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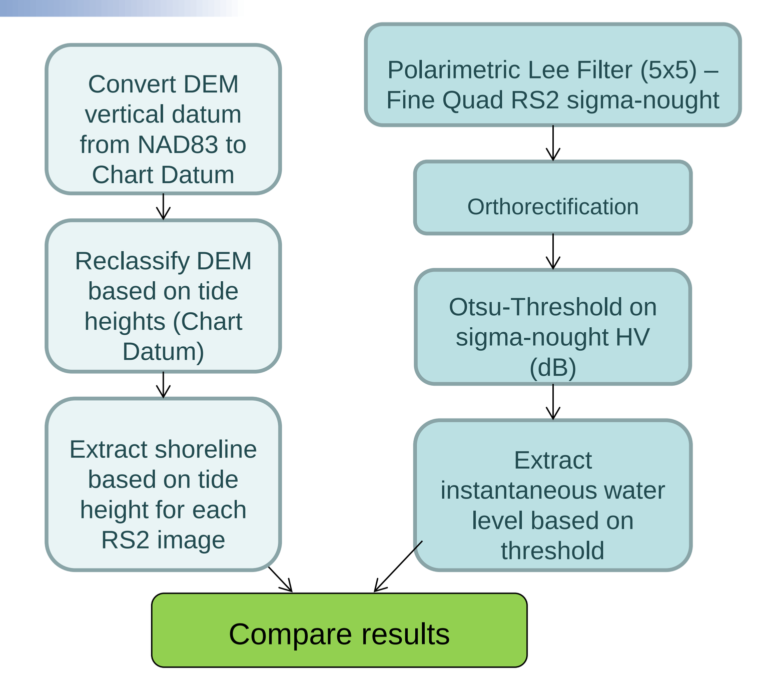
Analyzing coastlines extracted from RADARSAT-2 imagery: the effect of topographic and sea-surface conditions

BACKGROUND

Synthetic Aperture Radar (SAR) images capture the "instantaneous water level" at the time of acquisition and therefore the location of the extracted coastline will vary based on tide heights [1]. In SAR images, as calm water results in specular reflectance away from the sensor, a bi-modal distribution of the returned signal strength between water and land can occur. Manual selection of the threshold that separates the two modes of the distribution is easy but the optimum threshold will vary between images depending on incident angle and conditions at the time of image acquisition, and therefore this not practical for operational purposes. The Otsu thresholding method [2] is designed to automatically select the optimum threshold to differentiate two classes in an image, and has been widely applied to land/water separation, including in coastline extraction. However, the method relies on a bi-modal distribution, which is not always present in SAR images, or may not necessarily separate the two classes with high accuracy. Here, we investigate its applicability in macro-tidal environments.

METHODOLOGY

A flow chart of the methods used in this analysis is presented to the right. RADARSAT-2 (RS2) Fine Quad (FQ) images (sigma-nought HV) were filtered using a Polarimetric Lee Filter, and then orthorectified. The Otsu thresholding method was used to extract a binary water/land map from each image. The boundary of each of the classes was used to define the "coastline" location as a vector. Similarly, to analyze the quality of the results, digital elevation models were used to extract the location of the tide at the time of each image acquisition.



CASE STUDIES

Frobisher Bay, NU (Tidal range = 12 m)

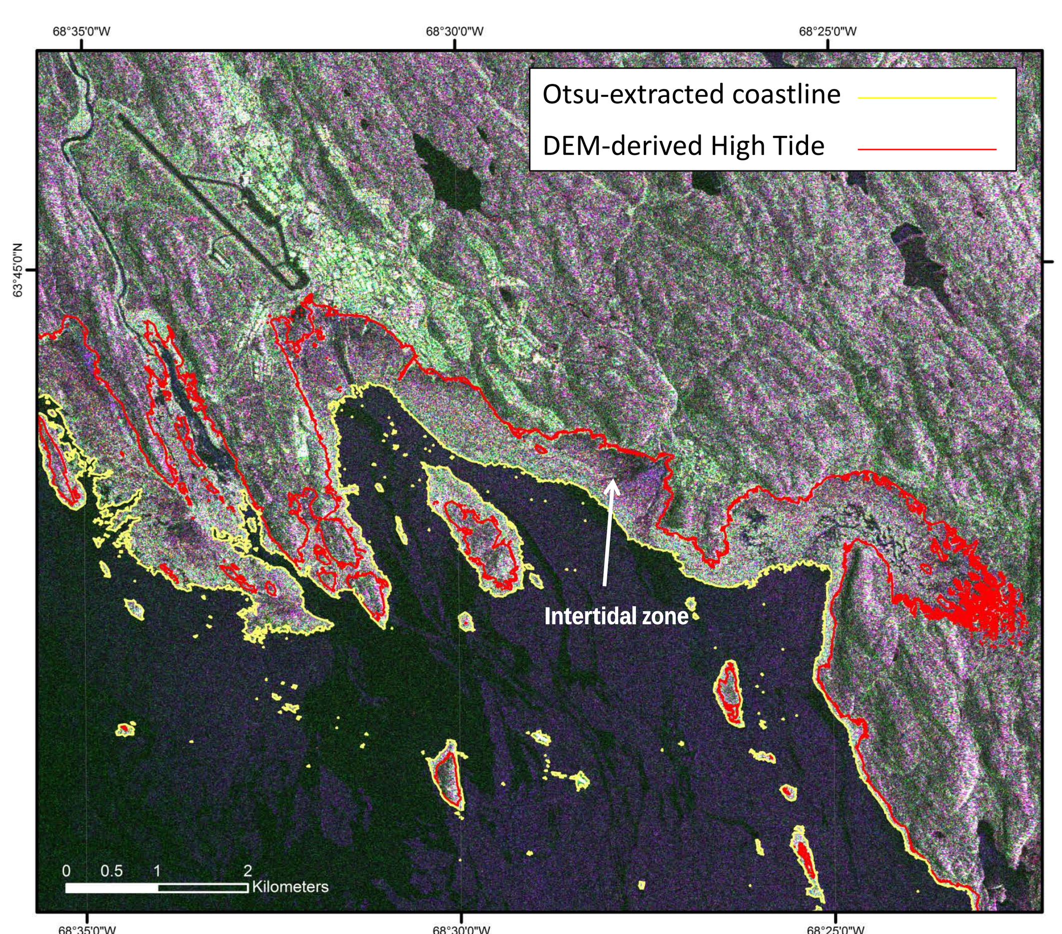


Image Acquired: FQ15 2013-10-12 7:04 am EST (RGB: HH, HV, VV)
Low tide: 6:50 am EST
Wind speed: 9 km/hr

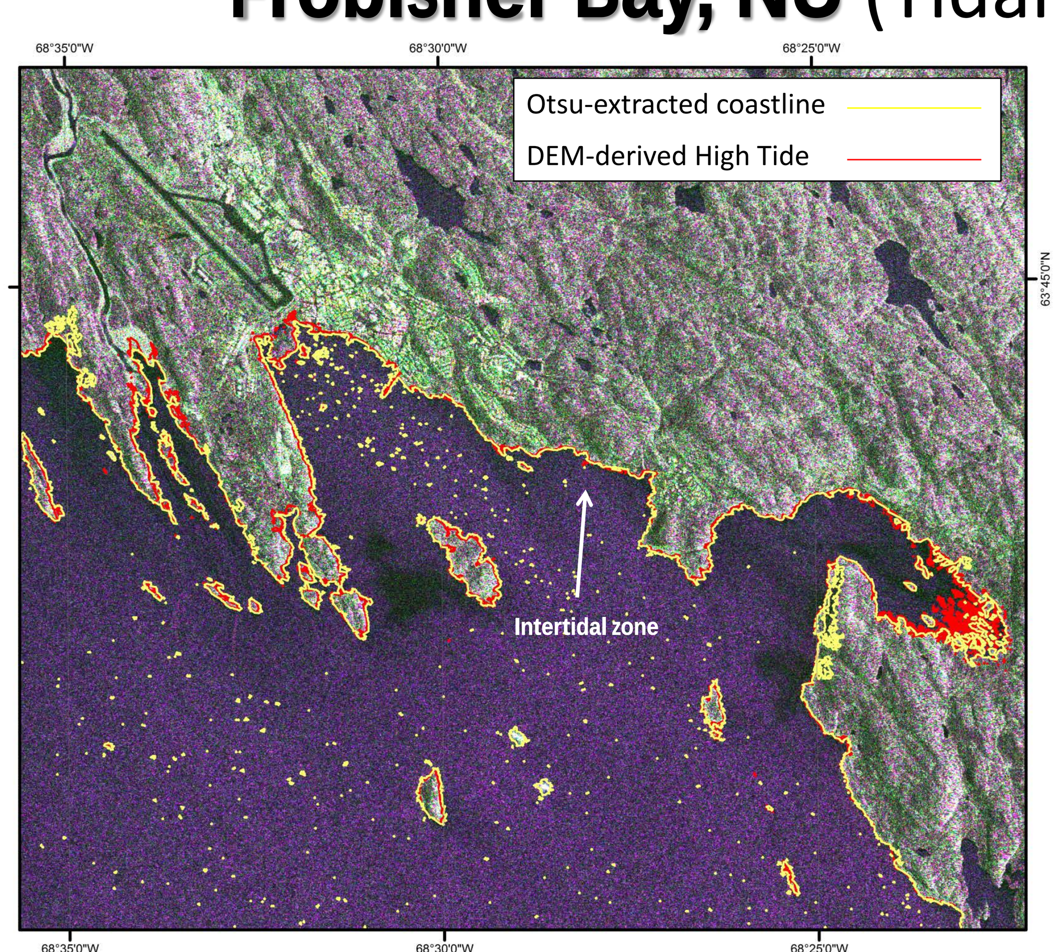
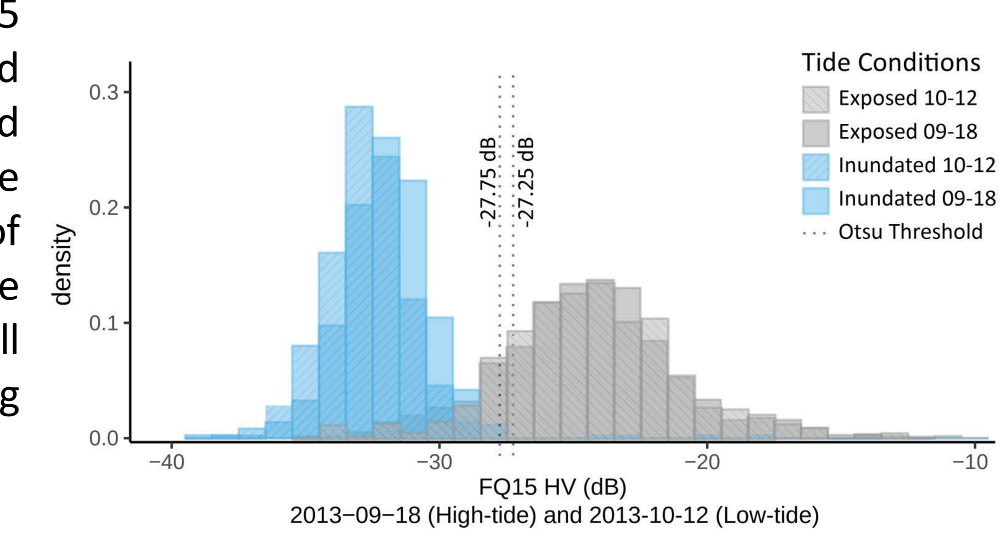


Image Acquired: FQ15 2013-09-18 7:04 EST (RGB: HH, HV, VV)
High tide occurred: 6:59 am EST
Wind speed: 24 km/hr

The two images show drastically different instantaneous water lines due to the high tides and low sloping topography in many area of the bay. The DEM available (ArcticDEM) was not suitable to extract the low tide line but the extent of the intertidal zone is clear in the low tide SAR image. Despite the different tide and sea surface conditions, the Otsu algorithm selected similar thresholds in these two FQ15 images. However, from the validated histograms, it is clear that the thresholding did not result in a perfect classification, and the threshold was not chosen at the minimum of the bi-modal distribution in either case. Note that windy conditions result in many small groups of pixels in the ocean being misclassified as land.

With thresholding methods, a post-hoc clean-up procedure must be completed. Since these errors are very small in relation to the total number of pixels, the misclassification rate is low. However, clean up procedures of these small groups of pixels often result in the erroneous removal of small islands.



Minas Basin, NS (Tidal range = 14 m)

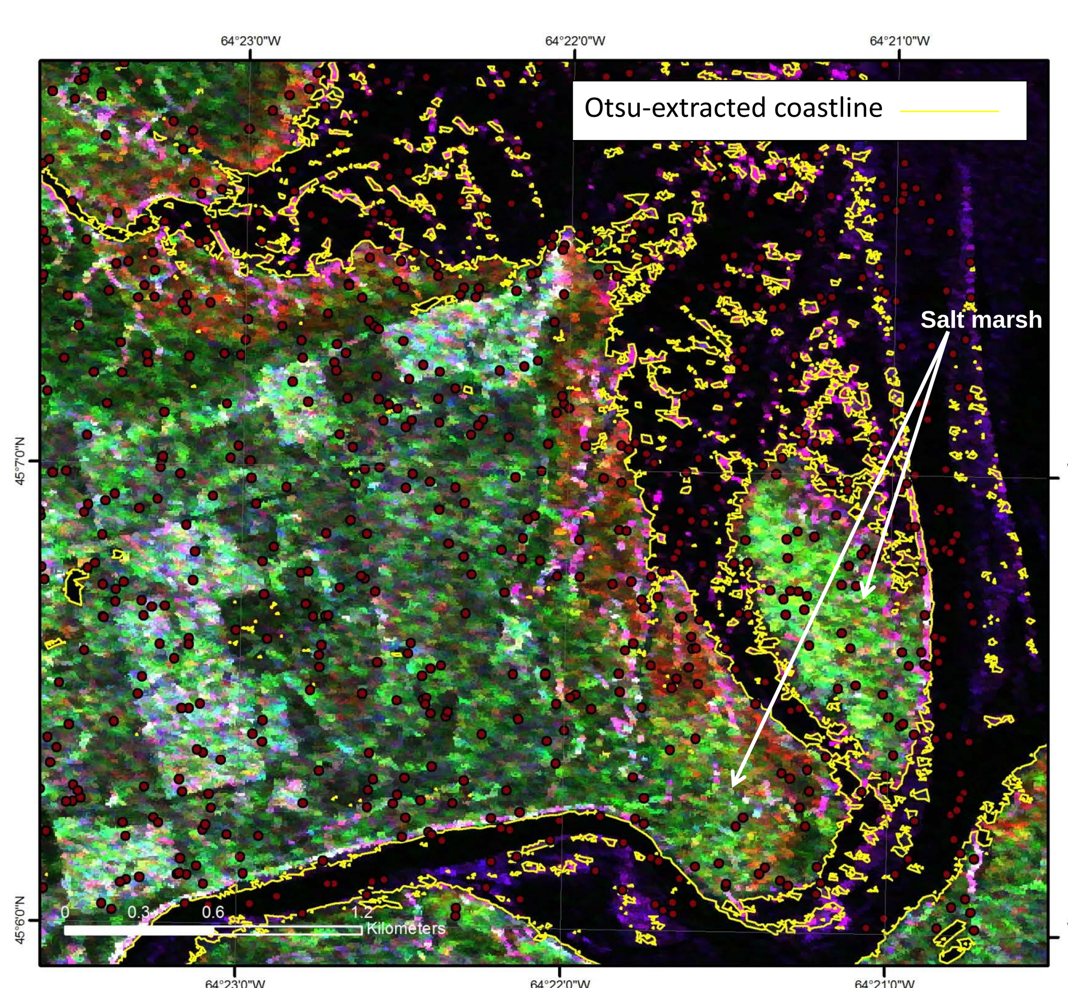
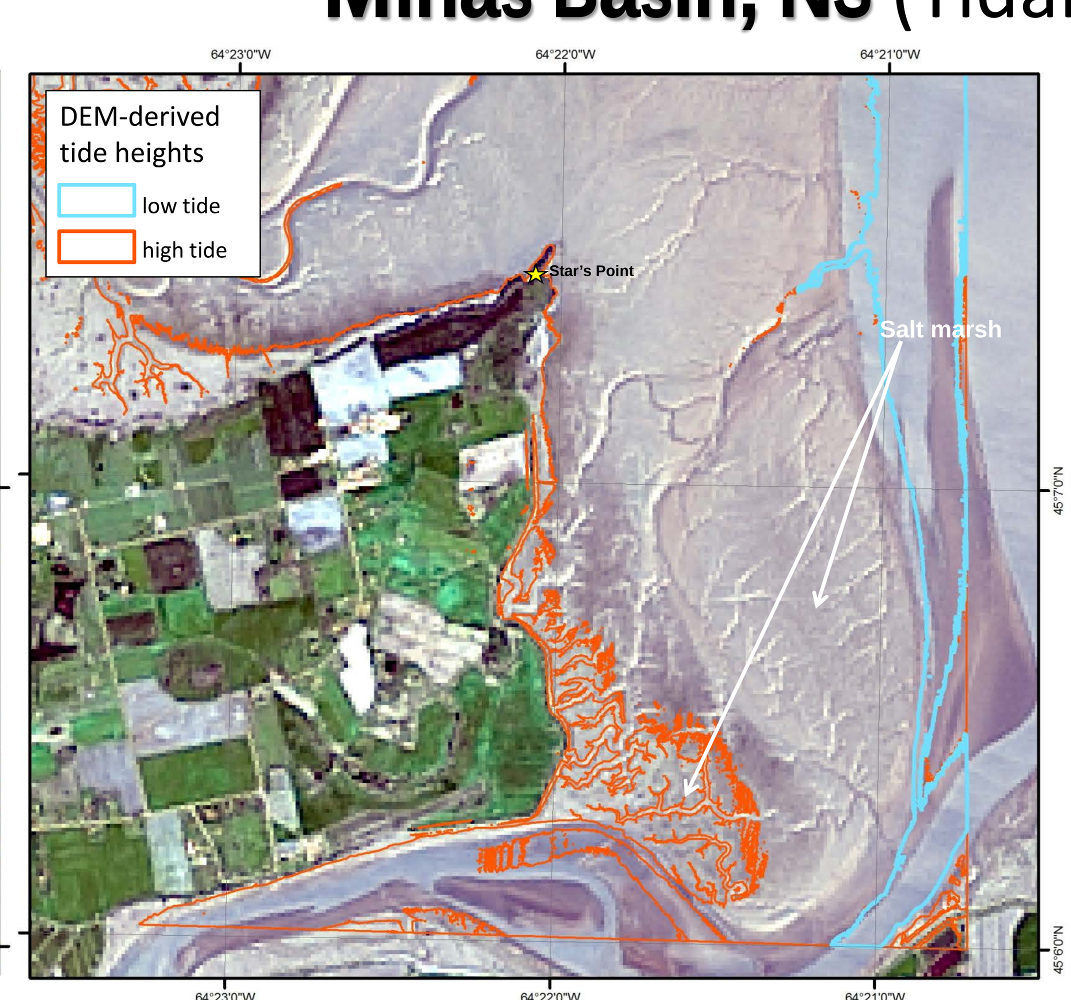
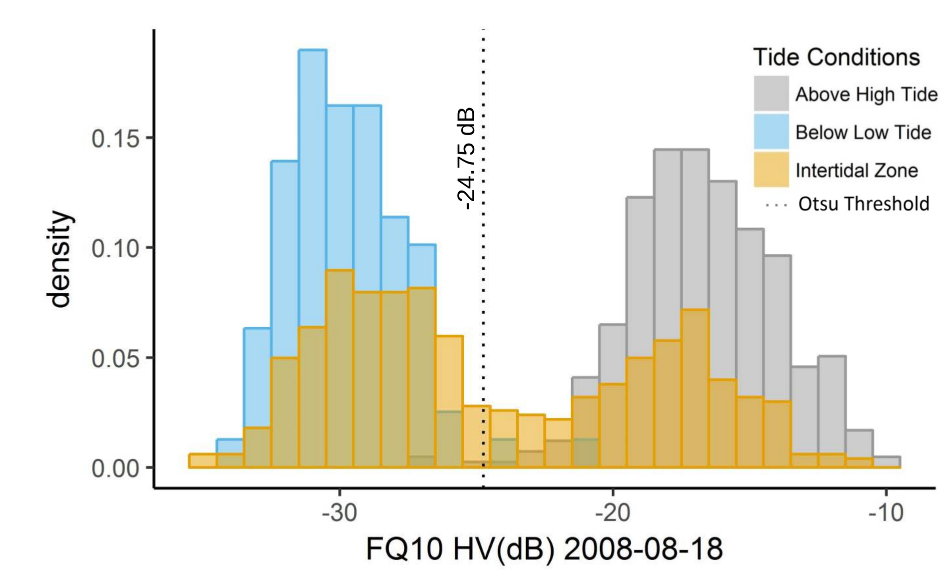


Image Acquired: FQ10 2008-08-18 10:31 ADT (RGB: HH, HV, VV)
Low tide occurred: 8:26 am ADT (1.28 m)
Wind speed: 5 km/hr



Shown for comparison: Landsat-8 with similar tidal conditions
Acquired 2017-05-17 12:00 pm ADT
Low Tide Occurred 12:17 pm ADT (1.78 m)

The mudflats of the Minas Basin cause specular reflectance [3] of the SAR signal and therefore their returned signal strength is very low. In the SAR image, mudflats appear the same as water and are misclassified as such. Strong returns (bright) occur in channels where banks are steep and roughness can be caused by accumulation of material. Although the data exhibit a bi-modal distribution, the Otsu threshold fails to classify the intertidal zone correctly and the extracted shoreline is several kilometers from its true location. Due to the extreme error in this case, in addition to the LiDAR estimates of tide heights, Landsat was also used to validate the low tide extent. Salt marsh will also cause issues for the Otsu method in high-tide cases where vegetation may be emergent above shallow water (not shown). These cases represents extreme examples but demonstrate that a more sophisticated algorithm is required.



CONCLUSIONS & FUTURE WORK

The Otsu method, while widely used for automatic coastline extraction from SAR images, results in an accurate representation of coastline position only in locations where the land and water represent a near-perfect bimodal distribution: where land pixels fall around the higher mode and water pixels represent the lower mode of the distribution, with little overlap between the two distributions.

In the examples demonstrated here, the Otsu method resulted in small errors in high wind conditions due to a rough sea surface, requiring a post-hoc clean-up procedure. It failed where the substrate was mud, due to specular reflectance. Future work will focus on improving the unbiased automatic classification of land, water and the intertidal zone, taking into account the specific to the characteristics of SAR data.

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REFERENCES

[1] Boak, E., Turner, I., (2005). J. of Coastal Research. 21(4).

[2] Otsu, N., (1979). IEEE Trans. Systems Man and Cybernetics. SMC-9(1).

[3] Mason, D., and Davenport, I., (1996). IEEE Trans. Geosc. and Remote Sensing. 34(5).

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AUTHOR: **Koreen Millard**
Defence Research and Development Canada – Ottawa Research Centre

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