Layer-finding in Radar Echograms using Probabilistic Graphical Models

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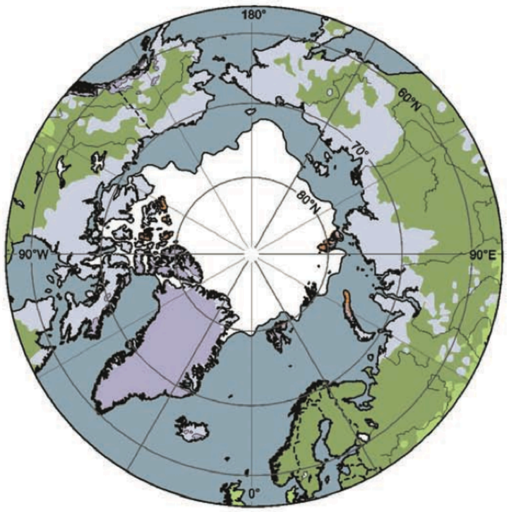
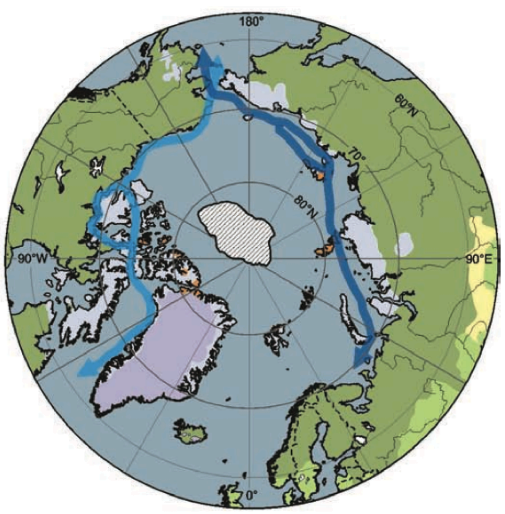
Ice and climate

Current conditions

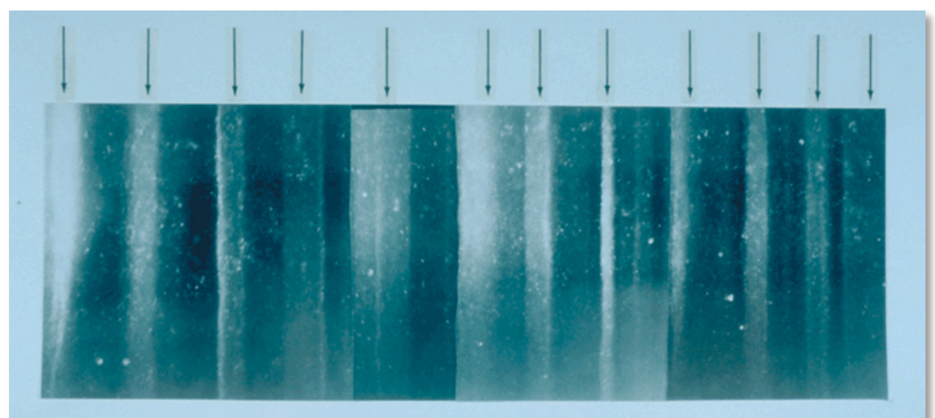


Projected conditions, 2085

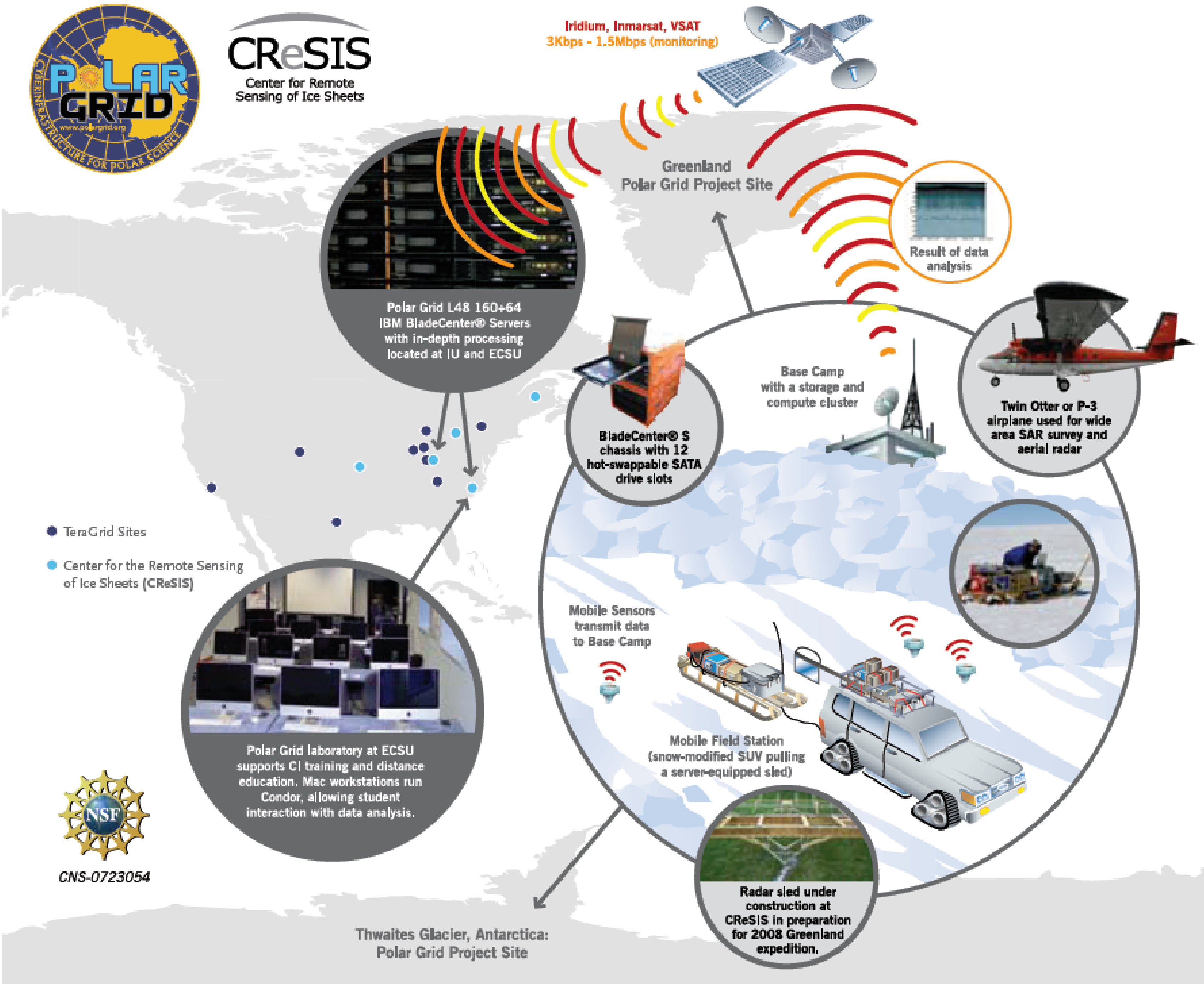


[IPCC 2007]

U.S. Antarctica Program

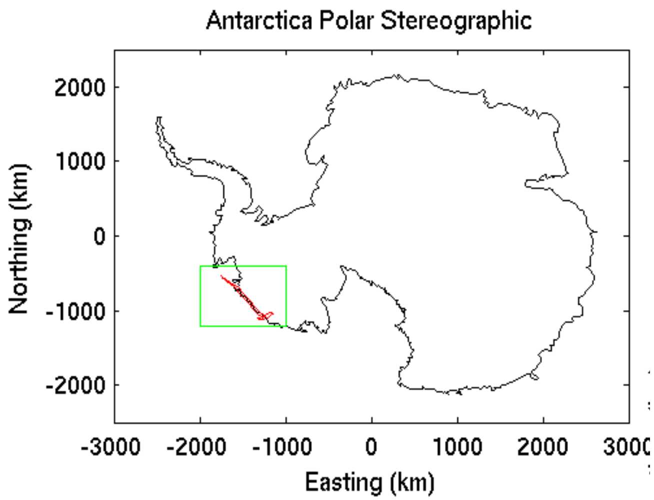


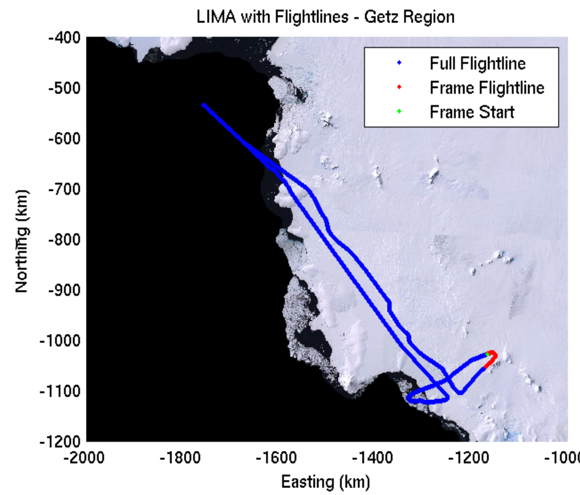
U.S. NOAA



CReSIS
Center for Remote Sensing of Ice Sheets
Iridium, Inmarsat, VSAT
3Kbps - 1.5Mbps (monitoring)
Greenland Polar Grid Project Site
Result of data analysis
Polar Grid L48 160+64 IBM BladeCenter® Servers with in-depth processing located at IU and ECSU
BladeCenter® S chassis with 12 hot-swappable SATA drive slots
Base Camp with a storage and compute cluster
Twin Otter or P-3 airplane used for wide area SAR survey and aerial radar
TeraGrid Sites
Center for the Remote Sensing of Ice Sheets (CReSIS)
Mobile Sensors transmit data to Base Camp
Mobile Field Station (snow-modified SUV pulling a server-equipped sled)
Polar Grid laboratory at ECSU supports CI training and distance education. Mac workstations run Condor, allowing student interaction with data analysis.
Radar sled under construction at CReSIS in preparation for 2008 Greenland expedition.
CNS-0723054
Thwaites Glacier, Antarctica: Polar Grid Project Site

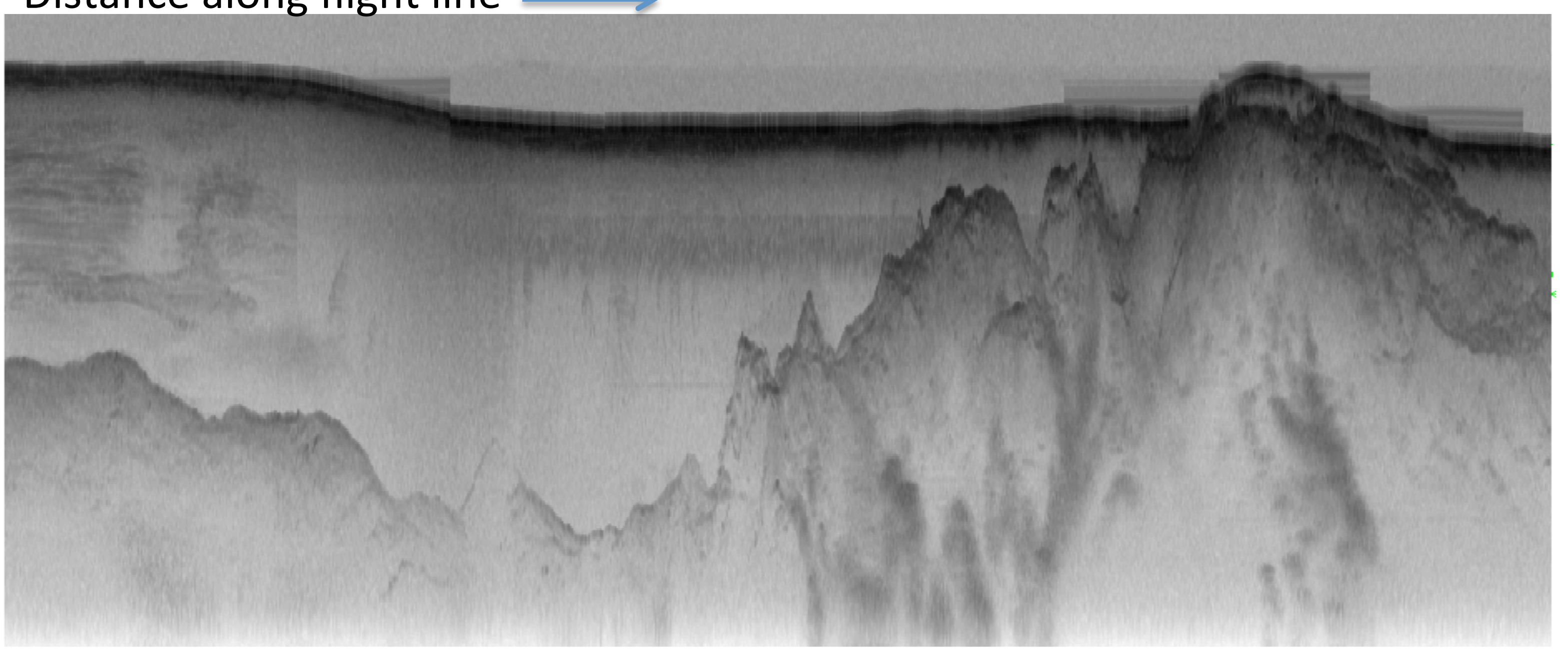
Ice sheet radar echograms



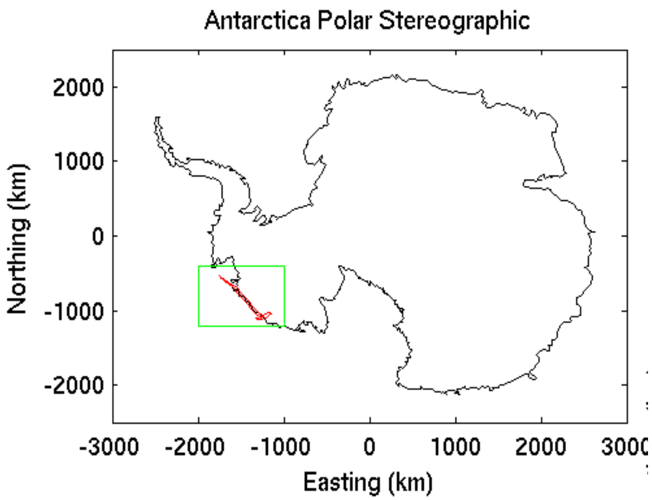


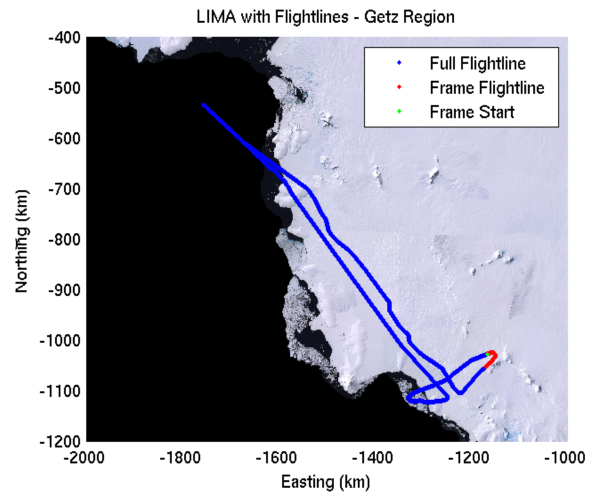
Distance along flight line

Distance below aircraft



Ice sheet radar echograms





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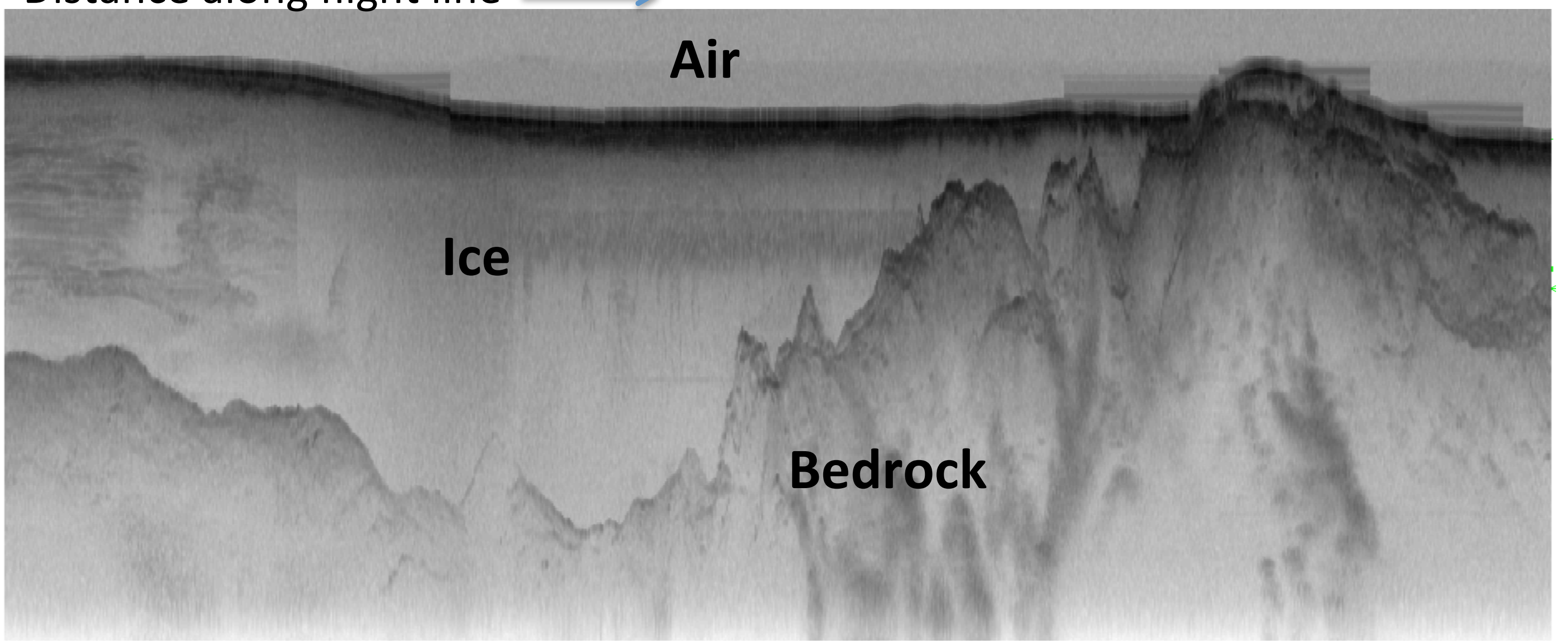
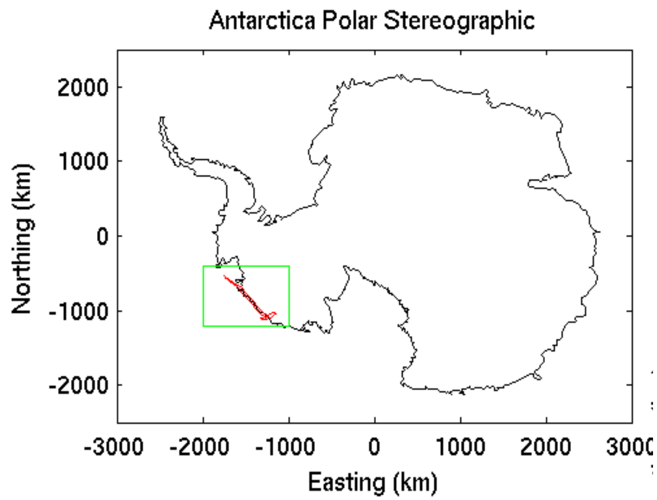
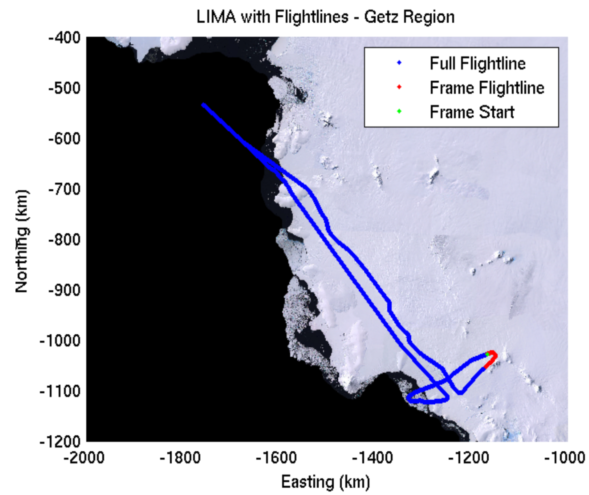


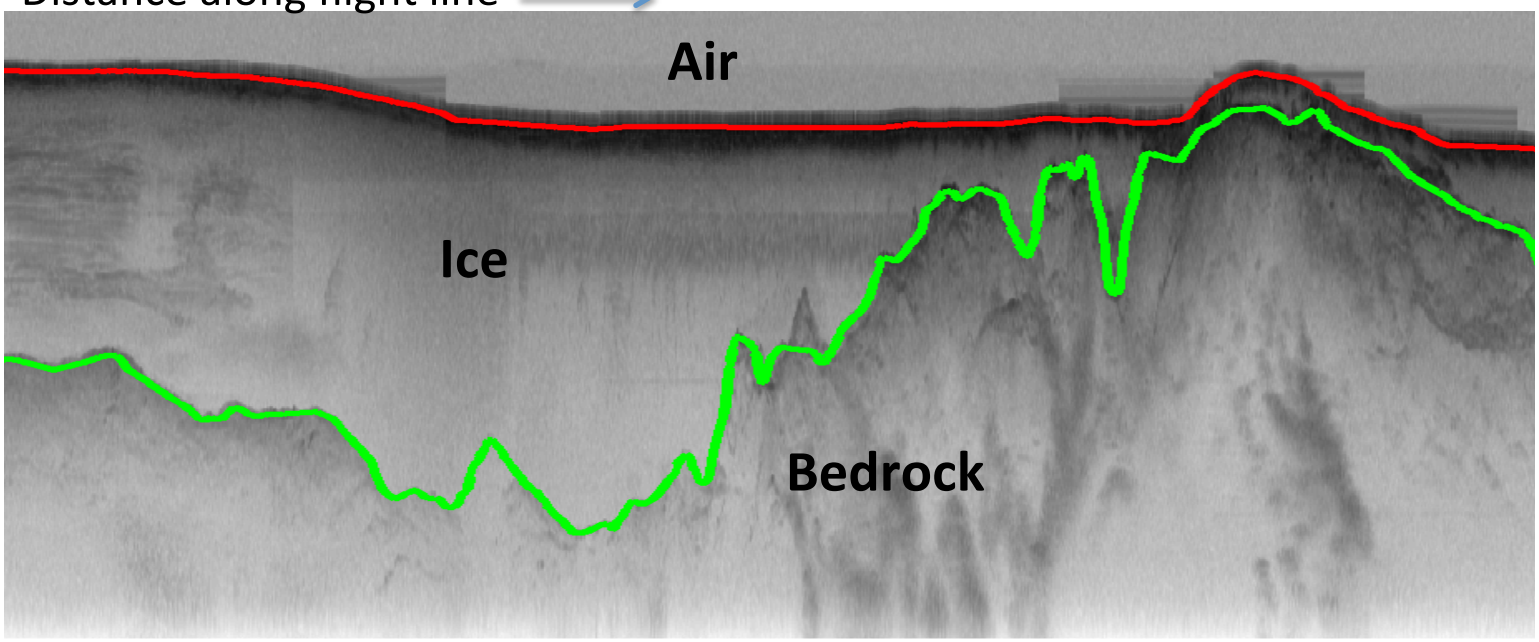
Ice sheet radar echograms





Distance along flight line →

Distance below aircraft ↓



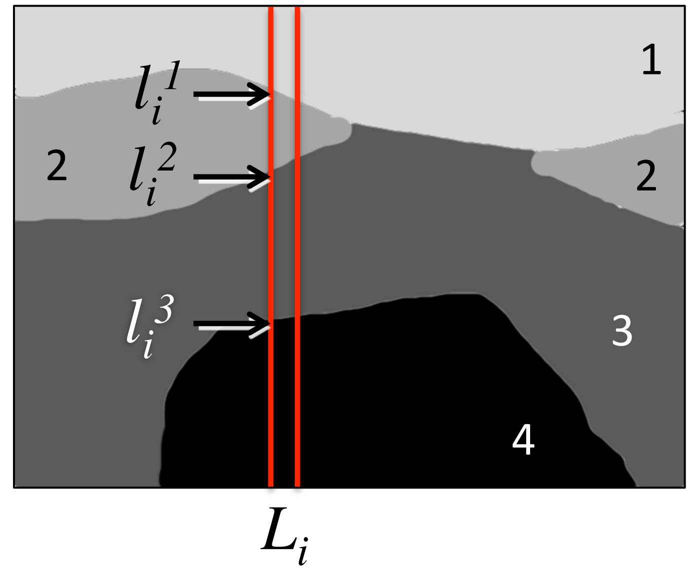
Related work

- General-purpose image segmentation
  – [Haralick1985], [Kass1998], [Shi2000], [Felzenszwalb2004], …

- Subsurface imaging
  – [Turk2011], [Allen2012], …
- Buried object detection
  – [Trucco1999], [Gader2001], [Frigui2005], …
- Layer finding in ground-penetrating echograms
  – [Freeman2010], [Ferro2011], …

Tiered segmentation

- Layer-finding is a *tiered segmentation problem* [Felzenszwalb2010]
  - Label each pixel with one of $[1, K+1]$, under the constraint that if $y < y'$, label of $(x, y) \leq$ label of (x, y')



- Equivalently, find *K* boundaries in each column
  - Let $L_i = (l_i^1, \ldots, l_i^K)$ denote the row indices of the *K* region boundaries in column *i*
  - Goal is to find labeling of whole image, $L = (L_1, \ldots, L_n)$

Probabilistic formulation

- Goal is to find most-likely labeling given image I,

$$L^* = \arg\max_L P(L|I) = \arg\max_L P(I|L)P(L)$$

Likelihood term models how well labeling agrees with image

Prior term models how well labeling agrees with typical ice layer properties

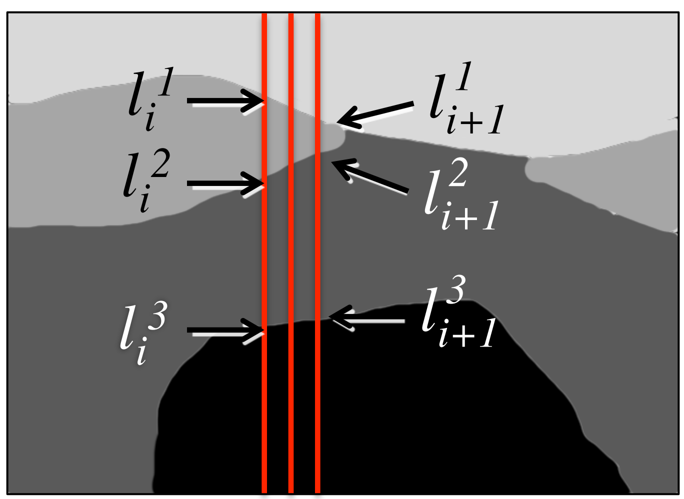
Prior term

- Prior encourages smooth, non-crossing boundaries

$$P(L) \propto \prod_{i \in [2,n]} \prod_{k \in [1,K]} P(l_i^k - l_{i-1}^k | \sigma_k) P(l_i^k | l_i^{k-1})$$

Zero-mean Gaussian penalizes discontinuities in layer boundaries across columns

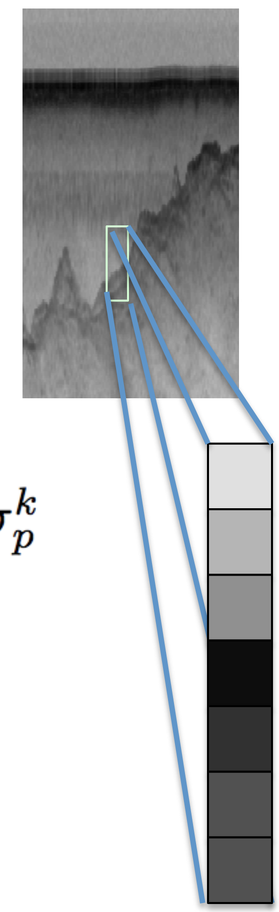
Repulsive term prevents boundary crossings; is 0 if $l_i^k < l_i^{k-1}$ and uniform otherwise



Likelihood term

- Likelihood term encourages labels to coincide with layer boundary features (e.g. edges)

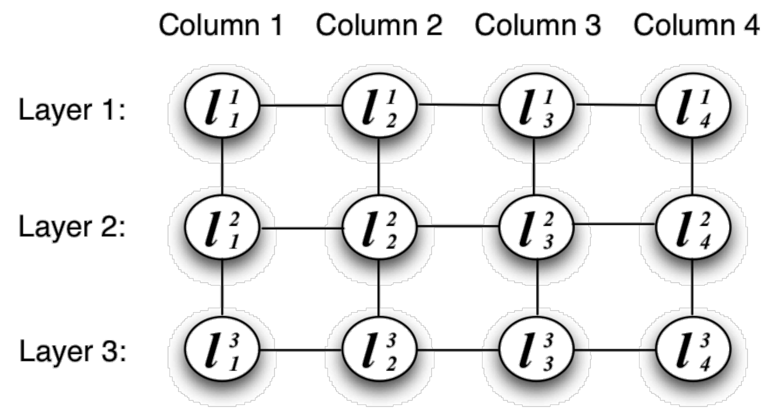
$$P(I|L) = \prod_{i \in [1,n]} P(I_i|L_i)$$



  - Learn a single-column appearance template T_k consisting of Gaussians at each position *p*, with μ_p^k, σ_p^k
  - Also learn a simple background model, with μ_0, σ_0
  - Then likelihood for each column is,

$$P(I_i|L_i) = \prod_{p \in I_i} P(I(p)|\mu_0, \sigma_0) \prod_{k \in [1,K]} \prod_{p \in T_k} \frac{P(I(p + l_i^k)|\mu_p^k, \sigma_p^k)}{P(I(p + l_i^k)|\mu_0, \sigma_0)}$$

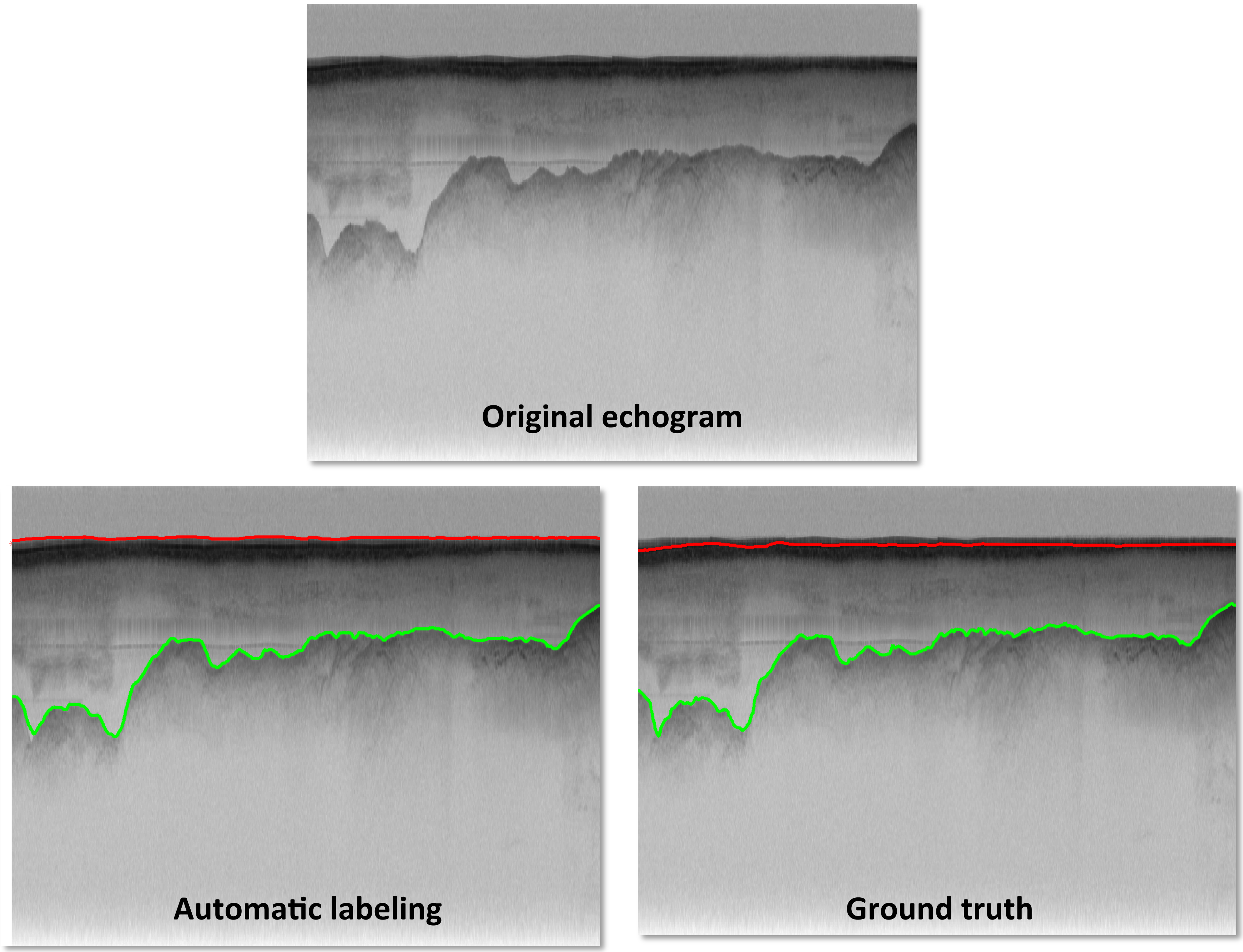
Efficient inference

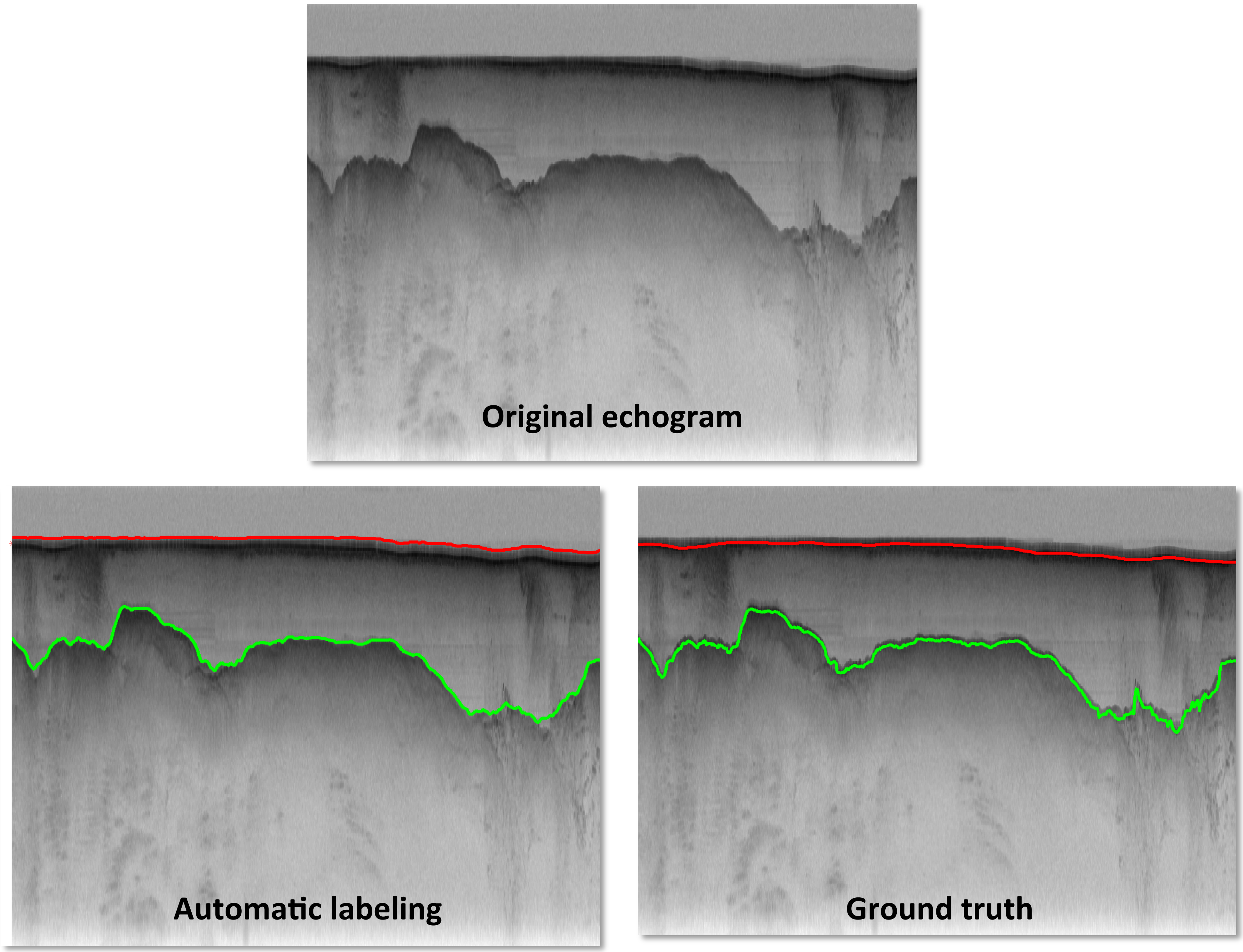


- Finding L that maximizes $\mathrm{P}(L \mid I)$ involves inference on a Markov Random Field
  - Simplify problem by solving each row of MRF in succession, using the Viterbi algorithm
  - Naïve Viterbi requires $O(Kmn^2)$ time, for m x n echogram with K layer boundaries
  - Can use min-convolutions to speed up Viterbi (because of the Gaussian prior), reducing time to $O(Kmn)$ [Crandall2008]

Experimental results

- Tested with 827 echograms from Antarctica
  - From Multichannel Coherent Radar Depth Sounder system in 2009 NASA Operation Ice Bridge [Allen12]
  - About 24,810 km of flight data
  - Split into equal-size training and test datasets


Original echogram
Automatic labeling
Ground truth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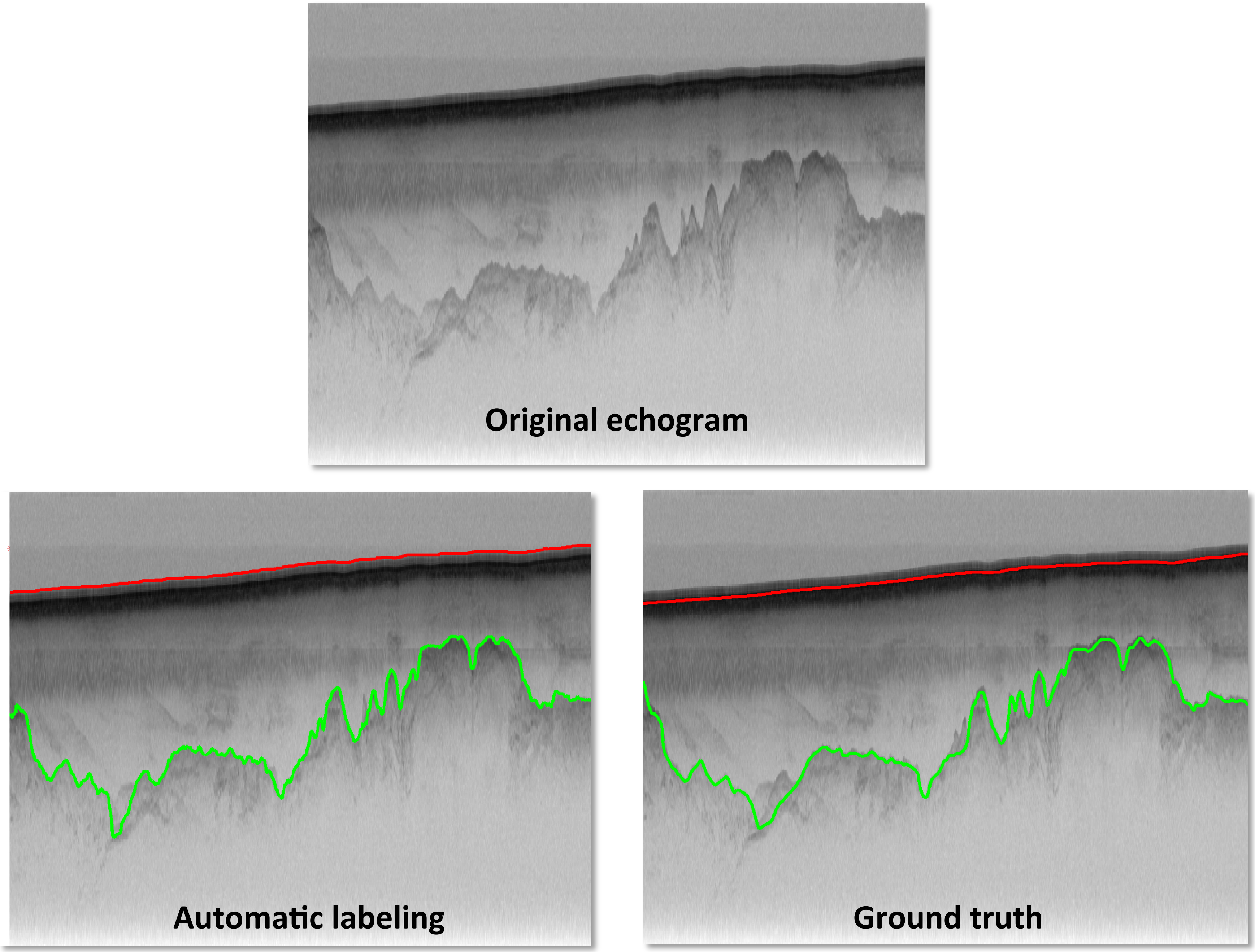
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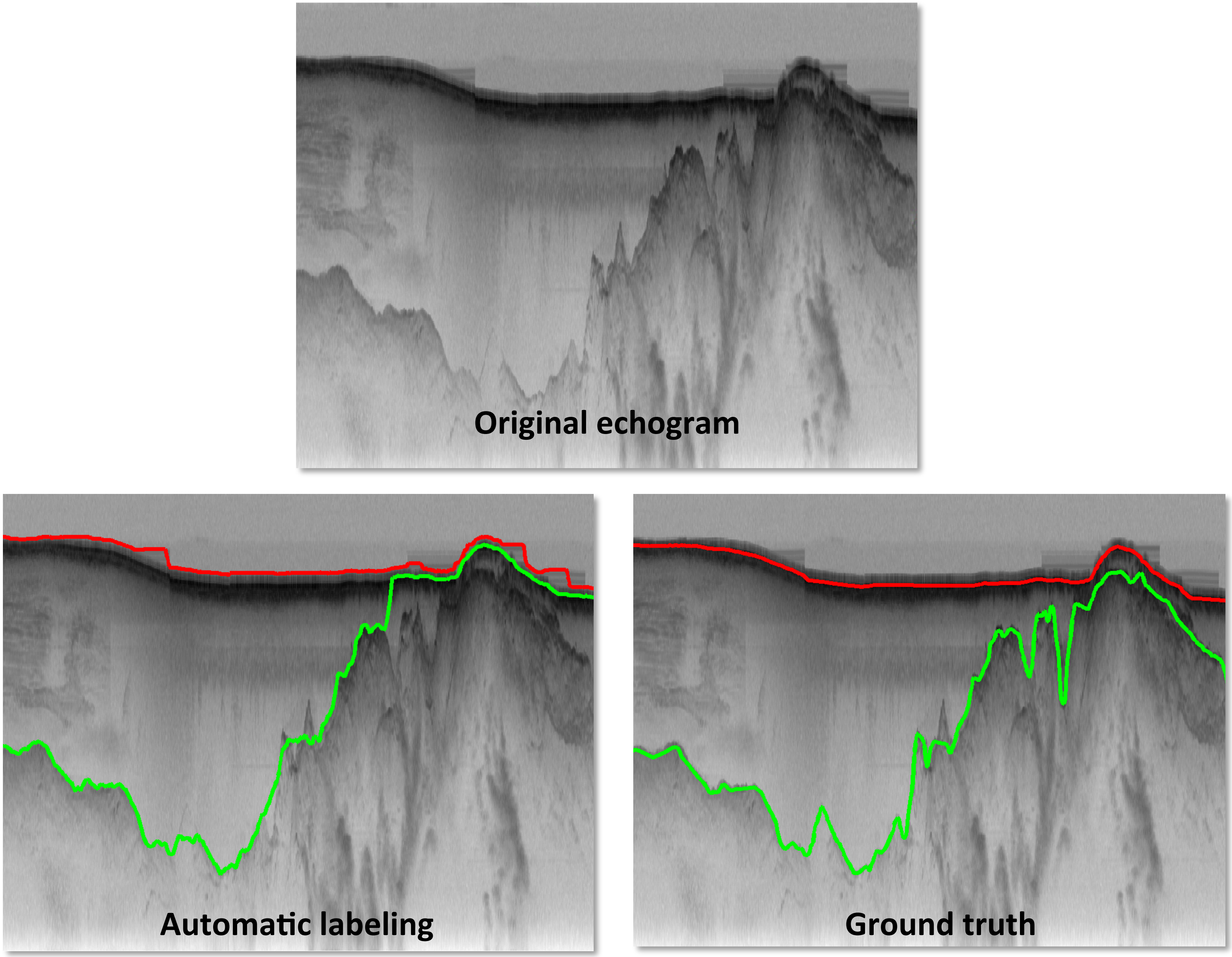
Original echogram
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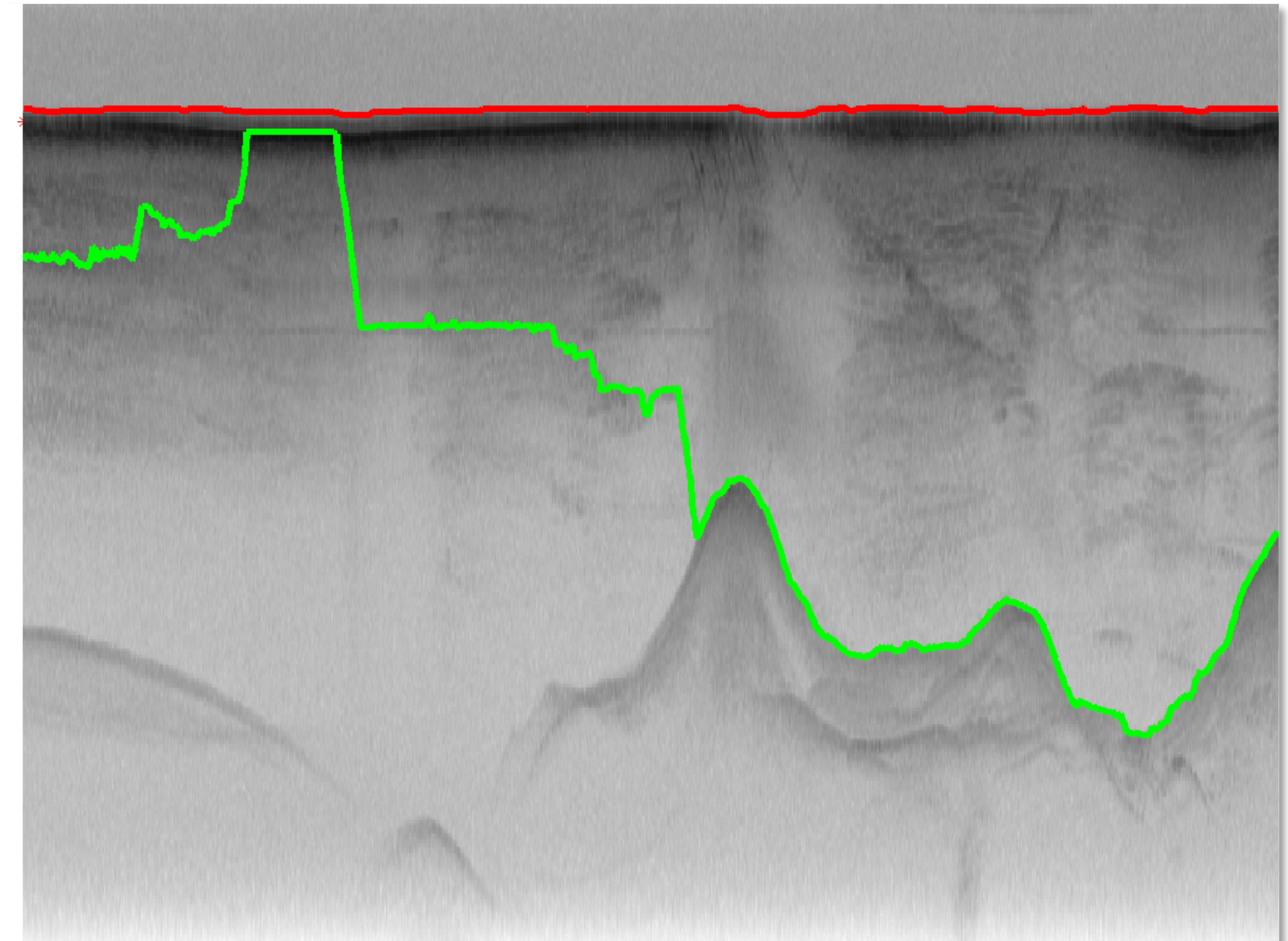
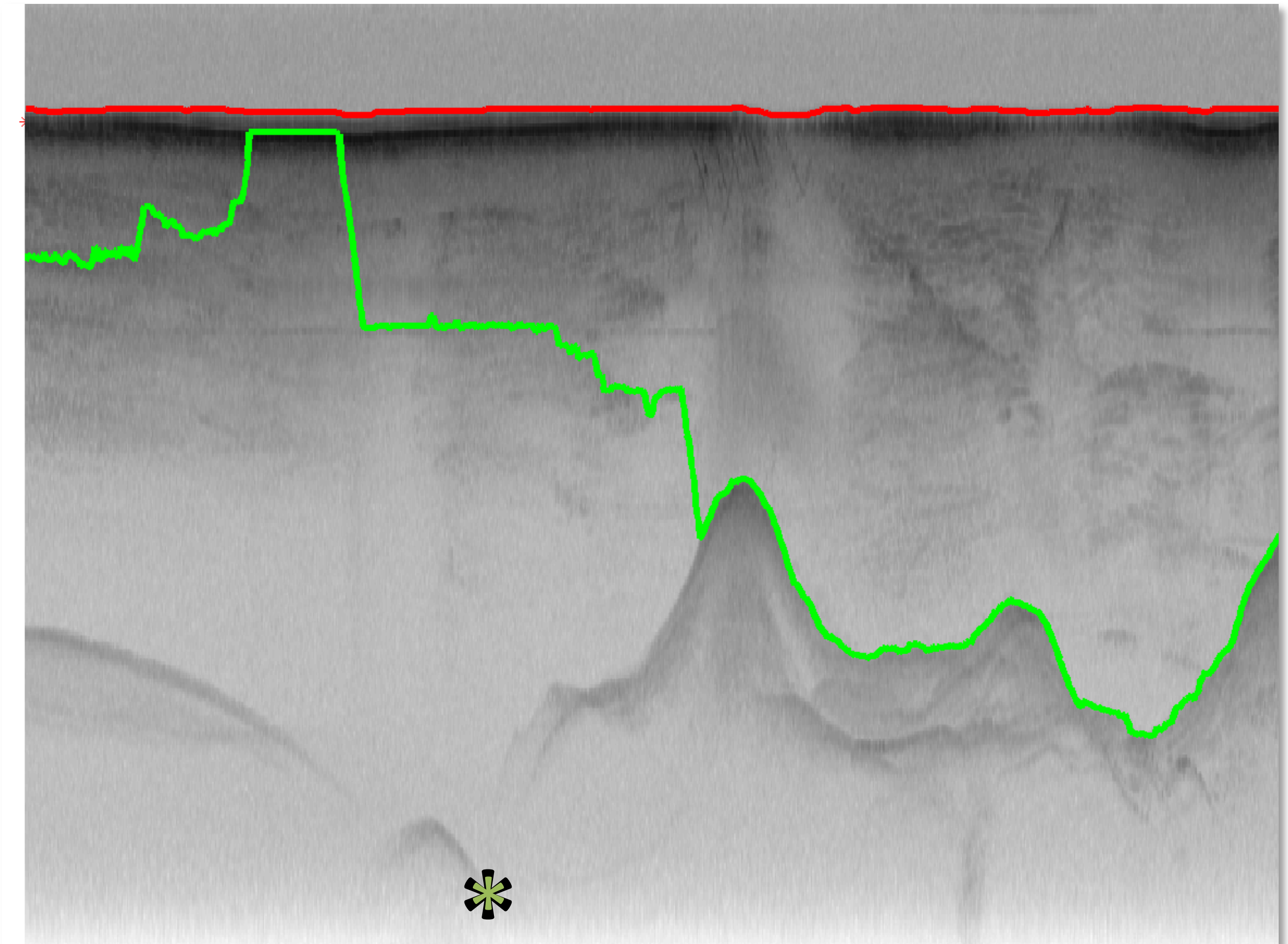
User interaction



User interaction



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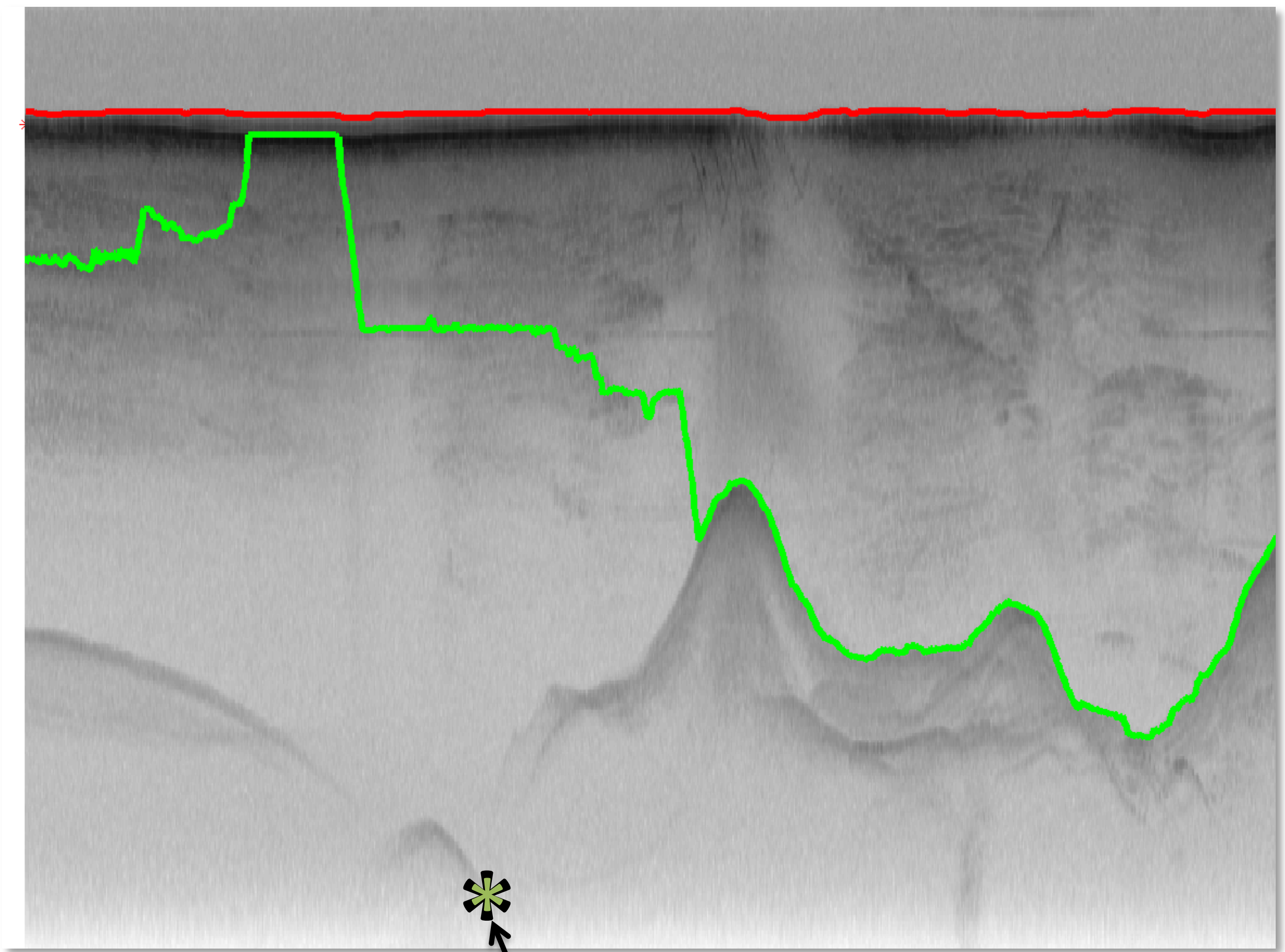
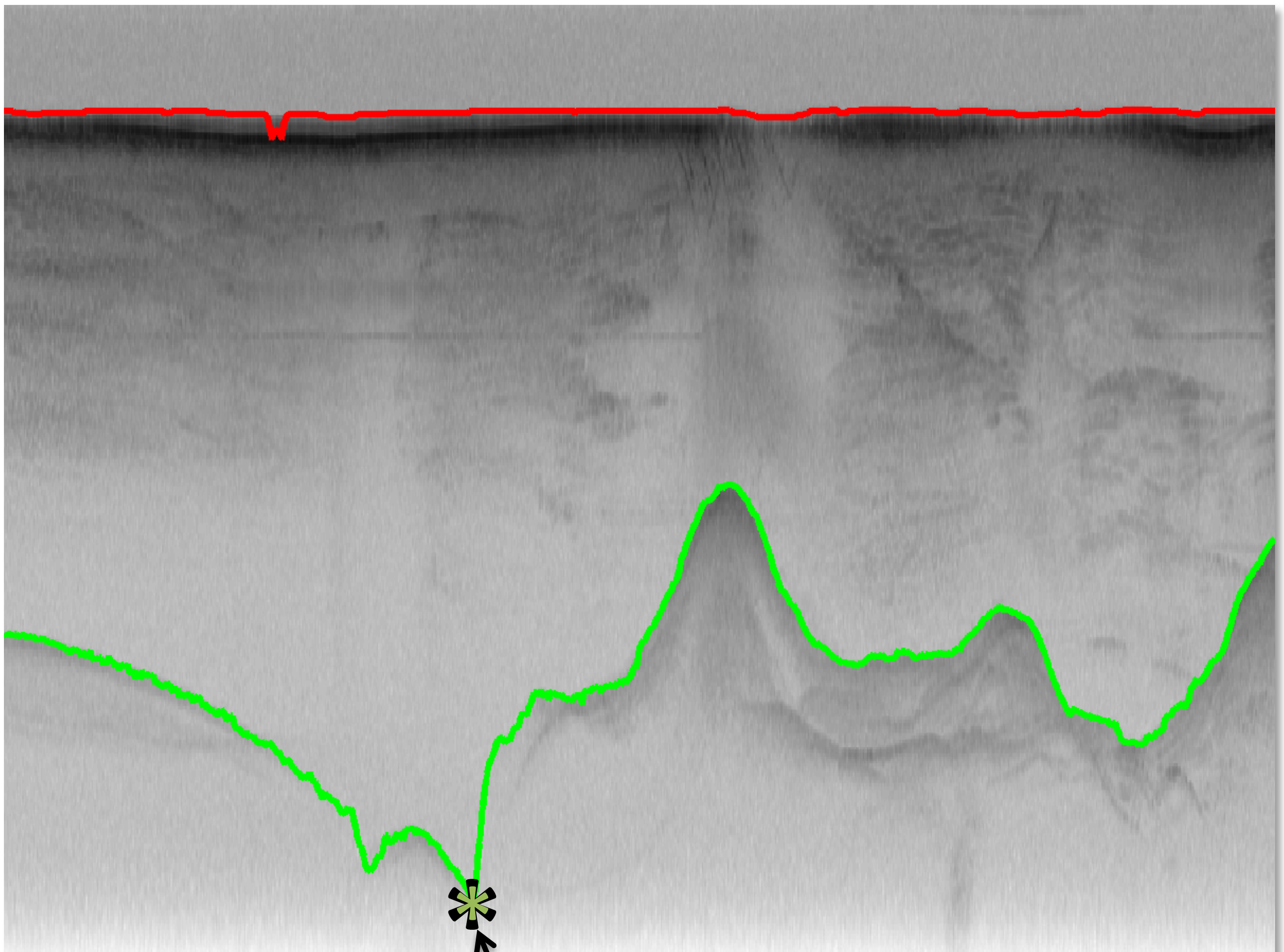


Modify $P(L)$ such that this label has probability 1

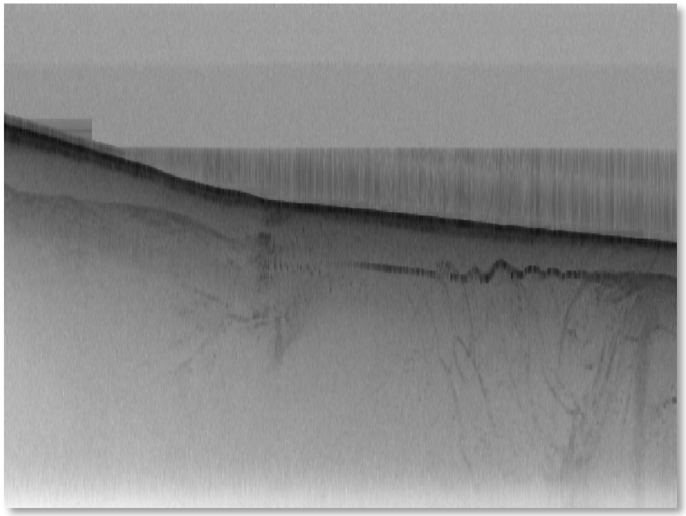
User interaction

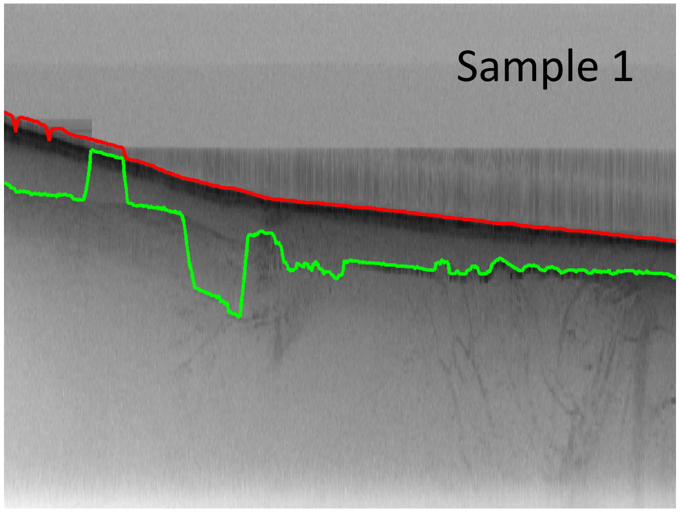


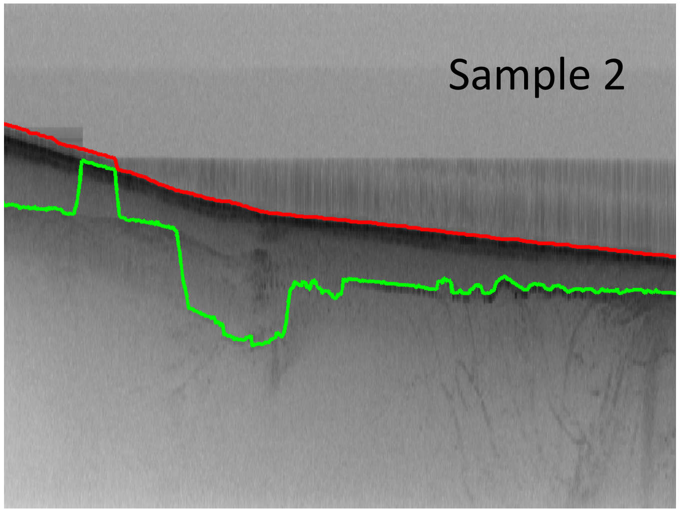
Modify $P(L)$ such that this label has probability 1

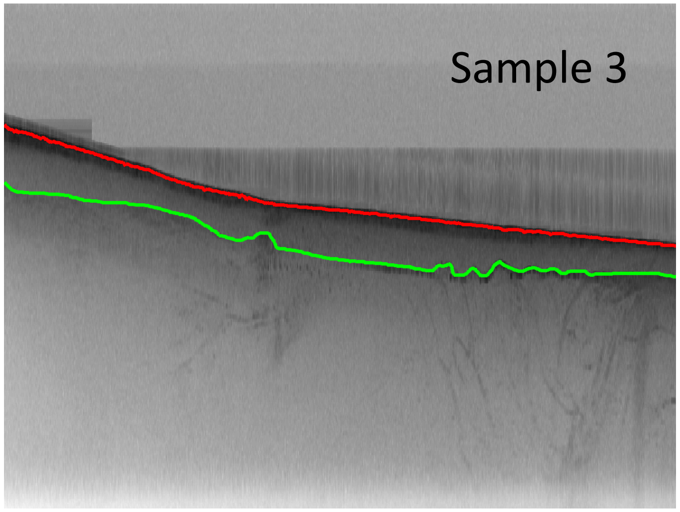
Sampling from the posterior

- Instead of maximizing $P(L|I)$, sample from it









Quantitative results

- Comparison against simple baselines:
  - **Fixed** simply draws a straight line at mean layer depth
  - **AppearOnly** maximizes likelihood term only

	Air-ice boundary		Ice-terrain boundary	
	Mean Err	Mean SE	Mean Err	Mean SE
Fixed	69.0	10955.9	89.7	14975.2
AppearOnly	19.6	2949.8	42.1	7686.2
Our approach	14.1	1719.6	32.0	5078.9

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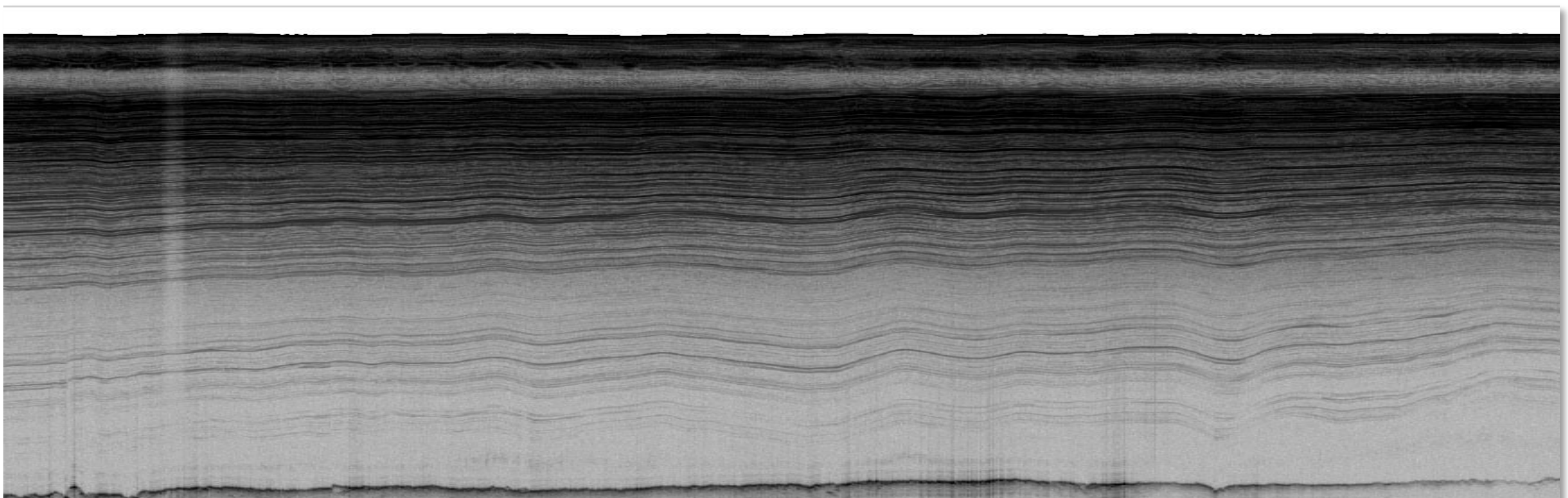
  - Further improvement with human interaction:

Ours, 1 pt	11.1	926.5	22.3	2652.5
Ours, 2 pts	10.1	718.6	18.3	1927.9
Ours, 3 pts	9.6	602.8	15.7	1470.2

Summary and Future work

- We present a probabilistic technique for ice sheet layer-finding from radar echograms
  - Inference is robust to noise and very fast
  - Parameters can be learned from training data
  - Easily include evidence from external sources
- Ongoing work: Internal layer-finding



Thanks!

More information available at:

http://vision.soic.indiana.edu/icelayers/

This work was supported in part by: