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Evaluation of Rutter Sigma S6 Ice Navigation Radar on USCGC Healy during Arctic Shield 20

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Homeland Security

N O T I C E

Mr. Timothy R. Girton
Technical Director
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320

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The R&D Center's technical point of contact is Mr. Alexander Balsley. Phone: 860-865-0474; Email: Alexander.Balsley@uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

The Coast Guard (CG) fleet is currently outfitted with Northrop Grumman/Sperry's BridgeMaster radar systems, which provide the basic information that navigators need in order to engage in a safe cruise. In the Arctic environment, however, the CG radar system is challenged when limited visibility and the presence of varying types of ice are encountered. Although the CG radar is able to detect the presence of ice to some degree, it is not able to roughly estimate the ice's thickness or clearly define the ice edge that separates an ice floe from a patch of open water.

The United States Coast Guard Research and Development Center explored this issue by evaluating the Rutter Sigma S6 Ice Navigation Radar through comparison with the existing BridgeMaster radar system on USCGC Healy during Arctic Shield 2014. The data collected indicate that the Ice Navigation radar is an improvement over the CG radar while the ship is in presence of multiple ice formations. The Ice Navigation radar, with its enhanced fidelity, was able to: clearly define ice floes; determine their relative thickness; detect pressure ridges; and identify patches of open water with ease.

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EXECUTIVE SUMMARY

The Coast Guard (CG) fleet is currently outfitted with Northrop Grumman/Sperry's BridgeMaster radar systems, which provide the basic information that navigators need in order to engage in a safe cruise. In the Arctic environment, however, the CG radar system is challenged when limited visibility and the presence of varying types of ice are encountered, from first year to multiyear ice formations. Although the CG radar is able to detect the presence of ice to some degree, it is not able to roughly estimate the ice's thickness or clearly define the ice edge that separates an ice floe from a patch of open water. Ideally, navigators on a ship would be able to use the radar to help chart an efficient path through an ice field to reduce transit time and fuel expenses. This includes a clear picture of the ice field on the CG radar display up to 6 nautical miles (nm) away. Additionally, a high-resolution radar display would enhance the efficiency of an oil spill response operation in ice-covered waters as responders would have a better understanding of the ice situation in which they are operating (which is subject to constant change). Another added benefit with a high-resolution radar display is the identification of open water where oil will collect during an accidental spill, which allows responders to quickly locate areas to concentrate response operations.

To meet this need, the United States Coast Guard (USCG) Research and Development Center (RDC) evaluated the Rutter Sigma S6 Ice Navigation Radar by comparing it to the CG radar system on the USCGC Healy during its Arctic Shield 2014 demonstration in the Chukchi/Beaufort Sea in the month of August. Objectives included conducting a side-by-side comparison between the Coast Guard's Northrop Grumman/Sperry BridgeMaster radar and the Rutter Ice Navigation radar systems to determine if the Sigma S6 processor is an improvement upon current radar processing capabilities. Data were collected simultaneously from both radar systems at multiple settings and conditions and photographs of the surrounding environment were taken during data captures to confirm radar information. Two different test approaches - stationary and underway testing - are outlined in Appendix A, Ice Navigation Radar Test and Evaluation Plan.

The data collected indicate that the Ice Navigation radar is an improvement over the CG radar while the ship is in the presence of multiple ice formations. The Ice Navigation radar with its enhanced fidelity was able to: clearly define ice floes; determine their relative thickness; detect pressure ridges; and identify patches of open water with ease. It also found other uses as the mission evolved, such as locating ice growlers or having the ability to track a small vessel as it broke through loose ice. The ship's officers found it to be a valuable asset not only for Arctic Shield 2014 but for other science missions in the Arctic environment and are currently working to permanently install the Ice Navigation radar onto the ship.

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ALOFTCON	Aloft Conning Station
ASB	Arctic Small Boat
CG	Coast Guard
nm	Nautical mile
OOD	Officer of the Deck
RDC	Research and Development Center
TCTO	Temporary Time Compliance Temporary Order
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter

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1 INTRODUCTION

The Coast Guard (CG) relies on radar to fulfill multiple vital missions. The Coast Guard (CG) fleet is currently outfitted with Northrop Grumman/Sperry's BridgeMaster radar systems, which provide the basic information that navigators need in order to engage in a safe cruise. A radar determines the distance of ships and their bearings as well as land targets. It serves to assist the Officer of the Deck (OOD) to make the necessary decisions to navigate safely through the open water.

In the Arctic environment, however, the CG radar system is challenged by limited visibility and the presence of varying types of ice, from first year to multiyear ice formations. Although the CG radar is able to detect the presence of ice to some degree, it cannot roughly estimate the ice's thickness or clearly define the ice edge that separates an ice floe from a patch of open water. Ideally, navigators on a ship would be able to use the radar to help chart an efficient path through an ice field to reduce transit time and fuel expenses. This includes a clear picture of the ice field on the CG radar display up to six nautical miles (nm) away. Additionally, a high-resolution radar display would enhance the efficiency of an oil spill response operation in ice-covered waters as responders would have a better understanding of the ice situation in which they are operating (which is subject to constant change). Another added benefit with a high-resolution radar display is the easy identification of open water patches within an ice field where oil will collect during an accidental spill. This would allow responders to quickly locate areas where response operations should occur.

To meet this need, the United States Coast Guard (USCG) Research and Development Center (RDC) evaluated the Rutter Sigma S6 Ice Navigation Radar (known henceforth as Ice Navigation radar) by comparing it to the CG radar system on the USCGC Healy during the Arctic Shield 2014 demonstration in the Chukchi/Beaufort Sea in the month of August.

2 BACKGROUND

As ice recedes further and further in the Arctic Ocean during the summertime, oil drilling and shipping opportunities are increasing. This leads to a greater possibility of oil spills and as such, the Coast Guard and its oil spill response partners need to be well prepared for responding to an incident in ice-covered waters during Arctic conditions. The RDC hosted a series of oil spill response demonstrations in the Great Lakes during the winter months from 2011 to 2013 and they increased in complexity over the years. A radar evaluation was performed in February 2013 on the USCGC Hollyhock. The RUTTER Sigma S6 was chosen because it was the only system available that could be connected to the existing CG system without interfering with navigation. The data collected in the Great Lakes indicated that the extra processing in the Ice Navigation radar system enabled the crew to identify different types of ice and its relative thickness as well. It proved to be superior to the CG radar system. The Ice Navigation radar system was mounted on the USCGC Healy in 2014 in a configuration identical to that used in the Great Lakes. The RDC performed another radar evaluation using the same two systems (Rutter Ice Navigation and Northrop Grumman/Sperry BridgeMaster radars) during Arctic Shield 2014 to determine if the same performance applies in an Arctic navigation environment. This report contains the results of the evaluation.

While Rutter manufactures other types of radar units, only the Ice Navigation radar system was evaluated. The Sigma S6 radar processor in the Ice Navigation radar system is unique in that it processes a full dynamic range of data (12-bit video) versus the 2-4 bit intensity in standard navigation processors (such as the CG radar) that are more than adequate to identify other vessels, buoys and points of land. This processor then is able to produce a higher quality image for better ice definition with its 256 video intensity levels. The processor uses the standard X-band out (Analog) usually set on a short pulse for better resolution.

3 OBJECTIVES

1. Conduct side-by-side comparison between the Coast Guard's Northrop Grumman/Sperry BridgeMaster radar and the Rutter Ice Navigation radar systems to determine if the Sigma S6 processor is an improvement upon current radar processing capabilities.
   A. Identify ice edges and open water within ice-infested fields to identify potential oil pooling.
   B. Identify pressure ridges and determine if navigation is improved with ability to determine paths of least resistance earlier
   C. Note similarities and differences between two radar systems for any other scenarios that may arise during the mission

2. Collect data simultaneously from both radar systems at multiple settings and conditions.

3. Capture photographs of surrounding environment during data captures to confirm radar information while the ship is stationary or underway.

4. Support oil-in-ice demonstration.

4 ARCTIC SHIELD 2014 ICE NAVIGATION RADAR DEMONSTRATION

The mission commenced when the USCGC Healy departed from the port of Seward, Alaska on August 7, 2014. The evaluation of the Ice Navigation radar system was not performed until the ice edge was reached in the afternoon on August 15, approximately 100 miles north of Barrow. Data collection occurred while the ship was in the presence of ice, which was encountered for seven days between August 15 and August 21.

4.1 Test Preparations

A Temporary Time Compliance Technical Order (TCTO) was acquired and provided instructions to temporarily install and test the Ice Navigation radar system. While the USCGC Healy was in port in Seattle, two Rutter technicians installed the Rutter computer and radar display in the Chart Planning Station, which was located in the ship's bridge. The computer was able to receive the necessary radar signals by attaching to the current BridgeMaster system onboard USCGC Healy. Additionally, it was able to connect to the ship's Gyro and GPS signals. The Rutter technicians also installed necessary programs in a RDC laptop to enable it to serve as a portable radar display in the Aloft Conning Station (ALOFTCON) when plugged into the Rutter computer (in the Chart Planning Station) with an Ethernet cable. Two RDC employees and two USCGC Healy crewmembers received a one-hour training session on the use of the Ice Navigation radar system from the Rutter technicians; these trainees were the primary operators during the Arctic Shield 2014 mission.

The Rutter system, along with the ability to store raw radar data, is capable of providing high-resolution screen captures for archiving and later analysis. The CG radar system did not have similar capabilities available, which necessitated the photographing of the radar display to record images. For this demonstration, a screen capture of the Ice Navigation radar display was taken every minute for the entire duration that the ship was in the presence of ice. This allowed the data recorder the freedom to take a photograph of the CG radar display with a handheld camera at certain intervals or when an unusual feature in the ice field appeared on either radar display. Having images of both radar displays at the same time allows a proper evaluation of the two radar systems.

The Ice Navigation radar display could be stationed in two possible locations: the Chart Planning Station on the bridge or the ALOFTCON. Figure 1 shows locations of the radar antenna, ALOFTCON and the ship's bridge.

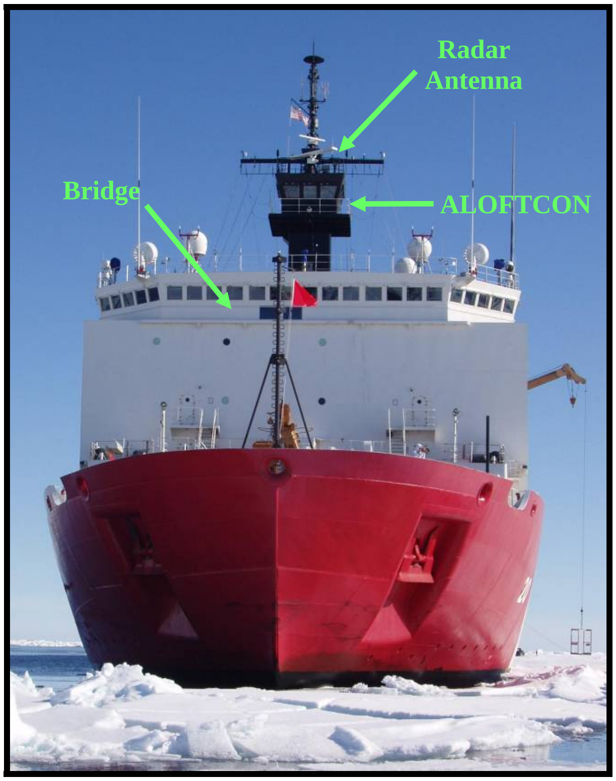


Figure 1. External view of USCGC Healy from the front.

The Chart Planning Station was the primary location on the bridge where the computer and radar display were established (See Figure 2). This setting was used during navigation when the OOD was comfortable with the amount of ice in the water, when the weather was clear enough, or when the ship remained stationary. However, one downside to this setup was that the crew found it cumbersome to check on the Ice Navigation radar on the bridge because the Chart Planning Station is located behind a bulkhead. This meant the OOD would need to leave his/her station for several seconds to check the Ice Navigation radar display for information about the upcoming ice configuration. Also, if the radar display was in another location (such as the ALOFTCON or the main console on the bridge), two people would be needed to be on the radio in different locations. They would have to communicate to each other what should be done to adjust the controls since one person would have eyes on the radar display and the other would control the keyboard and mouse.

If the weather deteriorated or thick fog appeared while navigating, the OOD transferred ship controls to the ALOFTCON to gain better visibility of the surrounding environment. When this occurred, a laptop configured with Rutter software was used to show the Ice Navigation radar display. This was made possible with an Ethernet cable that ran from the Chart Planning Station, where it was plugged into the Rutter computer, to the ALOFTCON where the other end was plugged into the laptop. This made for a very comfortable setup for the OOD as the Ice Navigation radar display was situated directly next to him/her while navigating (See Figure 3).

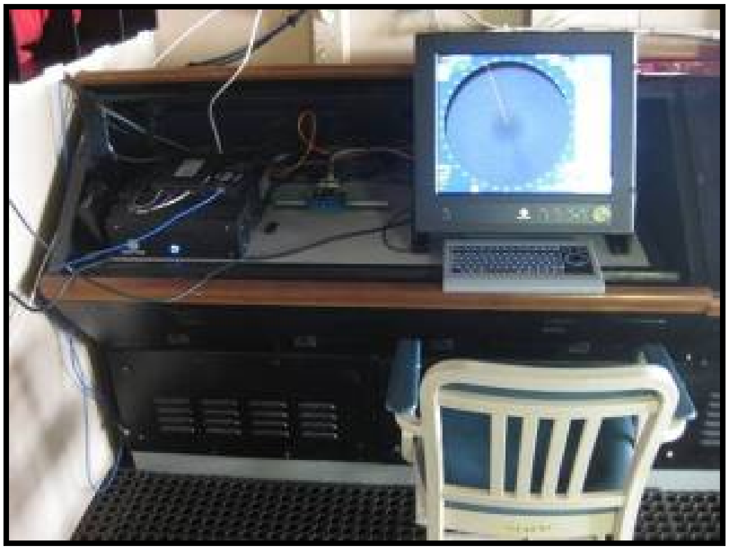


Figure 2. Setup of Rutter computer and radar display in the Chart Planning Station onboard the USCGC Healy.

Figure 3. Setup of Rutter-configured laptop in the ALOFTCON with OOD navigating.

4.2 Test Execution

Occasionally, data collection involved taking photographs of the CG radar display and then climbing to the ALOFTCON in order to take 360-degree view photographs at every 45 degrees to verify the surrounding environment. Two test procedures were performed during the cruise: stationary and underway testing. See Appendix A for the Ice Navigation Radar Test and Evaluation Plan.

RDC employees carried out the data collection for both stationary and underway testing. They had primary use of the Ice Navigation radar but it was also used by the ship's officers as well. After the radar's installation in April 2014 and prior to the Arctic Shield mission in August, the Ice Navigation radar was used by the crew members to aid their navigation through ice fields for other scientific missions. As a result, there were already some experienced users among the ship's crew members and officers when Arctic Shield 2014 was underway.

RDC employees were also responsible for setting up the laptop in the ALOFTCON anytime OODs opted to occupy the space during difficult navigation conditions. The CG radar system was not modified at all by the RDC employees as it was still the ship's primary means of navigation. However, the RDC employees would periodically ask the crew members if the range scale on the CG radar could be adjusted to provide a better side-by-side comparison for evaluation purposes.

4.2.1 Stationary Testing

While the ship was stationary, data collection consisted of: screen captures of the Ice Navigation radar display; photographs of the CG radar display; and the occasional 360-degree view of the surrounding environment from a handheld digital camera. Stationary testing generally took place during the daytime for the duration of oil spill response demonstrations. The stationary test procedure collected data to evaluate whether there is an improvement of the Ice Navigation radar system over the current CG radar system in defining the ice edges more clearly. It also served to monitor the movement of ice for the duration of the demonstration and ensured that the chosen open body of water remained large enough to carry out the demonstrations safely. Data (photographs and screenshots) were collected in support of the oil-in-ice demonstration and are not discussed here but can be seen in the "Arctic Technology Evaluation 2014 Oil-in-Ice Demonstration Report" written by Kurt Hansen (2015).

4.2.2 Underway Testing

The underway procedure was a way to evaluate the two radar systems during navigation through ice fields. The goal for navigators on ice breakers is to maneuver along a path of the least resistance through the ice-infested waters so that the ship may traverse safer and use the least amount of fuel possible. This meant avoiding thick ice floes whenever possible and aiming for patches of open water that would enable the ship to cruise at a quicker rate. As advanced as a radar may be, it is crucial that navigators still look through the windows on the bridge to make short-term decisions. The radar is a supplemental tool that helps to foresee the potential obstacles ahead that would allow the navigator to plan approximately 10 to 20 minutes in advance, depending on the ship's velocity. It is more helpful to the navigator if the radar is able to determine the relative thickness of ice and the certainty of open water patches approximately 3 to 6 nautical miles (nm) away. Thus the underway test procedure focused on determining if the Ice Navigation radar is an improvement over the current CG radar during navigation in ice fields. Data collection consisted of:

screen captures of the Ice Navigation radar display; photographs of the CG radar display from a handheld camera; and the occasional 360-degree view of the surrounding environment. Data collection took place when OODs utilized the Ice Navigation radar to scout for thick ice floes or patches of open waters. Additionally, data collection occurred when an interesting ice feature appeared (such as a pressure ridge, because it poses a challenge to navigators who may need to decide to avoid it completely or to cross the ridge perpendicularly).

The Ice Navigation radar found other unexpected uses as the mission progressed. The USCGC Healy crewmembers used it as a tool to help locate navigational buoys that were a part of the science mission, but not included in the oil spill response demonstration. Another member of the science team found the high fidelity of the processor to be particularly useful for locating growlers or large pieces of broken ice. The amount of detail that the Ice Navigation processor was able to provide impressed the crewmembers as it was able to track the progress that the Arctic Small Boat (ASB) made when it was deployed in loose ice and pushed its way out into the open water to perform its operations.

4.3 Data Summary

Selected data that was collected during Arctic Shield 2014 are organized in Table 1 and 2. There were over 500 photographs and screenshots collected during the radar evaluation; a few are chosen for this report to best demonstrate the differences between the two radar systems during stationary and underway testing or indicate a unique capability of the Ice Navigation radar. Within this report are six photographs of the CG radar display, 13 screenshots of the Ice Navigation radar display and 21 environment photographs. The other photographs and screenshots are available if additional analyses are needed.

Table 1. Stationary testing data summary.

Date	Time	Purpose	Weather	Ice Navigation Radar Scale (nm)	CG Radar Scale (nm)	Reference
8/15/2014	2016	Comparison of details between both radar displays.	Cloudy skies, clear visibility	3	3	Figures 4-7
8/16/2014	1051 - 1057	Performing technology demonstrations in a patch of open water.	Sunny, clear visibility	3	3	Figures 8-11
8/18/2014	1300-1400	Arctic Small Boat breaking ice to make a path for itself to a patch of open water.	Cloudy skies, somewhat foggy, limited visibility	1-3	-	Figures 35-38

Table 2. Underway testing data summary.

Date	Time	Purpose	Weather	Ice Navigation Radar Scale (nm)	CG Radar Scale (nm)	Reference
8/19/2014	2349	Detecting an ice field with the radar.	Cloudy skies, clear visibility	3	1.5	Figures 14-16
8/20/2014	0015-0100	Avoiding a thick ice floe.	Cloudy skies, little fog	3	1.5	Figures 17-23
8/20/2014	1445-1645	USCGC Healy becoming stuck in an ice floe.	Cloudy skies, foggy, low visibility	3	1.5	Figures 24-30
8/20/2014	1845-1700	Encountering a pressure ridge.	Cloudy skies, foggy, low visibility	3	3	Figures 31-34

5 TEST RESULTS

5.1 Stationary Observations

It should be noted that OODs do not follow any standard operating procedures with respect to radars. They adjust the radar settings according to their training, experience and personal preference. Since there are numerous scenarios that may be encountered while at sea, no specific radar settings have or will be incorporated into any standard operating procedures. During Arctic Shield 2014, the USCGC Healy crew did not establish any specific settings on either the CG radar or Ice Navigation radar systems.

The polar ice field surface features (e.g., open water, ice floes, and pressure ridges) were clearly identifiable on the Rutter radar display while not appearing well defined on the ship's CG radar display. Figures 4 and 5 demonstrate a side-by-side comparison of the Ice Navigation radar (Figure 4) and the CG radar (Figure 5) displays for the same location at the same time. Features identified on both radar displays were visually confirmed by climbing to the ALOFTCON and taking photographs of the 360-degree view of the surrounding environment that the radar displays captured (See Figures 6 and 7). The red line on Figure 4 represents the ship's heading and the series of photographs in Figures 6 and 7 begin with the ship's heading and rotate clockwise at every 45 degrees.

The side-by-side comparison in Figures 4 and 5 shows a significant difference between the two radar displays. The Ice Navigation radar display shows a greater level of details and the patch of open water in front of the ship is more clearly defined than what is shown on the CG radar display. Additionally, it is difficult to discern whether there is ice or open water on the CG radar display. The captain of the USCGC Healy indicated that it was difficult for the navigators to determine whether the radar display was showing an open body of water or a patch of smooth ice that appeared to look like an open body of water. As shown in Figure 5, there are many areas that look like open water whereas the Ice Navigation radar display shows an ice cover (Figure 4). For instance, approximately 170 degrees from the ship's heading and 1 nm away, the Ice Navigation radar display shows ice cover (see circle in Figure 4) whereas the CG radar display shows possibly open water (see circle in Figure 5). This is a clear example of what a high-fidelity radar system can do to help ship's navigators make more informed decisions.

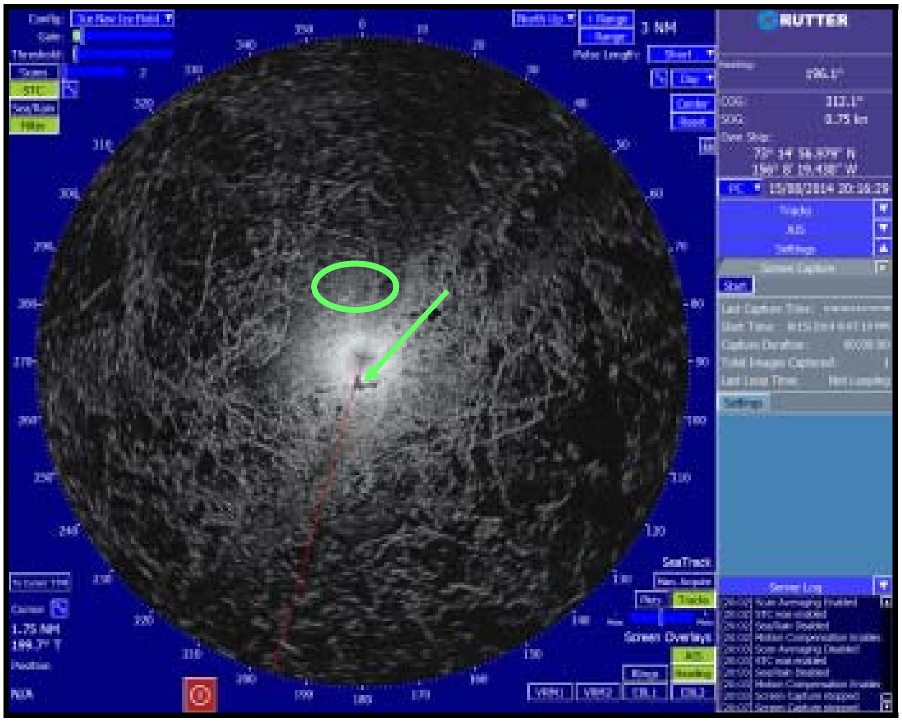
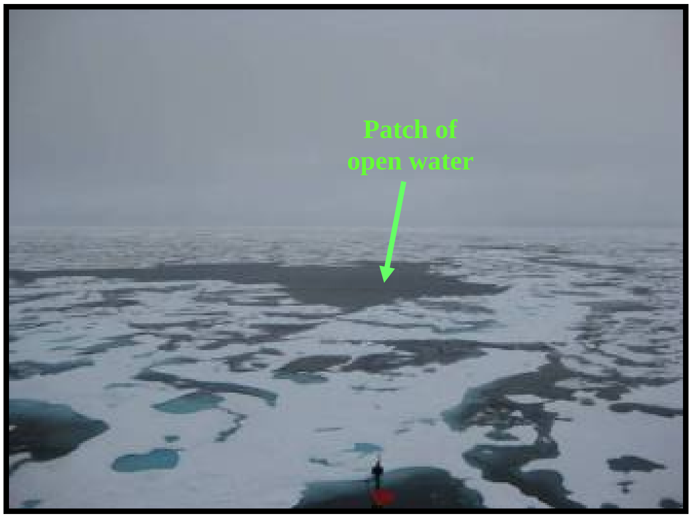


Figure 4. Ice Navigation radar screen capture during Stationary Procedure (3 nm range scale; arrow indicates the clearly defined patch of open water in front of ship; circle indicates ice field).

Figure 5. Photograph of Coast Guard radar display during Stationary Procedure (3 nm range scale; arrow indicates the patch of open water, which is difficult to discern on this display; circle suggests open water).



0 degree view

45 degree view

90 degree view

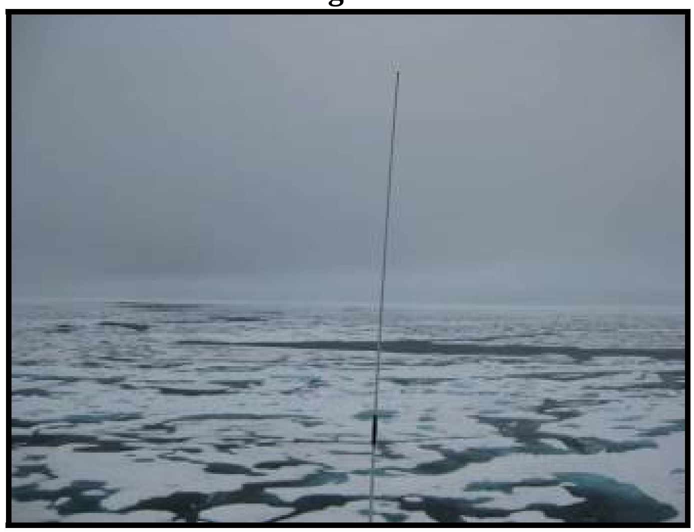
135 degree view

Figure 6. 0 - 135 degree relative bearing views of ice infested field.

180 degree view

225 degree view

270 degree view



315 degree view

Figure 7. 180 – 315 degree relative bearing views of ice infested field.

The ice and sea surface features were more clearly identifiable on the Rutter radar display out to a range of approximately 3 nm. At this same range, the CG radar system becomes unreliable as the ice conditions are not clearly visible. On the Ice Navigation radar, when the range increases, the resolution decreases slightly but it still provides more details when compared with the CG radar at the same range. The differences between the two are shown more clearly in Figures 8 and 9. This side-by-side comparison is one of the many examples that prove that the Rutter radar display provided significantly superior surface texture information, both in near and far range. In Figure 8 and the subsequent 360-degree view photographs in Figures 10 and 11, it is evident that the ship is facing a body of open water. However, the CG radar display (Figure 9) does not show the full extent of the open water directly in front of the ship. Additionally, there is very little information about the ice field after approximately 1.5 nm in the CG radar display.

Figure 8. Ice Navigation radar screen capture during Stationary Procedure (3 nm range scale; arrow indicates location of a small ice chunk in an area of open water).

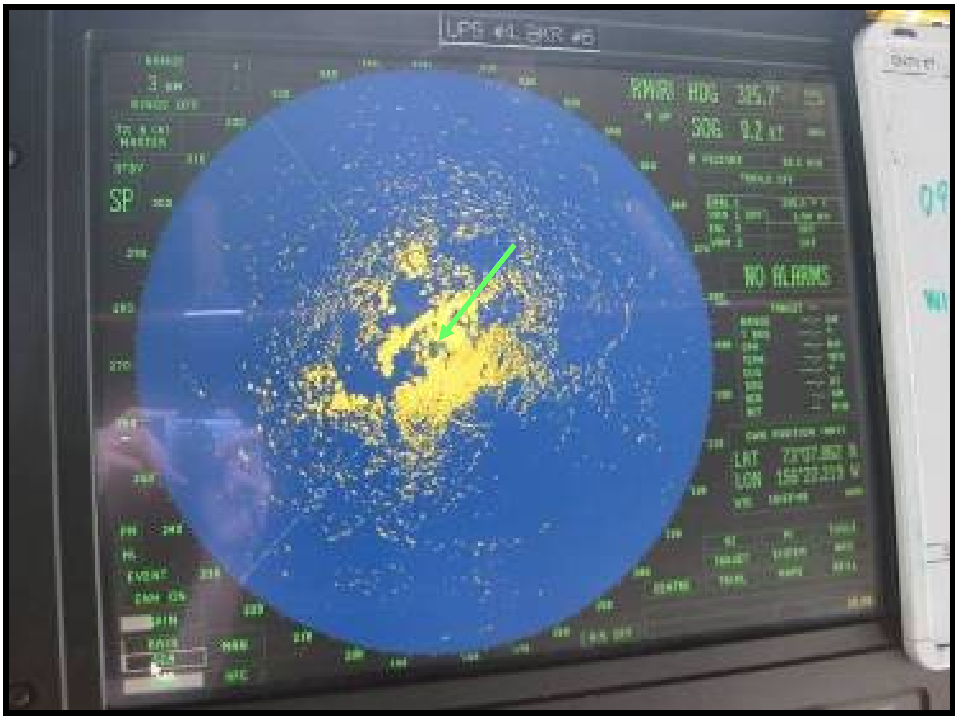


Figure 9. Photograph of Coast Guard radar display during Stationary Procedure (3 nm range scale; arrow shows how that particular region on the radar screen shows less resolution than that of Figure 8).

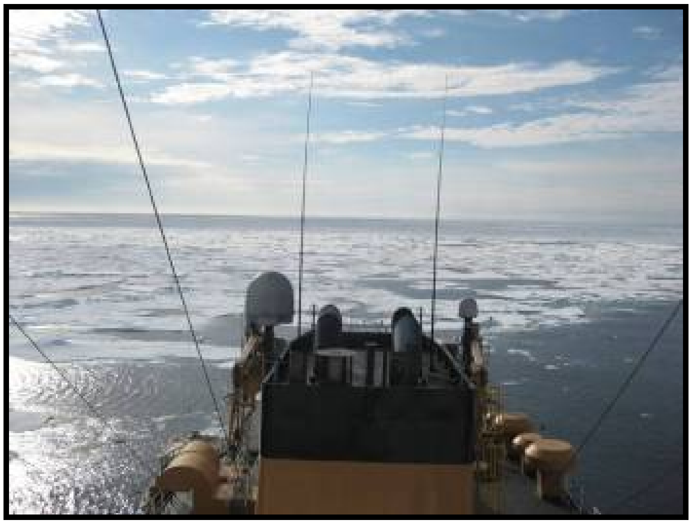
0 degree view

45 degree view

90 degree view

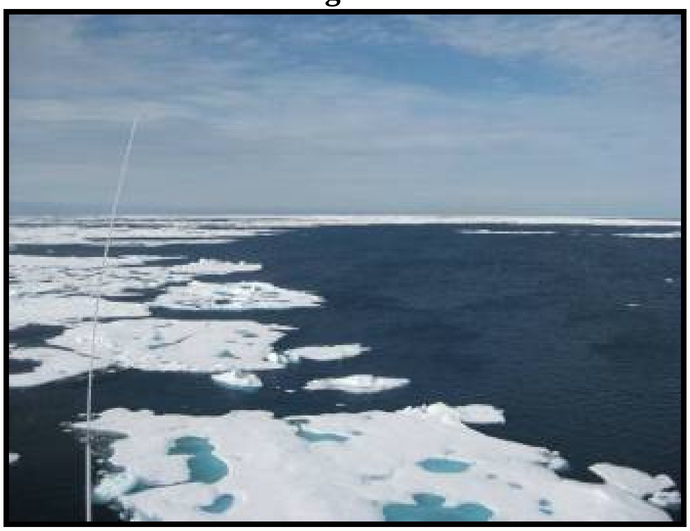
135 degree view

Figure 10. 0 - 135 degree relative bearing views of test area with open water.

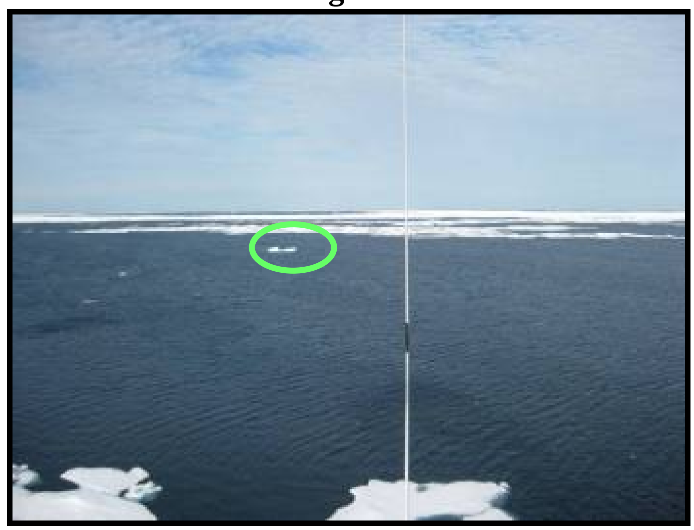


180 degree view

225 degree view



270 degree view



315 degree view

Figure 11. 180 – 315 degree relative bearing views of test area with open water (Circle indicates a small ice chunk visible in the Figure 8 radar image).

From the data collection, it is again evident that the Ice Navigation radar shows a clearer picture of the surrounding environment. It is even able to show clearly the path of broken ice behind the ship whereas the CG radar system vaguely shows this path in the ice. The small piece of ice circled in Figure 11 shows up on the Ice Navigation radar display (Figure 8) but is not clearly depicted on the CG radar display (Figure 9). These examples further illustrate that the Ice Navigation radar system provided useful, high resolution images of the surrounding icy environment.

5.2 Underway Navigation

The ALOFTCON with a Rutter-configured laptop was found to be the more ideal location for the Ice Navigation radar display as compared to the Chart Planning Station on the bridge. The laptop display could be set directly to the left where the OOD stands and in front of the window (See Figure 12). This vantage from the ALOFTCON allowed the OOD to see out the window and simultaneously observe the Ice Navigation radar display with ease (See Figure 13). When this setup was engaged, the current CG radar display in the ALOFTCON was not used since the laptop radar display provided a superior picture in a better location.

Figure 12. Rutter-configured laptop setup in the ALOFTCON.

Figure 13. OOD utilizing the Rutter-configured laptop during navigation during poor weather in the ALOFTCON.

It was learned that each OOD has his/her style of navigation through the ice. Some preferred to check in on the Ice Navigation radar display as often as needed on the bridge while others felt comfortable relying on the current Coast Guard radar display or his/her own view of the ice through the window. This was likely the case due to the ideal location of the CG radar display on the bridge within the main console, which was situated directly next to the raised step reserved for OODs. Anecdotally, the Ice Navigation radar system was popular among the ship's officers. However, it was not utilized as much as originally thought due to its poor location in the Chart Planning Station on the bridge although there was no other viable location. The ALOFTCON was rarely used since few OODs thought it worthwhile to navigate from there during the Arctic Shield mission; thus, the Rutter-configured laptop was not utilized as much as originally thought. During the previous science cruise that occurred in early summer after the radar installation in April and before the commencement of Arctic Shield 2014 in August, the Ice Navigation radar display was sometimes wired to be shown on one of the many monitors in the main console of the bridge. However, it takes time to do so and requires an Electronics Technician to perform the operation. This setup was not used during Arctic Shield 2014. Making matters more difficult, any setting changes for the Ice Navigation radar system while the radar display was on the main console had to be performed in the Chart Planning Station with the keyboard and mouse. This was a challenge because a bulkhead divided the main console from the Chart Planning Station. If there was a choice whether to use the CG radar or the Ice Navigation radar, if location was not an issue during navigation in ice-infested waters, the Ice Navigation radar was almost always preferred.

The ice encountered during Arctic Shield 2014 did not pose serious navigation challenges for the ship. Most of the time, the ship's crew would establish a destination and arrive there in a straight line. It would deviate from its course occasionally to avoid large ice floes or change the ship's heading to cross over a pressure ridge rather than run parallel to it. Still, the Ice Navigation radar was useful for the navigators in their awareness of upcoming ice conditions. Data collection during navigation showed that there were some ice features that the Ice Navigation processor captured that the CG processor did not. For example, on August 19 at 11:49 PM, the Ice Navigation radar system registered a thin ice sheet approximately 30 degrees to starboard of the ship's heading and 0.5 nm away (See Figure 14) while the CG radar system showed an empty space in the same region (See Figure 15). It can be interpreted to be a patch of open water but a photograph of the environment showed ice in the distance, not open water (See Figure 16).

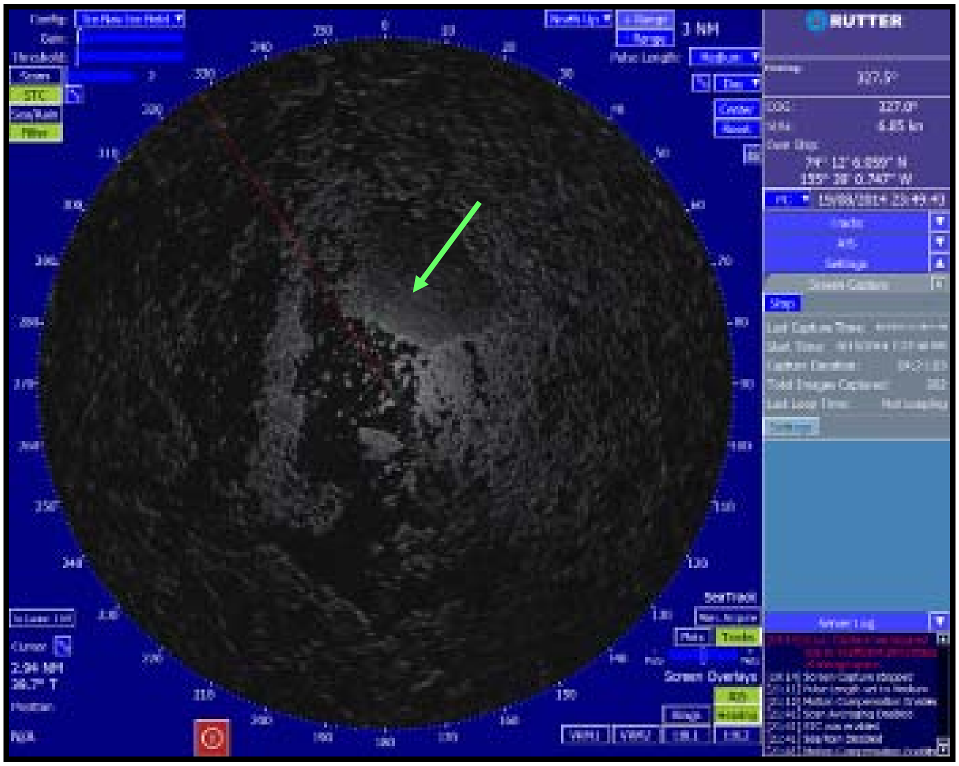


Figure 14. Arrow indicates thin ice field shown on Ice Navigation radar 30 degrees east of the ship's heading and 0.5 nm away (3 nm range scale).

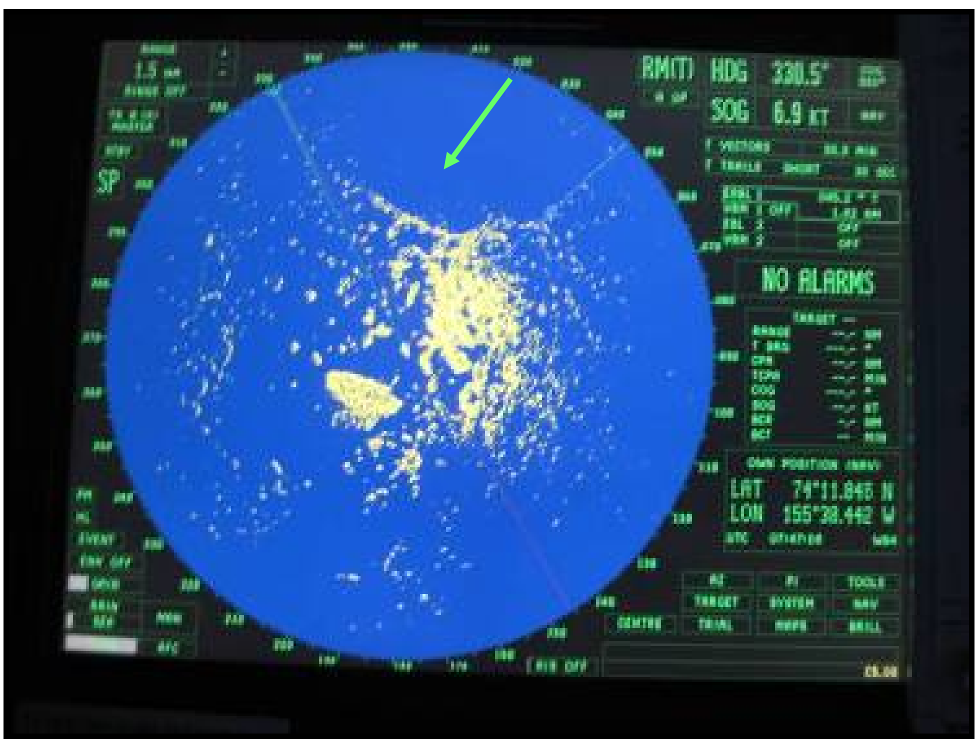


Figure 15. Arrow indicates lack of distinguishable ice field shown on CG radar 30 degrees east of the ship's heading and 0.5 nm away (1.5 nm range scale).

Figure 16. Ice field shown in the distance.

During one watch early in the morning on August 20, the OOD relied heavily on the Ice Navigation radar in the Chart Planning station and identified a large ice floe ahead that he took into account while navigating. Figures 17 to 20 show the path that the ship took to avoid breaking through the ice floe and maintain the ship's momentum. This particular ice floe was undetected through the window due to light fog (See Figure 21) but as the ship got closer, it became visible (See Figure 22). After the ship safely maneuvered around the ice floe, a photograph of the CG radar display (See Figure 23) was taken to compare the clarity of the ice floe in question to the Ice Navigation radar display as shown in Figure 20. The comparison between Figure 20 and Figure 23 of the ice floe south of the ship shows clearly that the extent of the ice floe is easily identified by the Ice Navigation radar but is not clearly defined by the CG radar. The ability to clearly define ice edges and identify the differences between ice and open water has large implications in choosing safer and more efficient shipping routes for the OOD.

Figure 17. Heading to the left of ice floe (Red line indicates ship's heading; green arrow indicates ice floe in question; 3 nm range scale).

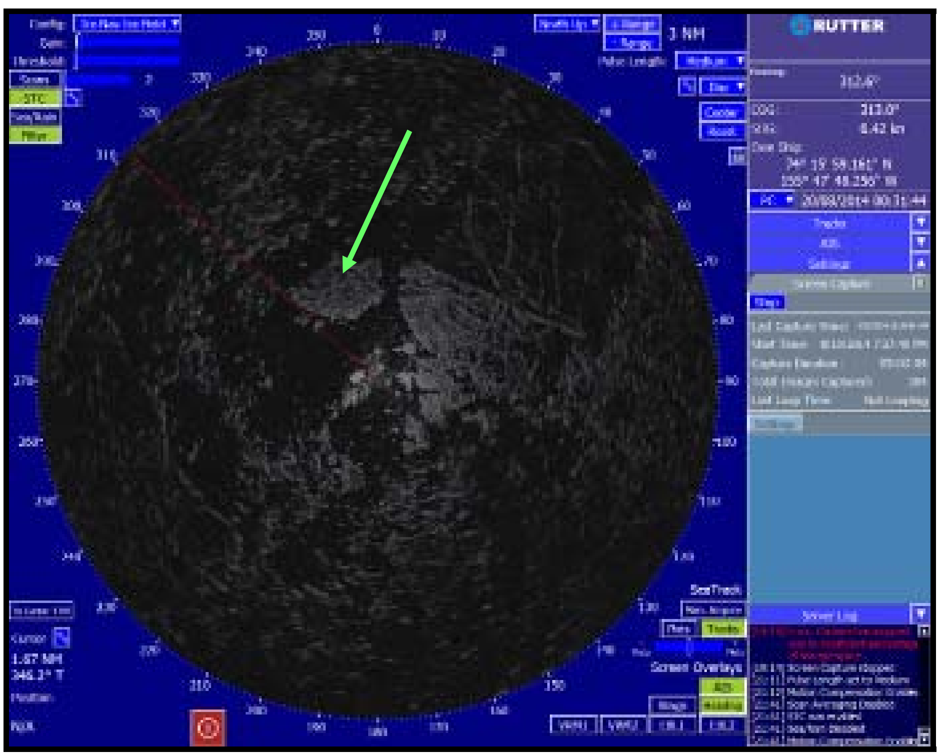


Figure 18. Avoiding the ice floe (3 nm range scale).

Figure 19. Rounding the ice floe (3 nm range scale).

Figure 20. Cleared of ice floe and heading for patches of open water (3 nm range scale).

Figure 21. USCGC Healy is approximately 0.5 nm away from ice floe to avoid but it is difficult to see.

Figure 22. Ice floe becomes visible as ship nears it.

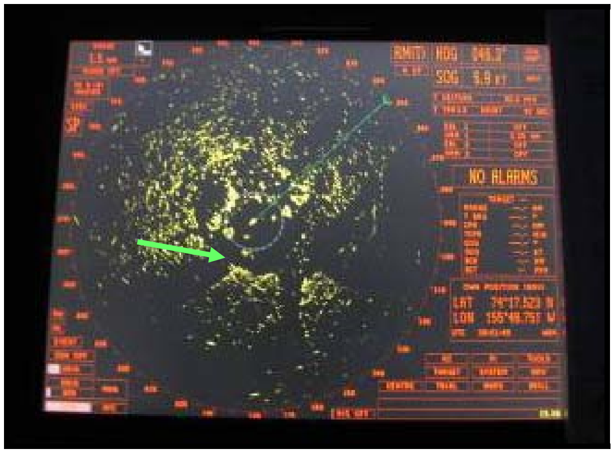


Figure 23. Extent of ice floe that was avoided (south of ship) is not clearly defined on CG radar (1.5 nm range scale).

At approximately 2:55 PM on August 20, the ship found itself stuck in an ice floe. The OOD at the time was on the main bridge and chose not to use the Ice Navigation radar since it was inconveniently located in the Chart Planning Station. He relied on the CG radar and the vantage from his standing position on the bridge. Figure 24 shows what the Ice Navigation radar display captured prior to the ship becoming stuck in ice. It was clearly evident that the radar display showed a large ice floe and it was possible to avoid it by heading to the right where a channel of open water existed with loose ice ahead of it (See green arrows in Figure 24). Figure 25 shows the ship stuck in the ice floe.

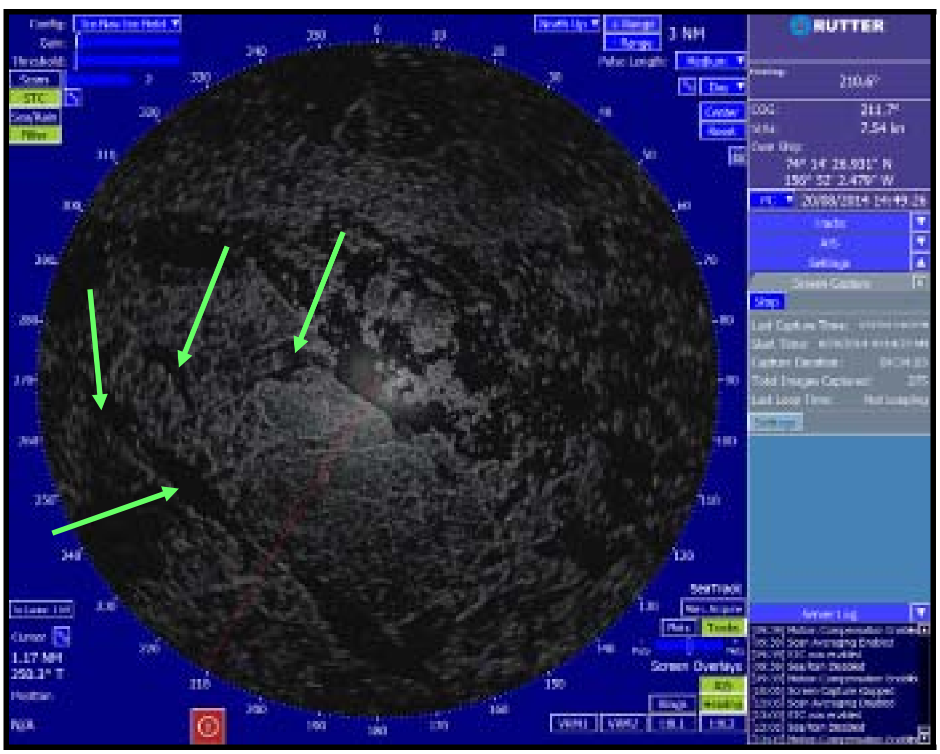


Figure 24. Upcoming ice floe that ship was stuck in; green arrows indicate the possible route ship could have taken; red line is ship's heading (3 nm range scale).

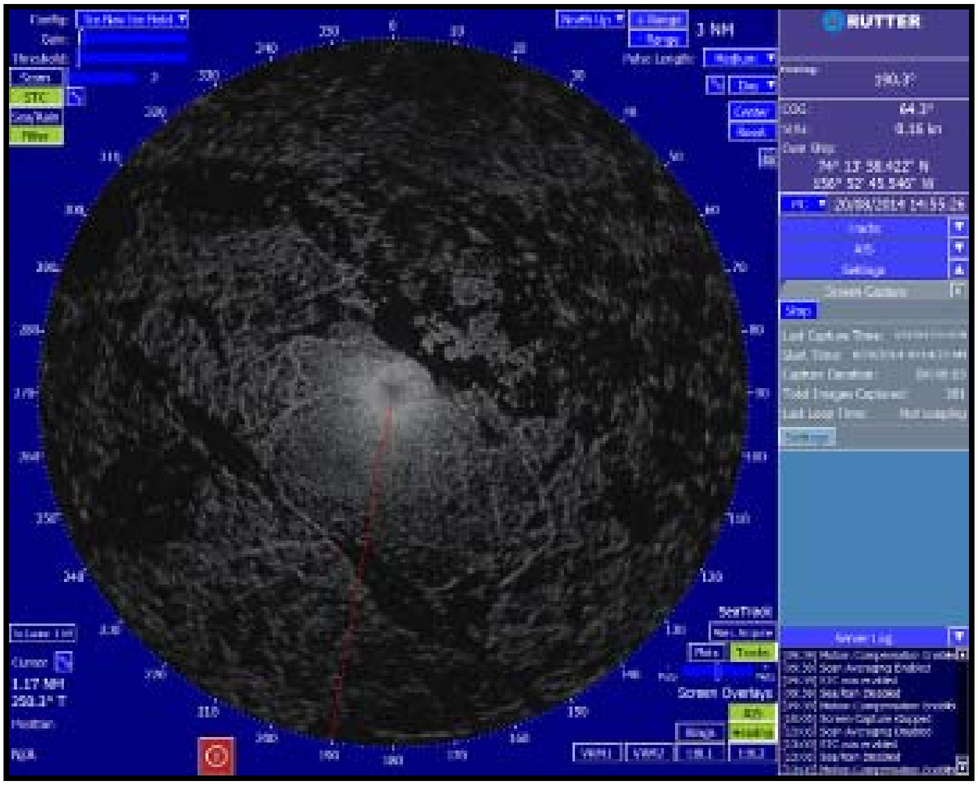


Figure 25. Ship is stuck in a large ice floe (3 nm range scale).

The crew attempted to remove the USCGC Healy from the ice floe but again, it did not consult the Ice Navigation radar. While attempting to continue breaking through the ice floe instead of reversing course, the ship became trapped in the ice floe for the second time. Figures 26 to 28 represent an eight minute timeframe of the entire hour that the ship was unable to create a clear path for itself. Little progress was made over an hour from 3:15 PM to 4:15 PM. Figure 29 was the CG radar display that the OOD relied on during the extrication of the ship from the ice floe. From the CG radar, there was little information about the surrounding ice when compared to Figure 28 and may have led the OOD to assuming that the next attempt through the ice floe would be easier than the first. Figure 30 shows the heavy fog encountered during this incident, increasing the dependency on the radar for a more efficient navigation. However, the Ice Navigation radar was little used during this sequence of events.

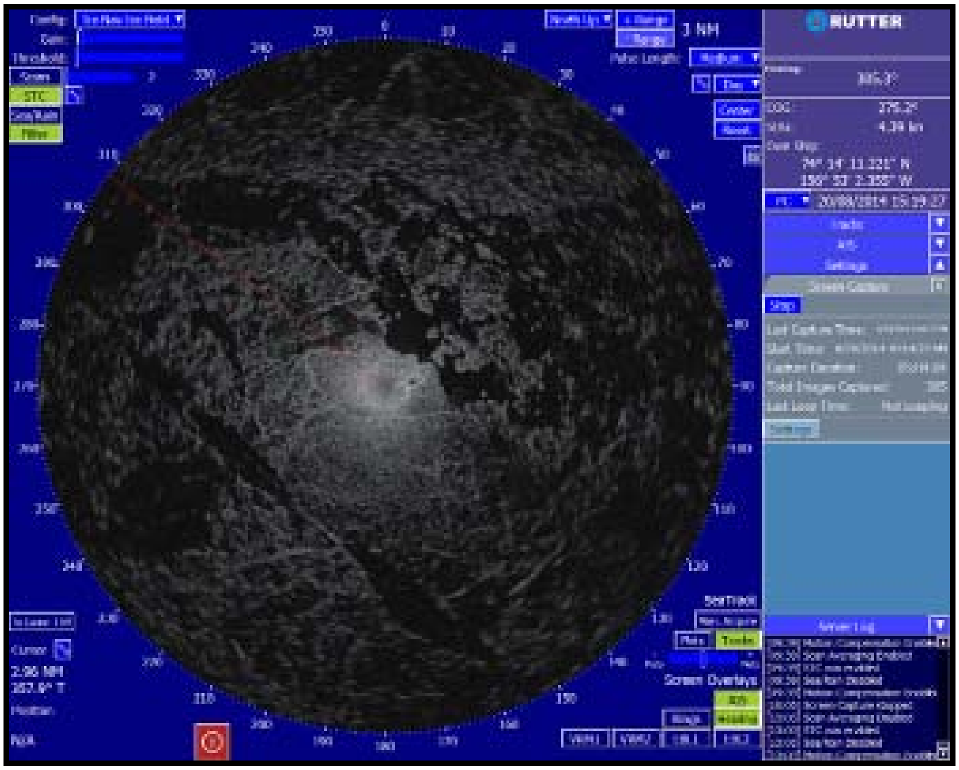


Figure 26. Ship attempting to extricate itself from the ice floe (3 nm range scale).

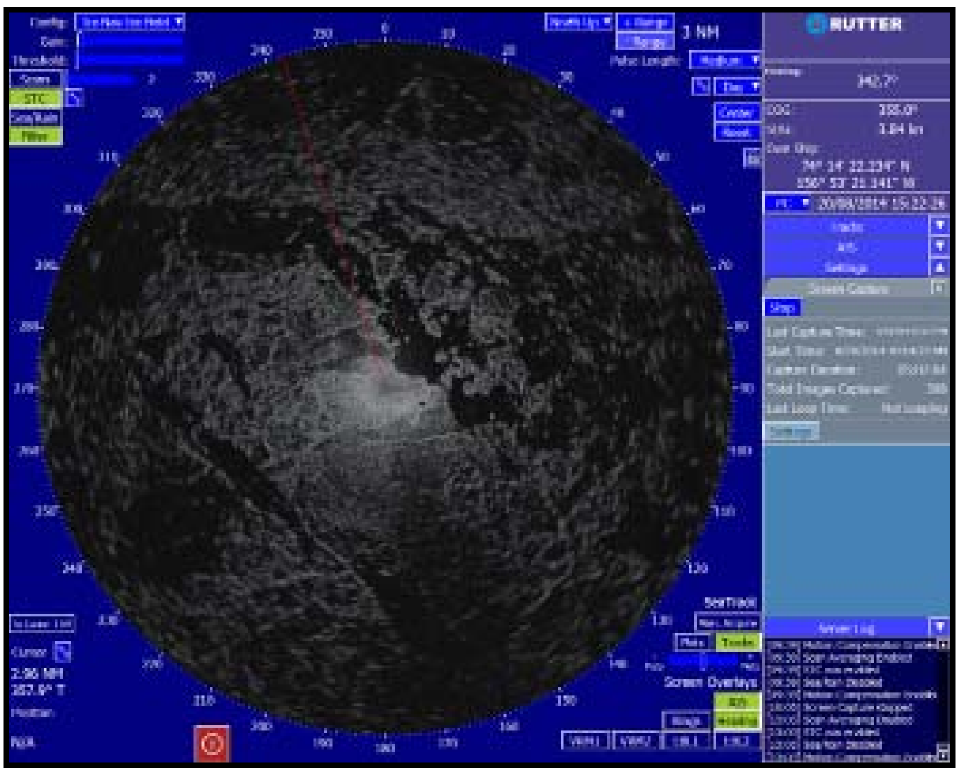


Figure 27. Ship attempting to extricate itself from the ice floe (3 nm range scale).

Figure 28. Ship attempting to extricate itself from the ice floe (3 nm range scale).

Figure 29. CG radar display while ship is stuck in an ice floe (1.5 nm range scale).

Figure 30. Ship is stuck in large ice floe and the effort to extricate the vessel from the floe was hampered by heavy fog.

Pressure ridges are important features in ice fields that navigators should be aware of. They are a result of two ice floes coming together to create thick strips of ice that become potential barriers for icebreakers. It is more effective, if there is no option to avoid them completely, to run into them perpendicularly while the ship has momentum. It is important to spot them on radar displays ahead of time so navigators may be prepared to either run into them perpendicularly or to avoid them completely. On August 20 at 6:42 PM, a large pressure ridge was detected on both the Ice Navigation and CG radar displays and this particular ice feature can be clearly discerned in Figures 31 to 32 (see green arrows). It takes more effort to notice this pressure ridge on the CG radar (See Figure 33).

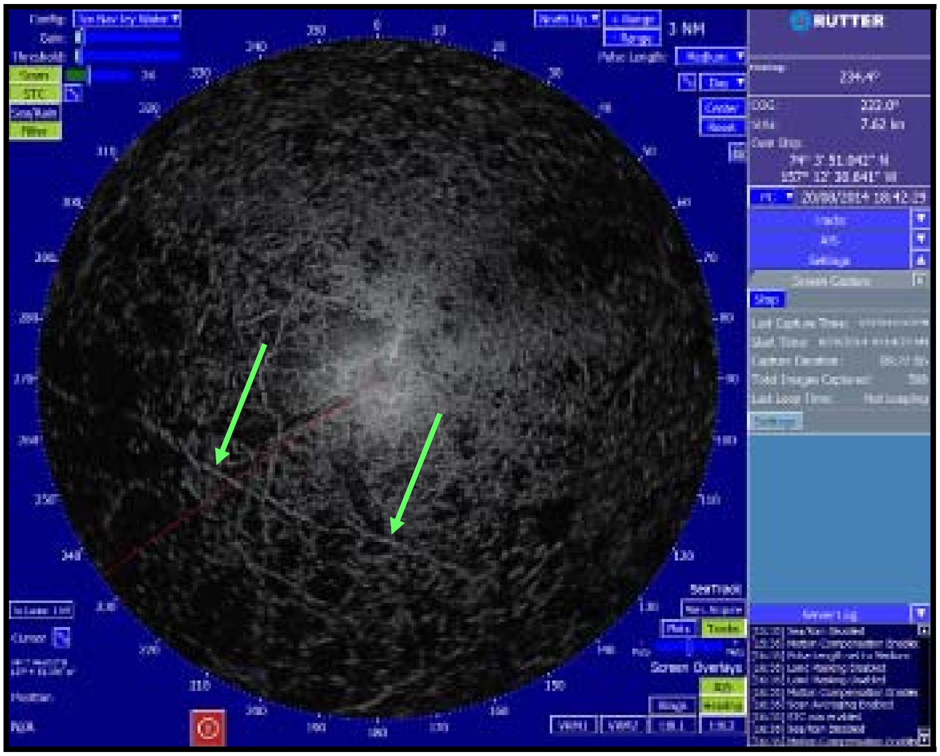


Figure 31. Pressure ridge approximately 1.5 nm away (3 nm range scale).

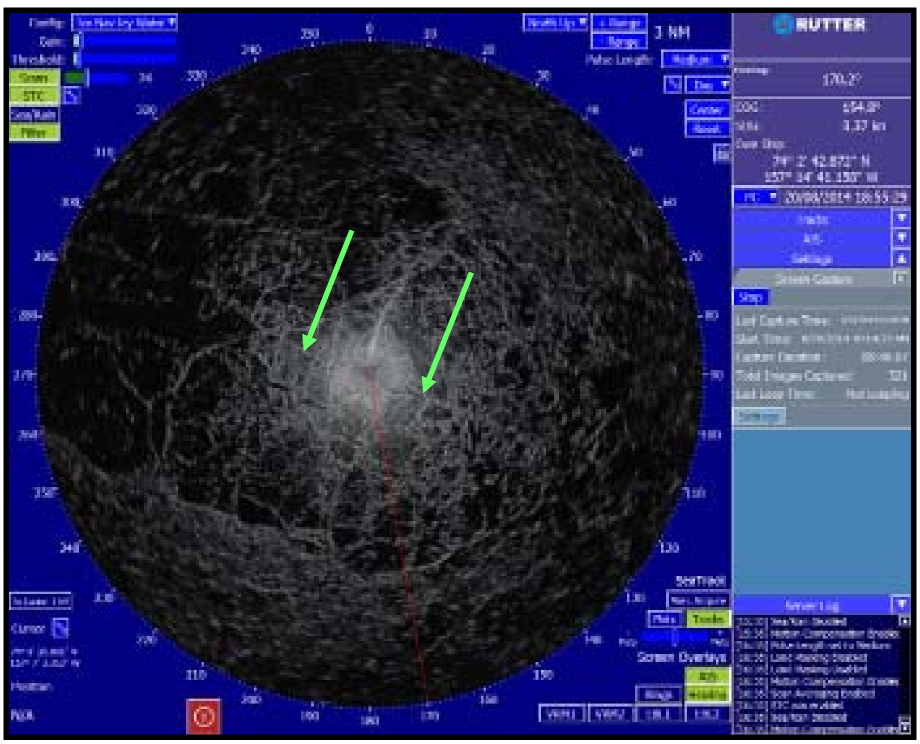


Figure 32. Ship crossing pressure ridge (3 nm range scale).

In heavy fog, it is difficult to make out pressure ridges with the naked eye but as the ship gets closer, they become easier to see (See Figure 34). The radar is useful in making decisions about the pressure ridges ahead of time instead of making an immediate decision.

Figure 33. CG radar display of pressure ridge (3 nm range scale).

Figure 34. Pressure ridge as seen through the window on the bridge.

It was noted that pressure ridges identified on the Ice Navigation radar display were not causes for concern to the OODs. This may be due to the fact that the ice encountered during Arctic Shield 2014 was not particularly thick. When they did see a pressure ridge from the window with the naked eye, they made decisions immediately to aim perpendicular to the ridge or to avoid it completely.

Unless thick ice floes were encountered and the visibility was near zero, there was no need to use the ALOFTCON location. The decision to move up to the ALOFTCON for navigation rested with the OOD of each watch group. Some may prefer to pilot the ship in the ALOFTCON even when there is not as much ice; some may prefer to remain on the bridge. The OODs mostly followed a straight line from one destination point to another without referring to the Ice Navigation radar. They preferred using the CG radar even in the fog. This may be attributed to the inconvenience of leaving the main console and walking over to the Chart Planning Station where the Ice Navigation radar display was located. OODs that did use the Ice Navigation radar were able to locate patches of open water near their established route and adjust the route as needed to avoid large ice floes. If paths of least resistance could be identified far in advance, adjustments in the routes can be easily made while staying in the same general direction towards the final destination. Another equally important reason to be able to identify open water patches in ice-infested waters is that they are likely locations where oil might pool during a spill.

5.3 Other Scenarios

During a technology demonstration on August 18, USCGC Healy drifted inside an ice field characterized with loose ice after arriving at a body of open water. Instead of powering up the ship's propellers and moving back into the open water for release of the Arctic Small Boat (ASB), the ASB was deployed into a small opening in the ice field and pushed its way back into the open water. It acted as a snowplow and pushed one piece of ice floe at a slow but steady clip until it reached open water. The ice-clearing path was captured by the Ice Navigation radar with clarity (See Figures 35 to 38), which impressed the ship's crewmembers.

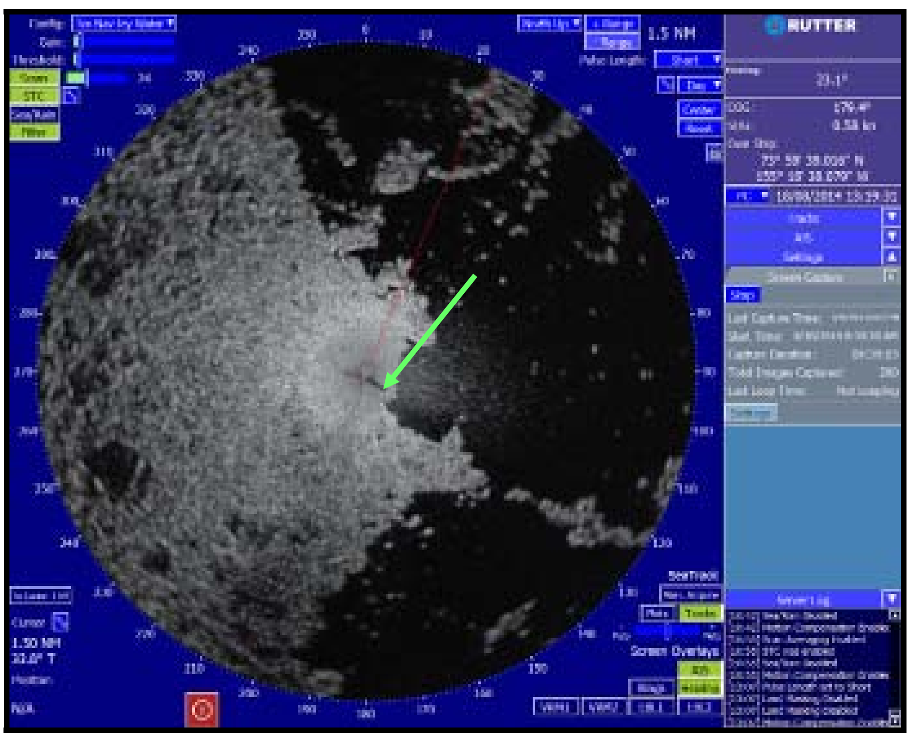


Figure 35. ASB at the start of clearing a path to open water (1.5 nm range scale; arrow indicates location of vessel heading roughly east and the track behind).

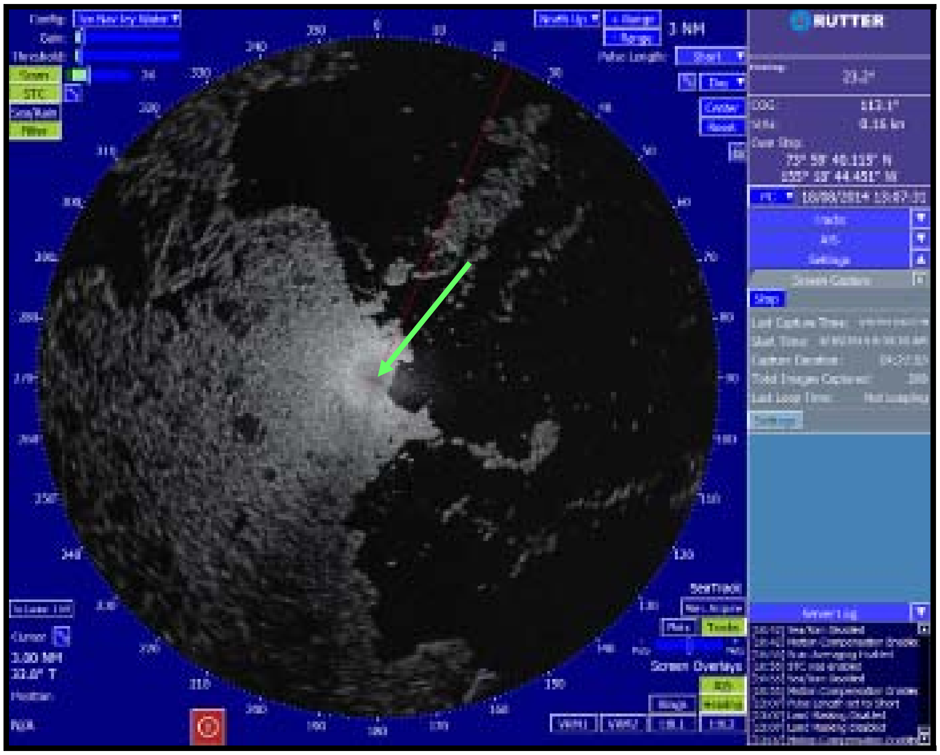


Figure 36. ASB clearing a path to open water (3 nm range scale; arrow indicates location of vessel heading roughly east).

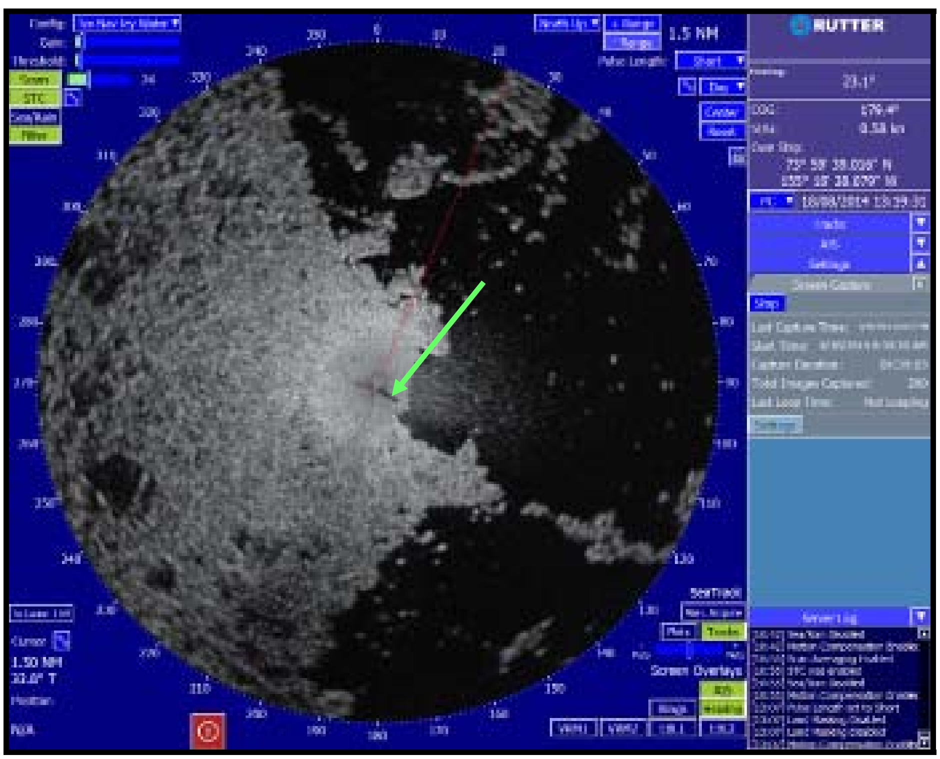


Figure 37. ASB reaching the open water (1.5 nm range scale).

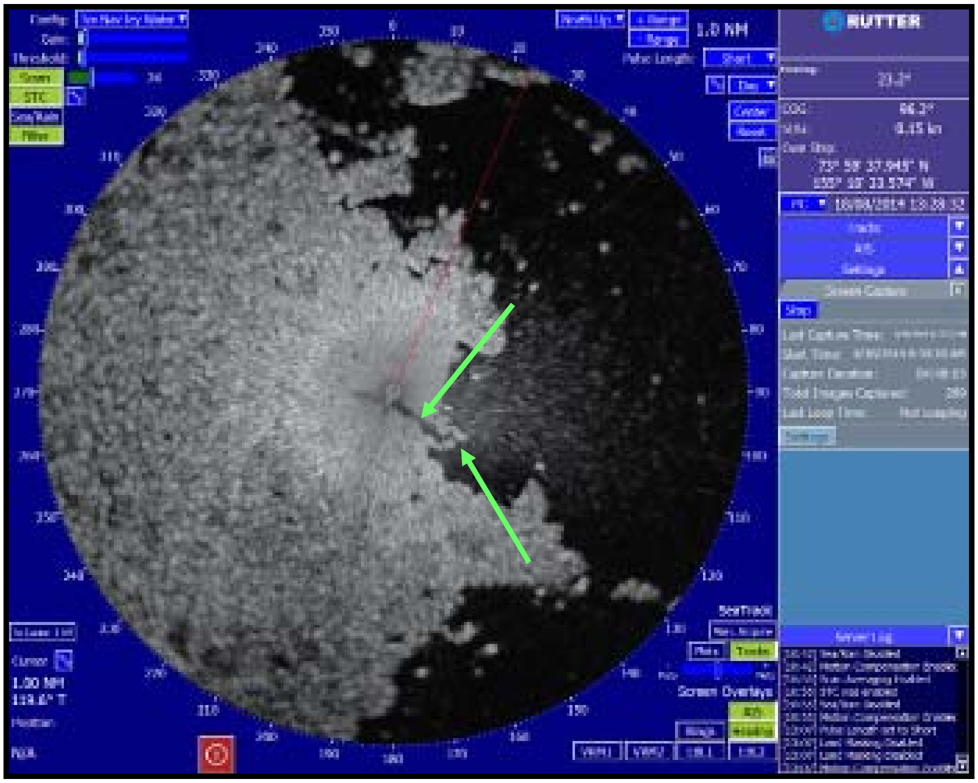


Figure 38. ASB in the open water (1 nm range scale; arrows indicate the path created by the ASB and that it reached the patch of open water).

The capture of the ASB clearing a path for itself demonstrates an added utility for the Ice Navigation radar. Not only does it detect the ice edge and type of ice with high resolution images but it can also provide improved situational awareness of polar operations that the USCGC Healy routinely performs. The radar can be extremely useful in assessing the safety of the crew, particularly in poor weather conditions when visibility is near zero.

6 CONCLUSIONS

The Ice Navigation radar system was a significant improvement over the current radar system on the USCGC Healy when attempting to define ice edges, locate thick ice floes and patches of open water. 360 degree view photographs of the surrounding environment in open water and ice-infested waters consistently validated the images seen on the Ice Navigation radar display (Figures 4-7 and 8-11). There were some instances where thin ice fields showed up on the Ice Navigation radar display that did not show up on the current CG radar display. Figures 14-16 represent an example of this occurrence. During underway testing, the Ice Navigation radar was able to clearly define upcoming ice floes (Figures 17-23), as well as pressure ridges (Figures 31-34), that aided the OODs in making navigational decisions. Both stationary and underway data show that the Ice Navigational radar was a definite improvement over the CG radar in terms of less ambiguity in interpreting the display, regardless of weather conditions.

The Ice Navigation radar proved to be useful when the ship was located at ice edges. Anecdotal evidence showed that while the ship was near an ice edge, whitecaps from the open water and ice were seen on the CG radar display with no distinction between the two. The Ice Navigation radar was able to average out intermittent hits, such as whitecaps so they were removed from the display while persistent targets, such as ice, ships, and Man Overboard Boats still remained. This proved to be extremely useful to the OODs since it reduced uncertainty of what surrounded the ship, especially in low visibility weather. The clear picture on the Ice Navigation radar allowed them to make well-informed decisions regarding navigation.

The Ice Navigation radar was used by the ship's crew in the months before the official evaluation during Arctic Shield 2014. It proved to be a valuable tool for them as they were able to find paths of least resistance through ice fields and thus saved on fuel costs. Personal communications with USCGC Healy officers reveal that the Surface Forces Logistics Center is planning a major overhaul of the bridge equipment and navigation systems in the near future. At that time, the Ice Navigation radar will be fully integrated onto the USCGC Healy. Two consoles of the Ice Navigation radar system are planned to be installed; one in the bridge and one in the ALOFTCON.

7 RECOMMENDATIONS

After comparing the two radar systems on the USCGC Healy during Arctic Shield 2014, RDC's recommendations are as follows:

- High resolution radars processors that specialize in defining ice edges and ridges and locating open waters should be pursued by all Coast Guard icebreakers.
- The Ice Navigation radar display should be stationed in the ALOFTCON and within the main console on the bridge, both with full controls to adjust settings at the same location.
- The Ice Navigation radar display in the ALOFTCON should be set at the eye level of the OOD who is navigating. Other potential uses for the Ice Navigation radar should be investigated so as to take advantage of its high-resolution capabilities. Possible examples include:
    - Locating buoys, ships and smaller boats such as Man Overboard Boats.
    - Tracking ice floes of interest.
- The Ice Navigation radar was equipped with Tracking and Automatic Identification System features but they were not utilized during Arctic Shield 2014 and should be investigated further.

8 REFERENCES

Hansen, K.A., "Arctic Technology Evaluation 2014 Oil-in-Ice Demonstration Report," USCG RDC Report CG-D-2015-XX, in preparation, 2015.

Yankielun, N.E., Barone, R., Cables, E., Locklear, C., Wilson, K., "Great Lakes Oil-in-Ice Demonstration 3 Final Report," Report CG-D 8-13, October 2013.

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APPENDIX A. ICE NAVIGATION RADAR TEST AND EVALUATION PLAN

A.1 OVERVIEW

A.1.1 Purpose

The Research and Development Center (RDC) will be evaluating the Rutter Ice Navigation radar by comparing it to the existing Coast Guard (CG) radar system.

A.1.2 Background

The Coast Guard relies on radar to fulfill multiple vital missions. In the Arctic, this sensor becomes crucial in times of limited visibility, especially when a vessel is transiting in ice-covered waters. In addition, the identification of open water where oil will collect during an accidental spill is important. In order to determine requirements, RDC mounted a Rutter radar on the USCGC Hollyhock in the Great Lakes in February 2013 in a configuration very similar to that being mounted on the USCGC Healy. The data collected indicated that the extra processing in the ice navigation radar enabled the crew to identify different types of ice and its thickness as well. An additional evaluation will be done on the USCGC Healy this summer to determine if the same performance applies.

The radar installation on the USCGC Hollyhock was temporary and so is the installation on the USCGC Healy. A letter of permission was provided for the USCGC Hollyhock installation dated 15 February 2013 by CG Surface Forces Logistics Center and confirmed for the USCGC Healy via email 2 December 2013.

A.1.3 Objectives

Conduct side-by-side comparison between the Coast Guard’s Northrop Gumman/Sperry BridgeMaster Radar and the Rutter Ice Navigation radar systems to determine if the Ice Navigation processor is an improvement upon current radar processing capabilities.

1) Collect data simultaneously from both processers as well as visual recording (cameras on vessel or mounted in an Unmanned Aerial System.
2) Collect data at multiple settings and conditions (e.g. range, etc).

A.1.4 Design of Tests

The tests will be conducted at multiple times during the cruise when the vessel is stationary and when underway. Times and conditions will be selected in coordination with the USCGC Healy crew given their experience and familiarity of the Rutter radar. Recording the data will utilize the screen record capabilities of the Rutter Sigma 6 processor and a hand-held camera to record CG radar display data. Photographs, videos and other environmental data will be collected through the other technologies that will be utilized for the oil-in-ice demonstrations.

A.2 TECHNOLOGY CONFIGURATION

A.2.1 Rutter Ice Navigation Radar

The system being evaluated is the Sigma S6 radar processor that Rutter Inc. manufactured in Canada. While Rutter also makes other radar units, only the Ice Navigator radar is being evaluated.

The key to this processor is that it processes a full dynamic range of data (12-bit video) versus the 2-4 bit intensity in standard navigation radar that are more than adequate to identify other vessels, buoys and points of land. This processor then is able to produce a higher-quality image for better ice definition (see Figure A-1). The processor uses the standard X-band out (Analog) usually set on a short pulse for better resolution. Figure A-2 shows setup of the processor and monitor in the Chart Planning Station on the USCGC Healy.

Figure A-1. Rutter Ice Navigation radar display with radar display turned on.

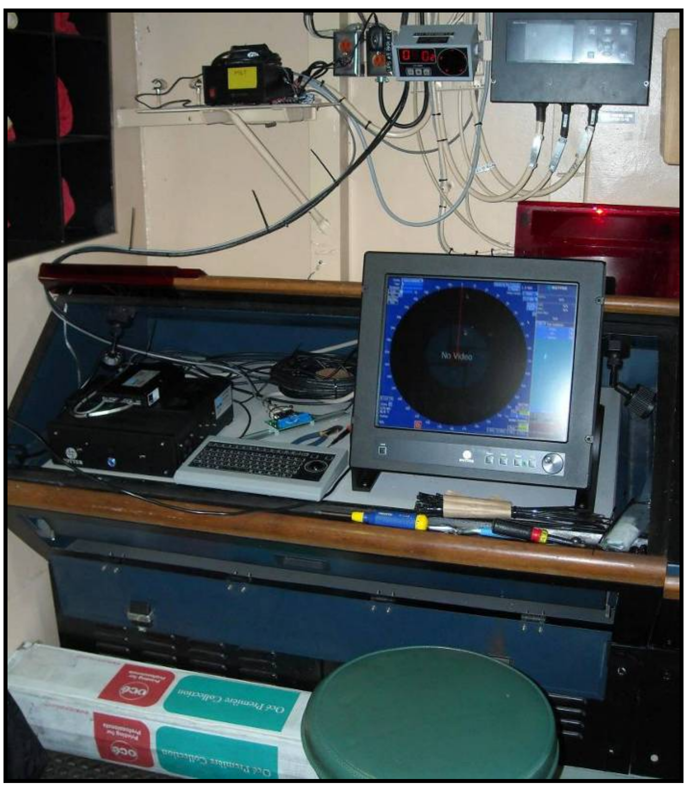

Figure A-2. Rutter Ice Navigation radar setup in the Chart Planning Station on the USCGC Healy.

A.3 METHOD OF TEST

A.3.1 General Test Procedures

Stationary Test Procedures

Photographs of the surrounding environment and the CG radar display are to be taken at a rate of once every two hours starting at 0800 until dusk. This way, the radar comparison can be made in day/night conditions to determine if the Ice Navigation radar is an improvement over the CG radar when visibility is low. A screenshot of the Ice Navigation radar display will be taken every minute and then automatically stored in a saved folder for later analysis. This obviates the need to photograph the Ice Navigation radar display during data collection.

If an interesting landmark nearby the ship emerges at any time of the day, the bridge is asked to notify either Alex Balsley or Kurt Hansen so data recording will take place. The next data recording is to occur four hours later or until another interesting landmark is sighted. This landmark will serve as a reference point on the radar screens when comparing the two systems (CG radar and Rutter Ice Navigation radar).

1) At the start of a data recording, begin with time stamped photos (local time) of the CG radar display.
2) Within two minutes of taking photos of the radar screens, climb to the ALOFTCON and take 360 degree vision photos starting in the direction of the bow. Turn clockwise roughly every 45 degrees and take photos until one faces the bow again. Eight photos shall be taken each time.
3) Record GPS location, weather conditions, and other information as specified in the Radar Observation Data worksheet. Indicate time in Local time as well. One worksheet is to be used per day of data recording.
4) Coordinate with Aerostat and/or UAS to capture images of the surrounding area during the time of their data recording whenever possible to provide a picture of the current ice conditions.
5) Anticipate approximately 3 to 5 data recordings each day.

Underway Test Procedures

Discuss with the Officer of the Deck (OOD) the desired course or information that is needed. This information could be a type of ice or openings in the ice. Identify a specific "marked" location or location of interest. Record information for key attributes and distance in log. If the ship is in a faster transit, determine how the OOD is using ice navigation to affect the course of the vessel.

1) At the start of a data recording, begin with time stamped photos (local time) of the CG radar display.
2) Within two minutes of taking photos of the radar screens, climb to the roof of the bridge and take a photo of ice nearby with a known radar signature and then the location of the "marked" location.
3) As the vessel approaches the marked object/location, take screen pictures and photographs every mile if at slow speed. Continue until the vessel's approach compromises the landmark shape.
4) If Aerostat or UAS is available, record video and still pictures from a distance before the vessel's location can alter any ice configurations.

A.3.2 Personnel Requirements

- RDC personnel in conjunction with ship's bridge watch.
- Assistance from other technologies during their deployments.

A.3.3 Data Requirements

Collect general information in Radar Observation Data worksheet (Attachment 1).

Identify camera and video data collected by other technologies.

A.4 ATTACHMENT 1 FOR APPENDIX A

Observer name: ______________________ Date: ______________________

Test number	Time of observation (GMT)	GPS location	Weather	Landmark	Photos	Aerostat	AUV	ROV	SWIFT