Nautical Radar Measurements in Europe - Applications of WaMoS II

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Abstract. This paper presents the remote sensing techniques of measuring sea states, currents and bathymetry by using an X-band nautical radar. It briefly describes the fundamental methods to infer sea state information (e.g., ocean wave and current parameters) from nautical radar imagery. In addition, this work describes in detail the performance of the Wave Monitoring System WaMoS II (a commercial system for real-time monitoring of wave fields based on nautical radar technology). Two examples of WaMoS II applications are presented: the first application is an example of the standard WaMoS II installation for sea state measurements, and the second application shows results of a research project aiming at the determination of shallow water bathymetry by means of nautical radar imagery.

1 Introduction

Wave information is usually derived from time series of the sea surface elevation measured at a certain location in the open sea. These measurements are carried out by in-situ sensors such as buoys, lasers, and pressure sensors with high temporal resolution (e.g., sampling frequencies of about 2Hz). However, deployments of such sensors are limited by the local water depth, as well as the mooring facilities. For instance buoys can be easily damaged by ships or during severe meteorological conditions. Furthermore, the use of point measurements assumes that the obtained wave information is representative for a particular area, which is often not the case, particularly in coastal waters, where coastal effects like wave refraction, diffraction, shoaling etc. take place. Under these conditions, the sea state can vary significantly in the area of interest.

Complementing these point measurements described above, the imaging of the sea surface based on remote sensing techniques provides information about the spatial variability sea state in the area of interest. One of these techniques is based on the use of ordinary nautical radars to analyse ocean wave fields.

It is known that, under various conditions, signatures of the sea surface are visible in the near range (less than 3 nautical miles) of nautical X-band radar images. These signatures are known as sea clutter, which is undesirable for navigation purposes. Therefore, the sea clutter is generally suppressed by filtering algorithms. Sea clutter is caused by the backscatter of the transmitted electromagnetic waves from the short sea surface ripples in the range of half the electromagnetic wavelength (i.e. ~1.5 cm). The longer waves like swell and wind sea become visible as they modulate the backscatter signal mainly via hydrodynamic modulation of the ripples by the interaction with the longer waves, tilt modulation due to the changes of the effective incidence angle along the long wave slope, and the partial shadowing of the sea surface by higher waves (Keller and Wright, 1975, Alpers et al., 1981; Plant, 1990; Wenzel, 1990; Lee et al., 1995).

Since standard X-band nautical radar systems allow the sea surface to be scanned with high temporal and spatial resolution, they are able to monitor the sea surface in both time and space. Hence, the combination of the temporal and spatial wave information allows the determination of unambiguous directional wave spectra. As nautical radar imagery covers an area of the sea surface it also allows the observation of spatial variations in the wave field. Furthermore, the use of nautical radar as a remote sensor allows to measurement of wave field features from moving vessels.

In the past different systems using nautical radars for measuring sea states have been developed. This paper focuses on one of these devices, the German system WaMoS II (**Wa**ve **Mo**nitoring **S**ystem), which is described in the following section.

2 The WaMoS II System

WaMoS II is a high-speed video digitising and storage device that can be interfaced to any conventional navigational X-band radar and a software package running on a standard PC. The software controls the radar and data storage. In addition, the WaMoS II software carries out the wave analysis and displays the results (see Fig. 1).

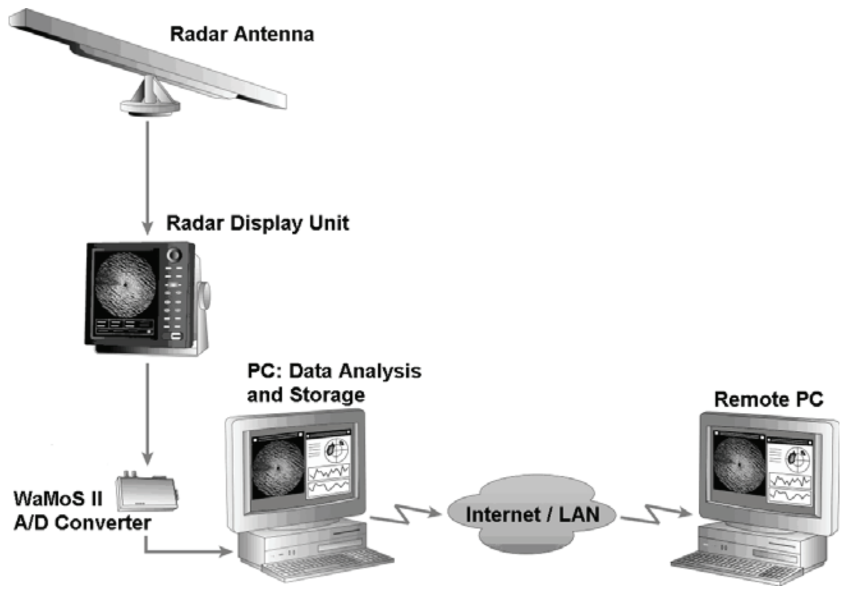

Fig. 1. Schematic of the different parts of WaMoS II and the data flow from the radar antenna to the user display.

The system was developed at the German GKSS Research Centre and the equipment was first tested in 1991. In 1994 the technology was transferred to OceanWaves GmbH in order to market and commercialise the system. Since then WaMoS II has been improved and expanded to cover ship and shallow water applications. Since 2001 the system has been type approved by the Germanischer Lloyd and Det Norske Veritas. During several applications WaMoS II proved to be a powerful tool to monitor ocean waves from fixed platforms as well as from moving vessels, especially under extreme weather conditions (Young et al., 1985; Ziemer and Rosenthal, 1987; Ziemer and Günther, 1994; Nieto-Borge et al., 1999, Hessner et al., 2001).

A typical WaMoS II wave measurement consists of the acquisition of a radar image sequence and the subsequent wave analysis. The sea clutter image sequence is transformed into the spectral domain by means of a three dimensional *Fast Fourier Transform* (FFT). First the surface current is estimated from the image spectrum by means of a least-squares-method using the dispersion relation for linear water waves as reference. Then the dispersion relation including the current component (Doppler) is used to filter the image spectrum. Finally, by applying a modulation transfer function the wave spectrum is determined. From this wave spectrum all kinds of commonly used types of wave spectra may be derived (wave number spectrum, frequency direction spectra, frequency spectra, etc) and various standard spectral wave parameters can be inferred.

The standard WaMoS II software delivers unambiguous directional wave spectra and time series of the integrated standard wave parameters significant wave height (H_s), peak wave period (T_p), peak wave direction (θ_p) and peak wave length (λ_p) in real time. These data can be made available to the user on the WaMoS II PC and can also be transferred to other stations via Internet, LAN, NMEA etc.

Recent further developments allow WaMoS II to obtain sea surface elevation maps (Nieto-Borge et al., 2004), individual wave parameters (Reichert et al., 2005), wave groups (Dankert et al., 2003), the near surface current fields (Dankert et al., 2004), bathymetry (Bell 2005, Bell et al., 2005, Hessner et al., 1999), and high-resolution ocean wind fields [Dankert et al. ,2005].

3 Limits, Resolution, and Accuracies

The standard WaMoS II analysis uses a continuous sequence of 32 radar images. Each radar image represents one antenna revolution. The sampling time depends on the radar antenna rotation rate. Using standard radars with rotation rates ranging from 1.5-3 s, WaMoS II can detect waves in the range of 0.025 Hz to 0.35 Hz. The actual range, resolution and accuracy can vary for each WaMoS II installation, depending on the particular radar and set-up geometry. Table 1 shows typical values of standard output parameters, corresponding resolution, and accuracies.

4 Applications

This section describes some of the applications of the WaMoS II technology for wave and current monitoring. For that purpose, two different locations are described: The WaMoS II station at the FINO[1] 1 platform in the North Sea and an installation at Teignmouth located at the British coast. These two locations have been selected because of the two different geographic and oceanographic conditions, as well as the specific application (e.g. FINO 1 station delivers wave field and meteorological information in

[1] FINO: Forschungsplattformen in Nordsee und Ostsee (Research Platforms in the North Sea and Baltic Sea)

real time and Teignmouth was a coastal station, which delivered bathymetry information from the analysis of the wave shoaling imaged by the radar).

Table 1. WaMoS II parameters.

Wave Spectra	Resolution	Range	
2-d frequency-direction	0.005 Hz	0.02 Hz – 0.35 Hz*)	
spectrum S(f,θ)	4°	0 - 360°	
1-d spectrum S(f)	0.005 Hz	0.02 Hz - 0.35Hz*)	
Wave parameters	**Accuracy*)**)**	**Range**	**Resolution**
Significant Wave Height H_s	+/- 10% or +/-0.5 m	0.5 – 20m***)	0.1 m
Peak direction θ_p	+/- 5°	0 – 360°	1°
Peak period T_p	+/- 0.5 s	3.5 - 40s*)	0.1 s
Peak wave length λ_p	+/- 10%	15 – 600m*)	1 m
Current parameters			
Current speed U	+/- 0.2 m/s	0 - 40 m/s	0.01 m/s
Current direction U_θ	+/- 2°	0 – 360°	1°

*) Typical ranges. The numbers depend on the radar hardware, the total time of measurement and therefore can vary for each individual installation.
**) Based on comparative wave measurements assuming an equally distributed error.
***) There is no limit in estimating the wave heights, but up to now, H_s of 20 m was the highest value measured with WaMoS II.

4.1 Offshore Sea-State Measurements in the North Sea

Within the framework of the German FINO programme the first platform FINO 1 has been in operation since September 2003 (see Fig. 2). The platform is located in the North Sea, approximately 45 km off the island of Borkum. The aim of the project is to record precise measurements of the meteorological conditions in the lower atmospheric boundary layer. A WaMoS II was installed to investigate the load and stability of the structure due to surface waves and currents.

The atmospheric and hydrographic measurements provide important input data for the design of offshore wind turbines and for improving atmospheric and oceanographic models thereby forming the basis for the safe and economical operation of wind turbines on the open sea (Herklotz, 2007).

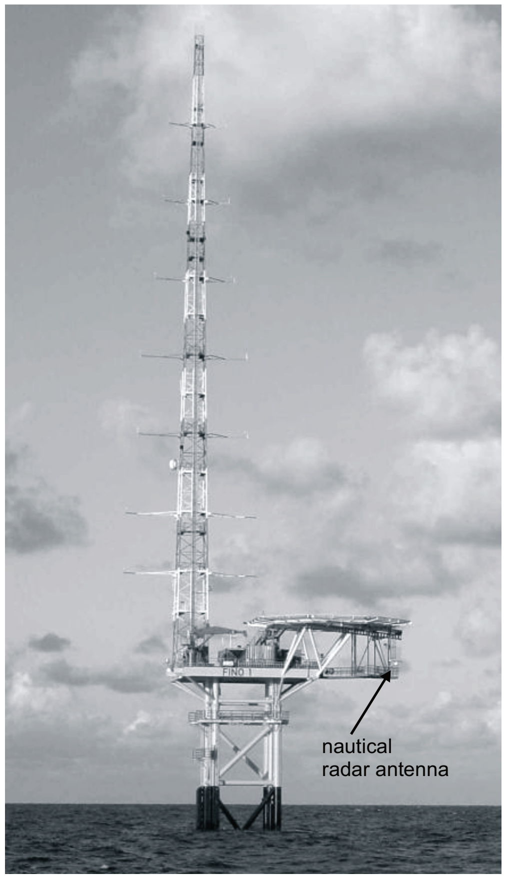

Fig. 2: The FINO 1 Platform. The nautical radar antenna used for the WaMoS II measurements is installed below the helicopter deck .

Fig. 3 and Fig. 4 show examples of radar images showing sea clutter and the corresponding wave spectra determined by WaMoS II. The first example shows a bimodal sea state with a dominant wind sea (red) and secondary swell (green).

The time series of H_s, T_p and θ_p shown in Fig. 5 were obtained using the WaMoS II (red) and the Waverider buoy (blue) deployed next to the FINO 1 platform. A good agreement between the WaMoS II and the buoy measurements can be seen. Slight deviations can be expected, as WaMoS II delivers spatial mean wave parameters while the buoy delivers wave parameters measured at a point.

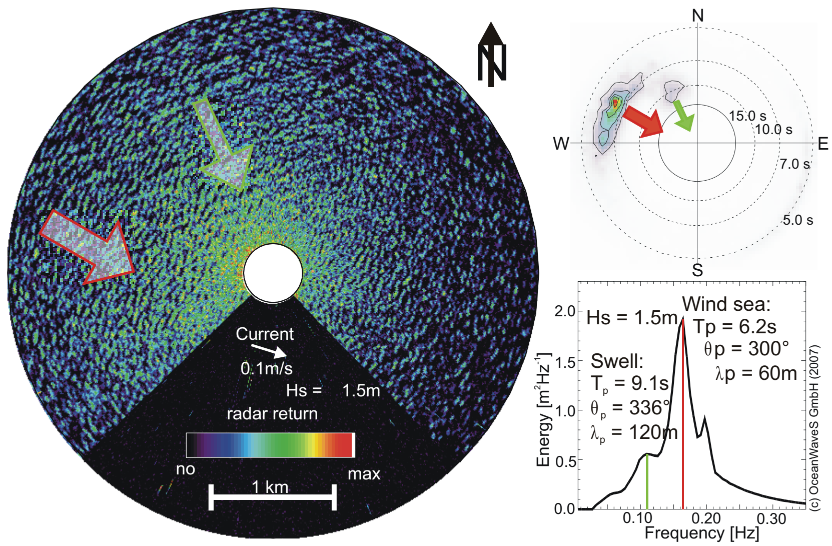

Fig. 3. Radar images measured onboard FINO 1 on Feb. 7th, 2006 0009 UTC. On the right the corresponding wave spectra and spectral wave parameter as obtained by WaMoS II are given.

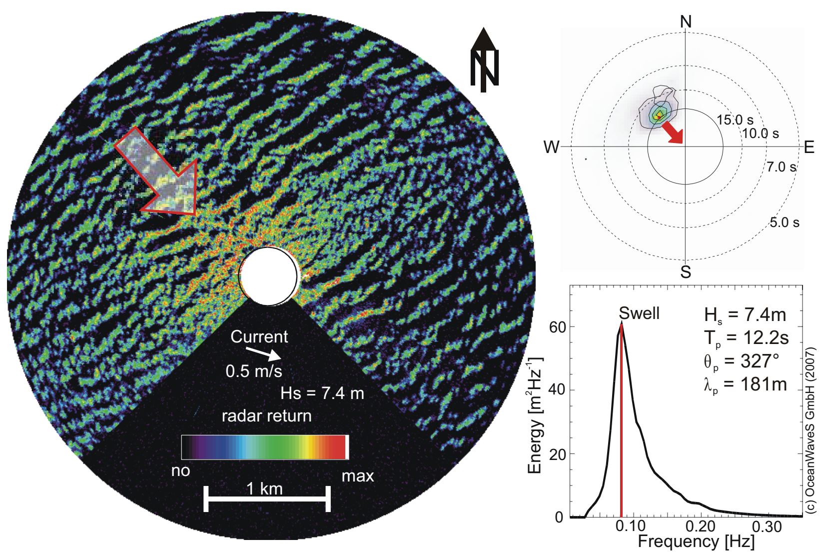

Fig. 4. Same as **Fig. 3**, but for Feb. 8, 2006, 1700 UTC.

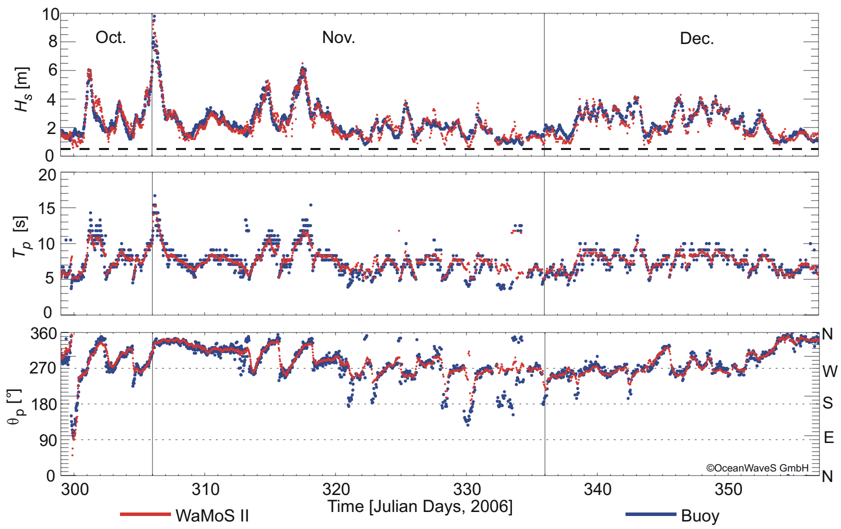

Fig. 5. Comparison of the significant wave height (H_s; top), peak wave period (T_p; middle) and peak wave direction (θ_p; bottom) time series obtained by WaMoS II (red) and a Waverider buoy (blue) at FINO 1.

4.2 High resolution bathymetry application: Teignmouth, UK

Within the EU funded COAST3D project a radar and digital recorder were installed at Teignmouth in order to obtain high resolution bathymetry from the nautical radar imagery. Within the study a validation of radar derived bathymetry by means of echo sounder surveyed bathymetry was performed.

Teignmouth is a small town on a locally south-east facing coastline in the south west of the UK, and the study area included a working port and tidal inlet to the Teign Estuary, a rocky headland and a length of straight groined beach. The tidal inlet is surrounded by a complex system of sand banks that evolve on a cyclic basis over the period of a few years.

The nautical radar was deployed on the shoreward end of Teignmouth Pier, approximately in the middle of the study area. A tide gauge was located on the same pier, and echo sounder surveys were carried out at the start and end of the experiment, but only to a distance of 1km offshore due to limits on the availability of the survey boat.

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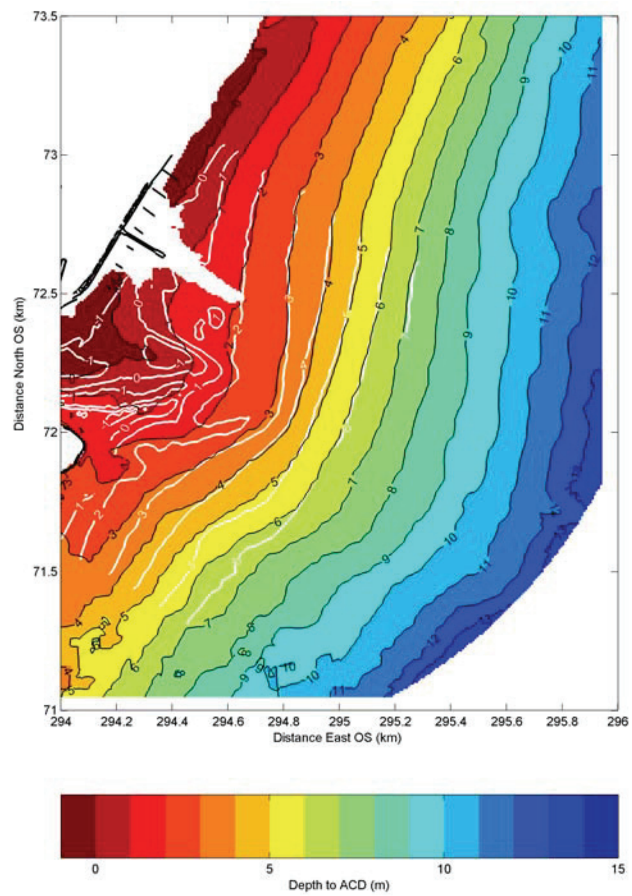

Fig. 6: The amalgamated bathymetry data for Teignmouth using one tidal cycle of hourly records. Radar derived bathymetric contours are shown in black, with the contours from the echo sounder survey shown in white for comparison. Depths are to Admiralty Chart Datum.

Sequences of 64 radar images with an antenna rotation rate of 2.4 seconds were recorded hourly during the deployment. Each image sequence was processed to map the spatial distribution of wavelengths at a range of wave frequencies, and the water depth inferred using the best fit to a wave dispersion equation that includes a correction for the amplitude dispersion of finite amplitude waves in shallow water (Hedges, 1976). A set of these water depth maps spanning one tidal cycle were corrected to be relative to chart datum using the tide gauge data and were averaged to give the amalgamated bathymetry shown in Fig.6. The radar derived bathymetry is shown in colour with depth contours marked in black at 1m intervals. The corresponding echo sounder survey contours are shown in white (Bell, 2005).

The complex system of sand bars around the mouth of the inlet is clearly visible from the survey contours. The maximum depth at the limit of the echo sounder survey is approximately 8m, although the radar derived water depths extend to almost twice the range of the survey and show maximum depths at this range of almost 14m.

The agreement between the depth contours of the radar derived bathymetry and the survey is excellent, particularly in this northern part of the area, with differences being on the order of centimeters.

It should be noted that to perform the echo sounder survey of the area represented by the white contours in Fig.6. required calm sea state conditions and approximately three days of ship time and man power. In contrast, the radar technology can produce a bathymetric map of almost double that range during wave events using only a few minutes of radar data although with slightly lower spatial resolution and accuracy.

5 Summary

The principles of sea state measurement using an X-band nautical radar have been described. In addition, the Wave Monitoring System WaMoS II has been also described giving some technical features and accuracies.

Two examples for the use of nautical radar data were presented. The first example shows results of a standard sea state monitoring application at the platform FINO 1 in the German Bight. The second example shows results of a deployment at Teignmouth in the UK with the objective of inferring shallow water bathymetry by means of nautical radar images. These two examples represent just a section of possible WaMoS II applications and show that nautical radar is a reliable tool for monitoring wave fields and related phenomena, such as the wave shoaling due to variable bottom topography.

Nowadays about 40 WaMoS II systems have been installed on different platforms at different locations world-wide. These installations include moving vessels, coastal stations and off-shore platforms and use the capabilities of the WaMoS II for real time monitoring. The data from these stations are mainly used to support safe off-shore and harbour operations and to provide weather services with sea state data.

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