Wave Measurements for the Monitas System

Jeff Hanson/WaveForce Technologies, Andrea Lübhen/OceanWaves, Pieter Aalberts/MARIN and Miroslaw Lech (Mirek) Kaminski/MARIN

ABSTRACT

The paper is one of the series of papers about the Advisory Monitoring System for controlling the fatigue lifetime consumption of FPSO hulls. The system has been developed within the Monitas Joint Industry Project (JIP). The name Monitas stands for Monitoring Advisory System. A key factor for proper lifetime prediction is an accurate assessment of the ocean surface wavefield. Therefore, a dedicated wave system analyses tool (XWaves) has been developed within the project that allows for online analysis of the measured wave data. The Monitas project recommends use of navigational radar for measuring waves. This paper compares the wave data obtained from such radar with that obtained from a wave buoy. The differences in obtained wave data from both instruments are illustrated and explained. The effect of these differences on fatigue lifetime consumption has been quantified. The paper also investigates how different wave data formats which are being used by the offshore industry affect the fatigue lifetime calculations. All comparisons and conclusions are based on real data collected from the Monitas system installed on board FPSO Glas Dowr. It has been concluded that navigational radar can be used as the instrument for wave measurements and that different wave data formats are acceptable providing the wave directionality data is preserved.

Introduction

Offshore installations such as FPSOs are continuously subjected to wave loading which results in fatigue damage leading to costly repairs. Often operators are unprepared for such failures because the actual conditions encountered during operations may be quite different than those used in the vessel design. The Monitas Joint Industry Project (JIP) aims at changing this situation through the development and demonstration of an Advisory Monitoring System (AMS) for FPSOs (L’Hostis et al., 2010; Kaminski, 2007). This system is further on referred to as the Monitas system (Monitoring Advisory System).

Accurate assessment of the ocean surface wavefield climatology experienced by the FPSO is a critical component of the Monitas system. Robust wave analysis routines in the Monitas system have been developed to decompose the observed wave field into individual wind sea and swell wave components (Hanson, 2009). The isolated wave components are converted to conventional spectral forms such as the JONSWAP energy-frequency spectrum (Hasselmann et al., 1973) with a cos^n directional distribution which are used in the design. The resulting sea state climatology is used by the Monitas system to perform a structural fatigue analysis for comparison with design lifetime estimates (Kaminski and Aalberts, 2010). As an end-to-end demonstration of the Monitas system, the FPSO Glas Dowr was outfitted to obtain all required ship environmental and operational data to perform a lifetime fatigue analysis based on actual conditions (Aalberts et al., 2010). Observations were made while Glas Dowr was stationed in the wave environment off South Africa for a 16-month period (June 2007 – September 2008). Required directional wave observations were obtained with ship-mounted dedicated conventional navigational X-band radar. For validation purposes, a directional wave buoy was deployed nearby. Shipboard meteorological and GPS navigation systems provided the remaining required inputs for conducting the fatigue lifetime analysis.

This paper is one of five papers that present the Monitas system and results of the Glas Dowr demonstration. The focus here is on the Monitas wave analysis module. Details are provided on the wave observation and analysis methods. A validation of the radar wave measurement system is also presented, including a summary of fatigue consumption based on both the radar and wave buoy measurement approaches. Finally, the paper shows how the use of different wave data formats describing the same wave data can affect the fatigue lifetime estimation.
Instruments
The Monitas wave analysis module requires wind, wave and ship navigation data to create an accurate accounting of the sea state history encountered by an FPSO. The specific observation systems that supported the FPSO Glas Dowr demonstration are described below.

The environmental conditions of the Glas Dowr, i.e. wind and waves, were measured with the anemometer, the wave buoy and the wave measuring system based on conventional navigational radar. In order to obtain the wave and wind data relative to ship’s heading, a DGPS navigation system was also installed.

Wave Radar
The wave measuring system based on conventional navigational radar is a cost effective alternative for a wave buoy. On the Glas Dowr the Wave and Surface Current Monitoring System WaMoS II was installed. The system was developed for real time measurements of directional ocean wave spectra by using conventional navigational X-Band radar. The measurements are based on the backscatter of radar energy from the ocean surface (sea clutter). The system works in real time and obtains directional ocean wave spectra as well as statistical sea state parameters. The system is especially useful under extreme weather conditions and during night when no visual observations are possible. The system consists of a high speed video digitising unit, which converts the analogous signal to a digital one, and a standard PC for data storage and analysis. Results are displayed on site, but can also be accessed via online connections. The system can be installed on offshore platforms, in coastal areas as well as on moving vessels. Since 2001, it is type approved by the classification societies Det Norske Veritas (DNV) and Germanischer Lloyd (GL) with respect to data accuracy and functionality.

A typical single system measurement consists of a sequence of 32 radar images. For analysis one or more rectangular or quadratic Cartesian windows are cut out. These sequences of Cartesian windows are then analysed in terms of the spatial and temporal variation of the detected sea clutter. From this unambiguous directional wave spectra and surface currents are deduced. Statistical sea state parameters such as significant wave height, peak wave period, peak wave length and peak wave direction are estimated by a straightforward analysis.

On the FPSO Glas Dowr, the system is connected to a navigational radar working with a 6 ft antenna. The antenna is installed at the stern of the ship in a height of 30 m and has, due to shadowing effects of ship structures, a 270 deg view. The rotation time of the antenna is 2.5 s. Thus the frequency resolution equals 0.0125 Hz. The sampling frequency is set to 20 MHz, which results in a spatial resolution of 7.5 m. Figure 1 shows a navigational radar image as obtained by the system on board FPSO Glas Dowr, on August 31, 2008, 07:11 UTC. The colour coding corresponds to the radar backscatter strength where black indicates no return and white maximum return. For analysis, the three rectangular windows depicted in Figure 1 were chosen, so that the system results correspond to an area of approximately 5.3 km². The radar to wave spectrum transformation algorithm was initially calibrated using a set of buoy wave height data from 2007. Data presented here are 20 minute average values. The system is further on referred to as the radar.

![Figure 1. Dedicated radar used for wave measurements and example of image obtained from it](image-url)
Wave Buoy
It was desired to have a known standard by which to validate the radar performance. To fulfill this need, a Datawell Directional Waverider buoy was moored nearby FPSO Glas Dowr in approximately 103-m water depth, see Figure 2. The buoy is a spherical, 0.9m diameter buoy which measures horizontal and vertical accelerations to infer wave height and direction over a frequency response range of 0.025 Hz to 0.59 Hz.

The buoy includes an onboard processor which was used to compute half-hourly energy-frequency spectra and directional moments from the measured wave height and direction time series. The resulting data were radio frequency transmitted to a receiver located on the Glas Dowr. As will be further described below, these wave parameter files are directly read by the XWaves ocean wavefield analysis tools that form the basis of the Monitas analysis module. A Maximum-Likelihood-Method (MLM) directional estimator is applied by XWaves to transform each buoy wave spectra and corresponding directional parameters set into full directional wave spectrum representation.

Anemometer and DGPS
Wind data is measured with an anemometer which provides wind speed and wind direction every second with a resolution of 0.02 knots and 1 deg, respectively. The heading is measured with a DGPS which provides the heading data with 5 Hz with an accuracy of less than 1 deg. Figure 3 shows the DGPS and the anemometer on the mast of the Glas Dowr. Post processing software analyses the half hour wind and heading data files and determines the half hour statistics per month of measurements. These statistics including date and time are written into mat files (MATLAB) which are input for the wave analysis program XWaves.
Automated Wave Analysis

Offshore wave environments are typically composed of a complex mix of locally-generated wind seas and various swell systems propagating from distant generation events. A careful sorting of this dynamic wavefield is required to accurately account for the wave loading history on offshore installations. This is accomplished in the Monitas wave analysis module using the proven technology contained in the XWaves ocean surface wavefield analysis toolbox (Hanson, 2009). Developed to isolate and track wind sea and swell wave systems in complex wave environments, this technology has been used for such applications as investigating North Pacific wind sea growth and dissipation (Hanson and Phillips, 1999), describing swell propagation across the Pacific (Hanson and Phillips, 2001), quantifying numerical wave model performance (Hanson et al., 2009), and isolating wave systems in the operational global wave model WAVEWATCH III™ (Tolman, 2009). The following sections describe the specific capabilities of XWaves used for wave data processing in the Monitas system.

Data Preparation

The XWaves analysis tools operate on shipboard wind speed and direction time series data and ocean surface directional wave spectra in matrix form, expressed in units of m²/(Hz deg). The standard clockwise meteorological directional convention of degrees from north is adopted for all wave and wind directions. Preparing the Glas Dowr data involved interpolation of the winds, spectral smoothing, data sub-sampling, and spectral interpolation. Each of these steps is described below.

Wind Interpolations - Wind speed and direction data obtained from the shipboard meteorological station are converted to vector components (u, v) and interpolated to the wave record time stamps. It is usually the intent to collect continuous wind and wave data. However, instrument, shipboard and weather issues generally result in occasional data gaps. Glas Dowr wind components were linearly interpolated through data gaps of up to 3-h duration. For gaps greater than 3-h duration, wind speeds and directions were estimated from the wave spectra (see Wave Partitioning below).

Spectral Smoothing - Since the measurement systems estimate wave spectra from data obtained over finite spatial and temporal domains, a certain level of uncertainty is to be expected in the results. To help mitigate noise due to sampling variability, a weighted average 3-h smoothing was applied to the wind components and wave spectral records. A key advantage of this smoothing is that spurious peaks in the wave spectra are removed, thus significantly improving processing efficiency.

Record Sub-Sampling - As described above, radar wave records are produced every 10 minutes while the buoy records are produced every 30 minutes. To provide consistent data sets for comparison and validation, both the radar and the buoy records were sub-sampled at a 1-h interval.

Spectral Interpolation - A final preparation step for the radar and the buoy spectra was to interpolate each directional spectrum matrix to a consistent set of frequency and direction bins. For the Glas Dowr analysis a frequency range of 0.03 Hz to 0.35 Hz at 0.01 Hz resolution and a direction range of 0 to 360 deg at 15 deg resolution were selected. Although these interpolations reduce the resolution of the input directional wave spectra, the impact on final results is negligible and the improvement of processing efficiency is very significant.

Wave Partitioning

Wave partitioning in XWaves uses an inverse watershed algorithm to isolate peak domains in directional wave spectra (Hanson et al., 2009; Hanson and Phillips, 2001). An iterative smoothing approach (Portilla et al, 2009) has been incorporated into the partitioning algorithm to successively combine neighboring peaks until the number of wave components is less than or equal to a maximum threshold set by the user. Wind sea peaks are identified using a directional wave age criterion (Hanson and Phillips, 2001). A new forwards- and backwards-looking trend algorithm adjusts partition boundaries over a user-specified time window to remove discontinuities. This further reduces noise in the system to produce wave systems that evolve naturally through time. For the Glas Dowr demonstration and following the design fatigue calculations, the analysis was set to produce no more than a single wind sea and a single swell partition at each time step. Figure 4 shows a sample wave spectrum partitioning and fitting results from the buoy record at 2251 UTC on 25 August 2008. Figure 4a shows the Cartesian plot view of directional wave spectrum components. The contour plot view of directional wave spectrum components is shown in Figure 4b whereas Figures 4c and 4d show the JONSWAP energy-frequency fits and cos²θ directional spreading fits, respectively. The evolution of extracted components from 15-31 August appears in Figure 5. Wave component significant wave heights, peak periods and mean directions are represented in the top panel of Figure 5 by vector lengths, origin and azimuth, respectively. Wave systems are color-coded with wind seas in black. The middle and lower panels of Figure 5 show the wind vectors and the significant wave heights, respectively.

As part of the partitioning algorithm, a wind speed and direction estimation procedure has been implemented to provide wind data through long record gaps. The first step is to estimate a wind sea and swell separation frequency (fₑ) from the shape of the full energy-frequency spectrum prior to partitioning (Wang and Hwang, 2001). A first-guess wind speed is then obtained by inversely applying the Pierson-Moskowitz (PM) model (Pierson and Moskowitz, 1964) to the spectral components at
frequencies higher than $f_c$. Wind directions are then estimated by computing a mean direction over the last 10 frequency bins of the spectral tail. Once the partitioning process is completed, the extracted wind sea partition is then used to refine the wind speed estimate using a second iteration of the inverse PM approach.
Spectral Fitting

The goal of spectral fitting in XWaves is to compute a variety of energy-frequency fit parameters and directional distribution parameters suitable for engineering design applications. An iterative least-squares fitting approach is employed. The Glas Dowr demonstration required fitting of both a JONSWAP variance density spectrum and a $\cos^2(\theta)$ directional distribution to the wave components. Sample results appear in Figures 4c and 4d. For each partition the fitted significant wave height ($H_s$), mean or zero-crossing period ($T_z$), peak enhancement factor ($\gamma$), and directional spreading parameter ($n$) were used in the sea state analysis.

Sea State Analysis

As part of the Monitas development effort a new sea state analysis module has been added to the XWaves toolset. This new module computes and displays sea state specification data for the development of Metocean design criteria. Products include joint probability and scatter tables for wind sea and swell as well as a variety of graphical sea state displays. A key product for advisory monitoring is a time-evolving history of wind sea and swell forcing parameters suitable for wave loading calculations. For the Glas Dowr demonstration, sea state data were formatted to provide input to the Bluewater FPSO hull fatigue analysis program (Bluefat). This required rotating the wave directions to be relative to the FPSO heading (180 deg = head on seas) and further sub-setting the wave data at a 6-h time interval. An example of a Bluefat sea state table produced by XWaves appears in Table 1.

Table 1. Example of sea state table

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>H_s</th>
<th>T_z</th>
<th>$\theta$</th>
<th>$\gamma$</th>
<th>n</th>
<th>H_s</th>
<th>T_z</th>
<th>$\theta$</th>
<th>$\gamma$</th>
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<td>199.0</td>
<td>1.5</td>
<td>3</td>
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<td>1.5</td>
<td>5</td>
<td>2.0</td>
<td>0.8</td>
<td>171.0</td>
<td>0.9</td>
<td>8</td>
</tr>
<tr>
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<td>5.1</td>
<td>189.0</td>
<td>2.5</td>
<td>6</td>
<td>2.0</td>
<td>0.9</td>
<td>164.0</td>
<td>1.2</td>
<td>8</td>
</tr>
<tr>
<td>2008-08-02</td>
<td>20:18:00</td>
<td>0.7</td>
<td>3.3</td>
<td>177.0</td>
<td>1.0</td>
<td>2</td>
<td>2.3</td>
<td>1.7</td>
<td>204.0</td>
<td>1.6</td>
<td>4</td>
</tr>
<tr>
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<td>5.8</td>
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<td>5</td>
<td>1.9</td>
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<td>6</td>
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<td>6.0</td>
<td>200.0</td>
<td>1.9</td>
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<td>0.9</td>
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<td>6.0</td>
<td>191.0</td>
<td>1.4</td>
<td>1</td>
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<td>5.8</td>
<td>194.0</td>
<td>1.4</td>
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<td>9.6</td>
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<td>6.8</td>
<td>4</td>
</tr>
</tbody>
</table>

Wave Radar Performance

A key objective of this study is to explore the utility of using the wave radar in advisory monitoring. Bulk and spectral wave properties, along with comprehensive wavefield climatology descriptions, are used to compare the wave radar performance with the buoy. The energetic southern-hemisphere winter months May-August 2008 were chosen for this analysis. All wavefield analyses and displays were made using the XWaves toolbox. A final evaluation of fatigue consumption using data from both instruments provides an end-to-end check on the Monitas system performance.

Wave Data Comparisons

Bulk wave spectrum properties such as $H_s$, $T_z$ and peak wave direction ($\theta_p$) provide a useful overall indicator of wavefield conditions. A comparison of the radar and the buoy derived bulk wavefield properties during August 2008 appears in Figure 6. The radar wave heights are fairly well correlated with those from the buoy (top panel), with the exception of underestimating the wave heights for the 2 peak events and occasional overestimations during the first 18 days of the month. The radar wave periods (middle panel) follow the trend of buoy statistics reasonably well, however between 5 and 18 August the radar periods are often biased 2-3 s low. The radar peak directions agree very well with those from the buoy (bottom panel). Occasional spikes in the wave direction statistics are generally caused by multiple wave systems, of similar energy level but from different directions, in the wavefield.

Further detail on the radar system performance is provided by the individual wave spectrum records. Three contrasting cases were selected and are identified by the vertical dashed lines marked A, B, and C on Figure 6.

Case A - (0810 UTC on 9 August 2008)

Case A represents an energetic swell event with significant wave heights greater than 6 m and relatively moderate winds of 13 m/s. A comparison of the radar and the buoy spectra from this event appears in Figure 7. The left panel of Figure 7 shows an over plot of buoy and radar energy-frequency spectra. The middle and the right panels show the radar and the buoy directional wave spectrum contour plots, respectively. Energy values in the contour plots are logarithmically scaled to the
peak. A dashed white horizontal line through the contour plots indicates the wind direction. The wind speed is given to the right of these lines. Figures 8 and 9 have the same format.

The radar energy-frequency spectrum looks like a smoothed representation of the buoy spectrum. Both of the energy frequency spectra have the same general shape; however there is clearly low frequency energy in the buoy spectrum that is not captured by the radar. The radar directional spectrum also looks like a smoothed version of the buoy spectrum. Furthermore the radar directional spectrum has an ambiguous high-frequency peak at about 90 deg that is not present in the buoy spectrum.

Case B (1109 UTC on 20 August 2008)
This case represents a time when the radar wave heights, periods and directions exactly matched those from the buoy (Figure 6). The spectra from this case, appearing in Figure 8, show that this is a complex wave field with wind seas from the East and swell from the South-West. The energy-frequency spectra from both instruments are bi-modal in shape. The lowest frequency radar peak is slightly up shifted in frequency. The complex directional spectra are nicely matched between the two instruments, with the exception of another small ambiguous high frequency peak at about 270 deg in the radar record.

Case C (0711 UTC on 31 August 2008)
Case C represents an actively growing wind sea with winds of 19 m/s and significant wave heights of approximately 8 m. The radar spectra from this case, appearing in Figure 9, are similar to Case A in that they appear to be a smoothed representation of the buoy spectra. The shape of the radar energy-frequency spectrum is broader than the buoy spectrum, resulting in insufficient energy at the spectral peak. Although this is partially balanced by an excess of the radar energy at lower frequencies, as Figure 6 reveals the wave height in Case 1 is underestimated by the radar. As with the other 2 cases, an ambiguous high frequency peak occurs in the radar spectrum at about 90 degrees opposing the wind seas.

Wavefield Climatology
In the previous section a detailed comparison of the radar and the buoy spectra and statistics was presented. For fatigue analyses, however, the overall wavefield climatology is a much better indicator of system response and hence the Monitas system performance. To assess the radar performance in representing the winter wavefield climatology at the Glas Dowr site, the wavefield observations from 15 May through 31 August 2008 were combined into a single observation set. The wave system climatologies represented by this extended data set are presented here.
Figure 7. Comparison of buoy (Waverider) and radar (WaMoS II) wave spectra – Case A

Figure 8. Comparison of buoy (Waverider) and radar (WaMoS II) wave spectra – Case B

Figure 9. Comparison of buoy (Waverider) and radar (WaMoS II) wave spectra – Case C
Useful climatology indicators are the distribution of wind sea and swell wave heights with directions. These distributions are presented in the wave height roses of Figure 10 for the wave data May-August 2008. There is a striking similarity in the radar and the buoy distributions. Results from both instruments show that dominant winter wind seas are predominantly from the West-Southwest, with occasional smaller events from the East. Dominant winter swells arrive from the South, with occasional swells from all South directions. The arrival of wind sea or swell from North directions is extremely limited due to the sheltering presence of Africa. The similarity of the radar and buoy roses suggests that the radar is doing a reasonable job at capturing the wave height and direction climatology for the site.

Wave period is also an important component of wave loading and fatigue computations. Wind sea and swell height and period scatter plots for the radar and the buoy winter for the same data sets appear in Figure 11. A striking observation here is that the radar periods do not extend above 15 s, while a small percentage of the buoy periods extend up to 20 s and beyond. Furthermore, the radar extreme wind sea and swell wave heights are somewhat lower than those in the buoy data set. This height bias is a result of the Case A and C extreme wave events described in the previous section.

Figure 10. Comparison of radar (WaMoS) and buoy (Datawell) wind sea and swell wave height and direction roses

Figure 11. Comparison of radar (WaMoS) and buoy (Datawell) wind sea and swell wave height and period scatter plots
Effect on Fatigue Lifetime Consumption

Within the Monitas project two different wave monitoring devices were used, the buoy and the radar. The measurements recorded within the project of both instruments were discussed in the previous section. This section discusses the effect of the application of both instruments on the fatigue lifetime consumption of the FPSO. In addition the effect of various formats of wave data is analyzed within this section. The analyses make use of the fatigue design tool Bluefat owned by Bluewater. Bluefat is a fatigue damage calculation program for FPSOs and is based on the spectral method without allowance for the directional wave spreading (i.e. the directional spreading parameter n equals infinity). This means that Bluefat results show the same results for different wave spreading. The software is suitable for fatigue calculations in the side shell, deck and bottom plating. For more detailed information on the program, reference is made to Aalberts et al., (2010).

Wave Buoy versus Wave Radar

This section discusses how the use of different wave measuring instruments, i.e. the Directional Wave Rider Buoy and the WaMoS II system, affects the calculated fatigue lifetime consumption of the FPSO. In the previous section a comparison between the radar and the buoy overall wavefield climatology was presented based on the measurements recorded from May 15 through 31 August 2008. The same data set was used for the fatigue lifetime analyses. Although the amount of data is insufficient for a fully comprehensive test of the method for all wave climates, it does provide a robust test of the fatigue lifetime analysis in one of the most extreme wave climates on the planet.

The fatigue lifetime consumption was calculated at 12 locations which are described in Aalberts et al., (2010). The locations were selected such that the stresses at these locations are dominated by different load components, e.g.: hull girder bending at deck (DL22), wave induced pressures at side shell just below the waterline (SL34) and both hull girder bending and wave induced pressures at side shell close to bottom (SL29). Figure 12 shows the calculated fatigue lifetime consumption based on measurements of the buoy and the radar. The results agree quite well. For the locations on deck (DL22) and the locations far below the mean water line (SL 29) the estimated fatigue lifetime consumption by the radar system is slightly larger, whereas for the locations around the mean water line (SL34) the estimated fatigue consumption by the buoy is slightly larger (or equal).

![Figure 12. Comparison of fatigue lifetime consumption based on wave data from buoy and radar (WaMoS)](image)

Wave Data Format

In general, for a fatigue lifetime analysis, scatter diagrams which show how often certain sea states will appear are used. A sea state is mainly defined by the significant wave height, the mean zero wave crossing period and certain shape of the spectral wave density function like Pierson-Moskowitz or JONSWAP. As have been shown in the previous sections, in most areas the seas are confused, i.e. the wave system at the site is a superposition of different swells and wind seas coming from different directions. Fatigue calculations using spectral methods for confused seas are not straightforward. Some additional assumptions have to be made. In general Classification Societies recommend calculating stresses from different sea components separately by using the same Response Amplitude Operators (RAOs) and combining them by the combined spectrum method (e.g. DNV and BV, 2004). A similar approach is used in the fatigue design tool Bluefat. A study was performed to analyze the effect of the format of wave data on the fatigue lifetime consumption.

The program XWaves has been developed in such a way that it can output the wave data in different formats commonly used in the design of offshore structures. In order to investigate the effect of wave data format on the fatigue lifetime consumption, different formats of wave data were prepared and used as input to Bluefat. For this investigation the 15 May 2008 up to August 30, 2008 data set was used. The following wave data formats, with sea states of 6 h duration, have been used:
A Time series of sea states with two wave components. These wave data format was used in the design calculations of the Glas Dowr FPSO, see Aalberts et al. (2010), and comprises of time series of 6-h sea states with both a wind sea and/or swell. Both wave components are described by significant wave height ($H_s$), zero-crossing period ($T_z$), peak enhancement factor ($\gamma$), and the relative wave direction ($\theta$) as shown in Table 1.

B Time series of sea states with either wind sea or swell. The total fatigue consumption was determined by the sum of the fatigue induced by wind seas and the fatigue induced by swell. Both wave components are described as in Case A.

C Directional scatter diagrams. In this directional scatter diagram the wind sea and swell is combined into one sea state with $\gamma=1.5$.

D Directional scatter diagrams for wind and swell. In these analyses two sets of scatter diagrams were calculated by XWaves, one set of wind sea directional scatter diagrams with $\gamma=1.5$ and one set of swell directional scatter diagram with $\gamma=4.0$.

E Single scatter diagram, like C but contributions from all directions are added together, as the vessel is weather vaning only head seas were assumed.

For all cases the directional spreading was disregarded as Bluefat does the same. Scatter diagrams used bin sizes of the mean zero upcrossing period $T_z$, the significant wave height $H_s$ and relative wave direction of 0.5 s, 1.0 m and 30 deg, respectively.

To determine the effect of various wave data on the fatigue lifetime consumption, program Bluefat was used. This program requires as input data time series of sea states with a wind sea and/or swell which are both described by the significant wave height, mean zero upcrossing period, relative wave direction and the peak enhancement factor. Wave data format A and B corresponds to the format for Bluefat wave data. In order to make wave data format C, D and E appropriate for Bluefat, the scatter diagrams were transformed into time series. As to wave format D, the fatigue consumption due to the wind seas and swell were added up.

Figure 13 shows the effect of buoy wave data with format A through E on the fatigue life time consumption estimated using the Bluefat software. The results show that:

- corresponding portside and starboard locations have almost the same fatigue lifetime consumptions
- different data formats result in fatigue lifetime consumptions that differ by 20% for the locations dominated by the overall bending (deck and bottom) and by 50% for the locations dominated by the direct wave action (side shell)
- wave data formats A, C and E provide conservative results for deck
- wave data format E provides unconservative results for the side shell

Similar results were found for the radar measurements, although the differences of the fatigue lifetime consumption based on the different wave data formats are slightly higher. It has to be noted that, in general, different data formats are associated with different formulations for the wave spreading. This effect does not appear in the presented results because the Bluefat software disregards directional spreading.
Conclusions
A unique wave analysis approach developed for the Monitas advisory monitoring system, packaged in the XWaves ocean wavefield analysis toolbox, provides automatic ingestion and processing of spectral wave data including systematic wavefield decompositions into distinct wind sea and swell wave components. Fitting these results with standard spectral forms results in time-evolving sea state information suitable for fatigue lifetime consumption estimates and advisory monitoring.

The radar wavefield analysis system was used to characterize wavefield properties as input to the calculation of fatigue consumption in advisory monitoring. Comparisons of the radar (WaMoS II) and the buoy (Waverider) wavefield properties show that the radar captures the wave climate reasonably well but with a few key differences from the buoy results. In general, the radar spectra appear to be a smoothed representation of the buoy results. This is possibly a result of the spatial averaging that is associated with the computation of the radar spectra from the radar image domain. This may also explain why the radar wave heights tend to be lower than those from the buoy during extreme events. The radar does extremely well in bimodal seas with a reasonable characterization of multiple peaks in the wavefield. A small subset of the buoy wave components exhibit peak wave periods lower than occurs in the radar records. This apparent 15 s period threshold on the radar peaks deserves additional investigation. An additional feature of the radar data is the presence high-frequency peaks at about 180 degrees from the wind sea peaks. These ambiguous peaks are likely a result of spatial aliasing of the smaller wave components by the MLM processor (Waals et al., 2002). Since these peaks have very low energy they are ignored by the wave analysis and recombined with the nearest neighbor components. Hence they have little or no impact on the final sea state results.

Based on results obtained in the extreme wave climate of the southern hemisphere winter, the differences between the application of the buoy or the radar to obtain a wave data input set for the fatigue analyses on the fatigue lifetime consumption are small providing that the radar has been calibrated once with the buoy data. This means that a navigational radar can be used as the instrument for wave measurements if the wave data are used for fatigue lifetime calculations. Also it was found that, in the investigated case, the effect of various wave data formats (scatter diagrams, time series etc.) as input data for the analyses is relatively small on the fatigue lifetime consumption providing the information on wave directionality is preserved.

Acknowledgements
The authors would like to acknowledge the support provided by the Monitas consortium members that have made the Monitas project possible: (in alphabetic order) Amarcon, American Bureau of Shipping, Bluewater Energy Services, Bureau Veritas, Chevron, Det Norske Veritas, IHI-marine United, Kawasaki Shipbuilding Corporation, Korean Register, Lloyd’s Register, MARIN, Petrobras, Samsung Heavy Industries, SBM - Offshore, Shell and Total. The views expressed in the paper are those of the authors and do not necessarily represent the unanimous views of all the consortium members.

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