Are *unexpected waves* as important as *rogue wa*

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Conclusion

- **The "surprise effect" of large waves, after a calm period, is significant**
- **Based on linear simulations, *unexpected* waves are expected frequently!**
  Isolated unexpected waves are most frequent in developed seas
  Unexpected wave groups are most frequent in young seas
- **Most *unexpected* waves are not *rogues***
- **Not every *rogue* wave is unexpected**

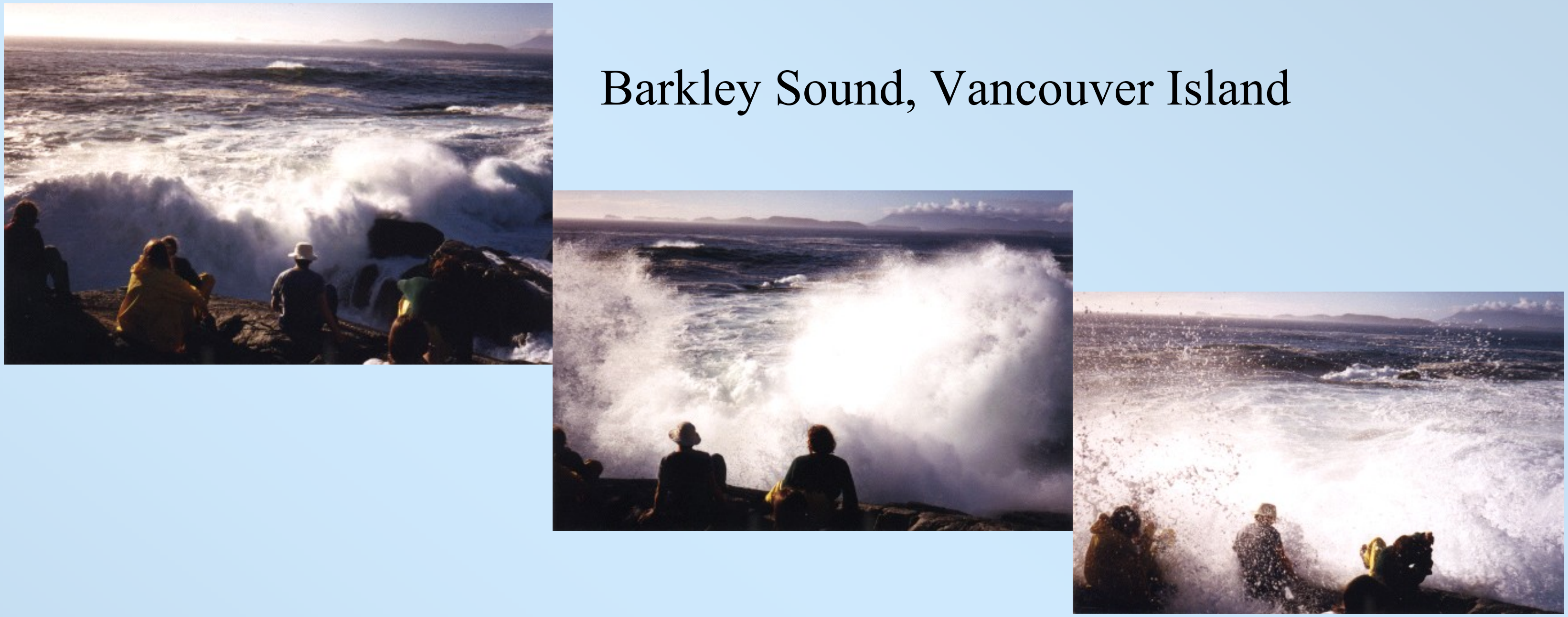
Project funding:

National Search and Rescue Secretariat Secrétariat national recherche et sauvetage

SAR NEW INITIATIVES FUND

Rogue waves – 2 examples from Vancouver Island

I



Barkley Sound, Vancouver Island

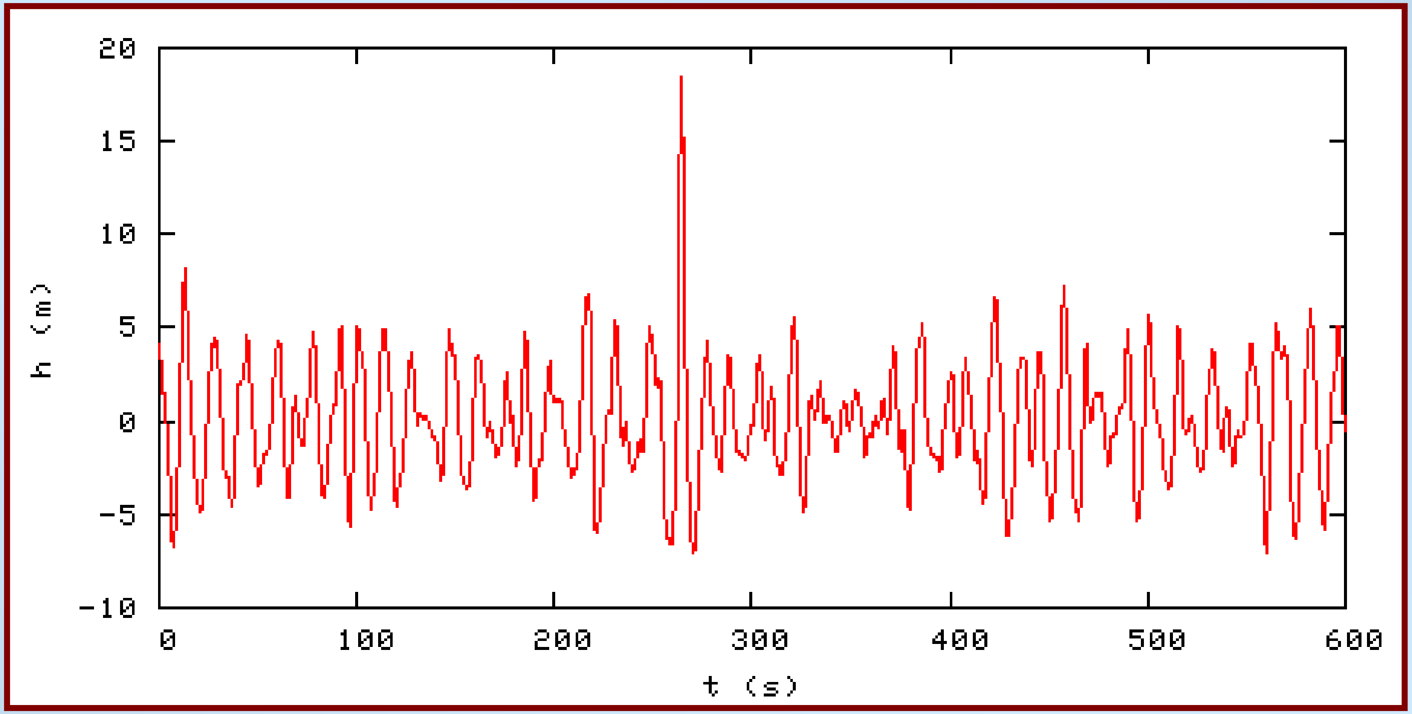
II

… Just yesterday, 5 hikers were airlifted off of the West Coast Trail when they were hit by a rogue wave and were sucked into a surge channel from which, they couldn't escape. The rescue, a joint Canadian/U.S. mission, involved several Canadian coast guard vessels, a Canadian Armed Forces helicopter, a U.S. Coast Guard helicopter and a U.S. research vessel.

June 15, 2007

Large wave was not anticipated

Rogue waves



“New Year’s Wave” at Draupner Platform (North Sea), January 1, 1995

- Damage to ships and offshore structure
  globally: 1 large ship per week
- Risk, loss of lives on beaches
  Vancouver Island: several people per year

Rogue wave occurrence

common ***rogue wave*** definition: $H_{rogue} \geq 2.2\ H_s$

$H_s = 4\sigma$: significant wave height
σ: rms surface elevation

Wave height distribution:
(linear theory, narrow-band frequency spectrum)

$$p(H) = \frac{H}{4\sigma^2} \exp\left[-\frac{H^2}{8\sigma^2} \right]$$

Rayleigh distribution

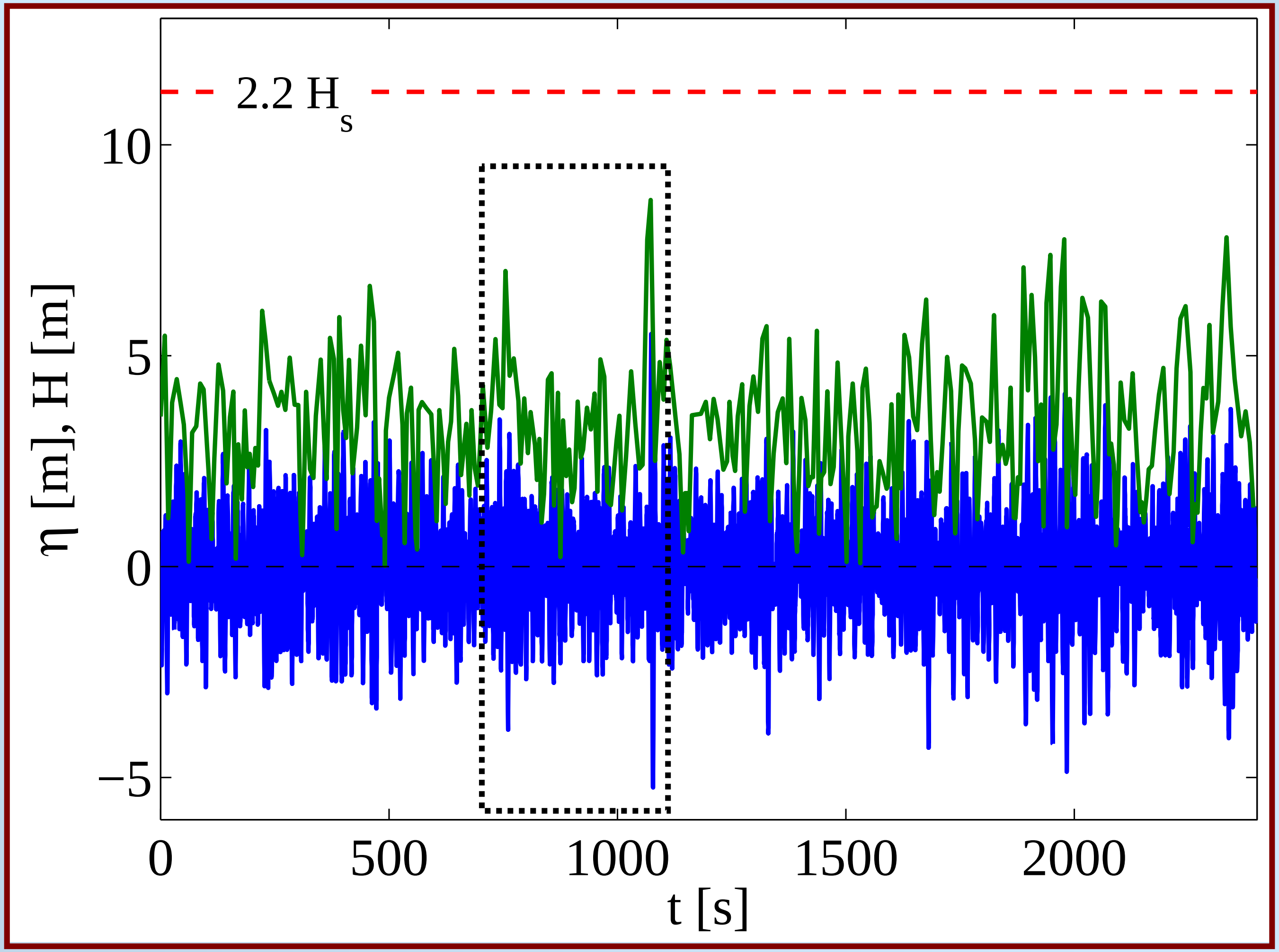
→ Exceedance probability: $P(H>2.2H_s) \approx 1/16800$

1 rogue wave every 2-3 days

Resonant non-linear interactions are expected to generate more frequent rogue wave occurrence

Unexpected waves

The rogue wave definition does not consider the "unexpectedness" of larger waves

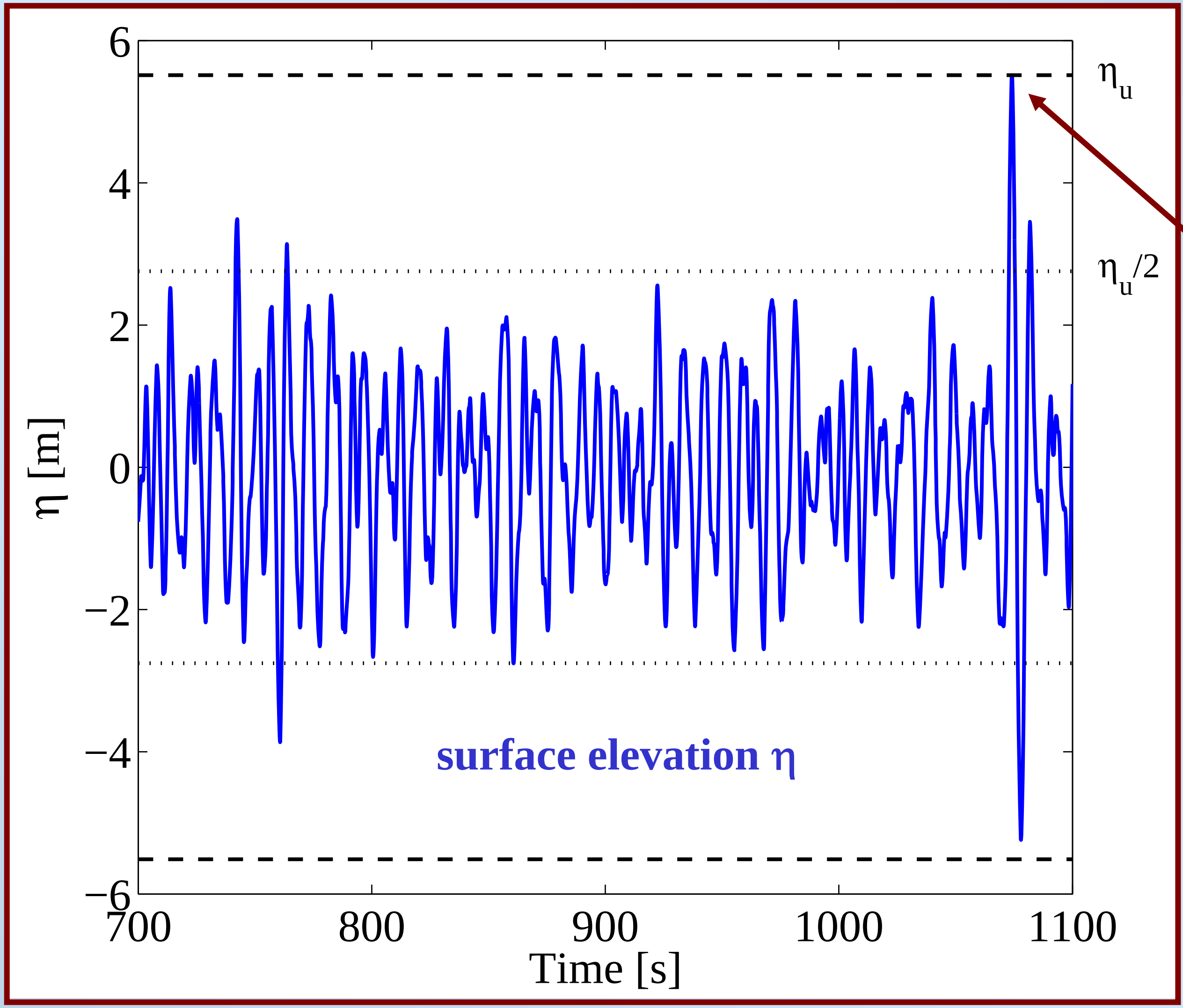


wave height H (trough to crest)

surface elevation η

simulated 40 minute surface elevation record
no rogue wave occurrence

Unexpected waves

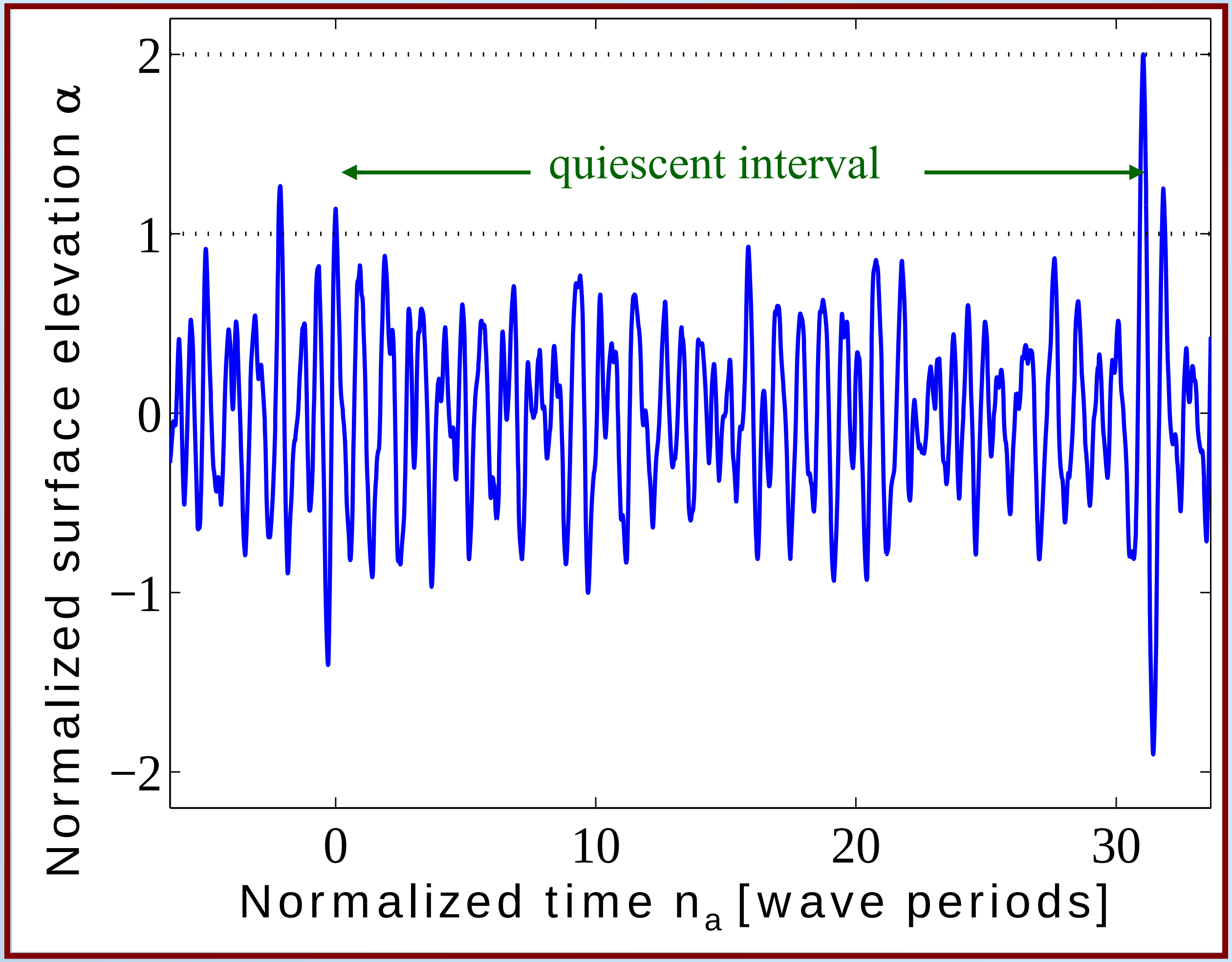


A wave crest twice as high as any in the preceding 300 s.

=

unexpected wave

Unexpected wave – general definition



unexpected wave

=

a wave crest
α times as high
as any of the
preceding n_a
crests.

(e.g., $\alpha \geq 2$, $n_a \geq 20$)

α: height ratio

n: length of quiescent interval

Unexpected wave – Monte Carlo simulations

- linear, random superposition of wave Fourier components
- Fourier components based on JONSWAP spectra, varying peak parameter γ

10 h time series, $6x10^4$ simulations

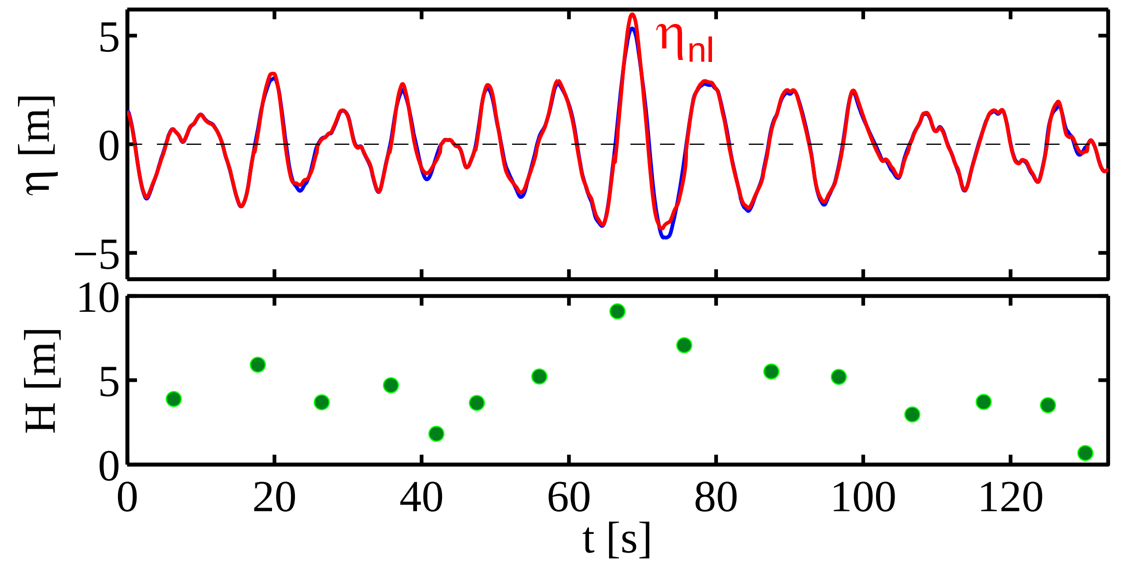
For each wave, find the nearest preceding wave with height $\geq 1/\alpha$

→ statistics of unexpected waves

Analyze: η: linear crest height

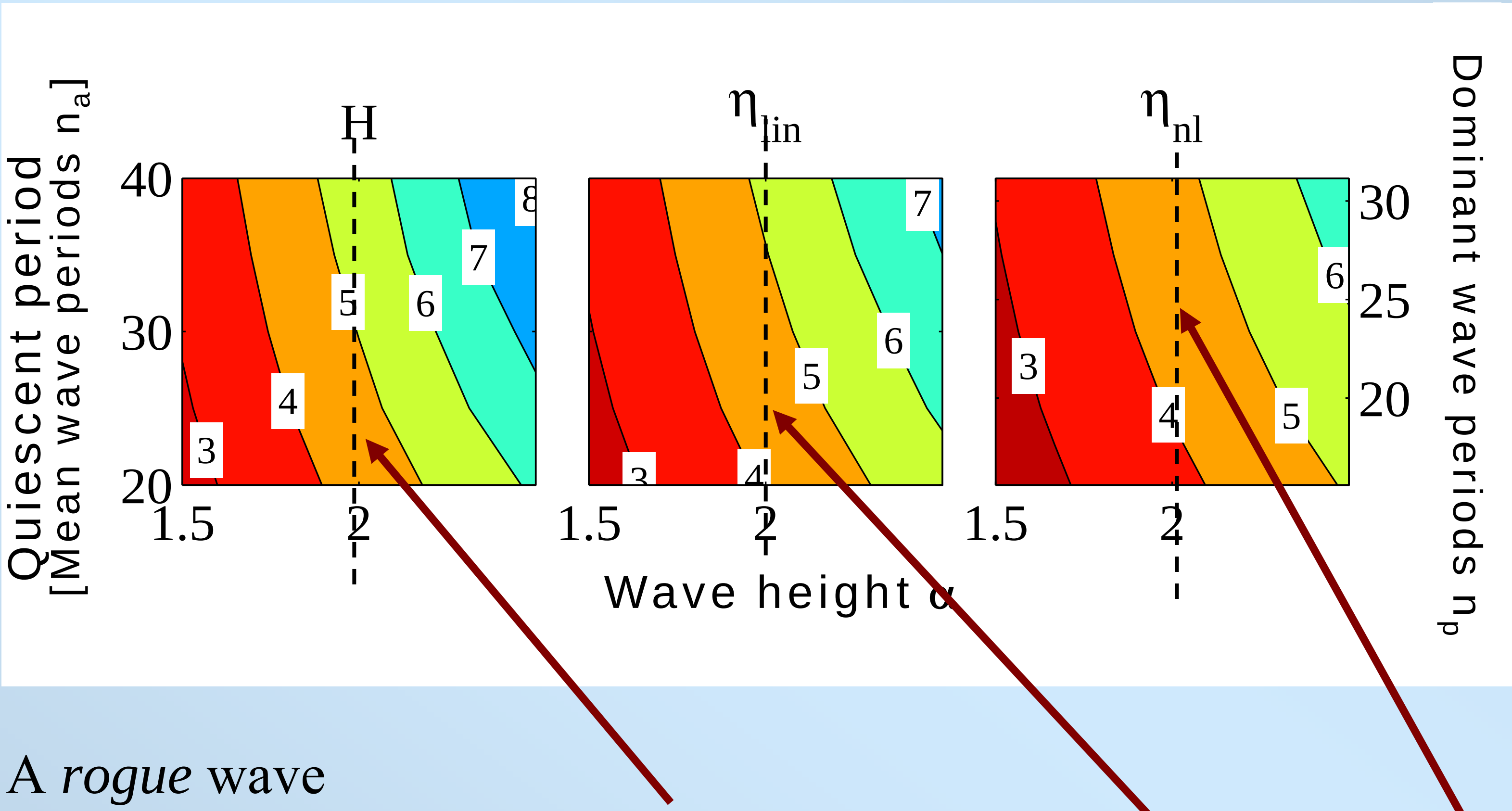
H: linear trough-crest wave height

η_{nl}: second order non-linear crest height $$\eta_{nl} = a\cos\theta + \frac{1}{2}ka^2\cos(2\theta)$$



Unexpected wave occurrence $R(\alpha, n_a)$

($\log_{10}$ of return time in peak periods)



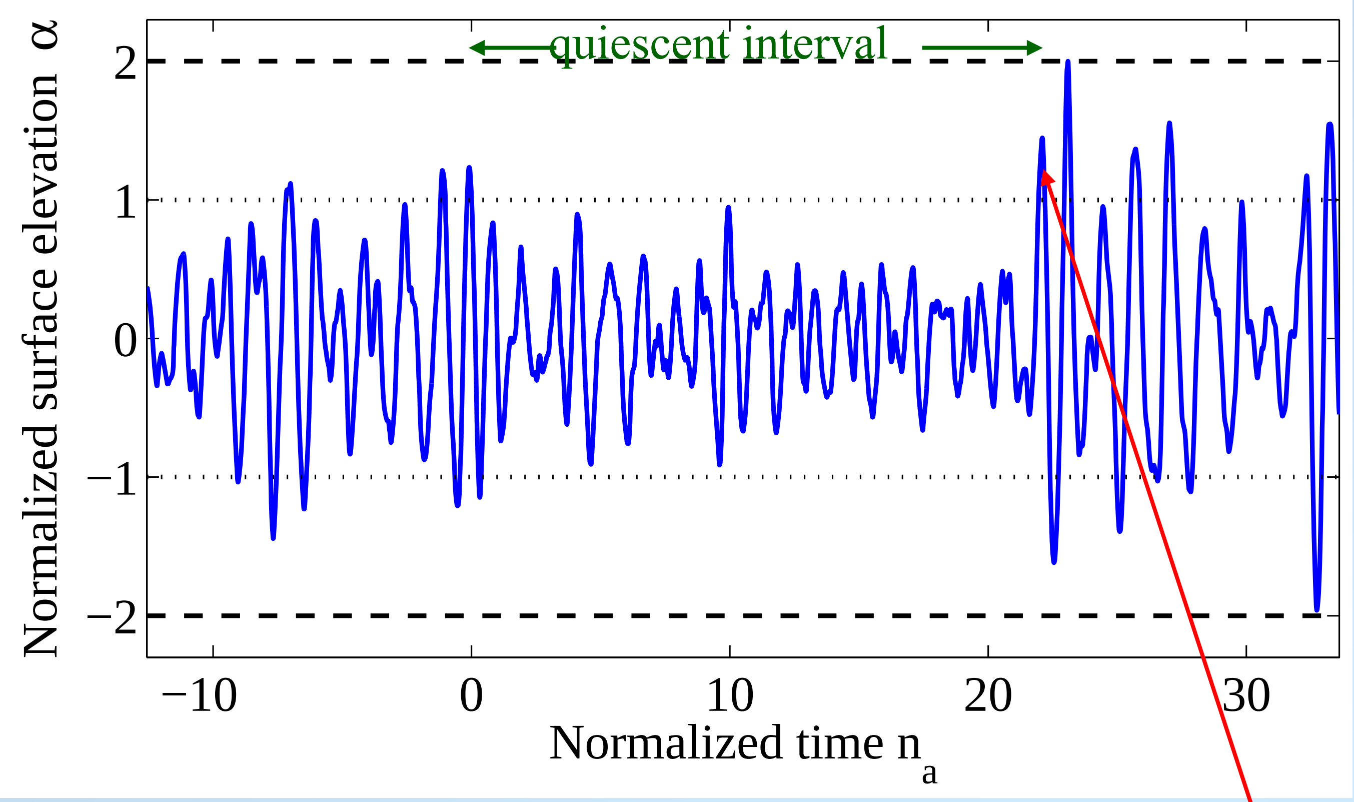
A *rogue* wave corresponds to the 4.23 contour, i.e. 1 in 16,800 waves (2 days).

An *unexpected* wave twice as big as any in the previous 22 periods is just as common.

25 periods

32 periods

Unexpected wave – relaxed definition

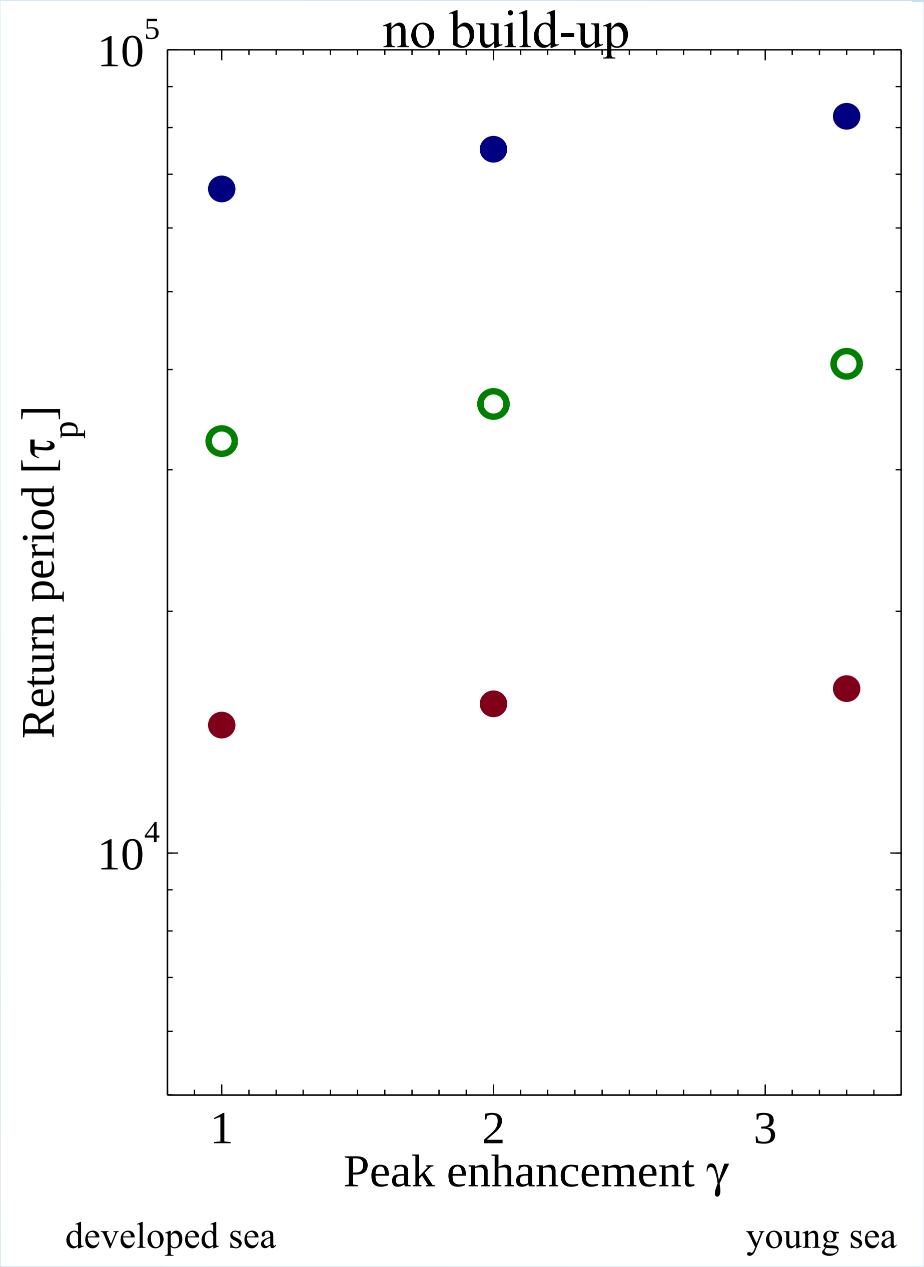


unexpected wave:

a wave crest **α times as high**
as any of the **preceding n_a** crests,
excluding **m** crests just prior.
(e.g., $\alpha \geq 2$, $n_a = 22$, $m = 1$)

Allowing for build-up of *m* waves prior to the unexpected wave

Return period – wave development



$\alpha = 2$, $n_p = 20$, $m = 0$

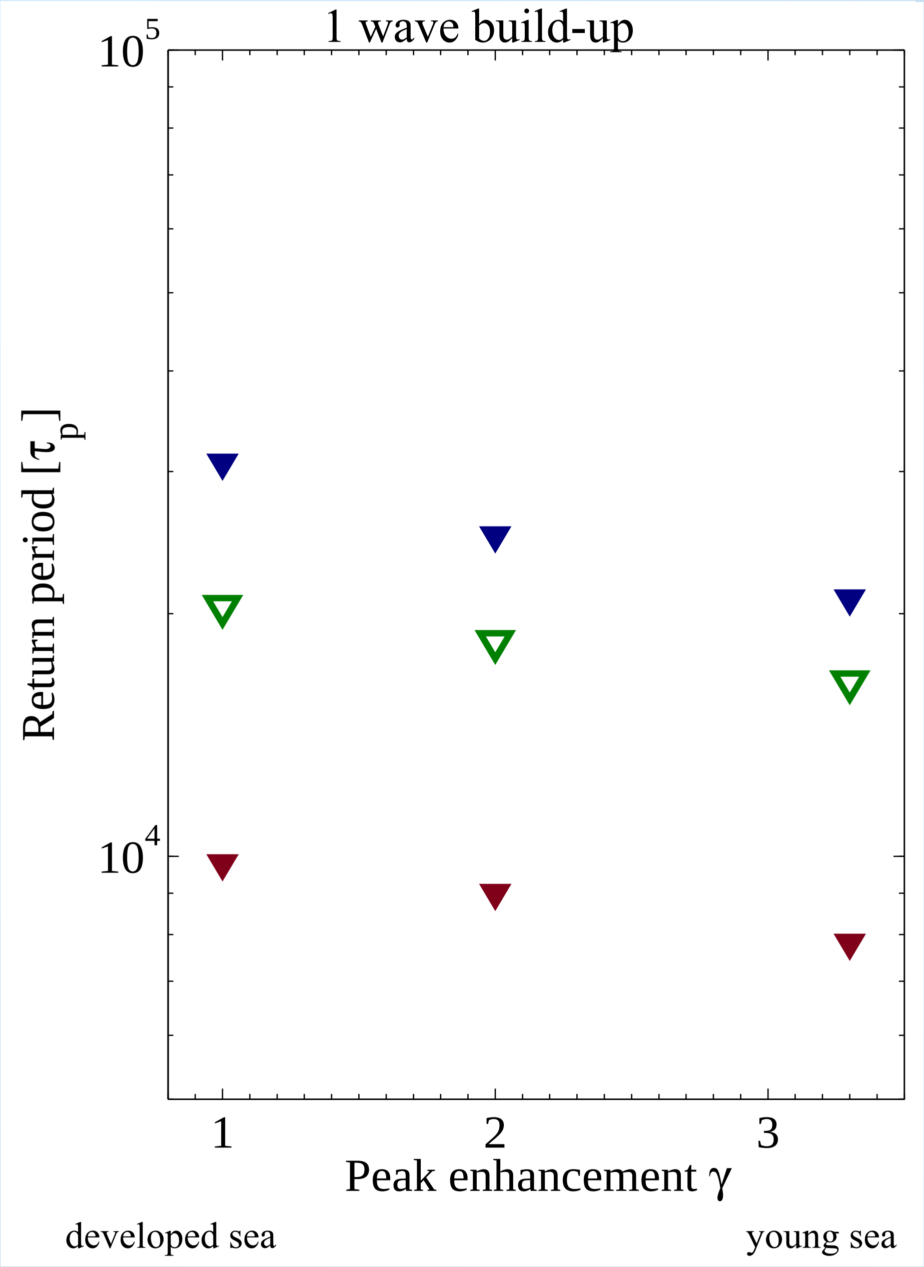
H

η

η_{nl}

Isolated unexpected waves more frequent in developed seas

Return period – wave development



$\alpha = 2$, n_p=20, m=1

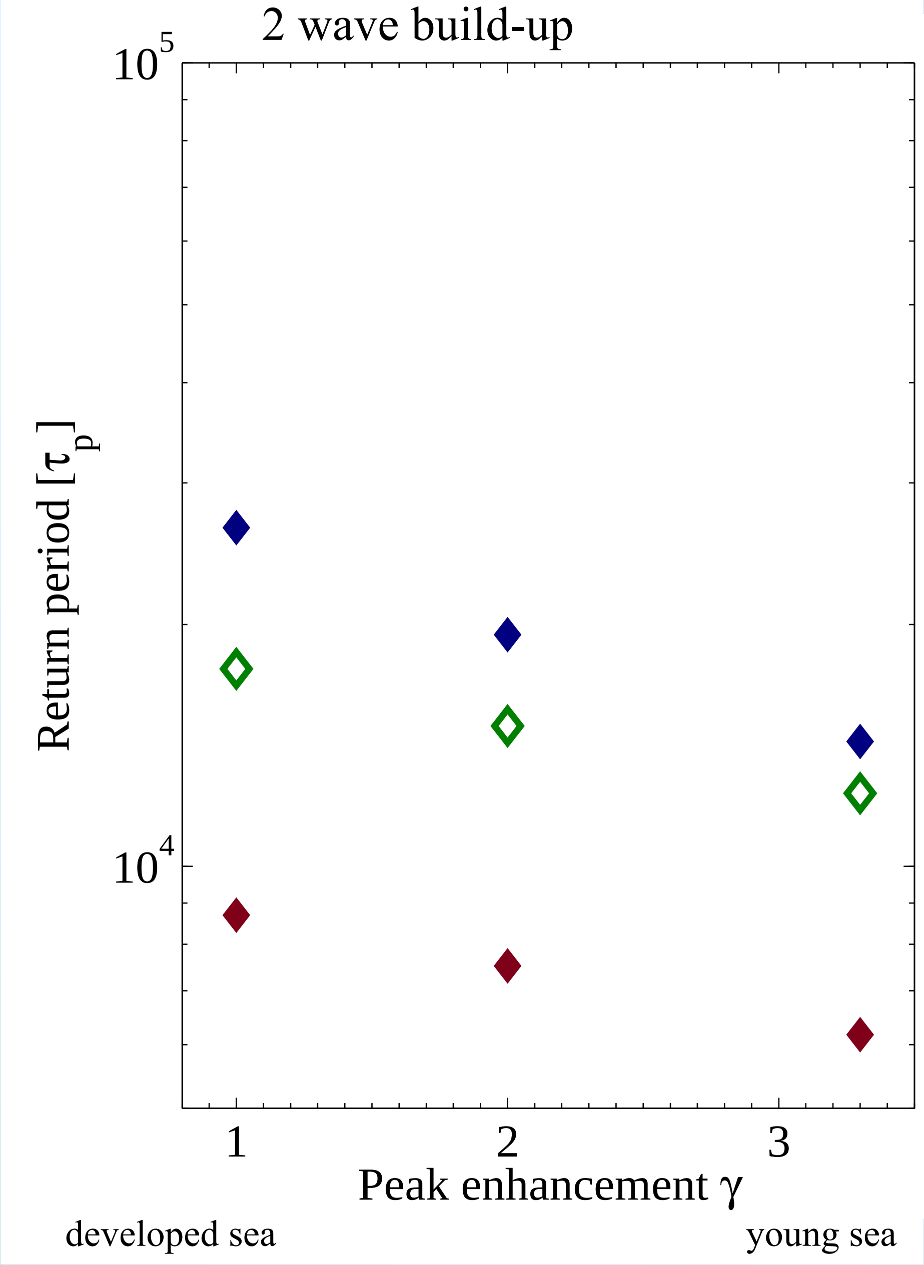
H

η

η_{nl}

Unexpected wave ***groups*** more frequent in young seas

Return period – wave development



$\alpha = 2$, $n_p=20$, $m=2$

H

η

η_{nl}

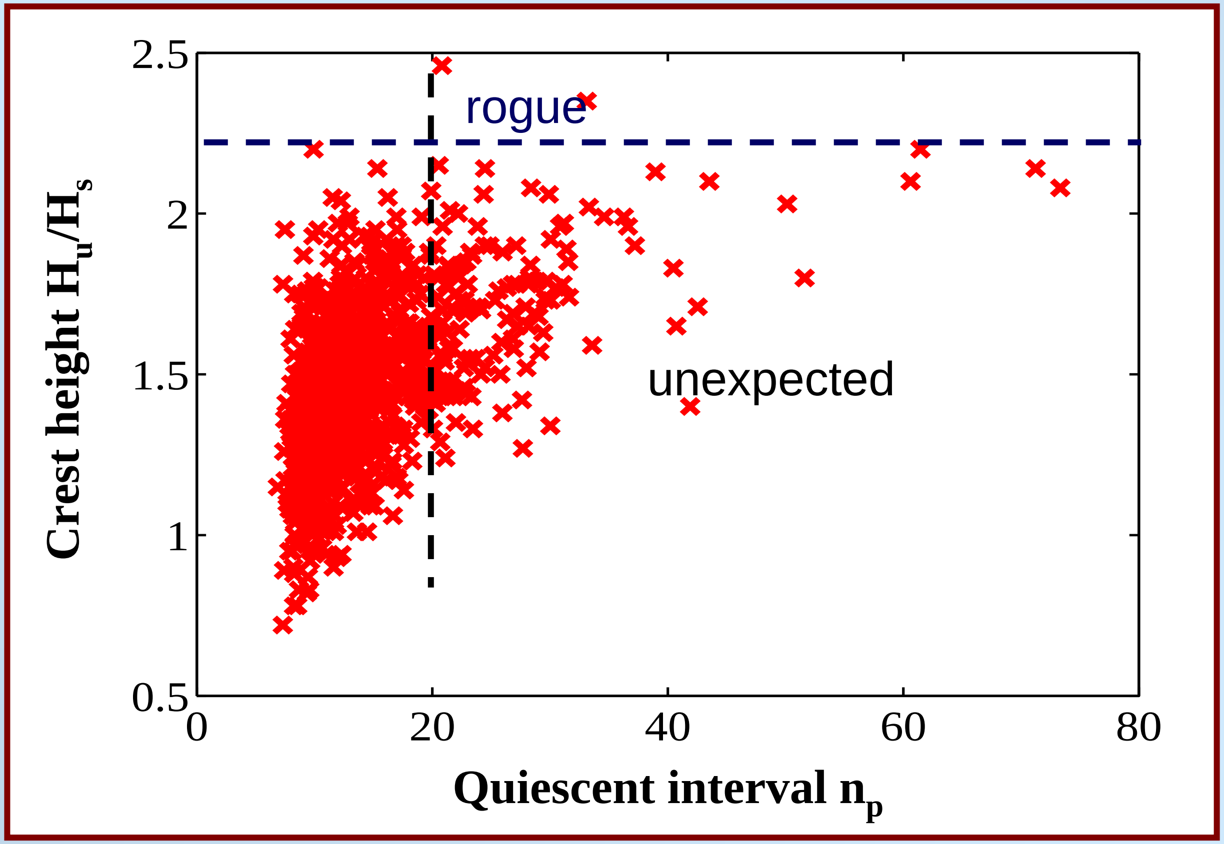
Unexpected wave groups much more frequent in young seas

Height of unexpected waves

10 h time series
10^4 simulations

$\alpha = 2$

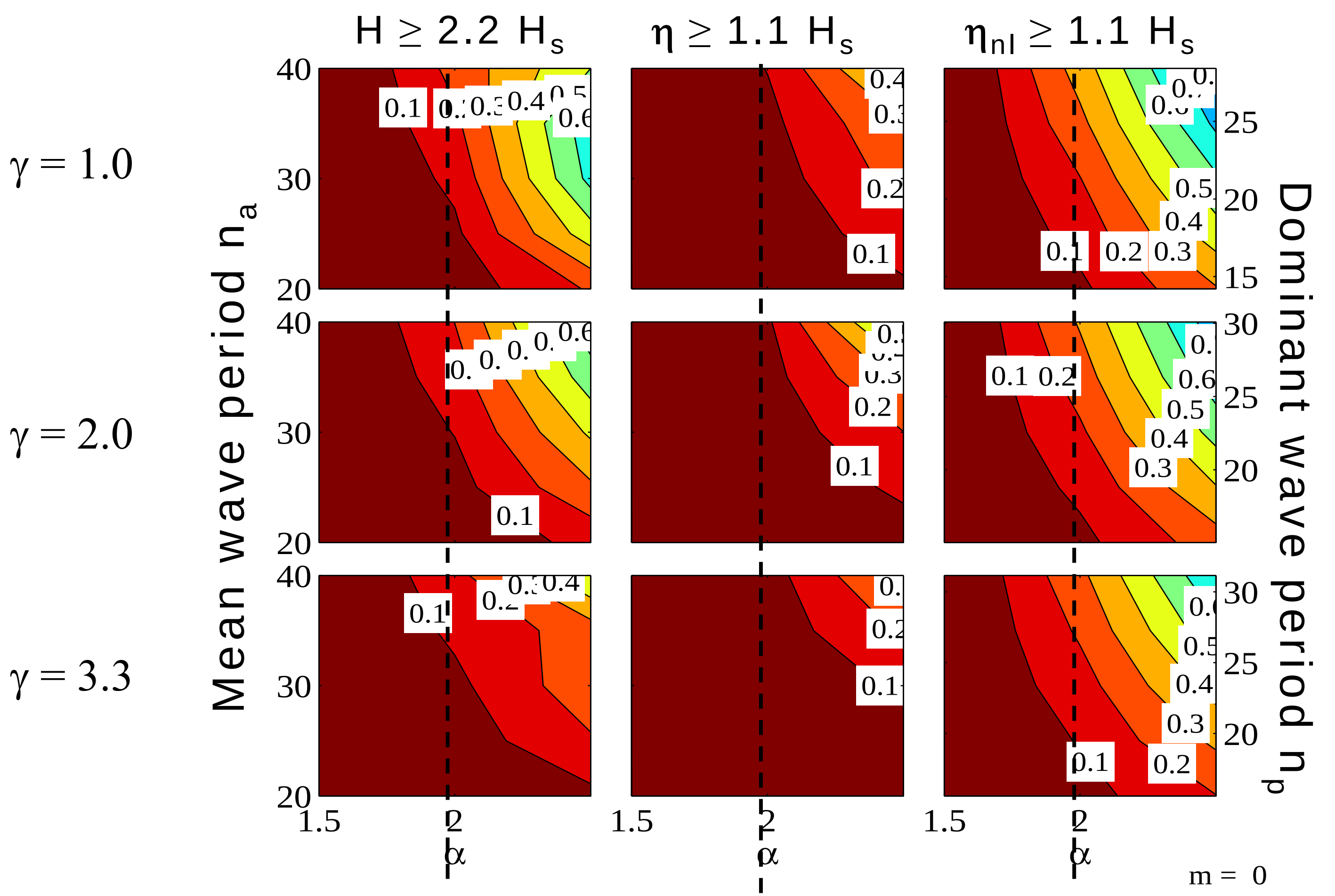
Height of most unexpected wave (largest n_p) in each simulation



Note: $n_p \geq 8$

Are unexpected waves rogue waves?

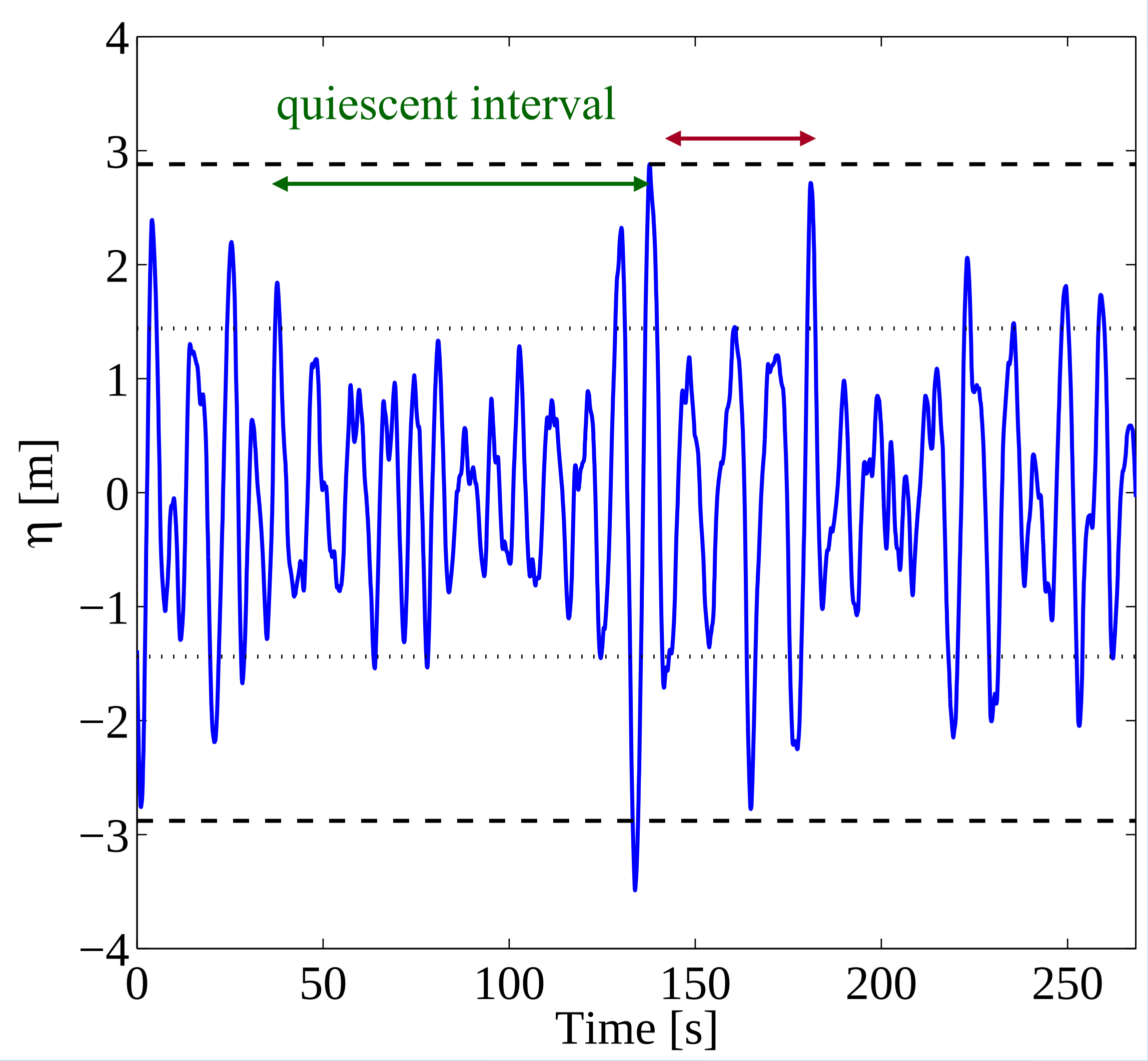
Fraction of unexpected waves that also qualify as rogue waves



H_s: significant wave height

Unexpected wave are generally not a *rogue* wave

Unexpected wave – subsequent quiescence



a wave crest
α times as high
as any of the
preceding and
subsequent n_a
crests.

n_a: minimum length of preceding and subsequent quiescent interval

Based on η, m = 1

Unexpected waves (2-sided) – occurrence rate

A wave twice as high as any of the preceding and following 30 waves occurs (α=2, n_a=30)

every O(10^8) waves, (based on H) ⟹ O(30) years recurrence

every $5x10^7$ waves, (based on η) ⟹ O(10) years recurrence

every $5x10^6$ waves, (based on η_{nl}) ⟹ O(1) year recurrence

Are 2-sided unexpected waves rogue waves?

Fraction of 2-sided unexpected waves ($a=2$, $n_a=30$, $m = 0$) that also qualify as rogue waves:

Based on H: 90%

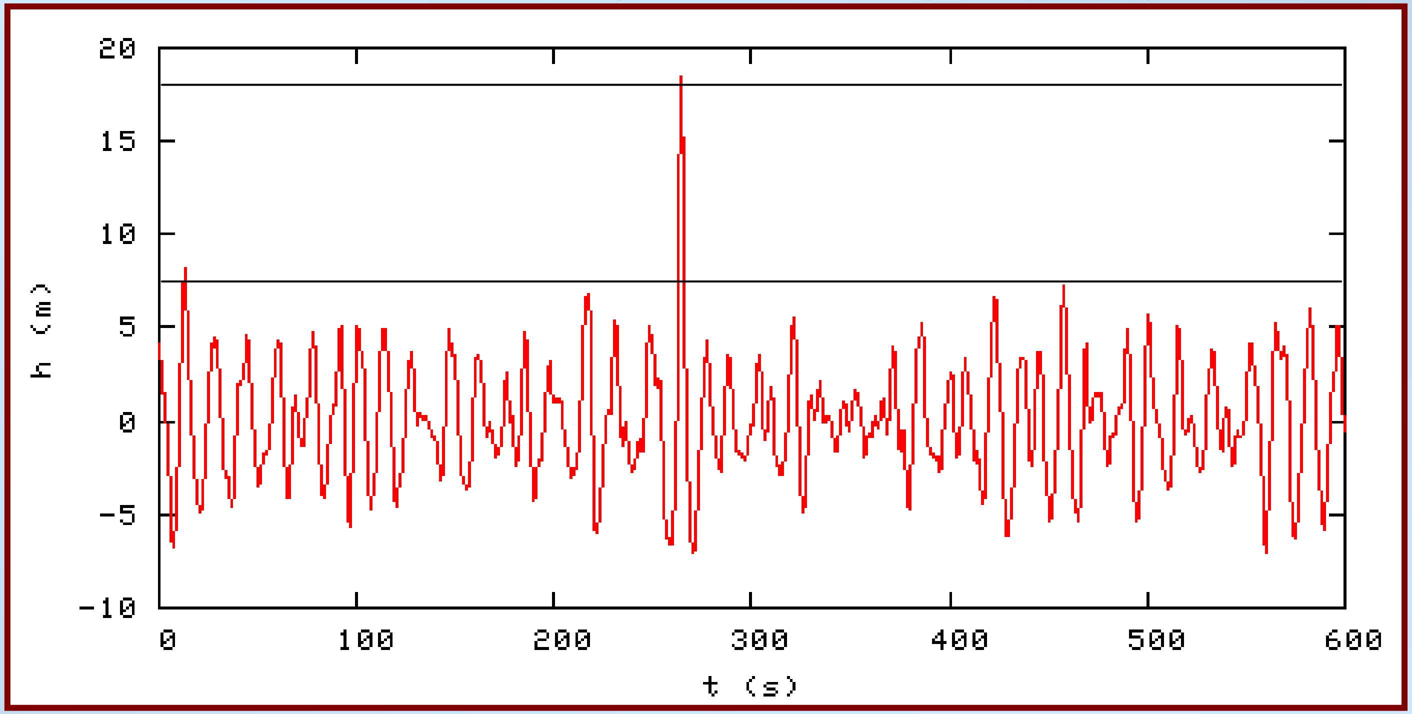
Based on η: 60%

Based on η_{nl} : 80%

Most *2-sided unexpected* waves are *rogue* waves

Rogue wave ?

"New Year's Wave" at Draupner Platform (North Sea), 1995



2-sided unexpected wave, α =2.3, n_p=15

Expected occurrence rate (based on η_{nl}) :

every 2 years !

(α =2.3, n_p=30: **Expected occurrence rate : every 30 years !**)

Conclusion

Based on Gaussian statistics,

unexpected waves are expected

- **recreational boating**
- **visitors to beaches**
- **deployments from offshore vessels**

20 to 30 wave periods quiescent conditions - significant

Appendix

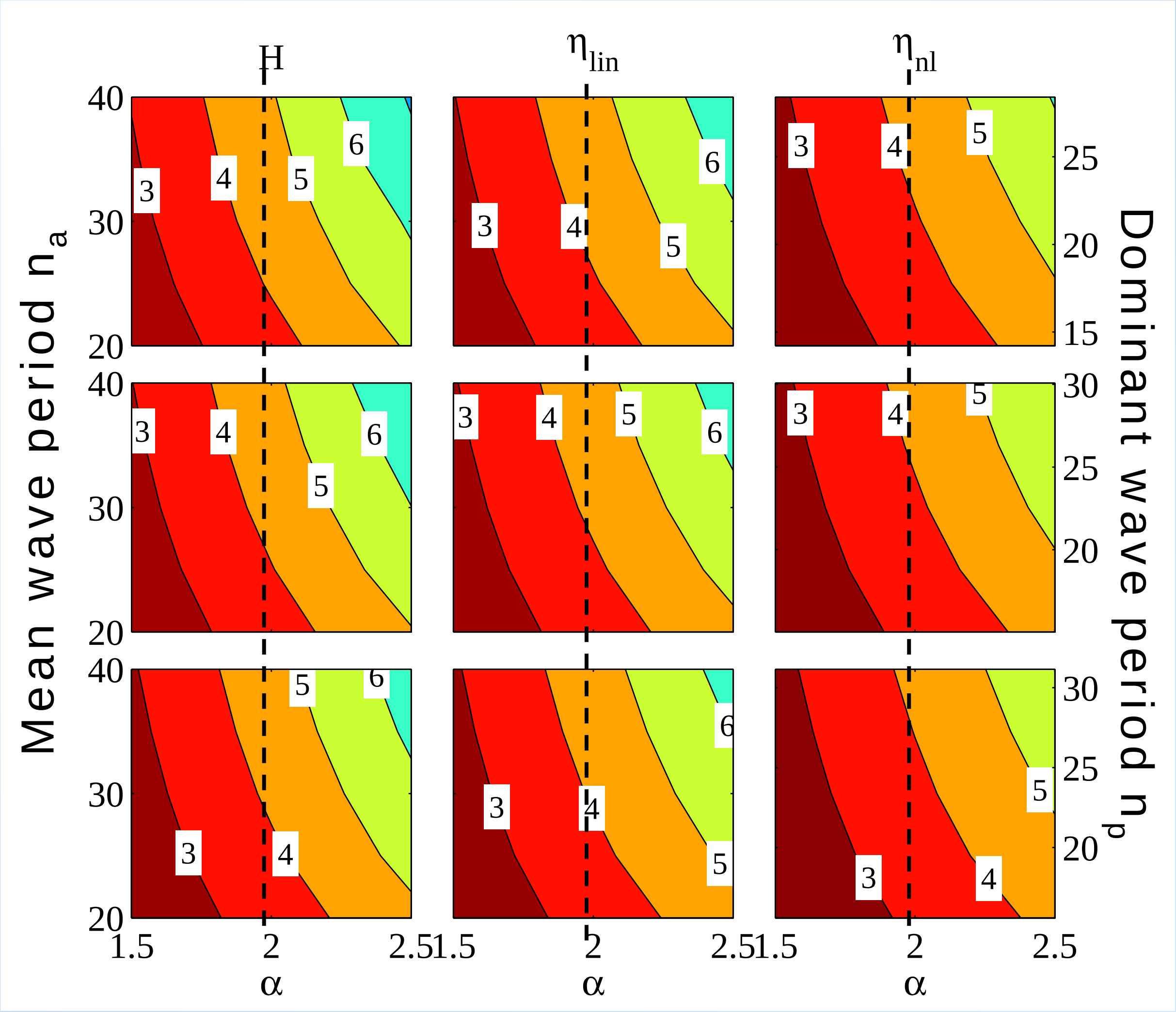
Unexpected wave occurrence $R(\alpha, n_a)$

($\log_{10}$ of return time in peak periods). 1 wave build-up

$\gamma = 1.0$

$\gamma = 2.0$

$\gamma = 3.3$



An *unexpected* wave (α=2, n_a=30, m=1) is more frequent than a *rogue* wave

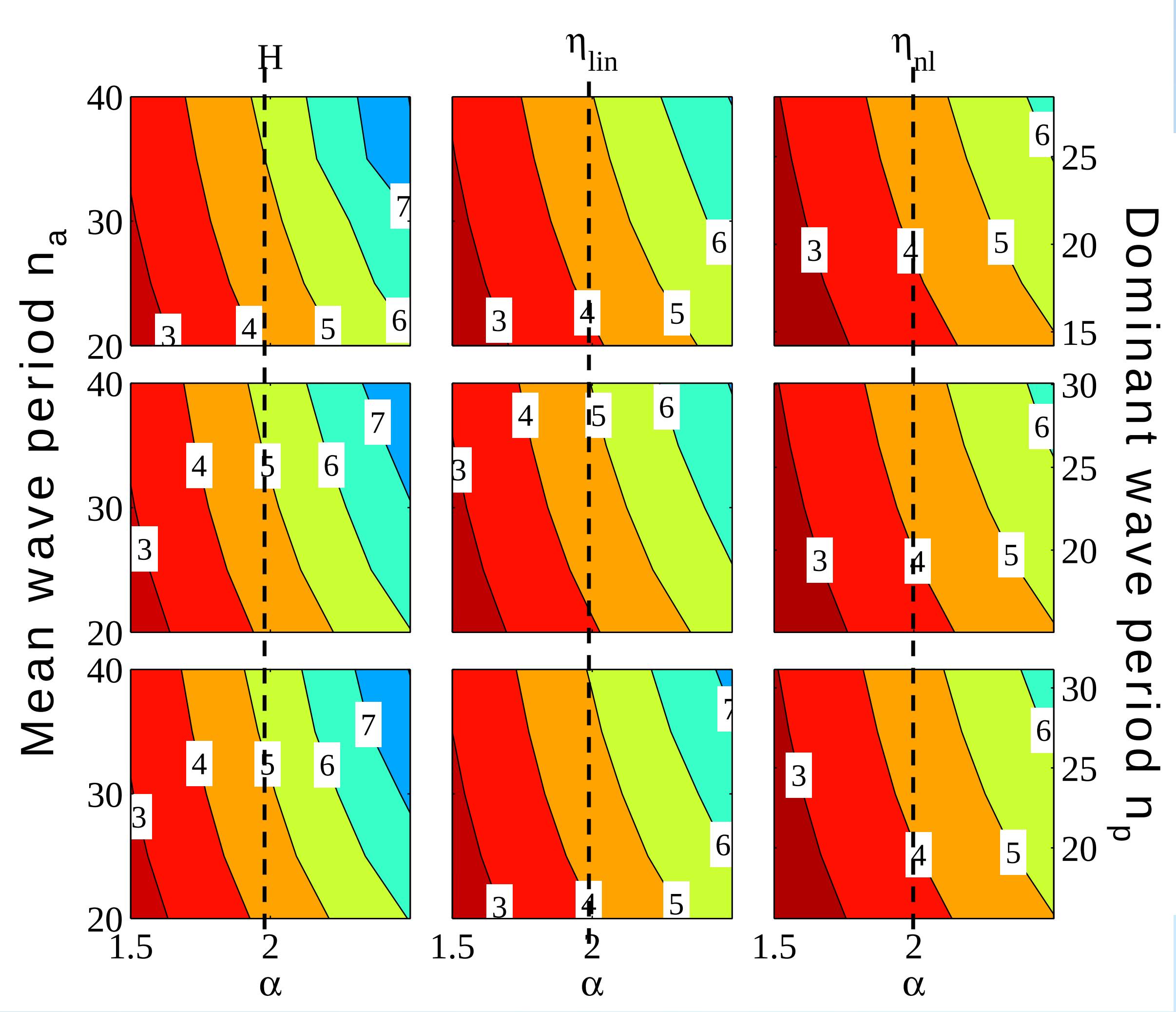
Unexpected wave occurrence $R(\alpha,n_a)$

($\log_{10}$ of return time in peak periods)

$\gamma = 1.0$

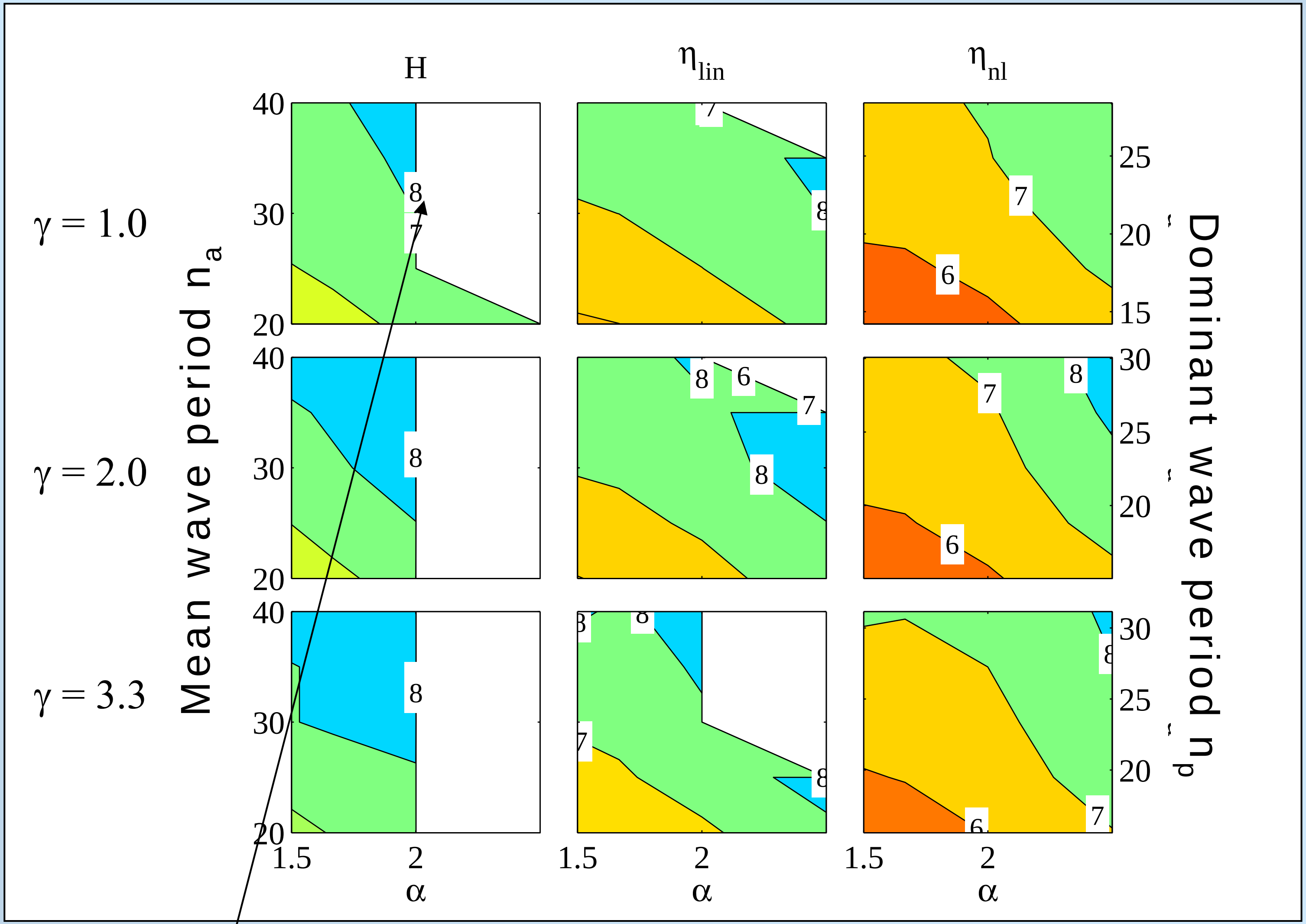
$\gamma = 2.0$

$\gamma = 3.3$



An *unexpected* wave is slightly less frequent in young seas

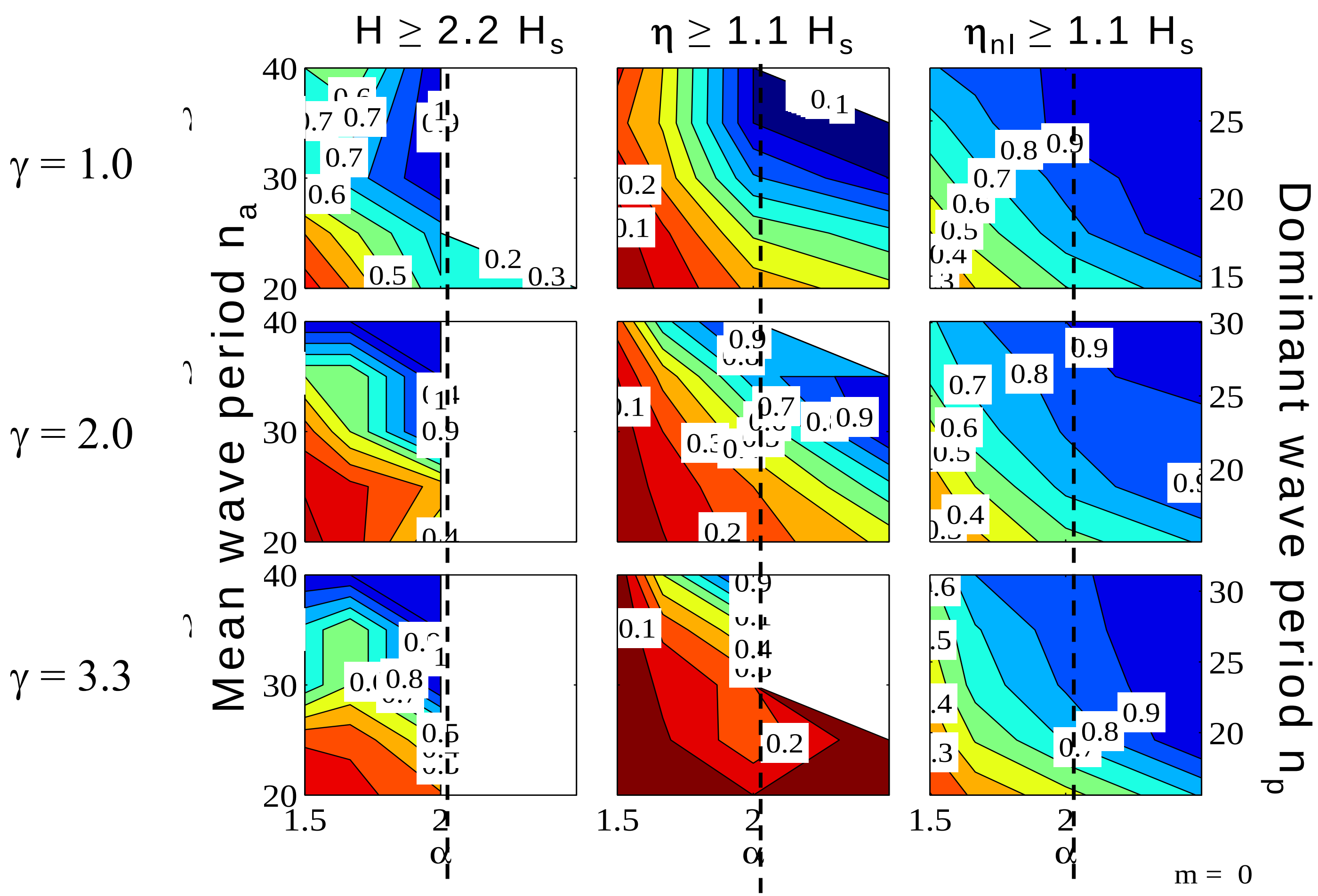
Unexpected waves (2-sided) – occurrence rate



A wave twice as high as any of the preceding and following 30 waves occurs every O(10^8) waves → O(30) years recurrence

Are 2-sided unexpected waves rogue waves?

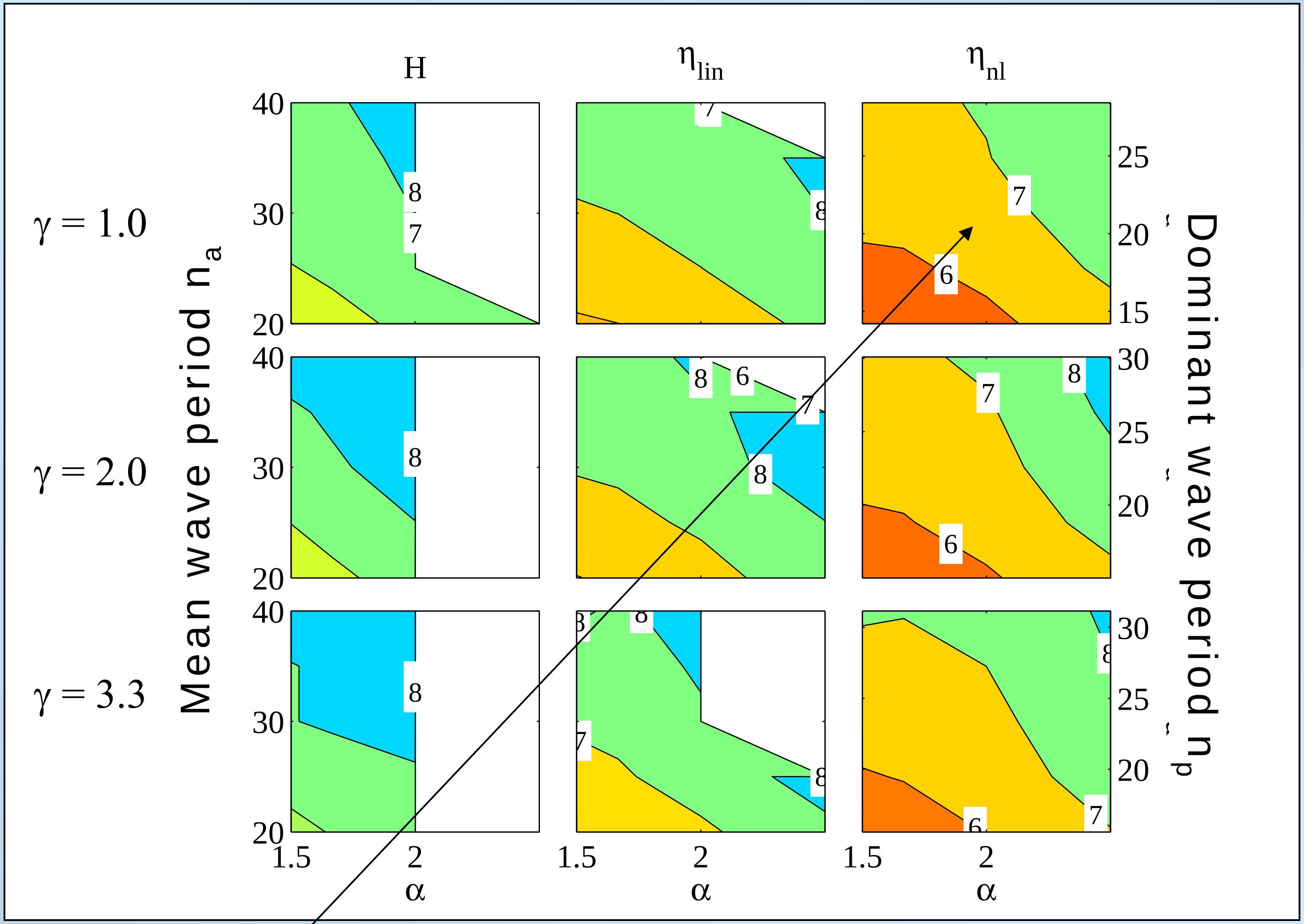
Fraction of unexpected waves that also qualify as rogue waves



H_s: significant wave height

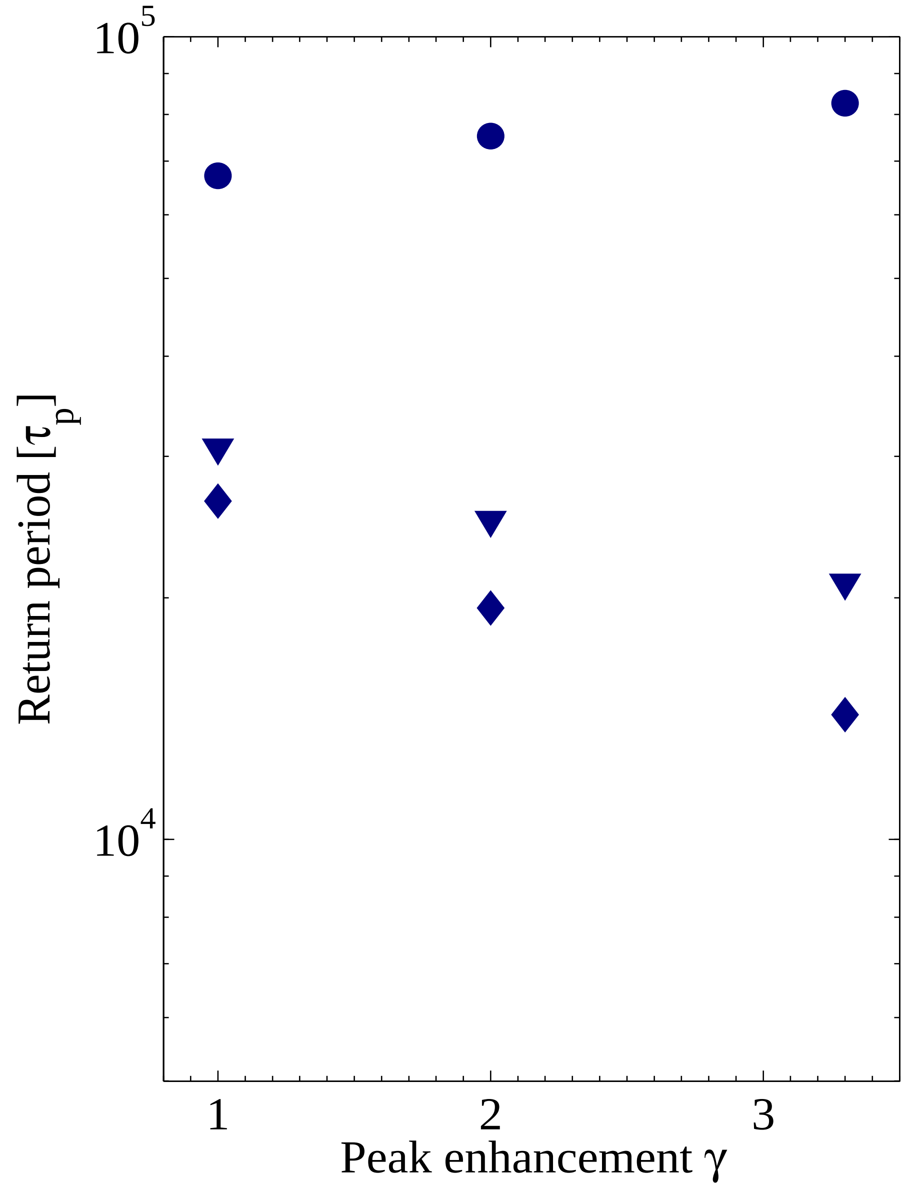
Most *2-sided unexpected* waves are a *rogue* wave

Unexpected waves (2-sided) – occurrence rate



A wave crest twice as high as any of the preceding and following 30 crests occurs every $5x10^6$ waves → 410 days recurrence

Occurrence probability – wave development, group length



developed sea

young sea

No build-up

1 wave build-up

2 waves build-up

$H > 2H_W$

$\alpha = 2$, n_p=20

Unexpected wave – Monte Carlo simulations

- linear, random superposition of wave Fourier components
- Fourier components based on JONSWAP spectra, varying peak parameter γ

10 h time series
10^4 simulations → statistics of unexpected waves

Analyze:
η: linear crest height
H: linear trough-crest wave height
η_{nl}: second order non-linear crest height $\eta_{nl} = a\cos\theta + \frac{1}{2}ka^2\cos(2\theta)$