Attenuation of Waves and Surge by Vegetation

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Wave Attenuation by Vegetation

- Sponsored by SERRI, DHS
- Lab/Field Experiments & Computational Modeling
- Ole Miss, LSU, NSL

Research Team

- **PI**: Dr. Weiming Wu

Computational modeling team:

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Laboratory experiment team:

- Dr. Daniel Wren (NSL), Dr. Yavuz Ozeren (NCCHE)

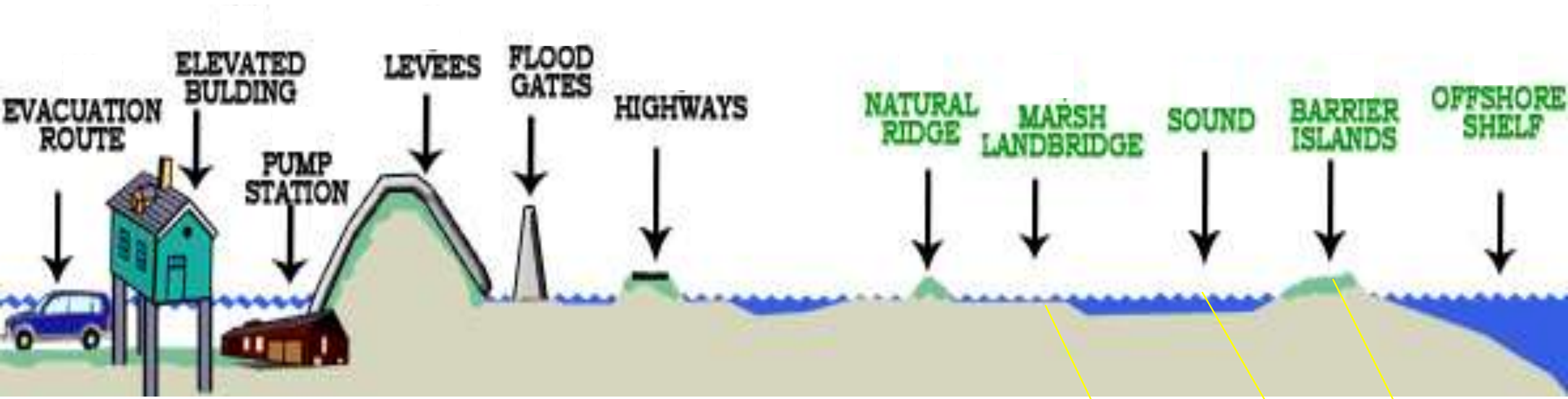
Field investigation team:

- Dr. Qin Chen, Dr. Guoping Zhang, Mr. Ranjit Jadhav, Mr. James Chatagnier, Kyle Parker, James Bouanchaud, Hem Pant (LSU)
- Dr. Marjorie Holland, Miss Ying Chen (UM-Biology)

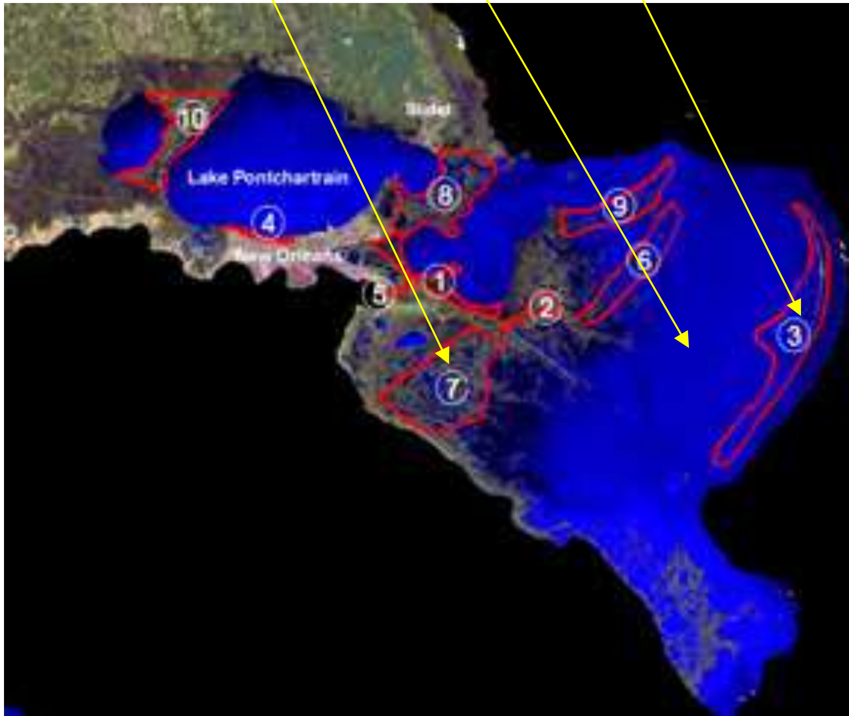
Laboratory and Field Experiments of Wave Attenuation by Vegetation

(Project period: 2009-2012)

Coastal Protection



John Lopez, 2006. Courtesy of Lake Pontchartrain Basin Foundation



- Multiple Lines of Defense

Surge/Wave vs. Vegetation

Vegetation attenuates waves and surge, while it is stressed by waves and surge.

Marsh Edge Erosion by Waves and Surges

Louisiana has lost 1,829 square miles of land since the 1930's (Barras et al. 2008, Britsch and Dunbar 1993)

Between 1990 and 2001, wetland loss was approximately 13 square miles per year- that is the equivalent of approximately one football field lost every hour (Barras et al. 2008). According to land loss estimates, Hurricanes Katrina and Rita transformed 198 square miles of marsh to open water in coastal Louisiana (Barras et al. 2008).

Studied Vegetation Species I:

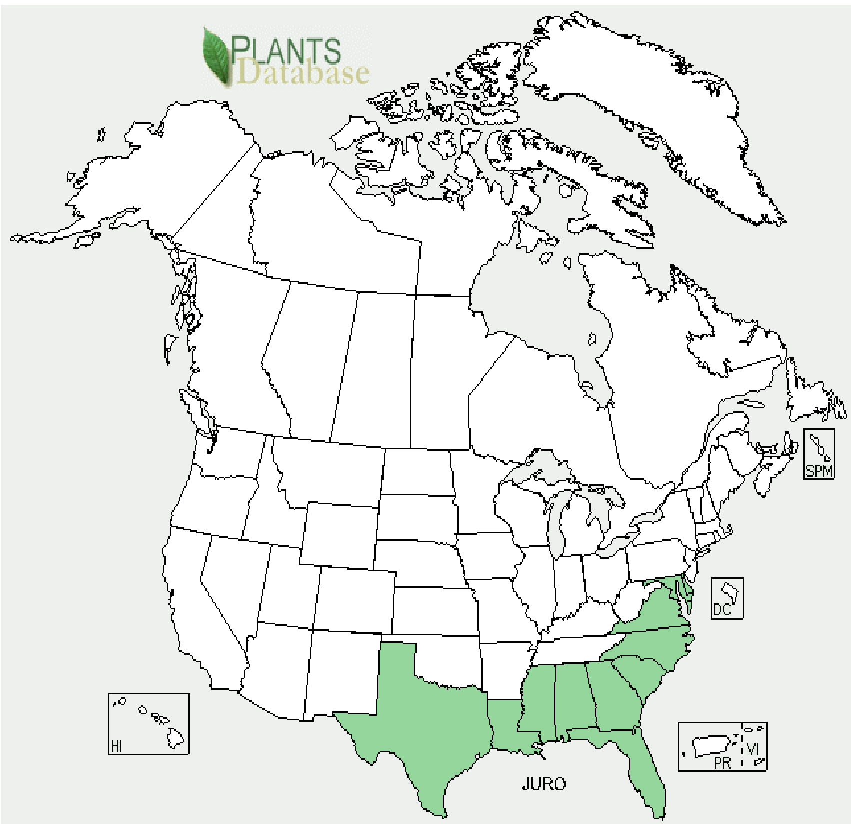
Spartina alterniflora Loisel.

http://plants.usda.gov/maps/large/SP/SPAL.png

Spartina alterniflora at Terrebonne Bay, LA (4/4/2011)

Studied Vegetation Species II:

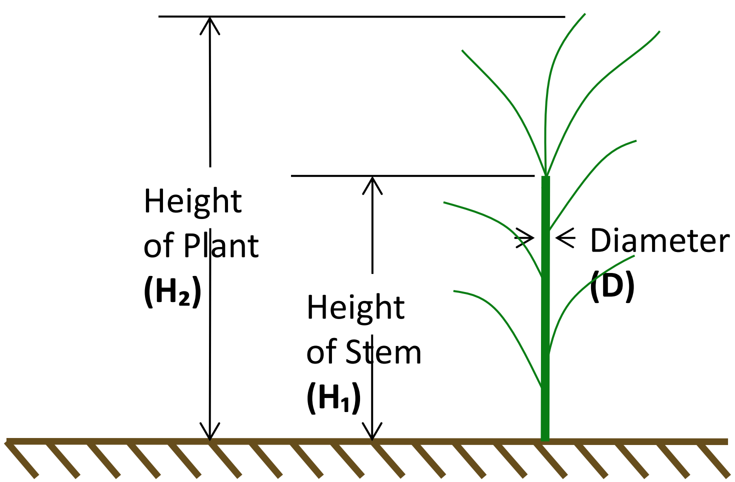
Juncus roemerianus Scheele

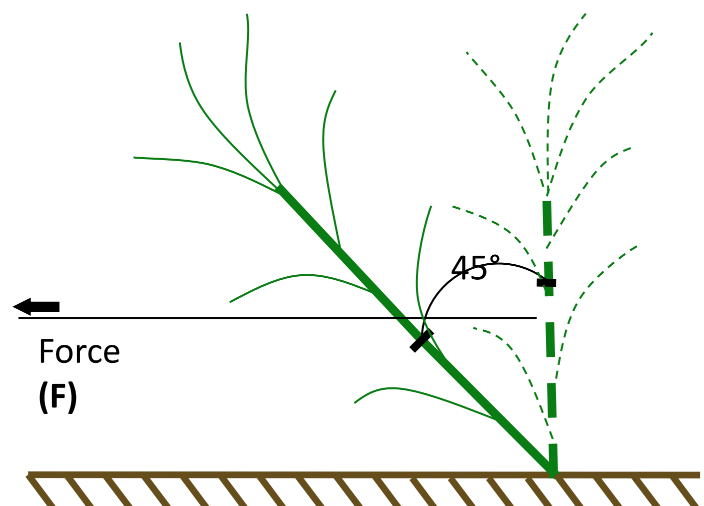


http://plants.usda.gov/core/profile?symbol=JURO

Smooth Cord Grass Bending Stiffness

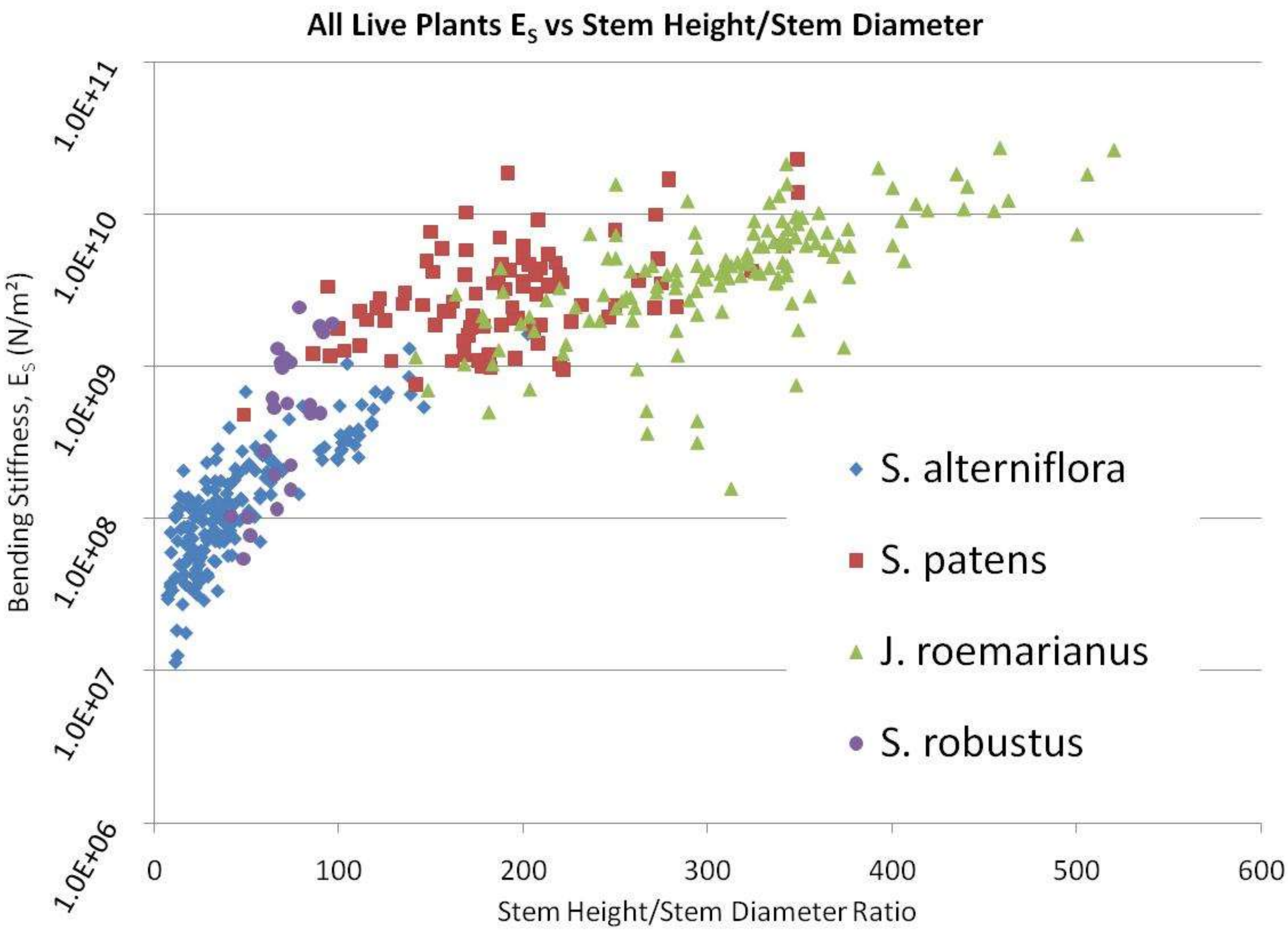
- Measurement Procedure:
  - Total plant height and stem height are measured
  - A clip is attached at half the stem height
  - Plants are pulled to a 45° angle
  - Force needed is measured with a force gauge
  - Plant is cut at base and maximum stem diameter is measured



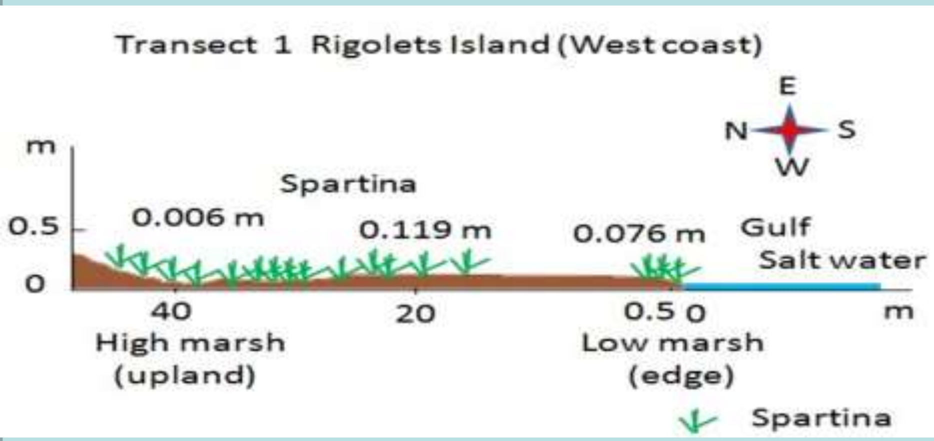


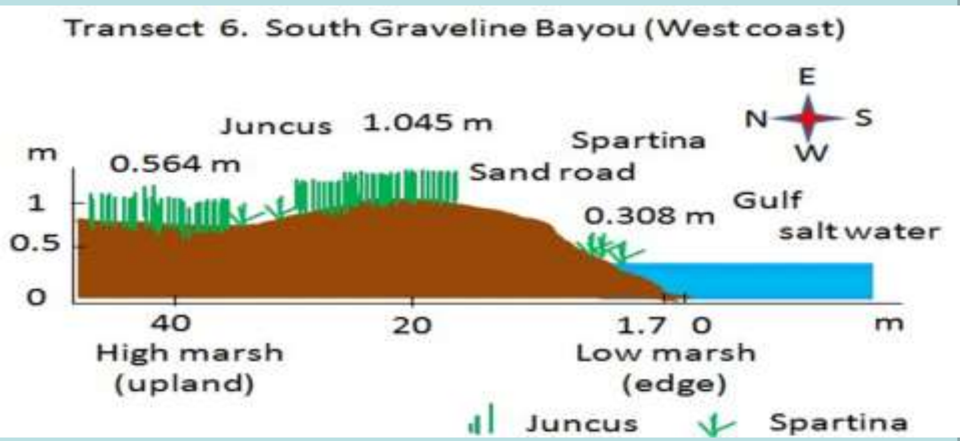
Vegetation Properties

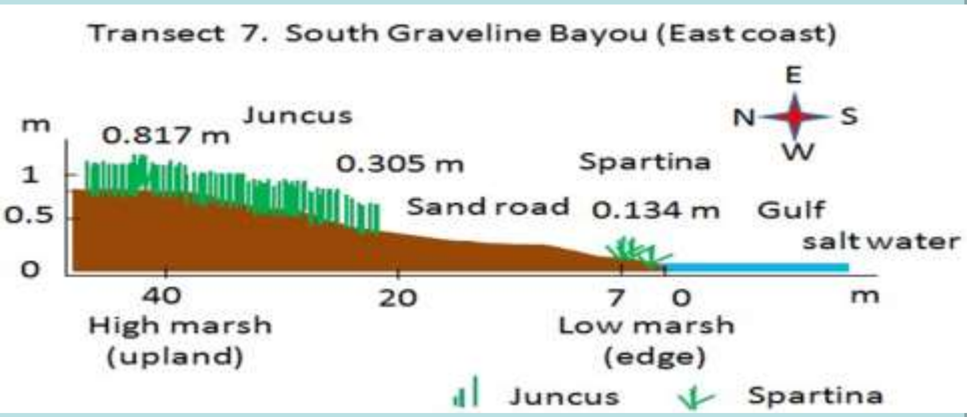
Plant Stiffness Modulus



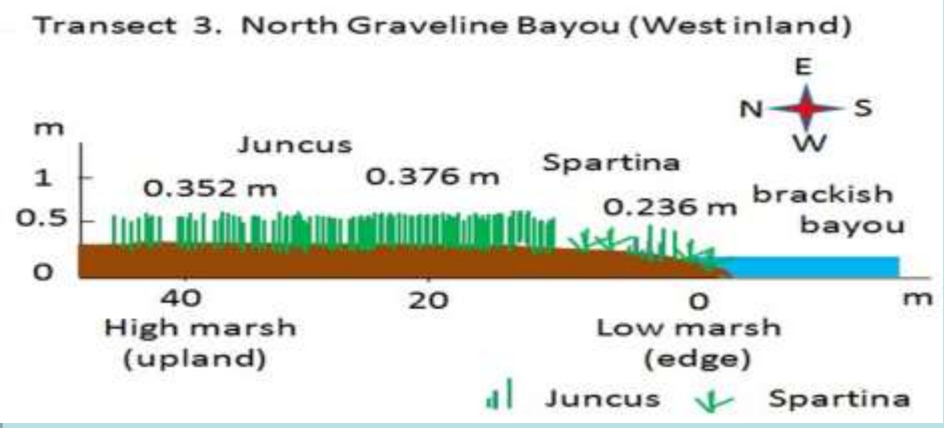
Zonation of eight experimental transects at Grand Bay and Graveline Bayou, MS (four coastal transects)

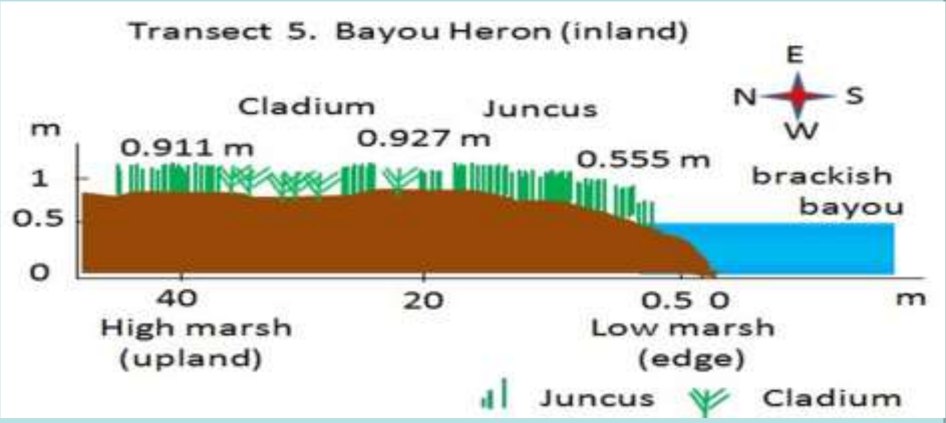


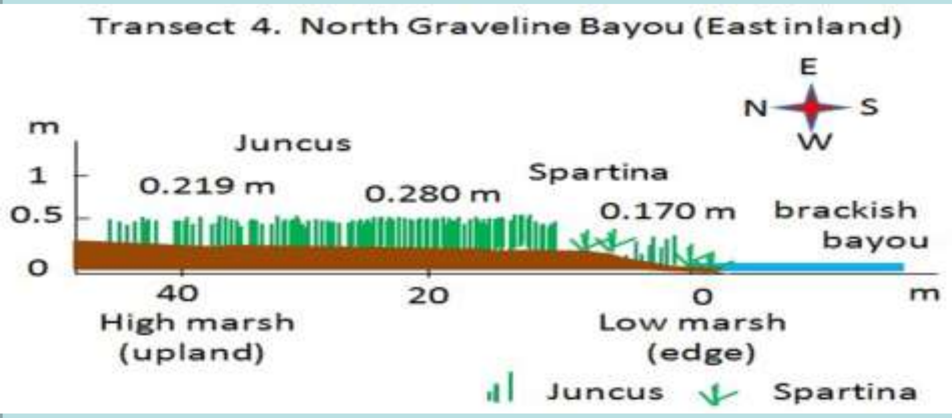


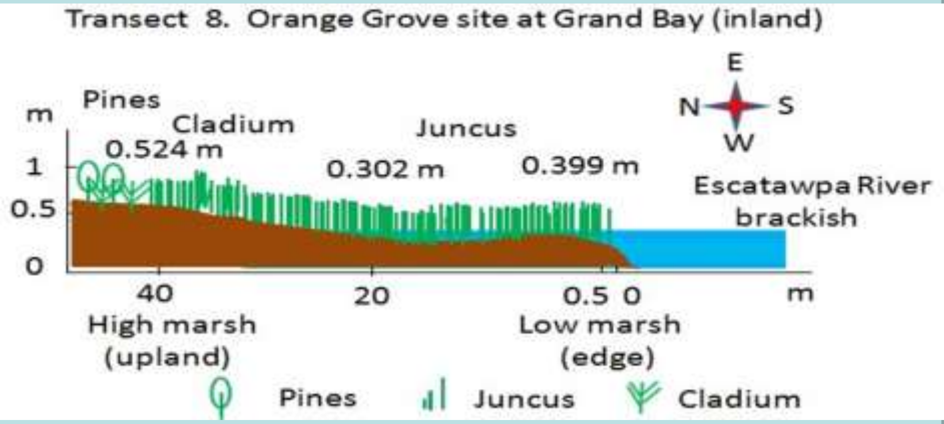


Zonation of eight experimental transects at Grand Bay and Graveline Bayou, MS (four inland transects)







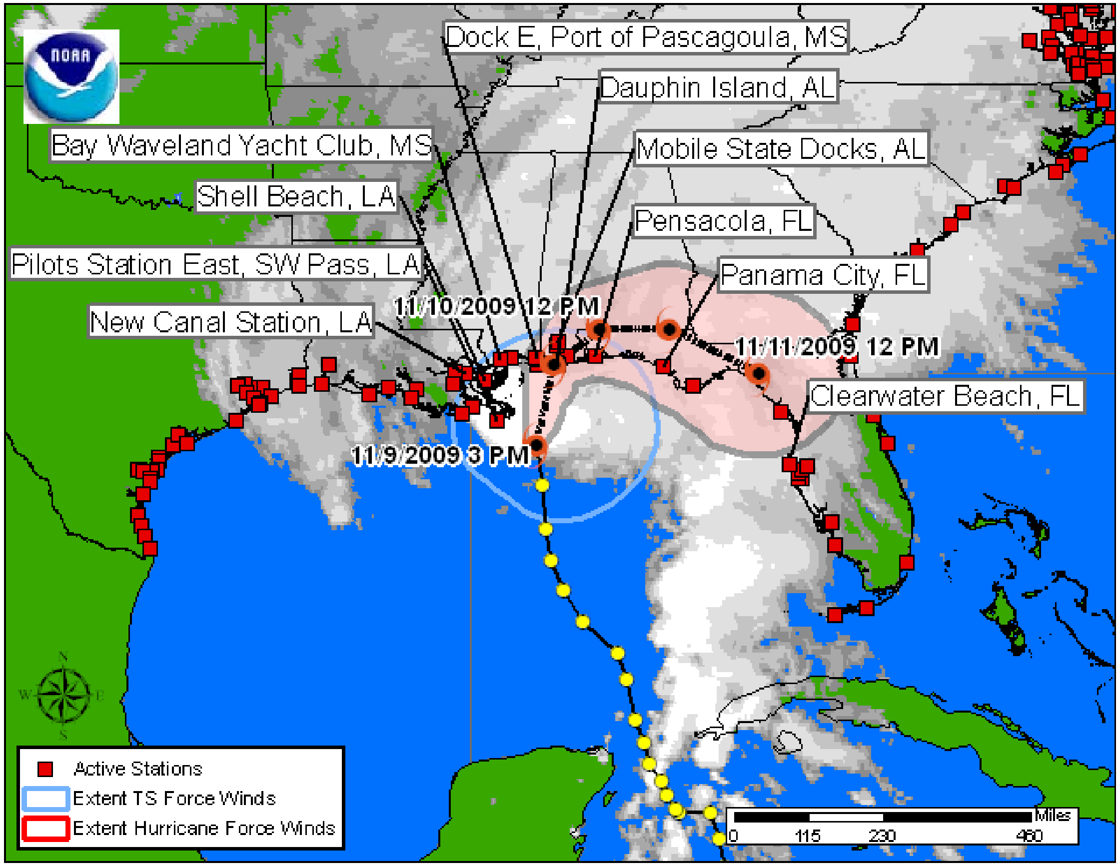


Vegetation characteristics of low and high marsh zones combined in eight transects

Zones	Dominant species	Live standing shoot heights (m)	Dead standing shoot heights (m)	Mean % cover	Rhizome thickness (cm)
Low marsh zone	*Spartina alterniflora*	0.45-1.40 (0.85)	0.30-0.75 (0.54)	71.41	0.49
	Juncus romerianus	0.78-1.45 (1.17)	0.67-1.52 (1.04)		0.54
High marsh zone	*Spartina alterniflora*	0.78-2.30 (1.34)	0.83-1.45 (1.11)	80.50	0.54
	Juncus romerianus	1.40-2.30 (1.73)	0.8-1.75 (1.30)		0.58

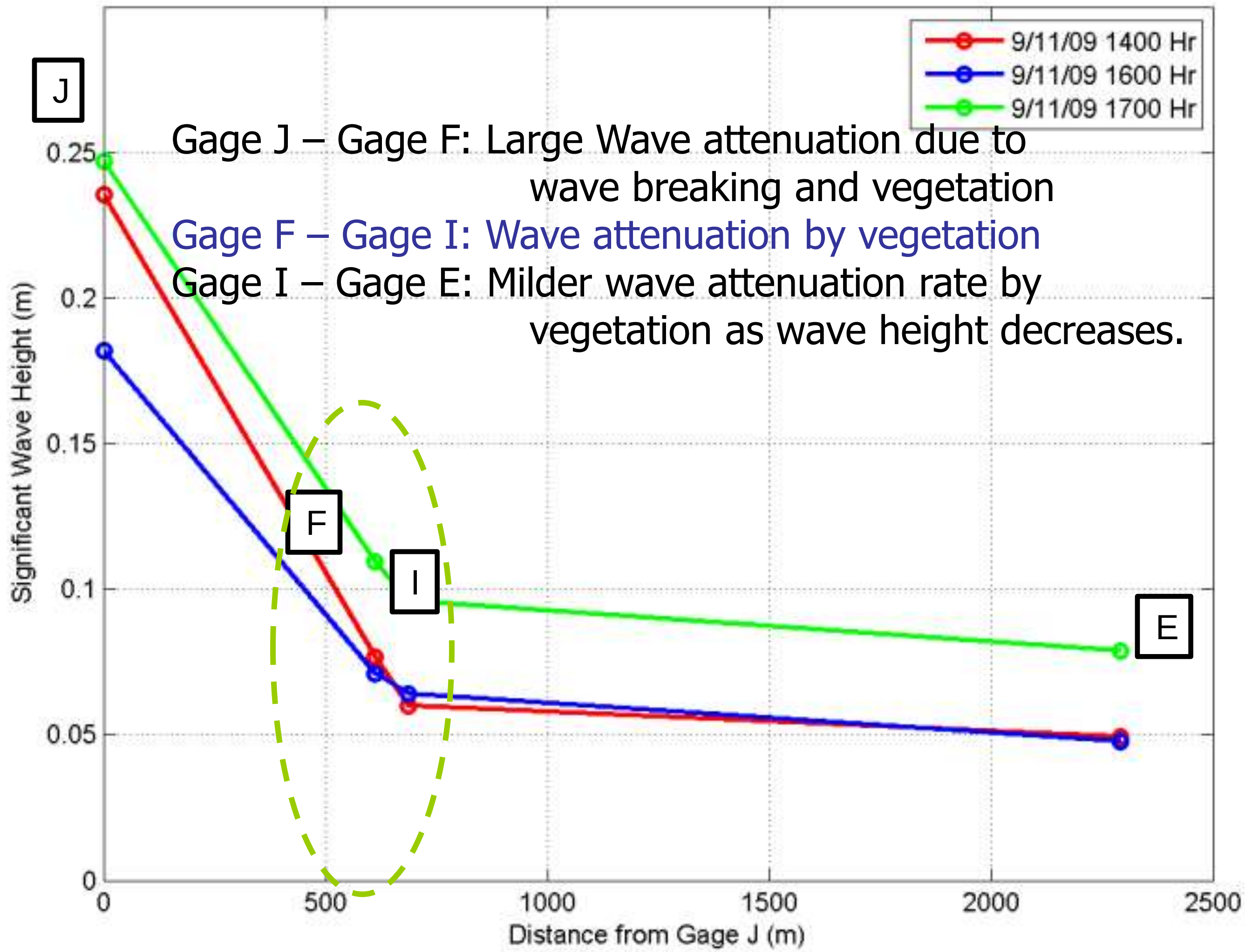
Short- term Rapid Deployment during Tropical Storm/ Hurricane
(Tropical Storm Ida Measurements)

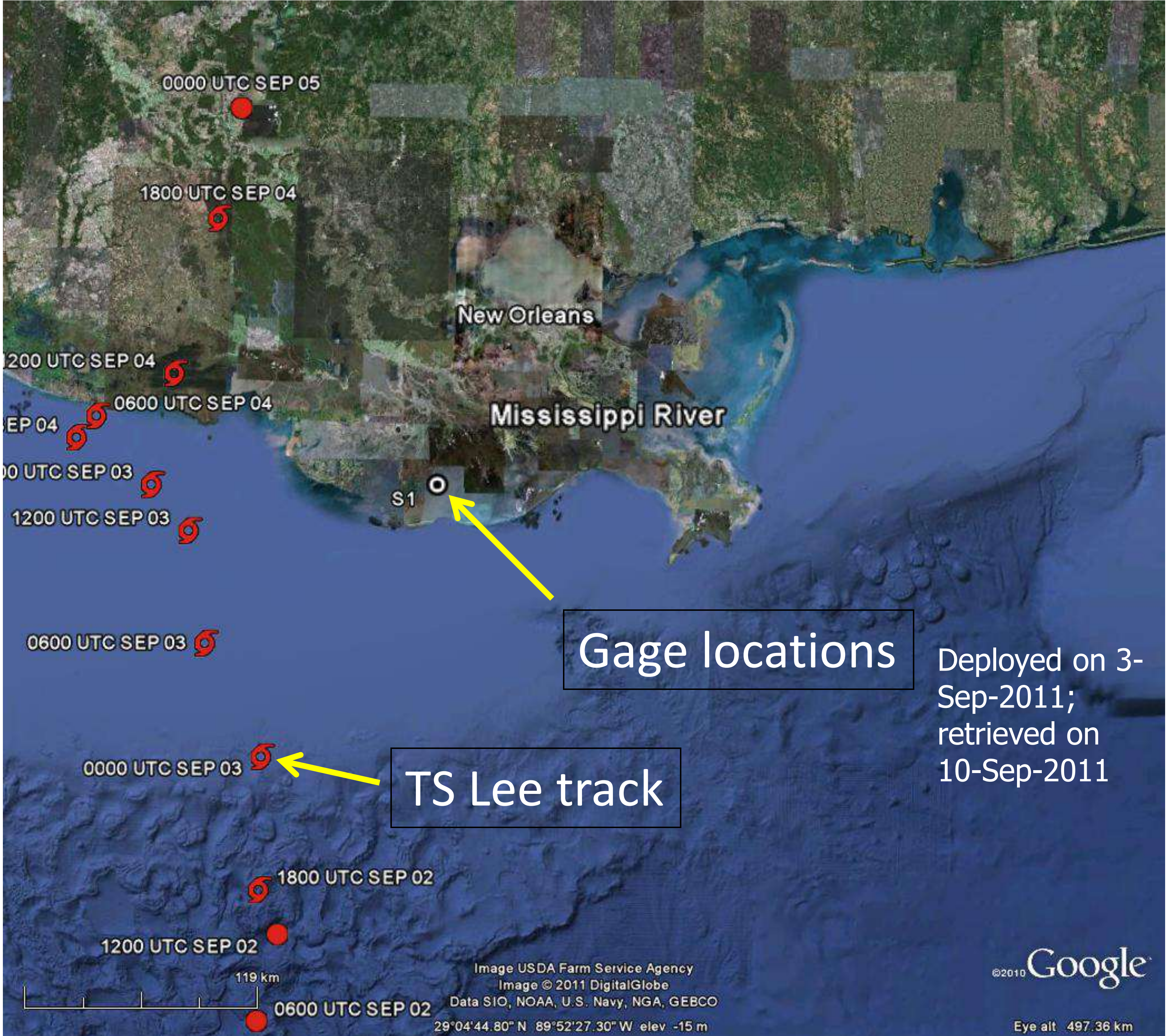
- Landfall on Nov. 10, 2009 on the Mississippi coast
- Five wave gages were deployed by LSU on Nov. 9, 2009 in Breton Sound, LA
- All gages were retrieved after 11 days
- Measured waves and surge analyzed

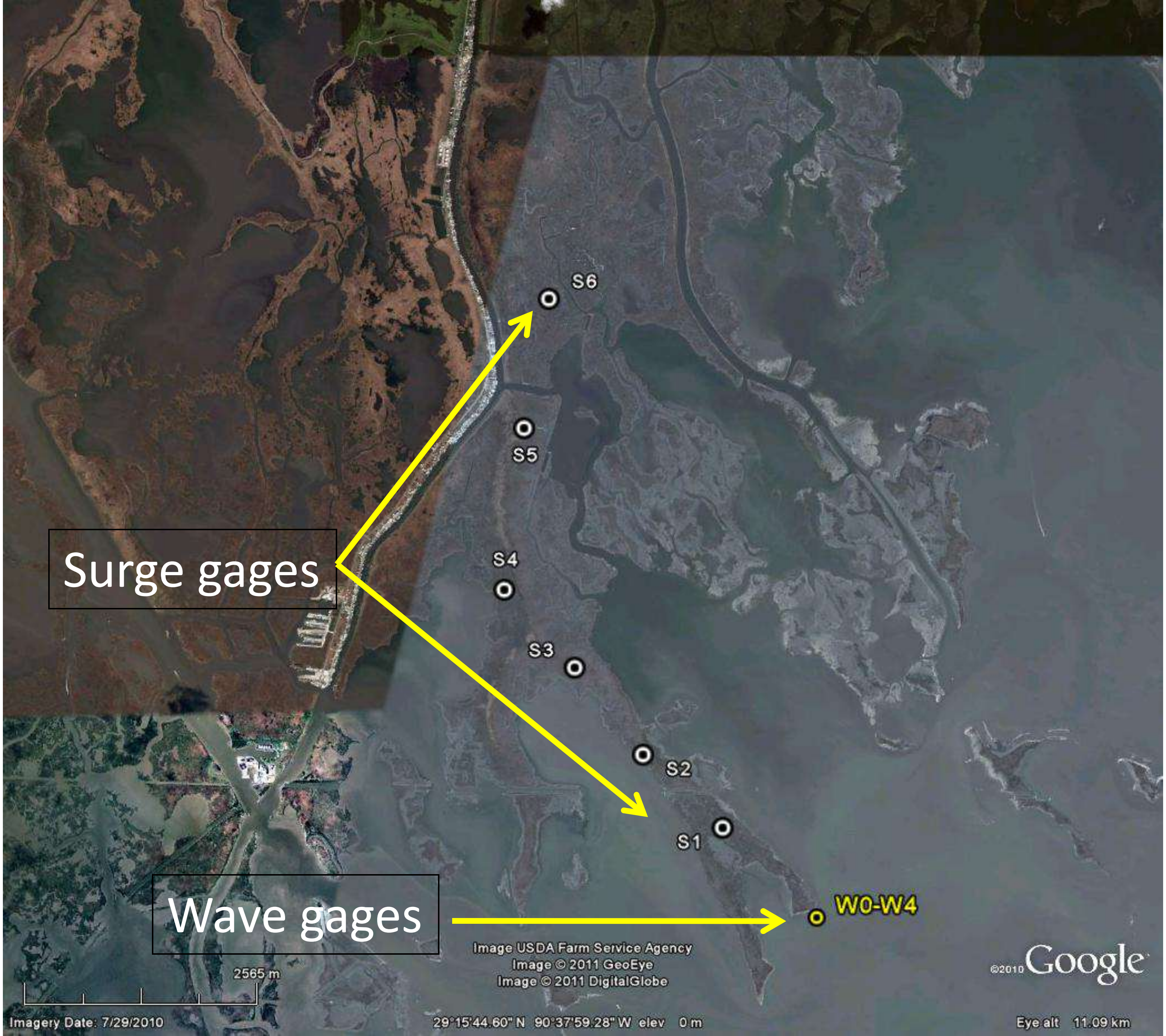


Tropical Storm Ida Deployment –Gage Locations

Tropical Storm Ida:
Measured Wave Height Attenuation

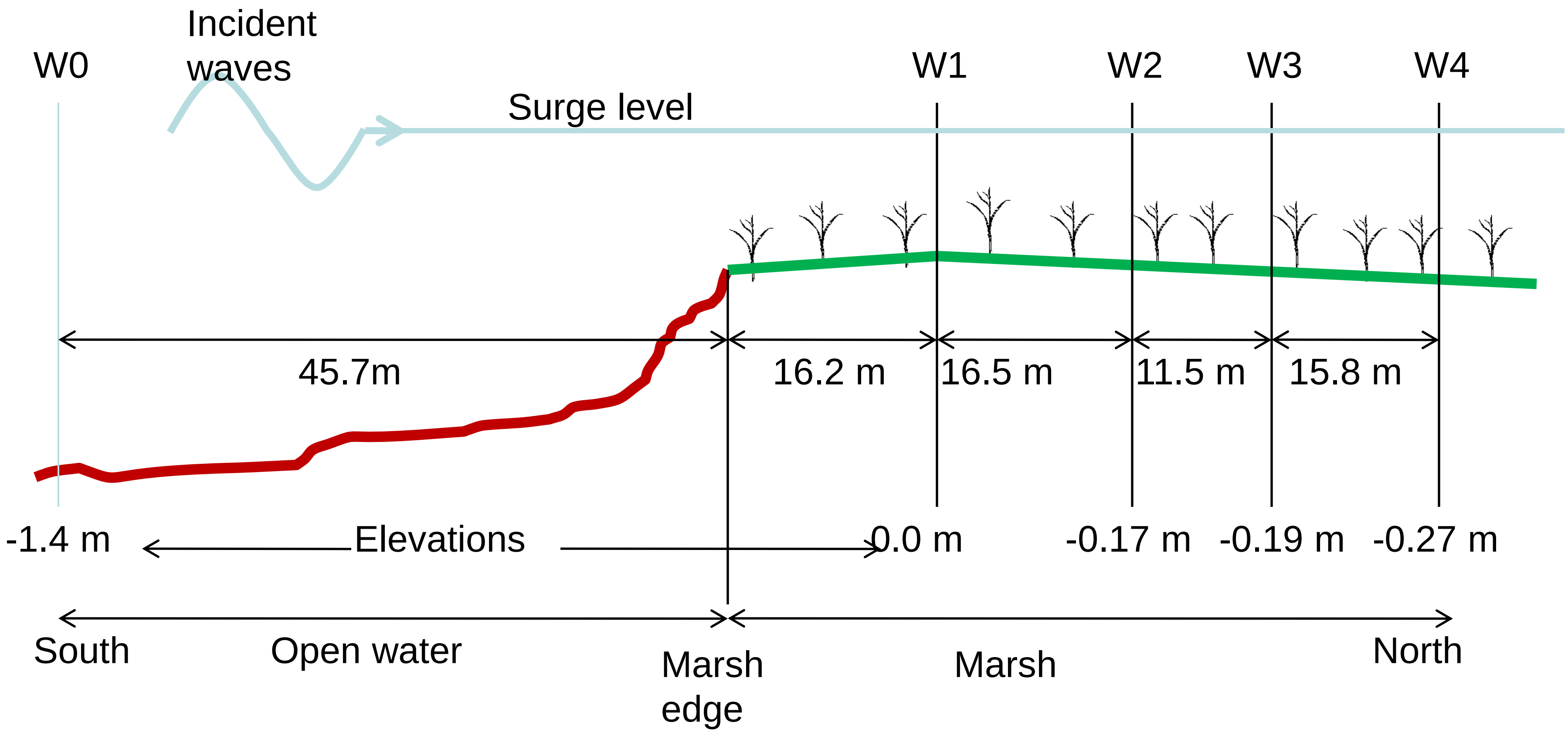


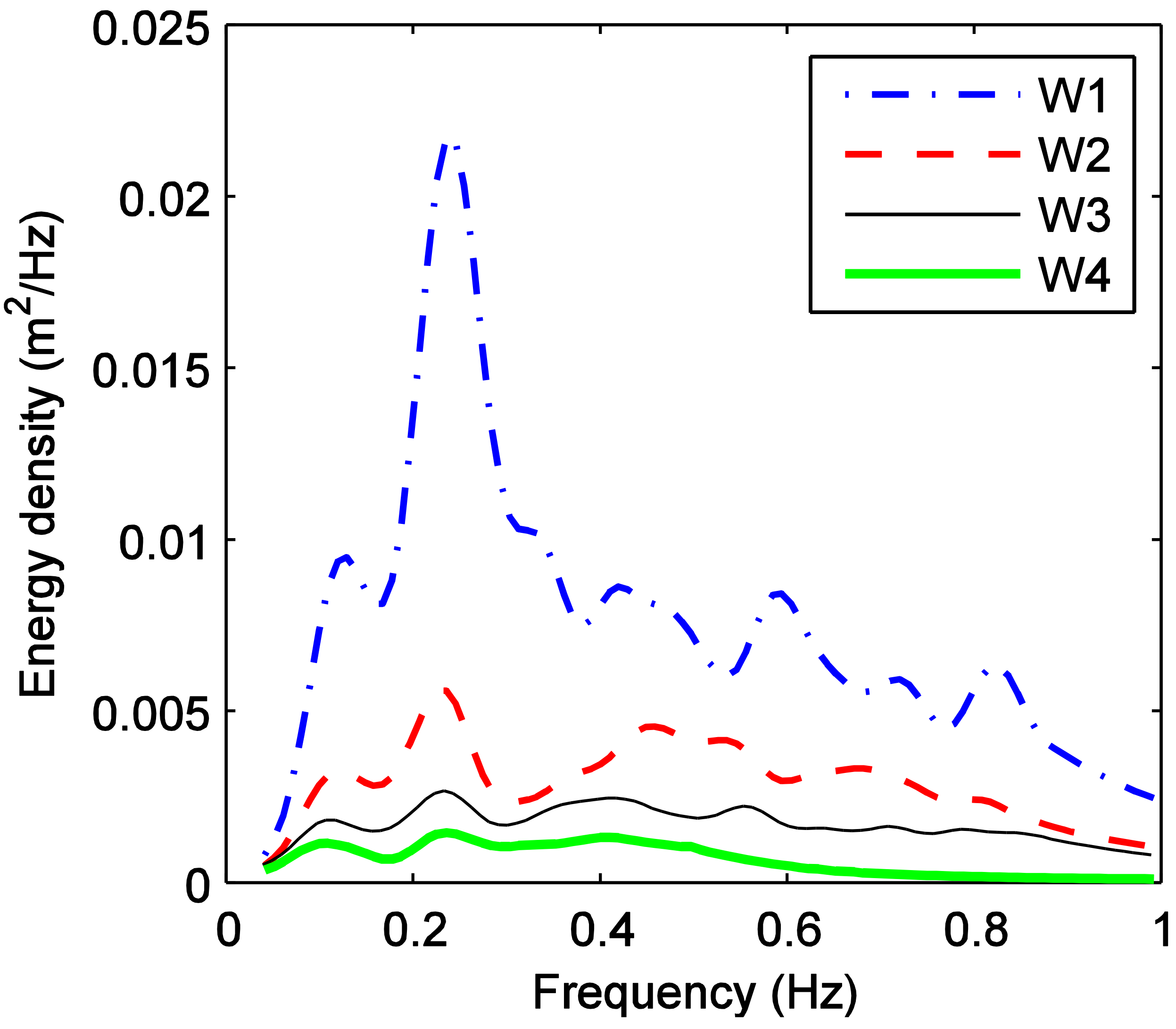

0000 UTC SEP 05
1800 UTC SEP 04
New Orleans
200 UTC SEP 04
0600 UTC SEP 04
Mississippi River
EP 04
0 UTC SEP 03
S1
1200 UTC SEP 03
0600 UTC SEP 03
Gage locations
Deployed on 3-Sep-2011; retrieved on 10-Sep-2011
0000 UTC SEP 03
TS Lee track
1800 UTC SEP 02
1200 UTC SEP 02
119 km
0600 UTC SEP 02
Image USDA Farm Service Agency
Image © 2011 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
29°04'44.80" N 89°52'27.30" W elev -15 m
©2010 Google
Eye alt 497.36 km



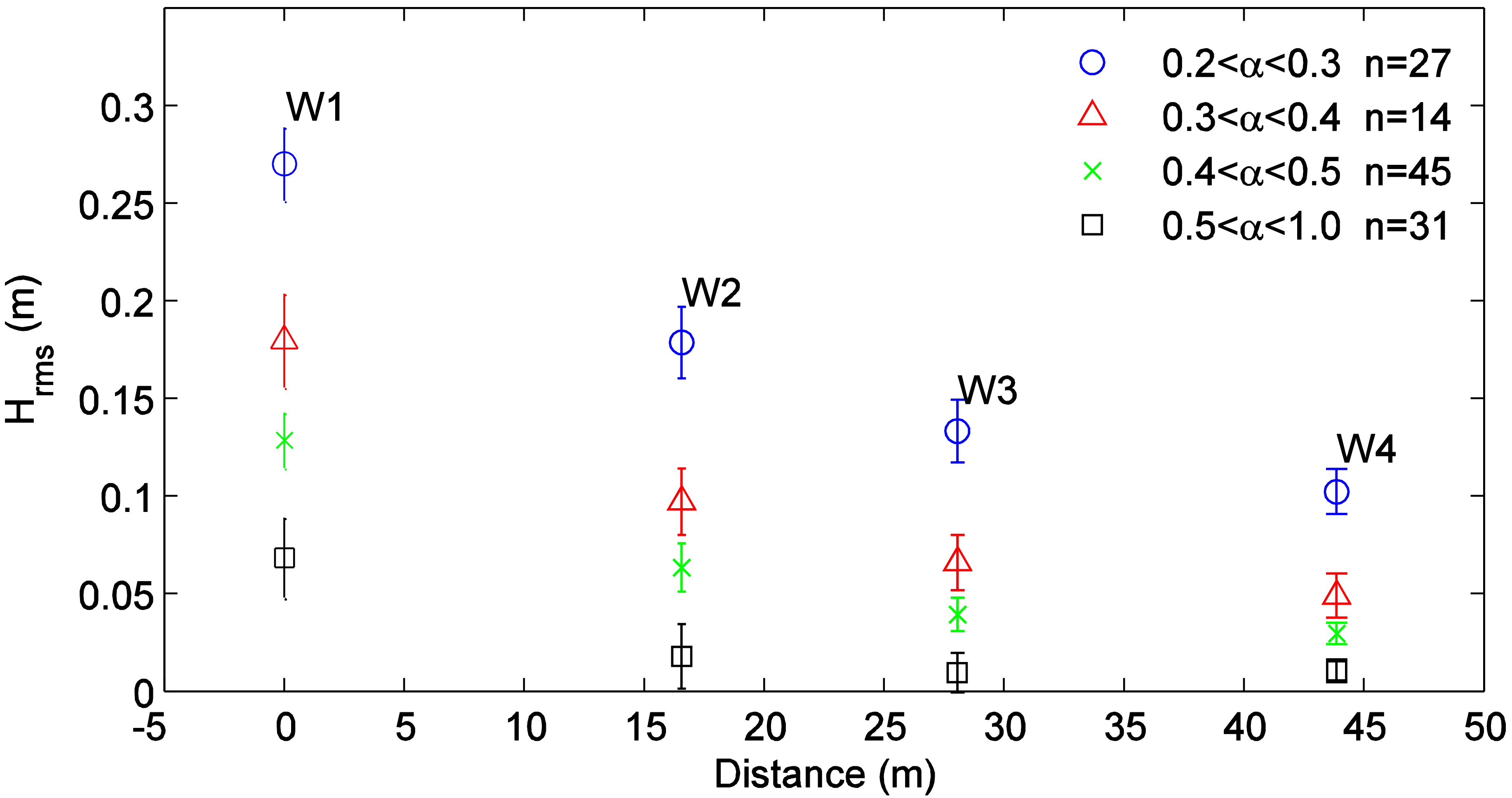
Surge gages
Wave gages
S6
S5
S4
S3
S2
S1
W0-W4
Image USDA Farm Service Agency
Image © 2011 GeoEye
Image © 2011 DigitalGlobe
2565 m
©2010 Google
Imagery Date: 7/29/2010
29°15'44.60" N 90°37'59.28" W elev 0 m
Eye alt 11.09 km

Details of wave gage locations





Sample of simultaneous wave spectra recorded at 4 marsh gages



Spatial variation of measured wave heights at four marsh gages for various ranges of submergence ratio, α, at gage W1. Number of records in each range is given by *n*. Symbols indicate mean values and vertical bars are ±1 standard deviation. Using α from one gage only for classification ensures that the same waves are followed across the transect to compute the mean.

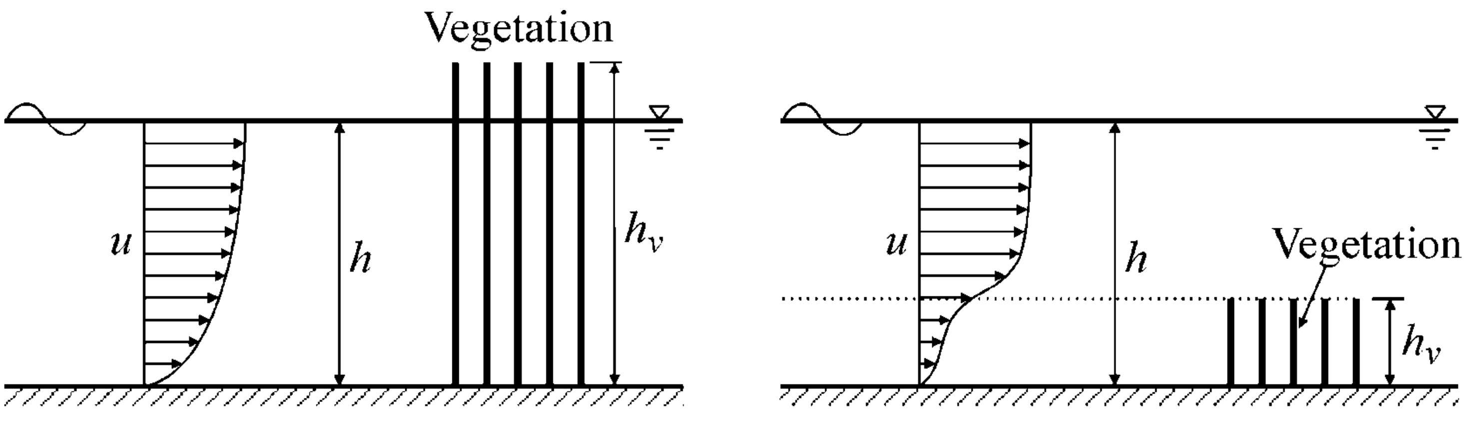
Drag Force of Vegetation

Clarkson UNIVERSITY defy convention

$$\vec{F}_D = \frac{1}{2} C_D \rho N_v A_v \left| \vec{U}_v \right| \vec{U}_v$$

For submerged vegetation, Stone and Shen's (2002) method:

$$U_v = \eta_v \left(\frac{h_v}{h} \right)^{0.5} U$$



(a) Emergent (b) Submerged

Wave Energy Dissipation through Vegetation (Mendez and Losada, 2004)

$$Q_v = \frac{1}{2\sqrt{\pi}} \rho C_D b_v N_v \left(\frac{kg}{2\sigma} \right)^3 \frac{\sinh^3(k\alpha h) + 3\sinh(k\alpha h)}{3k \cosh^3(kh)} H_{rms}^3$$

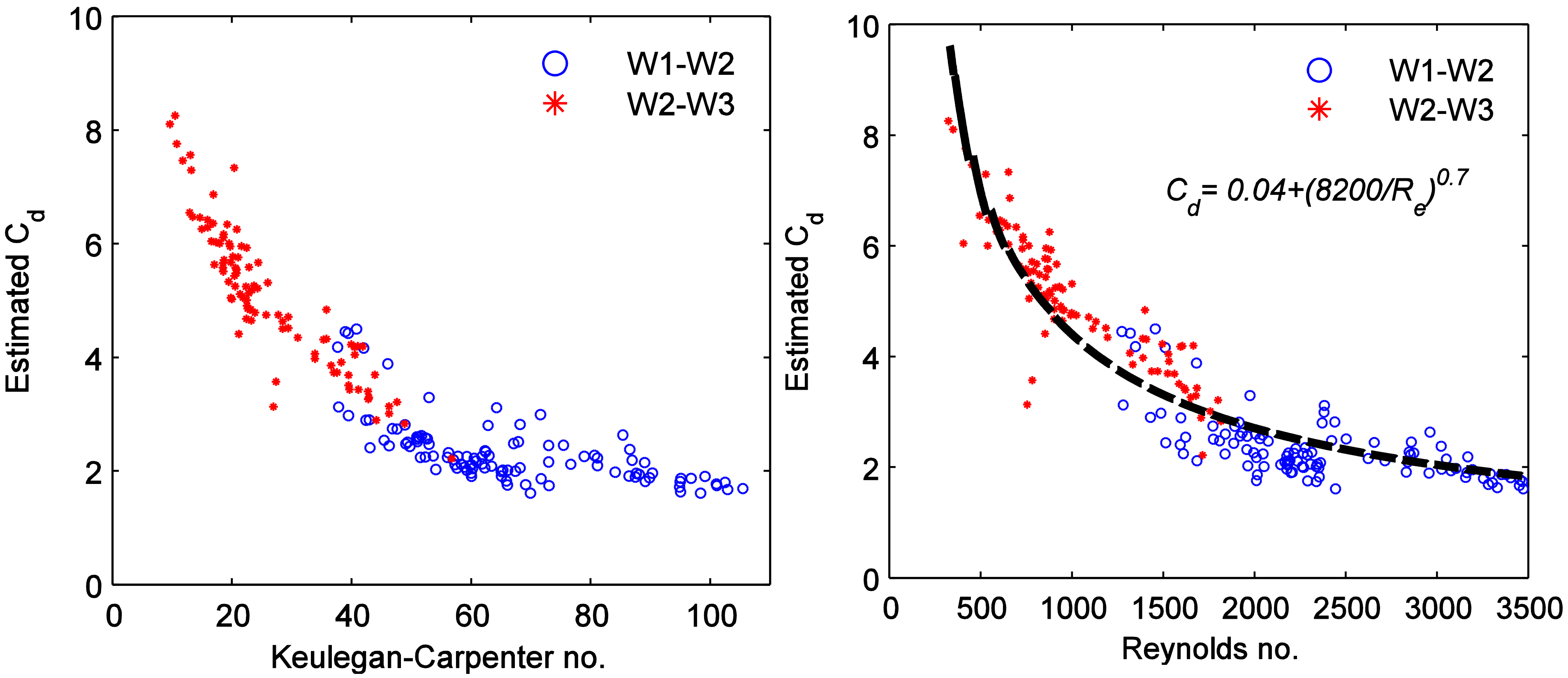
Assumptions:

(1) Linear waves
(2) Impermeable bottom
(3) Invariant Rayleigh wave height distribution
(4) Thornton and Guza's wave breaking criteria

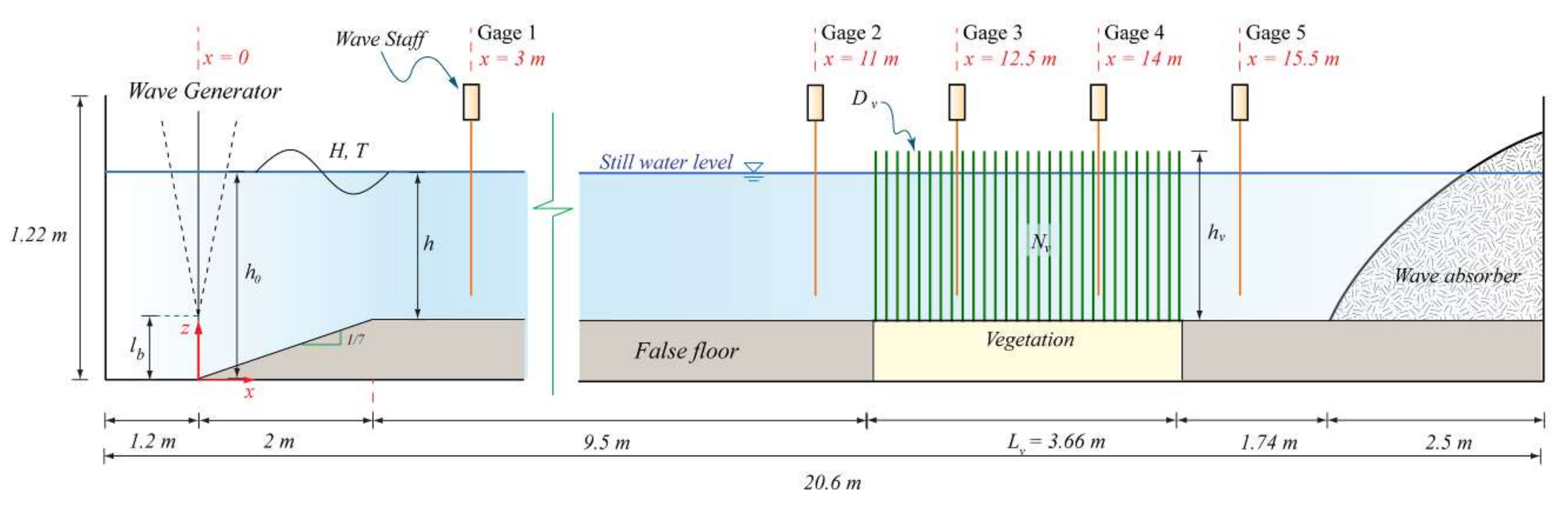
b_v = plant area per unit height of each vegetation stand normal to horizontal velocity (m)
N_v = number of vegetation stands per unit horizontal area (m^{-2})
C_D = drag coefficient for irregular waves
H_{rms} = root-mean-square wave height (m)

Terrebonne Bay, LA, 5/3/2009

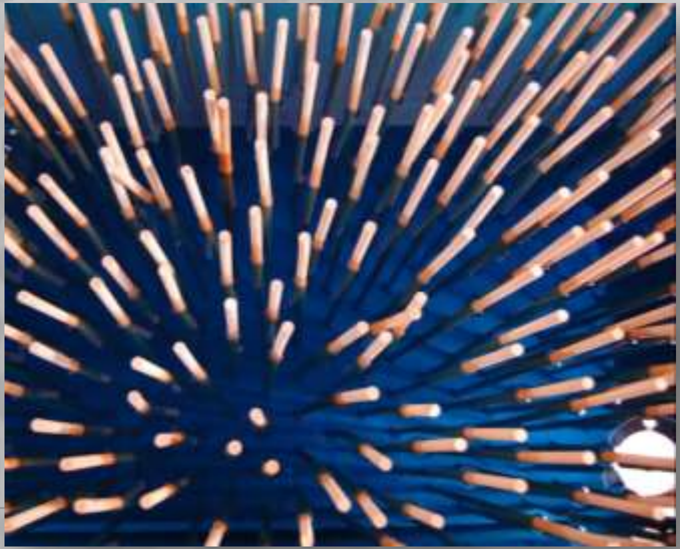
Estimated Vegetation Drag Coefficient C_d using Dalrymple (1984)



Laboratory Experiments

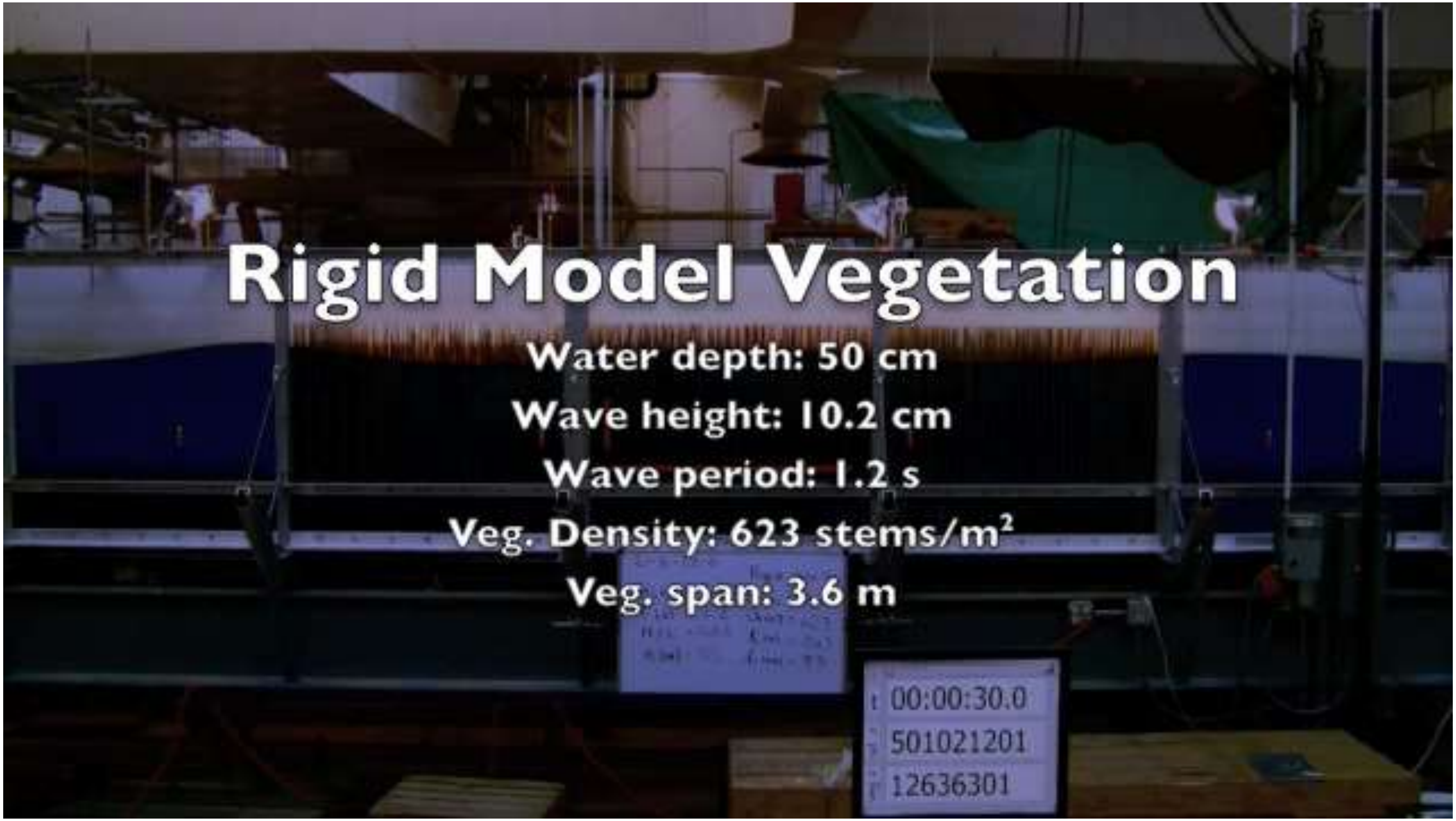


Rigid Vegetation



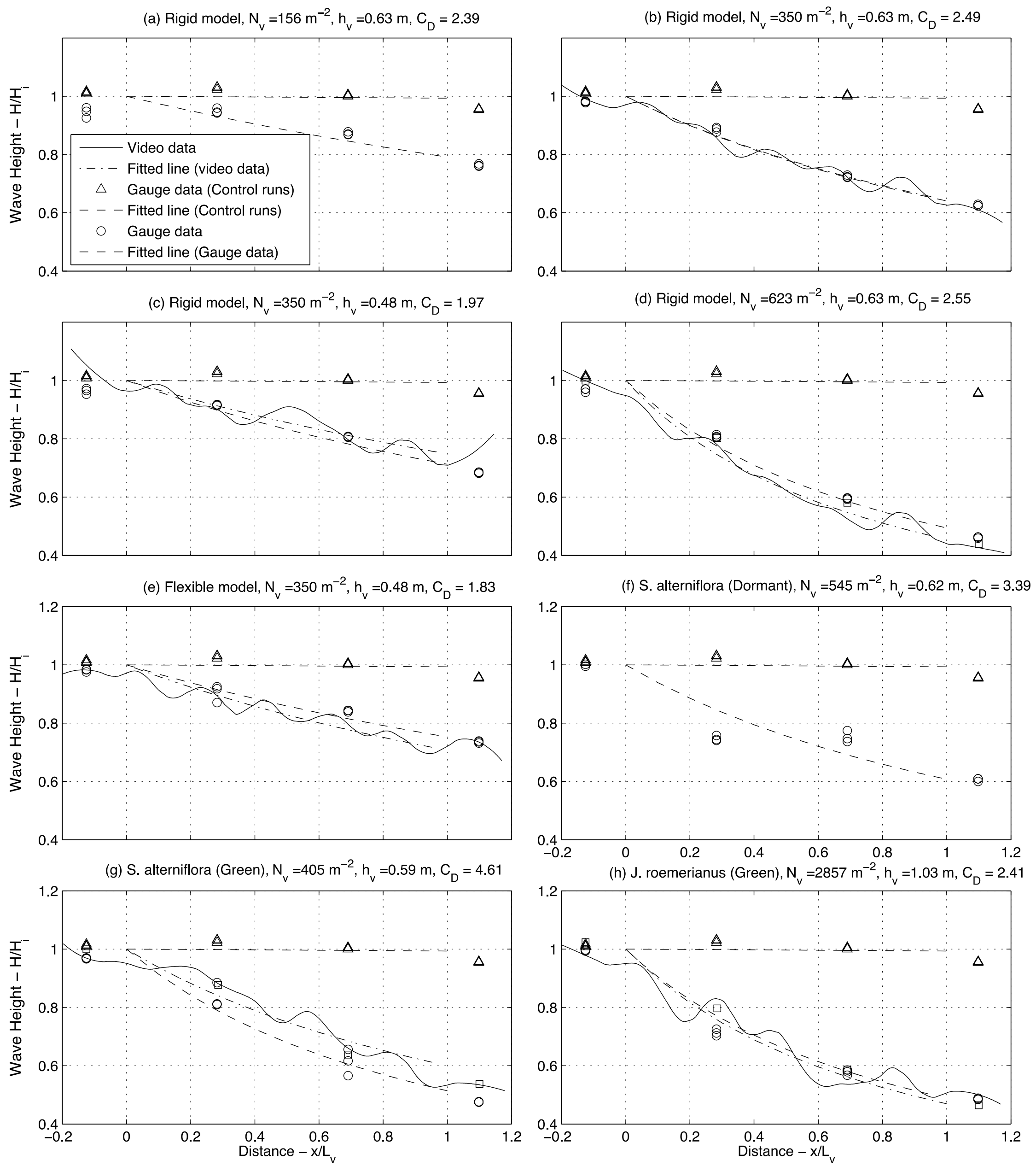
Live Vegetation

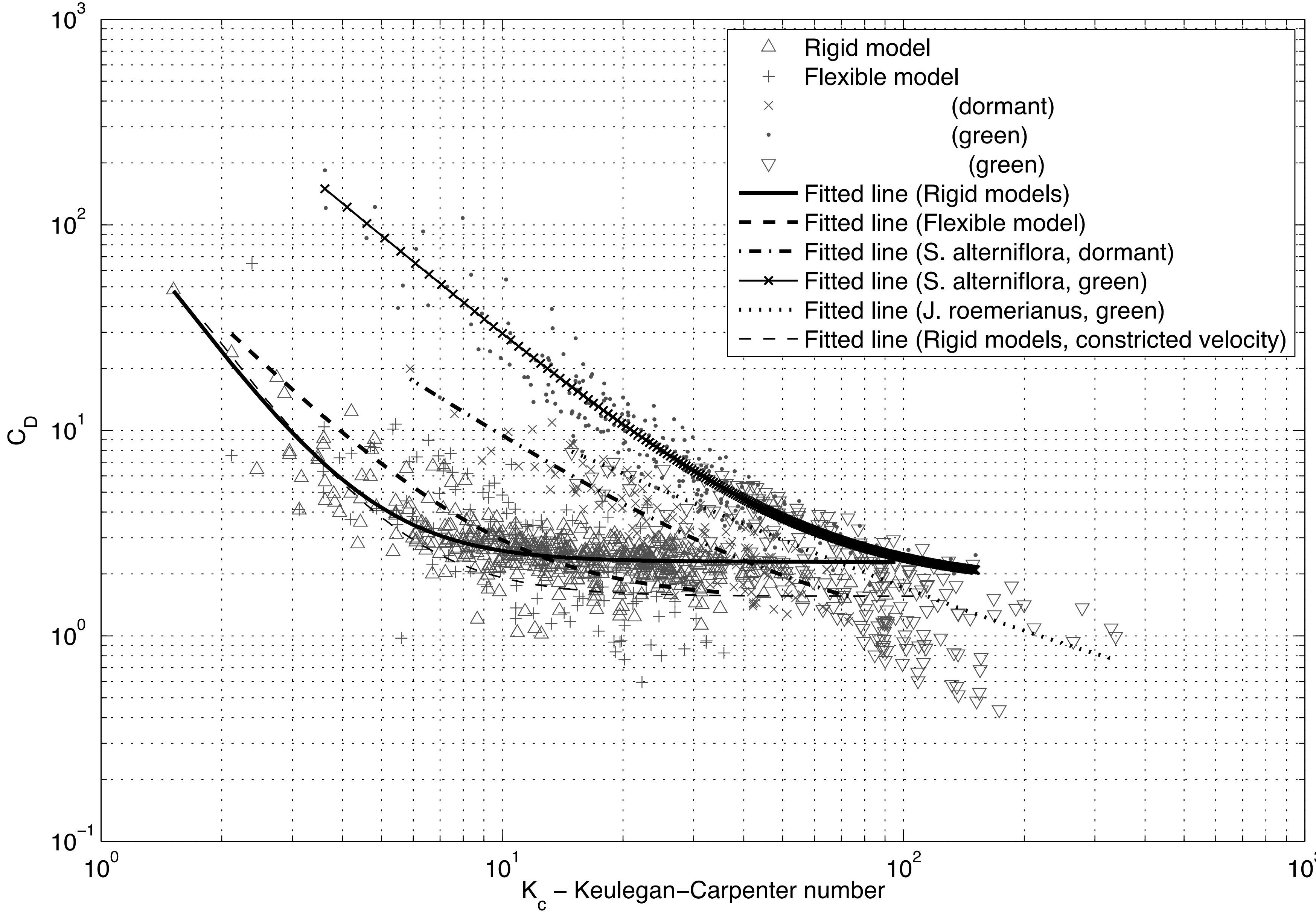
Video


Rigid Model Vegetation
Water depth: 50 cm
Wave height: 10.2 cm
Wave period: 1.2 s
Veg. Density: 623 stems/m²
Veg. span: 3.6 m
00:00:30.0
501021201
12636301

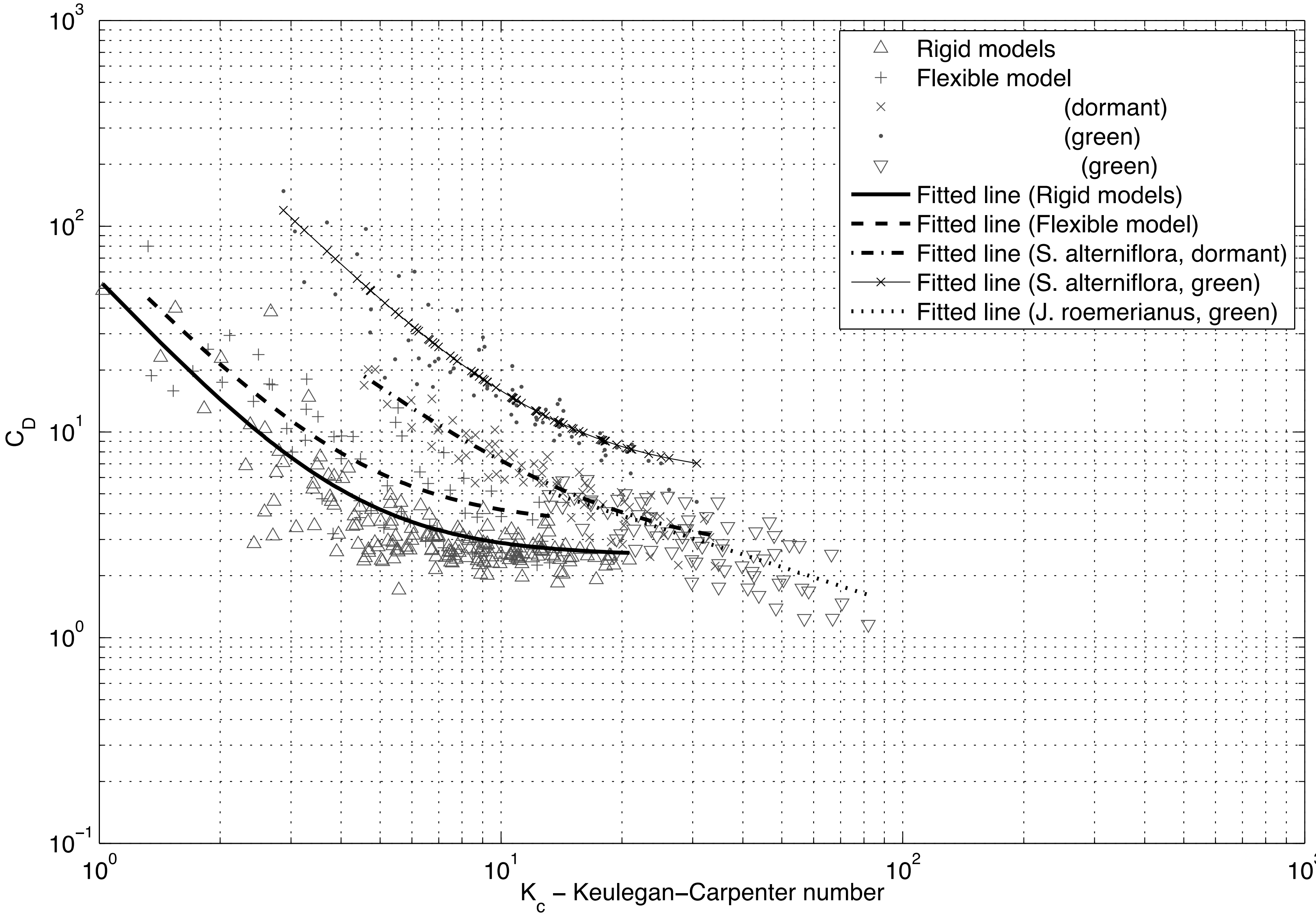
Video (Live Vegetation)

Wave heights affected by different vegetation



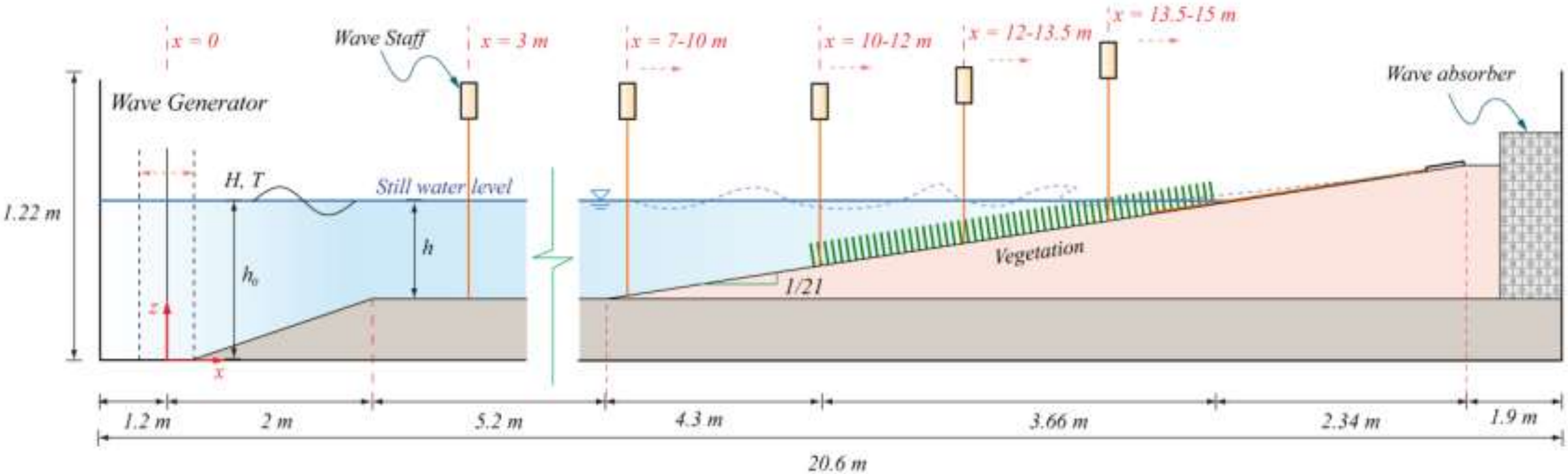


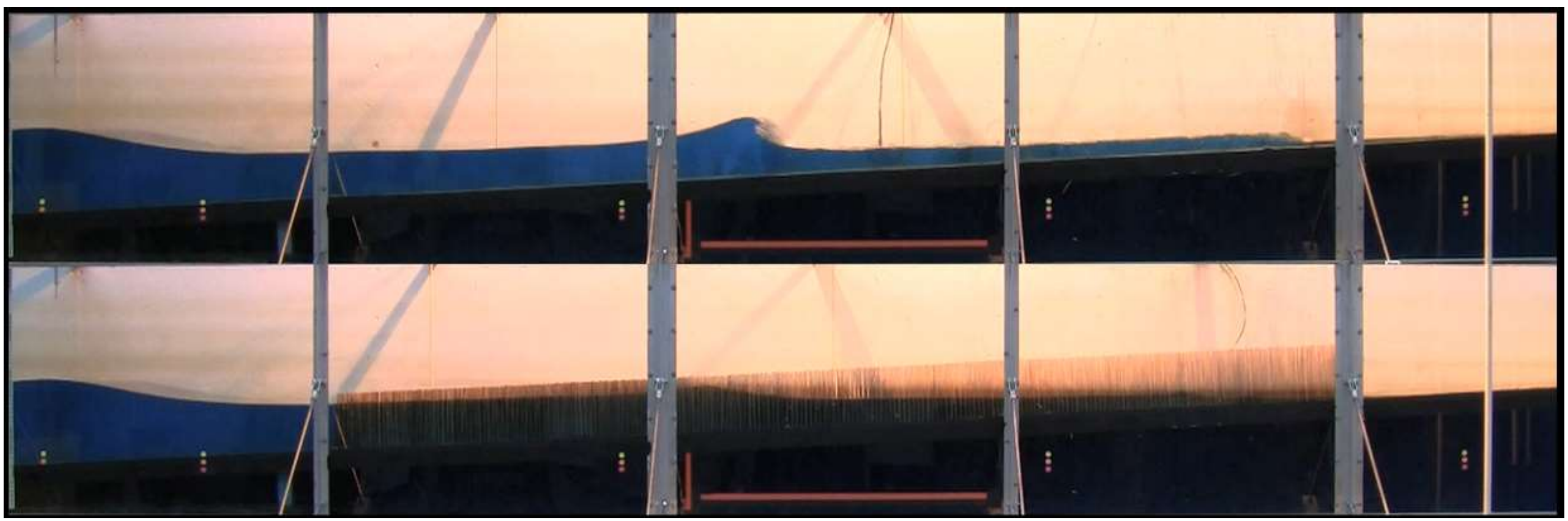
Average trends of the drag coefficient for rigid, flexible and live vegetation models under regular waves.



Average trends of the drag coefficient for rigid, flexible and live vegetation models under random waves.

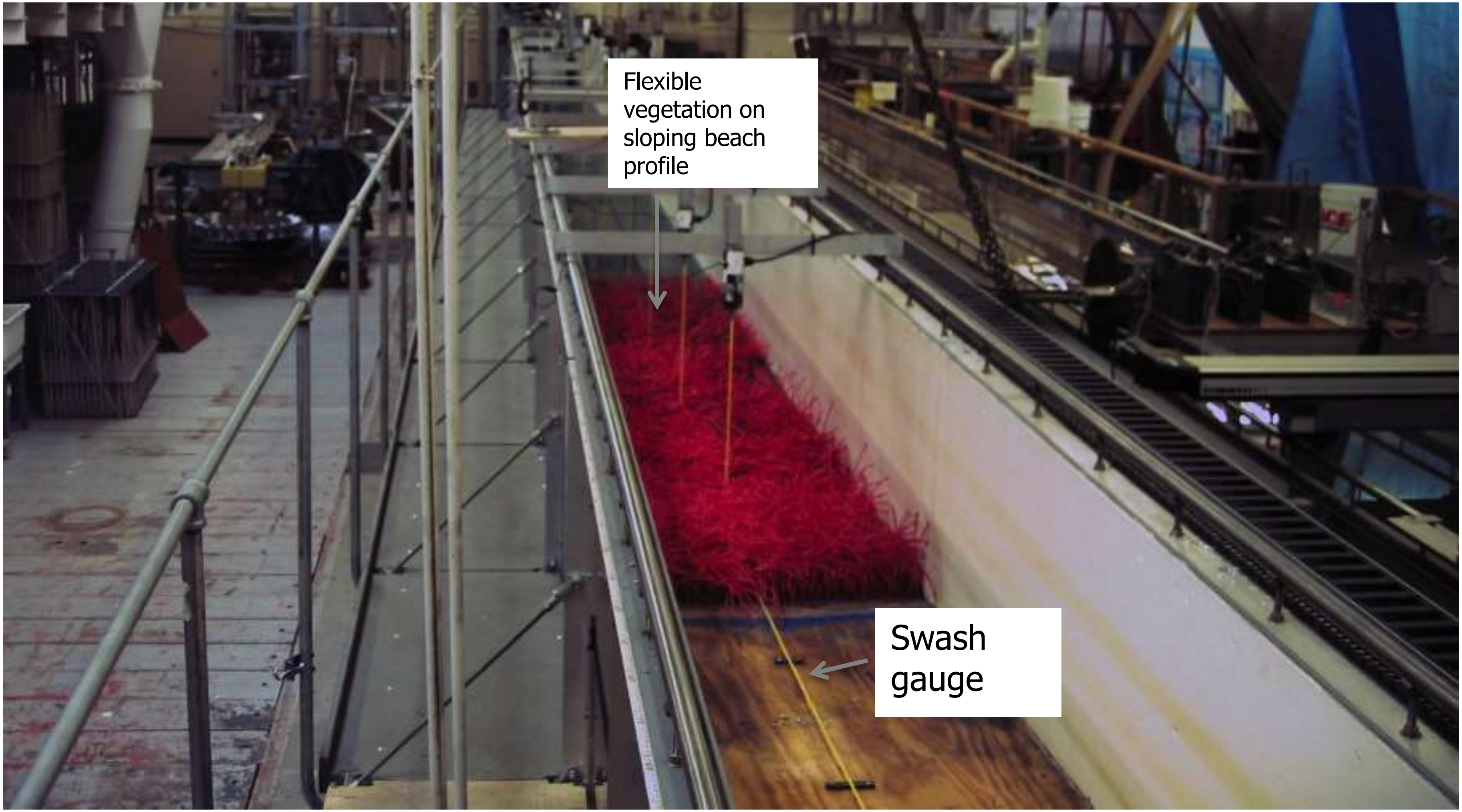
Sloping Beach Experiments



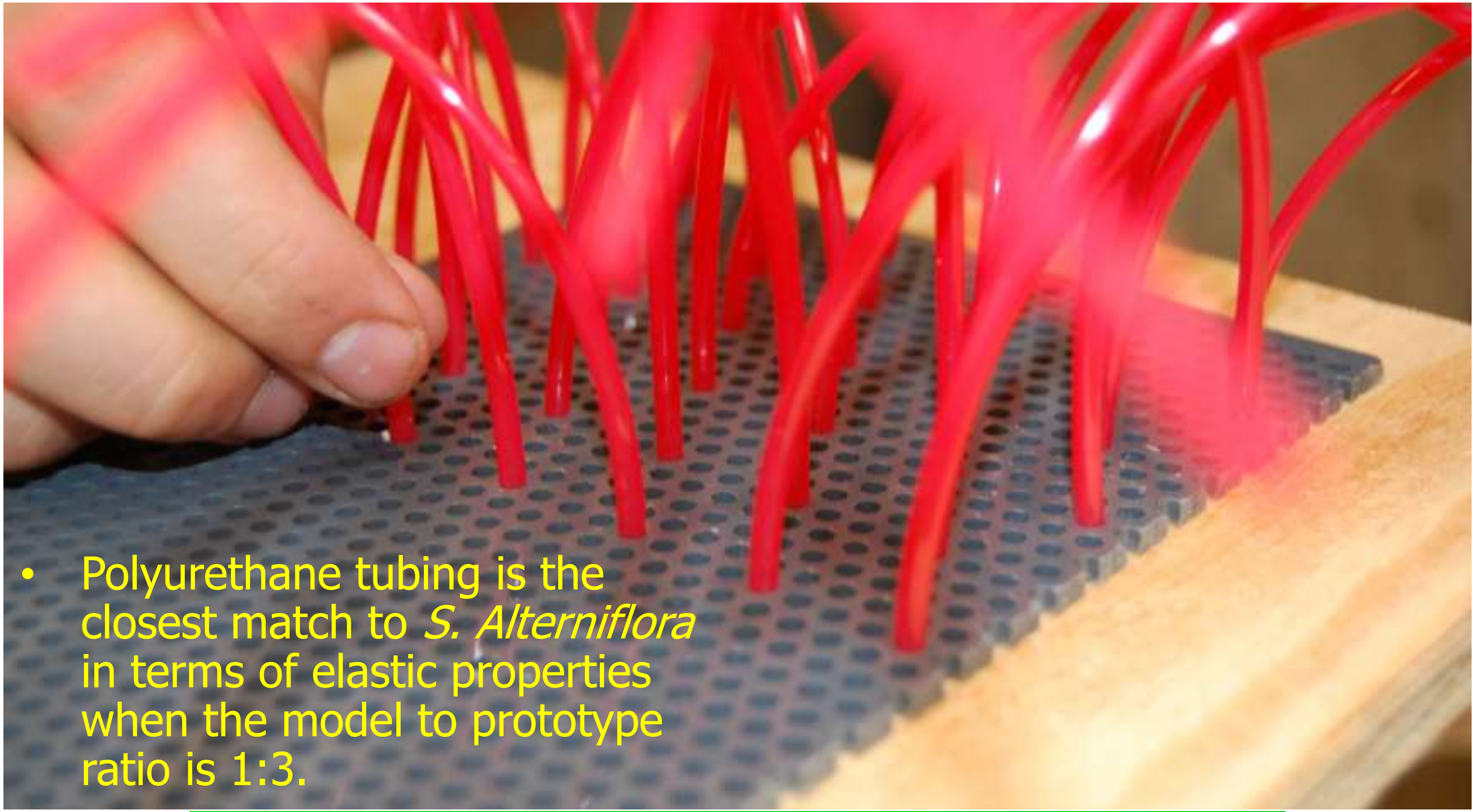


Wave Runup Experiment using Rigid Model Vegetation

Wave Runup Experiment using Flexible Model Vegetation



Flexible Model Vegetation



	EPDM rubber	Polyurethane	Model	Prototype
E (GPa)	3.86E-03	3.59E-02	9.46E-02	2.83E-01 (LSU team)
EI (Nt*m²)	1.60E-05	1.41E-04	1.17E-04	2.84E-02 (Feagin, 2010)

Computational Modeling of Wave Attenuation by Vegetation

Models Used for Wave Attenuation

- 1-D/2-D shallow water flow models with HLL approximate Riemann solver (Wu and Marsooli, 2012)
- 1-D Boussinesq wave model
- 2-D vertical Navier-Stokes model with VOF
- 3-D Navier-Stokes models with VOF (Marsooli and Wu, 2014)
- 2-D spectral wave transformation model
- 3-D shallow water model coupled with spectral wave transformation model (Wu, 2014)

Depth-Averaged 2-D Model for Long Waves (Wu and Marsooli, 2012)

Governing equations:

$$\frac{\partial h}{\partial t}+\frac{\partial (Uh)}{\partial x}+\frac{\partial (Vh)}{\partial y}=0$$

$$\frac{\partial}{\partial t}(Uh)+\frac{\partial}{\partial x}(U^2h)+\frac{\partial}{\partial y}(UVh)=-\frac{1}{\rho}F_x-gh\frac{\partial\eta}{\partial x}+\frac{\partial}{\partial x}\left(\nu_t h\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_t h\frac{\partial U}{\partial y}\right)-g\frac{n^2 m_b U\bar{U}}{h^{1/3}}$$

,

$$\frac{\partial}{\partial t}(Vh)+\frac{\partial}{\partial x}(UVh)+\frac{\partial}{\partial y}(V^2h)=-\frac{1}{\rho}F_y-gh\frac{\partial\eta}{\partial y}+\frac{\partial}{\partial x}\left(\nu_t h\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_t h\frac{\partial V}{\partial y}\right)-g\frac{n^2 m_b V\bar{U}}{h^{1/3}}$$

Drag and inertia forces::

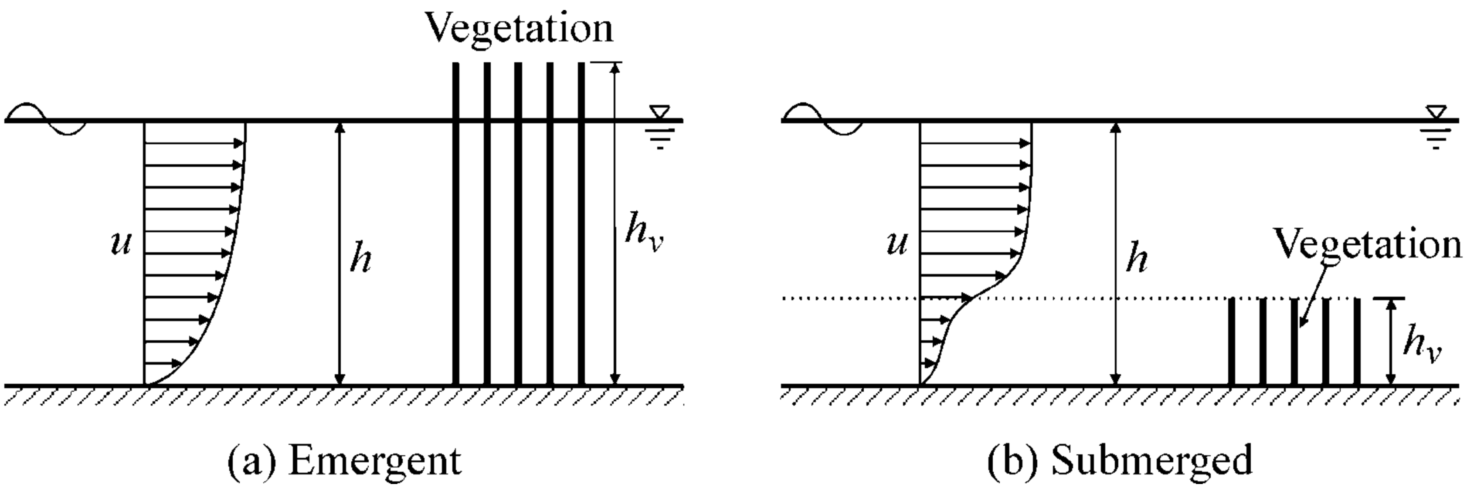
$$F_i=\frac{1}{2}\rho C_D N_v A_v U_{vi}\sqrt{U_{vj}U_{vj}}+\rho C_M N_v V_v\frac{\partial U_{vi}}{\partial t}$$

Drag Force of Submerged Vegetation

$$\vec{F}_D = \frac{1}{2} C_D \rho N_v A_v \left| \bar{U}_v \right| \vec{U}_v$$

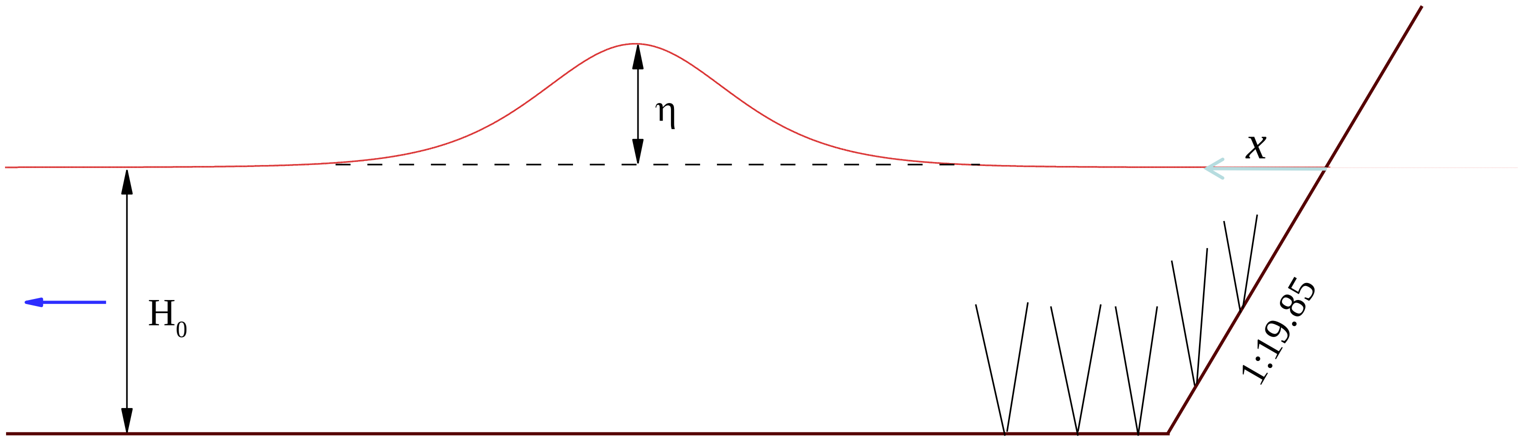
For submerged vegetation, Stone and Shen's (2002) method:

$$U_v = \eta_v \left(\frac{h_v}{h} \right)^{0.5} U$$



Solitary Wave Run-up (SWE Model)

Experimental study: Synolakis (1986)

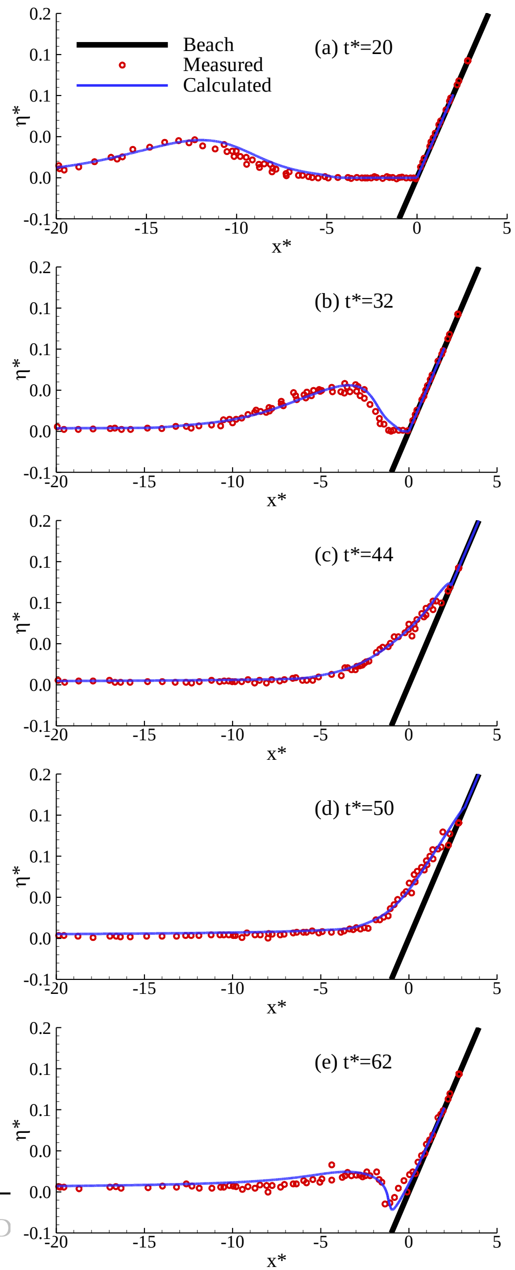


(a) Non-breaking wave for $H/H_0 = 0.0185$

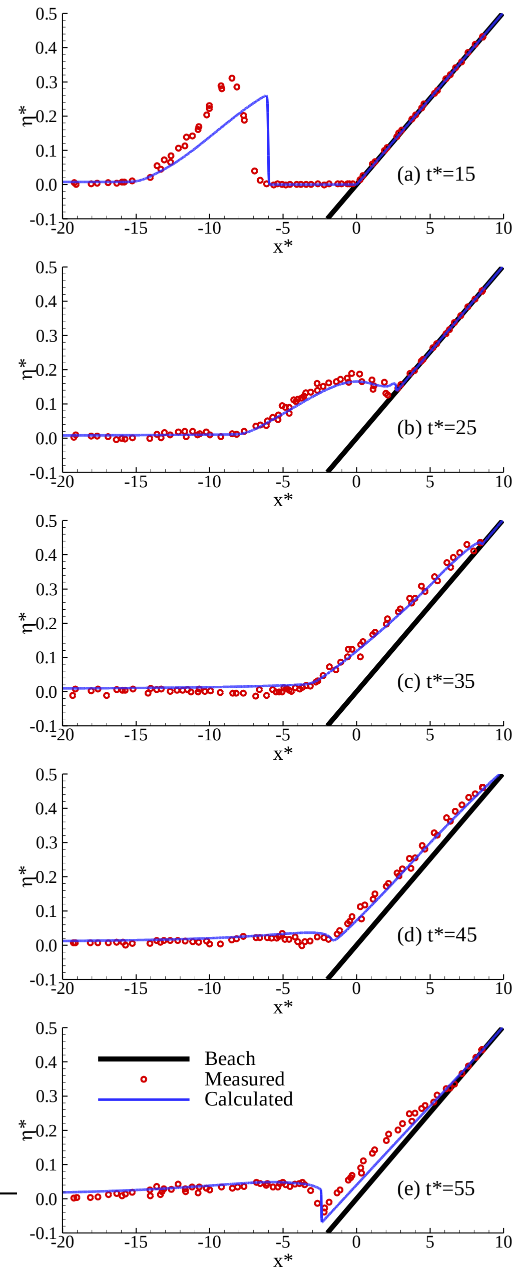
(b) Non-breaking wave for $H/H_0 = 0.04$

(c) Breaking wave for $H/H_0 = 0.3$

Non-Breaking and Breaking Wave Run-up over a Breach

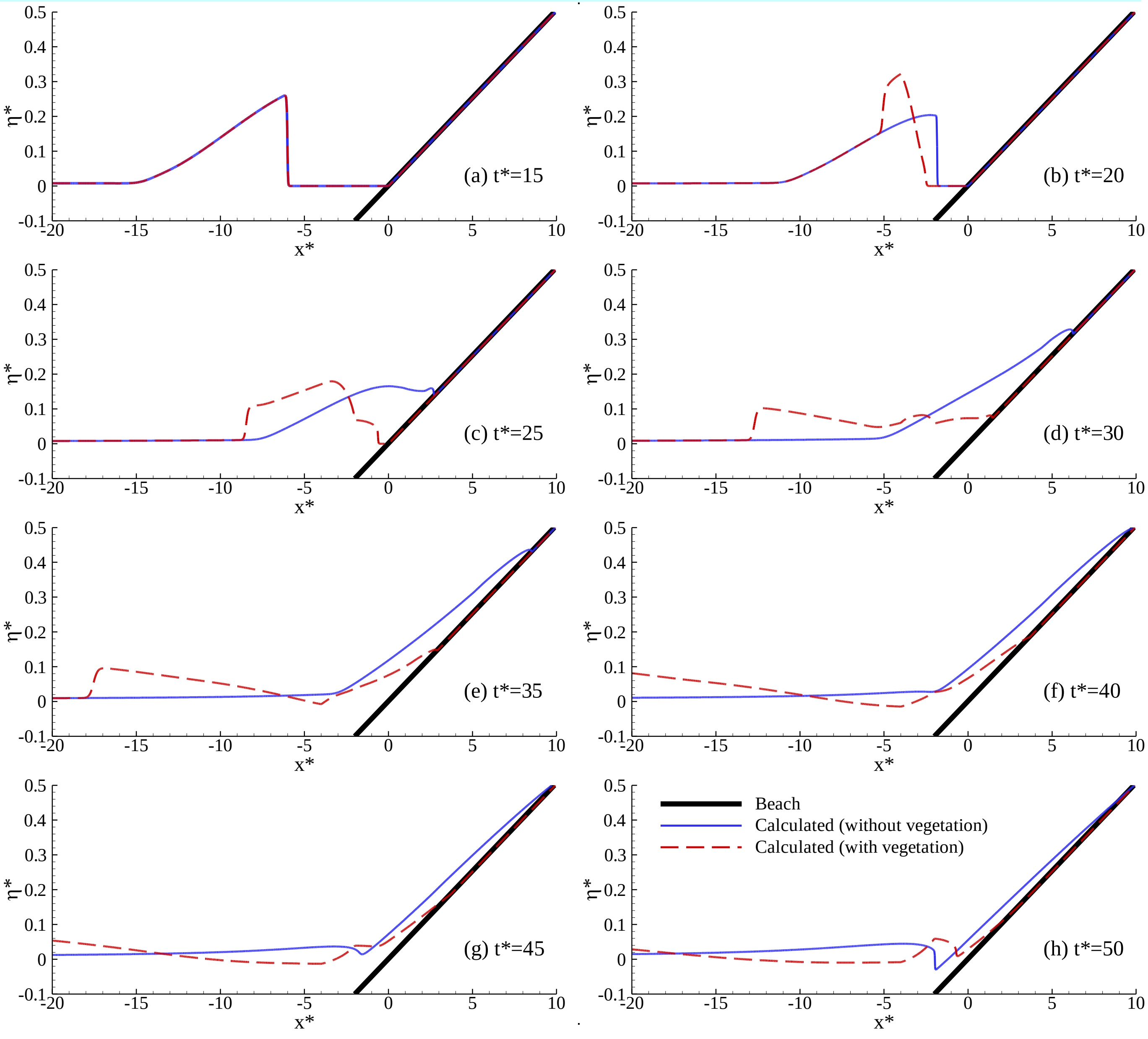


Run-up of H/H_0 = 0.04 solitary wave on 1:19.85 sloping beach



Run-up of H/H_0 = 0.3 solitary wave on 1:19.85 sloping beach

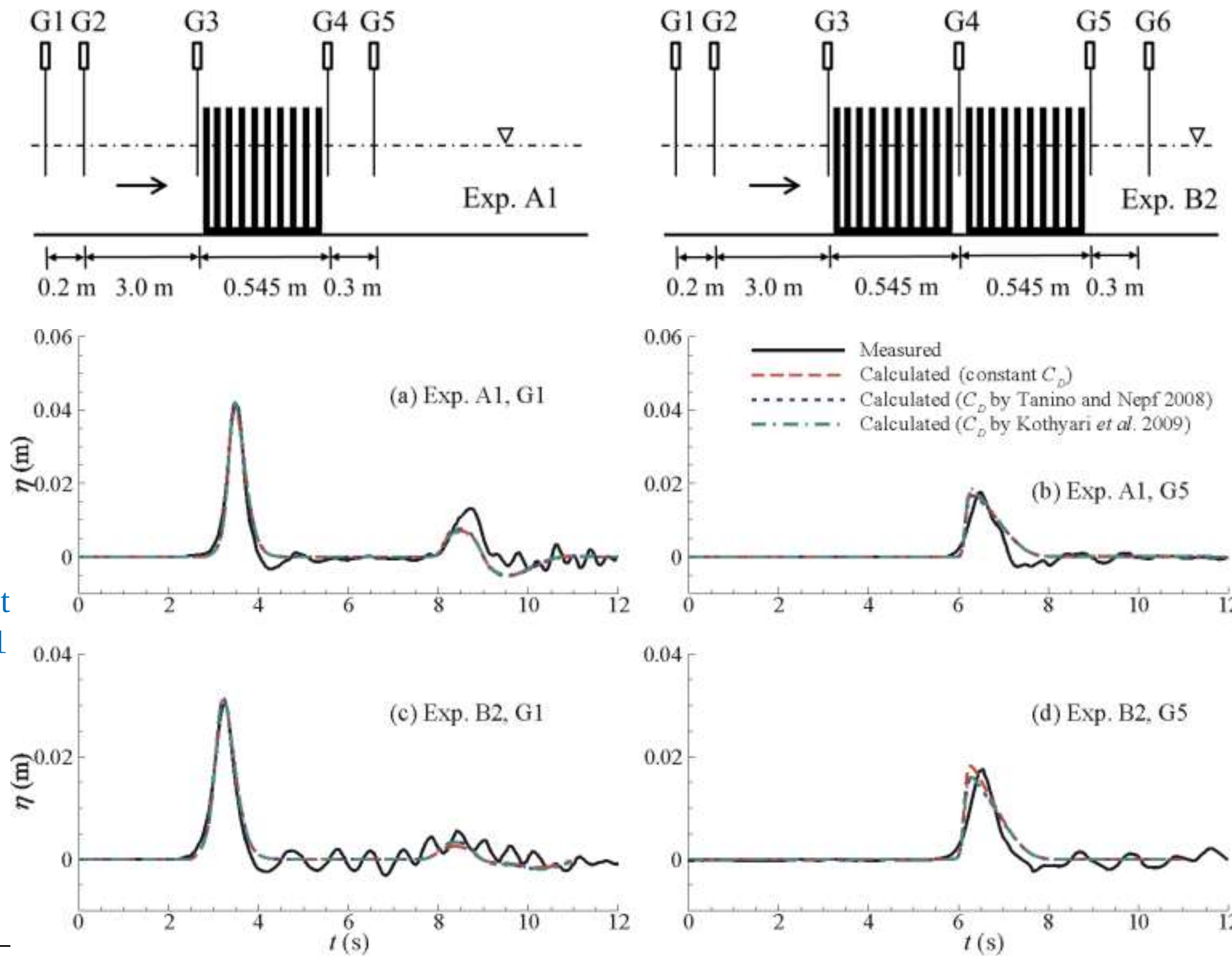
Breaking Wave Run-up on Vegetated Beach



Run-up of $H/H_0 = 0.3$ solitary wave on 1:19.85 vegetated beach

Solitary Wave through Vegetated Channel

Wave heights at gages G1 and G5



Simulations by Wu and Marsooli (2012), and experiments by Huang et al. (2011)

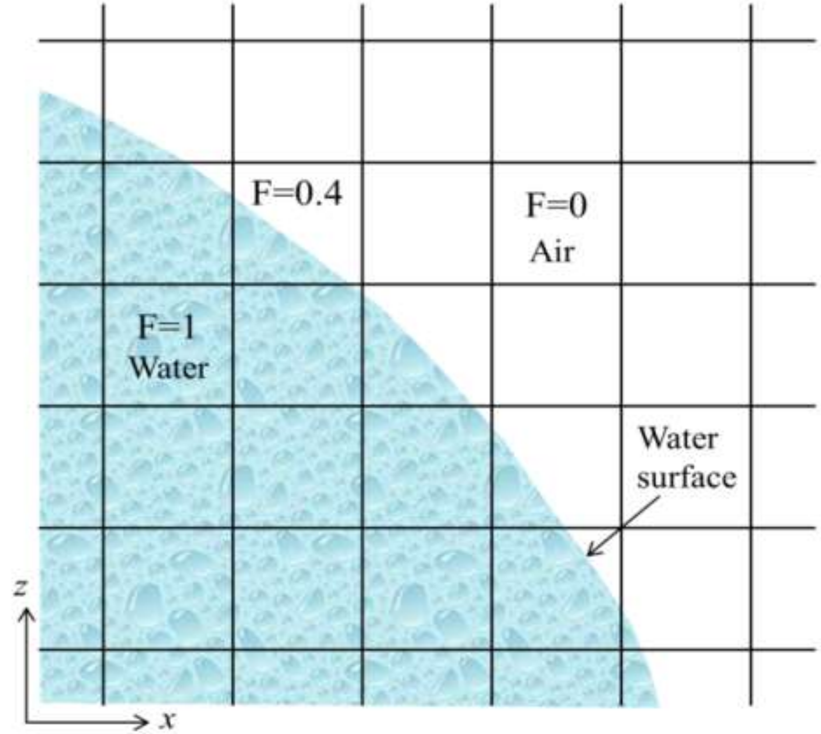
3-D RANS Model with VOF (Marsooli and Wu, 2014)

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} + \nabla \cdot (\mathbf{uu}) = -\frac{1}{\rho}\nabla p + \frac{1}{\rho}\mathbf{f} + \frac{1}{\rho}\nabla \cdot (\mu \nabla \mathbf{u})$$

$$\frac{\partial F}{\partial t} + \nabla \cdot (F\mathbf{u}) = 0$$

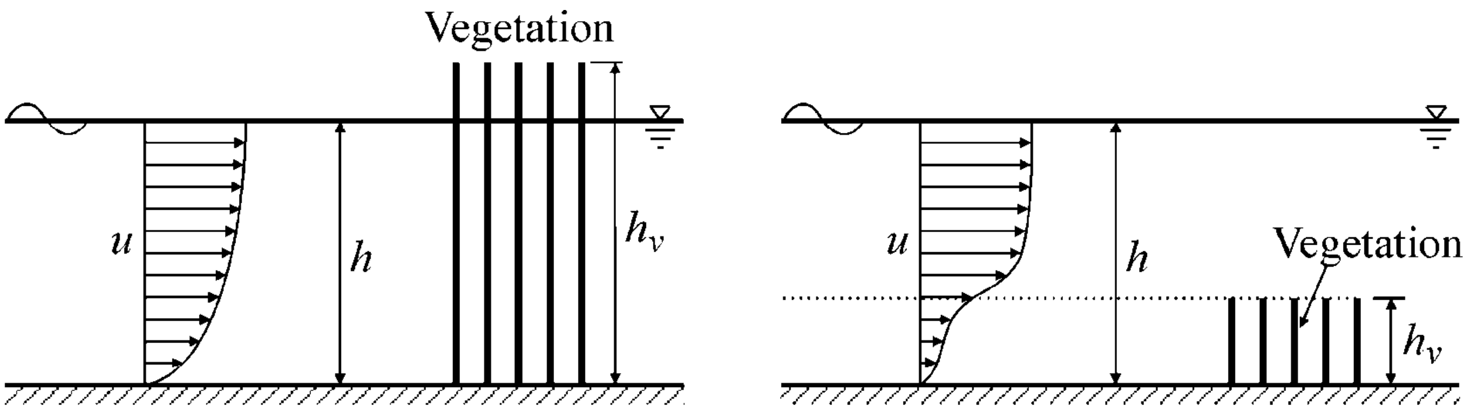
- Empty cell: F=0
- Fluid cell: F=1
- Surface cell: 0<F<1



Drag and Inertia Forces of Vegetation

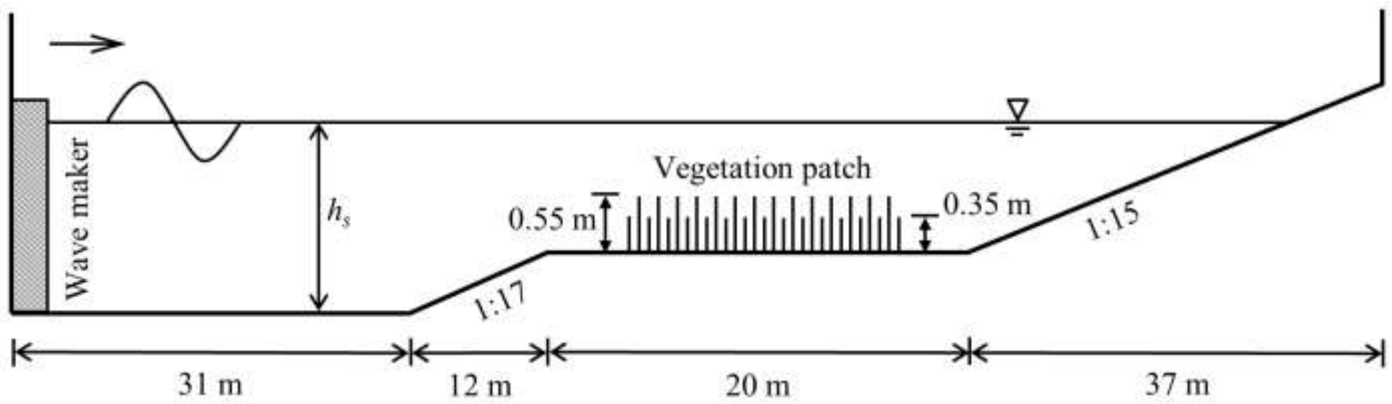
$$f_i = \frac{1}{2}\rho C_{D(i)} N_v b_v u_i \sqrt{u_j u_j} + \rho C_M N_v s_v \frac{\partial u_i}{\partial t}$$

where C_D =drag coefficient
C_M =inertia coefficient
N_v =density of vegetation (units/m^2)
b_v =front width of vegetation stem
s_v =horizontal coverage area of vegetation
ρ =fluid density



(a) Emergent (b) Submerged

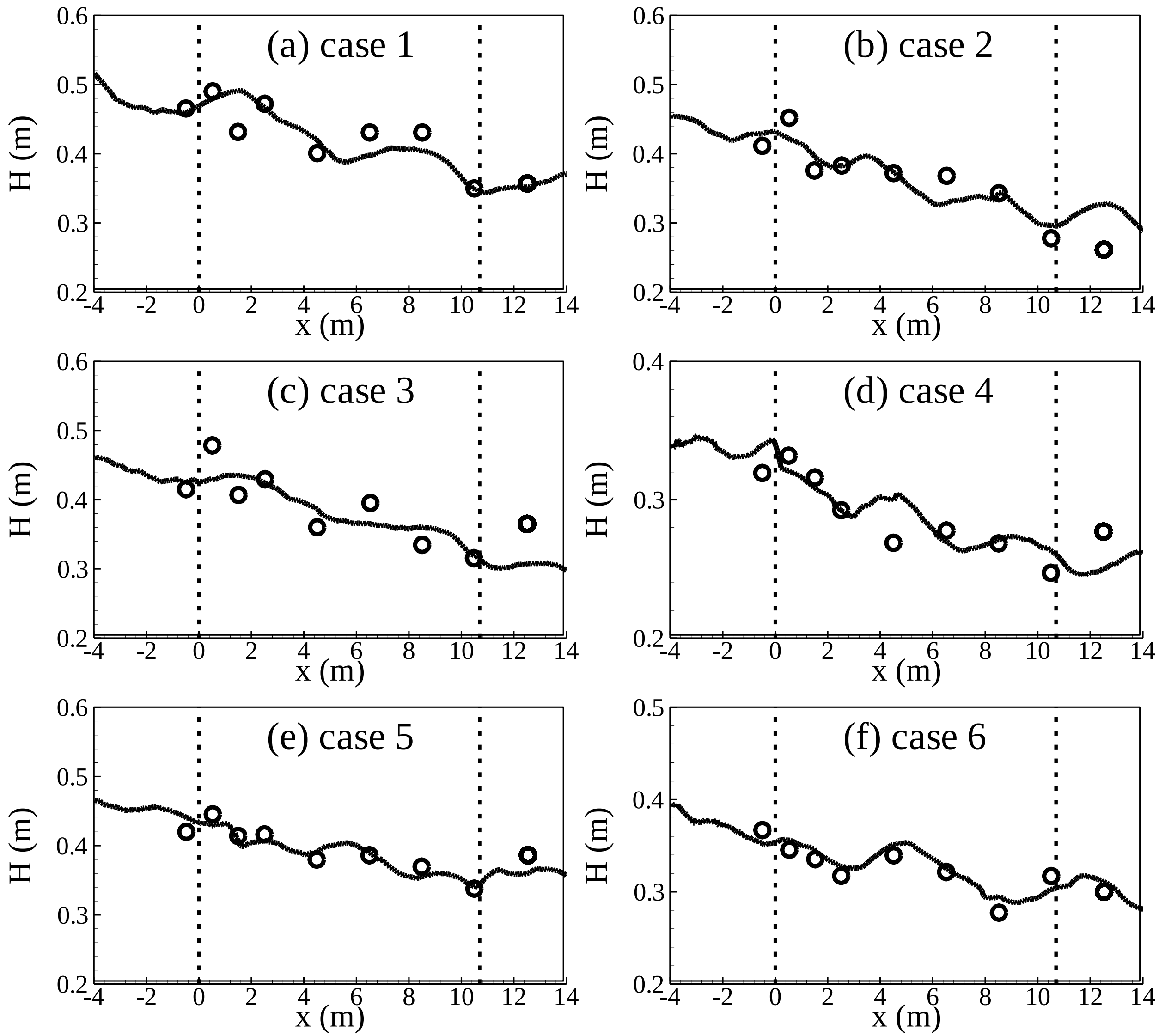
Test of 3-D RANS Model



Experimental runs of Stratigaki et al. (2011) tested by the present model

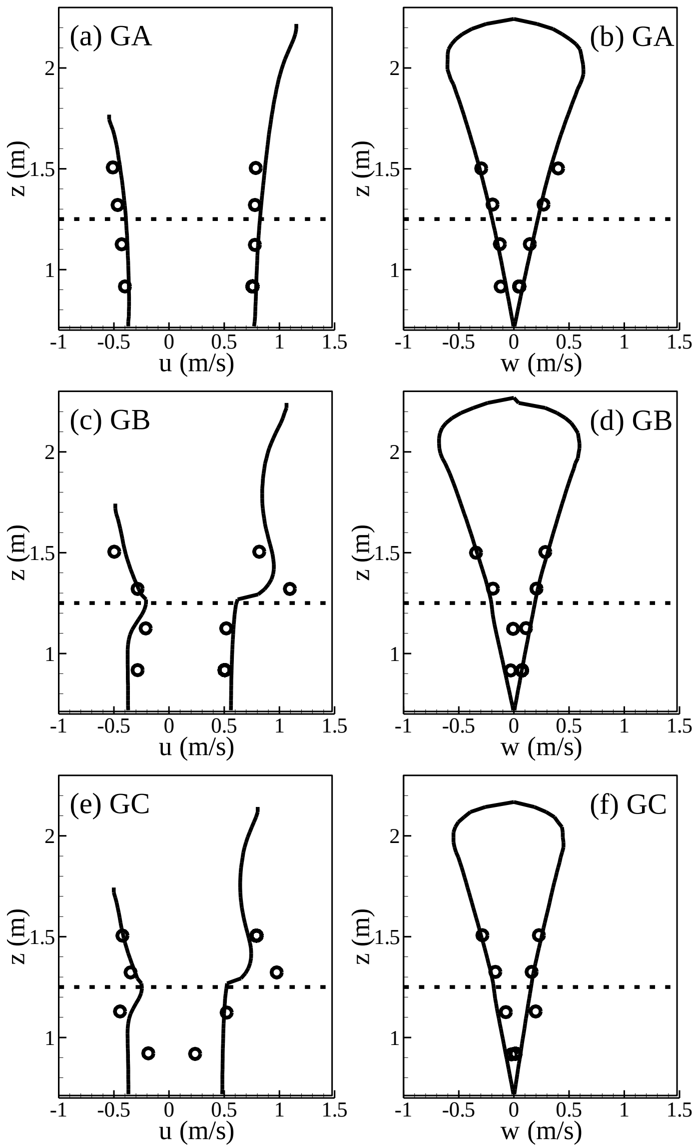
Case	Still water depth h_s (m)	Incident wave height H_i (m)	Wave period T (s)	Vegetation density N_v (stems/m^2)	Calibrated C_D
1	1.8	0.44	4.0	360	0.8
2	1.8	0.44	3.0	360	0.9
3	2.0	0.43	3.5	360	1.6
4	2.0	0.33	3.0	360	1.0
5	2.2	0.44	3.0	360	1.0
6	2.4	0.36	3.0	180	1.9

Test of 3-D RANS Model



Calculated (solid line) and Stratigaki et al. (2011) experimental (circles) wave height profiles inside the vegetation patch. *x* denotes the longitudinal distance from the upstream edge of the vegetation patch; vertical dashed lines denote the boundaries of the vegetation patch.

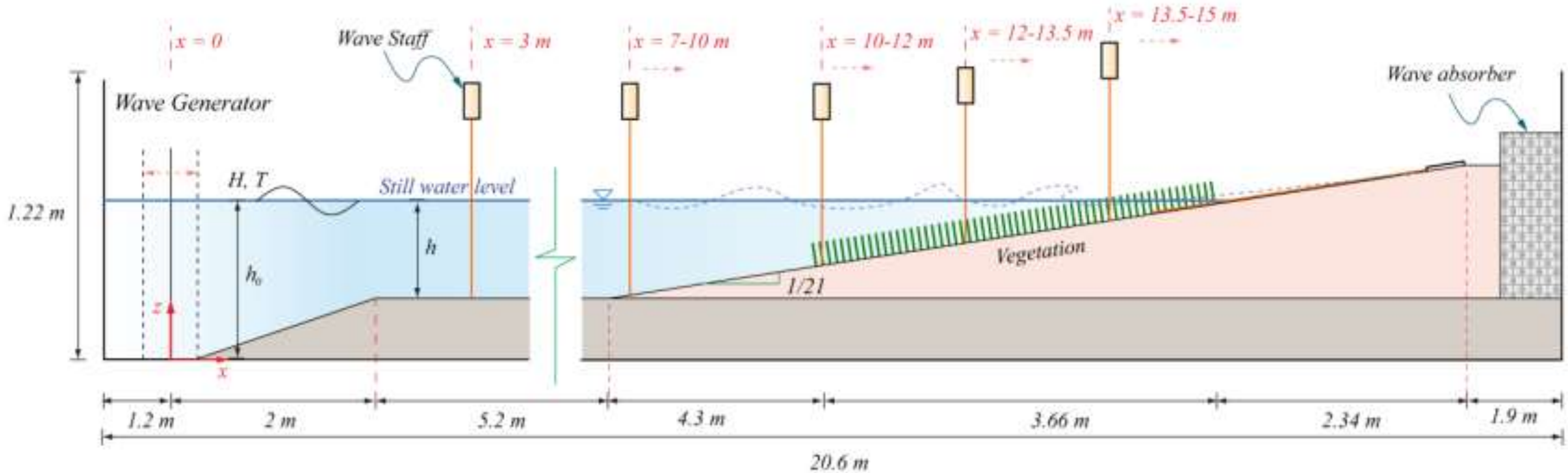
Test of 3-D RANS Model



Calculated (solid line) and Stratigaki et al. (2011) experimental (circles) vertical profiles of maximum and minimum stream-wise, *u*, and vertical, *w*, velocities for case 1; Horizontal dashed line denotes the vegetation height.

Points GA, GB, and GC are located 0.7 m upstream of the upper meadow edge, 2 m downstream of the upper meadow edge, and 2.7 m upstream of the lower meadow edge, respectively.

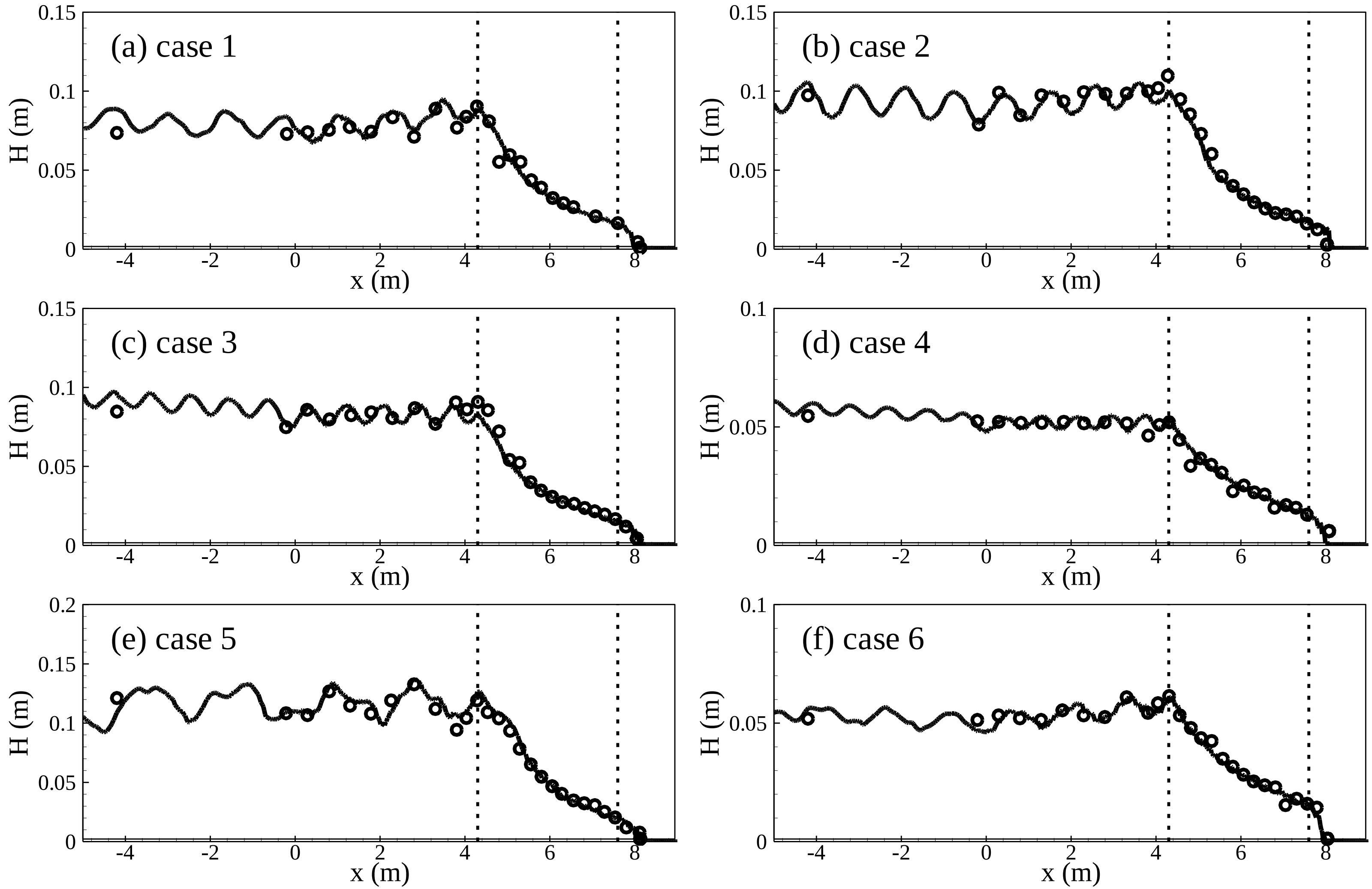
Test of 3-D RANS Model



Case	Vegetation type	Still water depth h_s (m)	Incident wave height H_i (m)	Wave period T (s)	Calibrated C_D
1	rigid	0.4	0.0757	1.6	1.7
2	rigid	0.4	0.0931	1.4	1.7
3	rigid	0.4	0.0873	1.2	1.7
4	rigid	0.4	0.0551	1.2	1.7
5	rigid	0.4	0.1200	2.4	1.7
6	rigid	0.4	0.0533	1.8	1.7
7	flexible	0.4	0.0757	1.6	1.0
8	flexible	0.4	0.0931	1.4	1.0
9	flexible	0.4	0.0873	1.2	1.3
10	flexible	0.4	0.0551	1.2	1.4
11	flexible	0.4	0.1200	2.4	1.1
12	flexible	0.4	0.0533	1.8	1.2

Experimental runs of NSL experiments over sloping bed tested by the present model

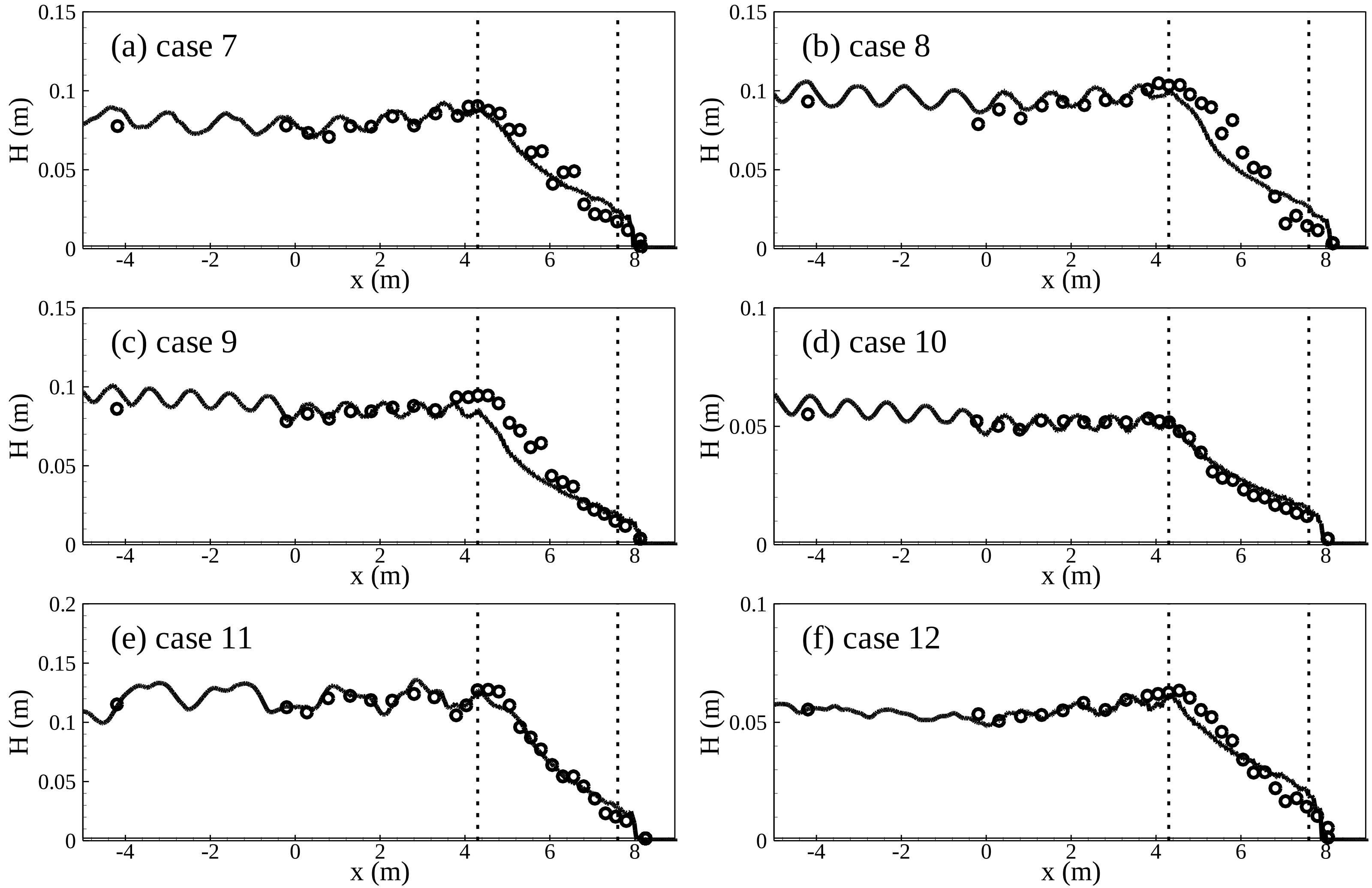
Test of 3-D RANS Model



Calculated (solid line) and NSL experimental (circles) wave height profiles inside the vegetation patch for rigid vegetation and sloping bed. *x* denotes the longitudinal distance from the toe of sloping bed; vertical dashed lines denote the boundaries of the vegetation patch.

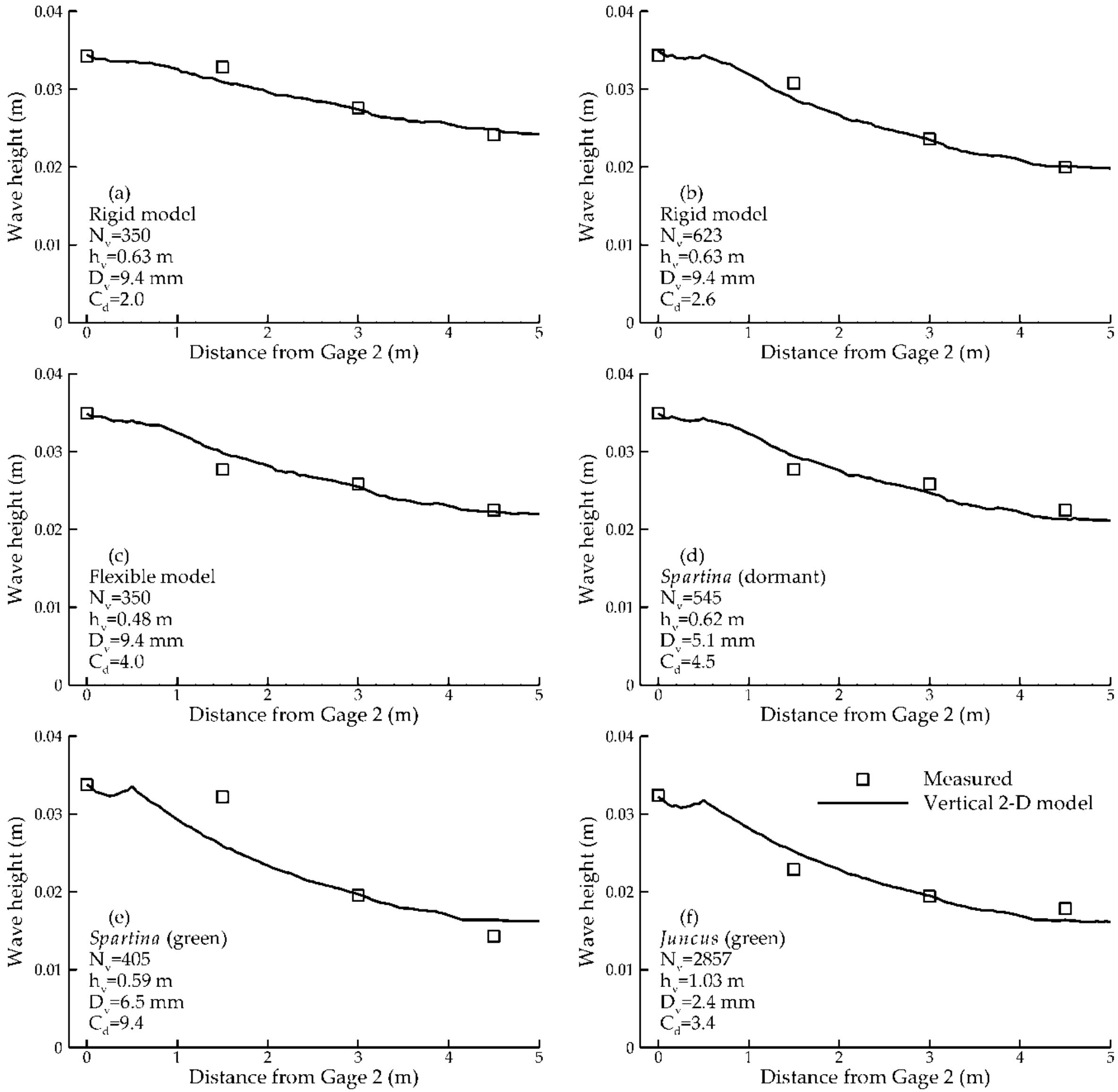
Test of 3-D RANS Model

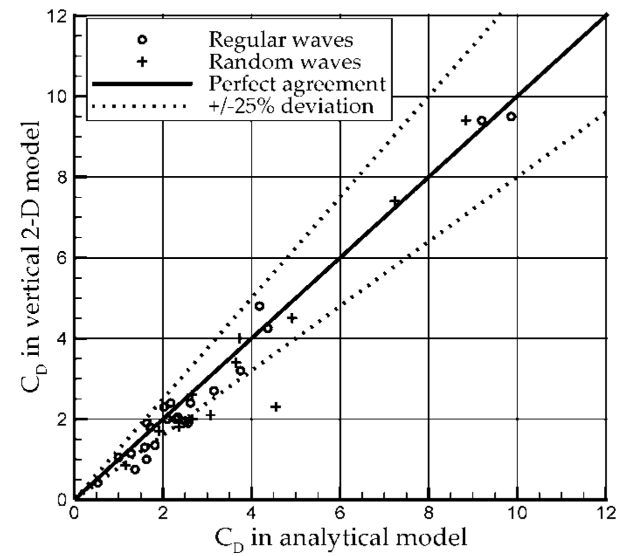
Clarkson UNIVERSITY defy convention

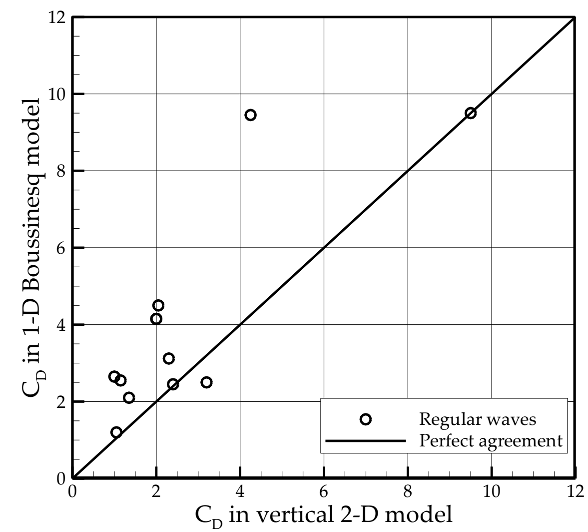


Calculated (solid line) and NSL experimental (circles) wave height profiles inside the vegetation patch for flexible vegetation and sloping bed. *x* denotes the longitudinal distance from the toe of sloping bed; vertical dashed lines denote the boundaries of the vegetation patch.

Random Waves through Vegetated Flume







Calculated by RANS model (Wu et al. 2013)

3-D Phase-Averaged Shallow Water Flow Model (Wu, 2014)

Governing equations:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

$$\frac{\partial u}{\partial t}+\frac{\partial (uu)}{\partial x}+\frac{\partial (vu)}{\partial y}+\frac{\partial (wu)}{\partial z}=-\frac{1}{\rho}\frac{\partial p_a}{\partial x}-\frac{1}{\rho}\left(\rho_0 g\frac{\partial \eta}{\partial x}+g\int_z^\eta \frac{\partial \rho}{\partial x}dz\right)$$
$$+\frac{\partial}{\partial x}\left(\nu_{tH}\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_{tH}\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_{tV}\frac{\partial u}{\partial z}\right)-\frac{1}{\rho}\frac{\partial S_{xx}}{\partial x}-\frac{1}{\rho}\frac{\partial S_{xy}}{\partial y}-\frac{1}{\rho}f_x+f_c v$$

$$\frac{\partial v}{\partial t}+\frac{\partial (uv)}{\partial x}+\frac{\partial (vv)}{\partial y}+\frac{\partial (wv)}{\partial z}=-\frac{1}{\rho}\frac{\partial p_a}{\partial y}-\frac{1}{\rho}\left(\rho_0 g\frac{\partial \eta}{\partial y}+g\int_z^\eta \frac{\partial \rho}{\partial y}dz\right)$$
$$+\frac{\partial}{\partial x}\left(\nu_{tH}\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_{tH}\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_{tV}\frac{\partial v}{\partial z}\right)-\frac{1}{\rho}\frac{\partial S_{yx}}{\partial x}-\frac{1}{\rho}\frac{\partial S_{yy}}{\partial y}-\frac{1}{\rho}f_y-f_c u$$

Clarkson UNIVERSITY defy convention

Eddy viscosity:

$$\nu_t = \sqrt{\left(l_{mV}^2 \left|\bar{S}_V\right|\right)^2 + \left(l_{mH}^2 \left|\bar{S}_H\right|\right)^2}$$

where $|S_V|$ and $|S_H|$ are shear strains in the vertical and horizontal directions; l_{mV} is the vertical mixing length: $=\kappa z(1-z/h)^{1/2}$ when $z<2h/3$ and $=2\kappa h/3^{3/2}$ when $z\geq 2h/3$; and l_{mH} is the horizontal mixing length = $\kappa \min(l, c_m h)$. Here, z is the vertical coordinate above the bed, l is the horizontal distance to the nearest solid wall, h is the flow depth, κ is the von Karman constant, and c_m is a coefficient which is set as about 0.3 in this study.

Bed shear stress

$$\tau_{bx} = \rho c_f u_b \sqrt{u_b^2 + v_b^2 + 0.5U_{wm}^2}, \quad \tau_{by} = \rho c_f v_b \sqrt{u_b^2 + v_b^2 + 0.5U_{wm}^2}$$

where u_b and v_b are the x- and y-velocities near the bed; c_f is the bed friction coefficient; and U_{wm} is the maximum orbital bottom velocity of wave.

Coupled with 2-D Spectral Wave Model (CMS-Wave)

Clarkson UNIVERSITY defy convention

Spectral wave-action balance equation (Mase et al. 2005):

$$\frac{\partial N}{\partial t}+\frac{\partial (c_x N)}{\partial x}+\frac{\partial (c_y N)}{\partial y}+\frac{\partial (c_\theta N)}{\partial \theta}=\frac{\kappa_w}{2\sigma}\left[\frac{\partial}{\partial y}\left(CC_g\cos^2\theta\frac{\partial N}{\partial y}\right)-\frac{1}{2}CC_g\cos^2\theta\frac{\partial^2 N}{\partial y^2}\right]-\varepsilon_b N-Q_v+Q$$

,

where $N = E(x,y,\sigma,\theta,t)/\sigma$; E is the spectral wave density representing the wave energy per unit water surface area per frequency interval; σ is the wave angular frequency (or intrinsic frequency); θ is the wave angle relative to the positive x-direction; C and C_g are wave celerity and group velocity, respectively; c_x, c_y, and c_θ are the characteristic velocities with respect to x, y and θ, respectively; κ_w is an empirical coefficient; ε_b is a parameter for wave breaking energy dissipation; Q_v represents the wave energy loss due to vegetation resistance; and Q includes source/sink terms of wave energy due to wind forcing, bottom friction loss, nonlinear wave-wave interaction, etc.

$$c_x = C_g\cos\theta + U \qquad c_y = C_g\sin\theta + V$$

$$c_\theta=\frac{\sigma}{\sinh 2kh}\left(\sin\theta\frac{\partial h}{\partial x}-\cos\theta\frac{\partial h}{\partial y}\right)+\cos\theta\sin\theta\frac{\partial U}{\partial x}-\cos^2\theta\frac{\partial U}{\partial y}+\sin^2\theta\frac{\partial V}{\partial x}-\sin\theta\cos\theta\frac{\partial V}{\partial y}$$

Wave Energy Dissipation by Vegetation (Mendez and Losada, 2004)

Assumptions:

(1) Linear waves

(2) Impermeable bottom

(3) Invariant Rayleigh wave height distribution

,

(4) Thornton and Guza's wave breaking criteria

(5) Without current

$$Q_v = \frac{1}{2\sqrt{\pi}} \rho C_D b_v N_v \left(\frac{kg}{2\sigma} \right)^3 \frac{\sinh^3(k\alpha h) + 3\sinh(k\alpha h)}{3k\cosh^3(kh)} H_{rms}^3$$

H_{rms} = root-mean-square wave height (m)

Total Energy Loss by Vegetation in Case of Currents and Waves Coexisted

$$Q_{tv} = \frac{1}{T}\int_0^T \int_0^{h_v} F_i u_{cwi}\, dzdt \approx \frac{1}{T}\int_0^T \int_0^{h_v} F_x u_{cw}\, dzdt = \frac{1}{T}\int_0^T \int_0^{h_v} \frac{1}{2}\rho C_D N_v b_v u_{cw}^3\, dzdt$$

Consider $u_{cw}=u_c+u_w$

$$Q_{tv} = \frac{1}{T}\int_0^T \int_0^{h_v} \frac{1}{2}\rho C_D N_v b_v u_c^3\, dzdt + \frac{1}{T}\int_0^T \int_0^{h_v} \frac{3}{2}\rho C_D N_v b_v u_c u_w^2\, dzdt + \frac{1}{T}\int_0^T \int_0^{h_v} \frac{1}{2}\rho C_D N_v b_v u_w^3\, dzdt$$

Due to current

Related to both current and waves

Due to waves

Considered thru drag force in the momentum equations

Considered thru wave energy dissipation in wave-action balance equation

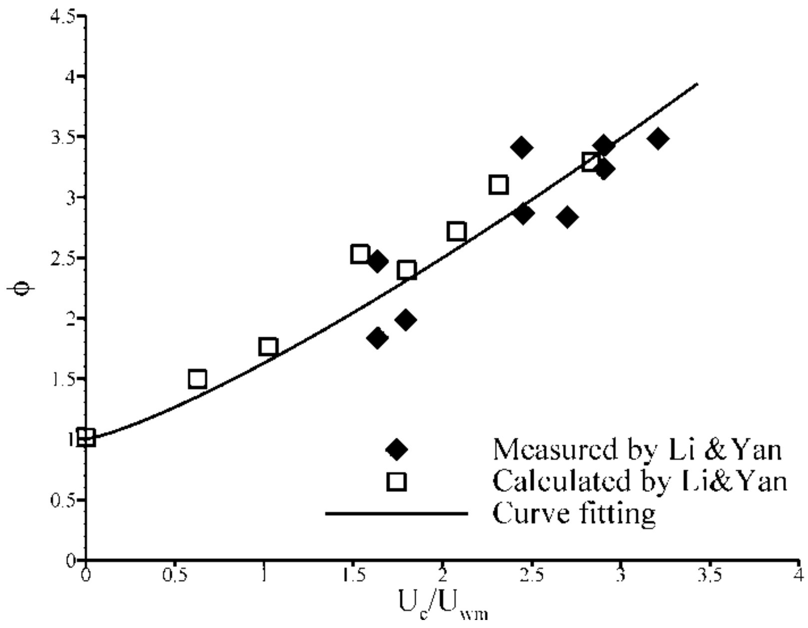
Wave Dissipation by Vegetation in Case of Currents and Waves Coexisted

The method of Mendez and Losada is modified as

$$Q_v = \frac{1}{\sigma 2\sqrt{\pi}} \rho C_D \phi b_v N_v \left(\frac{kg}{2\sigma}\right)^3 \frac{\sinh^3(kh_v) + 3\sinh(kh_v)}{3k\cosh^3(kh)} H_{rms}^3$$

by introducing a correction factor:

$$\phi = 1 + a\left(\frac{U_c}{U_{wm}}\right)^m$$



where U_c is the current velocity and U_{wm} is the maximum orbital bottom velocity of wave. m=1.25 and a=0.63, which are approximated using Li and Yan's (2007) data.

Wave Radiation Stress

Formula of Mellor (2008)

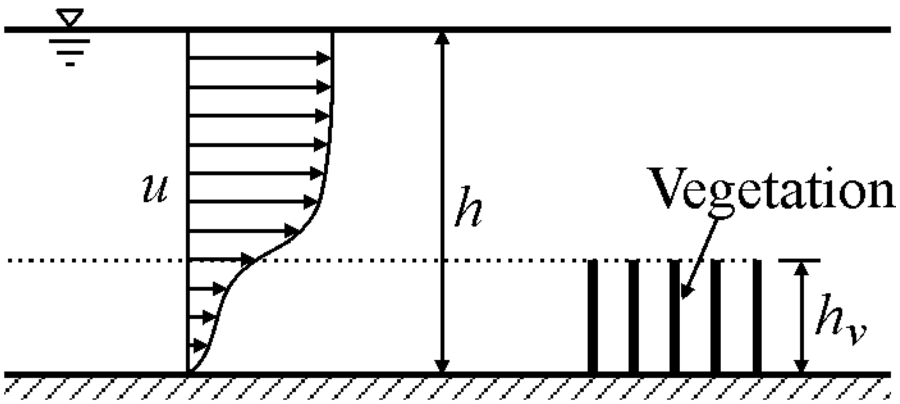
$$S_{ij} = \int_0^\infty \int_{-\pi}^{\pi} \left\{ k(f)E(f,\theta)\left[\frac{k_i(f)k_j(f)}{k(f)^2} \frac{\cosh^2 k(h+z')}{\sinh kD \cosh kD} - \delta_{ij} \frac{\sinh^2 k(h+z')}{\sinh kD \cosh kD} \right] + \delta_{ij} E_D(f,\theta) \right\} d\theta df$$

where E is the wave energy, k is the wave number, θ is the angle of wave propagation to the onshore direction, f is the wave frequency, h is the still water depth, D is the total water depth, z' is the vertical coordinate referred to the still water level, and E_D is a modified Dirac delta function which is 0 if $z \neq \eta$ and has the following quantity:

$$\int_{-h}^{\eta+} E_D dz = E/2$$

Flow in Channel with Submerged Vegetation

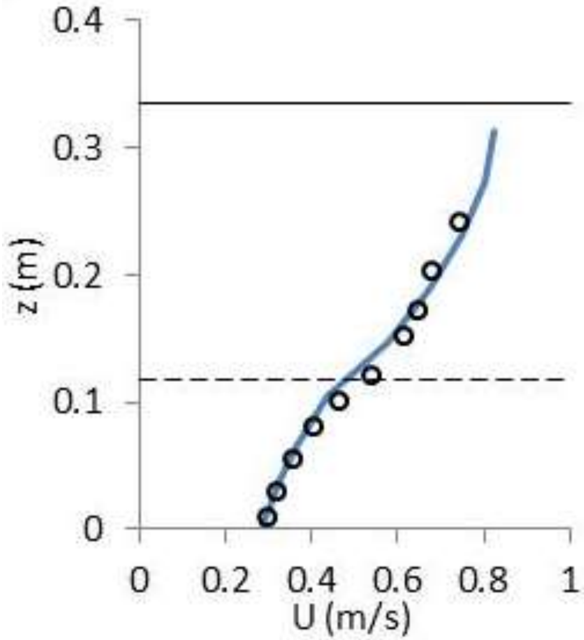
Experiment by Lopaz and Garcia (1997)

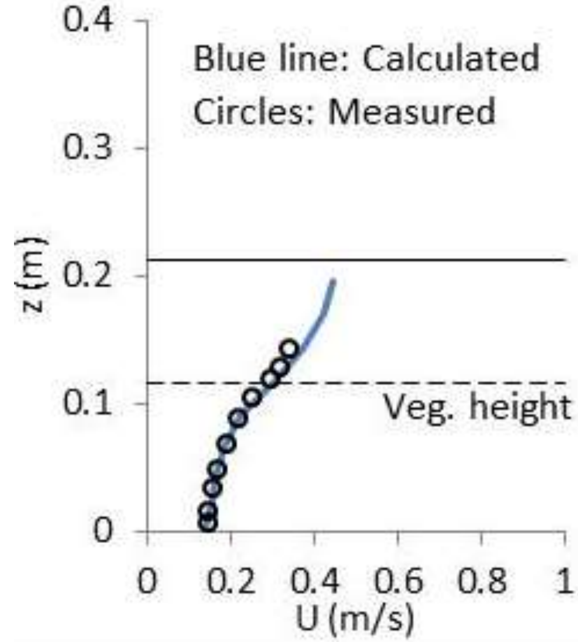


Rigid: Wooden cylinders
Flexible: Plastic drinking straws

Exp. No.	Discharge (m^3/s)	Flow depth (m)	Bed slope	Vegetation type	N_vD_v (1/m)	Vegetation height (m)	Drag coefficient
1	0.179	0.335	0.0036	Rigid	1.09	0.1175	1.1
9	0.058	0.214	0.0036	Rigid	2.46	0.1175	1.1
13	0.179	0.368	0.0036	Flexible	1.09	0.152	1.2
17	0.078	0.279	0.0036	Flexible	2.46	0.16	1.3

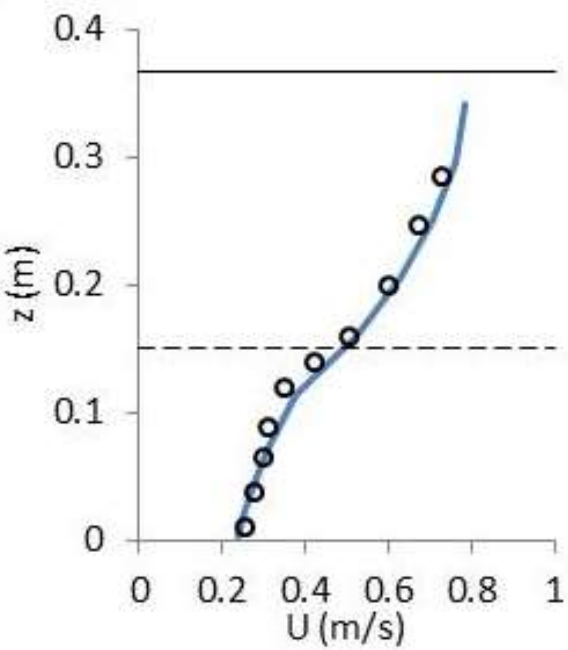
No. 1

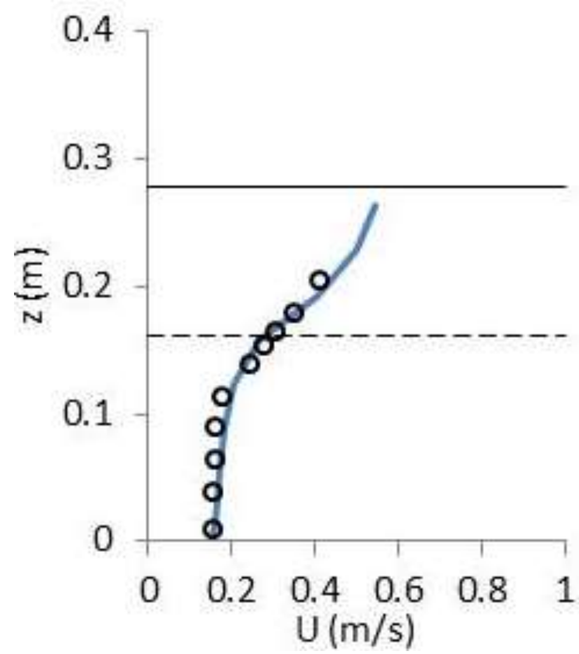




No. 9

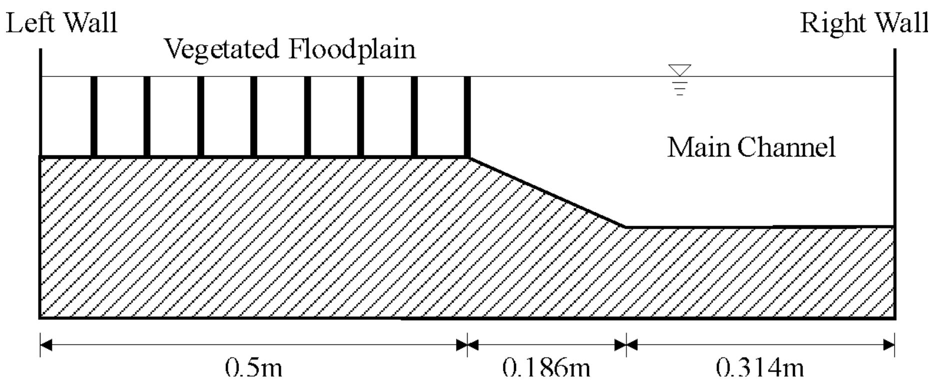
No. 13





No. 17

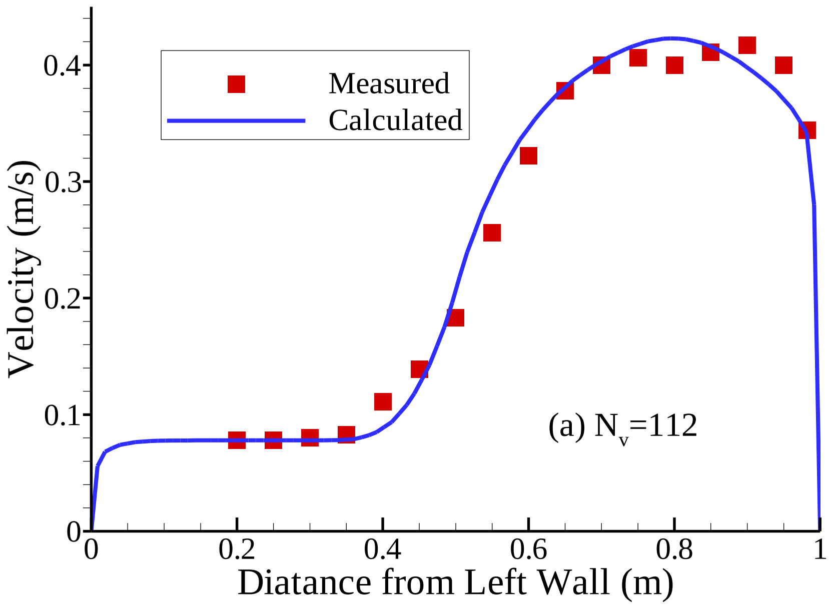
Flow in Compound Channel with Vegetated Floodplain

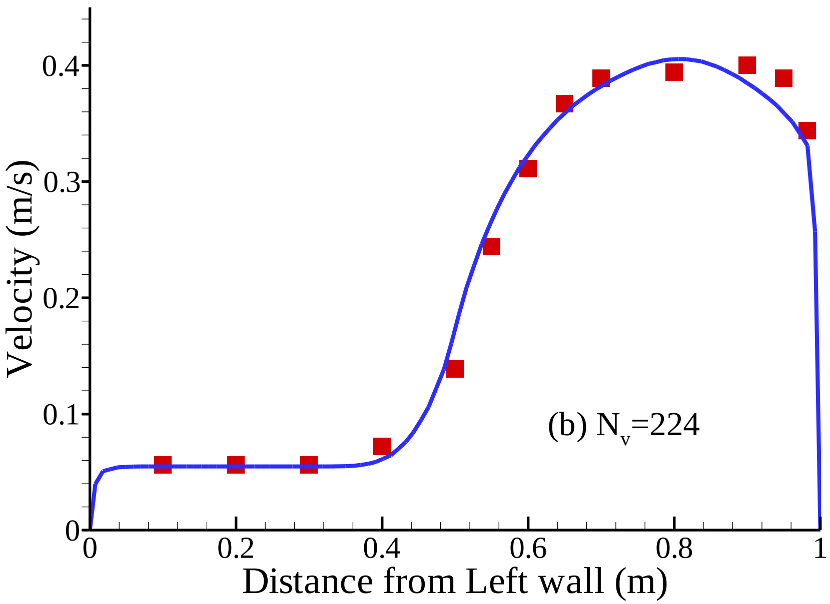


Experiment by Pasche and Rouve (1985)

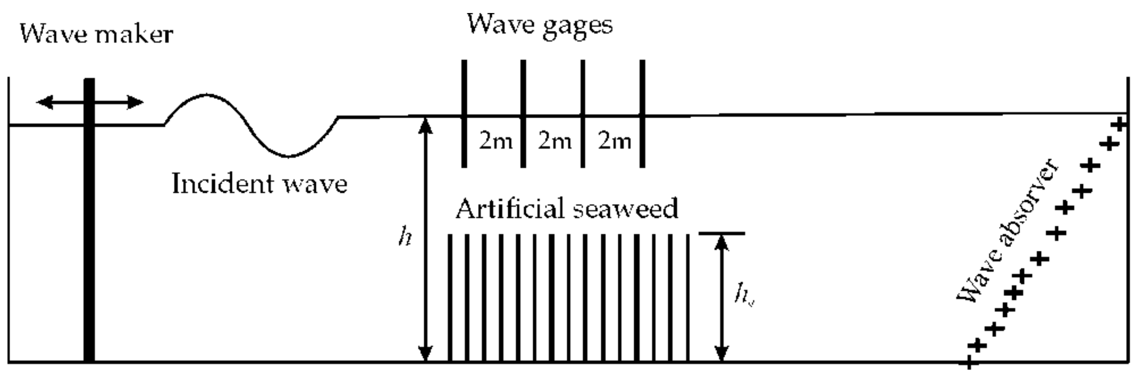
Vegetation: Rigid wooden rods

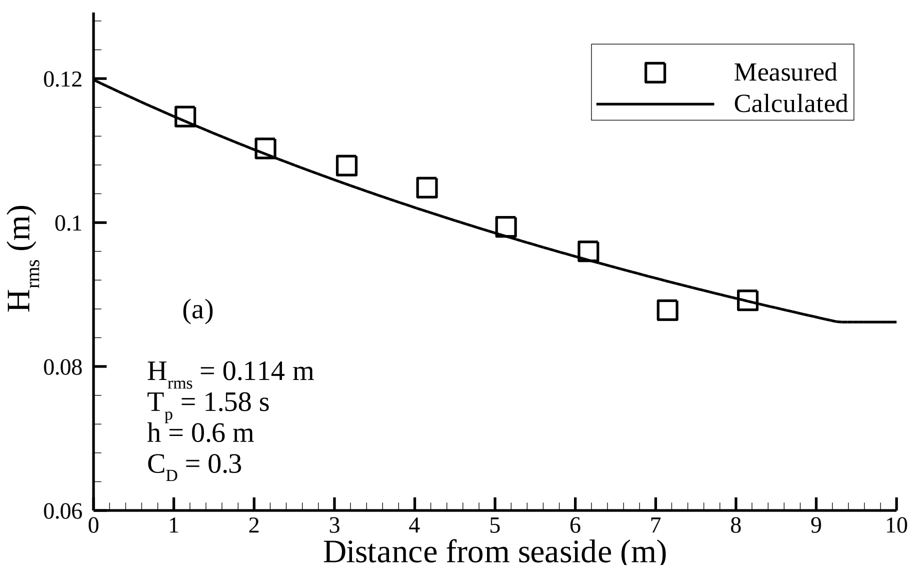
Exp. No.	Discharge (m³/s)	Bed slope	Vegetation type	N_v (1/m²)	Vegetation diameter (m)	C_D
1	0.0365	0.001	Rigid	112	0.012	0.45
2	0.0345	0.0005	Rigid	224	0.012	0.55

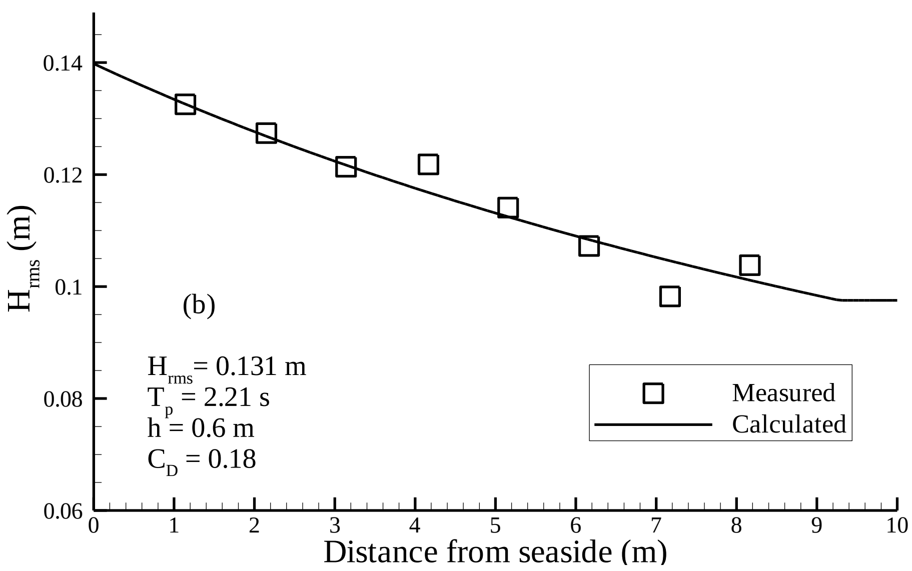




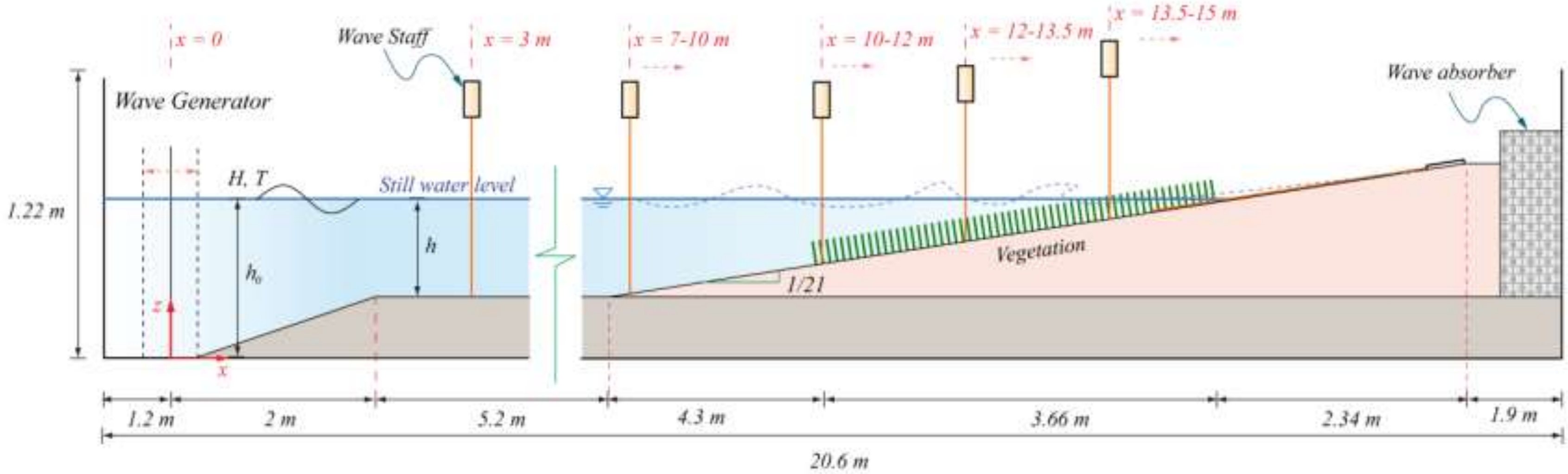
Random Waves through Vegetated Flume

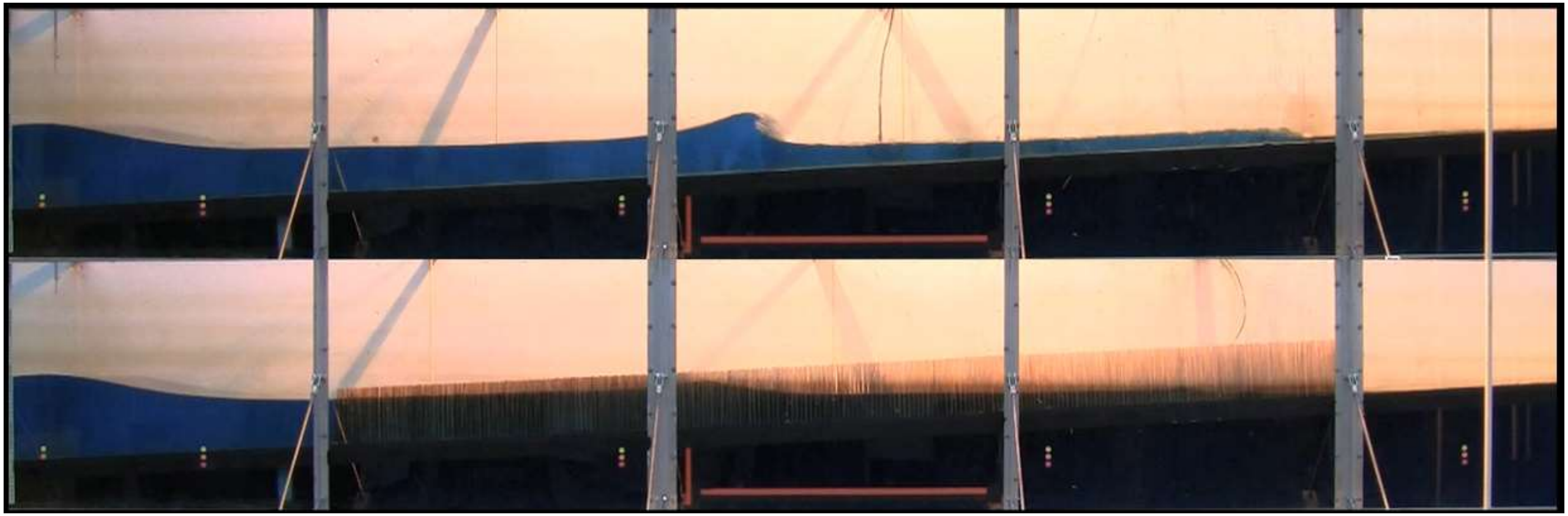


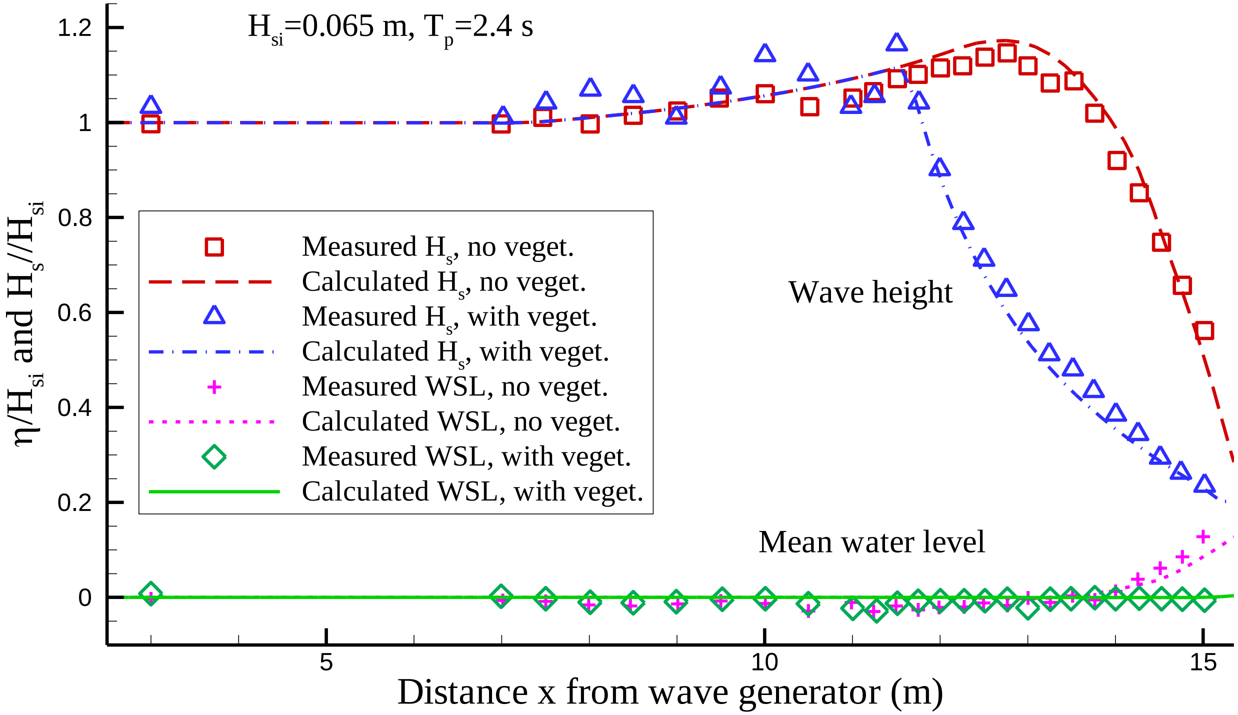




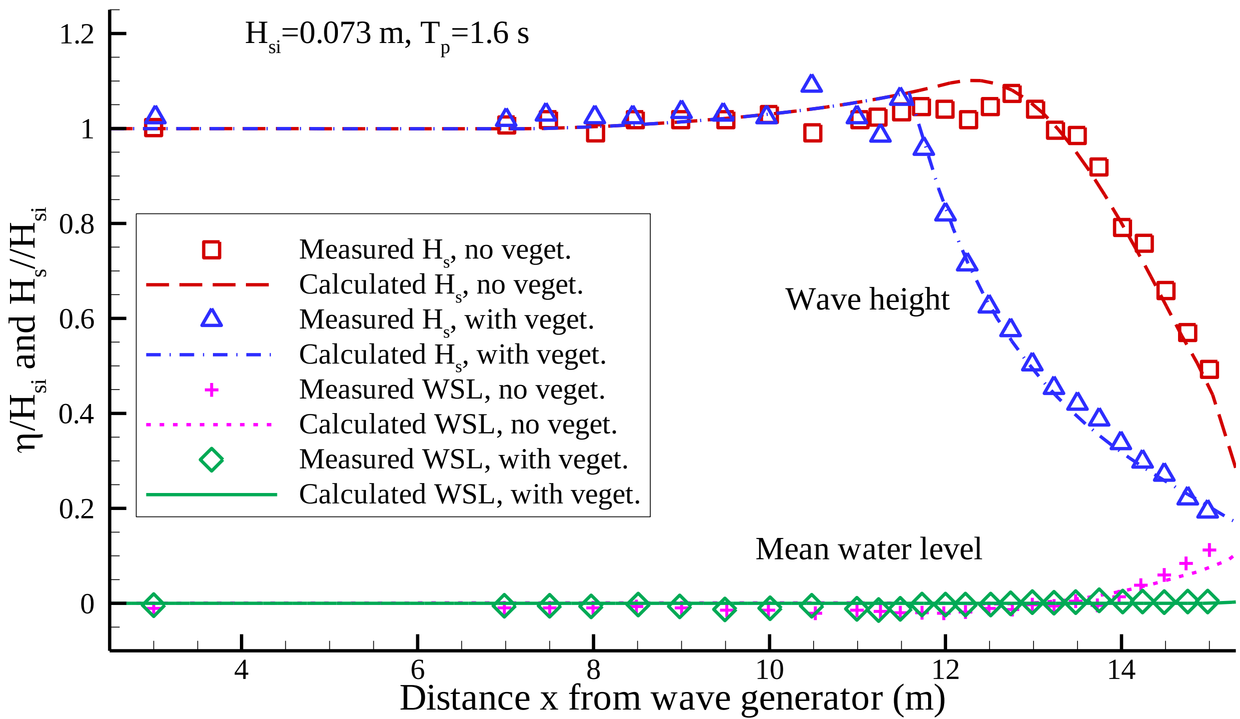
Side View of Wave Runup







H_si=0.065 m, T_p=2.4 s
Measured H_s, no veget.
Calculated H_s, no veget.
Measured H_s, with veget.
Calculated H_s, with veget.
Measured WSL, no veget.
Calculated WSL, no veget.
Measured WSL, with veget.
Calculated WSL, with veget.
Wave height
Mean water level
η/H_si and H_s/H_si
Distance x from wave generator (m)



H_si=0.073 m, T_p=1.6 s
Measured H_s, no veget.
Calculated H_s, no veget.
Measured H_s, with veget.
Calculated H_s, with veget.
Measured WSL, no veget.
Calculated WSL, no veget.
Measured WSL, with veget.
Calculated WSL, with veget.
Wave height
Mean water level
η/H_si and H_s/H_si
Distance x from wave generator (m)

Summary

- Effects of vegetation have been extensively investigated by field and lab experiments and numerical modeling.
- A large set of data have been collected and used to analyze the vegetation drag coefficient and wave energy dissipation.
- A series of numerical models have been developed to quantify the wave and surge reduction.
- The models have been tested using a number of laboratory experiments.
- The drag and inertia forces of vegetation are included in the 2D/3D momentum equations and the wave energy loss due to vegetation resistance is in the wave-action balance equation.
- The interaction between currents and waves is considered through a correction factor in the wave dissipation rate.

Publications Related

W. Wu, Y. Ozeren, D. Wren, Q. Chen, G. Zhang, M. Holland, Y. Ding, S.N. Kuiry, M. Zhang, R. Jadhav, J. Chatagnier, Y. Chen, and L. Gordji (2011). Investigation of surge and wave reduction by vegetation, Phase I Report for SERRI Project No. 80037, The University of Mississippi, MS, p. 315, with p. 465 Appendices.

W. Wu, Y. Ozeren, D. Wren, Q. Chen, G. Zhang, M. Holland, R. Marsooli, Q. Lin, R. Jadhav, K.R. Parker, H. Pant, J. Bouanchaud, and Y. Chen (2012). Investigation of surge and wave reduction by vegetation (Phase II) —Interaction of Hydrodynamics, Vegetation and Soil, Phase II Report for SERRI Project No. 80037, The University of Mississippi, MS, p. 395.

W. Wu and R. Marsooli (2012). "A depth-averaged 2-D shallow water model for breaking and non-breaking long waves affected by rigid vegetation." Journal of Hydraulic Research, IAHR, 50(6), 558–575.

W. Wu, M. Zhang, Y. Ozeren, and D. Wren (2013). "Analysis of vegetation effect on waves using a vertical 2-D RANS model." Journal of Coastal Research, 29(2), 383–397.

W. Wu (2014). "A 3-D phase-averaged model for shallow water flow with waves in vegetated water." Ocean Dynamics, 64(7), 1061-1071.

R. Marsooli and W. Wu (2014). "Numerical investigation of wave attenuation by vegetation using a 3D RANS model." Advances in Water Resources, Accepted for publication.

Y. Ozeren, D. Wren, and W. Wu (2014). "Experimental investigation of wave attenuation through model and live vegetation." Journal of Waterway, Port, Coastal, and Ocean Engineering (ASCE), published online, DOI: 10.1061/(ASCE)WW.1943-5460.0000251.