MovingCoasts – Svalbard Miljøvernfond prosjektnummer 19/65

Final Report

Development of a method to isolate the coastline position in high resolution from multispectral satellite data

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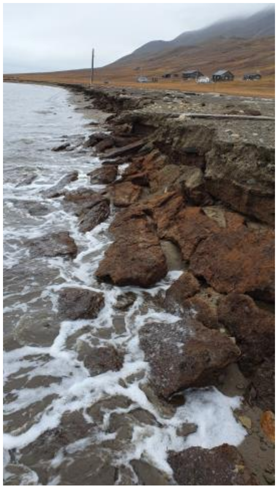

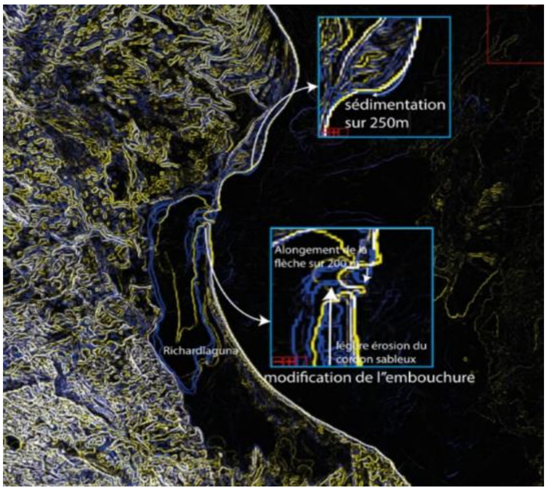

SVALBARDS
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Introduction

Coastlines are sensitive to the rapidly changing Arctic climate (Irrgang et al., 2022; Hanssen-Bauer et al., 2017) and rapid changes to the Svalbard coastline are also observed (e.g. Nicu et al. 2020, 2021, Ottem 2022). Currently quantitative measurements of coastline change in Svalbard is only done at specific localities, mostly close to specific objects of interest, while more remote locations are not being monitored. For the Isfjorden area a map of coastal zone geomorphology was developed by Jensen & Rubensdotter (2020), which allows assessment of physical processes impacting the shoreline. For other parts of Svalbard, no quantitative or qualitative assessment tools existed prior to this project, causing management of remote cultural heritage or natural environments to rely on observations during occasional visits. Shoreline change are also important indicators of changing wave climate, hydrology or erodibility (related to shorter freezing season, less ice and snow cover) and relevant for sediment production rates and transport and storage paths in case of pollution.

The aim of the MovingCoasts project was to contribute to solve this problem by making remote sensing tools available for monitoring coastline position and coastal change in Svalbard. From local observations around Longyearbyen, we know that coastline changes on cm to m scale/year and large lateral variation over short distances are common. A key feature of the Svalbard coastline is the complexity of coupled processes (e.g. hydrology, sediment supply and wave action) and high lateral variability of coastal processes. A study from the Longyearelva delta shows lateral variation from up to 7 m of erosion on the western side of the delta to 30 m of growth on the eastern side of the delta between 2009 and 2021 (Ottem, 2022). For a remote sensing-based tool to be of use for management decisions it needs to have a resolution better than the scale processes are acting on an annual scale, which is a challenge if just comparing shorelines on satellite images.

Repeated monitoring of coastline position for all of Svalbard requires a method, which can isolate the coastline from water, snow, ice, land and tides with high precision, verification through field observations and good understanding of how the coastline responds to processes common in Svalbard. The MovingCoasts project has delivered 1) a method to detect the shoreline with m-scale accuracy from multispectral satellite data. The method is developed for a test area in Forlandsundet and is currently being expanded to central Spitsbergen. 2) Coastline mapping and control positioning from the North eastern part of Prins Karls Forland. 3) Mapping and classification of coastal processes for the coastline for central Spitsbergen from orthophotos. Data will be available through the https://svalcoast.com website and eventually through scientific publications.

Procedure in the MovingCoasts project:

Spaceborne data provides unprecedented possibilities for monitoring earth surface change in real time, but also comes with challenges. For coastlines some challenges are 1) the sensitivity to the atmosphere (cloud cover) and 2) the spatial resolution, which is too coarse for the spatial scale of the processes shaping the coast. We initially planned to use the SAR technique, because it is not sensitive to the cloud cover, but learned during the processing that it was too sensitive to the water-land interface for us to be able to separate the coastline at a sufficiently high resolution. Previous studies from other regions detecting coastline changes from SAR data work at a lower resolution than what we were aiming for (e.g. Philipp et al. 2023). Instead, we employed multi-spectral remote sensing, and developed a method for isolating the coastline from multispectral data from sentinel 2. This is to our knowledge the first robust method to isolate the coastline from multispectral images and the results will be written up for submission to a peer-reviewed journal.

Ground calibration data were collected in two field campaigns. An intial survey in Adventdalen-Longyearbyen-Bjørndalen area in 2019 and in Forlandsundet – Prins Karls Forland in 2021. Fieldwork in 2020 was cancelled due to the Covid-19 pandemic, and the French partner was only able to participate in the 2019 field campaign due to travel restrictions.

In addition to site specific mapping and measurements we have expanded the regional mapping of coastal classes to cover most of Spitsbergen, to allow for testing methodology over different types of coasts. We used a modified version of classes developed during the DynaCoast project (Jensen & Rubensdotter, 2020, Environmental Protection Fund project number 16/105) to infer dominant coastal processes based on coastal geomorphology from orthophotos. It gives us an opportunity to extrapolate the changes oven the entire archipelago, as well as to classify the occurring processes, to determine how does climate change affects the environment and, reversely, which process is the best indicator of the climate change for monitoring at even larger scale.

Method development for multispectral data:

The aim of theoretical development of methods is to overcome the scale and atmosphere limitations of the multispectral data, and to solve the problem of lack of contrast between sea ice and coast in terms of electromagnetic response.

We acquired Sentinel 1 and Sentinel 2 data during 3 years over Svalbard. In parallel, we developed signal processing derived approaches for change detection that we evaluated on well known test sites. This algorithm development step is crucial as the simple two date comparison is not satisfying: it forces the selection of cloud free acquisitions (almost impossible to obtain over the whole image at high latitude), to apply edge detection filters to isolate the coastline and to average the results to remove the tide effect on the land-sea boundary migration. All these steps will result in potential bias and spatial resolution degradation.
As we obtained immediate promising results over Sentinel 2 data for coastal change detection, then we decided to put our effort on this technique. The project has worked with Sentinel 2 multispectral data from 2018 and 2021 to evaluate the possibility of detecting changes over a small timespan, for continuous monitoring purpose. The approach we developed uses two short time series which are separated by a more important period. Our approach based on short time series allows to exploit the statistical behavior of the pixels in time at various frequencies to first lead to clear land-sea separation and, second, to maximize the response of the pixel containing both media, the coastline. This short time series approach also allows to get rid on the tidal oscillation effect on the coastline position. We finally isolated the coastline with an accuracy which is better than the 10m pixel size, the approach we developed then allows to «see» inside the pixel. Based on the ground measurements, the first map we obtained confirms a at least metric resolution for change detection (Fig. 1). This method, obtained within the MovingCoasts project, is operational and can be automated for a time continuous survey. However, an improved estimation of the accuracy of the approach is needed and requires more investigations (length of the times series, with of the separation interval) and field measurements (accurate target positioning and photogrammetric 3D reconstruction at high resolution).

Two MSc student internships have been involved in the method development work at University of Caen: Romain Nougarède (2021-2022) were dedicated to the theory of the contrast of the statistical behaviors of the different surfaces. Thibault Meslin is investigating how to deepen the different surface separation to increase the accuracy of the change detection of the coastline.

This work is very promising because it forced us to optimize the observation strategy to exploit the best possible the 12 multi-spectral bands of Sentinel 2. Now, this approach can be employed with potentially higher performance using data from the recently launched Enmap satellite, which operates with 262 bands. All the signal processing derived approaches we developed can also be applied on SAR data.

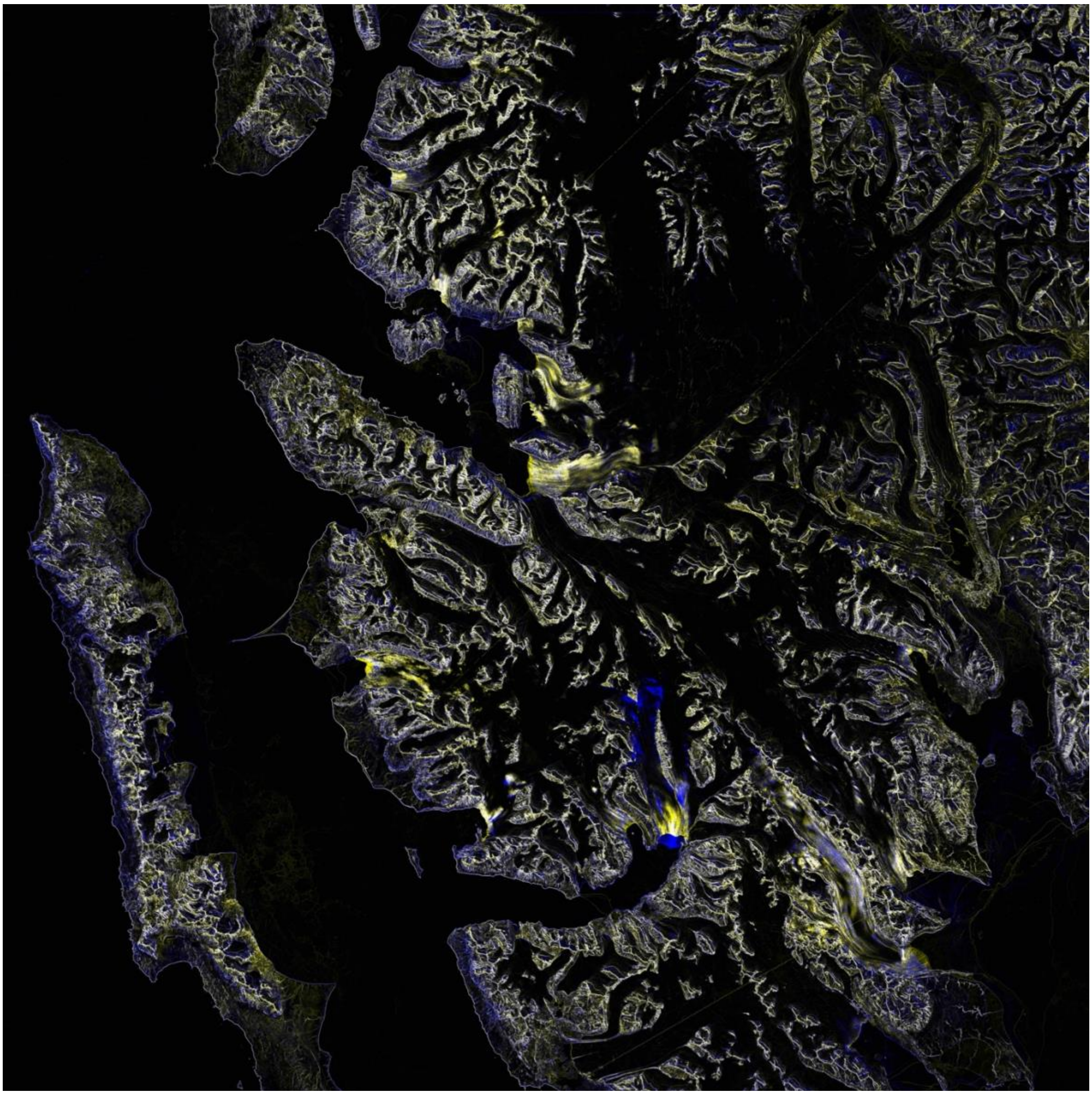

Figure 1: Change detection map 2018-2021. (white: stability, yellow : accretion, blue: erosion)

The map shown in Fig. 1 represents change detection from 2018-2021. A blue line towards the sea indicates erosion in the area and a yellow line indicates deposition. Details are seen when zooming into the map, and a couple of examples are shown with ground control comparison in figures 3, 4 and 5. The full version of the map will be available at svalcoast.com. The test area is currently being expanded to Central Spitsbergen and data will be released as they become available. Collaboration with users during the continuous development phase is possible.

Field-based description and validation for ground-truthing

Field observations were carried out on Prins Karls Forland in September 2021. Results are summarized and discussed in the MSc thesis by Hagen (2021) published by NTNU and available through https://svalcoast.com. Localities used are shown in Fig. 2. The coastal landforms were mapped and described in addition to aquiring reference ground control data. The coastline varies is primarily dominated by wave and longshore drift processes creating a shoreline morphology dominated by coarse gravelly beaches, sandy-gravelly spits and a very coarse-grained barrier ridge in front of the lagoon Richardlaguna. Recently exposed coasts where glaciers are retreating consist of moraine material. A tidal flat exists in the inner part of Selvågen.

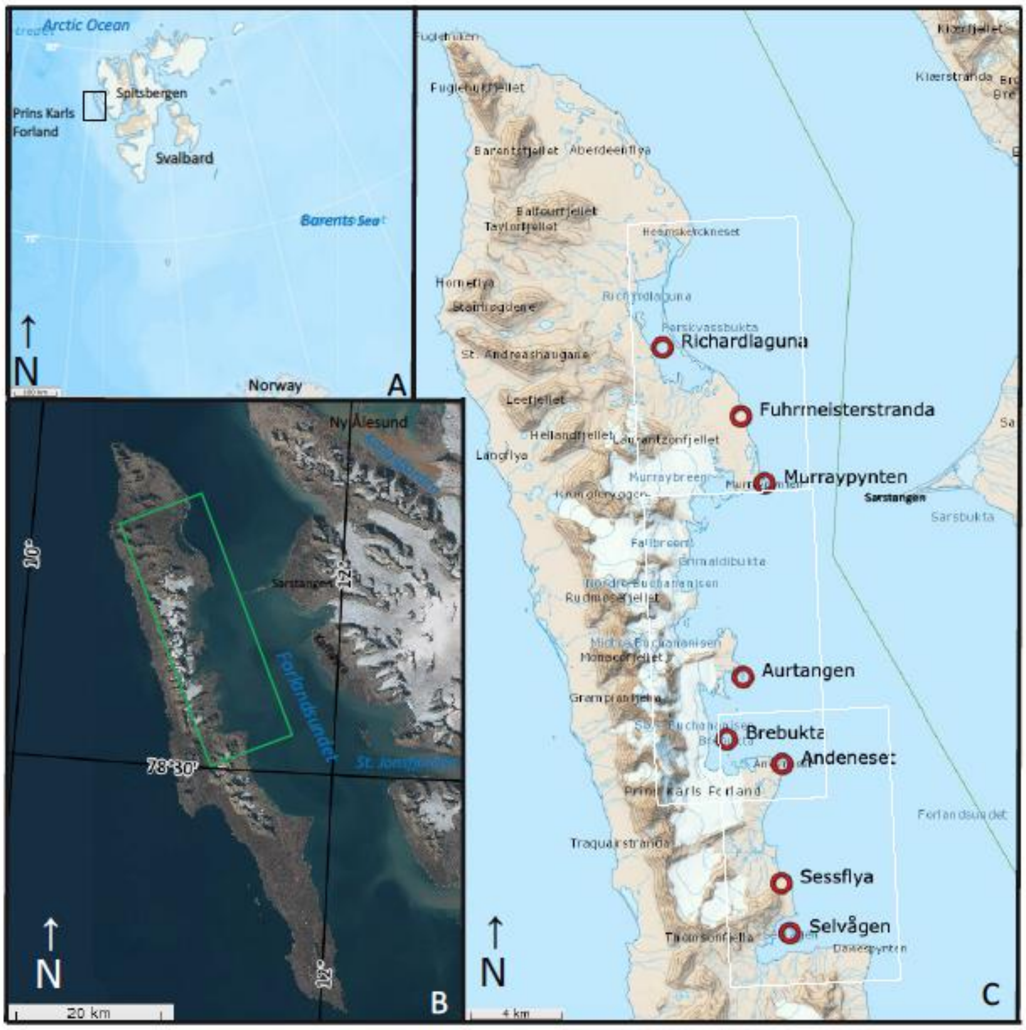

Figure 2:Localities for ground control observations and GPS control points (from Hagen, 2021)

The geomorphology of landforms, position of erosion scarps and wash-over deposits indicates changes in the shoreline over time and are important for verification of the change detected through multispectral data. The beach high-tide line was used as reference for the current beach position.

Present spit migration patterns and changes in barrier – lagoon openings are mapped and compared with positions earlier positions based on aerial images from 1936 and 2008 (Fig. 3).

Analysis of the multispectral dataset with the shoreline positions isolated shows that the resolution is within the scale of coastal change, as the change component over the two years time interval can be identified by two not overlapping colours. From the Richardlaguna area it is possible to differentiate between deposition in the northern part of the barrier to erosion further south. As the method for resolving shoreline position from multispectral data does not have a confirmed accuracy yet, we are not able to provide exact values of coastline change. It does however suggest some short-term variation superimposed on the long-term landward migrating pattern (Fig.4). More continuous field data in the test areas are necessary to clarify the validity.

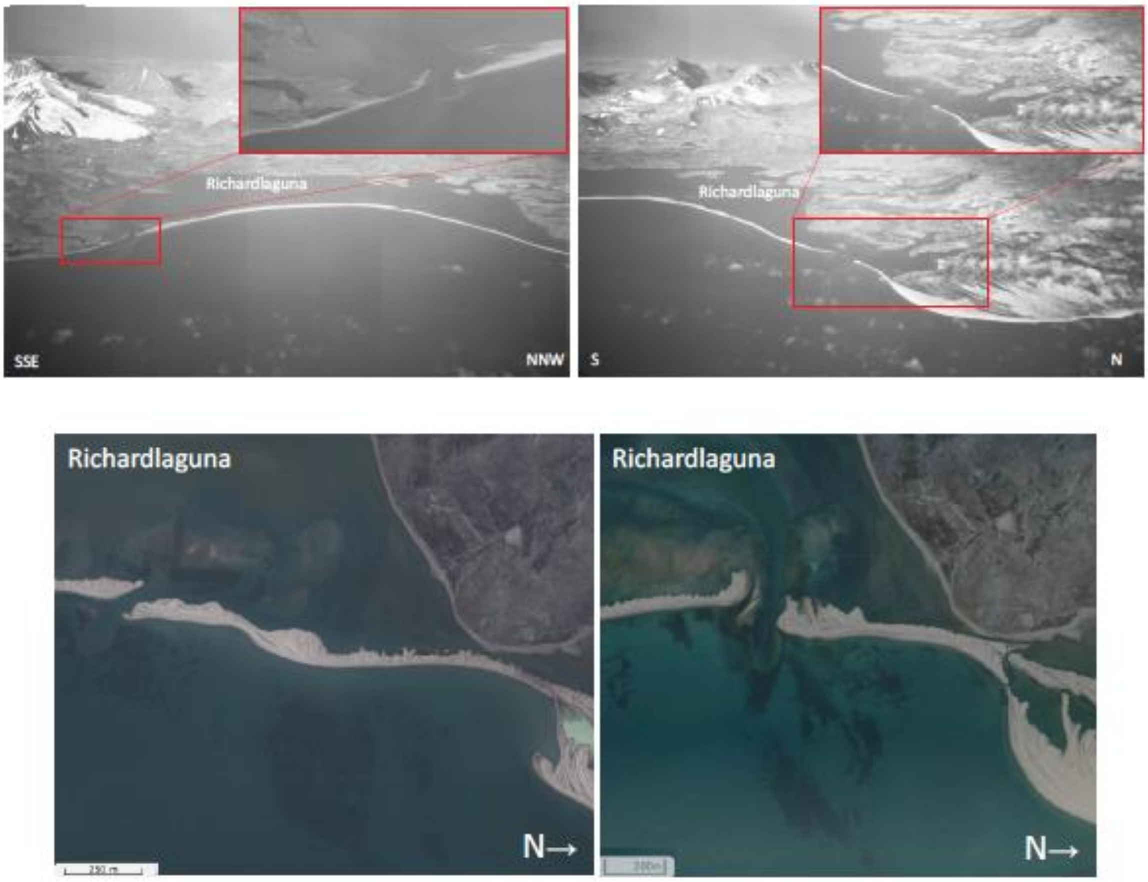

Figure 3: Barrier complex change from 1936 (top images) to 2008 (lower left) and 2021 (lower right) showing the barrier moving landward across the lagoon due to storms shifting sediments from the outer side of side of the barrier to the inner side. From Hagen (2021).

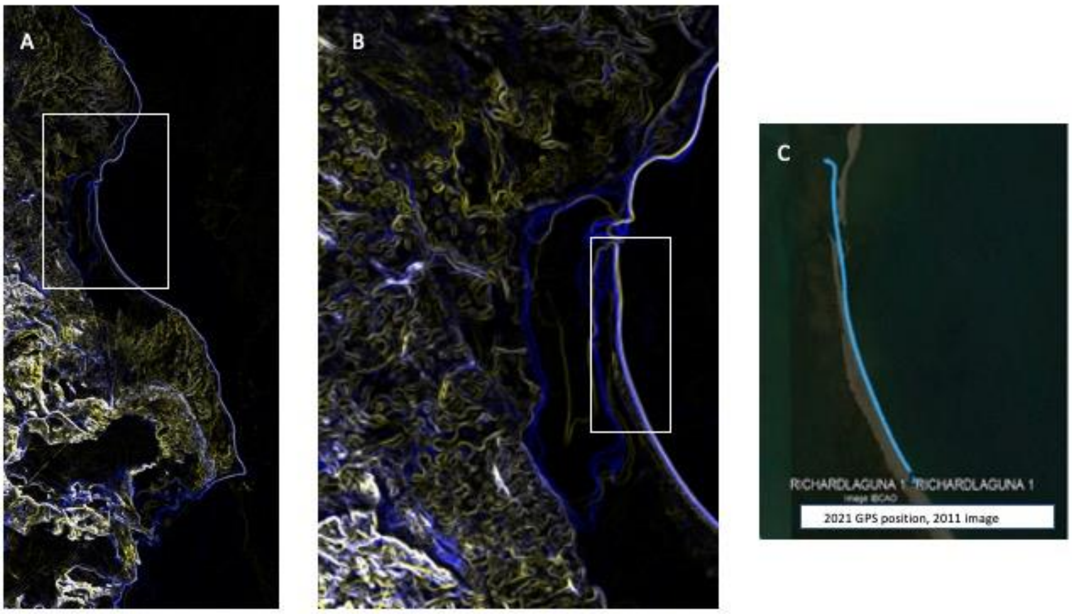

Figure 4: Coastline change 2018-2021 Richardlaguna isolated from multispectral data (a, b) and GPS position of the high tide line 2021 (c). Image C from Hagen (2021)

For northern Prins Karls Forland the multispectral dataset has been compared with long-term coastal change from 1936/1938 to 2021 (erosion = red colour in A, Fig. 5) and clear erosional signature (blue) from 2018-2021 (B, C, Fig. 5). The long term, coastal change result is described in Skinner (2021), a MSc thesis carried out in connection with the MovingCoasts project and available through https://svalcoast.com. With the lack of absolute values it is only possible to register that this may be a long-term trend, but future potential for better constrained accuracy will make it possible to study rate or relative values of erosional trends over time. Figure 5A is from MSc thesis by Skinner (2021) where a DEM made from aerial images from 1936/1938

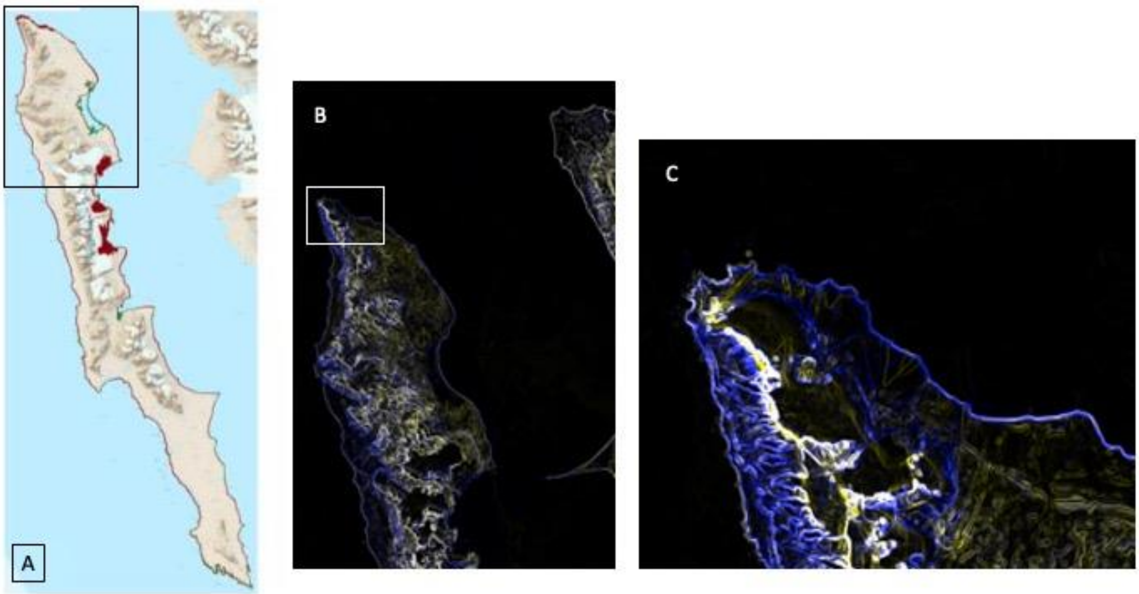

Figure 5: Coastline change 2018-2021 northern part of Prins Karls Forland isolated from multispectral data (a, b).

Regional coastal classification for regional upscaling

Regional mapping and description of the Svalbard coastline is generally lacking, meaning that baseline data for comparing analysis results are missing. Existing coastal classifications are either too low resolution for a coastal change purpose or developed from a marine ecology point of view that does not take the physical processes into account (e.g. Søreide et al. 2020). As part of the MovingCoasts project we have started classifying the Svalbard coastline according to classes defined by dominant physical processes as reflected in the geomorphology on site. An example of the classes and how they are expressed on a map is shown in Fig. 6, and an example of how an example of how processes such as fluvial – wave class combination is seen from the geomorphology is seen in Fig. 7. The classification map shows areas that are likely to respond (by erosion, deposition or lateral migration) if physical conditions change. For example "fluvial-wave" segments (green on Fig 6) will tend to become more fluvially dominated and develop deltas (i.e. deposition) if precipitation or meltwater increase and become more wave-dominated and retreat onto land (i.e. erosion) if wave amplitude or frequency increase, for example through decreasing sea ice cover during times of the year with frequent storms. The coastal class map will be used to understand the reasons for the coastline change patterns observed by remote sensing.

Figure 6: Principles for process based classification of the Svalbard coast. Mapping is done from orthophotos on scale 1:30:000.

Figure 7: Geomorphology of Sørdalsbukta, N Spitsbergen showing the present day geomorphology (left) of a fluvial delta advancing over and around a wave-generated spit indicating dominance of the fluvial process (hydrology and sediment availability control). On the right image from 1936 the same area was dominated by wave and longshore drift processes. In terms of coastline change, the shoreline has advanced significantly since 1936

Conclusion:

The most important result of the MovingCoasts project is the technique to isolate the coastline from land, sea, ice and tide from multispectral data. The potential to upscale the test area to first central Spitsbergen and then more remote areas is promising for developing a tool to monitor areas of the coast that is not frequently visited or for providing quantitative data on for example sediment budgets or pollution transport paths. The coastal classification map allows for comparison between coastline change data and coastal processes along the same coastline. Combined the two form a powerful tool to understand causes for observed coastline change in Svalbard.

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