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Interaction of Tsunamis with Short Surface Waves: An Experimental Study

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12th International Workshop on Wave Hindcasting and Forecasting and 3rd Coastal Hazard Symposium

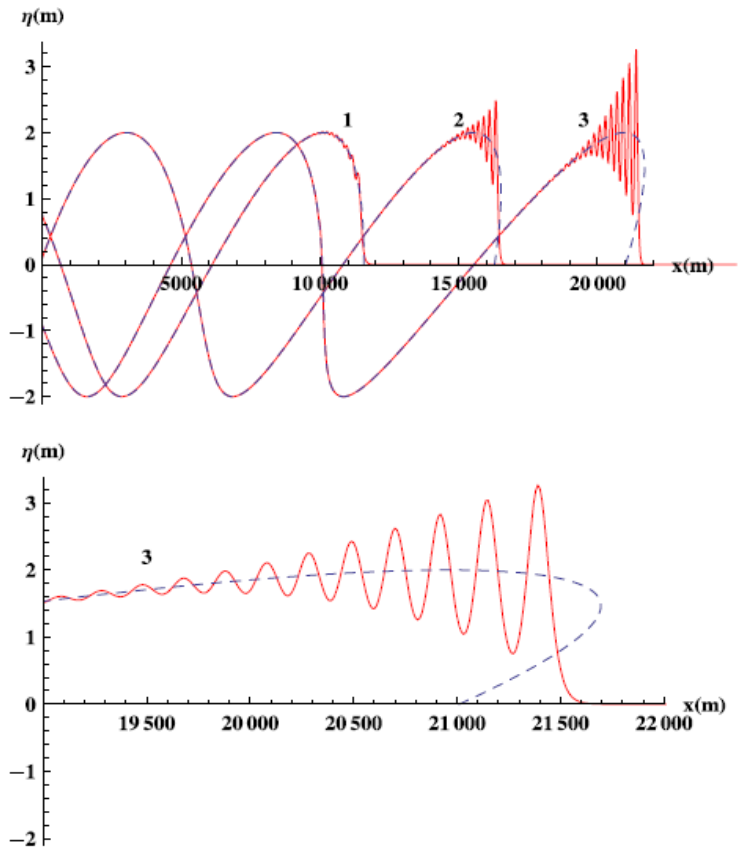
Motivation

2004 Indian Ocean Tsunami from Koh Jum Island

Motivation

- Generally – default paradigm for tsunamis: **solitary wave**
  - Used for lab studies of tsunami damage

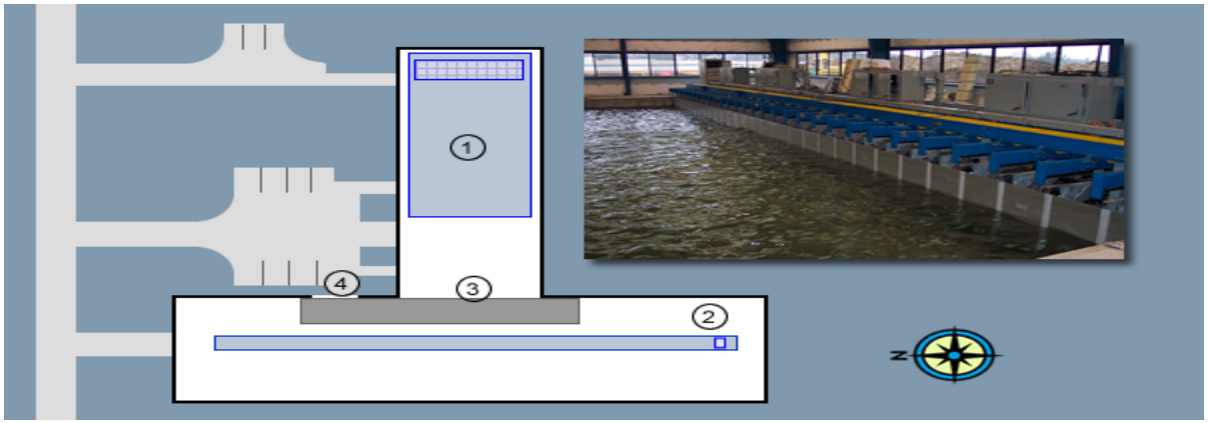
- Madsen et al. (2008)
  - Solitary wave paradigm flawed
  - Cause order of magnitude errors in spatial and temporal evolution over a sloping bottom

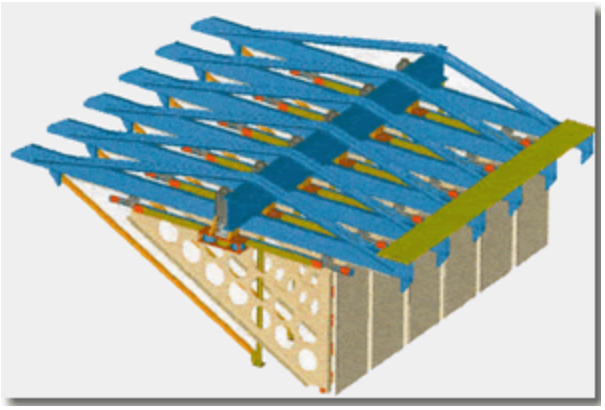


Interaction with the Swell Wave Field

- Hypothesis:
  - Overlying swell wavefield can have some subtle effect on underlying tsunami
    - Front face steepness
    - Wave-wave interaction
- Run long wave through random swell field
- Use transient analysis (wavelet, Hilbert-Huang) to investigate effects

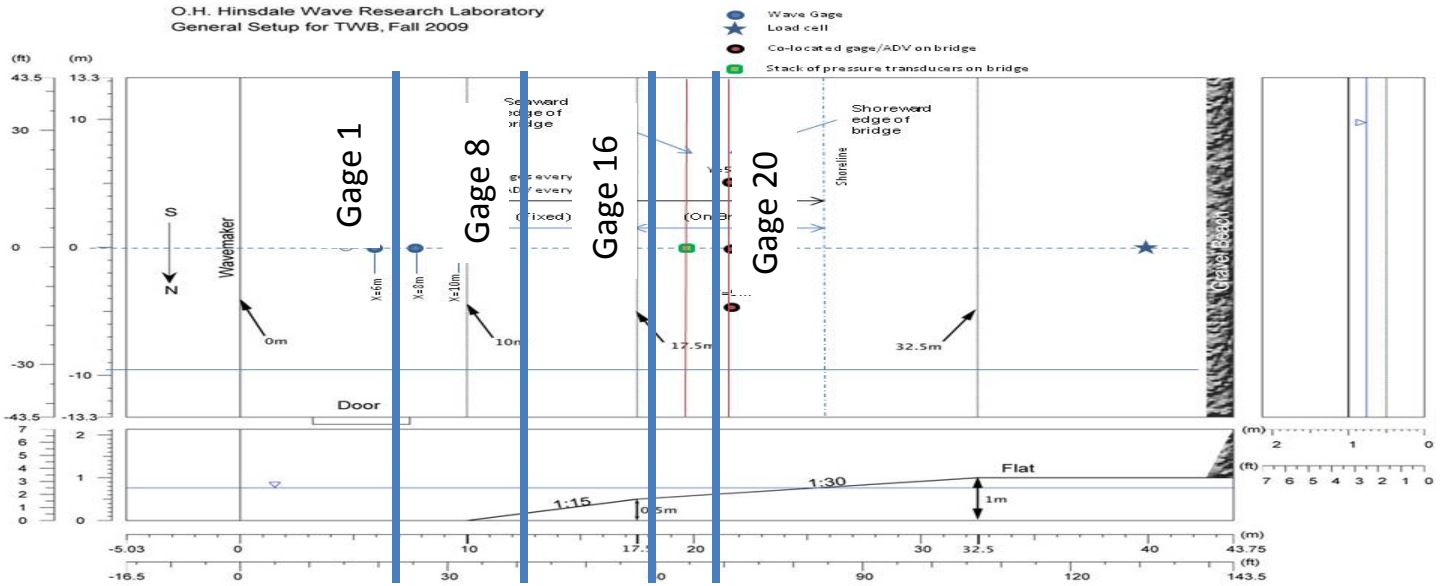
NEES Payload





- One year project from NEES program, National Science Foundation
- Use NEES Tsunami facility at Oregon State University
- Tsunami Wave Basin:
  - 48.8m x 26.5m x 2.1m
  - 29-paddle multi-directional piston wavemaker
  - 4 resistance gages and 2 ADVs on movable bridge

Test Conditions



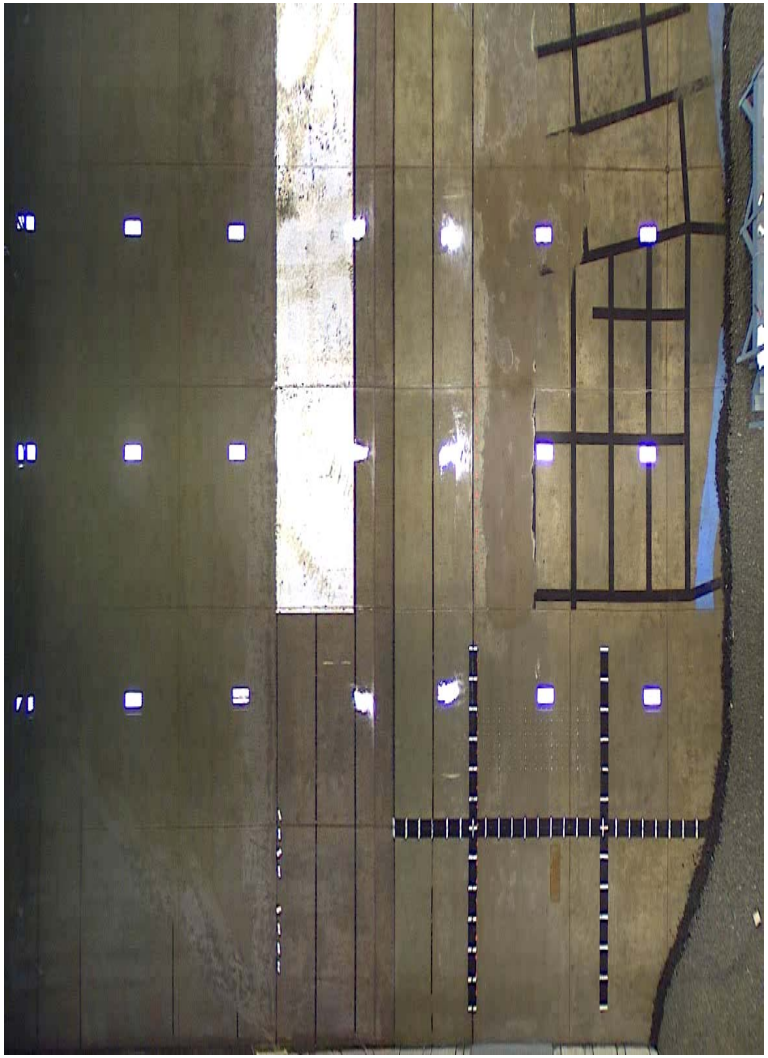
Test Number	Hs (cm)	Tp (s)	kh	δ=a/h	U_r
1	5	2	1	0.033	0.033
2	5	4	0.45	0.033	0.163
3	10	2	1	0.067	0.067
4	10	4	0.45	0.067	0.331

Tsunami "height" ~30 cm

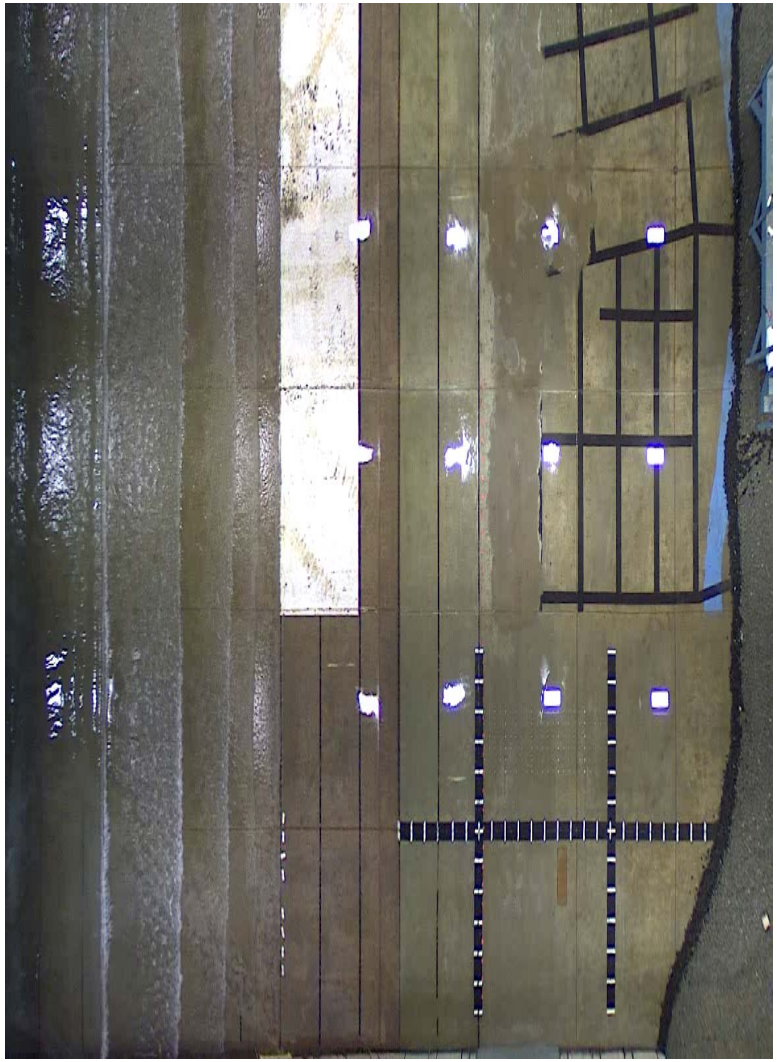
Water depth 0.75 m

Different runs with tsunami either in middle or end of swell record

Experiments



Tsunami Only

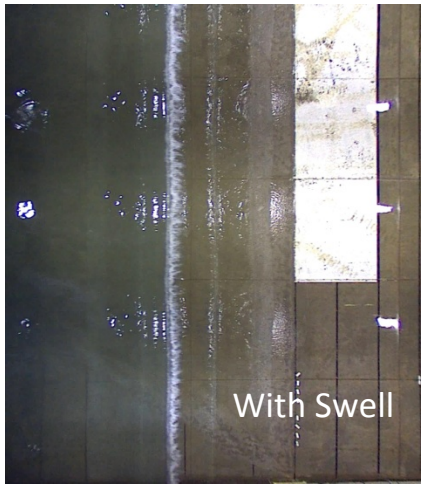


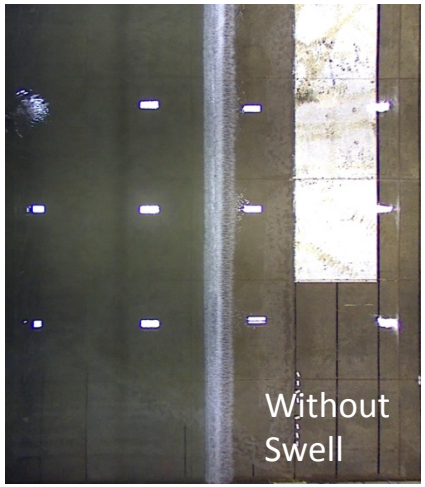
Tsunami with Swell

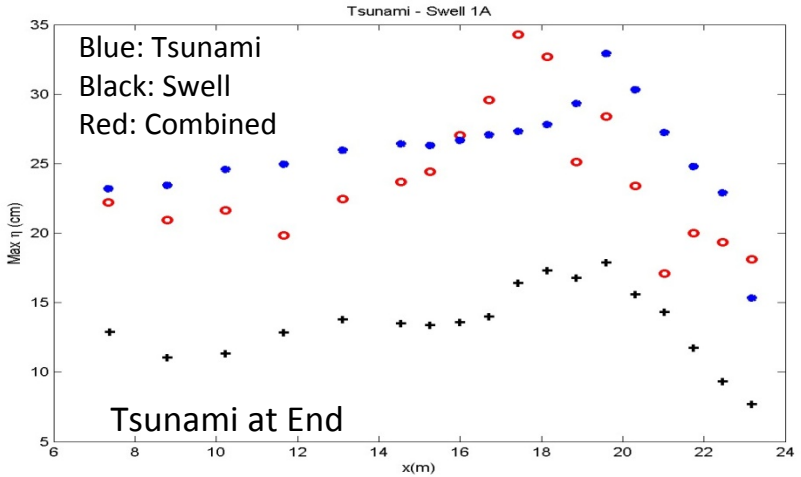
Analysis

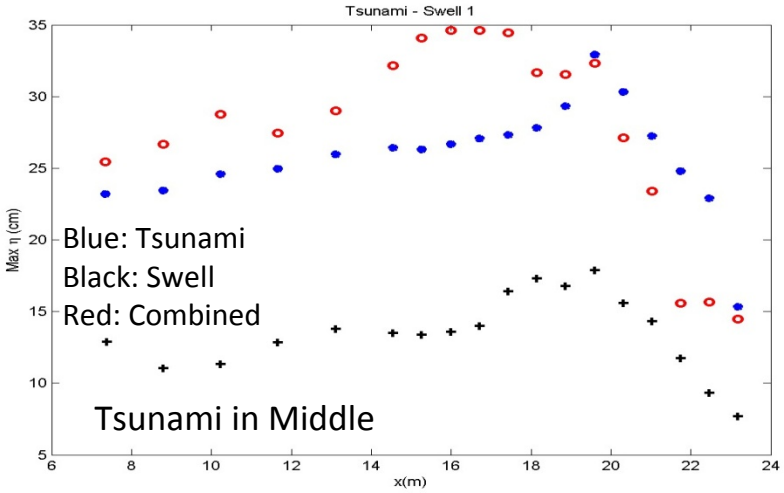
Maximum Surface Elevation

- As proxy for waveheight: maximum surface elevation in record
- Maximum surface elevation reached earlier with combined conditions than with either alone.
- Different results with tsunami in middle or at end of swell record.









Wavelet Analysis

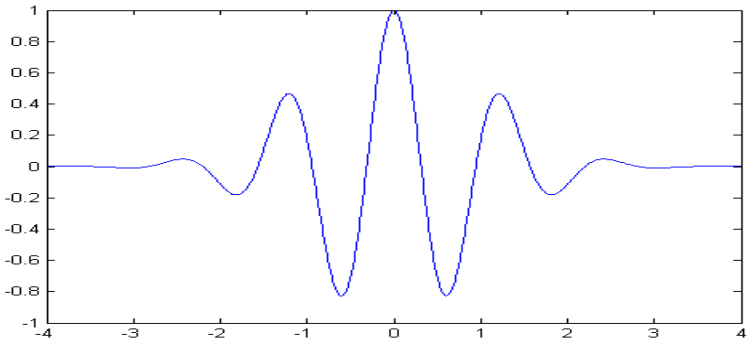
Morlet Wavelet Transform

• Data from experiment – periodic signal interacting with a transient signal

• Standard Fourier Transform techniques not suitable

• Wavelet transform – time-dependent frequencies

• Spectral densities as a function of frequency and time

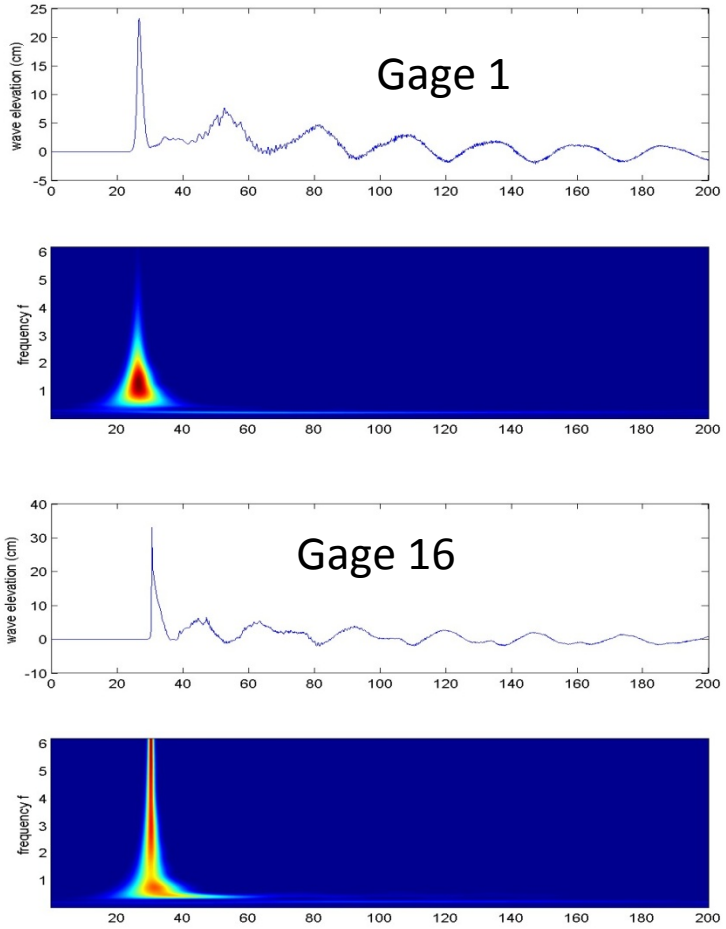


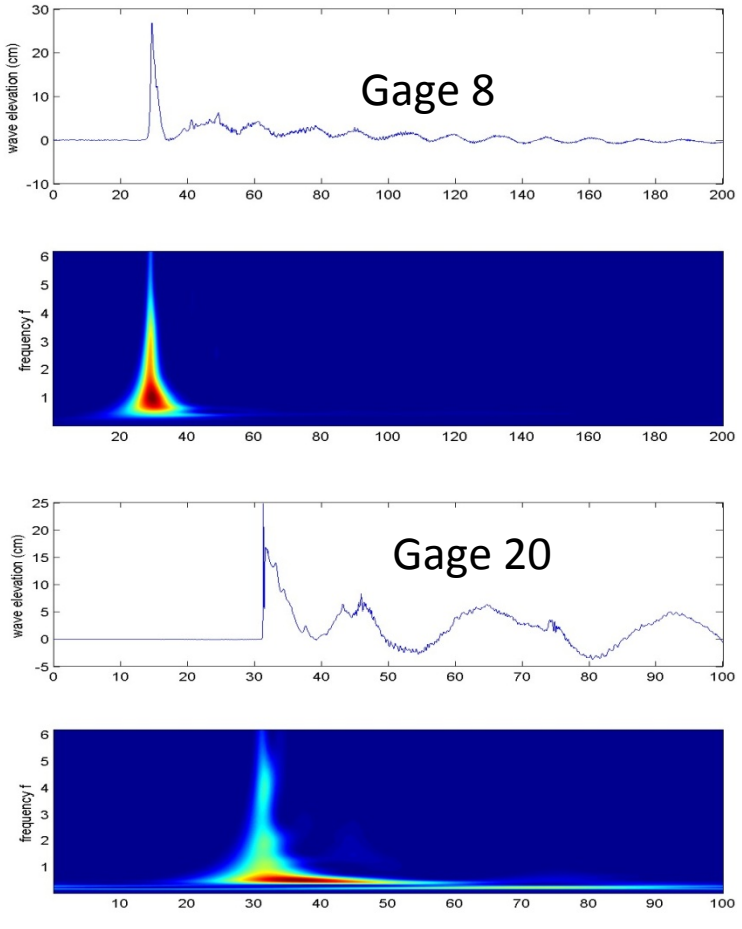
The Morlet Wavelet

$$\mathrm{WT}(a,\tau) = \int_{-\infty}^{\infty} x(t)\psi^{*}_{a,\tau}(t)dt,$$

$$\psi(t) = \pi^{-1/4}\exp\left(-\frac{t^2}{2}\right)\exp(i\omega_0 t),$$

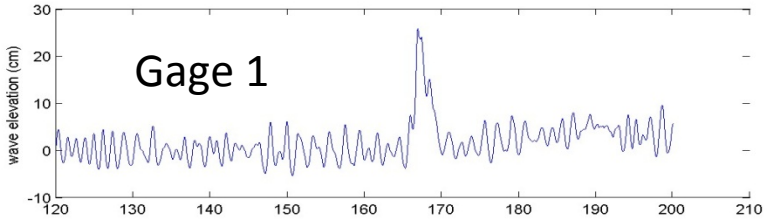
Wavelet Analysis

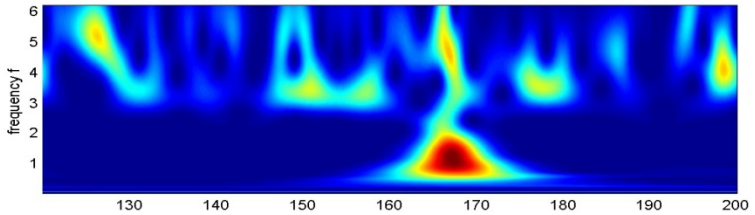


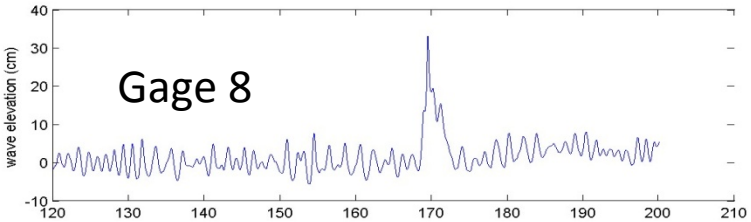


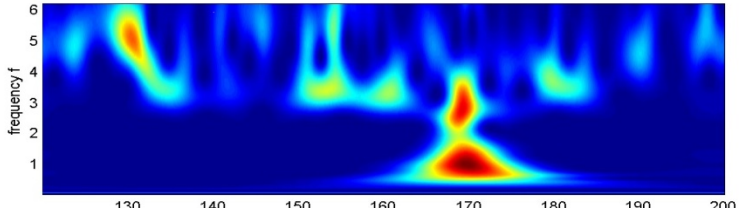
Tsunami Only

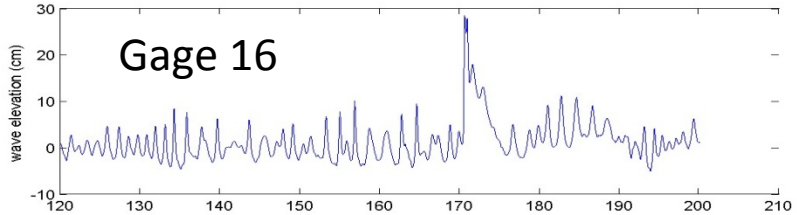
Wavelet Analysis

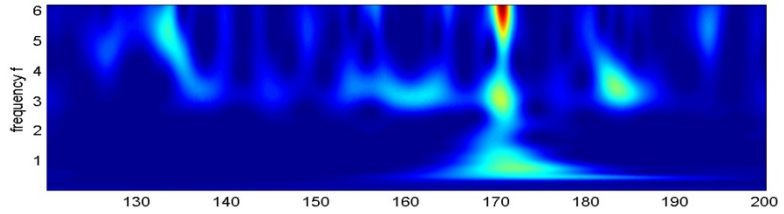


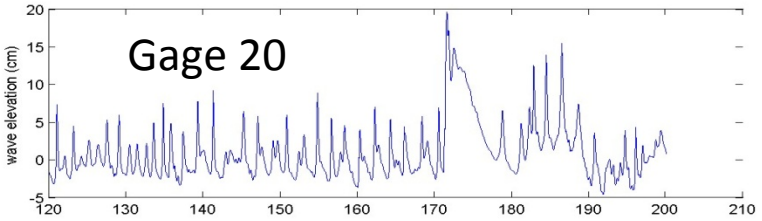


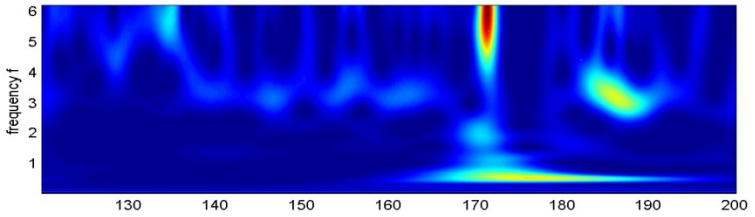






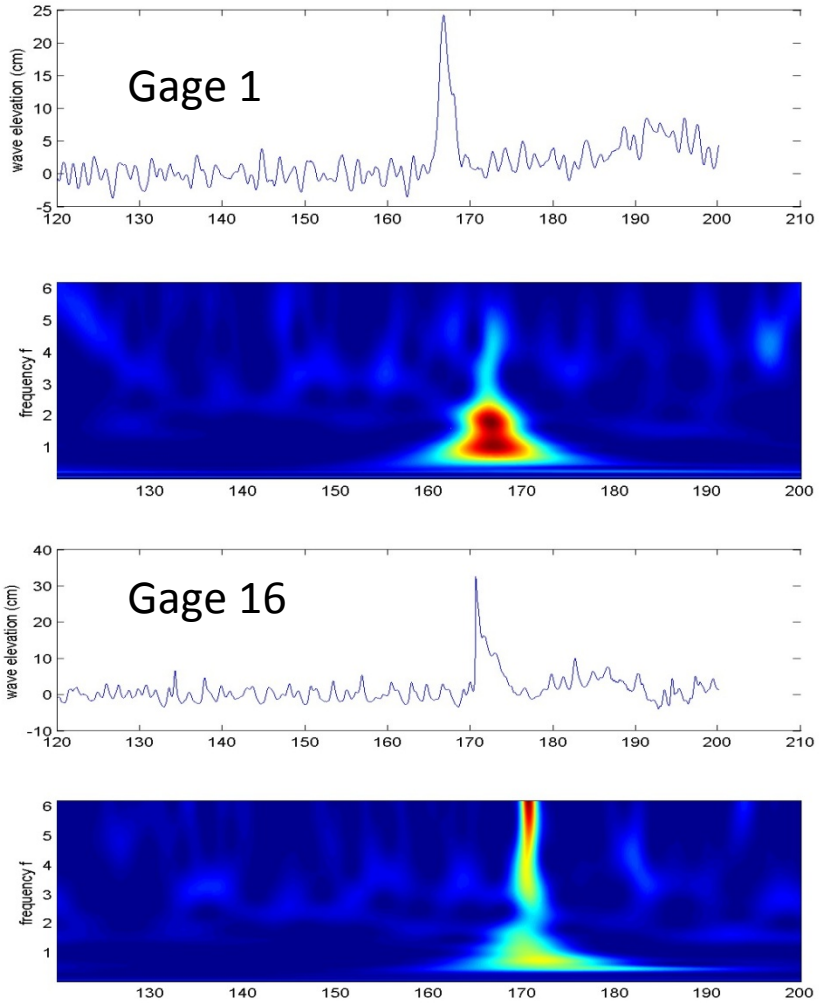






Tsunami with Swell: Hs=5cm, Tp=2s

Wavelet Analysis

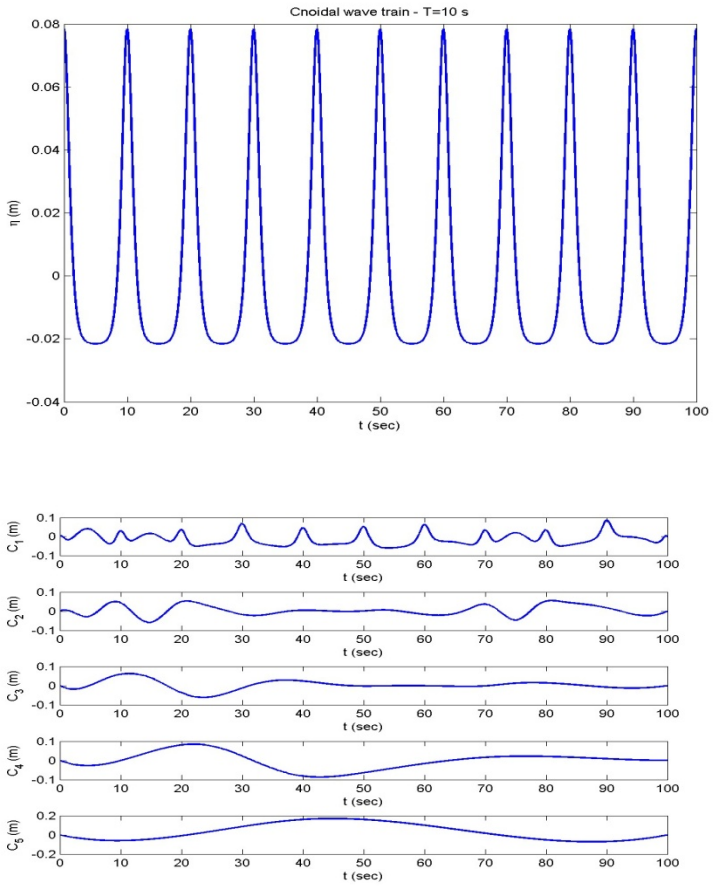


Tsunami with Swell: Hs=5cm, Tp=4s

Hilbert-Huang Transform

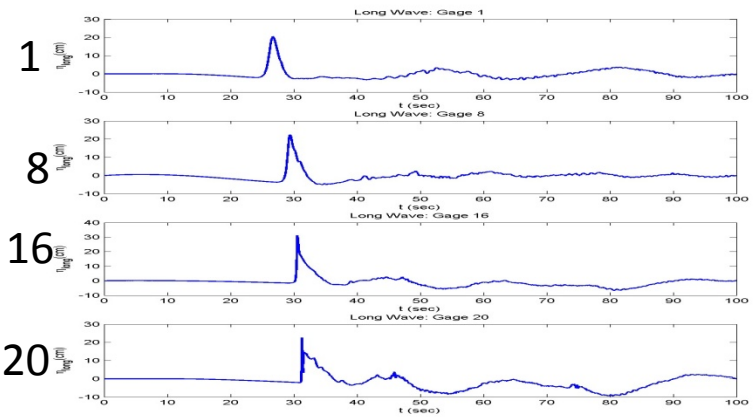
Hilbert Transform plus Empirical Model Decomposition

- Take original nonperiodic signal
- Calculate envelope with Hilbert Transform, then calculate mean
- Subtract mean from original signal
    - New signal
- Do this on each updated signal *k* times
- Result – mode c_1
- Subtract mode c_1 from original data – obtain new data
- Perform sifting process again
- Advantage:
    - No *apriori* basis function
    - Modes usually have some physical basis

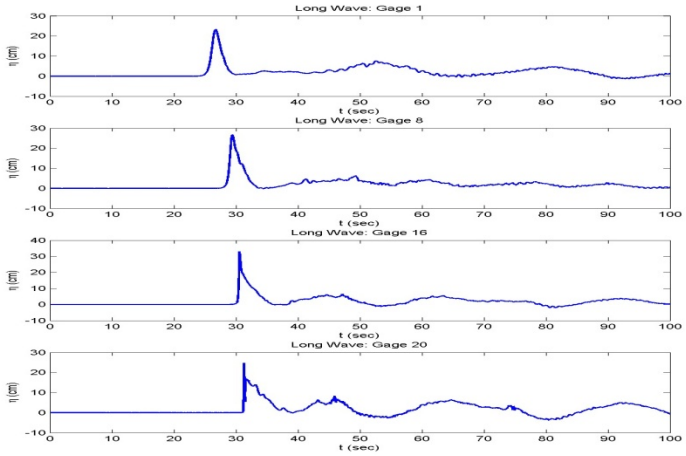


Top: Cnoidal wave. Bottom. First five HHT modes of cnoidal wave.

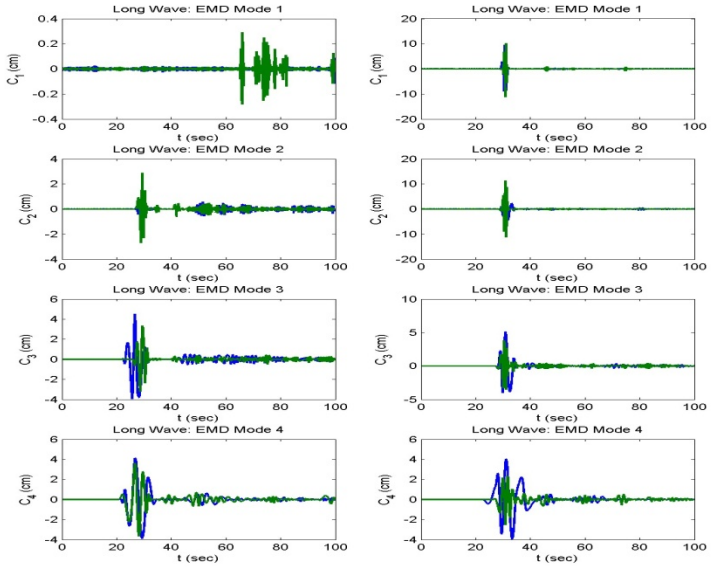
HHT of Tsunami



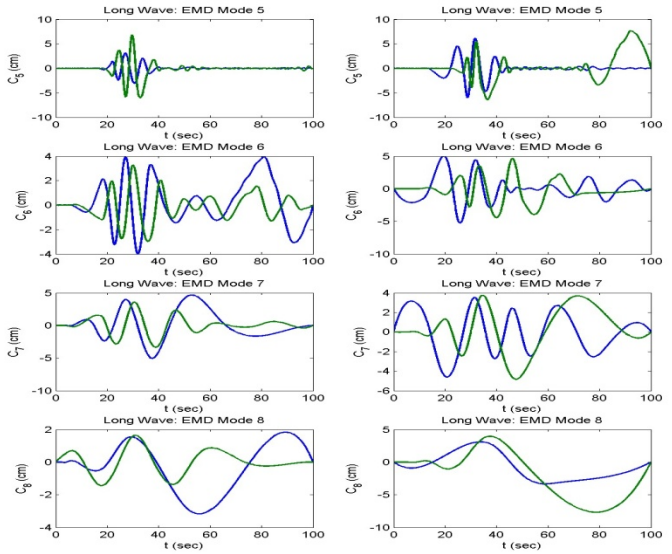
1 8 16 20



1 8 16 20



1 2 3 4



5 6 7 8

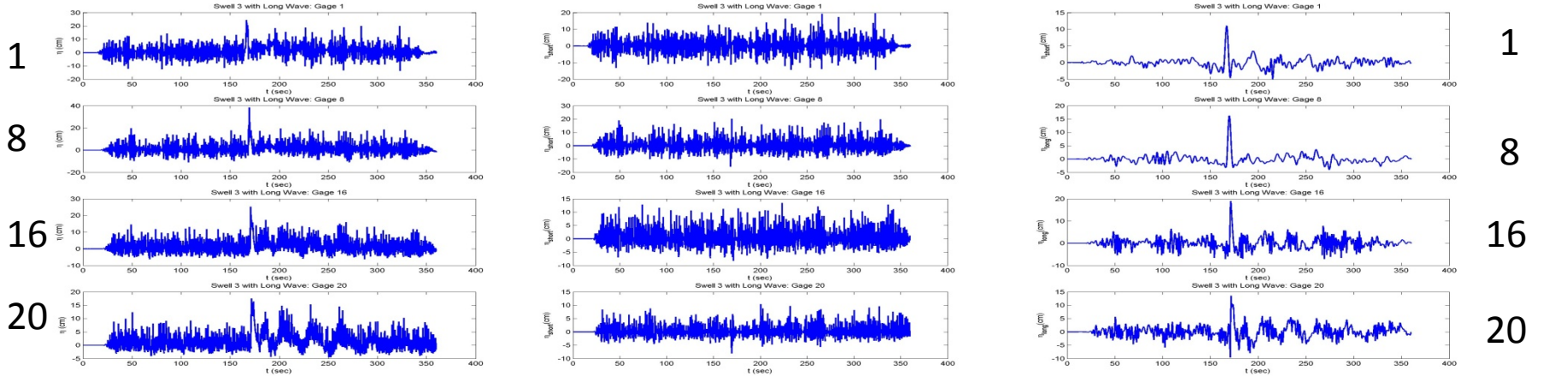
Blue: Gage 1
Green: Gage 8

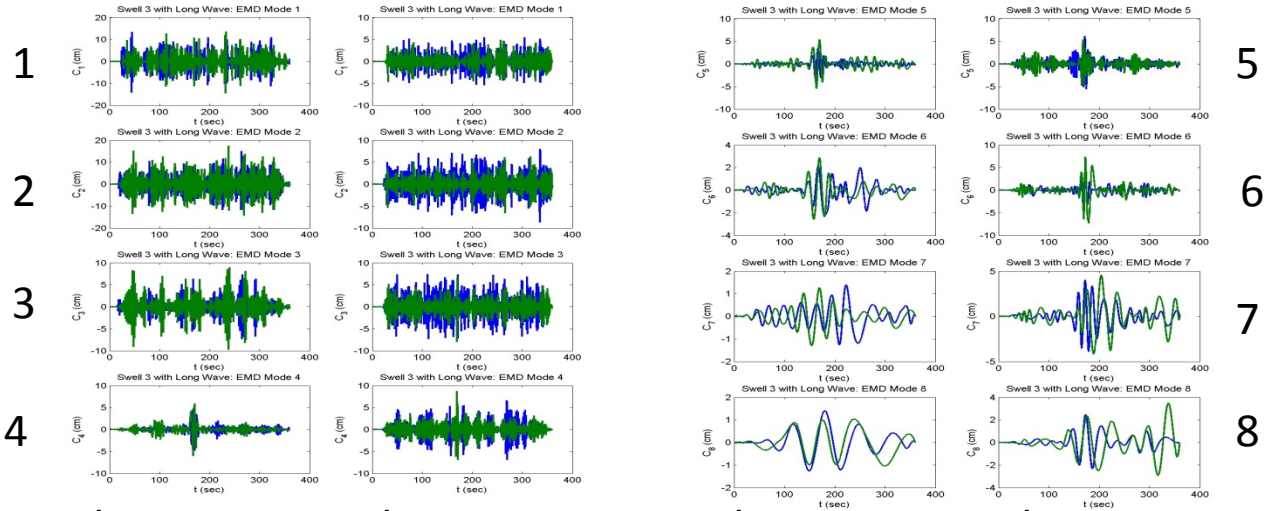
Blue: Gage 16
Green: Gage 20

Blue: Gage 1
Green: Gage 8

Blue: Gage 16
Green: Gage 20

HHT of Combined Tsunami-Swell





Blue: Gage 1 Blue: Gage 16 Blue: Gage 1 Blue: Gage 16

Green: Gage 8 Green: Gage 20 Green: Gage 8 Green: Gage 20

Steepness

Breaking: related to wave steepness $\frac{\partial \eta}{\partial x}$:

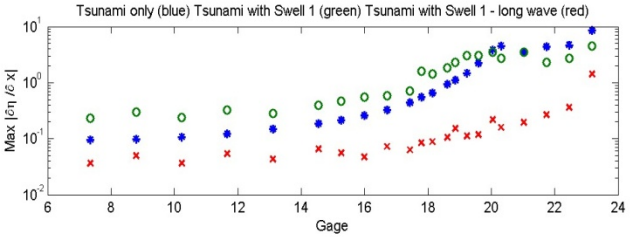
- Deduce steepness from:
  - Time series
  - Combined HHT modes (long/short motions)
- Look for maximum steepness

Approximate steepness by linear wave equation:

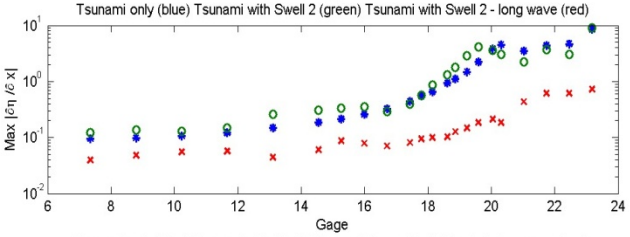
$$\frac{\partial \eta}{\partial x} = -\frac{1}{\sqrt{gh}} \frac{\partial \eta}{\partial t}$$

Steepness

1



2



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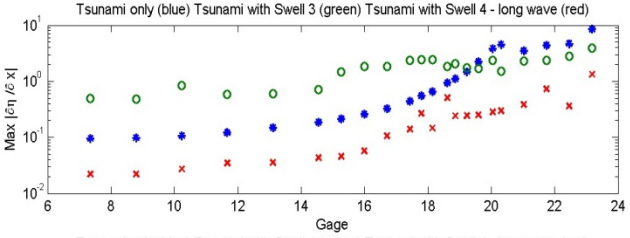

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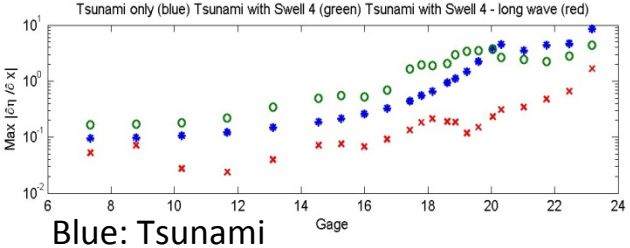
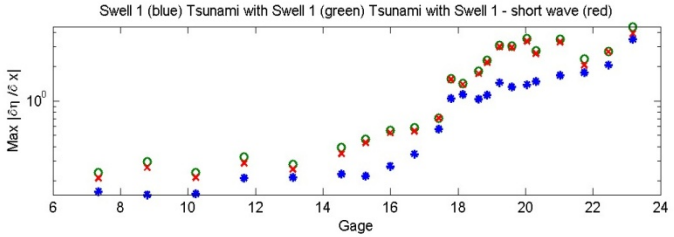


Blue: Tsunami
Green: Tsunami with swell
Red: Tsunami with swell – long wave

1



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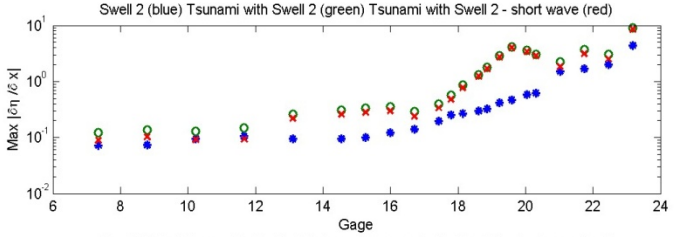

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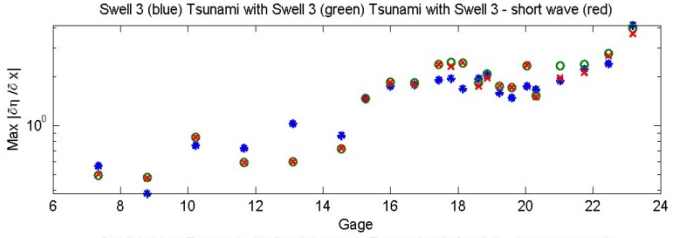

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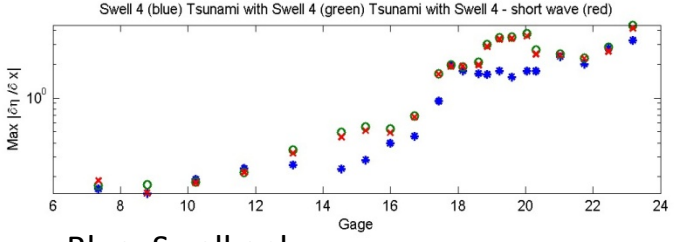

Blue: Swell only
Green: Swell with tsunami
Red: Swell with tsunami – short wave

Conclusions Thus Far

- It was hypothesized that the overlying swell field might have some effect on a long tsunami (front face steepness, etc.)
- Experiments were run at the NEES Tsunami Facility at Oregon State University
- Some indication of swell affecting maximum surface amplitude of overall wave field
- Wavelet analysis: spectral structure of tsunami affected by swell
- Use Hilbert-Huang Transform to break motion up into scales
- Analysis of steepness in combined motion: strong energy shift to high frequencies made more efficient with swell present.