Wave height distributions and spectral properties in the nearshore region

University of Victoria

Johannes Gemmrich,
University of Victoria, Canada

Pacific coast, Canada
<1 km from shore:
- **Pressure sensors, long-term record**

Public Safety Canada | Sécurité publique Canada

Funded through the Search and Rescue New Initiatives Fund (SAR NIF)

Natural Sciences and Engineering Research Council of Canada | Conseil de recherches en sciences naturelles et en génie du Canada

Discovery Grant

Canada

Location

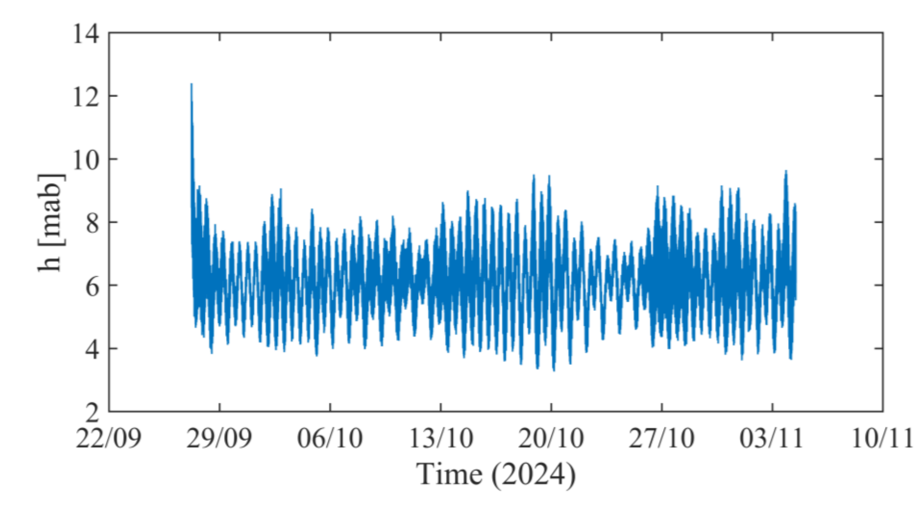
Pacific Rim
National Park,
Vancouver Island,
BC, Canada

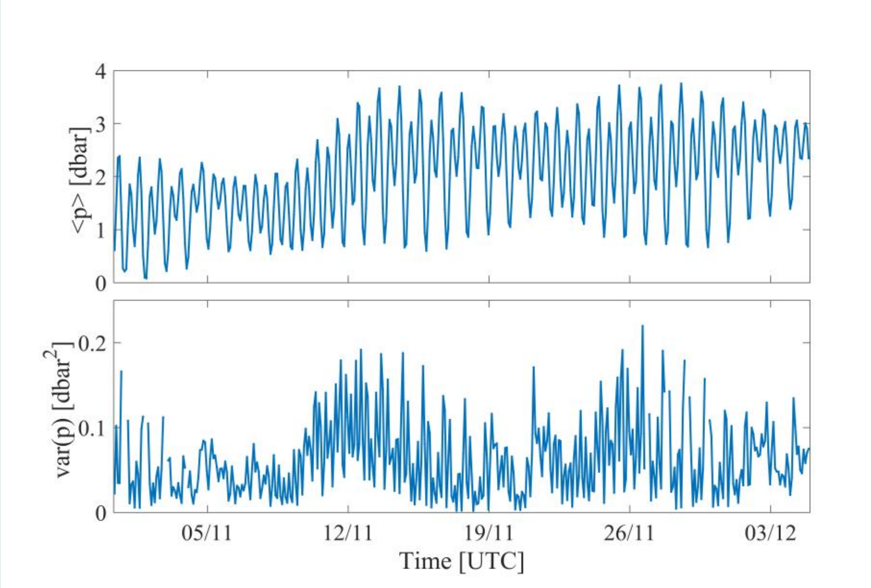
- **Harsh wave climate (H_s>8m, near shore)**
- **Long fetch**
- **Swell**

Observations: bottom-mounted pressure recorder (2Hz)

1 km offshore,
2 sites, D 8m, D= 6m

Inter-tidal zone





Total record length: 362 days

Pressure –> surface elevation

$$\eta_H = \frac{p - p_{atm}}{\rho g} - z_0$$

z_0: mean water depth

Hydrostatic

$$\eta_{SL} = \eta_H - \frac{z_0}{2g}\frac{\partial^2 \eta_H}{\partial t^2}$$

Shallow water, linear

$$\eta_{SNL} = \eta_{SL} - \frac{1}{g}\left[\left(\frac{\partial \eta_{SL}}{\partial t}\right)^2 + \eta_{SL}\frac{\partial^2 \eta_H}{\partial t^2}\right]$$

Shallow water, non-linear

- Applied locally in time
- Weakly dependent on low-pass filter

Contents lists available at ScienceDirect

Coastal Engineering

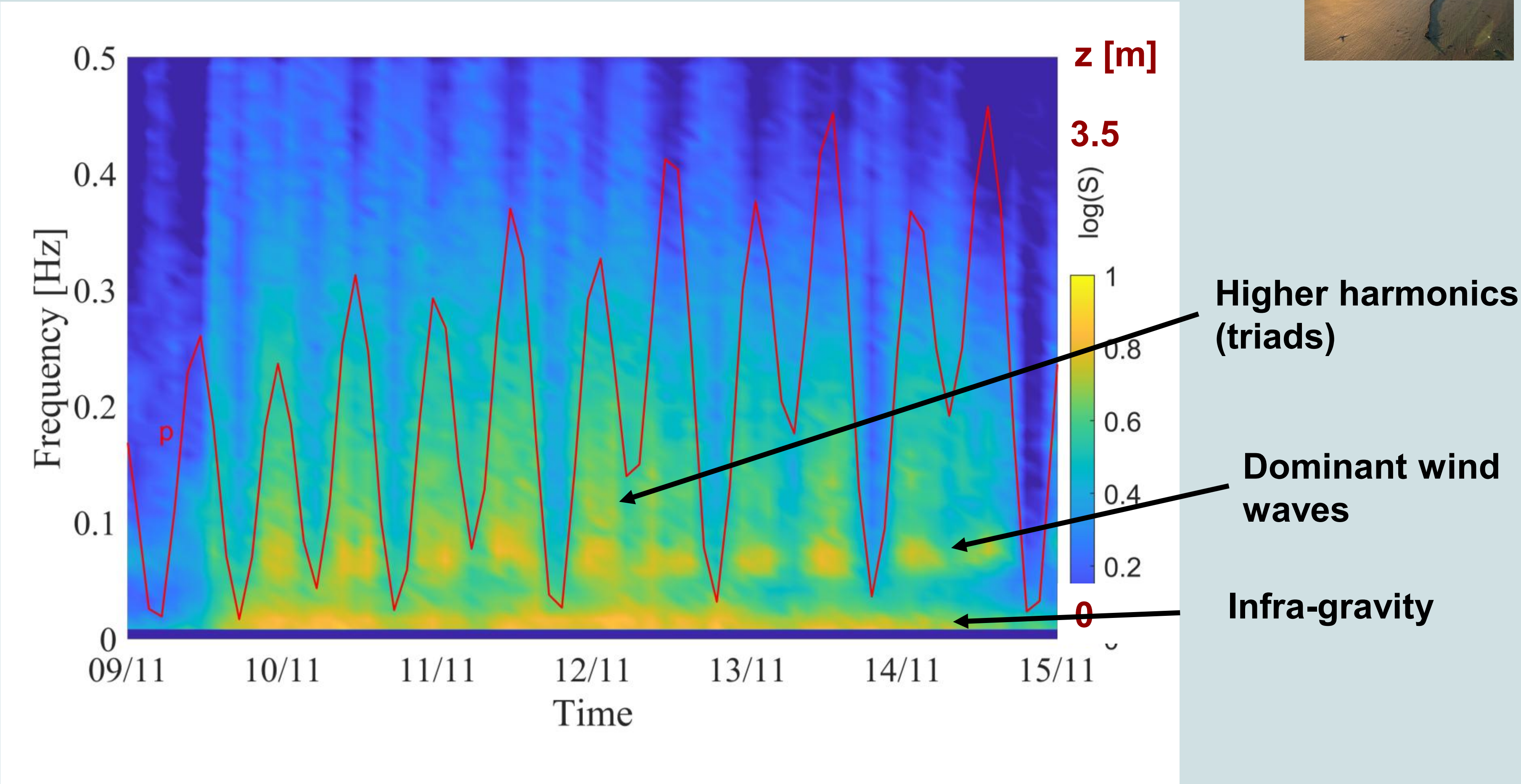
journal homepage: www.elsevier.com/locate/coastaleng

ELSEVIER

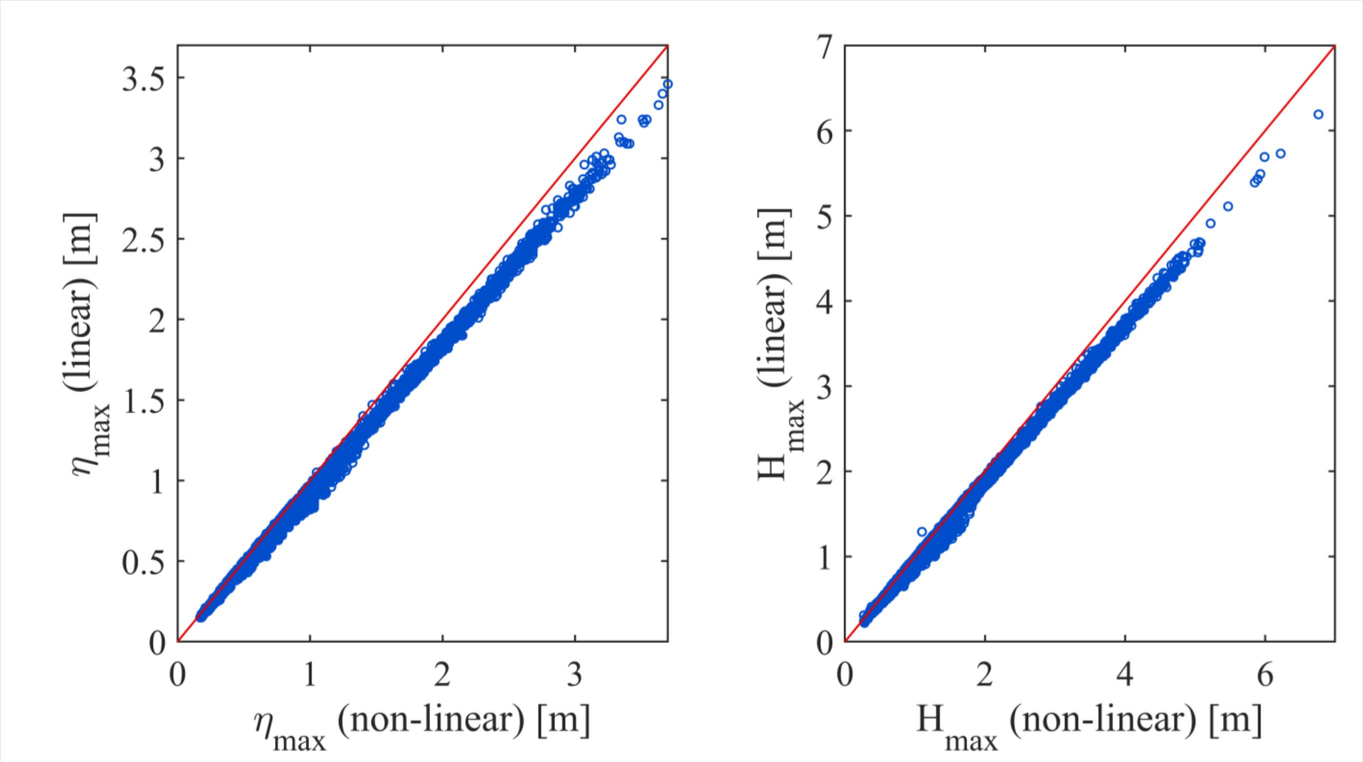
A nonlinear weakly dispersive method for recovering the elevation of irrotational surface waves from pressure measurements

P. Bonneton [a,*], D. Lannes [b], K. Martins [c], H. Michallet [d]

Spectral properties in varying water depth



Surface elevation retrieval – maximum height



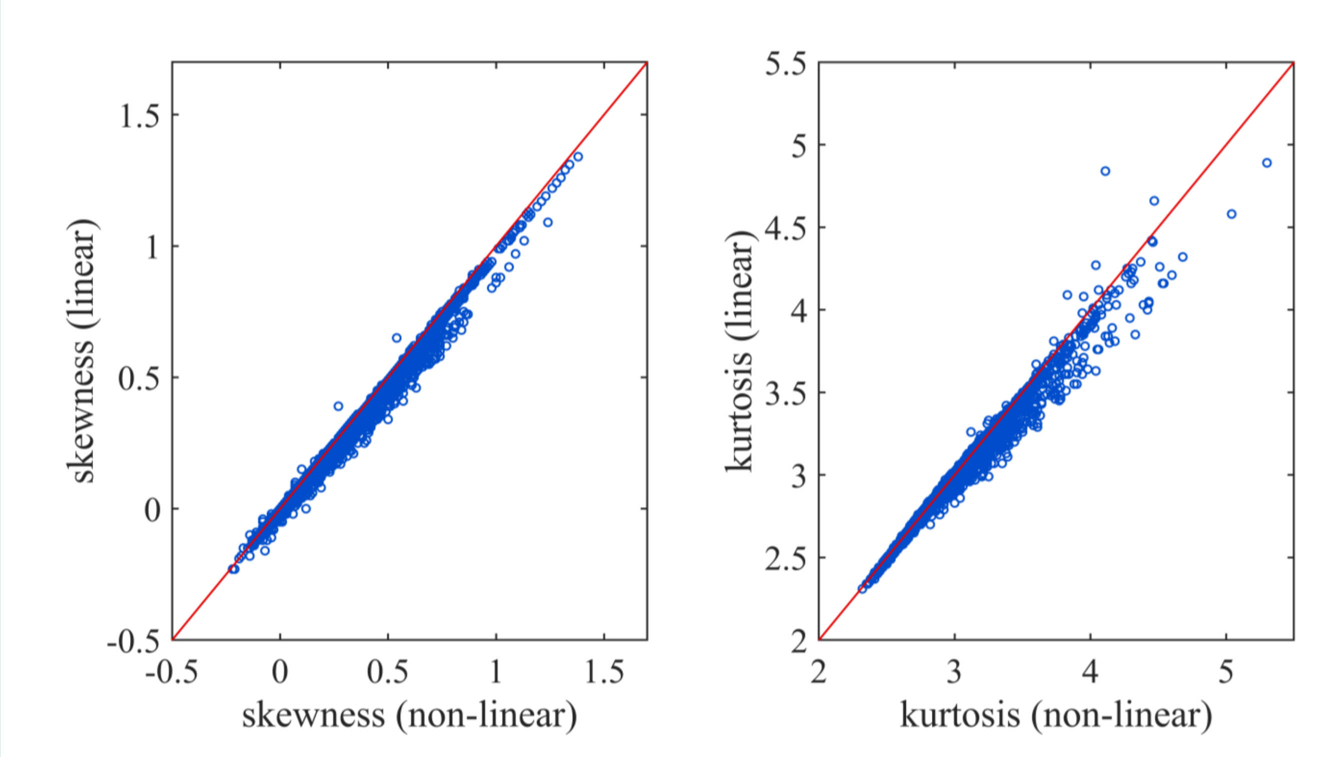
Under-estimation by linear method

Crest height: 8.2%

Wave height: 7.3%

8705 hourly data

Surface elevation retrieval – higher moments



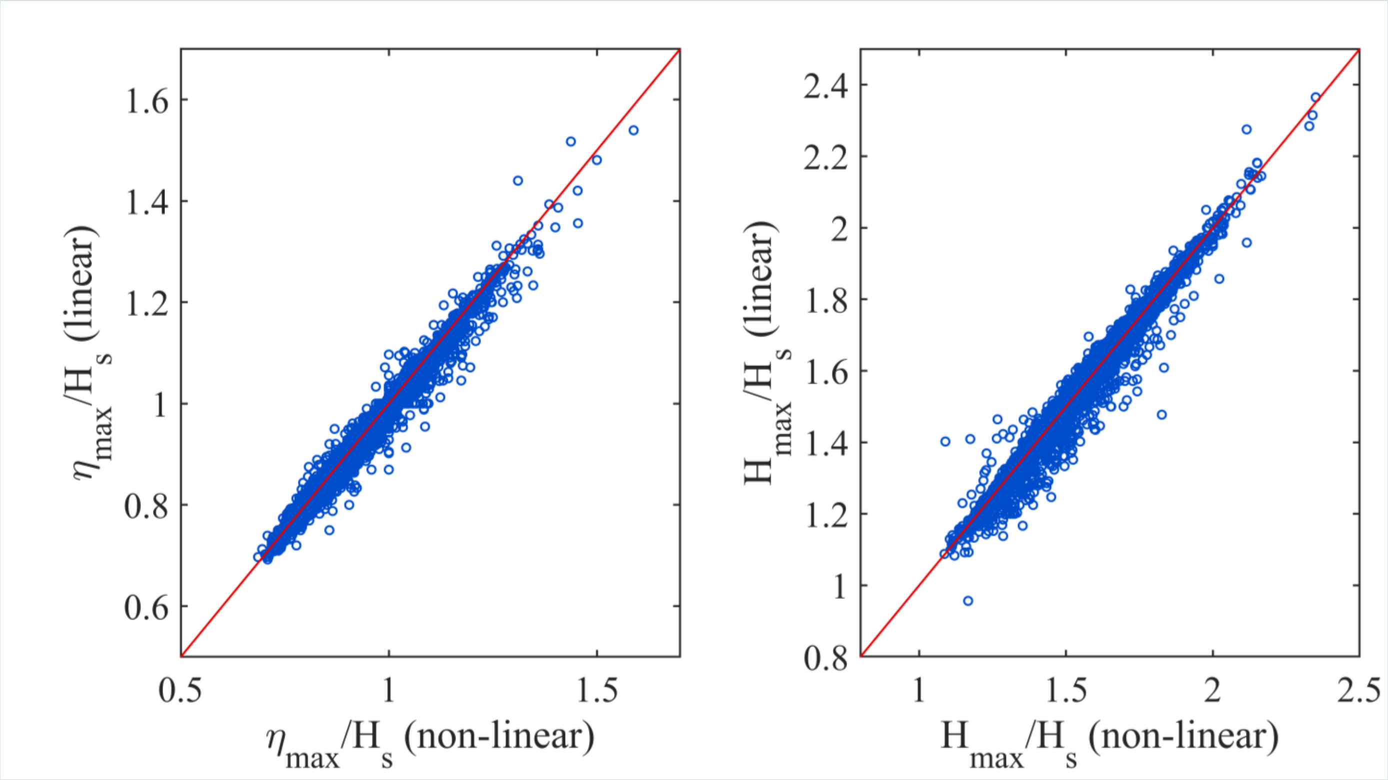
Under-estimation by linear methods

Skewness: 4.0%

Kurtosis: 7.3%

8705 hourly data

Surface elevation retrieval – normalized maximum height



Only small offset by linear methods

Crest height: 3.0%
Wave height: 0.7%

Useful parameter

Wave nonlinearity: Ursell number

$$Ur = 4\pi^2 \frac{H/D}{(kD)^2} \propto \frac{\mathit{relative\ wave\ height}}{(\mathit{relative\ water\ depth})^2}$$

Ur < 20: deep water, linear waves
20 < Ur < 50: intermediate nonlinearity
Ur > 50: shallow water, nonlinear waves

Presentation

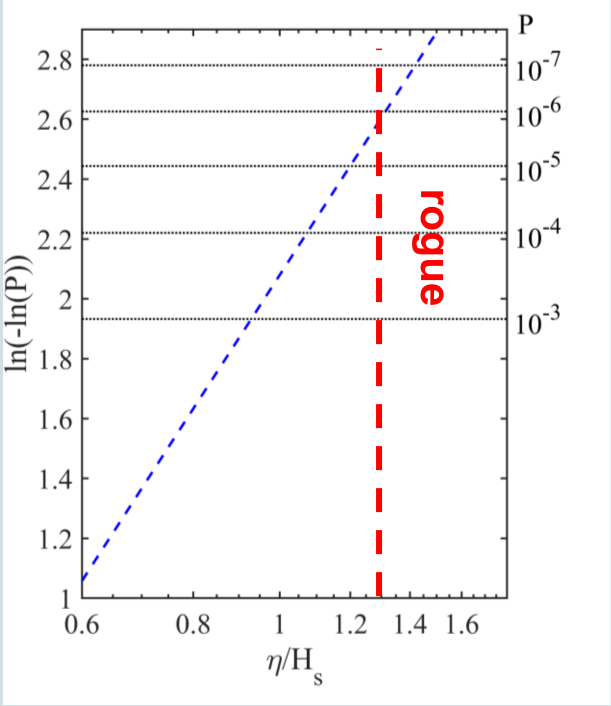
Weibull distribution:

$$P\left(\frac{\eta}{H_s} > z\right) = \exp(-\beta z^{\alpha})$$

$$\ln(-\ln(P)) = \alpha \ln(z) + ln(\beta)$$

Any Weibull distribution = straight line
α: slope, ln(β): y-value at z=1

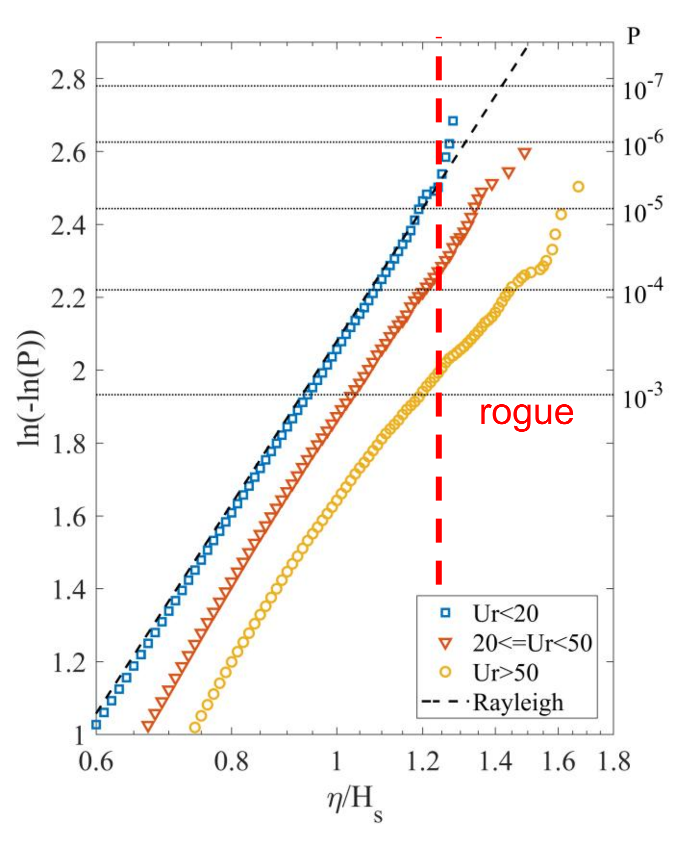
Note: Rayleigh distribution: α = 2, β = 8



Normalized height

Probability →

Crest height distributions – wave nonlinearity



Normalized crest height

Probability ↓

Crests are <u>taller</u> than in Gaussian sea

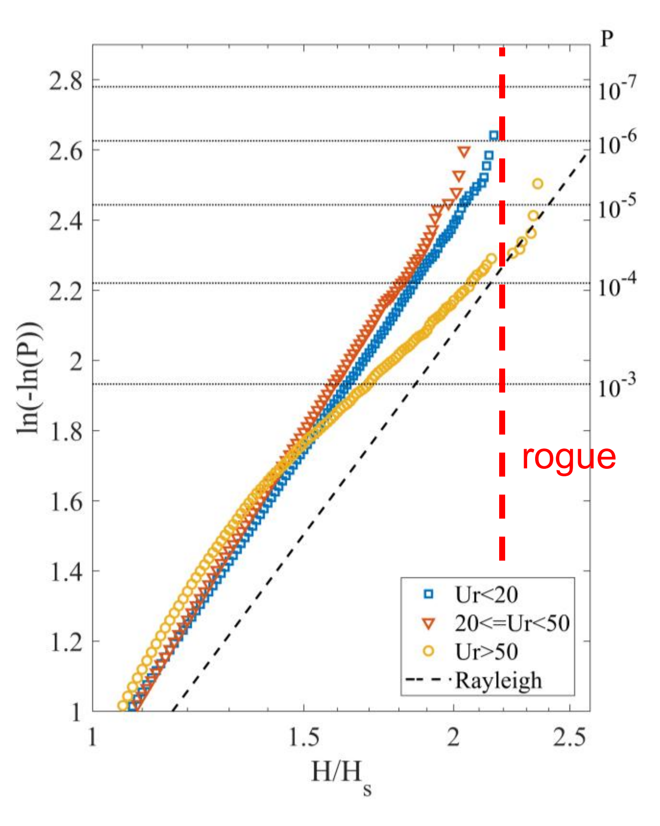
Frequent rogue crests ($\eta/Hs>1.25$)

Ur<20: Rayleigh distribution, $\alpha=2,\beta=8$

Ur>20: Weibull distribution, $\alpha=2,\beta<<8$

Ur>50: convex → extreme crests have increased probability (= true rogues)

Wave height distributions – wave nonlinearity



Normalized wave height

Probability ↓

Waves are <u>smaller</u> than in Gaussian sea

Very rare rogue waves (H/Hs>2.2)

Ur<50: Weibull distribution, α=2,β>2

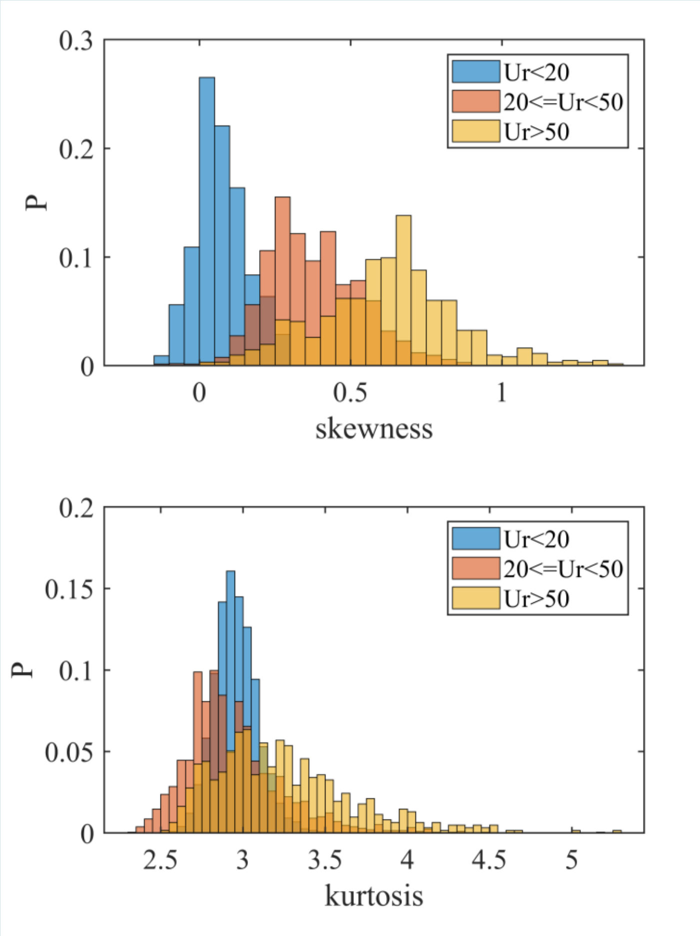
Ur>50: Composite Weibull Distribution

H/Hs<1.5: α=2.1

H/Hs>1.5: α=1.4

→ Larger waves more likely

Spectral properties - nonlinearity



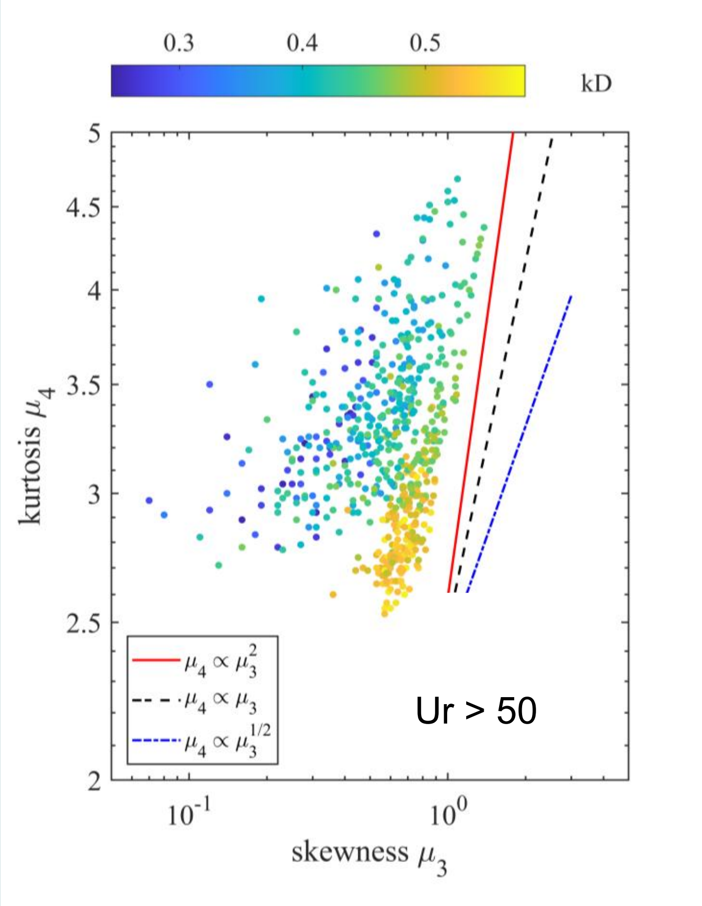
Skewness:

- Positive → Crest-trough asymmetry in shallow water
- Mean increases with nonlinearity

Kurtosis:

- Mean = 3 (Gaussian)
- Spread increases with nonlinearity

Kurtosis - skewness



$$\mu_4 \propto {\mu_3}^n$$

<u>2nd- order theory</u>:

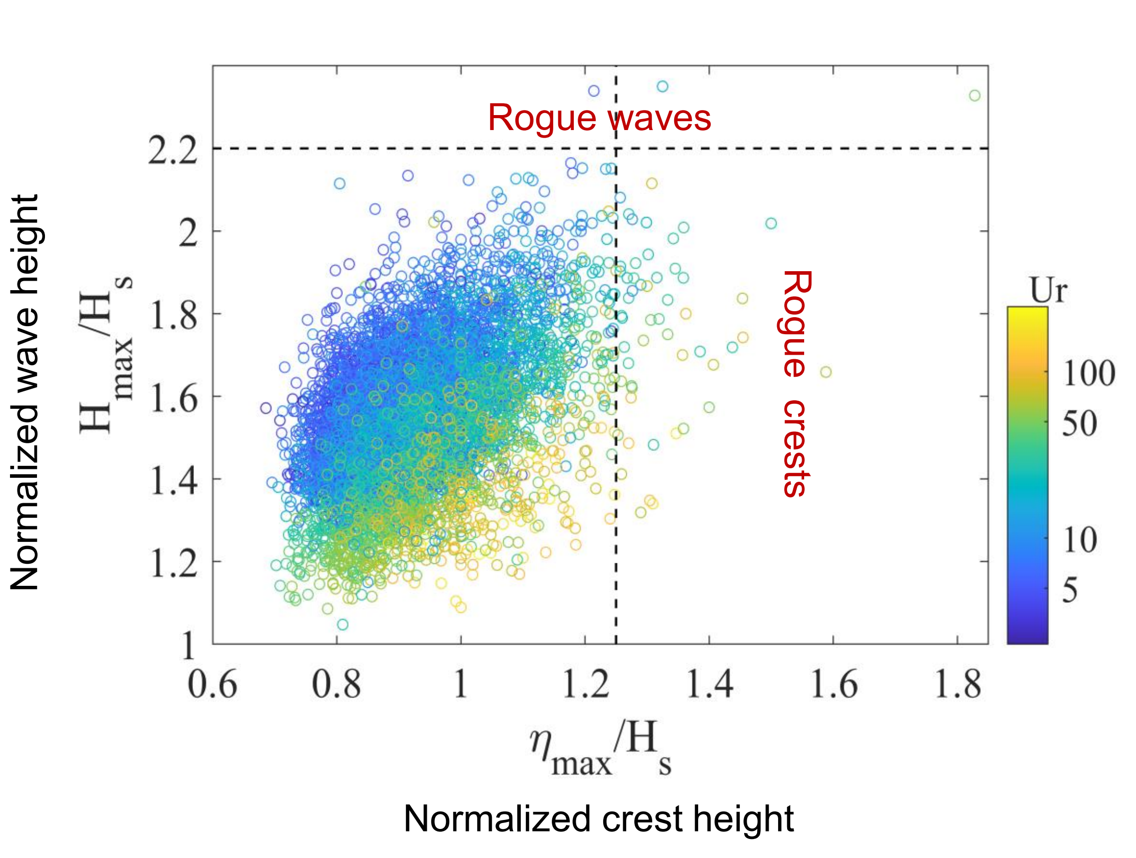
n = 2, also observed in wave tanks

<u>Observations:</u>

n = 1 for intermediate water depth kD>0.4

n < 1 for very shallow water kD<0.4

Maximum wave and crest height (hourly)



Maximum wave height:

- **Decreases with nonlinearity**

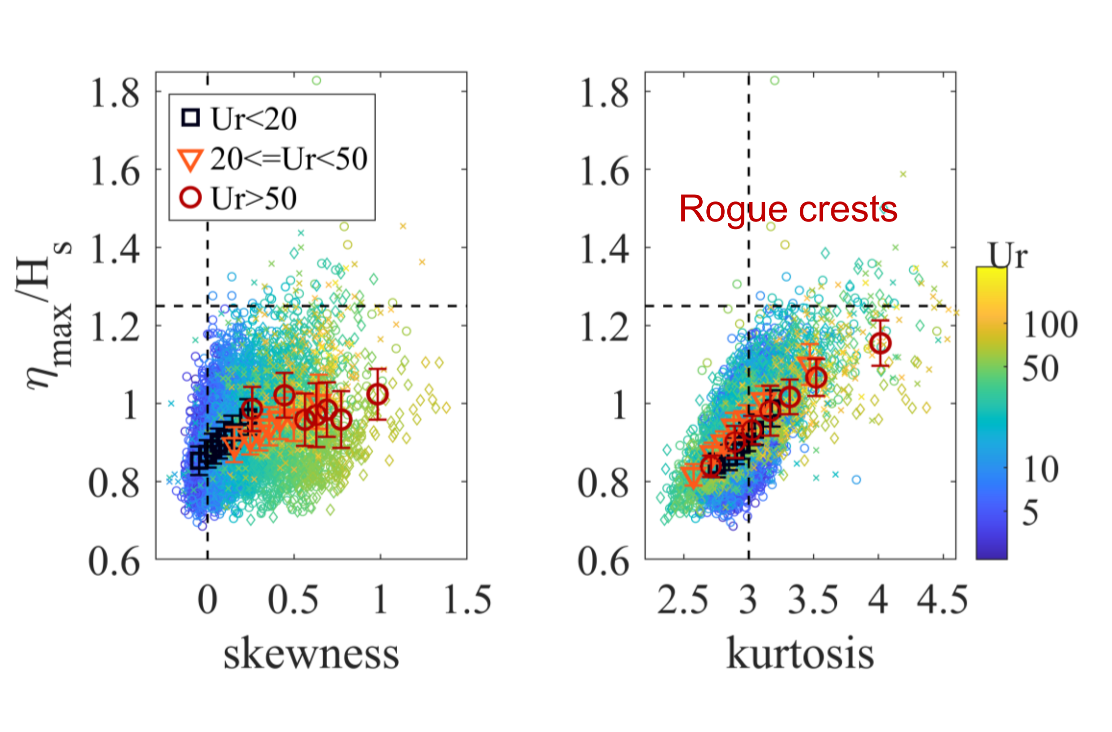
- **Rogue waves extremely rare (~ every few months)**

Maximum crest height:

- **Increases with nonlinearity**

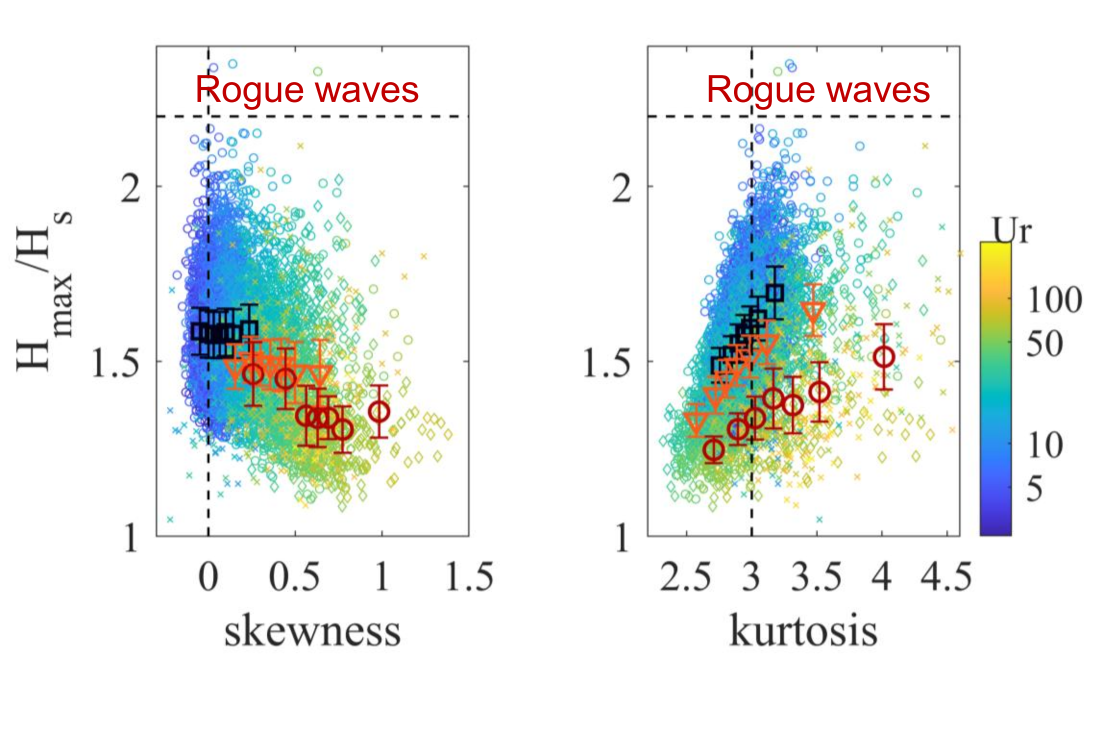
- **Rogue crests are common (~ every 10 h)**

Maximum crest height – higher moments



- **Independent of skewness**
- **Increases linearly with kurtosis**

Maximum wave height – higher moments



- **Independent of skewness, but decreases with nonlinearity**
- **Increases linearly with kurtosis**
  Dependence decreases with nonlinearity

Summary

- Nearshore fixed locations have wide range of wave nonlinearities
- Results from wave tanks or numerical models are idealized / not representative of real coastal ocean
- Nonlinear surface retrieval from pressure data required
- High crests and small H_W in shallow water
- Skewness – kurtosis: linear dependence
- Excess skewness → little effect on height maxima (crest and waves)
- Excess kurtosis → increased crest maxima, weak increase of wave maxima