Accuracy of Surface Current Velocity Measurements Obtained from HF Radar in Corpus Christi Bay, Texas

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***Abstract*-Surface current mapping by means of High Frequency radar is an operational oceanographic tool. Researchers have identified the basic sources of error associated with this technology. Further research evaluating errors relating to the HF radar system and corresponding algorithms can facilitate coastal environment data assimilation. Uncertainty due to two sources of error is studied to obtain a more complete accuracy of the HF radar-measured total surface current velocity vectors. The error sources include geometry of the two station HF radar system and limits of the deep-water wave assumption of the algorithm that calculates current velocity from the HF radar signal. The latter is of particular interest to our work in a shallow environment such as Corpus Christi Bay. Water depths in portions of this and other Texas bays will push the limits of the deep-water assumption for the wavelengths of interest. A map of Corpus Christi Bay illustrating quantified GDOP for each point on the radar grid and an applicable matrix transformation that accounts for error due to the deep water wave assumption. The deep water assumption error is quantified and shown to be minimal for depths as shallow as one meter.**

I. INTRODUCTION

The Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University Corpus Christi and the Texas Engineering and Experiment Station (TEES) deployed two High Frequency radar units to monitor Corpus Christi Bay. These SeaSonde® 25-MHz HF radar systems, manufactured by CODAR Ocean Sensors, collect real-time surface current velocities at high spatial and temporal resolution (Fig. 1).

Many comparative experiments of HF radar versus various *in situ* instruments have been performed with good results (e.g., [1], [2], [3], [4]). To further explore HF radar for use in a shallow-water enclosed bay we are studying the algorithms that produce surface current-velocity data. This paper delves into assumptions made by the standard algorithms that process radial data produced by the instrument. The potential error due to the geometry of the Corpus Christi Bay system is calculated, and a matrix transformation is presented that handles the unique use of this instrument in a shallow water environment. The effect of utilizing the deep water wave assumption is shown to be minimal for depths as shallow as one meter.

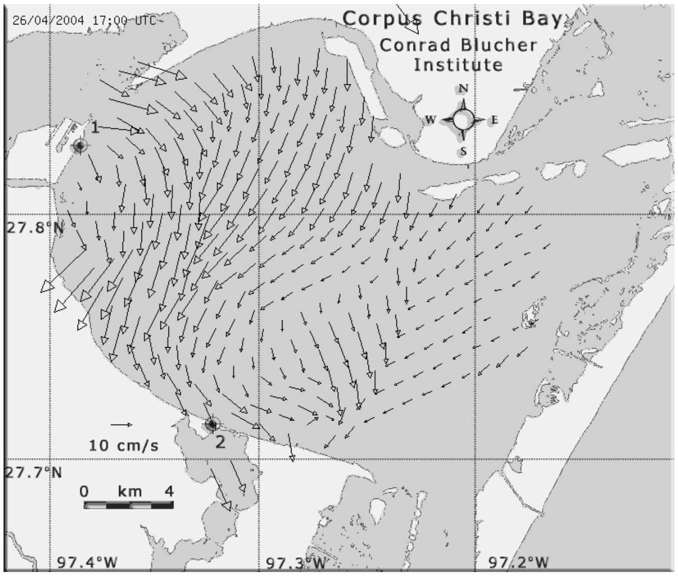

Figure 1. Total surface current vector map of Corpus Christi Bay for April 04, 2004 17:00 UTC unedited for GDOP.

II. GEOMETRICAL UNCERTAINTIES

In the area around the baseline (the line connecting the sites, Fig. 2), the radials are increasingly parallel, and the orthogonal component tends to zero. As the combining radial vectors deviate from orthogonality, the potential error in the total vectors increases.

The geometrical dilution of precision, or GDOP, is a coefficient of uncertainty that characterizes the effect of the geometry of the coupled radar system on the measurement and position determination errors [8]. A low GDOP corresponds to an optimal geometric configuration of radar stations [9].

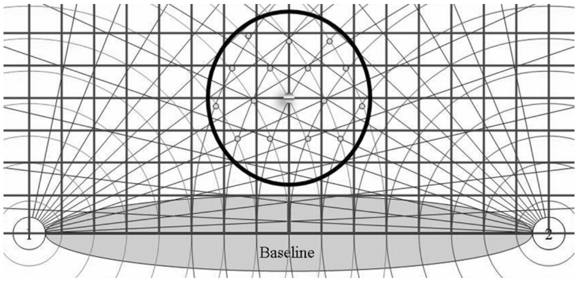

Figure 2. General illustration of the geometry of a rectangular grid and combining circle of a two-station network (not to the scale of Corpus Christi Bay).

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From [3], estimates for the errors in the north and east components are:

$$\sigma_n = \left[2 \left(\frac{\sin^2(\alpha)\sin^2(\theta) + \cos^2(\alpha)\cos^2(\theta)}{\sin^2(2\theta)} \right) \right]^{\frac{1}{2}} \sigma \tag{1}$$

$$\sigma_e = \left[2 \left(\frac{\cos^2(\alpha)\sin^2(\theta) + \cos^2(\alpha)\sin^2(\theta)}{\sin^2(2\theta)} \right) \right]^{\frac{1}{2}} \sigma \tag{2}$$

where, α is the mean look angle, θ is half of the angle of the intersecting beams (see Fig. 3), and σ the root mean square differences in the current estimates. The ratios σ_n/σ and σ_e/σ are the north and east GDOPs.

Researchers have used GDOP as a constraint to the HF radar measurement domain [1], or have eliminated GDOP errors by limiting comparisons to strictly radial vector data [10]. Here, GDOP is calculated for each grid point so that it can be directly applied to the determination of the accuracy of the east and north components of the total velocity vector.

Fig. 4 is created by calculating GDOP for each radar grid point in Corpus Christi Bay. Except for a region around the baseline, the GDOP is less that 2.0 for almost all the bay. Because of the location of the sites, there is even a small region close to the west end, in front of the entrance to the Port of Corpus Christi, where GDOP is also less than 2.0.

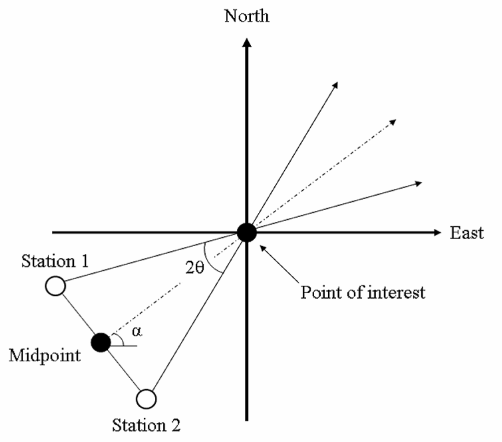

Figure 3. Adapted from Chapman et.al. 1997 to define α and θ. 2θ is the angle of intersecting beams and α is the angle that the line intersecting the midpoint and origin makes with respect to due east [4].

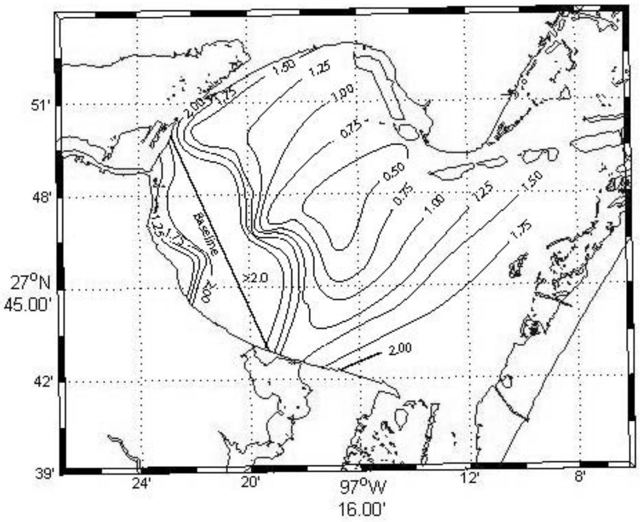

Figure 4. Contour map of Corpus Christ Bay illustrating GDOP

III. DEEP-WATER WAVE ASSUMPTION

HF radar algorithms assume the ocean waves are deep-water wind waves. The deep-water approximation is valid within 0.5% if the water depth h is greater than half of the wavelength, L. The theoretical speed of a wave using deep-water dispersion relation is given by [11]

$$C_d = \sqrt{g\left(\frac{L}{2\pi}\right)} \tag{3}$$

where g is the acceleration due to gravity and L is the wavelength of the ocean scattering wave

Fig. 5 illustrates the convenience of using the deep-water dispersion relation. For $h > L/2$, in the deep-water wave zone, the wave speed is constant for the known wavelength of the Bragg ocean scatter wave, L. In contrast, the wave speed in the intermediate zone is non-linear because of the hyperbolic tangent term in

$$C = \sqrt{\frac{gL}{2\pi}\tanh\left(\frac{2\pi h}{L}\right)} \ . \tag{4}$$

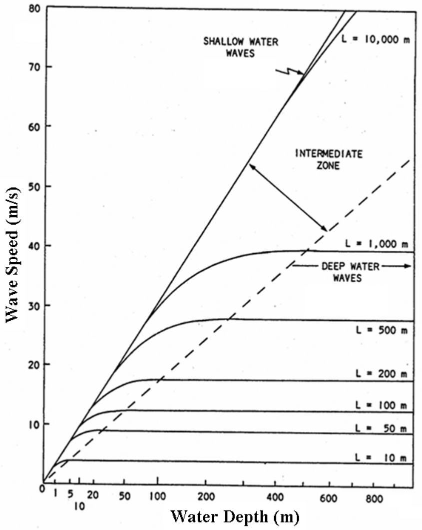

Figure 5. Wave speed versus water depth for various wavelengths [8].

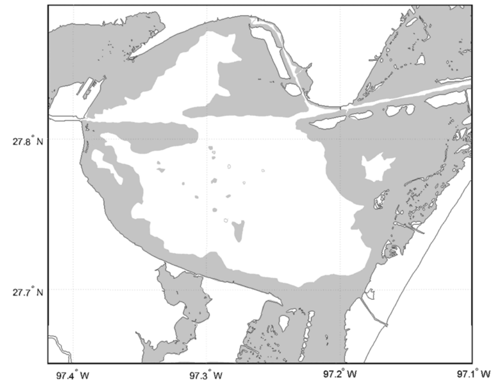

Figure 6. Illustration of areas (shaded in grey) in Corpus Christi Bay that may exceed the lower limit of water depth at 0.5% error. The values of water depth are obtained using NOAA navigational chart 11314.

Except in the dredged shipping channels, the water depth of Corpus Christi Bay is less than about 4.3 m (Fig.6). Some shallow regions of the bay violate the limits of the deep-water wave assumption for the wavelengths of the two deployed radars (Table I).

Most SeaSonde® radar systems have been set up and tested overlooking waters such as the Gulf of Mexico [1][2] and Long Island Sound [5] where the deep-water assumption is valid. Fig. 7 illustrates the influence of the deep-water assumption on total vector velocity measurements at the University Beach site. Note that simply de-rating the acceptable limit to a 1% error results in a difference of a few millimeters per second, and puts almost the entire bay into the "deep water" category.

Detailed bathymetry for Corpus Christi Bay has been conducted in limited regions only. The error introduced by using the deep-water assumption is applicable in the Corpus Christi Bay HF radar system at depths of less than three meters. To derive the function of error due to water depth, a composition of linear transformations is applied to the solution matrix, *C*. First *C* is translated by e_1 which is obtained by determining the limit of the full dispersion relation as water depth increases infinitely as shown in (4).

TABLE I
CORPUS CHRISTI BAY HF RADAR SITE CONFIGURATIONS WITH CORRESPONDING WAVELENGTHS OF THE ELECTROMAGNETIC WAVE AND BRAGG OCEAN SCATTER WAVE AND THE APPROXIMATE MINIMUM DEPTH FOR WHICH THE DEEP-WATER DISPERSION RELATION IS VALID.

Radar Site Name	University Beach	North Beach
Operating Frequency	25.25 MHz	26.24 MHz
Electromagnetic Wavelength	11.88 m	11.43 m
Bragg Scattering Ocean Wave Wavelength	5.94 m	5.72 m
Approximate Minimum Depth 0.5% Error	2.5 m	2.4m
Approximate Minimum Depth 1% Error	2.2 m	2.1 m

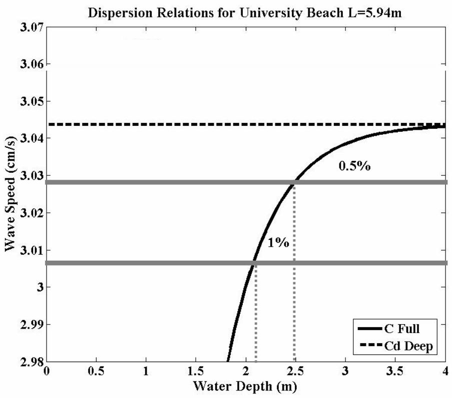

Figure 7. Wave speed against water depth for University Beach HF radar site wavelength. Solid grey lines represent the error bounds for deep-water wave speed and the dotted grey lines show the minimum depth for which the deep-water dispersion relation applies.

$$\lim_{h\to\infty}\left[\sqrt{\frac{gL}{2\pi}\tanh\frac{2\pi h}{L}}\right]=e_1 \tag{5}$$

For University Beach and North Beach respectfully, the values of $e^U{}_1$ and $e^N{}_1$ are

$$\lim_{h\to\infty}\left[\sqrt{\frac{9.8(5.94)}{2\pi}\tanh\frac{2\pi h}{5.94}}\right]=3.0438=e_1^U \tag{6}$$

$$\lim_{h\to\infty}\left[\sqrt{\frac{9.8(5.72)}{2\pi}\tanh\frac{2\pi h}{5.72}}\right]=2.9869=e_1^N\ . \tag{7}$$

The second transformation is a rotation about the x-axis applied to both site's data sets as

$$e_2=\begin{pmatrix}-1 & 0 & \cdots & 0\\ 0 & -1 & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & -1\end{pmatrix}_{m,n} \tag{8}$$

where e_2 is a square matrix and $m = n =$ size of data set. In matrix notation, the error can be applied to the discrete radial speed solution matrix, *C* as

$$error_h^U=C^U e_2-e_1^U \tag{9}$$

$$error_h^N=C^N e_2-e_1^N \tag{10}$$

If one is willing to accept an increased, but calculable bias in the error associated with the deep-water assumption, the surface current measurements from HF radar for applications in a shallow-water region are practical. In our case, a de-rating from 0.5% to 1.0% yields acceptable results over the entire bay, to within about 200 m of the shore.

IV. CONCLUSION

Error due to the geometry of the HF- radar system deployed for Corpus Christi Bay has been calculated (GDOP), and a matrix transformation has been developed to deal with the unique use of this instrument in a shallow-water environment. The error due to the deep-water wave assumption is shown to be nominal, on the order of millimeters per second for depths as shallow as one meter for an operating frequency of about 25MHz, and puts almost the entire bay into the “deep water” category.

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DISCLAIMER

This paper does not necessarily reflect the views or policies of the Texas General Land Office, Texas A&M University, Texas A&M University-Corpus Christi, the University of South Florida, or the other agencies providing financial and service support. Mention of trade names or commercial products does not constitute a commercial endorsement or recommendation for use.

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