# Layer Detection in Radar Sounder Images

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## Motivation

Glaciologists have conducted thousands of kilometers of radar surveys over ice sheets in Greenland and Antarctica to better monitor and predict these ice sheets' response to climate change. Analyzing these radargrams is a time-intensive process. In particular, glaciologists need to extract the surface and bed (bottom) of the ice to understand the ice thickness as well as the condition of the bedrock-ice interface, which significantly impacts the ice sheet's movement. To facilitate this research, we present improved techniques for identifying surface and bed layers in radargram images.

## Related Work

- [1] Edge detection accentuates englacial layers
  - Weakness: no provision for layers of having returns of varying widths and powers
- [2] Wavelet transform accentuates layers of varying widths, and Hough transform can help trace layers
  - Weakness: assumes smoothly varying layers, which is invalid for tracing the bed layer
- [3] Orientation-specific edge detection and layer tracing techniques using rotated Gaussian filters
  - Weakness: computationally intensive and assumes parallel layers
- None of [1], [2], or [3] address identifying the bed among other subsurface layers

## Data Set

- University of Texas Institute for Geophysics conducted airborne radar survey of Thwaites Glacier in '04/'05 [4].
- We processed 5 focused radargrams, each having a range spacing of 3m & azimuthal spacing of 17.5m [4].
- Data included human-assisted identification of bed and surface layers, which we used to score our methods
  - Results compared to human-assisted identification using a 20px and 50px threshold
  - 77,561 reference piks for surface layer
  - 63,130 reference piks for bed layer

[1] G. Freeman., et al. "Automated Detection of Near Surface Martian Ice Layers In Orbital Radar Data." *2010 IEEE Southwest Symposium on Image Analysis & Interpretation*. doi: 10.1109/SSIAI.2010.5483905
[2] S. Xiong, et al. "A New Method for Automatically Tracing Englacial Layers from MCoRDS Data in NW Greenland." *Remote Sensing*. 2018, 10(1), 43; doi:10.3390/rs10010043
[3] Panton, C. "Automated mapping of local layer slope and tracing of internal layers in radio echograms." *Annals of Glaciology*. 2014, 55(67); doi: 10.3189/2014AoG67A048
[4] J. Holt, et al. "New boundary conditions for the West Antarctic Ice Sheet: Subglacial topography of the Thwaites and Smith glacier catchments." *Geophysical Research Letters*. 2006, 33; doi:10.1029/2005GL025561

## Methods

**Pre-Processing**
- Rotated Gaussian filter
- Range-direction wavelet transform
- Sharpening filter
- Morphological top-hat filtering

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**Seed Point Selection**
- Peak detection in range direction
- 5-point median filter
- Morphological opening

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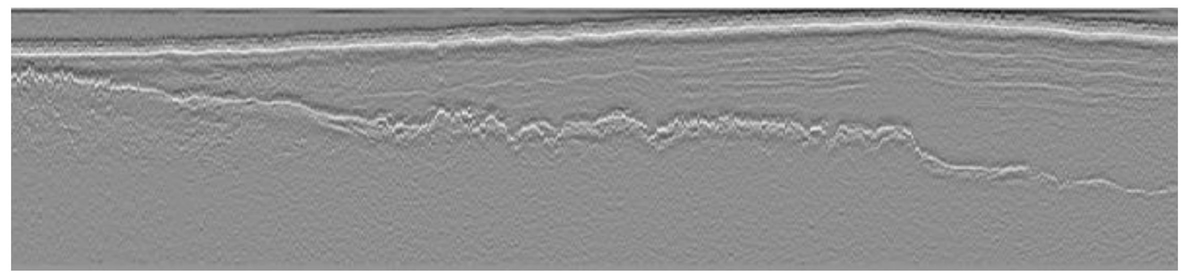
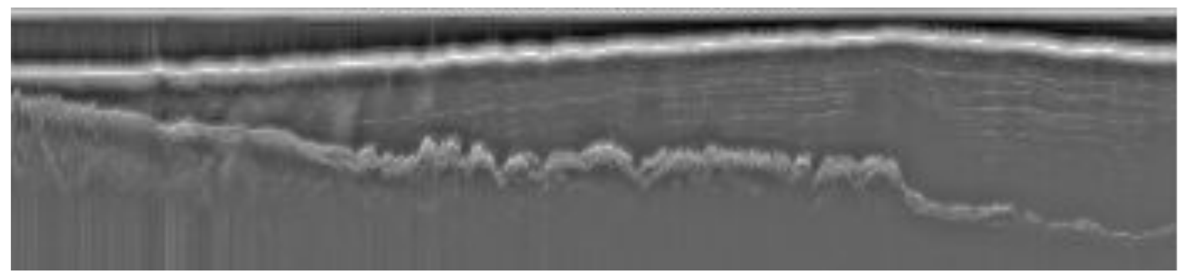
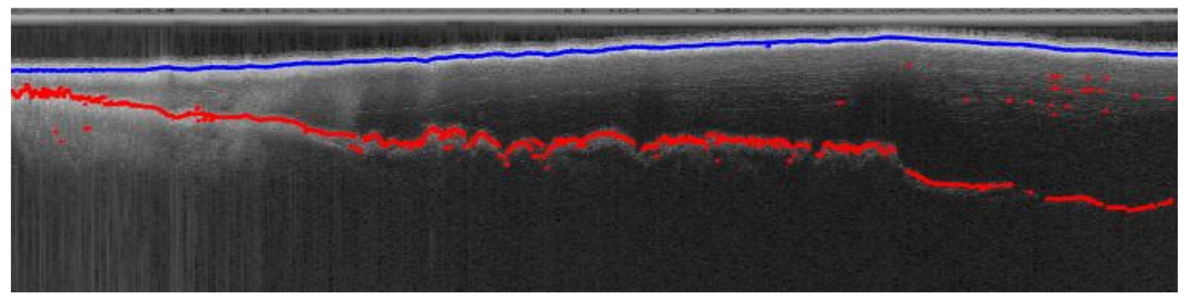
**Layer Tracing**
- Search local region around seed points for maximum values
- Dijkstra's algorithm



Top: Ricker wavelet transformed image, wavelet scales = {10, 11, ... , 20}, used in method (C).

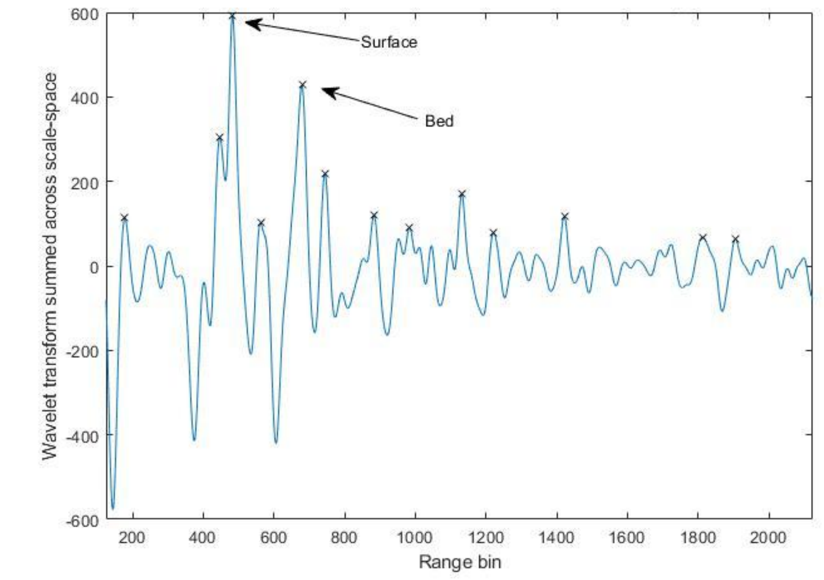
Bottom: maximum response to rotating Gaussian filter, theta = {-90,-89,...88,89}, used in method (B).

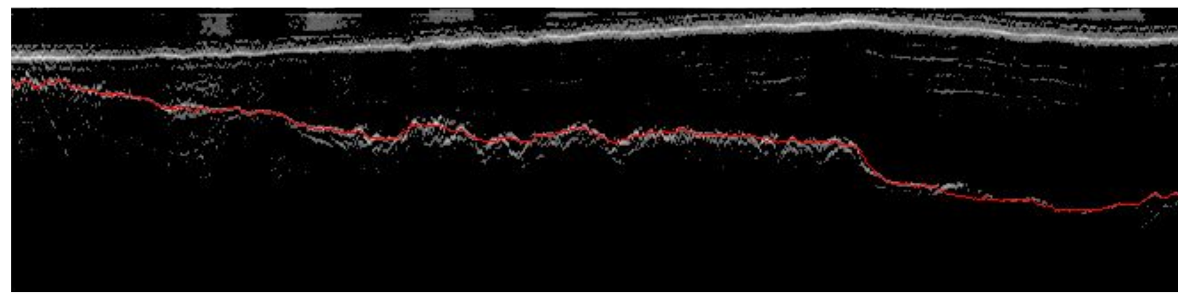




Top: surface (blue) and bed (red) from range-dimension peaks of wavelet transformed image, method (C).

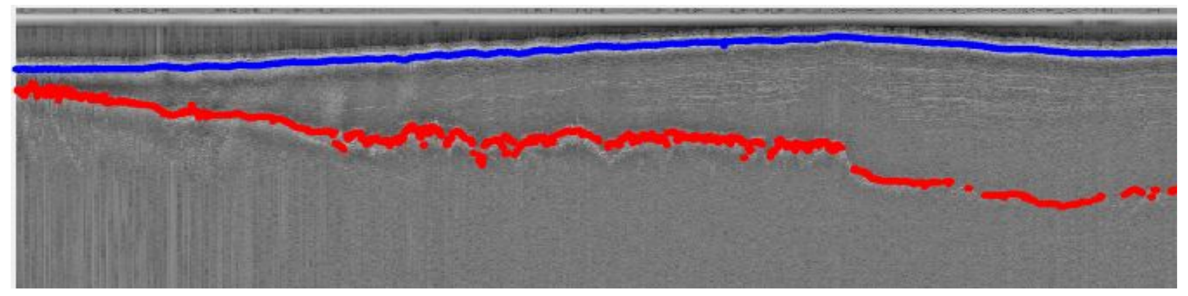
Bottom: peak detection for surface and bed piks for one column of wavelet transformed image, method (C).



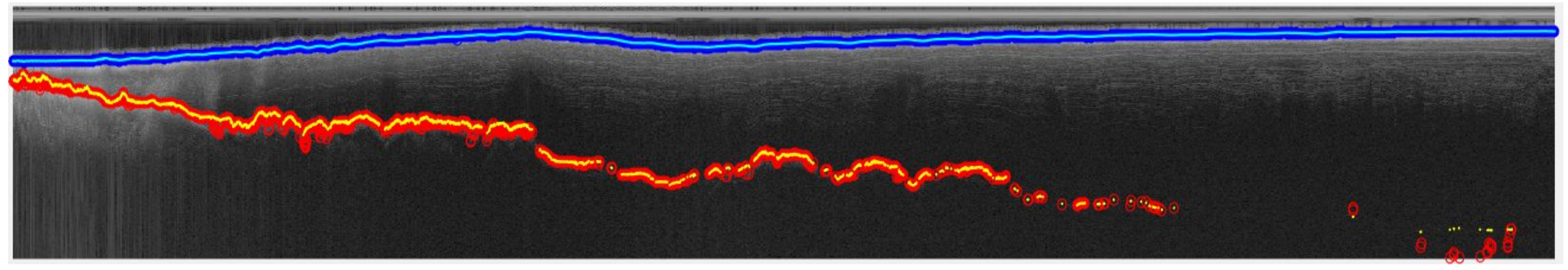



Top: bed traced using Dijkstra's algorithm, method (D).

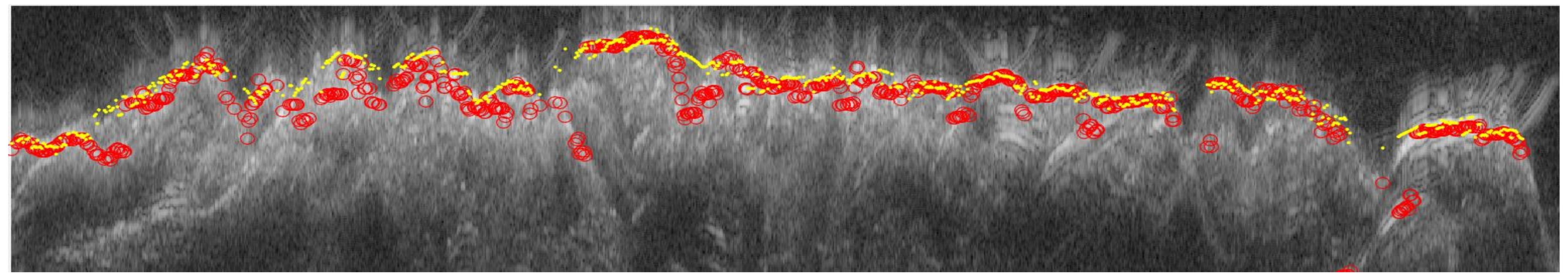
Bottom: local adjacent max search after morphological opening as input, method (E).



## Results



Radargram with reference piks for bed (red) and surface (blue) plotted as open circles. Output of method (E) for bed (yellow) and surface (cyan) plotted as closed circles. Close-up shown below.



| Method | Surface Pik within 20 pixels | Surface Pik within 50 pixels | Bed Pik within 20 pixels | Bed pik within 50 pixels | Processing time per column |
|---|---|---|---|---|---|
| (A) Peak detection on radargram | 99.9% | 100.0% | 40.2% | 57.5% | ~0.03 ms |
| (B) Local adjacent max tracing on Gaussian filtered radargram | 99.31% | 100.0% | 47.57% | 59.10% | ~36.7 ms |
| (C) Peak detection on wavelet tx'd radargram | 99.8% | 100.0% | 82.1% | 91.2% | ~3 ms |
| (D) Dijkstra's algorithm-based tracing | — | — | 18.3% | 53.9% | ~0.6 ms |
| **(E) Local adjacent max tracing on output of (C)** | **99.9%** | **100.0%** | **83.0%** | **93.1%** | **~3.6 ms** |