MONITORING PARAMETERS FROM AN HF RADAR: CASE STUDY AT COFFS HARBOUR, AUSTRALIA

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1. INTRODUCTION

A High Frequency (HF band) ocean radar is being installed at Coffs Harbour in northern New South Wales as a part of the Integrated Marine Observing System under the National Collaborative Research Infrastructure Strategy. The main features to be monitored are the East Australian Current (EAC) between the edge of the continental shelf (at about 35 km from the shore) and the eastern edge of the EAC at about 100 km from the shore; the meanders and eddies which bring EAC and deep water onto the shelf; and the wave field as it interacts with the EAC (refer to Fig.1). Near-shore applications include island and headland lee eddies which require high spatial resolution, while the understanding of erosion events requires high resolution wave and current fields. Here we show how an optimal radar configuration has been achieved which best matches the radar observations to the anticipated research applications in the area. The requirement to measure directional wave spectra over an extended area directs us to the phased array genre. The request for high spatial resolution corresponds to a wide bandwidth for the radar. The operating frequency impacts on the maximum range that the radar will achieve, and lower operating frequencies generally produce better directional wave spectrum outputs. The accuracy of the measurements of surface current is linked to the operating frequency and to the length of each time series used to produce radar Doppler spectra. The paper gives a definitive set of observed parameters, with a rationale for how the error bars arise and what the limitations are for the system.

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2. OPERATING RANGE

The operating frequency of the radar determines the maximum range for first-order echoes that will be useful for extracting surface current data, and the frequency also controls the performance of the algorithms to extract the directional wave spectra.

At the latitude of Coffs Harbour the continental shelf is about 25 km wide to the 120 m contour and then drops abruptly to be 300 m deep at about 30 km offshore. The main flow of the East Australian Current follows the outside edge of the shelf break, but at these latitudes billows and meanders are already forming. The oceanography of the shelf requires a range of only 40 km, and any extra range would be useful for the study of the dynamics of the EAC.

Figure 2 is a schematic which shows expected operating ranges for WERA systems at

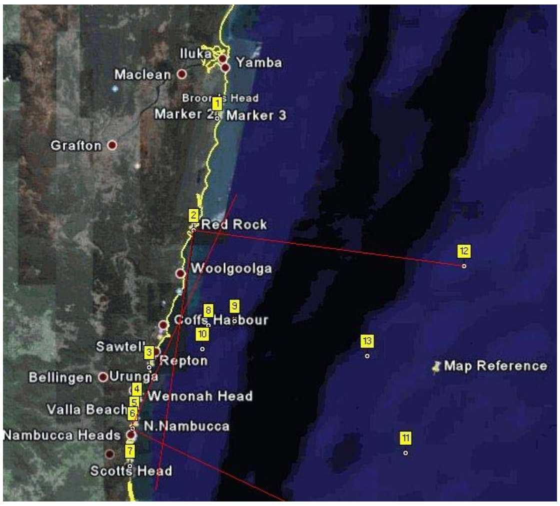

Figure 1. The Coffs Harbour radar site showing the preferred locations for stations at Red Rock and N.Nambucca. Reference points 11 and 12 are about 100 km from the shore. Points 8, 9, and 10 are in situ moorings to be used for comparison and validation work.

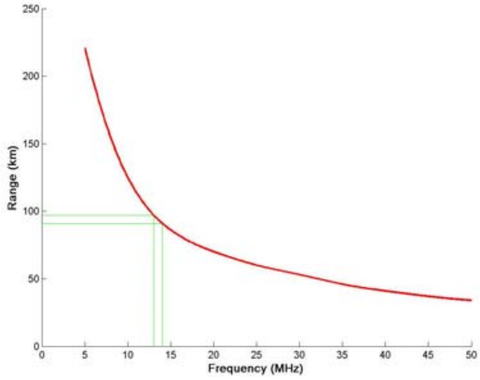

Figure 2. A stylised curve for typical working range as a function of frequency. The green lines give reference lines at 13 and 14 MHz.

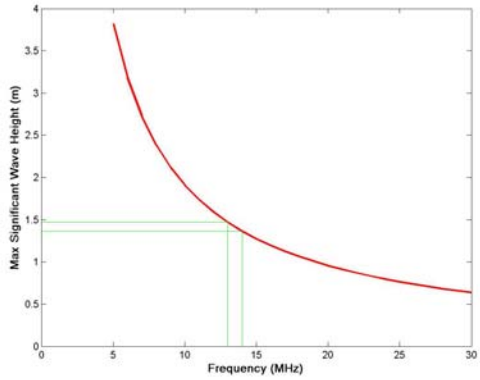

Figure 3. The maximum significant wave height condition versus radar frequency following Barrick 1977.

different frequencies. The operating range referred to here is the normally expected range over all times of the day and can be taken as a reasonable specification. There will be times when interference destroys the radar signal, and there will be times (mainly during daylight hours when the ionosphere has absorbing lower layers) when the radar will operate to 30% beyond the specified range. For coverage of the oceanography of the continental shelf in this region, this installation could operate at 30-40 MHz. An operating frequency of 12-14 MHz will give an operating range of 90-100 km.

3. DIRECTIONAL WAVE SPECTRA

HF ocean radar wavelengths are generally shorter than the wavelengths of the gravity waves at the peak of the wind wave spectrum. The Bragg scattering ocean wave is the one with wavelength half that of the radar electromagnetic wave. The longer waves in the gravity wave spectrum modulate the ocean Bragg wave by surging it forwards and backwards. This produces a phase modulation on the scattered electromagnetic wave and sidebands appear in the Doppler spectrum of the echoes. For a single modulating wave it can be shown that the sidebands are Bessel Functions of the first kind; and for a continuum of modulating sea waves there is a continuum of overlapping Bessel functions. This modulation approach to analysis is used by Gill and Walsh (2001). There are also discrete lines in the second-order spectrum produced by geometric effects.

Barrick used a 2D Fourier representation of the sea surface to calculate first-order and second-order echo spectra, and used the ratio of second to first order energies to calculate significant wave height (Barrick, 1977):

$$k_0 h_{sig} = 4\sqrt{2}R^{1/2}$$

where k_0 is the radar wavenumber. Approximations in this derivation require that $k_0 h_{sig} > 0.4$, and the requirement is shown in Figure 3.

The condition illustrated in Fig. 3 is not one that applies abruptly and other authors (e.g. Heron and Heron, 1998) have shown that an algorithm can be calibrated for wave heights about 3 times those indicated in Fig. 3.

The wave climate has been established by wave data taken from a series of wave rider buoys on the shelf off Coffs Harbour over a period of 31.62 years. The data are displayed in Fig. 4. The mean significant wave height over the period is 1.57 m and the highest recorded is 7.36 m. To be effective, wave height measurements need to be made on waves with heights between 0.3 and 4.5 m. The 4.5 m level is exceeded 0.3% of the time. The analysis for directional wave spectrum has similar limitations.

A radar operating in the 12-14 MHz band will measure significant wave heights up to about 4.5 m and will saturate for waves bigger than that which occur about 0.3% of the time.

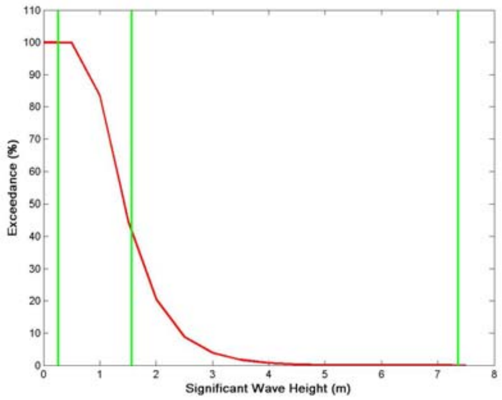

Figure 4. Exceedance data for Hsig on the shelf off Coffs Harbour. The vertical green lines show the minimum, the mean and the maximum significant wave height. Data provided by the Manly Hydraulics Laboratory and is owned by the Department of Environment and Conservation, NSW

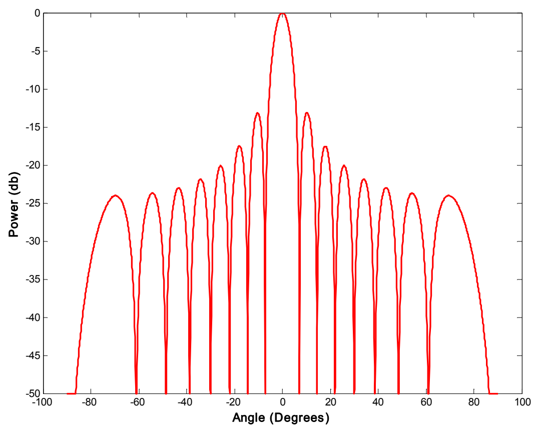

Figure 5. Antenna beam pattern for 16 elements spaced half a wavelength apart (db scale).

Table 1. Antenna beam widths (3db) in degrees for commonly used numbers of elements. The pixel width in km is given for a range of 15 km which corresponds to the mid-shelf region at Coffs Harbour.

Elements	4	8	12	16
3db Width (degrees)	26.1	12.6	8.30	6.16
Pixel width at 15 km (km)	6.83	3.30	2.17	1.61

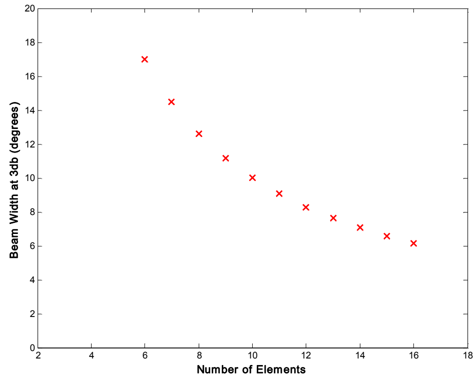

Figure 6. Beam widths (3 db) for different numbers of elements in the phased array spaced at half wavelength intervals.

4. SPATIAL RESOLUTION

For a phased array system, each pixel is determined in 2D polar coordinates by an increment in range and an increment in azimuthal angle.

4.1 Azimuthal Angle Resolution

Phase and amplitude signals are recorded for each individual element in the receive array of antennas. This means that beam forming can take place off line in an analysis phase of the data processing. The beam can be formed in any direction, and the question of resolution arises to determine how far apart the chosen directions have to be, to be uncorrelated. Fig. 5 shows the beam formed in the boresight direction.

4.2 Range Resolution

The WERA radar operates in a chirp modulation mode with a precision linear sweep of the transmitter through the allocated bandwidth , B. At any time there is a series of echoes at frequencies lower than the current transmitter frequency, and the frequency offset for each is a measure of the range for that signal. At the end of the transmitter sweep through the complete bandwidth the system carries out a Fourier analysis to convert frequency offsets into time delays, and from this the range is determined from the speed of the electromagnetic wave. The time resolution is $\Delta t=1/B$, and the corresponding range resolution is $\Delta r = c\Delta t/2$.

Table 2. Range resolution varies linearly with the radio spectrum bandwidth, B.

B (kHz)	25	50	75	100
Δr (km)	6.0	3.0	2.0	1.5

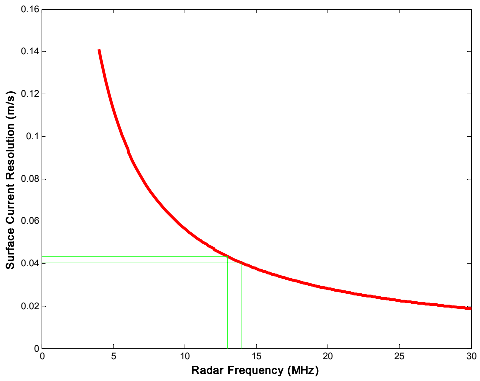

Figure 6. Surface current resolution for a range of radar operating frequencies, showing the inverse proportionality. These calculations are based on a time series ampling length of 266 seconds. The green lines are reference lines at 13 and 14 MHz.

The basic pixels are not square. If we specify a system which has 16 elements and 100kHz bandwidth then the pixels inshore from a reference range of 15 km will be elongated in the range direction, and offshore from the reference range they will be elongated in the azimuthal direction. The optimum configuration for this deployment has square pixels at a range of about 15 km, in the mid-shelf region.

The preferred configuration for the Coffs Harbour radar is 16 elements and a 100kHz bandwidth. This has 1.5 km x 1.5 km pixels in the middle of the shelf.

5. SURFACE CURRENT RESOLUTION

The resolution of the component of surface current radially from the radar station depends on the length of the time series taken at the Analogue/Digital Converters on the receivers, and on the radar operating frequency.

Starting with the dispersion equation for surface gravity waves

$$C_w = \text{sqrt}\{g/(2\pi\lambda)\}$$

and for electromagnetic waves

$$C_e = 2f\lambda$$

where λ is the wavelength of the Bragg wave on the sea surface, and using the expression for Doppler shift for reflection from an object travelling at v m/s

$$\Delta f = 2vf/C_e$$

It can be shown that the frequency shift due to a surface current component in the radial direction is

$$\Delta f = (g/2\pi\lambda)^{1/2} + v/\lambda.$$

If we know the accuracy of the measurement of Δf then we would know the resolution of the measurement of v.

The value of the frequency shift, Δf, is measured from a power spectrum produced by Fourier Transforming a time series of length T seconds. T is the length of one radar run, which for Coffs Harbour will be 266 seconds.

This duration is chosen so that the two radar stations can run in alternating 5 minute periods, giving an effective 10 minute sampling interval for currents. This is considered to be sufficient for detecting tidal and wind driven surface current features. With T fixed at 266 seconds the smallest increment in Δf is 0.00376 Hz and the quantum for v is linear with radar wavelength as shown in Fig. 6. At an operating frequency of 13 MHz the surface current resolution would be about 0.043 m/s.

6. CONCLUSIONS

The choice of an operating frequency in the 12-14 MHz band means that the operating range will be in the 80 -100 km interval, which should provide measurements beyond the strongest parts of the East Australian Current. A lower operating frequency would have produced longer ranges for data acquisition, but would compromise accuracy. The choice of the operating frequency in the 12-14 MHz band gives an accuracy of about 0.04 m/s for the radial components of surface currents when a time sampling of 5 minutes (alternating) is used for each radar station. If a higher operating frequency were used the surface currents would be measured more accurately. The setting of the operating frequency also fixes a limit of about 4.5 m for the measurement of significant wave heights before the second-order spectrum saturates The climatology of wave heights in the area indicates that this saturation effect will occur about 0.3% of the time. A lower operating frequency would raise this limit.

The setting of the radar bandwidth to 100 KHz fixes the spatial size of the pixels in the radial direction to 1.5 km. Combined with the azimuthal beam width of 6.16 degrees for a 16-element phased array, this gives square pixels in the middle of the continental shelf. Closer to shore the pixels are elongated in the radial direction (limited by bandwidth) and beyond the shelf edge they are elongated in the azimuthal direction (limited by beam width).

ACKNOWLEDGEMENTS

Figure 4 is based on data provided by the Manly Hydraulics Laboratory and it is owned by the Department of Environment and Conservation, NSW. This work is a product of the Australian Coastal Ocean Radar Network, the Integrated Marine Observing System, and the Australian National Collaborative Research Infrastructure Strategy.

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