What is True Sea State?

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1. INTRODUCTION

Availability of wave measurements in the North Sea has increased the last 2 decades with an increasing number of oil and gas fields. This fact, together with the development of information technology, plays a large role in the real time availability and amount of data available for wave research. The file sizes of wave profile data and directional spectra is relatively small compared to today's communications and server capacities, therefore these data may be sent continuously, as soon as they are registered. Such data are now available every 10 minutes from a few platforms in the North Sea. They are sent to a data server at the Norwegian Meteorological Institute (met.no) and available to forecasters within 2 minutes from end of recording. Weather reporting stations in Norwegian waters are chosen by the authorities (with recommendation from met.no) in such a way that coverage for weather and climate monitoring becomes as efficient as possible and for safety of operations at sea. Reporting of profile data is not yet a standard within the Norwegian sector.

Weather parameters are usually updates every 10 minutes, wave parameters every 20 minutes. Often rigs and platforms have several recorders, mainly for backup purposes. This paper deals with the differences in sea state noted through the monitoring of wave data from collocated recorders at Ekofisk (56.5 °N 3.2°E) in central North Sea and from stations further north in the North Sea, Statfjord (62.1°N,1.8°E) and Gullfaks (61.8°N,2.1°E), see Figure 1. The analysis has several focuses: the need of a standard method for calculation of significant wave height and the need of recommendations for spike removal from wave profile data.

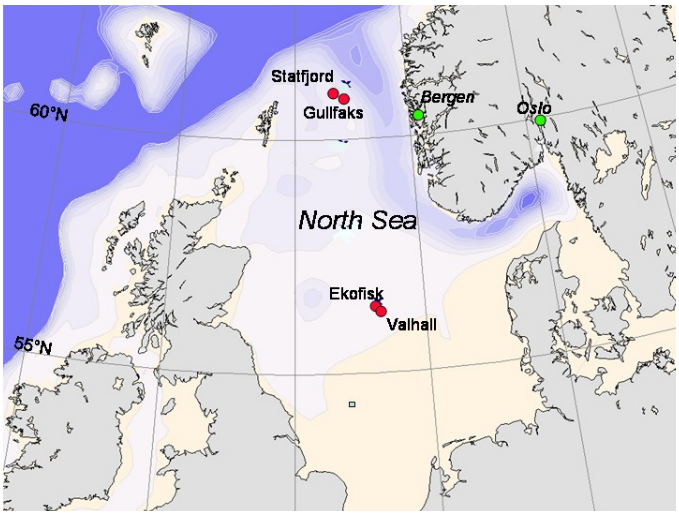


Figure 1 Offshore stations in the North Sea : Statfjord, Gullfaks in the North, and Ekofisk and Valhall in central North Sea.

Differences in Hs values from collocations induce problems when forecasting waves at a high detail to users at offshore installations: when operations are critical and allowed up to a certain level, and two or more wave recorders (could also be wind) are available, differences are tolerated to a certain degree, but larger biases make decision making difficult. Discussions with the system providers, organized because of biases between values given through storms from the sensors at Ekofisk (operated by ConocoPhillips) and Valhall (56.4°N 3.3°E, operated by BP) were also very instructive for this author. Sensor particularities or deficiencies are discussed in the present paper but more work is needed to fully document differences.

2. THE MIROS MICROWAVE RADAR

Many platforms in the North Sea and Norwegian Seas use a platform mounted MIROS microwave radar to record wave data. This system was new in the mid-80’s and attractive because it was less expensive in use compared to a buoy. Experience and analyses soon gave indications that the sensor had a bias between incoming and outgoing waves. The problem was connected to inclination on the sea [1]: The MIROS radar measures the spectral Doppler signal of the capillary waves riding the larger wind waves and swell, and evaluates a directional wave energy spectrum using a transfer function [2]. The software was adjusted, and several updates have been made as well since the first versions, like increasing directional resolution, including heave compensations enabling recording from large floating vessels as well (rigs, FPSOs).

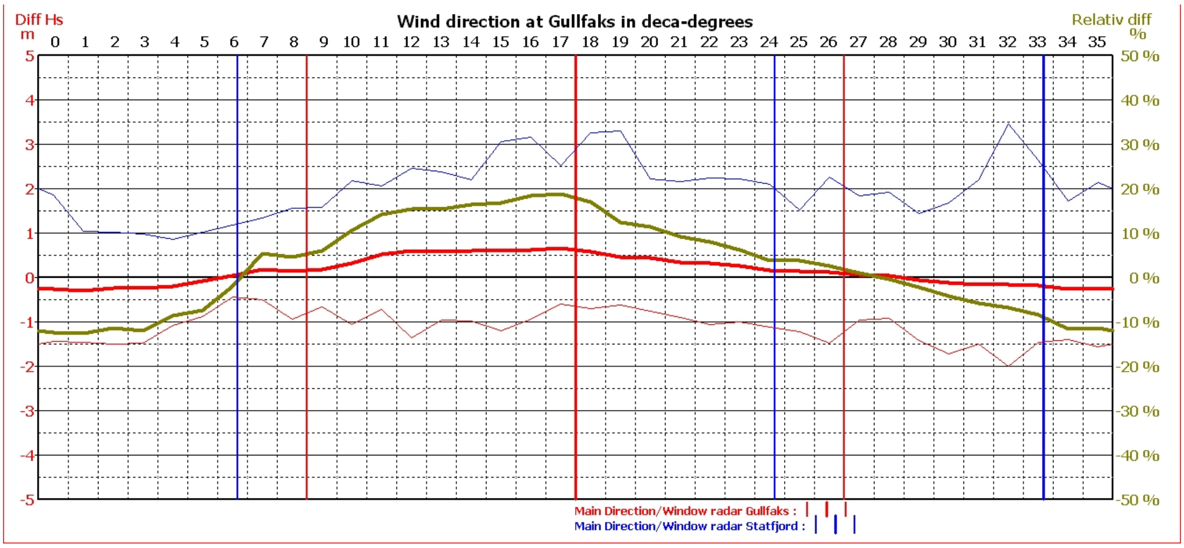


Figure 2 Bias (red) and relativ difference (kakigreen) between Hs at Gullfaks C and Hs at Statfjord as a function of measured wind direction. Data are from January 2007 to September 2009. Only data with wind (10m,10min) > 15 knots, and quality control checking out difference between Hs values larger then 5m. Lowest and highest curves are minimum and maximum registrated difference (bias).

Still a discrepancy is seen in receiding and incoming waves. This has been specially notable between MIROS radars placed on 2 platforms situated only a few km apart in the Northern North sea: Gullfaks (61.1°N 2.1°E) and Statfjord (61.2°N 1.8°E). The platforms are both operated by Statoil, and measurements are available for many users. Figure 2 is from an ongoing work by Rasmus Myklebust, forecaster at met.no in Bergen. Bias and relative difference between the significant wave heights as measured by the sensor at Gullfaks and at

Statfjord are compared to wind direction. It is clearly seen from this analysis covering data from the period January 2007 to September 2009 that there is a difference dependent of the wind direction. The MIROS sensor at Gullfaks has a radar sector centered around south (175°), while at Statfjord it is centered around NNW. When wind (waves) are coming from south, Gullfaks reports in the mean 20% larger waves than Statfjord, and when wind is coming from northerly directions Statfjord reports about 12% larger waves. This discrepancy may be partly due to sheltering effects of the platforms, or shadowing effects of large waves (but different wind regimes give discrepancies as well), or differences between Doppler signal from receiding and incoming waves.

Consequences of these discrepancies are either way important for marine operations and validation of forecasts. For example, one marine operation can be pursued when it should not (with consequence on increased risk of damages or failure) or another one is halted erroneously with subsequent unecessary increase of costs. Verifications of forecasts, model predictions, or of satellite values of Hs, have shown regional discrepancies ([3], [4] and [5]). In [4] we see larger biases between Envisat data and North Sea data compared to American buoy data, and one may question if this is because most of North Sea wave heights are from platform mounted wave sensors. The differences can be caused by platform leg interference with the waves, shadowing effects, and inherent differences between sensors.

3. WAVE PROFILE MEASUREMENTS

3.1. Introduction

Ekofisk has one of the worlds' longest record of measurements from non-directional Waverider buoys (Datawell). Other systems are also in use Norwegian waters: Norwave, Seatec, Seawatch, TriAXYS. At Ekofisk the wave profile measurements have been recorded with a sampling frequency of 2Hz and stored since 1981, at first only every 3 hours (and only when Hs was above 4m), later every hour, then continuously (one record per 20 minutes) since early 90's.

This authors experience on wave buoy data comes from analysing at first historical data in the period 1980 to 1991, later on monitoring real time data during storms in the period 1995 till today. In the first database, organised for a study by a consulting company Loginfo AS, it became clear that original time series were erased and only 'quality controlled' data were stored,[6] and [7]. The quality control erased spikes with amplitude larger than 5*RMS of the time series. Crests larger than 1.25 times the significant wave height were then treated as spikes. As we know now, this value is just at the lower limit of what we consider as extreme waves and should never have been erased this way.

There are 3 sensors reporting one-dimensional wave data at Ekofisk. A short description of the data is given in next section. Monitoring storms since 1991 has given an insight in variability and unsteadiness in the wave field during changing wind conditions. Some features are reported here and give background to questioning what true sea state is.

Since the mid-1990's wave profiles sampled at 2Hz have been available in real time from 3 sensors at Ekofisk: the Waverider buoy, and 2 other down looking sensors (radars and lasers). The types of downlooking sensors have varied during the last 15 years, as well as where they have been placed. At first, (since mid-80's) two downlooking radars were placed just south of the Tank, which gave waves much subject to lee effects. Then they were placed at north and south ends of the complex (two Optech lasers close to Flare South and North, see Figure 3). When all platforms north of the tank were decommissioned, the northern laser was replaced by the LASAR on the bridge between 2/4-B and K. The laser at Flare south was replaced by a Miros Range Finder (MRF, a microwave altimeter). In the summer 2009, the platforms in southern end of the complex were decommissioned, and the MRF was moved to the west side of 2/4-H.

3.2. Wave sensors at Ekofisk

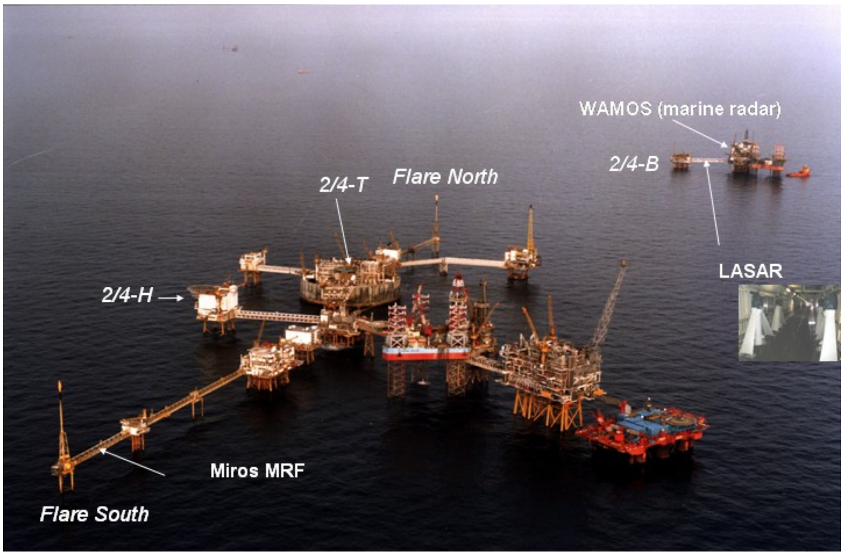


Figure 3 A picture from the Ekofisk Complex around 2002. The initial platform axis was from Flare South to North, direction NNW (~340 degrees). New platforms are now built in the east – west direction and the tank (2/4-T is empty, the wall around remains, and platforms North of it are decommissioned. In the North we see 2/4-B and 2/4-K, where the LASAR and the WAMOS are installed.

Data used in this analysis are from the period January 2007 to spring 2009. They include simultaneous measurements from the waverider buoy, MRF and the LASAR 2Hz data. The Waverider is placed within 1 nautical mile from 2/4-H, and should measure waves from the free field. The MRF data used here are from the period at Flare South (Figure 3), and may be affected by lee effects when waves come from a given sector around North. How wide this sector is is difficult to say. Probably will waves coming from between S and NW be unaffected by the constructions around. The LASAR consists of 4 Optech lasers placed in a 2.6 by 2.6 m square inside the bridge between 2/4-B and K (Figure 3). The waverider is a heave buoy, the MRF is a microwave based radar. The buoy samples wave profiles at 2Hz, while the MRF and the LASAR sample at 5Hz, but are resampled to two 2 Hz time series (data from the 4 lasers are merged to one 2Hz series). The LASAR system was mounted in 2003 to give directional and phase information. Here we will only discuss the one dimensional data and parameters retrieved from the 2Hz time series.

3.3. Wave buoy behaviour

The waverider is known as a wave follower. The anchoring system has an elastic cord in the upper part of the mooring that allows the buoy to move up and down without being too tightened to the anchor. But because of the forward motion at the top of the crest, and backward motion in the troughs, the buoy will stay too long at the tops, and too short in the troughs. The accelerometer in combination of known response transfer functions of this, will (should?) measure the correct heights of crests and troughs relative to each other. But average elevation (still water level) will be wrong, making crests and troughs in the average about the same, skewness will be close to zero. One may question the buoy behaviour in high waves and wind, or in strong currents. High winds will produce a surface current that may move the buoy far from the anchor position, stretching the elastic cord to the maximum. Observers have reported seeing the buoy avoiding the tops by going around, or going under. In the Canadian systems the wave profiles are recorded inside the buoy, at Ekofisk the data are sent from the buoy in real time to a receiving station. In the Canadian buoys one will therefore always have continuous data, and some data in extreme waves may be sampled from under the surface. At Ekofisk we will have missing data.

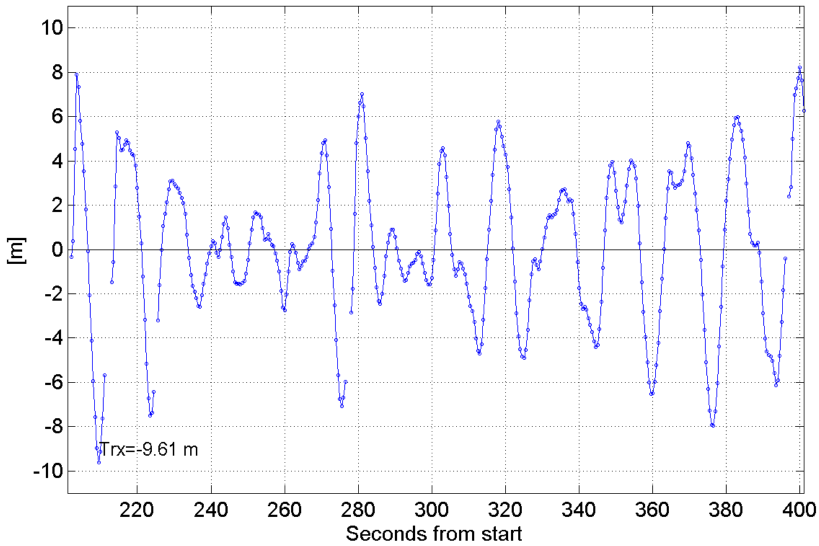
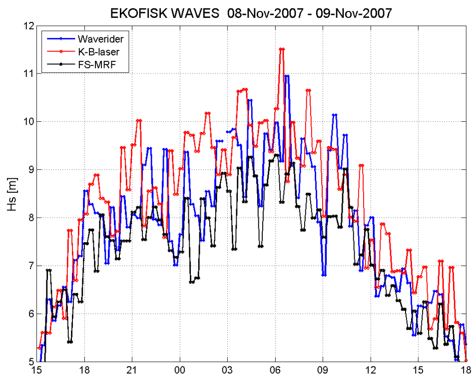


Figure 4 Example of sea surface height measurements during 200 seconds as evaluated from the accelerometer inside a waverider buoy at Ekofisk. In 4 of the waves (at about 215, 225, 275 and 395 seconds from start) we see missing data when the sea surface is going up.

In the records from 1995 to 2006 we never saw any missing records, but in 2006 the sampling system offshore was changed, and for a few months data (integral parameters) from the Waverider became spiky when waves increased above 3-4m. The problem was not that obvious in the summer season, but in the fall, with increasing sea states it became more common to have erroneous data. Finally analysis showed the problem was missing data being given default values -999m, making significant wave height abnormally high. It appears, when screening a few timeseries (see example in Figure 4), that the missing value periods occur when the sea surface increases rapidly to a high crest. No cases are seen at the top of a wave in the samples examined. If this is correct the linear interpolation that is used to correct data now should not be a major source to errors in wave statistics. This does not exclude, though, erroneous statistics due to the fact that the buoy is a wave follower. The example is from a storm with waves from North, Hs increasing to around 12 m shortly after the example given. At this time, the Waverider was SSW of the receiving antenna, perhaps 1,5km away. It is plausible that the northerly highest crests would interrupt the line of sight to the buoy.

3.4. Wave height variability

A large variability from one time series to the next one is seen in the storm monitoring. This is seen in all three sensors. An intercomparison is given in next section. Figure 5 shows an example of this variability through a storm on November 8th and 9th 2007. Panel (a) shows also how different significant wave heights are reported from the 3 in-situ sensors at Ekofisk (Waverider, MRF and LASAR). Panels (b), (c) and (d) show the 1, 2 and 3-hourly averages of the Waverider time series of significant wave height. The upper and lower curves are values +/- standard deviation in the observations of Hs within the 1, 2 or 3 hours considered. The longer averaging period decreases the maximum Hs in this storm from 11 to 10m, while 2 and 3 hourly averages decreases it to 9.5m. The standard deviations include maximum value of 11m in (b), but not in (c) and (d). Variation in Hs in this storm is large at the top, between 02 and 10 UTC. The 2-hourly average-curve tells us that waves had a higher regime (about 9.5m) between 03 and 09UTC, and a 9m regime the next two hours (09 to 11 UTC). Wave heights of 9.5m are also seen between 21 and 00 UTC on the 8th.



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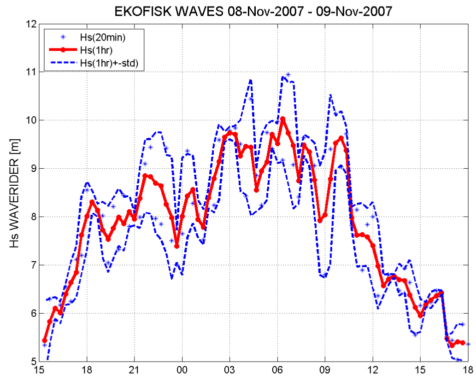

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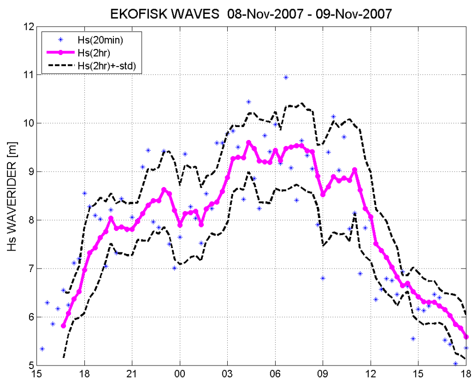
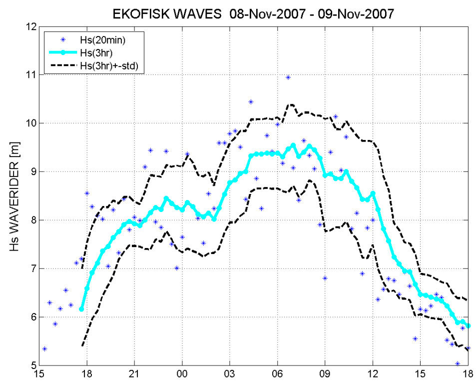


c)



d)

Figure 5 Variability in measurement of significant wave height Hs through a storm on 8th-9th November 2007 at Ekofisk. Top left (a) shows Hs from all three in-situ sensors at Ekofisk. Thick blue line is from Waverider, Red line is from the LASAR, Black line from Miros Range Finder. Panels a, b and c are 1, 2 and 3 hourly averages of Waverider Hs with upper and lower lines showing the values +/- standard deviation in observations within each 1,2 or 3 hourly period. Blue dots are observations.

The sampling variability of estimates of spectra has been analysed before [8]. They found that the uncertainties in the significant wave height and peak frequency estimates were approximately ±12% and ±5% at the 90% confidence level. The standard deviation between measurements within the 2-hourly windows is in the mean around 7 % of the 2-hourly Hs values, that in this database (see next section) range from 3 to 11 meters, with most of the measurements around 4 to 7 meters.

3.5. Wave buoy compared to the down looking sensors

In storm monitoring, the three sensors have often showed tendency to give different significant wave heights, with the MRF being lower than the Waverider, and the LASAR system giving highest waves (seen for example in Figure 5a). A simultaneous database has been extracted from the period January 2007 to spring 2009. Only storm data are used, and they are mainly from wind directions between SW and N. Scatter plots and Quantile plots are shown in Figure 6 and Figure 7. There is an obvious discrepancy in Hs between the MRF and Waverider, while difference between LASAR and Waverider is not that obvious in the scatter plot, but is seen in the Quantile plot. When waves are higher than 8m, both down looking sensors have same tendency compared to the buoy, and one may question if the waverider data are erroneous.

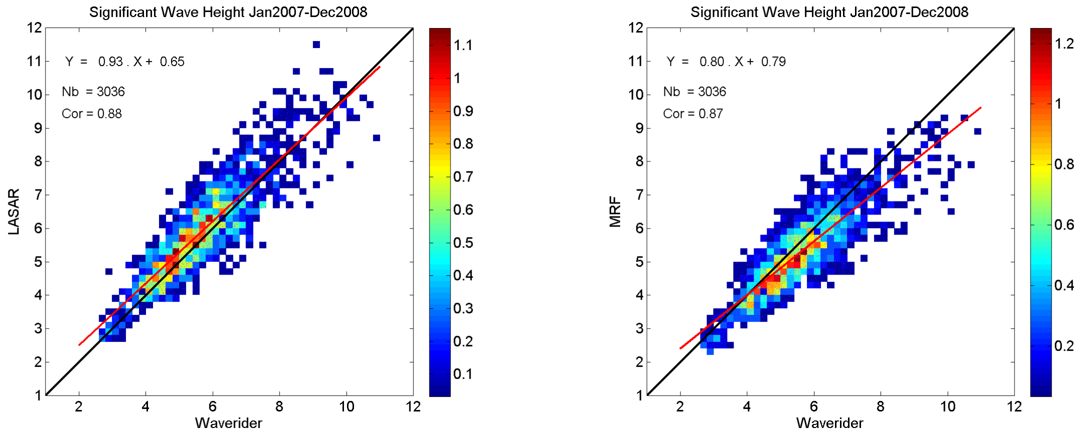


Figure 6 Scatter between Hs from LASAR towards Waverider (left) and MRF towards Waverider (right). Number of 20 minutes records is 3036. Correlation between the sensors are similar (0.88 and 0.87), but the difference between the sensors is most obvious for the MRF. Color coding gives percentage of cases counted within a 0.1x0.1 m range.

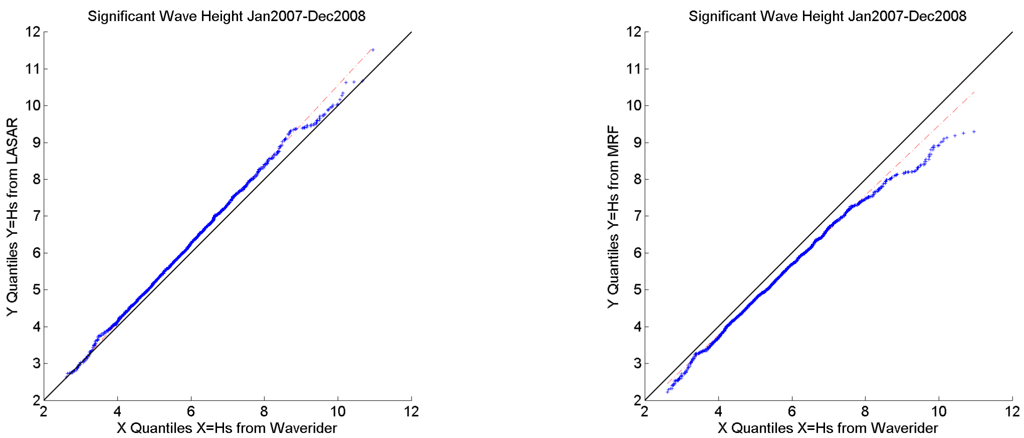


Figure 7 Quantile plots of the same cases in previous figure, comparing LASAR and Waverider (left) and MRF and Waverider (right).

Similar comparisons are performed with the one and two-hourly averages. The correlation increases then between the Waverider and the LASAR from .88 to .95 and .97 respectively, and between the MRF and the Waverider it increases similarly (from 0.87 to 0.93 and 0.95

respectively). The slope between the measurements of Hs from the LASAR and the Waverider becomes positiv when using the 2 hourly averages (1.02) while the slope between MRF and Waverider becomes less negative, 0.86 compared to 0.80). The Quantile plots are though similar to the originals shown in Figure 7. The slopes are constant in the range of Hs between 4 and 8-9m, while the highest values have a different behaviour, showing that the highest waves are problematic to measure. Which sensor fails the most is not answered here.

Since some of the differences might be due to lee effects from the platform constructions, the data are analysed against wind direction. In the 20 storms in 2007 and 2008 where there were simultaneous (and of good quality) observations from all three sensors, wind direction was mainly between WSW and North, with increased representation around W and NNW (Figure 8). From the distribution of average Hs within 10 degrees band (left panel) we can note:

- generally: average Hs is lowest when measured by MRF, and highest from LASAR. Waverider Hs is in between.
- The difference between Waverider and LASAR is negligible in southerly cases, where average Hs is also lower (3.5-4.5m).The MRF is slightly lower than the Waverider, which is easily explained by interference of waves with the legs of Flare south.
- Directions 230-250 (SW-WSW): we have been informed that the buoy is SSW of 2/4-H, so we can disregard the assumption that it is in the lee of the complex. We may assume that more sea spray influences the LASAR measurements due to the platform 2/4-B.
- Directions 260-020 (WSW-NNE): the MRF is lower than the Waverider: Is it lee effects from the complex north of MRF or a genuine error in the signal processing in the MRF?
- Directions 250-300 (WSW-WNW): LASAR vs Waverider is only slightly higher compared to the more open sector. We are here talking about differences of 2-3 % compared to 8-10% in average Hs values. We can deduce that the platform legs reduce the sea state by about 6%, but this is only a rough evaluation.

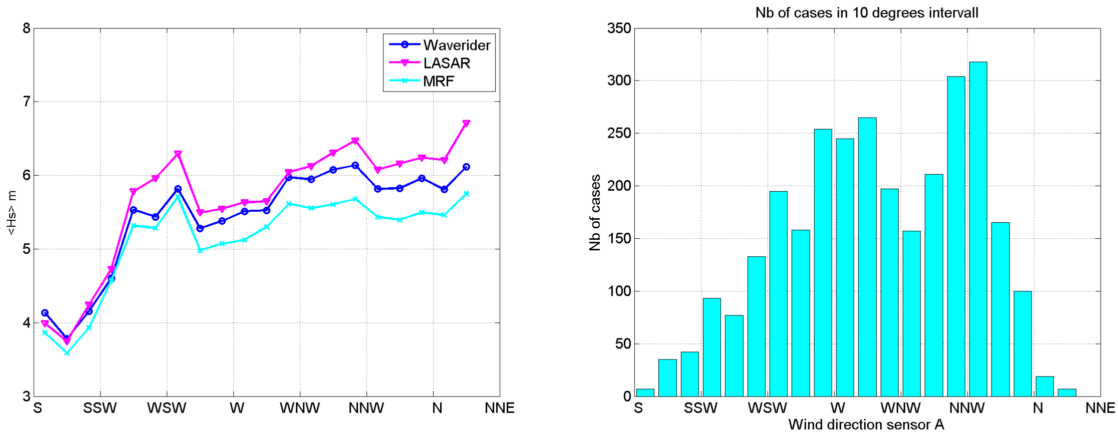


Figure 8 Left: Average significant wave height in 10 degrees interval between South and NNE from the 3 in-situ sensors at Ekofisk (Waverider, LASAR and MRF). Right: number of collocated observations in each 10 degree sector included in the analysis (20 storms with 3040 records in 2007 and 2008).

The MRF sensor (as well as all wave sensors some way or another) has a quality controle on each sample: here a tracking window of 10m is used, meaning that if one sample differs more than 10m from the previous one, the sample is rejected and an equal value is inserted. This will obviously smooth steep crests, and reduce maximum crest heights. The daily monitoring indicates that the MRF time series are as un-skewed as the Waverider (not shown here). The tracking window is plausible to give such an effect. How much this quality controle affects the measurements needs more analysis. Figure 8 (left) shows that there may also be shadowing effects from the constructions north of the sensor (difference in 8-12% in the sector WNW-NE) but same difference is also seen in what is believed to be an open sector (around W). It can be added that a similar difference is seen on Hs from a Saab radar at Valhall (about 25 km SSE of Ekofisk) in a comparison of 3 months of data. Such differences are large when values are used in validation, operations and design value estimations.

4. CONCLUSIONS

Significant wave height is a measure with a large uncertainty and variability. Spectral estimates of Hs have a 12% uncertainty at a 90% confidence level [8], but it is also seen that platform legs may reduce Hs in the mean by 6% when waves are measured in the lee (here typically 50-100 meters away). Totally unfiltered wave data from the laser array at Ekofisk suggest significant wave height may be about 2% higher that the waverider. What is true sea state is even more difficult to determine when waves get larger than 8-10 meters. A more thorough analysis of data is needed of the profile data (under preparation).

The experience gained from this analysis is also that there is a need of standards on spike removal and wave parameter calculations. Programmes for quality control and parameter extraction should be open software. Raw data should be stored.

5. AKNOWLEDGMENTS

The author acknowledges Statoil, ConocoPhillips and BP for provision of wave and environmental data. Thanks to Sturla Mæhre and Cathrine Netland Egset from MIROS and Frode Flåten from CononoPhillips for fruitful discussions about the instrumentation. This work is performed with partly support from the EU project EXTREME SEAS, Grant agreement no.: 234175.

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