EXTRACTION OF COASTAL WAVEFIELD PROPERTIES FROM X-BAND RADAR

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ABSTRACT

The dynamic wave field in a high-energy coastal environment is investigated using frequency direction wave spectra obtained by nautical X-band radar imagery. Nautical radars are generally used for navigation and ship traffic control. Under various conditions (wind speed > 3m/s, significant wave height > 0.5m[1]), signatures of the sea surface (sea clutter) become visible in the near range (less than 3 nautical miles) of nautical radar images. Swell and wind sea waves become visible in nautical radar images as they modulate the sea clutter signal. Since standard X-band nautical radar systems scan the sea surface with high temporal and spatial resolution, they are able to monitor the sea surface in both time and space. The combination of the temporal and spatial wave information allows the determination of unambiguous directional wave spectra.

Here, wave data collected from February-October 2005 at the US Army Corps of Engineers Field Research Facility (USACE-FRF) in Duck, North Carolina is presented. For the radar wave measurements the Wave and surface current Monitoring System WaMoS II was connected to a Furuno FR-7112 X-Band radar with a 6 feet open antenna and an update rate of 2.5s (24 rpm). The radar covers a range from 240m - 2160m from the antenna with a spatial resolution of 7.5m. The wave analysis was carried out over an area of 3.7 km^2 located in relative homogeneous bottom topography, off the near shore breaker bar system, in a water depth of 8m -10m.

The WaMoS II wave measurements were compared to those obtained from a pressure gauge array located in the same area. Earlier WaMoS II validations provide a general indicator of the quality of the measurement performance as they were carried out for standard integral wave properties over all existing wave systems such as mean or peak wave parameters. Here the XWaves ocean wave field analysis toolbox is used to compare data sets by means of a wave spectral partitioning analysis. This approach provides a more detailed validation especially for bi- and multi modal sea states, allows for a comparison of the heights, periods and directions of individual wind sea and swell components, and tracking the evolution of specific wave systems. Such analysis methods have been successfully applied in a variety of wave model validations.

The data comparison was carried out for different sea state and wind conditions. Preliminary results of the data comparison show that the WaMoS II system captures the temporal evolution of the individual wind sea and swell wave components entering the surf zone. A statistical error analysis of the isolated wind sea and swell wave systems provides a quantitative assessment of WaMoS II performance in a coastal setting.

INDEX TERMS: Marine radar, coastal wave monitoring, wave climatology, wavefield analysis, wave partitioning.

1. INTRODUCTION

The knowledge of the sea state as well as current and water level are key information for any kind of activities at sea and in coastal waters, ranging from navigation to coastal shore protection issues. The deployment and maintenance of *in-situ* sensors (e.g. buoys, ADCPs or pressure gauges) are time and cost consuming. Therefore a growing interest has been developed in using remote sensing technology to monitor waves, current and water depth.

Standard nautical X-band radars have demonstrated a great potential to remotely monitor waves, as their images show wave signatures of the sea surface in a range of 1-5 km from the radar antenna with high spatial (5-10m) and temporal (seconds) resolution. These radars are further very robust, easy to deploy and a space saving technology which make them an ideal sensor for short and long-term applications.

One remote sensing system based on conventional X-band radar technology is the Wave Monitoring System WaMoS II. This system was developed for real time measurements of unambiguous directional ocean wave spectra. Various WaMoS II data comparisons with in-situ wave data exist from offshore platforms, vessels, and from coastal stations ([3], [4], [5], [6], and [7]). Since 2001 the system is type approved by the Germanischer Lloyd and Det Norske Verital.

1 Typical values, which can vary for different installations

2. STUDY AREA AND INSTRUMENTS

The data used for the presented validation was acquired during a temporary WaMoS II installation at the U.S. Army Corps of Engineers (USACE) Field Research Facility (FRF), in Duck, NC, USA in September 2005 (Figure 1).

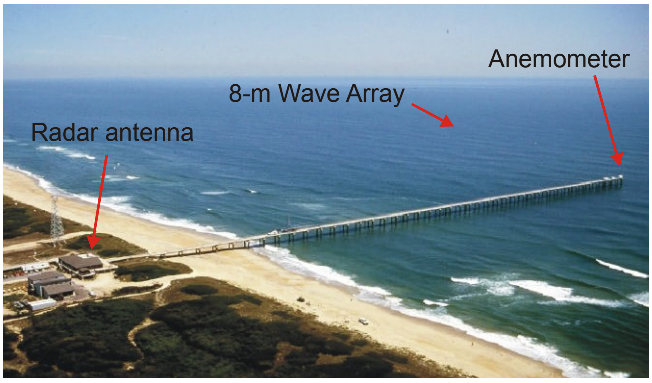

Figure 1: Photo of the Duck Field Research Facility (FRF) at Duck, USA, showing the FRF pier, support buildings and observation tower. The red arrows indicate the location of the radar antenna used for the WaMoS II, the wave array and the anemometer for the wind measurements.

This FRF facility was established in 1977 to investigate the near shore dynamics including waves, currents, and morpho-dynamics. The facility includes a 560 m long research pier (perpendicular to the coast line), a main laboratory and office building, field support buildings, and an observation tower.

For the wave analysis independent wave data and additional wind are required, which were obtained from an array of pressure sensors (8-m array) and a pier-based anemometer, respectively.

2.1. WaMoS II

The wave monitoring system WaMoS II consists of a conventional navigational X-band radar, a high speed video digitizing unit, a standard PC for data analysis and storage and a software packet to analyse and display the radar data. The wave measurements are based on the backscatter of radar energy from the ocean surface (sea clutter). Wind sea and swell waves become visible as they modulate the sea clutter. As the wave dynamics are affected by the local water depth and current WaMoS II can be used to also monitor these parameters. At Duck WaMoS II was run with Furuno 7112 radar. A 6ft antenna was mounted on top of one of the FRF buildings near the pier. This allowed for a free view to the Atlantic Ocean. WaMoS II obtained radar images within a range of 240m – 2160m from the antenna with a spatial resolution of about 7.5 m.

Figure 2 shows an example of a WaMoS II radar image. The coast line is marked yellow, the colour coding of the image corresponds to the radar backscatter strength, where black indicates no radar return and white maximum radar return. Land features as well as the FRF pier are visible as almost white signatures. The red dots indicate the locations of the reference sensors. The wave analysis was carried out for six rectangular (128 x 128 pixel) analysis areas, located about 850 m to 1810 m off the radar antenna. The white boxes indicate size and position of the WaMoS II wave analysis areas.

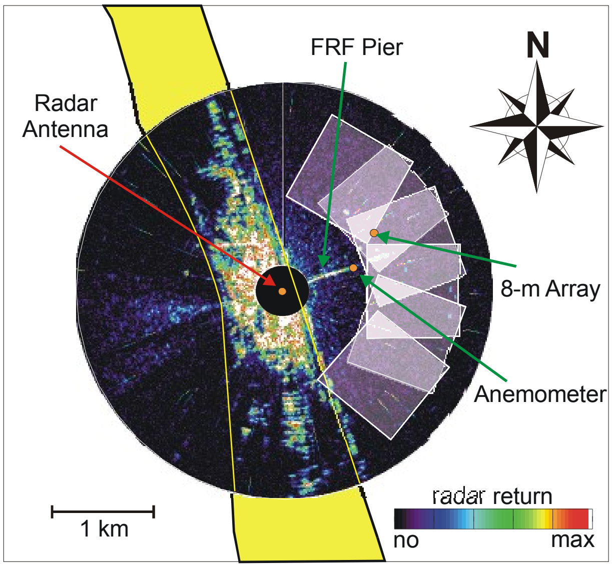

Figure 2: Sample of a WaMoS II X-band radar image. The coast line is indicated yellow, the WaMoS II analysis areas are marked white.

The imaging of ocean waves depends on the radar look direction relative to wave and wind direction. Figure 3 shows a comparison of two wave number spectra as obtained by WaMoS II on Sept. 4th, 12:00 UTC.

During the radar acquisition the wind was blowing with 7m/s from 30° (blue line). The left spectrum, which was obtained from an analysis area aligned with the wind (30°), shows a clearly visible wind sea wave system. The right spectrum obtained from an analysis area aligned across the wind (110°), shows no significant wind sea energy. In both cases the observed swell energy is almost equivalent. For the wave analysis only theses areas aligned with the wind direction (± 10°) are taken into account for the wave analysis.

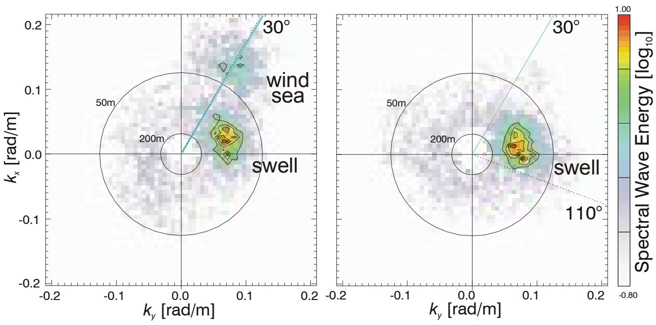

Figure 3: Sample WaMoS II wave number spectra as obtained for an analysis area in wind direction (left) and about cross wind direction (right).The dotted line indication the radar look direction, the light blue line indicate the wind direction.

The WaMoS II wave analysis delivers unambiguous directional wave spectra, surface currents and water depth information. The radar to wave spectrum transformation algorithm was initially calibrated using buoy wave height data. Statistical sea state parameters such as significant wave height (*Hs*), peak wave period (*Tp*) and direction (*θp*) are derived from the directional frequency spectra. The resulting

WaMoS II wave parameters are updated every 5 minutes and represent spatial means of 0.92 km^2 and temporal means of 2.7 minutes. For better comparisons with the reference data the WaMoS II wave data are also temporally averaged over 30 minutes. Data presented here are 20 minute average values. The wave spectra have a frequency and directional resolution of 0.0055 Hz and 4° respectively and cover a range of [0.0055 - 0.35] Hz and [0 - 360]°.

2.2. 8m - Array

The reference directional wave information was obtained by a direction wave array (later referred as 8-m array) composed of 16 bottom mounted pressure sensors arrange in a shore parallel and shore normal cross. The array is mounted approximately 0.5 m off the bottom in the vicinity of the 8-m isobath about 900 m. The frequency direction spectra have a resolution of 0.009 Hz and 2°, over a range of [0.0443 - 0.31]Hz and [330 - 150]° (180° off-shore) More detailed information on the 8-m array can be found at http://www.frf.usace.army.mil/.

2.3. Anemometer

Winds were measured by an RM Young Marine anemometer at the end of the pier at an elevation of 19.36 m (NGVD).
Resultant wind speeds and directions are determined by vector averaging the data and are reported relative to true north (Shore normal is 70 deg true). More detailed information on the wind measurements can be found at http://www.frf.usace.army.mil/.

2.4. XWaves

The sea state is generally a composite of different wave systems such as locally-generated wind seas and various swell systems propagating from distant generation events. Instead of simply comparing the peak or bulk wave parameters, as with previous WaMoS II validations, here we validate the WaMoS II performance in delineating individual wind sea and swell wave systems. This is accomplished using the XWaves ocean wave field analysis toolbox. XWaves is a proven technology for the isolation and tracking of wind sea and swell wave systems in complex wave environments, and the validation of wave measurement and modeling technology ([1], [2], [3], [4], and [9])
To prepare the WaMoS II and 8-m Array wave spectra for comparison, the following XWaves data preparation steps were performed:

2.4.1. Spectral Smoothing

Since the measurements 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 wave spectral records.

2.4.2. Spectral Interpolation

A final preparation step for the WaMoS II and the 8-m Array spectra was to interpolate each directional spectrum matrix to a consistent set of frequency and directions bins. For the FRF analysis a frequency range of 0.05 Hz to 0.31 Hz at 0.01 Hz resolution and a direction range of 330 to 150° (180° off-shore) at 10°resolution were selected.

2.4.3. Wave Partitioning

XWaves uses an inverse watershed algorithm to isolate peak domains in directional wave spectra ([2], [3]). An iterative smoothing approach ([8]) has been incorporated to successively combine neighboring peaks until the number of wave components is less than or equal to maximum threshold set by the user. Wind sea peaks are identified using a directional wave age criterion ([2]). For the FRF study, the analysis was set to produce no more than one single wind sea and two swell partitions at each time step.

3. DATA COMPARISON

The data comparison was carried out for the time period 1-30 Sep. 2005. Figure 4 shows directional frequency wave spectra as obtained by the 8m-Array and WaMoS II. At this time the wind was blowing with about 8.9m/s from 33°.
The gray areas indicate blind sectors of each system, the dashed line indication of shore normal direction, the blue line the wind direction. Both sensors observe a wind sea peak at about 40° and 0.186Hz (5.4s) and a swell system at 110° and 0.103 Hz (9.71s).

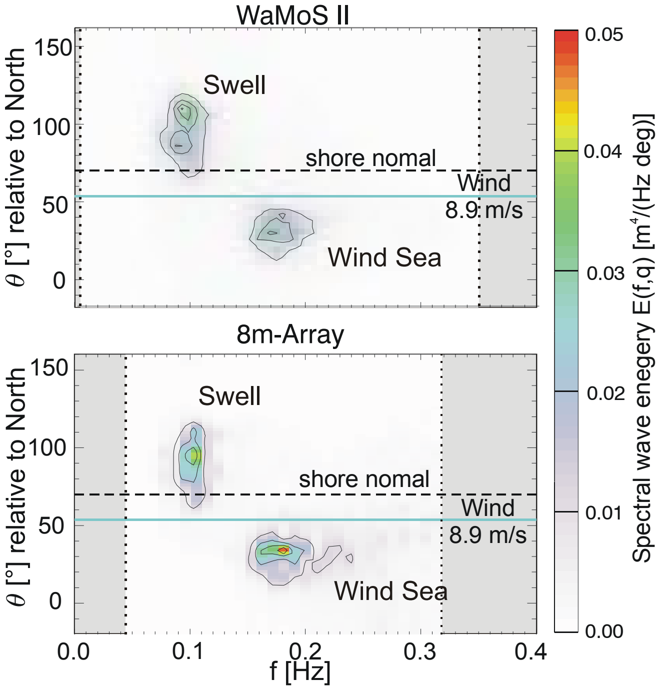

Figure 4: Sample of directional frequency wave spectra as obtained by 8m-Array (top) and WaMoS II (bottom) on Sept. 24th, 2005, 18:00 UTC.

A comparison of the Sep. 2005 significant wave heights extracted for the WaMoS II and 8-m Array systems appears in Figure 5. Here the wave systems have been divided into wind sea, young (local) swell and mature (distant) swell.
A selection of error statistics computed from these correlations is included in the figure. WaMoS II does a very good job at characterizing the wave field, especially for energetic time periods.

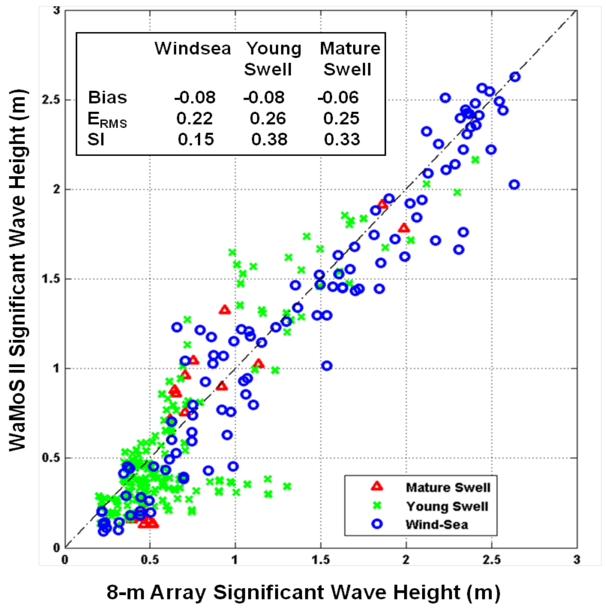

Figure 5: Comparison of WaMoS II and 8-m Array significant wave heights from individual wave systems

Wind seas exhibit exceptionally low errors at all wave heights. The scatter in young swell at very low wave height is likely a result of the 0.5-m cut off in the WaMoS II bulk wave height range.

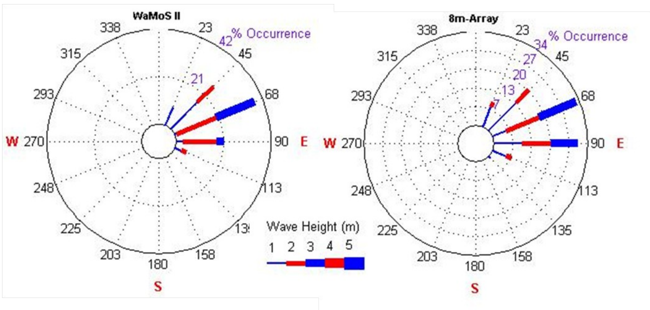

Figure 6: Wind Sea wave rose as obtained by XWaves for WaMoS II (left) and 8m-Array (right).

A useful climatology indicator is the distribution of wind sea and swell wave heights with direction. These distributions are presented in the wave height roses of Figure 6 and Figure 7 for the Sept. 2005 wave data data.

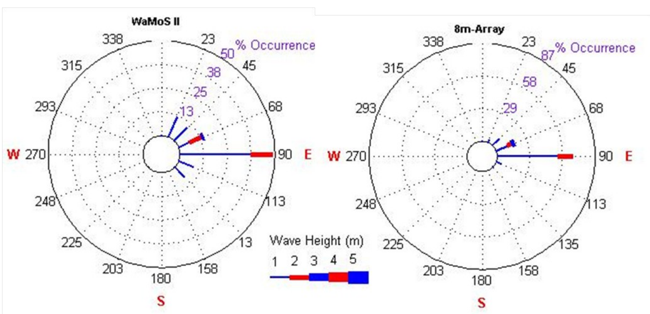

Figure 7: Swell wave rose as obtained by XWaves for WaMoS II (left) and 8m-Array (right).

There is striking similarity in the WaMoS II and 8m-Array wave component distributions. Results from both instruments show a dominant wind sea from the northeast, and a dominant swell from the east. This similarity in the WaMoS II and 8m-Array climatology demonstrates that WaMoS II is able to capture complex sea states in coastal waters.

4. SUMMARY AND CONCLUSIONS

For a validation of WaMoS II in a coastal zone, a wave component comparison with a pressure gauge array was presented. The validation is based on a data set obtained in Sept. 2005 at the FRF research field at Duck. The XWaves wave field analysis system was used to characterize and compare properties for all wind sea and swell wave systems passing through the area. The results demonstrate that WaMoS II is able to capture the coastal wave field climatology with reasonably low errors.

5. ACKNOWLEDGMENTS

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