Subglacial bed topography using machine learning and geostatistical analysis applied to 2D and 3D radar sounding

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Bed topography is an essential boundary condition in the ice sheet numerical models used to predict future ice mass balance relevant to sea level rise and to determine the flux gate in current ice mass balance estimates. Fine resolution measurements from 3D radar sounding are especially relevant to understanding the stability of grounding lines and calving fronts. In order to extract the ice bottom in hard-to-detect regions of the imagery and to handle complex mountainous terrain, we have developed several machine learning algorithms to track the ice bottom. We found that a Hidden Markov Model (HMM) solved via the Viterbi algorithm is very efficient but least accurate. A Markov Random Field (MRF) model solved via Tree Re-Weighted message passing (TRW-S) is most accurate but is also approximately 100 times slower. Since radar data is easily segmented for processing, this computation time is not an issue on a computer cluster. A Deep Neural Network (NN) model offers slightly lower accuracy but, unlike Viterbi and TRW-S, does not require external evidence such as surface elevation and ice mask. Manual picks can be used as ground truth and when operating on small portions of the imagery, even TRW-S is fast enough to run interactively. The best performing TRW-S algorithm achieves a mean tracking error of 5.1 pixels. Using these methods, we present a complete 3D mapping of the Canadian Arctic Archipelagos (CAA) and the first Operation Ice Bridge (OIB) campaign (2018 Arctic) mapped in 3D mode. We also present a geostatistical analysis of these results. The CAA dataset is already publicly released on our website and will soon be released on the National Snow and Ice Data Center OIB data portal. This dataset covers 4500 line-km, much of which is in mountainous terrain. The horizontal posting is 25 m and the vertical RMSE is 38±7 m based on 20 cross overs.