Expanding Maritime Domain Awareness Capabilities in the Arctic: High Frequency Radar Vessel-tracking

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***Abstract*— The arctic could be ice free during the summer by as early as 2040 [1]. This could alter the dominant shipping routes between Europe and Asia. The ability to monitor this traffic is hindered by lack of sensors, communication and power for the sensors. SeaSonde High Frequency radars were installed along the northwest corner of Alaska from July to December 2012. These radars were able to make simultaneous measurements of ocean surface currents as well as measure the position and velocity of vessels passing by the radar. This successful demonstration proves that High Frequency radar can be a valuable tool for providing maritime domain awareness and persistent surveillance capabilities in the arctic.**

***Index Terms*—geoscience, remote sensing, High Frequency, radar, oceans, vessel detection, surveillance, Arctic, polar region**

I. Introduction

Rutgers University, as a partner in the U.S. Department of Homeland Security's (DHS) Center for Secure and Resilient Maritime Commerce (CSR), has demonstrated vessel detection as a dual-use capability for their SeaSonde® HF Radar (HFR) coastal ocean current and wave monitoring network [2]. Real-time HF Radar current maps are being used for Search and Rescue (SAR), oil spill response, among other uses on over 130 systems around the U.S. and now Rutgers is providing real-time detections for the approaches to New York Harbor. These detections are supplied to the Naval Research Lab's (NRL) Open Mongoose data fusion engine. In a collaborative effort between Rutgers and the University of Alaska, Fairbanks (UAF), a partner in the DHS National Center for Islands, Maritime, and Extreme Environments Security (CIMES), this dual-use capability was demonstrated in the Arctic region, near Barrow, Alaska in the summer and autumn of 2012.

With longer periods and larger areas of ice-free and broken ice floes in the Beaufort and Chukchi Seas during the summer and autumn ice free seasons, there is increasing vessel activity from cargo ships, cruise lines, fishing vessels and those taking advantage of the opening of the Northwest Passage and Northern Sea Route[3]. In addition, 2012 marked the beginning of offshore oil exploration in the Chukchi Sea. With increased activity from both foreign and domestic vessels, the U.S. Coast Guard has increased its presence in Arctic Alaska [4] and, as such, there is a need for increased Maritime Domain Awareness (MDA) in this area as well. UAF deployed and maintained three Long Range SeaSondes and two High Resolution SeaSondes from June through November to monitor 2-D surface currents in the Chukchi Sea during the summer ice-free season. The SeaSonde (Figure 1) is a High Frequency radar system that has been traditionally been used for measuring ocean surface currents [5] and ocean wave parameters [6]. Having observed vessel echoes in prior deployments in the Chukchi, vessel detection software from CODAR Ocean Sensors was installed and run in real–time in parallel with current mapping software on the local SeaSondes.

The vessel detection capability of the SeaSonde was observed off the coast of California [7] and then demonstrated for a year long test study off the coast of New Jersey [8]. The SeaSonde is a compact direction finding radar system. Vessel detections with phased array HF radar have also been observed [9, 10]. The study presented here is one of the first demonstrations of the real time capability of the SeaSonde. All previous studies were performed by bringing archived spectra data to the laboratory and post-processing it for vessel detections. In order to demonstrate multi-use capability, the offline vessel detection software was translated into the C programming language to run in parallel with current mapping software on the SeaSonde system.

The Arctic region poses challenges to HF Radar vessel detection including: remote locations requiring specialized shelter, power and communications; extreme weather; the presence of ice floes, which have their own Doppler echoes in addition to sea clutter; and a different radio frequency environment with auroral influences[11]. These challenges and their affects on HF vessel detections as a dual-use capability in the Arctic are discussed and vessel detections in the Chukchi Sea are shown.

Figure 1: Receive antenna for the SeaSonde system on the right. A person atop an all terrain vehicle is on the left for scale

II. Methods

Three 5MHz (long range) SeaSondes were installed at Point Barrow, Wainwright and Point Lay Alaska (Figure 3). Two 25MHz (high resolution) SeaSondes were installed along the northern slope of Alaska in June 2012 (Figure 4). The radars were operated from July to December 2012. Four of the radars were powered with electricity from the power grid. The 25MHz radar at Point Barrow was powered with a remote power module (RPM) [12]. The RPM was equipped with solar panels and wind turbines, which charged a bank of 36 batteries with a total capacity of 3000 amp hours. The radars were configured to produce radial measurements of surface currents hourly.

The real time vessel detection software was installed at the 5 and 25 radars at Point Barrow. The vessel detection software utilizes two backgrounds and 6 combinations of coherent integration time and threshold level to produce detections [8]. The first background is a median type that averages in Doppler and range space. The second background is an infinite impulse response (IIR) filter that averages in time. So then any signal that is above the background by a certain threshold is counted as a detection, the classical constant false alarm rate (CFAR) detection

Vessel tracking, in its simplest form, takes place in three steps: (1) detection, (2) association, and (3) tracking. Detection uses different data processing algorithms to define peaks in the radar returns above a highly variable background of noise and clutter. The result, referred to as a pepper plot, produces a time-series of all the observed peaks (real or not) identified by their range, range-rate towards or away from the radar, and bearing. The association process decides which detections in the pepper plots of range, range rate and bearing are associated with a specific ship, clustering them for input to a tracker. The tracker then fits specific models for ship behavior (e.g. constant course and speed followed by a turning maneuver to a new constant course and speed) that enables both the past best fit and the projected track to be plotted on a computer screen.

Previous Department of Defense (DoD) sponsored research has confirmed that HFR are capable of detecting ships, and that given a known ship track for the association process, the resulting time series of range, range-rate and bearing could be used by a variety of trackers to produce accurate vessel tracks on a user's computer screen.

Figure 2: The remote power module (RPM) that powered the 25 MHz SeaSonde at Point Barrow.

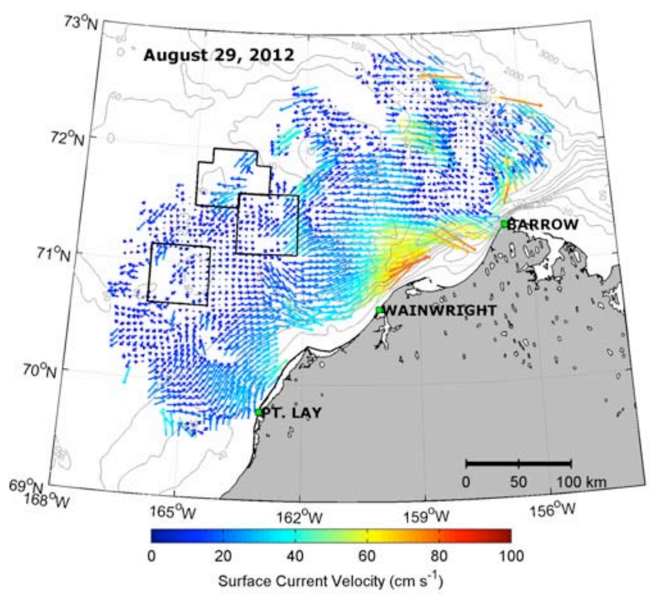

Figure 3: Map of the 25-hour average surface currents along the northern slope of Alaska for August 29, 2012. The magnitude of the surface current velocity is displayed by the colorbar along the bottom of the figure. The locations of the radars are shown as the green squares. Black boxes denote offshore regions slated for potential hydrocarbon development.

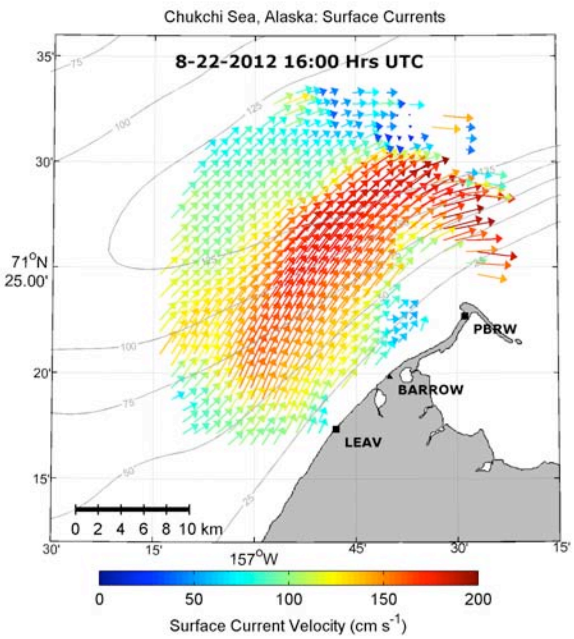

Figure 4: Map of the hourly average surface currents along the northern slope of Alaska using the 25 MHz HF radars. The locations of the radars are shown as the black squares.

III. Results

The five radars made hourly measurements of radial surface currents. The radial currents were combined to produce total vector currents (Figure 3 and Figure 4).

The 5 MHz system in Barrow (BASC) operated continuously from July 9 to December 4, 2012. The real time vessel detections were transferred via satellite communications from Barrow, Alaska to New Brunswick, New Jersey every 5 minutes. There were no vessels detected by the radar from July 9 to August 14 as sea ice prevented safe passage of vessels through the region. Sea ice retreat commenced in early August and the first vessels were detected on August 15.

The BASC radar detected vessels daily from August 15 until September 30. The vessel traffic then diminished in early November as the sea ice encroached on the shore. The vessel detection data was plotted (Figure 5) as a function of time by range, range rate and bearing relative to the individual radars. The detection data from the radar showed several valid detections. These are shown as the dots with signal to noise ratios above 20 dB and that move in a coherent fashion (Figure 5)

The vessel detection data was compared against available Automatic Identification System (AIS) (Figure 6) and Global Positioning System (GPS) data from vessels in the area. The position data from each of the vessels was converted to range, range rate and bearing data relative to the radars so as to be compared with the vessel detection data (Figure 7). Detections that were within half a range bin and within two Doppler bins of the radial velocity from the AIS data were counted as valid detections.

The data from September 9th and 10th was further analyzed, as there were a large number of vessels present in the detection data. The data was also analyzed when the Coast Guard ice breaker Healy and Research Vessel Norseman II were within 100 km of the radar site as these were high value targets. The results of this analysis are summarized in Table 1. A summary of the physical characteristics of the vessels detected is presented in Table 2 with most of the vessels being tugboats with an average length of 30 m.

The maximum detection range for each vessel was averaged into a single number, which was 51 km. The maximum of all the maximum detection ranges was 82 km for the Aiviq on September 9th. The average detection time was 18 hours with a maximum of 24 hours for the four of the vessels, the Aiviq, Arctic Seal, Nokea and Warrior. The radar has a 32 second update rate. The percentage of time detected was calculated by dividing the total number of detections by the number of update cycles within the detection window. The average detection rate during the study period was 51% with a maximum of 88% for the Coast Guard Ice Breaker Healy on August 22nd.

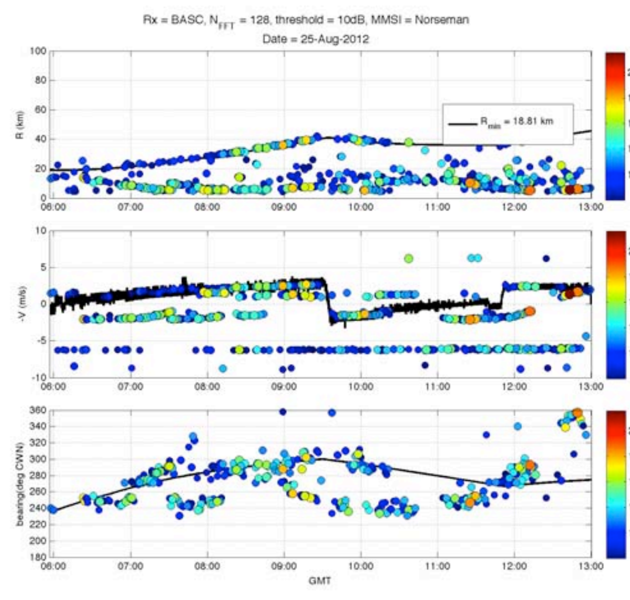

Figure 5: Time series plot of vessel detections from the 5 MHz radar at Point Barrow (BASC). The x-axis for all three plots is the hour of the day for September 1, 2012. The sub plots from top to bottom are vessel detection range, radial velocity (m/s) and bearing (degrees CWN). The color of the data points denotes the signal to noise ratio (dB) of the detection and is interpreted by the colorbar on the right. The ground truth information for one of the vessels is shown as the black line.

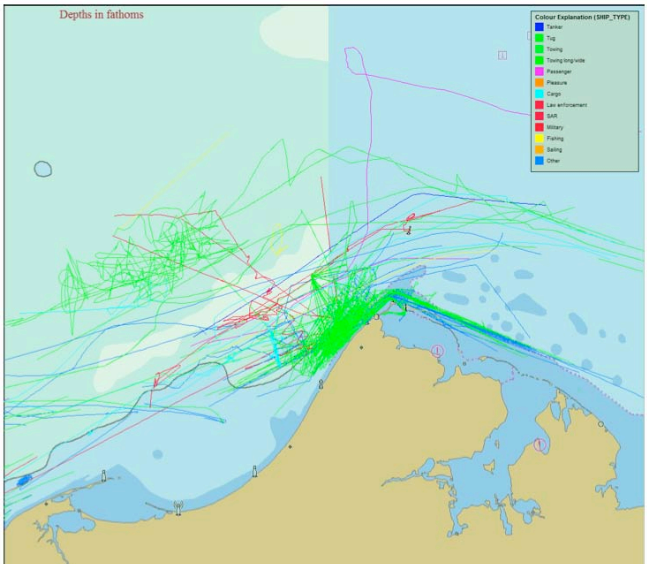

Figure 6: Tracks of vessels from the Automatic Identification System (AIS) from August 10 to September 10, 2012. The different colors denote the type of vessel.

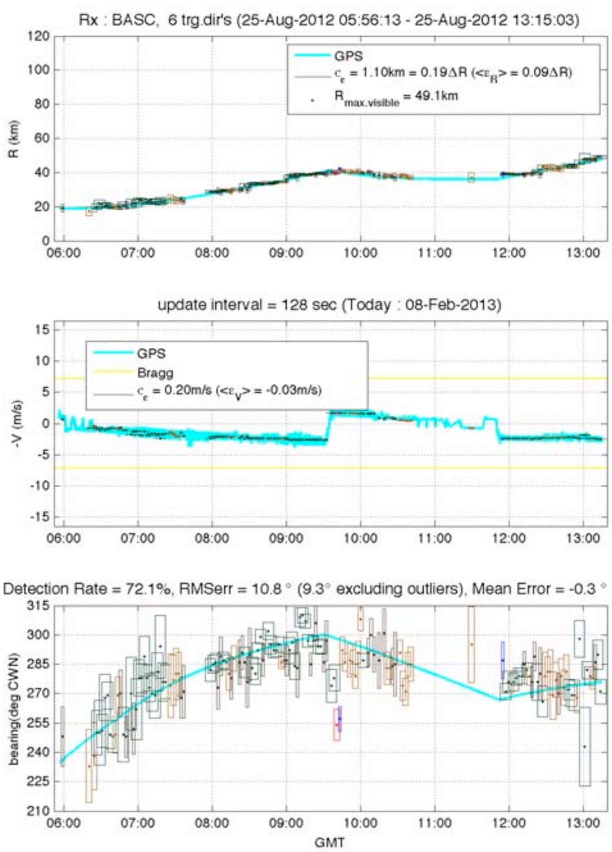

Figure 7: Range (top), radial velocity (middle) and bearing (bottom) of the research vessel Norseman II (aqua line) for August 25, 2012 from 06:00 to 13:30 GMT. The data was recorded via GPS and transmitted via AIS. The detections by the radar are shown as the dots with boxes around the detections that represent the error bars.

Table 1: Summary of vessel detections analyzed during the study period. The table presents the name of the detected vessel, the start and end time of the radar detections (Greenwich Mean Time), the percentage of time the vessel was detected, the maximum detection range (km) and the time of detection (hours).

Vessel Name	Start Time	End Time	Percentage of Time Detected	Maximum Detection Range (km)	Detection Time (hours)
Healy	8/22/12 10:00	8/22/12 21:00	88.3	71.1	11.00
Healy	8/22/12 21:00	8/23/12 18:37	35.9	70.8	21.62
Norseman II	8/25/12 5:56	8/25/12 13:15	72.1	49.1	7.32
Healy	8/26/12 23:00	8/27/12 2:22	81.2	16.3	3.37
Norseman II	8/29/12 9:00	8/29/12 19:00	58.1	53.2	10.00
Aiviq	9/9/12 0:00	9/10/12 0:00	26.1	81.9	24.00
Arctic Seal	9/9/12 0:00	9/10/12 0:00	21.6	52.4	24.00
Nachik	9/9/12 0:00	9/9/12 23:00	9.6	12.8	23.00
Nokea	9/9/12 0:00	9/10/12 0:00	68.5	23.2	24.00
Warrior	9/9/12 0:00	9/10/12 0:00	18.2	79.2	24.00
Lauren Foss	9/9/12 0:07	9/9/12 2:58	54.5	39.8	2.85
Sisuaq	9/9/12 9:05	9/9/12 17:12	70.8	74.8	8.12
Aiviq	9/10/12 0:00	9/11/12 0:00	48.5	72.1	24.00
Arctic Seal	9/10/12 0:00	9/11/12 0:00	53.6	45.8	24.00
Nokea	9/10/12 0:00	9/11/12 0:00	72	24.7	24.00
Sesok	9/10/12 0:00	9/10/12 23:44	49.2	17.2	23.73
Warrior	9/10/12 0:00	9/10/12 21:24	39.9	63.5	21.40
Pt.Oliktok	9/10/12 0:01	9/10/12 9:49	69.7	51.3	9.80
Pacific Raven	9/10/12 6:00	9/10/12 22:48	32.8	37.9	16.80
Healy	10/10/12 16:41	10/10/12 23:46	44.8	79.3	7.08
		Average	51	51	18
		Maximum	88.3	81.9	24

Table 2: Summary of the physical characteristics of the vessels detected during this study. The table presents the name of the vessel, the length (m), the breadth or the width (m) and the type of vessel.

Name	Length (m)	Breadth (m)	Type
Aiviq	109	24	Anchor Handling Vessel
Arctic Seal	37	10	Cargo
Healy	130	25	Coast Guard Ice Breaker
Lauren Foss	46	12	Tug
Nachik	23	10	Tug
Nokea	31	10	Tug
Norseman II	35	9	Research Vessel
Pacific Raven	31	10	Tug
Pt. Oliktok	30	10	Tug
Sesok	23	10	Tug
Sisuaq	90	19	Multi Purpose Offshore Vessel
Warrior	40	10	Tug

IV. CONCLUSIONS

SeaSonde HF radars were installed along the north slope of Alaska. They simultaneously generated measurements of ocean surface currents and vessel detections. The vessel detection data was compared against ground truth data transmitted via AIS or recorded on the vessel via GPS. The maximum detection range was 82 km with a maximum detection rate of 88 percent. The real-time dual use capability of the SeaSonde HF radar provides an ability to assess environmental security and shipping activity in a manner that reduces risk and enhances response.

The research advances of this study provide a tool to simultaneously maintain clear maritime domain awareness and conduct persistent surveillance activities over a large area. This information will be a valuable asset to the US Coast Guard, United States Northern Command (USNORTHCOM), the Alaska state Department of Emergency Management and Military Affairs, the Alaska Department of Environmental Conservation, the Alaska state Department of Natural Resources, and the Alaska North Slope Borough who all have a stake in keeping commercial activity in the Arctic safe and secure.

ACKNOWLEDGMENT

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.

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