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Changes in the Greenland Ice Sheet of the Southeastern Maniitsoq Coast from 1994-2004 and 2009-2019

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Abstract

Remote sensing mechanisms through the use of technology like the Landsat 5-7 Land Manager satellites are commonly used in conjunction with multispectral methods such as unsupervised classification to record and analyze changes in snow and ice over time in areas such as the Greenland Ice Sheet (GrIS). Unsupervised classification is a method of identifying, grouping, and labeling features in an image according to their spectral values and is therefore a good method of classifying snow and ice in areas such as Greenland. The goal of unsupervised classifications is to assign pixels into potentially meaningful subsurface classes based on similarities of geophysical responses, in order to create a final product that displays an accurate class map of the land cover of the area (Kvamme, 2019). Within the southwestern region of Greenland is the town Maniitsoq along the (GrIS) that is surrounded by natural canal-like channels and located in the Qeqqata municipality. The southwestern Maniitsoq Greenland territory lies within the northernmost area south of the Arctic Circle and contains big, long, and deep glaciers. Temperatures in southern Greenland do not exceed 20 °C within the summer months of June, July, or August. Greenland is warmest and driest on land closest to the ice sheet during these summer months (Topas Travel, 2019).

The location of our study area, the southwestern region of Greenland near Maniitsoq, was captured with Landsat imagery. The ice land cover was classified into three different sectional groups: changed snow/ice, unchanged snow/ice, and other. The research question of this project is as follows: how have the Greenland Ice Sheet glaciers along the eastern coast and inland Greenland changed from June through August of 1994-2004 and 2009-2019?

Keywords

remote sensing, GIS, Greenland Ice Sheet, ArcGIS, environmental science

Disciplines

Environmental Health and Protection | Environmental Sciences | Sustainability

Comments

Written for ES 363: Remote Sensing.

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12/12/19

Honor Pledge:

I affirm that I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation of the honor code.

X____Alyssa Kaewwilai____ X___Charlie Reisman____

INTRODUCTION

Remote sensing mechanisms through the use of technology like the Landsat 5-7 Land Manager satellites are commonly used in conjunction with multispectral methods such as unsupervised classification to record and analyze changes in snow and ice over time in areas such as the Greenland Ice Sheet (GrIS). Unsupervised classification is a method of identifying, grouping, and labeling features in an image according to their spectral values and is therefore a good method of classifying snow and ice in areas such as Greenland. The goal of unsupervised classifications is to assign pixels into potentially meaningful subsurface classes based on similarities of geophysical responses, in order to create a final product that displays an accurate class map of the land cover of the area (Kvamme, 2019). Within the southwestern region of Greenland is the town Maniitsoq along the (GrIS) that is surrounded by natural canal-like channels and located in the Qeqqata municipality. The southwestern Maniitsoq Greenland territory lies within the northernmost area south of the Arctic Circle and contains big, long, and deep glaciers. Temperatures in southern Greenland do not exceed 20 °C within the summer months of June, July, or August. Greenland is warmest and driest on land closest to the ice sheet during these summer months (Topas Travel, 2019).

The location of our study area, the southwestern region of Greenland near Maniitsoq, was captured with Landsat imagery. The ice land cover was classified into three different sectional groups: changed snow/ice, unchanged snow/ice, and other. The research question of this project is as follows: how have the Greenland Ice Sheet glaciers along the eastern coast and inland Greenland changed from June through August of 1994-2004 and 2009-2019?

METHODS

The study area of the southwestern region of Greenland near Maniitsoq is primarily known for its cold temperatures as well as its natural surroundings of glacial ice, snow, and fjords (Lindback and Pettersson, 2015). A Tier 1 image from USGS Earth Explorer was selected under the Landsat criteria. In Google Earth Engine, the Before and After imagery script was run for June 1st to August 30th for the years 1994-2004 and 2009-2019 in order to compare the changes in snow and ice cover between two ten-year ranges of time (Table 1). The summer months were selected because they are within the low snowfall period in Greenland so that there would be minimal issues distinguishing between genuine snow and ice. Normalized Difference Snow Index (NDSI) was calculated to indicate change in snow concentration utilizing the green/SWIR1(Band 2/Band 5) and by selecting two points of reference: very inland areas suspected to have unchanged snow/ice coverage and coastal snow/ice areas that were predicted to change due to their near coastal location to change over time. The same steps were repeated for the Annual Time Series script in order to detect changes and lack thereof of snow and ice over a large span of time. This was done in order to view the most drastic, noticeable changes of snow/ice. This script was also used to generate a graph indicating annual trends of index of change for areas inland that were primarily snow/ice in contrast to areas of land along the edge of the country.

In ArcGIS, the image classification toolbar was loaded, the 9 band index image with three classes were selected and classified using the “Iso Cluster Unsupervised Classification” tool. The layer was classified into 20 spectrally similar classes. The classes were then compared to the Landsat image and reclassified into the three classes defined in this study: changed ice/snow, unchanged ice/snow, and other (vegetation, barren land, etc.). The bands of a Landsat median image were changed to a 1 (red), 5 (green) , 6 (blue) in order to create a false color image to emphasize features that were snow and ice. The same image was also used to create a Normalized Snow Index (NDSI) change map in order to show areas of high and low change in regard to snow and ice. A Histogram Equalized contrast stretch was applied to image make features more distinguishable.

Additionally, an accuracy assessment was run to test the overall accuracy of the unsupervised classified image. This was done by creating a stratified random point sample. Each point was given a 15m buffer to make it comparable to a Landsat pixel. These 120 points were compared to the imagery present on the Landsat image based on a 25% majority of the buffer zone. The points were assigned a value corresponding to their land cover type. Using the random points file along with the "extract multiple values to points" tool and the "compute confusion matrix" tool a confusion matrix was created to show the overall accuracy of the classification.

RESULTS

The southeastern coast of Greenland has a surplus of fjords and tributaries (Figure 1) which can be indicated by the lightest snow/ice coverage along the middle and center inland regions of the country as indicated in red in the false color image (Figure 2). Darker snow and ice were found the southeastern region of the study map (Figure 2). Other land features indicated in turquoise were along the coastal regions of Greenland (Figure 2). The Landsat Median Before image for the study utilized 36 images while the after image utilized a greater amount of 248 images (Table 1). There was a high total accuracy of 95% (Table 2).

The majority of the outer region of Greenland consisted of factors that were not snow and ice while the middle regions that were snow/ice on exhibited trends of remaining unchanged. The outer regions of snow/ice surrounding the unchanged portions tended to change, especially the eastern edges within the study area (Figure 3). A Normalized Difference Snow Index (NDSI) of change in snow concentration indicated that the lowest amount of change occurred in coastal areas that were not snow/ice while the highest areas of change for snow/ice were in center, inland areas of Greenland (Figure 4). Annual trends indicated that inland areas tended to have index values that were primarily above 0.0 that fluctuated in amount excluding the only negative value of -0.38 in 1999. Coastal areas of Greenland only had negative index values that fluctuated less in magnitude in comparison to the inland index amounts. There is a gap in annual index trends between 1997 through 1999 (Figure 5). The majority of the study area consisted of “other” land cover (14,013,147.6 km^2) while the areas of stable snow/ice and retreated snow/ice had a difference of 282,421.8 km^2 (Table 3).

DISCUSSION

Greenland’s southeastern coast was selected as the study area because of the distinguishable changes of the Greenland Ice Sheet within the region (Figure 1; Cambridge et al., 2018; Fettweis et al., 2019; Lindback and Pettersson, 2015). Surface meltwater due to warming temperatures induced by climate change greatly contributed to overall ice sheet mass loss. Supraglacial fjords, streams, and rivers are oftentimes found within these coastal areas and lead to positive feedback loops in which melted glacial water causes other glaciers to melt and loose surface coverage (Fettweis et al., 2019). The ideal time of year to distinguish snow and ice from the GrIS for the purpose of this study was from June to August when there is a minimal amount of snow cover (Carmichael et al., 2020). A ten year time range from 1994-2004 and 2009-2019 was selected as a period of study in order to see the difference in snow coverage during an early and late stage of time (Table 1).

Utilizing the 1,5, and 6 band false color image, the GrIS and snow can clearly be distinguished from barren land (Figure 2). The bright red color represents the ice sheet which can be clearly separated from the turquoise color which symbolizes barren land. Much of the main ice sheet is farther inland away from the ocean and fjords. The farther location of the snow and ice protects the factors from rising ocean temperatures, salinity levels, and drastic decreases in pH due to climate change that would otherwise cause the snow and ice to melt (Figure 2; Cambridge et al., 2018). The unsupervised classification image greatly exemplifies the amount of retreating GrIS between the two ten-year time frames (Figure 3). The light blue color indicates changed areas of snow/ice which shows how much the ice sheet has retreated throughout approximately the last 20 years. Meanwhile, the dark blue color indicates unchanged snow/ice which was primarily found in farther inland areas that were not close to fjords or the oceanic coast (Figure 3).

The confusion matrix made from the classified map and the IndexBands of three different classified areas shows a 95% accuracy assessment which can be deemed reliable because it was a stratified random sample of points. Unchanged snow/ice and “other” had high user’s and producer’s accuracies of 100% respectively which contributed to the high amount of overall accuracy (Table 2). The orange regions in the classified image covers 60% of the total area in the image and is grouped as “other” which includes everything else except ice/snow. This “other” area is rather large in comparison to unstable and stable ice/snow because it includes a multitude of variables such as barren land, various types of vegetation, and the ocean (Figure 3; Table 3).

The white and light grey colors illustrate the high change of the ice sheet that was primarily inland and farther away from coastal ocean areas. This is where the snow and ice was away from factors like ocean water that would likely cause it to melt at a quicker rate (Figure 4).

The lowest amount of change occurred in areas that were classified as “other” because these barren and vegetation areas do not have snow and ice and therefore are less susceptible to change due to factors like retreating ice caps due to warming temperatures (Figure 3, Figure 4; Cambridge et al., 2018).

It is logical that inland values were all positive except for the first value because positive index values indicate that the area had copious amounts of snow and ice; these amounts fluctuated at positive values variations due to climatic patterns in accordance to the year the index was from (Figure 5). Higher peak values were likely during years with more frequent occurrences of accumulation. Lower peaks near the equilibrium line were from years of ablation which are part of glaciers’ natural balance of self-regulating their form. The year 1999 contained a negative inland index value because it was a particularly dry year for Greenland that lacked snow/ice (Figure 5; Fettweis et al., 2019). Coastal areas had negative index values because they did not contain snow and ice; positive index values mean there was snow/ice while negative values meant that there was an absence of snow/ice. The annual trend lines for inland and coastal areas were not present between 1997-1999 due to a lack of cloud-free imagery during the time period. Satellite images for inland areas were cloudy in 2013 as indicated by the 0.0 index point (Figure 5).

A similar study utilized Sentinel-2 satellite data to investigate complex patterns of ice movement and the hydrological conditions of the GrIS ice mass (Carmichael et al., 2020; Chen et al., 2019; Floriciouiu et al,. 2020; Lindback and Pettersson, 2015; Rignot and Kanagaratnam, 2006; Selmes et al., 2011; Zwally et al., 2002). It was discovered that the GrIS was drastically melting and that there was a change in the surface crystalline structure of the snow and ice as time progressed (Rignot and Kanagaratnam, 2006; Selmes et al., 2011). Another similar study utilized Landsat 8 data and imagery to track surface mass balance of the GrIS and found that the surface mass balance does not remain stable within a five year period (Grigsby et al., 2016). The two studies listed are related to our research project because all three projects analyze changes in ice and snow patterns of the Greenland Ice Sheet utilizing satellite imagery to track changes over a wide span of time.

A limitation in this study is that snow and ice may not have been completely distinguished from one another correctly. Although the low snowfall period of June-August in Greenland was selected, it is still possible that small amounts of snow may have accumulated atop of ice and was incorrectly classified as simply snow. In addition to that, regular debris may have been confused as ice debris (Barringer, 2011). This may have led to errors of both commission and omission due to inaccurate interpretation even though the total accuracy was rather high (Table 2). As a solution, a third classification class of “snow and ice” could have possibly have been created to make classification of the study area more accurate as well as have an even better resolution in order to properly distinguish ice from other debris. Another limitation to this study is that there was a lack of cloud-free imagery from 1997-1999, excluding two entire years of data from the median Landsat after image used for our study (Figure 5; Table 2). A longer time frame of 20 years could have also been used instead of 10 years to analyze the change in the GrIS in order to help compensate for the lack of cloud-free imagery.

Future potential studies include examining changes in the GrIS throughout a year-round basis as well as finding specified trends of changes in snow and ice throughout different regions of Greenland. This would allow researchers the opportunity to conduct an analysis of variance and individually examine areas of the country that may be more prone to changes in snow and ice than other areas. The results found in this study are significant to somebody who studies climatic changes over time or the effects of climate change on different types of land cover because it clearly exemplifies how effects of global warming such as rising temperatures and ocean salinity in conjunction with lowering ocean pH levels are causing lasting, severe impacts on the planet.

APPENDIX

Table 1. Landsat 5-8 imagery for southeastern Greenland region

Image	Date Range	Number of Images
Landsat Median Before	June 1st, 1994 - August 30th, 2004	36
Landsat Median After	June 1st, 2009 - August 30th, 2019	248

Table 2. Confusion matrix

Reference Source

Classified Map

	Unchanged Snow/Ice	Changed Snow/Ice	Other	Total	User's Accuracy (%)
Unchanged Snow/Ice	40	0	0	40	100
Changed Snow/Ice	5	35	0	40	88
Other	0	1	39	40	98
Total	45	36	39	120	0
Producer's Accuracy (%)	89	97	100	0	95

Table 3. Areas

	Unstable Ice/Snow	Stable Ice/Snow	Other
Area (km^2)	4,529,175.3	4,811,597.1	14,013,147.6
Percentage of Total Area (%)	19.39	20.60	60.00

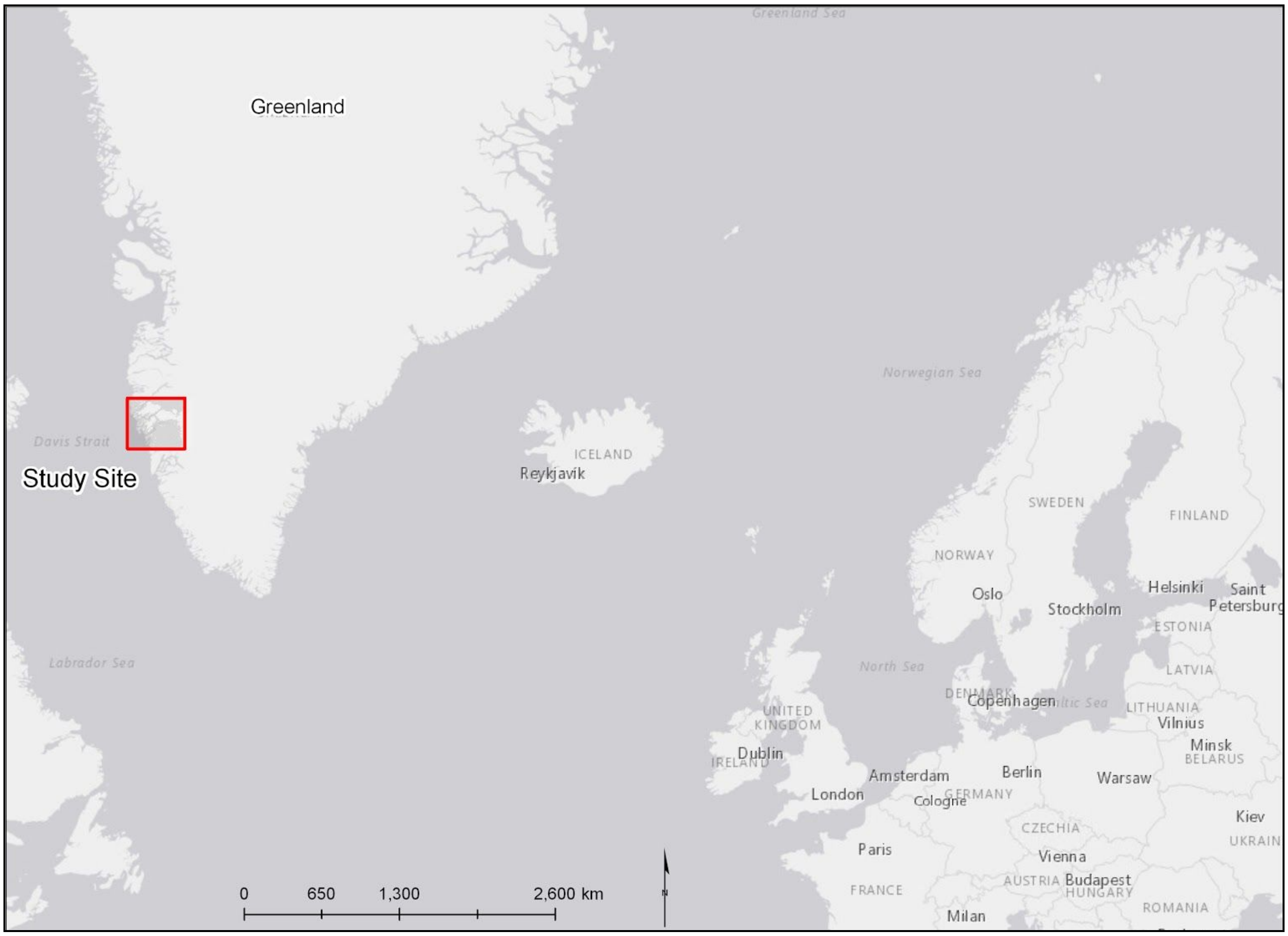

Figure 1. Locator map of surrounding Maniitsoq along southeastern coast of Greenland

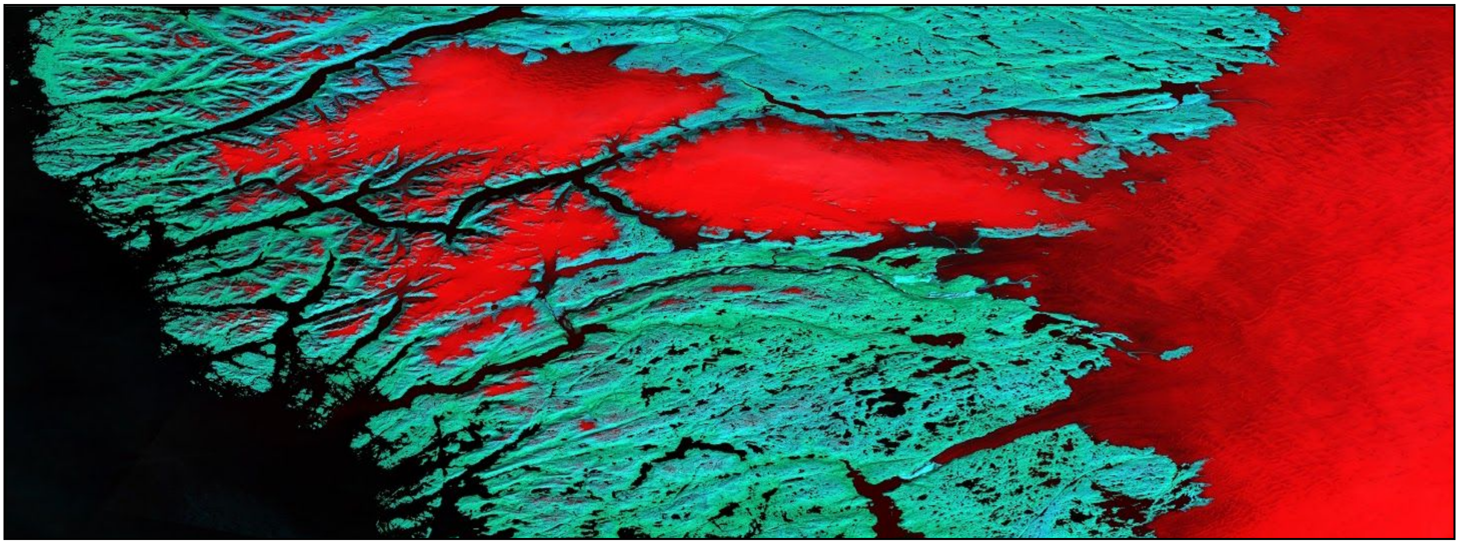

Figure 2. Red-band 1, Green band- 5, Blue- band 6 Landsat 5-7 Median After false color image of study area surrounding Maniitsoq along southeastern coast of Greenland

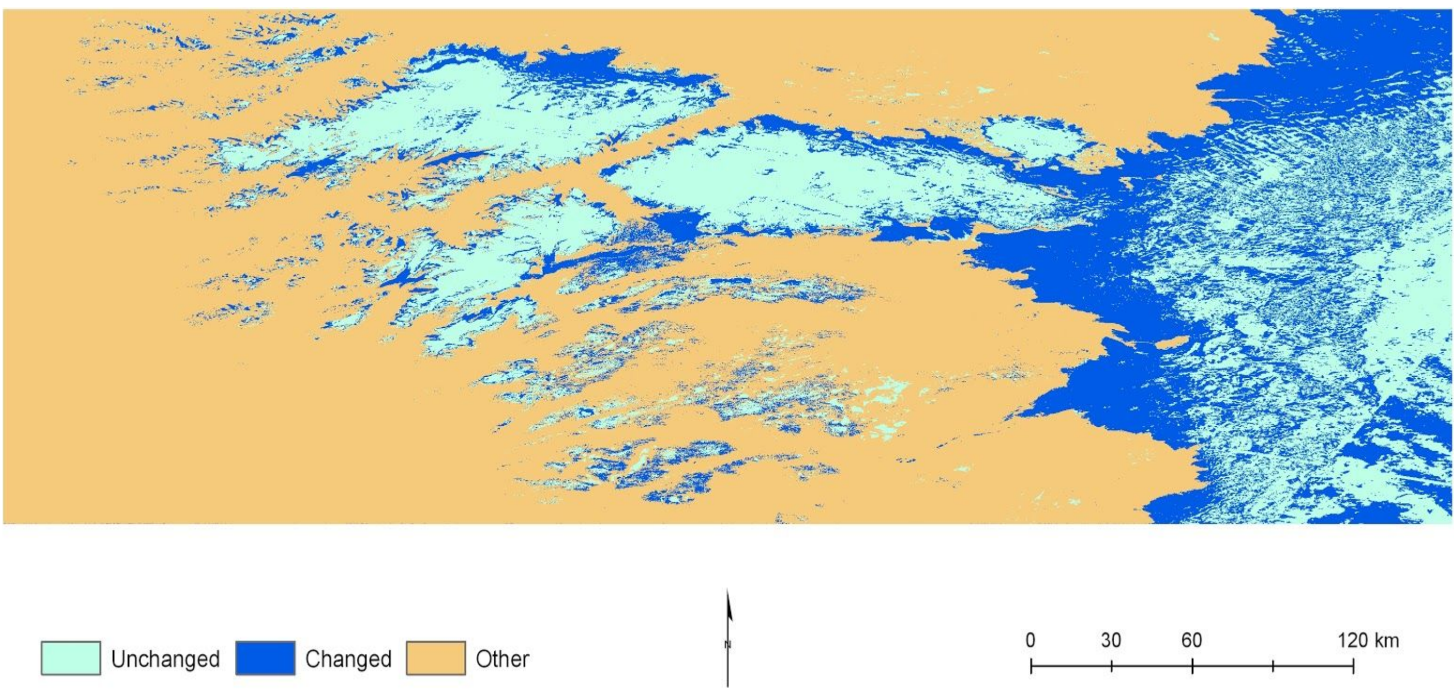

Figure 3. Unsupervised classified map of change in Greenland Ice Sheet

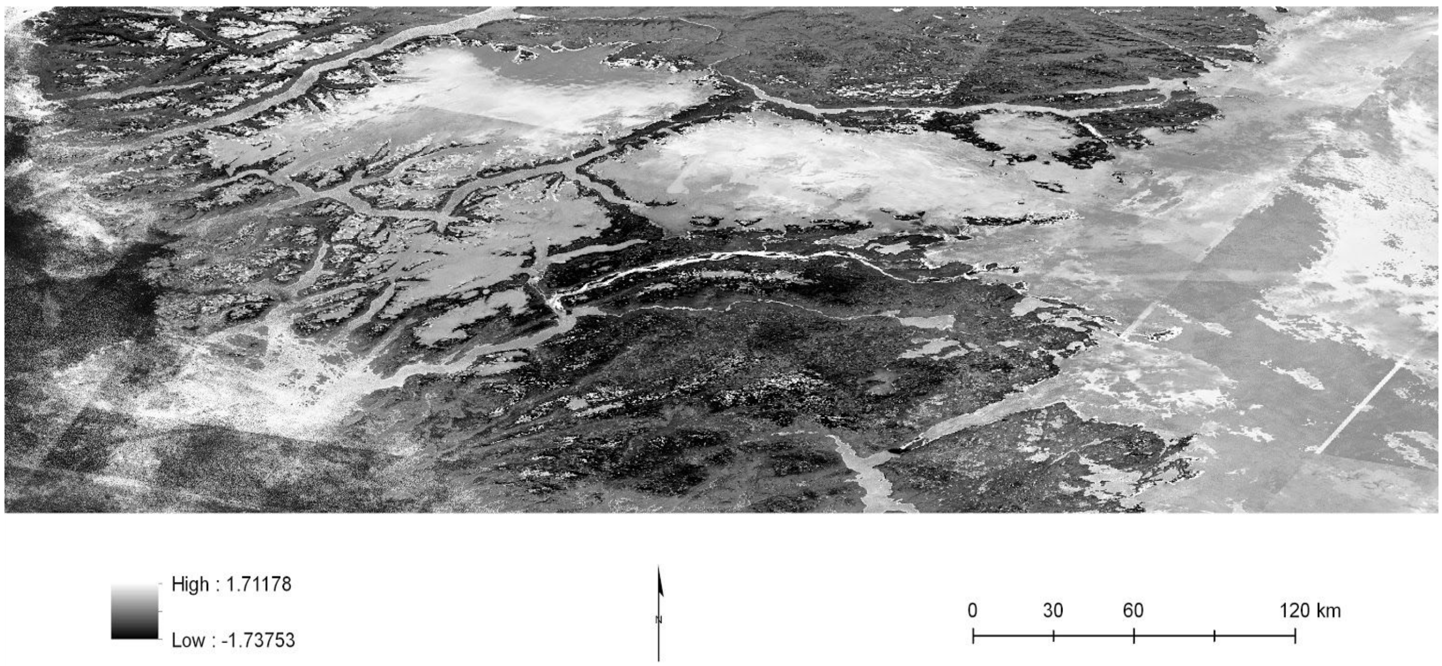

Figure 4. Normalized Difference Snow Index (NDSI) of change in snow concentration in Greenland

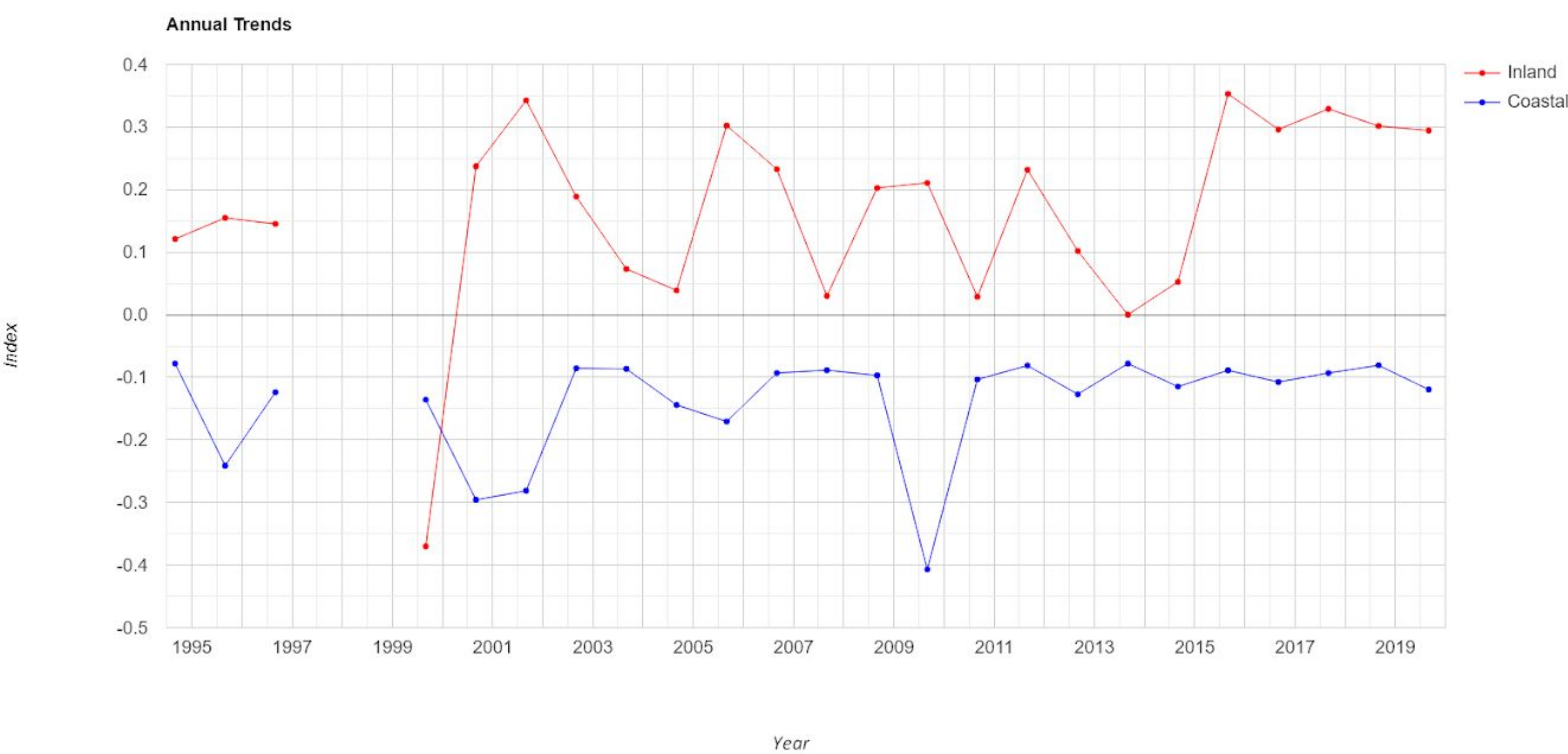

Figure 5. Annual time series graph for change in snow and ice in Greenland

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