OBJECT-ORIENTED ANALYSIS OF SEA ICE FRAGMENTATION USING SAR IMAGERY TO DETERMINE PACIFIC WALRUS HABITAT

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ABSTRACT

Long-term alterations in climate are causing changes in sea ice formation resulting in a potentially degraded habitat for Pacific walrus (*Odobenus rosmarus divergens*). Students from NASA's DEVELOP program worked with the U.S. Fish and Wildlife Service in Alaska to determine the usefulness of satellite imagery for studying walrus habitat on sea ice. Few studies use sea ice image processing methods to observe marine mammal habitats in polar regions because of the difficulty in obtaining multispectral imagery and georeferenced species location data points for the same time period. The dynamic nature of sea ice poses a challenge to remote sensing studies and matters are further complicated when additional data are incorporated. Passive multispectral sensors cannot penetrate the cloud base without information loss. In cases where heavy cloud cover exists, such as in the Alaskan Yukon-Kuskokwim Delta, radar sensors are preferred because they are relatively unaffected by clouds, have high temporal resolution, and operate day or night. This study presents a method for sea ice image analysis using remote sensing segmentation and classification techniques with RADARSAT1 Synthetic Aperture Radar. Results were associated with ground point data to determine the relationships of sea ice features to walrus' preferred habitat. MODIS data were utilized, where possible, to verify the classifications of sea ice surfaces obtained by RADARSAT1. The challenge and goal was to capture, display, and relate geophysical information from radar images that correlate with georeferenced species data points for the same time period.

INTRODUCTION

During the summer of 2006 the NASA DEVELOP program, a NASA Science Mission Directorate Applied Sciences Program that extends Earth science research to local, county, state, federal, and tribal governments, conducted a study at the NASA Ames Research Center on polar sea ice formations and their relationship to the Pacific walrus of the Subarctic coastal ecoregion. DEVELOP is a 10-week program where students utilize resources provided by NASA to address environmental issues with government agencies. The research and activities were student led, with advisors from NASA and partner organizations. Partner organizations for this project were the U.S. Fish and Wildlife Service (USFWS), University of Alaska Fairbanks (UAF), and the Alaska Satellite Facility (ASF).

Because of the decline in sea ice extent, duration, and thickness associated with climate change in the polar regions, it has become increasingly necessary to document life history characteristics of megafauna such as marine mammals (Fay and Ray 1968, Cooper *et al.* 2006). Studying the Pacific walrus (*Odobenus rosmarus divergens)* is of particular importance because very little information exists on population dynamics and supporting habitats, thus it makes little sense for the species to be used as an indicator of climate change until further studies are done. The Arctic ecosystem provides vital habitat for the Pacific walrus. Regional sea ice is used as a resting place, foraging, haulout, and reproductive space. Its spatial characteristics such as density and surface area guide walrus haulout locations for individuals and groups.

Our objective for this project was to initiate discussion on object-oriented approaches of sea ice segmentation and to present a practical application of this procedure. Linear swaths of 6 km and 12 km in width were segmented and classified to capture sea ice fragmentation features and to test relationships between the pack ice in the Bering sea and the location of Pacific walrus. Generally, two schools of thought exist on the relationship between sea ice and walrus haulouts: 1) walrus choose haulouts based on foraging sites and ice is not a determining factor; and 2) sea ice type and characteristics of the ice are critical to where walrus choose to haul out. This study lays the groundwork for further study on the possible established relationship between sea ice conditions preferred by the walrus.

WALRUS SURVEYS

Pacific walrus are found in the Bering and Chukchi Seas and are the only subspecies of walrus that inhabit U.S. waters. They are an important part of Alaskan native subsistence culture and the economy and therefore a stable population is crucial. The last population survey of Pacific walrus was conducted jointly by the United States and the Soviet Union in 1990, estimating a population of 201,000 walrus (Hills and Gilbert 1994, Gilbert *et al*. 1992). In 2002, 2003, and 2005 the USFWS conducted tests using airborne thermal imagery of the Pacific walrus in the Bering Sea to determine if this technology could be used to detect walrus groups on sea ice and estimate the number of walrus in each group (Burn *et al.* 2006). The 2002 study was used to determine the viability of using this technique to estimate the size of the Pacific walrus population. The 2003 and 2005 surveys were used to further improve the thermal imaging process. Airborne thermal imagery has been shown to be more efficient for determining the walrus population than previous methods for counting the number of walrus. The thermal imaging process provided a quicker and more reliable method for estimating walrus populations and it has been recommended that these tools and methods be used for future work in surveying large areas of sea ice and walrus locations.

In the fall season, when many of the previous surveys were conducted, the walrus population is segregated throughout its large ecoregion, with some animals associated with the ice edge in the Chukchi Sea, while others make use of terrestrial haulouts along the coasts of Bristol Bay, Alaska in the U.S., and the Chukotka and Kamchatka peninsulas in Russia (Burn *et al.* 2006). Fewer surveys have been conducted in winter and early spring, when the entire walrus population are almost exclusively on the pack ice of the Bering Sea with concentrations in the Gulf of Anadyr, south and west of St. Lawrence Island, and south of Nunivak Island (Fay *et al.* 1984). In order to survey while most walrus were in a single region, the 2002-2005 USFWS surveys took place in April, when the polar ice sheet extends the farthest south. Work conducted by Russian collaborators complimented that of the USFWS in examining walrus populations native to their own waters.

STUDY AREA

The Yukon-Kuskokwim Delta (Figure 1), similar in size to the state of Oregon, is one of the largest delta regions in the world. Rocky volcanic islands scattered throughout shallow portions of the Bering Sea provide a mix of polar and maritime ecosystems that appeal to millions of seabirds (cormorants, kittiwakes, murres, puffins, and auklets) and marine mammals (walrus, northern fur seals, ribbon seals, and sea lions). These biologically rich foraging grounds for the walrus and can reach depths up to 100m (Fay and Burns 1988, Ray *et al.* 2006). The high primary production in the water column is largely consumed by the macrobenthic community and large animals, including walrus, serve as apex predators in the food chain (Grebmeier *et al.* 2006). The benthic environment in the Subarctic coastal ecoregion, encompassing the delta, varies in depth from 25m to 75m (Burn and Speckman personal communication). A majority of the walrus for the 2003 and 2005 studies were found in the immediate vicinity of St. Lawrence Island and Nunivak Island, Alaska.

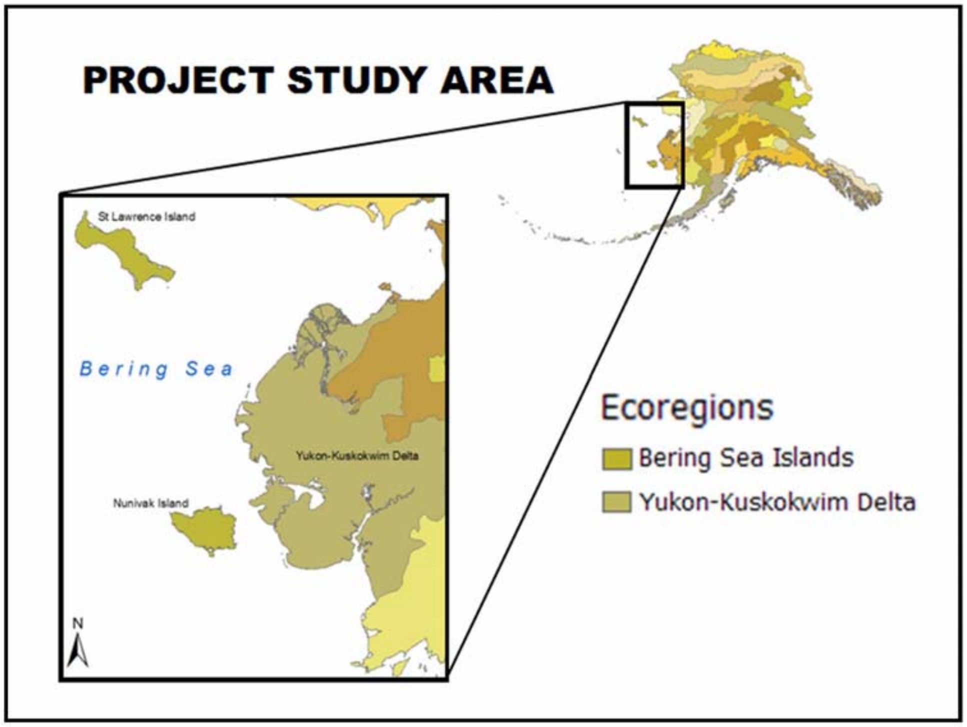


Figure 1. Yukon-Kuskokwim Delta and Bering Sea Islands ecoregion (USGS, 2006).

Bering/Chukchi Seas pack ice forms in the northernmost latitudes in late November and recedes in mid-July. Average thickness of the sea ice is 1.8 – 2.7 meters. Some areas of multiyear ice, or ice that has survived consecutive summer melts, can be as thick as 3.9 – 4.5 meters (NSIDC 2006c). Pushed by strong polar winds, the sea ice extends beyond the Bering Sea. In late November, sea temperatures in the Arctic Ocean begin to chill to -1.8°C and ice formation intensifies, often taking on a unique asymmetrical physical formation (Bowditch 2002). With the majority of the Arctic Ocean surrounded by land, ice floes (fractured, thickened ice) converge and pile up into thick ridges, allowing the dense ice to survive many melting seasons (NSIDC 2006c). During the winter months the sea ice covers an area of 5.8 million square miles (15 million square kilometers), encompassing the Arctic Ocean, Bering Sea, Hudson Bay, Baffin Bay, and the Chukchi Sea. The sea ice matrix at this time consists of fairly rounded floes with deformed surfaces composed of ridges and hummocks, separated by open water areas or leads. At the end of the summer, the first year ice, covering an area of roughly 2.7 million square miles (6.9 million square kilometers), recedes.

DATA

The flight path scanlines used for thermal imaging and associated attribute information used in this study were provided by the USFWS. The scanline widths were 6 km (2003) or 12 km (2005) with variable lengths. The scanlines were georeferenced and overlaid onto each radar image in the same region over four days (April 7 and 8, 2003; April 1 and 11, 2005). Walrus location information was gathered during thermal scanning by instruments on aircraft. A separate aircraft was used to acquire air photos and georeferencing information. The time lag between the thermal scanning aircraft and the georeferencing aerial photos aircraft limited the ability to know exactly where the thermal scanner identified walrus. It was only possible to identify those scanlines that had walrus and those that did not according to the USFWS thermal analysis. Future studies proposed by USFWS using thermal imagery will include exact georeferencing of thermal imagery through the use of a device that measures aircraft altitude, attitude, and speed at the time of thermal scan (Burn and Speckman personal communication, 2006). This approach would provide more accurate results by providing more information on walrus location, their immediate surroundings, and estimated degree of drift associated with imagery acquisition and thermal scan time.

Synthetic Aperture Radar (SAR) takes advantage of long-range propagation characteristics of radar signals and the complex information processing capability of modern digital electronics to provide high resolution imagery. SAR imagery is able to penetrate the cloud base and provides information on the pack ice matrix, which can be used to make distinctions between surface roughness, ice thickness, fragmentation and other pack ice characteristics through comparison with sea ice maps and manipulation in GIS and object-oriented classification tools (Tsatsoulis and Kwok 1998).

The Alaskan Satellite Facility (ASF) provided RADARSAT 1 SAR data at a resolution of 50m in a compressed CEOS format (ASF 2006a, 2006b). The geocoded GeoTIFF images were produced through the use of ASF SAR conversion tools that work with most Level 1 Alaska Satellite Facility products. The sea ice imagery was subset to the thermal image swath boundaries to minimize the amount of image processing necessary. The image swaths were then further segregated into where walrus were and were not found.

METHODS

In conventional per-pixel unsupervised classification image processing techniques, objects are separated from the background using techniques that include thresholding (Gonzalez and Woods 1992), region splitting and merging (Horowitz and Pavlidis 1976), relaxation (Hummel and Zucker 1983; Rosenfeld and Kak 1982) and others. In cases where separation among objects is desirable and the objects are known to be contiguous, as in the case of ice floes in SAR imagery (Soh *et al.* 1998), object-oriented image segmentation techniques are necessary. The process of object-oriented image segmentation has value over raster-based segmentation because it allows for examination of objects within their original spatial environment, as well as examination of individual polygons and their attributes.

Raster-resultant approaches such as the restrictive growing concept proposed by Soh *et al.* (1998) indicate that large ice floes (typically 500 to 2000m or greater) are difficult to capture if they tend to be touching several other floes or are branchy and are removed from the floe size distribution analysis. Since walrus tend to be attracted to ice floes that can support their weight, an analysis of floes capable of supporting the weight of a walrus group is necessary for determining links between species habitat and sea ice.

Image segmentation was conducted in the eCognition software environment (Definiens Software, Munich, Germany, 2004). The segmentation procedure creates polygons that represent the break in one object from another, such as the fragmentation of the sea ice floes. The segmentation algorithm was calibrated using a user-defined threshold of scale and heterogeneity and user-defined weightings on various data layers (Chubey *et al*., 2006). This is generally an iterative process whereby the user can input a series of scale combinations (e.g. scale factor, compactness, smoothness) such that the created polygons are large enough to capture features of interest. The creation of polygons musings imagery that accurately represent ice floes was problematic as the sea ice surface is extremely heterogeneous, particularly with medium thickness first year ice. Backscatter values tend to range widely and it was difficult to extract ice floe roughness features. To address this issue, adjacent polygons were merged based on a spectral similarity criterion. Objects were merged if they did not exceed a user defined heterogeneity threshold. The segmentation parameters chosen to capture ice floes, leads, and ice types within the image swaths relied on scale factor, shape factor, color, compactness, and smoothness parameters specified by the user. The value of image segmentation lies in the subsequent ability to look at the objects both in their context within the sea ice as well as their innate shape properties.

Four ice types were then selected through sampling within the raw radar image to represent the different ice types and were assigned to a class hierarchy: thick ice, medium thickness ice, thin ice, and water. The classification selection provided four homogenous classes composed entirely of one specific type of ice. An example of the segmentation procedure showing stages of image processing is provided in Figure 2. Samples were taken for each day that was representative of the different types of ice. The sample class hierarchy was applied across all of the image swaths for the corresponding day (i.e. 4 days required 4 sets of 4 classes). The samples for each class were taken across the whole image swath to ensure that the sample selection would include all pixel variability. Although this process was rather subjective in terms of specified class boundaries in the pixel range, the classification selections reflected obvious visual sea ice features found in the imagery such as open water, large leads, land etc. The pixel range selected per each ice type for each day is shown in Figure 2.

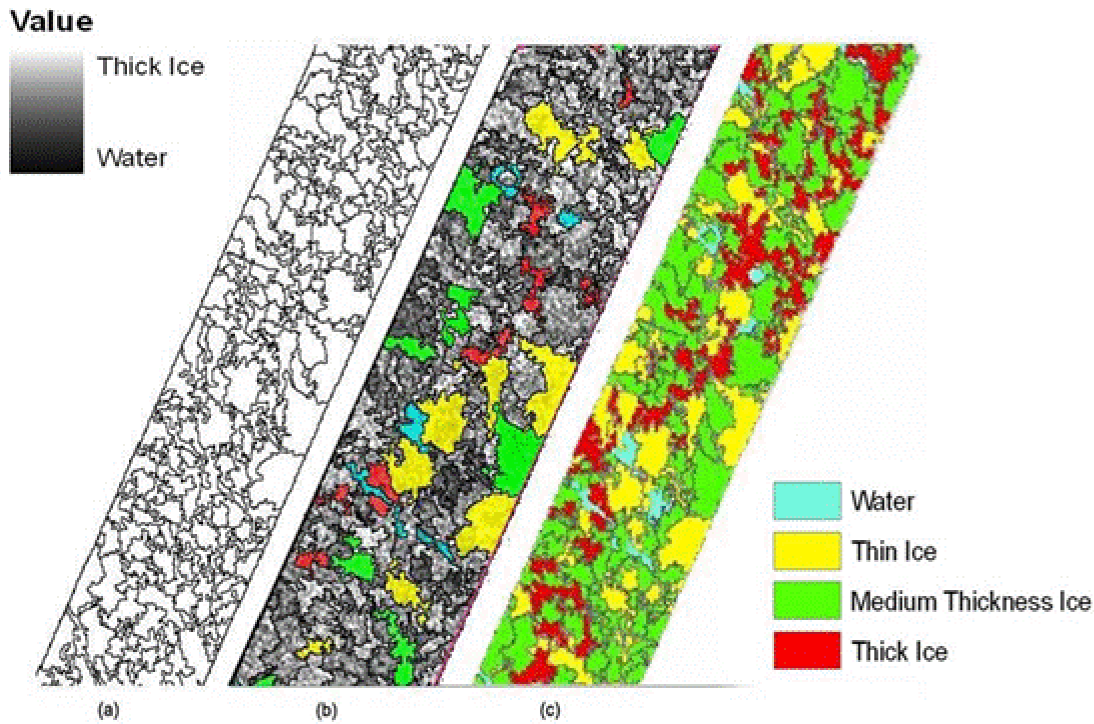


Figure 2. Image swath segmentation procedure showing (a) unclassified polygons of the raw image swath (legend does not apply), (b) supervised classification of the raw image swath, (c) completed classification of a raw image swath.

Average pixel brightness values display the range of values selected in the sampling procedure. Each day required selection of a different range of backscatter values to represent and create the hierarchy of thick, medium thickness, thin, and water classes. As the pixel class selection process was refined, the range of values used in selecting the different ice types were within given ranges that had minimal overlap or gaps between classes. For example, the April 5, 2005 pixel range used in selecting thick ice floes blended with classes chosen for medium thickness ice floes generally, the overlap is reduced as the familiarity with the classification procedure increases, as seen for April 11, 2005.

The NOAA National Ice Center (NIC) uses satellite imagery data, coastal vector overlays, and digitized boundaries to classify ice at a regional scale (NIC 2006). For example, using 625km² pixels, ice concentration is calculated at the center of each pixel to observe whether the pixel is sea ice or land (Moore and Laidre 2006). For the purposes of this study, the NIC ice chart scale was too small to capture features of interest within the image swaths but does provide a general picture of the regional scale ice types as a reference during the study periods. Initially, the NIC ice charts were overlaid onto the SAR image (Figure 3). According to NIC ice charts, in 2003 all the walrus were found in regions composed almost entirely of medium thickness first-year ice (70-120cm) with very small amounts of thick first-year ice and thin first-year ice. In 2005 the ice extent was minimal and seldom thicker than 30-70cm (thin first-year ice) so it was difficult to draw conclusions about walrus haulout behavior based strictly on sea ice fragmentation. A very small amount of medium first-year ice was found along the northern region of the Yukon/Kuskokwim shoreline. All of the walrus were found in areas made up mainly of thin first-year ice during the 2005 study. The dates, flight paths, imagery, and NIC classes shown in Figure 3 illustrate walrus location and sea ice extent as well as the available data used in the study.

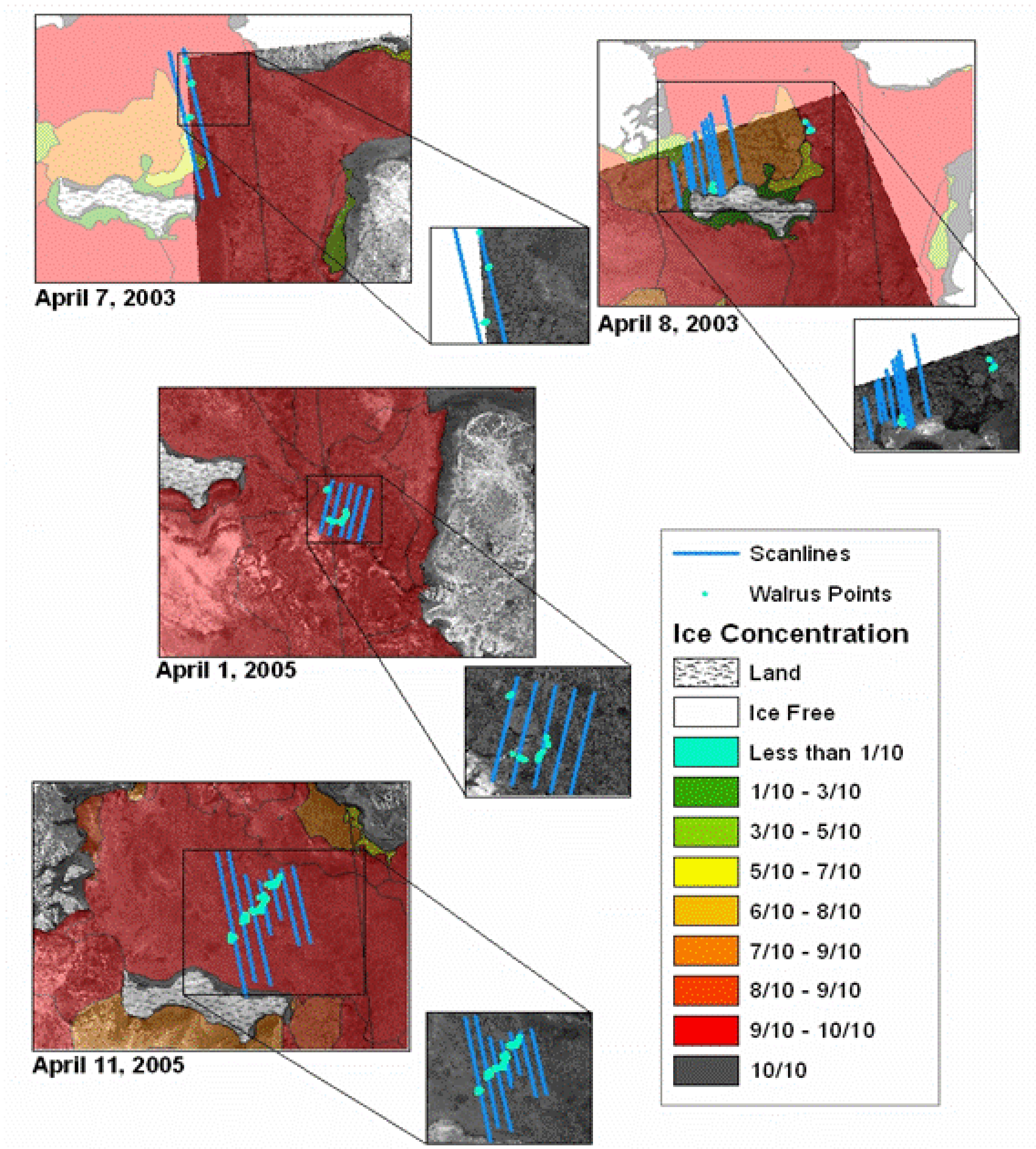


Figure 3. National Ice Center ice charts overlaid on RADARSAT SAR images for study dates illustrating walrus points and aircraft thermal flight paths. Insets show walrus point observations and thermal flight paths.

A second approach using traditional unsupervised classification techniques for capturing sea ice characteristics using SAR imagery was conducted and used for simple comparison with the supervised, object-oriented approach (Figure 4). The RADAR imagery was run through a single 9x9 then a single 3x3 Gamma-Map filter using ERDAS Imagine Radar's parameters option. The Gamma-Map filter performs spatial filtering on each individual pixel in an image using the grey level values in a filter window surrounding each pixel creating spatial similarity among nearby pixels (Lopes *et al.* 1993). The resultant raster imagery (Figure 4b) was then classified into 4 classes: thick ice, medium thickness ice, thin ice, and water. Although the focal filter extent used here is only one of several smoothing options available to capture similar pixel features, it illustrates the difficulty in capturing the fragmentation features of sea ice. We also classified the image using 10 classes to capture more backscatter variability. Both classifications over-generalized the sea-ice and did not seem to accurately represent the physical characteristics. The sea ice tended to have uncharacteristic rounded edges, as sea ice normally contains asymmetrical, straight, and rounded edges within floes. The despeckle function (despeckle algorithms developed to retain detail in subsurface images at the single pixel level) in ERDAS Imagine software was used without filtering and was not able to produce similar ice types or floes as well as an object-oriented approach.

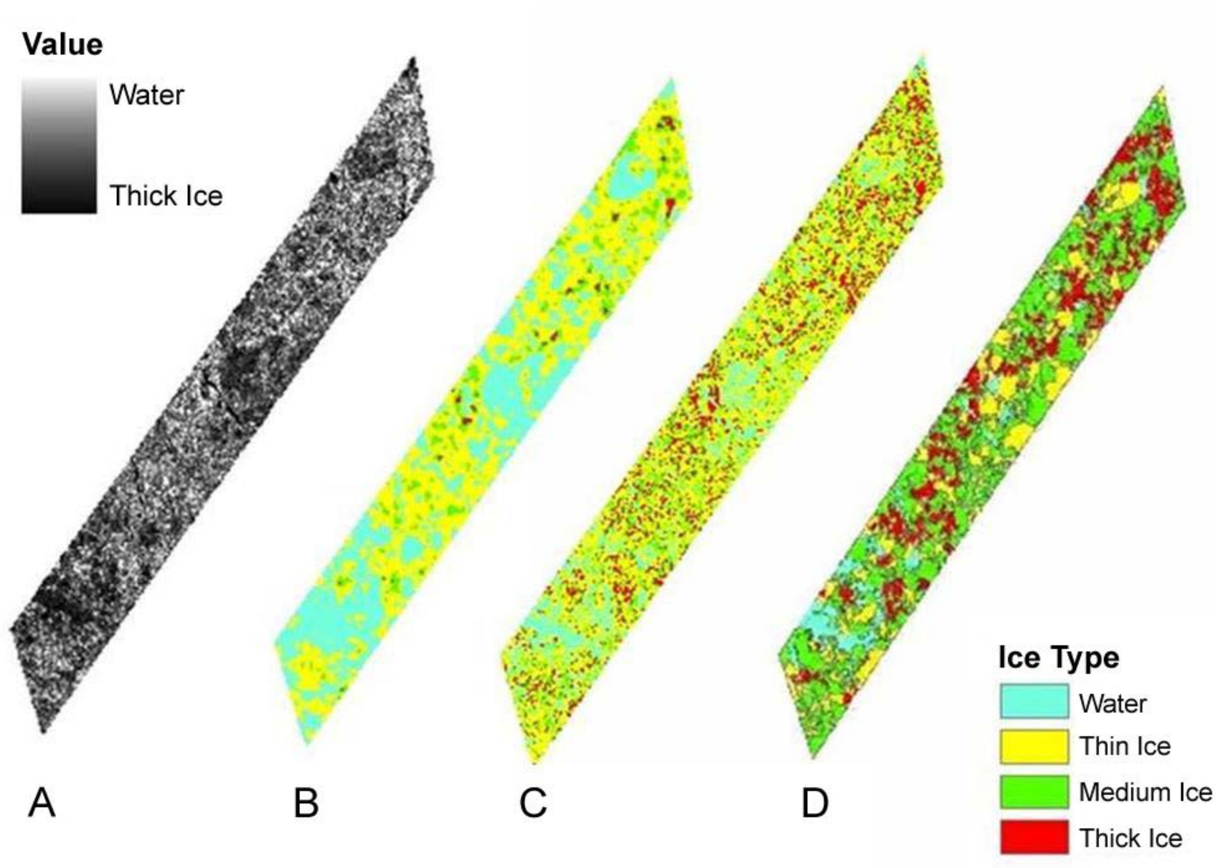


Figure 4. Image swaths at 12 km for April 1, 2005 showing a (a) raw unclassified image swath; (b) unsupervised classification of an April 1, 2005 image swath; (c) despeckled and unsupervised classification of an image swath; (d) a segmented image swath categorized into four classes of thick, medium, thin ice, and water (supervised classification).

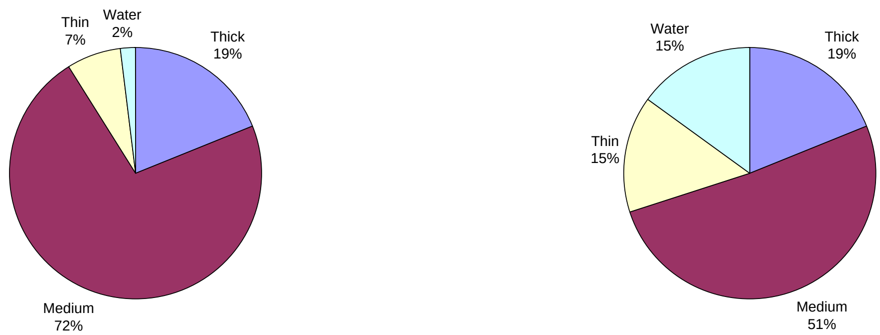
The segmented images captured a larger amount of individual ice floes (Figure 4d) whereas the raster-based approaches tended to incorporate easily identifiable features (water) into larger polygons that envelop smaller ice floes. The despeckled (Figure 4b) and despeckled/classified (Figure 4c) images, which showed various ice types within the classifications when segmented, captured few floes within polygons in the swath. This simple analysis helps to confirm the usefulness of object-oriented approaches to sea ice fragmentation using SAR imagery (Lopes *et al.* 1993, Lythe *et al.* 1999).

RESULTS

Polygon features—representing ice floe sizes—extracted in the segmentation procedure include: statistics on area, brightness, and number. Considering all image swaths together, medium thickness ice constituted the largest percentage of sea ice polygons (65.1% of total image swath area). Although the classification methods used do not follow NIC methods, the sheer amount of medium ice classified in the study corresponds with NIC ice charts.

It was only possible to identify thermal image swaths that had walrus (as indicated by the USFWS) and those image swaths that did not. Therefore, images were separated into two distinct groups. Group WW represented image swaths with walrus and Group NW represented image swaths with no walrus. The total area, area with walrus (Group WW), and area without walrus (Group NW), of all image swaths are 7,747.2km^2, 50,42.1 km^2, and 2,705.1 km^2 respectively.

Areas with walrus (Group WW) had a slightly lower surface concentration of thick ice a much higher concentration of medium thickness ice, and a lower concentration of thin ice than the image swaths without walrus (Group NW)(Figure 5).



(a) (b)

Figure. 5. Composition of Bering Sea Surface: (a) cumulative area of ice types within image swaths in which walrus were located (b) cumulative area of ice types within image swaths in which no walrus were located.

Relationships between Groups WW and Groups NW were analyzed and several distinct differences and similarities were determined. The area of polygons for the different ice types varies between image swaths with walrus and those without. Using an independent samples t-test for each ice type, scanline groups with walrus had significantly larger-sized medium thickness ice floes and smaller-sized thin ice floes (polygon size) at the 0.05 significance level. Thick ice flow sizes did not vary significantly between the total image swath with walrus and total without walrus.

CONCLUSION

There is a general consensus that walrus prefer mixed ice and old ice but little published research exists on specific studies of sea ice/walrus relationship. This study suggests that walrus prefer medium and some thin ice floes. By understanding where walrus congregate, it is possible to narrow the potential location of walrus and direct census collection resources to those locations. Further, understanding the habitat where walrus live gives insights to the ecology and behavior of the species. These insights can be useful for the conservation and stewardship of the walrus because they are important sources for food (meat and fat), clothing (hide), and ornaments (ivory) for native Alaskans.

The use of a segmentation technique resulted in better characterization of the sea ice than the per-pixel classification technique. The details within and between ice floes were maintained using the segmentation technique, while the per-pixel classification resulted in generalizing the floes. Additional work will be required to more accurately label the segmented polygons into different ice classifications. In addition, with georeferenced point locations of the walrus, future studies will be able to determine a more specific relationship between walrus and the ice floe type.

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