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"Spectral shapes and parameters from three different measuring systems"

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3: Environment and Climate Change Canada, Toronto, Canada

ERDC

COASTAL & HYDRAULICS LABORATORY

Norwegian Meteorological Institute

Environment Canada

WMO IOC jcomm

Comparing wave observations from 3 different sources of 2Hz data

- LASAR (Laser array)
  - height to MSL ~21m
  - 5Hz / 2Hz
  - 20min
  -
- Waverider Datawell 90 cm.
  - heave buoy
  - 2Hz
  - 20min
  - ~1.5km NW of Ekofisk
- Saab radar REX
  - height to MSL ~31m
  - 2Hz
  - 20min

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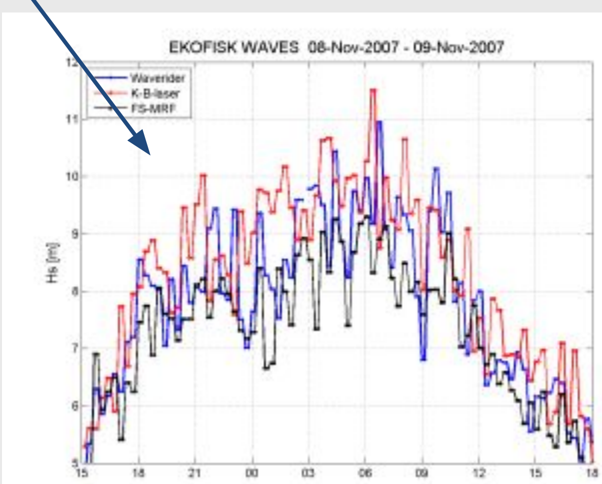
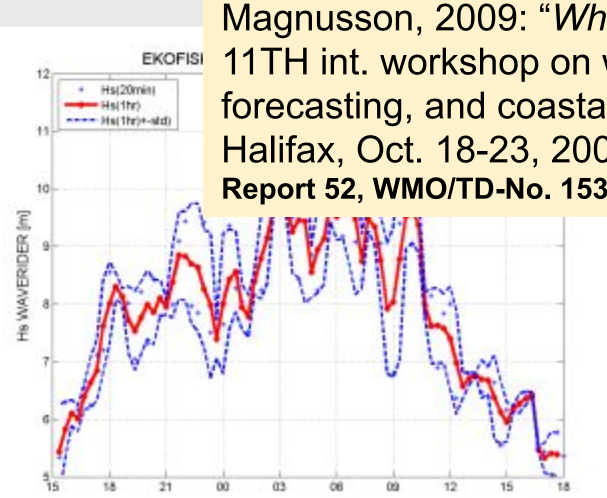
Background and motivation

Observations are used at MET Norway for validation of models and forecasts and for special extreme wave forecasting service for ConocoPhilllips.

- We observe
  - high variability in wave measurements from consecutive 20 minutes, and between different sensors
  - bias in Hs between different types sensors (buoy vs radar), analysis has shown that interference with constructions can not solely explain the differences





Magnusson, 2009: "*What is true sea state?*". 11TH int. workshop on wave hindcastng and forecasting, and coastal hazard symposium. Halifax, Oct. 18-23, 2009. **JCOMM Technical Report 52, WMO/TD-No. 1533**

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Observations are used for validation of models and forecasts and for special extreme wave forecasting service for ConocoPhilllips.

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  - bias in Hs between different types sensors (buoy vs radar), analysis has shown that interference with constructions can not solely explain the differences

Questions: —> *Can we identify differences in spectral shapes?*

—> What about other spectral parameters ?

Validation of global models

- Durrant et el. (2009) suggested that **NDBC versus Canadian buoys have a 10% difference compared to altimeter data.** Who is more correct?
- **JCOMM, Task Team on Wave Measurements** (follow on from the Pilot Project Wave Evaluation and Testing) is the basis for all of this work.
- ERDC-CHL use the data (6N NOMADS) to evaluate long-term wave hindcast covering all US coasts. —> make sure the data we are using to evaluate the model is of highest quality. There are 100's of years of buoy data (multiple sites covering decades).

—> a whish to have a wave experiment including diretional wave buoys at Ekofisk. Where also a stereo video system is also installed this year, cloe to the LASAR system.

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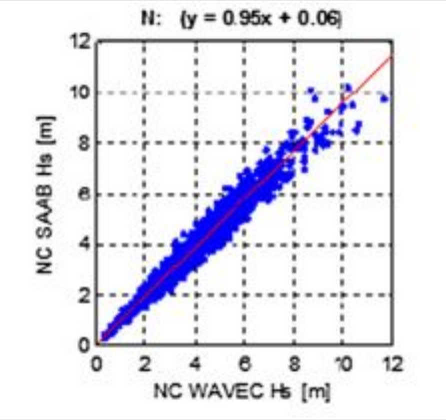
Saab radar analysis

Ewans, Feld, Jonathan (2014). “On wave radar measurements”. Ocean Dynamics (2014) 64:1281–1303, DOI 10.1007/s10236-014-0742-5

Comparisons of the Rex WaveRadars against the wave buoys show systematic differences in the significant wave height in some cases. The differences are less than 8 % and generally less than 5 %, and therefore more or less consistent with wave sensor inter-comparisons performed in the WADIC experiment (Allender et al. 1989). Nevertheless, an explanation for these differences is desirable. The differences cannot be explained by platform interference but appear to be more related to the specific setup of the instrumentation, for which we currently do not have an explanation.



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Accordingly, we acknowledge that further investigation of the field measurement setups is needed, to explain the differences between the results of the various inter-comparisons, and we note improvements in the WaveRadar "peak picking" algorithm might lead to improved fidelity of the simulations; but the results of this study support the conclusion that the WaveRadar provides good measurements of the surface wave elevation, not only for supporting offshore operational activities and engineering requirements but also for investigations into fundamental aspects of ocean surface waves.

Ewans, Feld, Jonathan (2014). "On wave radar measurements".

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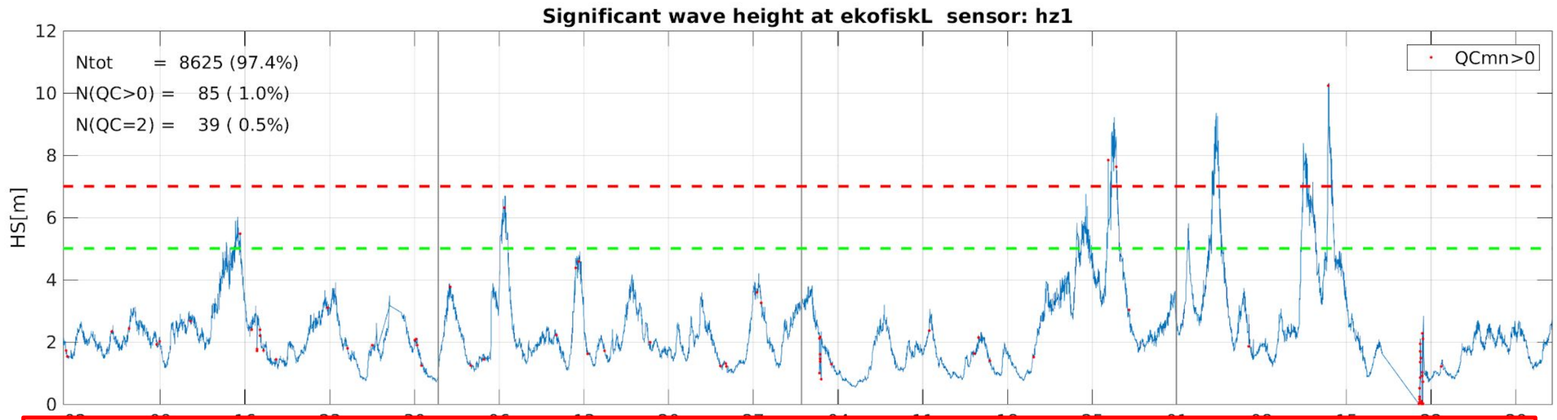
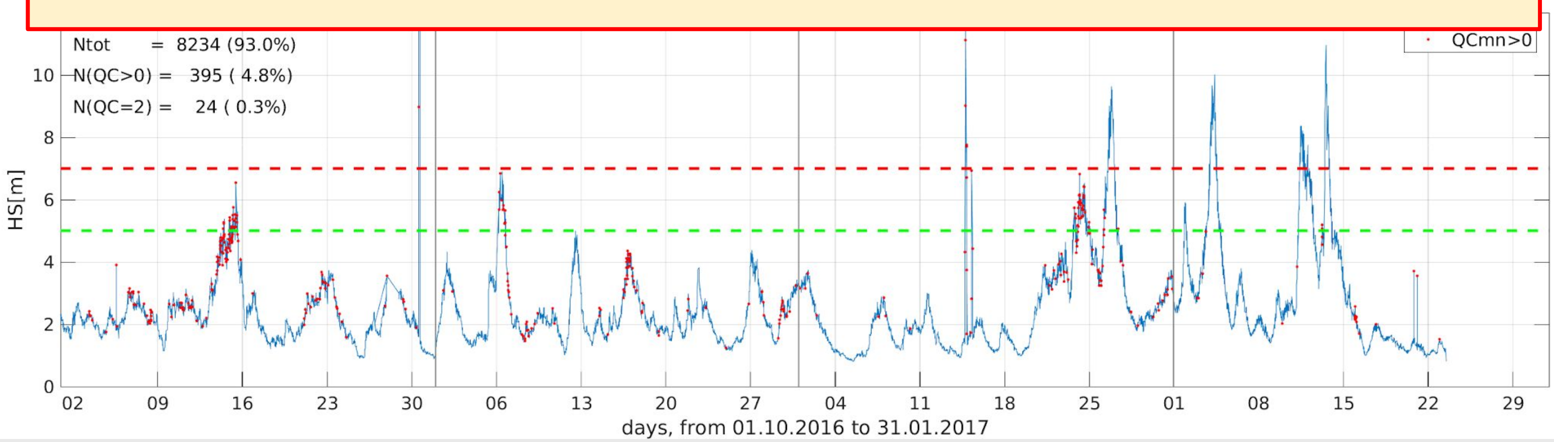
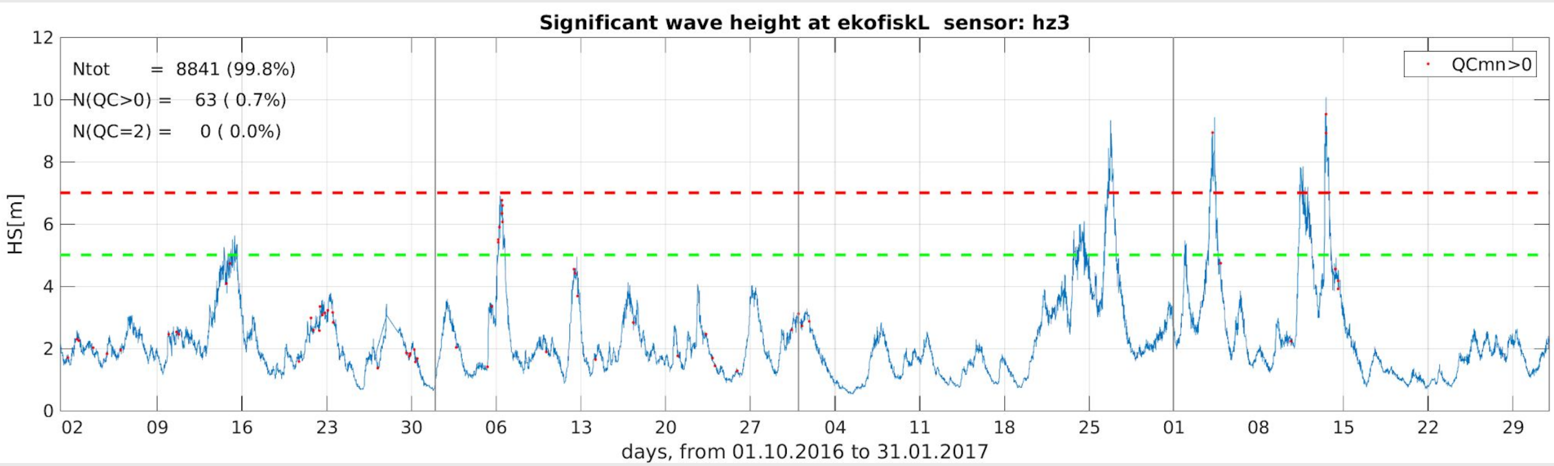
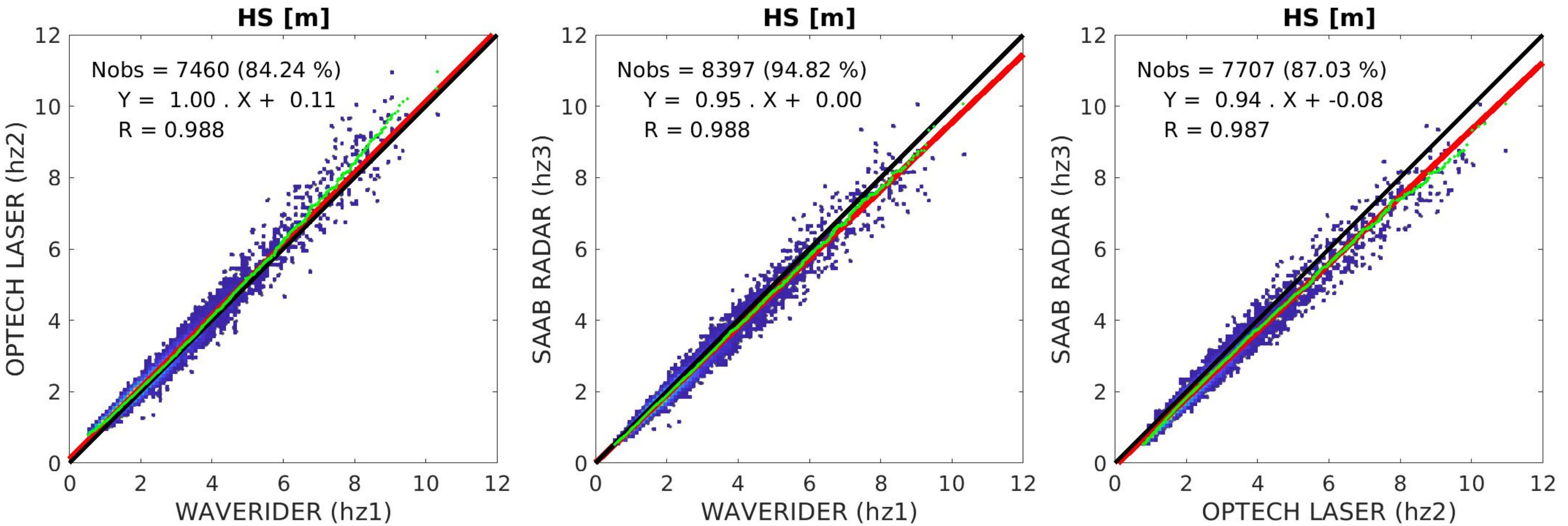


DATABASE - 3 time series (2Hz) - 4 months - 93 to 99.8 % return





HS = 4σ - 20 min (2Hz, 1:2400)



Hs [m]	Entries	slope	bias	R
Optech vs Waverider	7460 (84 %)	1.00	0.11	0.988
Saab vs Waverider	8397 (95 %)	0.95	0.00	0.988
Saab vs Optech	7707 (87 %)	0.94	-0.08	0.987

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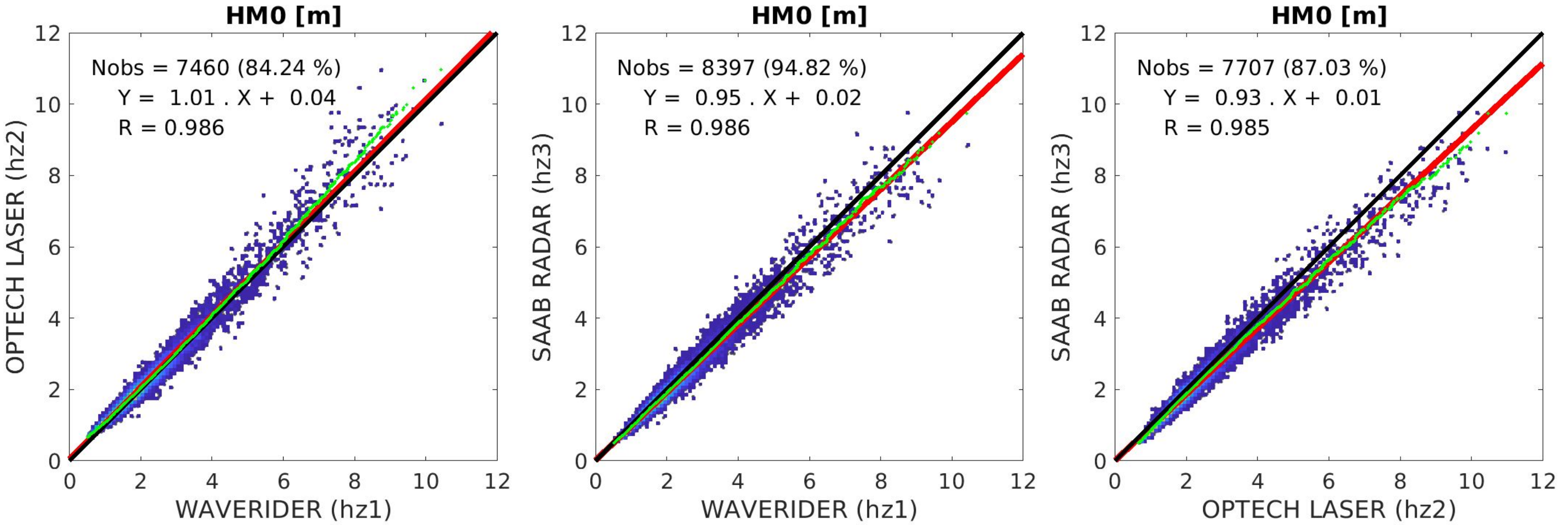
HM0 = 4.√M0 (.03-.5 Hz)



HM0 [m]	Entries	slope	bias	R
Optech vs Waverider	7460 (84 %)	1.01	0.04	0.986
Saab vs Waverider	8397 (95 %)	0.95	0.02	0.986
Saab vs Optech	7707 (87 %)	0.93	0.01	0.985

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Spectral parameters

$$m_n = \int_0^\infty f^n S(f)\, df$$

$$H_{m0} = 4\sqrt{m_0}$$

$$T_{m01} = \frac{m_0}{m_1}$$

$$T_{m02} = \sqrt{\frac{m_0}{m_2}}$$

$$s_p = \frac{2\pi}{g}\frac{H_{m0}}{T_p^2}$$

$$\nu = \sqrt{\frac{m_0 m_2}{m_1^2} - 1}$$

Spectral bandwidth Longuet-Higgins (1975)

$$Q_p = \frac{2}{m_0^2}\int_0^\infty f E(f)^2 \mathrm{d}f.$$

Goda Peakedness Parameter

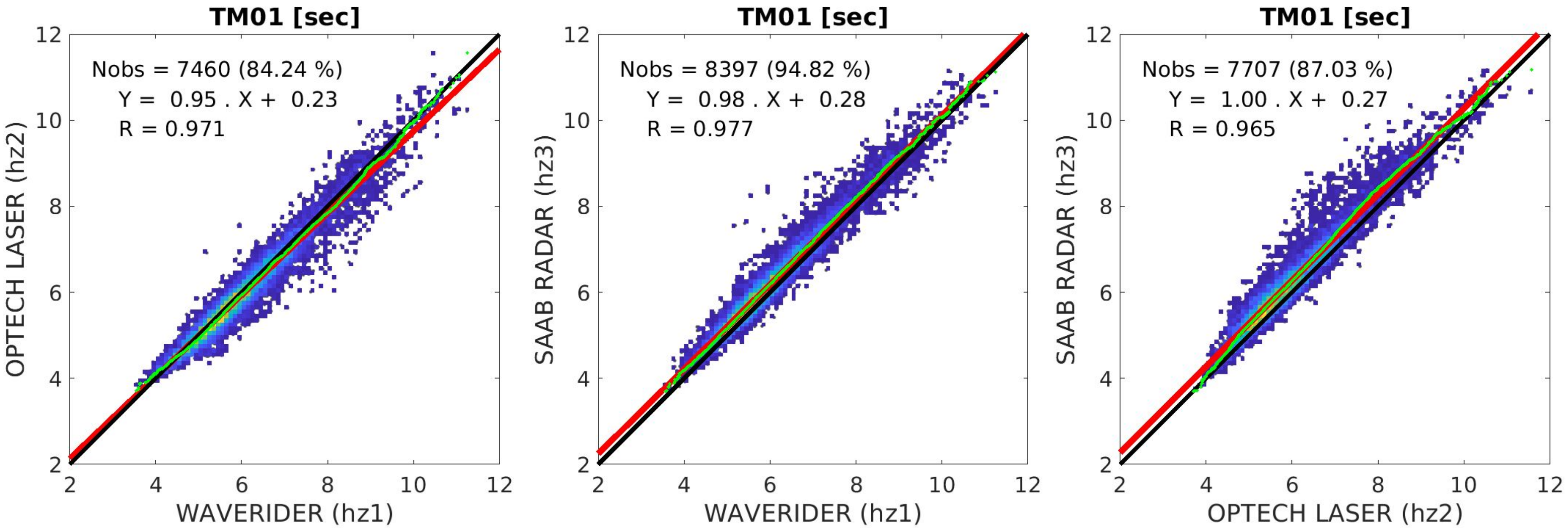
$$BF_j = \sqrt{2\pi}\frac{2\pi}{\Lambda_p}\sqrt{m_0}Q_p$$

(Janssen 2002)

$\sim s_p . Q_p$

$S_p(k_p) = ½ \,.\, Hm0 \,.\, k_p = \boldsymbol{\pi} \,.\, s_p$

TM01



TM01 [s]	Entries	slope	bias	R
Optech vs Waverider	7460 (84 %)	0.95	0.23	0.971
Saab vs Waverider	8397 (95 %)	0.98	0.28	0.977
Saab vs Optech	7707 (87 %)	1.00	0.27	0.965

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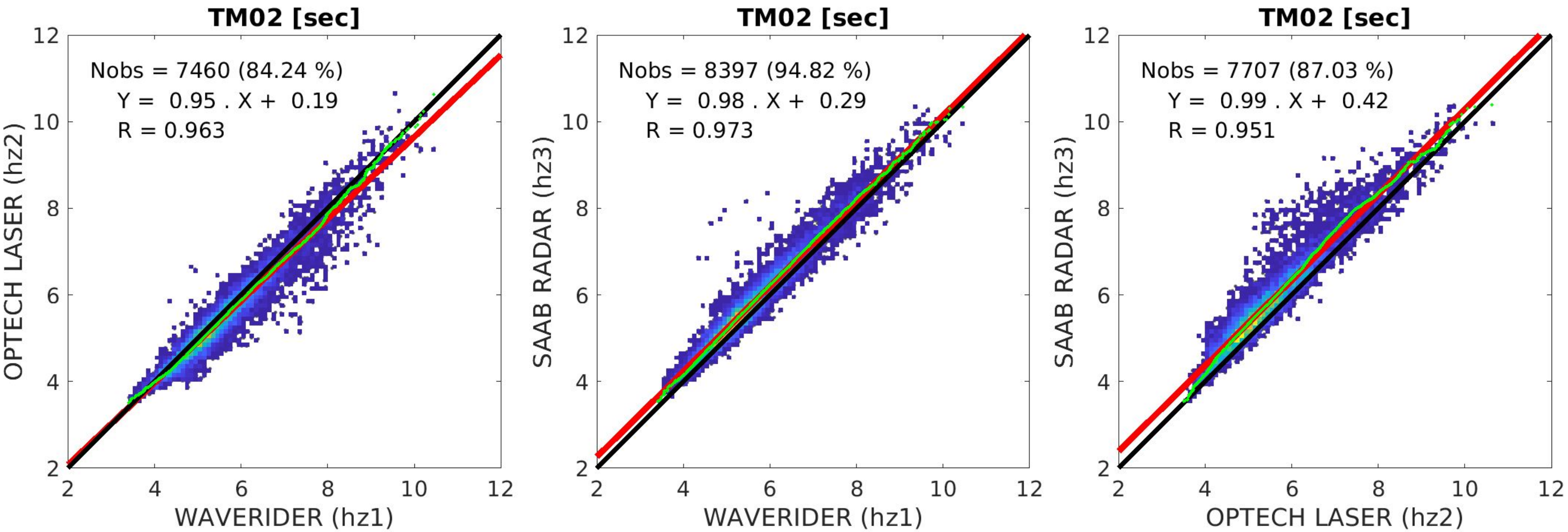
TM02



TM02 [s]	Entries	slope	bias	R
Optech vs Waverider	7460 (84 %)	0.95	0.19	0.963
Saab vs Waverider	8397 (95 %)	0.98	0.29	0.973
Saab vs Optech	7707 (87 %)	0.99	0.42	0.951

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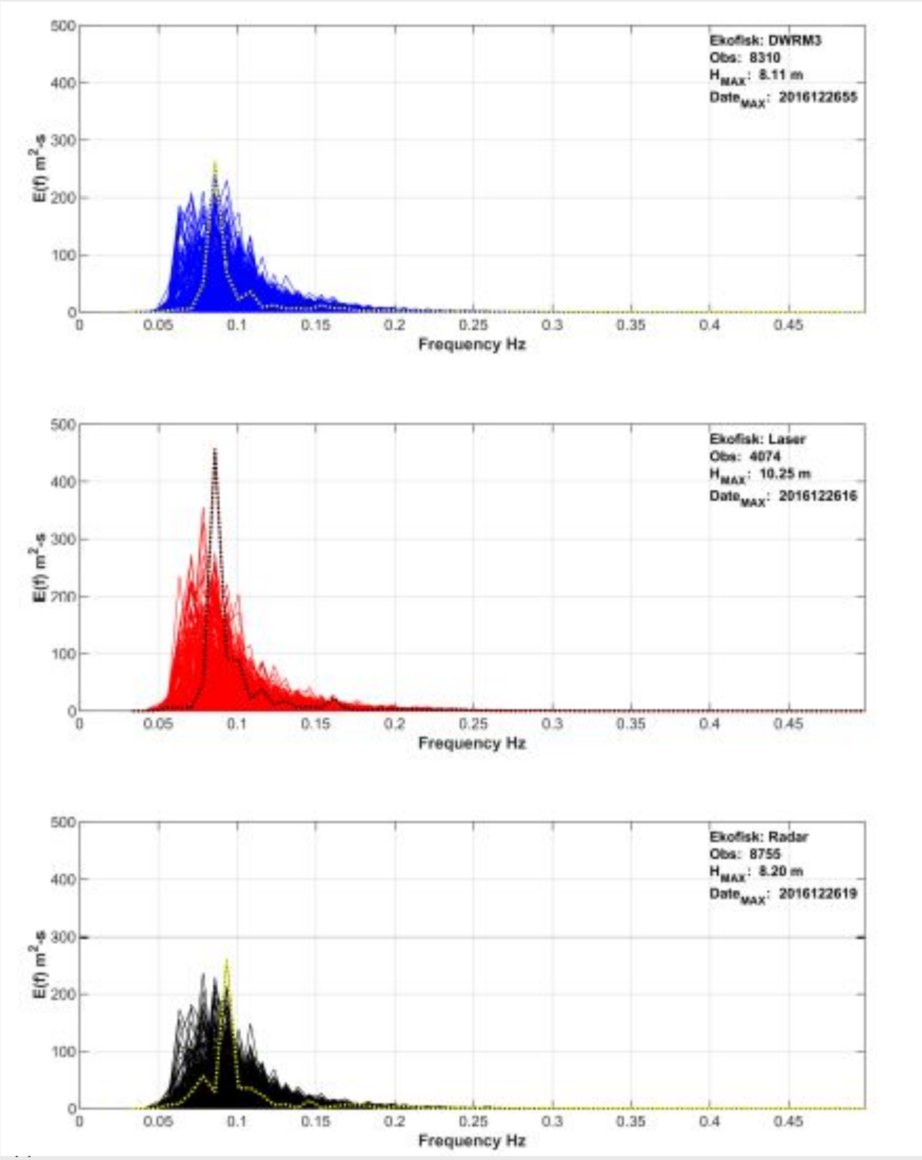
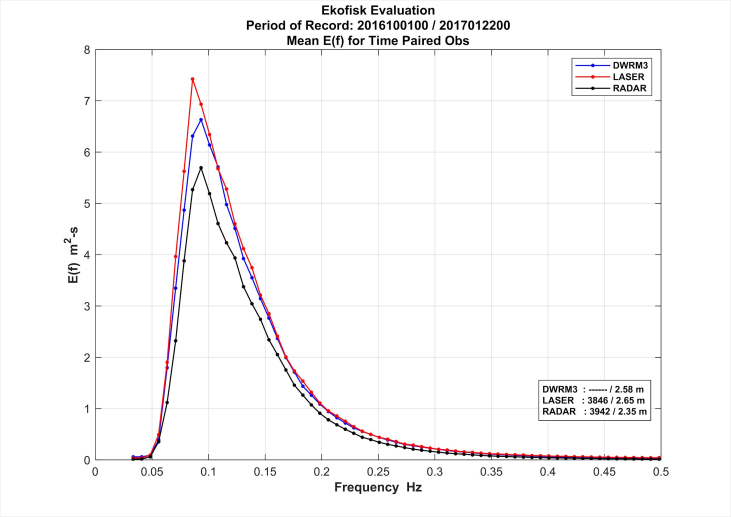
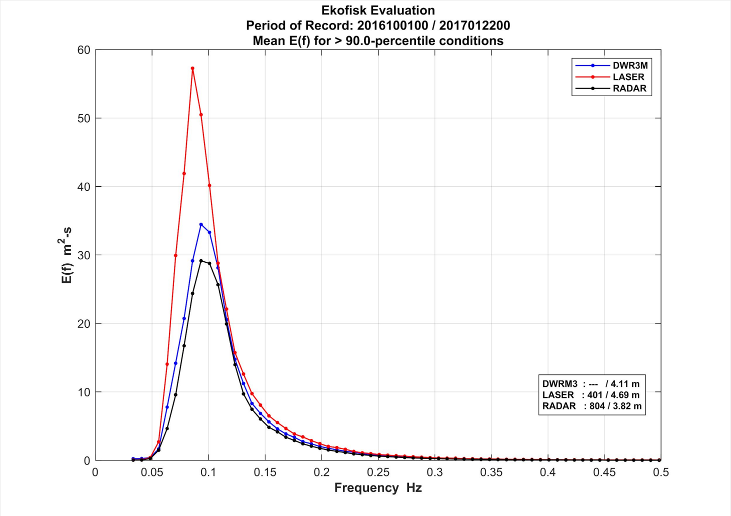
Spectral shapes







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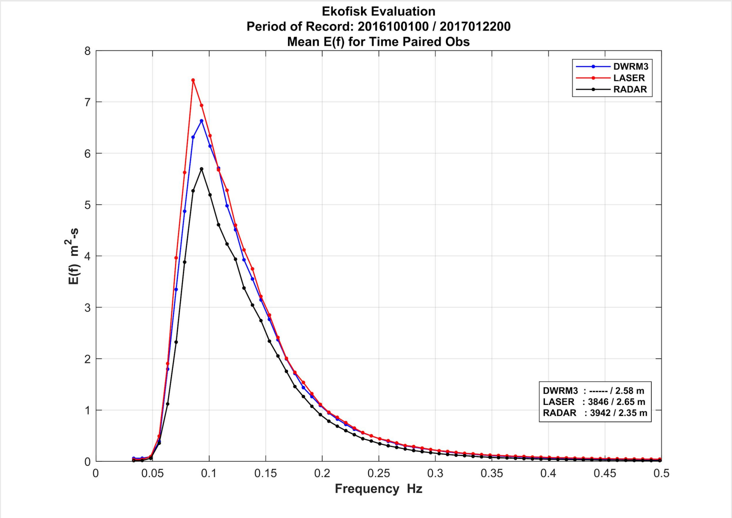
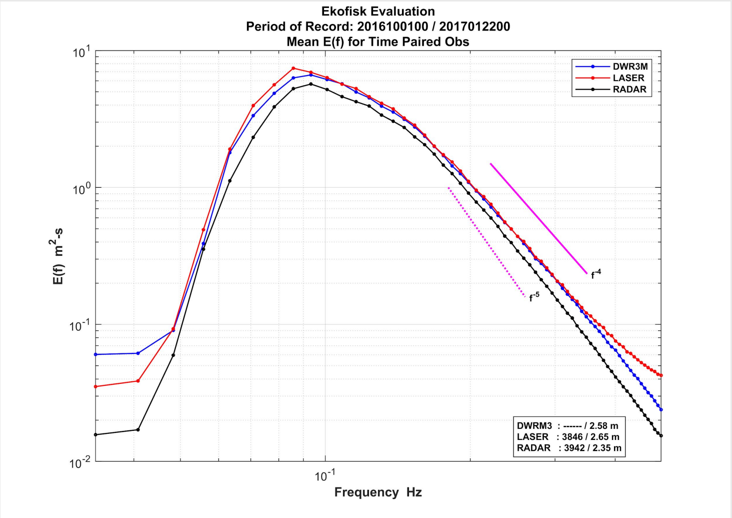
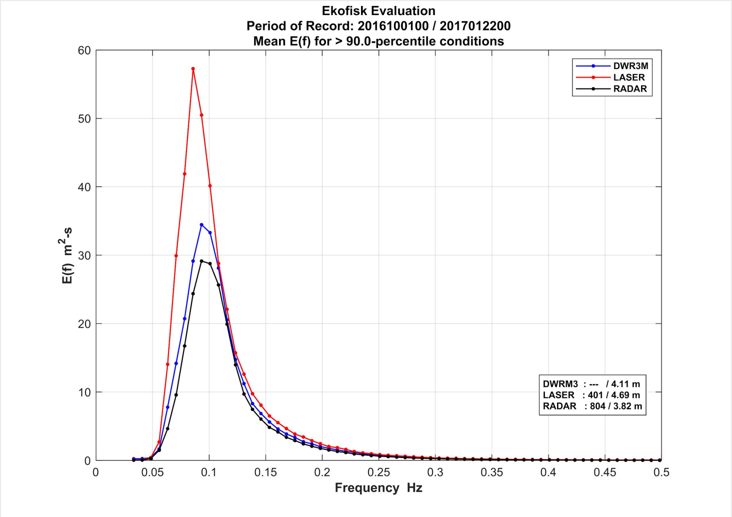
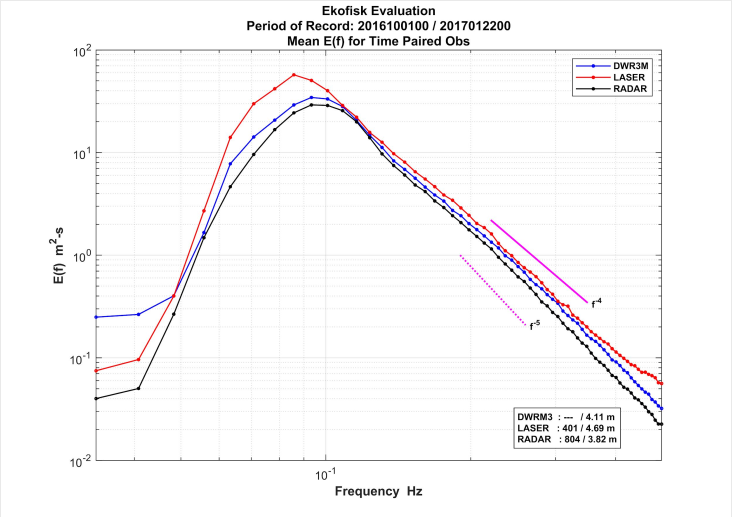
Standard and log-log scale









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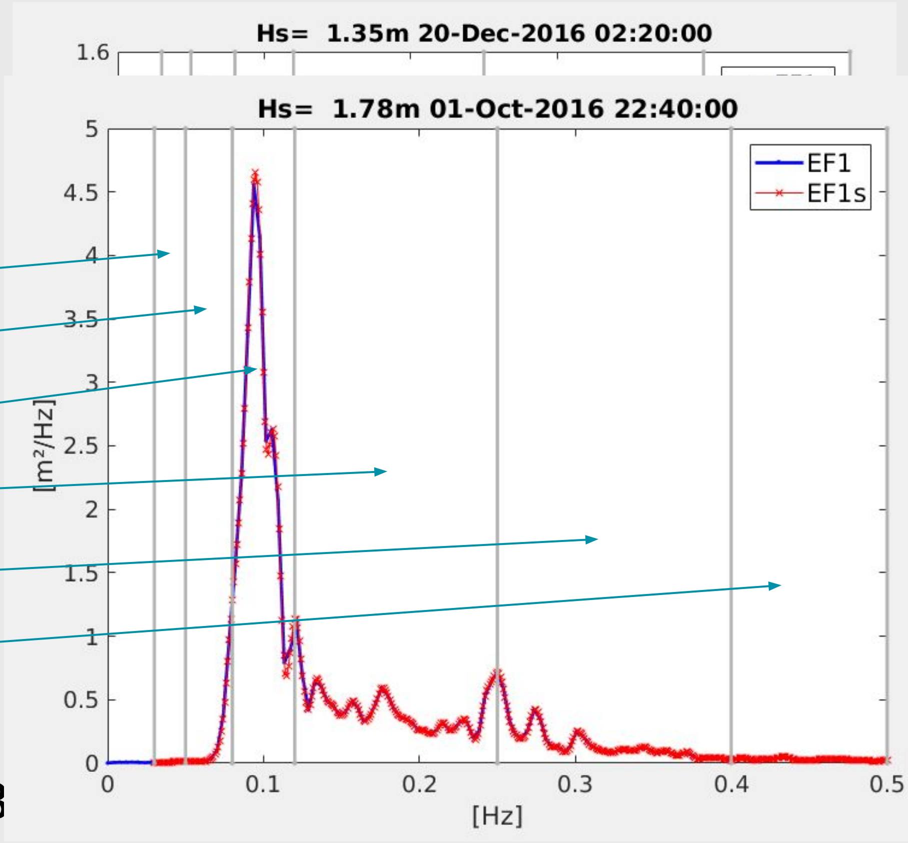
Spectral bands defined in JCOMM

Energy in given spectral bands:
(from JCOMM/PPWET)

0.03 - 0.50 Hz : All waves

0.03 - 0.05 Hz : Forerunners
0.05 - 0.08 Hz : Long Swell
0.08 - 0.12 Hz : Short Swell
0.12 - 0.25 Hz : Long Sea
0.25 - 0.40 Hz : Short Seas
0.40 - 0.50 Hz : Wind Chop



This partition was suggested by B

Adaptation to NORTHSEA

JCOMM freq.limits: [0.03, 0.05, 0.08, 0.12, 0.25, 0.4, 0.5] (ref: Bill O'Reilly)

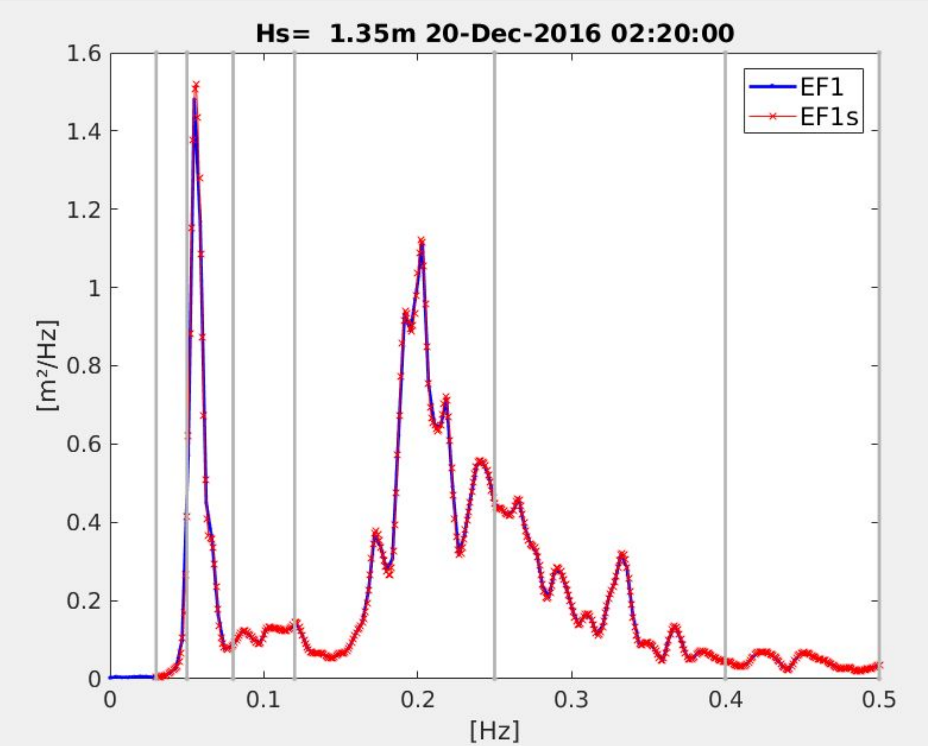
Equivalent periods: 20 12.5 10 8.3 4 2.5 2

6 frequency bands

New frequency limits: [0.03, 0.05, 0.0625, 0.08, 0.1, 0.125, 0.2, 0.5] Hz

Equivalent periods: [33.3 20 16 12.5 10 8 5 2] seconds

7 frequency bands 1 2 3 4 **5** **6** 7



Example with Hs = 1.35m and very long swell at Ekofisk!

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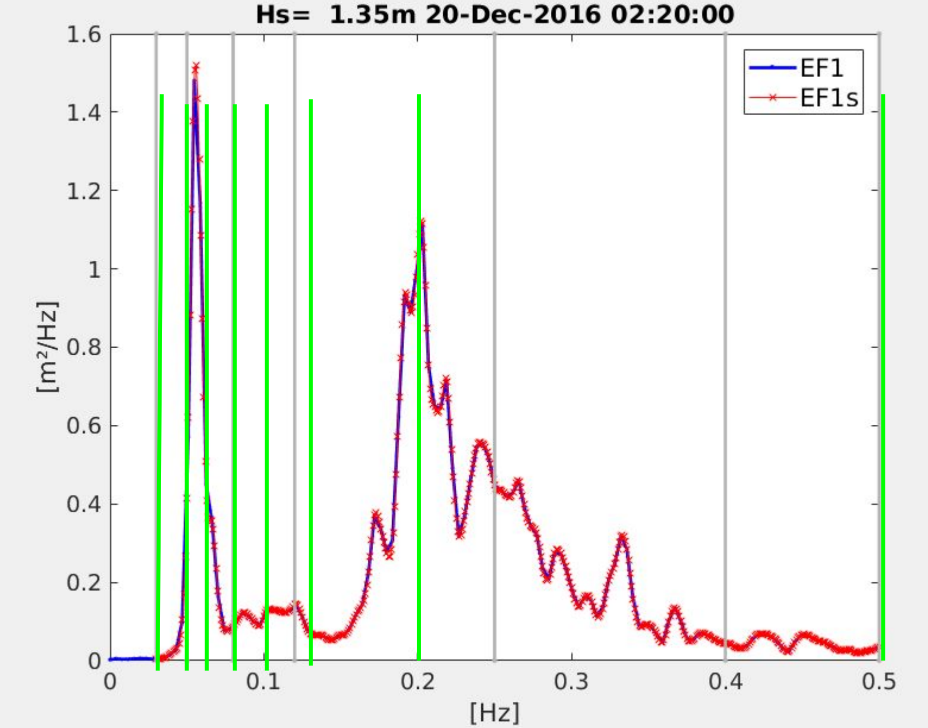

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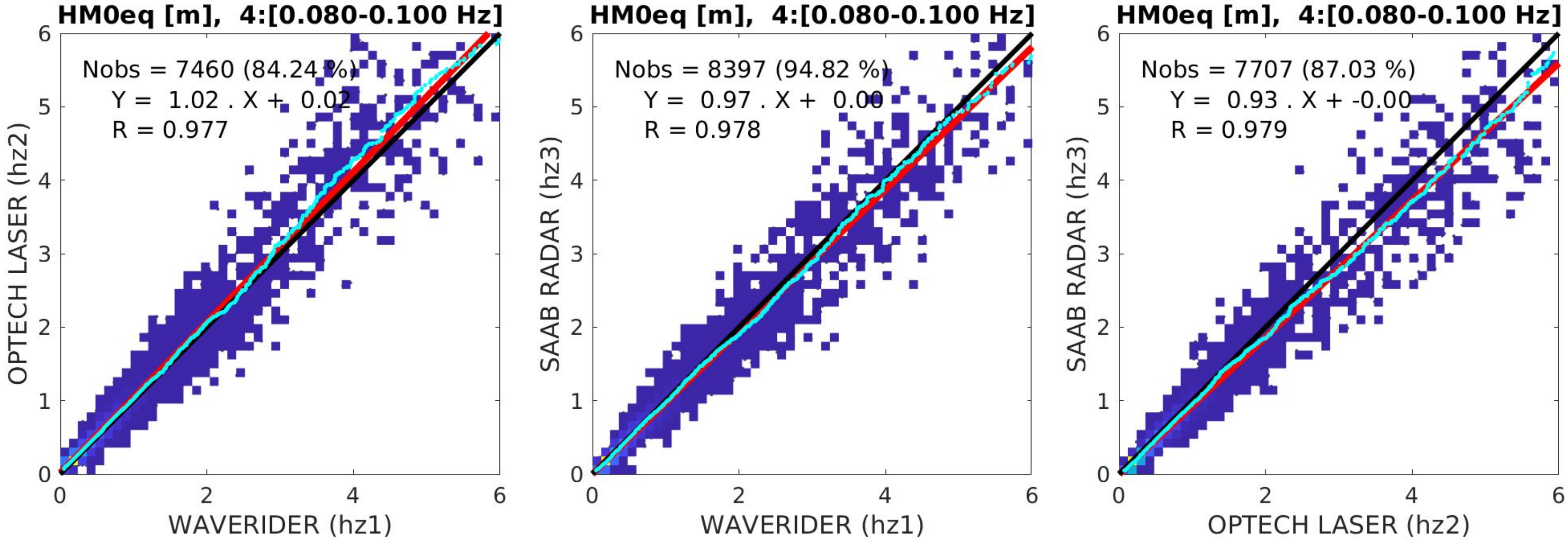
4: [0.08 -0.1] Hz , (12.5- 10 sec)



High variability,

Quite alike values - Identical statistics ?

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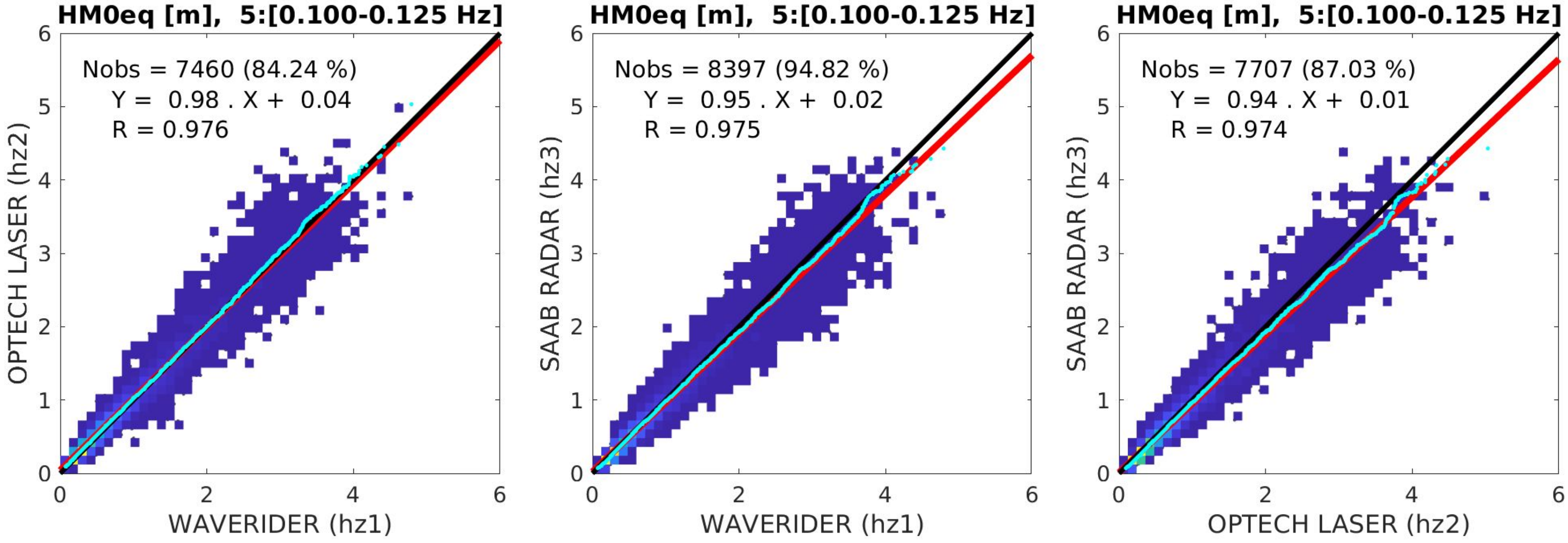
5: [0.1 -0.125] Hz , (10 - 8 sec)



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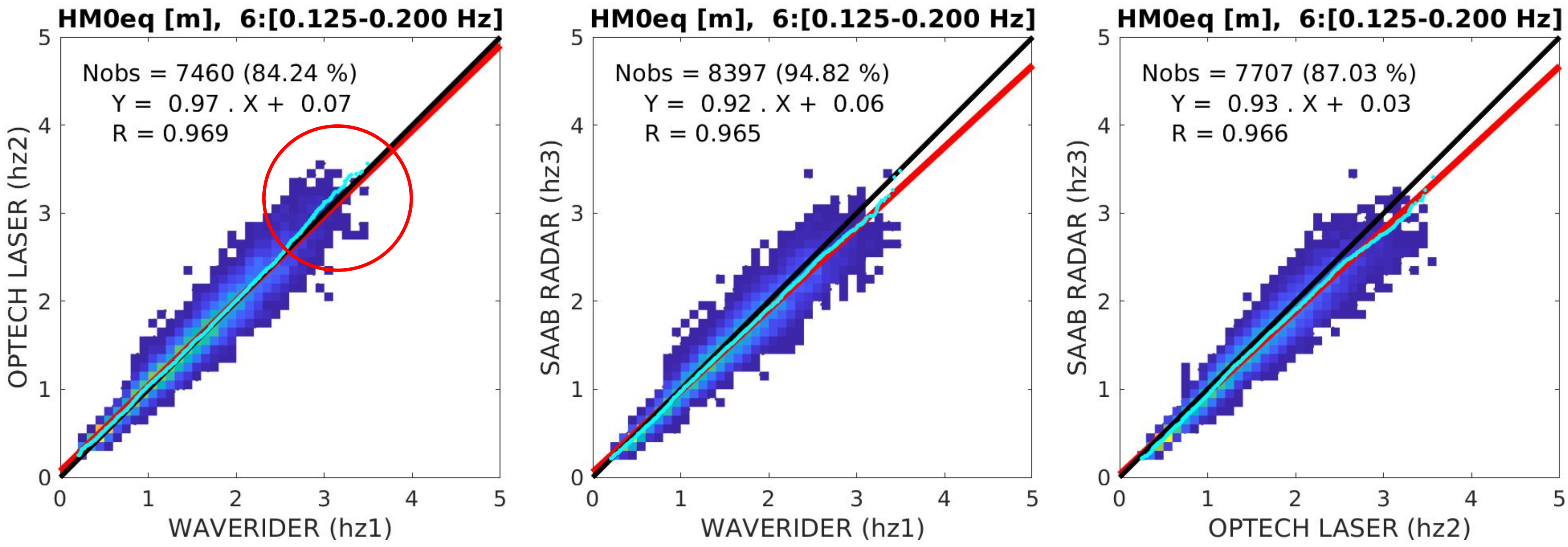
6: [0.125 -0.2] Hz , (8 - 5 sec)



More observations with higher values

Laser tends to estimate higher levels at the higher values

Saab deficit vs waverider at higher levels.Even more obvious against Laser.

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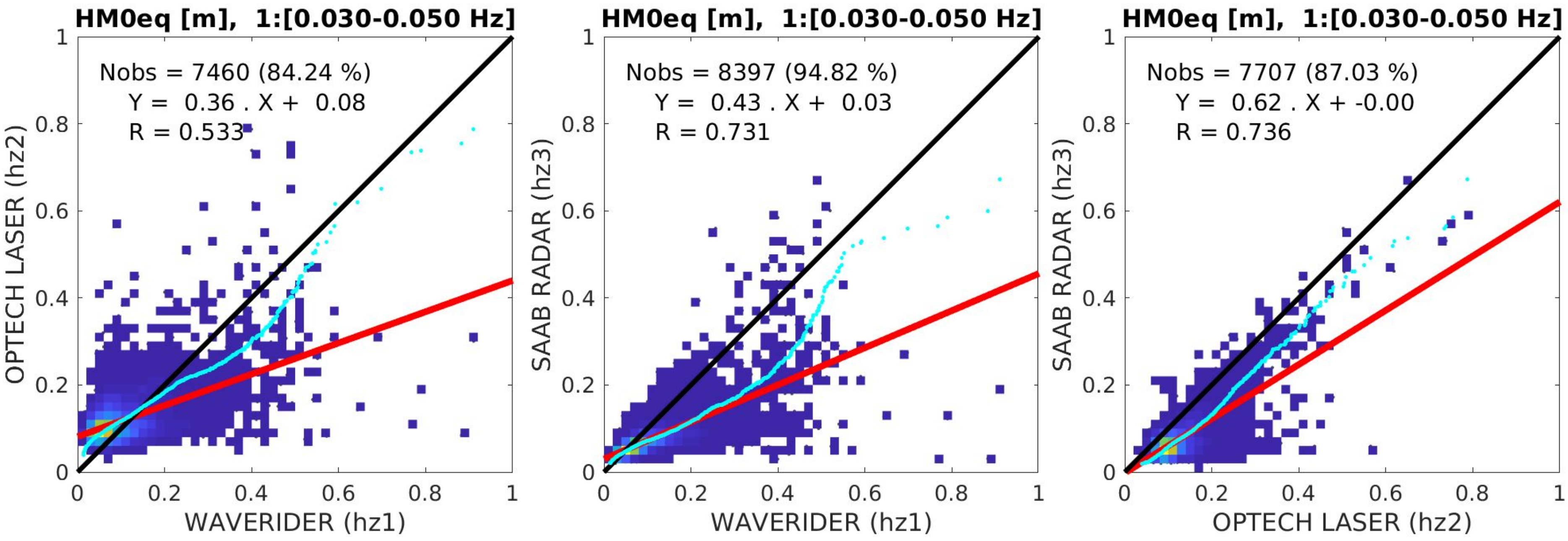
1: [0.03 -0.05] Hz   (33.3 -20 sec)



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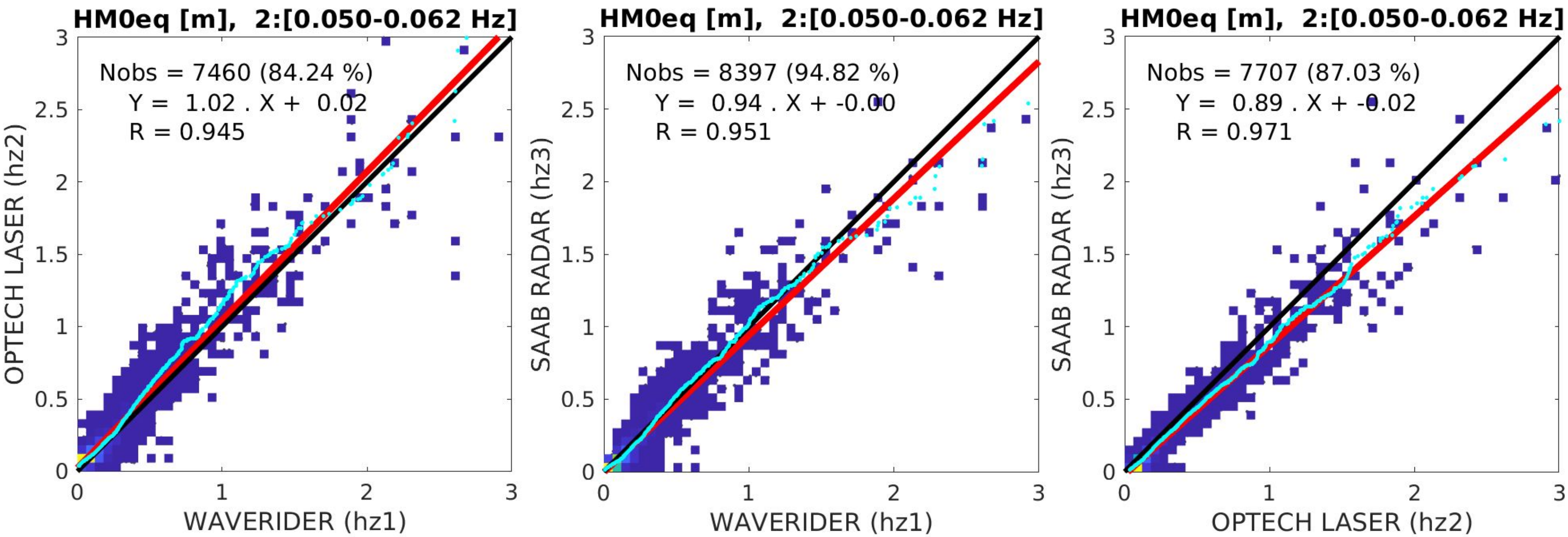
2: [0.05 -0.0625] Hz , (20- 16 sec)



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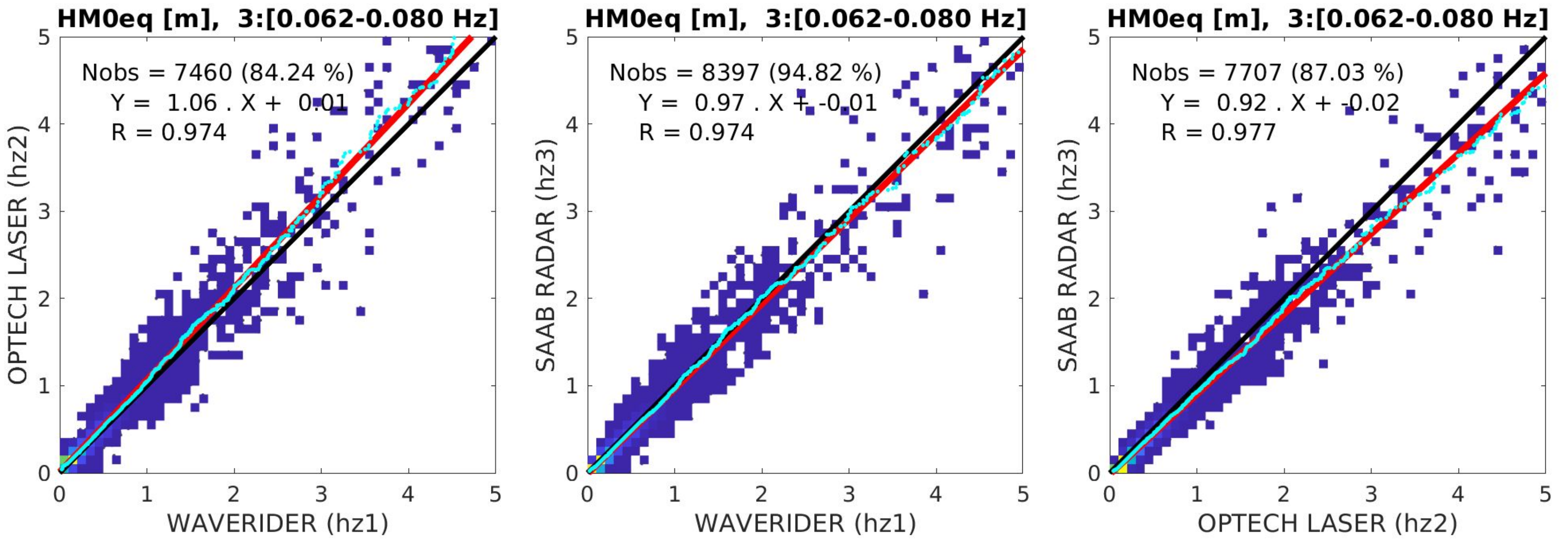
3: [0.0625 -0.08] Hz , (16- 12.5 sec)



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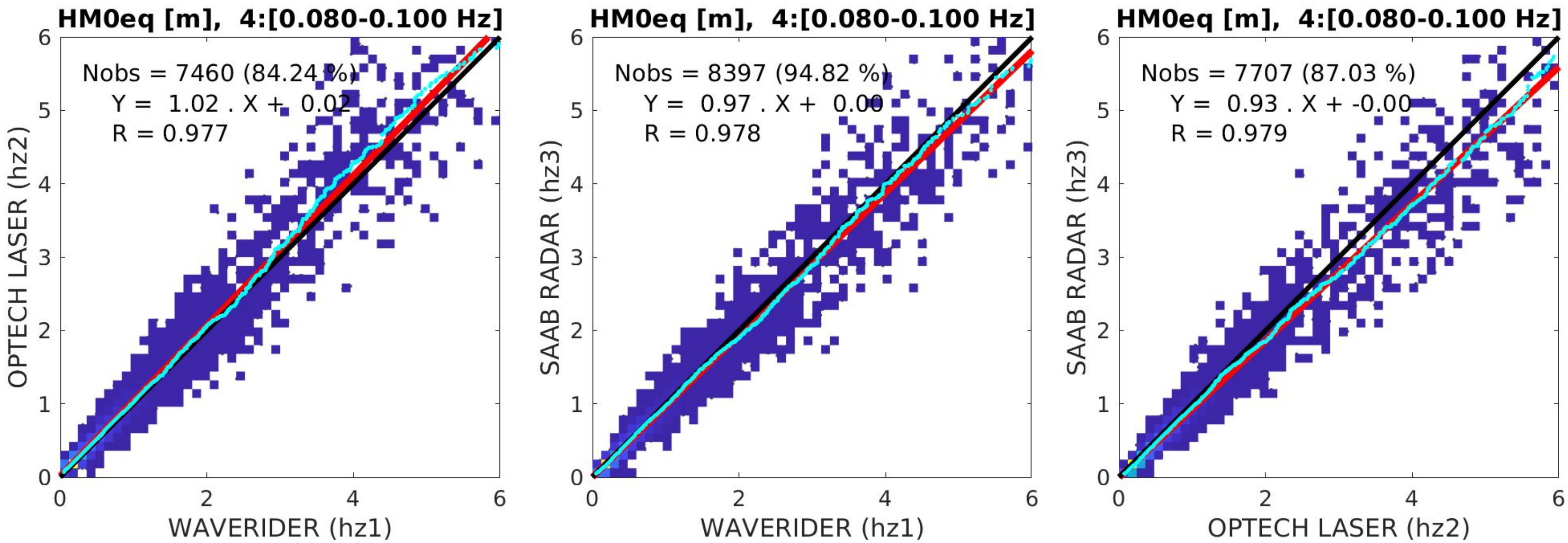
4: [0.08 -0.1] Hz , (12.5- 10 sec)



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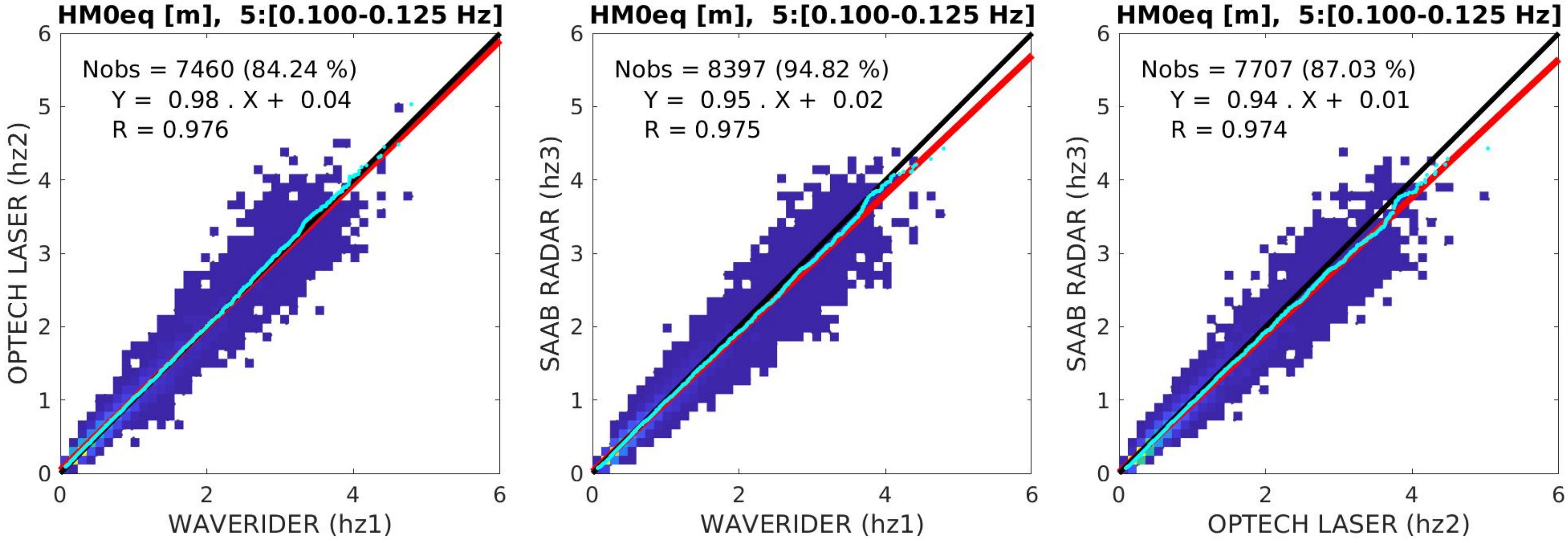
5: [0.1 -0.125] Hz , (10 - 8 sec)



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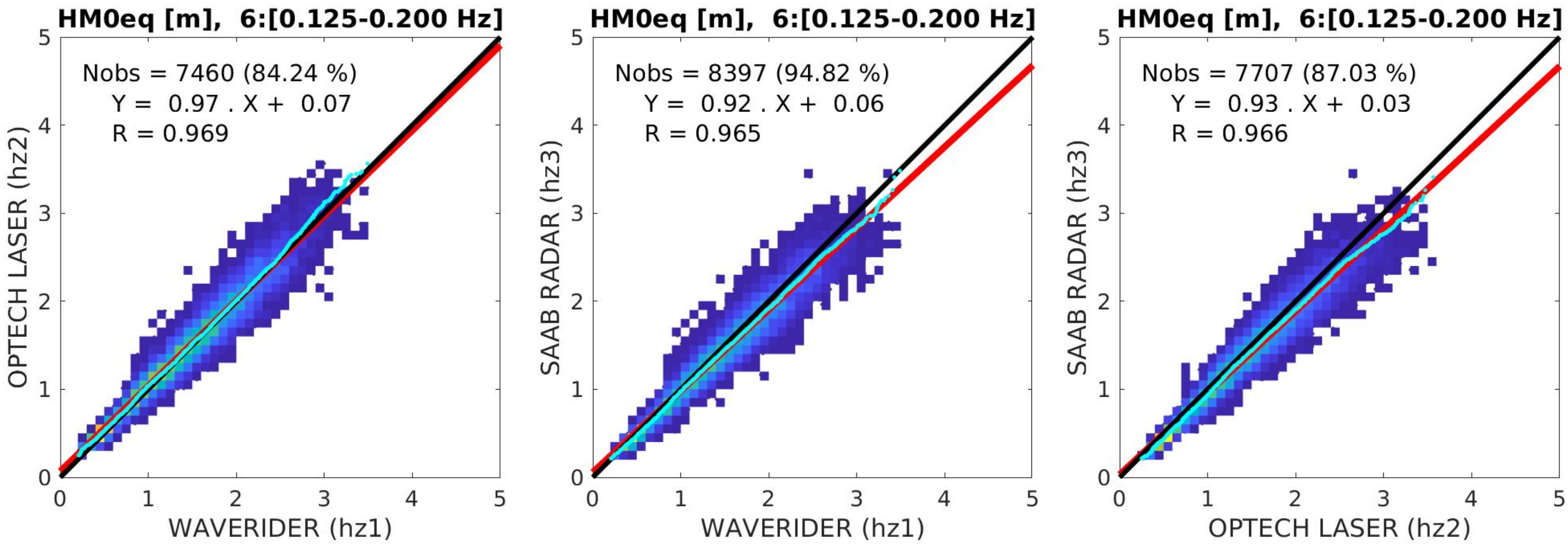

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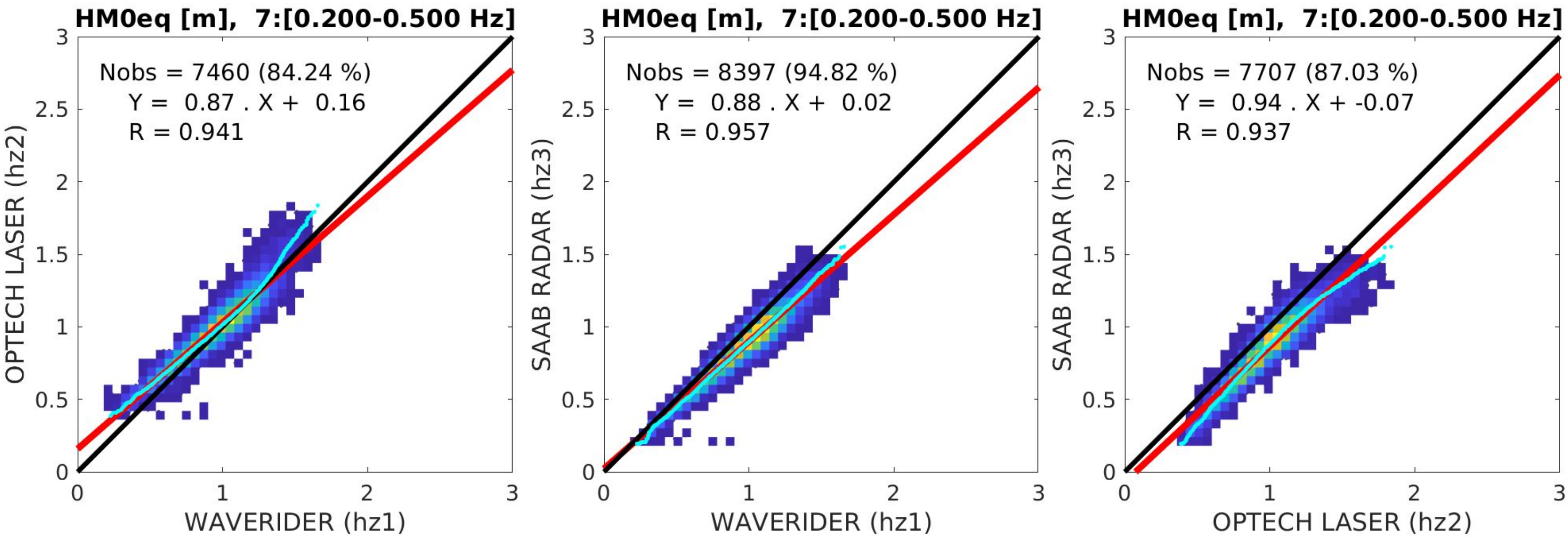
7: [0.2 -0.5] Hz , (5 - 2 sec)



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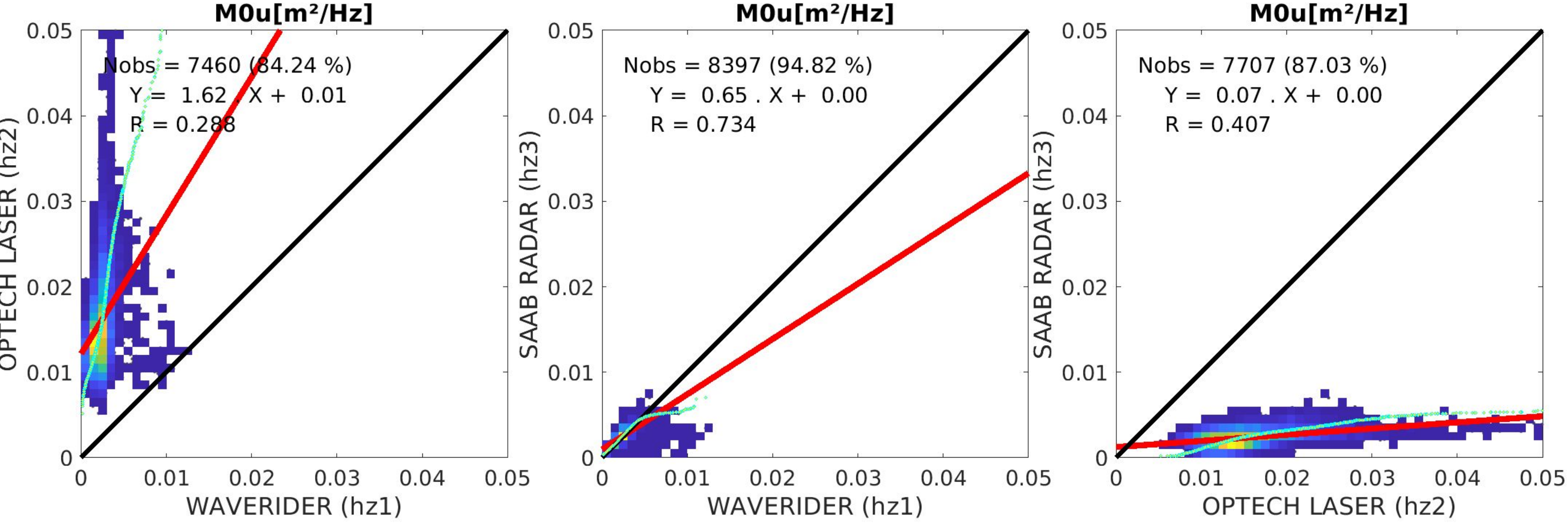
Hs_eq , freq > 0.05 Hz (outside HM0 calculations)



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Spectral parameters

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$$\nu = \sqrt{\frac{m_0 m_2}{m_1^2} - 1}$$

Spectral bandwidth Longuet-Higgins (1975)

$$H_{m0} = 4\sqrt{m_0}$$

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Goda Peakedness Parameter

$$T_{m01} = \frac{m_0}{m_1}$$

$$BF_j = \sqrt{2\pi} \frac{2\pi}{\Lambda_p} \sqrt{m_0} Q_p \sim \sqrt{2\pi}\ s_p.Q_p$$

$$T_{m02} = \sqrt{\frac{m_0}{m_2}}$$

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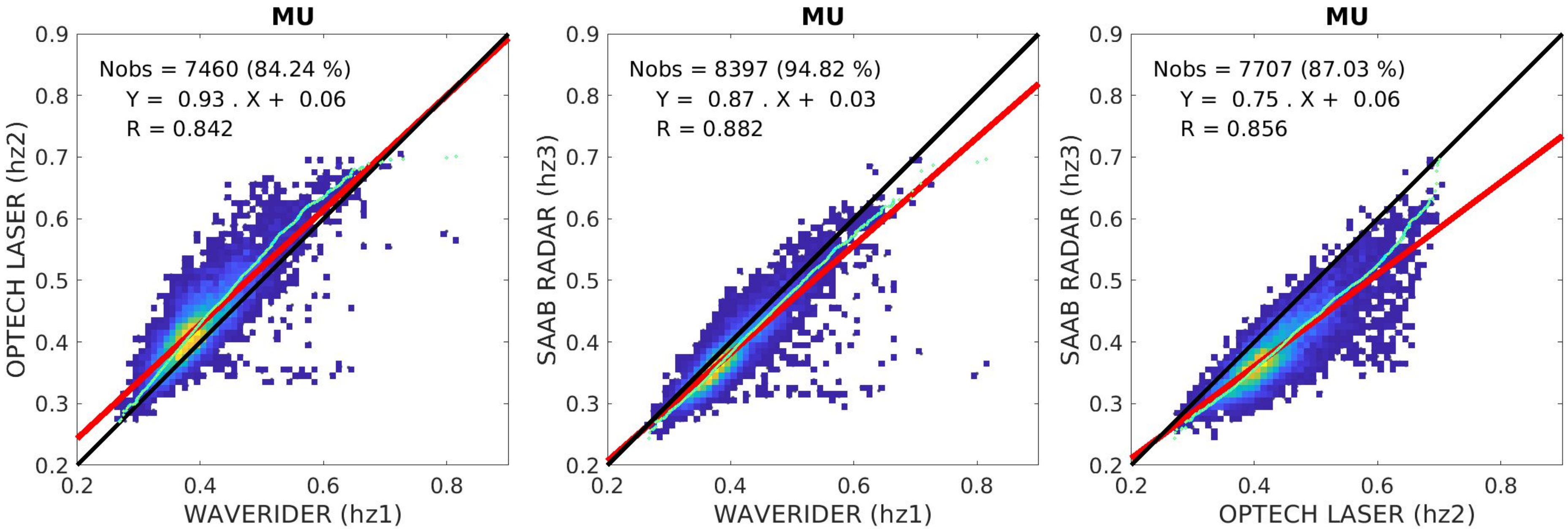
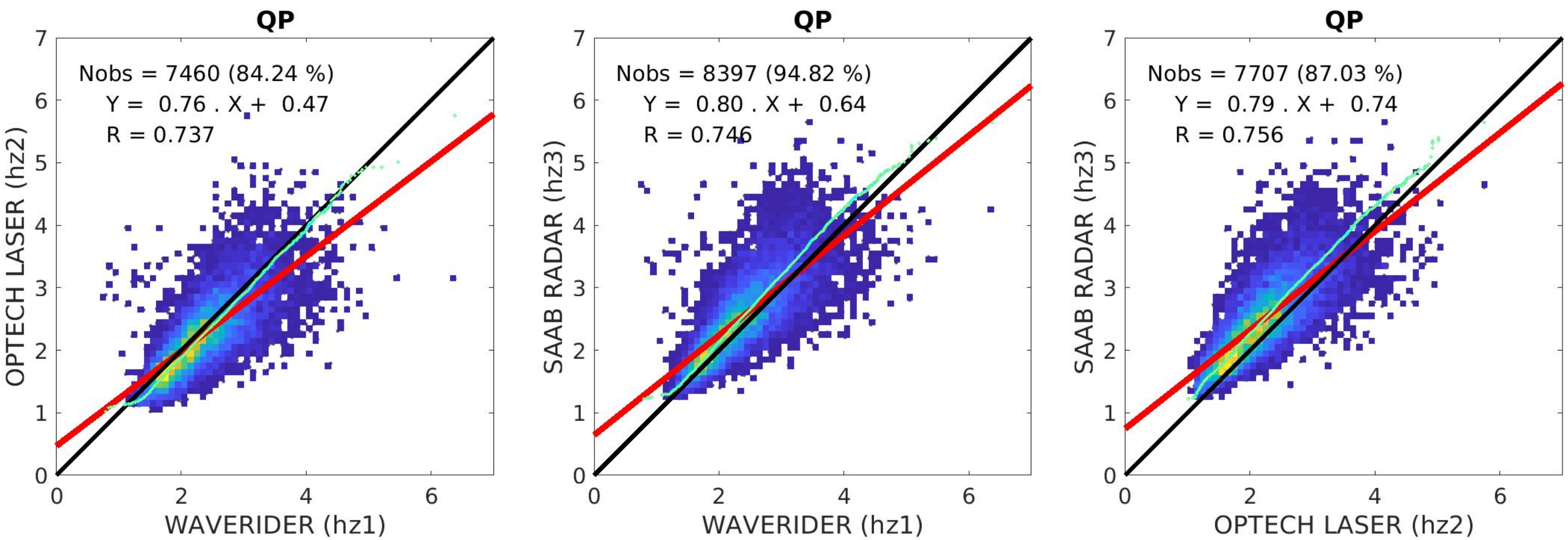


Goda peakedness

$$Q_p = \frac{2}{m_0^2} \int_0^\infty f E(f)^2 \mathrm{d}f.$$



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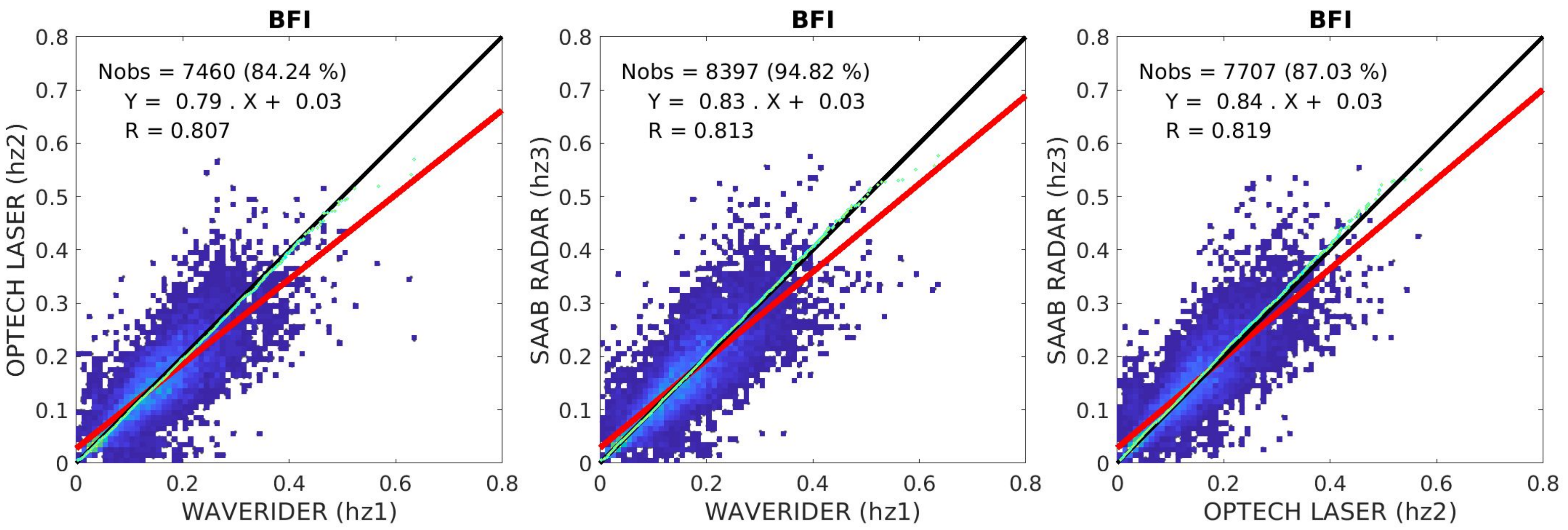

Large spread in colocated values, but distribution (qq plot) shows they have similar distribution.

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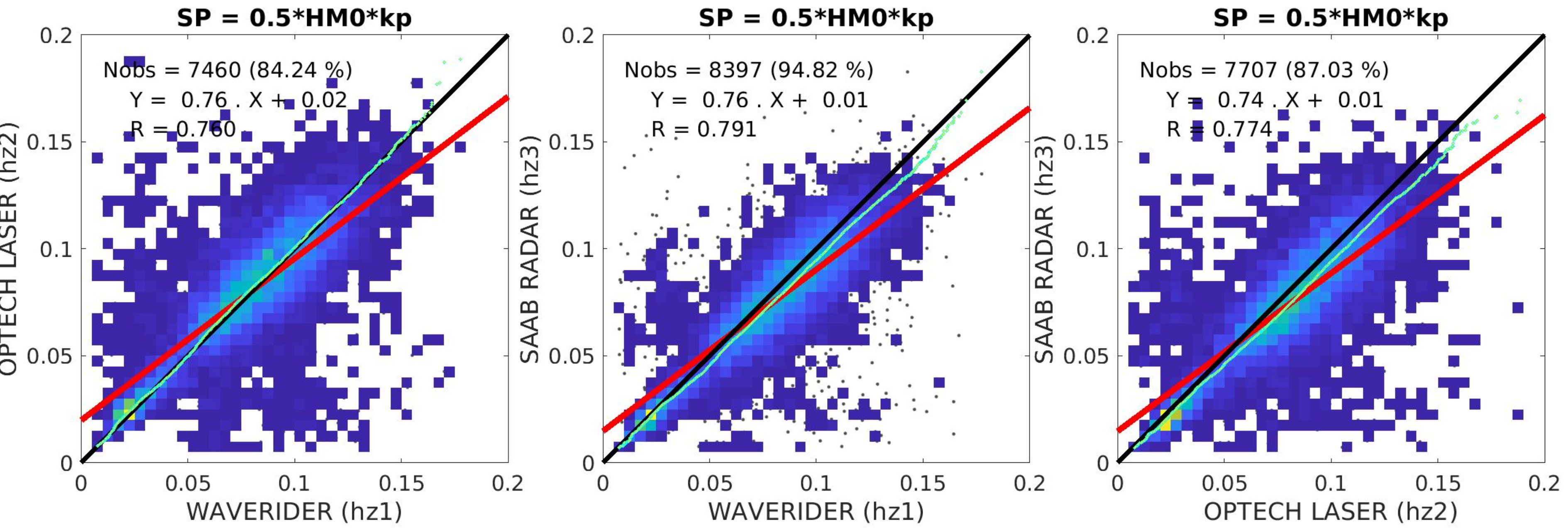
Steepness (depth dependent k_p)



Large spread in steepness values. Regression lines are not really relevant here.
Distribution of Laser and Waverider are similar
The saab radar shows lower steepness values then both waverider and laser.

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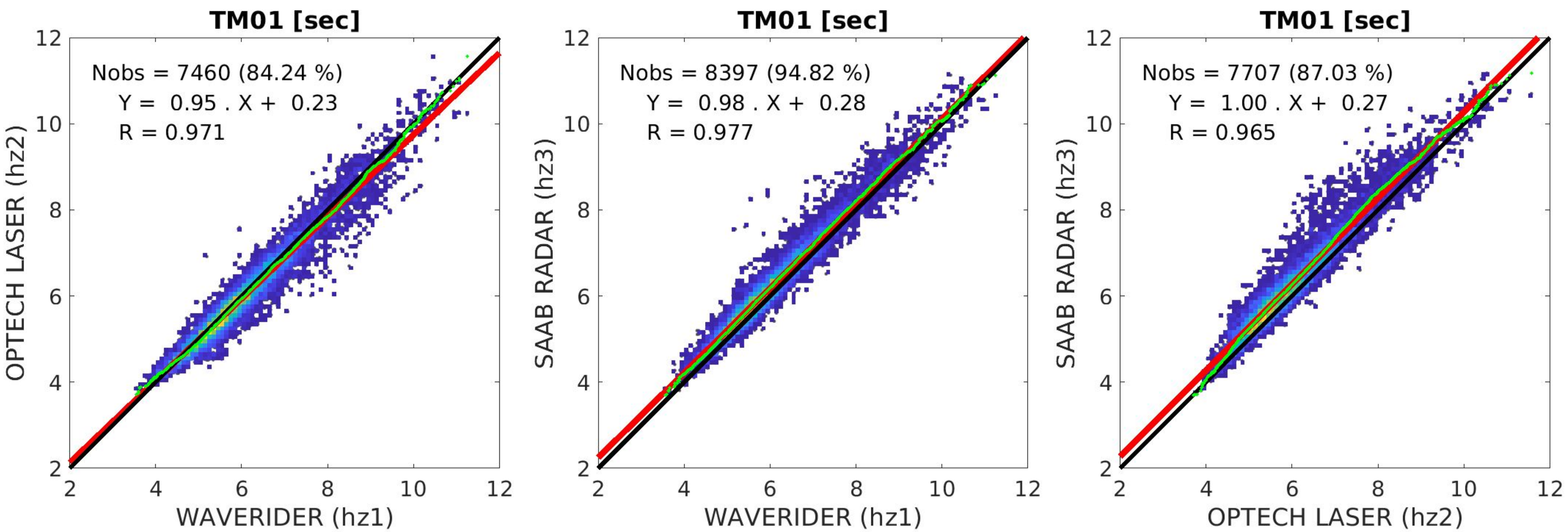
TM01



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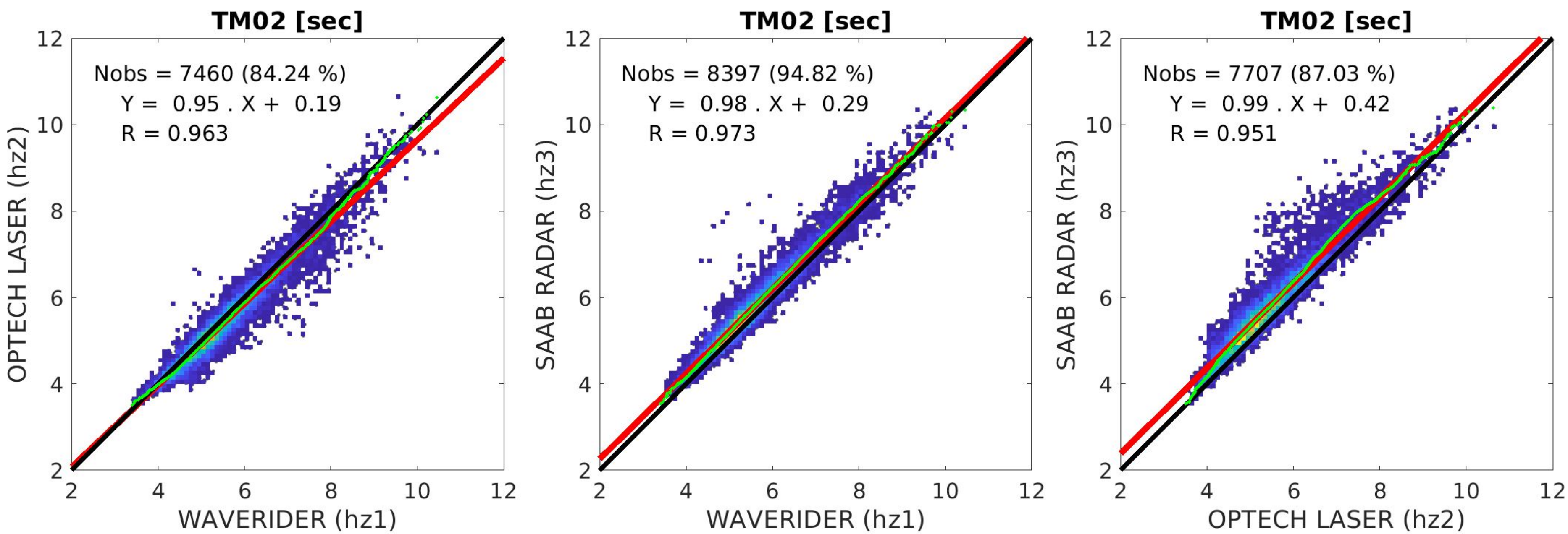
TM02



TM02 [s]	Entries	slope	bias	R
Optech vs Waverider	7460 (84 %)	0.95	0.19	0.963
Saab vs Waverider	8397 (95 %)	0.98	0.29	0.973
Saab vs Optech	7707 (87 %)	0.99	0.42	0.951

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Conclusions

- **Differences in spectral shapes:**
  - Saab below both except ~5-8 sec range
  - slope is ~10^{-4} for all, but laser tends to elevate around .35 Hz
  - Energy at peak and in front of peak is much higher with the laser.

- **Differences in spectral parameters**

Conclusions

- **Differences in spectral parameters**
  - HM0 : Saab is 5-8 % below waverider and laser
  - TM01 : Laser slightly lower than WR, Saab is higher
  - TM02: Bias between Saab and laser = 0.42 s
  - steepness: large variability but statistically similar
  - Bandwidth: slightly increasing from saab to waverider to laser.
  - Qp: Large variability but statistically smilar
  - BFI: statistically similar.

Concluding remarks

- One of the other universal questions is ‘how good is good enough?’ Now that depends on the use, but if we say we can live with a 10% error, that would mean we can live with using a 10m significant wave height that is actually 10m +/- 1m. Or it could be 9m or 11m… Is that close enough? I am not sure.

Future work

A new despiking software is under development (PhD student Mika Malila, Patrik Bolinger (MET), Susanne Støle-Hentschel (UiO))

we will extend the analysis using improved despiking and longer time series.

We hope for support for an extensive wave comparison experiment, deploying several other buoys in the surroundings of Ekofisk.

Acknowledgments

- To ConocoPhillips
  - For wave measurement systems
  - Installing WAMOS, LASER ARRAY, stereo video system
  - Supporting research at MET
  - Supporting work on stereo video system installation at Ekofisk
- ExWaMar, (Extreme Waves on Marine Structures), a Norwegian Research Council project (no 256466, 2016-2019) - Patners: DNV-GL, MET-Norway, University of Oslo (coordinator: Elzbieta Bitner-Gregersen)- Objectives: *Improve our understanding of Rogue waves and search for ability to forecast them*
- USACE (US Army Corps of Engineers)
- JCOMM and Environmental Canada

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Thank you for your attention

Oppheim, Voss, Norway.

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