# WaMoS II X-band radar wave profiles - examples from applications



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# WaMoS II X-band radar wave profiles - examples from applications

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**Abstract**
Nautical X-Band radars used for navigation can additionally be utilised as a tool to determine spectral and individual wave properties. The Wave Monitoring System WaMoS II, when connected to a conventional nautical X-Band radar detects full directional wave spectra and derived statistical sea state parameters as well as surface currents. WaMoS II is continuously improved: New features are developed for high-resolution current measurements, estimation of the water depth as well as for single wave detection. Particularly the development and derivation of sea surface elevation maps allows to investigate and describe the spatial and temporal development of 3-D ocean surface waves. The high resolution data can be fed into real time ship motion prediction models which then can forecast quiescent motion periods which are most relevant for various offshore operations.

## 1 Introduction

Many offshore operations are critically dependent on the prevailing sea state. Regarding safety of loading and crew, the development of systems to detect dangerous sea states automatically, and to provide a decision guidance for the navigation is discussed more and more within the shipping community. Wave measurements by X-Band radar are a reliable data source for such decision support systems.

Just recently, great interest has been expressed to combine X-Band radar wave data with ship motion forecasting models. Depending on the application, the interest is either to identify quiescent periods or particular high wave events.

In this paper, the development of WaMoS II to retrieve 3-dimensional sea surface elevation maps from X-band radar images is presented and discussed. The first example is from an offshore platform where a comparison could be made with wave buoy measurements and a numerical model under storm conditions. Recently the new capabilities were further refined and tested as part of the development of a system for real time on board prediction of quiescent motion periods. Results from these offshore trials will also be presented.

## 2 The WaMoS System

WaMoS II is a high-speed video digitizing and storage device and a software package running on a standard PC. The software controls the radar, the data storage, carries out the wave analysis and displays the results. The hardware can be interfaced to any conventional navigational X-band radar with the data being displayed locally but also transferable via Modem or Internet (Figure 1).

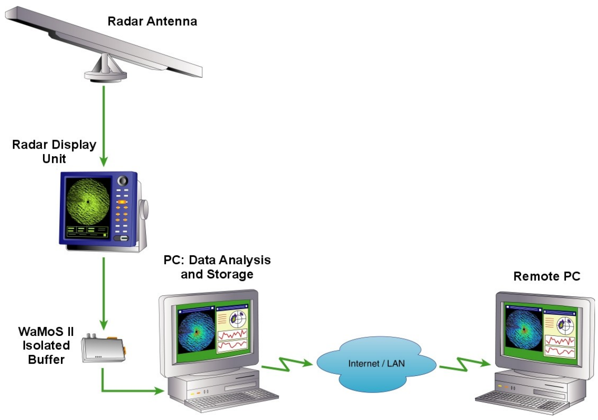


Figure 1: Sketch of standard WaMoS set up.

A typical WaMoS II wave measurement consists of the acquisition of 32 radar images and the subsequent wave analysis. The sea clutter image sequence (Figure 2) is transformed into an image spectrum by applying a three dimensional *Fast Fourier Transform* (FFT).

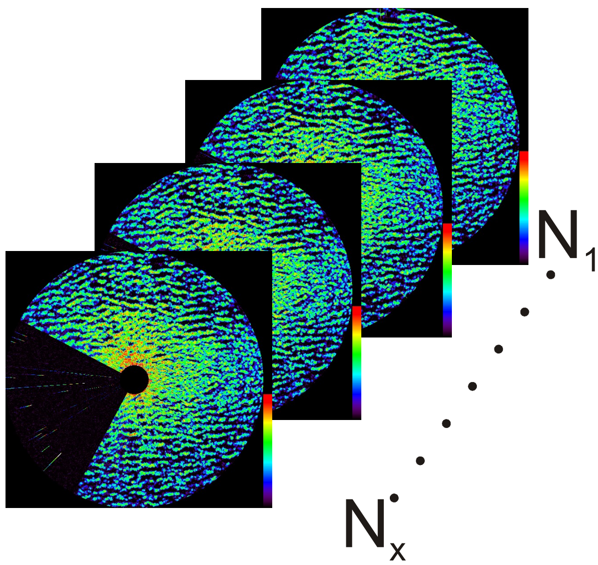


Figure 2: Radar image sequence with wave patterns

From there the surface current is estimated by means of a least-squares-fit using the dispersion relation as a reference. Then the dispersion relation including the current component (Doppler term) is used to separate all wave related spectral information from noise.

By applying a modulation transfer function the directional wave spectrum and all related statistical parameters, such as significant wave height ($H_s$), peak wave period ($T_p$), peak wave direction ($\theta_p$) and peak wave length ($\lambda_p$) are determined (Ziemer and Günther, 1994).

## 3 Sea surface elevation maps

To retrieve sea surface elevation maps, sequences of nautical radar images are inverted by applying a method proposed by Nieto et al. (2004). This approach considers shadowing to be the main imaging mechanism of ocean gravity waves in nautical radar images and is based on linear wave theory. It is assumed that the sea surface elevation consists of a linear superposition of several individual sinusoidal waves. By means of a FFT, a band pass filter based on the gravity wave dispersion relation, and the application of a transfer function, amplitude ($A_i$) and phase ($\phi_i$) of a number of individual sinusoidal waves ($N$) are determined. The surface elevation $\eta(\boldsymbol{x},t)$ at a given point and time is than given by

$$\eta(\mathbf{x},t) = \sum_{k,\omega} A_i \cos(\mathbf{k}_i \mathbf{x} - \omega_i t + \phi_i) \qquad (1)$$

where $\mathbf{x}$ is the position vector, $t$ the time, $\mathbf{k}$ the wave vector, $\omega$ the angular wave frequency.

### 3.1 Data from FINO offshore platform

The FINO platform was installed in 2003 and is located in the Southern North Sea. The platform is run and maintained by the German Hydrographic Institute. All on board atmospheric and oceanographic measurements are carried out to provide input for the design of offshore wind turbines and to improve numerical models on the basis for the safe and economical operation of wind turbines in the open sea (Fischer, 2007). Within this framework a WaMoS II was also installed to collect spectral wave data.

Since the installation, several storms went through the area, with two of them most probably having created very large waves. The platform got hit twice at a balcony, 16 m above sea level. Due to the damage caused on the lower working deck (Figure 3 and 4) some studies were carried out to discuss the occurrence, the forecast ability of such events and to check the reliability of the on board measurements.

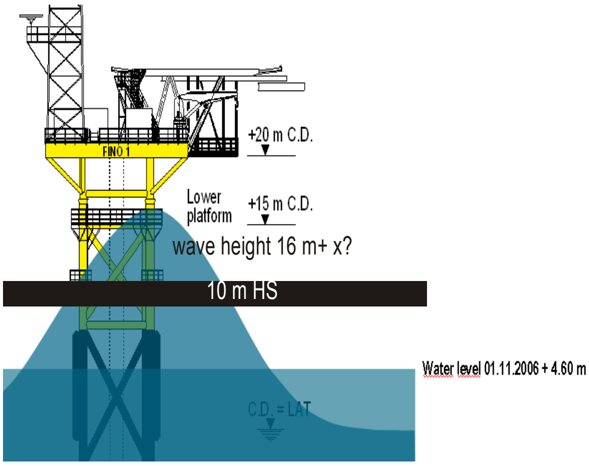

Figure 3: Sketch of FINO Platform with lower working deck, approximately 15 m above sea level. The black line is at about 10 m, corresponding to the significant wave height and the blue wave illustrates the reach of the water up to the lower deck, where damage occurred (Fischer, 2007).


Figure 4: Damage on lower working deck (Fischer, 2007)

One extreme wave event occurred in the night of Oct. 31/ Nov. 1, 2006. The low pressure system BRITTA with strong and long lasting north westerly winds created very high sea states in the entire German Bight.

Figure 5 shows the time series of the significant wave height from WaMoS II, a wave rider buoy and the operational wave model WAM for the time period 25 October–8 November 2006. The agreement between the measured and modeled data for this event, is impressive and shows the high capability of the operational wave forecast but also the reliability of the on board sensors (Behrens & Günther 2008).

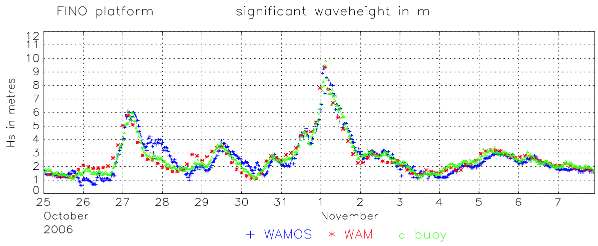


Figure 5: Comparison of significant wave height at FINO platform, recorded by a Wave Rider buoy, WaMoSII and computed by the operational wave model WAM for the time period 25 October–8 November 2006 – forecasting period is 39 to 48 hrs (Behrens & Günther 2008).

The maximum significant wave height *Hs* of 10.54 m was recorded at on Nov. 1st, at 3:30 UTC. Most probably at that time, single waves had hit the platform lower working deck at 15 m above the actual water level (see also figure 3 &4)

The discussion about the occurrence of waves that have reached a crest height of more than 15 m showed the necessity to carry out further research and better understand the properties of the sea surface (Hessner & Reichert, 2007).

A time series of radar images around the 1st of November was inverted by the above described inversion scheme. Then the wave heights at the location where the maximum occurred during this 36 hours period, were stored (white cross in Figure 6).

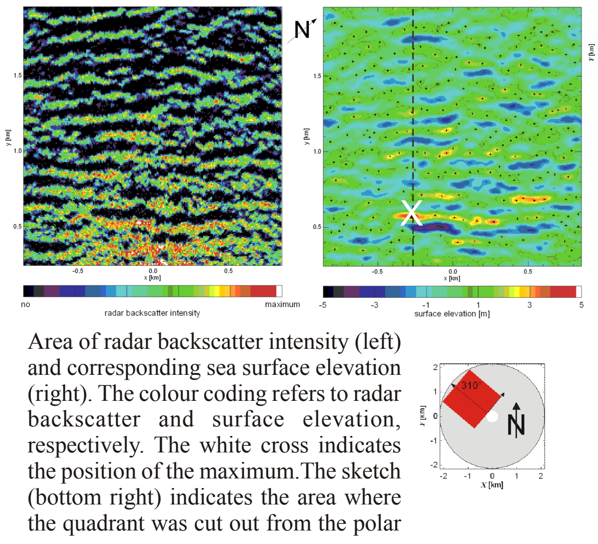


Figure 6: Sub area of radar image and corresponding inverted sea surface elevation map. Red areas are wave crests – blue areas are troughs.

Figure 7 shows the time series of wave heights, from trough to crest. At this location about 300 m off the platform, the wave heights reached 20.57 m at 2:15 AM. Unfortunately the measurement area does not reach all the way to the platform and by looking at this data set it can only be assumed that some of these waves might have increased until they reached the platform.

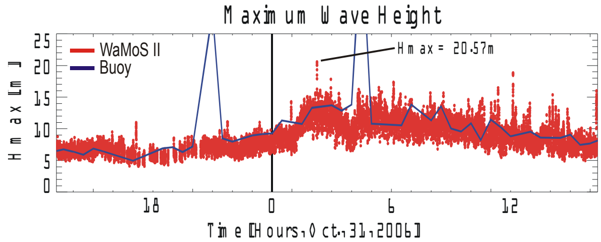


Figure 7: Time series of maximum wave height recorded during storm BRITTA, Oct. 31/Nov. 1, 2006 by a Wave Rider buoy (blue) and WaMoS II (red) at FINO 1.

However relevant for the damages on FINO are the crest heights of the individual waves. Therefore the maximum crest heights were also determined from the sea surface maps.

Within the shown time, a maximum crest height of 11.72 m was measured which proves that during the storm very large individual waves have occurred that may well have increased before reaching the platform(Figure 8).

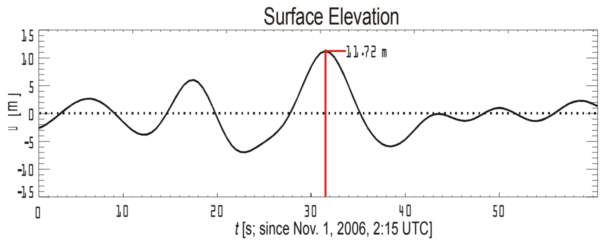


Figure 8: Time series of the sea surface elevation as obtained by WaMoS II inversion at the point where the maximum wave crest occurred. The red line marks the location of the maximum wave.

The above example gives an idea about the benefits to use radar for high resolution wave measurements. The retrieved sea surface elevation maps proved to be very useful to understand the occurrence of very high waves.

The next paragraph will give insight into another field of application which is focusing on quiescent periods rather than on large waves.

## 4 Predicting vessel motions

The ability to predict vessel motions in real time is of critical importance in the shipping and offshore industry. Certain types of operations, such as float-over-installation, ROV handling and helicopter landing depend heavily on wave impact or wave induced motions. In many cases only a short quiescent period in vessel motions is needed.

Sofar go/no-go decisions could only be made on the basis of eye observations of the incoming waves by experienced crew. Also numerical extrapolation from the vessel motions history can only predict the motions up to some 10 seconds ahead. To extend the prediction times of such quiescent periods, the Joint Industry Project 'Onboard Wave and Motion Estimator' (OWME) was set-up.

The project run by by a partnership consisting of MARIN, OceanWaveS and TU-Delft, focussed on offshore applications in mild seastates. The requirement of the project was the development of a system capable to determin the vessel motions some two minutes ahead (Najien at al. 2009).

### 4.1 The OWME concept

As platform motions originate from incident waves, the approach was based on measuring the 3-D wave field one nautical mile up-wave of the vessel by means of the X-band radar. The individual waves were extracted from the radar images, similar to the FINO data described in section 3.1.

At one pre-chosen spot from the quadrant that was pointing towards the waves, a one-dimensional surface elevation times series was produced, that was fed into the wave propagation model. The propagation model then computed the wave elevations at the location of the vessel up to two minutes ahead. Applying ship motion theory on these waves, the vessel motions in all six modes were then computed.

Critical in this approach is the computational time required to conduct the data processing – the longer the data processing takes, the shorter the prediction time will be. All of the data processing was completed by the CPU in just 13 seconds on a quad-core PC leaving approx. 2 minutes prediction time.

### 4.2 Real time testing and data verification

The OWME concept was verified against scale model tests both in long crested and short crested waves. Extensive short crested model tests were conducted in MARIN's Seakeeping & Manoeuvring Basin which measures 170 x 40x 6 m. In this basin a sea area of 1.2 x 1.2 nm including the vessel could be modeled at scale 1:70.

The model tests proved the feasibility of the concept and the accuracy of the wave propagation and vessel motion prediction model (Naaijen et al 2009).

After the successful laboratory tests, in September 2008 the OWME system was installed on an 80m offshore support vessel operating on Dynamic Positioning (DP) on the Gulfaks oil field in Norway. For the offshore trials the vessel was not only equipped with the WAMOS II X-band radar but also with a bow mounted downlooking radar and with an accurate motion sensor unit. Furthermore a directional wave rider buoy was deployed in the WAMOS window about one nm off the vessel (Figure 9).

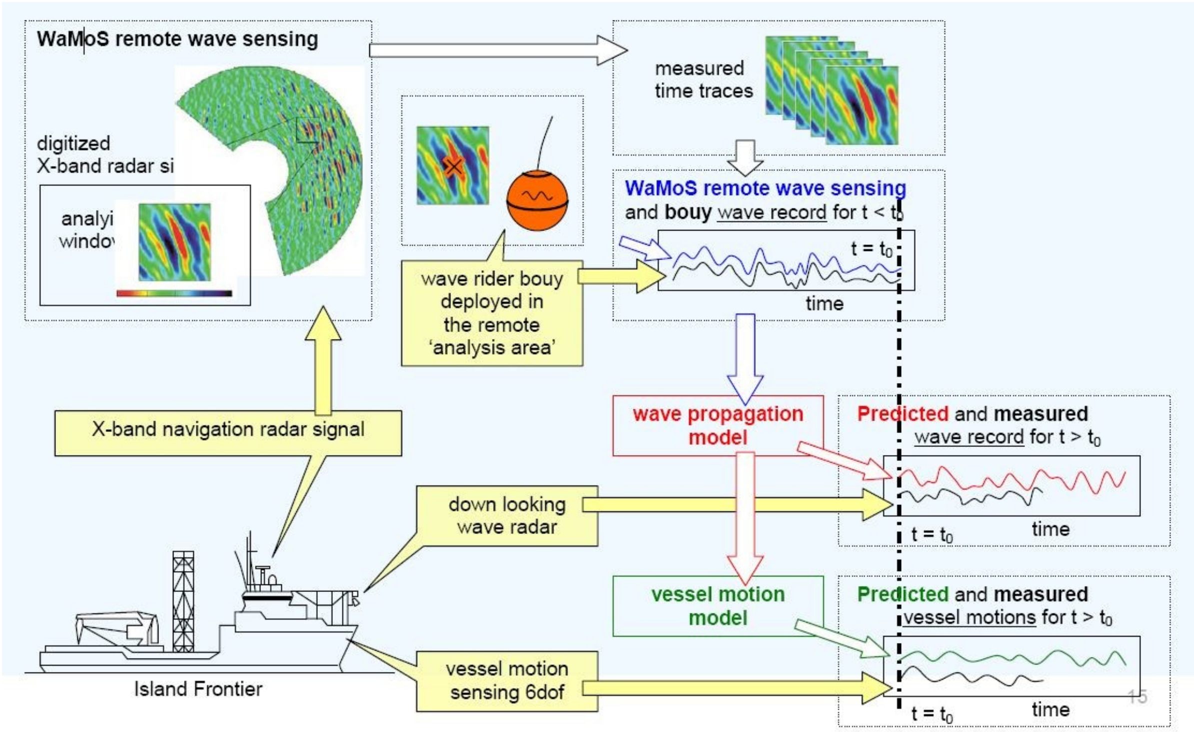


Figure 9: OWME real time prediction scheme. Sea surface elevations are retreived from X-band radar data. A 1-D wave height series is then fed into a wave forecasting model, which then is used as input to the vessel motion prediction model.

By measuring the remote wave elevations with a directional wave rider buoy, the local waves with a level gauge radar and the vessel motions by means of a motion sensor unit, a solid reference data set was obtained for validating the system. Each of the components of the OWME concept i.e. the wave sensing, the wave propagation and the vessel motion prediction could be tested separately as well as in combination.

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OWME predictions of the vessel motions were made for 42, 60, 90 and 120 seconds ahead and compared with the actual vessel motions as measured (Figure 10). The general outcome for all four forecasting periods was, that despite significant deviations in the actual amplitudes and phasing, the envelope of the motions was predicted correctly.

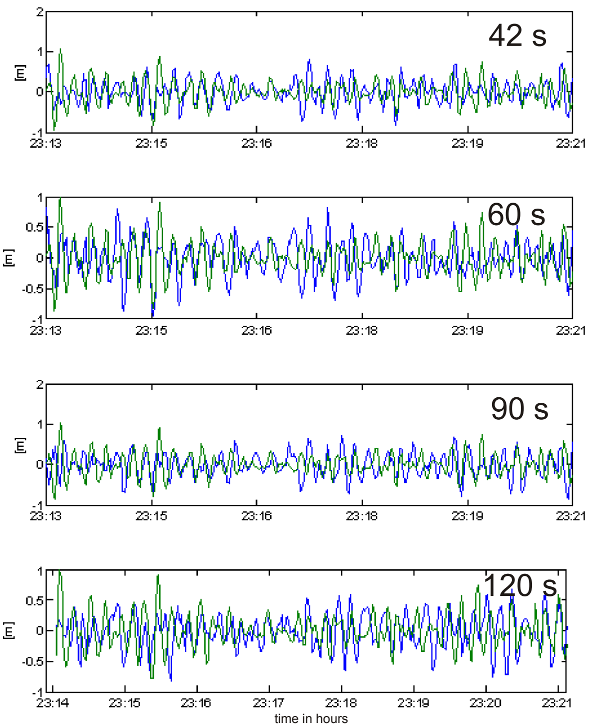


Figure 10: Vessel heave motion predicted 42 , 60, 90 and 120 seconds in advance by OWME system compared with the measured on board heave motion (Trials on Offshore Support Vessel at Gulfaks field, September 2008). The green lines represent the measured heave motions, the blue lines the predicted motions.

The above results show that the OWME system is capable of predicting quiescent periods of vessel motion up to two minutes in advance and can thus, contribute to the workability of offshore operation in otherwise limiting sea states.

It is however noted that the OWME system was developed for and is so far only tested in mild sea states.

## 4.3 Outlook

With these promising results, The OWME partners lead by MARIN plan to continue to work on the OWME concept, refine and enhance it, to make offshore operations safer and more efficient. At the same time OceanWaveS will continue the verification of the sea surface elevation data within the comings years in a large experiment off the coast of California.

The technology is in particular relevant for smaller vessels of the type that are increasingly undertaking operations such as well intervention, drilling, survey and installation, operations for which safety and workability are paramount.
The concept is also of interest for trading ships to avoid severe wave impacts and excessive motions by warning for severe incident wave elevations and excessive motions and loads.

## 5 Summary

WAMOS II developments have shown that X-band navigation radar images can be inverted into 3-D surface wave elevation maps. For storm conditions the derived wave elevations showed a good correlation with the data measured by a wave buoy. It has been demonstrated that for the first time this approach allows to estimate the maximum wave height from spatial wave data and to study extreme wave events and wave trains.

The procedure to derive surface wave maps has been further developed and integrated into the OWME system which is capable of predicting real time vessel and platform motions. Offshore trials have shown that the system is capable to predict quiescent periods in vessel motions up to two minutes ahead in mild wave conditions.

The measurement and derivation of 3-D ocean waves in space and time is unique and up to now not possible with any other shipborne monitoring system. This capability offers various application which are of great
interest to the safety and economy of shipping and offshore operations.

## 6 Acknoweledgement

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