Accuracy and Reliability of Ocean Radar WERA in Beam Forming or Direction Finding Mode

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***Abstract*—This paper introduces the over-the-horizon radar technique optimized for oceanographic applications. The relation between radar range and operating frequency will be explained as well as the radar resolution which depends on the radar bandwidth. The accuracy in azimuth strongly depends on the number of used receive antennae and samples demonstrate the high accuracy that can be achieved. The oceanographic data output are provided in near real-time with an individually optimized integration time for currents (5 to 10 min) and wave data (20 to 30 min). This method results in very reliable and accurate ocean data with a reported data availability of more than 98 % within the last 3 years. This excellent reliability makes these kind of instruments a perfect tool for harbor and coastal management to optimize SAR and pollution drift monitoring.**

Keywords; ocean radar, beam forming, direction finding, accuracy

INTRODUCTION OF WERA

The WERA system is a shore based remote sensing system to monitor ocean surface currents, waves and wind direction. WERA has some unique characteristics, it is using the FMcw technique in a non-interrupted mode to guarantee lowest noise operation and thus providing best signal to noise performance. Furthermore the flexible system design allows to operate WERA with a compact receive antenna array in direction finding (DF) mode or with linear antennas arrays in beam forming (BF) mode. With this unique feature it is possible to compare or combine these methods to optimize the site configuration for the specific application.

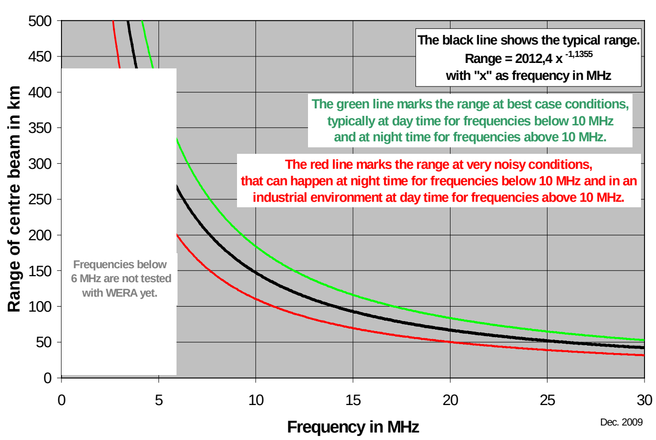

Figure 1. Typical WERA ranges versus operating frequency

In general the range of any ocean radar depends on the operating frequency. The range is increasing at lower frequencies but at lower frequencies the typically available radar bandwidth (depending on the frequency allocation) is decreasing and thus the spatial resolution is getting coarser. For this reason it is always better to use the highest possible frequency to get the required range. The typical ranges that a WERA beam forming system can provide are displayed in figure 1. Even if the transmit power of the WERA system is the lowest compared with other commercial radar systems the achieved range at a given frequency is slightly higher than with ocean radar system using interrupted FMcw mode. The non interrupted FMcw of the WERA system results in an optimal signal to noise performance and thus in the highest range/frequency value [1].

The angular accuracy and thus the useful resolution in azimuth depends on the number of used receive antennas. If a single spot receive antenna concept is used, in case of a WERA system a small square of four monopole antennae, the direction of a received signal is derived from the processed signals in the frequency domain by means of direction finding or Music algorithms. For that reason the accuracy in azimuth strongly depends on the integration time as this defines the resolution in the frequency domain [2]. Of course other site specific parameters such as ocean dynamics can limit the accuracy of such single point measurements [3]. Nevertheless this DF configuration has significant advantages, such as compact site geometry, wide angular field of view and reasonable costs. These are some of the reasons why most of the used ocean radars are DF systems.

Figure 2. Curved WERA receive array on a ranch in Cornwall, UK, with “bull proof” antennae for 12 MHz. The simple monopole antennae are 2.5 m in height and stable without any guy ropes

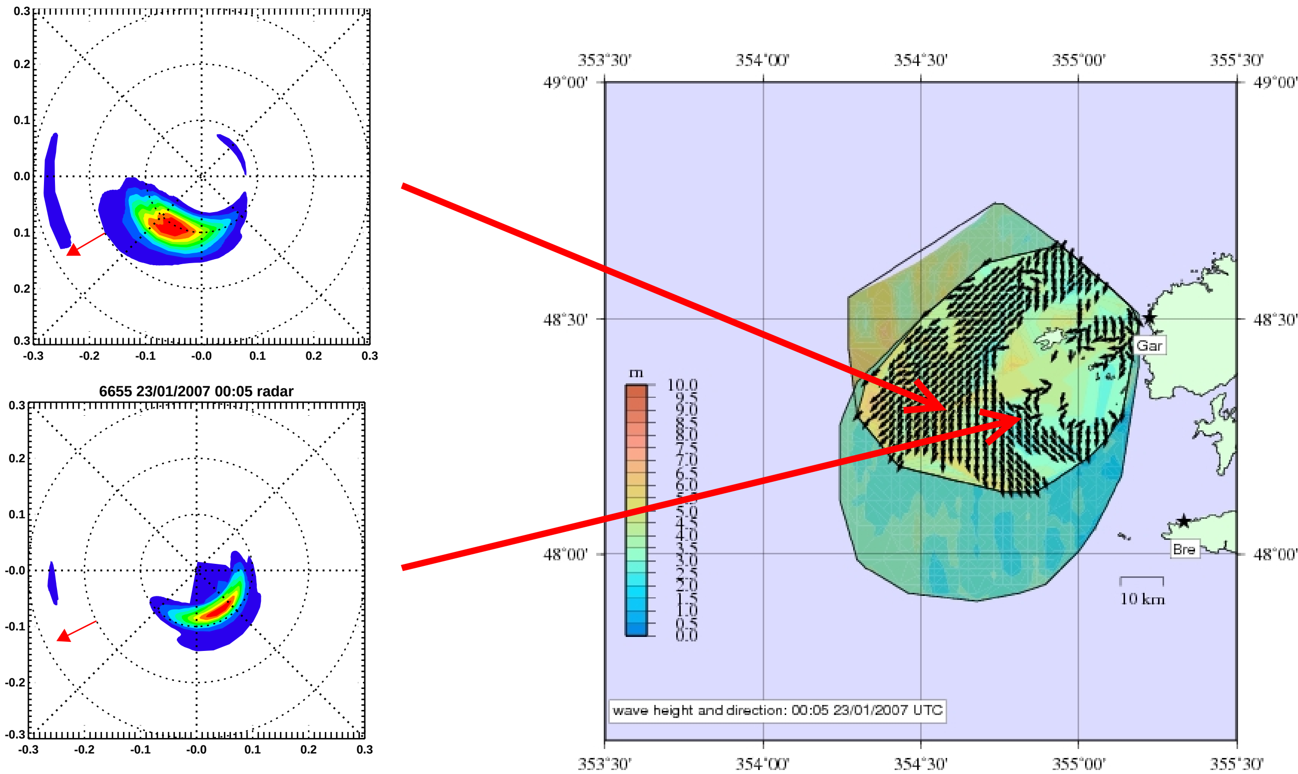

Figure 3. Map of significant wave height, off the coast of Brest, France, measured with a pair of 12.3 MHz 16 channel WERA systems. Two directional wave spectra from pixels just 12 km apart show clearly different wave characteristics. Data are kindly provided by Actimar and Seaview Sensing.

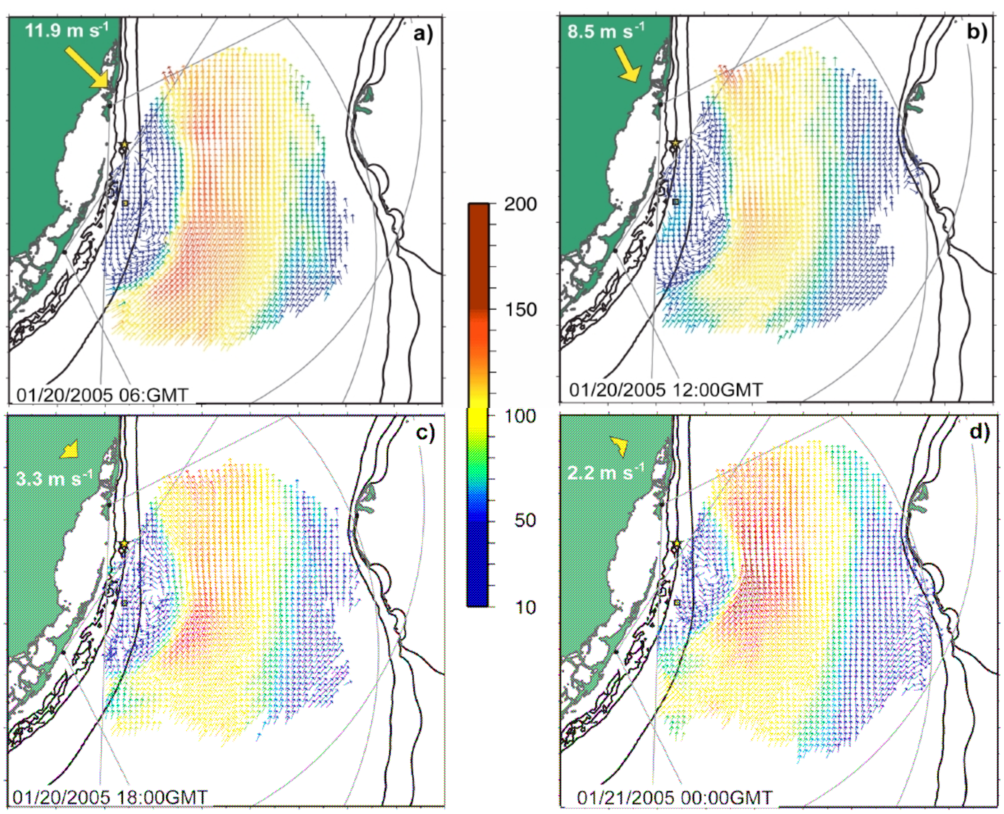

Figure 4: Surface current (cm s-1) evolution of a sub-mesoscale vortex through the EFS radar domain on 20 and 21 Jan 05 associated with atmospheric frontal passage with predominately northwest winds (large yellow arrow) of 12 m s-1

A longer antenna array in combination with the software BF method of the WERA systems provides access to ocean data that are resolved clearly in azimuth as well. The angular accuracy is excellent, up to values better than +/- 1° without any antenna field calibration as the WERA beam forming methods uses a "self calibration" algorithm [4]. The resolution in azimuth depends on the number of used antennae, 8 to 16 for WERA BF.

In addition to this advantage in accuracy the flexibility of the software beam forming allows to adapt the antenna array layout to site specific conditions. An arbitrary spaced antenna array can help to find a suited site location at a rocky coast or a curved array can be used to follow a given structure, see figure 2, or to extend the angular field of view.

From the Doppler spectra measured in BF mode wave information can be derived [5, 6] and even extreme dynamic current structures can be resolved [7]. The access to wave data on the grid (Pixel by Pixel) can be important in very dynamic ocean areas, such as the French coast near Brest, see figure 3.

Another important feature of the BF technique is the much higher temporal resolution compared with DF. Accurate and reliable current data can be provided with an integration time of just 3 to 5 min, this allows to measure very dynamic features such as small scale Eddies [8] as shown in figure 4.

These are the reasons why most of the WERA systems, more than 50, are operating in the BF configuration.

ACCURACY AND RELIABILITY

Publications of the results from systems installed all over the world have proved the accuracy of the WERA systems [9, 10]. A typical comparison of the WERA data with ADCP data measured at Liverpool Bay, UK, are displayed in figure 5.

The reliability of these ocean data was studied for more than 3 years at a permanent WERA installation at the French coast near Brest. This radar operates at a center frequency of 12.38 MHz with a bandwidth of 100 kHz (range cell size of 1.5 km) at 30 Watts rf-power. The accuracy was tested prior to the reliability study in a 2 months experiment. The comparison between the measurement data of the ADCP and the WERA system shows an excellent correlation factor of 0.947. The comparison between the data measured with a "Wave Rider" buoy and the WERA was showing a correlation factor of 0.88, also a very good agreement [7].

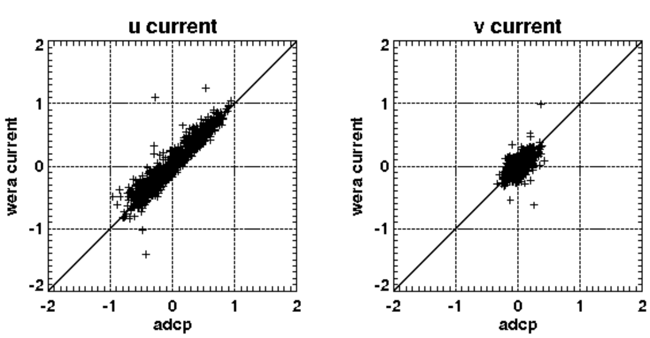

Figure 5. Liverpool Bay WERA u (left) and v (right) current components (m/s) compared with near-surface, fixed depth ADCP
Complex correlation 0.93, 3.8°

The customers demands for temporal availability of ocean current data for this application is very high, 98 % of the time current vectors from all pixels within a range of 40 km should be provided. This demand was fulfilled and 98.6 % of all data were provided within the last 3 years. A coverage map is displayed as figure 6 to display the achieved coverage for current vectors [11].

The basis to get such a high data availability is of course not just the high quality of the equipment but at least as important is well trained and attentive personnel to keep the system operational.

During the last 3 years 480 man-hours per year were required to obtain this high data availability from this pair of WERA stations. This man-power was used for data handling, service and administrative tasks. With this very effective operational service theoretical up to 8 WERA systems can be operated with just one full time engineer. Taking the man-power availability into account and some more remote located radar stations, a realistic number would be 5 to 6 WERA stations per full-time engineer.

Despite the high reliability of the hard- and software of the system, regular maintenance and use of the various monitoring features of the system is mandatory.

As the system is designed to operate remotely, it has automatic functions to monitor all relevant system parameters as well as environmental data. These monitoring functions can be configured to automatically send an email or SMS to the user if a certain threshold is reached.

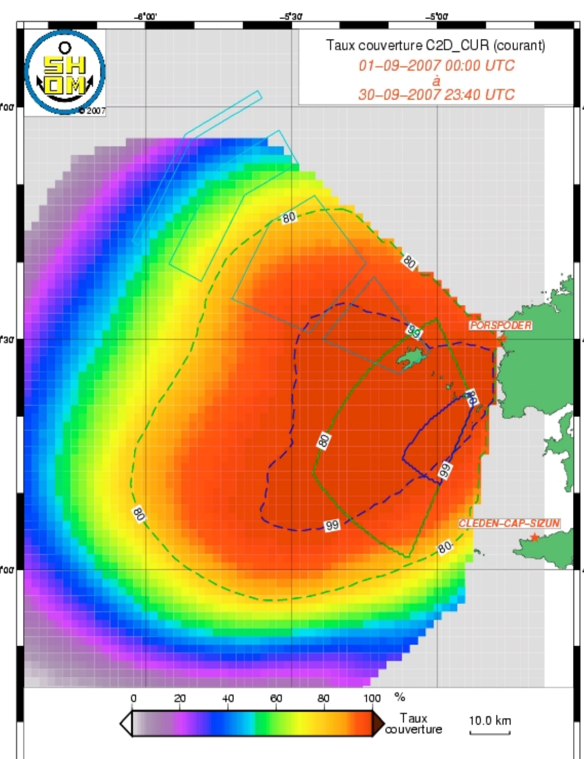

Figure 6. Required areas marked with solid lines
(availability 99 % = blue, 80 % = green)
Achieved areas are marked with dashed lines

BEAM-FORMING AND DIRECTION FINDING

WERA is used in most cases in beam forming configurations but as there are some limitations regarding the angular field of view the combination with direction finding techniques can provide some advantages. In table 1 the features of these both techniques are listed.

Feature	Phased-array with Beam Forming	Compact antenna with Direction Finding
Real-time data update rate	**5/10 minutes for currents and 10/20 minutes for waves**	Requires long data collection period to get full coverage. update rate of 20 to 60 minutes
Siting	Requires antenna array of 8 to 16 small antennas. Array length of 0.5 ... 1‰ of range	**Compact antenna system (3 x 3 to 12 x 12 m) increases ease of installation**
Currents	**High dynamic ocean current structures can be measured down to microscale.**	Mesoscale current structures can be measured, but resolution can be limited due to long integration times and low azimuthal accuracy .
Waves	**Measures the local wave data pixel by pixel. Directional spectra are available as well.**	Can only be measured at one or a few points and requires many assumptions. No access to wave data pixel by pixel.

Table 1. Comparison of WERA system features in DF or BF mode

Both techniques can be used with WERA and the features and limitations of both methods should be taken into account to find the best configuration for a specific application. Of course it is possible to combine both systems as Philippe Forget [12] has demonstrated. Even the combination of radar systems of different manufacturers is possible as an experiment in Florida has clearly shown [13], see figure 7. The definition of a standard data format by NOAA has simplified the combination of systems from different manufacturers.

CONCLUSIONS

Ocean radar is accepted as valuable instrument for a lot of applications in coastal waters. In case of an accident in coastal waters the current drift prediction of drifting persons or objects can be improved by using data provided by ocean radar. Several experiments in the extreme dynamic coastal waters near Brest have shown that even here the WERA data based predictions are significantly better than model based predictions.

Ocean radar systems are generally very reliable as the instrument is installed on shore. Even if the investment may be higher compared with some buoy deployments, the maintenance costs are significantly lower. The beam forming configuration has the advantage of some redundancy and as a higher immunity against external interference resulting in outstanding data availability.

NEW DEVELOPMENTS

Actually the development of new techniques for WERA is focussing to increase the flexibility for the site geometry. This will simplify the installation of this shore based systems and should reduce the costs for the required site preparation and installation.

ACKNOWLEDGEMENT

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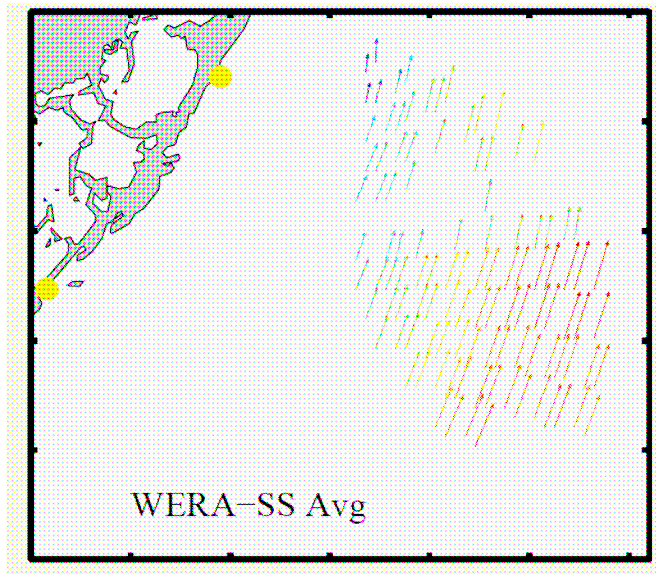

Figure 7: Current vectors derived from eight-day average of WERA and Seasonde data from 2005,data are kindly provided by L. Shay, RSMAS

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