

# APPLICATION OF CONVENTIONAL MARINE RADARS FOR MEASURING OCEAN WAVE FIELDS IN SHALLOW WATER CONDITIONS

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## ABSTRACT

This work presents the estimation of wave field properties derived from X-band marine radar measurements taken close to coastal locations, where the wave fields are affected by the finite water depth conditions. The work is focused on the detection of individual waves and their related characteristics, such as the estimation of the local and instantaneous wave envelope derived from the wave elevation fields estimated from X-band marine radar time series.

*Index Terms*— Ocean waves, marine radar, X-band

## 1. INTRODUCTION

Wave information is usually derived from time series of the sea surface elevation measured at a specific ocean position (e.g. the mooring point). These measurements are carried out by in-situ sensors such as buoys, lasers, and pressure sensors. However, deployments of such sensors are limited by the local water depth, as well as the mooring facilities. Buoys, for instance, 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 punctual measurements described above, the imaging of the sea surface based on microwave remote sensing techniques provide information about the sea state variability in the area of interest. One of these techniques is based on the use of ordinary X-band marine radars to analyze the spatial and temporal behavior of ocean wave fields at grazing incidence conditions [1,2,3]. Those X-band marine radars are the most common radar system used for navigation purposes, as well as for ship traffic control on coastal locations.

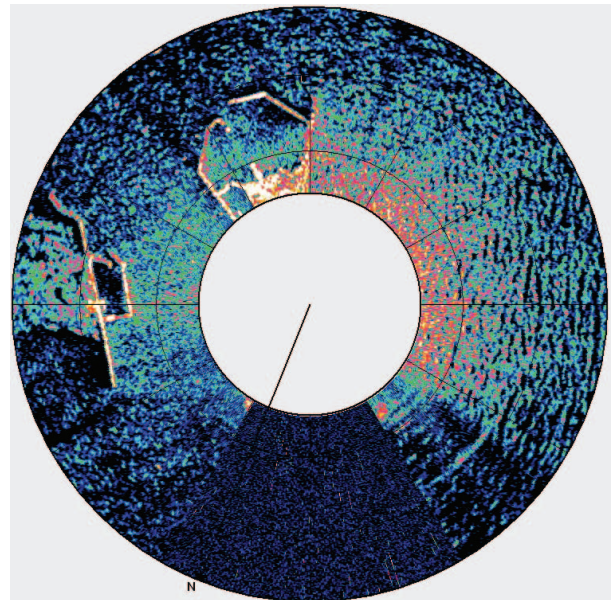


Fig. 1. X-band marine radar image of the sea surface measured at a coastal location.

It is a well-known fact that radar images are affected by the sea surface conditions. This effect makes difficult the detection of targets of interest, such as moving vessels. Therefore, radar operators commonly know the radar signal caused by the sea as sea clutter, which is an undesirable signal for standard radar applications because it introduces noise for target detection purposes. On the other hand, the sea clutter contains information of the variability of the sea surface in space and time. Hence, the sea clutter signal can be analyzed to extract sea state parameters. Fig. 1 shows an example of radar image of the sea surface in a coastal location. These data have been acquired in the vicinity of the German island of Helligoland. It can be seen the variability of the wave field due to the changeable bottom topography. In addition the effect of the breakwater on the wave field can be appreciated as well.

This work presents some results derived from X-band marine radar measurements taken close to coastal locations, where the wave fields are affected by the finite water depth conditions.

## 2. DESCRIPTION OF THE MEASURING SYSTEM

The results shown in this work have been obtained using the German system WaMoS II (Wave Monitoring System) WaMoS II is a high-speed video digitizing and storage device that can be interfaced to any conventional navigational X-Band radar [2]. The system can be operated from coastal sites, moored platforms, as well as from moving vessels. The WaMoS II software controls the radar image acquisition and the data processing and storage. A typical WaMoS II wave measurement consists of the acquisition of radar image sequences (see Fig. 2), where the sampling time of the image time series is given by the antenna rotation period, and the spatial resolution of the data set are derived from the range and the azimuthal resolution of the marine radar. Fig. 3 shows a scheme of a typical WaMoS II installation. The actual range, resolution and accuracy can vary for each WaMoS II installation, depending on the used radar and set-up geometry.

The temporal sequences of radar images acquired by the WaMoS II system are Fourier transformed to obtain the spectral features of the sea clutter. Hence the so-called three-dimensional image spectrum  $I(\mathbf{k}, \omega)$  is derived, where  $\mathbf{k}=(k_x, k_y)$  is the wave number vector and  $\omega$  is the wave frequency. The next step is to apply an inverse modeling technique [2] to the three-dimensional image spectrum to estimate the three-dimensional wave spectrum  $F(\mathbf{k}, \omega)$ . Once the wave spectrum is obtained, their related sea state parameters can be derived [7]. The different steps of the techniques that conform the inverse modeling method are described in [2,3,4,5,6].

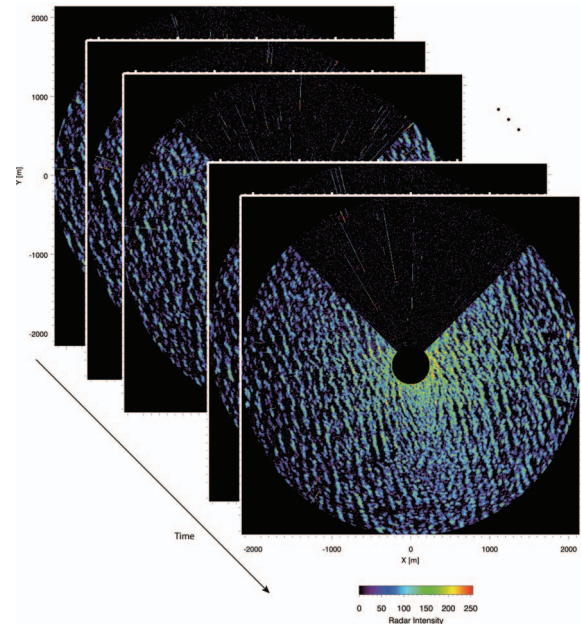


Fig. 2. Example of a X-band marine radar image time series. The measurement was taken at a water depth of 20 meters.

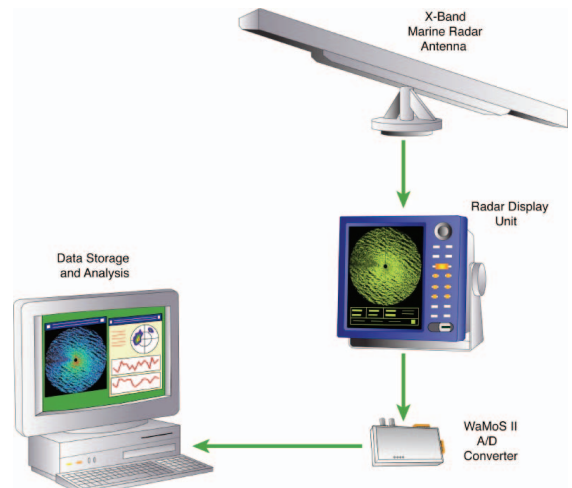


Fig. 3. Scheme of a WaMoS II installation.

## 3. DETECTION OF INDIVIDUAL WAVE HEIGHTS FROM MARINE RADAR IMAGES

The estimation of spectral features mentioned in the previous section are valid to describe averaged information of the wave fields, such as significant wave heights, wave periods, etc. For coastal applications, where the variable bottom topography induces variability in the wave field propagation, the analysis has to be carried out taking into account the local conditions [8, 9].

An additional information than can be derived from the radar data set is the estimation of the imaged sea surface [5, 10]. Therefore, studies of individual waves and their related properties as they propagate to the coast can be achieved.

This estimation method is based on the assumption that the shadowing is the dominant modulation mechanism at grazing incidence and HH polarization conditions [5]. To show that assumptions, Fig. 4 illustrates the image spectrum derived from a subwindow of a radar image time series and the spectrum of the illumination mask, which is defined takes the value of 1 if the sea surface location  $\mathbf{r}$  at time  $t$  is illuminated by the radar and, otherwise, it takes the value of 0 if is not illuminated. The illumination mask can be easily computed by thresholding the sea surface time series. It can be seen that the spectrum of the illumination mask contains information of the wave field (e.g. dispersion relation [1, 2, 3], higher harmonics [5,7], group line [7], etc.). Furthermore, it can be seen that both spectra (e.g. image spectrum and illumination mask spectrum) have similar shape.

Fig. 5 illustrates the sea surface estimation after the application of the inversion method applied to the data shown in Fig. 2. Once the sea surface is estimated, individual wave properties can be derived. One of these properties is the study of wave groups towards the estimation of the local and instantaneous wave envelope, which is the subject of the next section.

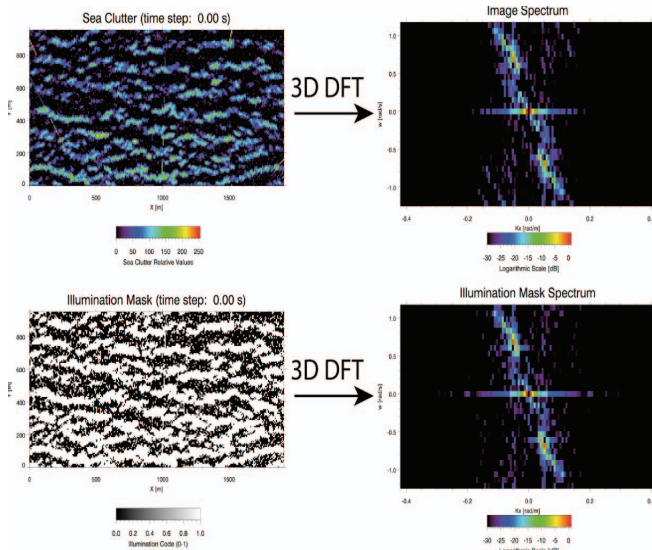


Fig. 4. Transect along the wave propagation direction of the image spectrum (top-right) compared with illumination mask spectrum (bottom-right).

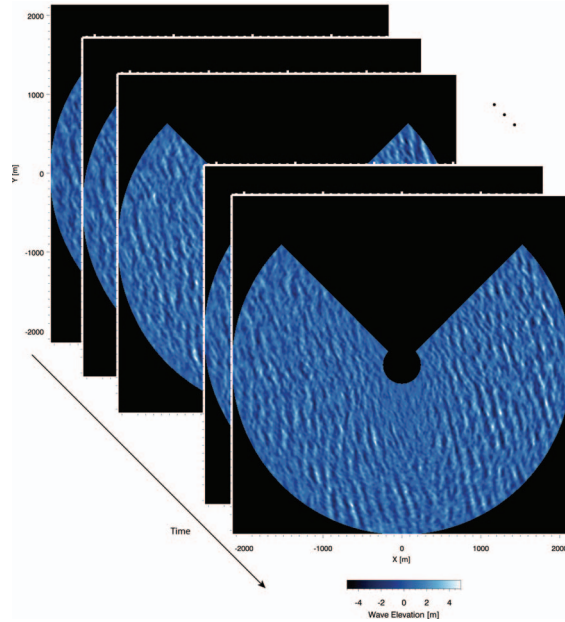


Fig. 5. Wave field estimation derived from the X-band radar image time series shown in Fig. 2.

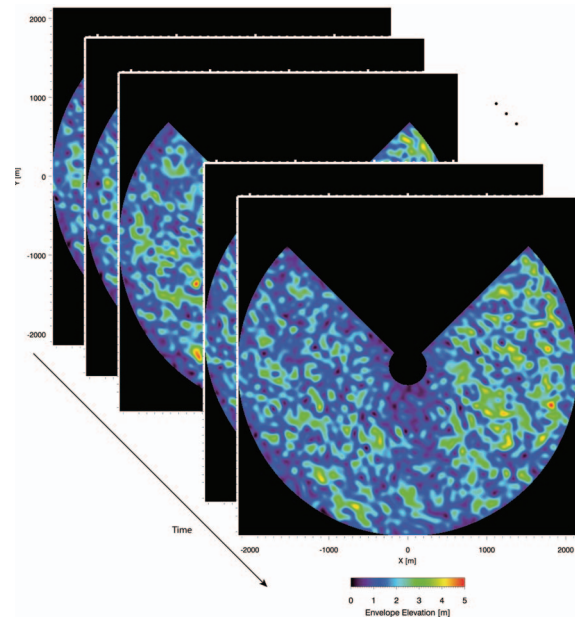


Fig. 6. Local and instantaneous envelope  $a(\mathbf{r}, t)$  erived from the RT applied to the wave elevation map shown in Fig. 5.

#### 4. WAVE GROUPING ANALYSIS IN 3D

Once the wave elevation field  $\eta(\mathbf{r}, t)$  is estimated, individual wave properties of the sea surface can be derived. One of these properties is related to the analysis of the wave grouping phenomenon. In one dimension (e.g. time series of wave elevation records) the three-dimensional envelope can be computed by using the Hilbert Transform (HT). In a



higher dimensional space there is no a unique generalization of HT. This work used the so-called Riesz Transform (RT) [11], which is a  $n$ -dimensional generalization of the HT, to compute the wave envelope as a function of the spatial coordinates  $\mathbf{r}=(x, y)$  and time  $t$ . From the RT a four-dimensional vector field  $\boldsymbol{\eta}(\mathbf{r}, t)$  is constructed as

$$\bar{\boldsymbol{\eta}}(\mathbf{r}, t) = \left( \eta(\mathbf{r}, t), \hat{\eta}_x(\mathbf{r}, t), \hat{\eta}_y(\mathbf{r}, t), \hat{\eta}_t(\mathbf{r}, t) \right)^T, \quad (1)$$

where  $\hat{\eta}_x$ ,  $\hat{\eta}_y$ , and  $\hat{\eta}_t$  are respectively the RT along the  $(x, y, t)$  axes. Hence, the local and instantaneous envelope is derived as  $a(\mathbf{r}, t) = |\bar{\boldsymbol{\eta}}(\mathbf{r}, t)|$ . Fig. 6 shows the estimation of the three-envelope  $a(\mathbf{r}, t)$  derived from the inverted wave elevation field shown in Fig. 5. So, this technique can permit to estimate the properties of the wave energy propagation in the spatial and temporal domain. In addition, Fig. 7 shows a transect of the spectrum of the wave envelope along the wave propagation direction, it can be seen how the spectral components of the envelope  $a(\mathbf{r}, t)$  is distributed along a subset in the  $(k_x, k_y, \omega)$ -domain related to the group velocity of the wave field.

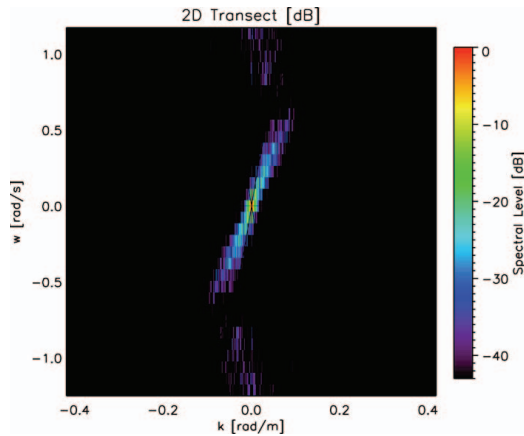


Fig. 7. Transect of the spectrum of the local and instantaneous envelope  $a(\mathbf{r}, t)$  shown in Fig. 6.

## 5. CONCLUSIONS AND OUTLOOK

Spectral, as well as individual wave properties, can be derived by using temporal sequences of ordinary X-band marine radar images of the sea surface. This analysis permits to scan the sea surface in the spatial domain  $(x, y)$  and the temporal domain  $t$ . From these data sets additional spatio-temporal information of the wave fields can be derived such us wave grouping information.

## 6. ACKNOWLEDGEMENTS

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