Synthetic Aperture Radar Indicators of Biological and Fisheries Activity in the Bering Sea

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ABSTRACT

The use of Synthetic Aperture Radar (SAR) spaceborne observations for routine monitoring of the marine environment is steadily increasing. SAR is an active microwave sensor that can operate through clouds and without the need of daylight illumination, thus affording it a very useful all-weather all-day characteristic. Under the right wind and viewing angle conditions, SAR can detect the effect of biogenic substances on the sea surface roughness. These substances damp capillary and small gravity waves principally responsible for the detected SAR signal. Ocean slicks produced by biogenic material can be of natural or man-made origin. Natural slicks are commonly found in highly productive regions of the ocean and are commonly associated with algal bloom events. Man-made biogenic slicks can result from the discharge of processing residue during fishing operations.

Extensive RADARSAT-1 SAR observations acquired over the Bering Sea as part of the NESDIS Remote Sensing Program SAR monitoring activities provide clear indications of 1) significant biological activity and 2) the presence of large-scale fishing operations in the region. In some cases, when daytime cloud-free observations are possible, SeaWiFS ocean color satellite data have confirmed SAR signatures as resulting from enhanced biological activity. SAR can also easily locate large fishing fleets, due to a high radar backscatter return from ships, as well as slicks produced during the operation of certain fisheries. These observations demonstrate the potential of SAR as a monitoring tool for regional biological, fisheries, and fisheries management investigations in the Bering Sea.

INTRODUCTION

As part of pre-operational ocean remote sensing a activities being conducted in Alaska by the National Oceanic and Atmospheric Administration (NOAA) National Environmental, Satellite, Data, and Information Service (NESDIS), a large number of RADARSAT-1 Synthetic Aperture Radar (SAR) observations over the Bering Sea are being acquired and analyzed. RADARSAT-1 is a Canadian satellite carrying a C-band (5.3 GHz, 5.6 cm) SAR with HH polarization. As an active microwave sensor, SAR can operate through clouds and without the need of daylight illumination, which make it a useful all-weather day/night ocean monitoring tool. The most common SAR modes acquired over the Bering Sea are ScanSAR Wide (500 km swath width and 100 m resolution, although, typically mapped down to 200 m resolution) and Standard (100 km swath width and 25 m resolution). NESDIS and the National Ice Center (NIC) have developed a near real-time data distribution system for obtaining these data from the Alaska SAR Facility (ASF) University of Alaska Fairbanks acquisition station through the NESDIS Satellite Active Archive (SAA) in Suitland, MD[1].

Under the right wind conditions, SAR can be used to identify areas of high biological productivity. Natural sea surface slicks are commonly found in highly productive regions of the ocean[2]. These features are usually associated with phytoplankton blooms. In general, oil slicks dampen the capillary and short gravity waves responsible for the microwave energy reflected back to the SAR instrument. Contrast between relatively dark (low reflected or backscattered energy) slick areas and the surrounding wind-roughed sea surface background allows the slicks to be detected in the SAR imagery, at least under moderate wind speeds[3,4].

Biogenic slicks can be divided into two major categories, natural and man-made. Substances naturally released by plankton and fish into the environment can produce so-called natural biogenic slicks. Man-made biogenic slicks result from the release into the environment of organic matter during activities such as fish processing or aquaculture feeding. These substances can be very effective at damping the wind generation of Bragg waves producing filaments or extended regions of low backscatter in the SAR imagery. Although detectable at moderate wind speeds, these substances will tend to mix down into the water column at higher wind speeds (above 5 or 6 m/s). At wind speeds below 2 m/s, the background backscatter level becomes extremely low and the required contrast for the detection of the slicks is lost.

Another important feature of SAR is its ability to detect "hard targets" over the ocean, including ships, oilrigs, and icebergs. These targets can be easily detected since, except for high winds or near range observations, they tend to be much more reflective of the SAR microwave energy than the surrounding ocean background. SAR hard target detection is being used routinely for operational vessel detection, traffic monitoring, and fisheries activity monitoring programs in the U.S., Canada and Europe. Automated algorithms based on a Constant False Alarm Rate (CFAR) are now frequently used to derive rapid information on vessel positions from SAR imagery[5]. CFAR algorithms detect ships by first generating a local estimate of the probability density function (PDF) of the background ocean, then calculating a threshold such that there is a specified small probability (i.e., the false alarm rate) of finding pixels above this threshold. Pixel samples that have a value greater than the threshold are considered to represent ships.

BIOLOGICAL ACTIVITY IN THE BERING SEA

Ocean color sensors such as SeaWiFS have been used to identify and map algal blooms from space in a quantitative fashion[6]. The relatively coarse spatial resolution (of the order of 1 km) and their inability to "see" through clouds can significantly limit the observations of these features. SAR capability for day and night all-weather observations as well as its high spatial resolution could be used to complement ocean color sensor observations. The combination of these

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two types of observations should enhance our ability to map and monitor phytoplankton blooms from space.

The observation of slick features in SAR imagery of the Bering Sea is frequent and most be linked to the high productivity of the region. An example of a full ScanSAR image showing a region of abundant slick activity is shown in Fig 1. This image was acquired in July of 1998 and shows regions of low backscatter around St. Matthew I. The area enclosed by the square in Fig 1 is shown at a much higher resolution in Fig 2. This image shows the prevalence of slicks in the region. At the time of the observation, these features were originally interpreted as being associated with the presence of biological activity.

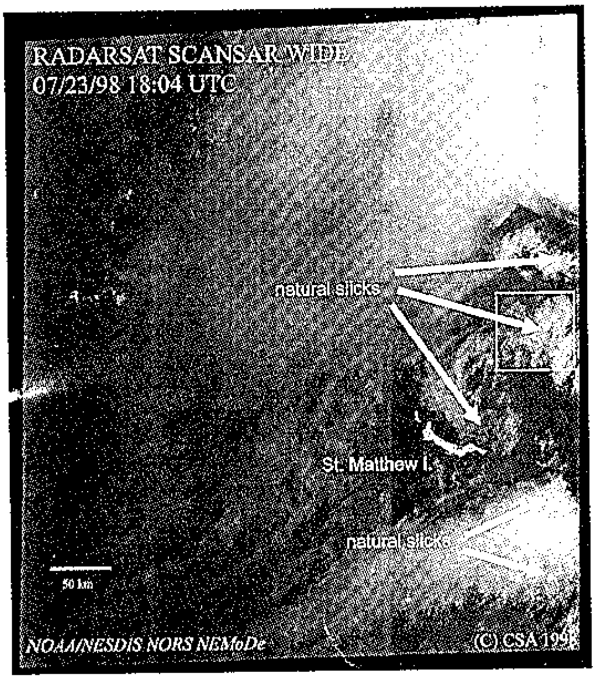

Figure 1. RADARSAT-1 ScanSAR Wide SAR image of the Bering Sea acquired on 23 July 1998 18:04 UTC and showing suspected biological activity around St. Matthew Is.

Figure 2. RADARSAT-1 ScanSAR Wide SAR Fig. 1 sub-image of the Bering Sea region north of St. Matthew Is. acquired on 23 July 1998 18:04 UTC.

Fortunately, a large break in the cloud cover allowed for SeaWiFS observations of the ocean surface to be acquired over the region three days earlier than the SAR observations shown in Figs. 1 and 2. A true color image processed by the SeaWiFS Project at NASA/Goddard Space Flight Center is shown in Fig.3. This image indicates the considerable spatial extend of an algal bloom, suspected to be a coccolithophore bloom. The presence of this algal bloom episode was observed for several days, at least through cloud breaks, in the available SeaWiFS data.

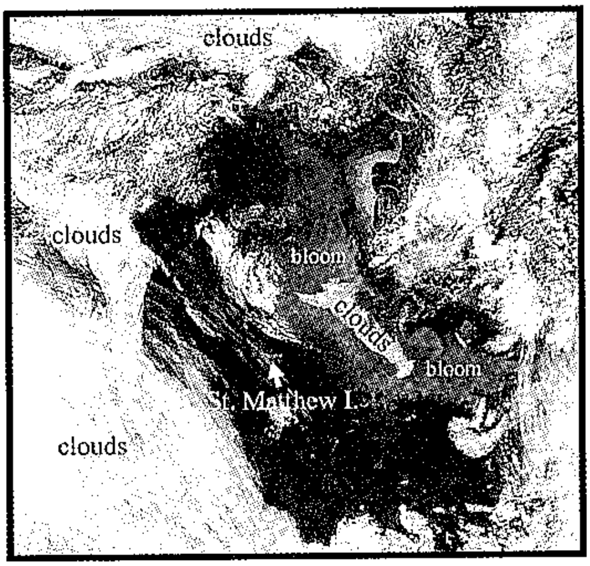

Figure 3. SeaWiFS true color image of the northern Bering Sea acquired on 20 July 1998 00:46 UTC.

The bio-optical characteristics of the seawater as observed by SeaWiFS fully support the previous interpretation of the prevailing surface slick activity observed by SAR as being of a biological nature. Our experience with SAR observations in the Bering Sea has shown that these slick features are indeed a common occurrence during the summer months. The fact that the SAR observations can be made under total cloud cover conditions provides a way to extend the optical observation and monitoring of algal blooms in the region.

FISHING ACTIVITY IN THE BERING SEA

The location and movement of fishing fleets operating in the Bering Sea can be easily monitor every two to three days with the present routine acquisitions of RADARSAT-1 SAR data at ASF. Vessel location information, along with environmental conditions such as ice distribution and sea-state, can and are being used in a pre-operational mode to manage time-critical or hazardous fisheries operations in the region.

Alaska fisheries where SAR ship detection is being tested by state management include the Togiak herring roe, Bristol Bay sockeye salmon, and the Bristol Bay and Eastern Bering Sea red king crab, and snow crab fisheries. An example of how SAR can help with the management of these and many other fisheries in the region is demonstrated by the SAR observations of the sockeye salmon fishing fleet in the Alaska Peninsula Egegik Bay on June 30, 1999 and shown in Fig. 4. The sockeye salmon fishery is conducted by a large contingent of boats (up to 1,000). These drift gillnet boats are 32 ft (10 m) in length by regulation and most of them are made of aluminum. The vessels in this fishery operate in large clusters. Figs. 5 and 6 show a closer look at the two cluster regions indicated in Fig.4.

There is a particular enforcement problem at Egegik since the boats are required to align themselves along a management line defined for important biological and allocation reasons. The boats must stay on one side of the line to allow fish swimming alongshore to make it through to other destined areas. Since the line is the best place to fish, many boats have been rammed in the wild commotion. SAR can easily indicate the actual distribution of the fleet over an extended area as shown by Figs. 5 and 6. A single enforcement vessel available on the grounds cannot adequately cover the region. SAR can help by providing a view of the evolution of these clusters from which a decision on where to provide an enforcement presence can be made.

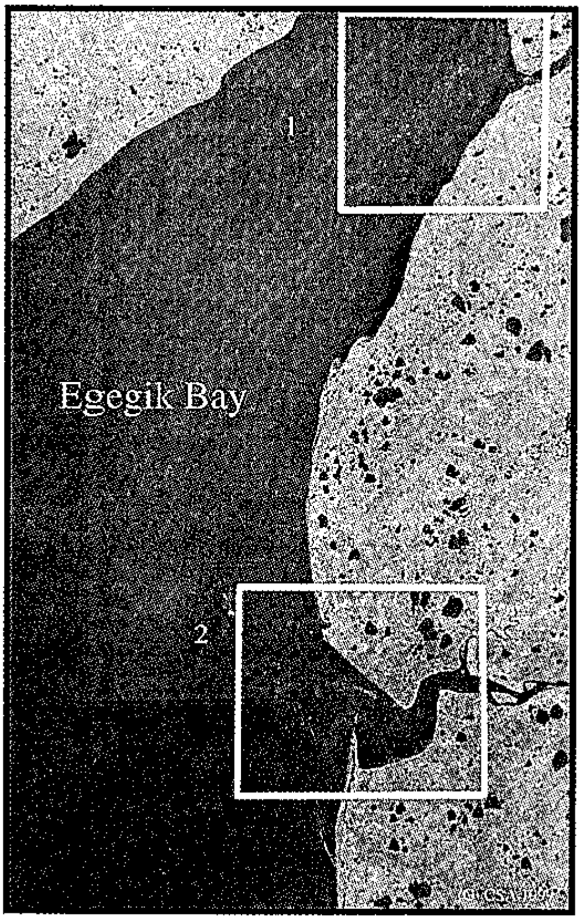

Figure 4. RADARSAT-1 Standard SAR image of the Alaska Peninsula Egegik Bay region on 30 June 1999 16:50 UTC.

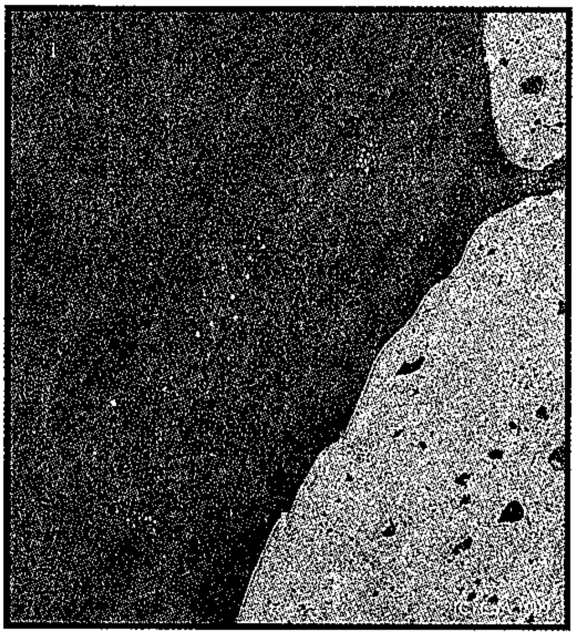

Figure 5. RADARSAT-1 RADARSAT-1 Standard SAR Fig. 4 sub-image of the Alaska Peninsula Egegik Bay region (square 1) acquired on 30 June 199916:50 UTC.

Figure 5. RADARSAT-1 RADARSAT-1 Standard SAR Fig. 4 sub-image of the Alaska Peninsula Egegik Bay region (square 2) acquired on 30 June 199916:50 UTC.

A fishery where management and enforcement activities can benefit from the use of hard target and slick detecting capabilities of SAR is the Bering Sea walleye pollock trawl fishery. This economically important fishery is conducted by an international fleet in Russian Exclusive Economic Zone (EEZ) west of the U.S.-Russia Bering Sea boundary and also by a U.S. fleet in waters of the eastern Bering Sea, just north of the Aleutians. Fishing for pollock in the Bering Sea is characterized by processing onboard a large number of trawl-processors involved in the fishery. Fig. 7 shows the distribution of a cluster of vessels from the Russian trawl fishing fleet and associated processing slick signatures[7].

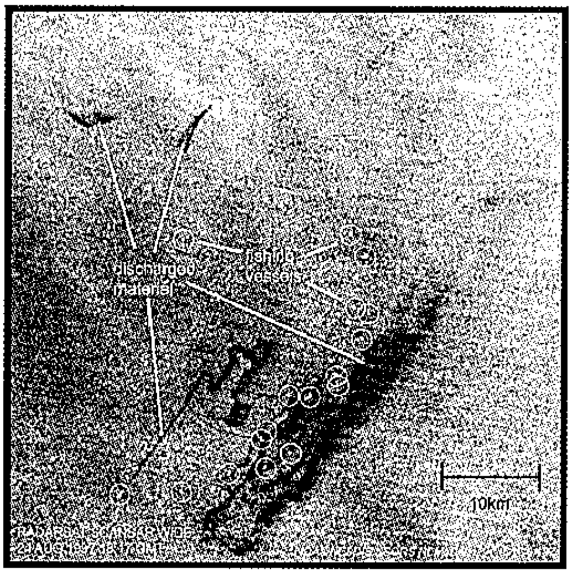

Figure 7. RADARSAT-1 ScanSAR Wide image showing a cluster of the pollock trawling fleet in the Russian EEZ on 24 August 1997 18:17 UTC.

It is well known that large amounts of fish processing byproducts and bycatch are discharged from these vessels during normal pollock trawl operations, as seen in Fig. 8. Visual on-site observations of the slicks generated by discharged material in the fishing grounds are common. Fish oils in the discharged material will dampen the capillary and short gravity waves in the same way that naturally occurring slicks do.

In fact, slick pattern observations associated with trawl fishing in the Bering Sea are very common in SAR imagery. They can provide an indication of areas being actively fished (vessels and slicks present) as well as of areas already harvested (only slicks present). It should be pointed out that these slick patterns are distinctly different in shape and distribution from natural biological slicks such as those shown in Fig. 2.

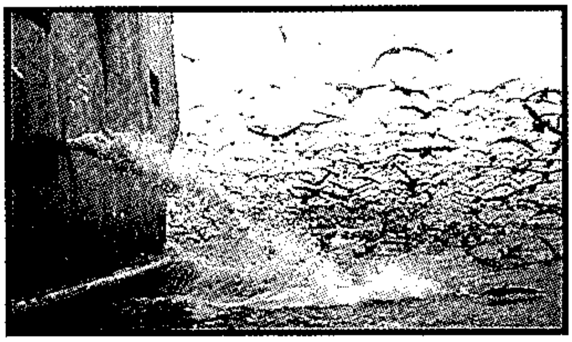

Figure 8. Photograph of a trawl-processor discharging processing residue in the Bering Sea. (Courtesy of Green Peace).

A good example of how the distribution of vessels and slicks are typically found to delineate the general orientation of the U.S.-Russian boundary is shown in Fig. 9. From this image, it is apparent that SAR observations provide a unique tool for the monitoring trawling activities in this sensitive region.

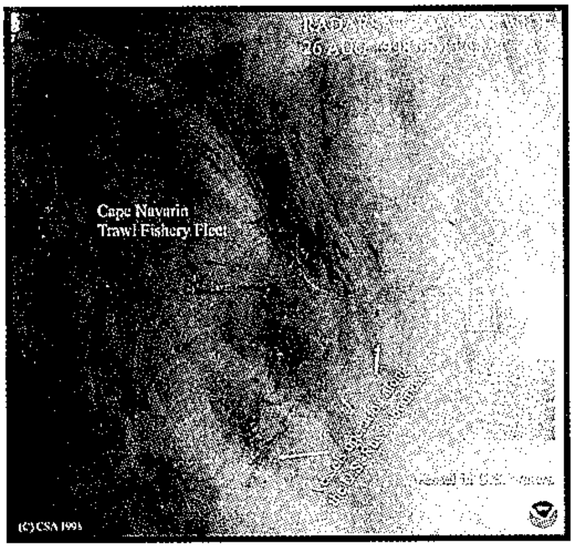

Figure 9. RADARSAT-1 ScanSAR Wide image showing the distribution of the pollock trawl fishing fleet and associated processing slicks in the western Bering Sea on 26 August 1998 16:50 UTC.

It has been determined by the U.S. Coast Guard (USCG) that foreign vessels fishing along the maritime U.S.-Russian boundary cross the line to fish illegally in U.S. E.E.Z. waters. An example of how SAR monitoring can detect and confirm such violations is shown by the set of ScanSAR Wide observations shown in Figs. 10 and 11. The Fig. 10 observations were acquired on 18 June 1999. The vertical white line on both figures indicates the location of the U.S.-Russian boundary. A large cluster of the international trawl fishing fleet is found to be operating right on the boundary with a number of vessels actually crossing into U.S. E.E.Z waters as it is clearly indicated by the arrow. In contrast, although the observations on 5 July 1999 shown in Fig. 11 still show a large cluster linearly aligned with the boundary, the vessels are now found at a considerable distance from the boundary. It is curious that a single vessel is detected to the right of the boundary at this time (see arrow and circle in U.S. waters), which, although unconfirmed, we suspect to be a USCG cutter on patrol. The presence of a USCG cutter could certainly explain the observed compliance by the fishing fleet.

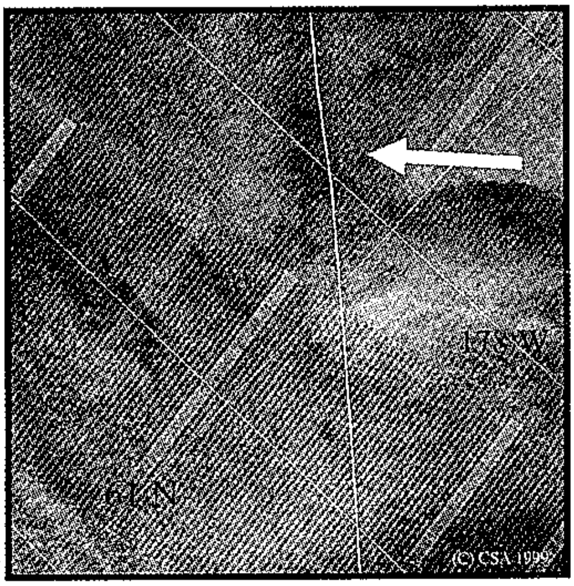

Figure 10. RADARSAT-1 ScanSAR Wide image showing the pollock trawl fishing fleet operating right at the Bering Sea U.S-Russian boundary on 18 June 1999 05:38 UTC.

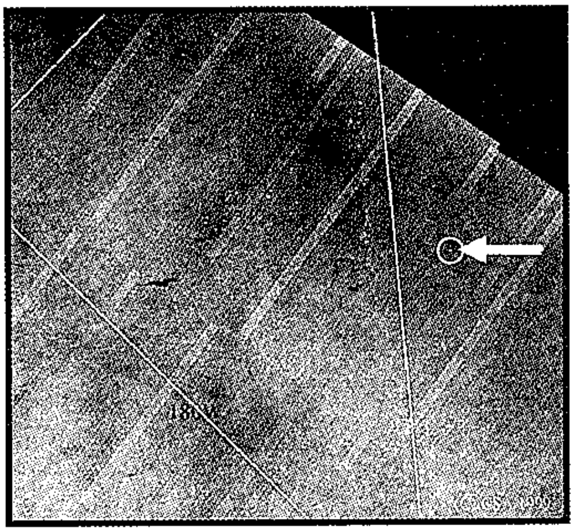

Figure 11. RADARSAT-1 ScanSAR Wide image showing the pollock trawl fishing fleet properly operating west of the Bering Sea U.S-Russian boundary on 5 July 1999 05:42 UTC.

CONCLUSIONS

We have shown examples of how spaceborne SAR imagery can provide indications of biological and fisheries activity in the Bering Sea. These observations can be used in support of biological, fisheries management and enforcement activities. SAR slick detection capabilities can provide information about regions of enhanced primary productivity. While phytoplankton biomass can be quantitatively assessed using ocean color, the sub-pixel variability and fine structure of the blooms can be studied using a SAR image even under cloud cover conditions.

SAR ship detection provides information on fishing vessel location and fleet distribution patterns. In the case of vessels that discharge processing residue back to immediate environment, the detection of slicks can provide information about the fishing operations. For example, fishing residue slicks persisting over a region can serve as an indicator of previously harvested areas long after the fishing fleet has moved out.

SAR monitoring of the highly productive Bering Sea fishing grounds can in fact complement other reconnaissance platforms by providing observations of both legal and illegal fishing activities. SAR imagery can aid in the operations of Alaska state fisheries management and federal enforcement and regulatory agencies. At a minimum, spaceborne SAR observations should allow for the efficient use of other available sensors and assets, thus decreasing surveillance and enforcement operating costs.

Spaceborne SAR observations clearly provide a unique tool for the effective and efficient monitoring of biological and commercially important ocean areas. The continued and affordable availability of these observations to biological and fisheries research, management, and enforcement authorities in the Bering Sea should continue to be fully supported by the U.S. government.

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