Multi-Frequency HF Radar
For Mapping Current Shear and Vector Winds

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***Abstract* – A new radar is in final stages of development and testing by Imaging Science Research (ISR), Inc., under sponsorship by the Office of Naval Research. The system is based on digital receiver technology incorporated into a PC operating environment. The capability of broad band operation across the whole HF band and beyond allows for new applications in both ocean sciences and ship traffic control. Use of bistatic geometry simplifies logistics and allows all data acquisition and processing to be done at a single site. The use of multiple frequencies for ocean science application allows one to measure current shear in the vertical dimension over depths of the order of a few meters. Recent results by other co-workers has shown that under some conditions, such vertical shear can be used to infer wind speed over the radar cell by matching the stress across the surface boundary layer.**

I. INTRODUCTION

Mapping of ocean currents by HF radar has developed into a commercial off-the-shelf capability, with the original OSCR radar developed in England, the CODAR systems developed in the US, and most recently the WERA system developed in Germany. All of these systems make use of the ability of HF radar to measure the Doppler shift due to the phase velocity of the specific ocean wave that is one-half the radar wavelength. This phase velocity is modified by the mean ocean currents averaged over the radar cell, and it is the radial component of the current vector that is measured. The radar effectively picks out the ocean wave component from the directional spectrum that is traveling toward and away from the radar, so the actual phase velocity for that wave component is modified by the local radial ocean current field. A diagram of this scatter and the measured Doppler shift is shown in Figure 1, due to early work by Harlan at NOAA..

HF radar sees the ocean surface as a nearly perfect conductor, and can thus propagate over the horizon in a surface wave mode to ranges as far as two hundred miles or more, depending on the radar frequency chosen. The lower the frequency, the less the propagation loss and the longer the coverage range.

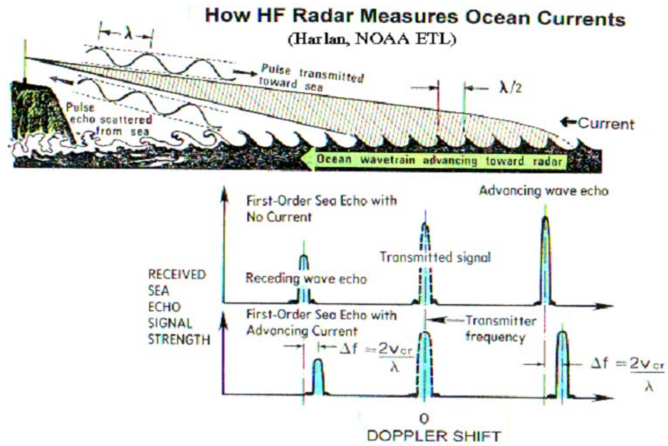

Figure 1. Diagram of HF radar sea scatter and Doppler spectra with and without current present.

The scatter satisfies first order perturbation theory well at HF, and was developed by Barrick in the early 70's [1]. The Doppler spectrum created by processing a sequence of pulses collected over the order of several minutes at a pulse repetition frequency of several Herz produces a pair of Doppler spectrum peaks due to the first order scattering mechanism. The prime offset from zero in the first plot of Figure 1 is due to the resonant component phase velocity, for waves traveling away and toward the radar that result in peaks symmetric about zero Doppler. Their amplitudes reflect the azimuthal spectral component amplitudes from the azimuthal spread of components over 360^o, components that are some angle θ relative to the wind, and $\theta+\pi$ to the wind direction. If θ =90o, then the amplitudes are equal, since the components are at right angles to the right and left of the wind and wave direction. When aligned along the wind direction, the relative amplitudes are typically 24 to 26 dB different. Such information was used to map wind direction at long range using ionospheric propagation, and could define the location of storm centers quite accurately [2, 3].

The first demonstration of ocean radial current measurement was made using over-the-horizon propagation on the Gulf Stream location at NRL using the same MADRE radar that was used for wind direction mapping [4]. Subsequent work by NOAA personnel using Navy radars continued this OTH work, the most recent reporting a quantitative test of the method when land boundaries are present [5]. Surface wave measurements of currents were first reported by Lipa and Barrick [6], leading to the development of the commercially successful CODAR system.

II MULTIFREQUENCY MEASURE OF CURRENTS AND WIND SPEED

The utilization of a pair of HF radar frequencies showed that the currents varied with radar frequency, the lower the frequency the smaller the radial current measure [7]. The shift in direction with frequency appeared to follow that predicted by Eckman rotation. Later work using four frequencies verified these observations [8], and the data appeared to fit a logarithmic profile with depth. It was concluded that the radar sensed currents to the order of a 4% fraction of an ocean wavelength. Comparisons with in-situ ADCP measurements were quite good.

The measure of the logarithmic profile satisfies Monin-Obukov theory of turbulence and mixing, according to the following equations.

$$u(z) = \frac{u_*}{k}\left[\ln\left(z/z_0\right) - \psi\left(z/L\right)\right]$$

where

u_* is the friction velocity

k is the von Karman constant 0.4

z_0 is the roughness length

L is the Monin - Obukhov length

This equation holds in the water and air, and logarithmic profiles are predicted in both mediums under equilibrium conditions. The stress across the interface, τ, is constant under these conditions, so that we can relate the surface velocities by continuity of stress across the interface:

$$\rho_A \, u(z)_A = \rho_W \, u(z)_W \quad at\ z=0$$

where the subscripts A,W refer to air and water, respectively. Thus with a measure of the logarithmic profile of the current shear one can determine the surface value of each current and wind speed and estimate the corresponding logarithmic profile of the wind speed. From this one can estimate the wind a fixed altitude and map the vector winds forcing the subsurface current shear. Vesecky, et al, [9] demonstrated such a capability using four frequencies, and the results compared quite well with winds measured by a buoy in one of the radar cells. This capability to map winds and current shear over a large area provides an extra dimension for use by oceanographers and atmospheric scientists in developing predictive models for winds and waves in coastal areas, although much work remains to be done.

III. MULTI-FREQUENCY HF RADAR

A discussion of the design of our multi-frequency HF radar has been presented in another paper in these proceedings [10]. We showed examples of our prototype radar's ability to collect 32 radar frequencies simultaneously. Figure 2 below shows a plot of the HF band and the corresponding depth estimates dependence on radar frequency. The corresponding height of the monopole required in a log-periodic array (LPA) design that we discussed there is also shown. It becomes clear that the required heights soon become unrealistic from the standpoint of guying. Alternatively, commercial antennas with purchase and deployment costs of greater than $100K are available, but require much more space than most sites can allow. The LPA design we discussed in [10] circumvents this height difficulty, and allows the full range of the HF band as usable for ocean current shear measurements.

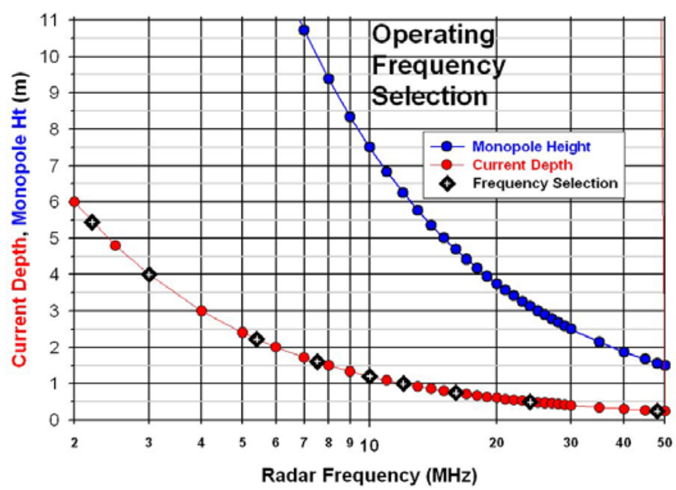

Figure 2. Current depth and antenna height plotted versus radar frequency.

1V. SUMMARY

We have provided some background on HF radar multi-frequency current measurements. We discussed the requirements of a multi-frequency antenna design to cover the HF band for such measurements, and offered a solution of a log-periodic array using our newly designed low height profile elements to circumvent unrealistic and expensive quarter wavelength monopole elements for this band. We have built such a system to cover 3-30 MHz and are currently testing the system.

We will continue to collect data through the summer months at our U.S.A.C.E. Field Research Facility at Duck, NC, to complete system testing and to derive measurements of current shear and wind speed estimates. At the conference, we will report on these results in more detail.

REFERENCES

[1] Barrick, D.E., Theory of HF/VHF propagation across the rough sea. Part II: Application to HF/ VHF propagation above the sea, Radio Science, vol. 6, 1971, pp. 527-533.

[2] Long, A.E., and D.B. Trizna, "Mapping of North Atlantic winds by HF radar backscatter interpretation, IEEE Trans. Antennas Propagation", vol. AP-21, 1973 pp. 680-685.

[3] Stewart, R.H. and J.R. Barnum, "Radio measurements of oceanic winds at long ranges: an evaluation", Radio Science, vol. 10, 1975, pp. 853-857.

[4] Trizna, D.B., "Mapping ocean currents using over-the-horizon HF radar, International Journal of Remote Sensing, **3**, 1982, pp. 295-301.

[5] Georges, T. M., J. A. Harlan, R. R. Leben, and R. A. Lematta , "A test of ocean surface current mapping with over-the-horizon radar", *IEEE J Geosci Remote Sensing* vol. 36, no. 1, 1998, pp. 101-110.

[6] Lipa, B.J. and D.E. Barrick (1983), Least-squares methods for the extraction of surface currents from CODAR crossed-loop data: Application at ARSLOE, IEEE J. Oceanic Engr., vol. OE-8, pp. 226-253.

[7] Fernandez, D.M., J.F. Vesecky and C.C. Teague, Measurements of upper ocean surface current shear with high-frequency radar, J. Geophys. Res., 101, 1996, pp. 28,615-28,625.

[8] Teague, C.C, J.F. Vesecky, Z.R. Hallock, "A comparison of multifrequency HF radar measurements and ADCP measurements of near-surface currents during COPE-3", IEEE J.O.E, Vol 26, 2001, pp. 399-405.

[9] J.F. Vesecky, J. Drake, C.C. Teague, F.L. Ludwig, K. Davidson, J. Paduan, "Measurement of wind speed and direction using multi-frequency HF radar", Proceedings of the 2002 International Geoscience and Remote Sensing Symposium, Toronto, 24 - 28 June 2002.

[10] Trizna, D.B., "Dual use multi-frequency radar for current shear mapping and ship target classification", Oceans 2003 Proceedings, 22-25 September 2003, San Diego.