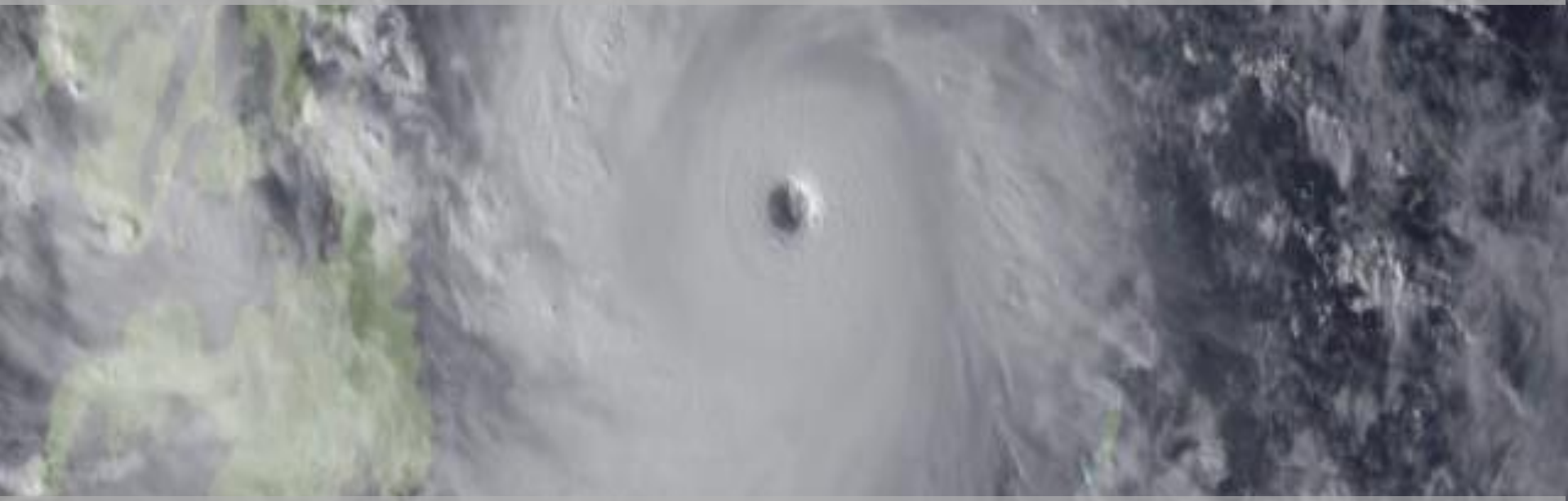
# Computational Analysis on the Generation of Extreme Infragravity Wave Runup

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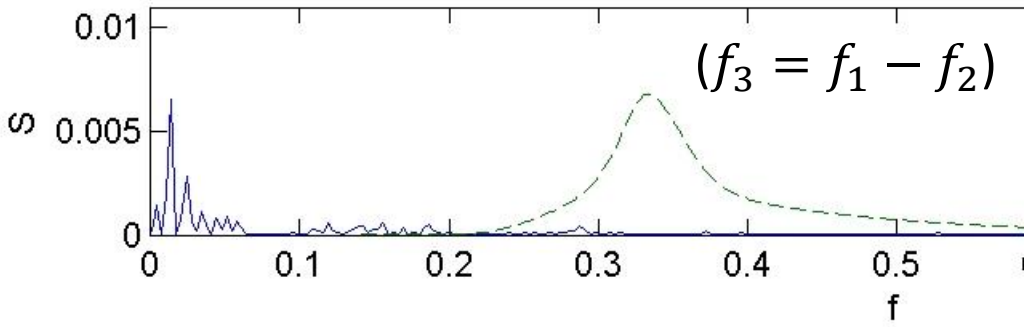
# Motivation

- Extreme IG runup poses a threat to coastal communities since they cause destruction and fatalities each year.


- What are the generation mechanisms of extreme IG waves?
- What is the optimum frequency resolution to study these events? How often and under what circumstances they occur?

# Background

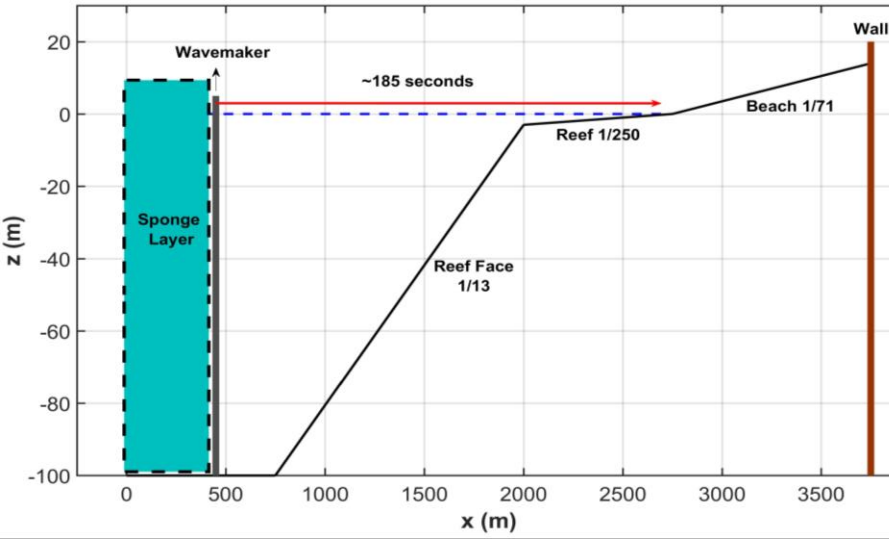
- IG waves: low frequency gravity waves (30-300s or more)
- Generated through nonlinear interactions / unsteady wave setup
- IG always exists, but becomes large in the nearshore with nonlinear (steep) sea and swell
- Local bathymetry can lead to IG resonance (both cross-shore and long-shore)

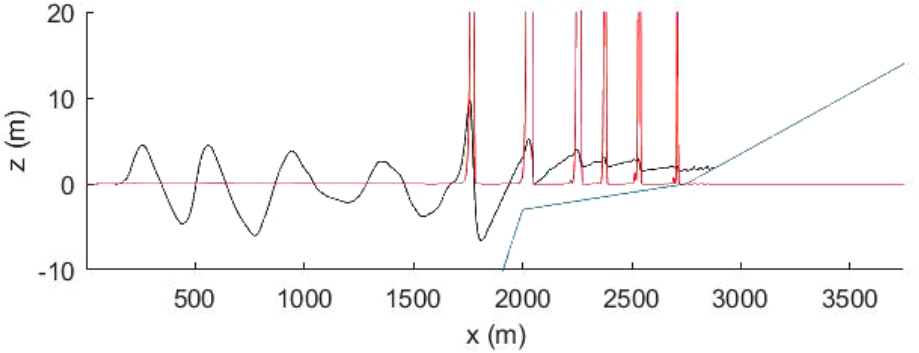


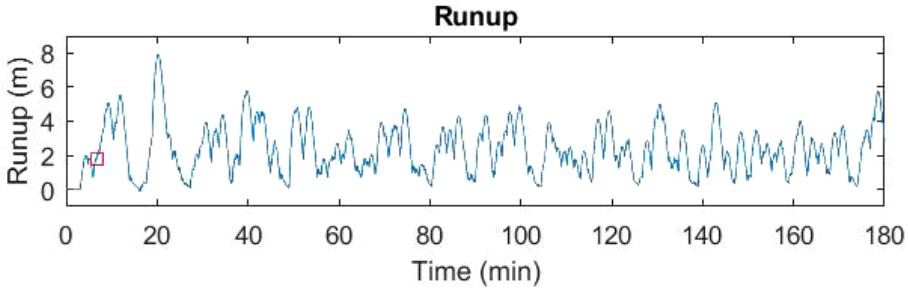

# IG Extreme Runup Observations

Hernani, Philippines

# Transect and Model Setup

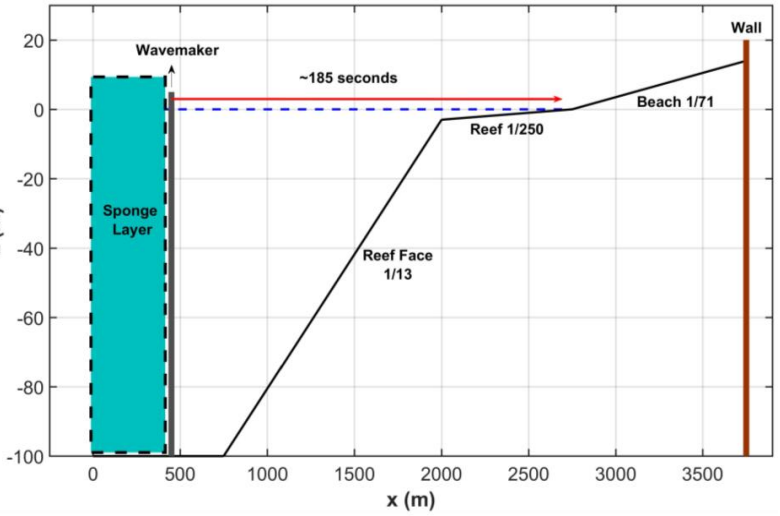


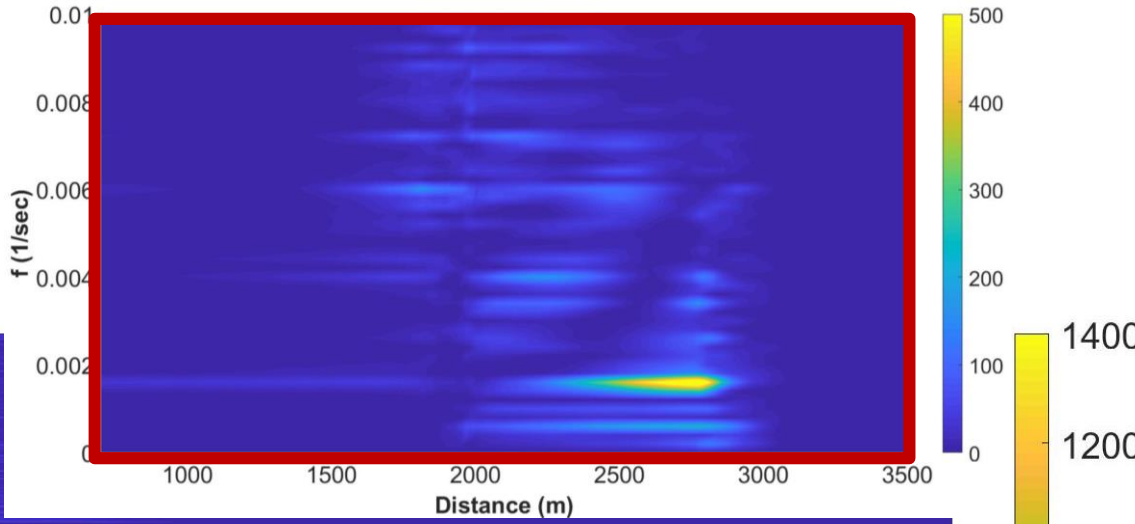



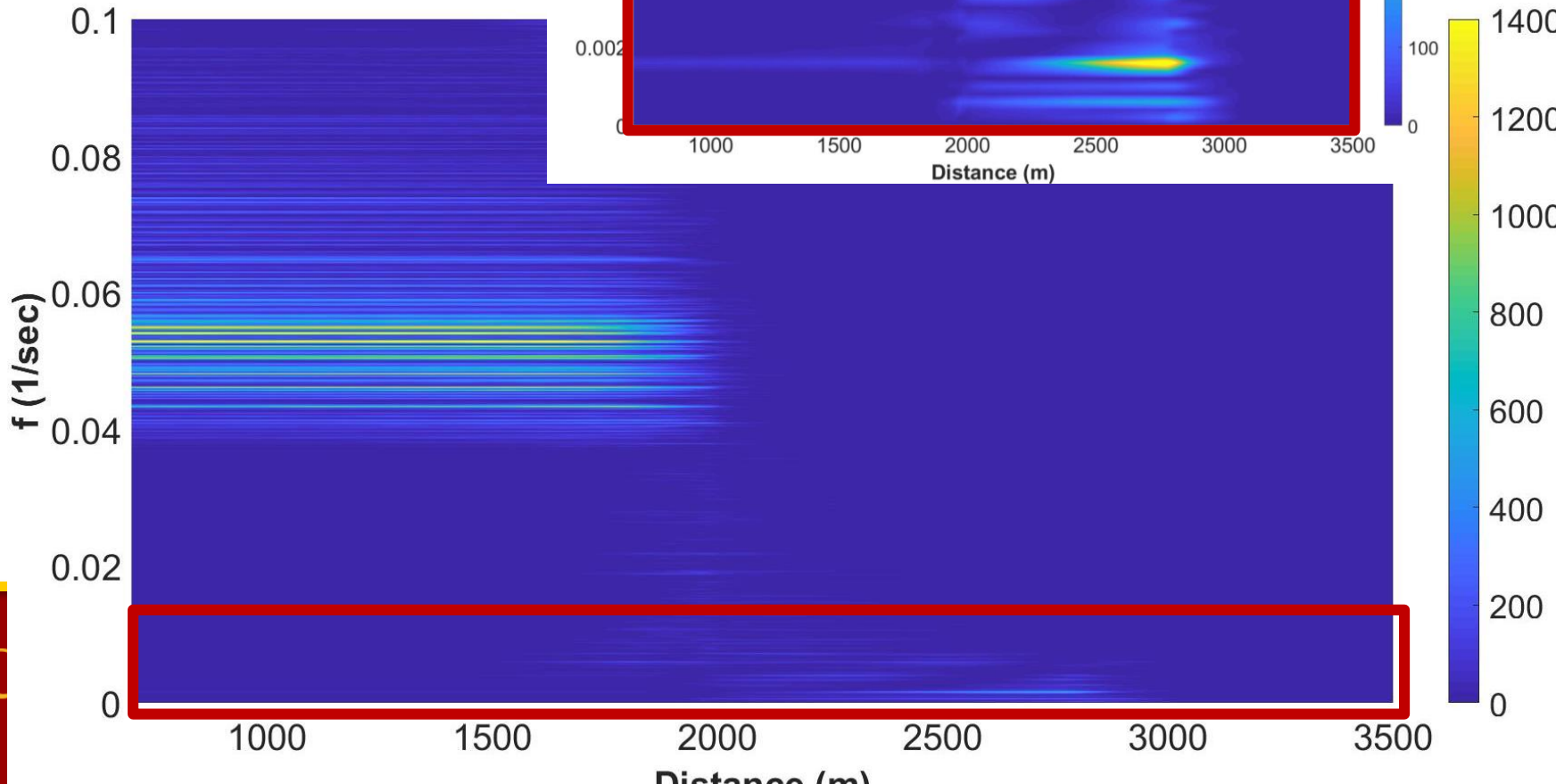




- COULWAVE: Incident wave condition is a JONSWAP spectrum
- In COULWAVE the spectrum is broken down into a set of discrete amplitude/frequency sine waves with some specified Δf and each with a unique random phase.

# Frequency Spectrum



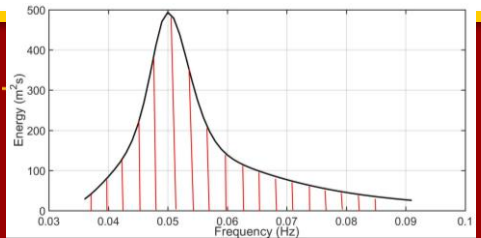



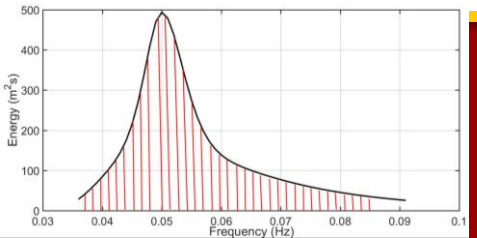
# Modelling

- Tested 100 different combinations of significant wave heights ($H_s = 3\ to\ 12\ m$) and peak periods ($T_p = 13\ to\ 22$ sec)
- Testing three different frequency resolutions: $\Delta f_c = 10^{-4}$, $\Delta f_f = 10^{-5}$ and $\Delta f_{ft} = 5 \times 10^{-6}$ Hz
- Since the wave pattern repeats itself every $^{1}/_{\triangle \mathrm{f}}$ seconds
- To make a valid comparison we compared the same amount of waves: $5sims * \Delta f_{ft}$ = $10sims * \Delta f_f$ = $100sims * \Delta f_c$
- Each run had its unique random phase seed

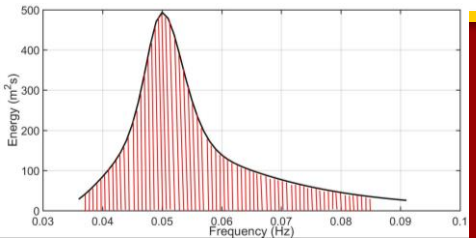
Coarse




Fine

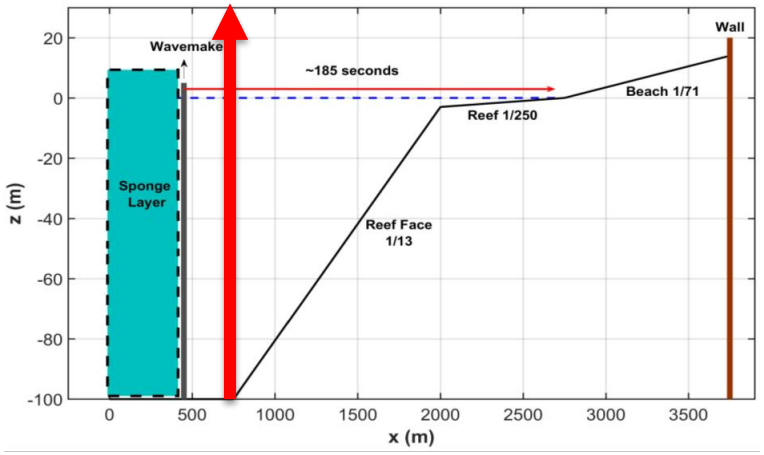


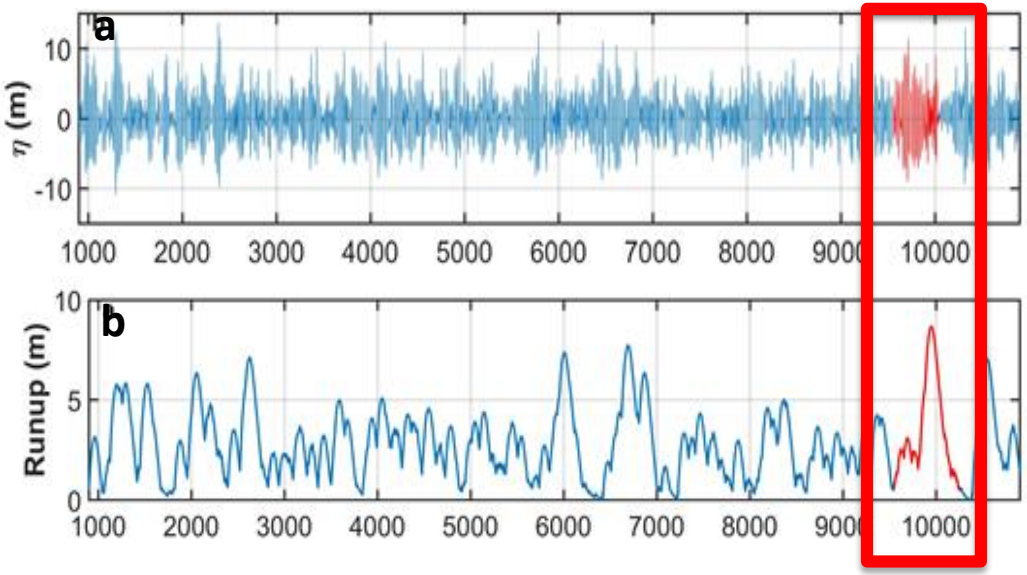

Finest



# FSE and Runup

x = 750 m

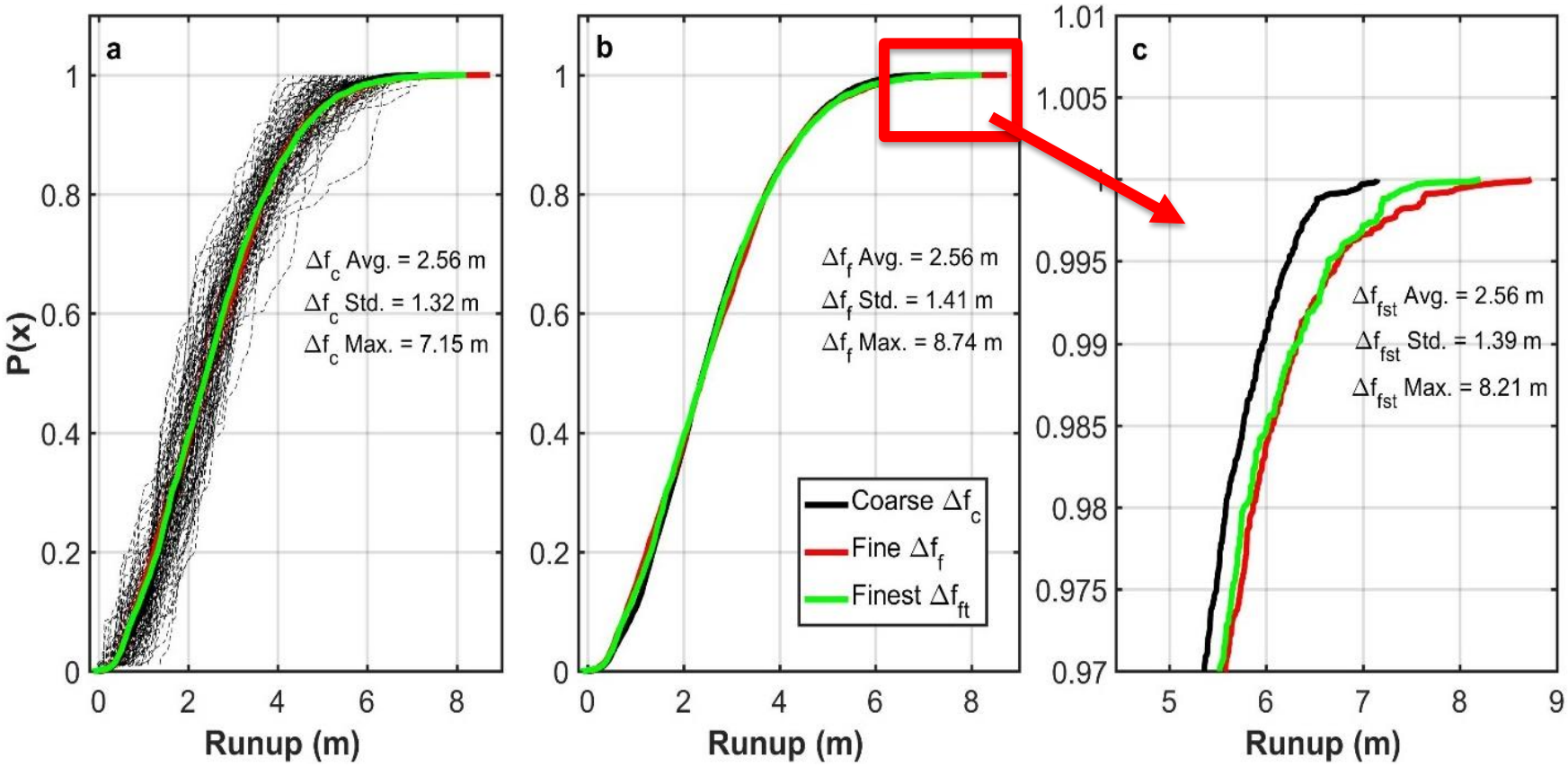


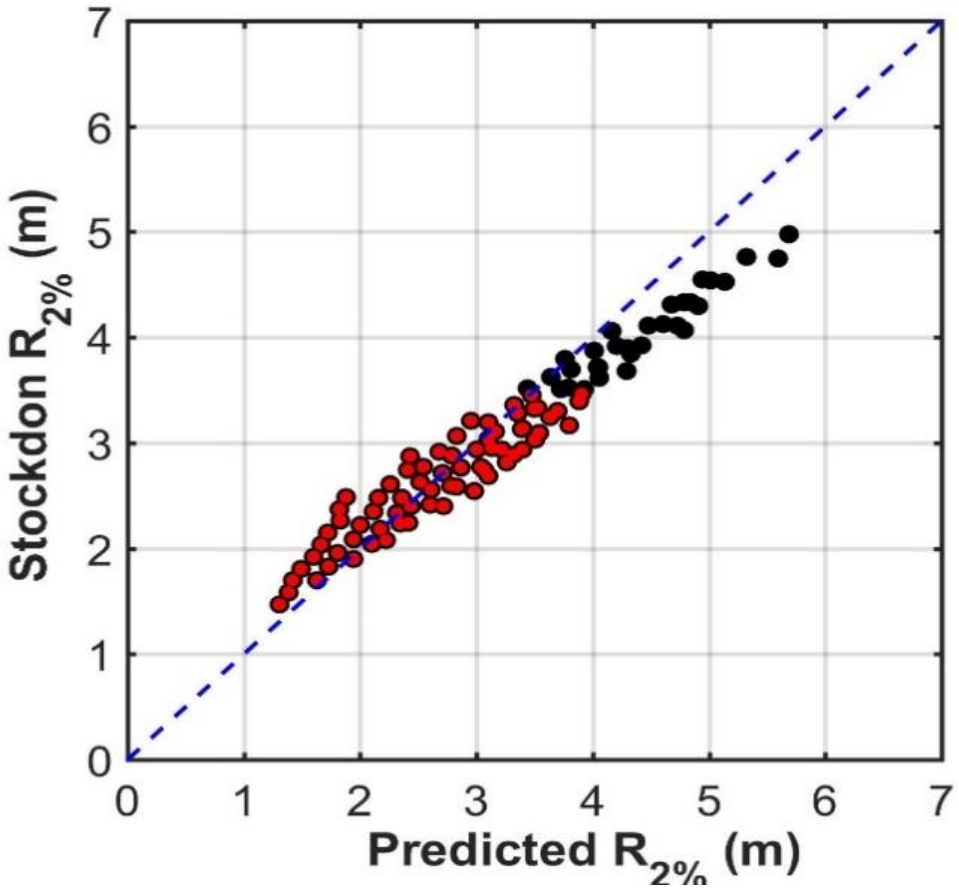

Extreme event!

- Time series of free surface elevation at $x = 750\ m$, before the waves reach the face of the reef and runup timeseries

# Runup CDF


a
b
c
P(x)
Runup (m)
Runup (m)
Runup (m)
Δf_c Avg. = 2.56 m
Δf_c Std. = 1.32 m
Δf_c Max. = 7.15 m
Δf_f Avg. = 2.56 m
Δf_f Std. = 1.41 m
Δf_f Max. = 8.74 m
Δf_fst Avg. = 2.56 m
Δf_fst Std. = 1.39 m
Δf_fst Max. = 8.21 m
Coarse Δf_c
Fine Δf_f
Finest Δf_ft

# COULWAVE vs Stockdon (2006)

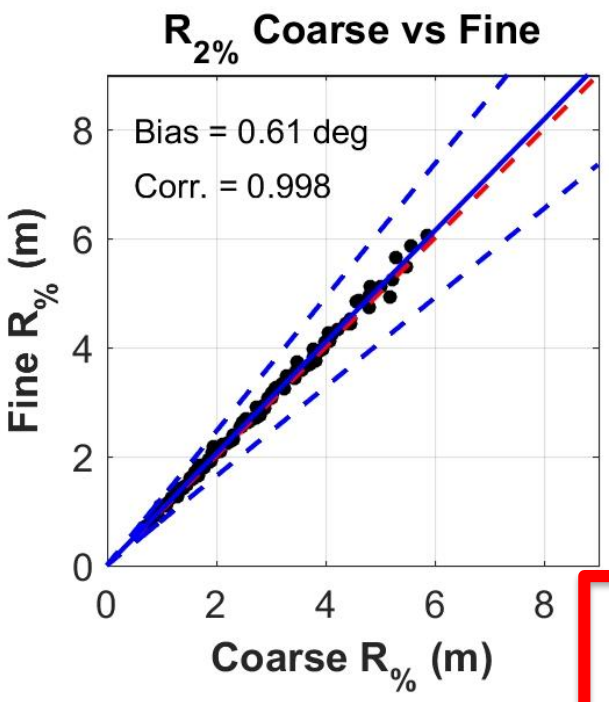


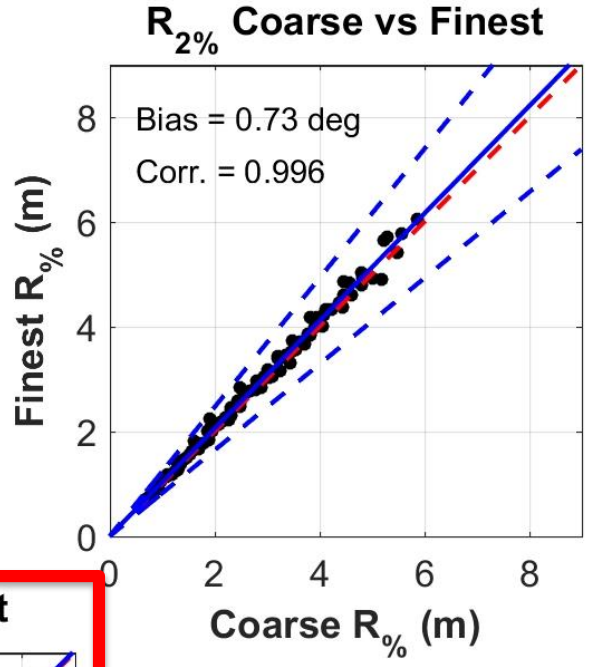

**R = 0.97**
**RMSE = 0.35 m**

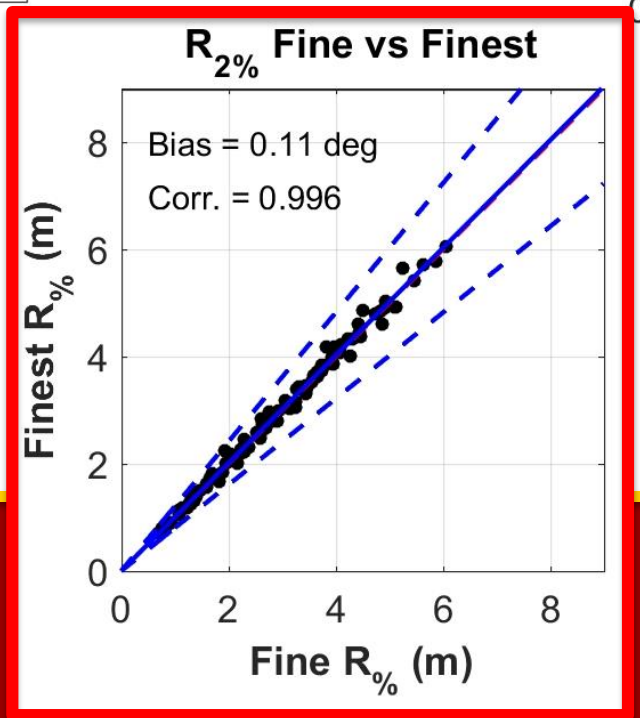
**RED**: Within S2006 limits (0-3.5 m)

**BLACK**: Outside S2006 limits (>3.5m)

# Optimum Frequency Resolution



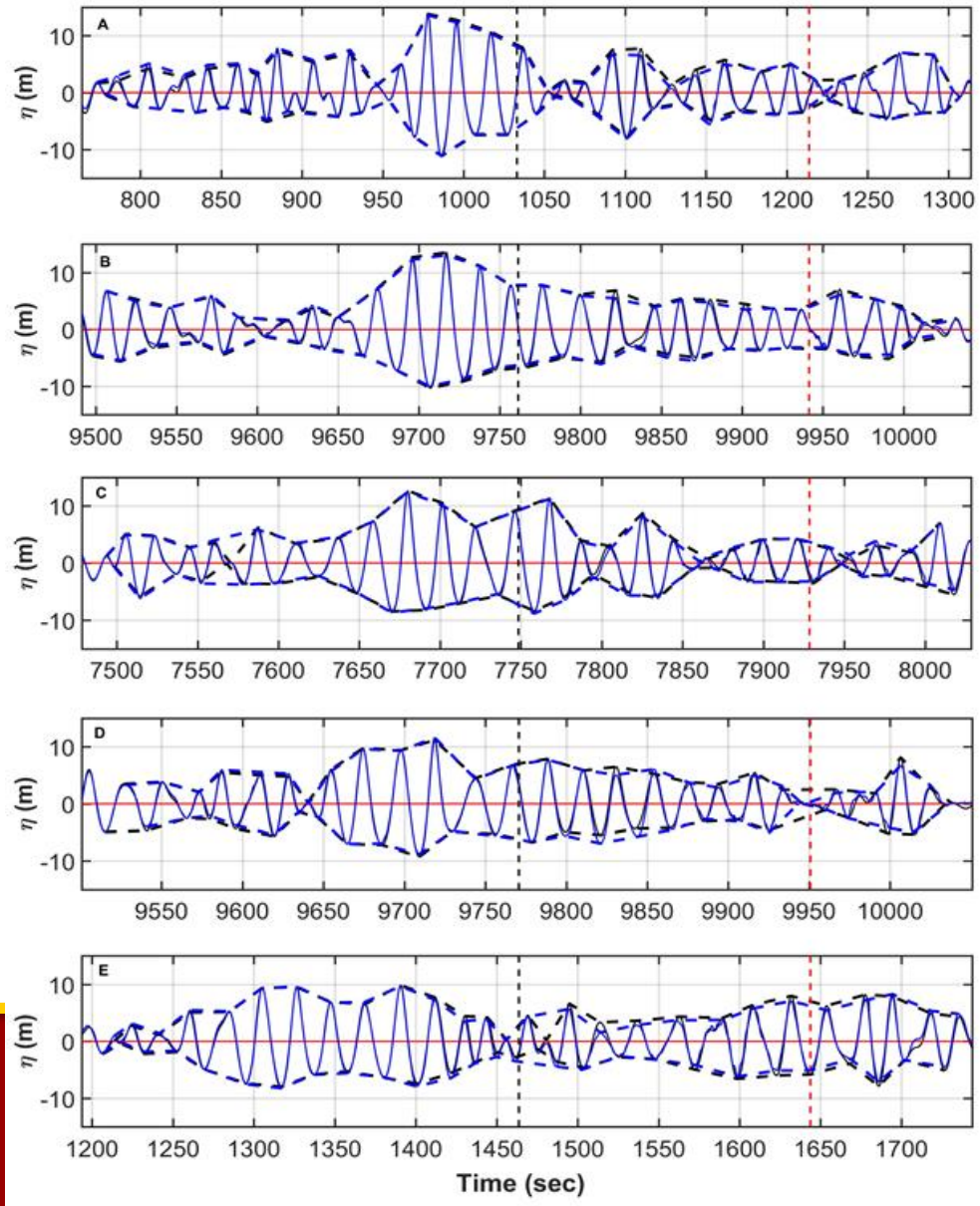



# Generation Mechanisms

- An extreme runup event is defined in this study as a runup elevation prediction that is $5\sigma$ from the mean.
- A total of 5 extreme events out of 1,875,000 simulated waves .
- Based on this , for every 69 days of energetic wave conditions at a single location, we can expect one extreme runup event to occur.
- The wave parameters found for the generation of the extreme event:
  - Event 1: $H_s = 12\ m\ T_p = 20\ sec$
  - Event 2: $H_s = 11\ m\ T_p = 21\ sec$
  - Event 3: $H_s = 11\ m\ T_p = 22\ sec$
  - Event 4: $H_s = 12\ m\ T_p = 22\ sec$
  - Event 5: $H_s = 12\ m\ T_p = 22\ sec$

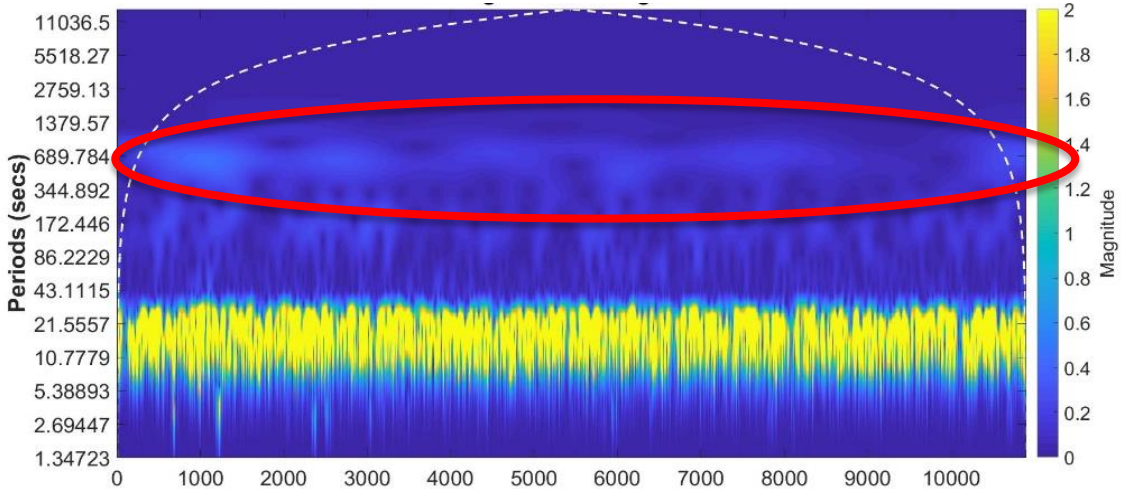
# Characteristics of the Envelopes

- Particular characteristics of the envelope :
  1. 1-2 energetic pulses are needed
  2. Envelope duration >180 sec
  3. Number of waves > 9 waves
  4. Mean H > 11m
  5. Mean T > 19 sec

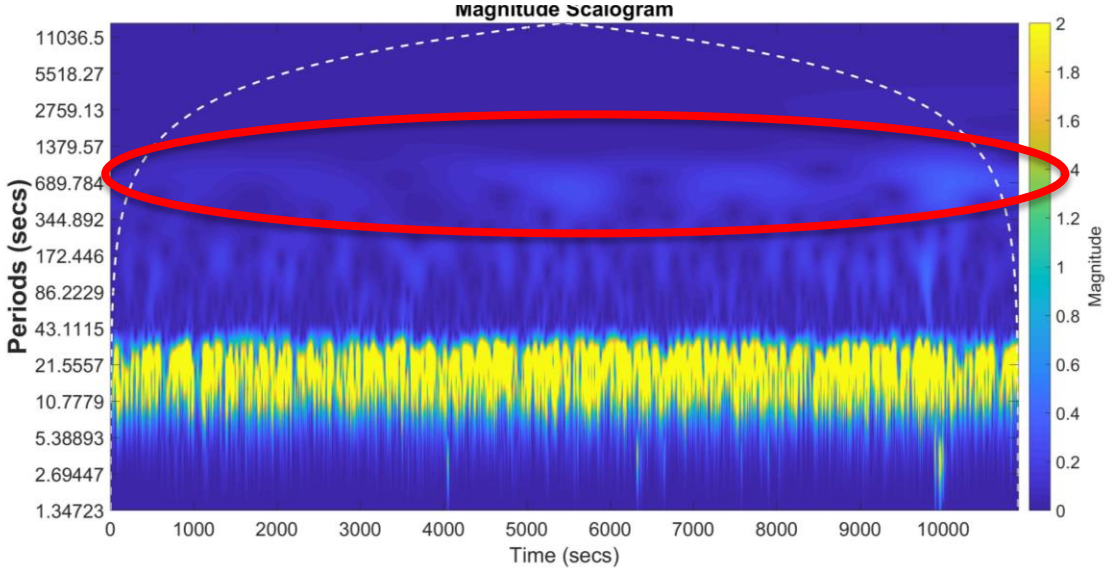


# Wavelet Analysis: Event 1 and 2

Event 1: $H_s = 12\ m\ T_p = 20\ sec$

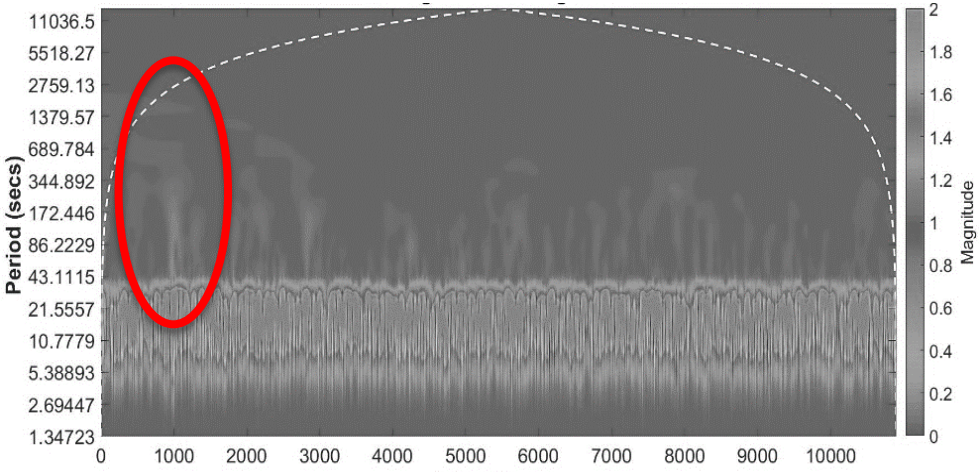



Event 2: $H_s = 11\ m\ T_p = 21\ sec$

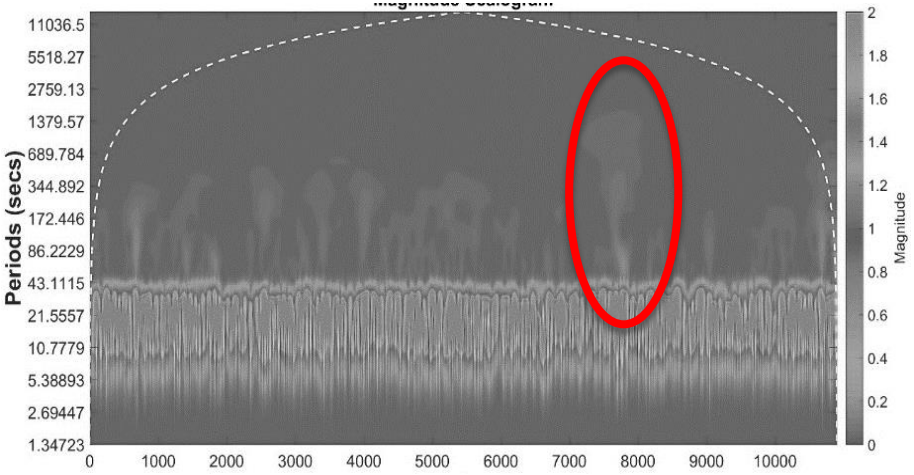


# Wavelet Analysis:
# Events 1-3 Constant d offshore

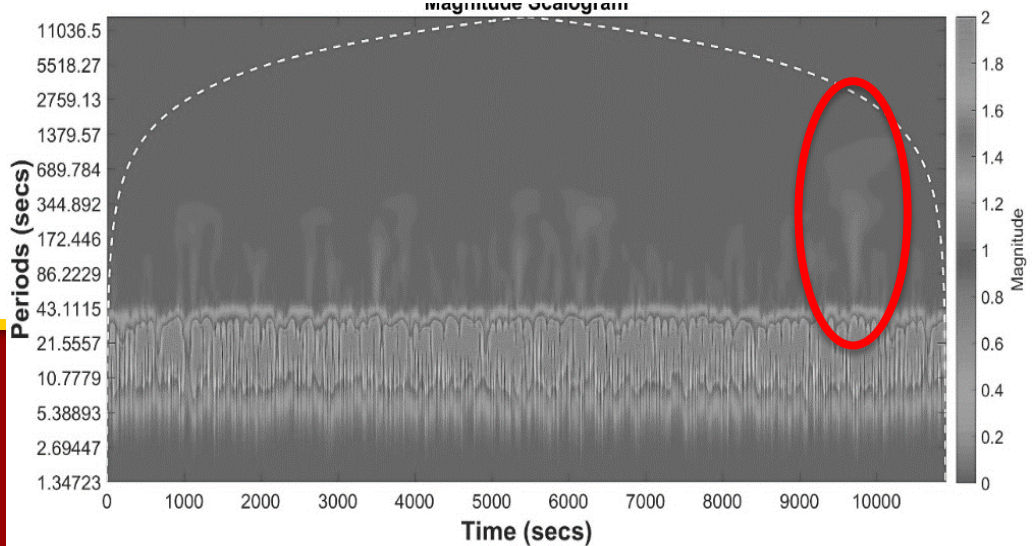
Event 1: $H_s = 12\ m\ T_p = 20\ sec$




Event 2: $H_s = 11\ m\ T_p = 21\ sec$

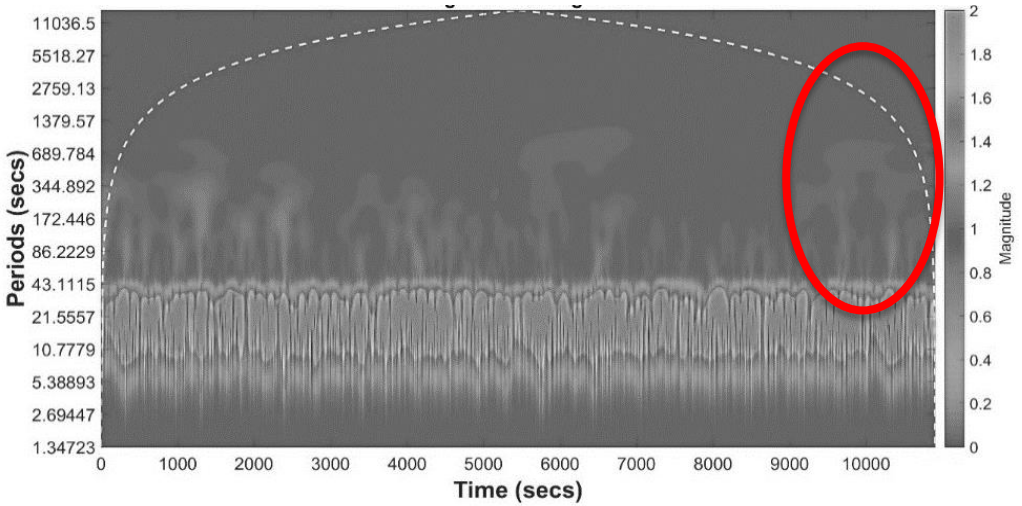



Event 3: $H_s = 11\ m\ T_p = 22\ sec$

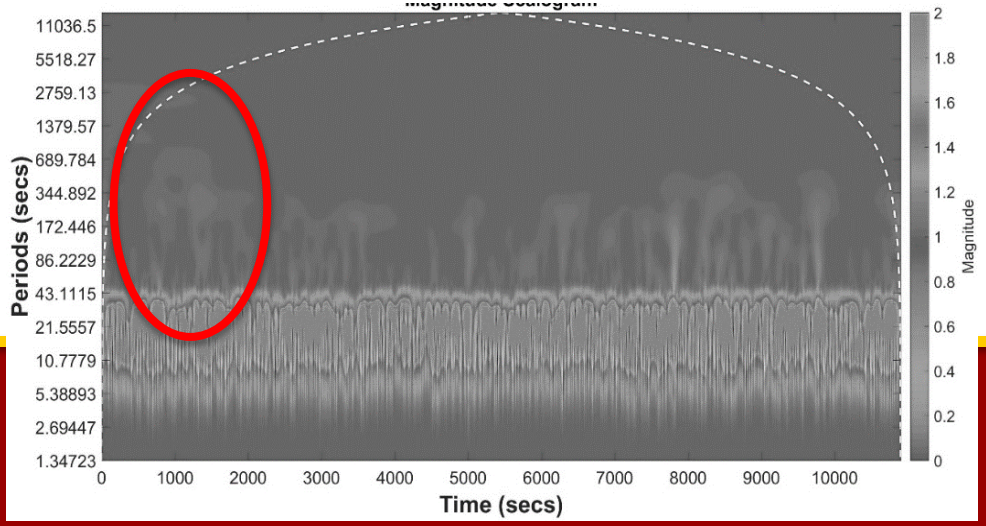


# Wavelet Analysis: Event 4 and 5

Event 4: $H_s = 12\ m\ T_p = 22\ sec$




Event 5: $H_s = 12\ m\ T_p = 22\ sec$

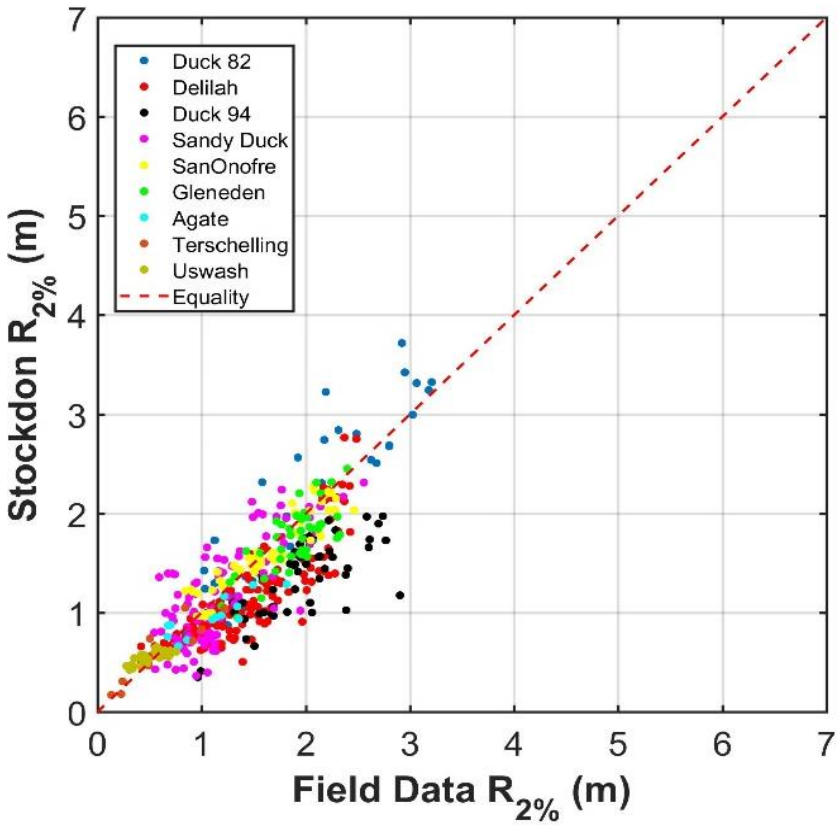


# Conclusions

- For high energy wave conditions, with beaches that have IG-dominated runup, in order to get numerically convergent extreme tail measurements ($R_{2\%}$ - $R_{0.05\%}$ ) values, a Δf of $10^{-5}$ and $5 \times 10^{-6}$ Hz is needed.
- This is more than 100 times smaller than what is typically used in these Boussinesq / coastal phase-resolving models.
- The reason for such a small Δf is because the integrated low frequency energy transfer is sensitive to a fine resolution of the interacting frequencies.
- Very Important to indicate input frequency resolution for IG wave studies
- A total of 5 extreme runup events were identified out of 1,875,000 simulated waves. Based on this we can expect an extreme event happening every 69 days of energetic wave conditions.
- Based on the envelope analysis, extreme events depends on the arrival time of the pulses, the amplitudes and periods of the waves in each packet, the duration of each packet, and the geometric properties of the shelf.
- The wavelet analysis revealed that the reef resonance contributes to the extreme events
- Energetic nonlinear transfer plumes were present right before the extreme event. These plumes indicate that there is leakage of energy from low periods to higher periods suggesting triad interactions are taking place.

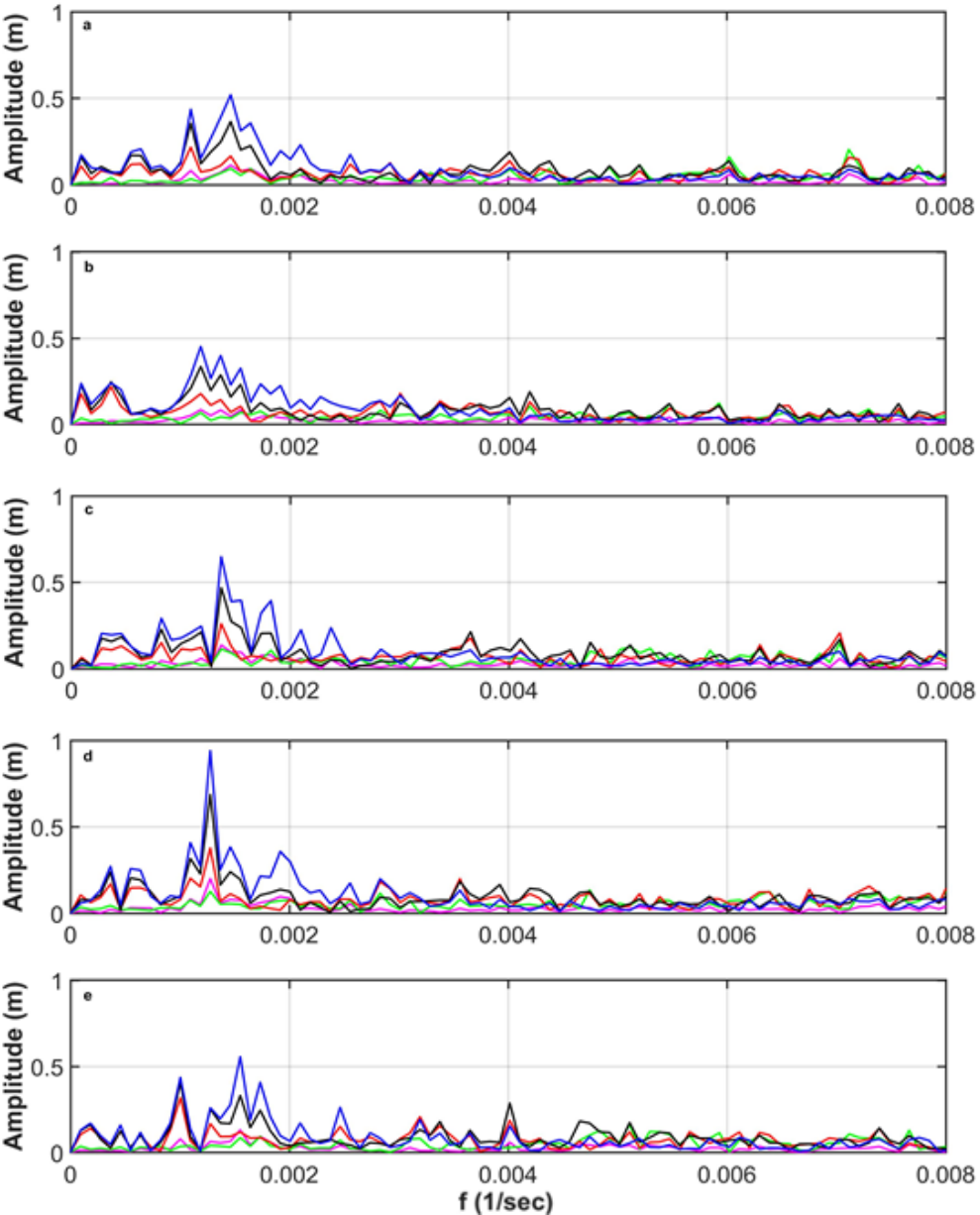

# QUESTIONS?

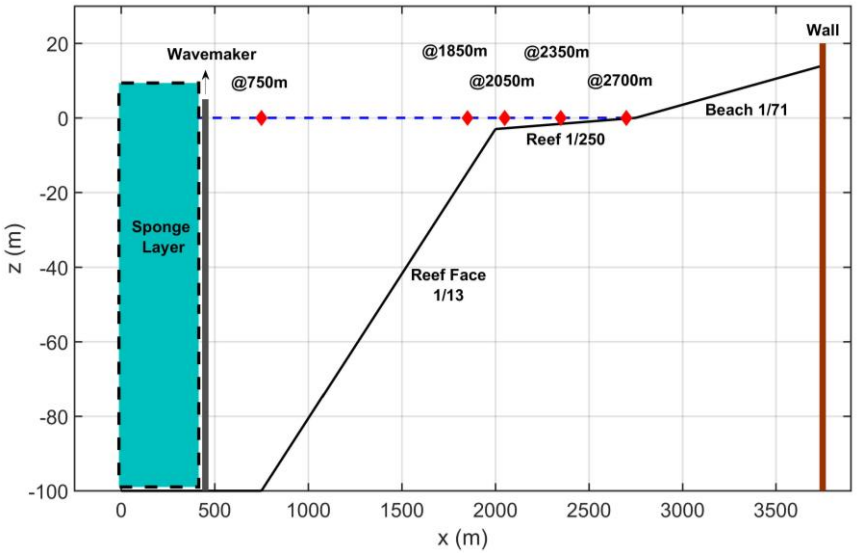
# Runup: Stockdon et al. (2006)




- Developed using 10 different data sets and it includes contribution from IG waves
- There is some scatter In the data
- Largest observed runup height is 3.5 m.

# IG Amplitude Spectrum




- Most of this energy is found in between 0.001-0.002 Hz due to the reef resonance.
- In these extreme events the IG waves contribute wave amplitudes of 0.5 m to almost 1m near the shoreline