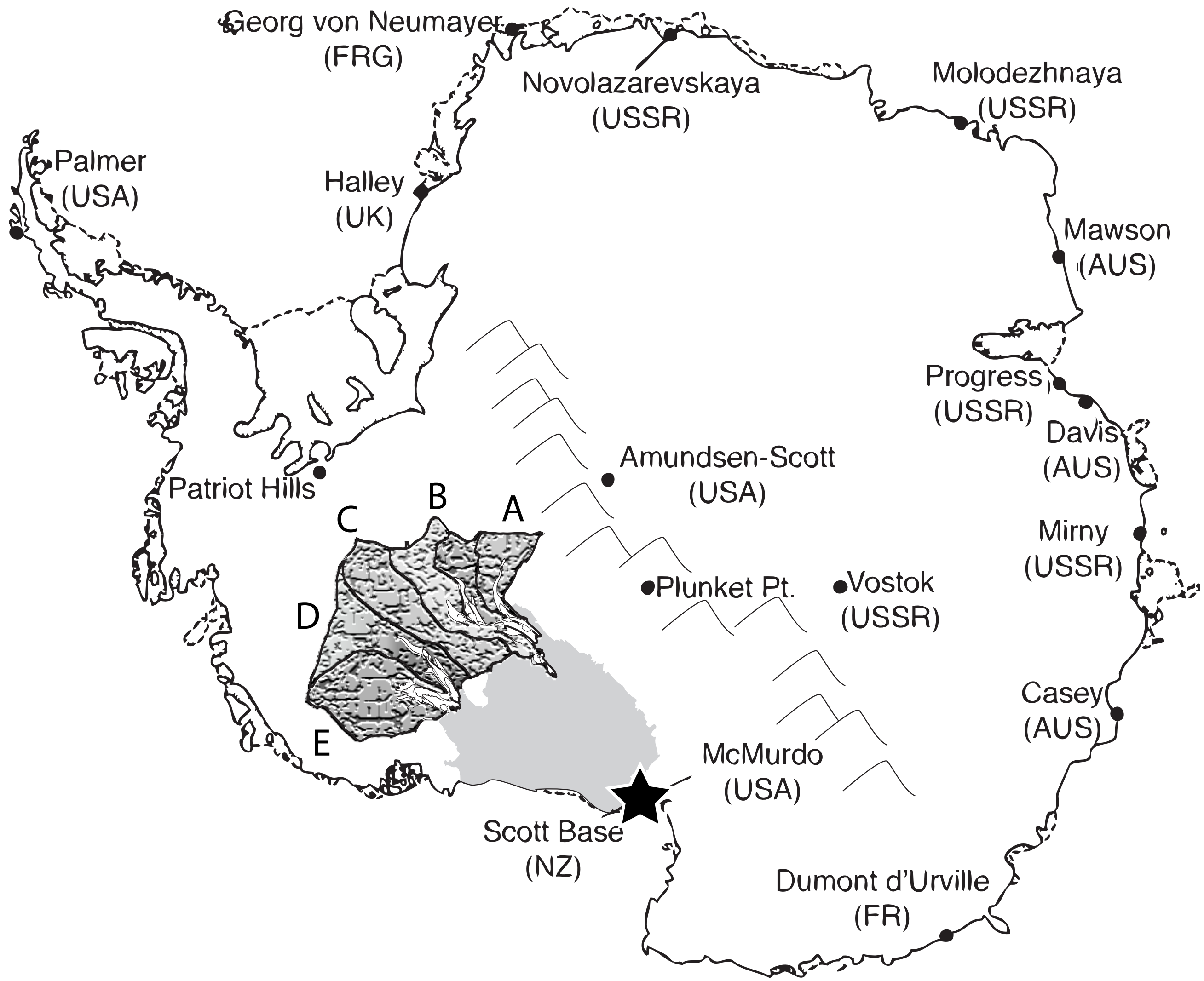
Autonomous Crevasse Detection using a Robotic Ground Penetrating Radar System

Rebecca M. Williams
Ph.D. Candidate
Thayer School of Engineering
Dartmouth College

Committee:
Laura E. Ray, PhD (Dartmouth)
Jim Lever, PhD (CRREL)
Steve Arcone, PhD (CRREL)
Bob Hawley PhD (Dartmouth)

Places we would like to go



why it's hard

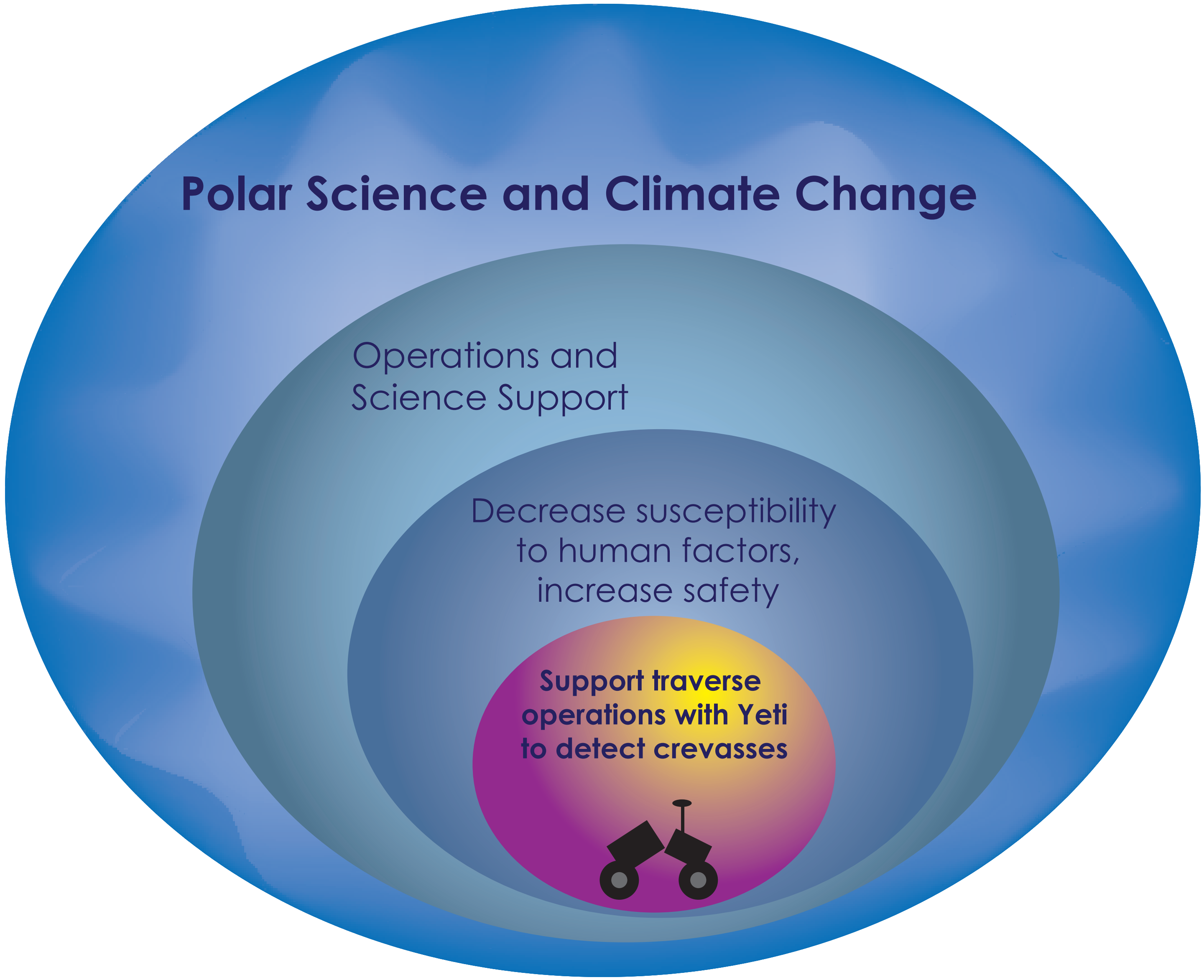
— physical hazards

— lack of natural resources

— human factors

— $$$

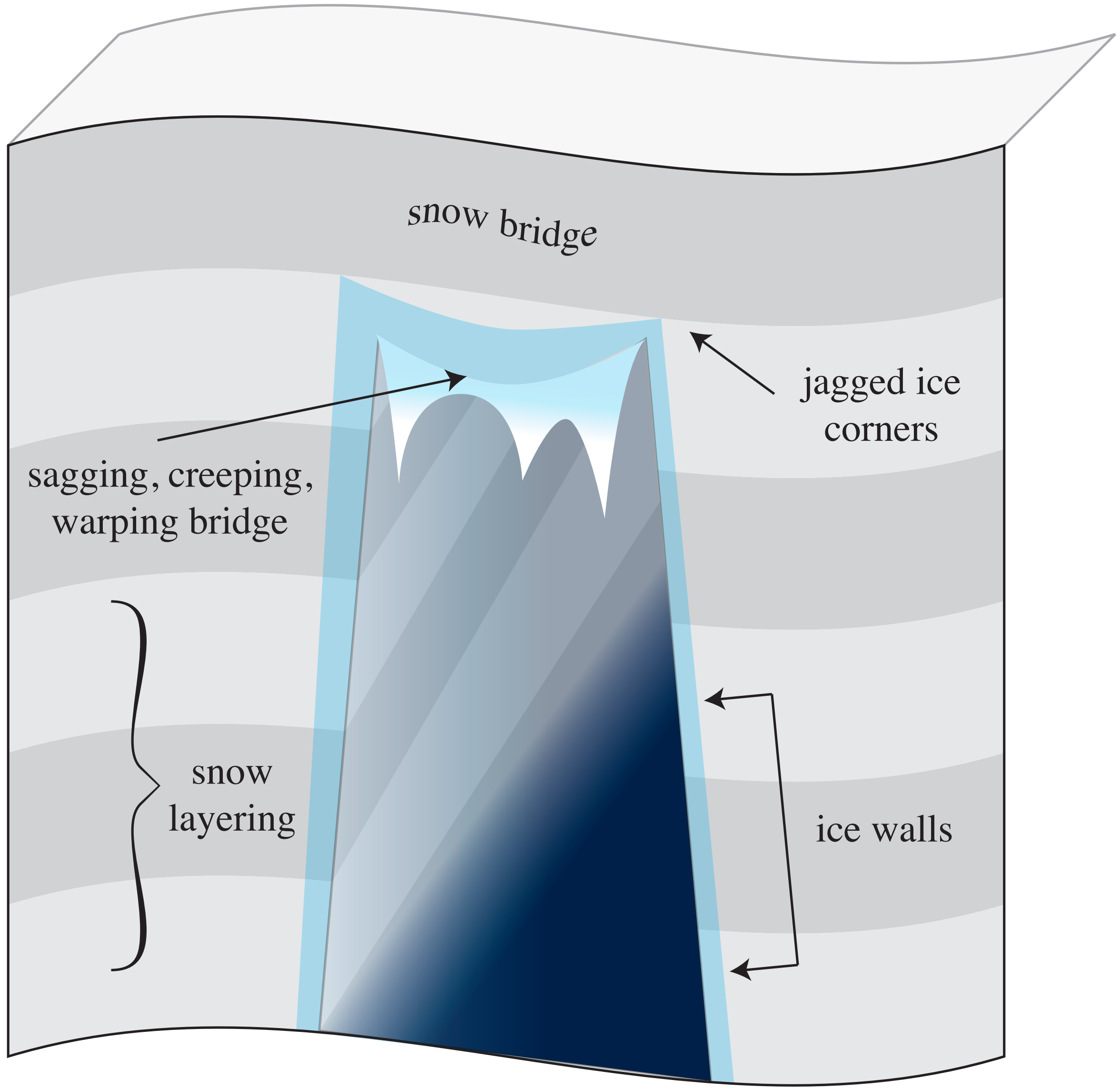
Broad Goals



Polar Science and Climate Change
Operations and Science Support
Decrease susceptibility to human factors, increase safety
Support traverse operations with Yeti to detect crevasses

Crevasses

Crevasses



snow bridge
jagged ice corners
sagging, creeping, warping bridge
snow layering
ice walls

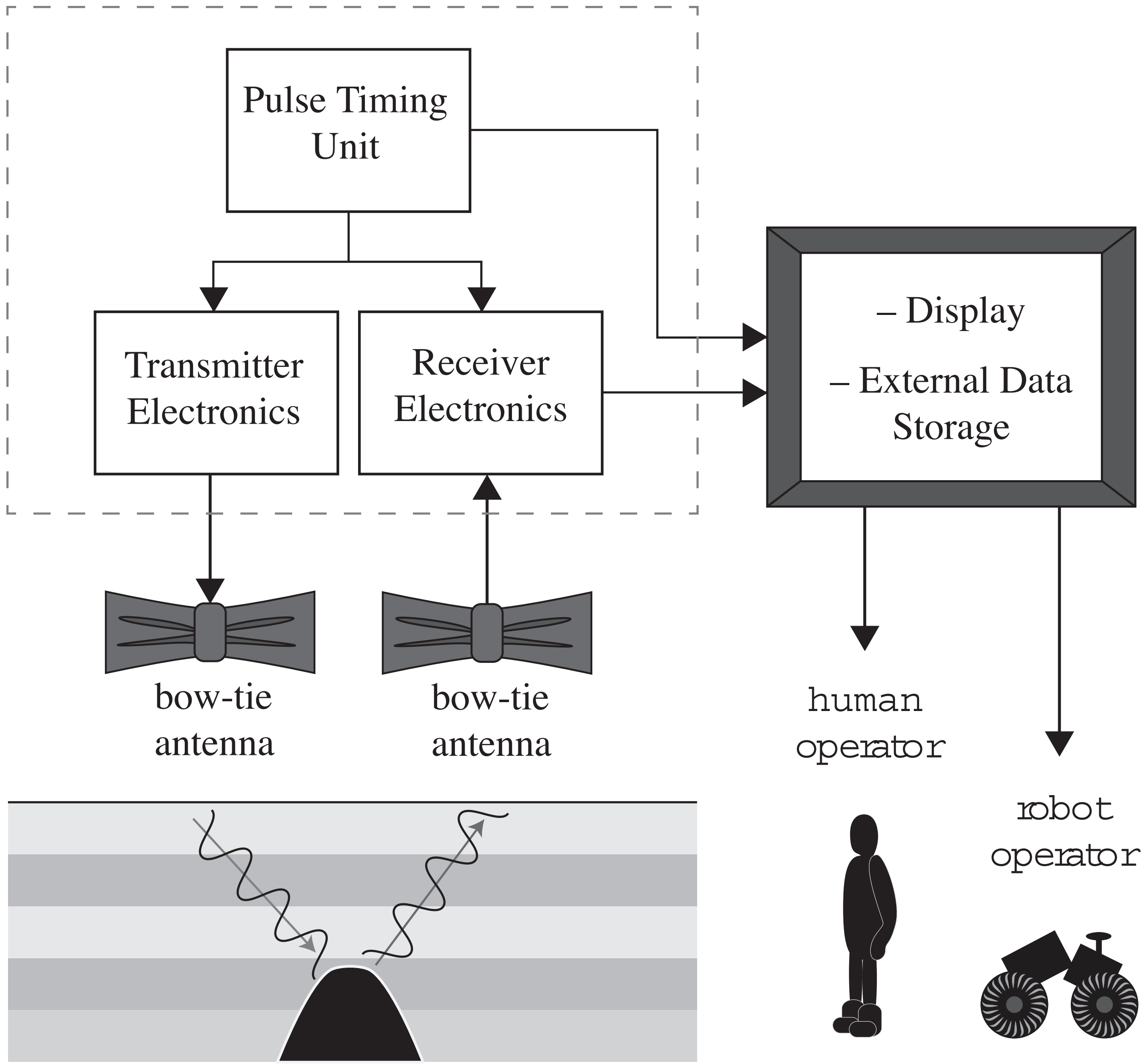
Crevasses

before

after

Ground Penetrating Radar

Ground Penetrating Radar (GPR): Basic Components



Ground Penetrating Radar:
Wave Transformations

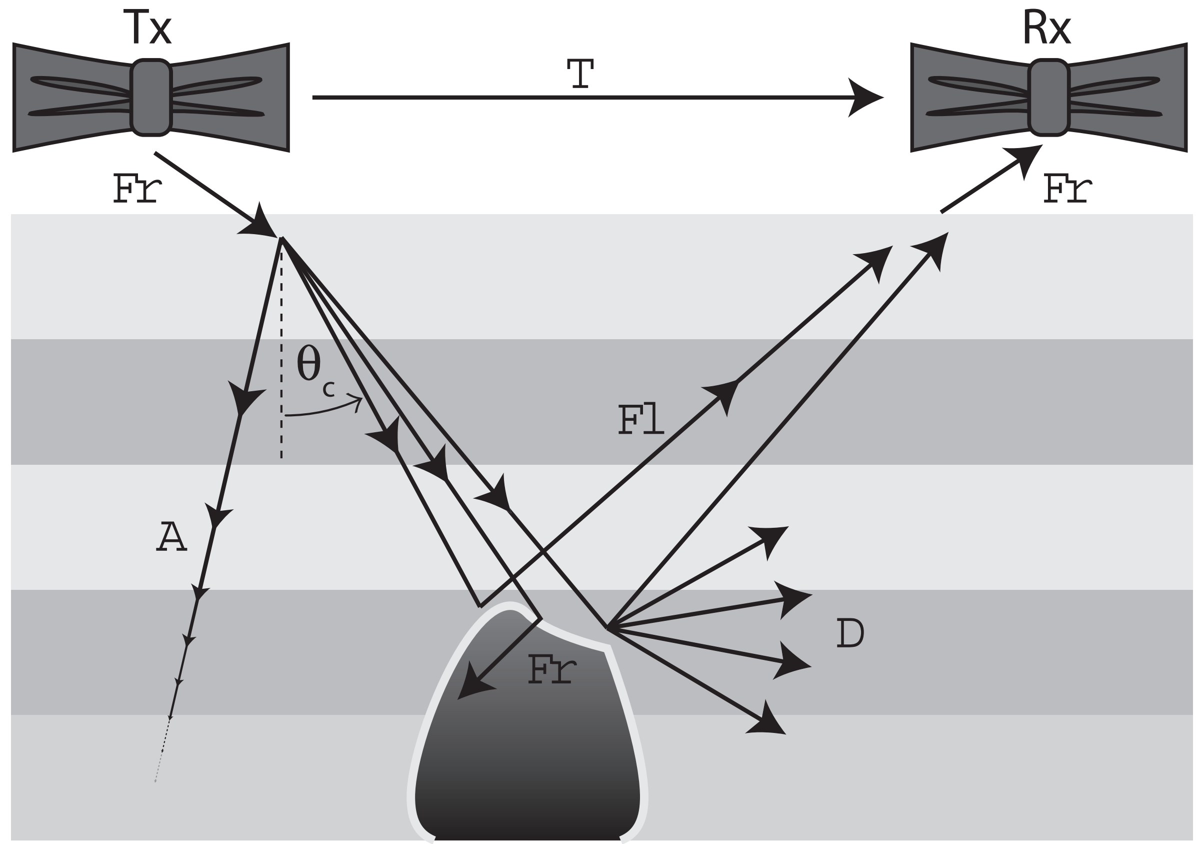
(T) Transmission: propagation without attenuation

(A) Attenuation: decay in signal amplitude

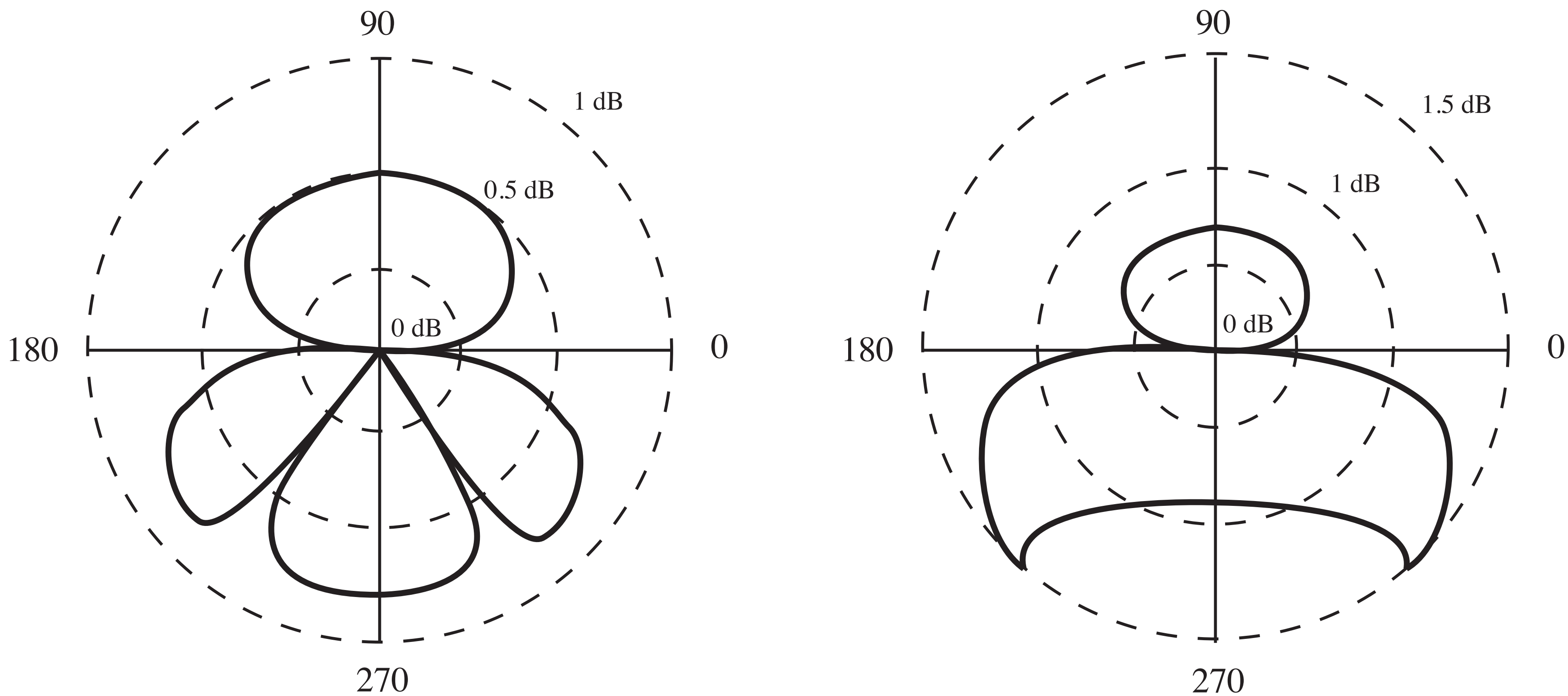
(Fl) Reflection: change in signal direction at interface

(Fr) Refraction: change in signal direction and speed at interface

(D) Diffraction: spreading and interference of waves at discontinuity

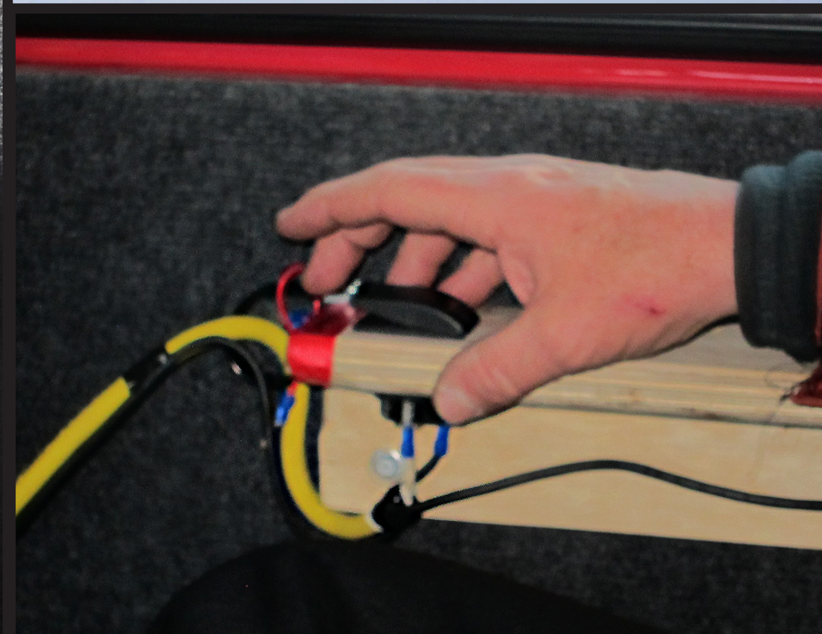


Antennas



antenna radiation patterns

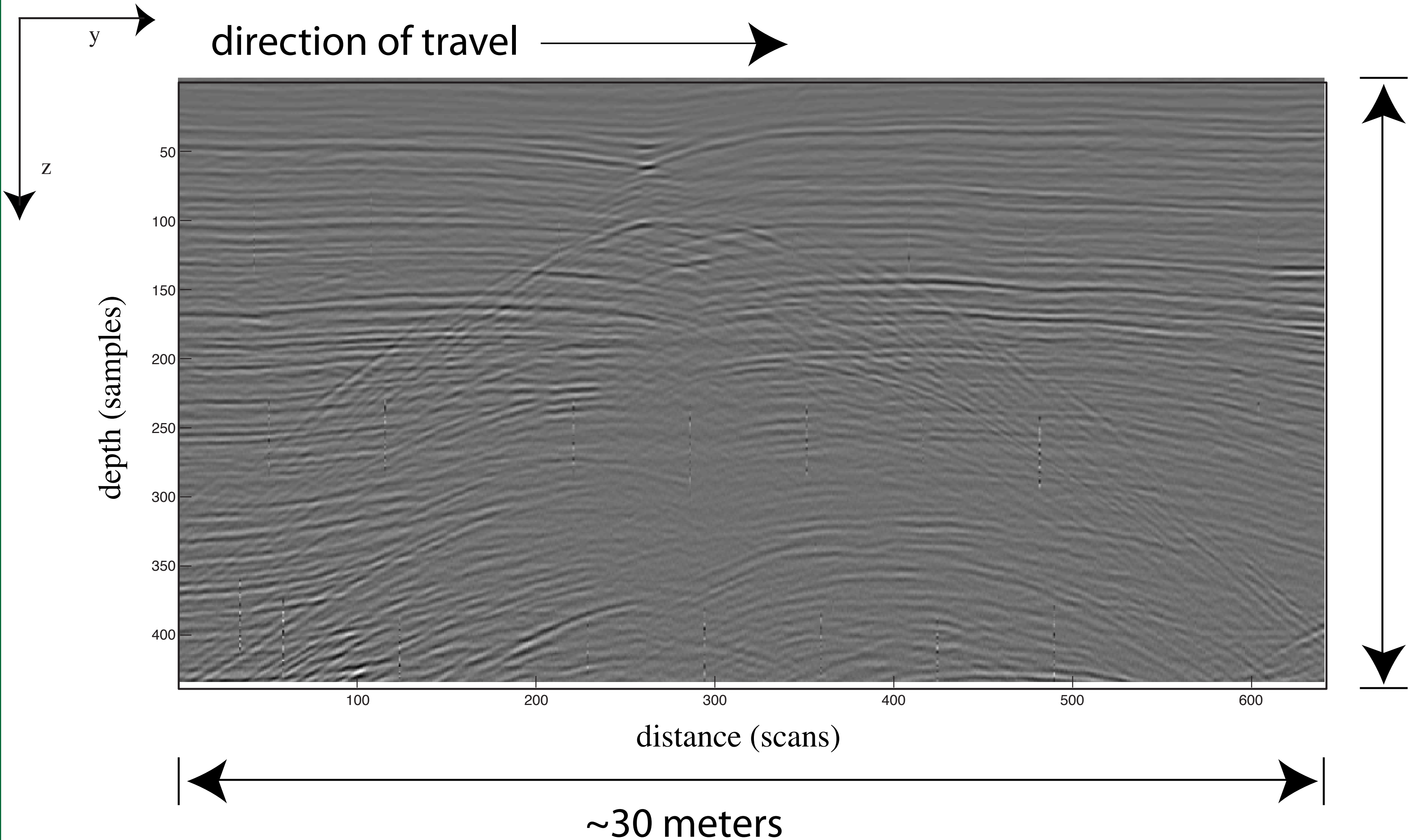
GPR for Glaciers



Yeti

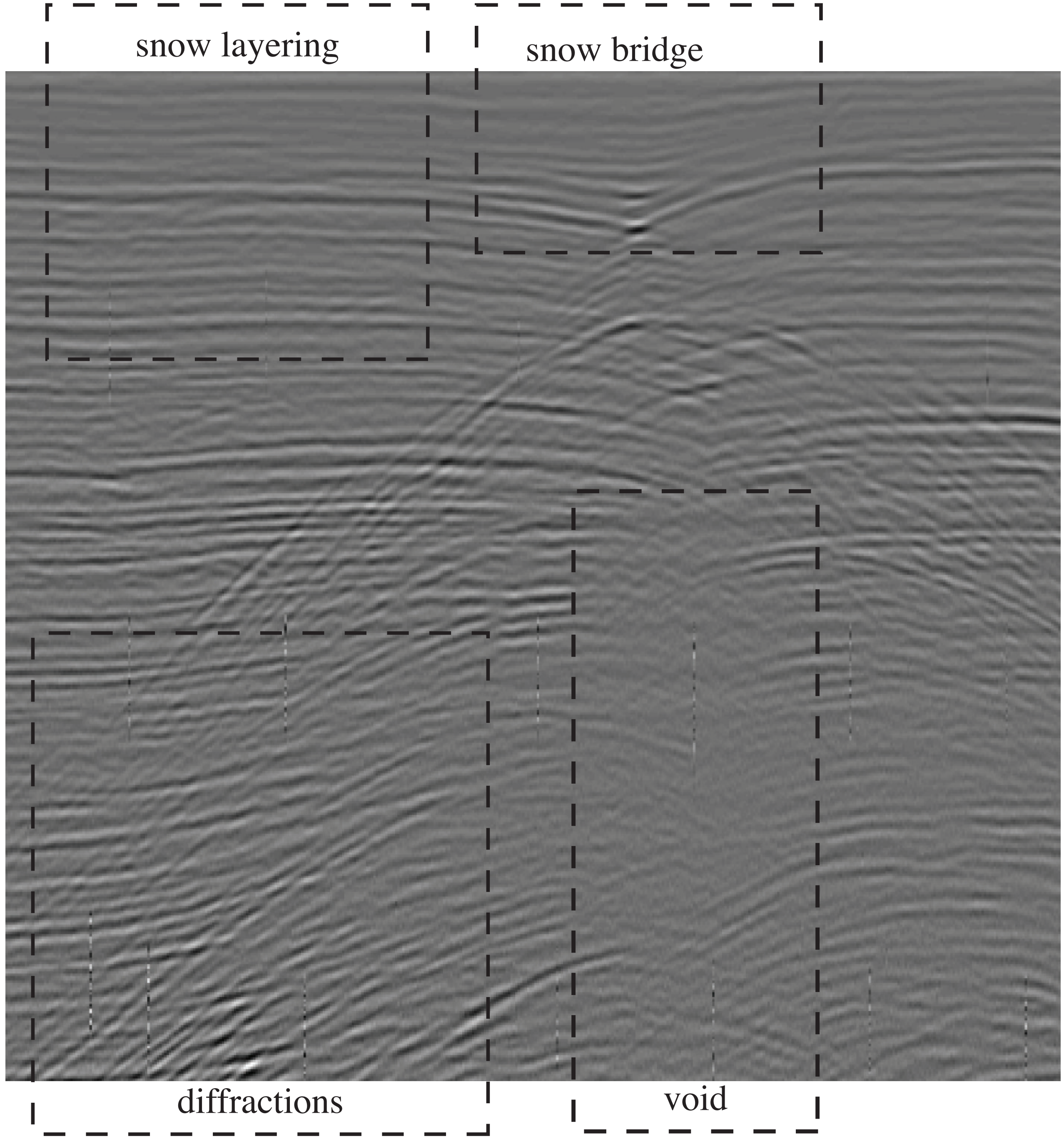
- — 70 kg + GPR
- — differential drive, articulating chassis
- — untethered, 9 battery bay (48VDC)
- — 3 to 6 hour range, 7 km
- — radio link, GPS (Novatel)
- — waypoint following using principal integral control

Radargrams



y
z
direction of travel
depth (samples)
50
100
150
200
250
300
350
400
100
200
300
400
500
600
distance (scans)
~12.5 meters
~30 meters

Crevasse Radargram Features



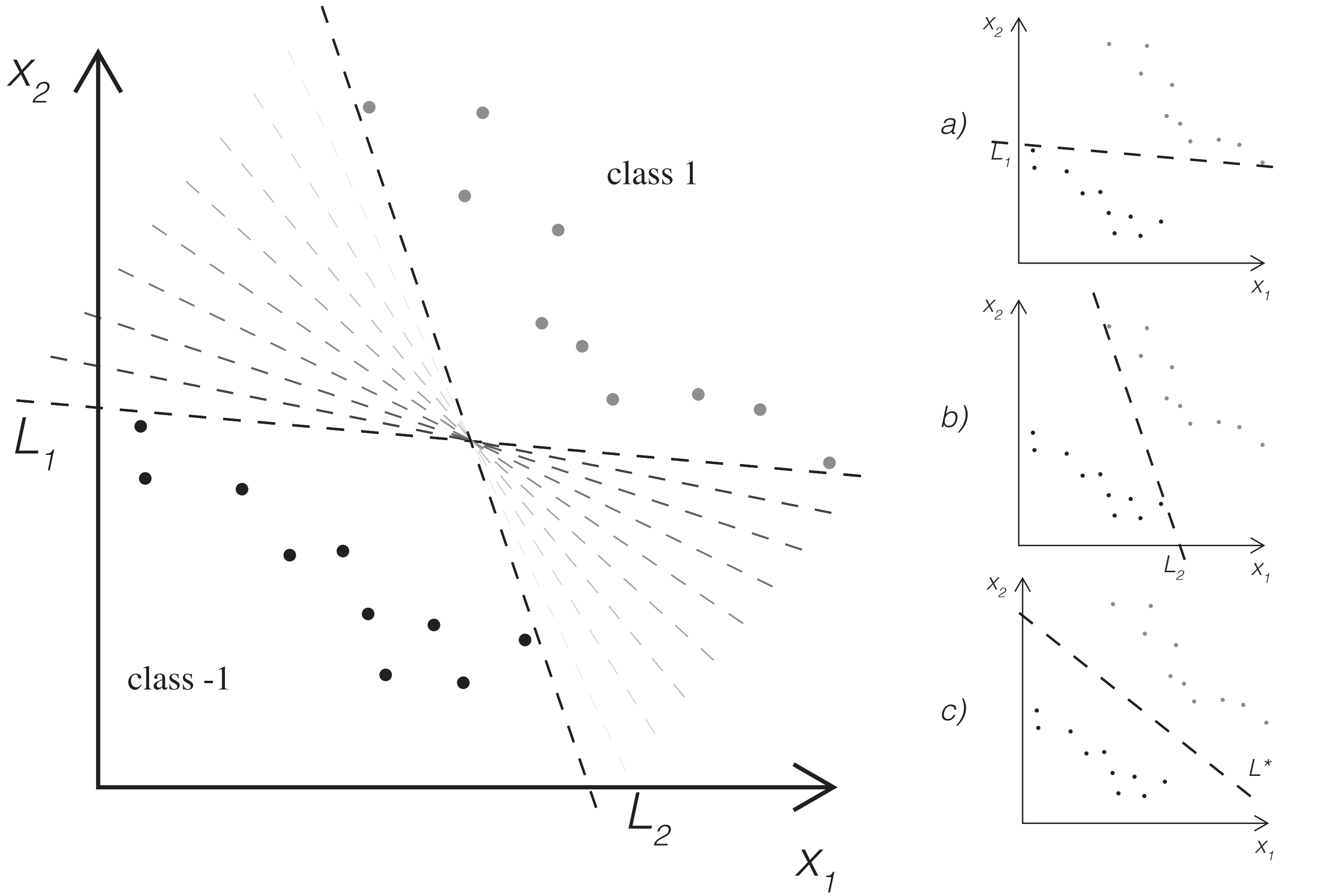
Machine Learning

Computational models perform:
1. Learning
2. Inference
3. Prediction

Comprised of:
1. Training examples
2. Model/mapping
3. Testing examples

To evaluate learning:
1. Build model
2. Test
3. Calculate error, adapt

Support Vector Machines



$$\underset{\mathbf{w},b}{\arg\min}\ \frac{1}{2}\mathbf{w}^{\mathrm{T}}\mathbf{w} \qquad \text{subject to} \quad y^i(\mathbf{w}^{\mathrm{T}}\mathbf{x}^i + b) \geq 1 \quad \forall i \tag{4.14}$$

[Cortes 1995]

successful classification depends on:

- mathematical separability of example data
  - note there are technically three “classes” of scans: *void*, *diffractions*, and *firn*
- soft margin for non-separability
- evenly distributed training data
- number of training examples

[Cortes 1995]

Processing

GPR Processing: Literature

– texture mapping [Torrione 2007]

– down sampling [van Kempen 1999], [Hsu 2002]

– image inversion* [Wilson 2007]

– feature-based (wavelets, fuzzy sets) [Cassidy 2009]

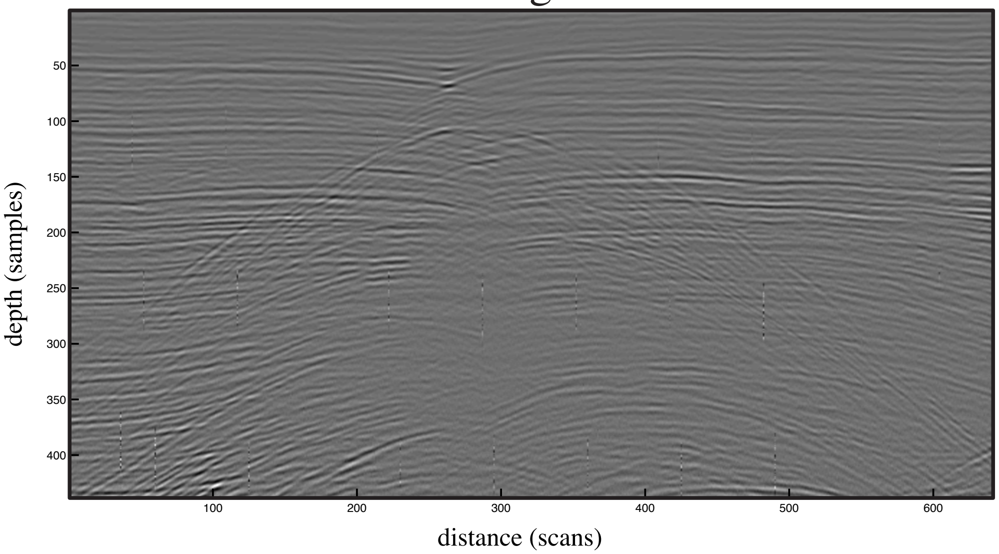
– adaptive algorithms (kalman filter, contrast stretch*) [Torrione 2006]

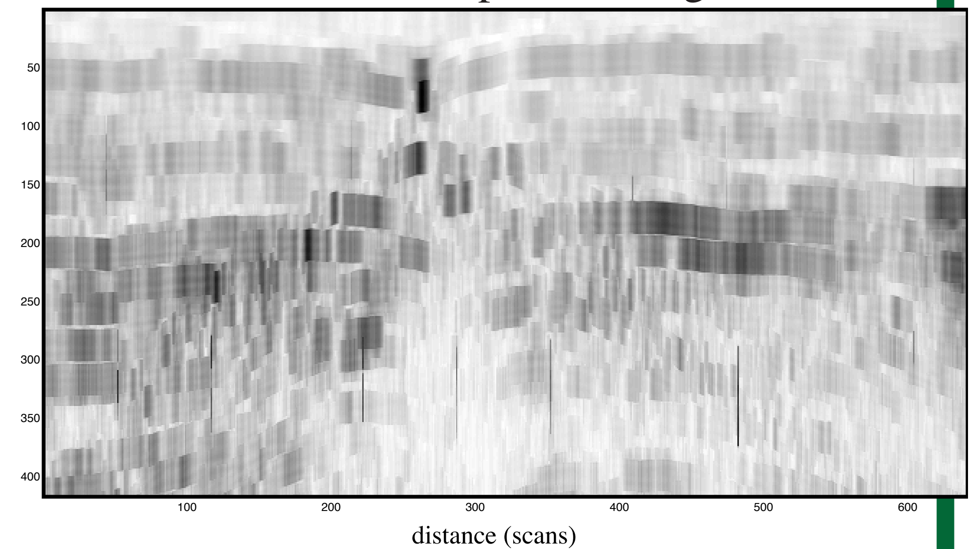
– edge histogram detection* [Torrione 2007]

– spectral analysis* [Wilson 2007]

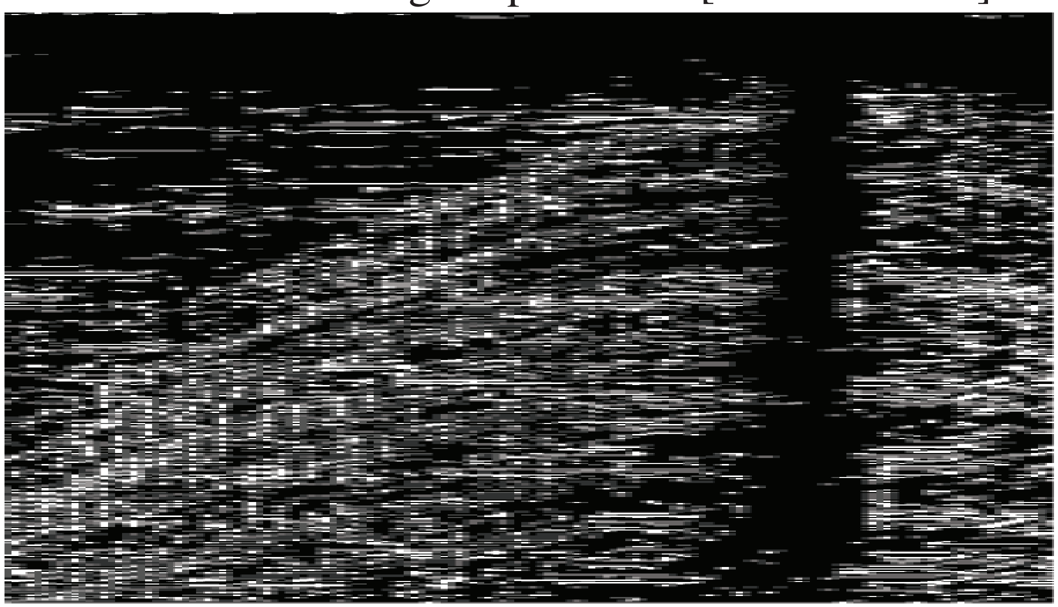
, * requires entire radargram

Processing





Texture feature coding adapted from [Torrione 2004]

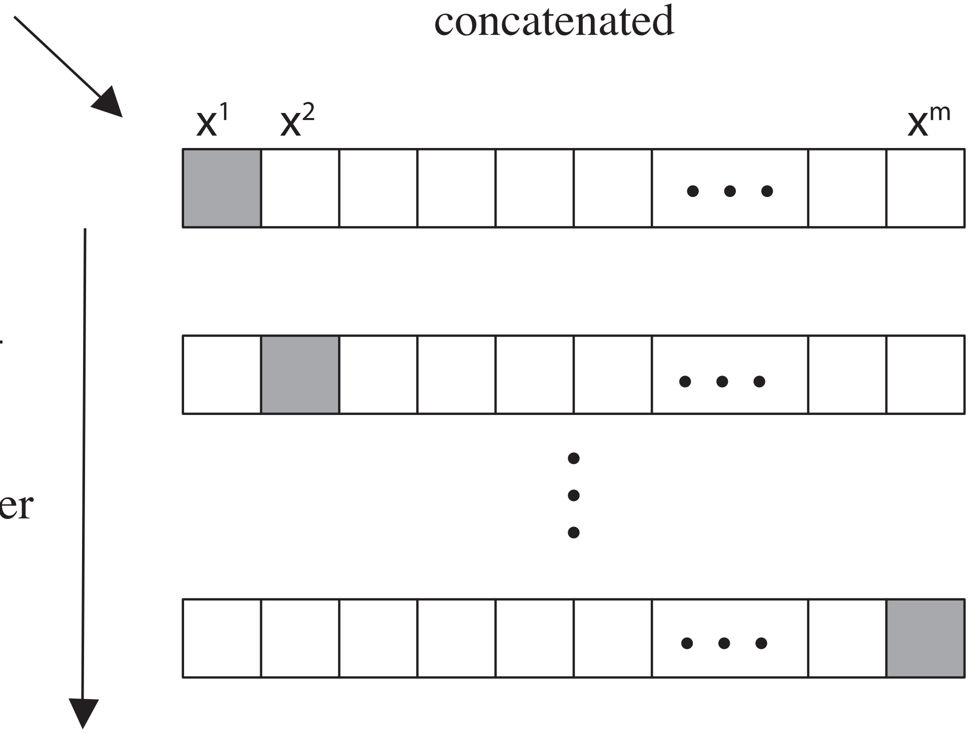


Results

Model Validation:
Leave-one-out Cross Validation (LOOCV)

each block: one crevasse example x^i

gray block: testing example
rest of blocks: training examples, concatenated

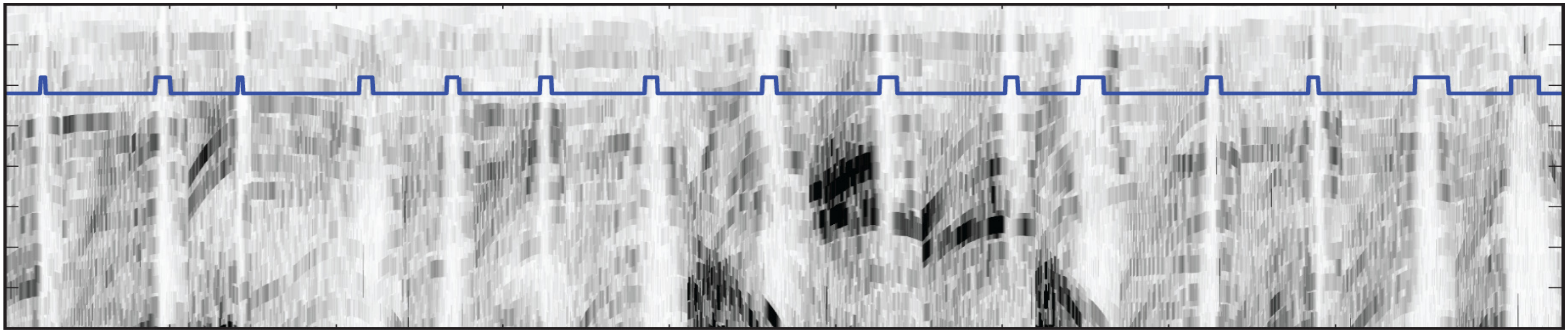


each array: one "leave-out" iteration

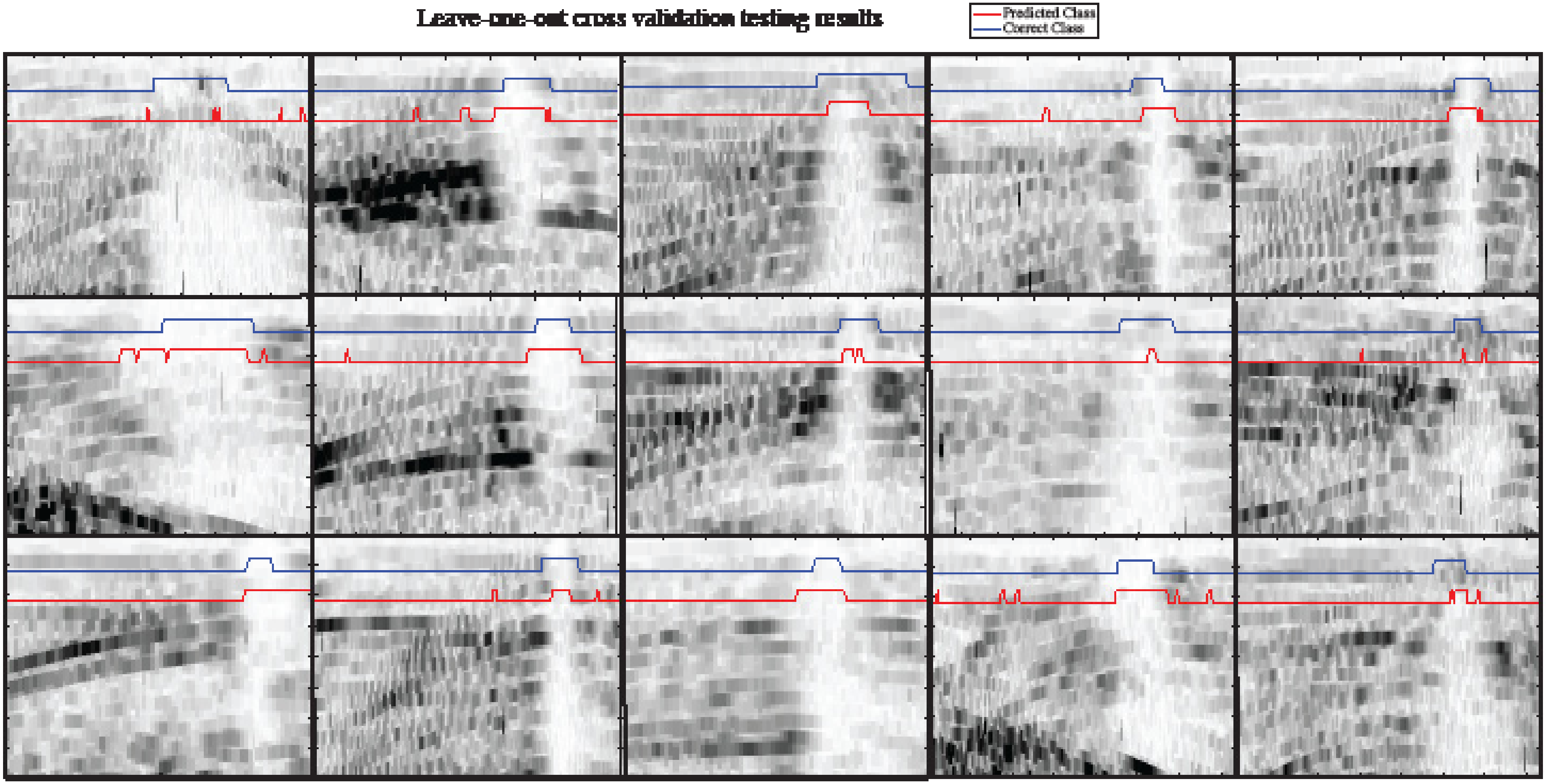
total iterations = number of crevasse examples

LOOCV approximates the generalization error when averaged OR
how the model will perform on an independent test data set

“Down Sampled” Training Set

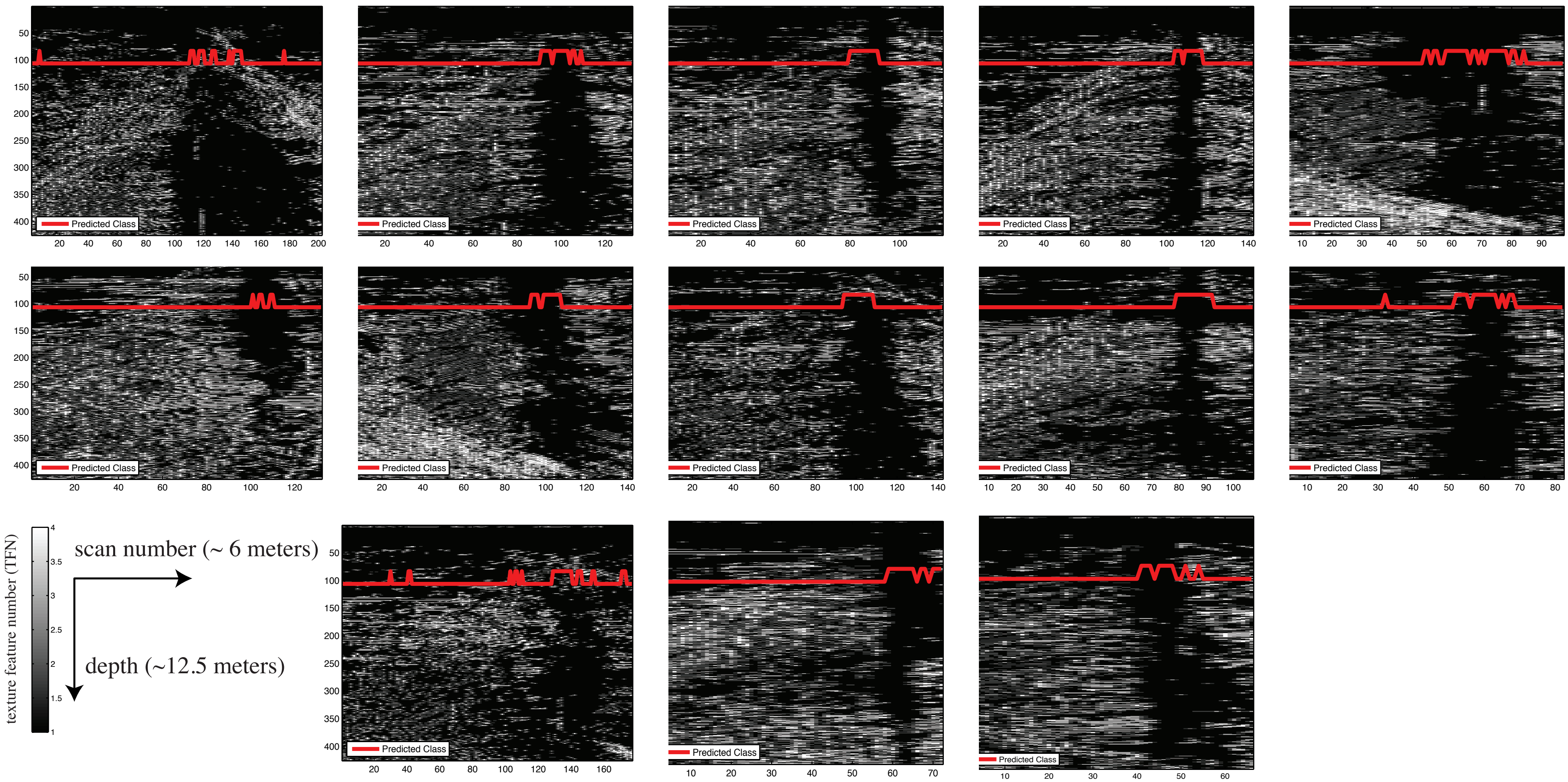


Leave-one-out cross validation testing results



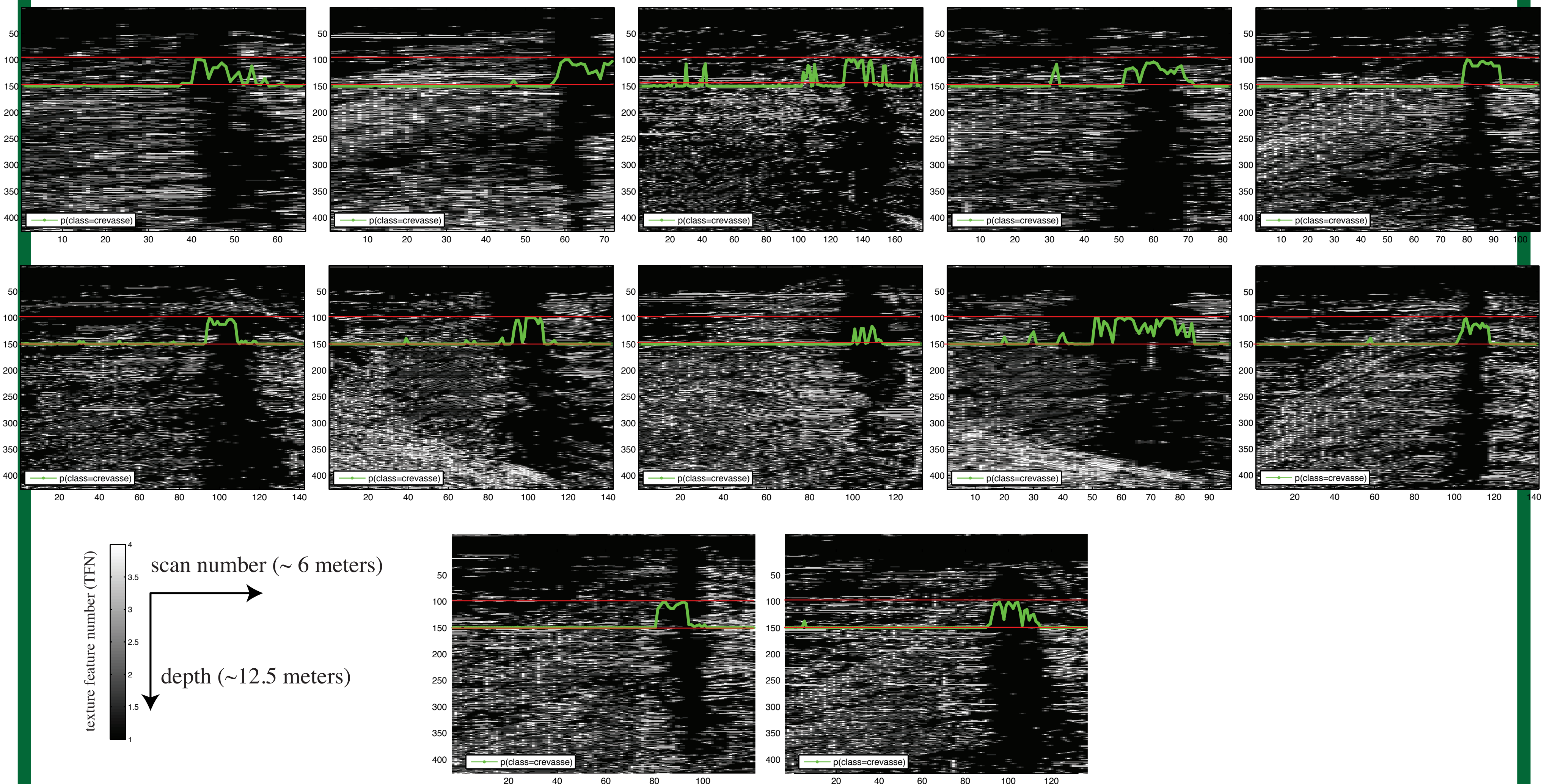
Results:
Texture Feature Number SVM

Texture Feature Number (TFN) Cross Validation Results



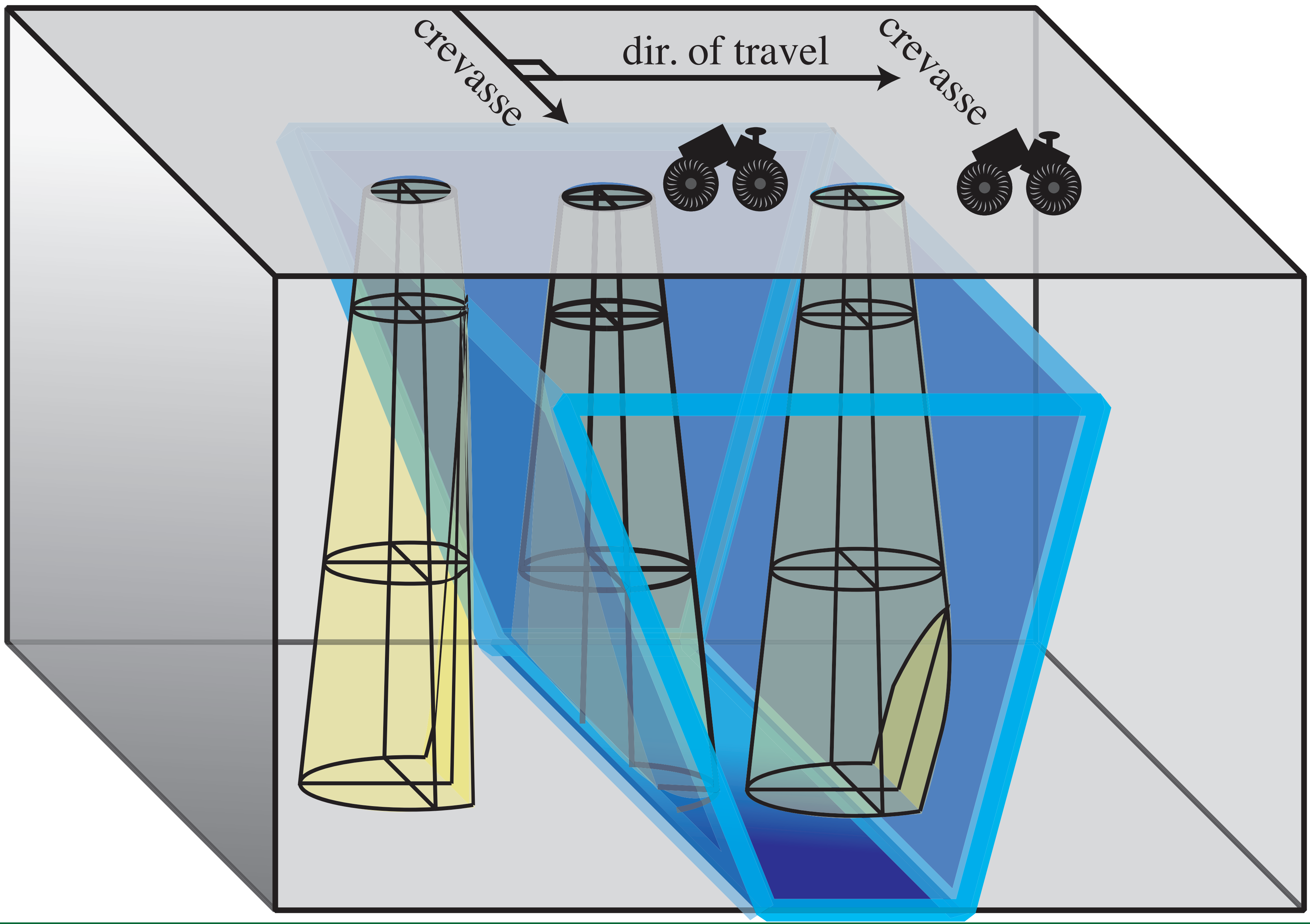
Results:
SVM Probability Extimates

Texture Feature Number (TFN) Cross Validation Probability Estimates

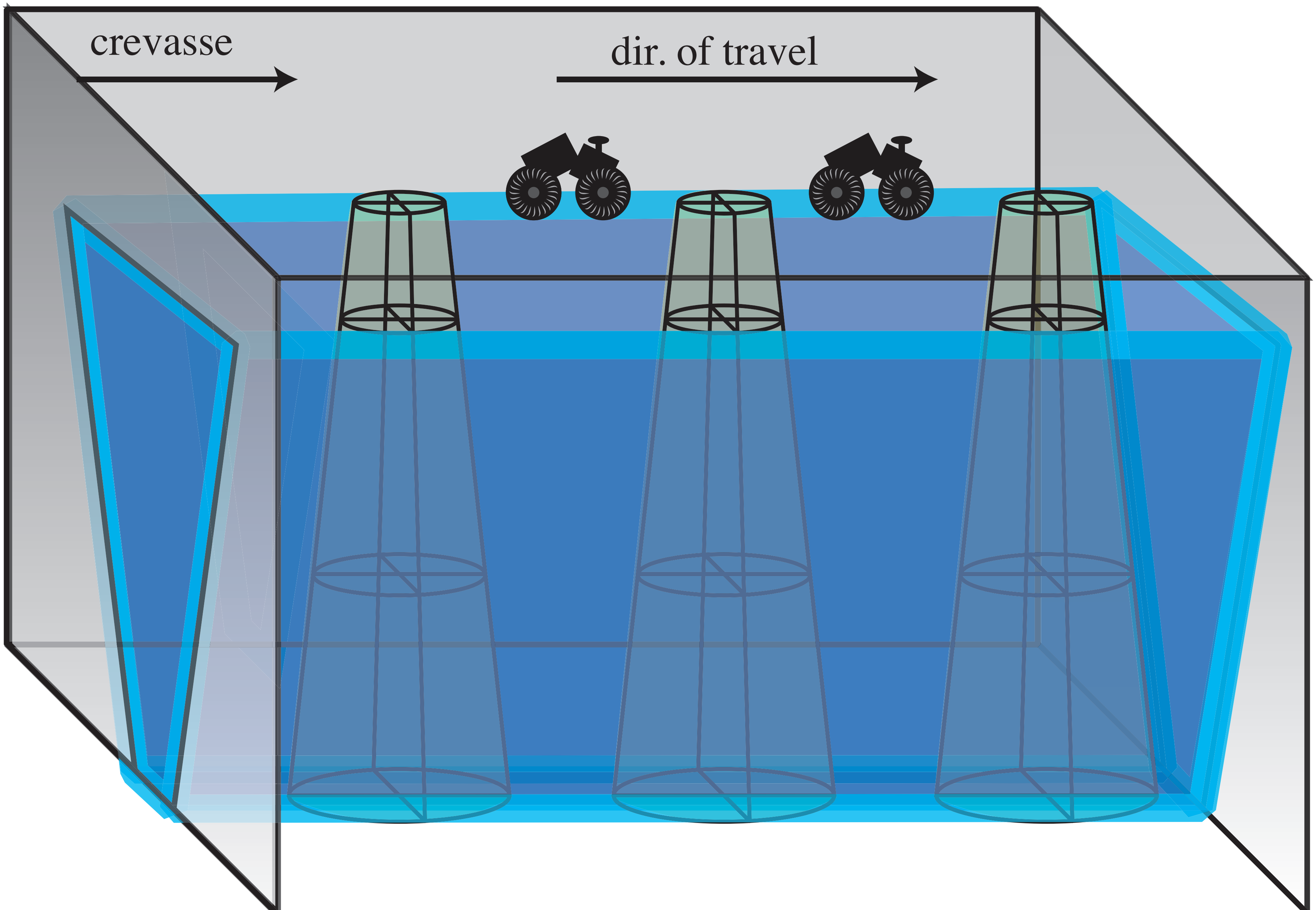


Next Steps

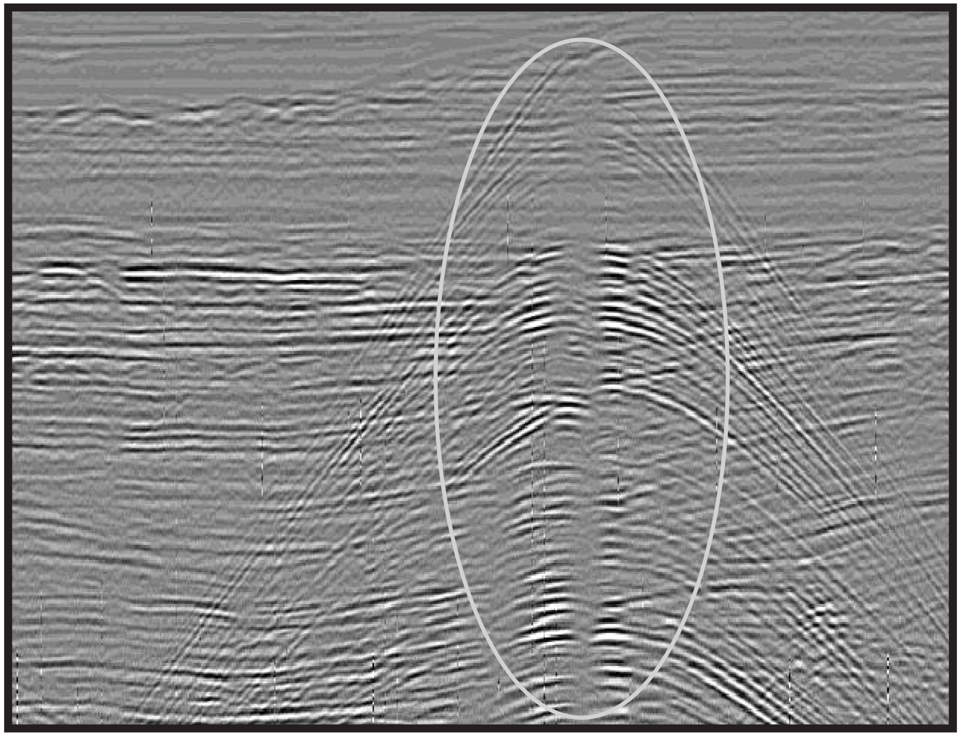
Large Strike Angle



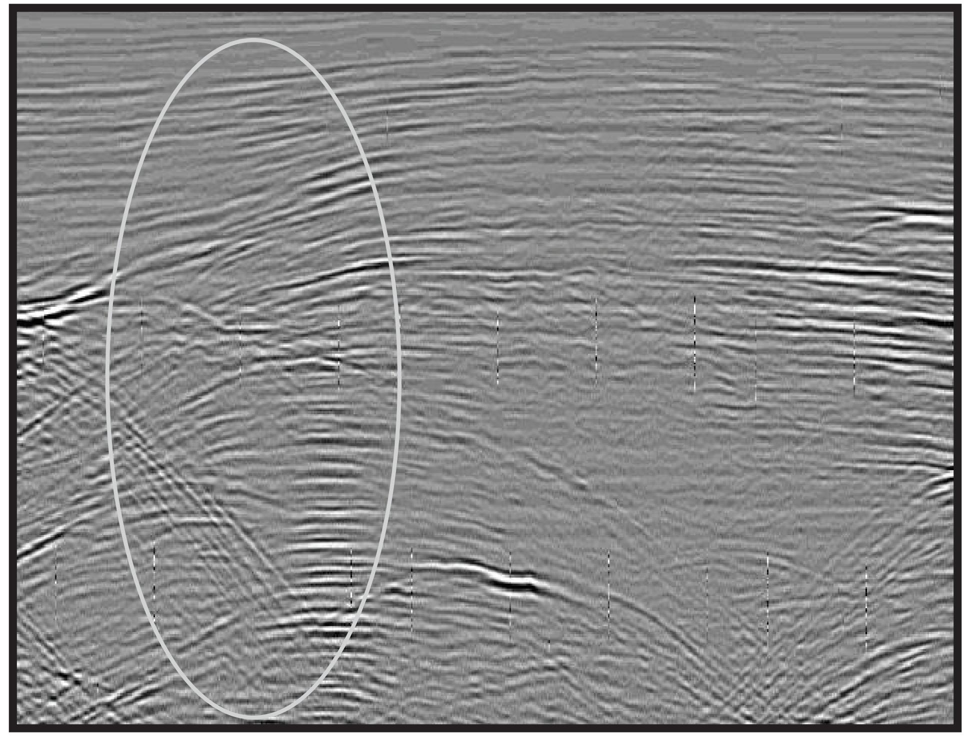
Shallow Strike Angle



Strike Angle

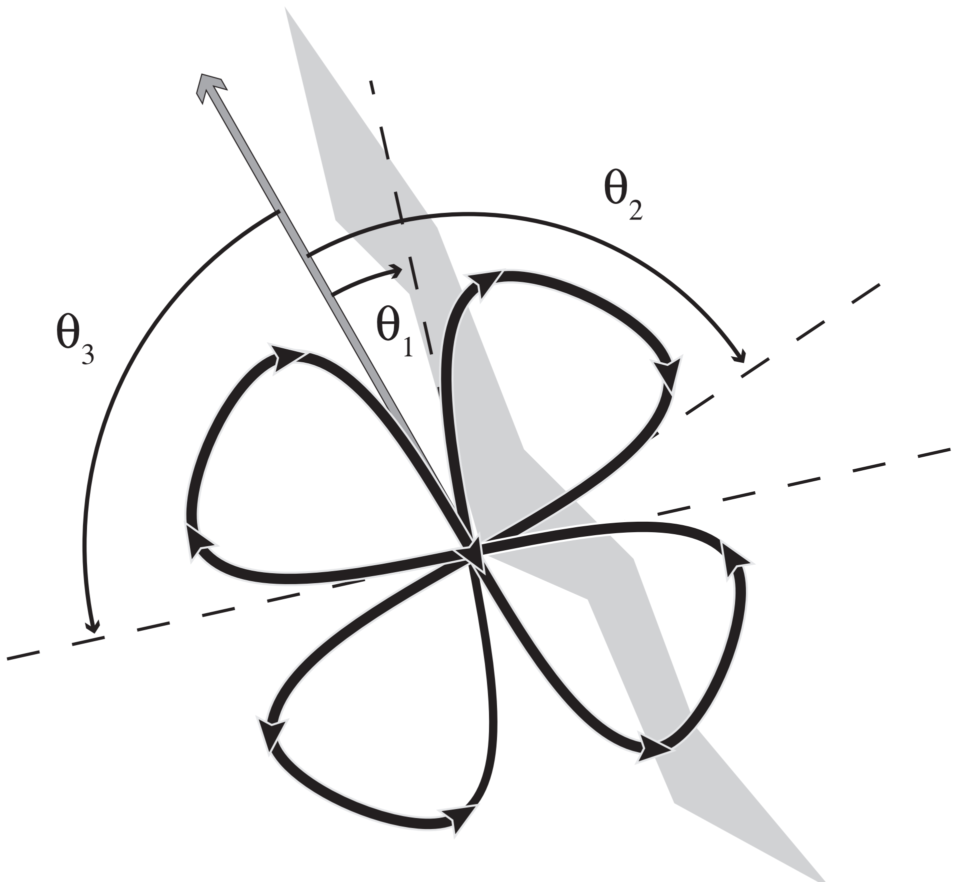


near-perpendicular (wide) strike angle

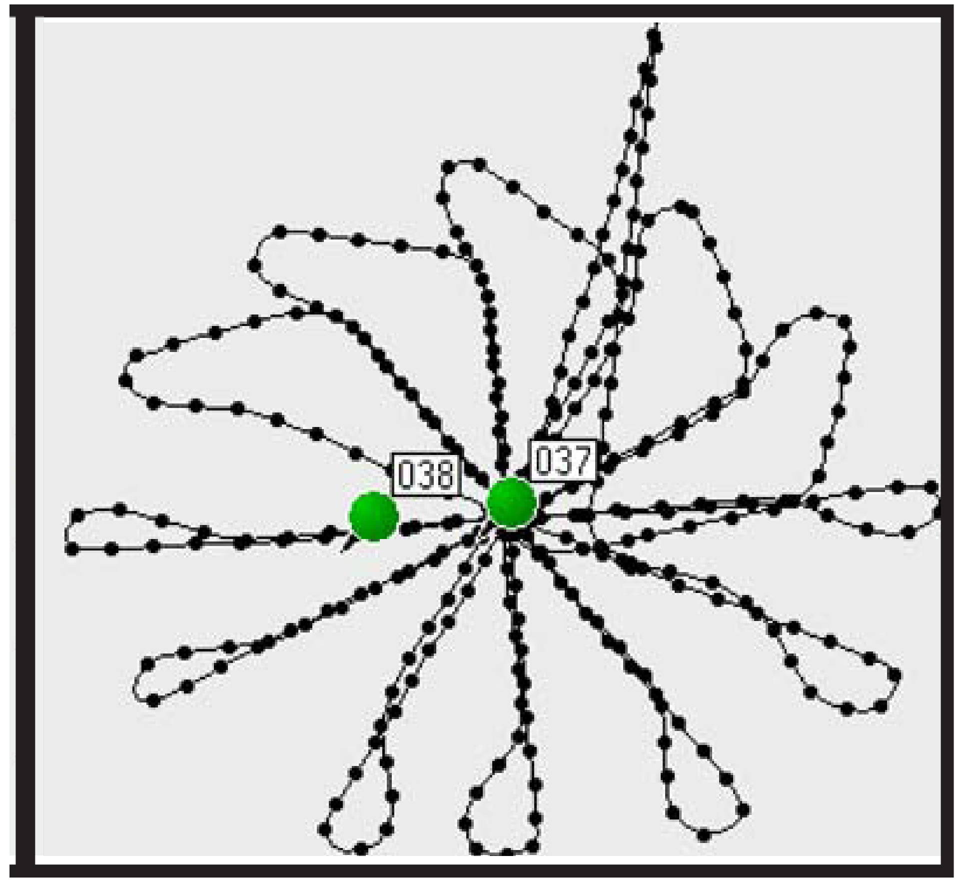


near-parallel (shallow) strike angle

Rosettes



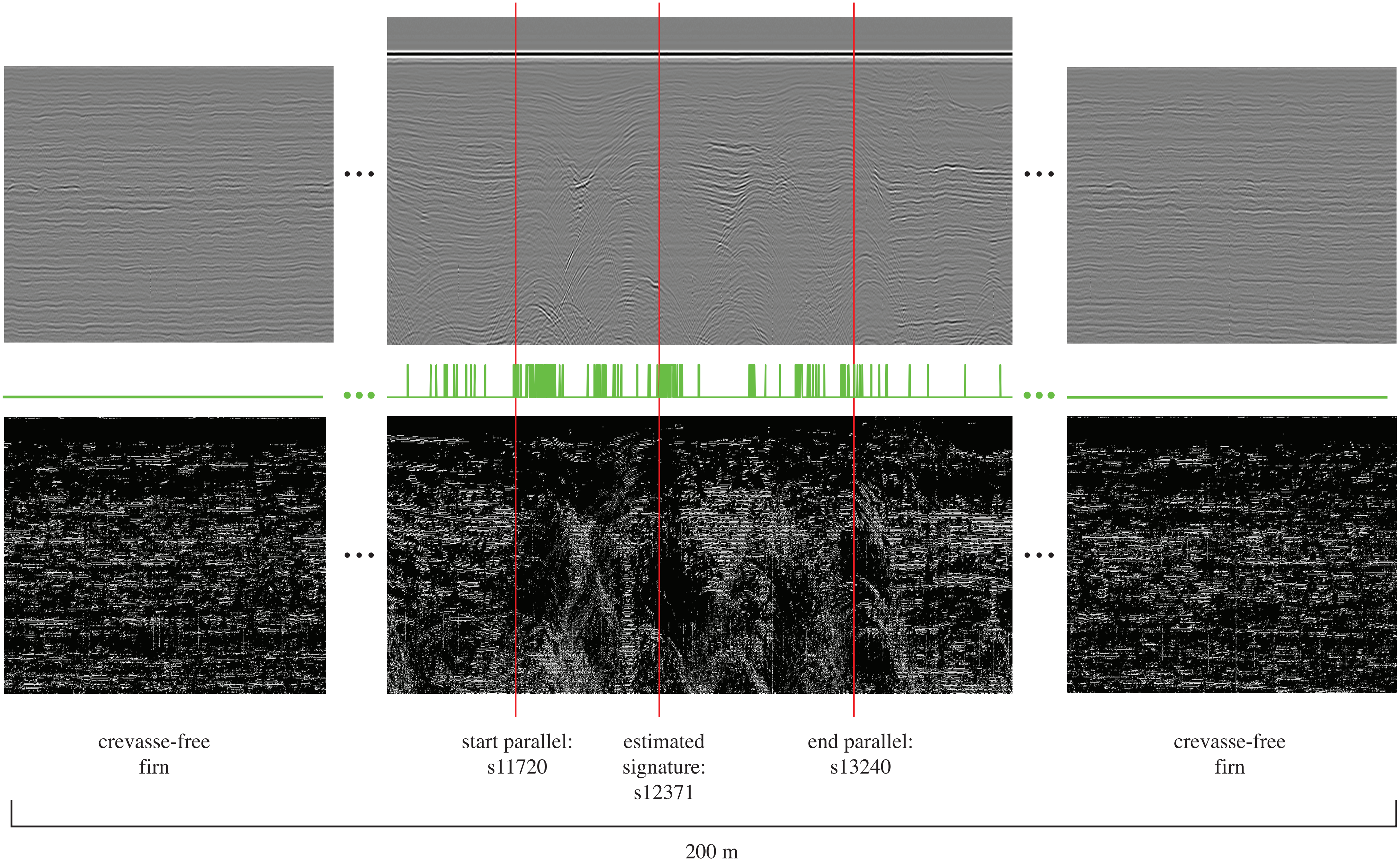
robot path
strike angle w.r.t. reference
crevasse angle = reference



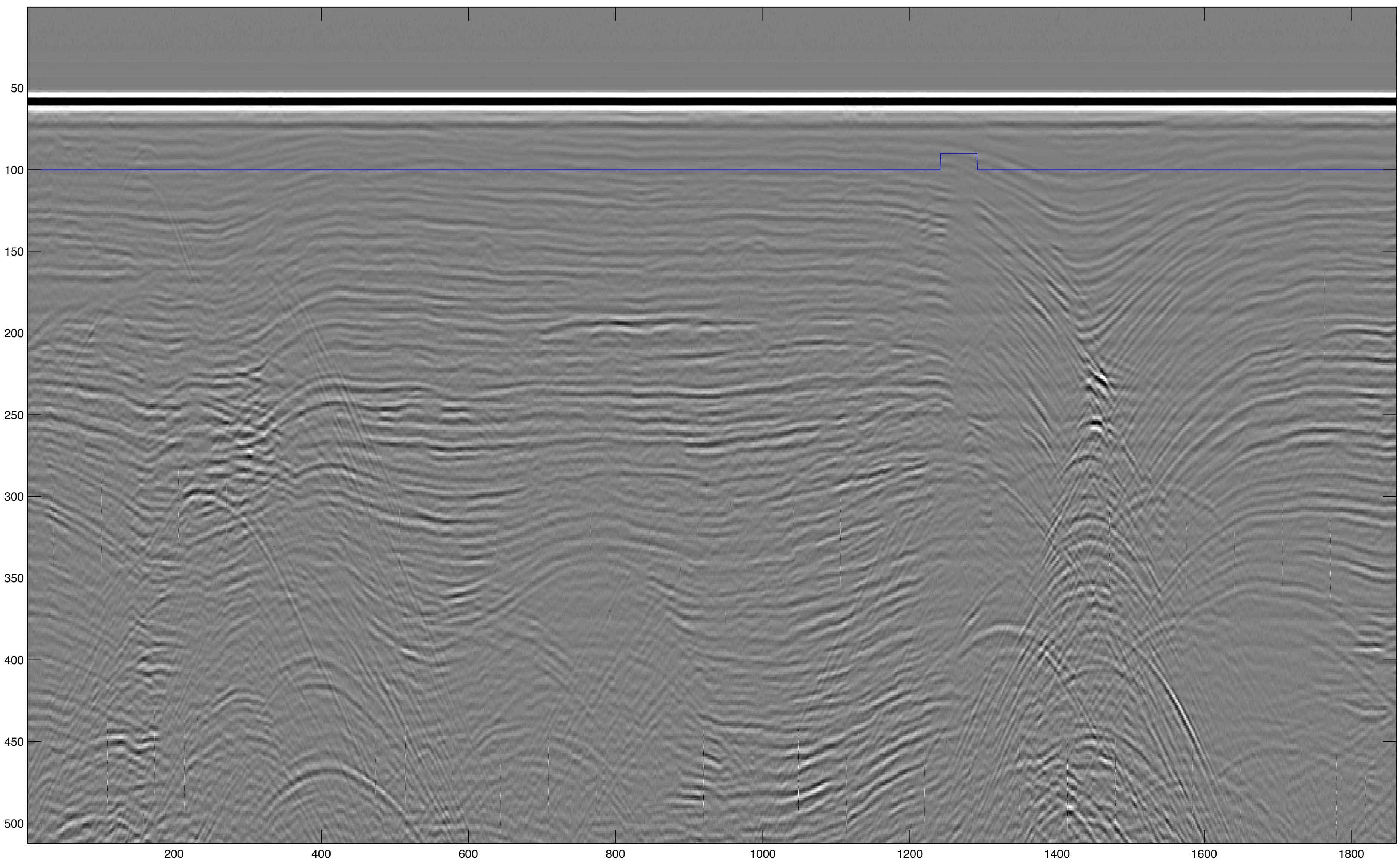
[Trautmann, 2011]

question: will crevasse spacing interfere?

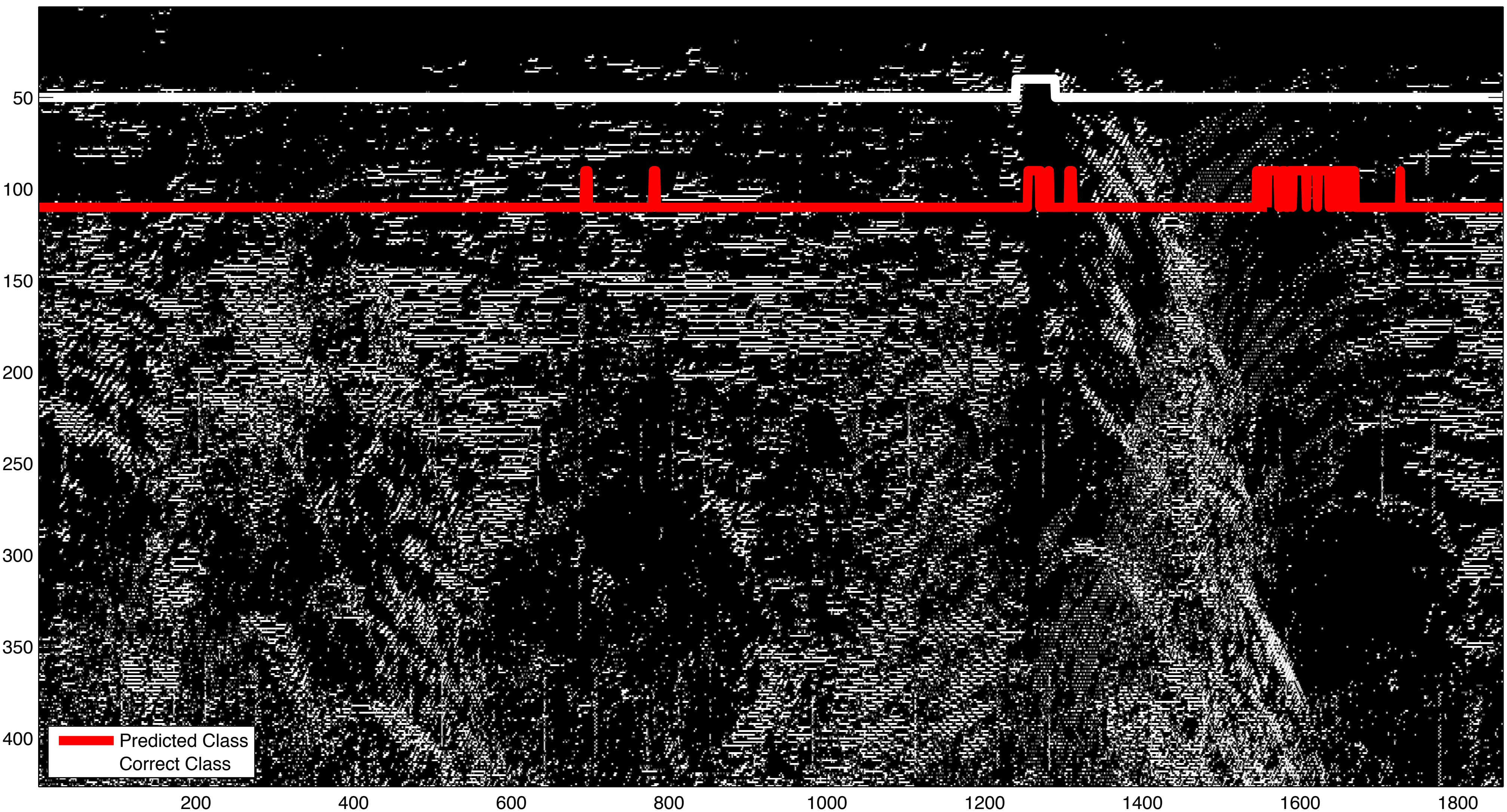
Strike Angle: 0 degrees (estimated)



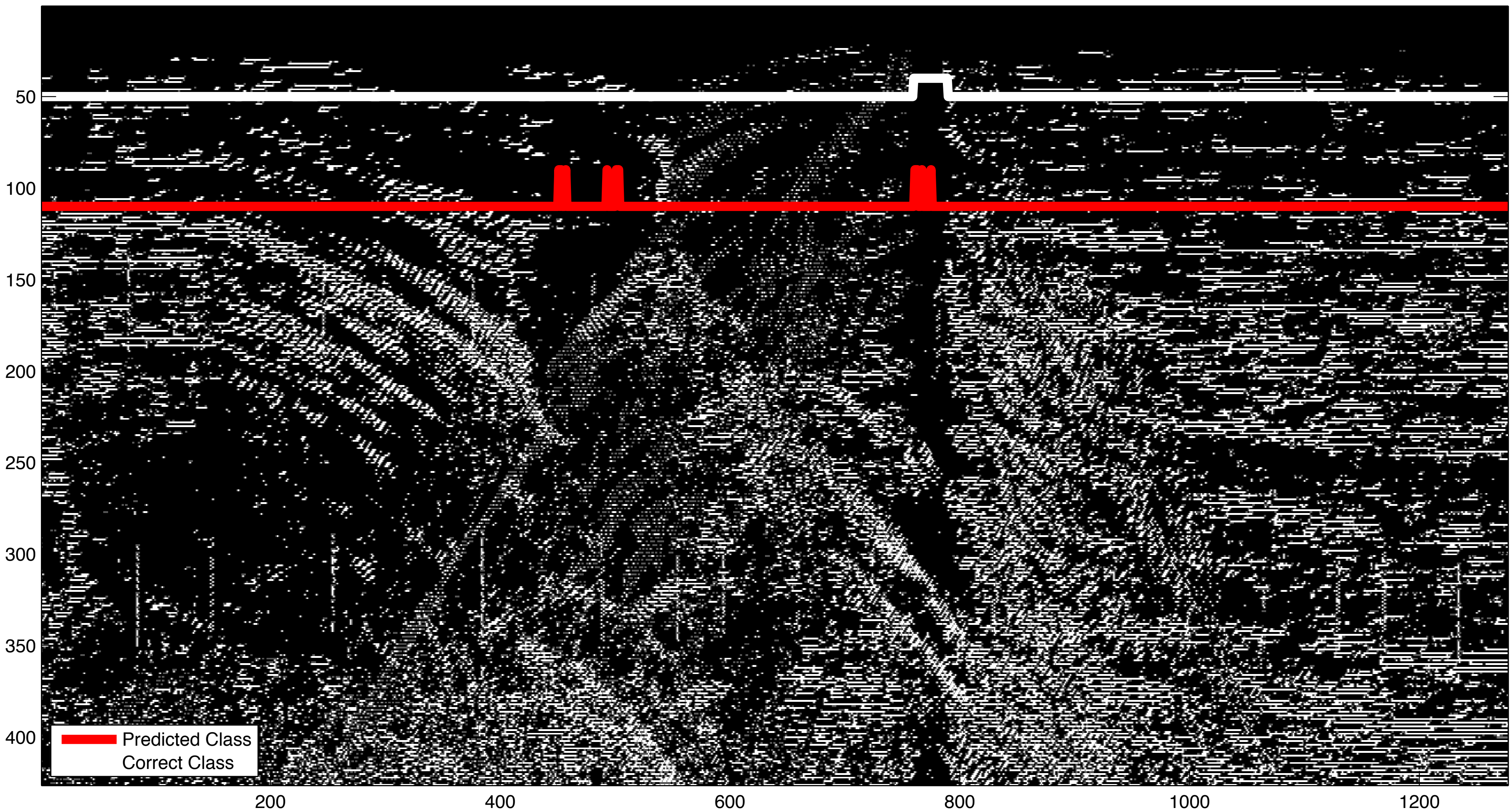
Strike Angle: 30 degrees (estimated)



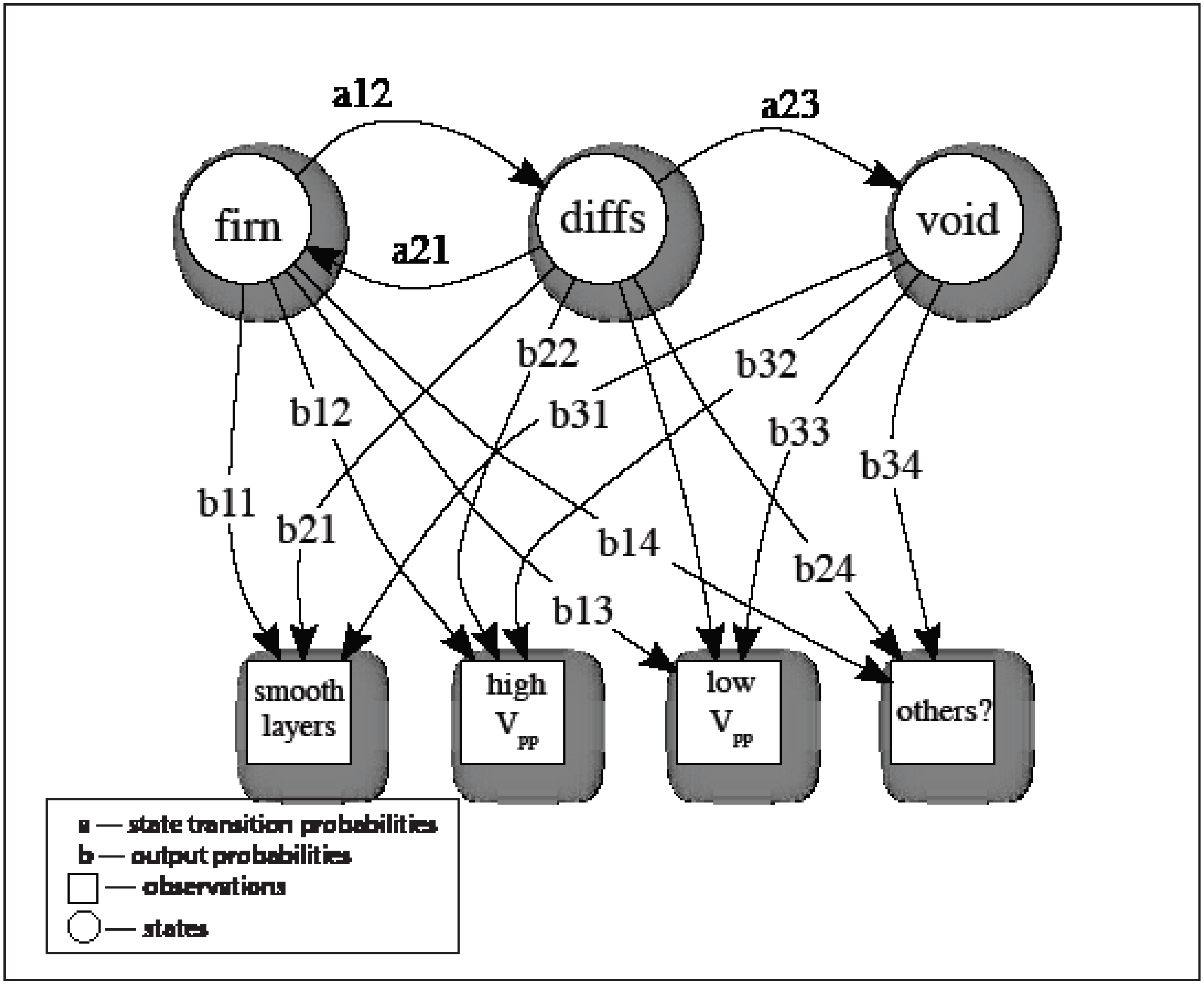
Strike Angle: 30 degrees (estimated)



Strike Angle: 60 degrees (estimated)



Hidden Markov Models for Strike Angle



[Rabiner 1989]

References

N. J. Cassidy, "Ground Penetrating Radar Data Processing, Modelling and Analysis," in Ground Penetrating Radar: Theory and Applications (H. M. Jolt, ed.), ch. Chapter 5, pp. 141–176, Elsevier, 2nd ed., 2009.

J.N.Wilson,P.Gader,W.-H.Lee,H.Frigui,andK.C.Ho,"ALarge-ScaleSystematic Evaluation of Algorithms Using Ground-Penetrating Radar for Landmine Detection and Discrimination," IEEE Transactions on Geoscience and Remote Sensing, vol. 45, pp. 2560–2572, Aug. 2007.

H. Frigui, K. C. Ho, and P. Gader, "Real-Time Landmine Detection with Ground- Penetrating Radar Using Discriminative and Adaptive Hidden Markov Models," EURASIP Journal on Advances in Signal Processing, vol. 2005, no. 12, pp. 1867– 1885, 2005.

P. Torrione and L. M. Collins, "Texture Features for Antitank Landmine Detection Using Ground Penetrating Radar," IEEE Transactions on Geoscience and Remote Sensing, vol. 45, pp. 2374–2382, July 2007.

C. Cortes and V. Vapnik, "Support-Vector Networks," Machine Learning, vol. 20, pp. 273–297, 1995

T. Jebara, Discriminative, Generative and Imitative Learning. Ph.d., MIT, 2002

L. Rabiner, "A Tutorial on Hidden Markov Models and Selected Applications in Speech Recognition," Proceedings of the IEEE, vol. 77, no. 2, pp. 257–286, 1989

C.-W. Hsu and C.-J. Lin, "A comparison of methods for multiclass support vector machines.," IEEE transactions on neural networks / a publication of the IEEE Neural Networks Council, vol. 13, pp. 415–25, Jan. 2002.

L. van Kempen and H. Sahli, "Ground Penetrating Radar Data Processing: A Selec- tive Survey of the State of the Art Literature," tech. rep., Vrije Universiteit Brussel, Brussels, 1999

T. M. Mitchell, "The Discipline of Machine Learning," Machine Learning, no. July, 2006.

C. Bishop, Pattern recognition and machine learning. Information science and statis- tics, Springer, 2006.

C. Horng, "Texture Feature Coding Method for Texture Classification", Optical Engineering, 2003

Acknowledgements

Laura Ray
Jim Lever
Steve Arcone
Allan Delaney
Ken Corcoran
Eric Trautmann
Mary Albert
Ross Virginia
Bob Hawley
Mom and Dad