High Frequency Radar Measurement Resiliency with Bistatics

Chloe Baskin, Hugh Roarty,
Lucas Marxen, Scott Glenn
Center for Ocean Observing Leadership
Rutgers University
New Brunswick, NJ USA
chloe.baskin@rutgers.edu

Chad Whelan, Don Barrick
CODAR Ocean Sensors
Mountain View, CA USA
chad@codar.com

Abstract— **Increasing the resiliency of High Frequency radar measurements has been a priority within the community for the past several years. One method to increase resiliency is through the use of a bistatic radar configuration, which is unique to the SeaSonde HF radar. This is achieved by separating the transmit and receive stations and then linking them through the Global Positioning System (GPS) reference time signal. A study was undertaken to determine the impact of bistatic data on the surface current measurements of the Mid Atlantic Bight. Simulation software was used to model different permutations of transmit and receive stations to determine if there was an optimal configuration. The software modeled the Geometric Dilution of Statistical Accuracy (GDOSA) of the HF radar coverage area. GDOSA describes regions where combination from radials to totals is of high accuracy because the crossing angle between measurements from two different radars is orthogonal. The converse to this are regions where the total vector measurement are of low accuracy because the measurements from two different radars are nearly parallel. The scenarios tested included the bistatic measurements from the adjacent two, three and four stations on either side of a receive station. The simulation was applied to the 5, 13 and 25 MHz networks that are operated as part of the Mid Atlantic Regional Association Coastal Ocean Observing System (MARACOOS). We also simulated radars being offline to determine if any were more critical than others. Initial findings indicate that the area of highest data quality can be increased by a factor of five when the network is fully bistatic. The use of three or four adjacent radars did not increase the coverage compared to the adjacent two radars. The results of the site outage tests indicated that the loss of certain sites could reduce the coverage of the network by as much as 55%. The results found here have implications for the approximately 300 High Frequency radars that are in operation around the globe. With the addition of a hardware and software to make the network bistatic the coverage area with the highest accuracy can be increased by a dramatic amount.**

Index Terms—HF radar, remote sensing, quality control, bistatic, MARACOOS, Ocean Observing

I. MONOSTATIC, BISTATIC, AND MULTISTATIC

The Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) is a regional association of the US Integrated Ocean Observing System (IOOS). It has pushed for increasing the quality and resilience of its High-Frequency radar network (Figure 1). Increasing the quality and resiliency of the HF radar network is important not only for an improved understanding of the movement of organic and inorganic material through the coastal ocean, but also for the United States Coast Guard search and rescue. The United States Coast Guard uses the real time surface currents to help reduce the search area of rescue missions [1]. Increasing the quality of the measurements and the resiliency of the radars, especially in storms, can potentially save lives.

Currently the Mid-Atlantic HF Radar Network has a total of 45 HF radars, which is composed of 17 long-range (5MHz), 7 standard range (13MHz), and 21 high-resolution radars (25MHz). The long-range radars provide coverage of the entire Mid-Atlantic Bight (MAB) and have a range of 200 km offshore. The standard range radars cover the coast of New Jersey to study offshore wind resource [2]. The high-resolution radars measure the currents of the five major estuaries in the region. Currently all the radars in the region run in a monostatic mode.

A monostatic configuration, sometimes referred to as a backscatter, is when the HF radar transmits and receives from the same site resulting in a radial measurement of current. A bistatic configuration [3] can be accomplished by using a GPS reference time signal to link separated transmit and receive stations. The geographical separation of transmit and receive sites leads to an elliptical geometry for current measurements. A multistatic configuration is a network that is run in monostatic and bistatic mode. Using a bistatic or multistatic system can increase the quality of the radar signal.

The bistatic configuration will allow for a higher quality of coverage as it will increase the number vector solutions for the total vector combination as well as adding solutions with different bearing angles to reduce the geometric error. Additionally a bistatic system can result in higher resiliency since during storms or hurricanes if a monostatic system stops reporting, then a coverage gap can develop. In a bistatic configuration, the surrounding radars

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will be able to provide coverage in the area of the malfunctioning radar.

The combination of radial velocities into a total vector measurement carries with it a position dependent error on the vector solution. For instance, the total vector measurement along the baseline between two radars will be poor as both radars are incapable of measuring the component of the current perpendicular to the baseline. This is described as the Geometrical Dilution of Precision (GDOP) [4, 5]. The concept of GDOP has been expanded upon to be described as the Geometric Dilution of Statistical Accuracy (GDOSA) [6]. The GDOSA is not meant to be used with measured data. It is meant as a tool to estimate total vector quality based on the number and location of radar stations in the network.

This specific study will be conducted with radars covering the MAB and radars that cover the Lower Bay portion of the New York Harbor. There will be two scenarios on the MAB comparing the effectiveness of bistatics with the current monostatic system. In the New York Harbor, there were five scenarios tested, three of which are comparing the current monostatic situation with a bistatic configuration. The last two situations deal with the addition of a new station at either Old Bridge, NJ or Union Beach, NJ.

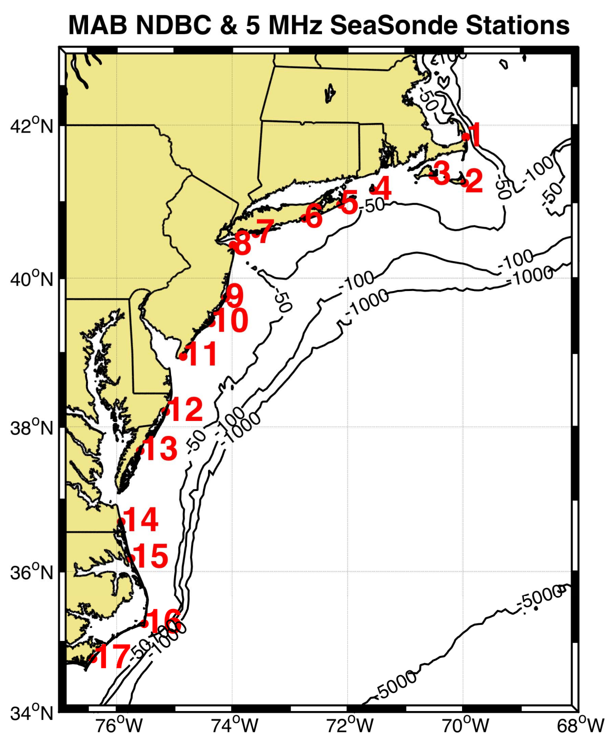

Figure 1: Location of the HF radar stations (red triangles) sites used in this study. The four-letter site code represents the name of each site.

II. Methods

CODAR Ocean Sensors provided the GDOSA code that was used. GDOSA was used to estimate the quality of proposed radar sites. GDOSA calculates the inaccuracies in the 'u', 'v', and 'w' [4]. The 'w' is equivalent to the total velocity and is derived from the vector components 'u' and 'v'. The 'u' component is the horizontal movement and the 'v' is the vertical movement. Inaccuracies are calculated using a series of formulae that determine when the radial measurements are orthogonal. As the angles between the radial measurements approach being orthogonal the accuracy increases.

The GDOSA code utilizes a pair of configuration files as input, a site file and a pairing file. The site file stores the coordinates for the station, along with the range, frequency and coverage bearing angles. Each site is also assigned a site identification number. The pairing file lists which stations are bistically linked to one another. The GDOSA code then combines the monostatic and bistatic configuration to assess the multistatic configuration.

A. The Mid-Atlantic Bight

There are a total of 17 long-range radar sites in the Mid Atlantic (Figure 1, Table 1). GDOSA code was run where each station was in monostatic and then the pairing file was modified to put the network in a multistatic mode. Figure 2 outlines the bistatic pairings that were established. The MAB was divided into north, central and southern sub-regions [1]. In each sub-region, a station was selected to receive the bistatic signals from all other stations in the sub-region. The next station in the list would receive the remaining bistatic signals and so forth. For example, the five stations in the north combine to form 11 bistatic pairings.

The GDOSA code delineates areas of good (low uncertainty) to poor (high uncertainty) total vector combination. The spatial coverage area for each uncertainty bin for the different pairings was calculated. The minimum uncertainty zone is a range between 0 - 0.25 (Table 2). There are 5 bins, including the maximum uncertainty zone, ending at 3. We also measured the coverage drop where each of the 17 stations was removed from the network to gauge the coverage loss in a monostatic and bistatic configuration.

Table 1: Each long-range site from north to south is numbered along with the 4-letter site code for the station. This table corresponds with each numbered stations in Figure 1.

Site #	Site Code
1	NAUS
2	NANT
3	MVCO
4	BLCK
5	AMAG
6	MRCH
7	HEMP
8	HOOK
9	LOVE
10	BRIG
11	WILD
12	ASSA
13	CEDR
14	LISL
15	DUCK
16	HATY
17	CORE

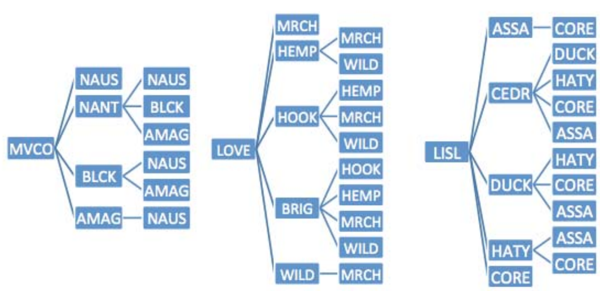

Figure 2: A chart that describes the bistatic pairing of the radars. It is to be read left to right and top to bottom. For example, MVCO recieves the reflected signal from NAUS, NANT, BLCK, and AMAG.

B. New York Harbor

In New York Harbor there are 2 sites, each 25MHz (Figure 6). One station is located in Port Monmouth, NJ (PORT) and the other is located in Great Kills, NY (SILD). Here we tested 5 different scenarios 1) both stations in monostatic mode 2) SILD as the bistatic transmitter 3) PORT as the bistatic transmitter 4) the addition of a third site in Old Bridge, NJ (Figure 9) and 5) the addition of a third site in Union Beach, NJ. The two new sites were tested to see which improved quality and resiliency of the system the most. Then each scenario was compared to one another in terms of area coverage area of each uncertainty bin.

III. Results

A. The Mid-Atlantic Bight

For the 5 MHz radars covering the MAB, the bistatic configuration (Figure 4) greatly improved the coverage along the coast when compared to the monostatic configuration (Figure 3). Table 2 shows the spatial coverage area of each uncertainty bin for the monostatic and bistatic scenario. The area of minimum uncertainty increased by 71,682 square kilometers in the bistatic pairing, an increase of 188%. Overall the total area increased approximately 40,000 km^2. These results suggest that a multistatic system would give the highest quality of signal along the East Coast. However the switch to a multistatic system adds an additional 40 elliptical files to be processed with 17 radial files. The number of files that to be processed would more than double, leading to potential strain on the operators to maintain 57 data streams over the current load of 17.

The impact of losing an individual radar station was also analyzed. Figure 5 shows the coverage area of the lowest uncertainty bin (0-0.25) for the monostatic network. Each column lists which station was removed from the network. The loss of Station 9 in Loveladies, NJ causes the largest decrease in coverage for the network. This helps inform our resiliency steps as to which stations are critical for operations.

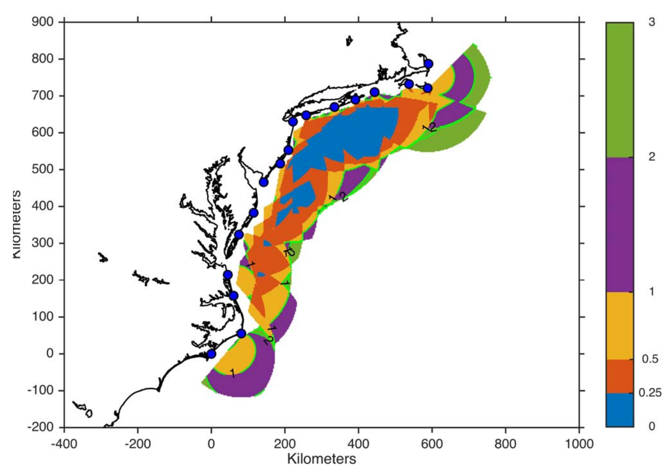

Figure 3: A graphic depicting the coverage of radars under a monostatic configuration. The blue area is the highest signal quality, as it has the lowest uncertainty.

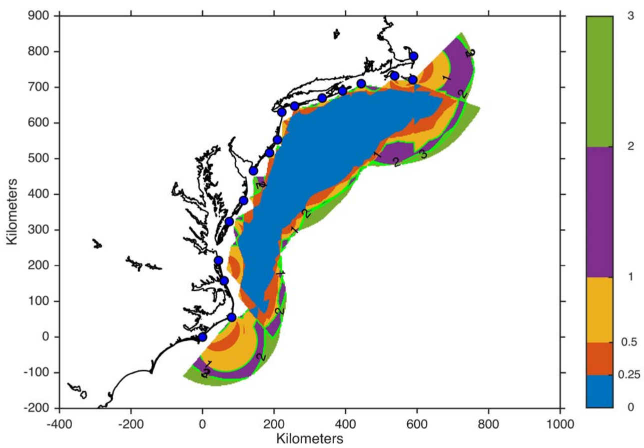

Figure 4: A graphic depicting the coverage of the radars under a multistatic system. The amount of high quality signal coverage has increased compared to the monostatic configuration.

Table 2: The signal quality range brackets and the area in square kilometers. The highlighted row is the "minimum uncertainty zone".

Signal Total vector coverage and uncertainty	Area (Sq. Km.)		Area gained/lost
0.0 – 0.25	38,138	109,820	71,682
0.25 - 0.5	46,444	28,725	-17,719
0.5 – 1.0	41,700	34,719	-6,981
1.0 – 2.0	40,444	33,669	6,775
2.0 – 3.0	24,600	24,756	156
TOTAL AREA	191,326	231,689	40,363

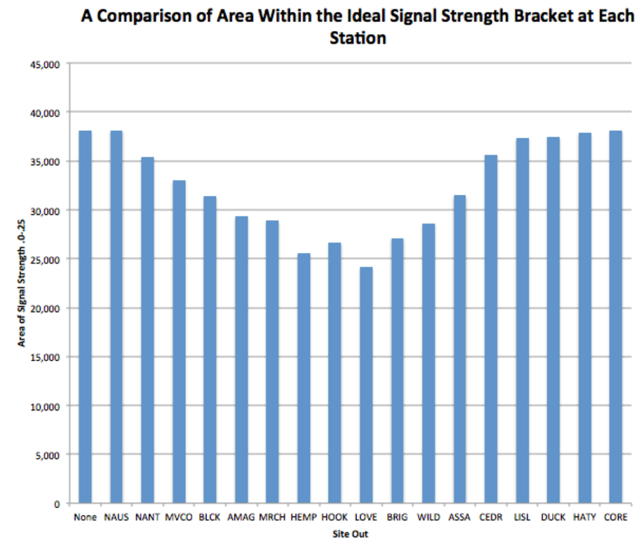

Figure 5: The impact on total coverage the when an individual site is offline. Each bar represents the station that is offline and the y-axis denotes the coverage area (km^2) of the 0-0.25 uncertainty bin.

B. New York Harbor

In New York Harbor, with the current sites SILD and PORT (Figure 6), the total area on a backscatter system is only 150 square kilometers (Table 3). With a multistatic system transmitting from SILD (Figure 7), the total area does not increase but the quality does. In the backscatter system there is no coverage in the first two signal quality bins (0.0 -0.5). In the multistatic system transmitting from SILD there is a 43.75 square kilometer increase in the second highest signal quality bracket. When the system is multistatic and transmitting from PORT (Figure 8) the total area increases by about 31 square kilometers. When compared to the existing backscatter only configuration, the multistatic system of transmitting from PORT results in higher quality.

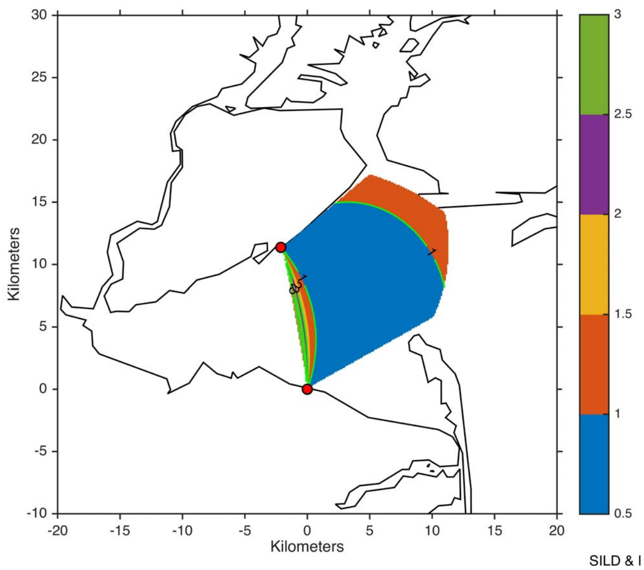

Figure 6: The coverage of the current radar sites in NY Harbor. This is a monostatic configuration with SILD and PORT. The resiliency of this configuration is low.

The addition of another site in Old Bridge, NJ increased the total area and the overall quality of the network (Figure 9). With the addition of Union Beach (Figure 10) the coverage area increased but not as much as with the addition of the Old Bridge site. The code in its current state does not allow for land masking so that explains the coverage on land. This is a drawback that will be addressed and fixed in a future release.

A graphical representation of Table 3 is shown in Figure 11. This confirms that scenario 4 is optimal for increasing the coverage in New York Harbor.

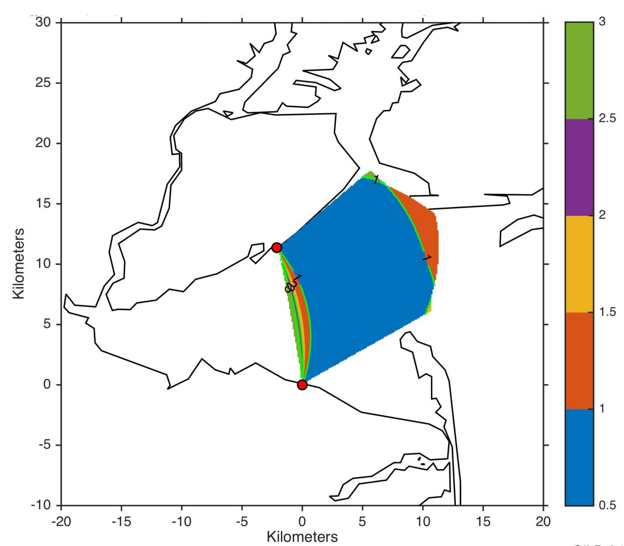

Figure 7: Coverage of the NY Harbor multistatically transmitting at SILD. This system has higher resiliency due to the bistatic pairing.

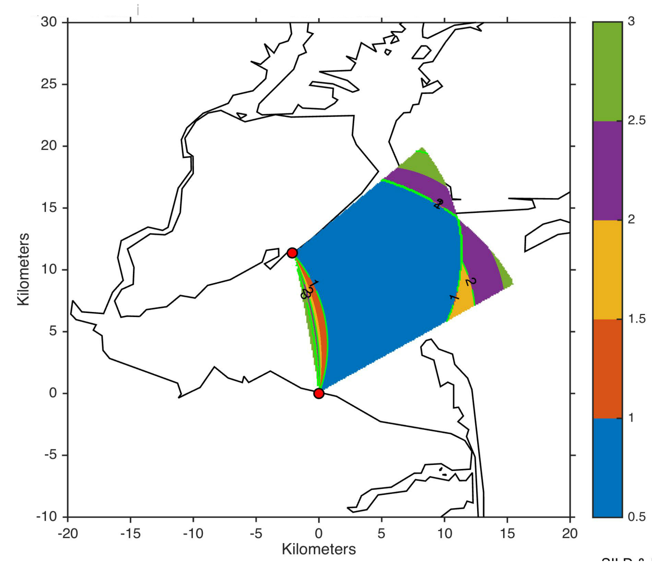

Figure 8: A graphical depiction of the NY Harbor sites in a multistatic configuration transmitting from PORT. This is more resilient due to the bistatic configuration.

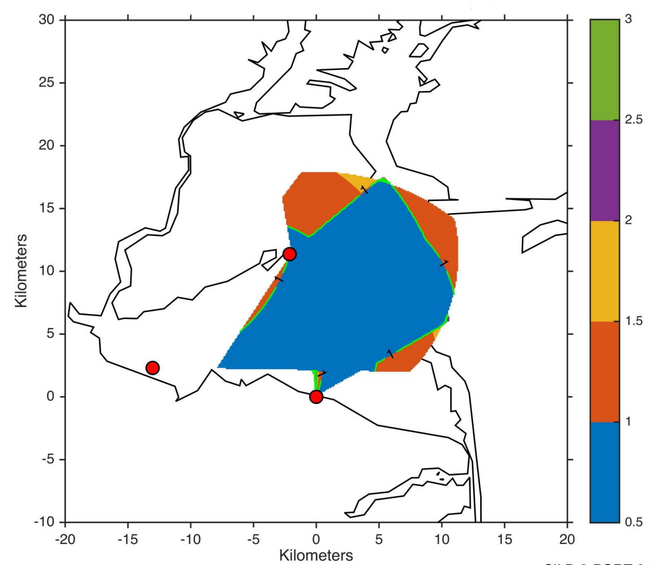

Figure 9: The NY Harbor sites in a monostatic configuration with the addition of a site in Old Bridge, NJ. Even though this is a monostatic configuration the resiliency has increased due to the additional site.

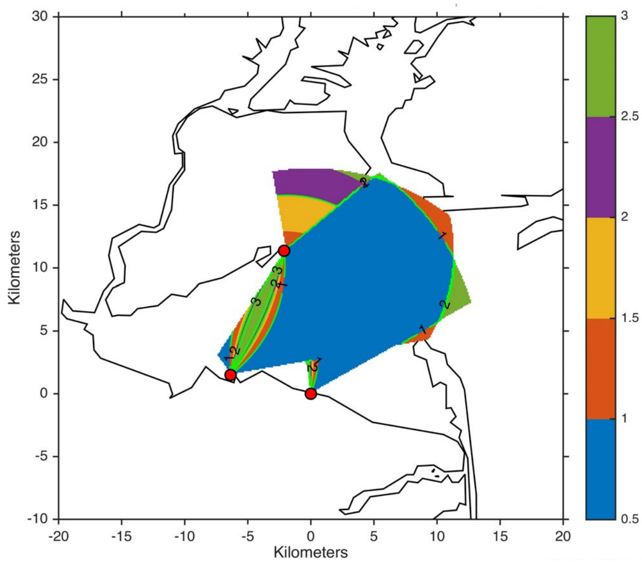

Figure 10: The NY Harbor sites in a monostatic configuration with the addition of the Union Beach site.

Table 3: The signal quality for each scenario in New York Harbor. Scenario 1 is the current status in NY Harbor. Scenario 2 is a multistatic configuration transmitting from SILD. Scenario 3 is a multistatic configuration transmitting from PORT. Scenario 4 is a monostatic configuration with the addition of Old Bridge, NJ site. Scenario 5 is a monostatic configuration with the addition of Union Beach, NJ site.

Scenario	1	2	3	4	5
Signal Total vector coverage and uncertainty	**Area (Sq. Km)**				
0.0 – 0.25	0	0	0	0	0
0.25 – 0.5	0	43.75	50	93.75	93.75
0.5 – 1.0	106.25	81.25	81.25	87.5	68.75
1.0 – 2.0	37.5	18.75	12.5	50	18.75
2.0 – 3.0	6.25	6.25	37.5	0	43.75
Total Area	150	150	181.25	231.25	225

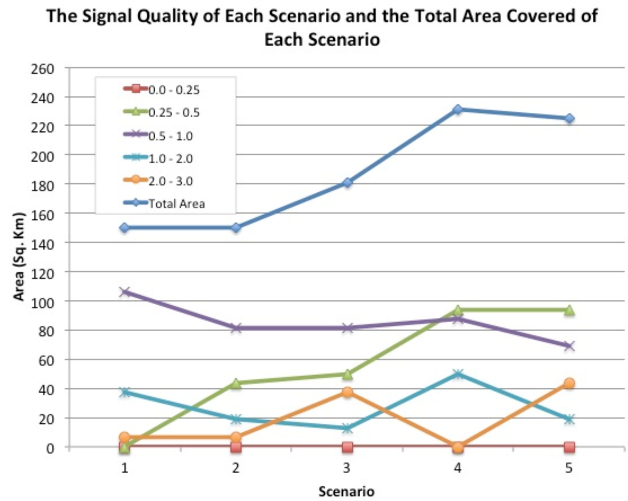

Figure 11: A graphical representation of each scenario for New York Harbor and the coverage area for each uncertainty bin.

IV. Conclusion

Increasing the resiliency and accuracy of HF radar through bistatics is possible. GDOSA is an effective tool to calculate if a multistatic configuration will decrease the uncertainty of the total vector measurement. As seen in the MAB, the uncertainty can drop drastically with the addition of bistatic pairings. The multistatic configuration in the MAB added 40 more elliptical files that need to be analyzed which could be a potential challenge for quality assurance and quality control measures.

In New York Harbor GDOSA predicted that transmitting from SILD will yield a higher quality than if the bistatic signal originated from PORT. It has also proved itself useful with predicting future CODAR sites. After comparing the addition of an Old Bridge or Union Beach site, Old Bridge provides more coverage. When the Old Bridge site is eventually installed tests will be run to compare the predicted coverage with the actual coverage.

V. Acknowledgments

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