Validation of a CFAR Vessel Detection Algorithm Using Known Vessel Locations

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The National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) is in the second year of a two-year demonstration of Synthetic Aperture Radar (SAR) derived products called the Alaska SAR Demonstration (AKDEMO). This demonstration provides near real-time SAR data and derived products, including wind images and vectors, hard target locations, along with ancillary data, to specific users in the government community. One of the derived products are vessel positions obtained from a constant false alarm rate (CFAR) vessel detection algorithm developed by Veridian ERIM. This algorithm has been tested and validated to maximize the number of ships found while minimizing the number or false alarms on one SAR image of the Red King Crab fishery in Bristol Bay on October 18, 1999. This resulted in using a detection statistic threshold of about 5.5, depending on image resolution used. Until now, this validation has been done with only general knowledge of fishing fleet size and location, but no in situ vessel information. During the Red King Crab Fishery in Bristol Bay in October 2000, twenty-one Alaska Department of Fish and Game fishery observers recorded the position of the vessels they occupied (and sometimes the wind speed), during two ScanSAR overpasses on October 18 and 19, 2000. These ScanSAR passes, with a width of 480 km, cover the region of the fishery and many of the vessels with recorded positions. This paper presents the results of a validation of the SAR vessel detection algorithm using these observer reported vessel positions along with information on vessel size and local wind speed.

Introduction

U.S. Government and State agencies such as the U.S. Coast Guard, the Alaska Department of Fish and Game (ADF&G), and the National Marine Fisheries Service (NMFS) participate in fishery enforcement in the Alaska region. This entails aircraft flights, ship observers, and other expensive and time-consuming activities. Satellite data has the promise to enhance the information these agencies currently use for enforcement, and possibly to cut their costs by targeting regions of greatest interest for the most efficient use of resources. A particularly good type of data for vessel detection is synthetic aperture radar (SAR). For almost two years, the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) has been providing ship position information to these agencies. This information is automatically generated by a Constant False Alarm (CFAR) vessel detection algorithm developed by Veridian ERIM [1] under the context of a pre-operational system called the Alaska SAR Demonstration (AKDEMO) at NOAA/NESDIS [2]. SAR data is taken daily over the Bering Sea and Gulf of Alaska and processed through the CFAR algorithm to produce vessel positions. This, along with other data sets and derived products, is distributed to users through a password protected web interface.

Work has been conducted to find the appropriate threshold for vessel detection using the Veridian ERIM CFAR algorithm [1][3]. These results relied mainly on general ship fleet information or by visually inspecting the SAR images as validation. In the current study, twenty-one ADF&G observers on vessels participating in the Bering Sea Red King Crab Fishery recorded their position (and sometimes ambient wind speed) at the times of SAR overpasses on October 18 and 19, 2000. These SAR passes are processed through the CFAR algorithm and the vessel positions are compared to the recorded positions of the 21 ships. The vessel sizes are also used to make conclusions about the minimum size of vessel that can be detected. Also, as in [1] and [3], the entire fleet size and length information is used to make conclusions about the algorithm's parameters.

Data

The SAR data is from the Canadian RADARSAT-1 satellite, which was launched in November 1995 into a sun-synchronous polar orbit with an ascending equator crossing time (local time) of 6:00 p.m. It has a 5.6 cm C-band SAR with HH polarization. RADARSAT-1 has the ability to revisit a spot within the Bering Sea region, at approximately 60 degrees latitude, every 1 to 2 days. The sensor mode used in this study is ScanSAR Wide B with a swath width of 480 km. The Alaska SAR Facility (ASF) in Fairbanks, Alaska, receives data within the Alaska station mask directly from the satellite. They in turn provide SAR data in near real-time (within approximately 6 hours) to users through the NOAA Satellite Active Archive (SAA). The AKDEMO workstation then processes the SAR data with the Veridian ERIM CFAR algorithm, producing both an ASCII file with a list of ship locations and a graphic of the SAR image with ship locations overlaid, within approximately 10 minutes.

VESSEL DETECTION ALGORITHM

The vessel detection algorithm works by locating regions of bright image samples that are statistically different from the surrounding ocean clutter [1]. This procedure is often referred to as a constant false alarm rate (CFAR) process since it is a relative measure based on the local statistics of the background clutter and thus keeps the number of false alarms constant as the mean of the clutter varies. It uses a local window with a size based on the image's resolution for a signal box that is assumed to contain a ship, a buffer window that contains the signal window, and a background window that contains the buffer window (and thus also the signal window). These windows are moved through the image as a set, shifting by one image sample each time. At each position, the mean image value within the signal box is calculated, m_s, as well as the mean and standard deviation of the image values within the background box but not within the buffer box (m_b and σ_b respectively). A detection statistic, d, is then calculated as $d = (m_s-m_b)/\sigma_b$. Finally, a threshold, T_o, is applied to d: if $d \geq T_o$ then a ship has been detected within the signal box, if $d < T_o$ then no ship has been detected. More information on the CFAR algorithm can be found in [1].

RESULTS

The Bristol Bay red king crab fishery opened at 4:00 pm AST on October 16, 2000 and closed at 9:00 pm on October 20, 2000. Registered to take part in the fishery, were 246 vessels, and for the first time there were ADF&G observers on approximately eight percent of the catcher vessels. Twenty-one of these observers agreed to record their position and wind speed (if available) at the time of SAR overpasses. Two SAR overpasses occurred during the time the fishery was open. The first was on October 18 at 17:06 GMT and the second was October 19 at 4:33 GMT. This ScanSAR Wide B SAR data was processed "quicklook" which means the data is delivered in the near-real time mode with 200 m resolution

TABLE 1

10/18/00

Threshold(T_o)	detections	false alarms	Min length
9	69	0	38.4
8	77	3	37.7
7	82	4	37.5
6	91	6	36.3
5	94	16	35.7

10/19/00

Threshold(T_o)	detections	false alarms	Min length
9	71	0	38.4
8	78	0	37.7
7	90	0	36.6
6	94	6	35.7
5	98	23	35.4

and 100 pixel spacing. ScanSAR Wide B data can be processed up to 100 m resolution, but not in near-real time. In past studies [1][3] it was found that there was not much of an improvement in accuracy with the 100 m data and the number of ships detected at this resolution appeared to be limited by the false alarm rate. False alarms are those detections that are outside of the known fishing area and they have low detection statistics. It was also found that for 200 m resolution data, a detection threshold, T_o, of 5.5 was the best to use to maximize the detections and to minimize the false alarms. With only data on ship fleet size, and no positions, it was determined that vessels above 35-38 m could be detected with this CFAR algorithm.

This type of analysis was done again with the data from October 18 and 19 for detection thresholds of 5, 6, 7, 8, and 9. The results are shown in Table 1. As the threshold is lowered, more detections are found. At some point false alarms begin to appear. By taking a count of the registered vessels organized by their length, a minimum length of possible detection can be inferred. For example, if 82 vessels above the length of 37.5 m were registered, and the CFAR algorithm found 82 vessels at a threshold of 7 (as in Table 1 above for 10/18/00), then the minimum length of vessel detection can be said to be 37.5 m. This has been done for

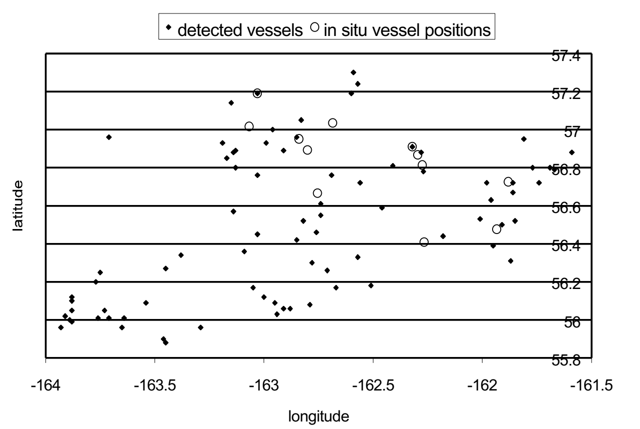

Fig. 1. Map of detected vessels and position locations of observer vessels.

each threshold value on each day of data and the minimum lengths are listed in Table 1. The results are approximately the same as those for the 1999 Bristol Bay king crab fishery [1][3] in that the minimum detected vessel length is approximately 36 m.

With the position data provided by the vessel observers, we hoped to find the true minimum vessel length detectable by SAR. Fig. 1 plots the targets detected in the 10/18/00 SAR image with diamonds, and the in situ measured positions of vessels with observers with circles. In this example the CFAR algorithm was run with a threshold of 6.5 to eliminate any false alarms, since as can be seen in Table 1, the false alarms start to increase at thresholds lower than this. The measured position of these vessels is in the center of the circle with the circumference representing the bounds of error. The error considered here is the position error in the SAR of 240 m plus 2 standard deviations of 93m, the error caused by rounding the detection statistic to hundredths, and the error possibly introduced by an azimuth shifting (represented as 500m). Using these bounds, on 10/18/00 only 5 vessels with observers are possibly detected and by the same process on 10/19/00 only 4. Table 2 shows the vessels participating with observers and their length, whether they were in the SAR image (local) area on each day and whether the CFAR algorithm detected them. It would be assumed that the largest vessels would be detected first and that from our earlier assumptions, that no vessel under 36 m could be detected. This is not what was found though. For example, on 10/18/00 the Alaska Challenger, which is 29 m in length, was detected. It is possible that with 246 vessels fishing in the region, that larger vessels were close to some of the observer vessels under 36 m and were detected instead. But this doesn't explain the fact that the large observer vessels weren't detected a majority of the time. Another possible error could be that the vessels were moving and if the time the position was recorded was not exactly the SAR overpass time, they could have changed position. But while fishing, it is hard to imagine that the majority of vessels were moving at a speed so as to move them out of the bounds of error already assumed. The orientation of the vessel with respect to the SAR look direction and the local wind and wave conditions could also be factors influencing detection success.

TABLE 2
VESSELS PARTICIPATING WITH OBSERVERS

vessel name	length (m)	local 10/18	detect 10/18	local 10/19	detect 10/19
Alaska Challenger	29.0	X	X		
Alaskan Enterprise	30.5	X			
Arctic Sea	32.0			X	
Baranof	32.9	X		X	X
Blue Dutch	32.9	X		X	
Dominator	34.1				
F/U Gunmar	37.8	X	X	X	X
Fierce Allegiance	40.8			X	
Katie K	45.7	X			
Katrina EM	46.0			X	
Lady Simpson	49.8	X	X	X	
Mar Gun	50.3	X		X	X
North American	50.6			X	
Northern Orion	51.2	X			
Pavlov	52.4			X	
Pro Surveyor	54.9	X	X	X	X
Spirit of the North	54.9	X	X	X	
Westward Wind	57.0	X		X	

CONCLUSIONS

The results using general information about the Bristol Bay red king crab fishing fleet during the 2000 season on two days when SAR data was taken (10/18/00 and 10/19/00) were the same as were found from the 1999 fishery in previous studies [1][3]. Minimum vessel size detected by the CFAR algorithm was inferred to be 36 m. But the in situ data provided by the observers on a portion of the fishing fleet did not validate this conclusion but instead left questions as to sources of error in this study. Possible errors may have come in the time between the actual SAR overpass and the time the observers took their position. Also, possibly the region of error that was used around these positions in Fig. 1 was not assumed correctly. There also may be other reasons that are not currently known. Further validation work is necessary to find the limit on length detection with the CFAR algorithm by Veridian ERIM using in situ measurements.

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