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Exelis Visual Information Solutions

Automated Mapping of Rapid Arctic Ocean Coastal Change Over Large Spans of Time and Geography

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Systematic, automated mapping of Arctic Ocean coastal erosion, deposition, and rate of change using Landsat archive data

ENVI IDL

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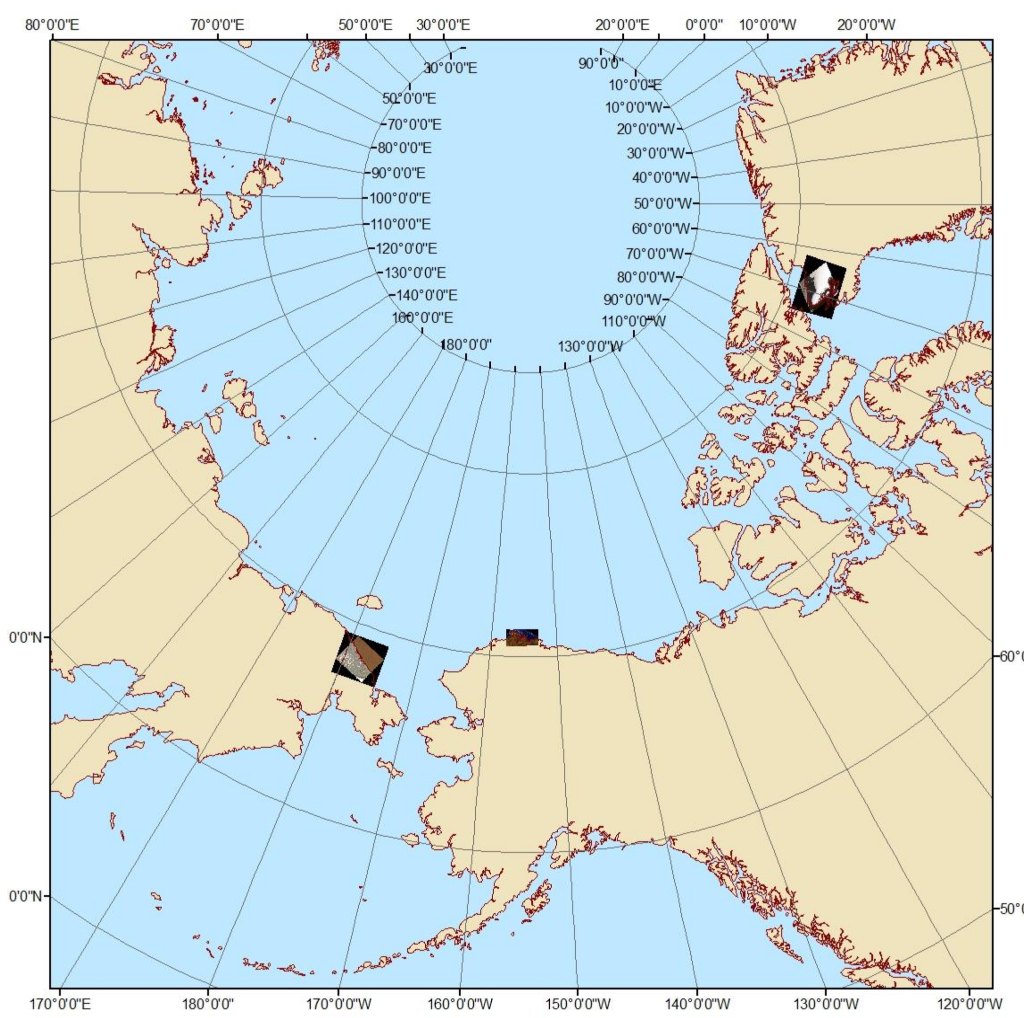

Figure 1 Regional siting of the three study areas in this project. From left, Chukchi Sea coast southeast of Mys Schmidta Siberia, Drew Point, Alaska, Qaanaaq Coastline near Thule, Greenland.

Introduction

Coastal and high latitude regions show many of the global effects of climate change earlier and more intensely than elsewhere. Current longer periods of ice-free conditions, in combination with a rising sea level and thawing permafrost, can result in accelerated Arctic Ocean coastline change and erosion. Areas dominantly composed of ice-cemented peats and silt-rich permafrost have proven to be especially susceptible to rapid erosion. Anderson et al. (2009; Geology News) have measured erosion rates at sites along the Alaskan Arctic Ocean coast of 15 m per year. The continental scope of these changes, as well as the remote and inhospitable nature of the study area make geologic remote sensing techniques particularly well suited for studying coastal erosion along the over 45,000 km of Arctic Ocean coastline. Applying object-based image analysis techniques to Landsat archive data allows for mapping Arctic Ocean coastline changes across decades. Landsat data (from sensors MSS 1-3 and TM/ETM 4, 5, and 7) provide imagery as frequently as every 16 days since July 1972, are well-calibrated both radiometrically and geometrically, and are freely available from USGS EROS Data Center Archive (http://earthexplorer.usgs.gov).

Hand-digitization of Arctic Ocean coastline changes over several decades would require an impractical amount of time and expense and would introduce additional error due to analyst differences in image feature interpretation. Object-based image analysis techniques have been shown (Hulslander, et al., 2008; GEOBIA 2008 Proceedings) to produce results similar to but more consistent than those from groups of human analysts. Earlier work has also shown (Hulslander, 2010; AGU Fall Meeting) that using object-based analysis on Landsat Archive data can be used to map Arctic Ocean coastline change within a Landsat scene and that it can be fully automated (Hulslander, 2011; AGU Fall Meeting).

Here, results show that this methodology can automatically and consistently map Arctic Ocean coastline change in Landsat datasets distributed both geographically and temporally. Furthermore, these results indicate the possibility of producing a pan-Arctic Ocean coastline map on a roughly triennial basis for the past 30-plus years. Significantly, there is wide variation in the presence or absence of coastal erosion and deposition at high latitudes. Major contributors in this variance include geomorphologic, meteorological, oceanographic , and anthropogenic factors.

Methods

1. Using a GIS (ArcMap 10.x), perform an intersection between a global continents polyline and the known WRS-1 and WRS-2 Landsat image footprint polygons, available from USGS at http://landsat.usgs.gov/tools_wrs-1_shapefile.php, http://landsat.usgs.gov/tools_wrs-2_shapefile.php
2. From the Landsat Archive, accessible at http://earthexplorer.usgs.gov, choose scenes by the path/row information from the previous step and retrieve any scenes sufficiently free of clouds and ice.
3. Use an automated script to generate a mask of the background no-data regions. Use the mask in all subsequent steps.
4. For each Landsat scene to be used, use an object-based image analysis package (ENVI Feature Extraction), define and export all objects defining the image by using ENVI 4.8 scale and merge values of 60/70 and 70/90 for MSS and TM data respectively. For TM and ETM data, all bands should be used for object definition, while with MSS data it is best to exclude the NIR band to minimize the influence of striping effects.
5. In ArcMap, use the global continents polyline to remove from the image analysis objects any polygons which intersect or are within 3 km of the roughly known coastline. Using the global continents polygon set, separate the remaining image objects in to two sets: those which are well within known land areas, and those which are well within known oceanic areas.
6. Re-run the ENVI feature extraction on the Landsat scene with the same scale and merge values, but now use the land and water polygon sets as training data for classification, producing an object-based classification result with land and water classes.
7. Repeat the above steps on every Landsat scene available with clear coverage of the study area.
8. Perform thematic change detection between each time step to isolate only those areas which had been classified as land which later changed to water (erosion), as well as water which was then later classified as land (deposition). Each area of change has an attribute of both type of change (erosion or deposition) as well as a timestamp of when the change was recorded (the date of the second image in the change detection pair).

Results and Discussion

- Automated object definition and separation using coarse resolution GIS layers has been shown in these tests to reliably delineate shoreline by using only "Land" and "Water" classes. These classification results are sufficiently reliable and accurate to feed directly to thematic change detection tools for generating maps of both type of change in coastline morphology (erosion or deposition) and time of the change. Moreover, this methodology can be scaled in a completely automated fashion to handle a much larger continental-scale of detailed coastline change analysis.
- Clouds, cloud shadow, and excessive ice cover on either land or sea can introduce error.
- Rapid coastal erosion occurring in Alaska is not seen in similar landscape morphologies in Siberia or Greenland, showing there are multiple controls over extant coastal erosion.
- A predictive model of Arctic coastal erosion is possible but must include factors such as landscape morphology, geomorphology, ocean currents, ice dynamics, permafrost dynamics, turbidity, and meteorology.
- Thick cloud cover and cloud shadow over the coastline can cause error in classification, as can excessive amounts of ice across the scene as a whole. An efficient MSS cloud mask algorithm will be required.
- Landsat 8 is the only mission that can possibly fulfill the need for ongoing monitoring of the rapid changes currently seen along the Arctic coast associated with active climate change.

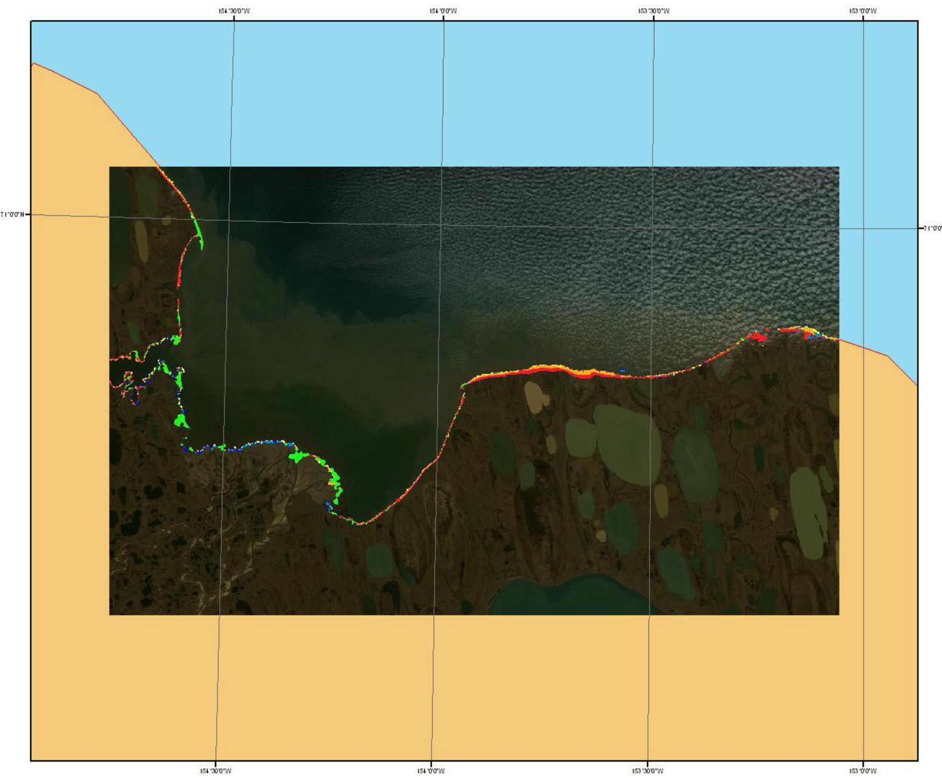

Figure 2 Detailed view of Drew Point and analysis results. Yellow areas are erosional losses from 1974 to 1978, orange from 1978 to 1999, red from 1999 to 2008. Dark blue areas are deposition from 1974 to 1978, light blue from 1978 to 1999, green from 1974 to 2008.

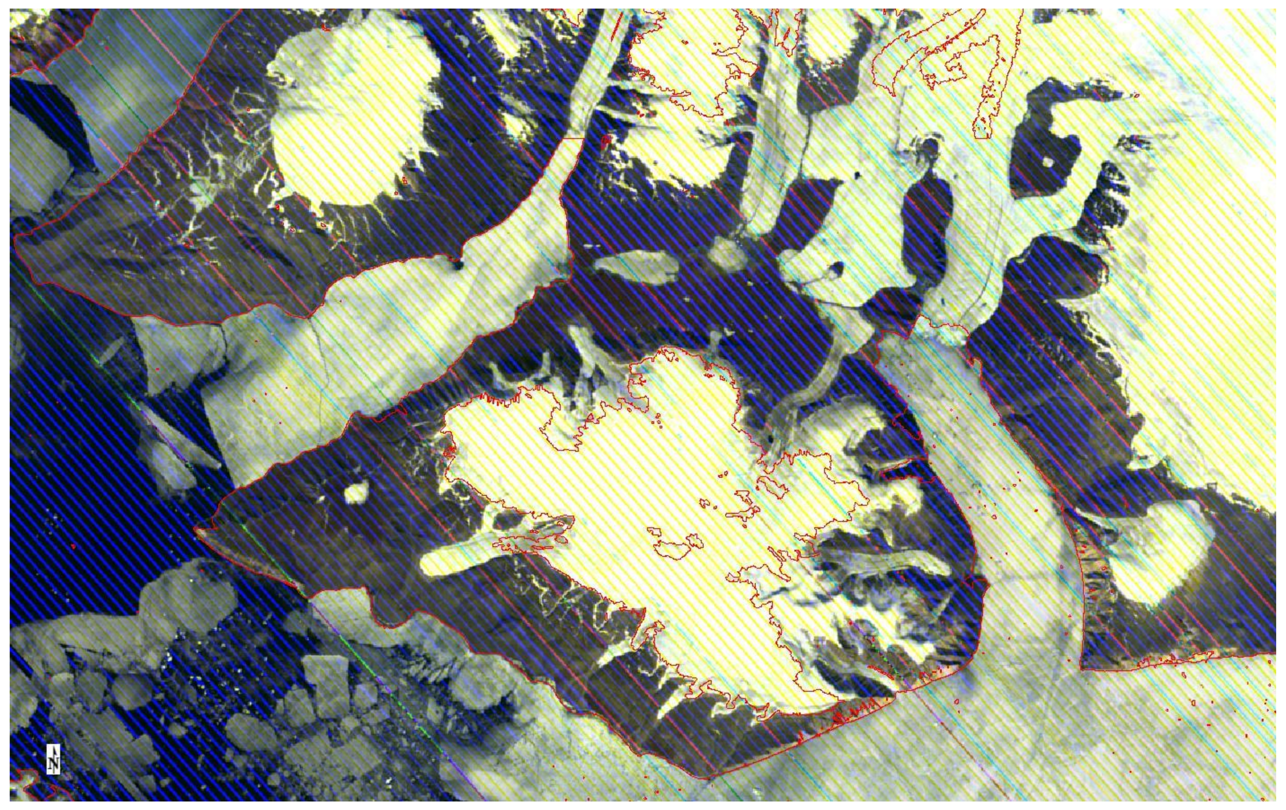

Figure 3 Qaanaaq Coastline, Greenland, 1975. Coastlines were automatically extracted from a 2002 scene (the most recent clear data available). Colored banding is a known artifact in some MSS data.

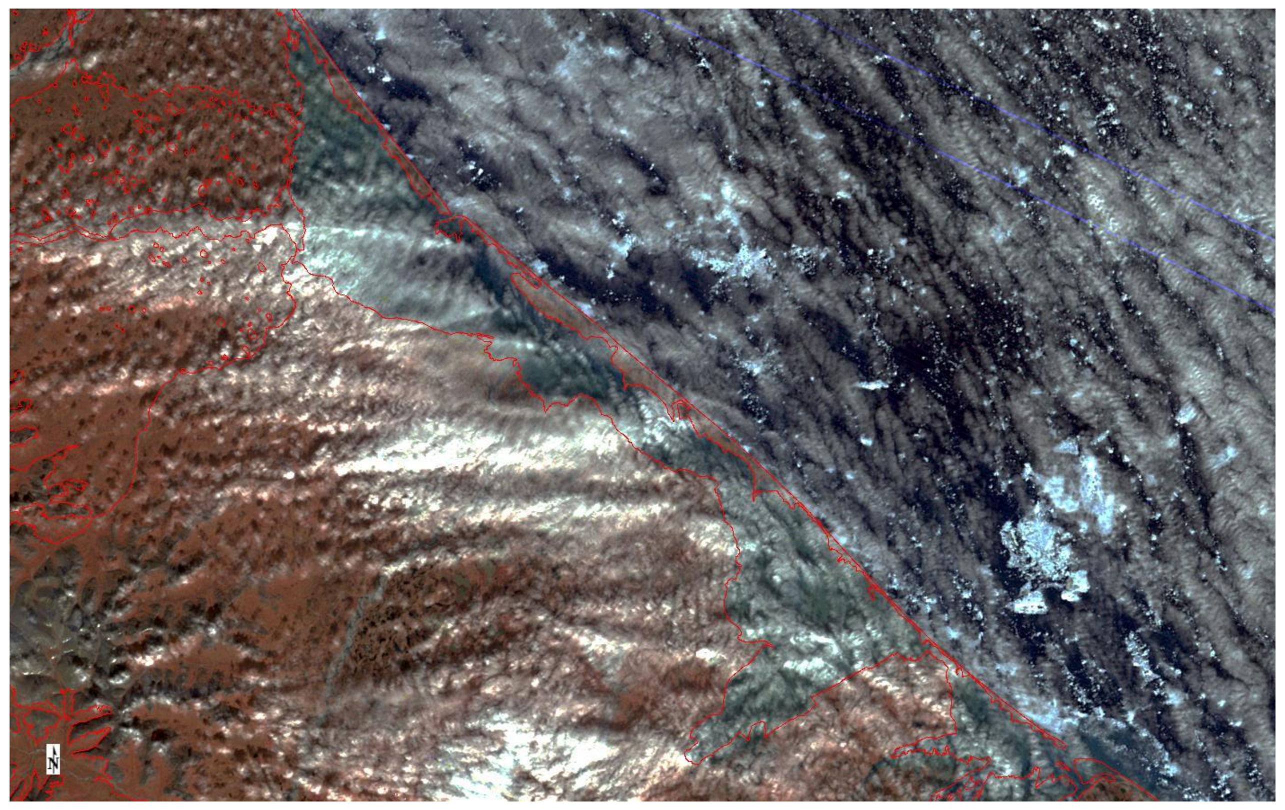

Figure 4 Amguema River region, Siberia, 1977. Coastline vectors (red) were automatically extracted from 2005 data.

Figure 5 Amguema River region, Siberia, 1995. Coastline vectors (red) were automatically extracted from 2005 data.

1974

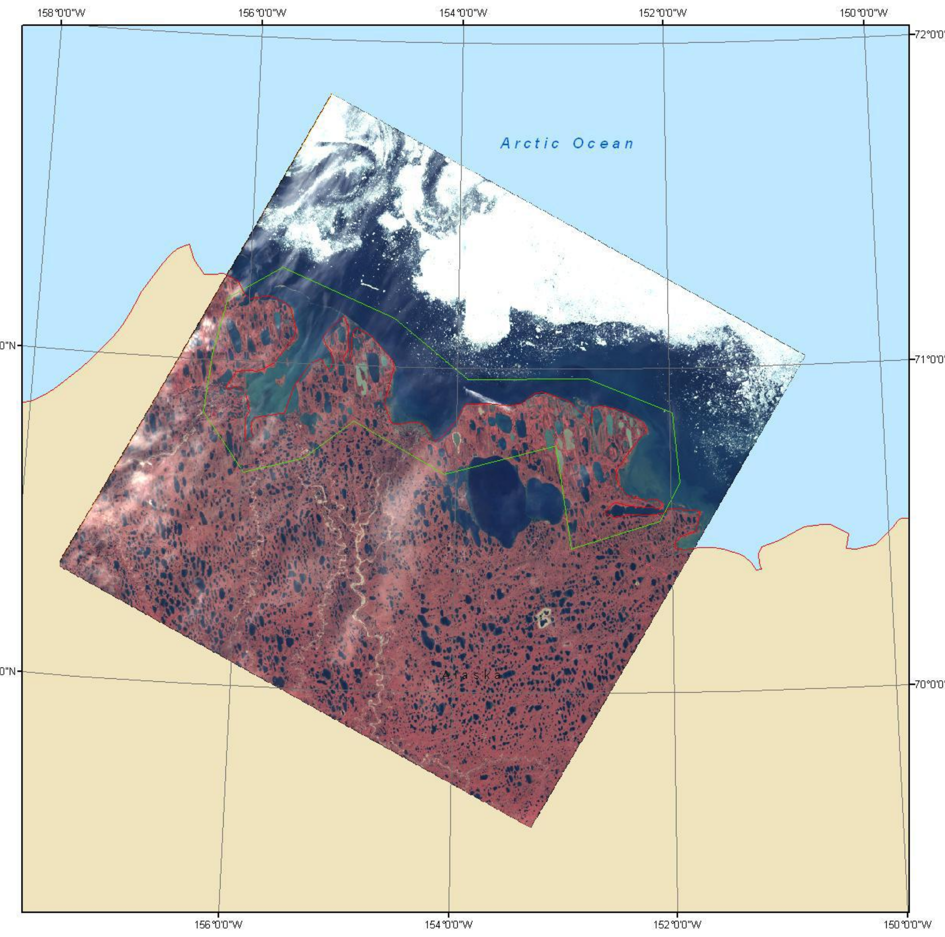

Figure 6 Drew Point study area as captured by Landsat MSS in 1974. (Green polygon denotes Drew Point Study Area)

1978

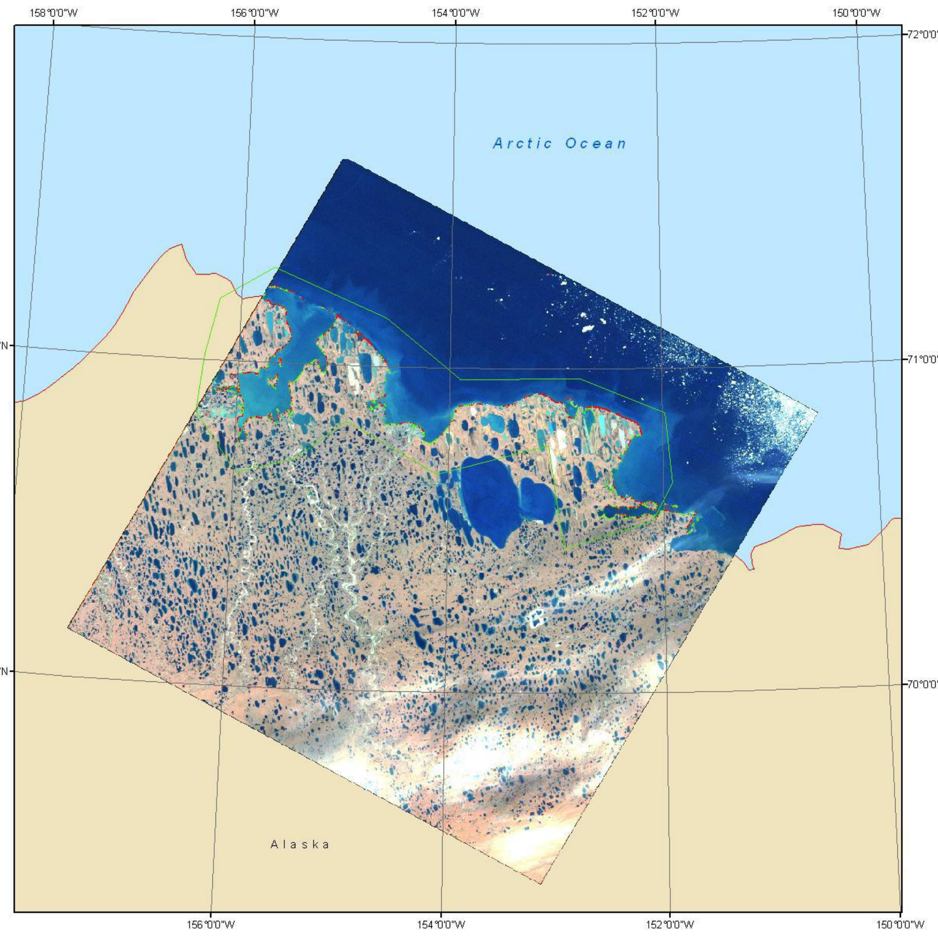

Figure 7 Drew Point study area in 1978. Eroded coastline in red, new coastline in green. (Green polygon denotes Drew Point Study Area)

1999

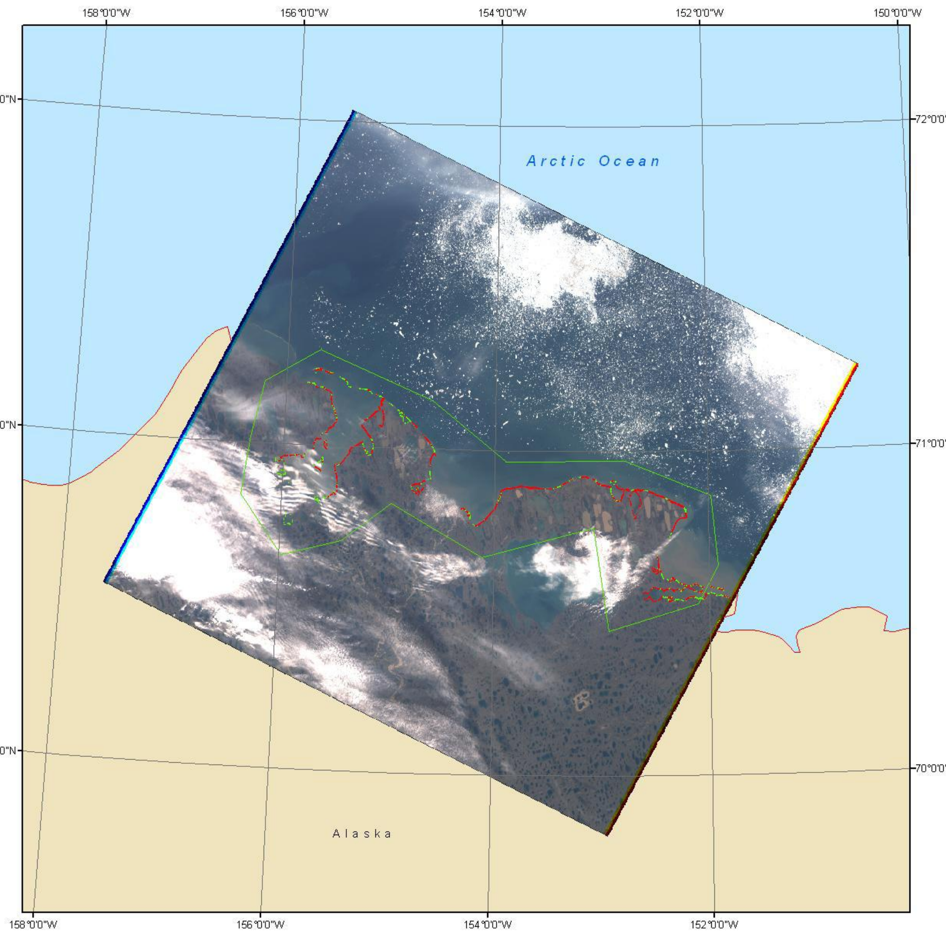

Figure 8 Drew Point study area in 1999. Eroded coastline in red, new coastline in green. (Green polygon denotes Drew Point Study Area)

2008

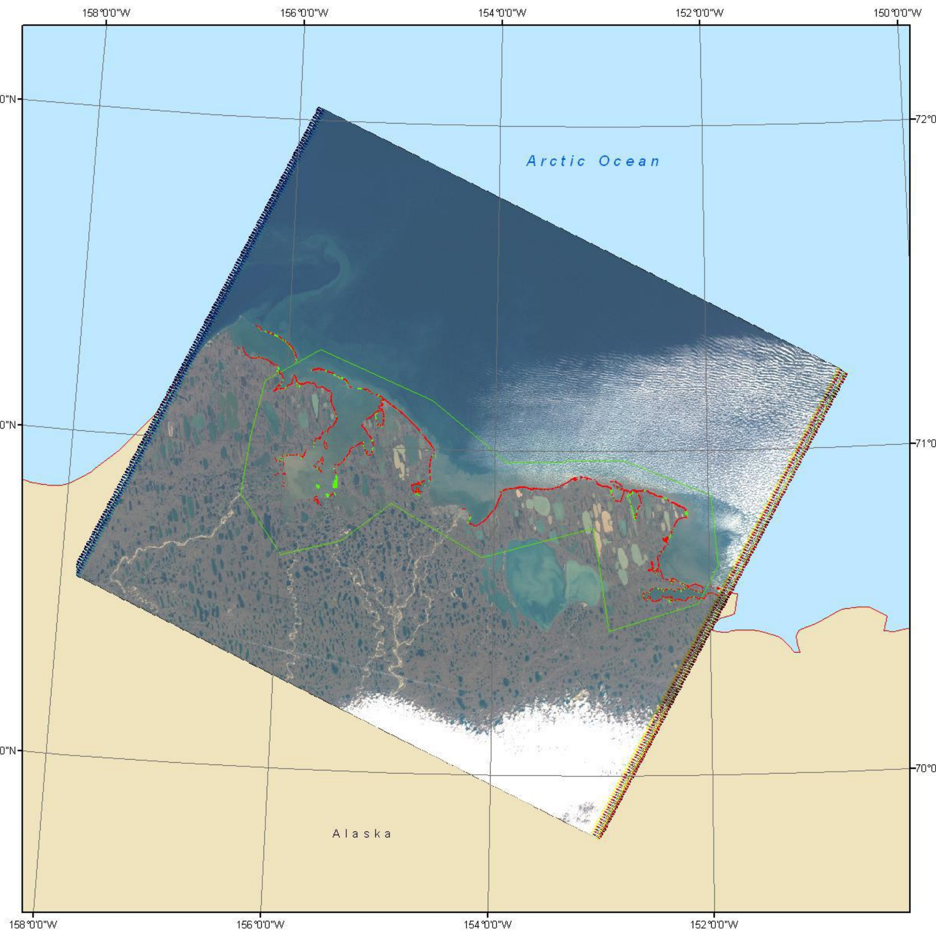

Figure 9 Drew Point study area in 2008. Eroded coastline in red, new coastline in green. (Green polygon denotes Drew Point Study Area)