Mapping iceberg calving from Antarctic ice shelves

Consideration of data types

Since the scope of the study is at the regional to continental scale, satellite remote sensing would be the primary data source for the mapping. If available, time-lapse cameras, lidar surveys or seismic measurements would be a useful complement to satellite imagery, particularly during the initial fracturing stage leading to the formation of new icebergs (e.g. Banwell et al., 2017; Köhler et al., 2019). One of the challenges of using satellite images to monitor iceberg calving is that fractures may be covered at the surface and/or smaller that the pixel size in imagery (Banwell et al., 2017). These factors, in addition to the typically several days orbital repeat period means that calving may not be discovered until well after it has occurred. The use of complementary datasets at a local scale may be used to calibrate the analysis of iceberg calving using satellite images and perhaps most importantly, to quantitatively assess how well it performs from the perspective of temporal and spatial resolution.

Both optical and radar (SAR) imagery could be suitable to the iceberg mapping. Optical satellites, e.g., Sentinel-2, give higher spatial resolution but are limited by the presence of clouds so that the availability of sufficiently cloud-free scenes may significantly limit temporal resolution. Short daylight hours at high latitudes during the austral winter also hampers the detection of icebergs using visible wavelengths, though thermal infrared may still be useful (e.g. Shuman et al., 2018). Since radar signals penetrate cloud covers and Sentinel-1 SAR data products with pixel size of 10-40m are widely available, I would use this as the backbone of the iceberg mapping. Optical satellite imagery could be used for comparison and to assess the performance of the SAR based mapping, where available.

Algorithm design

I interpret that the main goal of this mapping task is to track the movement of icebergs that have calved from ice shelves around Antarctica, with a particular focus on the large tabular icebergs with length scales of several hundreds of meters to kilometres (for which the spatial resolution of Sentinel-1 should be sufficient). The icebergs then need to be resolved from a background of open sea or sea-ice. For this to work well there must be a sufficient contrast in radar backscatter between iceberg and open sea (there should be good contrast in this case) and between iceberg and sea ice (contrast more challenging in this case). Whether the surface temperature is above or below freezing is also significant, since liquid water or wet snow on the iceberg surface significantly reduces the amount of radar backscattering. As a result, for frozen surface conditions icebergs appear as bright targets relative to a darker background of sea-ice or open water, while they may appear as dark targets for wet surface conditions (Wesche and Dierking, 2012). The first part of the detection algorithm is then to maximise the edge contrast between the iceberg and open water/sea ice (both with the addition of speckle noise), using appropriately selected spatial filtering and/or multi looking.

A simple approach would then be to threshold and segment the pre-processed SAR images (perhaps using additional morphological filtering). An alternative approach would be to train a convolution neural network to classify icebergs from pre-processed satellite images, which would rely on manually classifying a training dataset of icebergs, open sea and sea-ice. Monitoring the coastal drift of the icebergs would then require an object tracking scheme to track icebergs across repeat satellite passes, such as using a 2D cross correlation.

An alternative (complementary) approach to monitoring the calved icebergs would be to monitor the calving front of the ice shelves. Monitoring the detailed changes in the coastline at the calving front of ice shelves can help to constrain the mass loss from the Antarctic ice sheet, in addition to the dynamics of the ice-shelf advance and calving process (e.g. Qi et al., 2020).

Processing techniques/facilities – Google Earth Engine

I think that Google Earth Engine could be usefully applied to this project, particularly given the desire to scale up to the continent scale. Petabytes of Landsat and Sentinel imagery are hosted on the Google servers and Google Earth Engine also provides the server capacity to run the data analysis in the cloud. One can simply send a JavaScript or Python script from their local machine in order to run continental scale analyses on the remote servers. The Google Earth Engine contains built in functions for satellite data calibration, pre-processing, image segmentation and classification that could be usefully employed to efficiently develop a functional algorithm.

Initial data exploration and processing

Figure 1 illustrates the scene coverage for a demonstrative 15-day period for the Sentinel-1 ascending orbital geometry and extra wide swath acquisition mode. While there are some areas of the Antarctic coast with data gaps, it appears feasible to map a large portion of the coastline using Sentinel-1 imagery. Figure 2 illustrates the expected backscatter contrast for icebergs against a background of sea ice for frozen surface conditions (bright target due to relatively strong volume scattering of dry ice/snow). Scene edge artefacts and inconsistent backscatter, particularly for open water, are also evident and would require more effective pre-processing to remove (they may also be due to the spatially variable number of scenes used to calculate the average backscatter).

Figure 3 shows an initial iceberg, sea ice, open water classification result using Google Earth Engine with Sentinel-1 data and a gradient boosting decision tree algorithm trained with 20 sample points per class. The classification result is qualitatively poor and tends to misclassify, e.g., sea ice with high backscatter as iceberg and sea ice with low backscatter as open water. The results could likely be improved by better pre-processing, e.g., to address incidence angle and sea state that likely affect radar backscatter consistency between scenes for open water. A convolutional neural network approach could also be worth investigating, as it may be trained to recognise higher level textural and shape features across pixel neighbourhoods. Such higher level features are likely to better distinguish between sea ice and icebergs than the contrast in backscatter alone can.

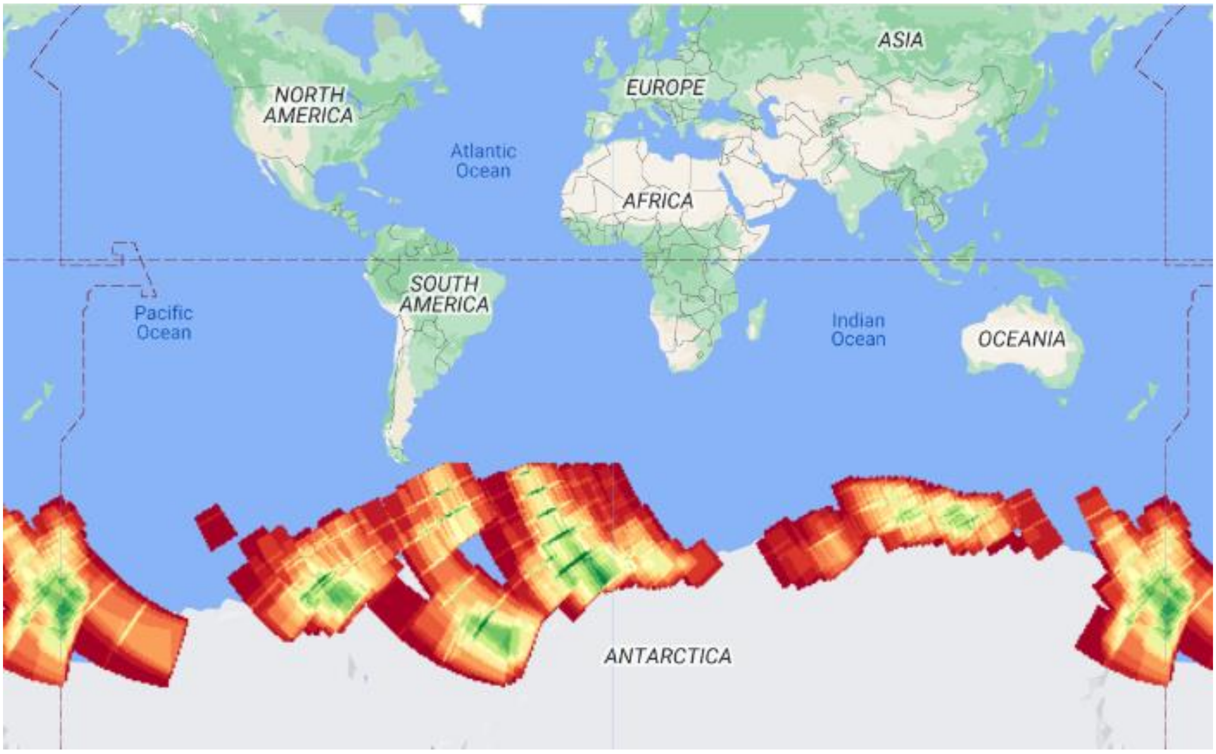

Figure 1 – Sentinel-1 ascending orbit, extra-wide swath coverage (red=1 scene, green=19 scenes) for 15-day period 01-Jun-2020 to 16-Jun-2020 for latitudes south of -55°.

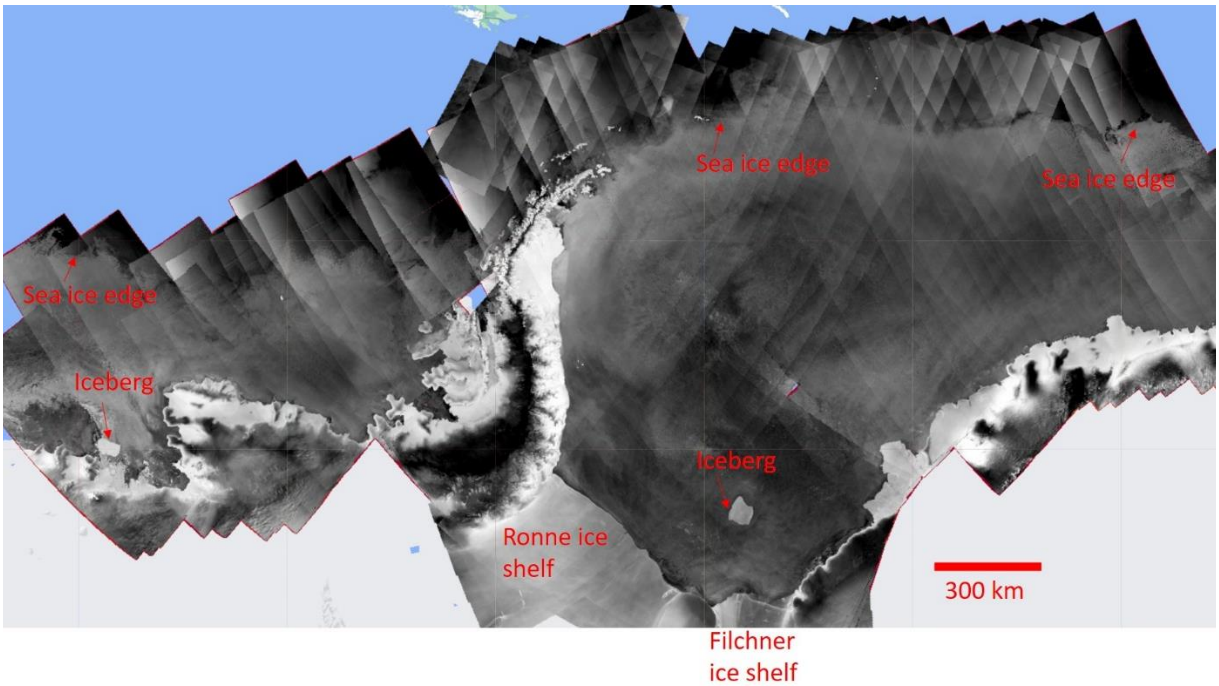

Figure 2 – Sentinel-1 average backscatter intensity (black low to white high) for HH polarisation scenes for 15-day period 01-Jun-2020 to 16-Jun-2020 (austral winter) illustrating contrast between ice shelf, iceberg, sea ice and open water.

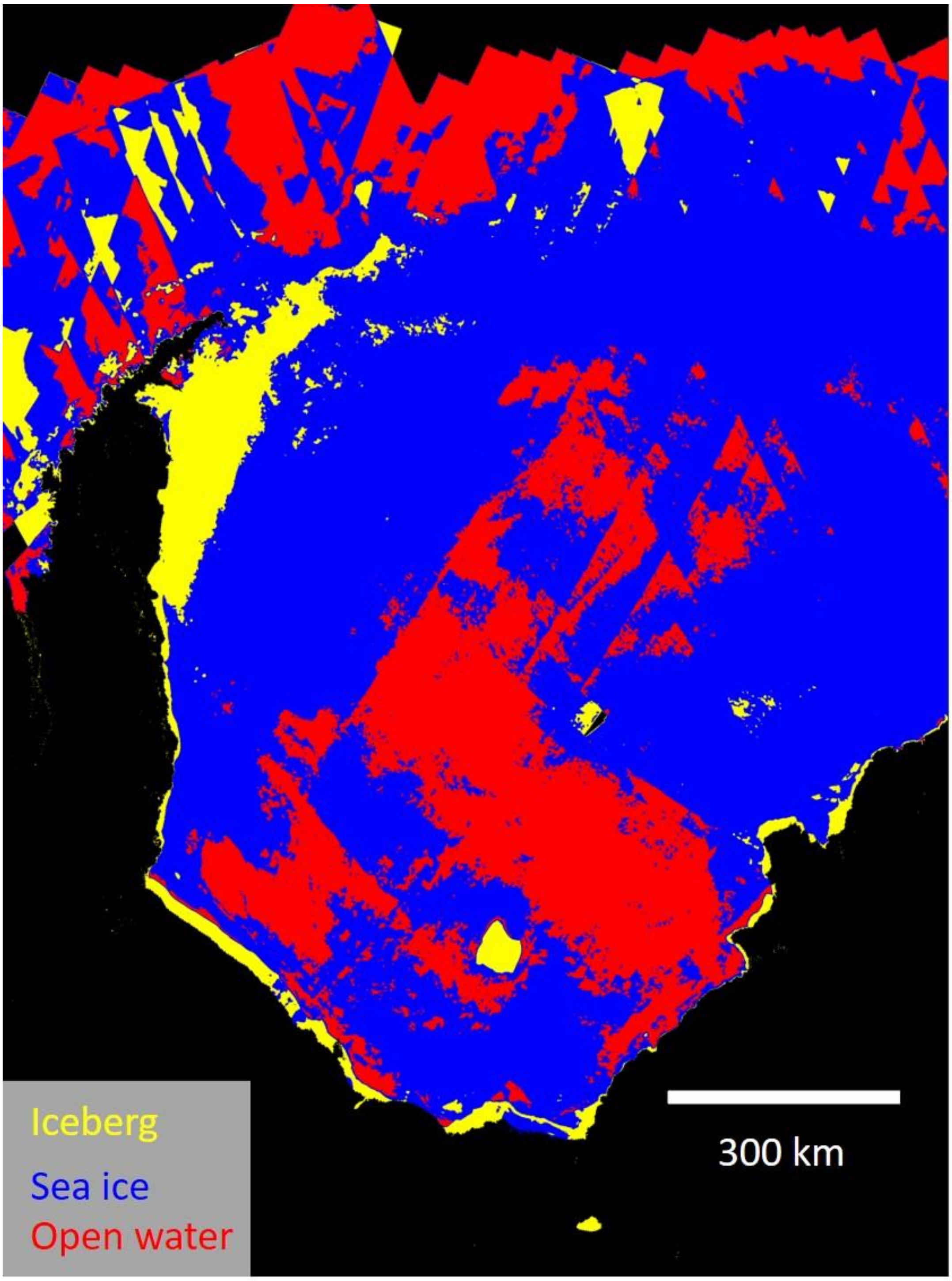

Figure 3 – Example of iceberg, sea ice, open water classification based on average radar backscatter (Sentinel 1 HH polarisation, ascending orbits 01-16 June 2020) using a gradient boosting decision tree algorithm trained on 20 sample points per class. The classification result is quite poor due to the variable radar backscatter of the different classes, particularly sea ice and open water (as illustrated in Figure 2).

References

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