Duke UNIVERSITY

Ground Tracking in Ground Penetrating Radar

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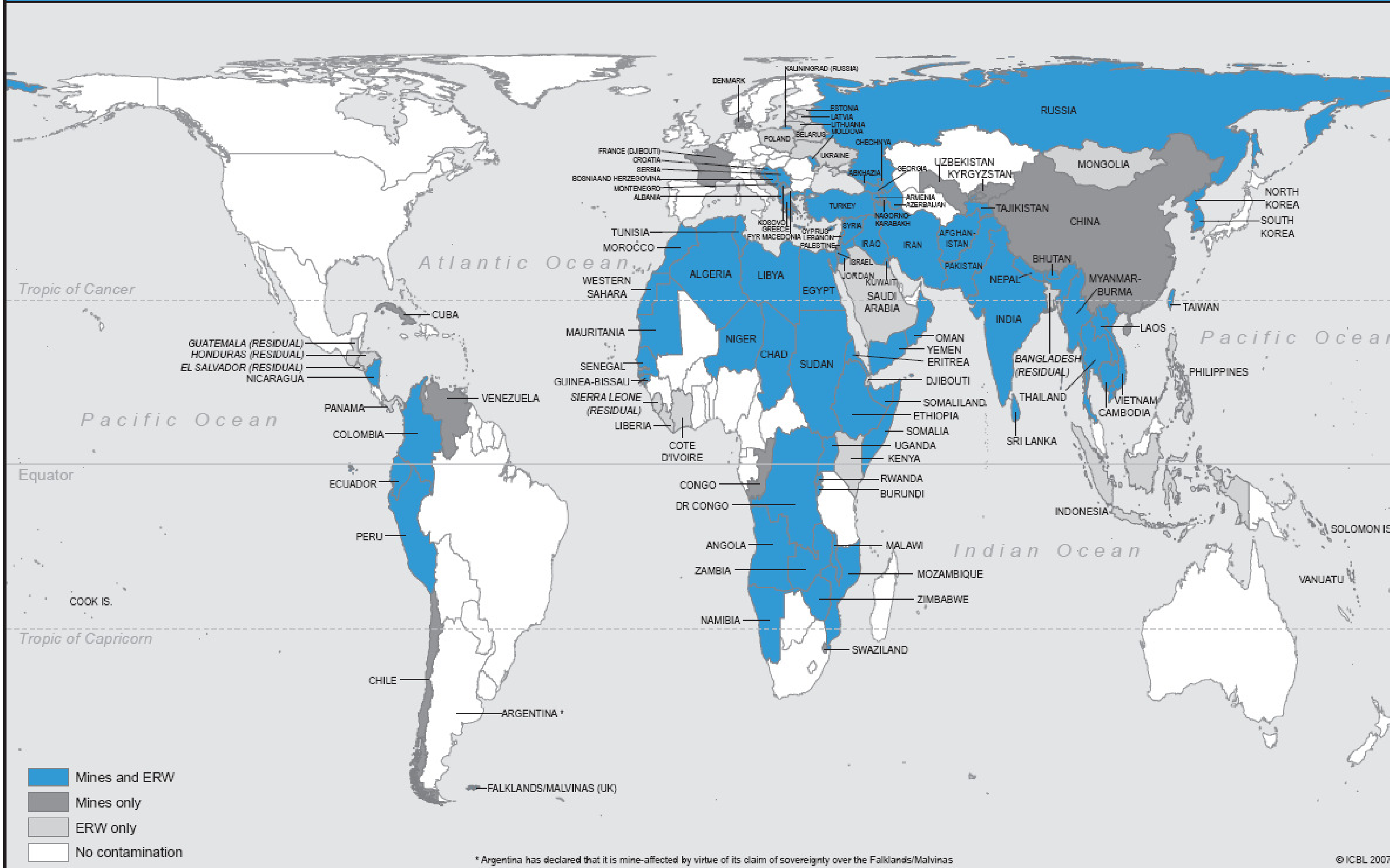
SSPACISS

The Landmine Problem

Global Contamination from Mines and Explosive Remnants of War (ERW)



Landmine Monitor Report, 2007

Cost of Landmine Detection

- Demining is a high-risk and high-cost operation
  - Costs ~$1,000 to remove and disarm a $3 mine (Machel, 1996)
  - Reducing the false alarm rate of a mine detection system is a major area of research
- EMI ("metal detector") sensor modalities are the most common today
  - Due to large amount of metallic clutter in postwar regions, EMI has high false alarm rates

Ground Penetrating Radar (GPR)

- Detects subsurface objects by measuring reflections of an electromagnetic pulse
  - Reflections caused by changes in electrical properties (ε,μ)
- Easily detects nonmetal targets
  - Unlike conventional EMI "metal detector" sensors

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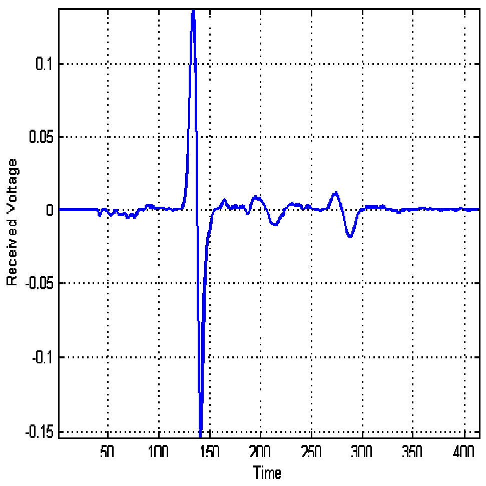
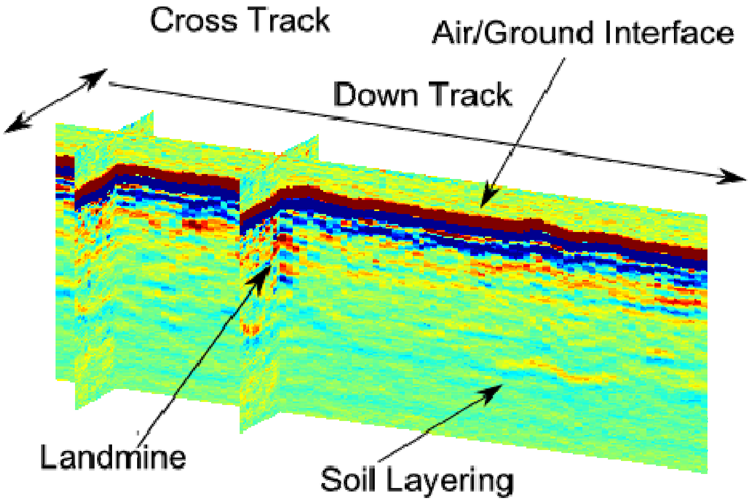
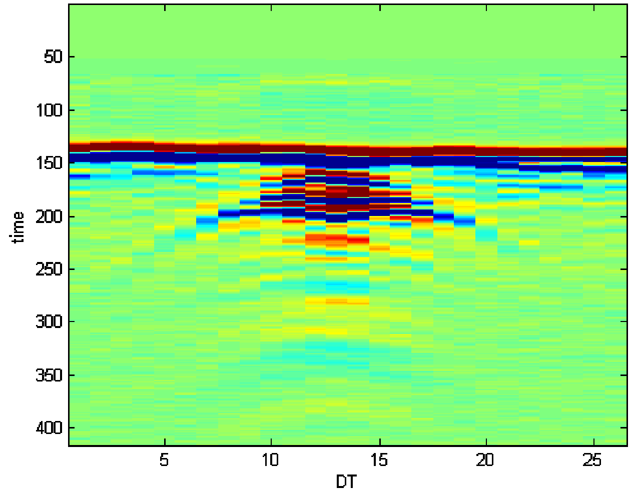
Examples of GPR Data

Sample A-scan

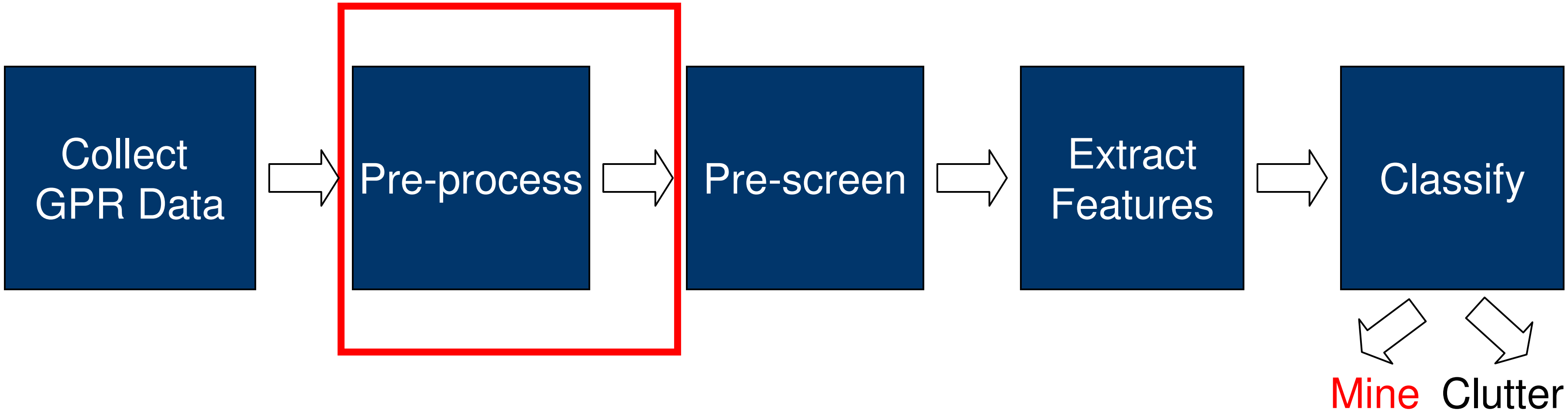




Sample B-scan



Processing GPR Data

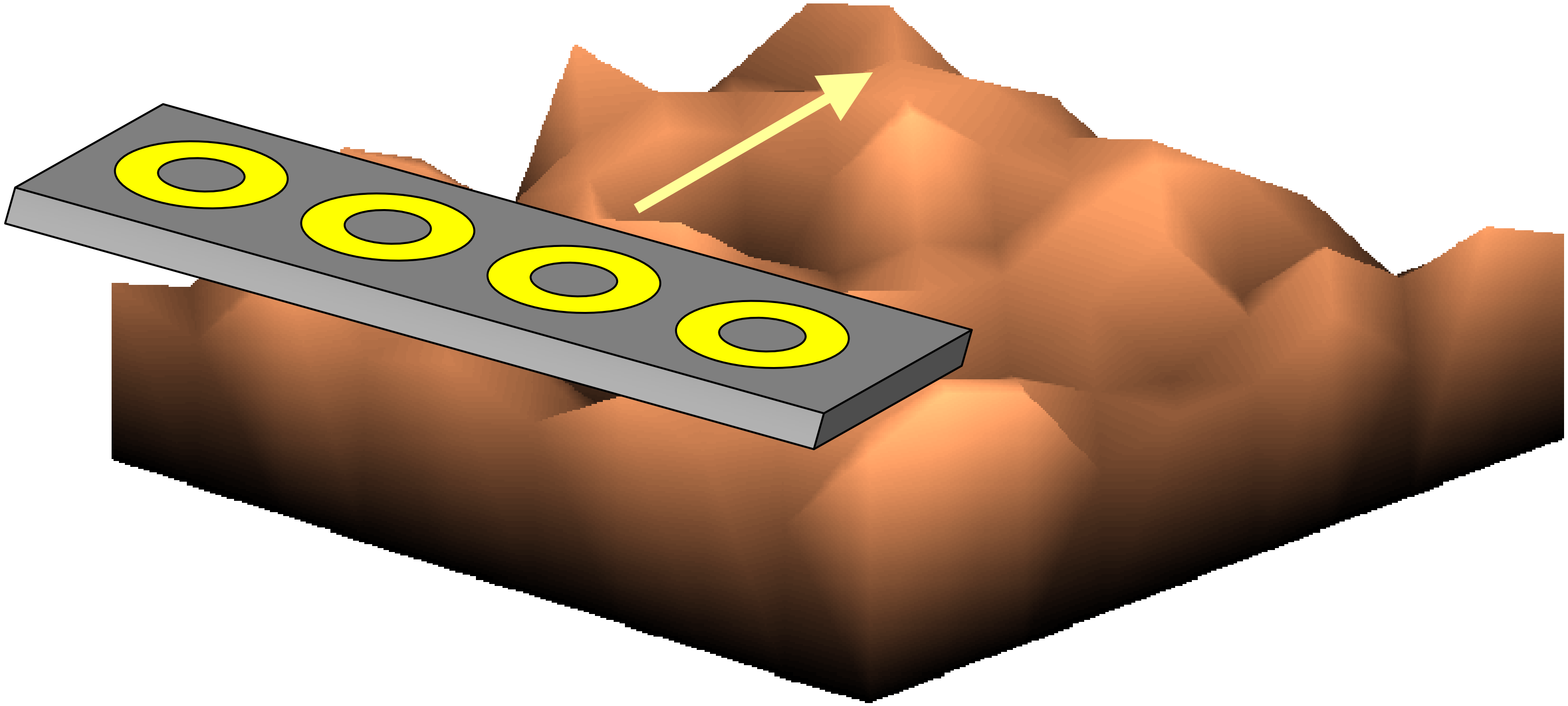


- After data is collected, preprocessing is performed to filter out noise and align "ground-bounce"
- Prescreening algorithm finds anomalies in the data that may be mine signatures
- A feature-based classification algorithm decides whether the "alarms" are the result of landmines or non-mine objects (clutter).

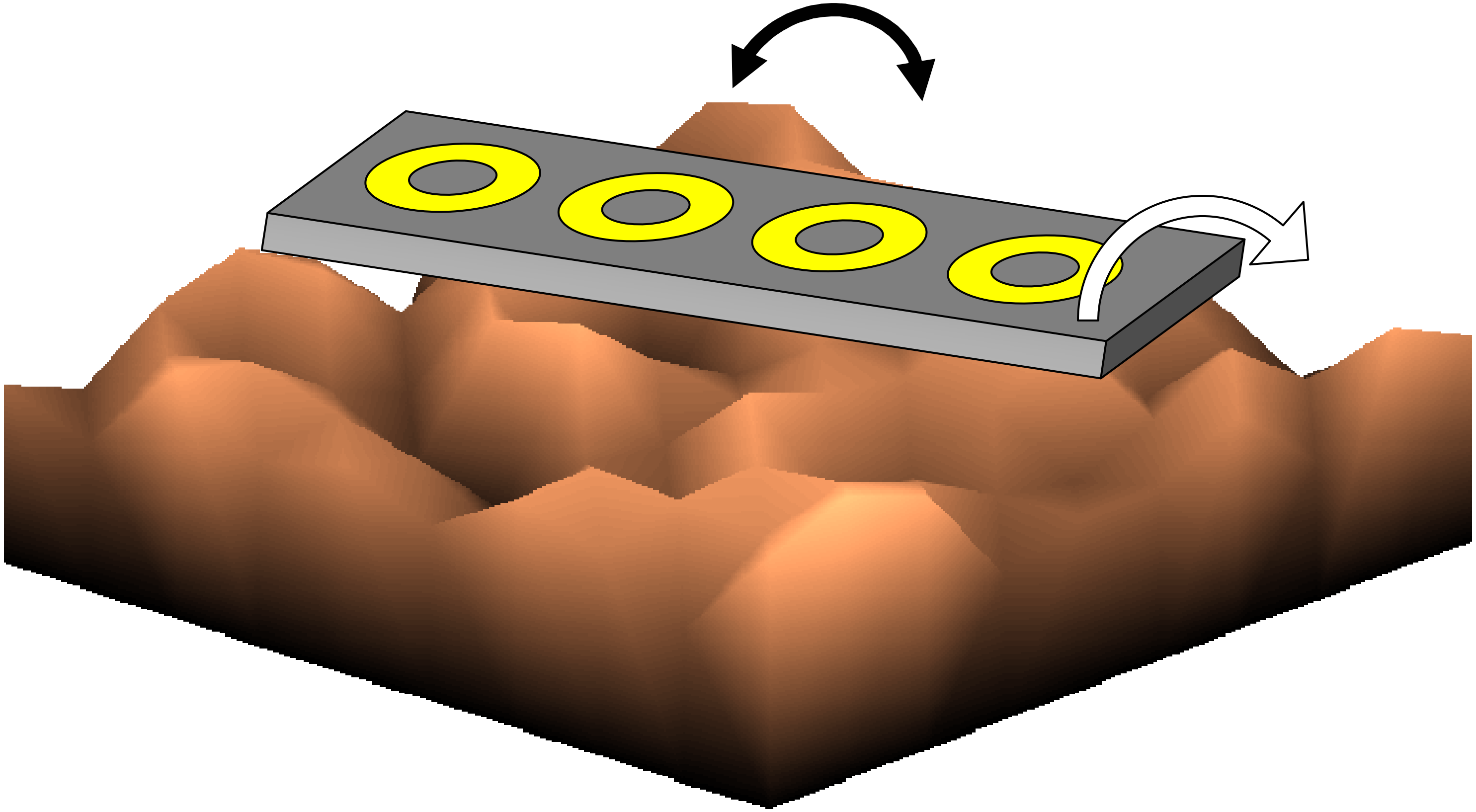
Factors Complicating GPR Data Interpretation

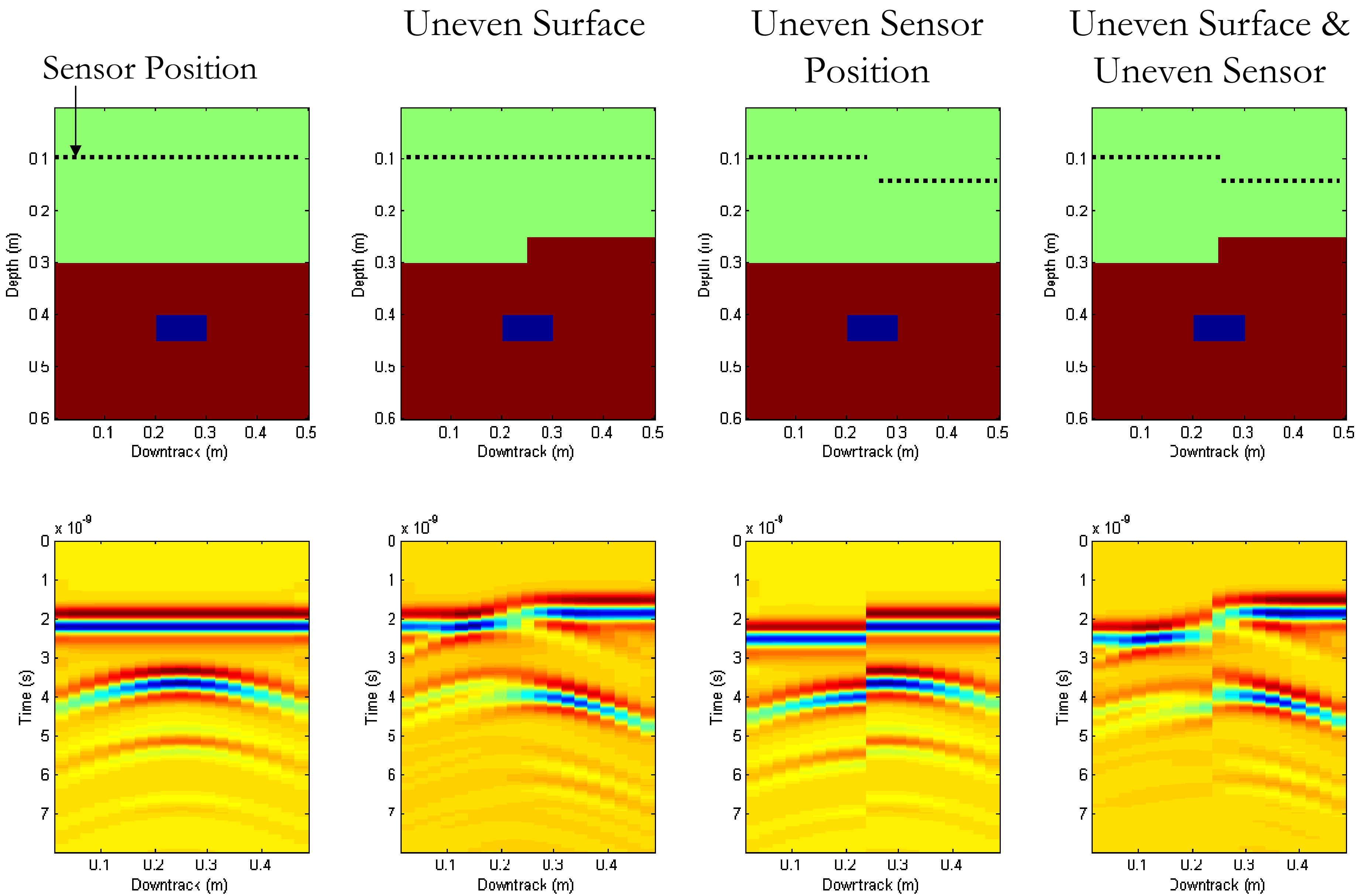
- Sensor positional uncertainty
- Ground height variation
- Surface clutter
- Shallow-buried mines

Level Sensor, Rough Surface



Uneven Sensor, Uneven Surface



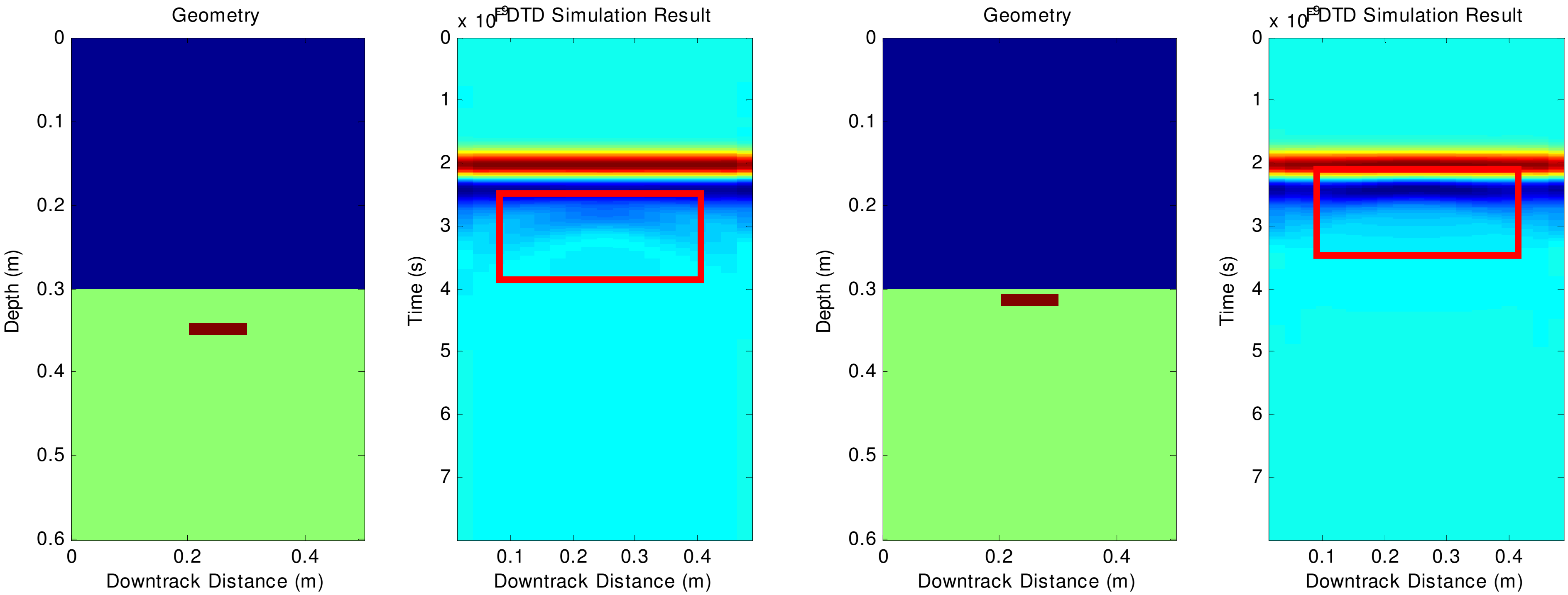

Sensor Position
Uneven Surface
Uneven Sensor Position
Uneven Surface & Uneven Sensor
Depth (m)
0.1
0.2
0.3
0.4
0.5
0.6
Downtrack (m)
0.1
0.2
0.3
0.4
0.5
x 10^-9
Time (s)
0
1
2
3
4
5
6
7

Surface Clutter

Mine Field at Golan Heights

Photo by David Shay, Under GNU Free Documentation License

Shallow-buried Target



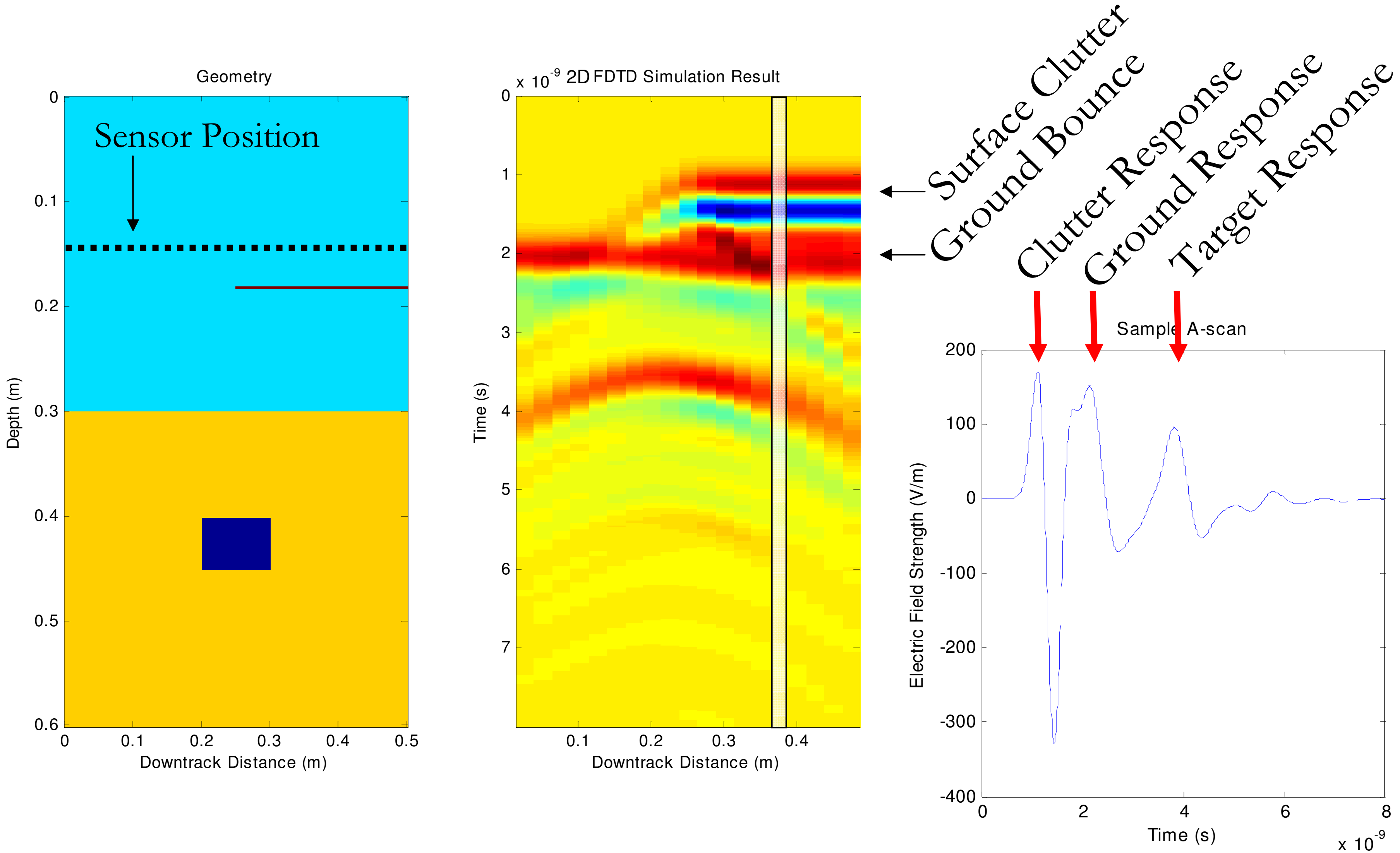
Ground Bounce
Obscures Target

The Problem Summary

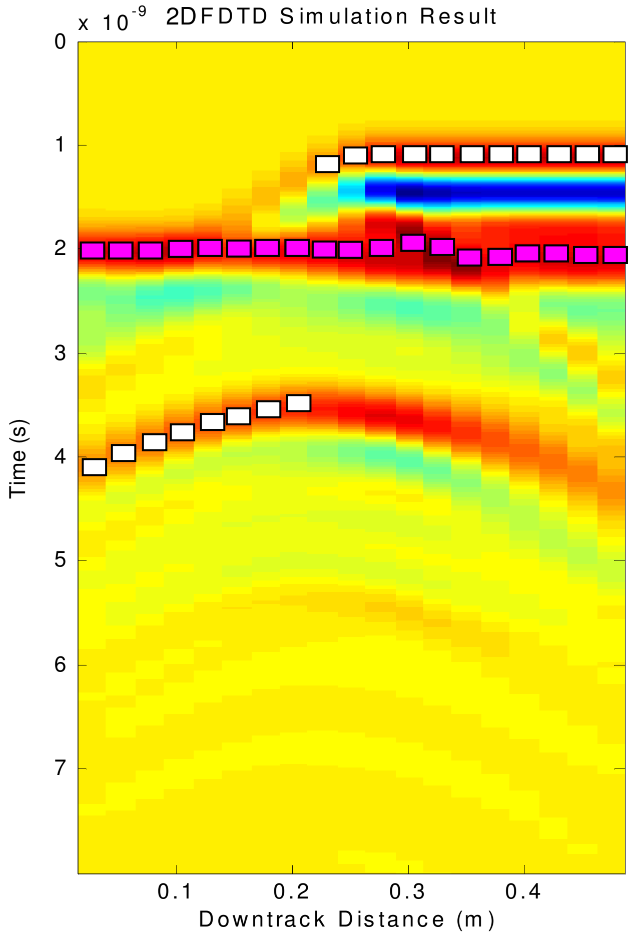
- Surface clutter
- Shallow-buried mines – Mixed into the ground-bounce
- Ways to remediate:
  - Ground alignment and ground bounce removal
- Knowledge of ground height and sensor height (ground tracking) is needed for remediation
- Ground tracking is difficult because of:
  - Sensor positional uncertainty
  - Ground height uncertainty

The Approach

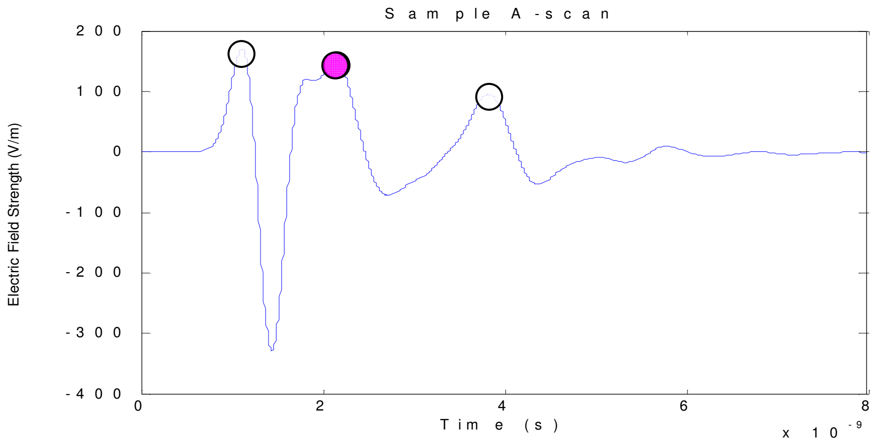
The Approach



The Approach



- Identify the largest local maxima in each A-scan of 3-dimensional FDTD data
- Choose the local maxima which maximizes an optimization criterion – this requires a model



A Model for the Ground

Ground Model

- Need a **tractable** method for estimating how "ground-like" a choice of local maxima are
- Gaussian Markov Random Fields (GMRFs) can be used as texture models (Chellapa, 1985), (Li, 2001)
- The GMRF is computationally tractable since it depends only on a neighborhood system
- The GMRF has tunable parameters that can be trained, and can create a wide variety of textures

[1] Torrione, Dissertation, 2008
[2] Torrione and Collins, SPIE, 2008

GMRF

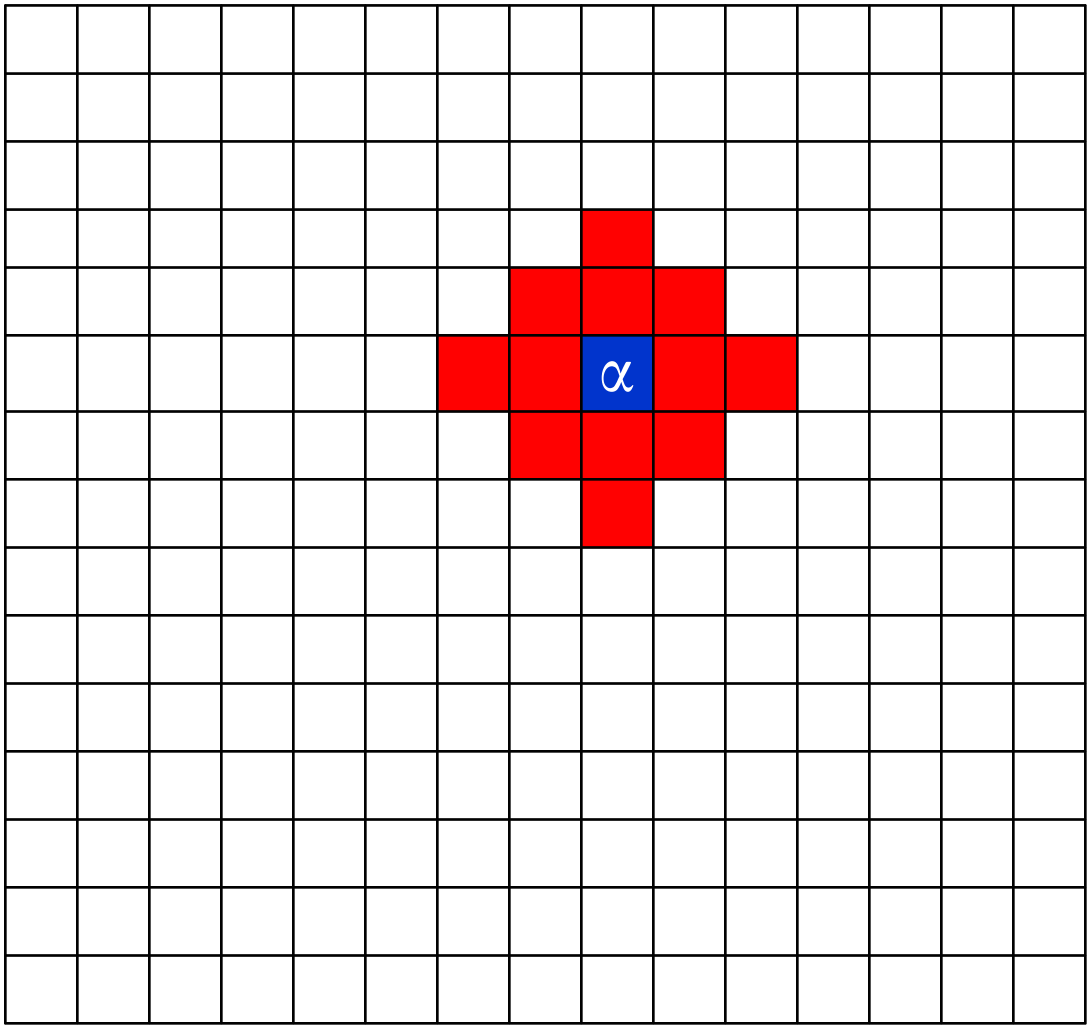
- Conditional probability distribution of a pixel given its neighborhood [1]:

$$p(f_i \mid f_{N_i}) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{ -\frac{1}{2\sigma^2} \left[f_i - \mu_i - \sum_{i' \in N_i} \beta_{i,i'} (f_{i'} - \mu_{i'}) \right]^2 \right\}$$

- Global pseudo-likelihood: $p_{pseudo}(f) = \prod_i p(f_i \mid f_{N_i})$

[1] Li,2001

Markov Random Field



Pixel of Interest: α

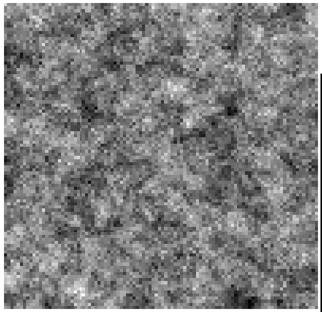
Neighbors

Conditionally Independent pixels

The distribution of α is conditionally independent of all other pixels given the neighborhood

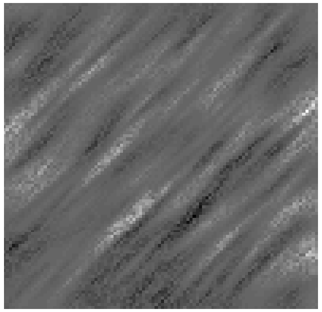
→For modeling ground, this is a simplifying assumption for tractability

Gaussian Markov Random Field Examples



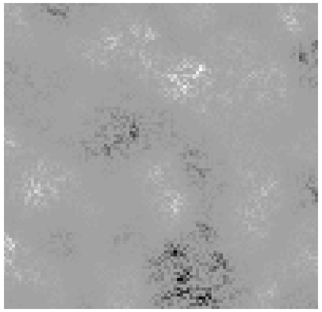
Neighborhood:

		10	10	10		
		10		10		
		10	10	10		



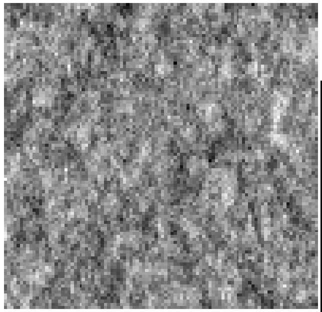
Neighborhood:

					1	5
				5	10	1
				30	5	
			1			
	5	30				
1	10	5				
5	1					



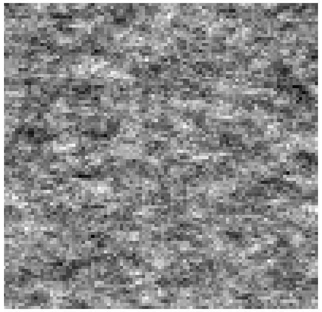
Neighborhood:

			1			
		1	3	1		
	1	10	10	10	1	
1	3	10	0	10	3	1
	1	10	10	10	1	
		1	3	1		
			1			



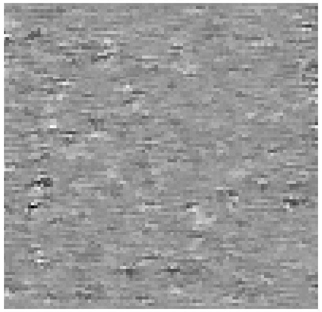
Neighborhood:

		2	10	2		
		1	0	1		
		2	10	2		



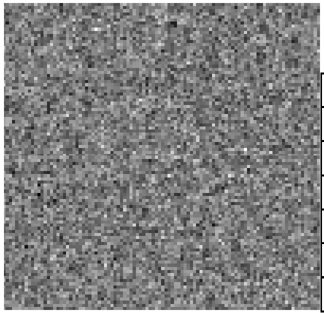
Neighborhood:

		2	1	2		
		10	0	10		
		2	1	2		



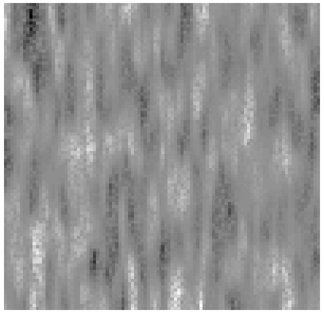
Neighborhood:

		1	1	1		
		2	0	3		
		-1	-1	-1		



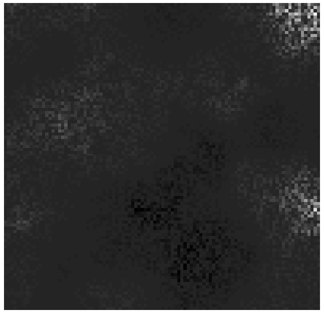
Neighborhood:

			1			
		1	1	1		
			1			



Neighborhood:

			1			
			3			
		0.5	10	0.5		
		1	0	1		
		0.5	10	0.5		
			3			
			1			



Neighborhood:

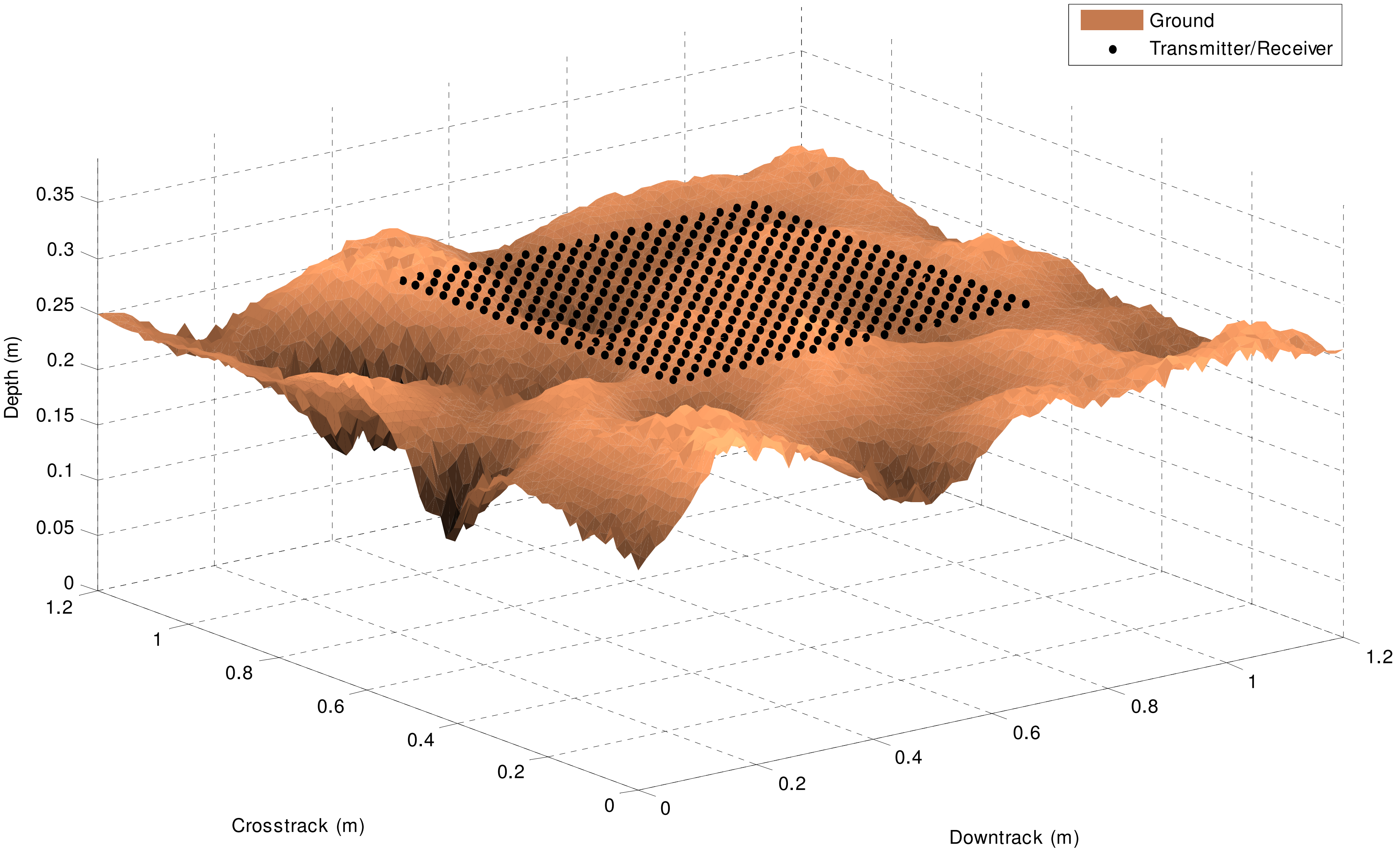
			1			
		3	5	3		
	3	2	1	2	3	
1	5	1	0	1	5	1
	3	2	1	2	3	
		3	5	3		
			1			

Determining the Ground Height Using the Model

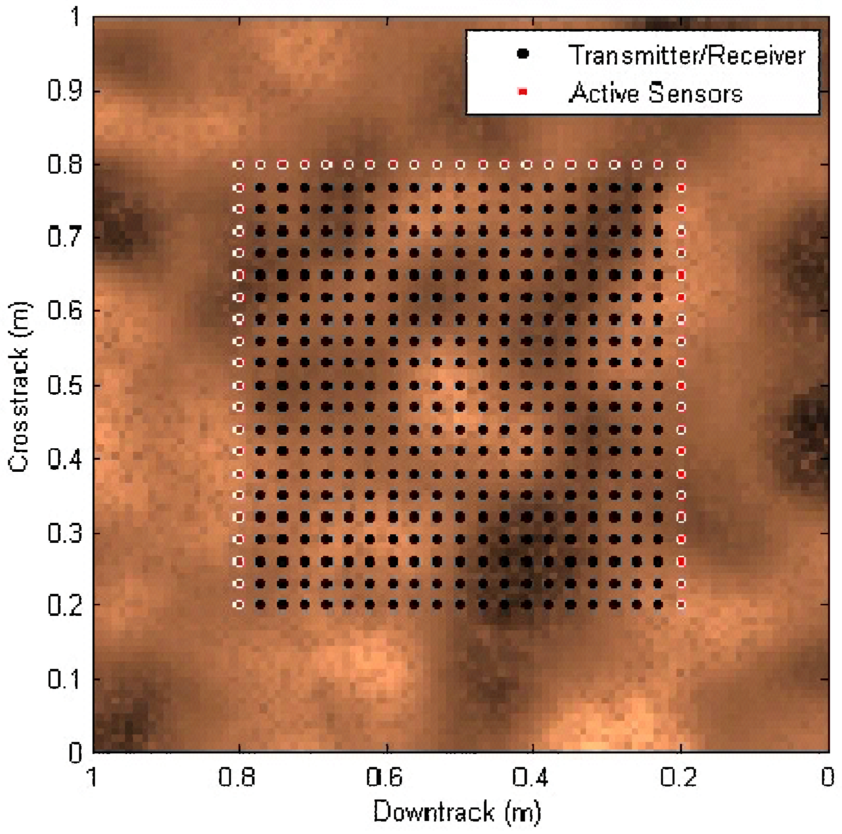
- Given the local maxima at each sensor position
  - Maximize the Pseudolikelihood (Besag,1975) of the ground heights from the available choices
- Optimization: use Simulated Annealing, a stochastic optimization technique
  - Criterion: Maximize the Pseudolikelihood of the GMRF
  - The optimizing set of locations is the ground height estimate

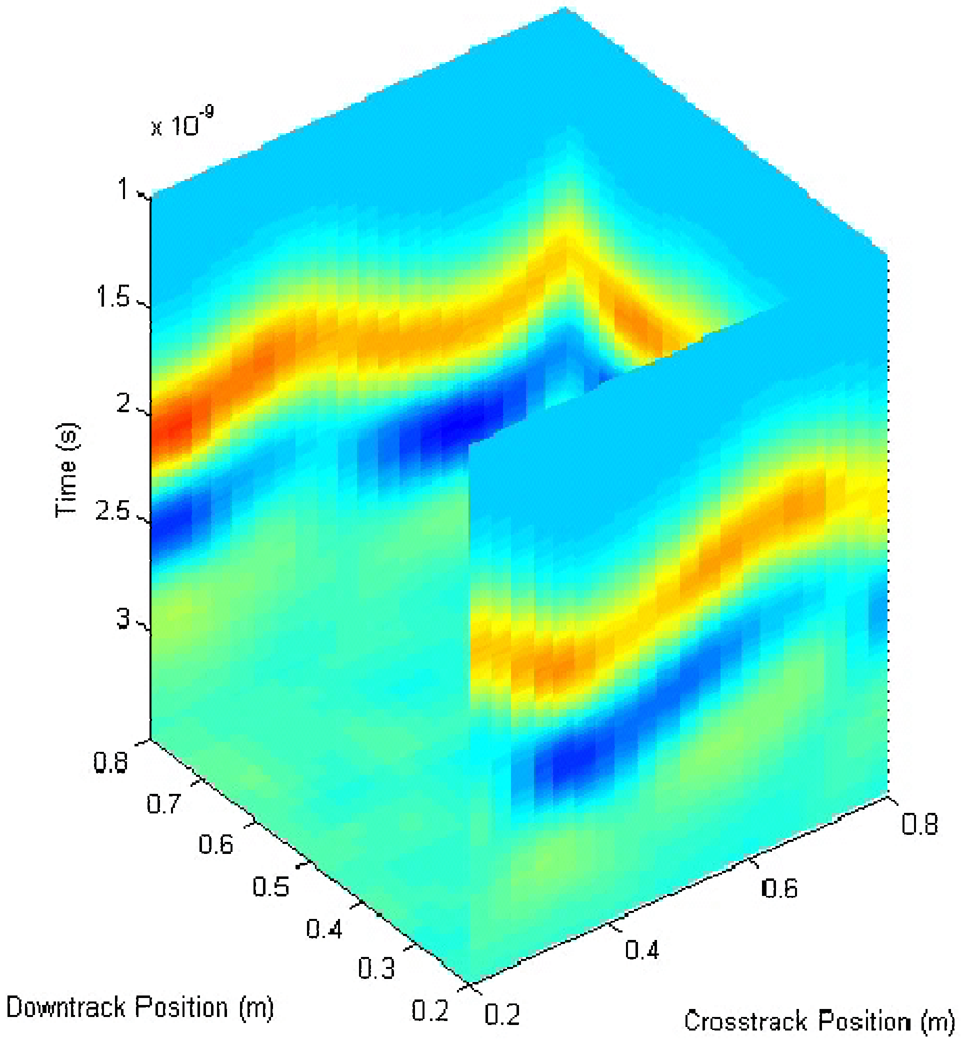
Preliminary Results of Ground Height Estimation

Simulated Surface and Sensor Positions



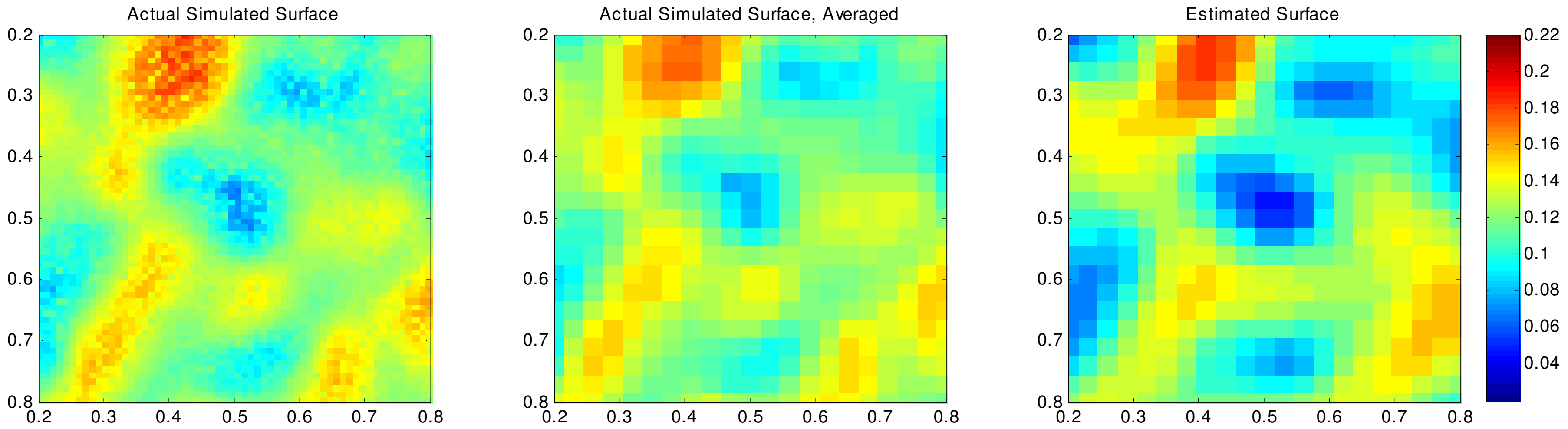
Sensor Positions and Simulated FDTD Output





Estimation Results

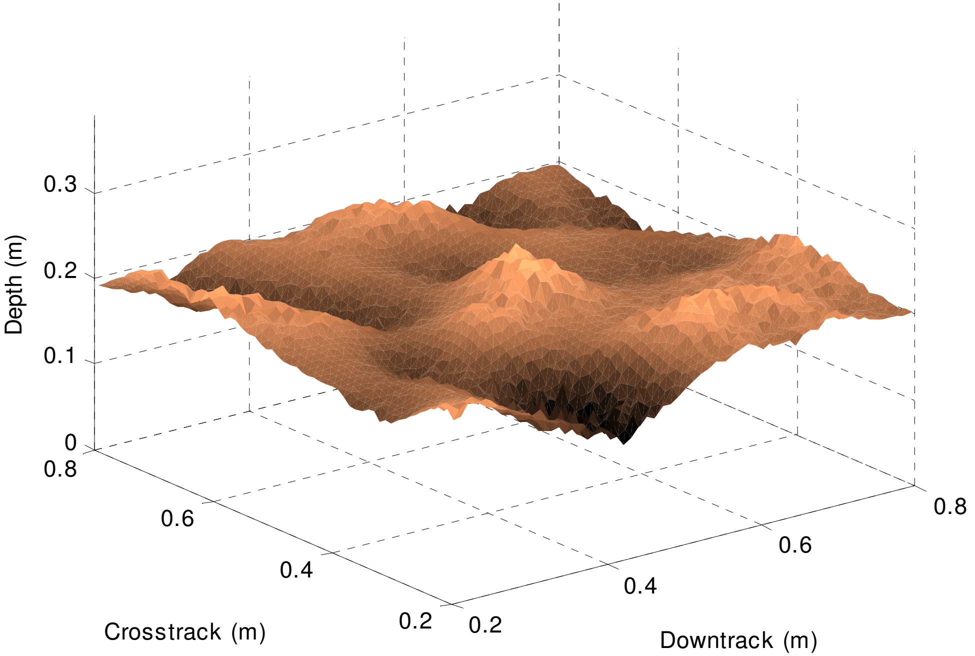
Simulated Ground | Averaged Ground | Estimated Ground



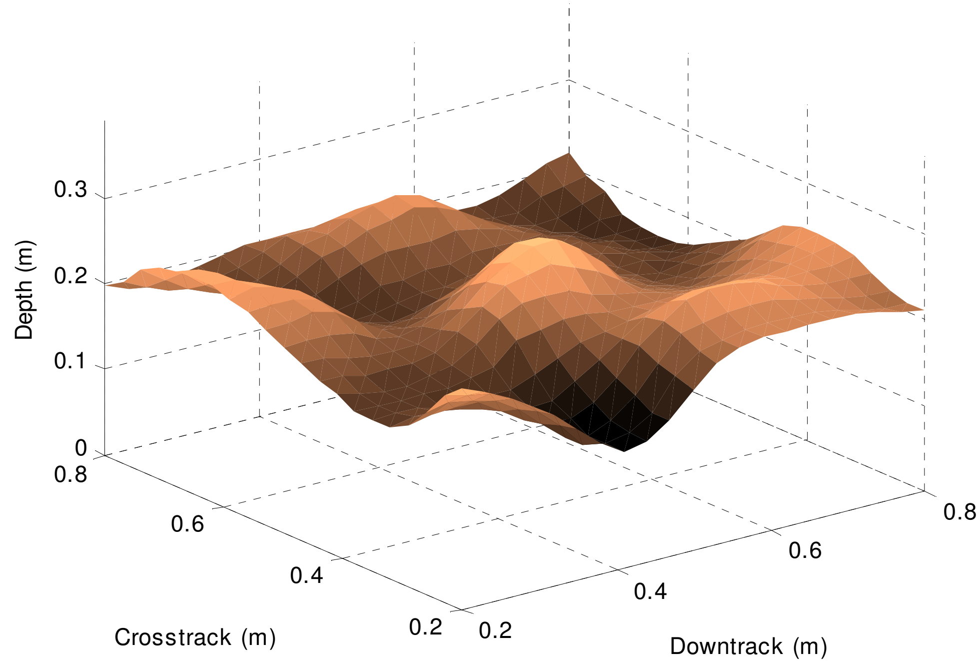
Method:

- Determine time of arrival local maxima Invert time to get distance

Estimation Results in 3-dimensions



Simulated Ground



Estimated Ground

Future Work

Future Work

- Simulate surface clutter FDTD models
- Determine the effect of the variance of surface height on the estimate of ground height
- Develop a method for incorporating sensor positional uncertainty

Thank You!

Questions?