WERA: REMOTE OCEAN SENSING FOR CURRENT, WAVE AND WIND DIRECTION

Introduction to the Principle of Operation

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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 will follow the curvature of the earth. This over the horizon oceanography radar can pick up back-scattered signals (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 will demonstrate the features and flexibility of the system: high resolution monitoring (range cells 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 will be discussed to enable interested user to estimate the potential of this technology for their specific application.

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 polarised electromagnetic wave is coupled to the conductive ocean surface and will follow 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 at NOAA in 1977 by Don Barrick et al. [2].

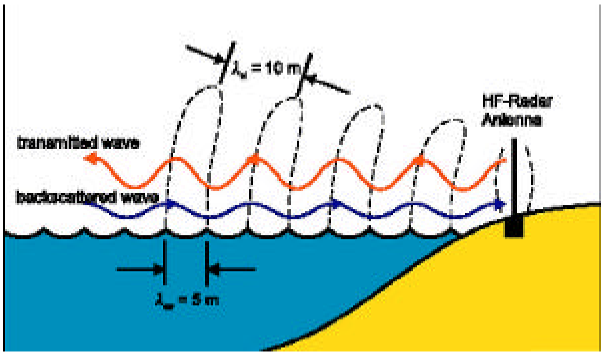

Fig. 1: Principle of operation (Bragg Effect)

The Bragg Effect describes the amplification effect of a back-scattered electromagnetic wave having twice the wavelength as the ocean wave, e.g. for a 30 MHz radar signal with Lambda 10 m is the corresponding ocean wave 5 m to fulfil the Bragg condition. Reflections from waves that fulfil this condition will generate a dominant signature in the received signal due to the amplification effect. 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.

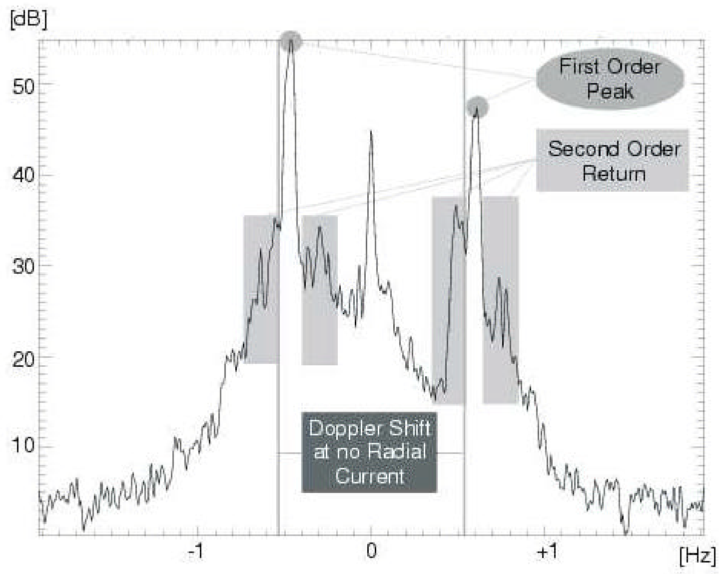

Fig. 2: Typical Spectrum from a WERA system, 1st order Bragg lines, shifted slightly off-centre, with superimposed 2nd order lines carrying the wave information

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 lines up or down in frequency. This little frequency shift is the information used to calculate the velocity of the ocean current at each individual grid point.

With the help of sophisticated software a lot of valuable information can be generated from these spectra, like ocean current maps, wave spectra maps and wind directions [4, 5]. Actual projects are working on using these systems for wind speed measurements and ship tracking [6, 7].

2. SYSTEM CONCEPT

The described WERA system is a new development carried out in 1995 at the University of Hamburg by Klaus-Werner Gurgel et al. [3]. 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 actual transmitted signal, thus the range is frequency coded.

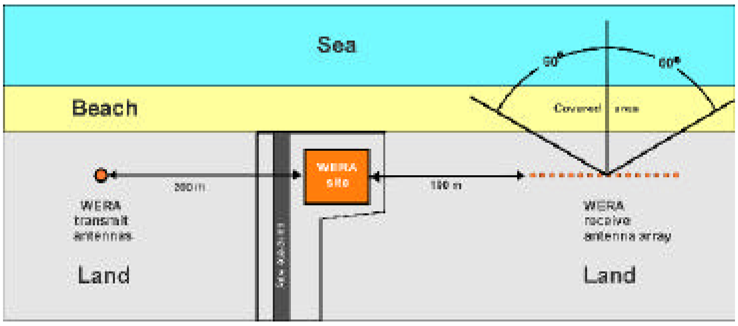

Fig. 3: Typical WERA site geometry

The radar is continuously transmitting very low rf power, no gating or pulsing sequences are used. The required de-coupling between transmitter and receiver has to be achieved by means of using separate locations for Rx and Tx antennae. This results in a very typical site geometry with two separated antenna arrays, like sketched in figure 3.

The receiver is continuously switched on, to pick up signals from all over the defined range. The analogue signal processing is carried out 100 % in parallel to transfer all amplitude and phase information of each antenna to the digital processor units. These systems provide best signal to noise performance due to the extreme low noise FMcw transmission mode.

The azimuthal resolution is typically 1° defined by the used software (Beam Forming algorithm) but the accuracy is less than 1° and depends on the length of the linear antenna array (typically 15° with 8 antennae and 3° with 16 antennae). The linear array antenna configuration is limiting the angle of the field of view to ±60°.

The alternative system configuration is using the Direction Finding algorithms and a compact receive antenna array of just 4 antennas. This will result in a field of view of 360° but will reduced the angular accuracy. Furthermore the 1st order Bragg lines will get much wider, caused by the much wider "focus" of this smaller receive array, and thus the 1st order lines will cover the 2nd order Bragg lines carrying the wave information. When using the Direction Finding technique the risk is very high that the 2nd order Bragg lines are covered by smeared out 1st order lines.

The complete system concept is very flexible to allow for set-ups in these different configurations. Furthermore the hardware is modular and broadband so that a modification for short range or long range is possible as well.

3. MEASUREMENT RESULTS

In the meantime, WERA systems are installed world-wide. And the resulting current and wave data is validated by means of comparisons with buoy measurements. During a 6 weeks experiment at the Norwegian Coast in February 2000 current and wave data were acquired [8, 9] displayed below.

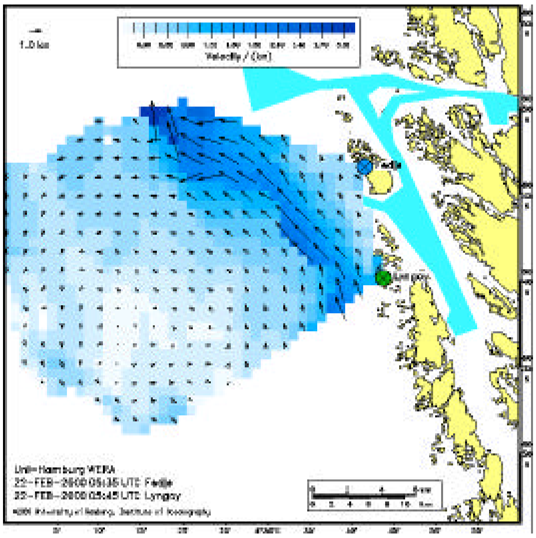

Fig. 3: A surface current field (arrows) measured at the Norwegian coast with 1.4 km resolution. A coastal jet connected to an eddy can be observed.

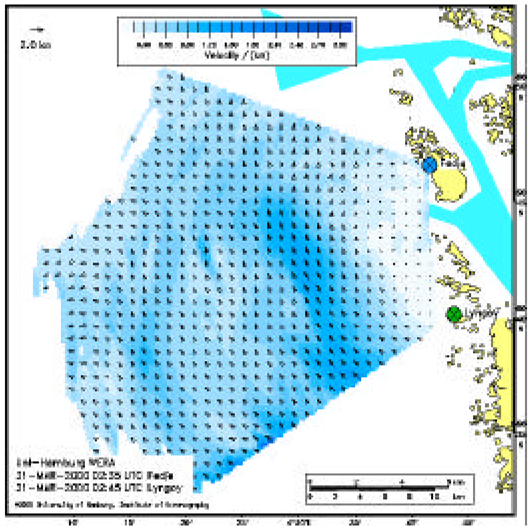

Fig. 4: A surface current field in high resolution mode (300 m). An area with very low current velocities can be seen between the coast and the jet.

At the Atlantic coast near Brest (France) a 2 months experiment gave a lot of valuable data for current, wave and wind measurements as well as for ship tracking. These results are going to be published by ACTIMAR and their project partners within the next months.

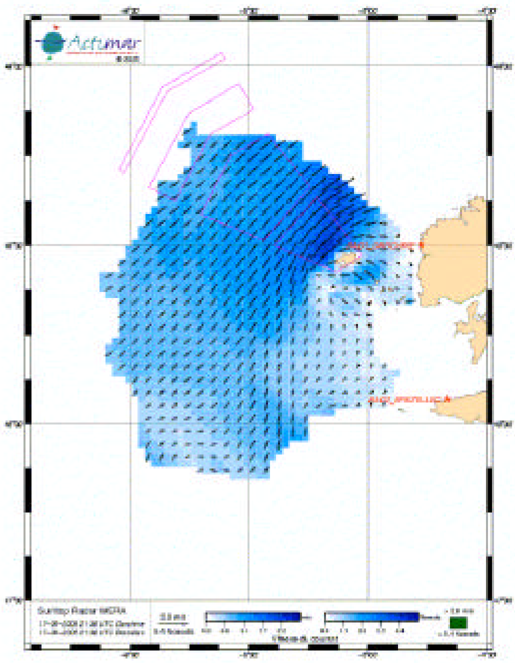

Fig. 5: Surface current field from the SURLITOP experiment 2005. 1 map every 12 minutes.

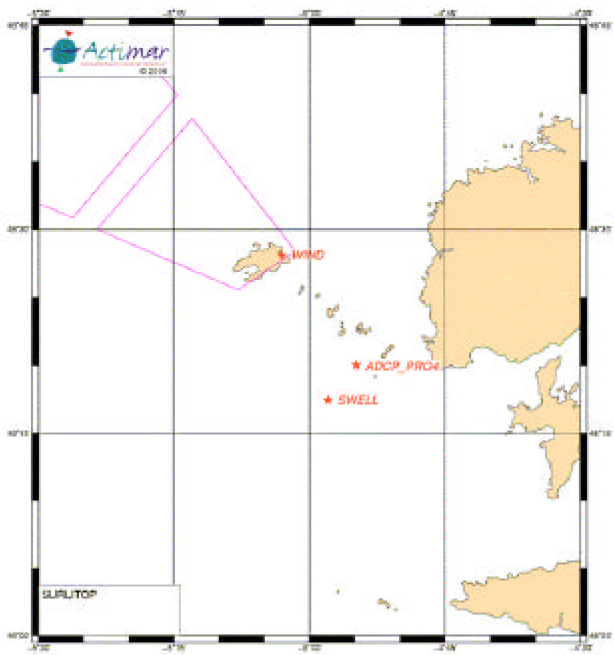

Fig. 6: Sensor locations for validation of radar data.

For validation some buoys were placed within the field of view of the radars. The correlation between the ADCP data and WERA currents were excellent. Some drop outs during that experiment were caused by power failure and a defective power amplifier of the used laboratory radar system borrowed from the University of Hamburg.

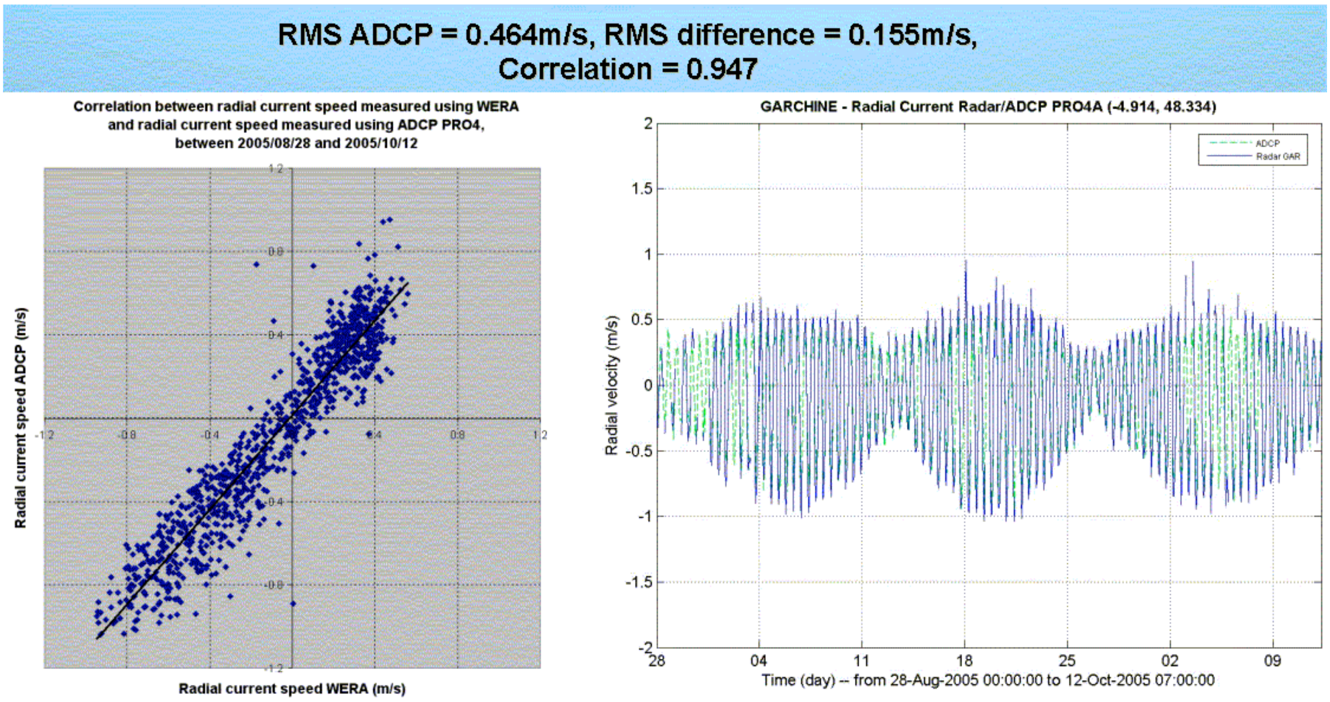

Fig. 7: The current speed measured with WERA was compared with an ADCP measurement

For the wave measurements the data were averaged over 1 hour to generate maps same as for the wind direction maps.

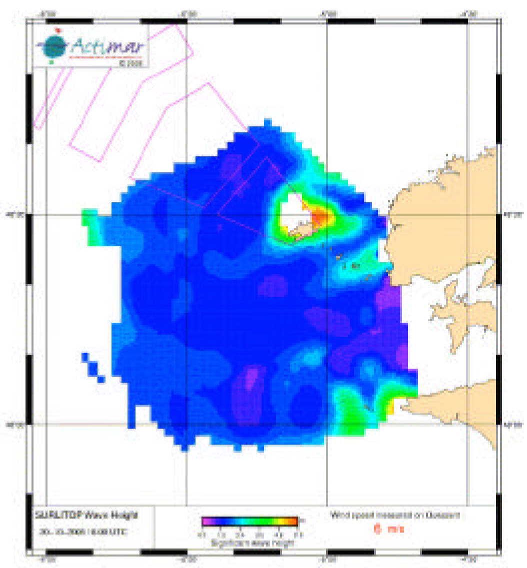

Fig. 8: Map of significant wave height, averaged over 1 hour

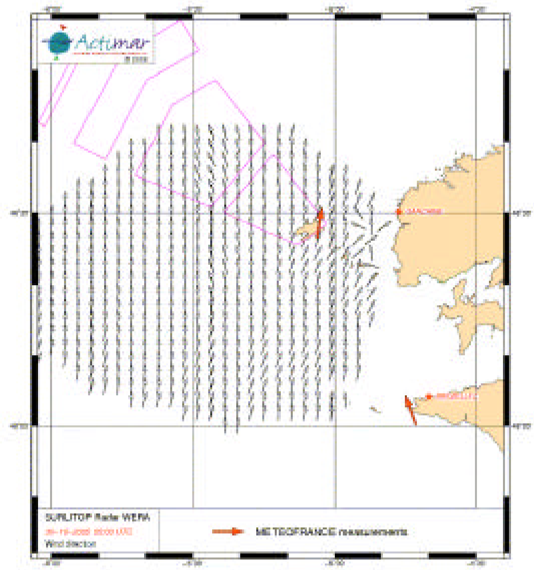

Fig. 9: Map of wind direction, averaged over 1 hour

For wave measurements the 2^{nd} order Bragg lines are used. These lines have a much smaller amplitude and for this reason the range for wave measurements is typically reduced to about 50 % compared with the range for current measurements. The correlation for the wave measurement is displayed in figure 10 and shows an increasing uncertainty for higher sea states.

These wave data were generated with the software package from the University of Hamburg [5], another algorithm developed by Lucy Wyatt will give additional information such as directional wave spectra [4]. This software package is available for the WERA system as well.

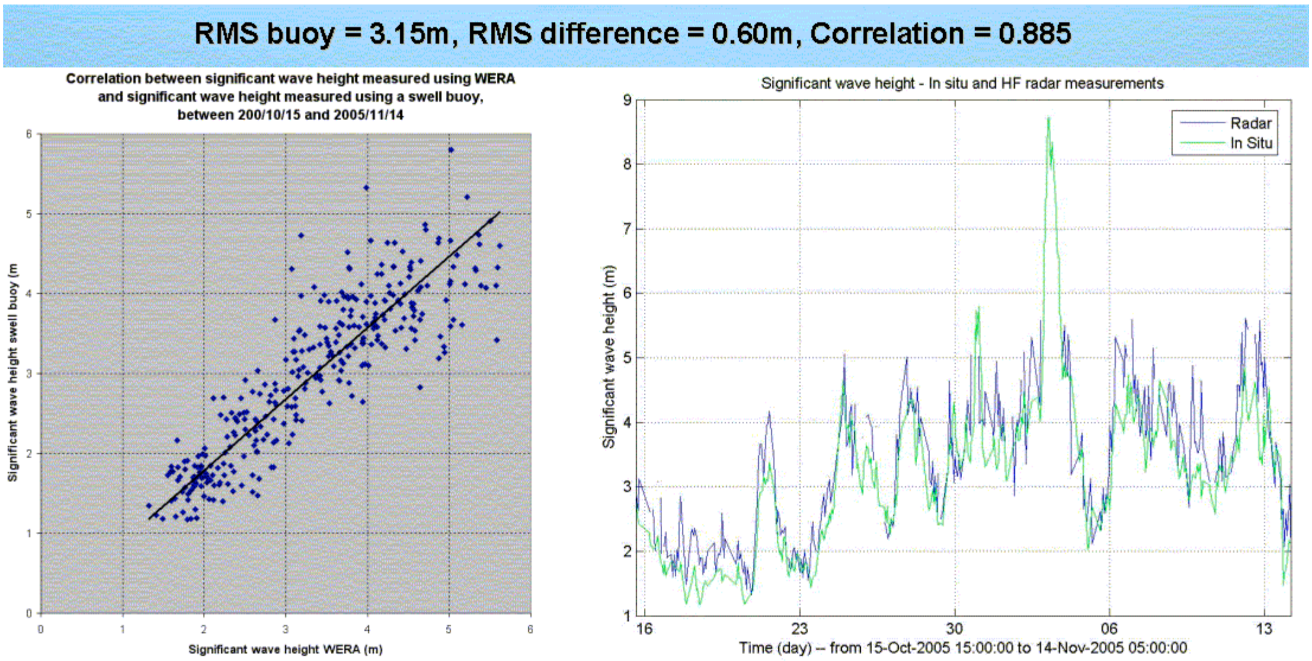

Fig. 10: The WERA measurement of significant wave height compared with a RMS buoy

For the wind direction measurements, the typical in-balance of the 1st order Bragg lines are used. The range for these measurements comes close to that as for the current fields, see figure 9. The correlation is quite good for higher wind speed situations, refer to figure 11.

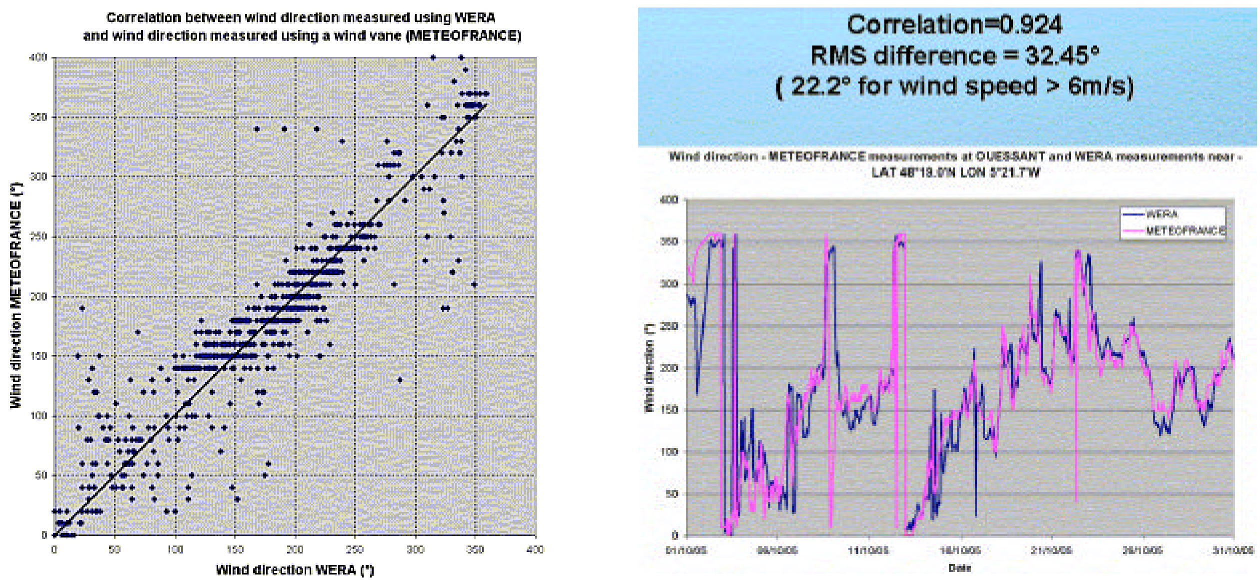

Fig. 10: The WERA measurement of wind direction compared with a wind vane on the island

Similar correlation were carried out during various experiments at the Norwegian, Spanish, British and US coast [10, 11, 12].

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:

1 – Range

Range depends on operating frequency, a **lower frequency** results in longer range.

- A **lower frequency** will increase the sensitivity to external interference causing drop outs
- **Lower frequencies** will increase the variance in range (day to night)
- At **low frequencies** the available bandwidth will be reduced resulting in coarser range resolution
- For a **low frequency** the corresponding Bragg wave will be long
  (8 MHz => Bragg wave = 19 m)
  Is this wave length always available in the ocean wave spectrum of the field of view ?
- At **low frequencies** the linear antenna array will be quite long

Range depends on salinity. Lower salinity will strongly reduce the range [14].

2 – Range resolution

The range resolution depends on the allocated bandwidth.

- With increasing bandwidth the risk of having external interference in-band will increase
- Increasing bandwidth will increase the resulting data volume

3 – Field of view

For a linear array configuration the field of view is limited to +/- 60° and the array needs to be installed almost parallel to the coast line. The direction finding configuration does not have this limitation but will deliver data with reduced quality.

4 – Site Geometry

For any WERA site a separation of the transmit and receive antenna arrays of at least 150 m is required. It is preferred to have the linear receive array and the transmit array exact in-line.

The antenna arrays should be installed quite close to the water front (< 300 m) or on a cliff. In case of a cliff like geometry, it is possible to get the required array separation in vertical direction, e.g. the transmit array down hills in-front of the receive array.

Fig. 11: Antenna array for a 16 MHz WERA on a public beach in Miami (USA)

5. CONCLUSIONS

The shore based radar system WERA is a powerful oceanographic instrument giving reliable information about large ocean areas. It is easy to install and flexible for various application making it attractive for scientific experiments as well as for permanent installations for applications like SAR or vessel traffic services. For all applications, is important to take the specific local boundary conditions into account.

6. ACKNOWLEDGEMENT

We wish to thank the team of ACTIMAR (France), in particular Vincent Mariette, Nicolas Thomas and Veronique Cochin to provide the latest WERA data from the Surlitop experiment.

7. LITERATURE

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