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Ground based remote sensing as a tool to measure spatial wave field variations in coastal approaches

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ABSTRACT

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The wave monitoring system WaMoS II was developed for real time measurements of directional ocean wave spectra. The system is based on a standard marine X-band radar and can be operated to monitor the sea state from fixed platforms, in coastal areas or from moving vessels. In contrary to wave buoys it allows for temporal and spatial wave analysis. Wave data are needed in coastal areas to help increase safety of ship navigation and improve coastal protection strategies. This paper presents data obtained from the island of Sylt, Germany and at the entrance to Port Phillip Bay, Australia. Both regions are characterised by a complex bottom topography that leads to a highly spatially variable wave field. The wave transformation such as refraction, shoaling, and dissipation are described and quantified. WaMoS II proves to be a powerful tool to monitor changes of sea state caused by local topography.

ADDITIONAL INDEX WORDS: *WaMoS II, X-band radar, wave transformation.*

INTRODUCTION

In coastal areas sea state measurements are needed to support weather and ship routing services. In addition, wave data gained growing importance in the protection of the coastal zone from eroding forces of wind, waves, and currents in recent times.

With the WaMoS II wave radar various phenomena of wave transformation caused by local effects, such as varying topography and currents, can be monitored. This paper discusses two very different WaMoS II coastal stations. One is located at the southern tip of the island of Sylt, Germany and one at the entrance to Port Phillip Bay, Australia.

WAVE MONITORING SYSTEM WAMOS II

The wave monitoring system WaMoS II uses the output of any nautical X-band radar to measure sea state and surface current parameters in real time. The system can be installed on board vessels and platforms, or be operated from any coastal site.

WaMoS II measurements are based on the backscatter of microwaves from the rough ocean surface, called 'sea clutter' (Lee *et al.*, 1995). The ocean's roughness, centimetre sized ripples, is generated by the local wind. The sea clutter is modulated by the long ocean waves like wind sea and swell (Alpers *et al.*, 1981). It becomes visible in the unfiltered video signal of any nautical X-band radar as a stripe-like pattern.

WaMoS II hardware allows for the acquisition and storage of digital radar images. It is comprised of a nautical X-band radar, the digital WaMoS II converter and a standard PC. WaMoS II software analyses the spatial and temporal evolution of the sea clutter within rectangular analysis windows to determine the unambiguous directional wave spectrum. Spectral sea state parameters such as significant wave height, peak wave period, and peak wave direction for both wind sea and swell are derived.

Various WaMoS II data comparisons with in-situ wave data from offshore platforms, vessels, and coastal stations were performed showing the overall good performance of this device (Nieto *et al.* 1999, Vogelzang *et al.*, 2001, Hessner *et al.*, 2001).

WAVE MONITORING ON THE ISLAND OF SYLT

Location

The island of Sylt (Southern North Sea) is suffering from a constant loss of land, mainly caused by storms (ALW, 1997). Since March 2002 the German GKSS research centre is operating a coastal WaMoS II station at the the southern tip of Sylt. The wave field in the area is highly variable and characterised by strong tidal streams.

WaMoS II is installed on a light house, with the antenna being mounted at approximately 40 m above sea level. The location is marked in the centre of the inner black circle, shown on the map presented in figure 1. At this station radar images are sampled within a range of 450 m to 1650 m – the area between the two black circles. WaMoS II is set-up to determine the sea state and surface current parameters within nine different analysis windows. The rectangular areas are situated around the southern tip of Sylt (see map). Each box covers an area of 0,36 km².

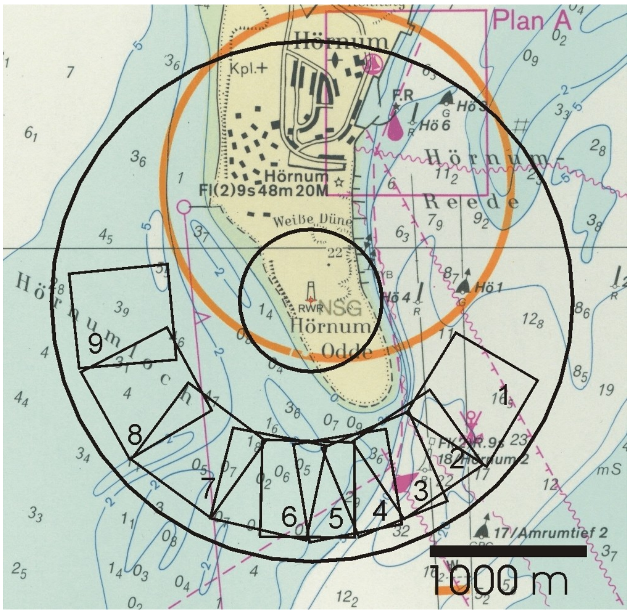

Fig. 1: Map of the southern tip of Sylt with the positions of the nine WaMoS II analysis windows (BSH 2005).

Data Comparison

The data captured at this station show a high spatial variability. Therefore representative data comparisons could only be carried out for certain window positions. The different window positions allow to quantify the changes in the wave field that are related to changes in the topography and tidal currents. Reference data was available from a wave buoy located near WaMoS II box 9.

Figure 2 shows a time series of *Hs*, *Tp*, and *θp* obtained by WaMoS II in box 9 on Sylt and reference data for the time period from 14th of March, 2004 until 25th of March, 2004. As can be seen, the data show a high degree of correlation.

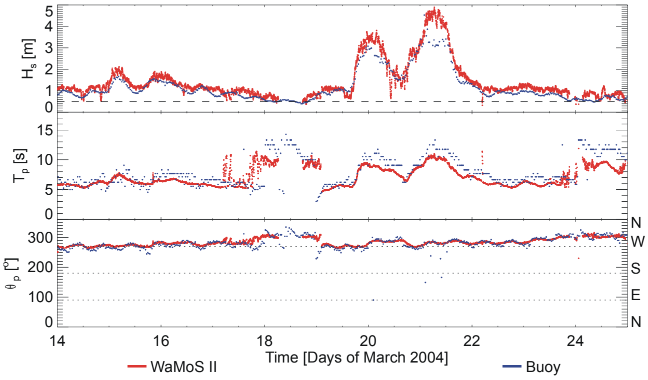

Fig. 2: Time series of *Hs*, *Tp*, and *θp* obtained with WaMoS II (red) and a buoy (blue) on Sylt, March 2004.

To better illustrate the degree of agreement for the significant wave height, *Hs*, figure 3 shows a comparing scatter plot of approximately 4500 measurements taken in 2004. The data are plotted as percent of total measurements. The linear trend of the data strengthens the previous finding, that WaMoS II *Hs* data from window position 9 is in very good agreement with the buoy data.

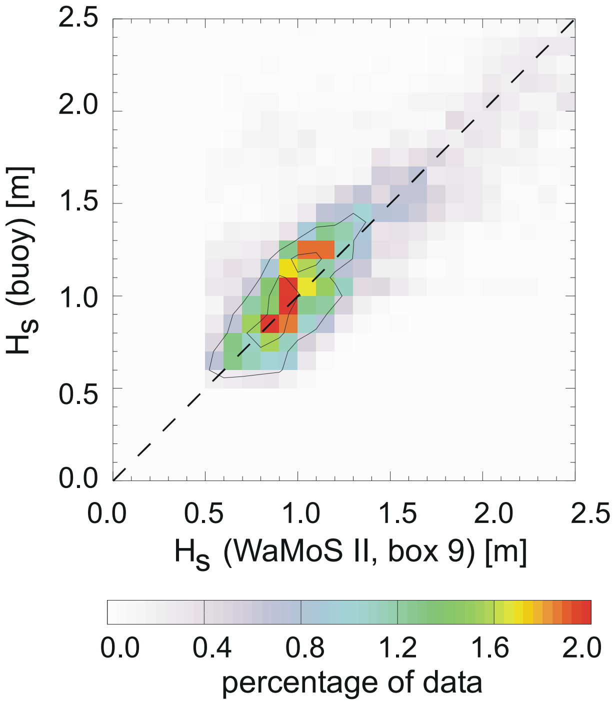

Fig. 3: Scatter-plot of WaMoS II and buoy *Hs* data collected in 2004.

Wave transformation

The wave field around the southern tip of Sylt is highly variable as it experiences shoaling, refraction, and dissipation on the equally variable topography (GKSS, 2004).

Figure 4 shows a radar image as obtained by WaMoS II on Sylt on the 21st of March, 2004, 11:45 UTC. The radar signature of the waves is easily recognisable as a stripe-like pattern. The wave refraction is illustrated by the changing orientation of the yellow bars that represent wave troughs. Wave shoaling can also be observed in the image: Waves travelling from west reach shallow water. The decreasing water depth leads to a decrease in wave speed that can be seen as a shortened wave length in the lower right sector of the image.

The set-up as it was chosen for Sylt makes it possible to quantify these effects by comparing time series of different analysis windows. For each individual window, the directional wave spectrum and all statistical parameters can be derived for exactly the same time.

As an example, the dissipation of wave energy will be analyzed. Here, data from box 6 positioned South of Sylt will be related to the wave data obtained from box 9.

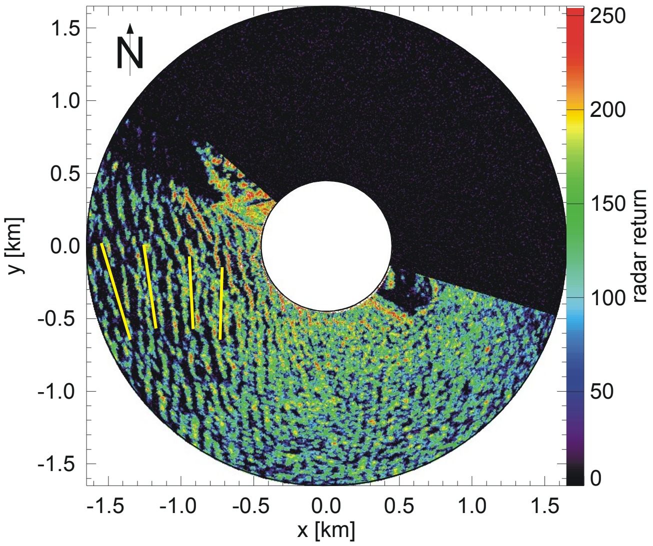

Fig. 4: Radar image as obtained by WaMoS II on Sylt on the 21st of March, 2004, 11:45 UTC. The yellow bars represent wave troughs.

The area in box 9 is exposed to the open sea with relatively deep water, the area in box 6 is relatively shallow. Waves approaching the shore, among others, transfer energy to the sea floor. Consequently, wave height decreases, which can be seen quite clearly in the data. Figure 5 is a scatter plot that compares *Hs* in box 9 with *Hs* in box 6. The data shown in the plot were obtained during the years 2003 until 2005 and are plotted as percent of the roughly 67500 measurements. As can be seen in the figure, *Hs* measured in box 9 is much higher than in box 6.

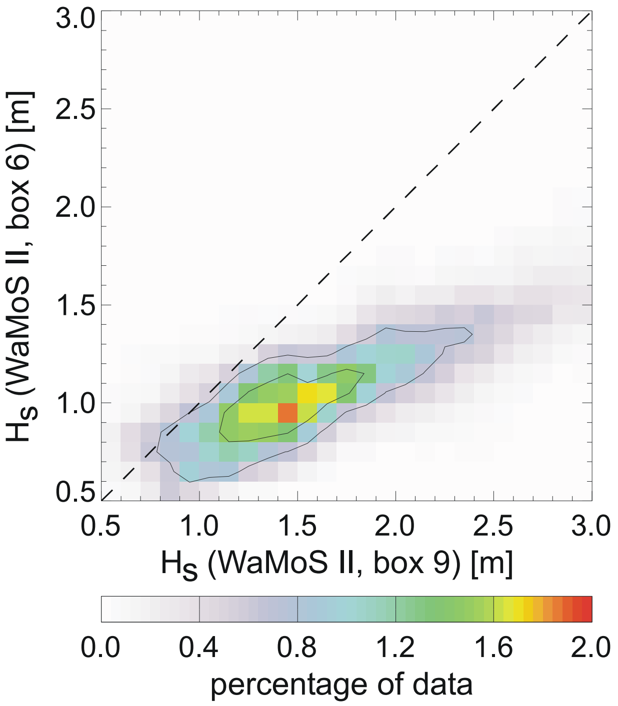

Fig. 5: Scatter-Plot of *Hs* data collected by the WaMoS II station on Sylt in box 9 and box 6 from 2003 until 2005.

The quantification of dissipated wave energy is one essential value to estimate coastal erosion.

The data from Sylt showed that WaMoS II can measure the sea state accurately in shallow water. In additional it was the first time that this kind of data was analysed in order to quantify wave transformation. The potential of spatial and temporal wave data became clearly visible by this study. With increasing coastal and harbour activities a profound understanding of theses processes is essential.

Another WaMoS II station, showing similar effects in the raw data, is located at Point Lonsdale, South of Melbourne, Australia.

WAMOS II AT MELBOURNE

Location

Since June 2006 the Port of Melbourne Corporation (PoMC) operates a WaMoS II wave monitoring system, mounted on the light house at Point Lonsdale. The WaMoS II station covers the narrow entrance to Port Phillip Bay. All ships entering Port of Melbourne have to pass this location. The aim of this installation is to provide representative wave data for the shipping channel in real time, taking into account the strong spatial gradients.

The area of interest can be characterised by an uneven seabed, strong tidal streams and related to this, a highly spatially and temporally variable wave field.

Figure 6 shows a navigational map of the entrance to Port Phillip Bay. The light house is located in the centre of the map. The maximum range of operation of the PoMC WaMoS II station is indicated by the transparent radar image. In relation to that, the positions of some in-situ sensors in vicinity to the shipping channel (marked in red) are displayed. The map also gives an idea of the complex topographic structure of the area.

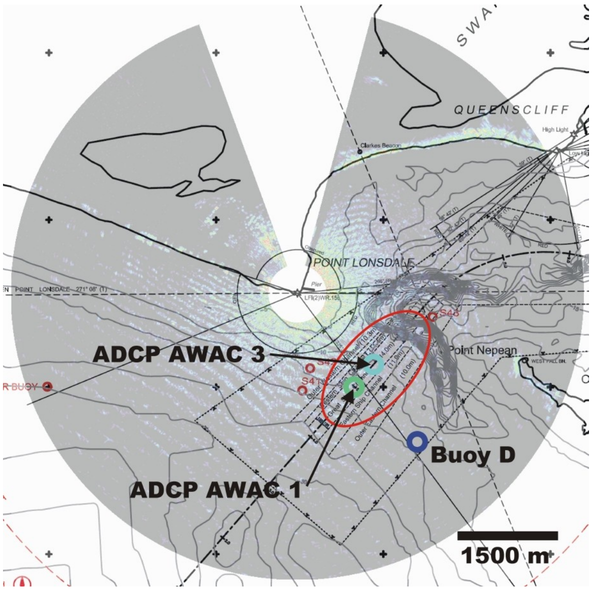

Fig. 6: Map of the entrance to Port Phillip Bay with the positions of some wave sensors deployed in the area. The shipping channel is marked with a red ellipse. The range of radar coverage is 4600m.

Initially carried out comparisons between all different sensors so far have shown that most of the times the wave heights increase during ebb tide and that they generally are higher in the entrance to Port Phillip Bay than they are a few hundred meters to the East. The radar image analysis also showed large spatial gradients for significant wave height and peak wave direction.

In the following, the focus is on the ability to quantify wave transformation effects by analysing nautical X-band radar images.

Wave Transformation

As already described in the first section of this paper, topography and tidal current, both have a strong effect on the prevailing wave conditions. This is reflected by a strong spatial gradient (some 100 meters) of the wave heights, also showing an additional temporal variation (tidal scale).

The long swell mainly approaching from the South experiences refraction, defraction, and reflection on both the topography and the current edge. The wave properties also change significantly over a tidal cycle. As radar images contain both, spatial and temporal sea state information, WaMoS II data provide an additional insight into the complex structure of the whole area.

To illustrate this, figure 7 shows a radar image captured with WaMoS II at Point Lonsdale on June 16th, 2006, 18:02 AEST. The radar antenna is located in the centre of the image which covers a range of approximately 4 km. On the right and in the upper area of the image land signatures are visible. The white area on the upper side is blanked due to the light house.

The long surface waves are clearly visible as stripe-like patterns. Starting from left, long almost regular wave patterns approaching from South-West are visible. By moving further anti-clockwise, a 2nd wave system with a straight south component can be seen, with some waves moving out of this area towards the right into the channel entrance.

This radar image gives a clear picture of the complexity of the wave situations that can be encountered at the entrance to Port Phillip Bay. It is an inhomogeneous wave field with various structures. The shipping channel (marked in red) is about 1000 m off the coast and shows an irregular wave pattern.

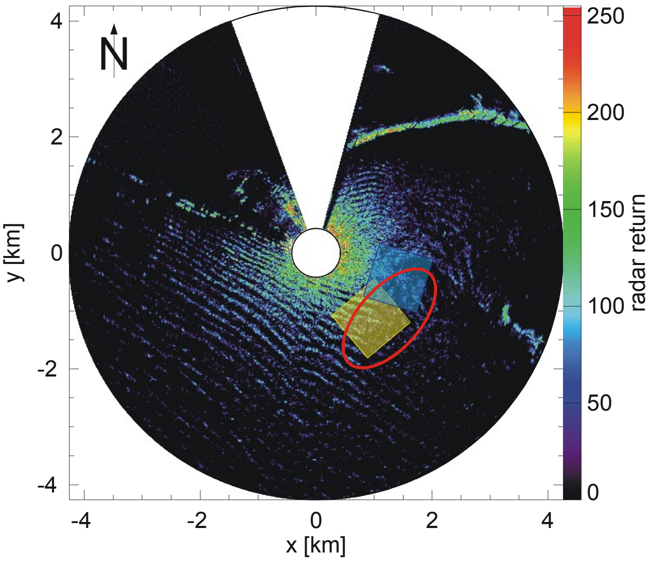

Fig. 7: Radar raw image from Point Lonsdale, June 16th, 2006, 18:02 AEST. The shipping channel is marked with a red ellipse.

The effects of wave reflection on the current and topography edge at the entrance to Port Phillip Bay can be seen in WaMoS II spectral data. By carrying out a spectral analysis for two small sub areas of the radar image (yellow and blue, cf. figure 7), an attempt was made for its quantification.

As an example, the 2D-wave number spectra from July 13th, 2006, shortly after low water, calculated for the yellow and blue window are presented in figures 8 and 9 respectively. The wave field in figure 8 shows a southerly wave peak, whereas in figure 9 a southerly and an easterly wave peak are visible.

The significant wave height *Hs* related to figure 9 was 4.1 m for this event, giving a peak wave period *Tp* of 14.6 s and a peak wave direction *θp* of about 197°.

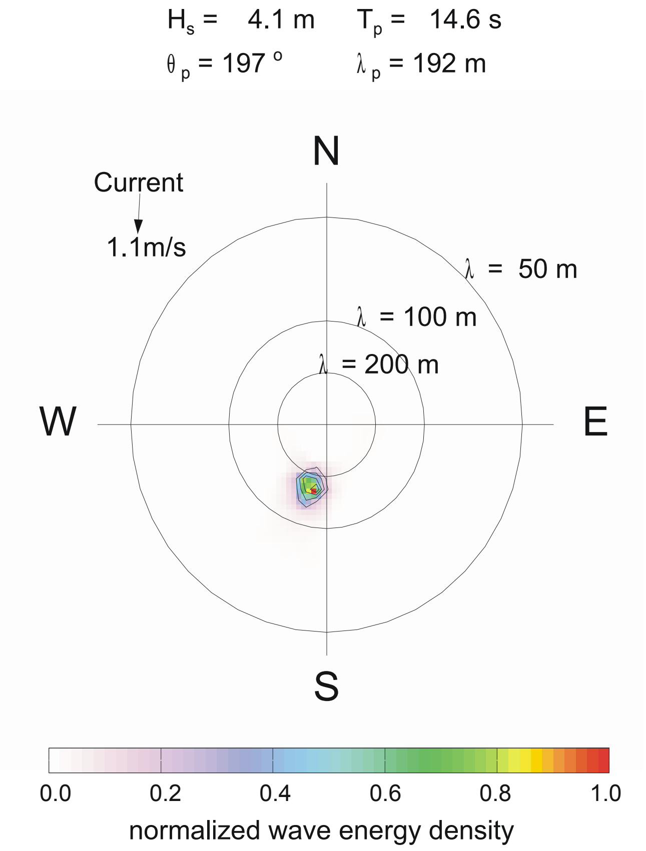

Fig. 8: 2D-wave number spectrum for July 13th, 2006, 19:20 AEST (yellow window).

The wave number spectrum calculated from the other sub-area, presented in figure 9 depicts one wave system approaching from South and a second one travelling from East to West. The significant wave height calculated from this spectrum is 2.4 m, the peak wave period 16.7 s, and the peak direction is 132 deg.

In this spectrum the different swell systems are informative; *Tp1* being 16.6 s, with a direction of 100° and *Tp3* being 14.1 s, having a southern direction of 192°. As *Tp3* is in the same order of magnitude as *Tp1*, for both direction and period, evidence is given that waves are reflected while entering the Bay. The above described phenomena are representative to all data being analysed so far. A more extensive study, also considering comparisons between WaMoS II and in-situ data is planned to be carried out.

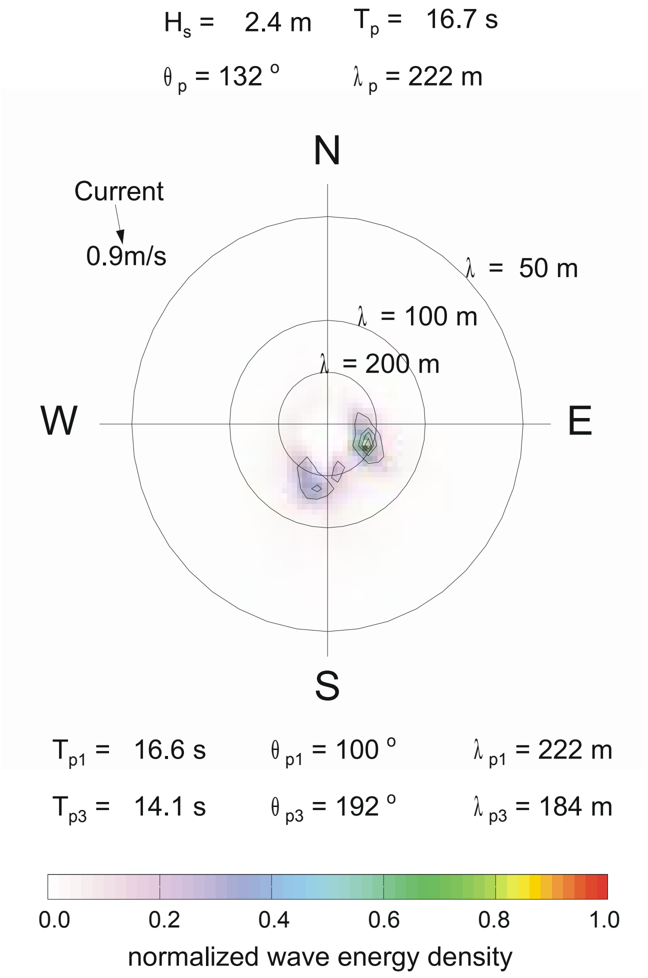

Fig. 9: 2D-wave number spectrum for July 13th, 2006, 19:20 AEST (blue window).

The clearly visible spectral differences on such a small spatial scale, are promising findings from the WaMoS II data analysis and emphasize the need for spatial wave data in the area.

CONCLUSION

Two examples from coastal WaMoS II applications were given, showing the potential of this remote sensing system for coastal sites. The data analysis from both stations show that spatial sea state variations can be measured giving a detailed picture of the coastal effects. In this paper special emphasis was given to, sea state changes caused by local topography and surface currents.

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