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Oceanography radar system WERA: features, accuracy, reliability and limitations

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Abstract

The WERA system (WavE RAdar) is a shore based remote sensing system to monitor ocean surface currents, waves and wind direction. This long range, high resolution monitoring system based on short radio wave radar technology. The vertical polarised electromagnetic wave is coupled to the conductive ocean surface and follows the curvature of the earth. This over the horizon oceanography radar can pick up back-scattered signals from the rough ocean surface (Bragg effect) from ranges of up to 200 km. The physical background, technical concept and environmental boundary conditions are explained. Results for various installations from all over the world demonstrates the features and flexibility of the system: high resolution monitoring (range cell size of 300 m) over a range of 60 km or long range applications with 3 km range cell size, all generated with the typical high temporal resolution of 10 minutes. The technical performance depends on the site geometry, system configuration and the environmental conditions. These aspects are discussed to enable interested users to estimate the potential of this technology for their specific application.

Key Words: *Radar, WERA, Current, Waves*

1. Introduction

The WERA system (WavE RAdar) is a shore based remote sensing system using the over the horizon radar technology to monitor ocean surface currents, waves and wind direction. This long range, high resolution monitoring system operates with radio frequencies between 5 and 50 MHz. A vertical polarized electromagnetic wave is coupled to the conductive ocean surface and follows the curvature of the earth. The rough ocean surface interacts with the radio wave and due to the Bragg effect back-scattered signals can be detected from ranges of more than 200 km. This effect was first described in 1955 by Crombie [1] and the first radar system using that effect was developed by Barrick et al [2] at NOAA in 1977.

The Bragg effect describes the coupling of the electromagnetic wave with the ocean wave field. To fulfill the Bragg conditions the electromagnetic wave length needs to have twice the wavelength as the ocean wave, e.g. for a 30 MHz radar signal with $\lambda = 10$ m, the corresponding ocean wave is 5 m. Reflections from waves that fulfill this condition will generate a dominant signature in the received signal spectrum due to in-phase summation of amplitudes. The expected signature is a Doppler shifted signal with a specific Doppler Shift given by the velocity of the gravity wave that fulfils the Bragg condition. Figure 1 illustrates this idea.

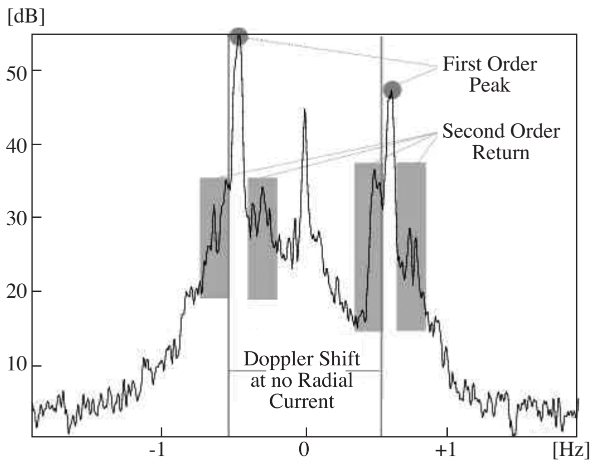

Figure 1. Typical Spectrum from a WERA system; 1^{st} order Bragg lines, shifted slightly off-centre, with superimposed 2^{nd} order lines carrying the wave information.

These Doppler shifted signals will be symmetrical around the normalised centre frequency, as long as the ocean surface does not move. An ocean current will shift these Bragg peaks up or down in frequency. This additional frequency shift contains the information used to calculate the velocity of the ocean current.

With the help of sophisticated software, a lot of valuable information can be extracted from these spectra, like ocean current maps, wave spectra maps and wind directions [3, 4]. Actual projects are working on extending the WERA system for measurements of wind speed and ship tracking [5, 6].

2. System concept

The concept of the WERA system has been developed at the University of Hamburg by Gurgel et al [7] in 1995 and the hardware development was completed in 2000 at Helzel Messtechnik GmbH. The WERA system is operating in a frequency modulated continuous wave mode (FMcw). A continuously swept rf-signal is transmitted. The reflected signal has a frequency offset compared to the actually transmitted signal, thus the range is frequency encoded.

The radar is continuously transmitting very low rf power, no gating or pulsing sequences are used. The required de-coupling between transmitter (Tx) and receiver (Rx) has to be achieved by means of using separate locations for Rx and Tx antennae.

The receiver is continuously switched on to pick up signals from all ranges. The analogue signal processing is carried out in parallel to retain all amplitude and phase information of each antenna until it is digitized. The required complex signal processing is carried out on a personal computer in near real time mode. These systems provide best signal to noise performance due to the extreme low noise FMcw transmission mode.

The azimuthal beam width is typically ±3° defined by the length of the used array and the accuracy is better than 1° typical. The accuracy depends on environmental conditions and other parameters as described by Gurgel et al [8]. The linear array antenna configuration limits the field of view to an angle of ±60°.

An alternative system configuration is the Direction Finding mode using a compact receiving antenna array of just 4 antennas. This will result in a field of view of up 360° but will reduce the data quality. Furthermore, this configuration does not allow extraction of reliable wave information.

The WERA system concept is flexible to allow for installations in these different configurations. Furthermore, the hardware is modular and broadband so that a modification for short range or long range systems is possible as well.

3. Measurement results

There are more than 30 WERA systems installed world-wide and the resulting current and wave data are validated by means of comparisons with buoy measurements; see, e.g., [9, 10].

Since 2003 two WERA systems are installed in Florida, the results from validation experiments are published by Lui et al [11] and Shay et al [12].

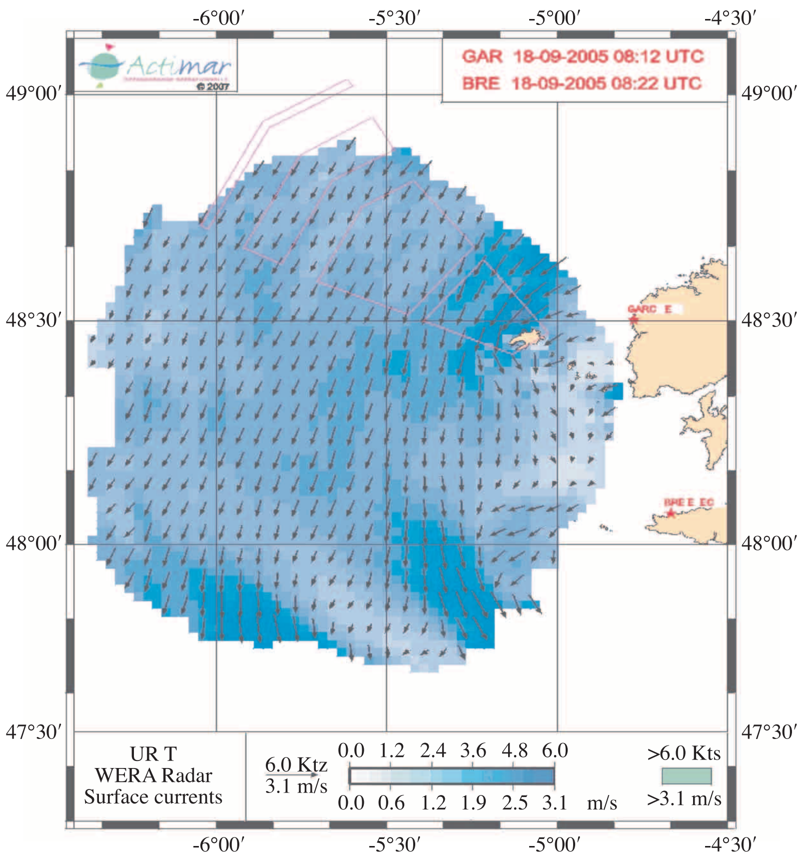

Figure 2. Surface current field from the French coast near Brest, 2005, averaging time for acquisition was set to 12 minutes.

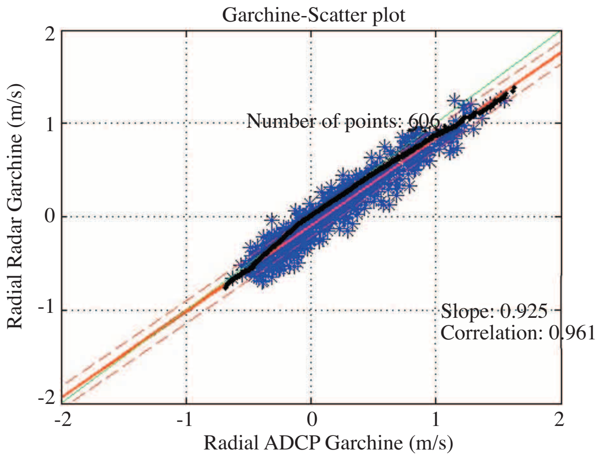

Figure 3. The current speed measured with WERA was compared with an ADCP measurement (ADCP location about 25 km offshore) resulting in a correlation factor of 0.947.

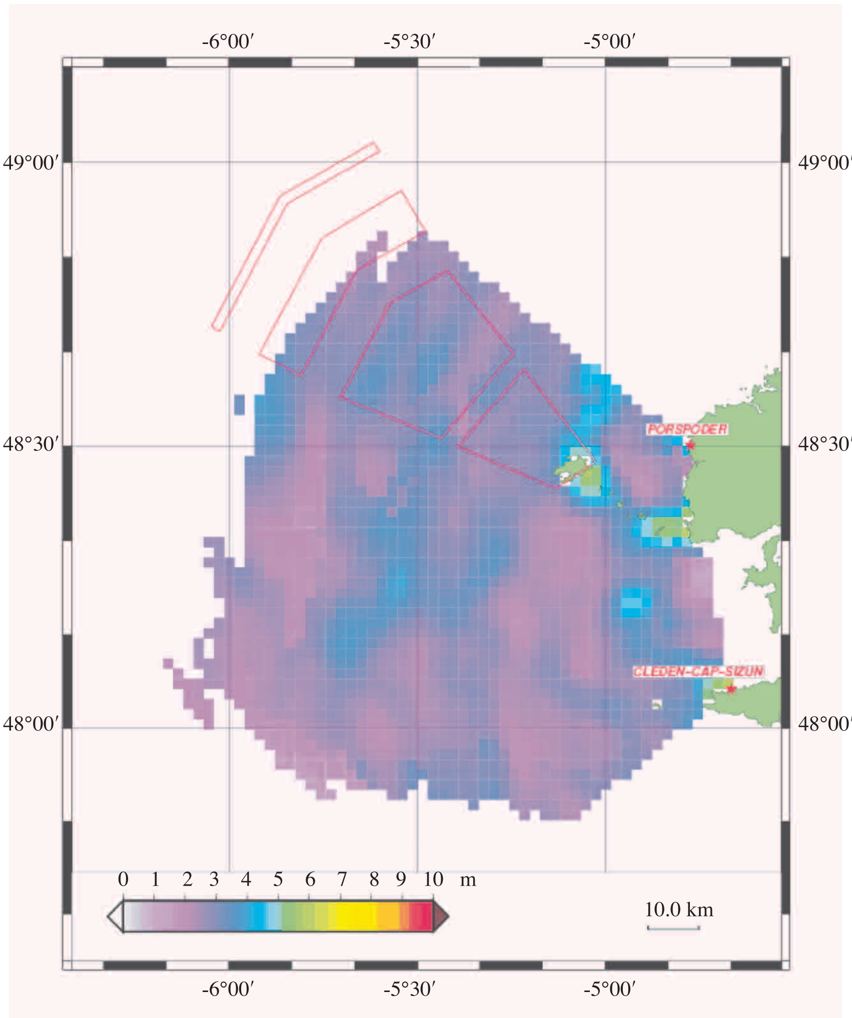

Figure 4. Map of significant wave height from the same area as before, averaged over 1 hour.

From a 2 months experiment at the Atlantic coast near Brest (France) results of ocean currents, wave, wind direction as well as ship tracking are published by ACTIMAR and their project partners [13]. For validation some buoys were placed within the field of view of the radar. The correlation between the ADCP data and WERA currents were excellent, better than 0.9 for currents and 0.88 for significant wave height.

A typical current map is displayed in Figure 2 and the according comparison between the radar current data from one range cell with data from an ADCP located within this rage cell is displayed in Figure 3. These current measurements were integrated over 12 minutes.

For wave measurements, the data are typically averaged over a longer period, at least 20 minutes, to achieve the required measurement accuracy. The map displayed in Figure 4 is an averaged data set of 1 hour.

From the 2^{nd} order side bands around the Bragg peaks the wave information is derived. These side bands have a much smaller amplitude and, for this reason, the range for wave measurements is typically reduced to about 50% of range for current measurements. The correlation between the radar and buoy wave measurement is displayed in Figure 5.

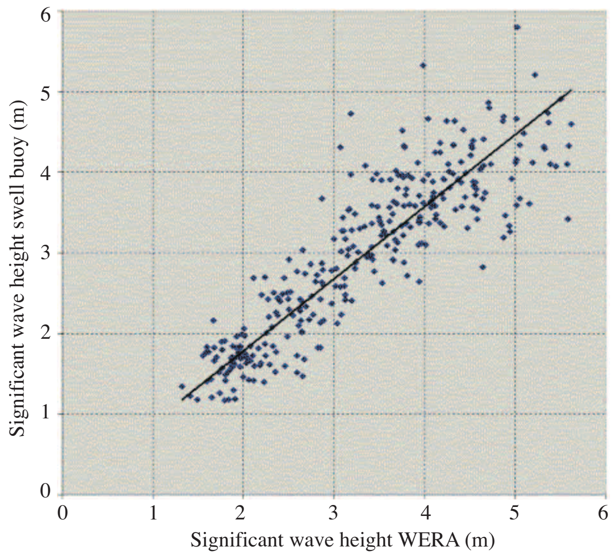

Figure 5. WERA measurement of significant wave height compared with a wave buoy located about 30 km offshore with a resulting correlation of 0.885.

4. Boundary conditions for wera installations

For the application of this remote ocean sensing system, there are some physical, oceanographic and technical parameters that need to be taken into account to define the optimal site geometry and system configuration for a specific application. From the users point of view the main aspects are radar range, resolution, accuracy, field of view and site geometry.

Radar Range (Figure 6) depends on operating frequency (lower frequency results in longer range). But the operating frequency will effect some other important system parameters. These effects, listed below, need to be taken into account as well.

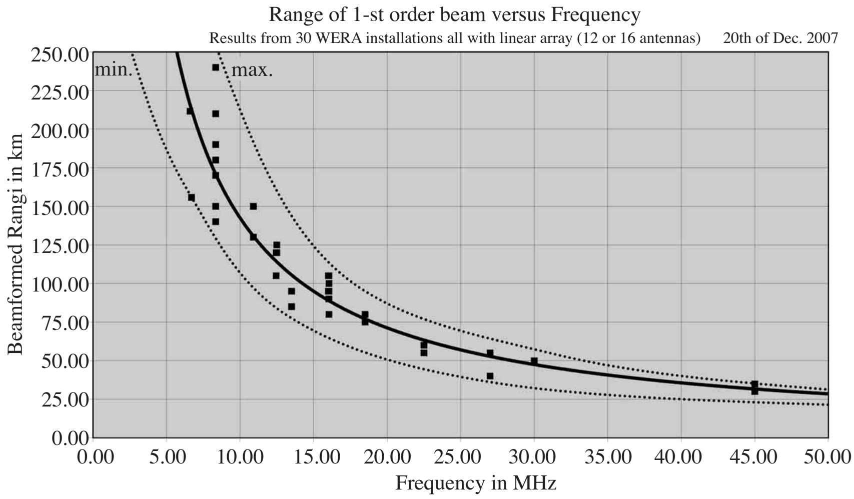

Figure 6. Radar range for 1^{st} order Bragg lines versus operating frequency. The two blue lines indicate the typical day to night variation. The range for wave data is typ. 45% of the sketched value.

Decreasing the frequency will increase the sensitivity to external interference, which can cause data corruption. At lower frequencies, short wave reflections at the ionosphere will lead to increased background noise that comes in from far distances. This can lead to a high variance in range from day to night.

At lower frequencies, it is harder to get a wide operating bandwidth (to be approved by the local authorities, e.g. FCC). The operating bandwidth will determine the range resolution (range cell depth), e.g. 3 km @ 50 kHz or 300 m @ 500 kHz operating bandwidth.

Even the site geometry is effected by the operating frequency. The length of the linear antenna array, with the typical $\lambda/2$ antenna spacing, will increase with decreasing frequency. For a 12 channel long range system, the array length can come close to 200 m, whereas a short range system requires just about 50 m. That means, the best compromise between these parameters and the required range has to be found.

In addition to that, the range depends on salinity as well. Lower salinity will strongly reduce the range.

The accuracy for ocean current velocity depends on operating frequency f_o and averaging time. With decreasing frequency the resulting Doppler shift f_{DS} for a given velocity v will decrease and the Bragg resonant wave length l_B increases:

$$f_{DS} = f_o \cdot v/c. \tag{1}$$

$$l_B = c/(2 \cdot f_o). \tag{2}$$

The phase velocity v_B of the ocean wave, that fulfils the Bragg conditions, depends on the wave length:

$$v_B = \sqrt{}(g \cdot l_b/(2\pi). \tag{3}$$

This phase velocity causes the Doppler shift observed. Since this little frequency offset contains the ocean current information, the measurement accuracy for ocean current velocity depends on the frequency measurement and this is determined by the integration time.

The field of view of a linear array is limited to $\pm 60^\circ$ and the array needs to be installed almost parallel to the coast line. The alternative direction finding configuration does not have this limitation but will deliver data with reduced quality.

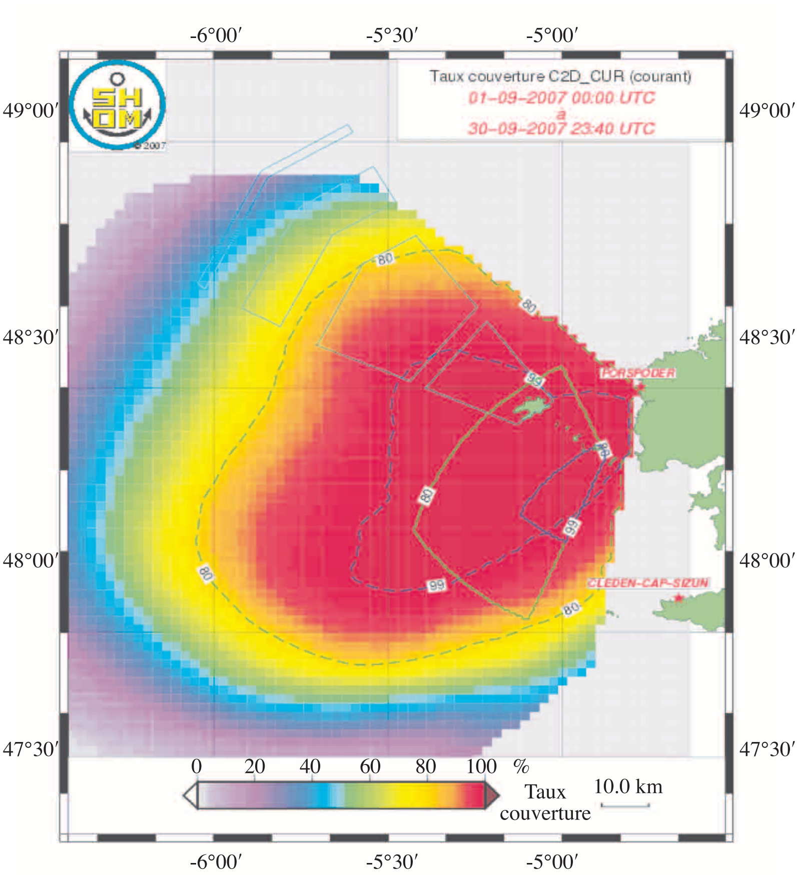

Figure 7. Data availability, the required areas are marked with solid lines; the achieved areas are marked with dashed lines.

Figure 8. WERA Antenna array on a public beach in Miami.

The reliability of this shore based remote ocean sensing technique is very high, with 98% data availability, reported from a deployment in France [14], displayed in Figure 8. The customer demands for spatial coverage are of WERA measurement data and the achieved results in September 2007 are presented in Table II and Figure 7.

A typical antenna installation is displayed in Figure 8, a linear array configuration for 16 MHz with a range of about 100 km.

5. Conclusion

The shore based radar system WERA is a powerful oceanographic instrument giving reliable information about large ocean areas. The flexibility makes it attractive for scientific experiments, as well as for permanent installations for applications like search and rescue or vessel traffic services. Even if it is easy to install, it isn't a "plug and play" system. For all applications, it is very important to take the specific local boundary conditions into account.

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