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

Introduction
Coastal land 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 covered by ice-covered potholes and little-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 slope 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 40,000 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, 7) provide imagery as frequently as every 10 days since July 1972, are well-calibrated both radiometrically and geometrically, and are freely available from USGS EROS Data Center Archive (https://landsat.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; GISCAH 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 feasibility 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 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. 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, 7) provide imagery as frequently as every 10 days since July 1972, are well-calibrated both radiometrically and geometrically, and are freely available from USGS EROS Data Center Archive (https://landsat.usgs.gov/)

2. 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; GISCAH 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).

3. 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 feasibility 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.

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 dataset with geographic and time of the change analysis.

Cliffs, cloud shadows, and excessive ice cover on either land or sea can introduce errors.

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 1 Detailed view of Drew Point study area. 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 2 Drew Point study area as captured by Landsat MSS in 1974.

Figure 3 Regional sizing of the three study areas in this project. From left, Chukchi Sea coast southeast of Ny Alesund Svalbard, Drew Point, Alaska, Qaanaaq Coastline near Thule, Greenland.

Figure 4 Amguema River region, Siberia, 1974 to 1978, light blue from 1978 to 1999, green from 1974 to 2008.

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

Figure 6 Drew Point study area as captured by Landsat MSS in 1974.

Figure 7 Drew Point study area in 1978. Eroded coastline in red, new coastline in green.

Figure 8 Drew Point study area in 1999. Eroded coastline in red, new coastline in green.

Figure 9 Drew Point study area in 2008. Eroded coastline in red, new coastline in green.