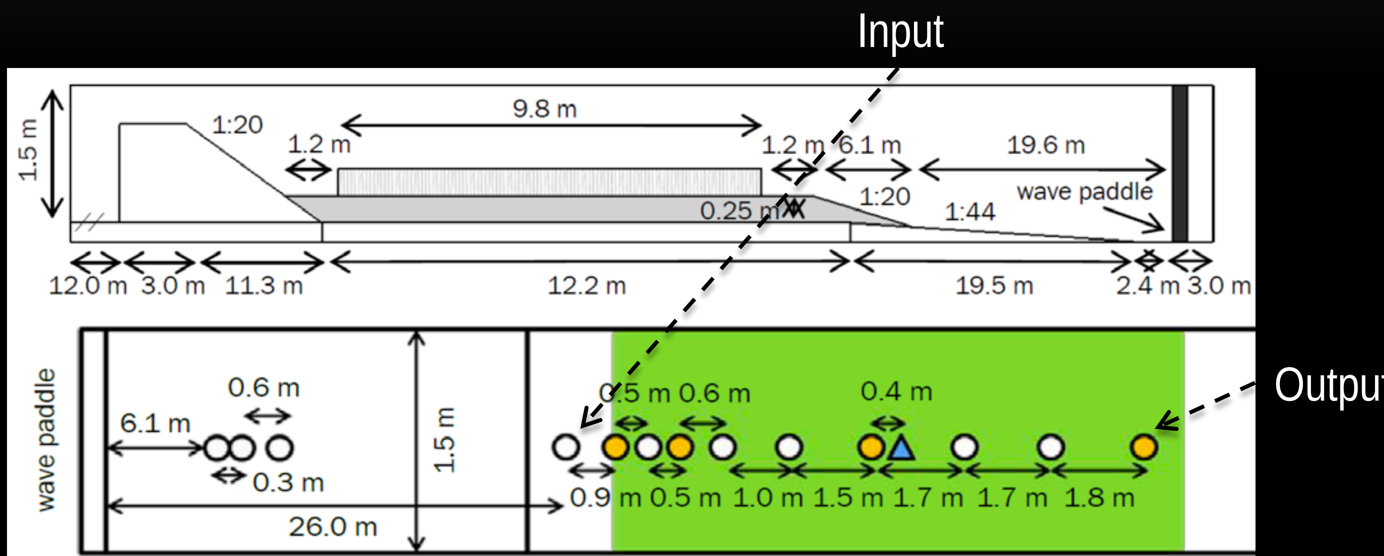
VEGETATION MODELS



Dissipation Rate Dependence on Frequency

COMPARISON TO DATA

Anderson et al. (2013) – ERDC/CHL TR-13-XX



	h, at vegetation (m)	T_P (s)	f_P (Hz)	H_{RMS} (m)	h_{veg}/h
Test 1	0.533	1.5	0.667	0.111	0.78
Test 3	0.533	2.0	0.500	0.111	0.78
Test 6	0.457	1.5	0.667	0.081	0.91
Test 12	0.457	2.0	0.500	0.192	0.91

COMPARISON TO DATA

Root-mean-square height

$$H_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} H_n^2}$$

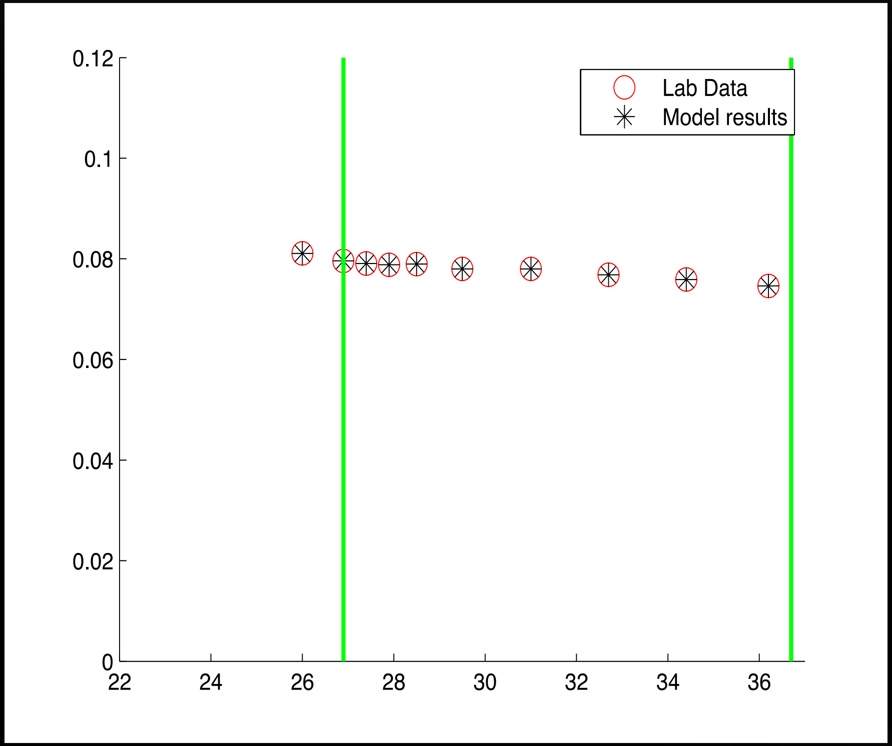
Skewness

$$S = \frac{\left\langle \eta^3 \right\rangle}{\left\langle \eta^2 \right\rangle^{3/2}}$$

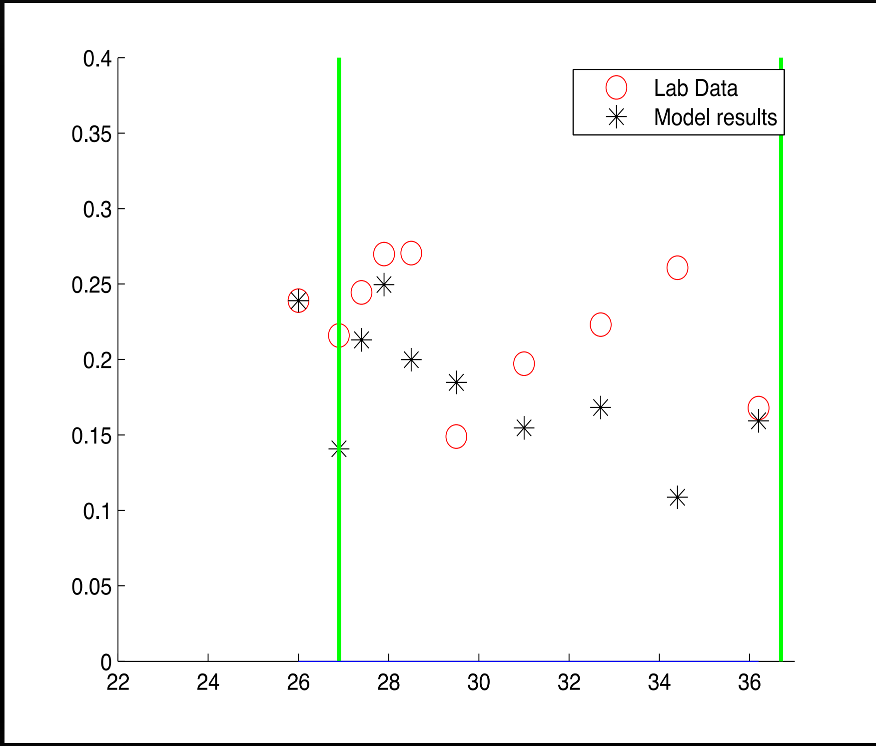
Bispectra (Bicoherence)

$$B(f_l, f_m) = \left\langle A_l A_m A_{l+m}^* \right\rangle$$

COMPARISON TO DATA



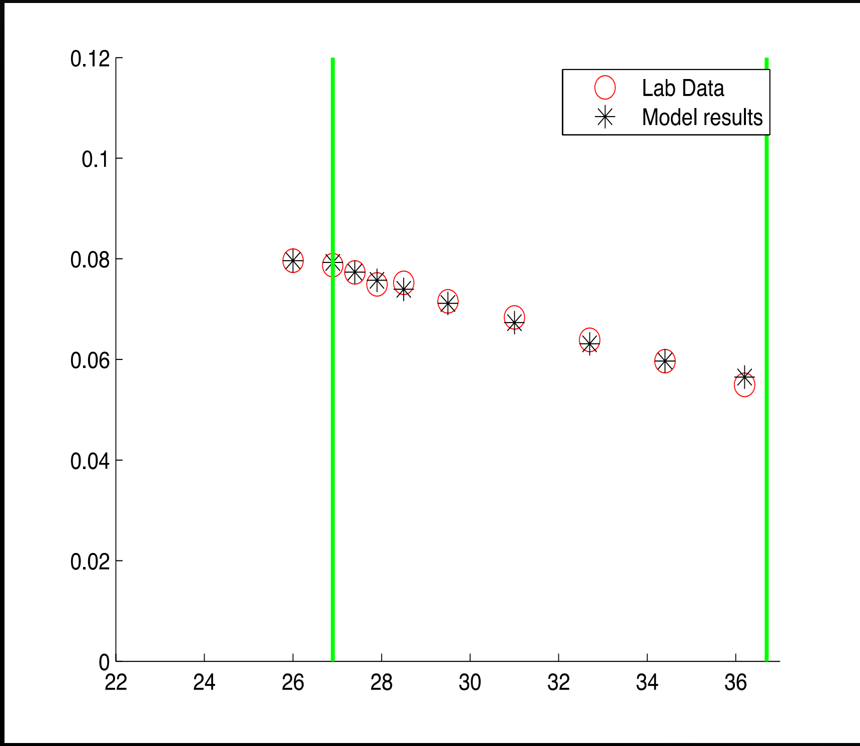
Test 1 - Hrms



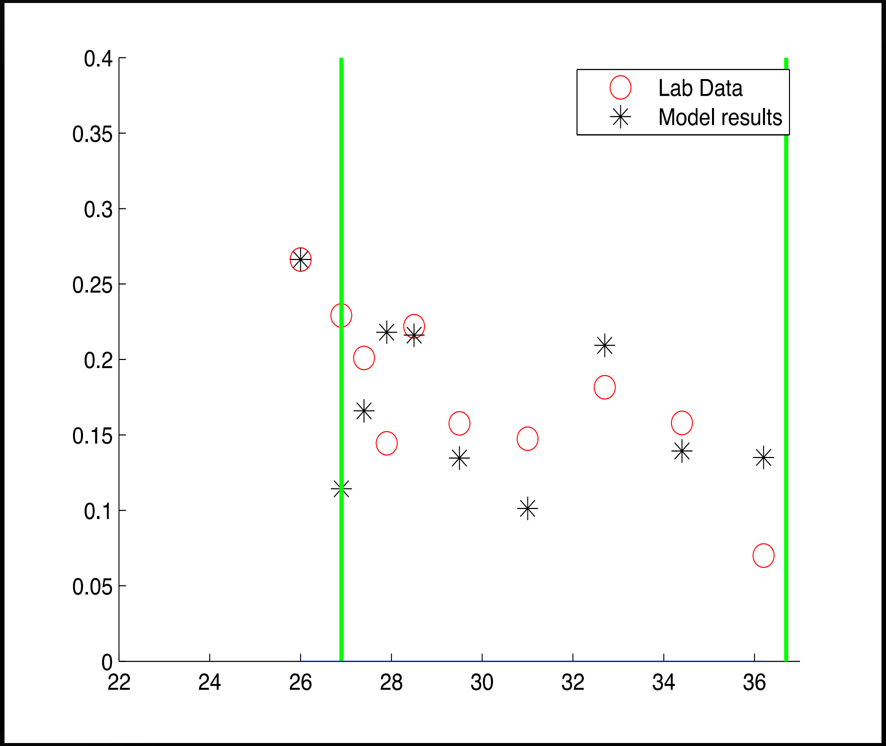
Test 1 - Skewness

No vegetation

COMPARISON TO DATA



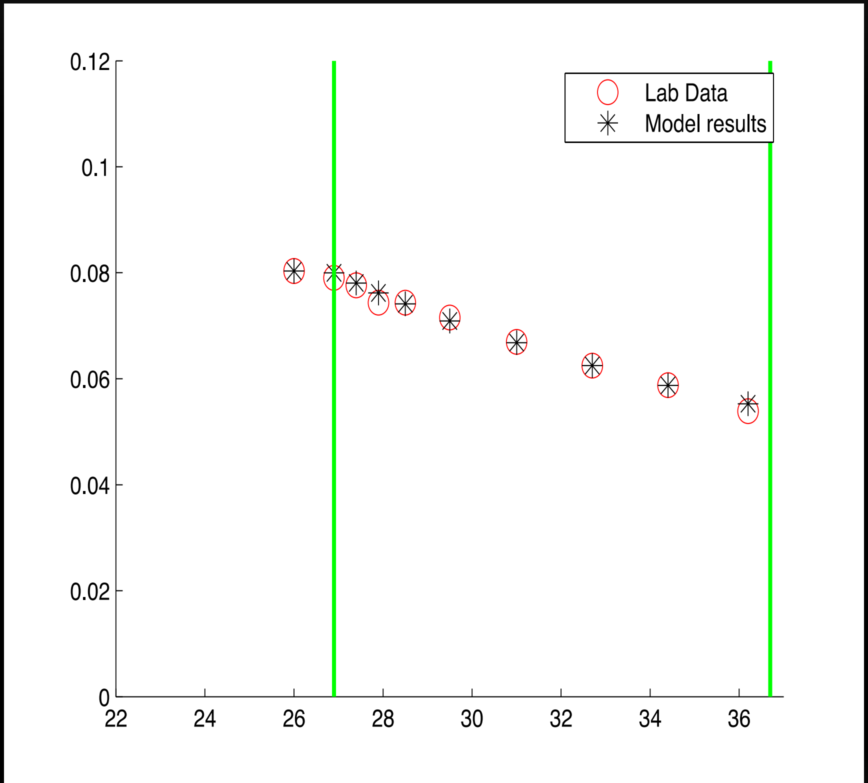
Test 1 - Hrms



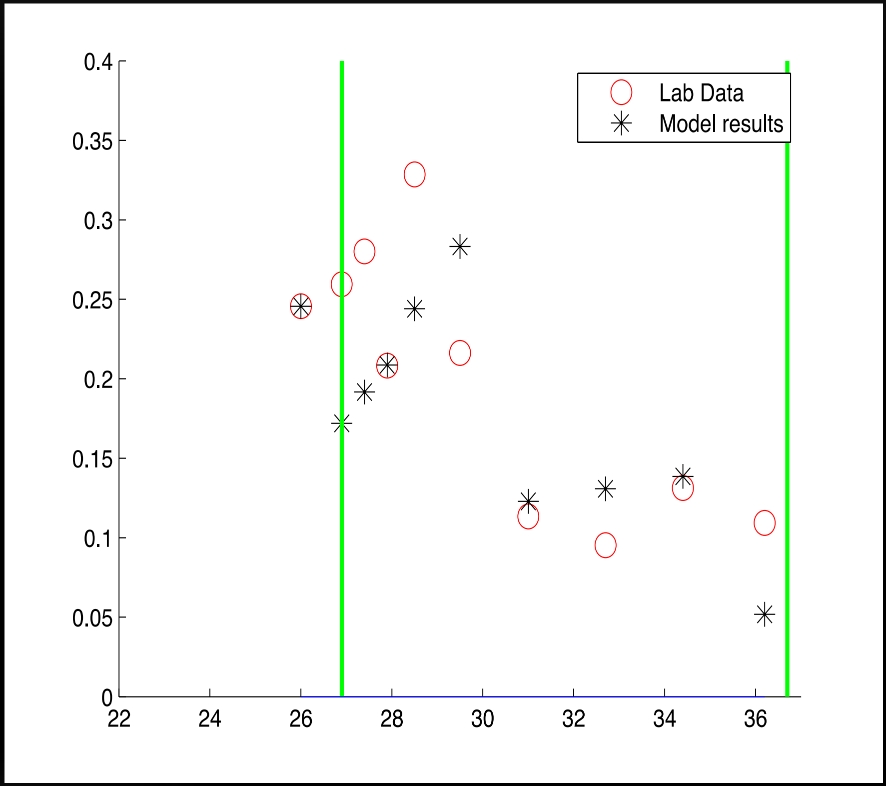
Test 1 - Skewness

Depth averaged U

COMPARISON TO DATA



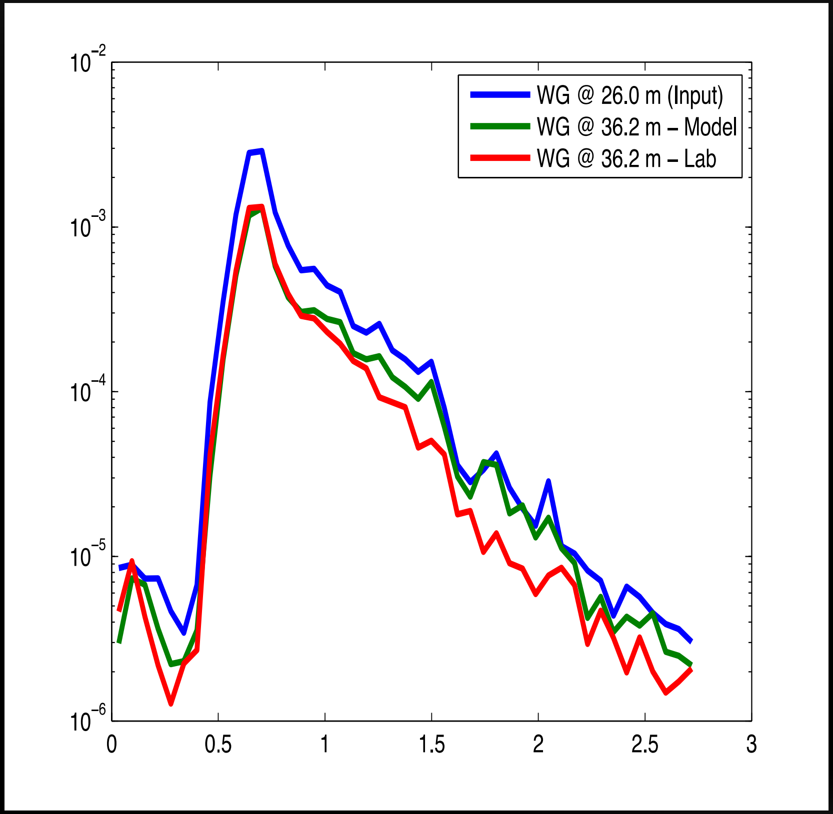
Test 3 - Hrms



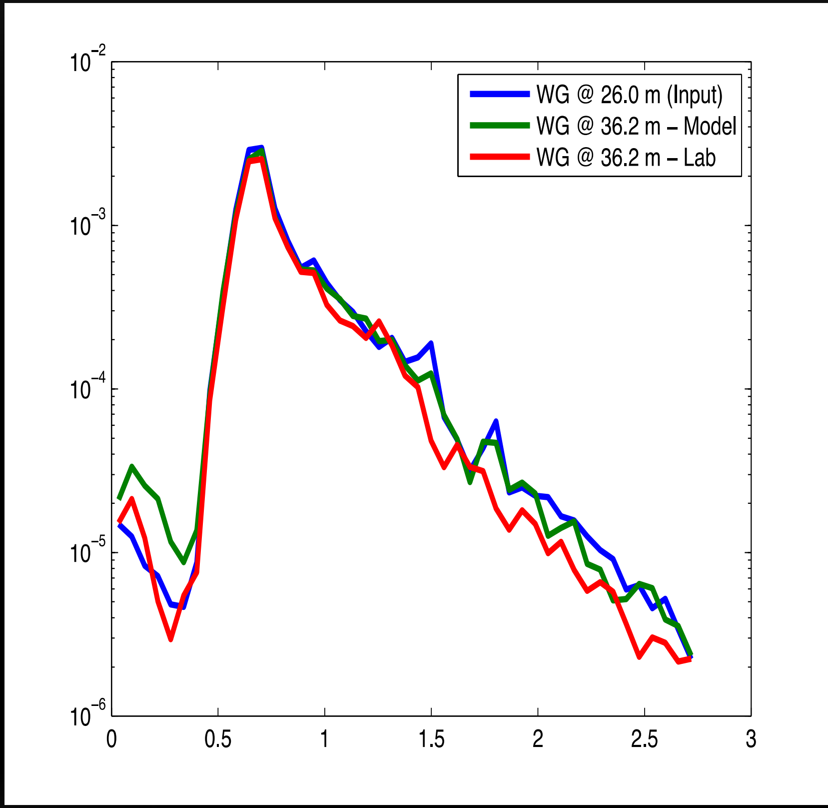
Test 3 - Skewness

Depth averaged U

COMPARISONS TO DATA



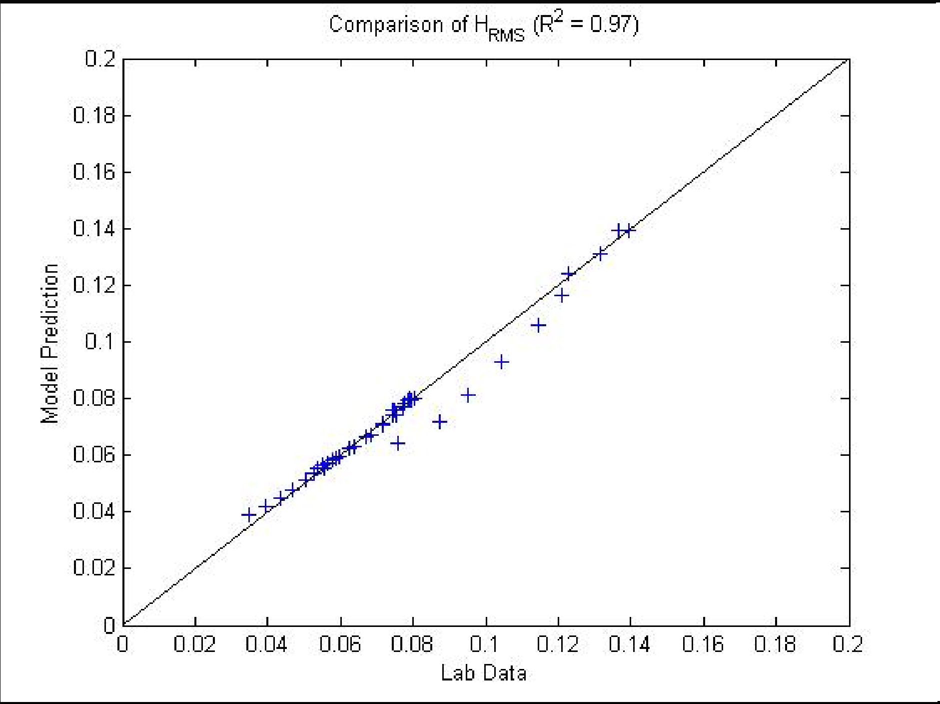
Spectra – Test 1

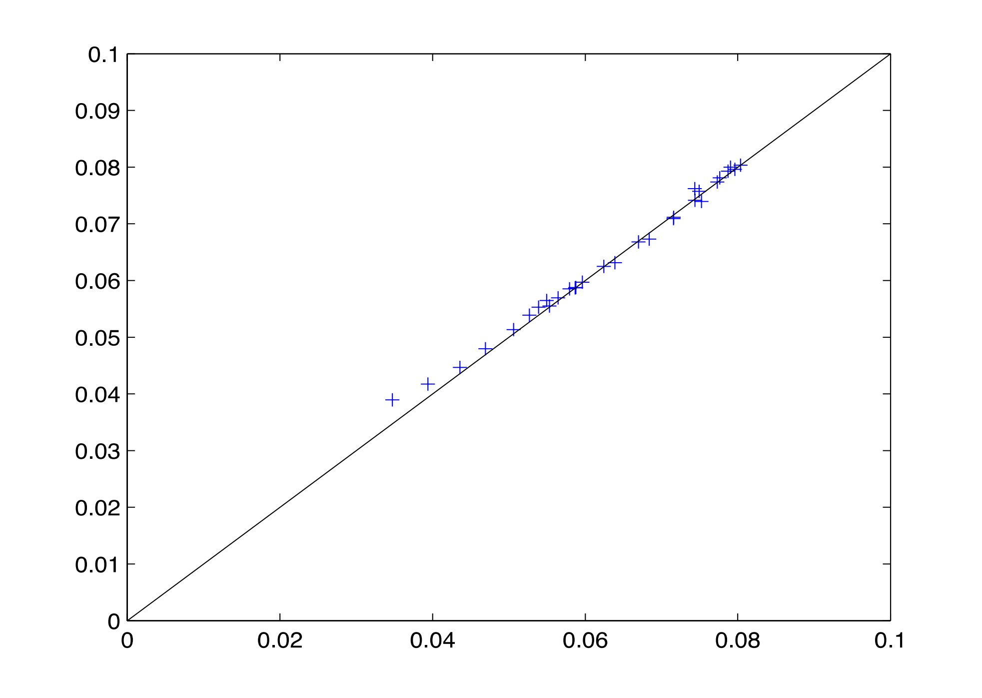


Spectra – Test 1 (No Vegetation)

Depth averaged U

COMPARISON TO DATA



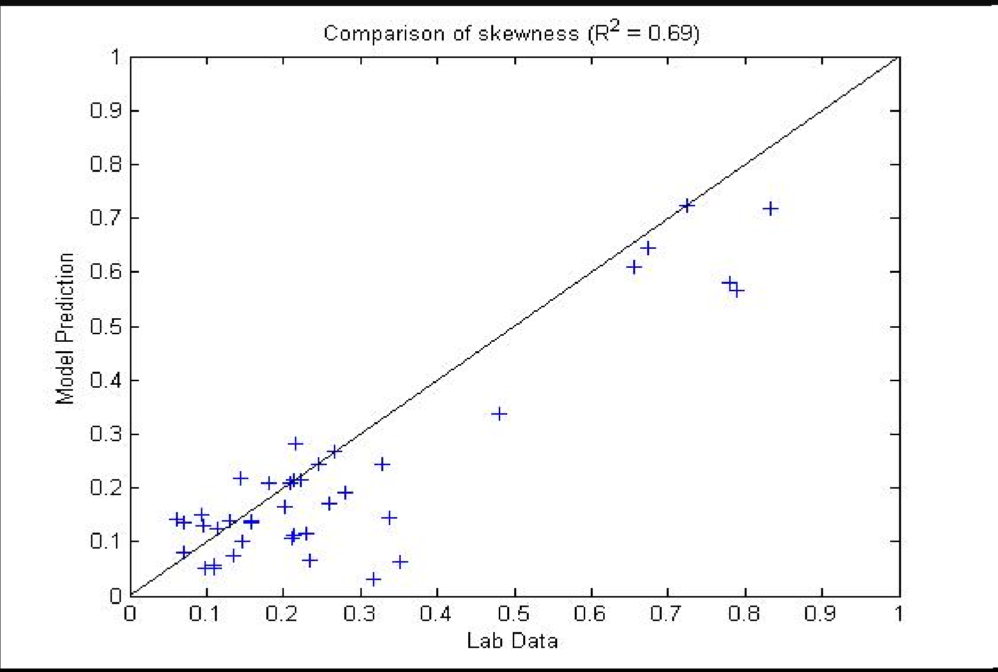


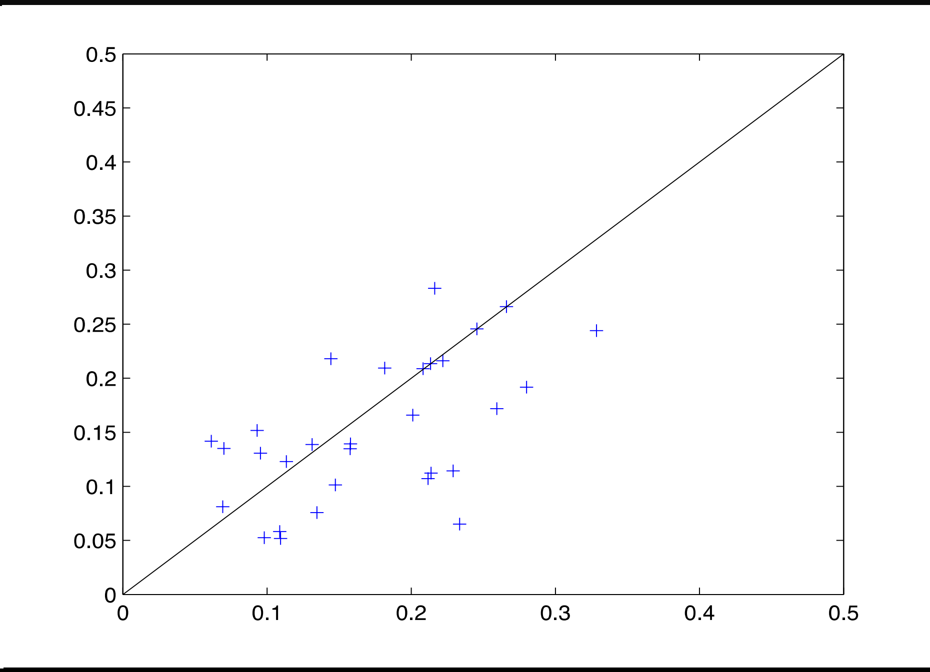
Hrms – U at stem head

Hrms – Depth integrated U

(Test 12 not included)

COMPARISON TO DATA





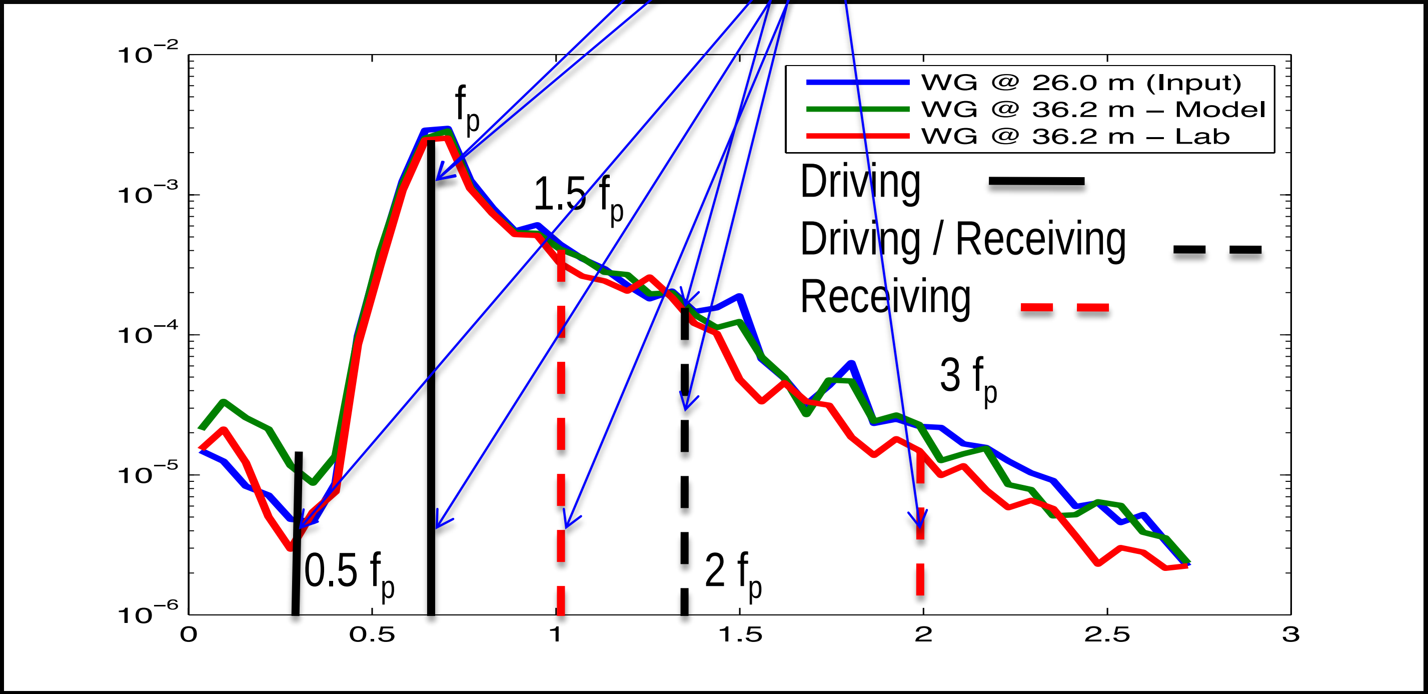
Skewness – U at stem head

Skewness – Depth Integrated U

(Test 12 not included)

COMPARISONS TO DATA

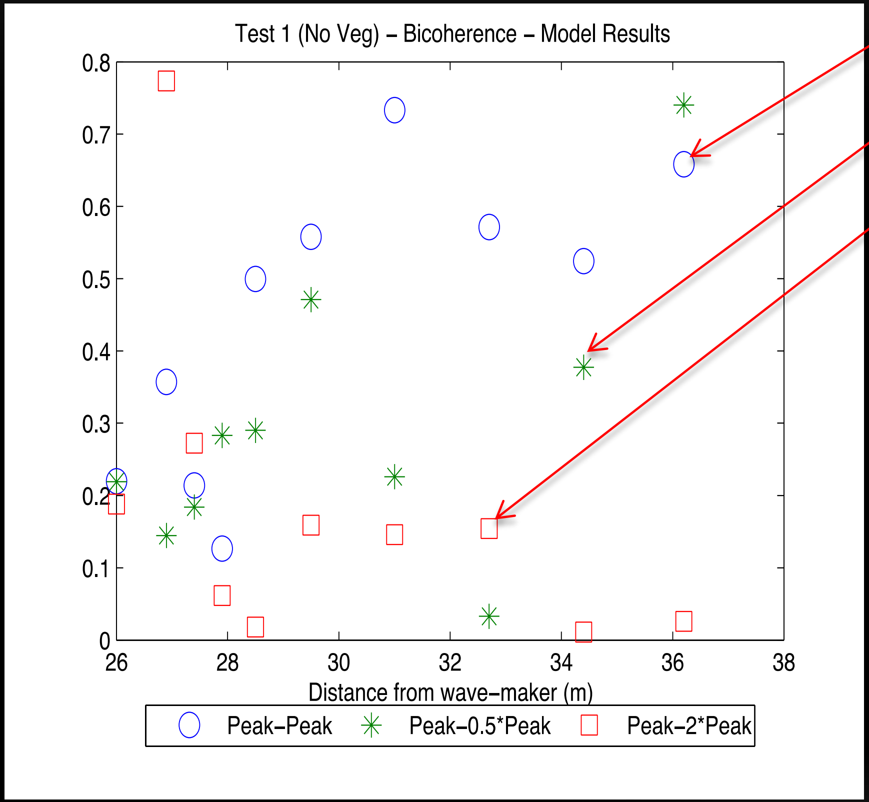
(fp, fp, 2fp): harmonic
(fp, 2fp, 3fp): harmonic
(0.5 fp, fp, 1.5fp): off-harmonic



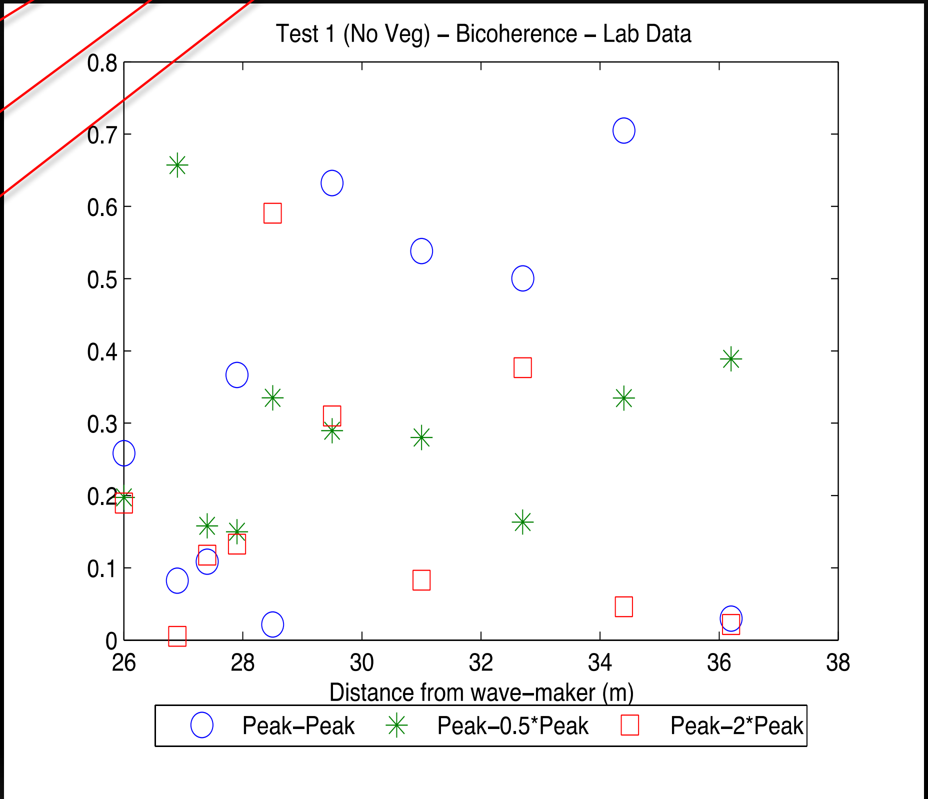
Bicoherence – Interacting Triads

COMPARISONS TO DATA

$(f_p, f_p\ 2f_p)$: harmonic
$(0.5f_p, f_p, 1.5f_p)$: off-harmonic
$(f_p, 2f_p, 3f_p)$: harmonic



Bicoherence – Test 1 Model

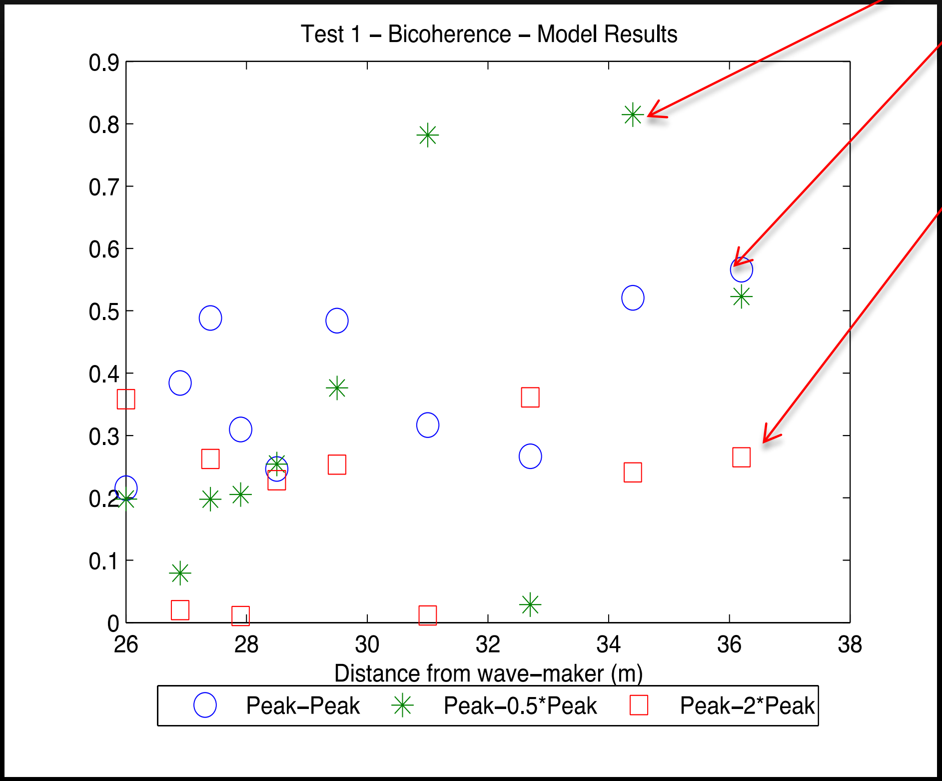


Bicoherence – Test 1 Data

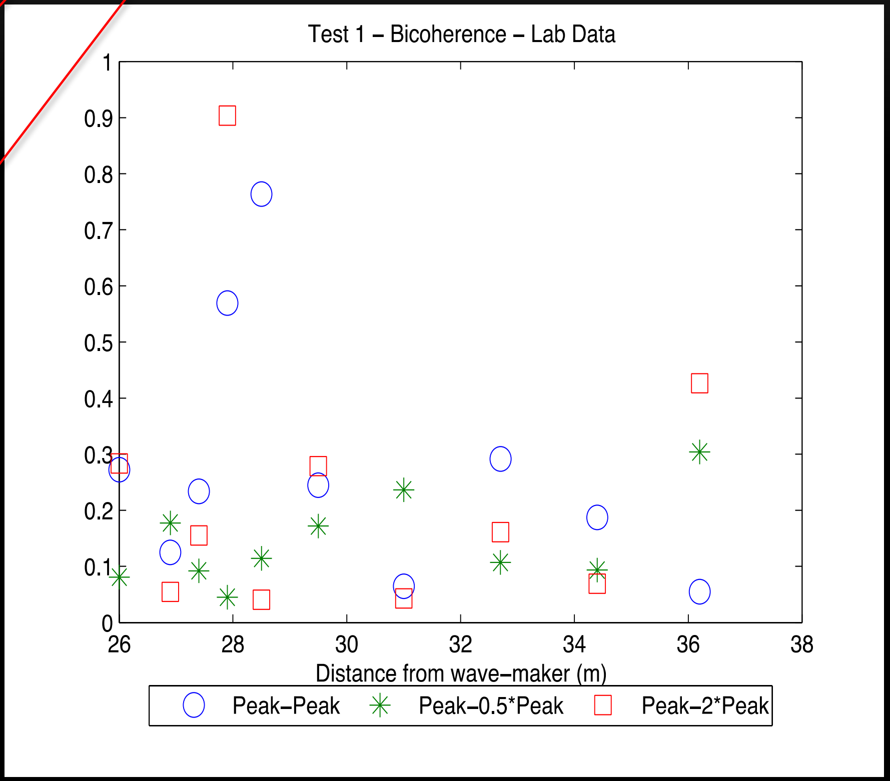
No Vegetation

COMPARISONS TO DATA

(f_p, f_p $2f_p$): harmonic
($0.5f_p$, f_p, $1.5f_p$): off-harmonic
(f_p, $2f_p$, $3f_p$): harmonic



Bicoherence – Test 1 Model



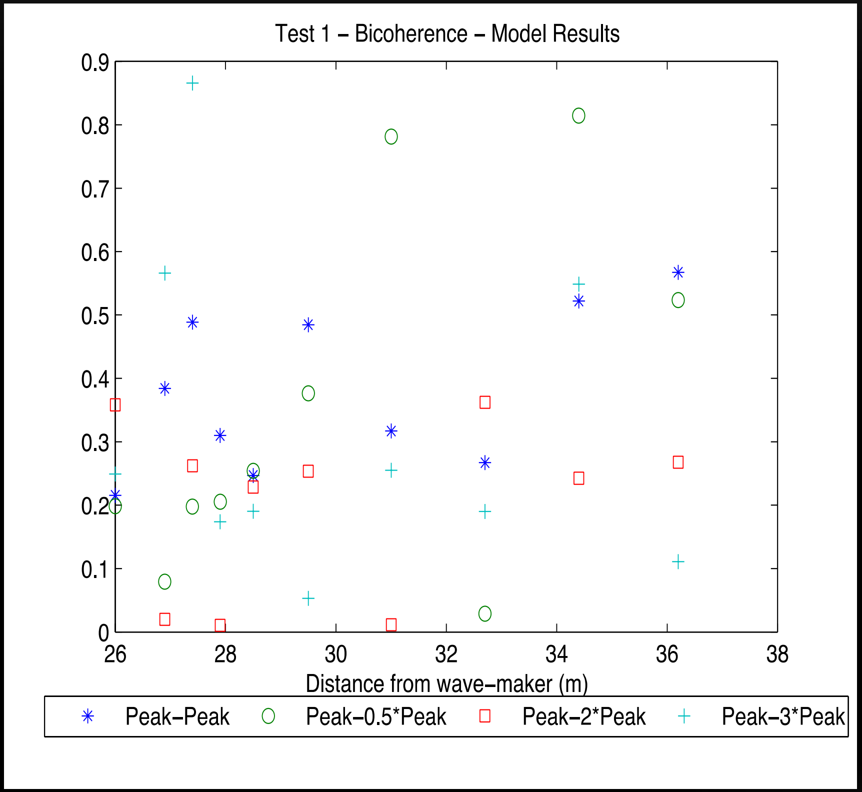
Bicoherence – Test 1 Data

Depth averaged U

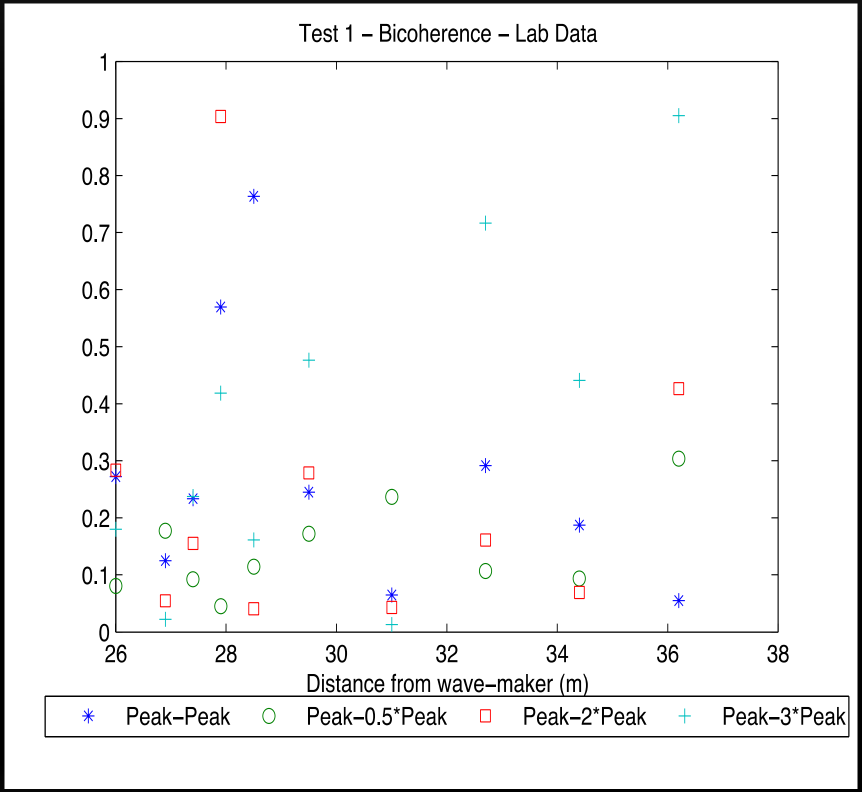
CONCLUSIONS AND FUTURE WORK

- A nonlinear frequency domain wave model (Kaihatu and Kirby 1995) incorporating dissipation by vegetation was developed.
- Vegetation damping model: Kobayashi et al. (1993)
  - Two different drag coefficient calculations: Kobayashi et al. (1993) and Mendez and Losada (1999)
  - Mendez and Lozada compared well to data
- Compared to data from Anderson et al. (2013)
  - Good comparisons of bulk parameters (Hrms)
  - Fair comparisons to skewness and bicoherence
    - Interaction of nonlinearity and vegetation dissipation needs improvement
      - Nonlinear estimate of *u*?

COMPARISONS TO DATA



Bicoherence – Test 1 Model

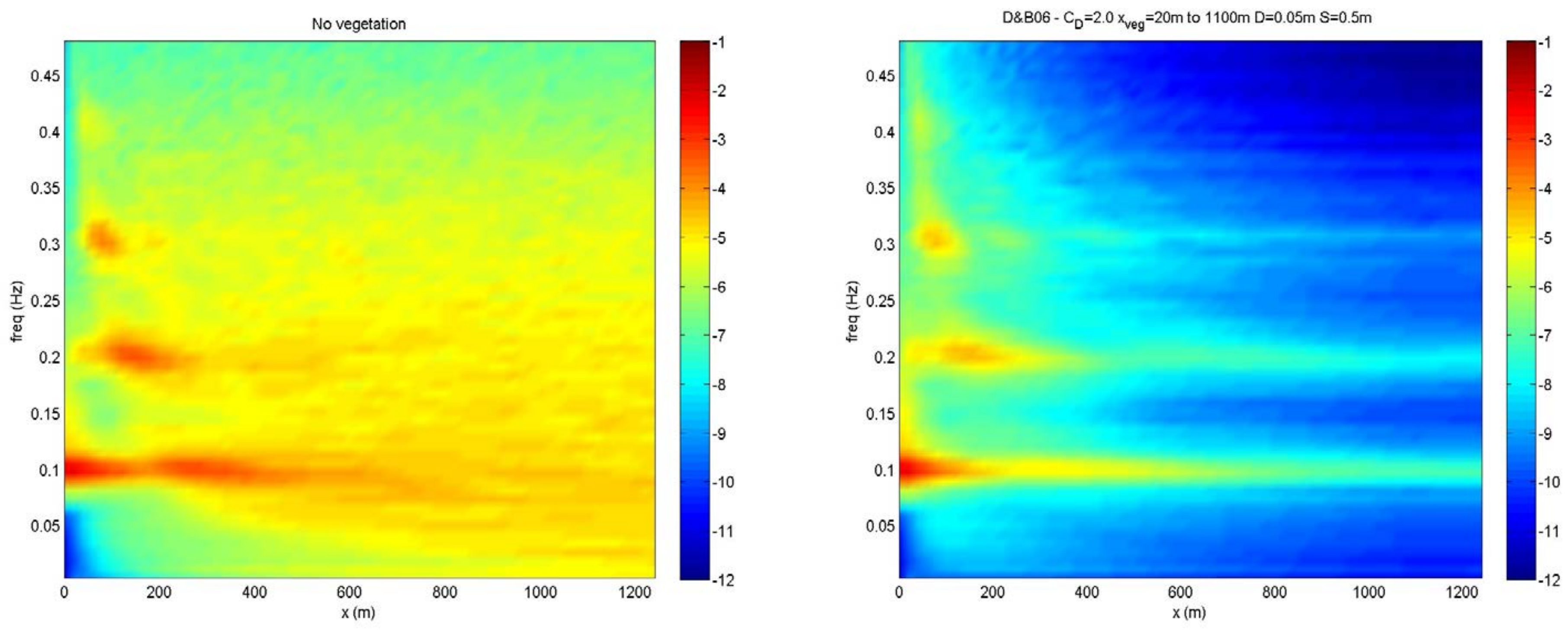


Bicoherence – Test 1 Data

U integrated over depth

NONLINEAR WAVE MODEL

Wave Spectra – Nonlinear Model with Dean and Bender (2006) dissipation



No Vegetation

With Vegetation (C_D =2.0)