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The State of the Art and Science of Coastal Engineering

Observation of Nearshore Wave-Wave Interaction Using UAV

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Infragravity Wave

Nearshore wave-wave interaction develops long wave called as "**infragravity wave**".

- ✓ Enlarge the damage caused by stormy waves.
  (e. g., Haiyan in Philippines, 2013; Irma in U.S.A., 2017)
- ✓ Give significant impacts on morphology change.
  (e.g. Russell, [1993]; Roelvink et al., [2009])

How They Develop??

- ✓ Change of radiation stress by wave group (Longuet-Higgins and stuwart, [1962]).
- ✓ Oscillation of wave breaking points (Symonds et al., [1982]).

How They dissipate??

- ✓ Energy transfer to the shorter waves (Henderson, et al., [2006]).
- ✓ Infragravity wave also cause breaking (Battjes et al., [2004]).

To understand the detail of the infragravity wave dynamics, it is important to observe real wave fields with high resolution in time and space.

Research Purpose

To deal with the problem….

UAV technology (Unmanned Aerial Vehicle)

⇒made it easy to obtain aerial photos/videos.

This technology has been applied to coastal researches these days.

(e. g., Mancini *et al*., [2013]; Matsuba and Sato, [2018])

Numerical Simulation

⇒We can reproduce wave fields in the field.

Previous study showed reproduced wave field agrees well with the observation and can be used to compliment field observation.

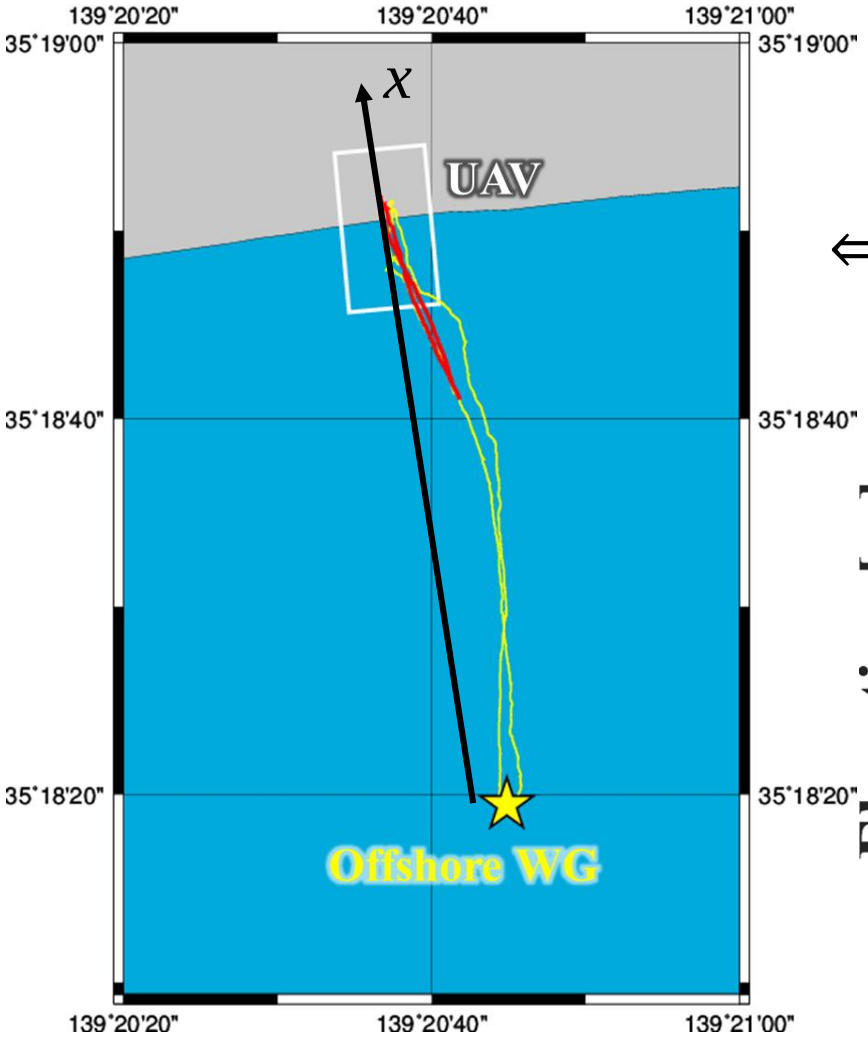
(e. g., Rijnsdorp, et al.[2015]; Shimozono, et al. [2015])

Purpose

To analyze the process of the infragravity wave development with field observation using UAV technology and with numerical simulation to reproduce the wave fields in detail

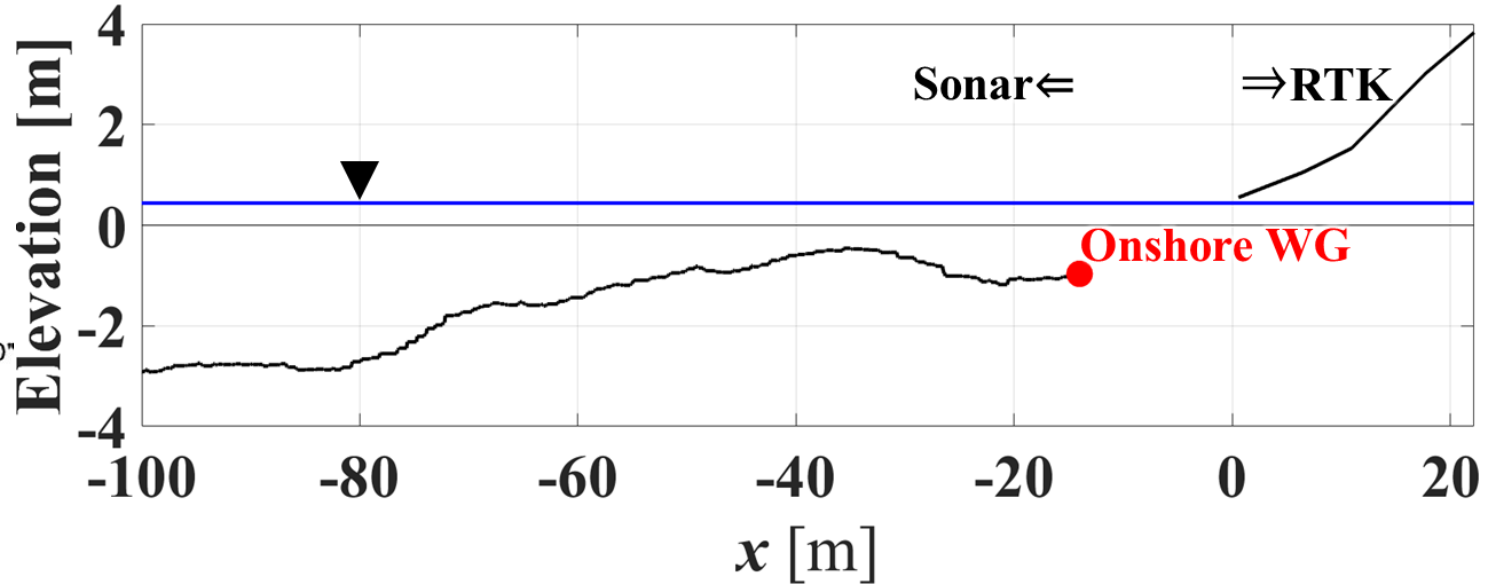
Field Observation

On Hiratsuka Coast, Japan, at Jan 28th 2017.
UAV video shooting, bathymetry survey using a fish finder, wave gauge deployment.



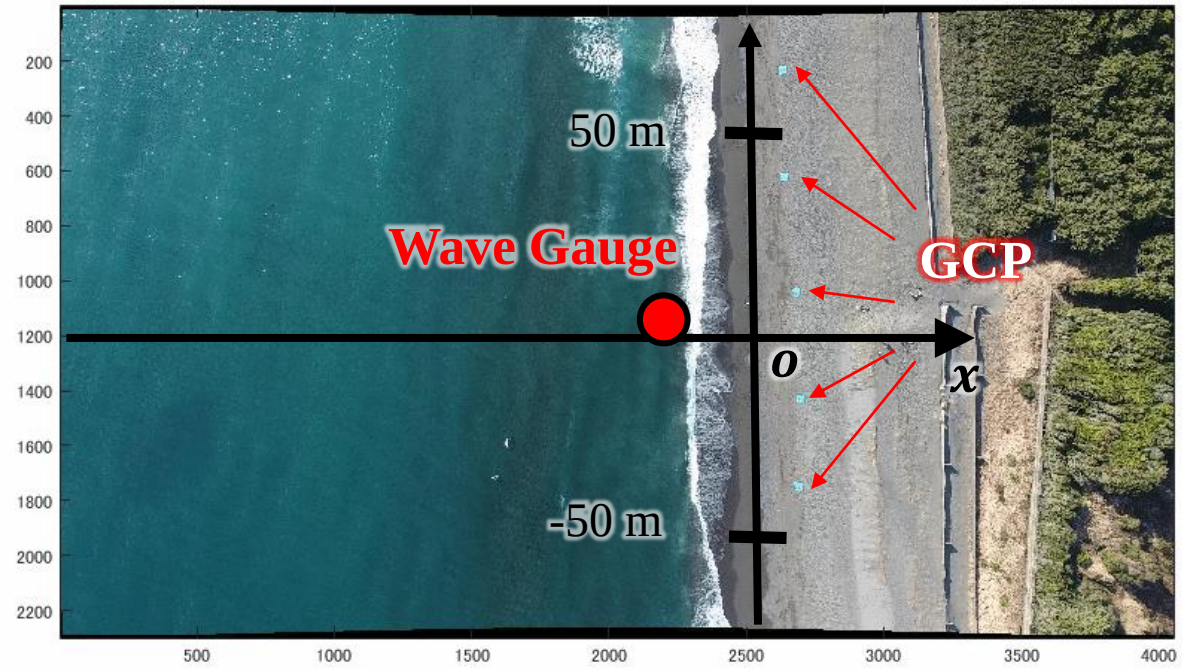
⇐ Overview of the field survey

⇩ Measured cross-shore profile



UAV Video Shooting

Name	DJI PHANTOM4
Flight time	25 min
Image Resolution	4000 × 3000
Video Resolution	3840 × 2160

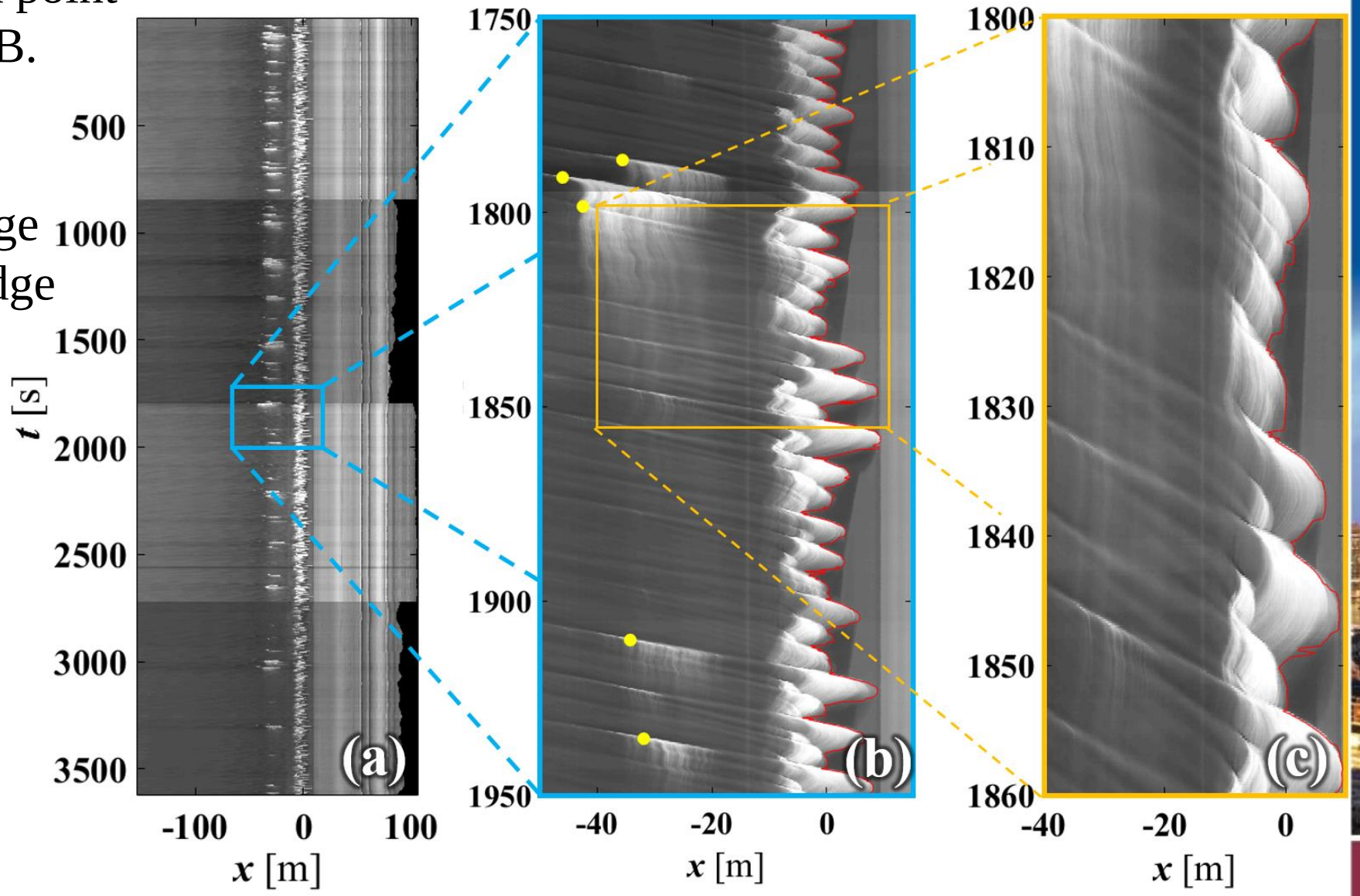


- ✓ We used two UAVs alternately and took almost 1 hour video at a height of 150 m.
- ✓ Some blue sheets were deployed alongshore, which are used as the ground control points. Based on these sheets, each video frame was rotated.

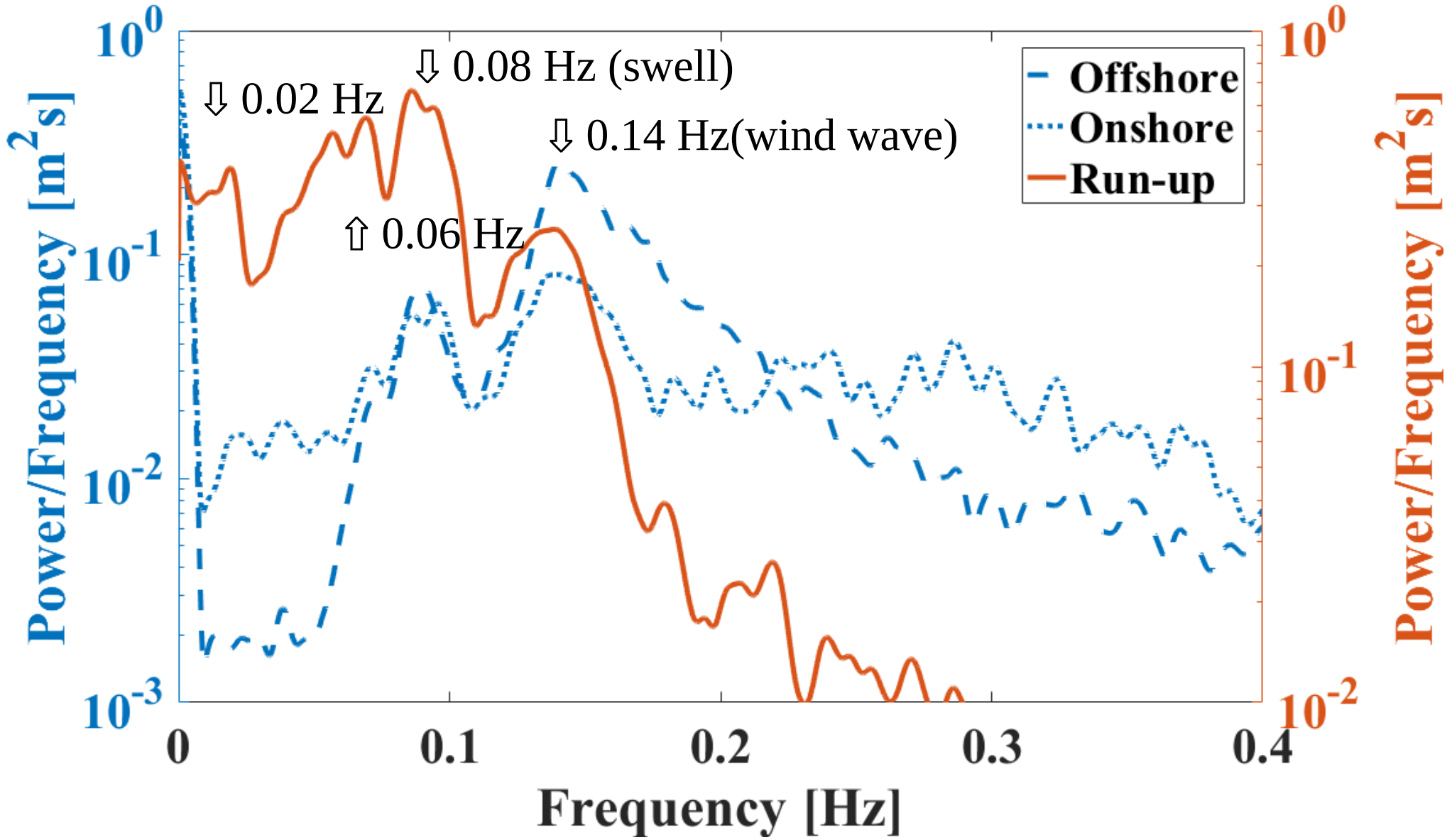
Time Stack Image of Cross-shore Direction

The brightness at each point was calculated by RGB.

From this time stack image, shoreline change was extracted using edge detection technique.



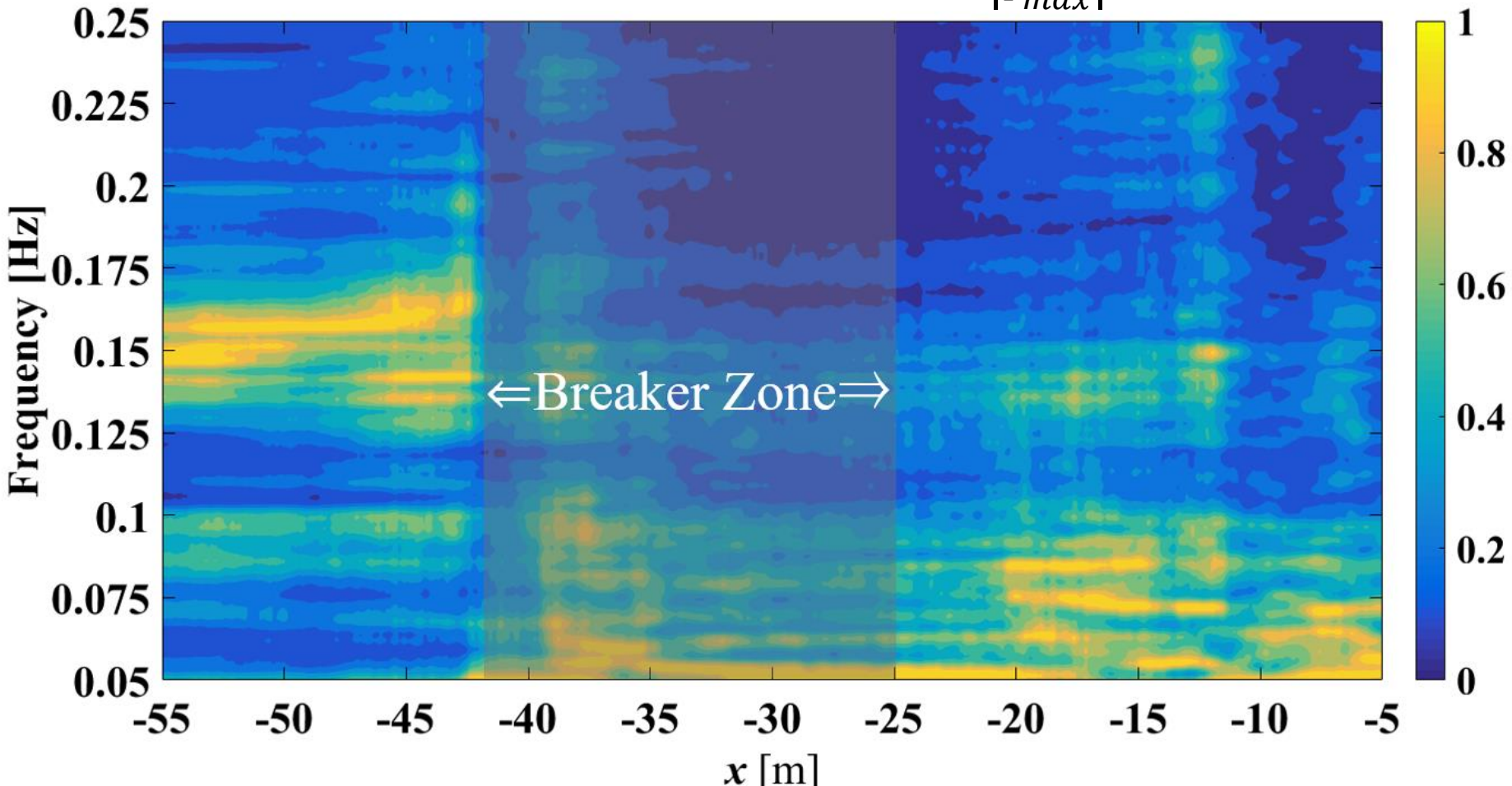
Measured Power Spectra



Normalized Power Spectra Estimated by Brightness

Spatial distribution of power spectra was also estimated by brightness change.
It is normalized by the maximum at each point.

$$A_f = \frac{|P_f|}{|P_{max}|}$$ (P: power spectra of the brightness)



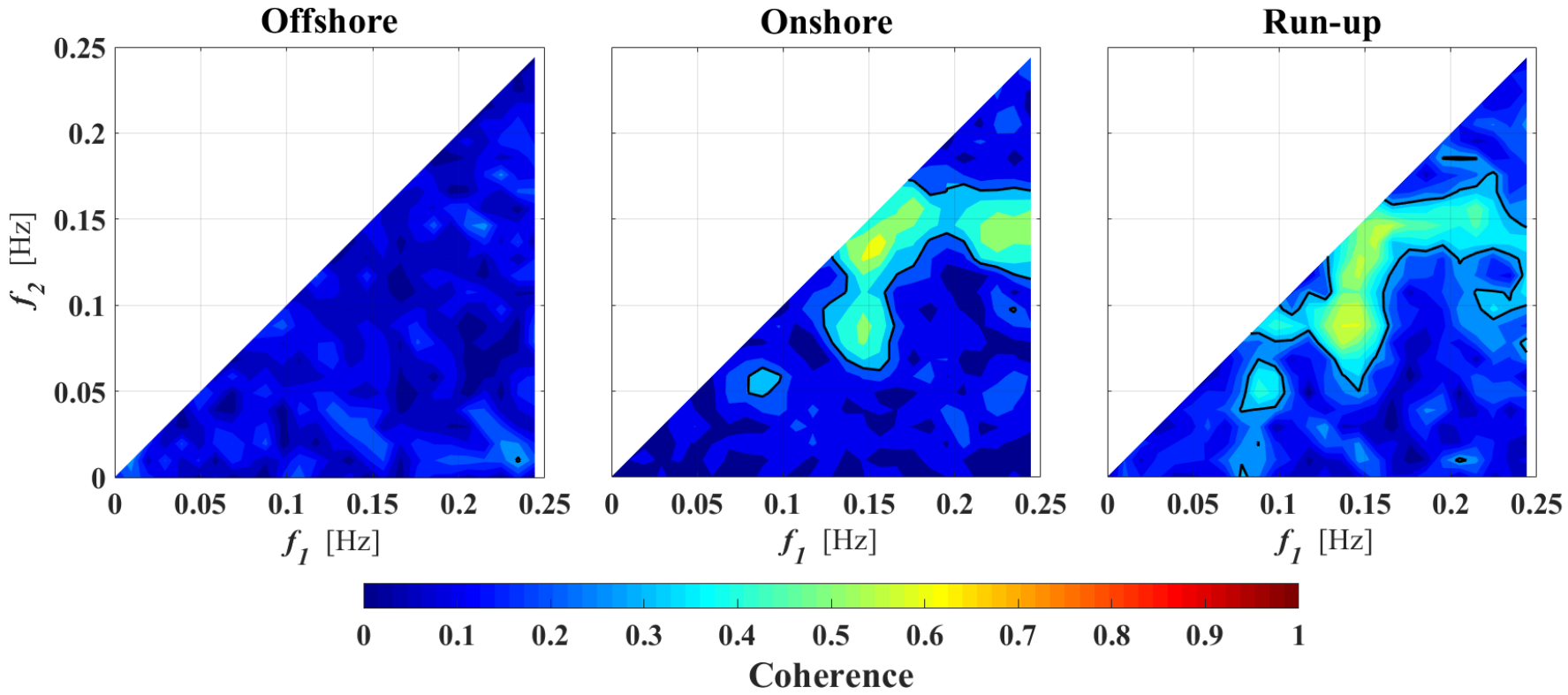
Bicoherence

For the triad frequency components, (f_1, f_2, f_3), which satisfies $f_1 + f_2 = f_3$

$$\text{Bicoherence}: \quad b(f_1, f_2) = \frac{\left|E\left[\langle X\rangle_{f_1}\langle X\rangle_{f_2}\langle X\rangle^*_{f_3}\right]\right|}{\left(E\left[\left|\langle X\rangle_{f_1}\langle X\rangle_{f_2}\right|^2\right]E\left[\left|\langle X\rangle_{f_3}\right|^2\right]\right)^{\frac{1}{2}}}$$

where $\langle X\rangle_f$ indicates the complex Fourier series amplitude of signal X.

(Hasselman, *et al.*, 1973, Kim and Powers, 1979)



Numerical Model

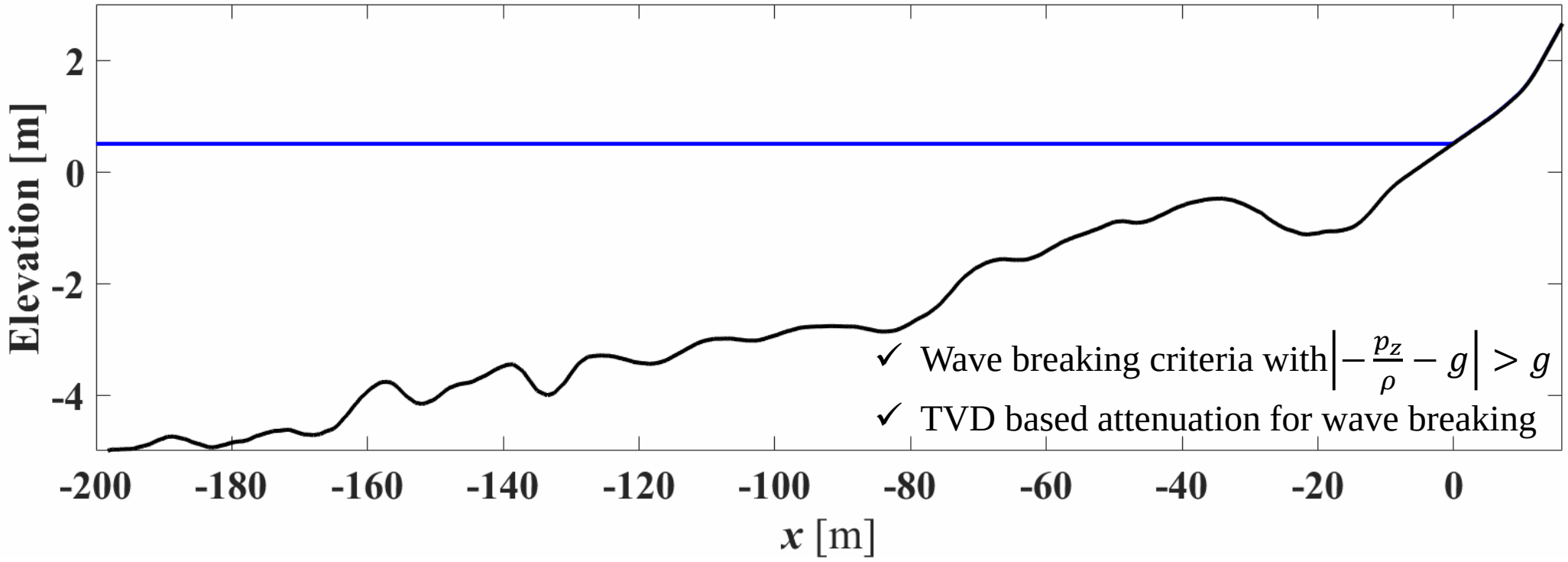
Governing Equations: 1D fully nonlinear dispersive model.

$$d_t + (du)_x = 0$$

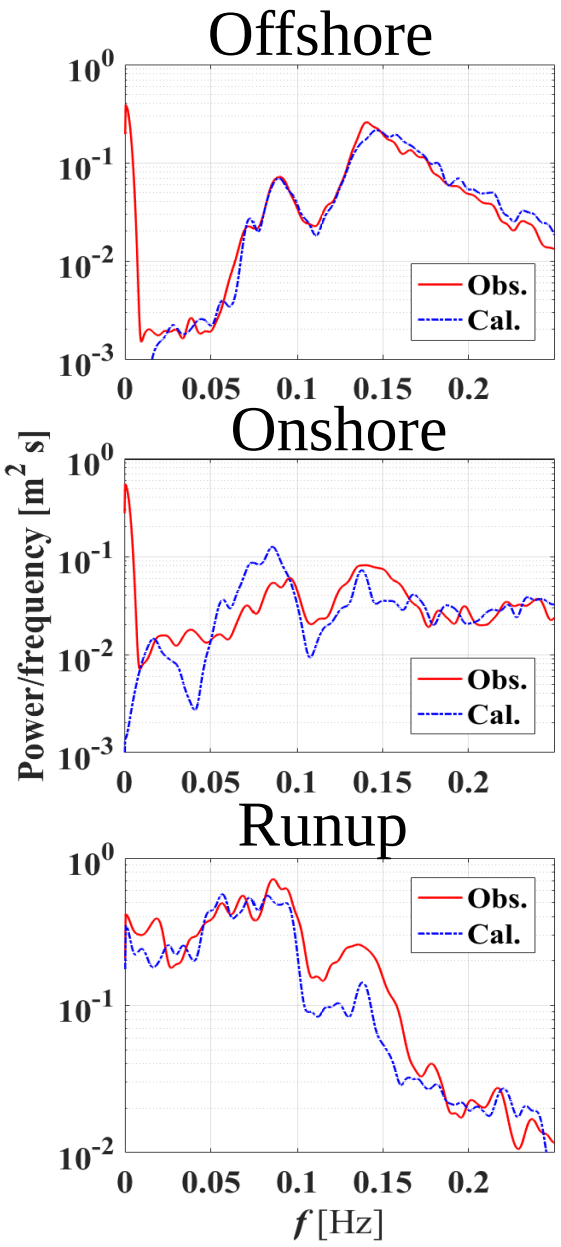
$$d\left(\Gamma_0 - \gamma d^2 \Gamma_{0xx}\right) = \left(\frac{d^3}{3}\Gamma_1 - \frac{d^2}{2}\Gamma_2\right)_x + z_{bx}\left(\frac{d^2}{2}\Gamma_1 - D\Gamma_2\right) + F_{fr}$$

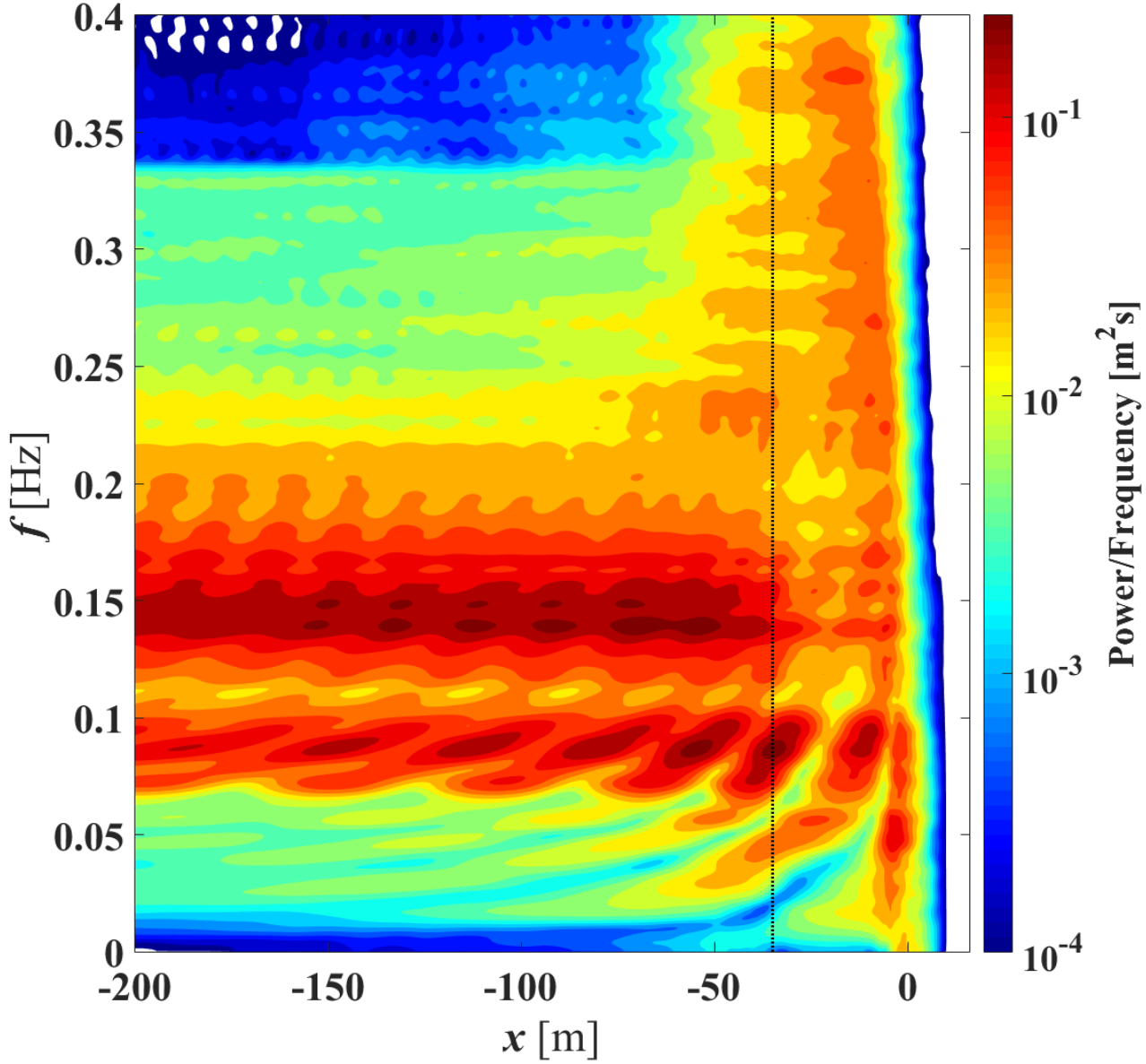
$$\begin{cases} \Gamma_0 = u_t + uu_x + g\eta_x \\ \Gamma_1 = u_{tx} + uu_{xx} - u_x^2 \\ \Gamma_2 = z_{bx}(u_t + uu_x) + z_{bxx}u^2 \\ F_{fr} = -\dfrac{gn^2 u|u|}{d^{\frac{1}{3}}} \end{cases}$$

(Shimozono, et al. 2015)



Modeled Power spectra





Energy balance equation

Henderson, et al. (2006) derived the energy balance equation for long waves including nonlinear interaction effects.

$$\frac{\partial F_f}{\partial x} = W_f - D_f$$

$$\begin{cases} F_f = F_{L_f} + F_{NL_f} = hgC_f(\eta, u) + gC_f(\eta, u'\eta') \\ W_f = -C_f\left(\frac{\partial}{\partial x}\left(hu'^2 + \frac{1}{2}g\eta'^2\right), u\right) \\ D_f = c_D\langle |u| u_{IG}^2 \rangle_f \end{cases}$$

(Rijnsdorp, et al., 2015)

Under assumptions with

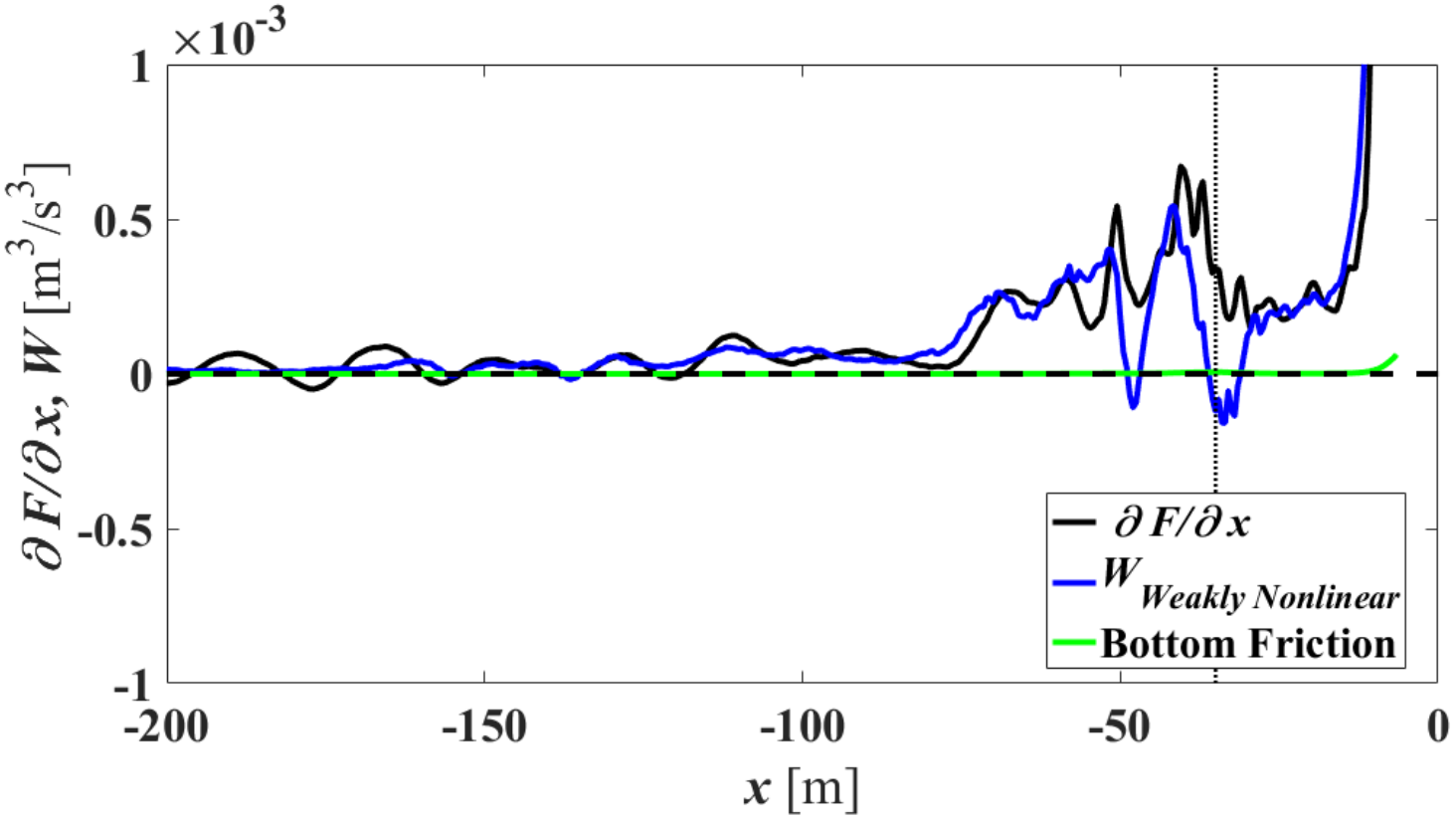
1. Satisfy long wave condition.
2. **Weakly nonlinear interaction**
3. Quasi-steady state

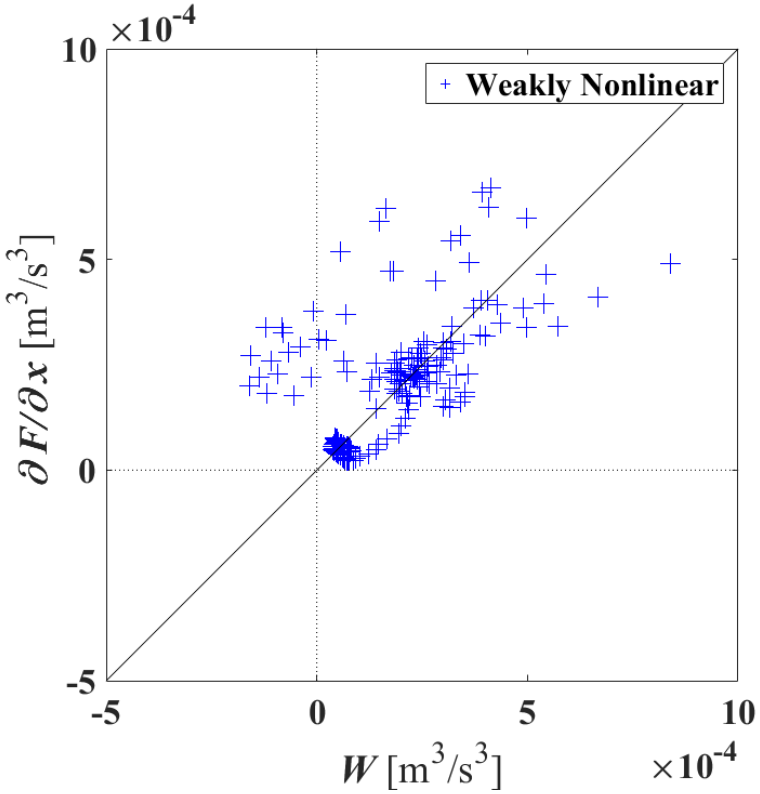
Energy balance

Calculated energy flux and energy transfer did not balance near the sand bar, and energy transfer term seemed to be underestimated.

⇒Several previous studies showed almost same results in observation and also in numerical calculation

(e. g., Henderson, et al.[2006]; Fiedler, et al.[2015]; Rijnsdorp, et al.[2015]; and so on)



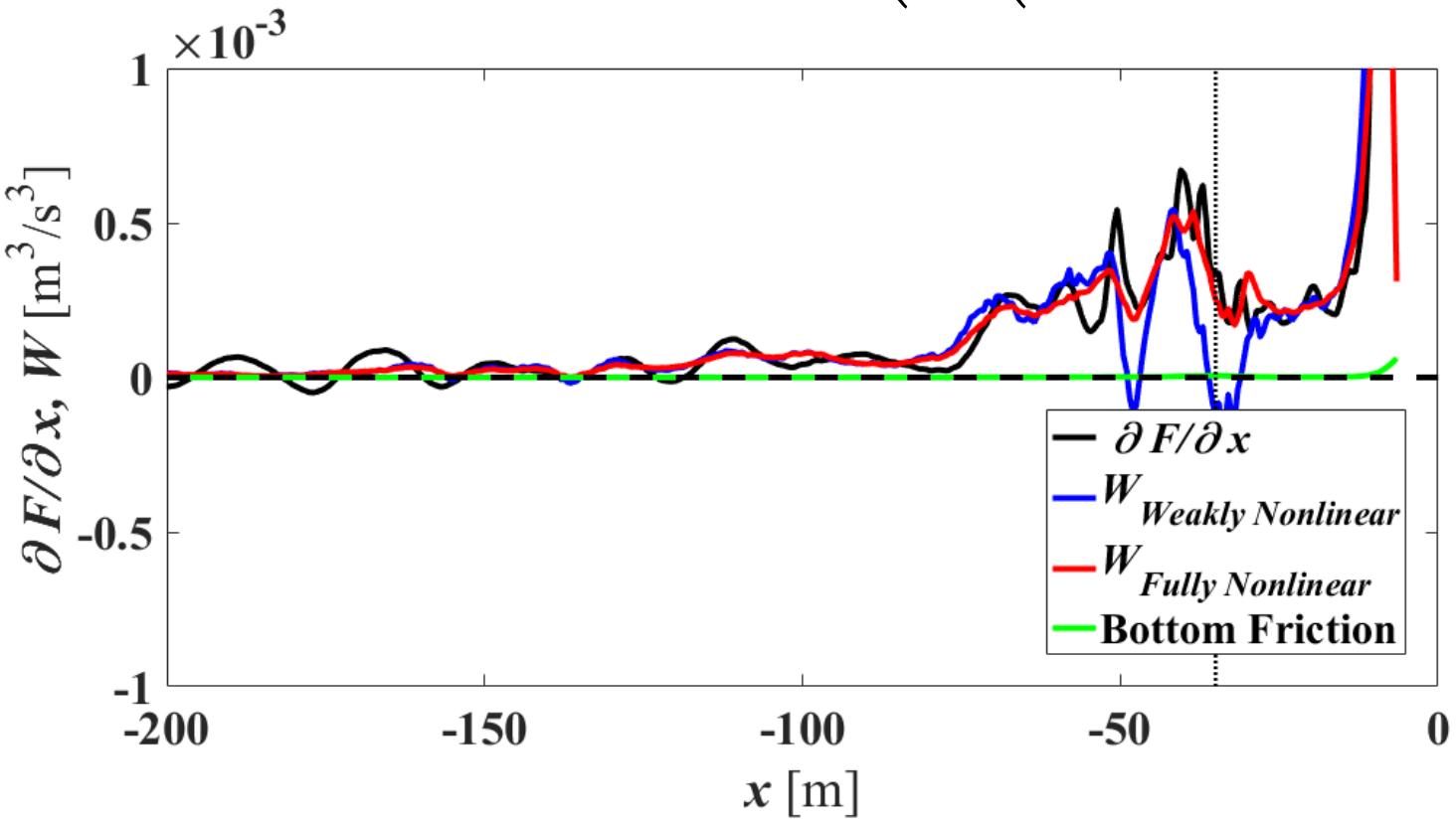


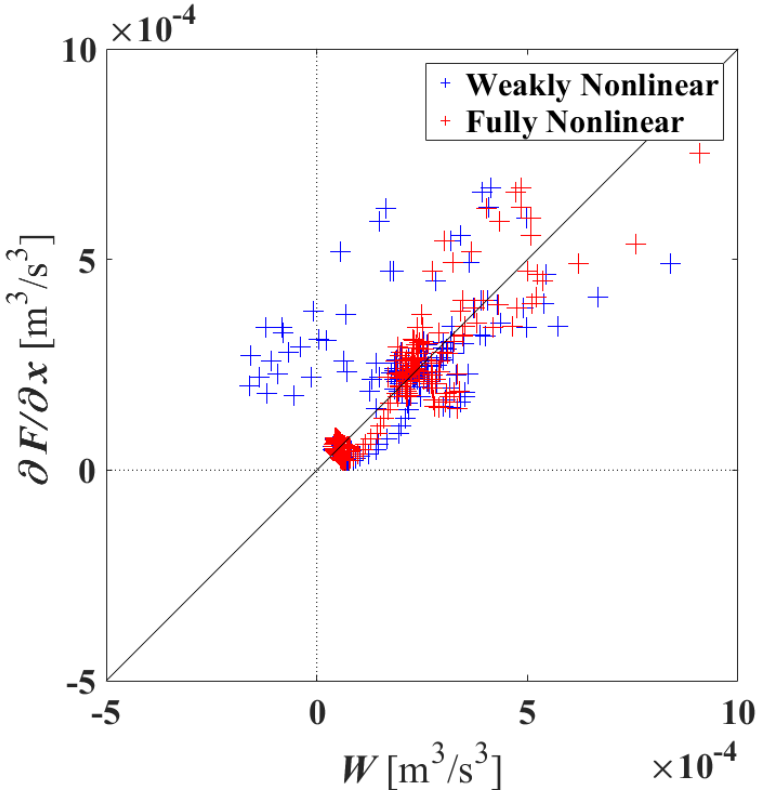
Energy balance

The original equations assumed Weakly nonlinear interaction and smaller order of IG components compared with SS components.

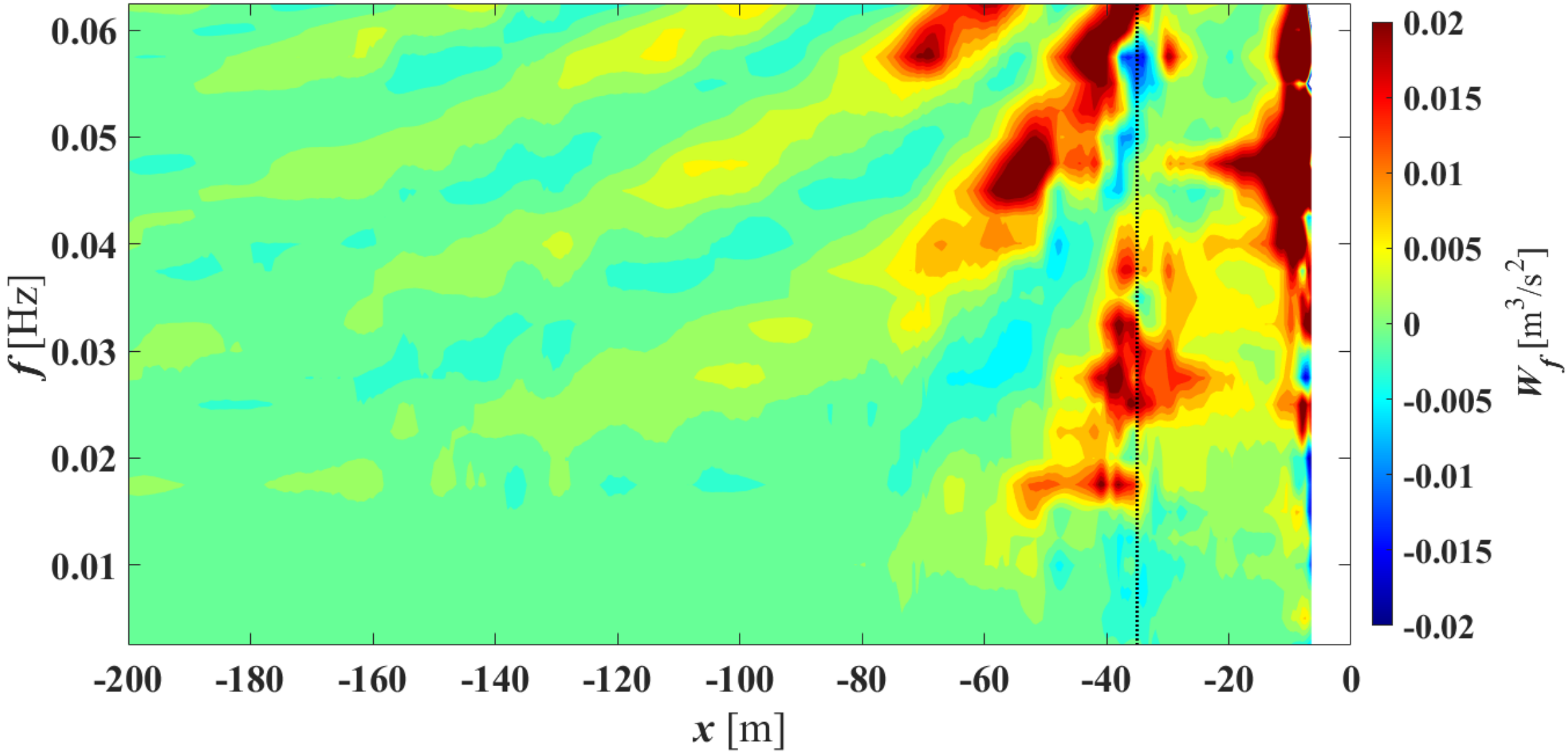
⇒We changed energy transfer term to fully nonlinear.

$$W_f = -C_f\left(\frac{\partial}{\partial x}\left((h+\eta)u^2 + \frac{1}{2}g\eta^2\right), u + \frac{u\eta}{h}\right)$$





Energy Transfer: W_f



Conclusion

By field observation…

- ✓ We observed the infragravity wave development in nearshore and run-up, which was caused by the nearshore wave-wave interaction.
- ✓ By UAV based approach, harmonic wave generation was confirmed, and drastic change of wave fields across the sand bar was estimated, suggesting energy transfer from SS components to IG components.

By numerical approach…

- ✓ We confirmed the highly reflective condition, including the development of the complex standing waves .
- ✓ The nearshore infragravity wave development, and also dissipation around shoreline were observed.
- ✓ It was suggested that higher order nonlinear interaction can not be neglected around the sand bar.

Thank you for listening!!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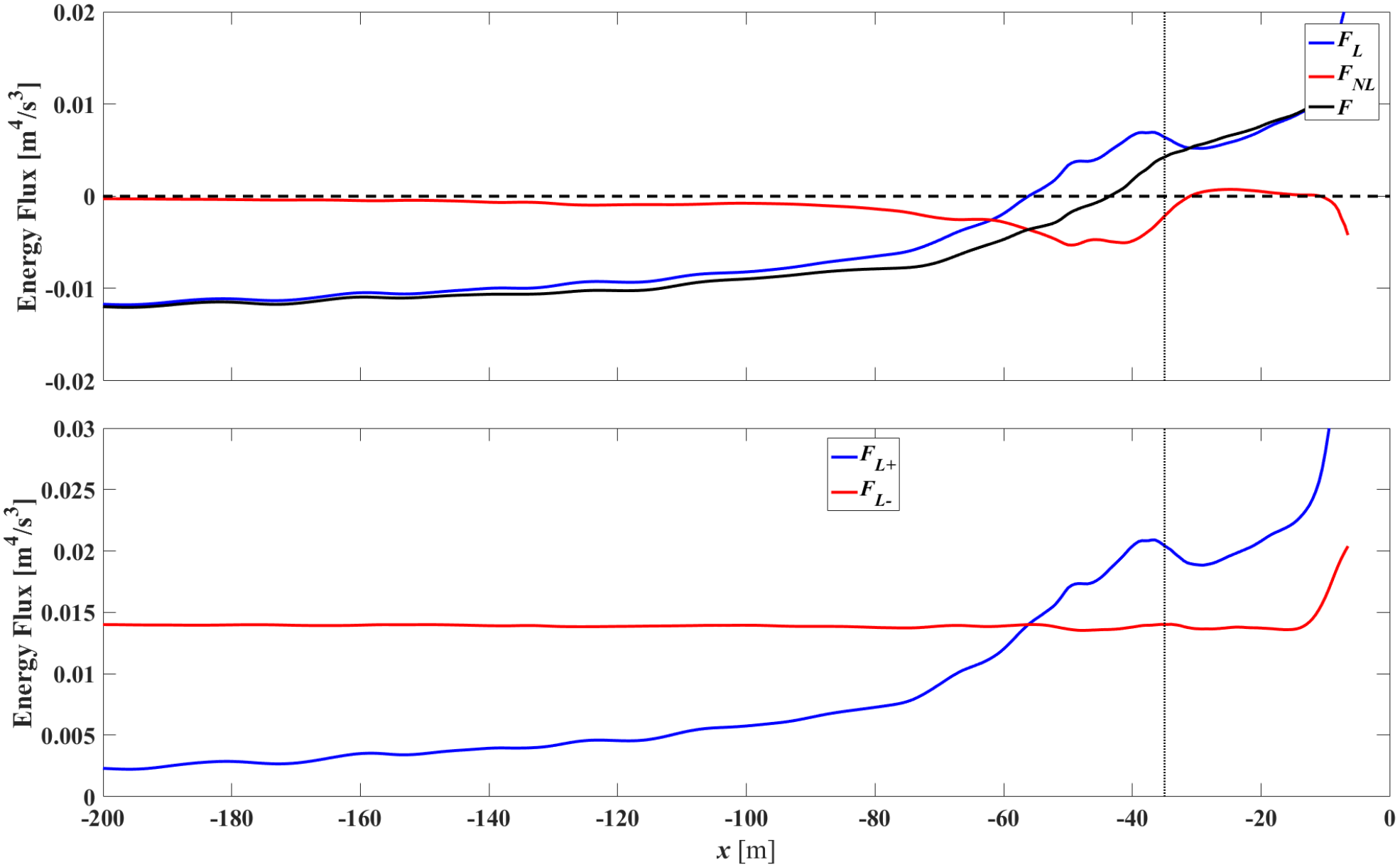
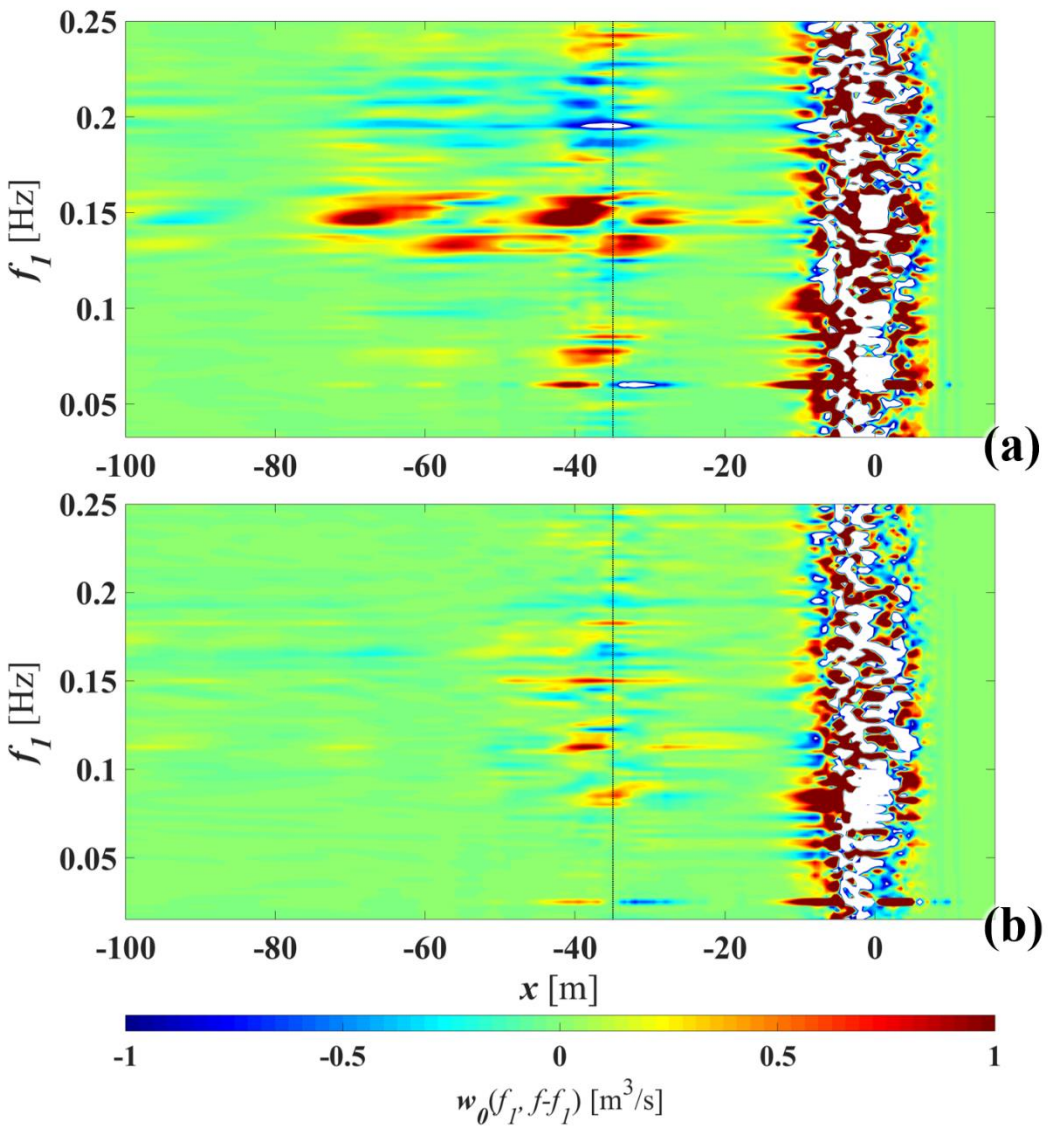
Energy Flux

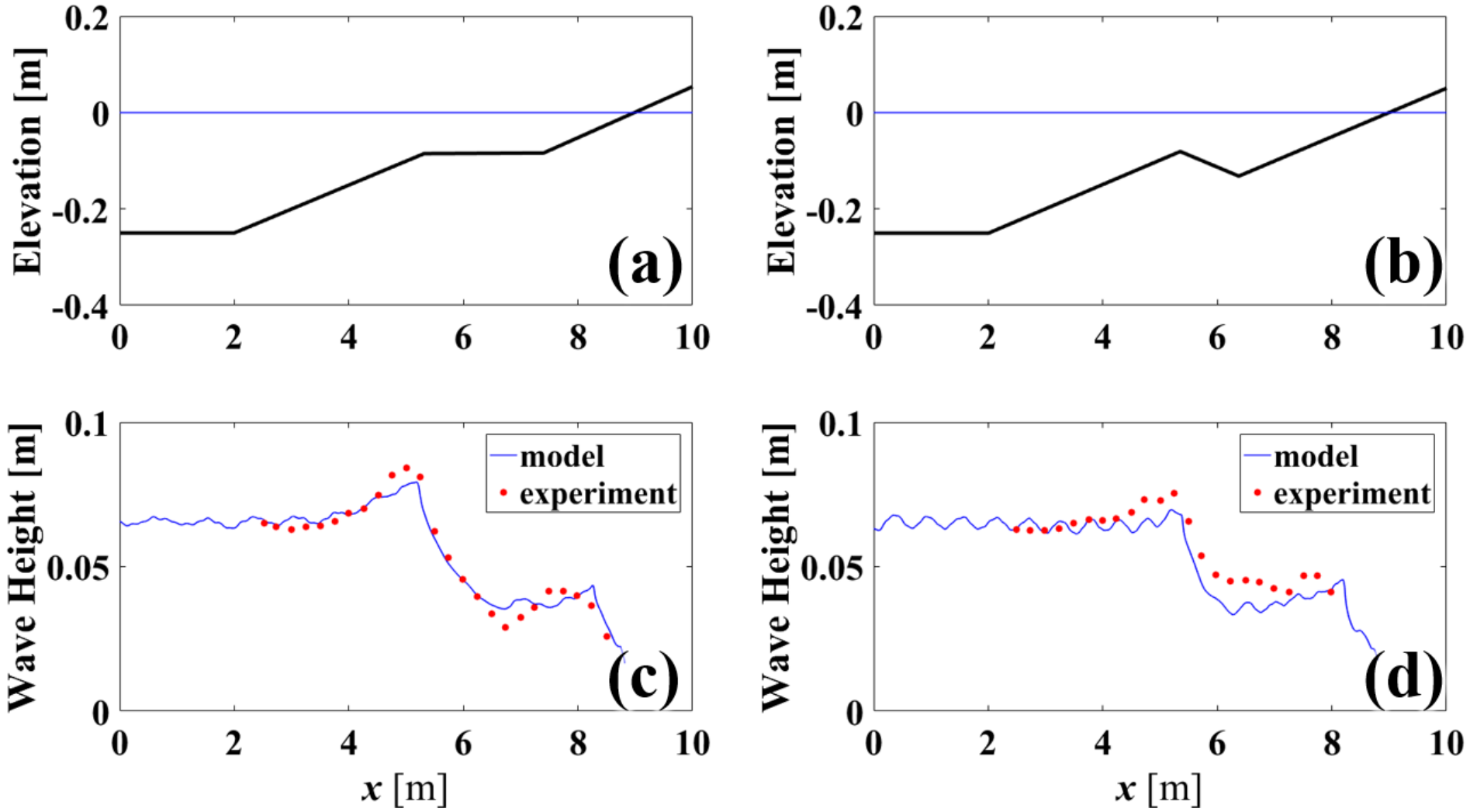

0.02
0.01
0
-0.01
-0.02
Energy Flux [m^4/s^3]
F_L
F_NL
F
0.03
0.025
0.02
0.015
0.01
0.005
0
Energy Flux [m^4/s^3]
F_L+
F_L-
-200
-180
-160
-140
-120
-100
-80
-60
-40
-20
0
x [m]

$$W_{0f} = \int_{f_1} w_0(f_1, f - f_1) df_1$$

$$w_0(f_1, f - f_1) = -C_{f_1, f-f_1}\left(\frac{\partial hu}{\partial x}, u, u\right)$$

$$-C_{f_1, f-f_1}\left(hu, \frac{\partial u}{\partial x}, u\right) - gC_{f_1, f-f_1}\left(\eta, \frac{\partial \eta}{\partial x}, u\right)$$




Elevation [m]
0.2
0
-0.2
-0.4
0
2
4
6
8
10
(a)
(b)
Wave Height [m]
0.1
0.05
0
model
experiment
(c)
(d)
x [m]