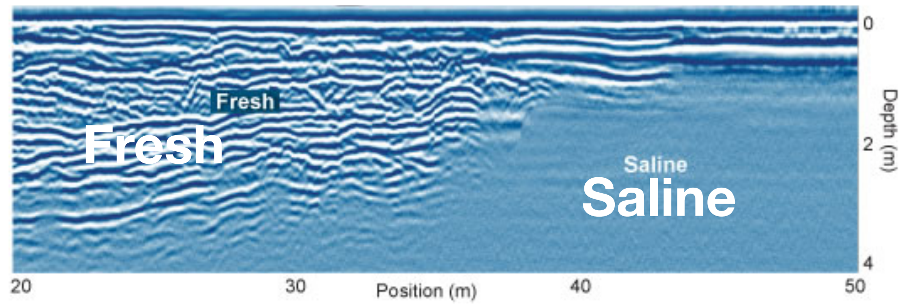
Ground Penetrating Radar

DISC
2017
Electromagnetics
Fundamentals and Applications

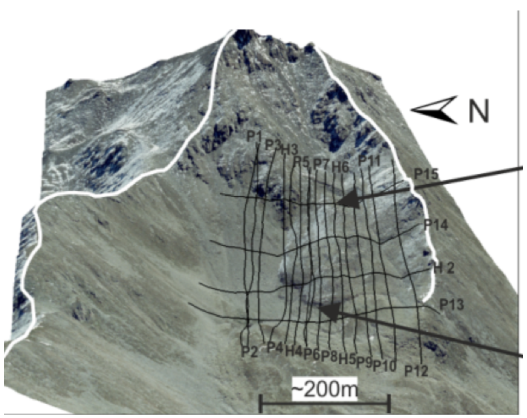
Motivation

Sink holes

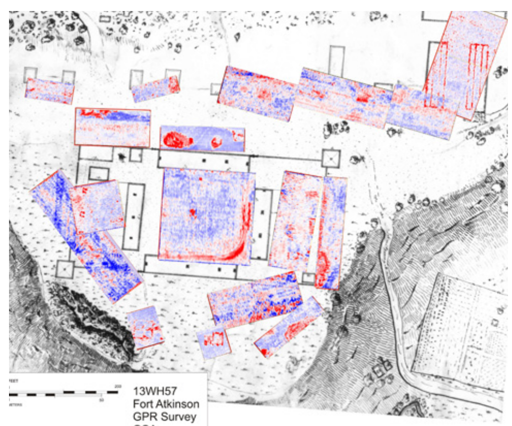
Salt Water Intrusions



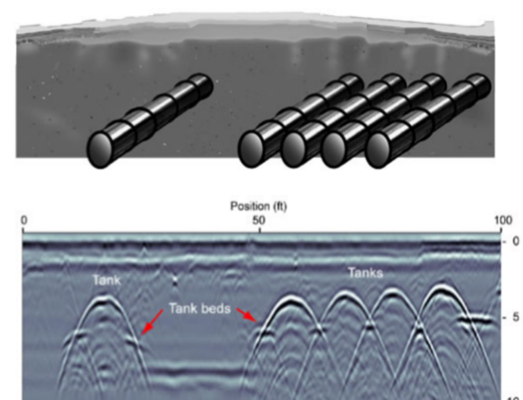
Rock glacier



Archeology



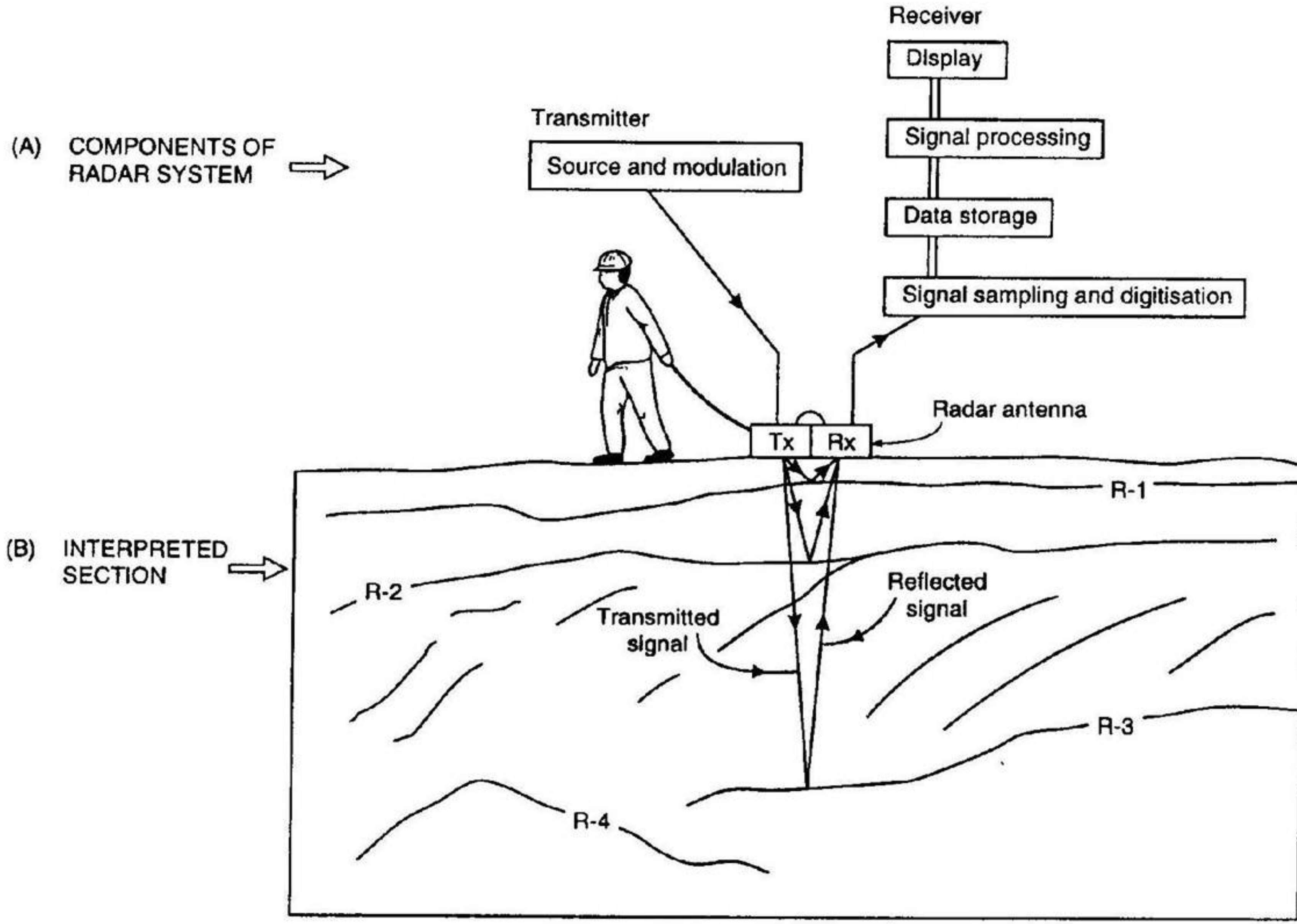
Underground tank



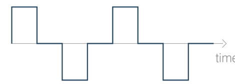
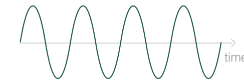
Outline

- Basic experiment
- Physical property
- Physics
- Data and Processing
- Field examples
- Driverless Vehicles
- Case History: Rock Glacier

Basic Experiment



Basic Equations

	Time TDEM 	Frequency FDEM 
Faraday's Law	$\nabla \times \mathbf{e} = -\dfrac{\partial \mathbf{b}}{\partial t}$	$\nabla \times \mathbf{E} = -i\omega \mathbf{B}$
Ampere's Law	$\nabla \times \mathbf{h} = \mathbf{j} + \dfrac{\partial \mathbf{d}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J} + i\omega \mathbf{D}$
No Magnetic Monopoles	$\nabla \cdot \mathbf{b} = 0$	$\nabla \cdot \mathbf{B} = 0$
Constitutive Relationships (non-dispersive)	$\mathbf{j} = \sigma \mathbf{e}$ $\mathbf{b} = \mu \mathbf{h}$ $\mathbf{d} = \varepsilon \mathbf{e}$	$\mathbf{J} = \sigma \mathbf{E}$ $\mathbf{B} = \mu \mathbf{H}$ $\mathbf{D} = \varepsilon \mathbf{E}$

* Solve with sources and boundary conditions

Basic Equations: Wave Equation

First order equations

$$\nabla \times \mathbf{e} = -\frac{\partial \mathbf{b}}{\partial t}$$

$$\nabla \times \mathbf{h} = \mathbf{j} + \frac{\partial \mathbf{d}}{\partial t}$$

$$\mathbf{j} = \sigma \mathbf{e}$$

$$\mathbf{b} = \mu \mathbf{h}$$

$$\mathbf{d} = \varepsilon \mathbf{e}$$

Second order equations

$$\nabla^2 \mathbf{h} \underbrace{- \mu\sigma \frac{\partial \mathbf{h}}{\partial t}}_{\text{diffusion}} \underbrace{- \mu\epsilon \frac{\partial^2 \mathbf{h}}{\partial t^2}}_{\text{wave propagation}} = 0$$

In frequency

$$\nabla^2 \mathbf{H} + k^2 \mathbf{H} = 0$$

$$k^2 = \omega^2 \mu\varepsilon - i\omega\mu\sigma$$

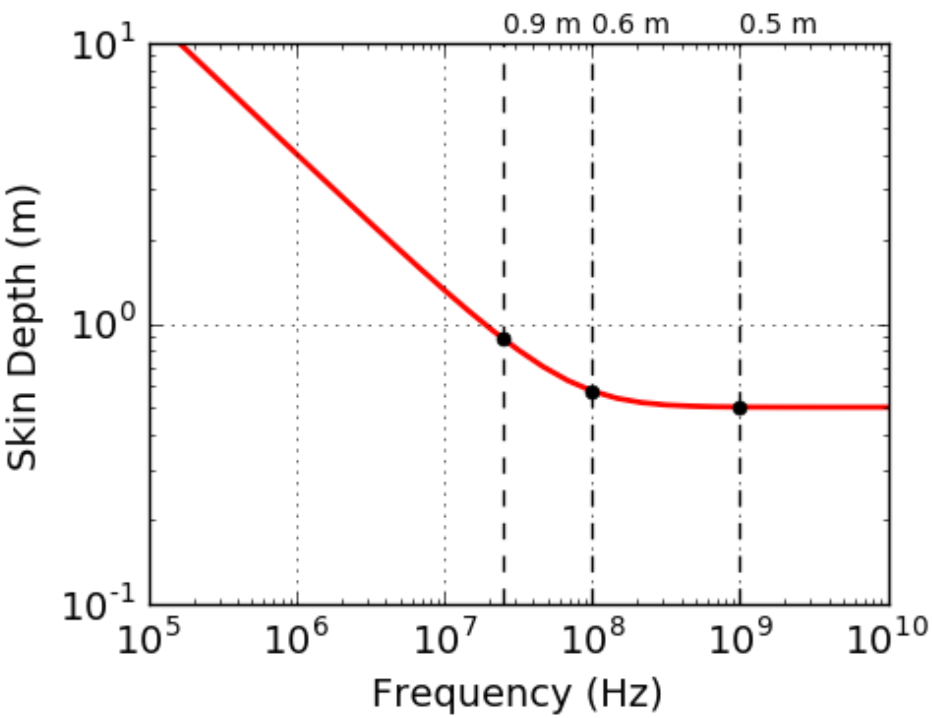
* Same equation holds for E

Physical properties

$$v = \frac{c}{\sqrt{\varepsilon}}$$

Material	ε_r	V_{avg} **(m/ns)**	σ **(ms/m)**	**Penetration Depth (m)**
Air	1	3	0	∞
Fresh Water	80	0.033	0.5	285
Sea Water	80	0.01	3000	< 0.1
Ice	3 - 4	0.16	0.01	3000
Dry Sand	3 - 5	0.15	0.01	3200
Saturated Sand	20 - 30	0.06	0.1 - 1	145
Limestone	4 - 8	0.12	0.5 - 2	30
Shales	5 - 15	0.09	1 - 100	1
Silts	5 - 30	0.07	1 - 100	1.3
Clays	5 - 40	0.06	2 - 1000	0.2
Granite	4 - 6	0.13	0.01 - 1	65
Anhydrites	3 - 4	0.13	0.01 - 1	55

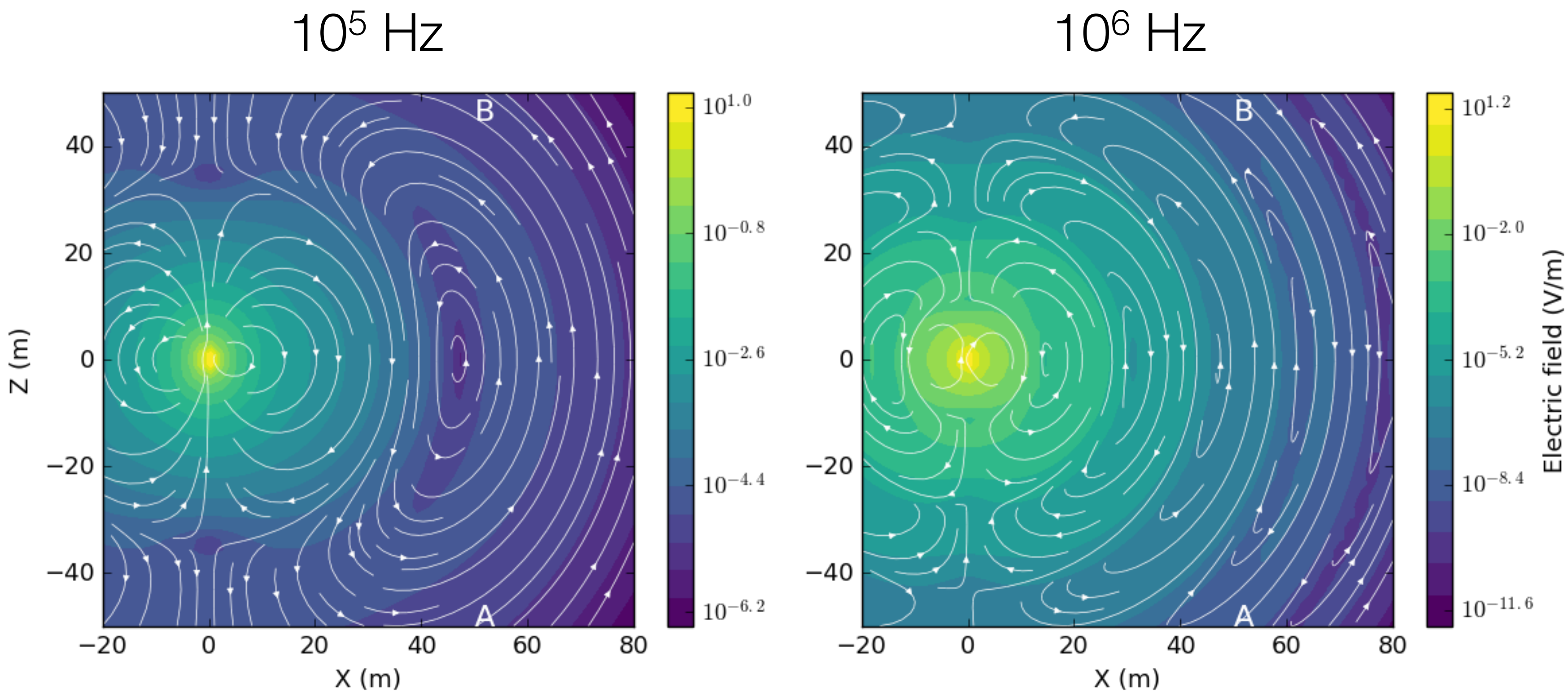
Attenuation: Skin Depth



δ : skin depth

$$\delta \approx \begin{cases} 503\sqrt{\dfrac{1}{\sigma f}} & \text{for } \omega\varepsilon \ll \sigma \\ 0.0053\,\dfrac{\sqrt{\varepsilon_r}}{\sigma} & \text{for } \sigma \ll \omega\varepsilon \end{cases}$$

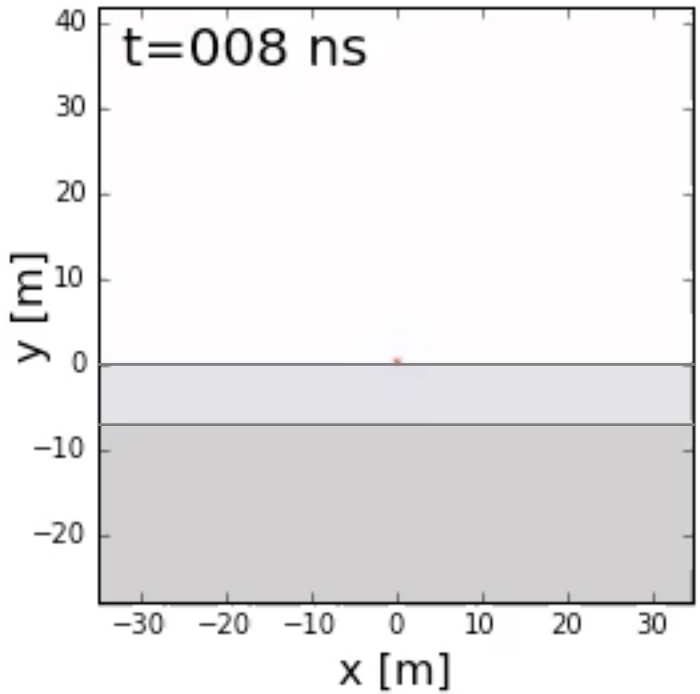
Electric Dipole in a Whole Space

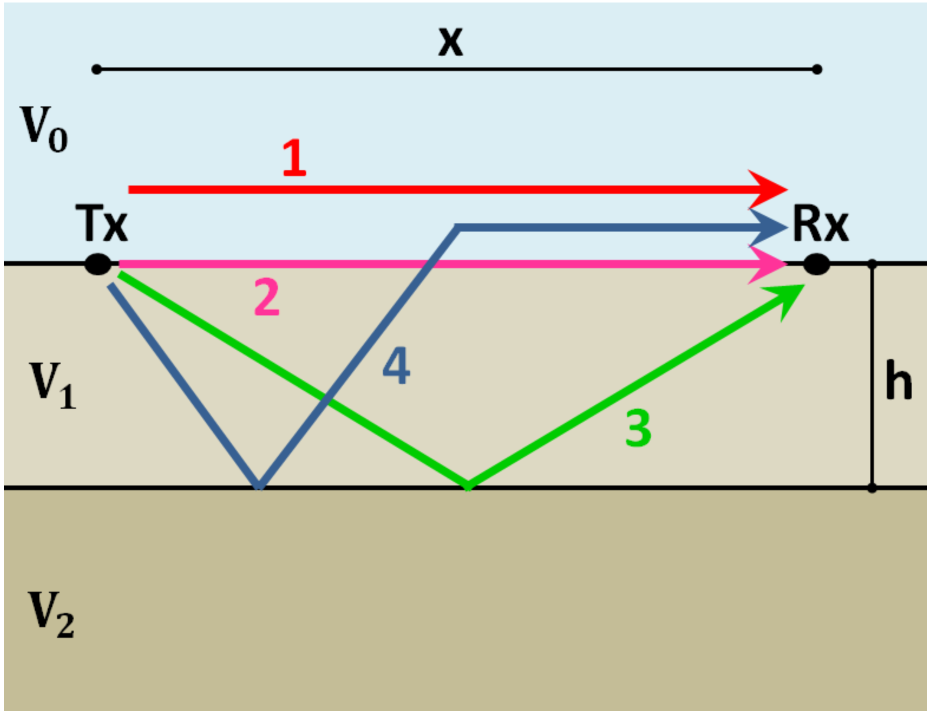


$$\lambda = \frac{v}{f}$$

Waves and Rays

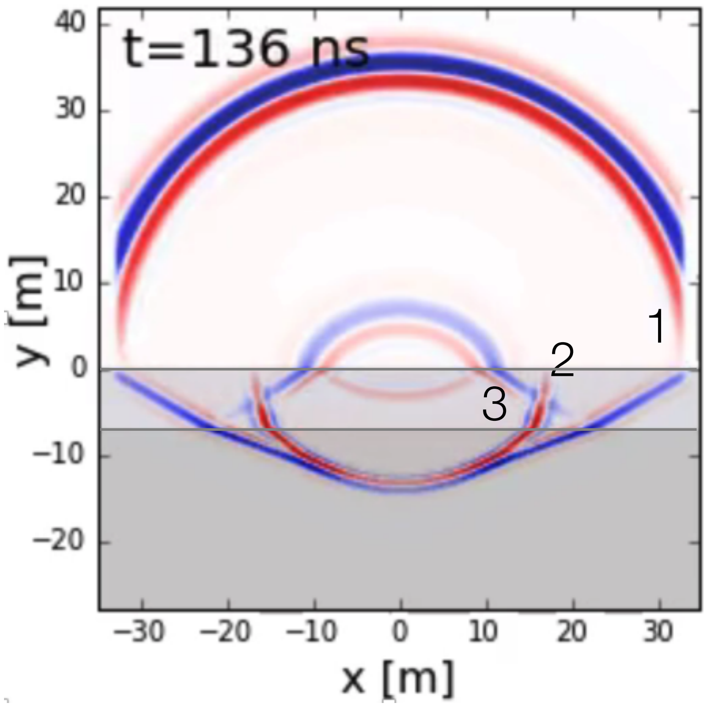
$$v = \frac{c}{\sqrt{\varepsilon}}$$

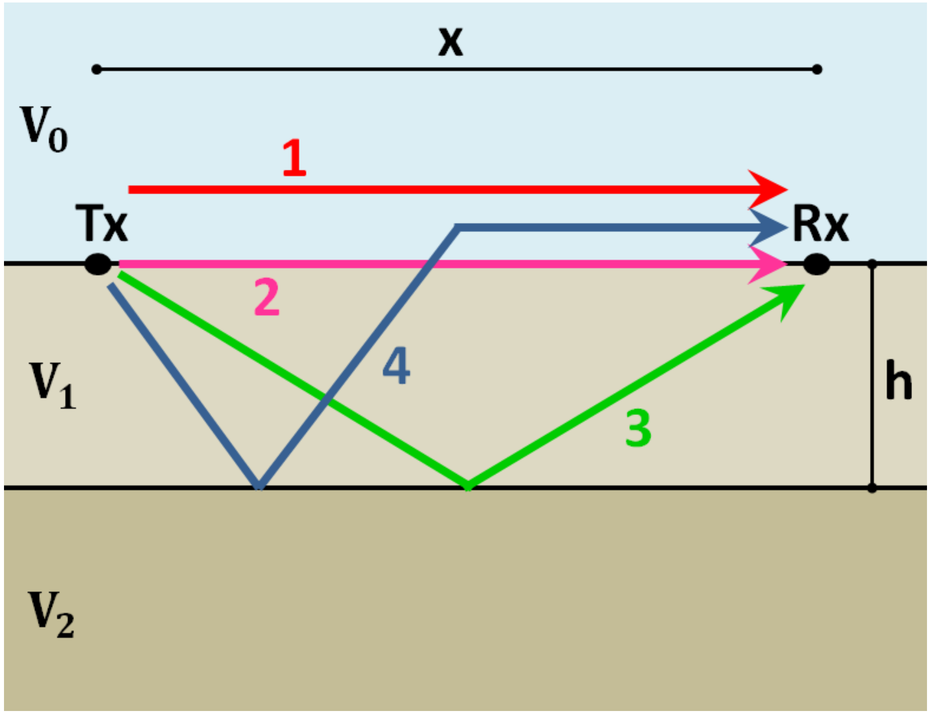




Waves and Rays

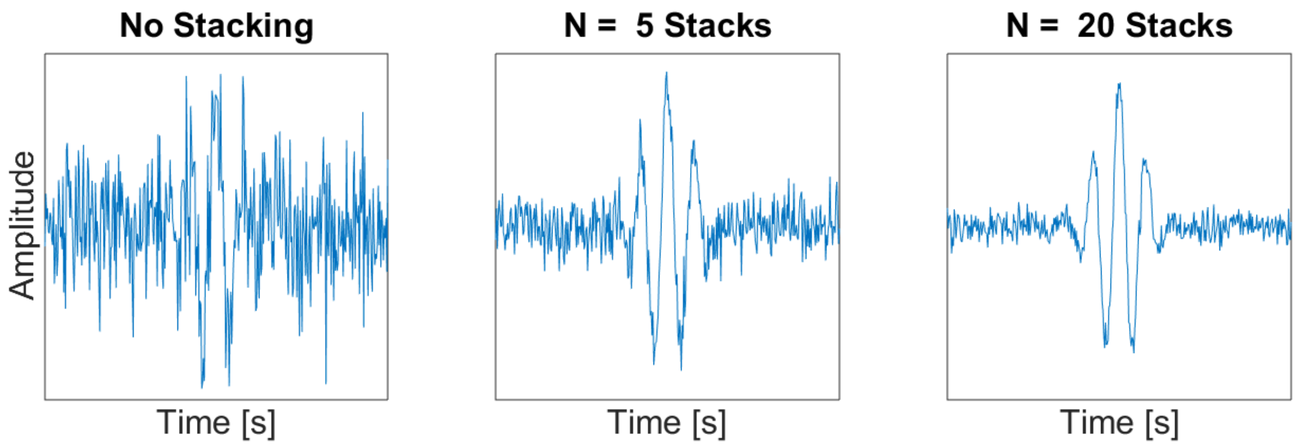
$$v = \frac{c}{\sqrt{\varepsilon}}$$



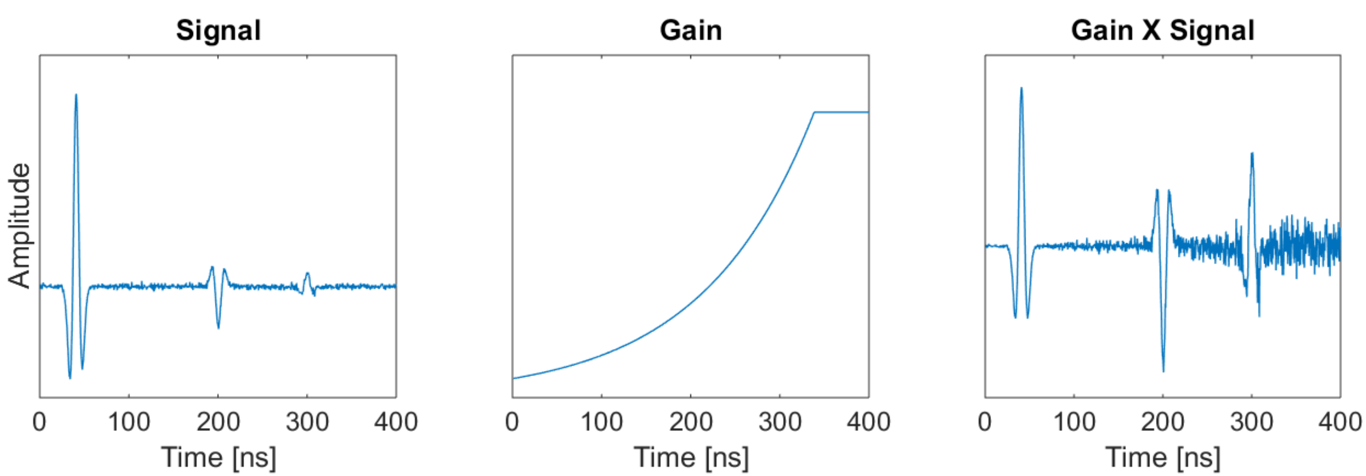


Processing

Stacking

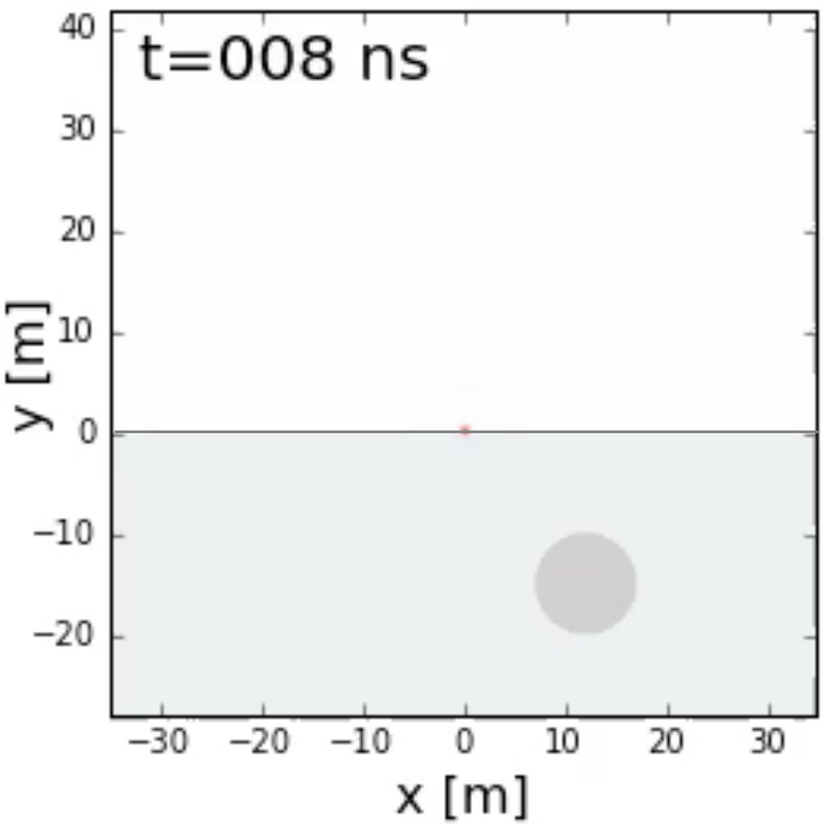


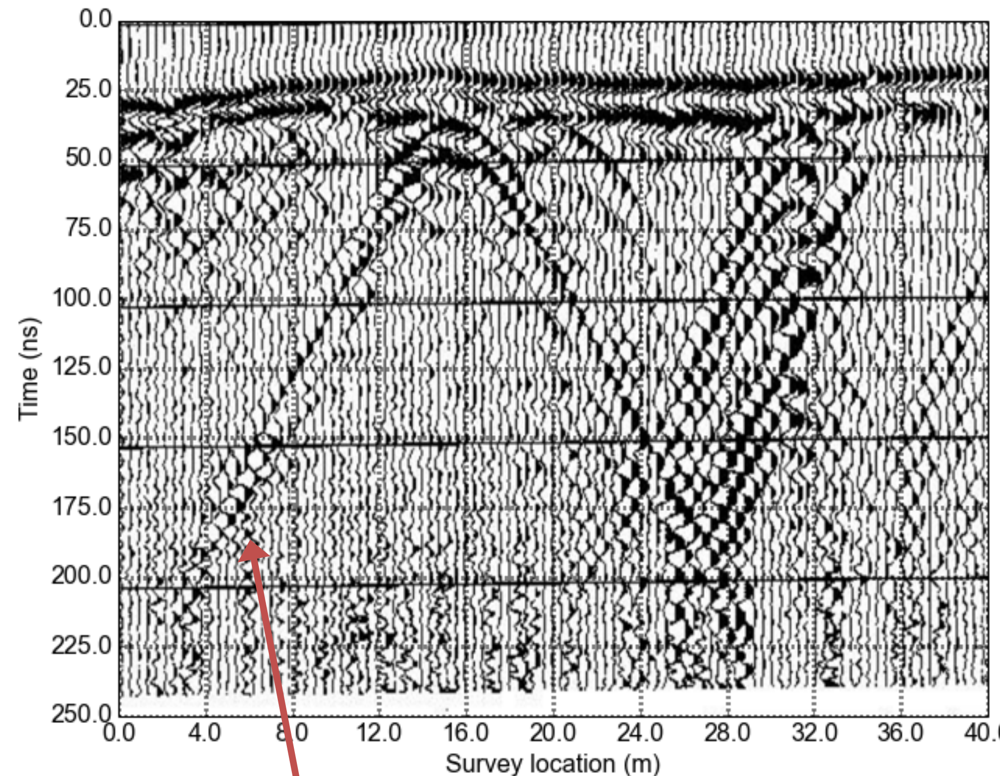
Gain Control



Radargrams

$$v = \frac{c}{\sqrt{\varepsilon}}$$

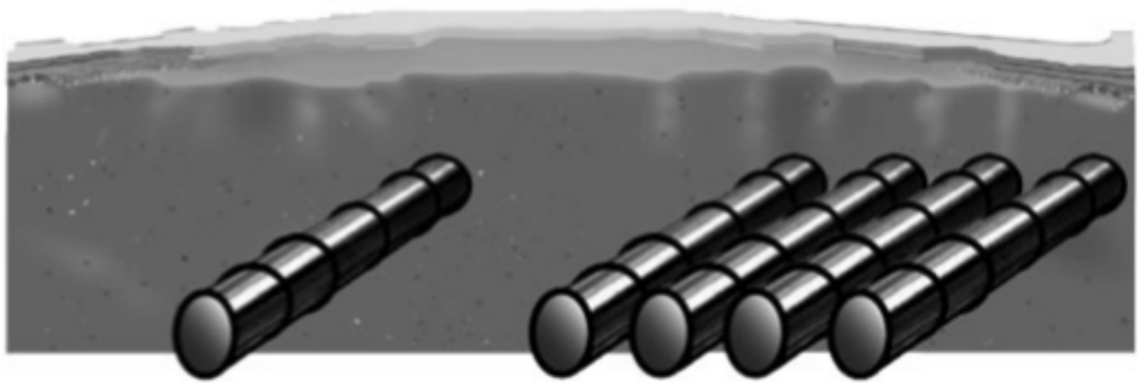


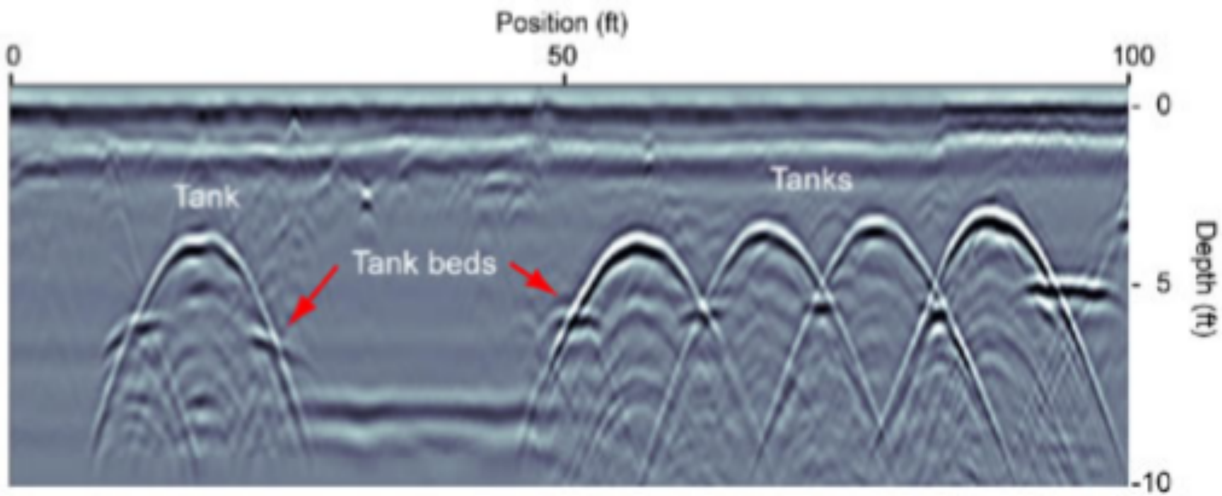


Hyperbola

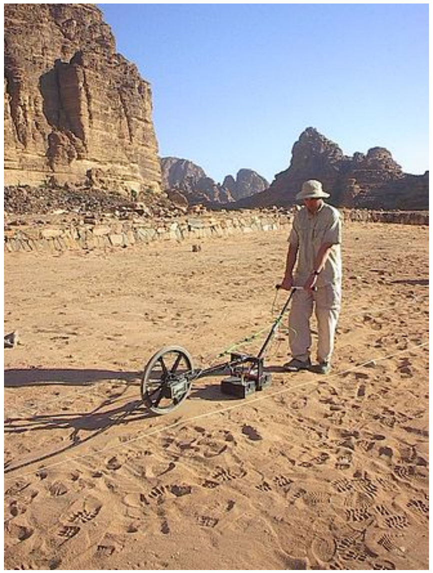
slope ~ 2/v

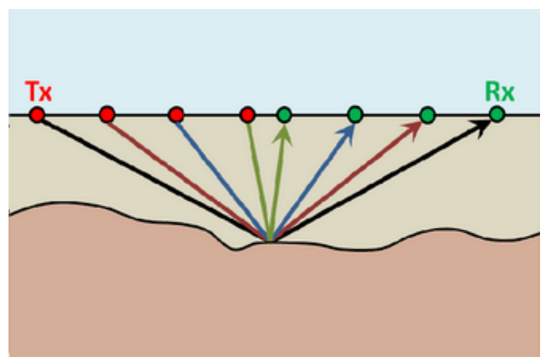
Radargrams



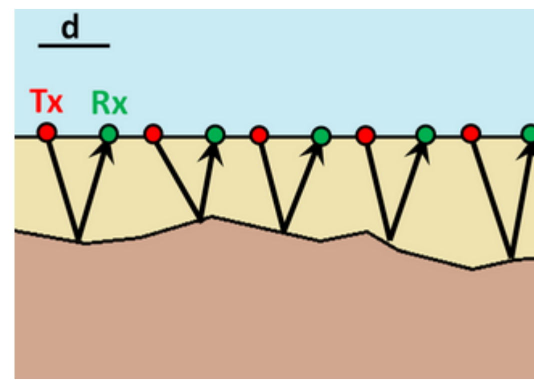


GPR systems





Common midpoint



Common offset

Outline

- Basic experiment
- Physical property
- Physics
- Data and Processing

- Questions?

- Field examples
- Driverless Vehicles
- Case History: Rock Glacier

Environmental Test Survey

Problem

- Characterize soil and identify potential aquifers

Why use GPR?

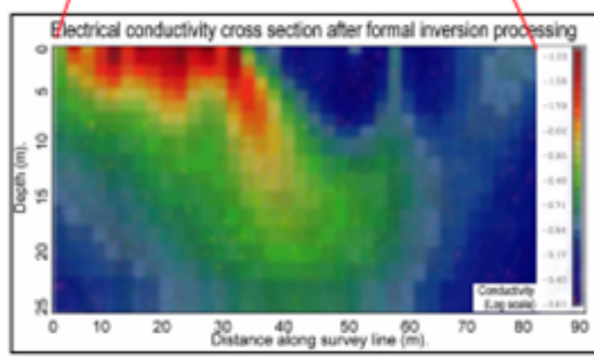
- Dielectric permittivity varies with
  - Water content
  - Lithologies

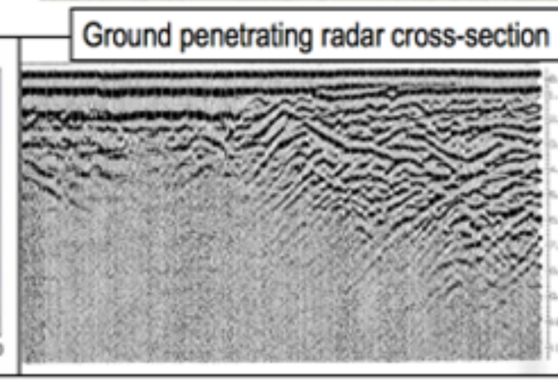
Survey and Data

- Zero offset data colocated with DC resistivity

Processing and Interpretation

- Attenuation of GPR signals on western side: higher conductivity
- Near surface structure from reflecting events





Locating Underground Storage Tanks

Problem
- Locate buried storage tanks and tank beds

Why use GPR?
- Conductive tanks, tank beds are strong reflectors

Survey and Data
- Zero offset data (250 MHz)

Processing and Interpretation
- Hyperbolic signatures from tanks
- Flat tank-bed reflectors
- 3D image constructed from radargrams

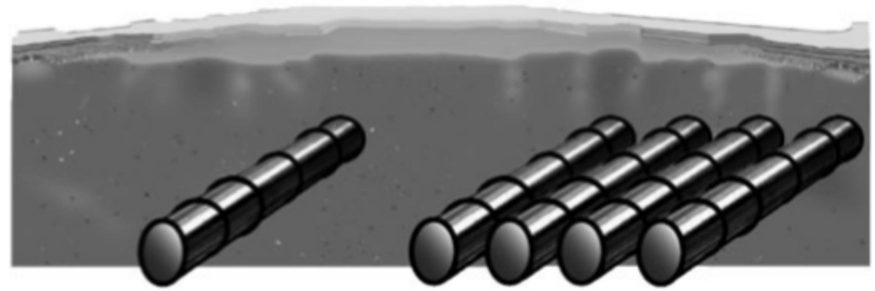


Fig. Geophysical problem

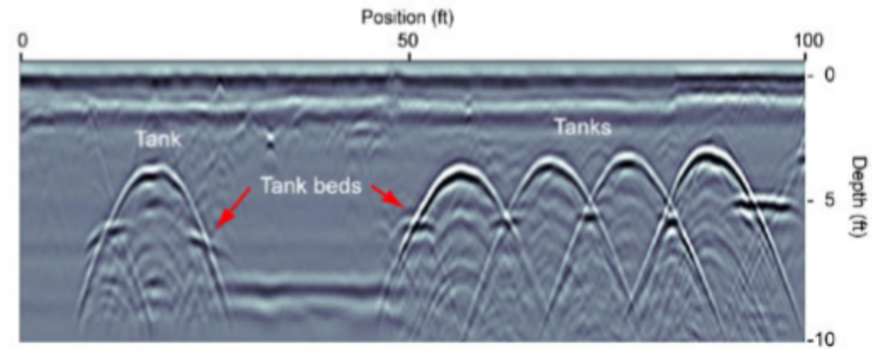


Fig. 2D Radargram profile perpendicular to storage tanks

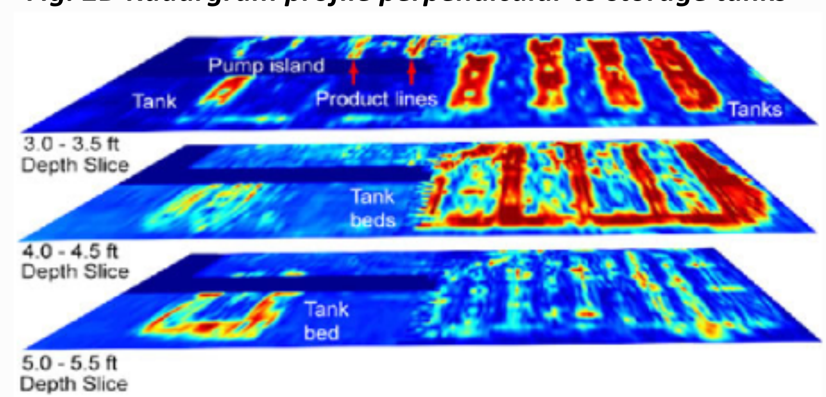


Fig. 129 3D interpolation from several GPR survey lines.

https://www.sensoft.ca/case-studies/underground-storage-tanks/

Mapping Peat Thickness

Problem

- Estimate peat thickness

Why use GPR?

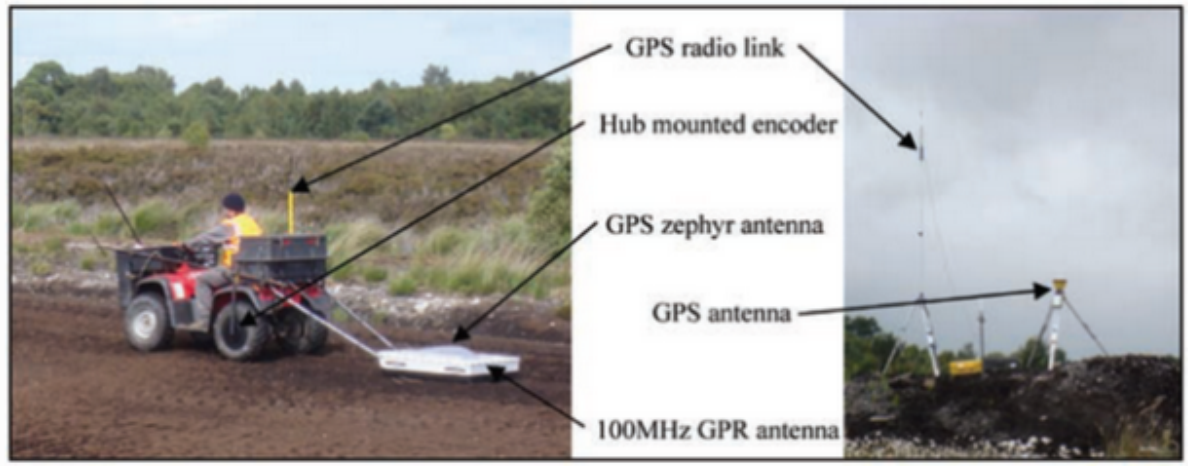
- Strong reflector at base of the peat

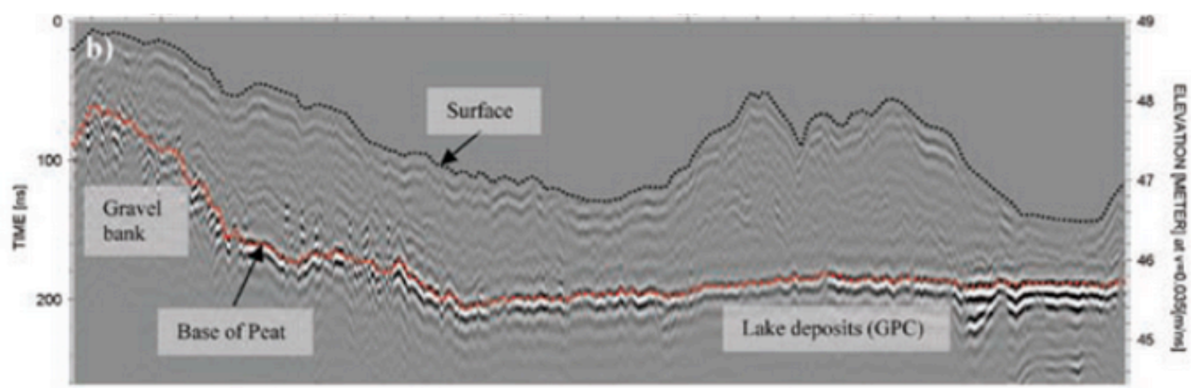
Survey and Data

- Zero offset data (100 MHz)
- Profiles every 60m
- LIDAR collected for local topography

Processing and Interpretation

- Arrival time to depth conversion
- Topography correction with LIDAR
- Peat layers up to 2m thick
- Additional reflectors indicate internal structure of peat





nora.nerc.ac.uk/8920/1/Hodgson_et_al_preprint.pdf

Subsurface Utility Mapping

Problem

- Locate iron-cased water pipes and PVC-cased gas lines at an intersection

Why use GPR?

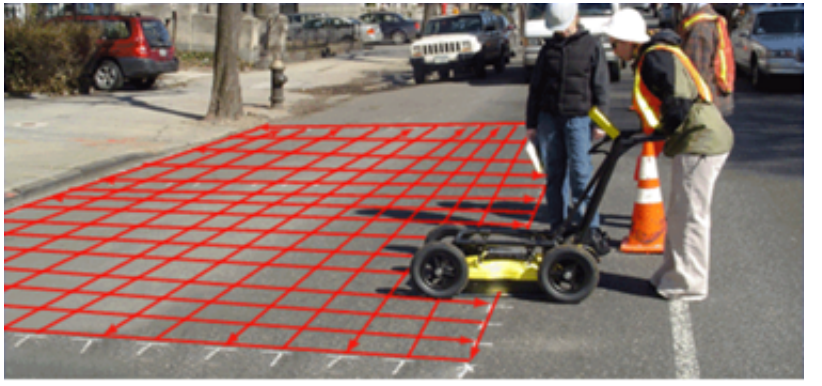
- Iron pipes very conductive → strong GPR reflector
- PVC v. low dielectric permittivity → GPR reflector

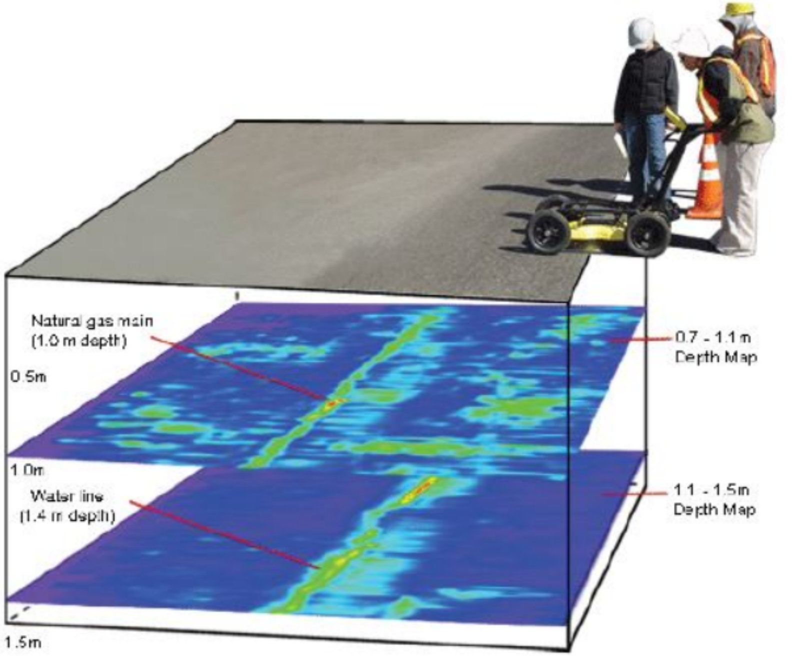
Survey and Data

- Zero offset data (250 MHz)
- 0.5m line spacing, 8m x 23m grid

Processing and Interpretation

- Arrival time to depth conversion
- Natural gas main at 1m depth
- Water line at 1.4m depth





https://www.sensoft.ca/case-studies/locating-pipes-cables_subsurface-utility-mapping/

Underground Potash mines

Problem

- Locate water/brine leaking into potash mine

Why use GPR?

- Potash has low relative permittivity (~5).
- Water/brine has high dielectric permittivity (~80).

Survey and Data

- Zero offset data along mine shaft

Processing and Interpretation

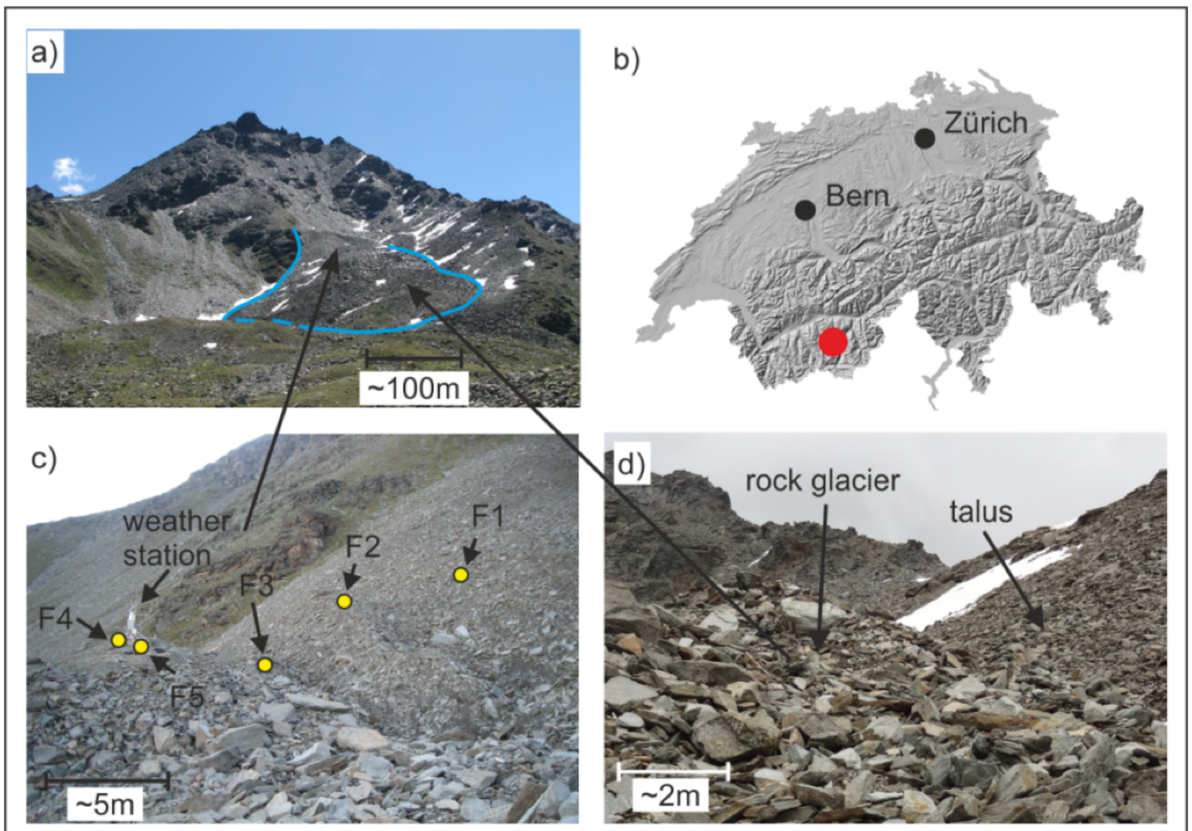
- Arrival time to depth conversion using velocity of 0.13 m/ns for anhydrites

Fig. Inflow problems in a mine

Fig. GPR survey along ceiling of a mine shaft. Courtesy of: https://www.sensoft.ca/

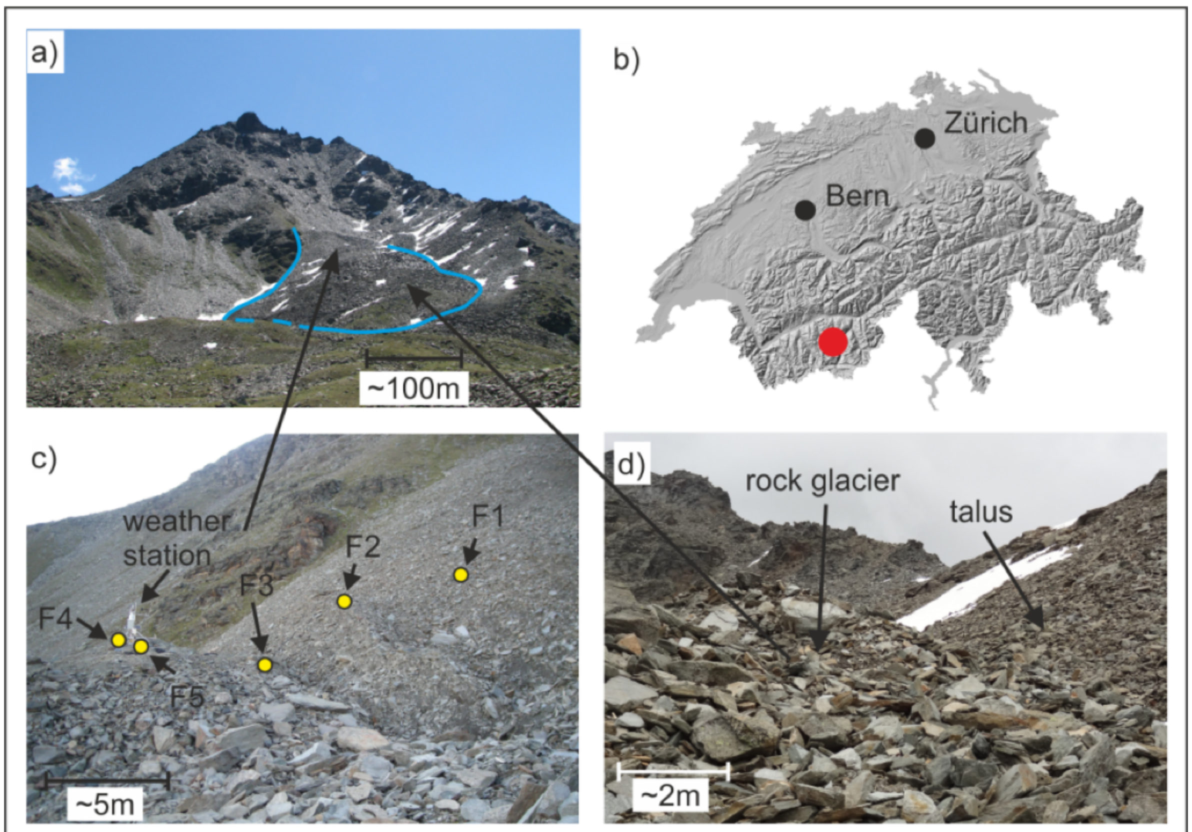
Case History: Furggwanghorn

Merz et al, 2015



Setup

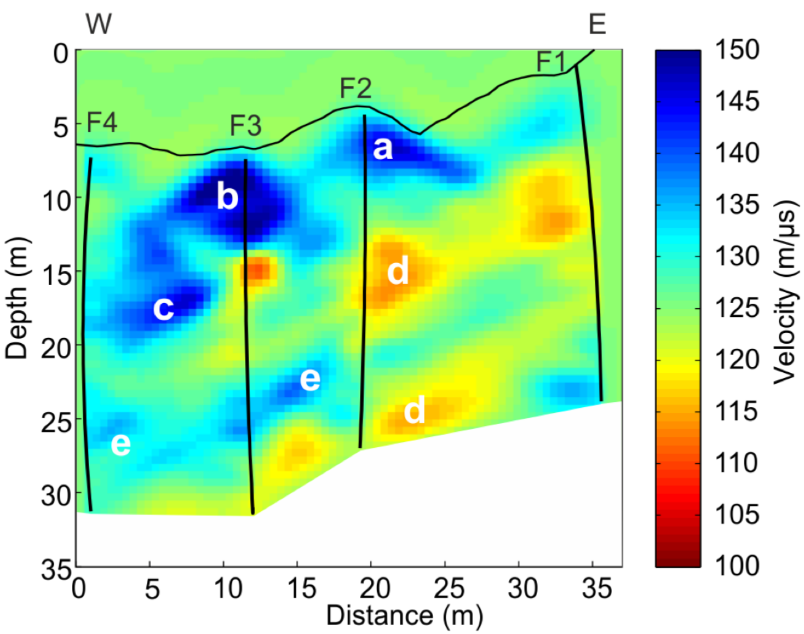
- Downslope movement shown to increase from 1.5 m/yr to 4.0 m/yr.
- Aim: characterize rock units and evolution of glacier
- Surface GPR: unsuccessful (too close to scatterers)
- Helicopter GPR used



Properties

$$v = \frac{c}{\sqrt{\varepsilon}}$$

Velocity from cross well GPR

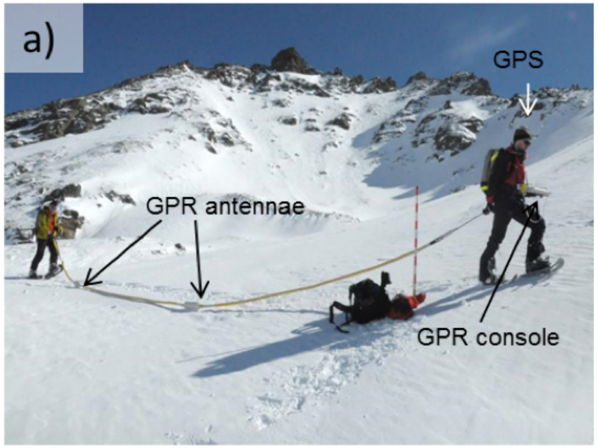


Material	**Velocity (m/µs)**
(a & b) Unconsolidated sediments	> 140
(c) Ice	> 140
(d) Ice + partial melt	110 - 130
(e) Compact debris	130 – 140
Saturated sediments	80 -100
Bedrock	110 -130

Survey

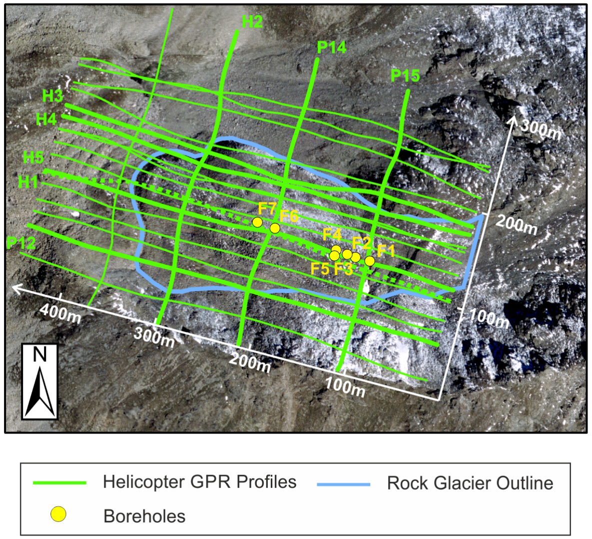
- Initial Ground-Based Survey
  - 2 systems
  - Frequencies: 25 MHz and 50 MHz
- Heli-GPR
  - Frequency: 60 MHz
  - Flight height: 15-20 m
  - Line separation ~15 m

Ground-GPR



Heli-GPR

Survey lines

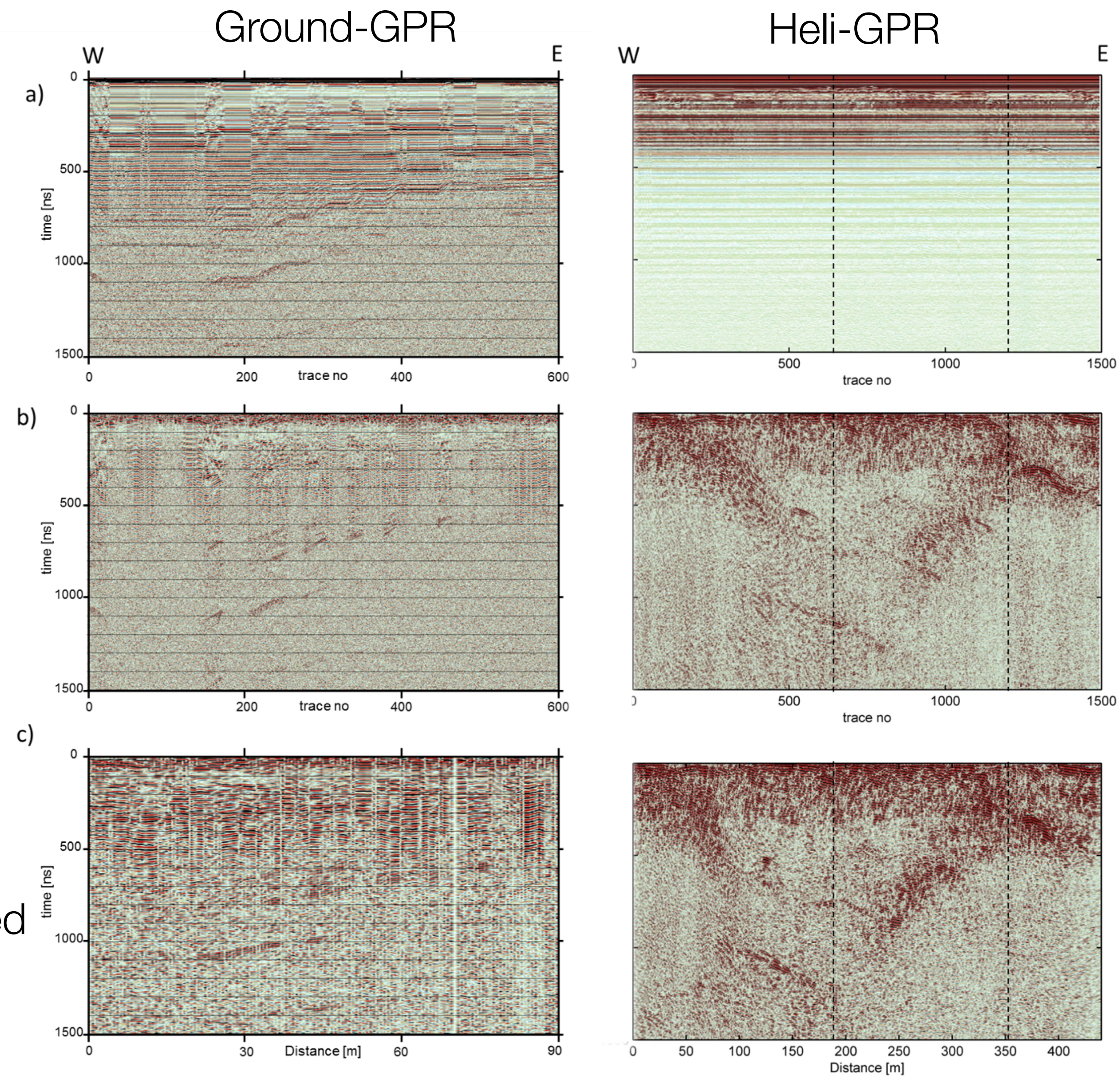


Data and Processing

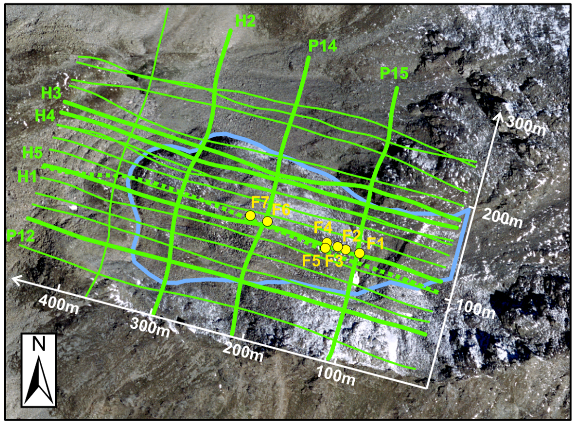
Raw

Filtered

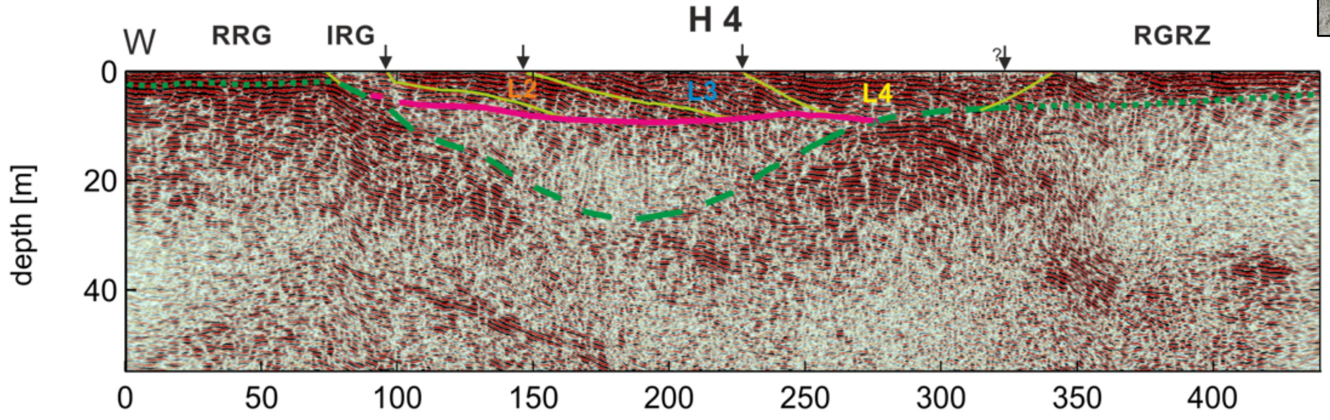
Final Processed



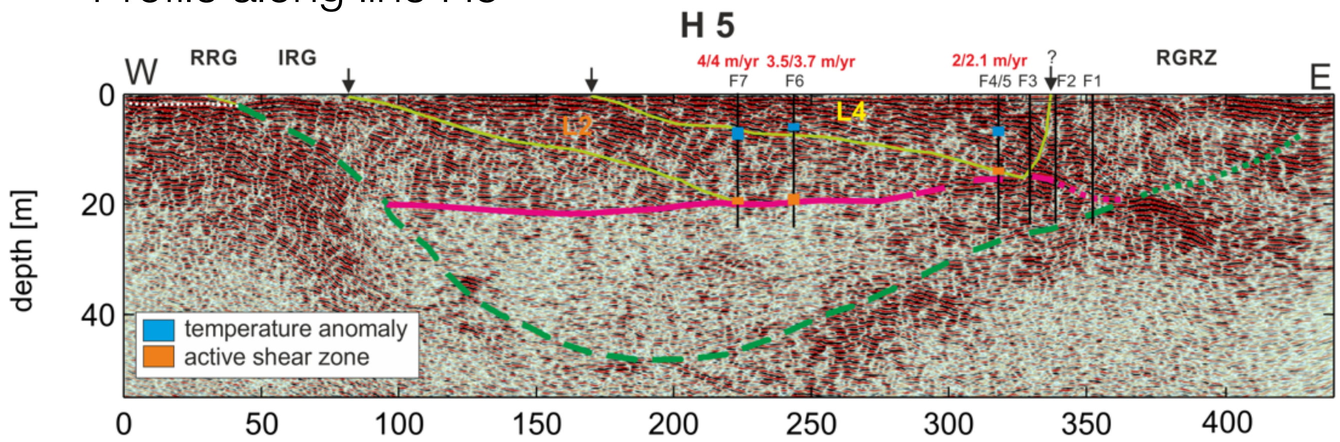
Interpretation



Profile along line H4



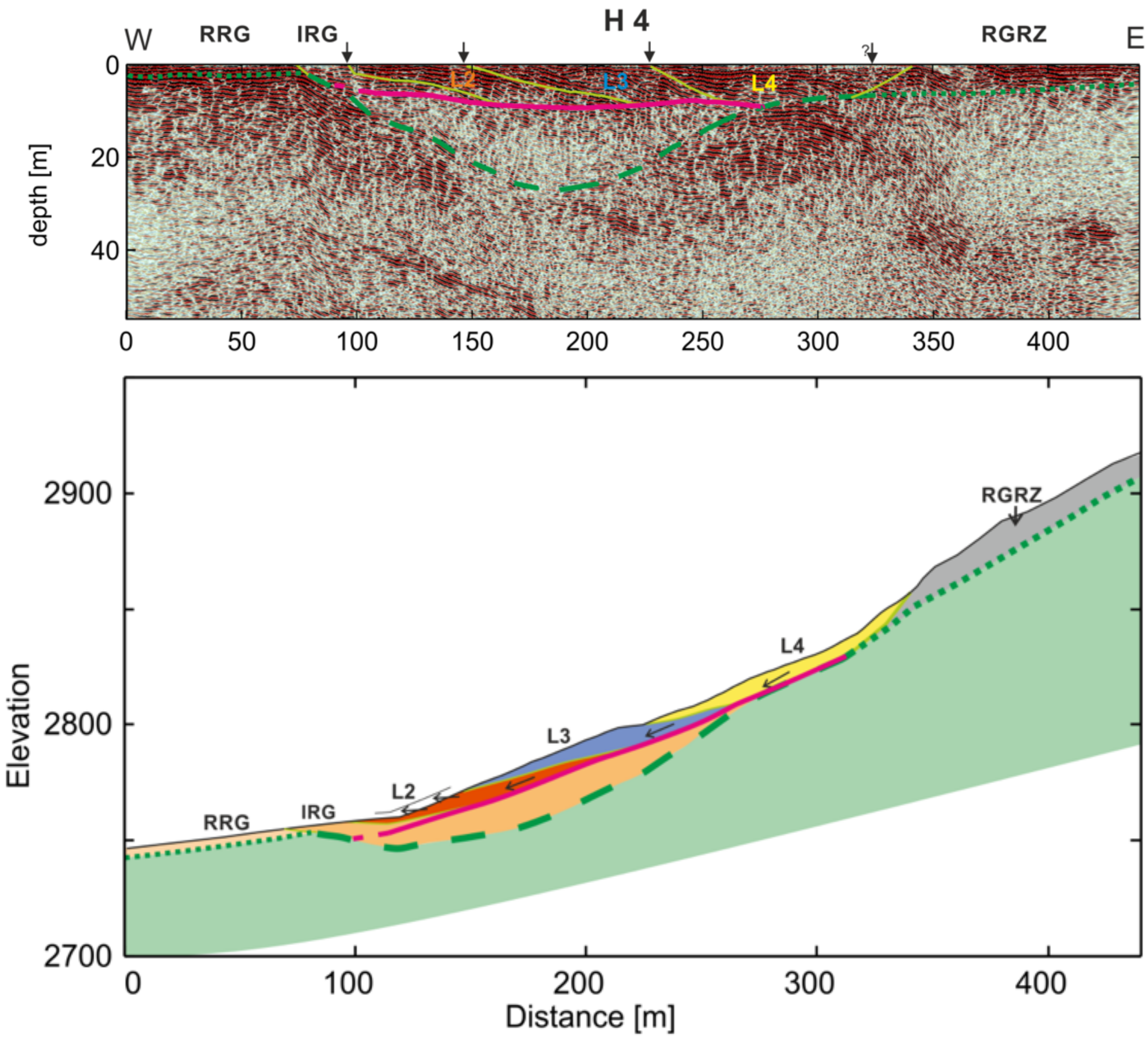
Profile along line H5



- Bedrock surface
- Major shear zone between ice-rich and ice-poor regions
- Fault zone boundaries of rock lobes

Synthesis

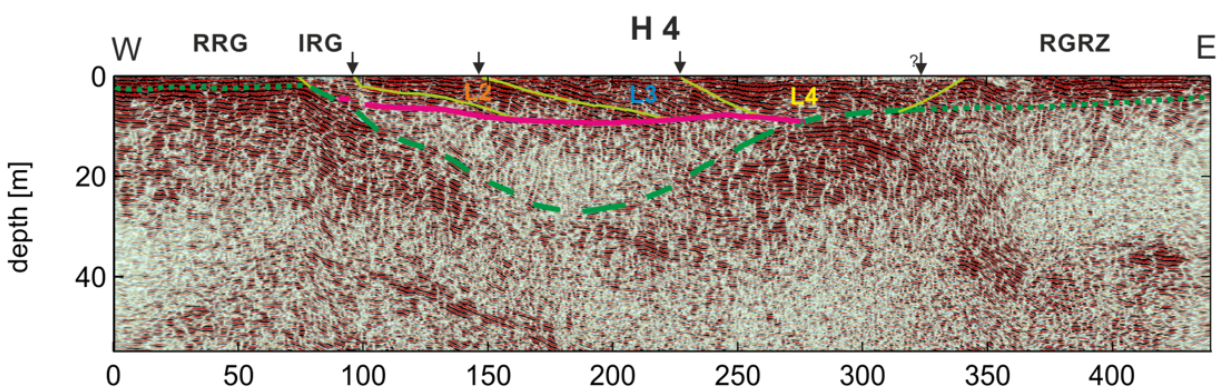
Final Structural and Kinematic Model



- Interpreted with thin-skinned tectonic model
- Major shear zone acts as a décollment
- Rock glacier lobes act as nappes
- Lobes appear to move down-slope
- Tectonic model applicable to other glaciers

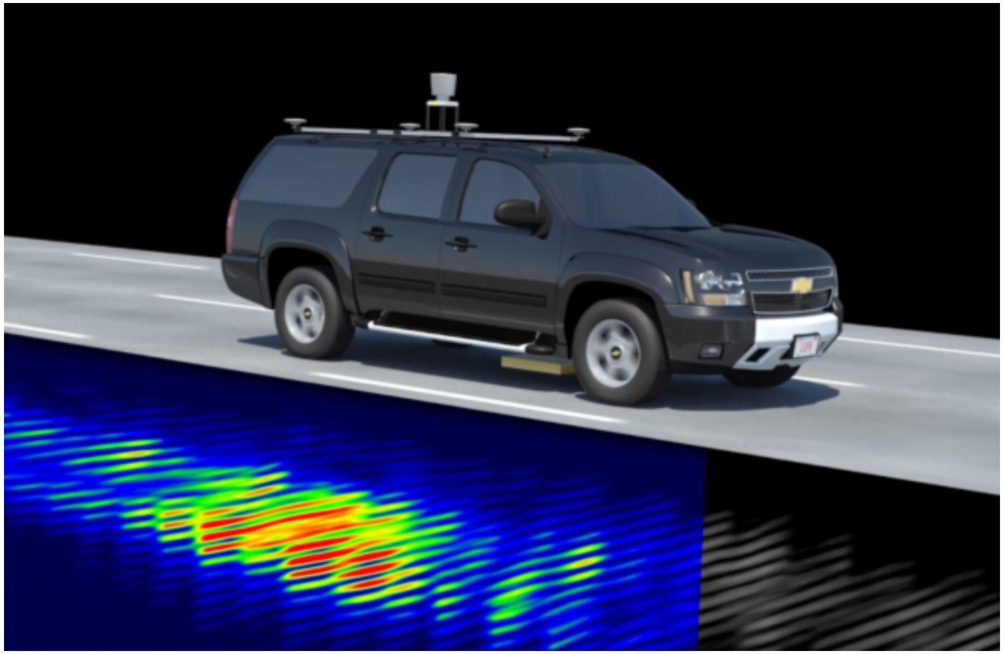
Summary

- Basic experiment
- Physical property
- Physics
- Data and Processing
- Case history: rock glacier



LGPR
Localizing GPR for driverless vehicles

MIT Lincoln Labs with GSSI



Journal of Field Robotics
[Volume 33, Issue 1,](http://onlinelibrary.wiley.com/doi/10.1002/rob.21605/full#rob21605-fig-0003) pages 82-102, 27 MAY 2015 DOI: 10.1002/rob.21605
http://onlinelibrary.wiley.com/doi/10.1002/rob.21605/full#rob21605-fig-0003

Typical Sensors

Sensors

- GPS
- Lidar
- Camera

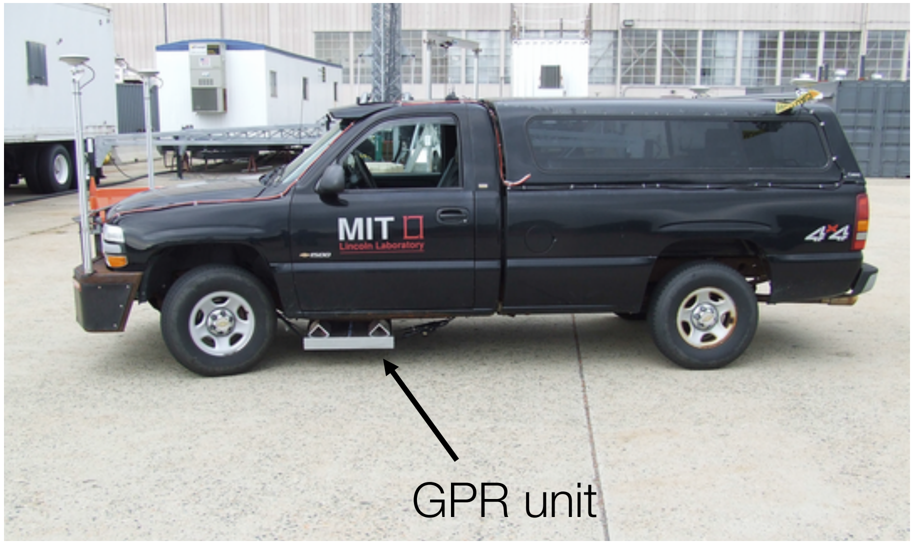
- Work fine in good weather

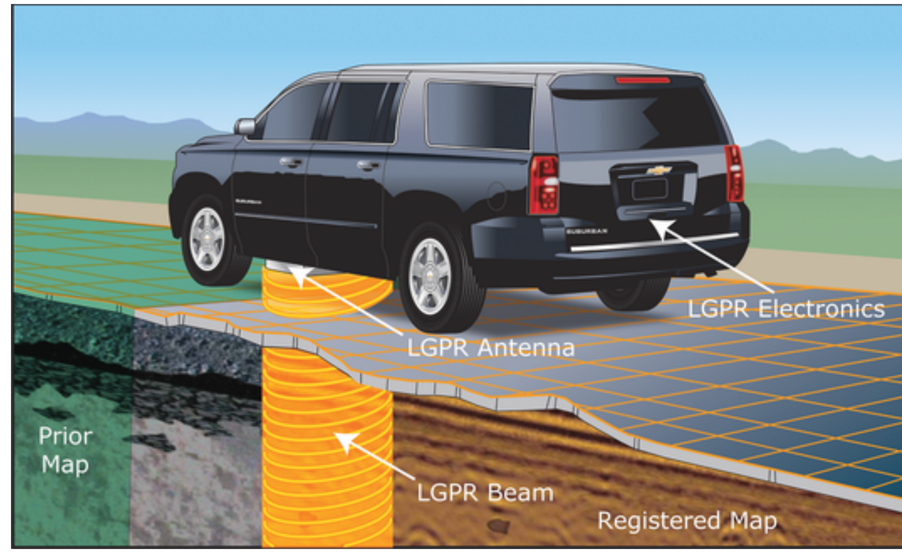
What happens when

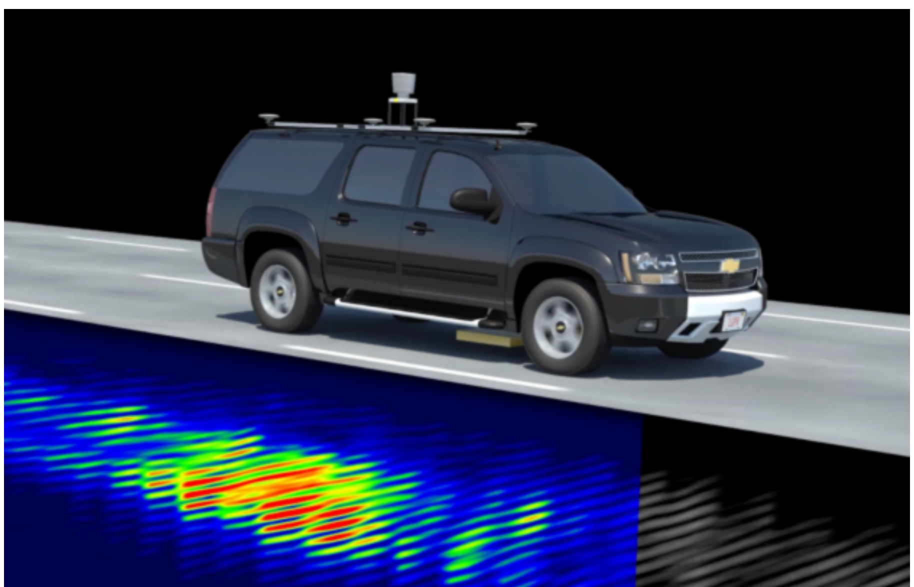
- Bad weather
  - rain, snow, sleet, fog, …
- Changes
  - signs, road stripes, vegetation, …

Need additional sensor data

Localizing Ground Penetrating Radar

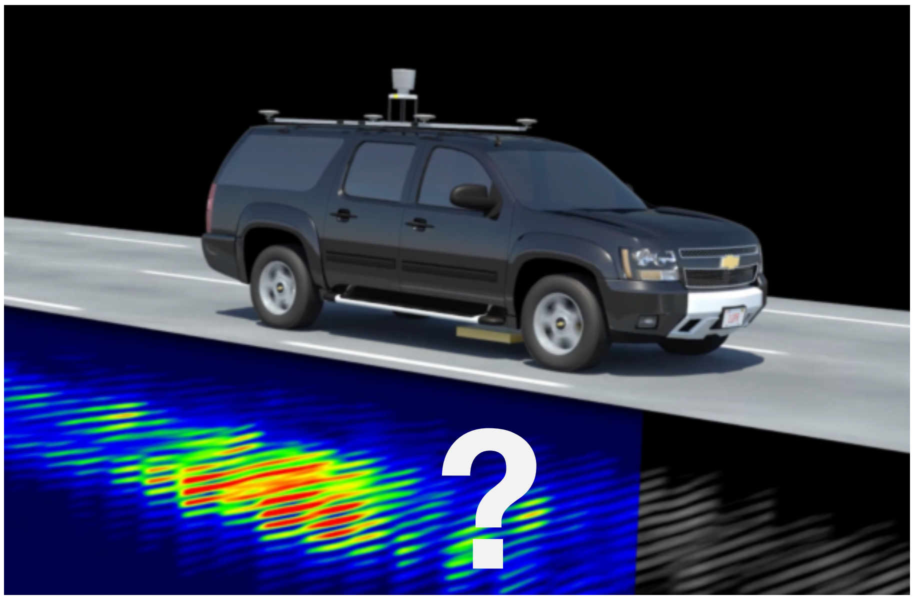


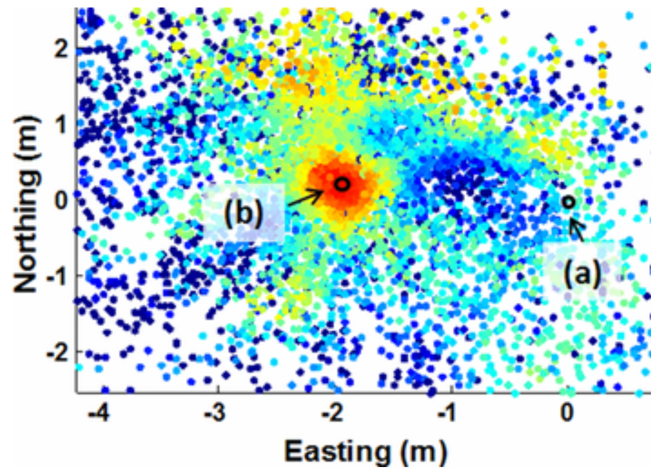




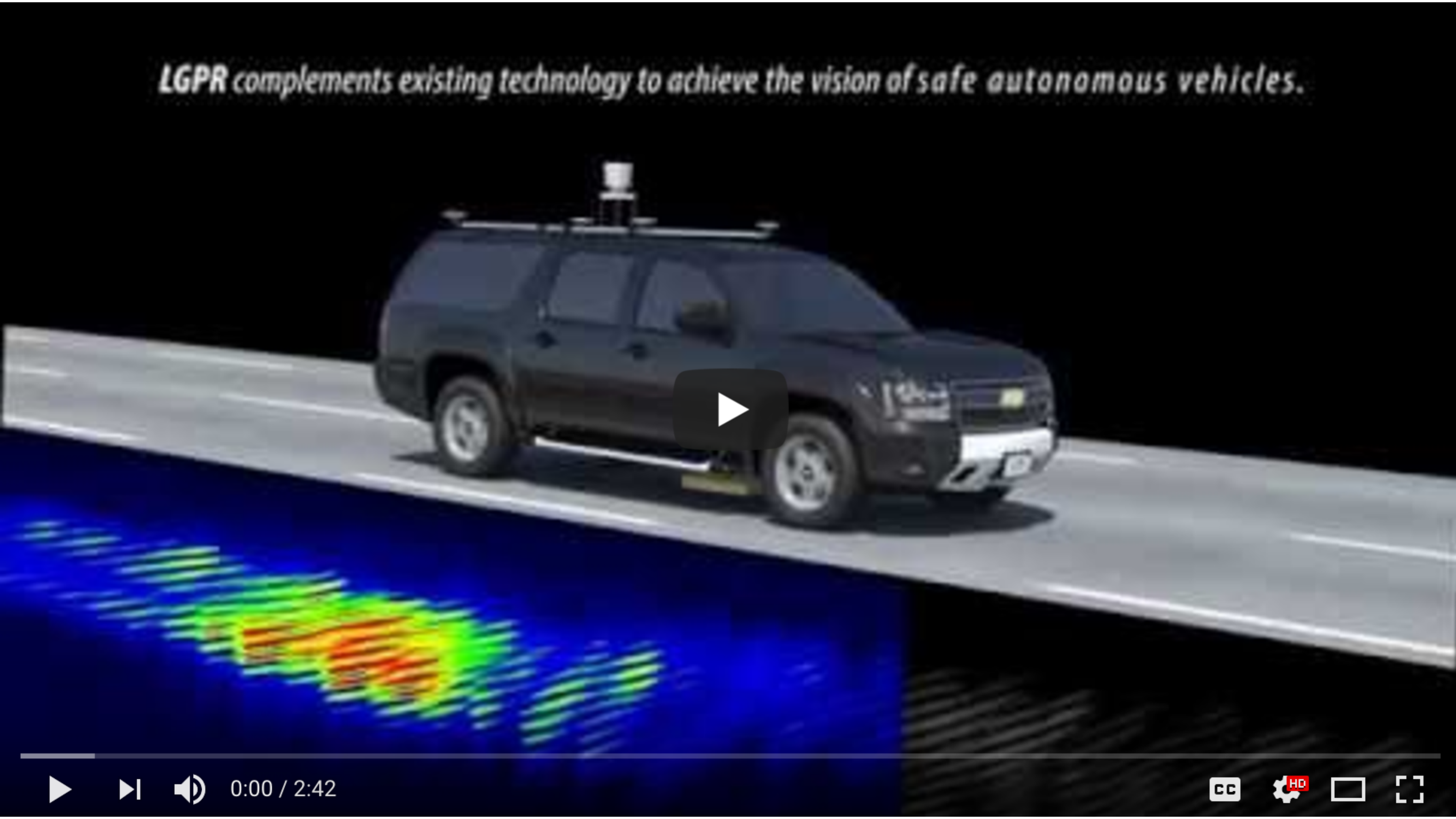
- Collect reference GPR data on clear day
- Store reference data set

Localizing Ground Penetrating Radar



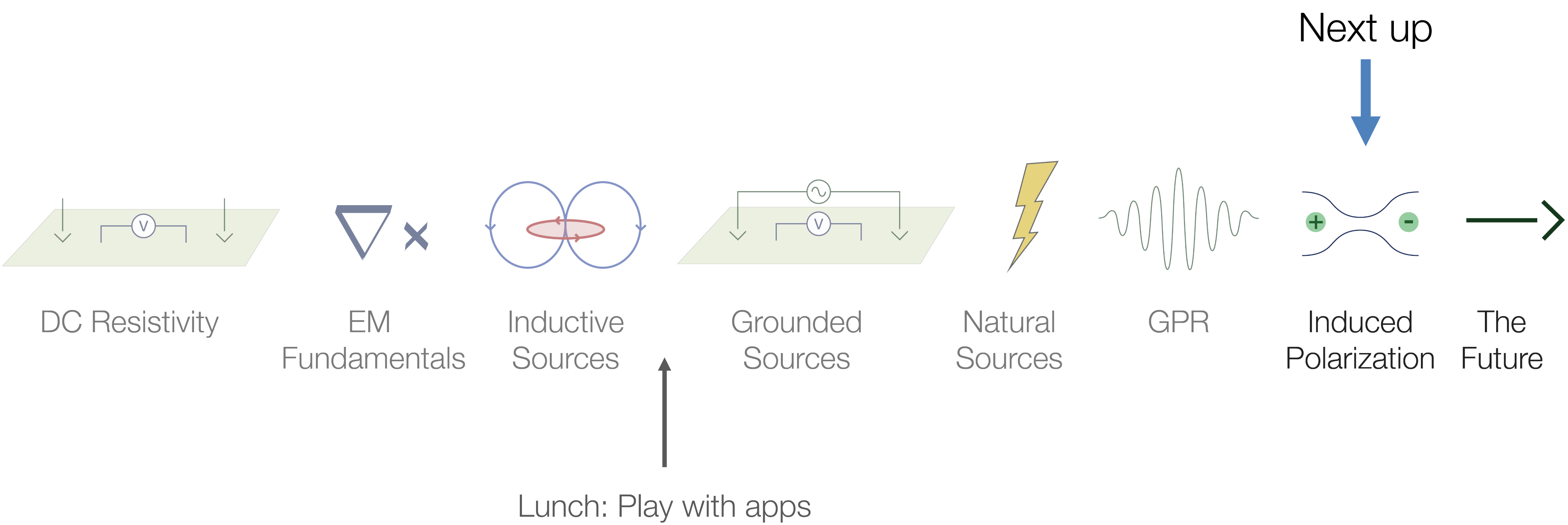


Cross correlate real-time data with reference data to find location



https://youtu.be/rZq5FMwl8D4?t=20s

End of GPR



Next up
DC Resistivity
EM Fundamentals
Inductive Sources
Grounded Sources
Natural Sources
GPR
Induced Polarization
The Future
Lunch: Play with apps