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Buoy, Radar and Laser evaluation at the Ekofisk platform

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- *Presentation given in "WAVES, STORM SURGES AND COASTAL HAZARDS" Melbourne, Nov 10-15, 2019*
- *Magnusson, A.K., Jensen, R. & Swail, V. :* ***Spectral shapes and parameters from three different wave sensors****. Ocean Dynamics* ***71,*** *893–909 (2021).* https://doi.org/10.1007/s10236-021-01468-7

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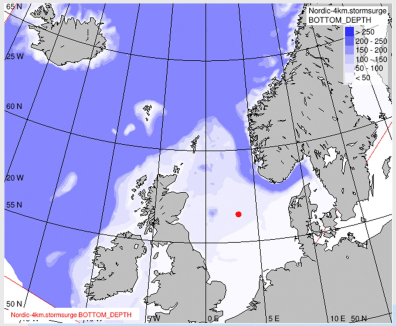

Comparing wave observations from 3 different sensors

BACKGROUND:

MET provides a special extreme wave forecasting service for ConocoPhilllips

⇨ need GOOD observations and backups !

MOTIVATION:

- **Validation of forecasts and models**
- **Critical during extreme wave forecasting**
- **..and other sensitive offshore operations**
- **Studies of extreme waves**

Quality of forecasts

is dependent on good measurements

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Forecasters adapt their forecasts to measurements.

*A consequence of forecasting 5% too low values relative to 'true sea state' is that we risk **giving 'green light' to operations that should not start or continue**, and **risk that risk-reducing measures are not implemented in time**.*

Example of risk reducing actions on a platform:

- *hinder people to work at lower levels exposed to waves*
- *hinder people to go outside platform premises through a door facing the weather.*
- *disconnect a bridge between a floating rig to a bottom fixed platform.*
- *stop oil and gas production to hinder environmental emissions in case of pipe ruptures.*

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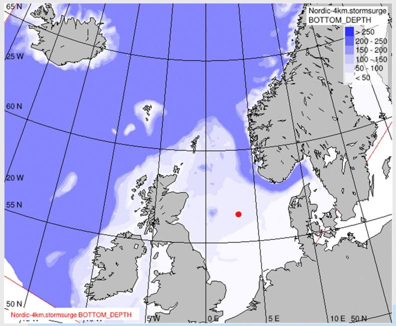

Comparing wave observations from 3 different sensors

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

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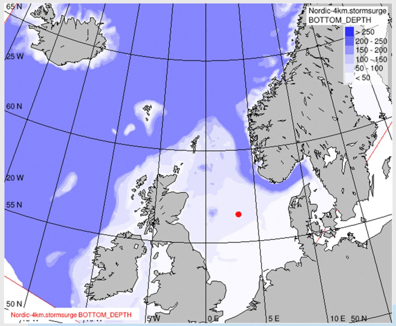

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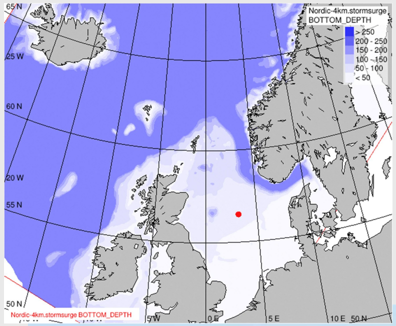
  - height to MSL ~31m

Waverider has long been seen as a ‘standard’ because of worldwide and numerous deployment.
WaveRadar Rex (or ‘SAAB’) is widely used on offshore platforms

Can the LASAR setup tell us “TRUE SEA STATE”?

alternatively: How do they compare?



Comparing wave observations from 3 different sensors

BUT: We experience biases in Hs !

These might be due to <u>lee effects</u> caused by constructions, but we suspect that is <u>not the single cause.</u>

Question posed:

Can we identify differences in spectral shapes?

Are spectral shape parameters very different ?

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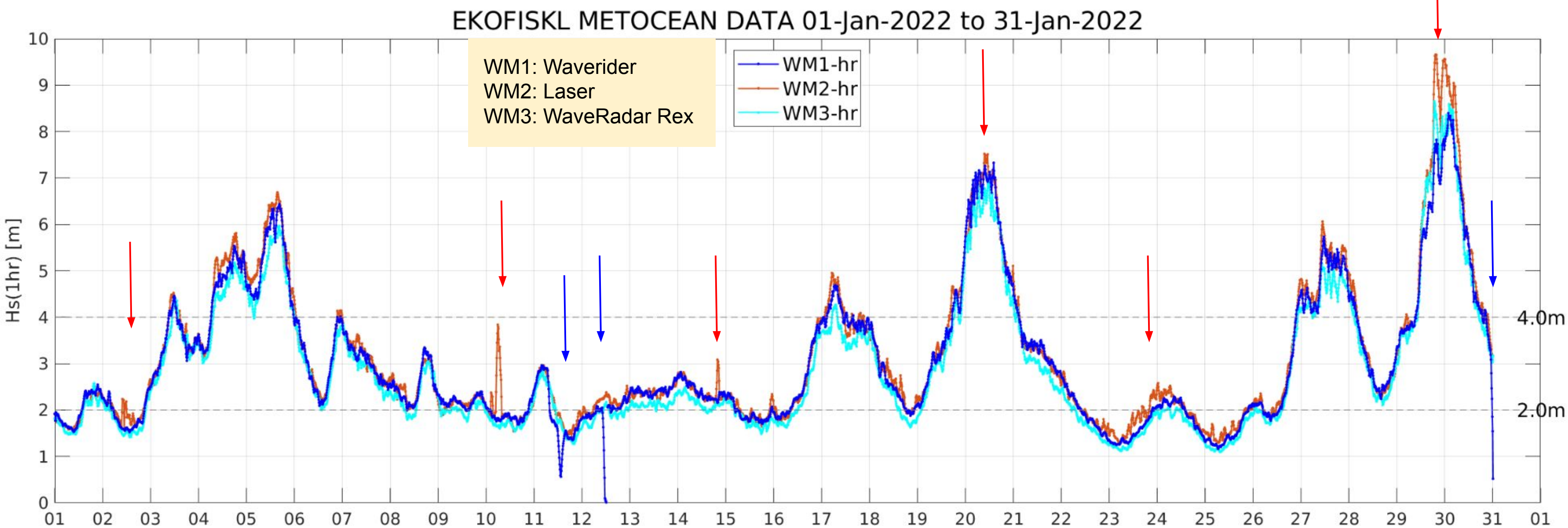
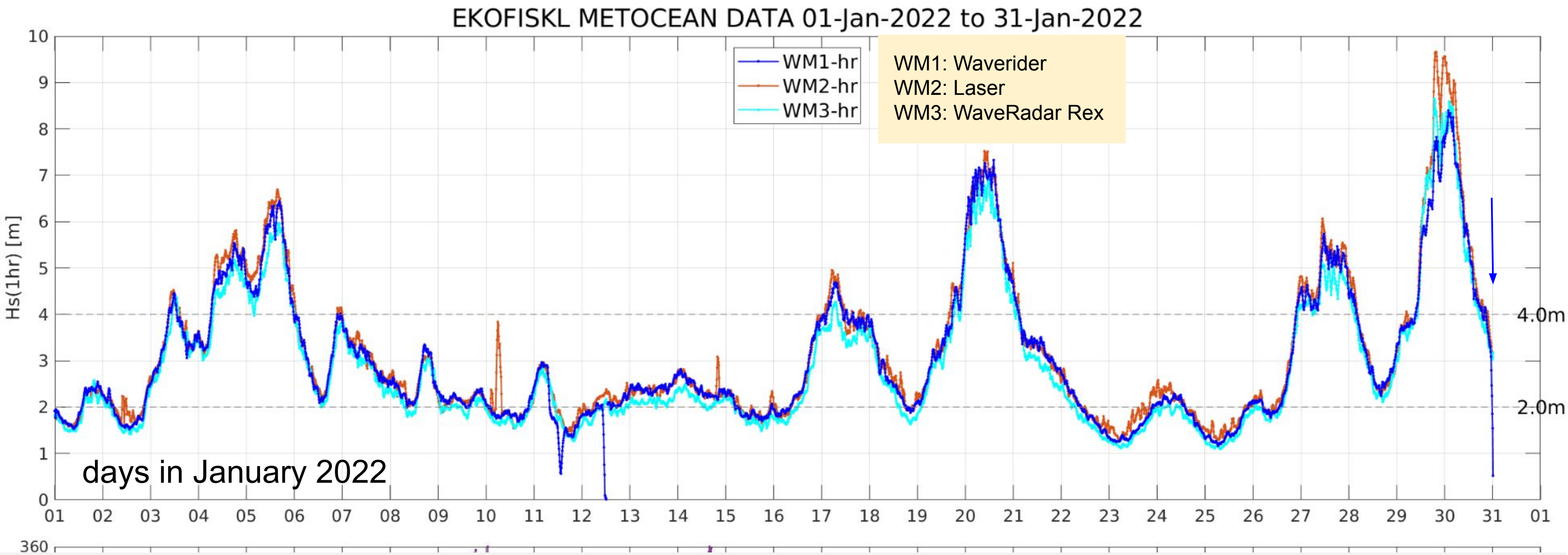


Timeseries of hourly Hs values from Waverider (blue), Laser (brown) and WaveRadar (cyan)

- There are periods of spiky or perhaps doubtful values
  (although: this example from January 2022 does not have that many!)



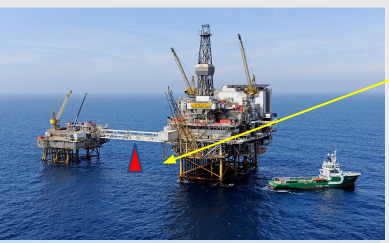
Timeseries of hourly Hs values from Waverider (blue), Laser (brown) and WaveRadar (cyan)

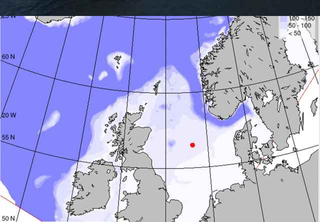
We see:

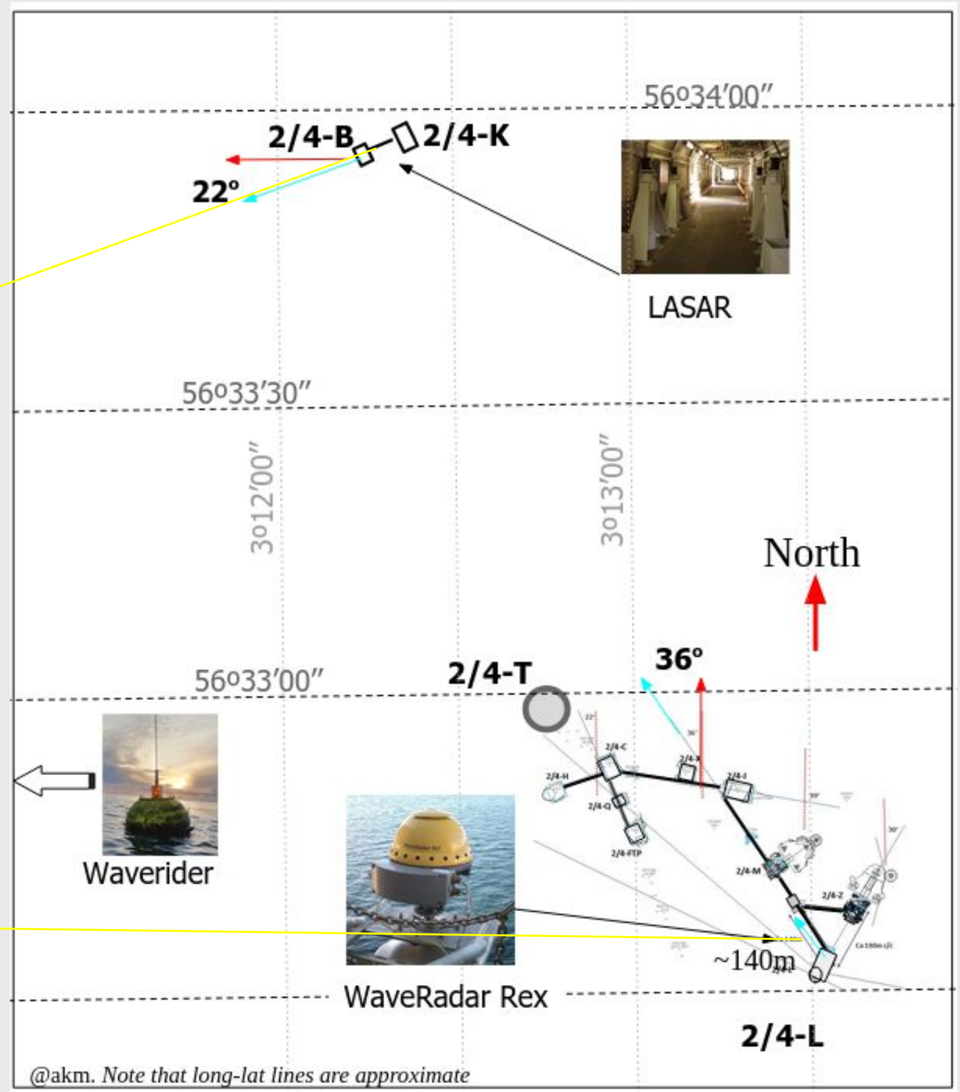
- Sometimes (a few times) all sensors overlap well
- Most of the time Hs from WaveRadar (WM3) is below the two other sensors
- Hs-Laser (WM2) is sometimes above Hs-Waverider (WM1)
- on 29-30th the Waverider is lowest of all.
- on 31st all data are missing

Platform interference ("lee effects")

- Waverider is in 'open waters'
- Laser is on bridge between 2/4B and 2/4-K, oriented 22 degrees 'South of W-E' axis
- Radar is on bridge north of 2/4-L. Bridge is 140 m long, oriented 36° west of North.







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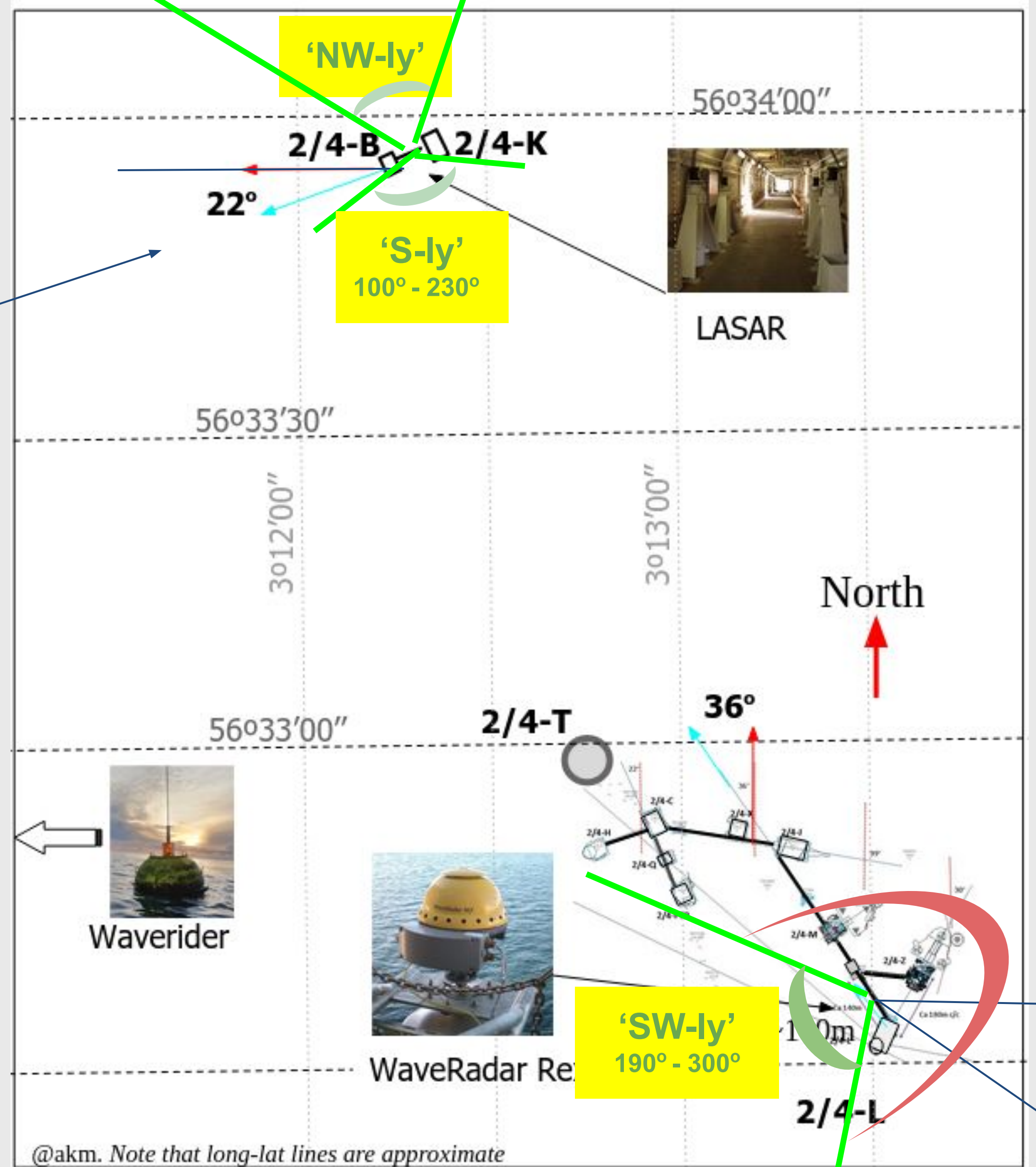
Green sectors: 'open'

Shadowing effects (and more sea spray that may deteriorate the data) can be expected from the platform constructions.

- In NW and S-ly wind conditions, the Laser footprint is exposed to open wave field, while Radar is in 'lee' of several platforms in N-ly conditions.

- In SW-ly sector (190°-300°) the WaveRadar is expected to see open / unaffected wave field.



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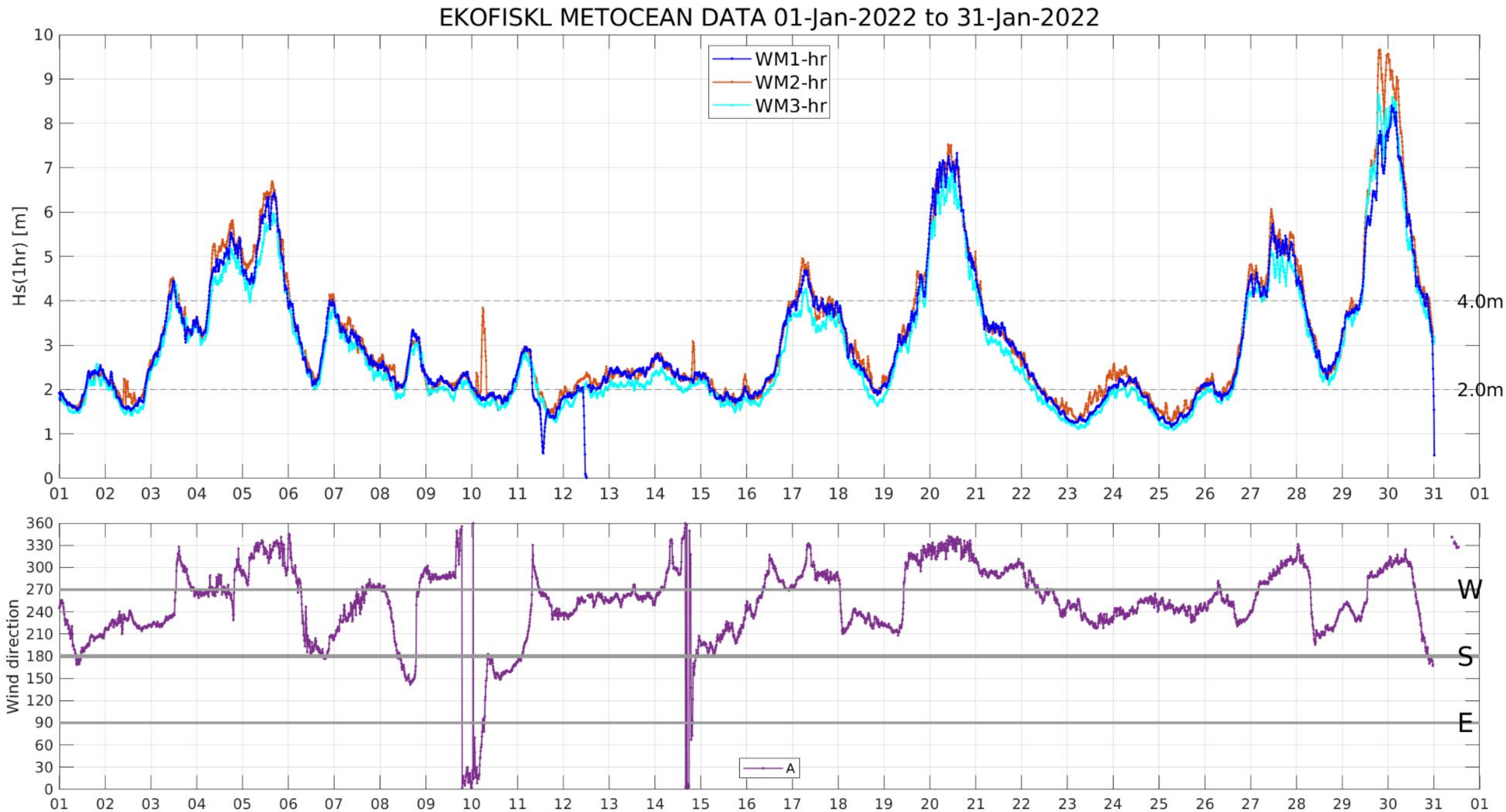
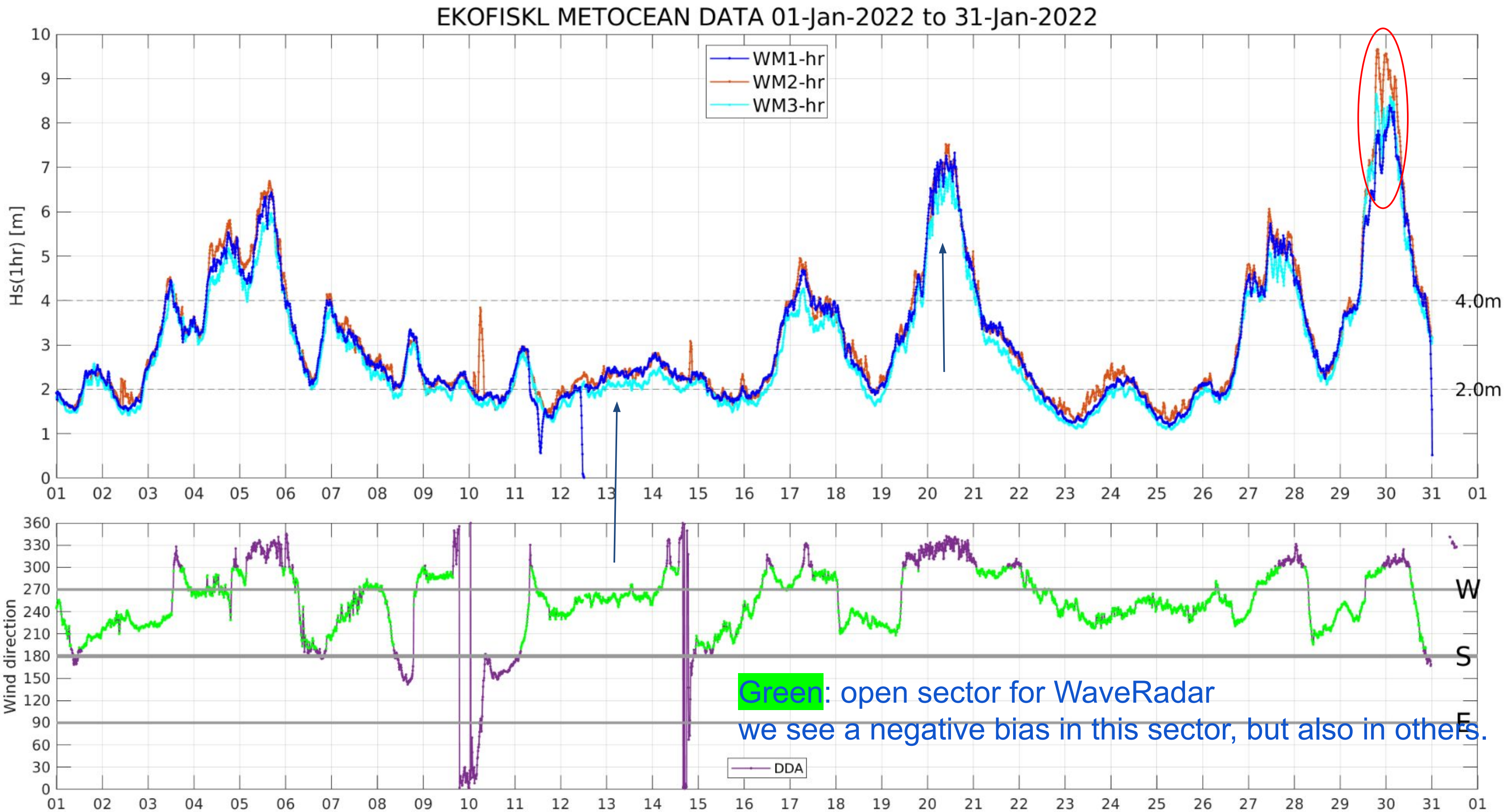
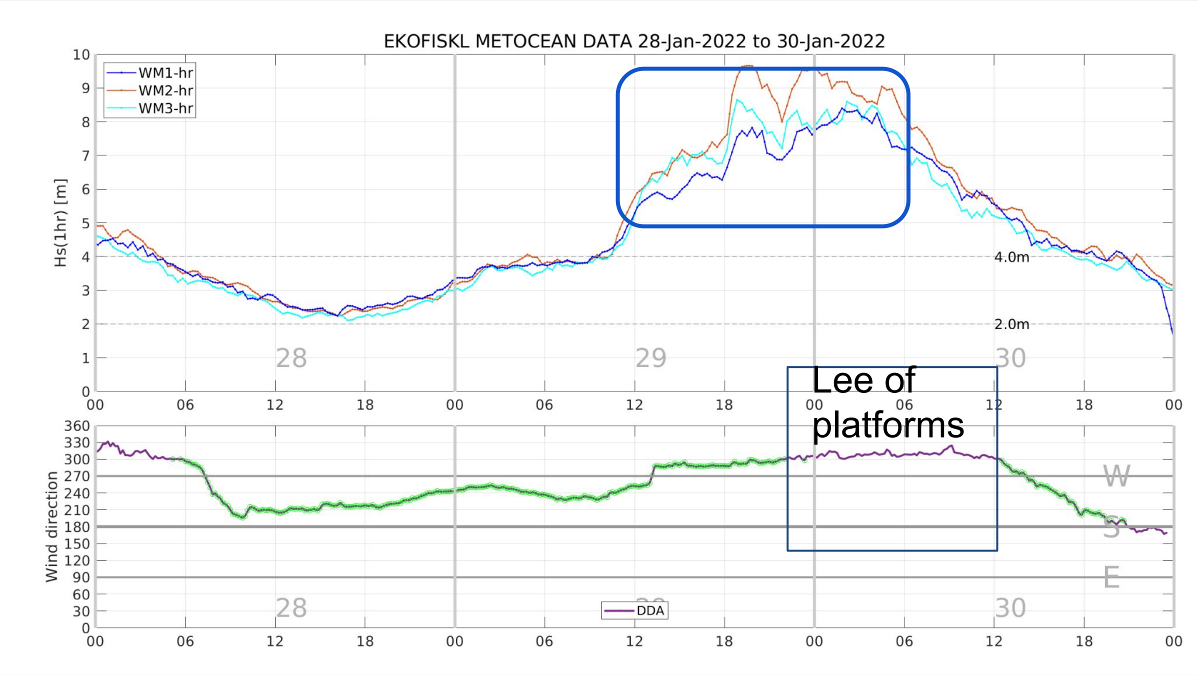

EKOFISKL METOCEAN DATA 01-Jan-2022 to 31-Jan-2022
WM1-hr
WM2-hr
WM3-hr
Hs(1hr) [m]
4.0m
2.0m
Wind direction
A
W
S
E



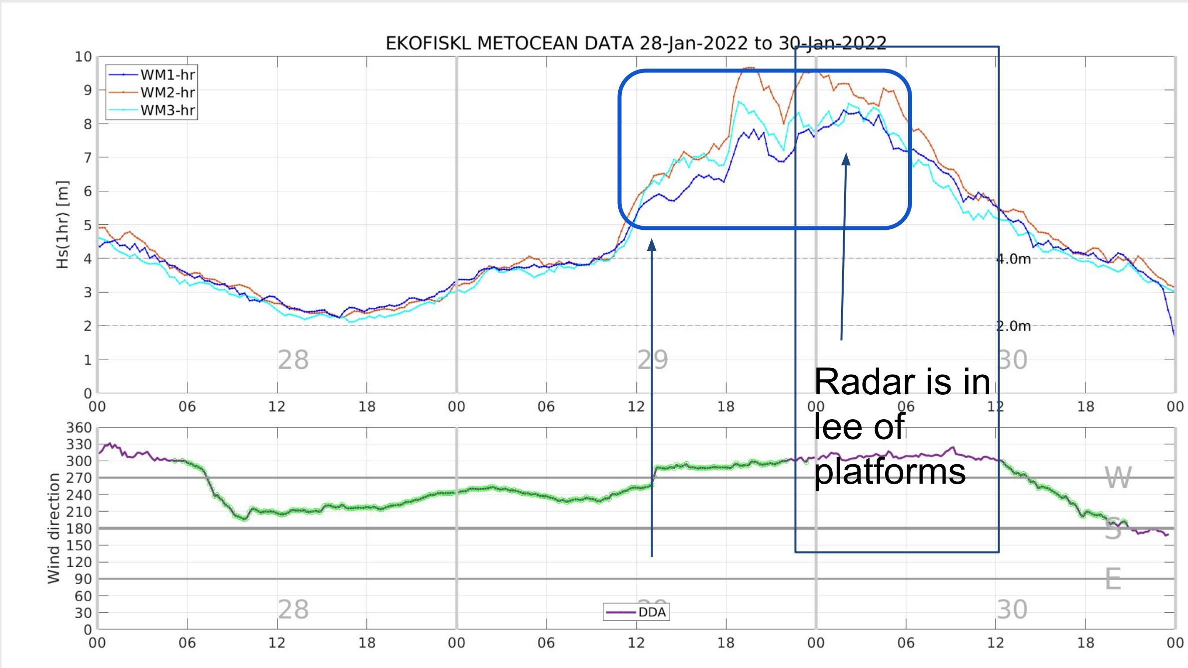
Green: open sector for WaveRadar
we see a negative bias in this sector, but also in others.



Case 29.-30. January, when waverider has lowest Hs.

At peak of storm:
Maximum Hs is between 8.5 and 9.8 m.

Very unusual with
Hs (Radar) > Hs (Waverider)



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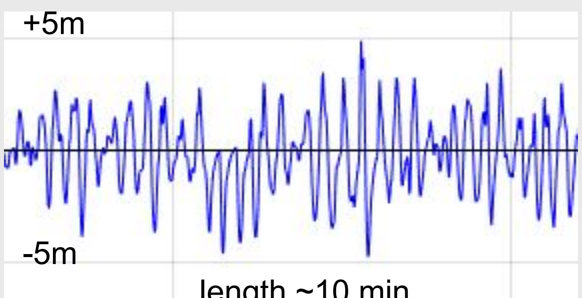
Waverider time series show an erroneous behaviour (example from 13 UTC)



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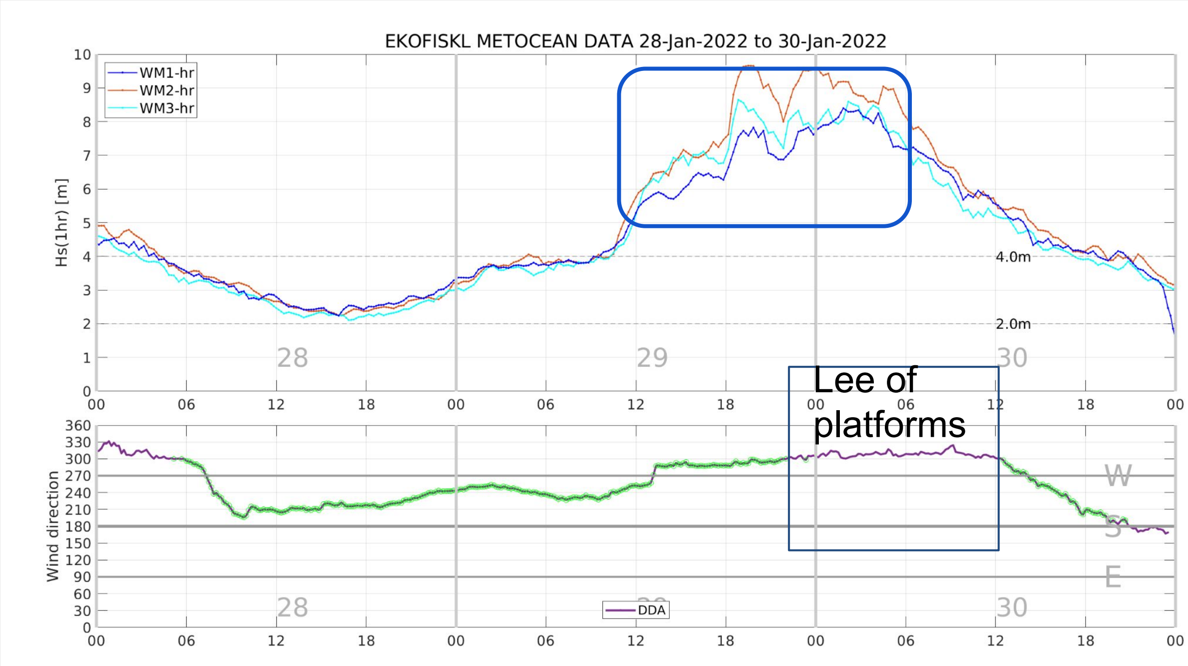

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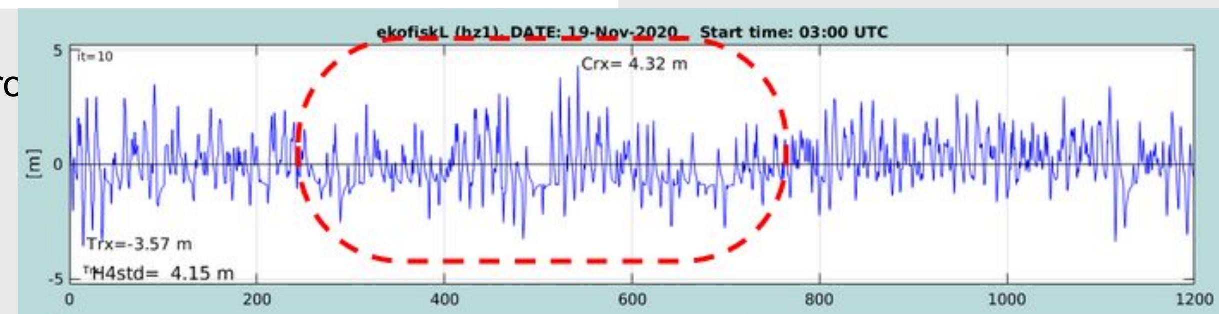
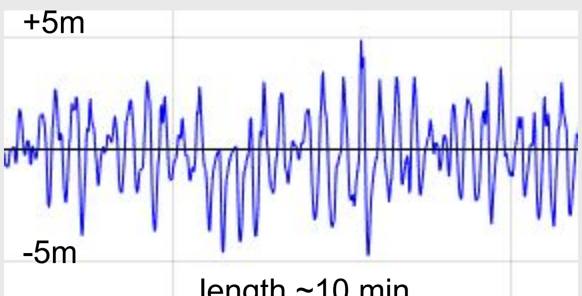
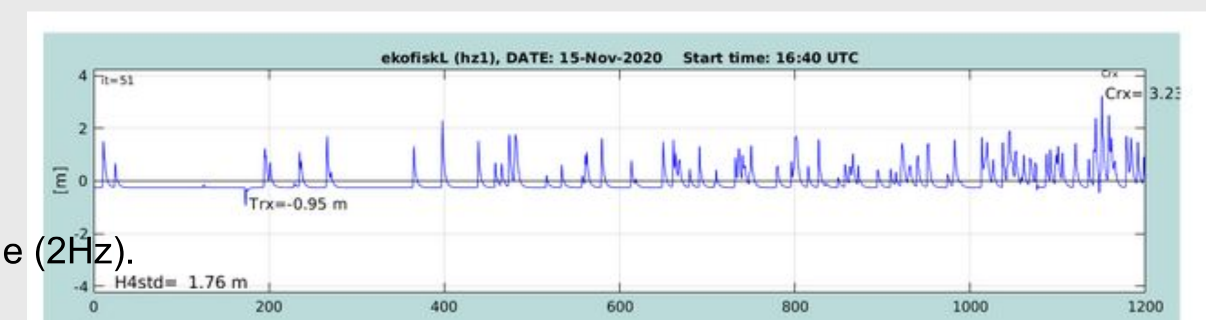
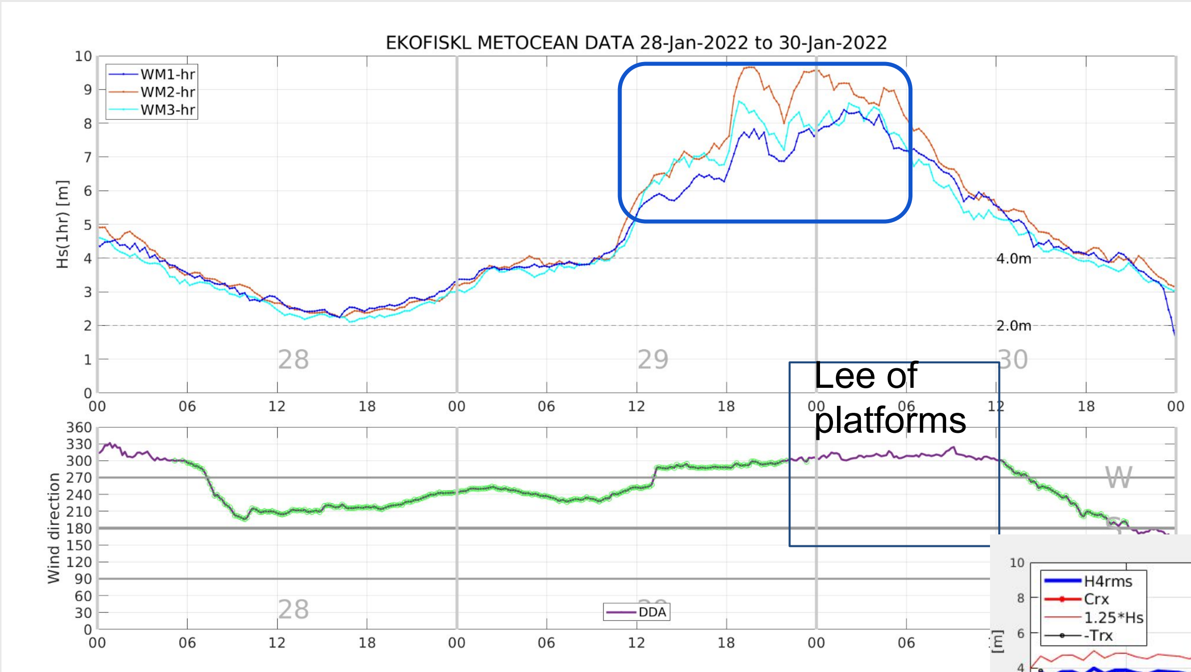


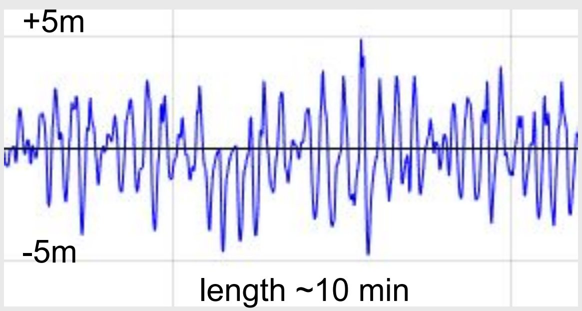


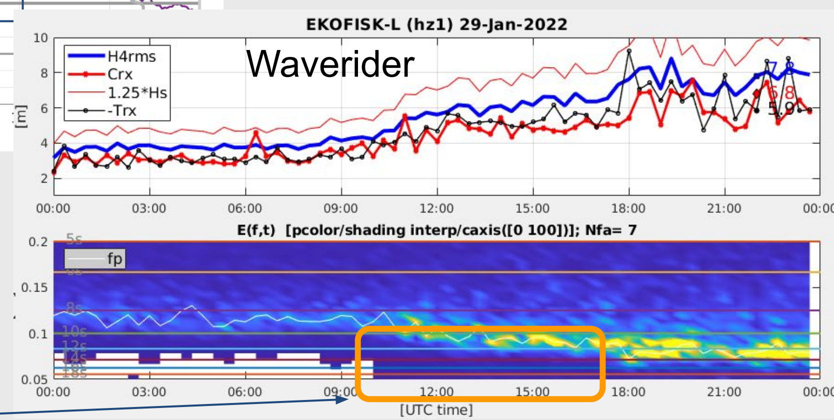


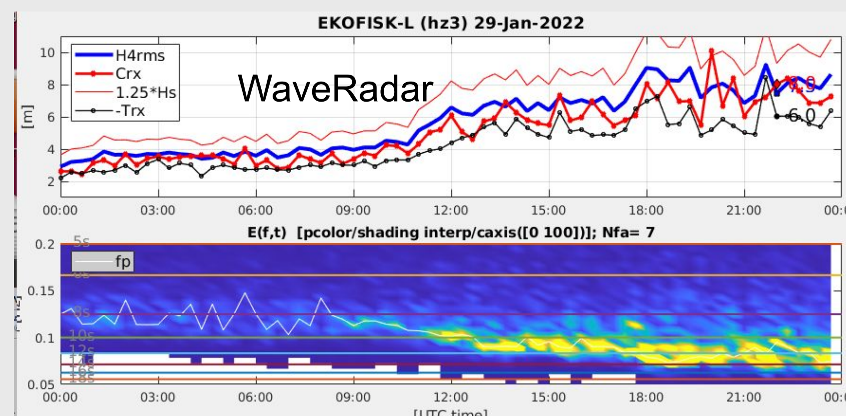
20minutes of waverider wave profile (2Hz).

Error is MAYBE related to error in receiver. Changing antenna on buoy did not fix problem.


EKOFISKL METOCEAN DATA 28-Jan-2022 to 30-Jan-2022
WM1-hr
WM2-hr
WM3-hr
Hs(1hr) [m]
4.0m
2.0m
28
29
30
Lee of platforms
Wind direction
W
DDA

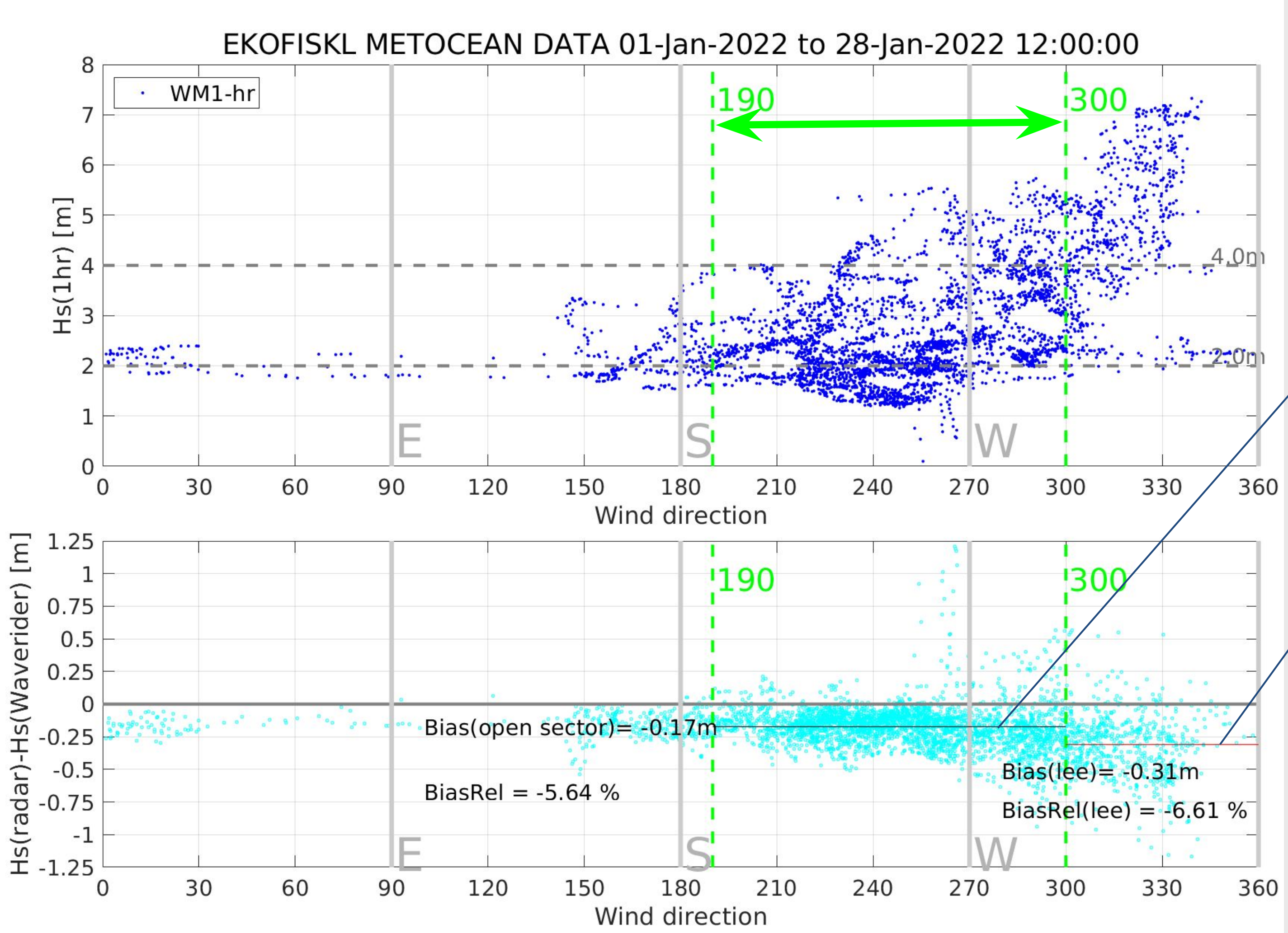

+5m
-5m
length ~10 min


EKOFISK-L (hz1) 29-Jan-2022
H4rms
Crx
1.25*Hs
-Trx
Waverider
[m]
E(f,t) [pcolor/shading interp/caxis([0 100])]; Nfa= 7
fp
[UTC time]


EKOFISK-L (hz3) 29-Jan-2022
H4rms
Crx
1.25*Hs
-Trx
WaveRadar
[m]
E(f,t) [pcolor/shading interp/caxis([0 100])]; Nfa= 7
fp
[UTC time]

January 2022 Distribution on wind direction

Comparing WaveRadar to Waverider - (Open sector: 190° - 300°)



	Open	Lee
Bias [m]	-0.17	-0.31
Relativ Bias [%]	-5.64	-6.61

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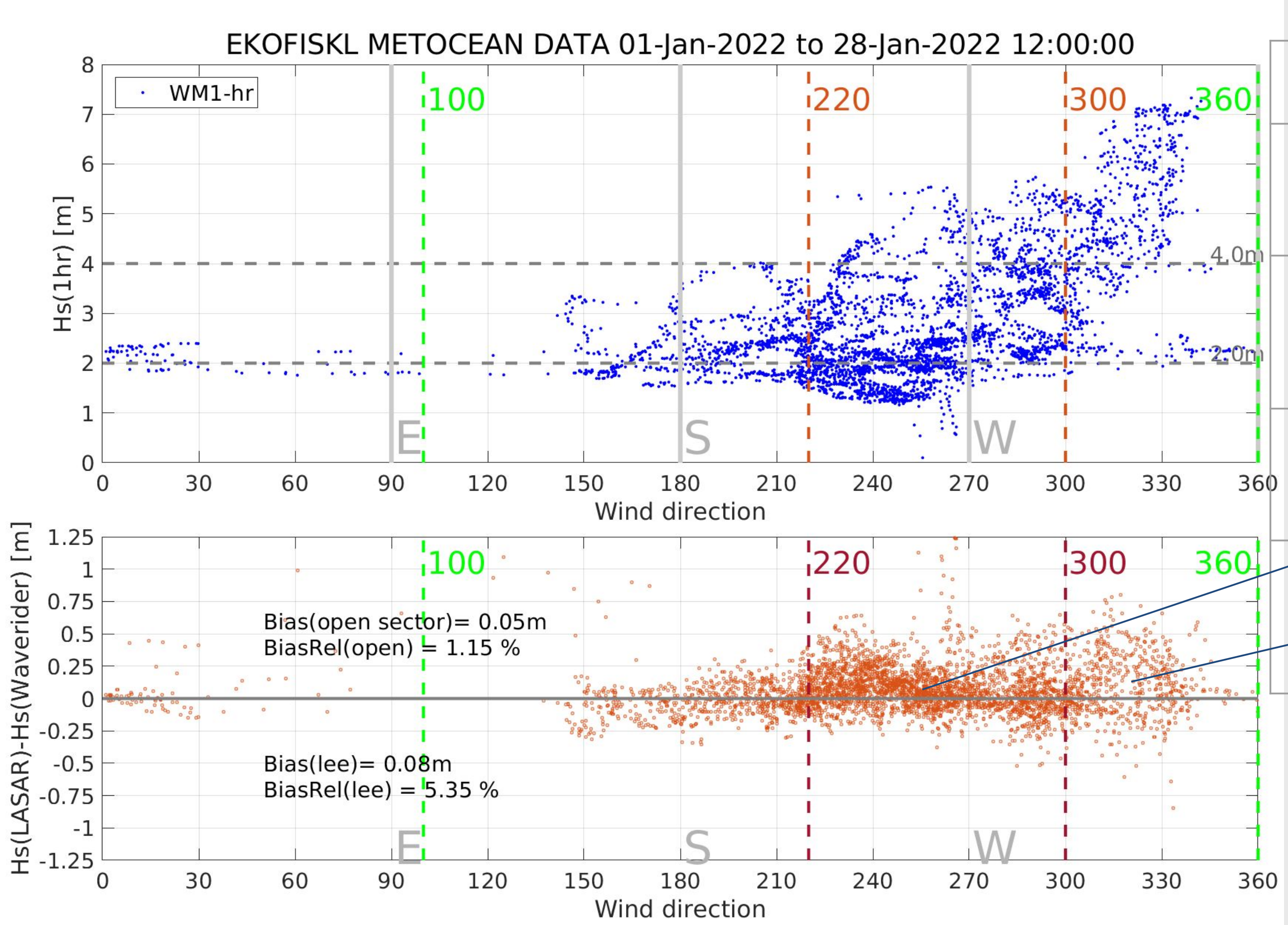
January 2022 Distribution on wind direction

Comparing LASAR Hs to Waverider Hs - Open sector: 100°-220° + 300°-360° (different from WaveRadar)



	Open	Lee
Bias [m]	-0.17	-0.31
Relativ Bias [%]	-5.64	-6.61
Bias [m]	0.05	0.08
Relativ Bias [%]	+1.15	+5.35

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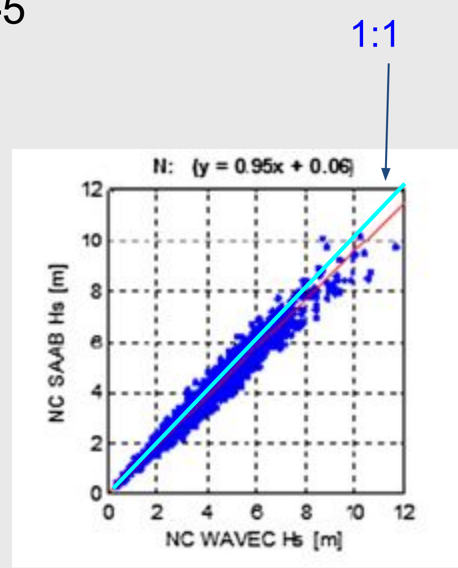
Saab radar analysis

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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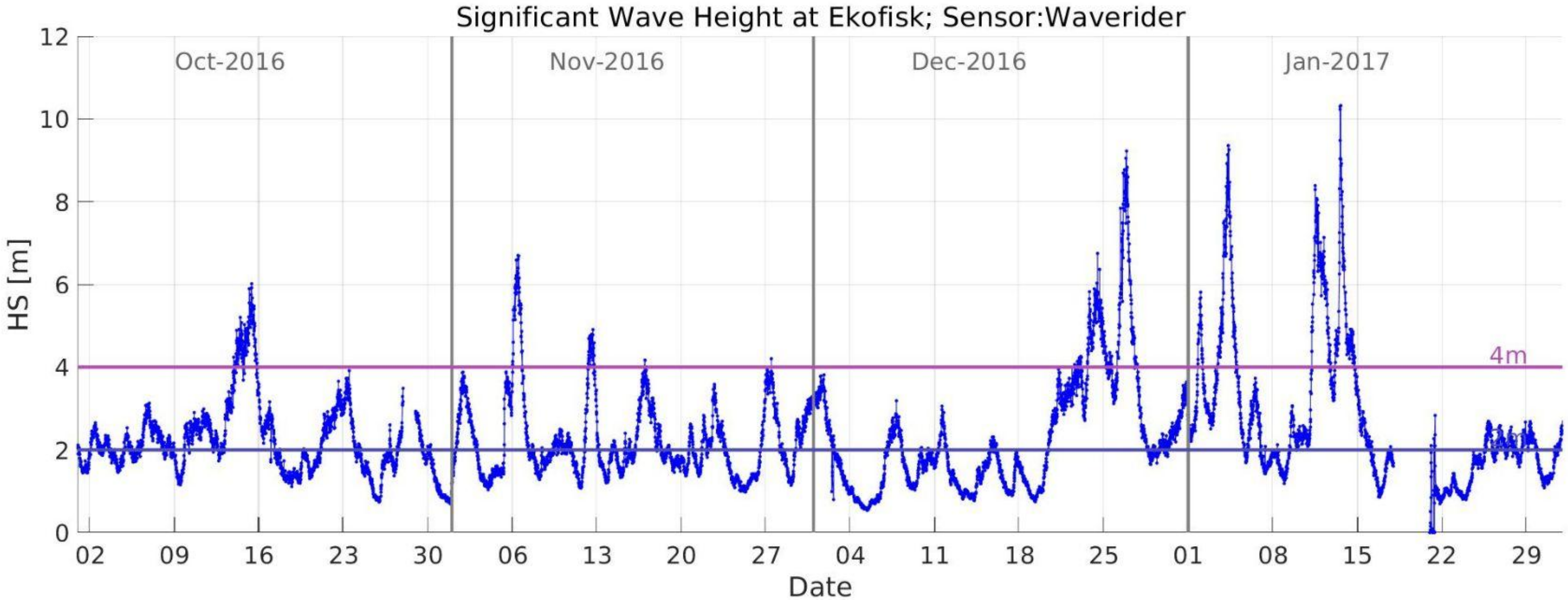
Spectral shapes

—> Can we identify differences in spectral shapes?

—> What about other spectral parameters ?



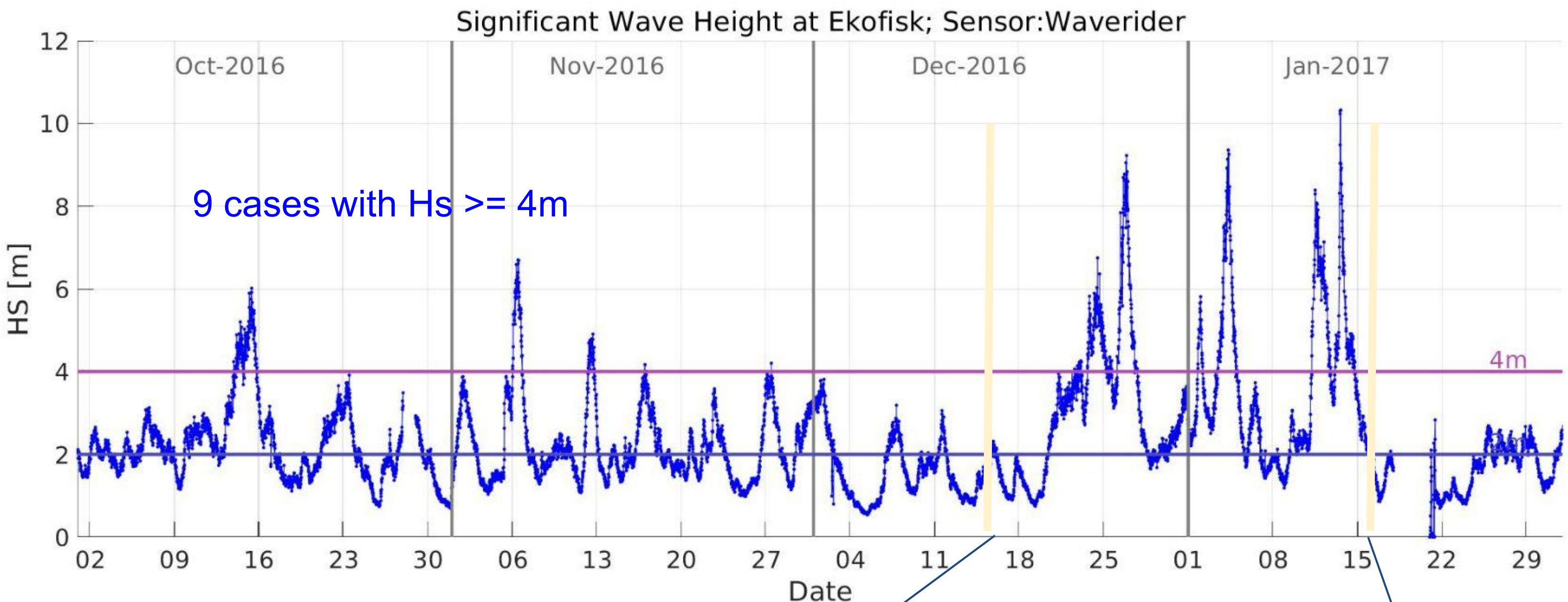
Analysis period: 4 months

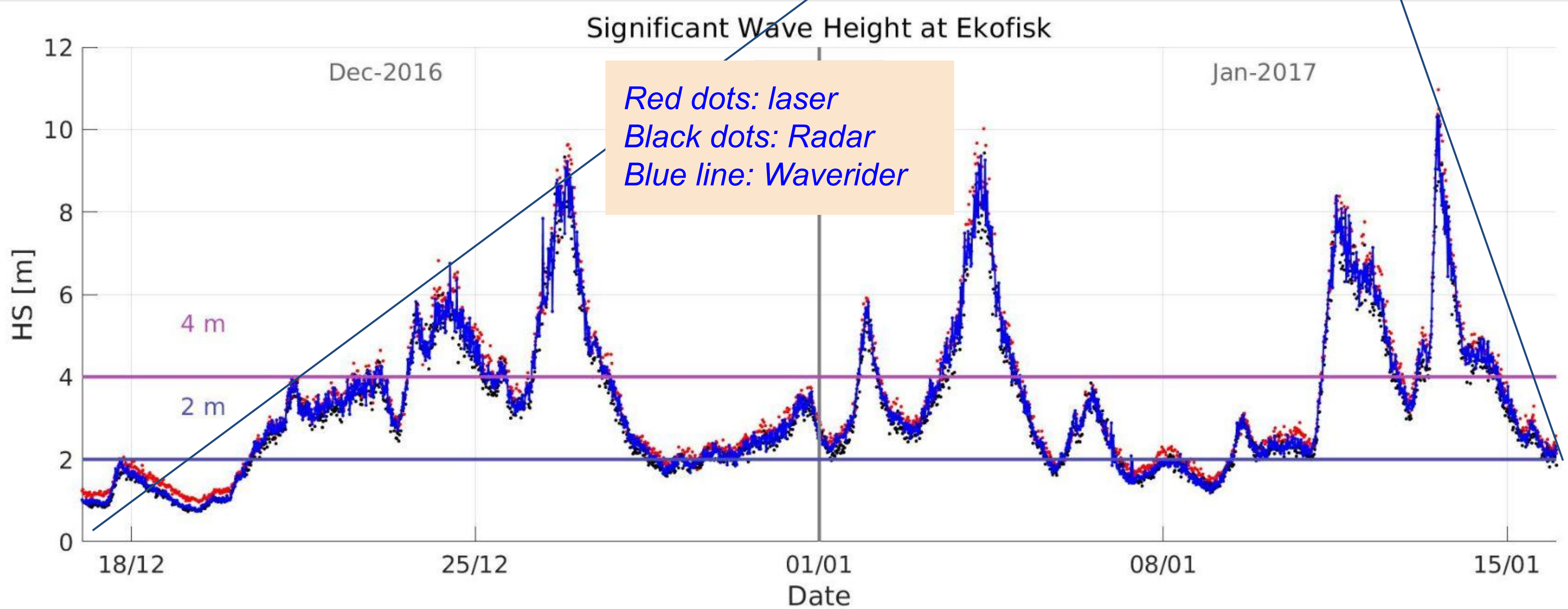
(in *Magnusson, Jensen, Swail: Spectral shapes and parameters from three different wave sensors.* Ocean Dynamics **71,** 893–909 (2021).

1. October 2016 to end January 2017 (4 months)

Includes

- 8 storms with Hs > 6m m and above
- of which: 4 cases with Hs > 8m.





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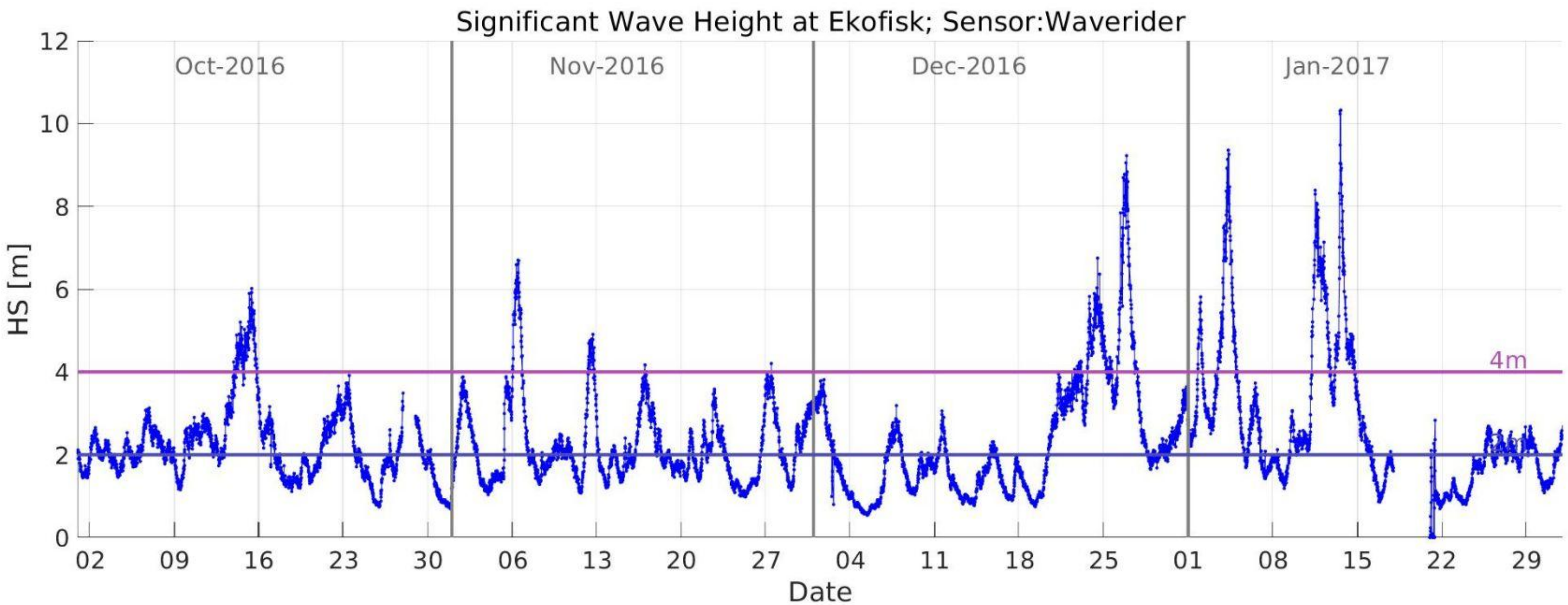

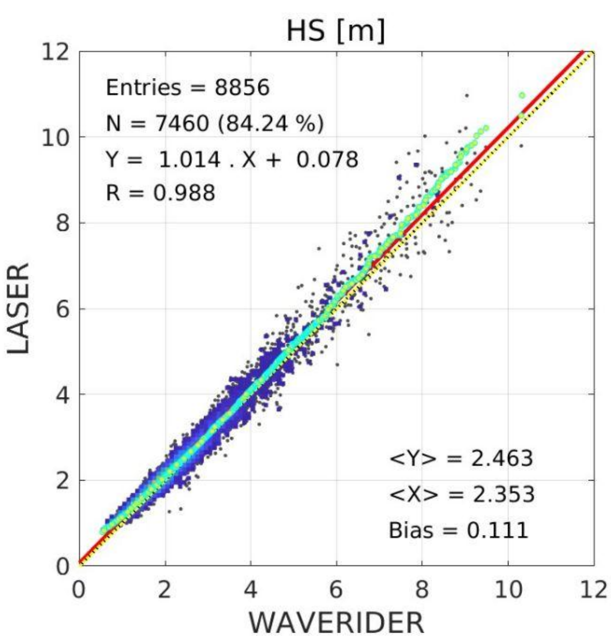

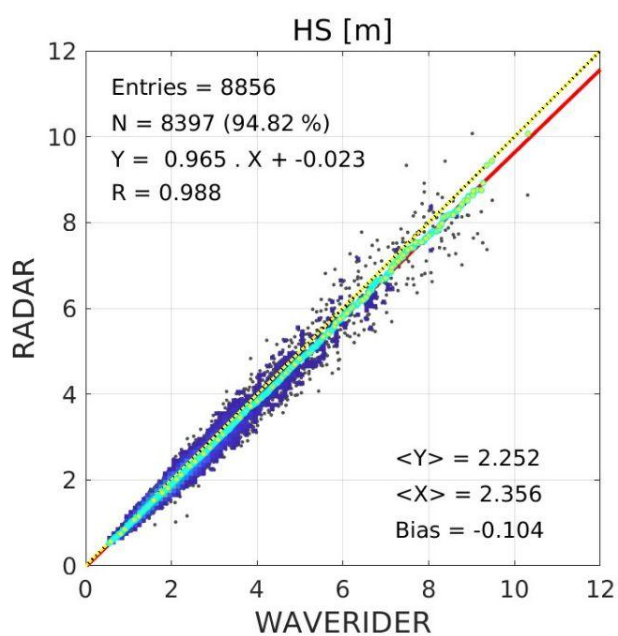

	<Hs>	Bias
Laser	2.46 m	0.111
Waverider	2.35 m	
Radar	2.25 m	-0.104
Waverider	2.36 m	

Slopes: 1.014 and 0.965

Red lines are regression lines using linear regression by the maximum likelihood effective variance method (linfitef.m by Kimmo Kahma, 1991, ref: Orear,J 1982: Last squares when both variables have uncertainties J.Am Phys 50(10)

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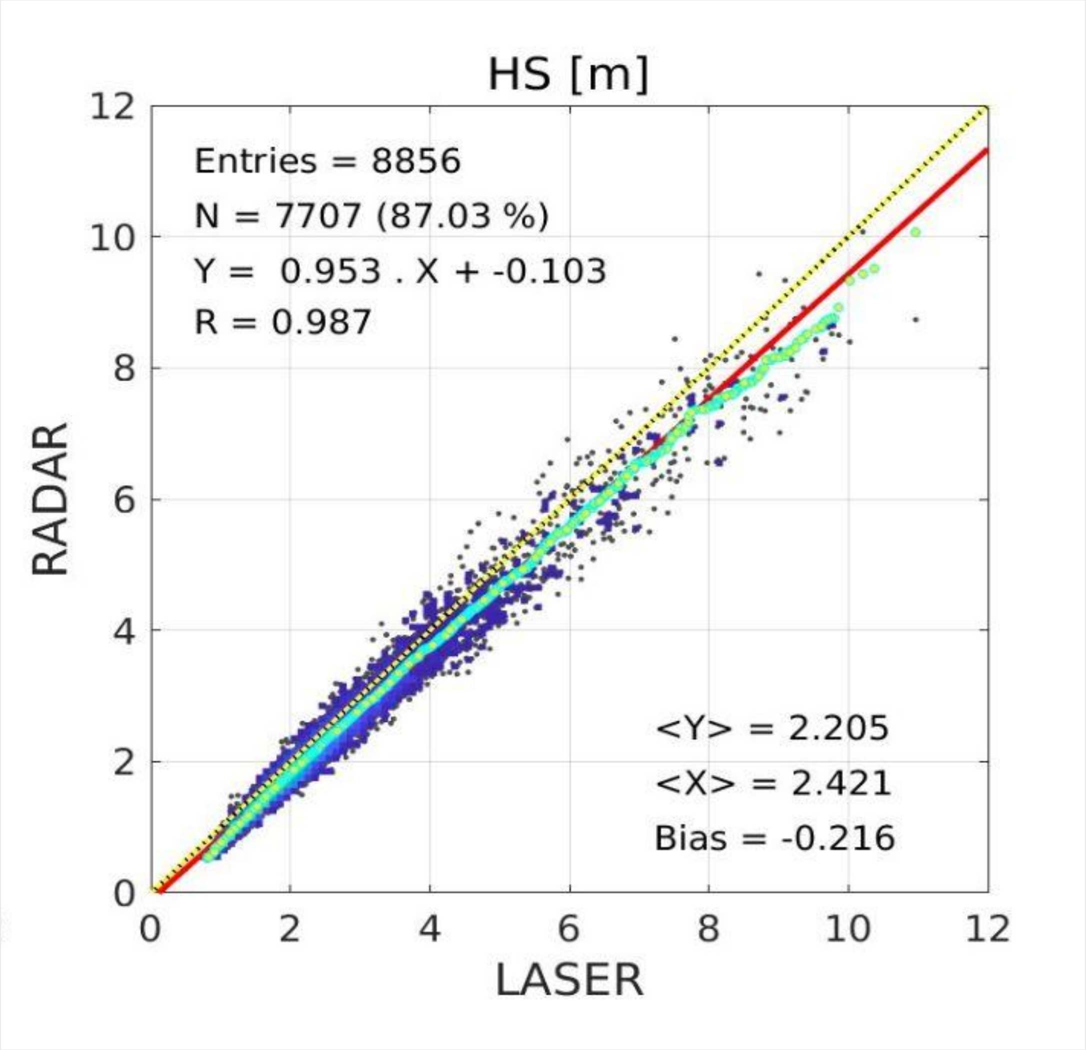
Comparing WaveRadar vs Laser: bias -10%



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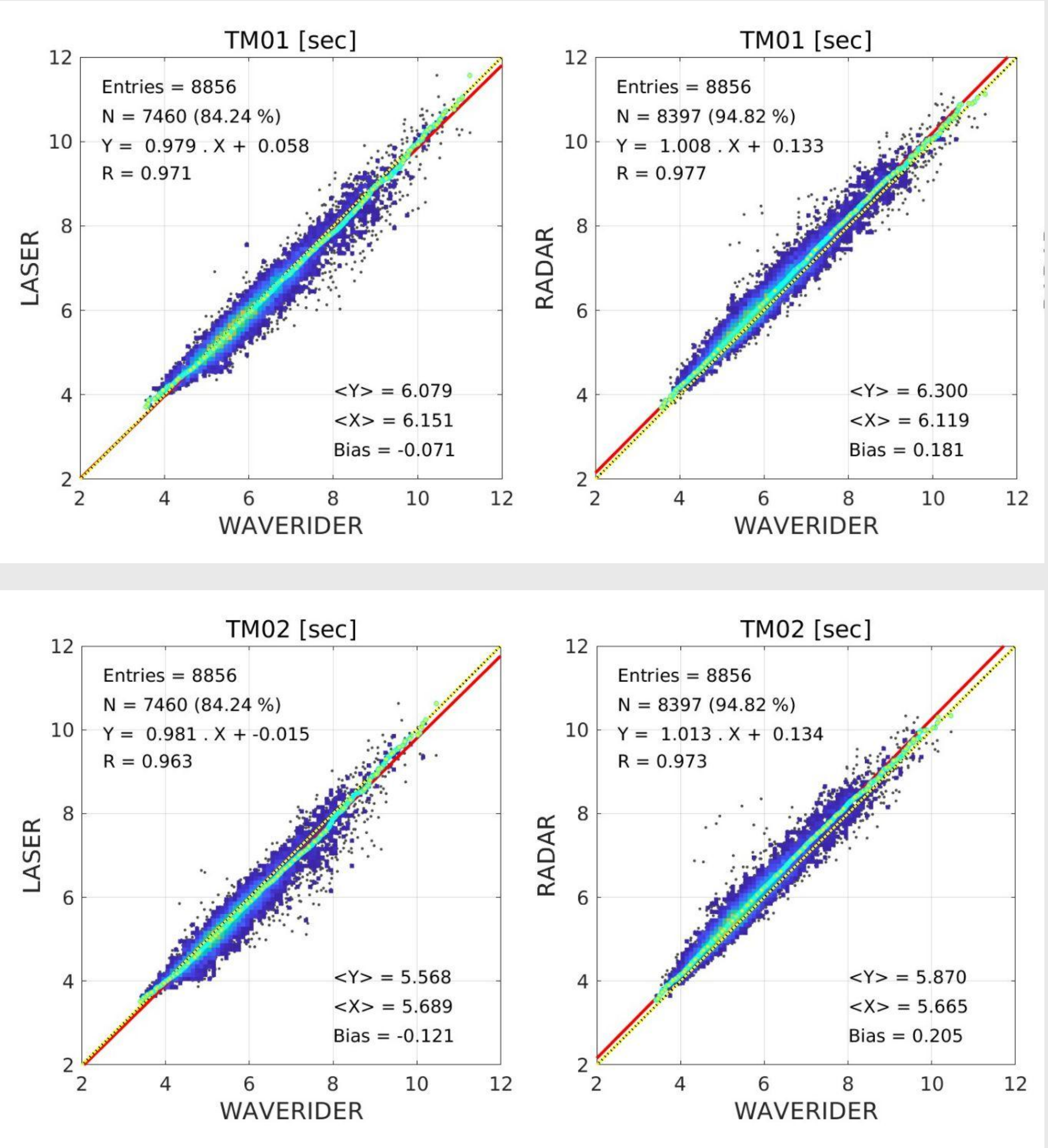
Wave periods TM01 and TM02



	<TM01>	Bias
Laser	6.08 s	-0.071
Waverider	6.15 s	
Radar	6.30 s	+0.181
Waverider	6.12 s	
	<TM02>	Bias
Laser	5.57 s	-0.121
Waverider	5.69 s	
Radar	5.87 s	0.205
Warerider	5.67 s	

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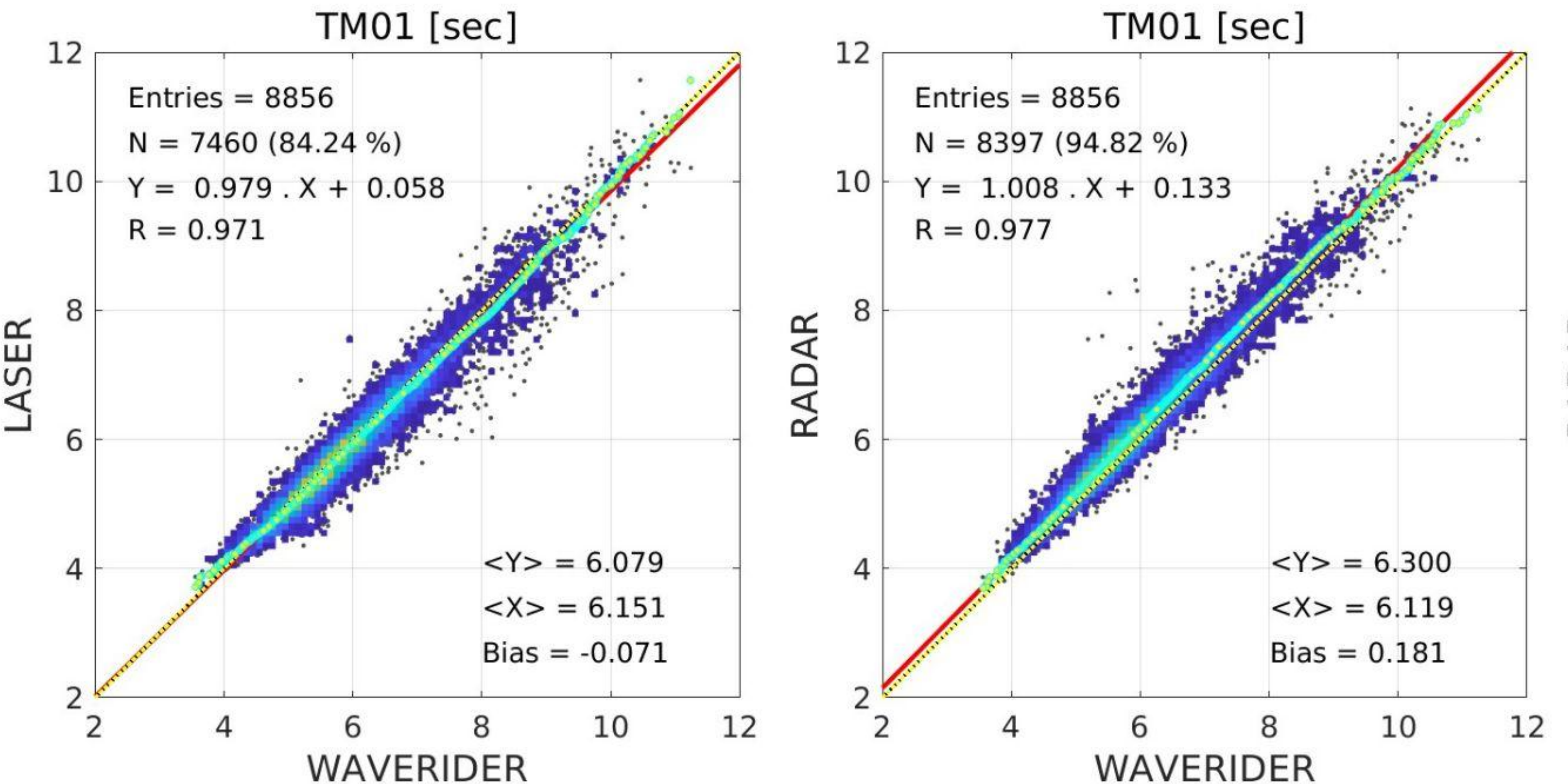

Comparisons are overall very good, with some natural scatter, and some bias, where Laser bias is negative, giving smaller periods than the Waverider, and WaveRadar bias positive, giving larger periods than the waverider and the laser. The difference between WaveRadar and Waverider is twice the difference between Laser and Waverider. implications for f.ex. steepness is shown hereafter.

Fatigue on constructions depends on (a.o.) number waves passing by….

In ONE YEAR (365*24*60*60 seconds), how many waves?

- with **TM02 = 5.87 s (Waverider)**→ ~ **5.562 Million waves** in a year
- with **TM02 = 5.67s (WaveRadar)**: ~ **5.372 Million waves** in a year.

Counting waves with a WaveRadar would, with the average TM02 given during the 4 months considered here (just an example), give 180.000 (-3.2 %) less waves when measured with a WaveRadar compared to a Waverider →

less strain or 'fatigue' on constructions

… right or wrong?

Counting with **a laser** we would get 2.1% more waves than with a waverider.

…. right or wrong?

Just an example to demonstrate that small differences in wave periods do make a difference.

	<TM01 >	Bias
Laser	6.08 s	-0.071
Waverider	6.15 s	
Radar	6.30 s	+0.181
Waverider	6.12 s	
	<TM02 >	Bias
Laser	5.57 s	-0.121
Waverider	5.69 s	
Radar	5.87 s	0.205
Warerider	5.67 s	

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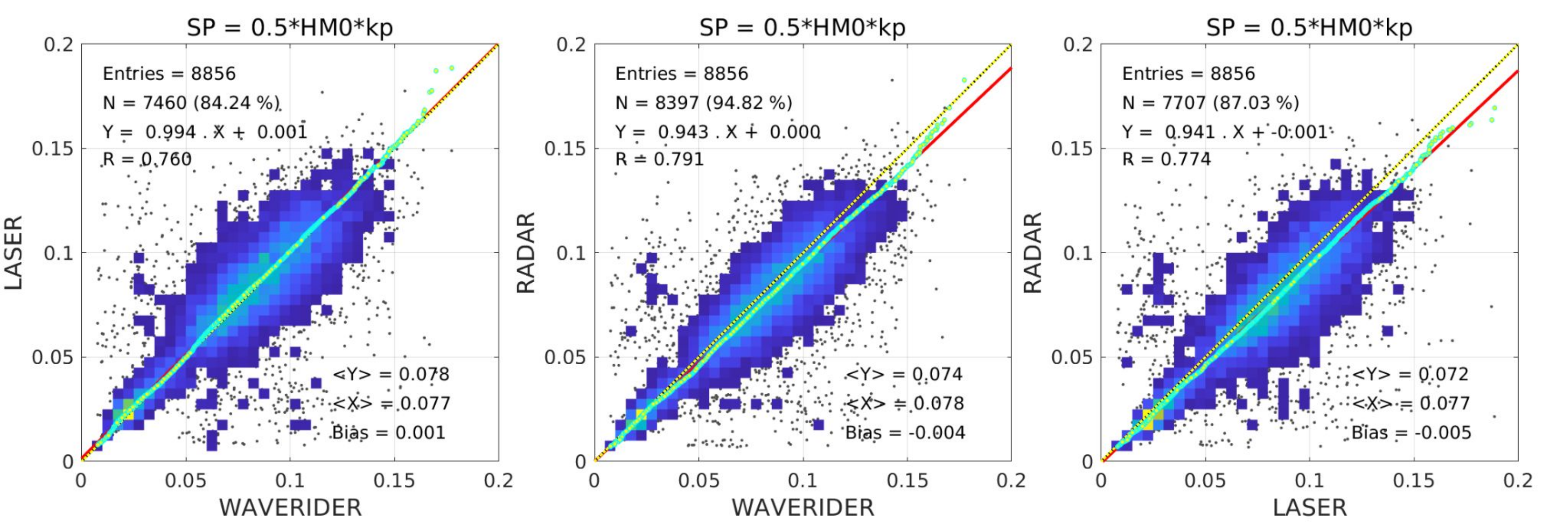
Steepness (depth dependent k_p)

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

WaveRadar steepness is 5.1 % lower than with Waverider
Laser steepness is 1.3 % higher than with Waverider

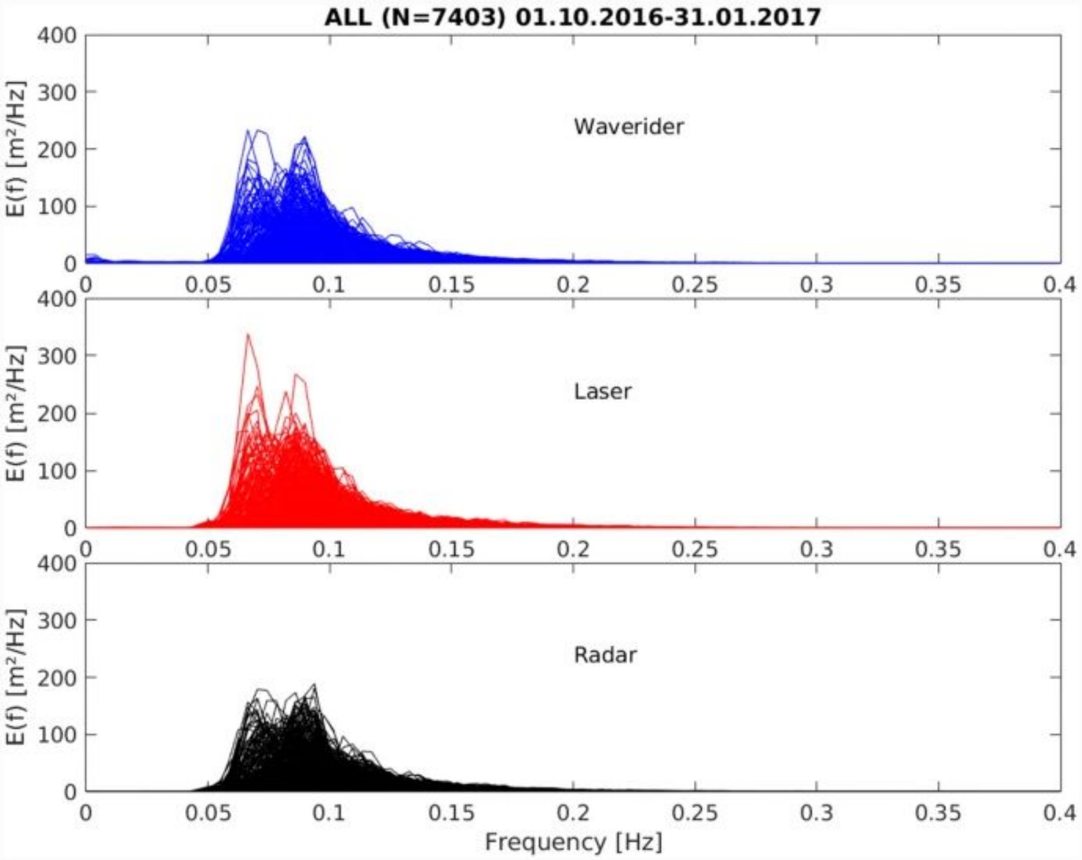
There is a large spread in steepness values, but bulk of **laser** data are similar to **waverider** data while the **Radar** values are lower than both **Laser and Waverider.**

Laser: Regression line and qq-plots are superposed to 1:1 line.



Differences in spectra

Fig. 7



All collocated spectra (entries = 7403) for, from top to bottom: Waverider, Optech laser and WaveRadar Rex

From:

Magnusson, A.K., Jensen, R. & Swail, V. : ***Spectral shapes and parameters from three different wave sensors****. Ocean Dynamics* ***71,*** *893–909 (2021).* https://doi.org/10.1007/s10236-021-01468-7

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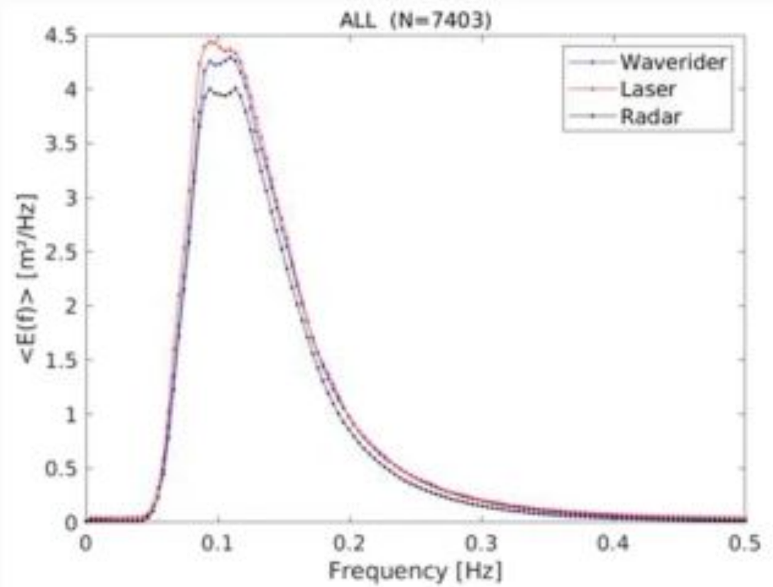
Averaging all spectra measured during the 4 months

Fig. 8



We see differences in

- Peak energy
- In the tail (saturation range,)

Left: <E(f)>, right: <f^4.E(f)>

Fig. 8

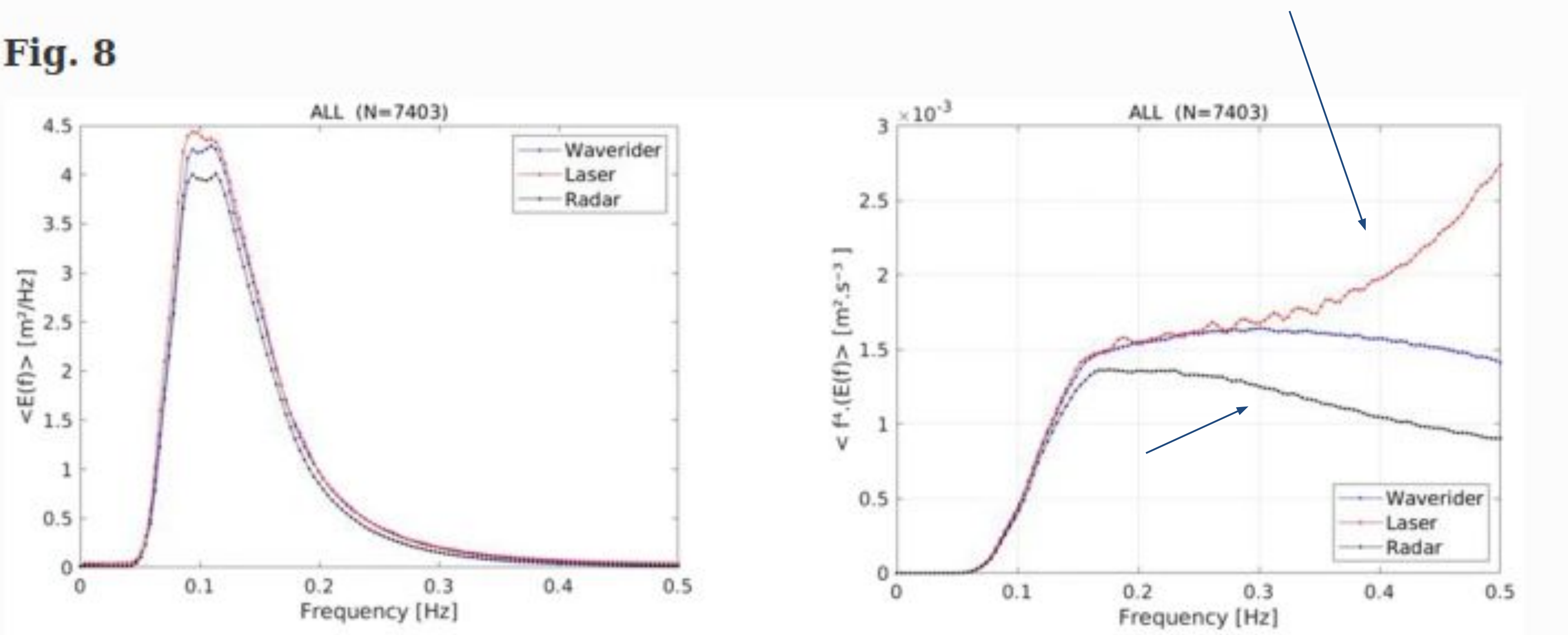


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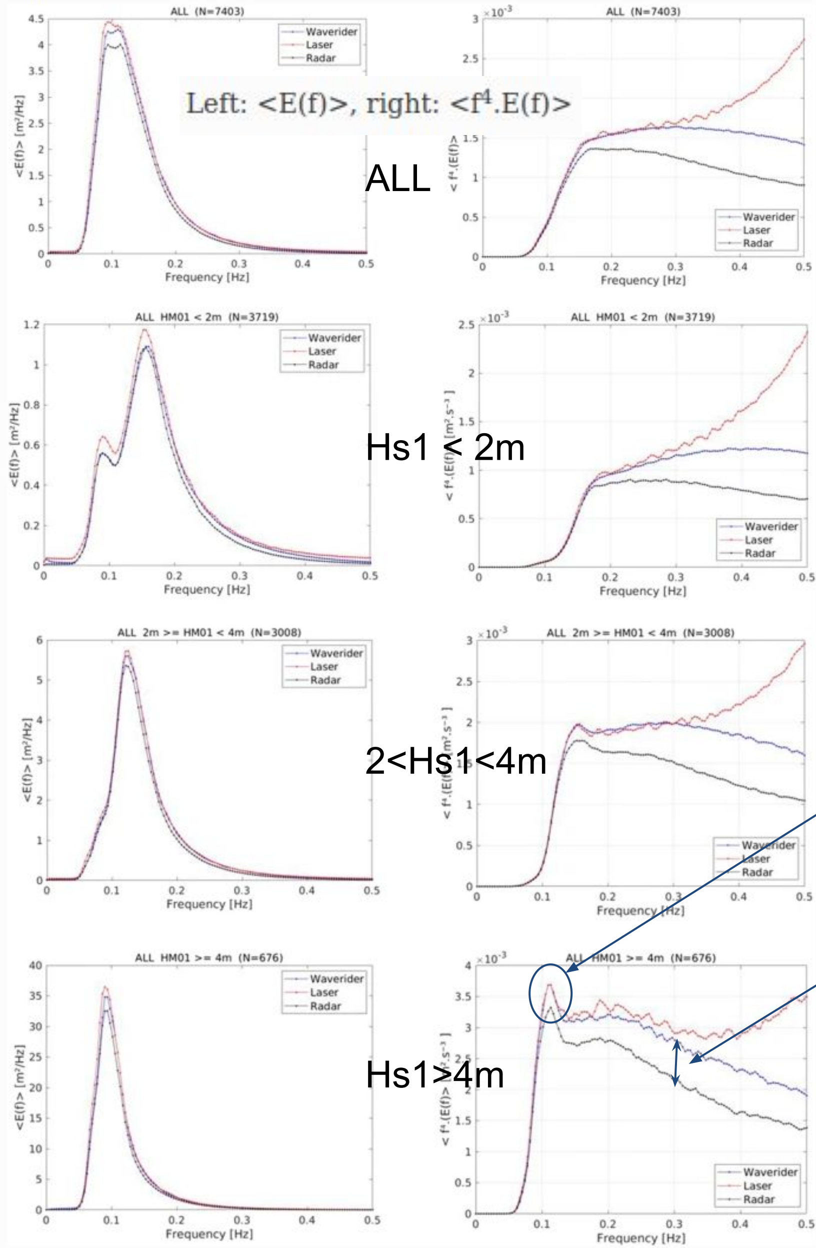
Fig. 8



Average spectra from Waverider (blue), laser (red) and radar (black) from October 2016 to January 2017, sorted from top to bottom in groups of: all 7403 (100%) collocated spectra, all 3719 (50.2%) cases with HM01 (Waverider) < 2m, all 3008 (40.6%) cases with HM01 between 2 and 4m and all 676 (9.1%) cases with HM01 ≥ 4m. Left: <E(f)>, right: <f^4.E(f)>

To be noted:

(*based on comparison to waverider)*

- ➢ **Laser:**
  - peak levels are always higher
  - Spectral 'tail' starts with similar shape to waverider, but at 0.3Hz: has increasing energy at higher frequencies

- ➢ **WaveRadar Rex:**
  - In general: lower peak energy levels
  - Spectral tail: energy deficit compared to both Waverider and Laser

Tail level: Important for wave heights, periods, breaking / wind input parameterization

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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

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

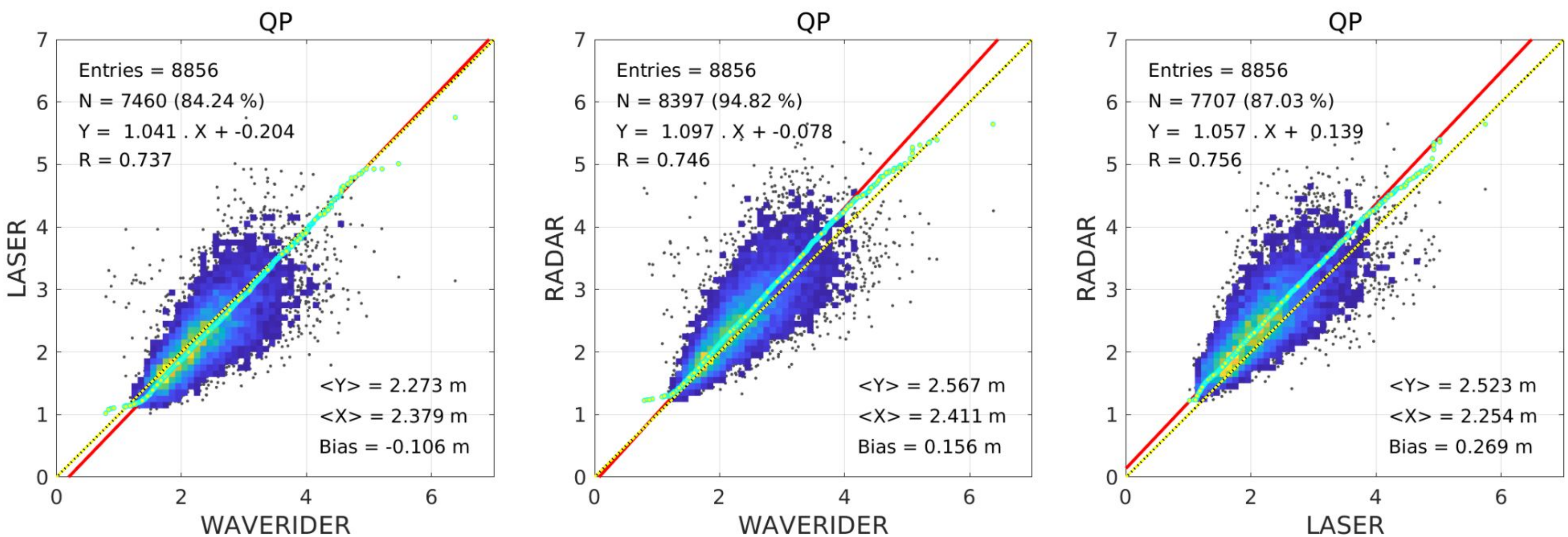
Goda peakedness

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

There is a large spread in all comparisons. For the bulk of data:

- the laser measures a slightly lower Qp (- 4.4%) than the Waverider,
- the radar is 6.5% higher. Difference between laser and radar is **12%**.

Odd result, since we saw spectra indicate peak energy is lower with the radar.
Maybe this is an artifact that the Radar has a lower energy level at high frequencies (?).



Regression below is calculated using linfitef.m
qq-plot overlaps the regression lines in the bulk of the data. Deviations occur in extreme low and extreme high values.

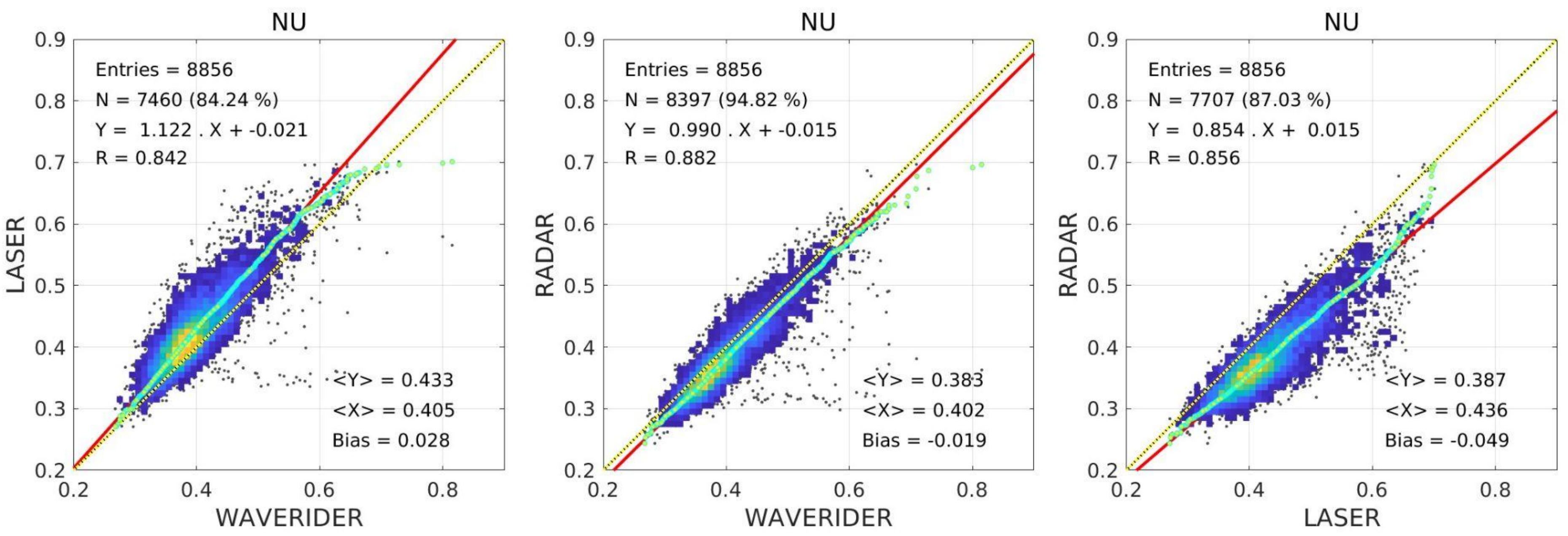
Spectral bandwidth

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

Laser value is in the mean ~7% higher than waverider value. This indicates larger width, but this can be an artifact of the higher energy at high-frequency tail.

Radar has ~5% lower peakedness than the waverider.

Radar: it seems the lower energy level in the saturation range of the spectra influence the results on both peakedness Qp and spectral bandwidth.



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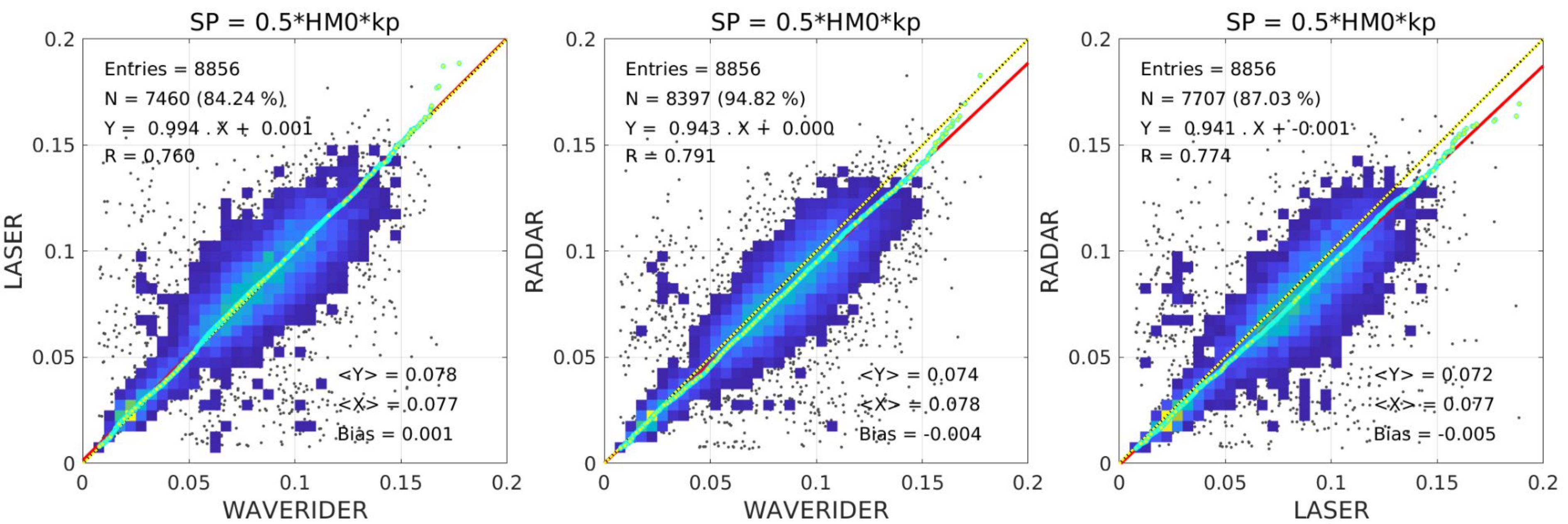
Steepness (depth dependent k_p)

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

There is a large spread in steepness values, but bulk of **laser** data are similar to **waverider** data while the **Radar** values are lower than both **Laser and Waverider.**

Laser: Regression line and qq-plots are superposed to 1:1 line.



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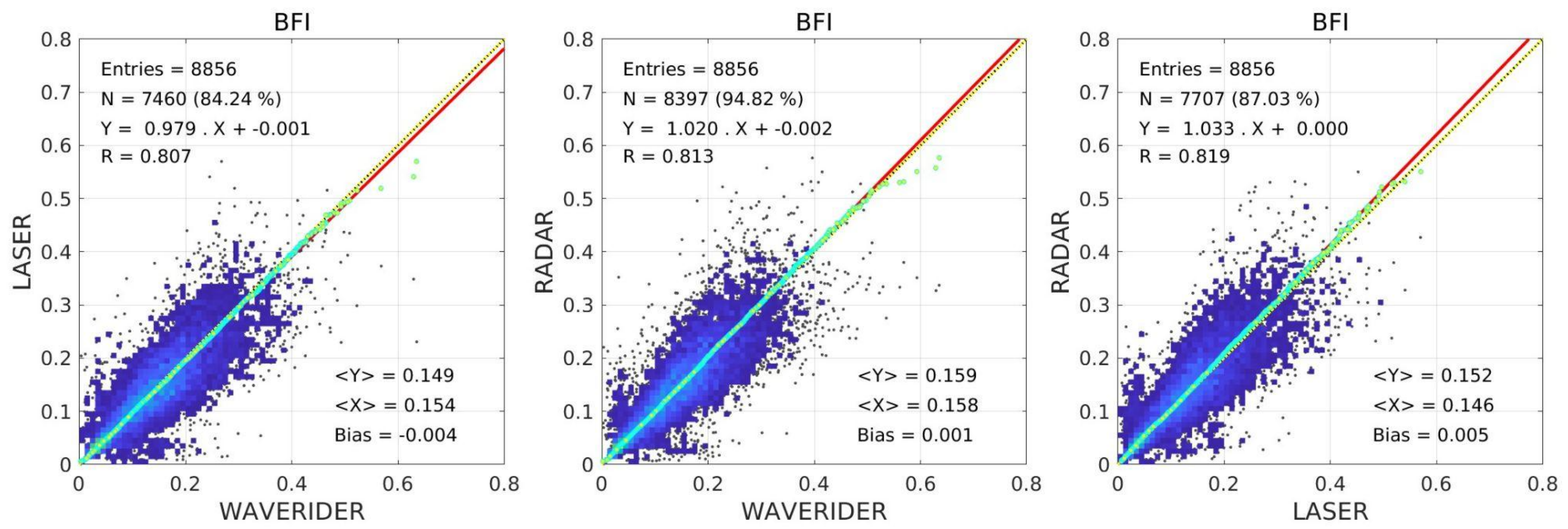
BFI

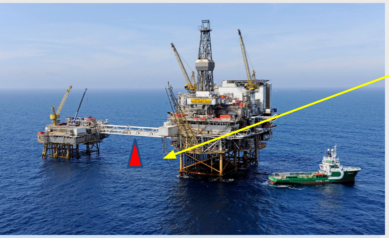
$$BF_j = \sqrt{2\pi}\frac{2\pi}{\Lambda_p}\sqrt{m_0}Q_p \sim \sqrt{2\pi}\ s_p.Q_p$$

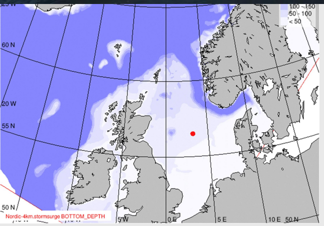
Large spread in colocated values of BFI, but distribution (qq plot) shows they have similar distribution.
Bias is of order 3% or less.

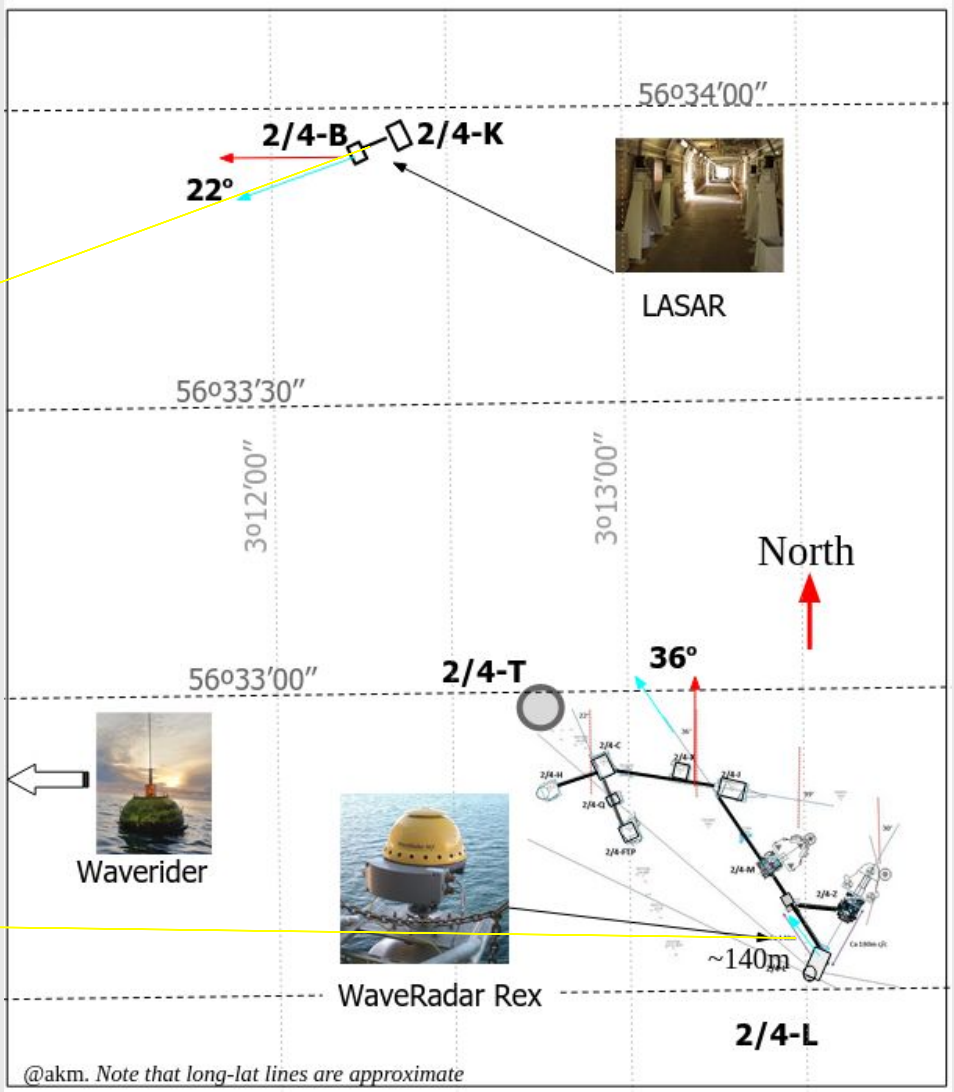


Platform interference

- Waverider is in ‘open waters’
- Laser is on bridge between 2/4B and 2/4-K, oriented WSW-ENE (248° to 068°).
- Radar is on bridge north of 2/4-L, oriented NNW-SSE (224° - 144°). ENE of site is also another platform - 2/4-Z.







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Separation in sectors

Shadowing effects may be expected from the following directions:

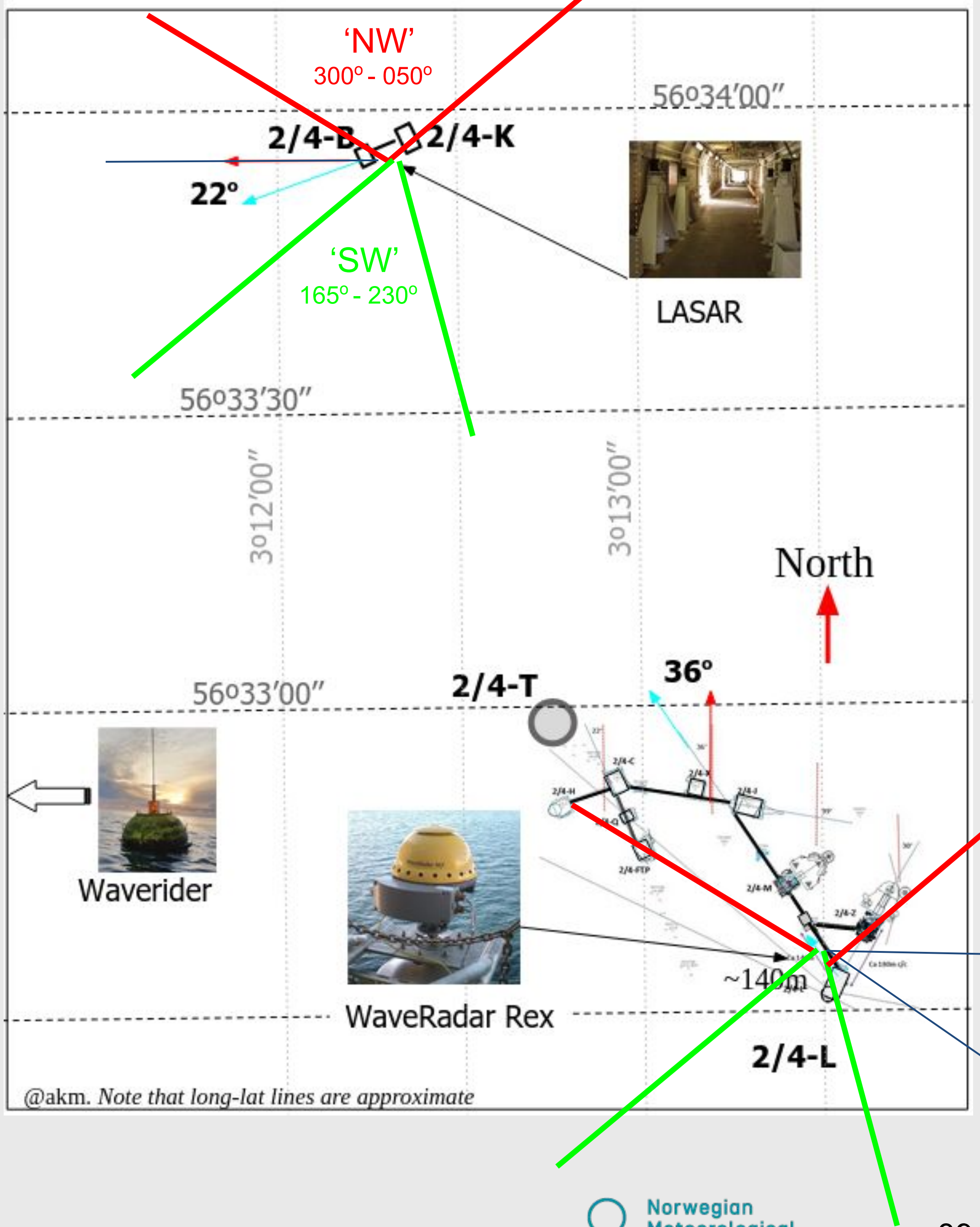
- Laser: roughly from 230º to 270º and from 050º to 090º
- Radar: roughly from 125º to 165º and from 300º to 080º

Analysis in paper:

data sorted using wind direction :

➢ **‘SW’ directions [165º - 230º]**

➢ **‘NW’ directions [300º and 050º].**



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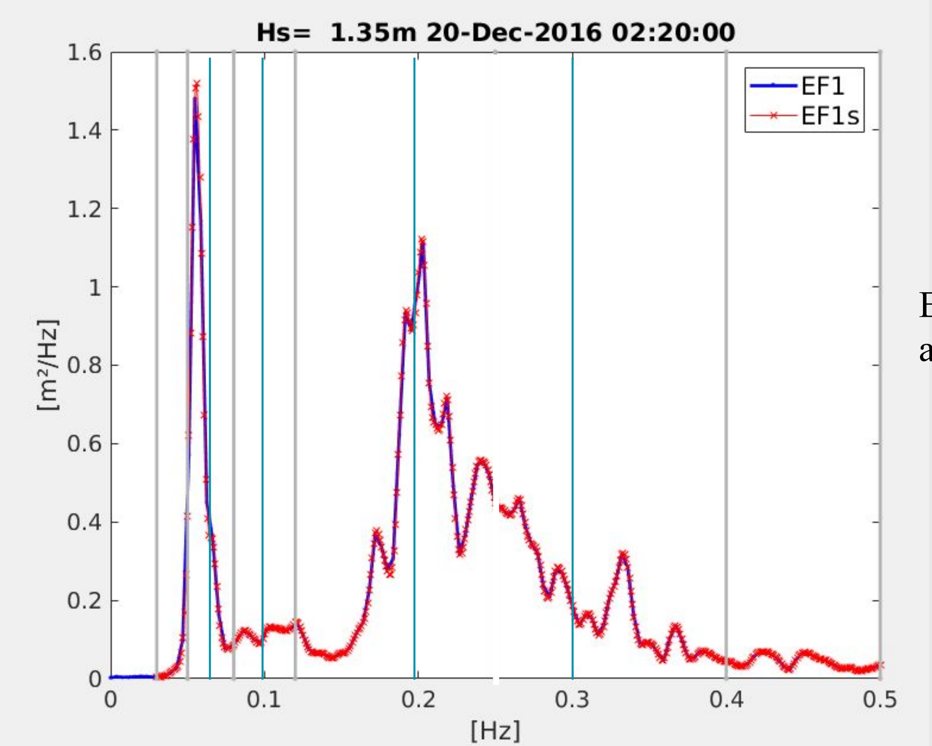
Comparison is evaluated using Equivalent significant wave heights in 9 frequency bands

$$HM0_{eq} = 4.\sqrt{m_{0eq}} \;, \quad \text{with } m_{0eq} = \int_{lf1}^{lf2} E(f).\,df$$

	1	2	3	4	5	6	7	8	9	
f [Hz]	0.03	0.05	0.0625	0.08	0.10	0.125	0.2	0.3	0.4	0.5
1/f [sec]	33.3	20	16	12.5	10	8	5	3.3	2.5	2



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

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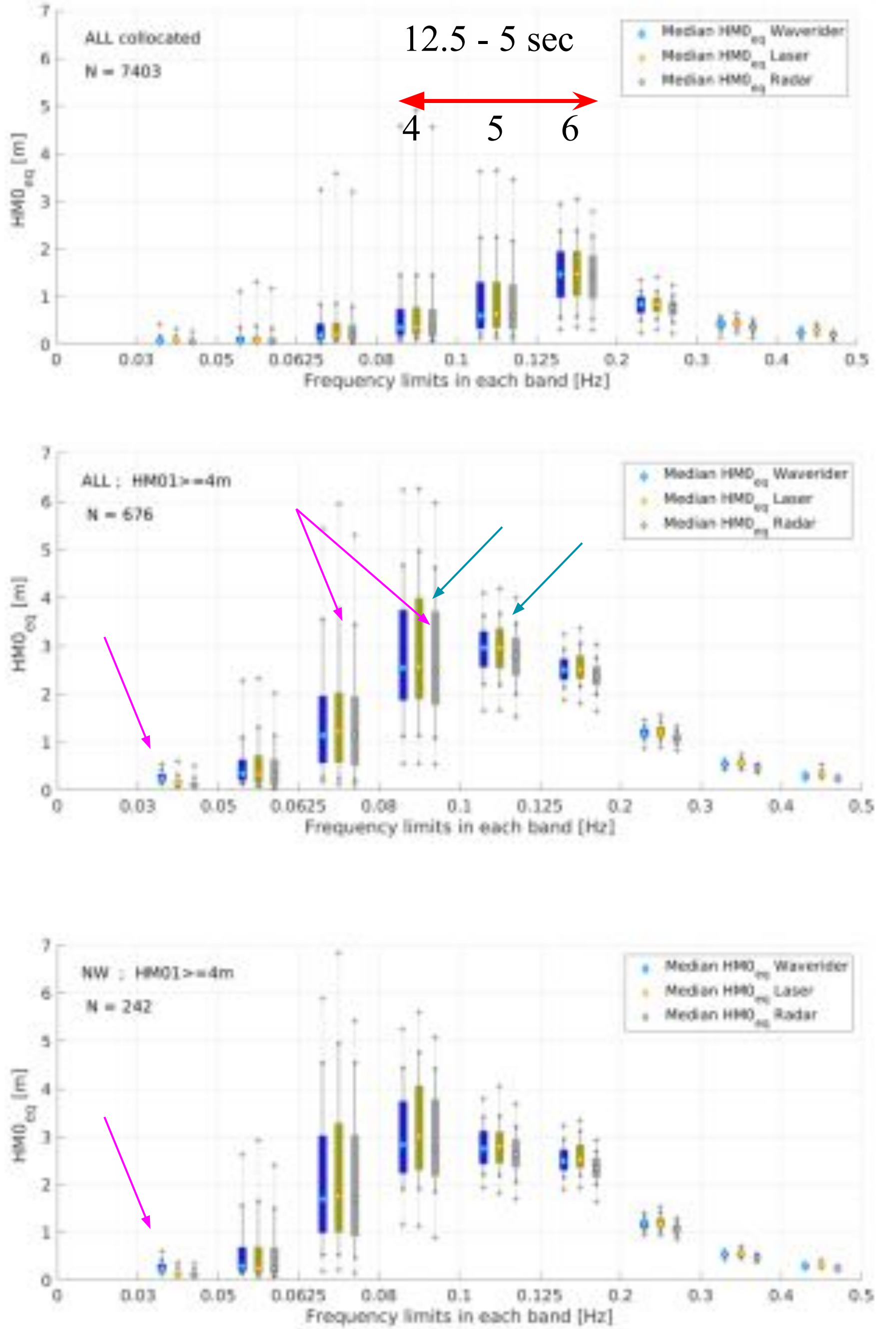

Fig. 10 Distribution of $HM0_{eq}$ from the Waverider (blue), laser (light green) and radar (grey) over different frequency bands (note that frequency axis is not linear) Boxes include values from 25 to 75 percentiles, solid lines 10 to 90 and dotted lines the 1 to 99 percentile values Top: All colocated (7403) values, center: only cases with HM01 ≥ 4m (676 entries), and bottom: 'NW' cases and HM01 ≥ 4m (242 entries)

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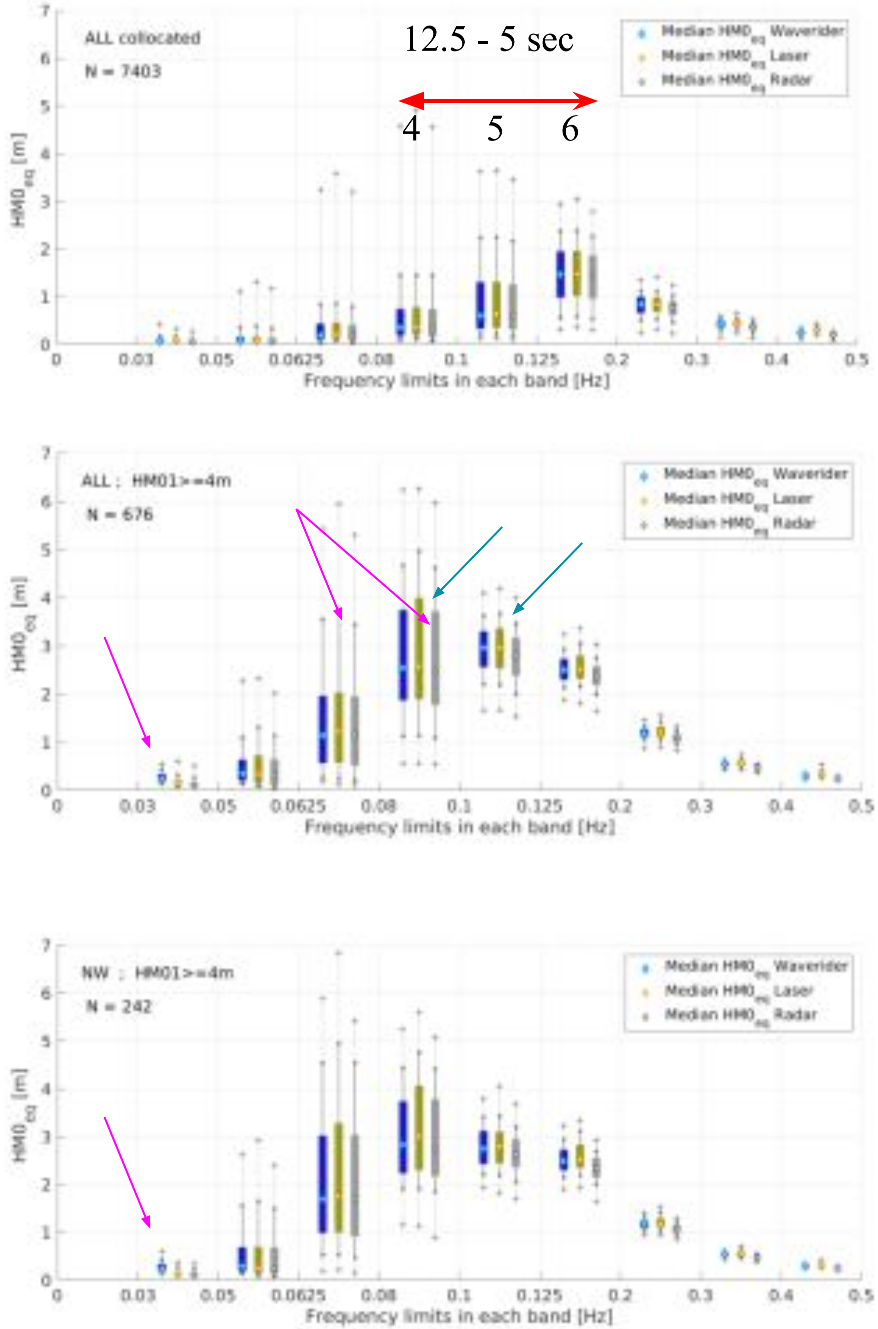

- Waverider has more energy than laser and radar in very low frequencies (0.03-0.05 Hz or > 20sec)

- Radar:

➢ values are lower with Radar when considering all Hs>4m

➢ more significantly in NW directions

- Laser:

➢ ALL values: energy same as waverider except at f >0.2Hz

➢ Hs >= 4m: 75-prctile energy level is higher than both Waverider and Radar

➢ Same in NW cases

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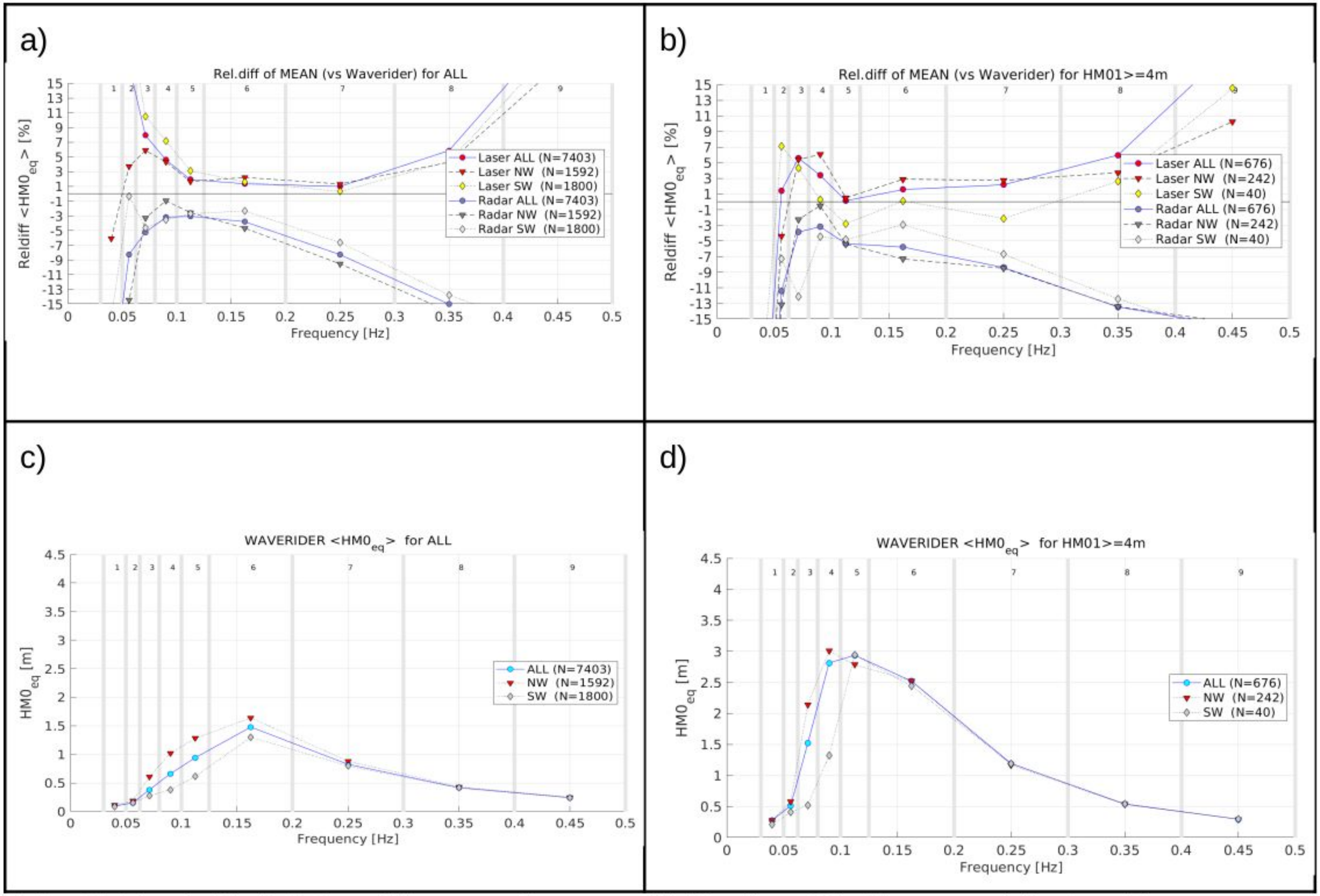

Fig. 11 Top (a,b)**:** Relative difference of average $HM0_{eq}$ (eq. 11) of Laser and Radar with respect to the Waverider in the nine frequency bands defined in Table 4. a) including all sea states, b) only high sea states (<HM01> ≥ 4m). Bottom (b,c): Waverider average $HM0_{eq}$ in the same frequency bands for c) all sea states, d) high sea states (<HM01> ≥ 4m). Three lines for each case include either all directions, or only NW or SW cases

Some conclusions

1. The Waverider measures spurious energy at very low frequencies (from 0.0625 Hz and below, or 16 s and above). These are not measured by the radar or laser and found to be erroneous (supported by visual inspection of wave profiles)

2. The higher tail in Laser spectra is a result of spikes still not removed by the standard quality assurance used.

3. At the spectrum peaks (of averaged spectra), the laser reports higher energy compared to Waverider and radar.

4. The radar measures 3 to 9% less energy in the most energetic bands when considering all cases and 5 to 9 % less in the highest wave cases (HM01≥ 4m).

5. The deficit in energy in the saturation range frequencies present analysis indicates that platform structures cause a reduction in the wave energy captured by the radar of about **4%** in the frequency ranges higher than 0.125 Hz (8s and smaller).

6. In low frequencies, 0.0625 to 0.08 Hz (12.5-16 sec), waves (that is swell) are coming from north.

   Average equivalent Hs (Hseq) with Waverider is 0.5m in band 3 (12.5-16s). Here the WaveRadar Hseq is 5-13% lower, (7 to 10 cm).

7. In the rear face of the spectrum, energy deficit seen in the WaveRadar increases by 2% due to shadowing effects.

Future work

Use a new database of corrected LASAR data (5Hz) despiked using a GP Gaussian Process regression

Malila M.P., Bohlinger P., Støle-Hentschel S., Breivik Ø., Hope G. and A.K.Magnusson: A Nonparametric, Data-Driven Approach to Despiking Ocean Surface Wave Time Series. Journal of Atmospheric and Oceanic Technology, Volume 39: Issue 1. (2022) https://doi.org/10.1175/JTECH-D-21-0067.1

By this:

- correct the tail (hopefully) in laser-spectra and evaluate the effects on spectral parameters
- Give improved comparison between sensors. Hopefully identifying periods when Laser gives ‘true sea state’, enabling to better identify pros’ and cons’ of waverider and radars.

Acknowledgments

- To ConocoPhillips
    - For wave measurement systems
    - Installing WAMOS, LASER ARRAY, stereo video system at Ekofisk
    - Supporting research at MET
    - Supporting work on stereovideo system installation at Ekofisk and new research on waves 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

Experimental devices recently deployed at Ekofisk (2/4-K):

- Stereowave cameras, since 2020, to study wave breaking / wave statistics based on method developed at ISMAR, Benetazzo et al.
- AWAC (Acoustic Wave and Current Profiler) is deployed within the footprint area of the stereovideo cameras