DIRECTIONAL WAVE SPECTRA MEASUREMENT BY AN ARRAY OF RADAR GAUGES

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Introduction

Up to now, measuring directional wave spectra has been costly and required intensive maintenance. Since the demand for such information has been constantly growing, the German Federal Institute of Hydrology – bfg began to develop a low-cost, non-contact directional wave monitoring system based on cost-efficient radar liquid-level sensors, originally designed for industrial mass-applications. Since July, 2012, a first test assembly has been mounted at the gauging station “Borkum Südstrand”, which is located in the southern North Sea close to the island of Borkum (figure 1, left).

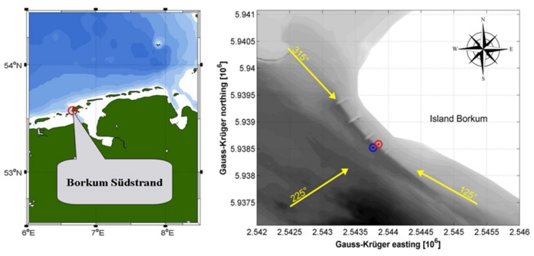

Figure 1 Location of the gauging station “Borkum Südstrand“ in the southern North Sea (left) and illustration of the topography and the local particularities of the observation site (right). The red circle denotes the position of the radar array, attached to the gauging station, and the blue circle marks the position of the buoy. The yellow arrows demonstrate the directions perpendicular and parallel to the coastline.

This study presents first data records made by this new system during the winter season. To evaluate the accuracy, a Datawell Directional Waverider buoy MK III was deployed close to the gauging station (figure , right).

Methodology and data processing

In 2006, the German Federal Institute of Hydrology - bfg developed a wave monitoring system, based on a single radar sensor. This particular sensor emits a series of electro-magnetic pulses at a frequency of 26 GHz twice per second and, in turn, detects these pulses when they are backscattered at the water surface. Since the traveling time of each pulse is proportional to the distance between the radar sensor and the water surface, the water surface elevation can be easily calculated (figure 2, left).

The newly developed directional wave monitoring system is based on an array of four of those sensors (figure 2, right). Simultaneous recordings of wave profiles at the fixed sensor positions are used to derive the directional information of the sea state.

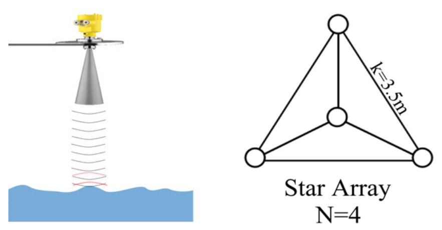

Figure 2 Sketch of the single sensor measuring principle (left).The geometrical design, a star shaped array according to Goda [1985], is illustrated on the right side. The circles represent the sensor positions.

Results

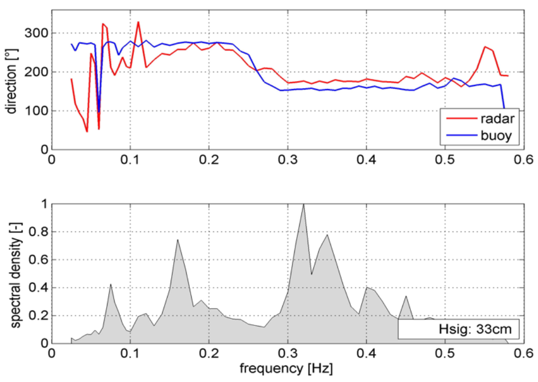

Figure 3 Comparison of the directional wave spectra of the two measuring systems shown for one time span. The upper panel illustrates the spectral directional distribution and the lower one the normalized spectral density.

Principally, the results of both measuring systems reveal the same patterns in the section with a high spectral density. The resulting directional wave spectra of the radar system and those of the Waverider buoy are shown by the example of the 24th November 2012, 19:00-19:30 in figure 3.

In this period, the sea state was dominated by two main directions. Waves with frequencies up to ~ 0.27 Hz are coming from a westerly direction and those with higher frequencies come from the south. However, the results indicate systematic deviations between the two measuring systems (figure 4).

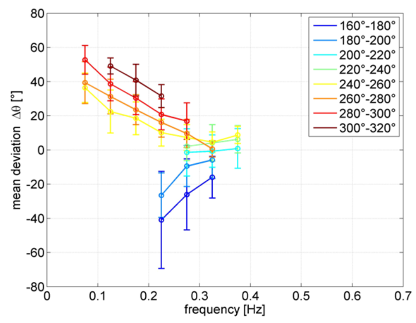

Figure 4 An illustration of the frequency dependence of the mean deviation $\Delta\theta=\theta_{buoy}-\theta_{radar}$ (bin size: 0.05 Hz) for different wave directions (160°-320°).

Since the propagation velocity of waves in shallow water reduces with decreasing water depth, the wave direction turns cross-shore when the water becomes more shallow. This is most likely the reason that constrains the wave motion at the gauging station towards the cross-shore direction (~225°).

However, the direct calculation of the refraction effect is impractical because of the varying water levels and sparse information about the beach profile. Hence, in this study a simple approach is preferred. The directions determined by the radar-gauge array θ_{radar} were adjusted by the equation:

$$\theta_{radar}(f,\theta_{in}) = \begin{cases} \theta_{radar} + [(a\cdot\theta_{in}+b)\cdot(\frac{-f}{0.315}) + (a\cdot\theta_{in}+b)+c] & \forall \quad f < 0.315\,Hz \\ \theta_{radar} & \forall \quad f >= 0.315\,Hz \end{cases}$$

with the frequency f and the parameters a=1.204, b=-273.5° and c=-0.6°, calculated using a linear regression.

The development of the dominant wave directions over time, derived by the two monitoring systems, agree very well (figure 5).

It is noteworthy, that there is an upper (~300°) and a lower limit (~150°) in the detected wave directions. This result fits with the assumption, that beyond these directions wave generation is severely restricted by the island of Borkum (see figure 1).

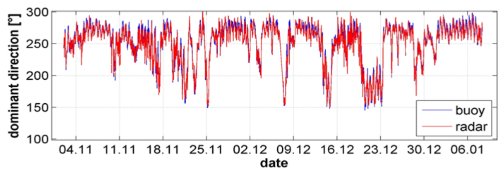

Figure 5 Illustration of the temporal variations of the dominant wave direction calculated by both measuring systems.

The standard deviation of the directions derived by the two monitoring systems is σ=3.4° (H_{sig}>0.6m) and σ=7.3° for the entire data set.

A closer look at the temporal variation of the dominant direction suggests an additional pattern, which appears to be a superimposed uniform oscillation.

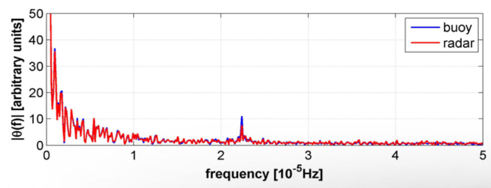

Figure 6 The single-sided amplitude spectrum of the dominant wave directions.

In the single-sided amplitude spectra (figure 6) a significant peak becomes apparent at f=$2.237\cdot10^{-5}$ Hz (which corresponds most likely to the M2 tide). Additional studies will be carried out to analyze, whether the occurrence of the tidal signal is based on wave-current interactions or on the varying water level.

Conclusion & Outlook

The extension of the low-cost, non-contact monitoring system (using an array of four radar sensors) provides reasonable directional information of the sea-state.

When considering the influence of refraction, the results are in good agreement to those derived by a Datawell Directional Waverider buoy MKIII, with a standard deviation of the dominant directions of σ=3.4° (H_{sig}>0.6m). Moreover a tidal signal is detected in the directional time series. Additional studies in this regard will be carried out. Besides an exact accuracy evaluation will be done with the data of the second test assembly at the research platform FINO1 (www.fino1.de). In the vicinity of this site, there are no obstacles, like islands, that might influence the sea state in any direction.

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