2nd International Workshop on Waves, Storm Surges and Coastal Hazards.
11-15 November 2019

equinor

Field data vs laboratory data

Are the wave crest height distributions in the field and laboratory similar ?

Gunnar Lian
Sverre Haver

Wave crest height distribution

- Neglecting wind and current, the crest height distribution is a function of the wave steepness and the water depth.
- When the waves become very steep, the crest height is limited by breaking.
- Why focus on the crest height ?
  - Wave-in-deck can cause an extremely large impact load.

Design crest height

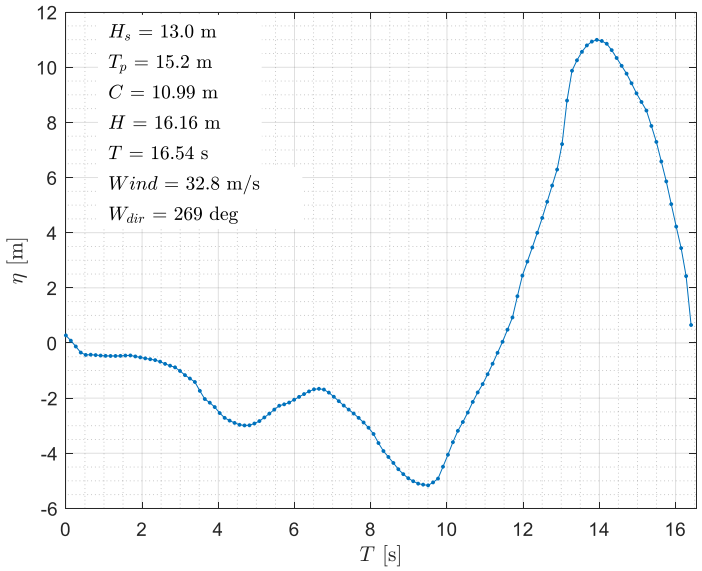
- A common approach to estimate the design wave crest is by utilizing the Forristall second order crest height distribution.
- The design crest height(q-annual probability of exceedance crest height) is estimated at a point, over an area, the design crest height will increase.

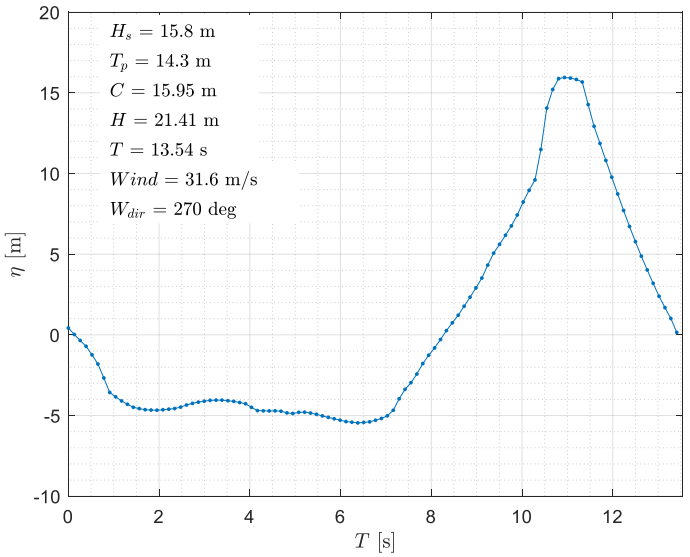
- Limitation of second order crest height distribution
  - It does not include wave breaking
  - It is limited to second order

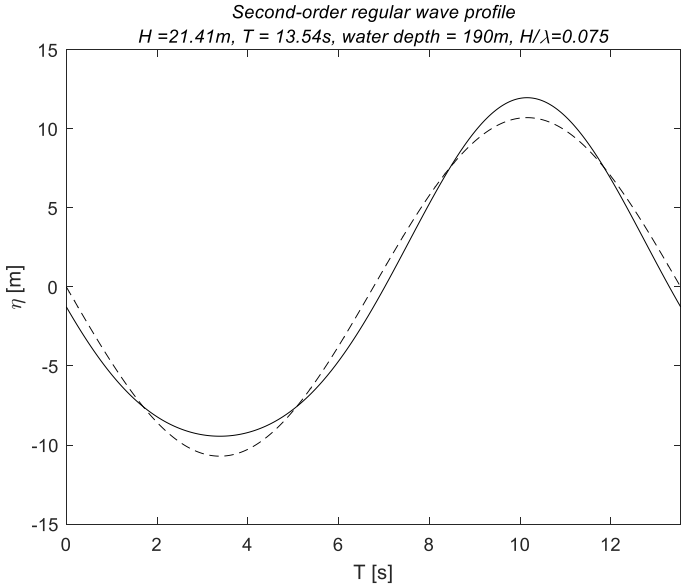
  } Counterbalance ?

- **Given its limitations, will the second-order crest height distribution still produce a reasonable long-term q-annual probability of exceedance crest height estimate ?**

Real ocean wave vs 2nd wave





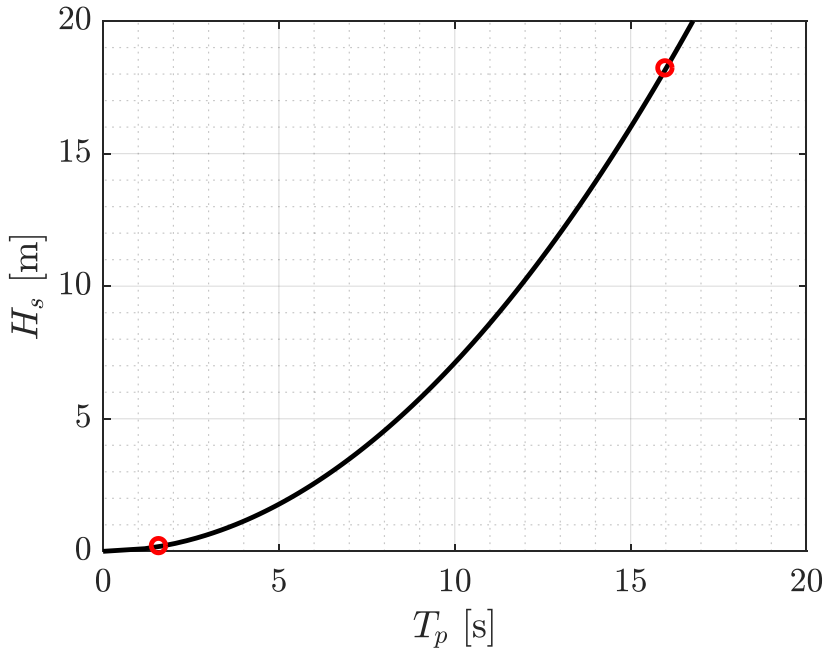


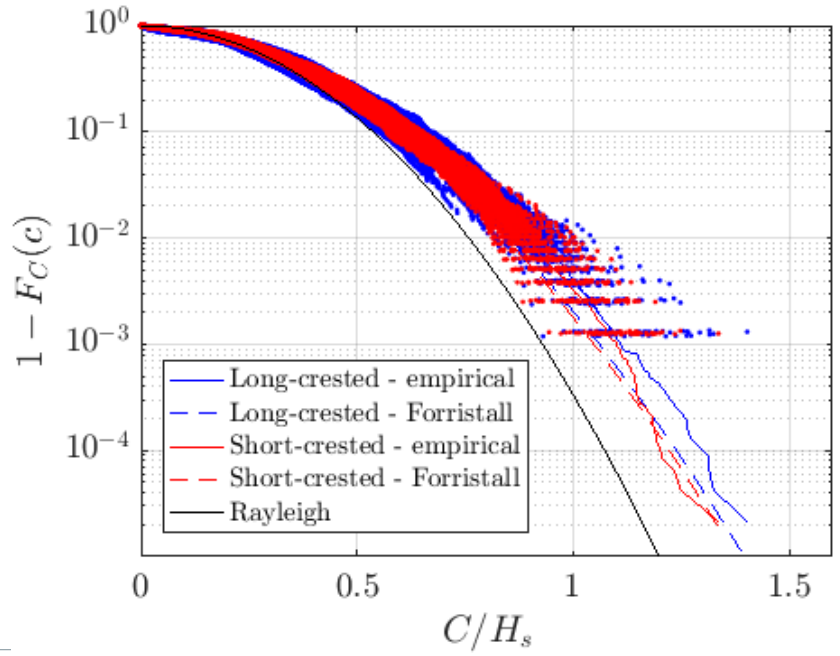
If the asymmetry of a steep breaking wave is neglected, the extreme <u>local</u> load effect is grossly underestimated.

Laboratory test of crest height distributions

- Laboratory testing in small scale is used to estimate the response and load effects from realistic ocean conditions.
- It is assumed that the physics of the ocean wind-generated waves can be reproduced using a wave maker.
- A fundamental assumption is that we can Froude scale.
    - Physics assumed constant for constant sea state steepness,

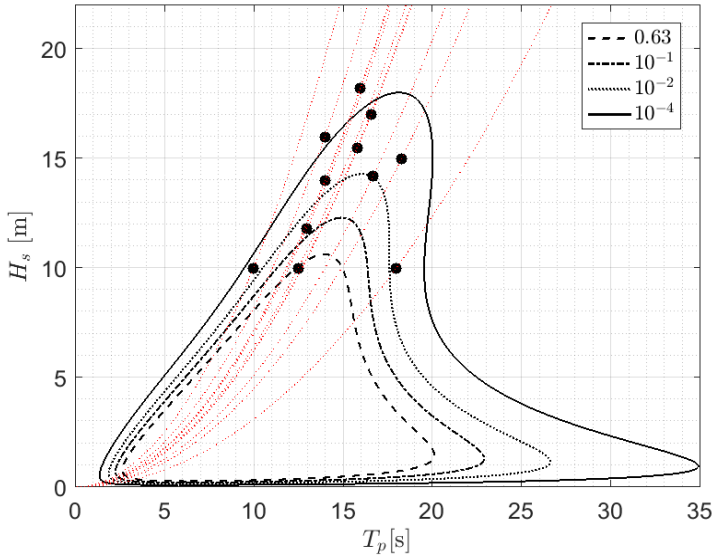
        --> can test in Hs 0.18 m to determine what will happen in the real ocean in Hs 18 m.

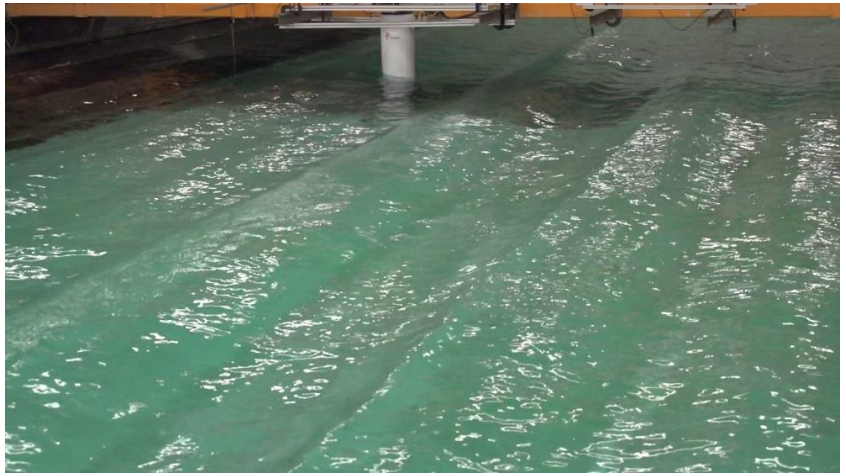


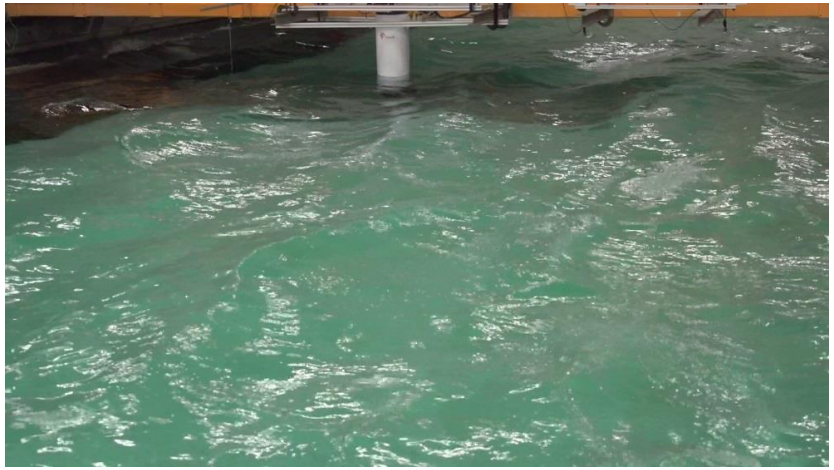


Crest height distributions from Column slamming test at Imperial College

- 11 sea states
- 60 realizations in each sea state
- Long-crested and short-crested waves

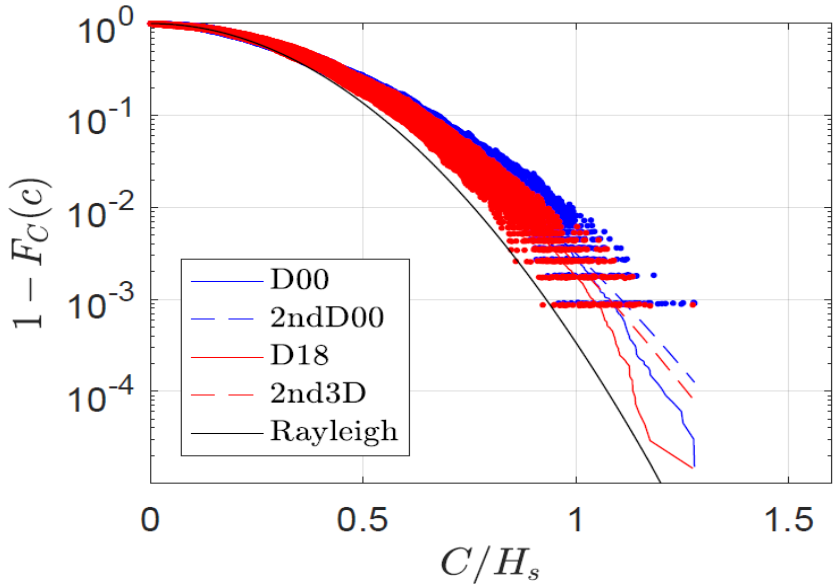




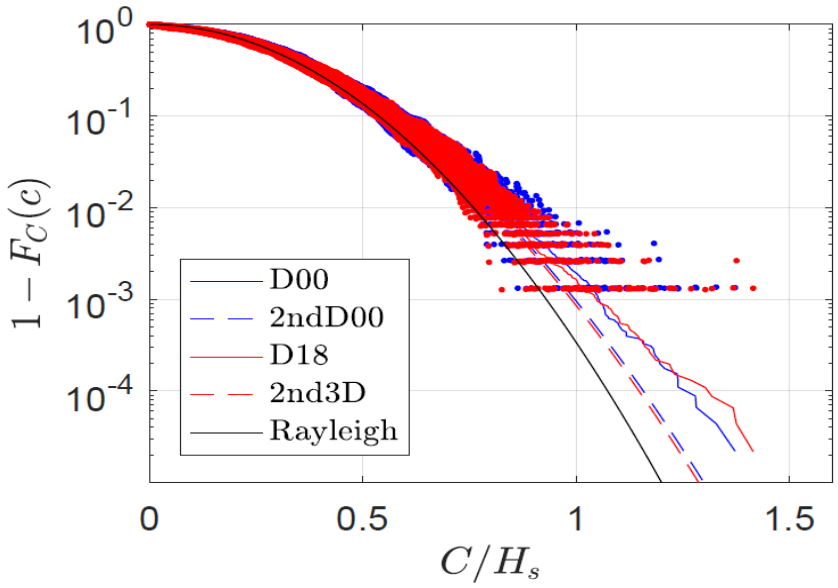


Example of short-term distribution from laboratory

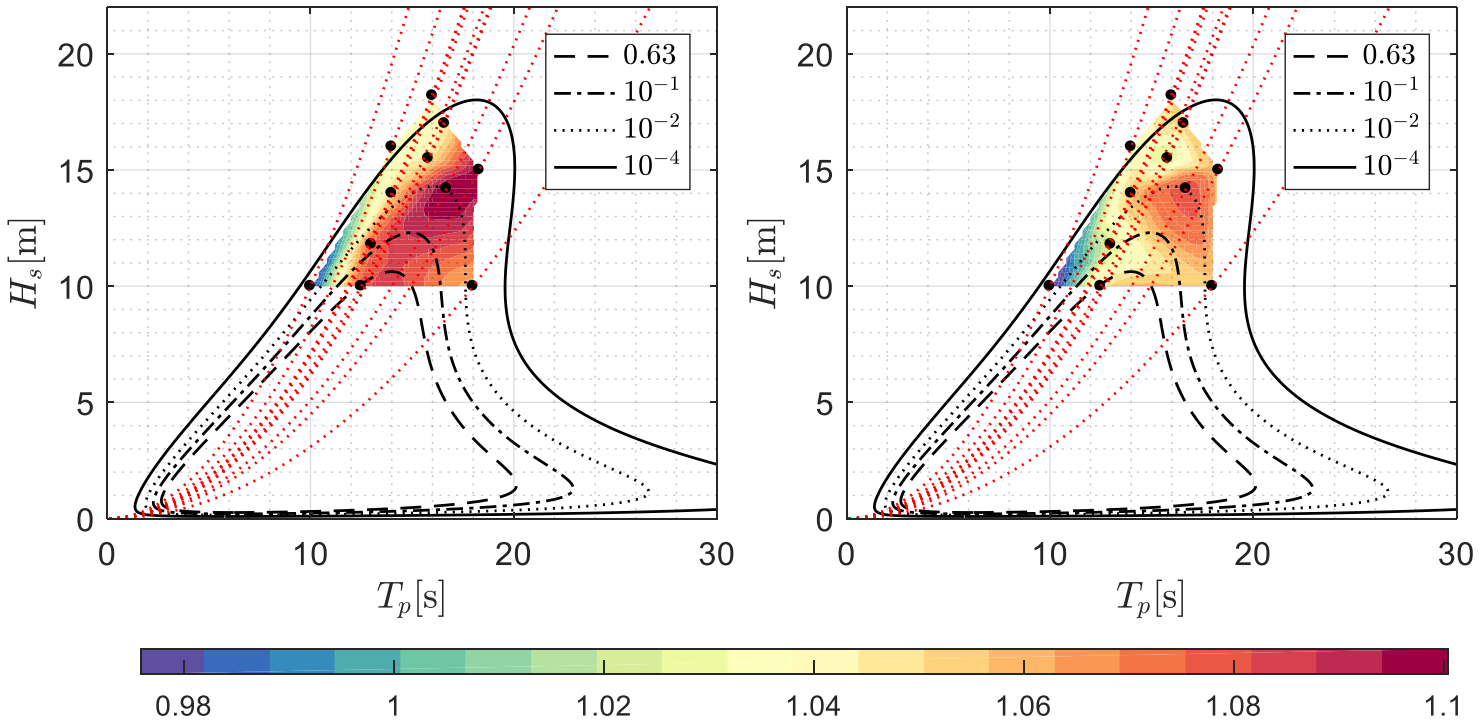
Hs=10 m & Tp = 10 s



Hs=10 m & Tp = 18 s



Short-term amplification beyond second-order in Lab.



Long-term analysis

$$F_{X_{3h}}(x) = \iint_{h,\,t} F_{X_{3h|HsTp}}\left(x|h_s,t_p\right) f_{Hs,Tp}\left(h_s,t_p\right) dt_p dh_s$$

Return period (years)	5	10	100	1000	10000
Crest height [m] – Short-crested waves	13.2	14.1	16.9	19.8	22.6
Departure from second order, SC	1.03	1.03	1.04	1.04	1.04

Field wave data measurement

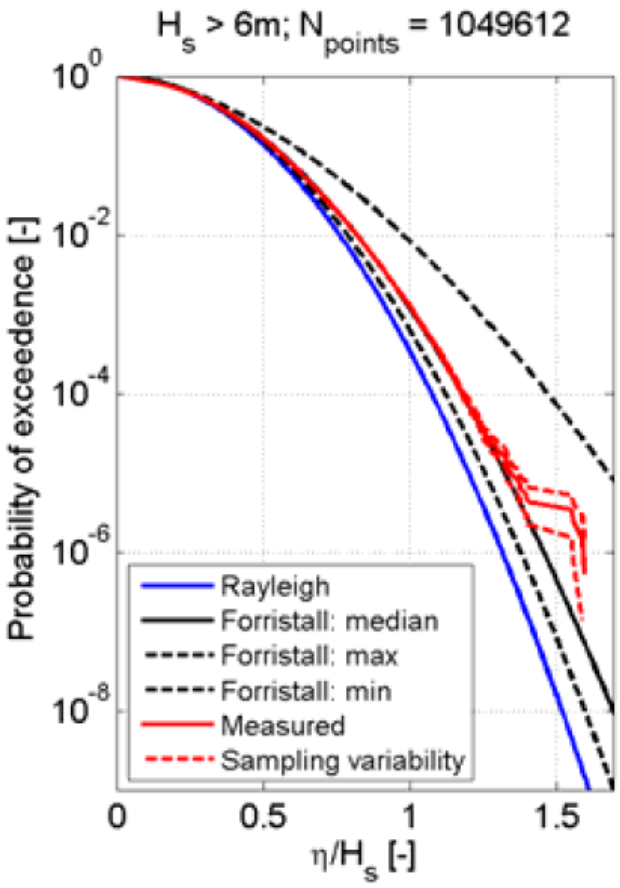
- The field data is often measured using SAAB REX WaveRadar.
  - For review of accuracy ref: What Does a Wave Radar Actually Measure ? , Ewans et.al. http://www.waveworkshop.org/13thWaves/

- The Microwave beam from the center of the antenna is 10° wide. I.e. for 26 m ASL the footprint is 4.53 m in diameter. At a crest height of 10 m the averaging diameter is about 2.8 m.

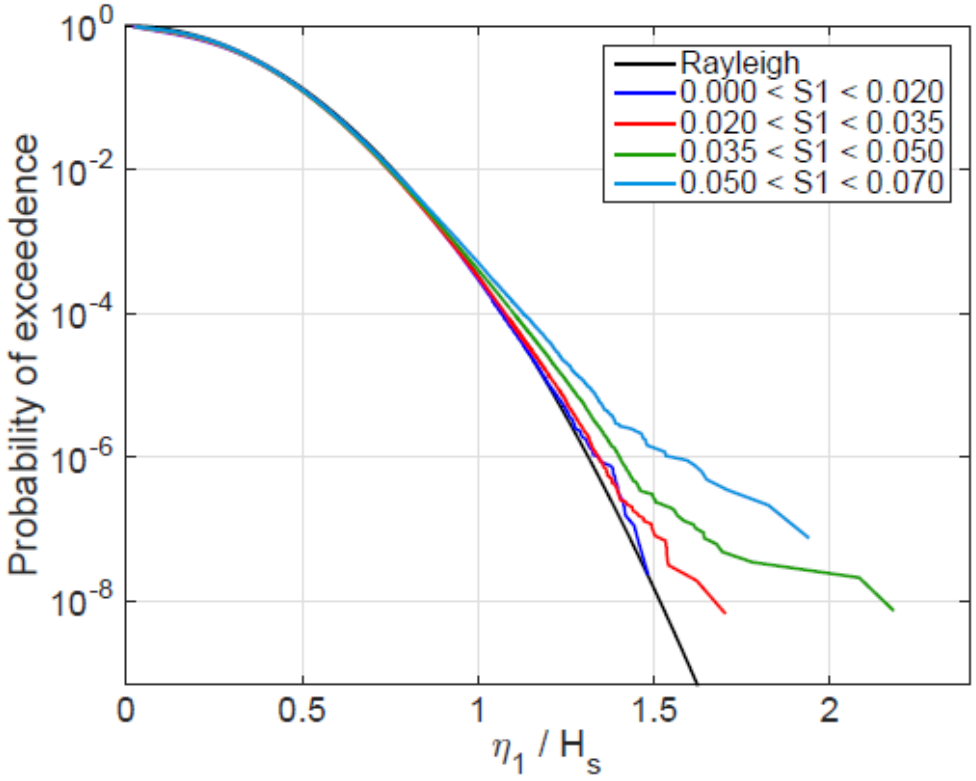
- NNS is sampled at 7.68 Hz and the rest of the data at 2 Hz

Some previous work on field data

OMAE2011-49846NEW INSIGHTS IN EXTREME CREST HEIGHT DISTRIBUTIONS (A SUMMARY OF THE 'CREST' JIP)
Buchner et.al



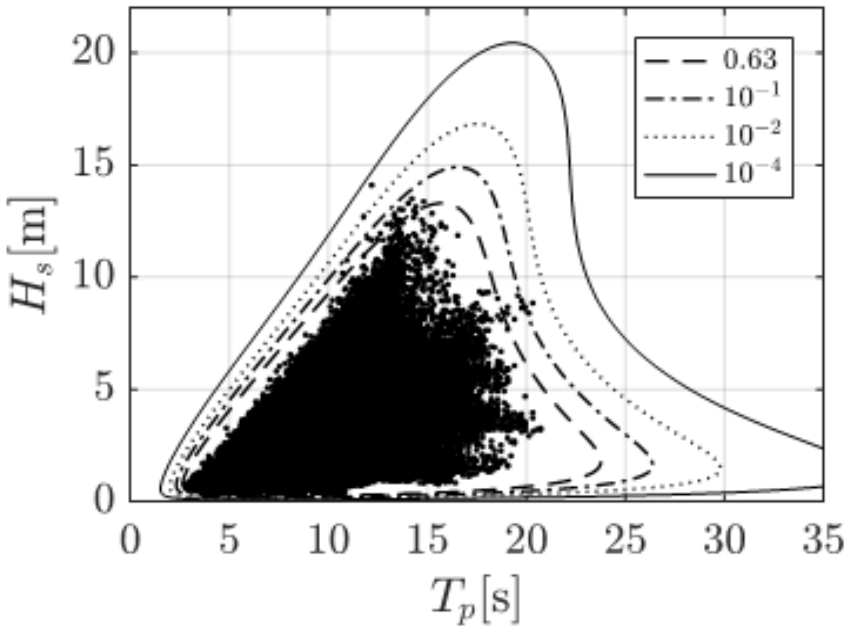
OMAE2016-54363. EXAMINING FIELD MEASUREMENTS OF DEEP-WATER CREST STATISTICS
Makri et.al



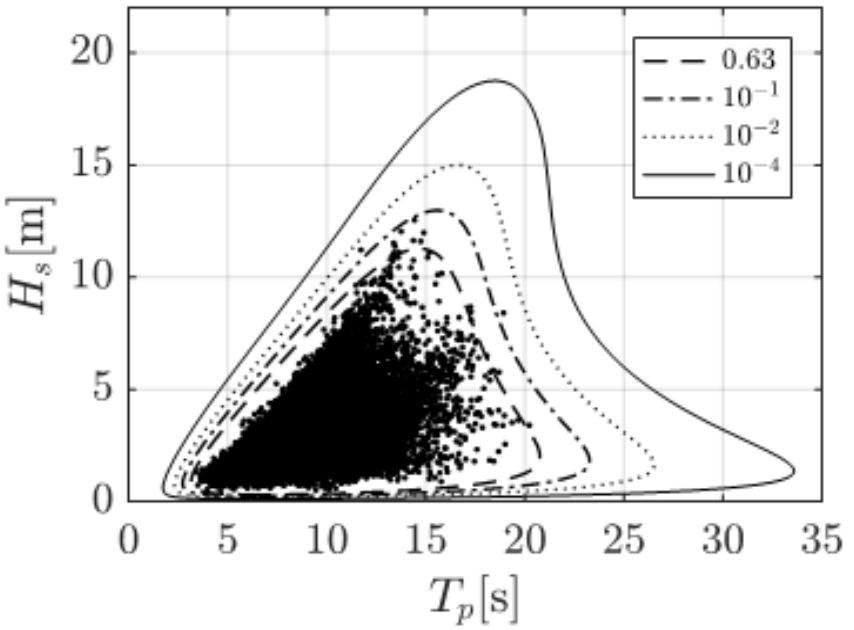
(a) Forristall model: binned by mean steepness S_1.

Field measurements Northern North Sea (NNS)

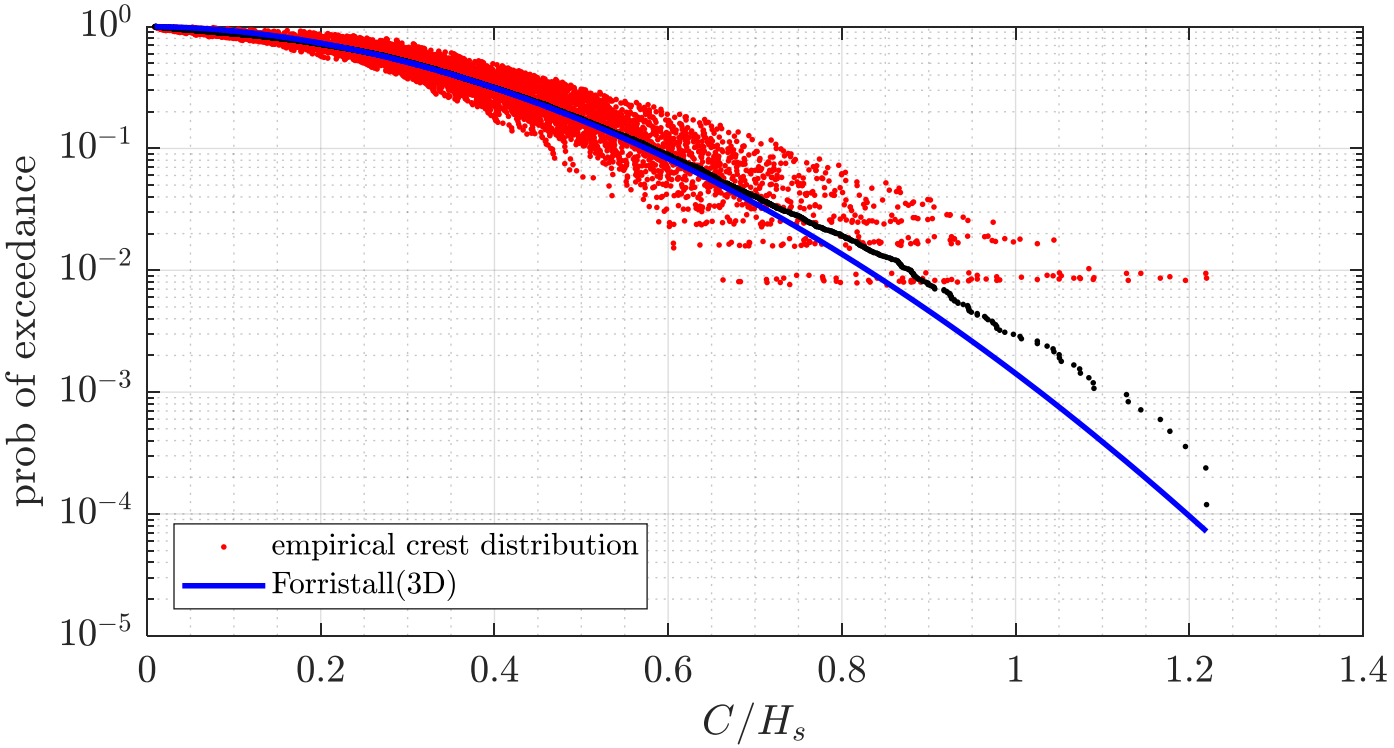
20-minutes measurements



3-hour measurements



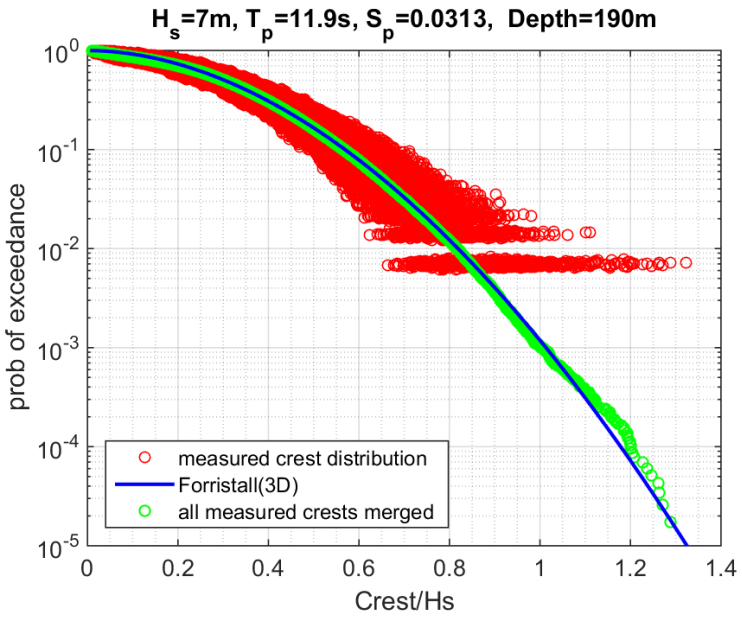
Field data - January the 26th 2012 - NNS

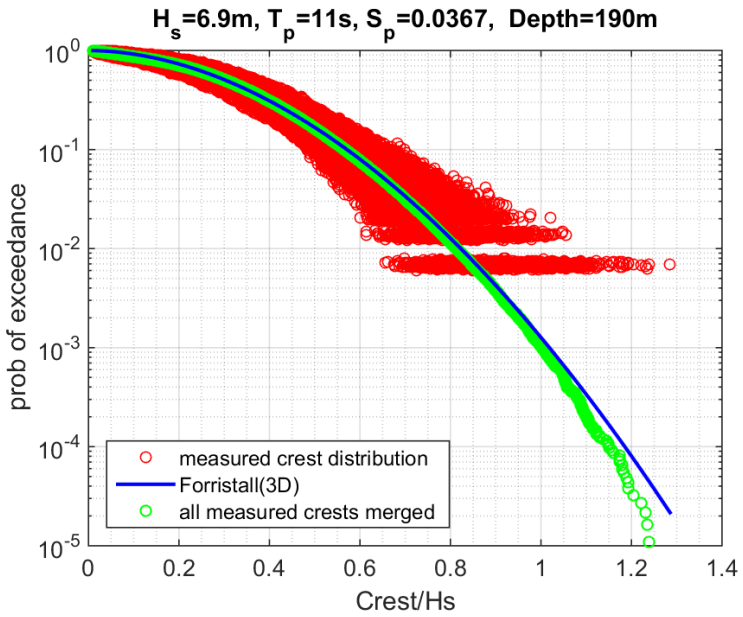


Binned field data

Total hours of measurement in each sea state class

H_s [m] \ T_p [s]	9	10	11	12	13	14	15	16	17	18
7	26.0	194.7	441.3	276.0	125.0	70.3	41.3	29.0	25.3	9.0
8		22.7	183.7	174.3	49.3	28.3	14.7	15.0	12.7	
9			26.3	81.7	59.7	17.0	7.0			
10				26.0	49.3	16.3				
11					17.0	12.3				





NNS(2004-2018) - 12703 sea states - 20 min. max (sampled at 7.68 Hz)

Second-order crest height distribution function of the largest crest in 20-min:

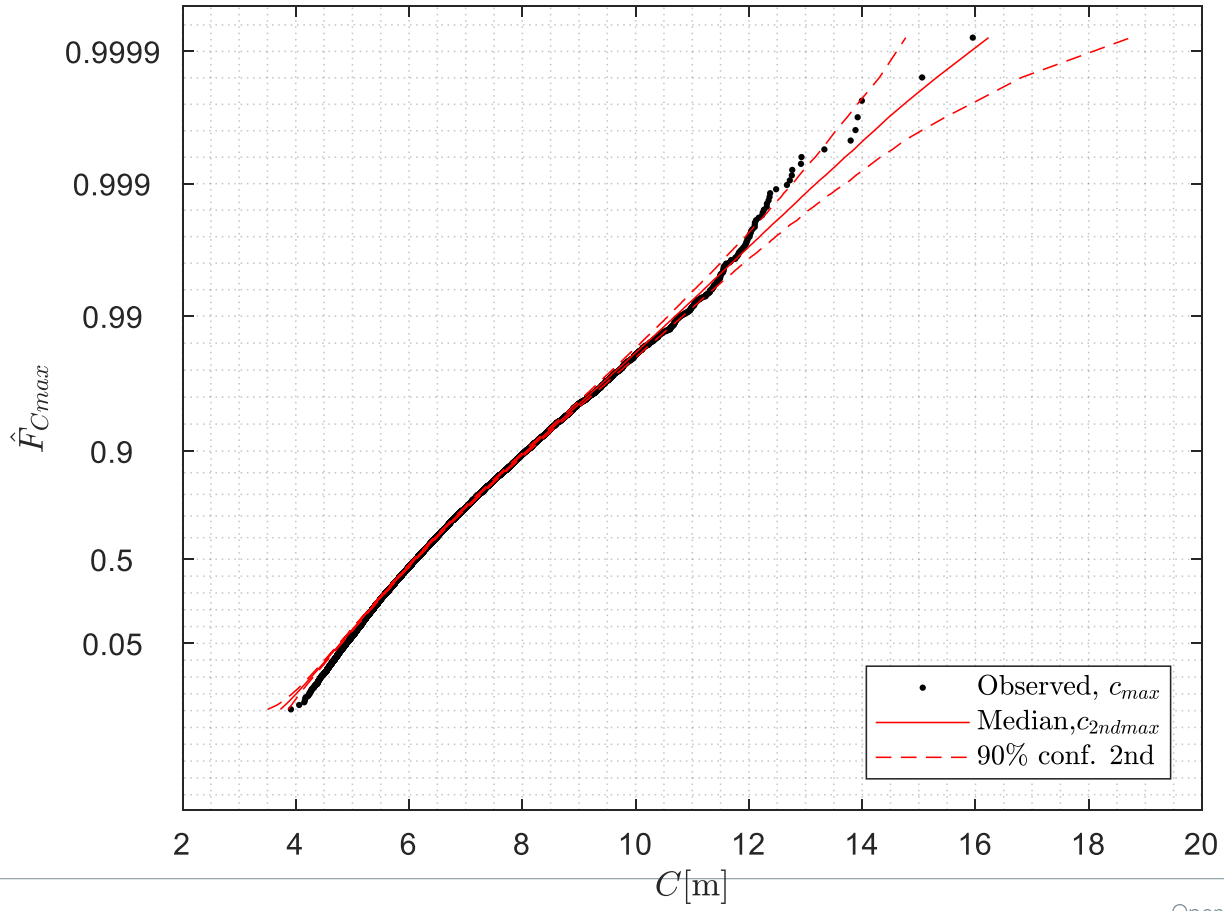
$$F_{C,20min}(c) = \left(1 - exp\left[-\left(\frac{c}{\alpha_C H_S}\right)^{\beta_C}\right]\right)^{n_{20min}}$$

A possible 20-min max can be generated by:

$$c_{max,20min} = \alpha_C H_S \left[-ln\left(1 - R^{\frac{1}{n_{20min}}}\right)\right]^{\frac{1}{\beta_C}}$$

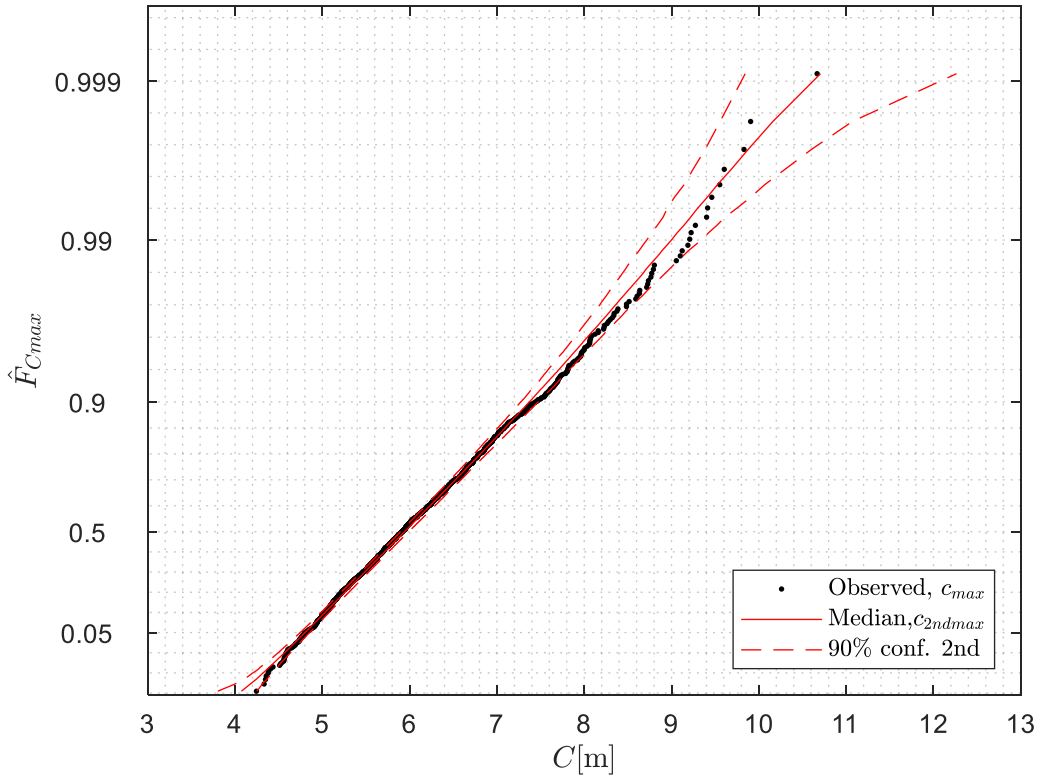
Where R is a random number between 0 - 1

Observed max crest height vs 2000 bootstrap from Forristall for 20-min. sea states.

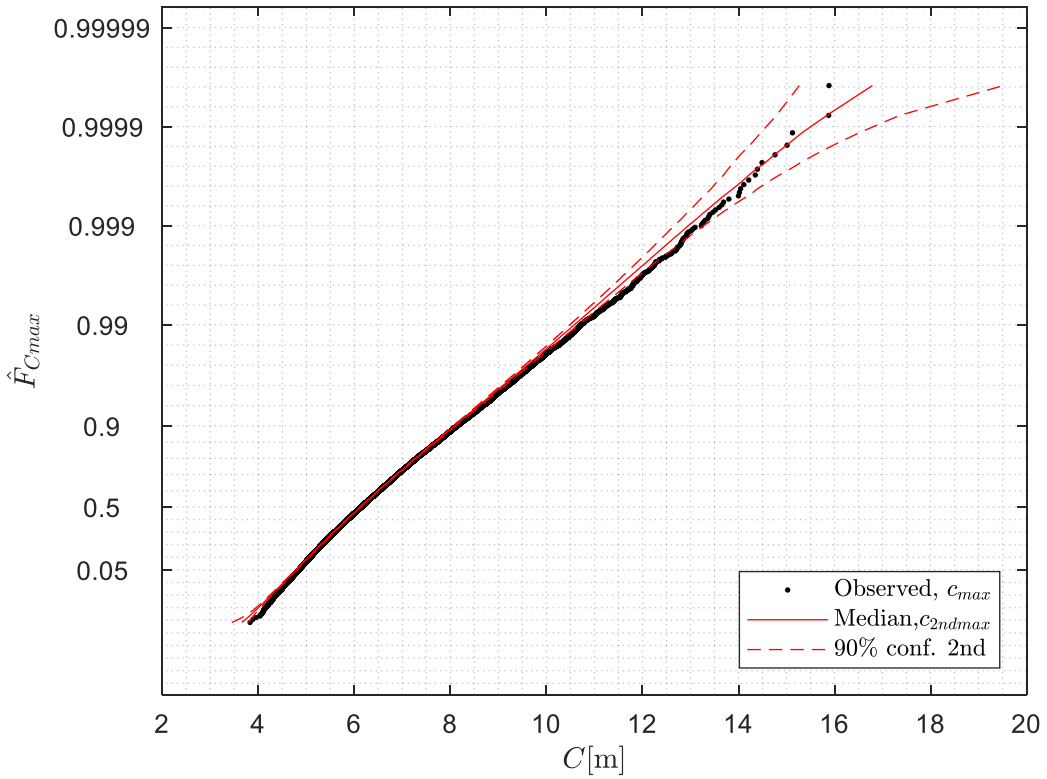


Other data sampled at 2 Hz

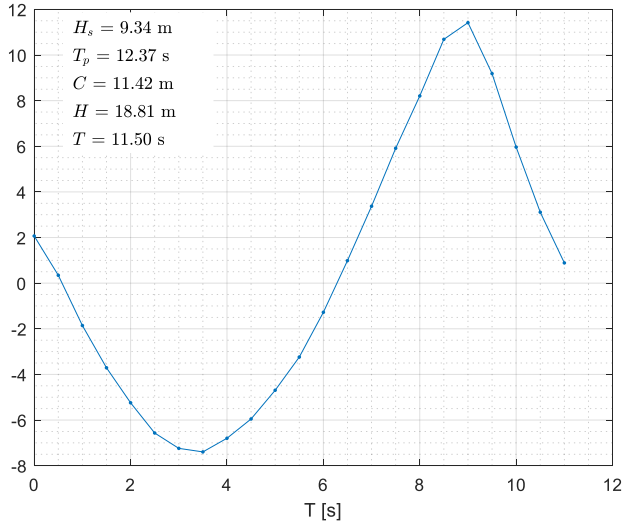
SNS, Hs > 6 m (1130 20-min sea states)

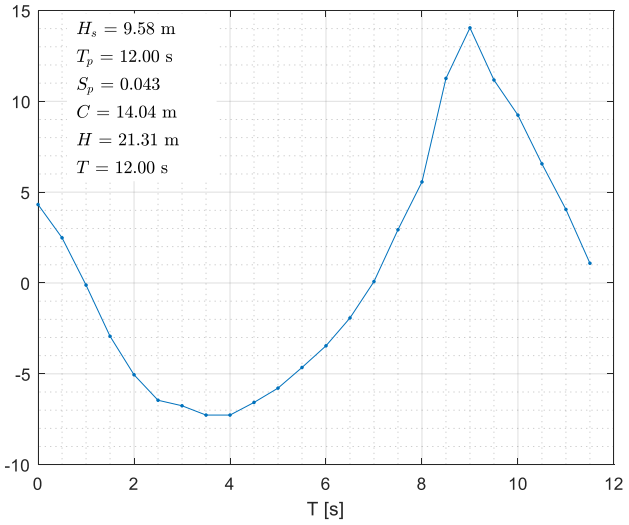


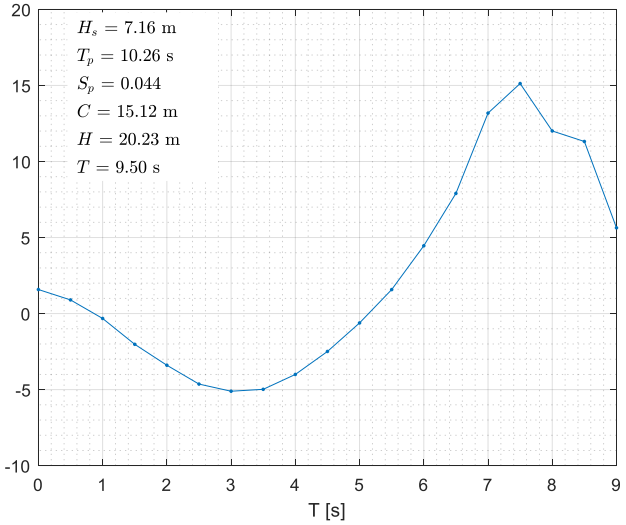
PL data Hs > 6m; 25943 20-min



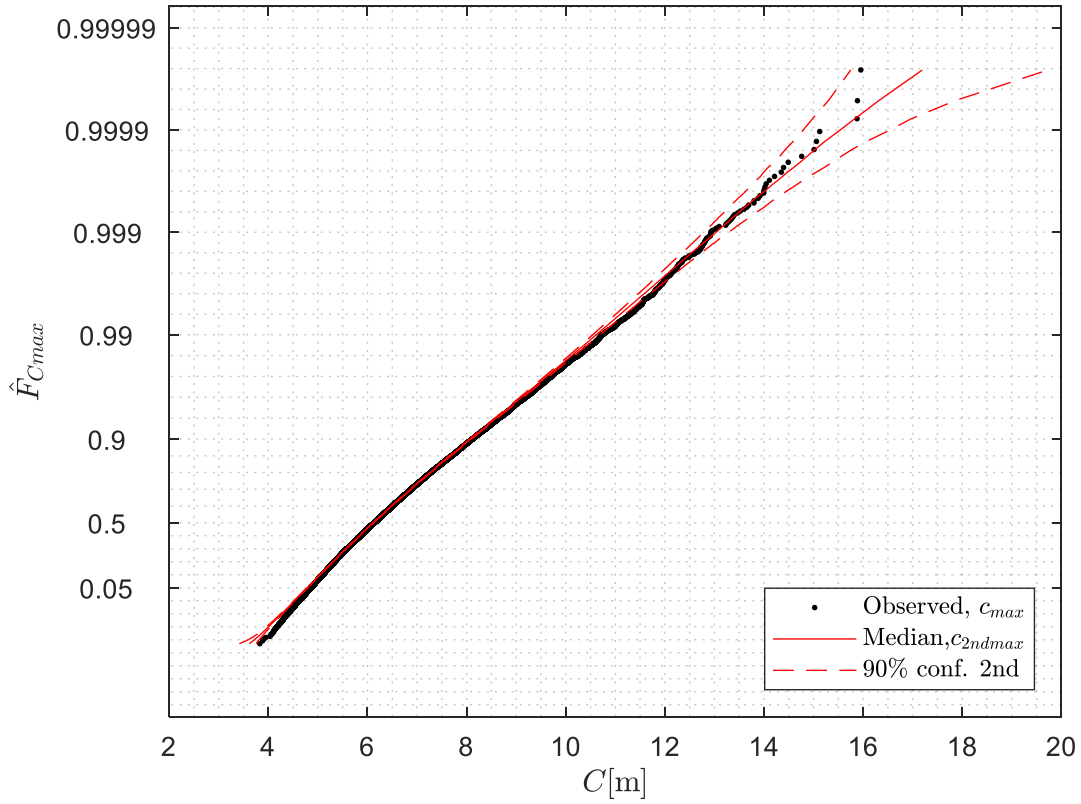
Uncertainty due to low sampling frequency ?





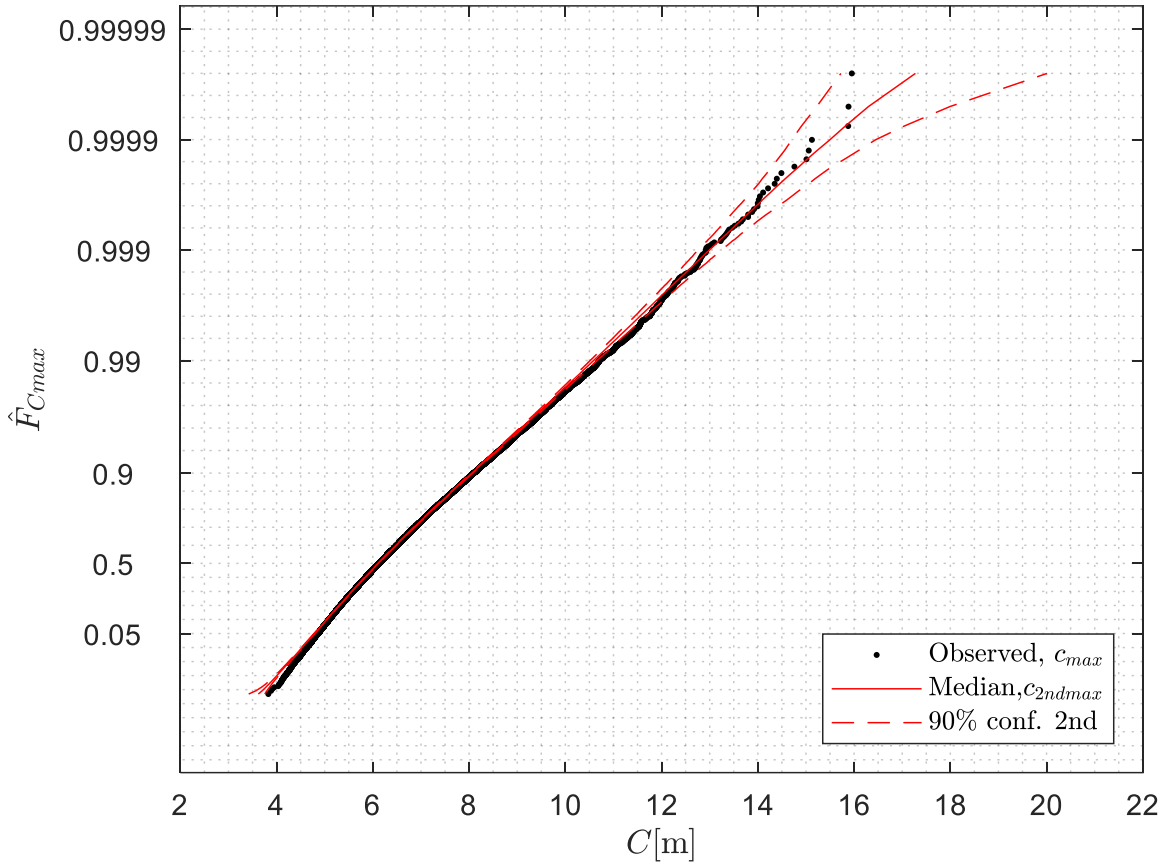


All PL and NNS Data



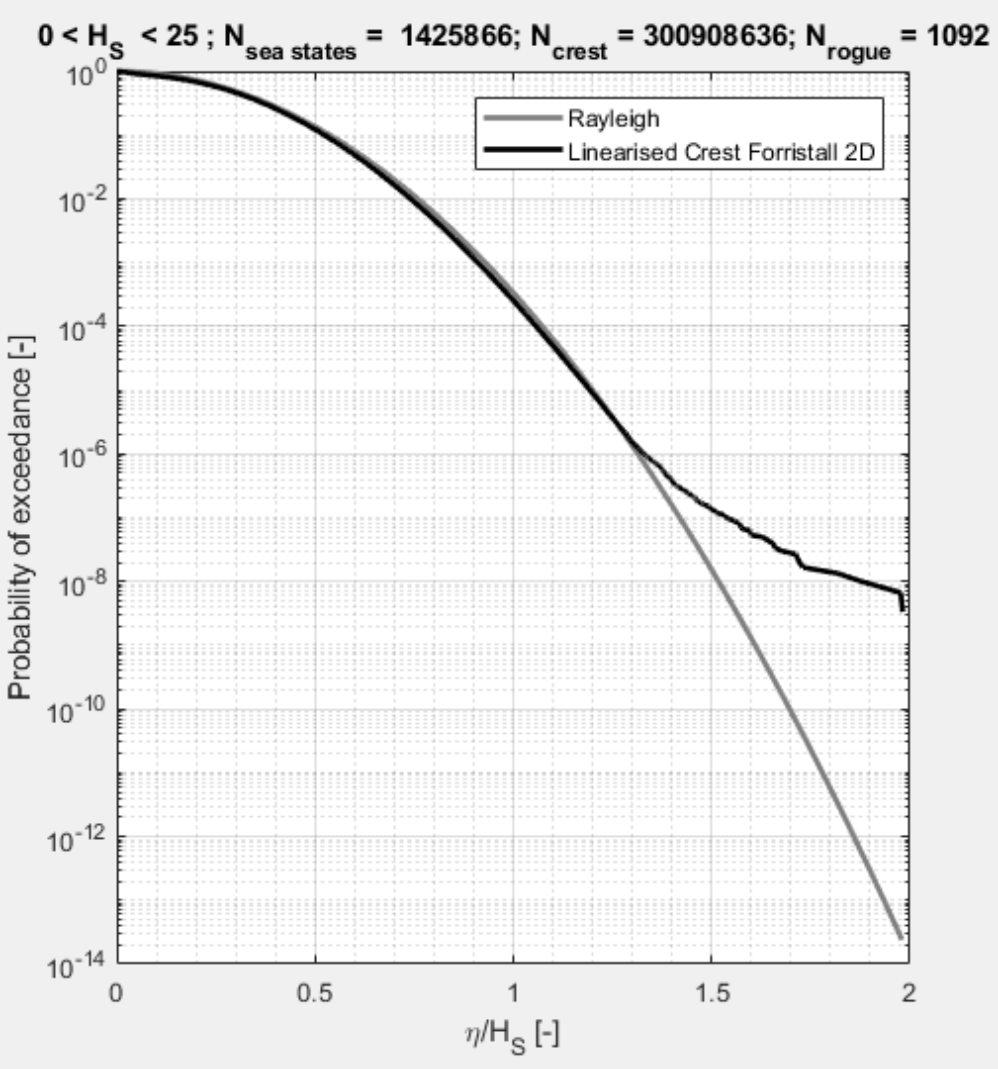
Hs > 6m; 38646 20-min

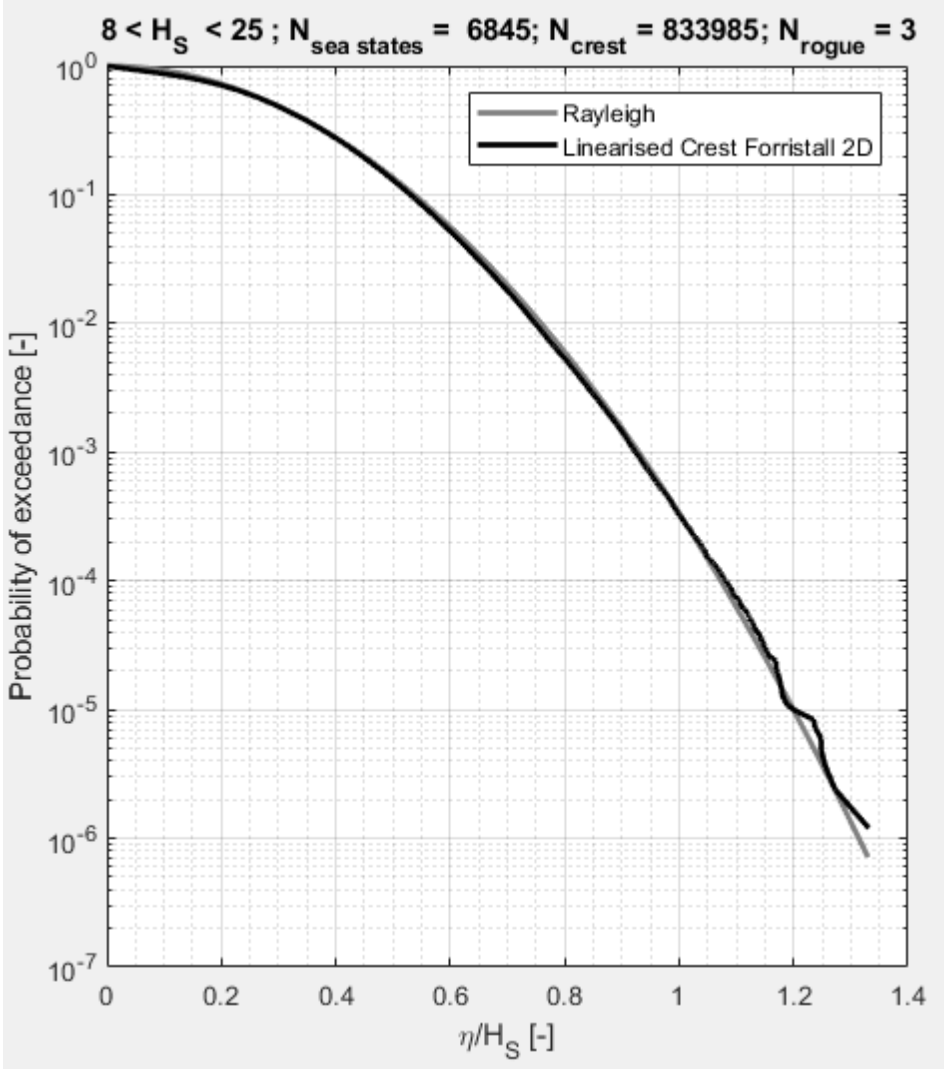
All Data (equivalent to approximately 50 years of date, for the NNS location)



Hs > 6m; 39759 20-min

All Data





post processed by Børge Kvingedal

Conclusion / Discussion

The field data indicates that the long-term distribution of the wave crest heights is well described by the Forristall second order model while the basin indicate 4 % amplification above second order.

Possible candidates for the difference :

We are not comparing "apples with apples"

- The true wave spectra in the ocean(including several wave systems, current and varying wave spreading) is to complex to be approximated by a JONSWAP spectrum with wave spreading of 18 degree.

Field data are not measured correct

- Is the WaveRex radar appropriate ?
- Filtering of data ?

Can the wave Basin effects lead to the differences ?

- Wave are generated by wave paddles, will this give different physics than when generated over a long fetch by wind ?
- Can reflection in the basin affect the crest distribution ?

Can we expect more breaking waves in the ocean than in the basin ?

- In the ocean the wind energy is feed into the waves, can this lead to more wave breaking
- Less dissipation of energy due to white capping in the basin ?

A basic assumption is that Froude scaling is appropriate(at least for the surface elevation), is it ? Yes let's hope so

Laboratory testing is performed to estimate response in extreme sea states. To compare field and basin data, more high quality data from the field is needed, we appreciate any contribution !

- NOTE: Although the second-order crest height distributions seems to be reasonable, the local load effect from steep breaking waves will be grossly underestimated using second-order wave theory.

Acknowledgment

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- Dr. Børge Kvingedal, Equinor is acknowledged for preparation of some figures included in this presentation.

Thank you !