

Geometric Dilution of Precision of HF Radar Data in 2+ Station Networks

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Introduction

The goal of this Directed Independent Study (DIS) is to provide a basic understanding of High-Frequency Radar, what it is and how it works, and then to examine the concept of Geometric Dilution of Precision in HF Radar networks and how GDOP affects data accuracy. Methods of calculating GDOP are explained, followed by a sample calculation of several points in Corpus Christi Bay, and a comparison of GDOP determination methods. This analysis will be considered in the implementation of a five-site radar network on the Texas Gulf Coast by the Conrad Blucher Institute.

High Frequency Radar is a tool that measures real-time surface currents. An example of the usefulness of this technology is that of environmental contaminant tracking. Many pollutants that can be introduced to a coastal environment are surface borne, such as oil. The dispersion of these pollutants depends on the movements of near-surface currents. High Frequency radar technology allows for us to accurately predict the trajectories of such pollutants. It has many other useful applications as well, such as navigation, port and bay management, and hydrodynamic and ecological modeling.

“Radar” is an acronym for RADio Detection And Ranging. The kind of Radar being discussed here is High-Frequency Radar, specifically CODAR Radar (Coastal Ocean Dynamics Application Radar), but from this point on I will simply be referring to “HF Radar”. The frequency range that HF Radar produced by CODAR Ocean Sensors, Inc. operates at is 4-50 MHz, which allows for radio wavelengths between 10 and 100 meters.

A normal radio typically consists of transmitter and receiver circuitry and an antenna. In the case of CODAR radar, the transmitter and receiver units each have their own antennas. The transmitter sends out a signal through an omni-directional transmit antenna, which covers a large area of surface water on which are riding normal wind waves, assumed to be “deep water,” i.e., conform to linear deep water wave theory. This transmitted radio signal is simply energy in the form of radio (electromagnetic) waves that are then “bounced back” or “scattered from” the surface of the water. In particular the incident electromagnetic waves will interact constructively or resonate with water waves with the half their wavelength leading to Bragg Scattering of the incoming radio waves. The return Bragg Scatter signal is then processed to extract the surface current velocity. The surface current velocity is actually a second-order measurement derived from the Doppler shift of the reflected radar signal. Figure 2 shows a general radar sea echo spectrum with Doppler shifted peaks away from the Bragg peaks.

The radio signal only “sees” surface water waves that have a wavelength that corresponds to one-half of the radio signal wavelength. This process is referred to as Bragg Scattering. Figure 1 shows a schematic of the relationship between incident and reflected radar waves and surface water waves. The radar unit is actually looking at hundreds of wave crests per area and averaging the information. All of these hundreds of waves reflecting back may sound confusing, but it is useful to think about Bragg Scattering as a sort of filtering process. Out of the many waves (some short, some long) that are moving across the surface of the water, the only waves that are in phase with the

signal, and hence constructively interfere, are the water waves that are half of the signal wavelength.

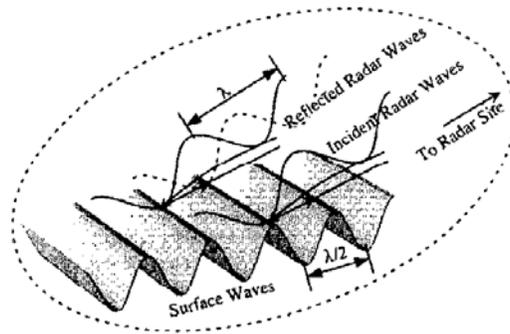


Figure 1. Bragg scattering

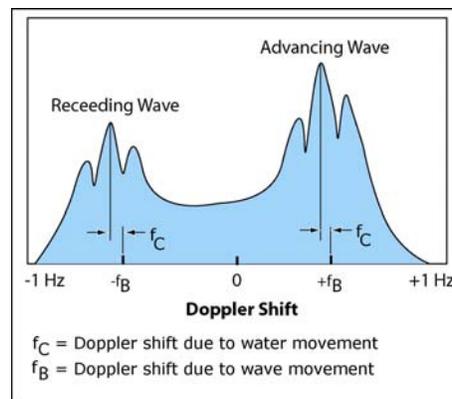


Figure 2. Doppler shift in a radar sea echo spectrum

Before defining the Geometric Dilution of Precision in radar systems it is necessary to briefly discuss uncertainties in radial and total velocity vectors. Belinda Lipa [2003] authored a paper detailing inherent radial and velocity vector uncertainties and their derivation. Radial vector uncertainties can result from spatial variations in the radial current component, such as horizontal shear, variations in the current velocity field over time, analysis errors, such as incorrect antenna patterns, or noise in the radar spectral data. The spatial errors increase with distance from the radar, as the circumference of the measurement area increases. The radial vector uncertainty is an estimate based on the calculation of the standard deviation of all velocities for a certain area. The velocity vector uncertainty is propagated from the uncertainty in the radial vector, and is determined using linear error propagation. The current version of CODAR's SeaSonde output software includes the spatial uncertainties in unmerged radial files. Once these uncertainties are known for a network, a GDOP study is needed to improve the data quality by correcting for the influence of station geometry.

It is important to note that two radar stations are necessary to resolve a current vector, as one station can only "see" the water moving toward and away from it. This is why two or more stations are necessary to get complete current vectors. The geometry of these stations is crucial to the minimization of errors. The Geometric Dilution of Precision (GDOP) is the coefficient of the uncertainty, which relates the uncertainties in

radial and velocity vectors. The GDOP is a unit-less coefficient, which characterizes the effect that radar station geometry has on the measurement and position determination errors [Levanon, 2000]. A low GDOP corresponds to an optimal geometric configuration of radar stations, and results in accurate surface current data. Essentially, GDOP is a quantitative way to relate the radial and velocity vector uncertainties. Don Barrick [2002] refers to GDOP as a baseline instability problem along the line joining two radar stations. Near the baseline, total vectors are not accurate because the radial velocities are nearly parallel [Barrick, 2002]. Figure 3 shows the instability field for a pair of radial radars, and demonstrates how the polygon geometry of intersecting radials varies around the surface current measurement area. In the developmental stages of a radar network it is necessary to find the optimum (lowest) GDOP possible for the network in question [Levanon, 2000]. Two radar systems are fairly common, but the Conrad Blucher Institute is developing a five-radar network, which will cover much of the Texas Gulf Coast. This configuration presents a complex GDOP scenario. A thorough analysis of GDOP is crucial to the establishment of this network. The uncertainties are already known in the situation, so we will proceed to finding the coefficient of the uncertainties, or the GDOP.

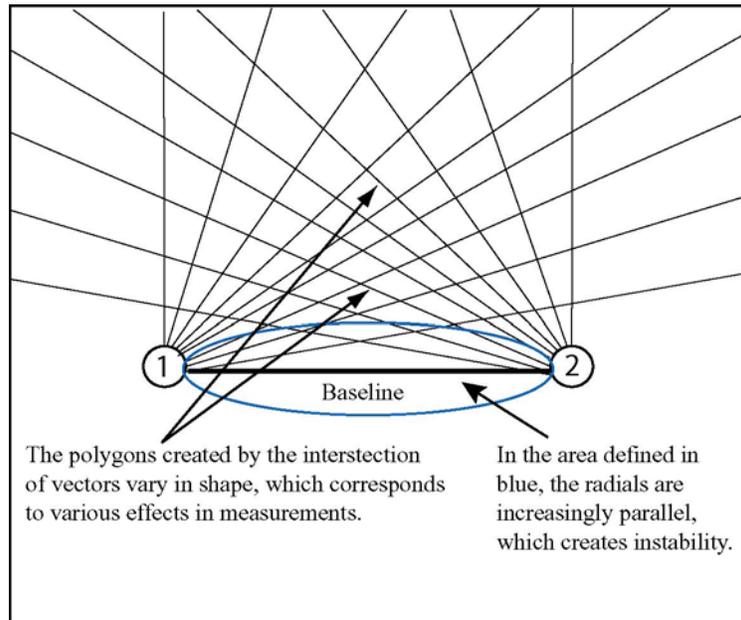


Figure 3. Geometry of radial vectors.

Methods

Two methods for determining the GDOP for a network configuration will be discussed. The traditional method employs the GDOP equations. The equations to calculate the north-south and east-west components of GDOP are as follows [Chapman et. al 1997]:

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

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

where,

σ_n = North component of GDOP

σ_e = East component of GDOP

α = Mean look angle (See Figure 5)

θ = Half of the angle of intersecting beams (See Figure 5)

σ = rms (root mean square) current differences

Three points were chosen in Corpus Christi Bay and the GDOP for each individual point was calculated, just for example. These calculations were performed in an Excel spreadsheet. The Conrad Blucher Institute has two stations that monitor this bay. Figure 4 shows the locations of the radar sites and the chosen GDOP locations. Their relative GDOP's were predicted based on their location relative to the radar stations (labeled CCB1 and CCB2, see Table 1 for more information), and these marker points are labeled “High”, “Mid”, and “Low”. Table 1 shows the necessary information and data.

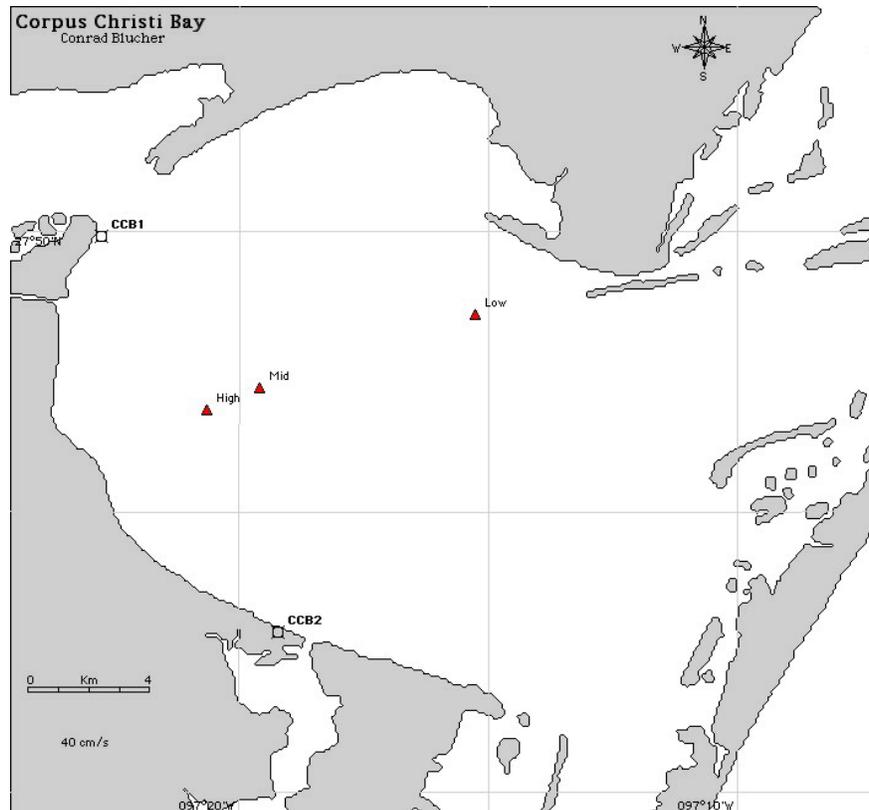


Figure 4. Chosen points for GDOP calculation in Corpus Christi Bay.

Table 1. Radar Station Positions

Radar Station	Position
North Beach (CCB1)	97°22'47''W, 27°49'54''N
University Beach (CCB2)	97°19'14''W, 27°42'52''N

Table 2. Marker information and angles for GDOP calculation

Marker Point	Position	Angles		GDOP	
		Mean Look (α)	Intersecting (θ)	GDOP _n	GDOP _e
High GDOP	27°46'49.2''N 97°20'39.1''W	51.0°	84.8°	4.94	6.08
Mid GDOP	27°47'12.8''N 97°19'35.6''W	56.8°	70°	1.30	1.78
Low GDOP	27°48'31.2''N 97°15'15.7''W	22.6°	51.5°	1.09	0.944

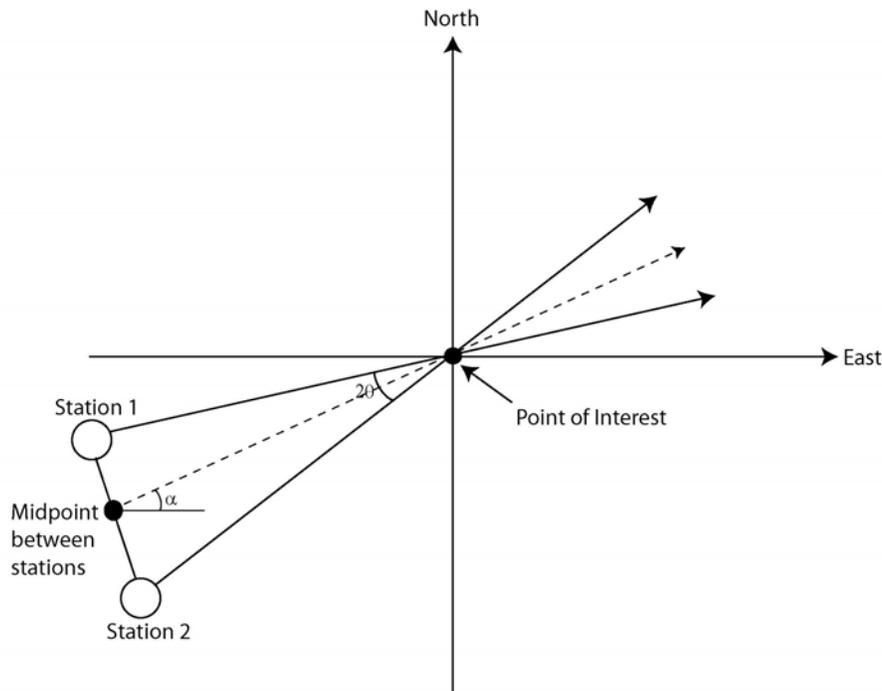


Figure 5. Adapted from Chapman et. al 1997 to define α and θ . 2θ is the angle of intersecting beams and α is the angle that the line intersecting the midpoint and origin makes with respect to due east.

Don Barrick of CODAR Ocean Sensors is in the process of incorporating this procedure into the standard output. He is developing the necessary algorithms using Matlab, which will calculate the GDOP of a network based on the latitude and longitude of the radar stations. The Matlab version calculates the GDOP for every position of the water current vectors, unlike the three simple points that were calculated for example. This will be a great benefit in QA/QC (quality assurance and quality check) for any radar system.

Conclusions

In this analysis, the inherent uncertainties in radar data have been discussed, and their relationship to the Geometric Dilution of Precision. In order to properly determine the GDOP of a given station configuration, a great deal of calculation is necessary to look at every point the radar produces a current measurement for. Obviously this is a time consuming method with a significant margin for human error. Don Barrick's Matlab routines will be modified for use to calculate the GDOP for an area of interest, which will prove extremely useful and greatly reduce the amount of time and effort necessary to deal with this error determining stage of radar network implementation. The ideal scenario is to have this process automated and incorporated with the uncertainties and measurement produced by the radar and included in the output. This incorporation can be done with the development of a database, which can be queried. This database is currently being developed for use in the implementation of the Conrad Blucher Institute's radar network on the Texas Gulf Coast. CBI will use Don Barrick's Matlab routine to help position the sites.

References

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