Bistatic Vessel Detection from the CODAR SeaSonde

Kristen Holenstein, Collin Dobson, Michael Smith, Hugh Roarty, Scott Glenn
Coastal Ocean Observation Laboratory
Rutgers University
New Brunswick, NJ USA
kmholenstein51190@gmail.com

Donald E. Barrick
CODAR Ocean Sensors
Mountain View, CA USA
don@codar.com

***Abstract*— Large numbers of ships travel up and down the East Coast of the United States daily, ranging from recreational vessels to cargo vessels. Especially busy areas are the approaches to New York Harbor. New York currently is the third-busiest port in the United States and it is growing rapidly [1]. The large number of vessels that travel in and around New York, and the expectation of increased numbers, makes Maritime Domain Awareness important for this region.**

To increase Maritime Domain Awareness, Rutgers University is now using their SeaSonde® HF Radar coastal ocean current and wave monitoring network for vessel detection. The vessel detection system focuses on the approaches to New York Harbor, where ship traffic is greatest. The capability of this system was tested along the New Jersey coastline in October 2012.

The vessel detection software, developed by CODAR Ocean Sensors and Rutgers University, was installed on two 13 MHz HF Radar sites. The data analysis for this paper focused on the period from October 22, 2012 to October 26, 2012. The three sites utilized were located in Belmar, Sea Bright and Seaside Park, New Jersey. The network was run in multistatic mode, which is a combination of monostatic and bistatic transmitters and receivers. A transmitter and receiver were located at the Sea Bright and Seaside Park stations. Each of these stations operated in monostatic mode where the transmitter and receiver are geographically collocated. A transmitter was placed at the Belmar site and acted as a bistatic transmitter where its signal was received at the Sea Bright and Seaside Park stations. So a total of four signals were processed using the three stations. The stations were able to operate in bistatic mode by synchronizing their signals through the use of the Global Positioning System (GPS) time signal. The bistatic data vessel detection data obtained from the two sites were compared against the Automatic Identification System (AIS) for verification. The use of bistatic vessel detection data will increase the number of detections on a single vessel by increasing the range of the system as well as adding different look angles when the vessel passes through the Bragg or zero Doppler clutter regions.

Maritime Domain Awareness is vital for areas with heavy ship traffic, such as New York Harbor. The Automatic Identification System (AIS) is a self-reporting system, and may not always be used. The vessel detection capability of the HF Radar system will provide information on ships that are not reporting on AIS. The use of vessel detection from HF Radar will provide a valuable layer that the US Coast Guard can utilize to increase its Maritime Domain Awareness.

***Keywords*—HF radar, MARACOOS, vessel detection, bistatics, maritime domain awareness**

I. Introduction

Maritime Domain Awareness (MDA) is the effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment of the United States [2]. High Frequency radar is an effective tool to achieve MDA. HF radar has been assimilated into models for effective oil spill response [3-5], utilized in the planning of Coast Guard Search and Rescue (SAR) cases [6, 7] and used to determine the fate of coastal plumes [8, 9]. All of these applications will increase maritime domain awareness for personnel in the US Coast Guard (USCG) responsible for Search and Rescue activities and National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration responsible for providing scientific support for hazardous material spills. A more recent application of coastal HF radar systems is the detection of vessels passing the radar [10, 11]. Currently the USCG relies upon the Automatic Identification System (AIS) to track vessels in coastal areas. One drawback of this method is that AIS is a self-reporting system [12]. The National High Frequency Radar Network [13] has the potential to provide another layer to MDA with the vessel detections from the coastal radars.

One obstacle to overcome with HF radar for vessel detection is the clutter from the sea. Any target with a radial velocity close to the Bragg velocity will be difficult to detect due to the large echo of the sea. Figure 1 shows the spectra from a 13 MHz surface wave HF radar. The Bragg speed for 13 MHz is ±4 m/s (±8 knots). Any vessel travelling with this radial velocity will produce an echo that will fall within the Bragg scatter and prove difficult to discern against the echo of the ocean. This sea-clutter problem can be overcome through sea-clutter cancellation

978-0-933957-40-4

algorithms [14]. Another method to overcome this deficit is through the use of bistatic vessel detections. The transmit signal from another radar station or at sea buoy [15] can illuminate a vessel at sea. The echo from the target can be received at a shore radar station. The echo from the bistatic signal would not be masked by the sea-clutter as compared to the backscatter signal from the radar due to the different geometry.

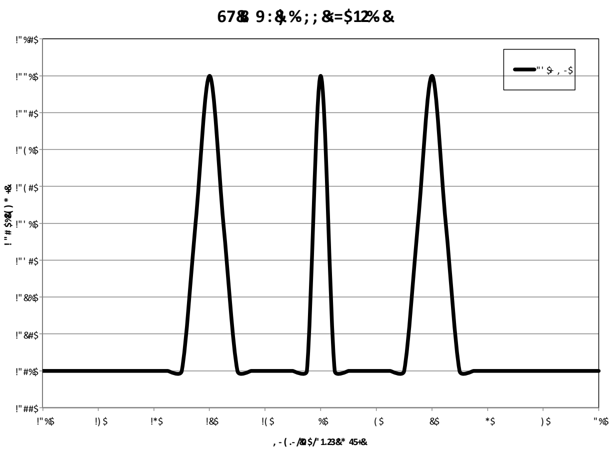

Figure 1: Diagram of the Bragg spectra from a 13 MHz HF radar with a. The x-axis is radial velocity (m/s) and the y-axis is signal power (dBm).

II. METHODS

A 13 MHz network was established in New Jersey for the study of the offshore wind energy resource [16] and vessel detection [17]. Radar stations were located in Sea Bright, Belmar and Seaside Park, New Jersey (Figure 2). A CODAR SeaSonde was located at the stations in Sea Bright and Seaside Park. A CODAR bistatic transmitter (Model SSBT-100-0012) was located at the station in Belmar. All three systems were equipped with the SeaSonde SHARE-enabled transmitter. This allowed the systems to operate on the same frequency conserving bandwidth while also allowing for multiple transmit signals to be received on a single receive station. The stations at Sea Bright and Seaside Park received their own transmit signal (monostatic mode) and the transmit signal from the bistatic transmitter located in Belmar (bistatic mode). The combination of monostatic and bistatic operations is described as a multistatic network [18, 19].

This configuration was operated from October 22-25, 2012. The radar stations were equipped with CODAR Ocean Sensor's real-time vessel detection software. That meant the vessel detection data would be generated every 32 seconds and could be transferred back to an aggregation center. The file size for each detection file was on the order of 10 kB. So the detection file could easily be transferred back over the communication mode for the station (cable internet for Sea Bright and cellular modem for Belmar).

The systems officially transmitted on 13.45 MHz with 50 kHz of bandwidth. This equates to a range resolution of 3 km for currents. The signal from hard targets like ships will be seen in several range cells so an interpolation scheme is used within the vessel detection software to increase the range resoltion to approximately 0.5 km.

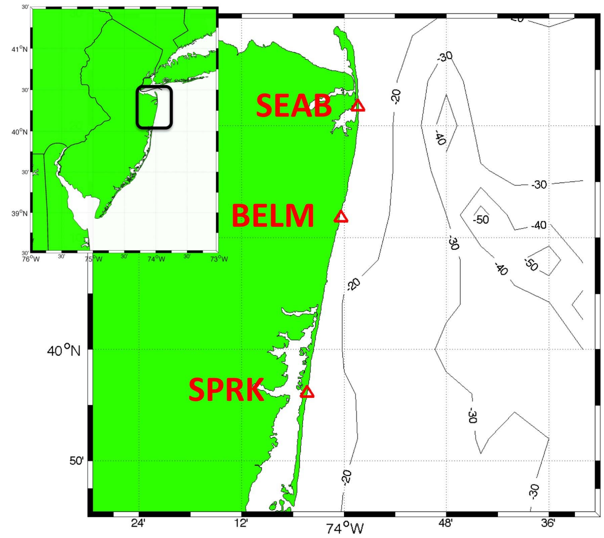

Figure 2: Study area off the northern coast of New Jersey. The locations of the radar stations are indicated by the red triangles with the four-letter site code. Bathymetry contours in meters are also shown. The inset shows the general location of the experiment.

Measured beam patterns [20] were used at each of the receive stations in order to obtain the most accurate bearing measurements of the target. Range and radial velocity measurements of the radar are not affected by beam patterns, only the bearing estimate is affected by the beam patterns.

A. Vessel Information

The four vessels were used during this experiment were the CMA CGM Dalila, CSAV Laja and Ever Radiant which are all large cargo containers and the Eagle Beaumont which is a crude oil tanker. Basic information on the vessels is provided in Table 1.

Table 1: Particulars of the vessels used in this experiment.

Vessel Name	Length (m)	Breadth (m)	Gross Tonnage
CSAV Laja	261	32	39906
CMA CGM Dalila	334	43	89787
Ever Radiant	293	32	53103
Eagle Beaumont	253	44	57456

Automatic Identification System (AIS) receivers were located at the Sea Bright and Belmar stations. The receivers were model SM161R-2 manufactured by Shine Micro. The receivers were outfitted with omnidirectional Very High Frequency (VHF) antennas to receive the AIS signal. The data from the receivers were transferred in real time over the Internet and recorded and time stamped at the aggregation center at Rutgers University. The time, latitude and longitude from the AIS data were converted to range, velocity and bearing relative to the particular radar station.

B. Vessel Detections

Vessel detections were generated at both the Sea Bright and Seaside Park radar stations. The detection data included range, radial velocity and bearing measurements of possible targets. Each of these measurements is accompanied with the corresponding uncertainty. The detection signal to noise ratio (SNR) on each of the three receive channels is also reported along with a radar cross-section estimate for the vessel. An example plot of the monostatic detections is given in Figure 3 and the bistatic detections are shown in Figure 4.

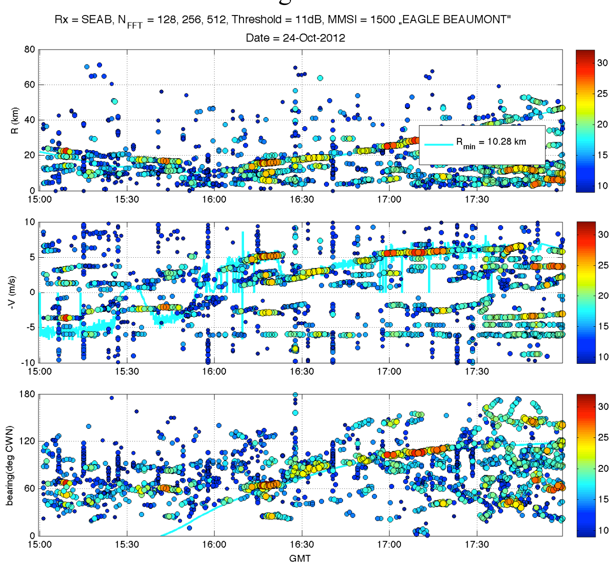

Figure 3: Monostatic Detections from the Sea Bright radar station from 15:00 to 18:00 GMT on October 24, 2012. The panels from top to bottom are range (km), radial velocity (m/s) and bearing (degrees CWN). The track of the Eagle Beaumont is shown as the aqua line in each of the panels. The color of the dot represents SNR on channel 3 of the radar.

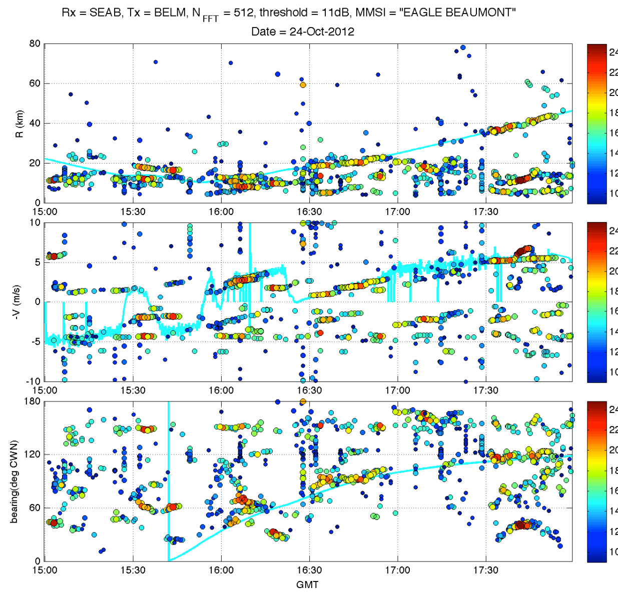

Figure 4: Bistatic Detections from the Sea Bright radar station from 15:00 to 18:00 GMT on October 24, 2012. The radar at Sea Bright acted as the receiver and the radar at Belmar was the transmitter. The plot description matches that of Figure 3.

III. RESULTS

The range, velocity and bearing data from the AIS is used to validate the detections by the radar. This also helps elliminate any false alarms in the radar data. Taking the plot of the monostatic detections from Figure 3 and only keeping the detections that are close in range and bearing to the Eagle Beaumont yields Figure 5. The same process was repeated for bistatic detections in Figure 4 to yield only the associated data in Figure 6.

The benefit of the two data streams is that targets that are hidden in the Bragg or zero Doppler region of one radar can not simultaneously be hidden in the second radar. For example in Figure 6, the Eagle Beaumont is travelling at the Bragg speed of the bistatic signal between 17:00 and 17:30. This leads to no detections of the vessel by the bistatic signal. However the monostatic detections by the radar at Sea Bright have good coverage during this time period as the vessel was just outside the Bragg region. The Bragg region is denoted by the yellow horizontal lines at ±4 m/s in the middle panel of Figure 5 and Figure 6.

And again there was a lack of monostatic detections at 16:07 in Figure 5. This deficit was overcome by the bistatic detections at the same time period in Figure 6. For the rest of the time period there were consistent detections by both the monostatic and bistatic signals. This highlights the second benefit of the bistatic data source which is multiple observations of the same target. This will increase the probability of detection and also lowering the false alarm rate.

Another example comes from the Ever Radiant. It was leaving New York Harbor at 18:30 on October 24, 2012.

National Oceanic and Atmospheric Administration, United States Department of Homeland Security

At 19:15 the vessel passes through zero Doppler relative to the radar at Sea Bright as it travels along the coast. So the radar at Sea Bright was not able to make any detections of the vessel due to the zero Doppler clutter region. However, the bistatic signal transmitted from Belmar and received at Sea Bright did make detections on the vessel during this time period.

All the detections that match the Ever Radiant are plotted on a map in Figure 7. The Belmar station (black circle) acted as a bistatic transmitter and the signal from that station was received at both the Sea Bright and Seaside Park station. The bistatic detections doubled the number of measurements on the vessel. The scatter of the detections around the track increases between 40° and 40° 10' latitude. The bearing uncertainty increase from the detections at Sea Bright were due a drop in the signal to noise ratio [21]. This causes a scatter when the detections are placed on a map even though the radar makes an accurate measurement of target range and radial velocity.

One way to over come this scatter is through the use of a tracker to smooth out the target track. One other way to make more accurate position estimates of the target is to make use of the detections from another radar. At 40° N latitude, just as the errors in the bearing estimates from the radar at Sea Bright are starting to increase, the radar at Seaside Park is starting to detect the vessel with low bearing and position error. Combining these multiple datasets to form a more accurate track of the vessels path will be for future work.

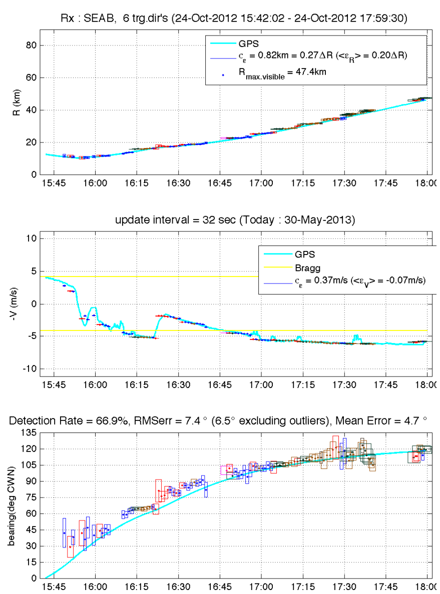

Figure 5: Monostatic detections by the radar at Sea Bright associated with the track of the Eagle Beaumont from AIS. The dots represent the detections while the boxes surrounding them represent the length of the FFT (width) and the uncertainty of the measurement (height). The different colors represent the type of background and fft length used for the detection.

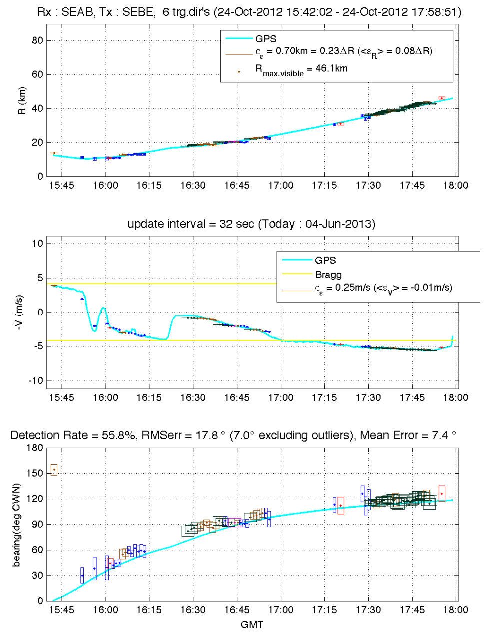

Figure 6: Bistatic detections by the radar at Sea Bright associated with the track of the Eagle Beaumont from AIS. The plot description matches that of Figure 5.

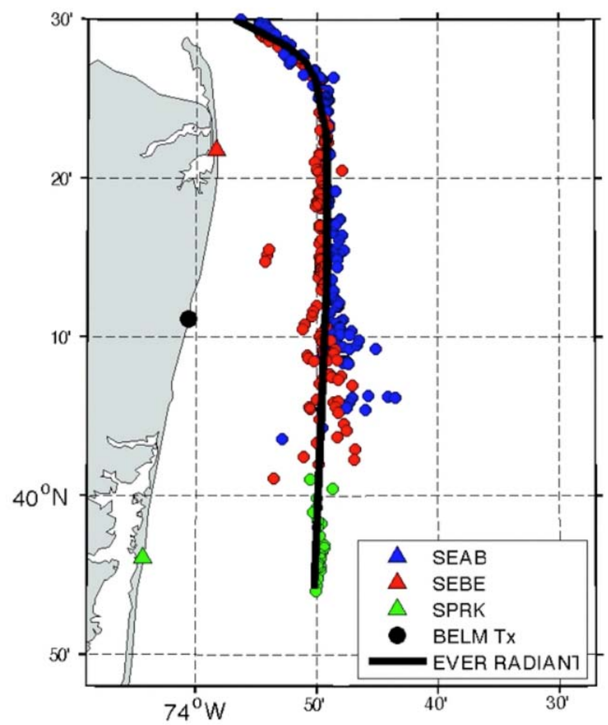

Figure 7: Detections from multiple sources of the Ever Radiant. The monostatic detections from Sea Bright are shown in blue, the monostatic detections from Seaside Park are in green and the bistatic detections (Belmar is the transmitter and Sea Bright is the receiver) are shown in red. The radar stations are shown as the icons on land and the track of the vessel is in black.

IV. CONCLUSIONS

The bistatic vessel detection capability has been demonstrated for the SeaSonde HF radar. This was accomplished by synchronizing the transmit signal between the shore stations through the use of GPS timing. This capability can reveal targets that are hiding in the zero Doppler or Bragg region of a monostatic radar. It also provides an additional measurement of the vessel position or velocity, thereby reducing the error of the measurement. Future work will focus on developing algorithms to combine these multiple data streams for a more refined end product.

ACKNOWLEDGMENTS

This material is based on work supported by the U.S. Department of Homeland Security under Award No. 2008-ST-061-ML0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

This work was funded by NOAA Award Number NA11NOS0120038 “Towards a Comprehensive Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS)”. Sponsor: National Ocean Service (NOS), National Oceanic and Atmospheric Administration (NOAA) NOAA-NOS-IOOS-2011-2002515 / CFDA: 11.012, Integrated Ocean Observing System Topic Area 1: Continued Development of Regional Coastal Ocean Observing Systems.

REFERENCES

[1] A. J. Hawkins, "Surge in shipping has New York hot on L.A.'s heels," *Crain's New York Business,* vol. XXVIII, p. 36, August 6-12, 2012.

[2] National Plan to Acheive Maritime Domain Awareness, U. S. Department of Homeland Security, 1-33, 2005

[3] M. Yaremchuk, P. Spence, M. Wei, and G. Jacobs, "Lagrangian predictability in the DWH region from HF radar observations and model output," *Deep Sea Research Part II: Topical Studies in Oceanography,* 2013.

[4] A. J. Abascal, S. Castanedo, R. Medina, I. J. Losada, and E. Alvarez-Fanjul, "Application of HF radar currents to oil spill modelling," *Marine Pollution Bulletin,* vol. 58, pp. 238-248, 2009.

[5] S. W. Tinis, D. O. Hodgins, and M. Fingas, "Assimilation of radar measured surface current fields into a numerical model for oil spill modelling," *Spill Science & Technology Bulletin,* vol. 3, pp. 247-251, 1996.

[6] D. S. Ullman, J. O'Donnell, J. Kohut, T. Fake, and A. Allen, "Trajectory prediction using HF radar surface currents: Monte Carlo simulations of prediction uncertainties," *J. Geophys. Res.,* vol. 111, p. C12005, 2006.

[7] J. Harlan, A. Allen, E. Howlett, E. Terrill, S. Y. Kim, M. Otero, S. Glenn, H. Roarty, J. Kohut, J. O'Donnell, and T. Fake, "National IOOS high frequency radar search and rescue project," in *OCEANS 2011*, 2011, pp. 1-9.

[8] S. Y. Kim, E. J. Terrill, and B. D. Cornuelle, "Assessing Coastal Plumes in a Region of Multiple Discharges: The U.S.‚àíMexico Border," *Environmental Science & Technology,* vol. 43, pp. 7450-7457, 2009/10/01 2009.

[9] P. M. DiGiacomo, L. Washburn, B. Holt, and B. H. Jones, "Coastal pollution hazards in southern California observed by SAR imagery: stormwater plumes, wastewater plumes, and natural hydrocarbon seeps," *Marine Pollution Bulletin,* vol. 49, pp. 1013-1024, 2004.

[10] H. J. Roarty, M. Smith, S. M. Glenn, and D. E. Barrick, "Real-time beyond the horizon vessel detection," *Proc. SPIE 8714, Radar Sensor Technology XVII,* pp. 87140Z-87140Z, 2013.

[11] H. J. Roarty, D. E. Barrick, J. T. Kohut, and S. M. Glenn, "Dual-Use Compact HF Radars for the Detection of Mid- and Large-Size Vessels," *Elektrik, Turkish Journal of Electrical Engineering and Computer Sciences,* vol. 18, pp. 373-388, 2010.

[12] T. Hammond, M. McIntyre, D. Chapman, and A.-L. Lapinski, "The Implications of Self-Reporting Systems for Maritime Domain Awareness," *DRDC Atlantic TM 2006-232,* pp. 1-40, 2006.

[13] J. Harlan, "A Plan to Meet the Nation's Needs for Surface Current Mapping," *NOAA IOOS,* p. 64, September, 2009 2009.

[14] B. T. Root, "HF-over-the-horizon radar ship detection with short dwells using clutter cancelation," *Radio Science,* vol. 33, pp. 1095-1111, 1998.

[15] H. J. Roarty, M. Smith, E. Handel, S. M. Glenn, and D. E. Barrick, "Expanding the coverage of HF radar through the use of wave powered buoys," in *Oceans, 2012*, 2012, pp. 1-4.

[16] H. Roarty, J. Riscica, L. Palamara, L. Bowers, G. Seroka, J. Kohut, S. Glenn, and R. Dunk, "Analysis of the wind resource off New Jersey for offshore wind energy development," in *Oceans, 2012*, 2012, pp. 1-4.

[17] H. Roarty, E. Lemus, E. Handel, S. Glenn, D. E. Barrick, and J. Isaacson, "Performance Evaluation of SeaSonde High-Frequency Radar for Vessel Detection," *Marine Technology Society Journal,* vol. 45, pp. 14-24, 2011.

[18] J. I. Glaser, "Fifty years of bistatic and multistatic radar," *Communications, Radar and Signal Processing, IEE Proceedings F,* vol. 133, pp. 596-603, 1986.

[19] E. Hanle, "Survey of bistatic and multistatic radar," *Communications, Radar and Signal Processing, IEE Proceedings F,* vol. 133, pp. 587-595, 1986.

[20] J. T. Kohut and S. M. Glenn, "Improving HF Radar Surface Current Measurements with Measured Antenna Beam Patterns," *Journal of Atmospheric and Oceanic Technology,* vol. 20, pp. 1303-1316, September 01, 2003 2003.

[21] S. M. Glenn, D. E. Barrick, and W. J. Browning, "Development and Demonstration of Shiptracking Capabilities for a Dual-Use Multi-Static Long-Range HF Radar Network," *Office of Naval Research,* pp. 1-95, 2004.