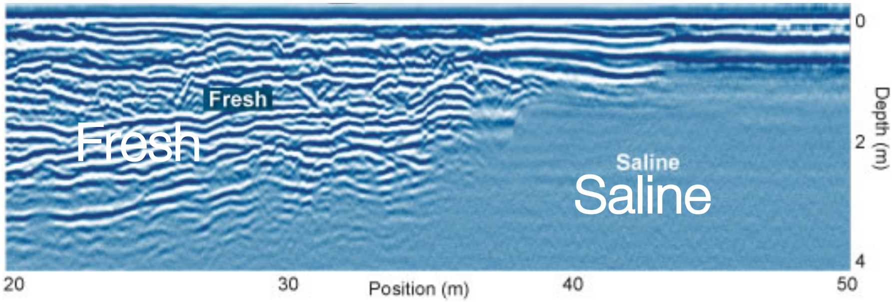
Ground Penetrating Radar

GeoSci.xyz

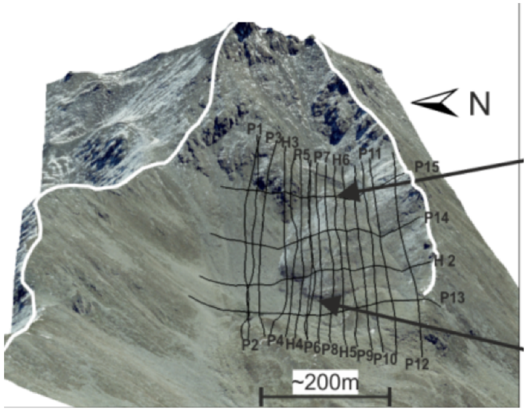
Motivation

Sink holes

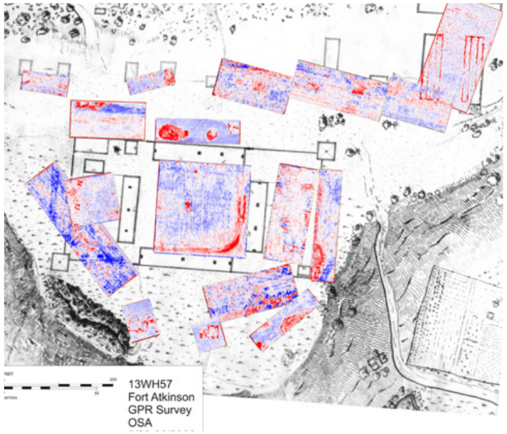
Salt Water Intrusions



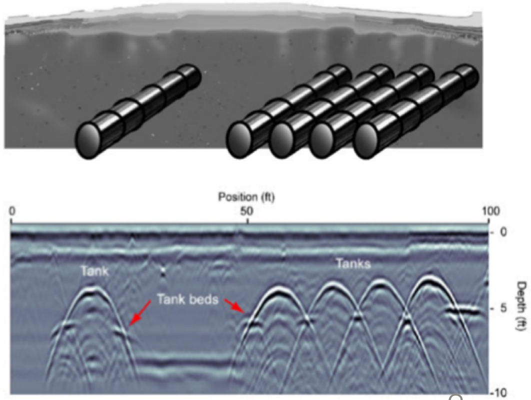
Rock glacier



Archeology



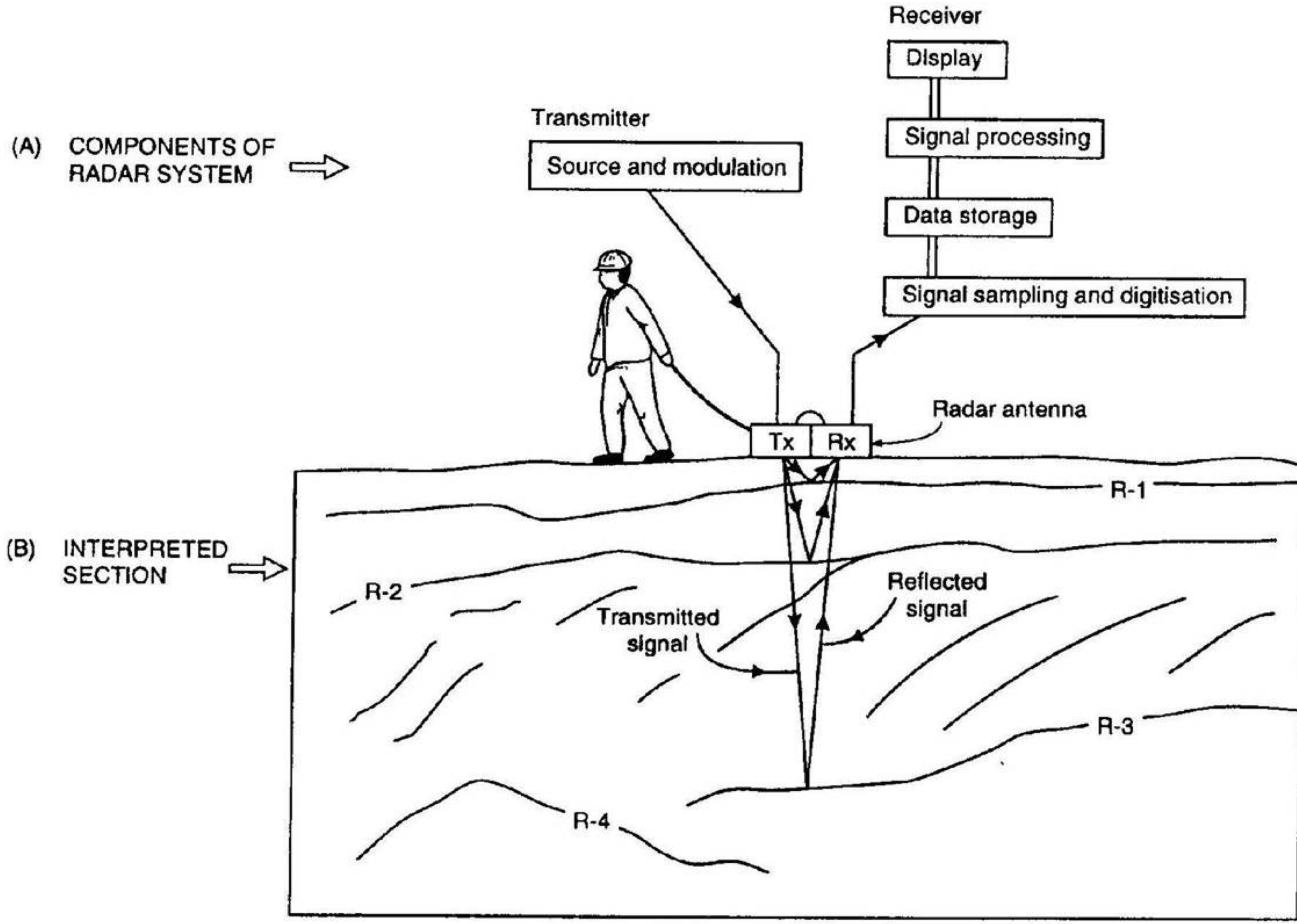
Underground tank



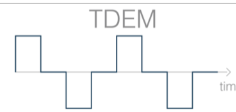
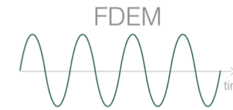
Outline

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

Basic Experiment



Basic Equations

	Time 	Frequency 
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

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

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

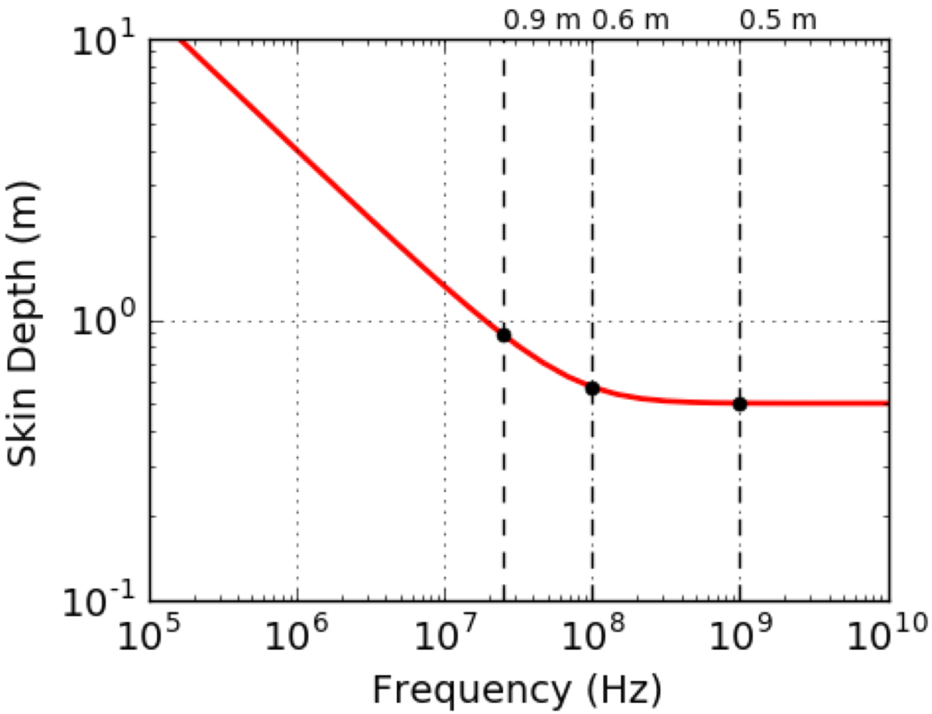
* Same equation holds for E

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

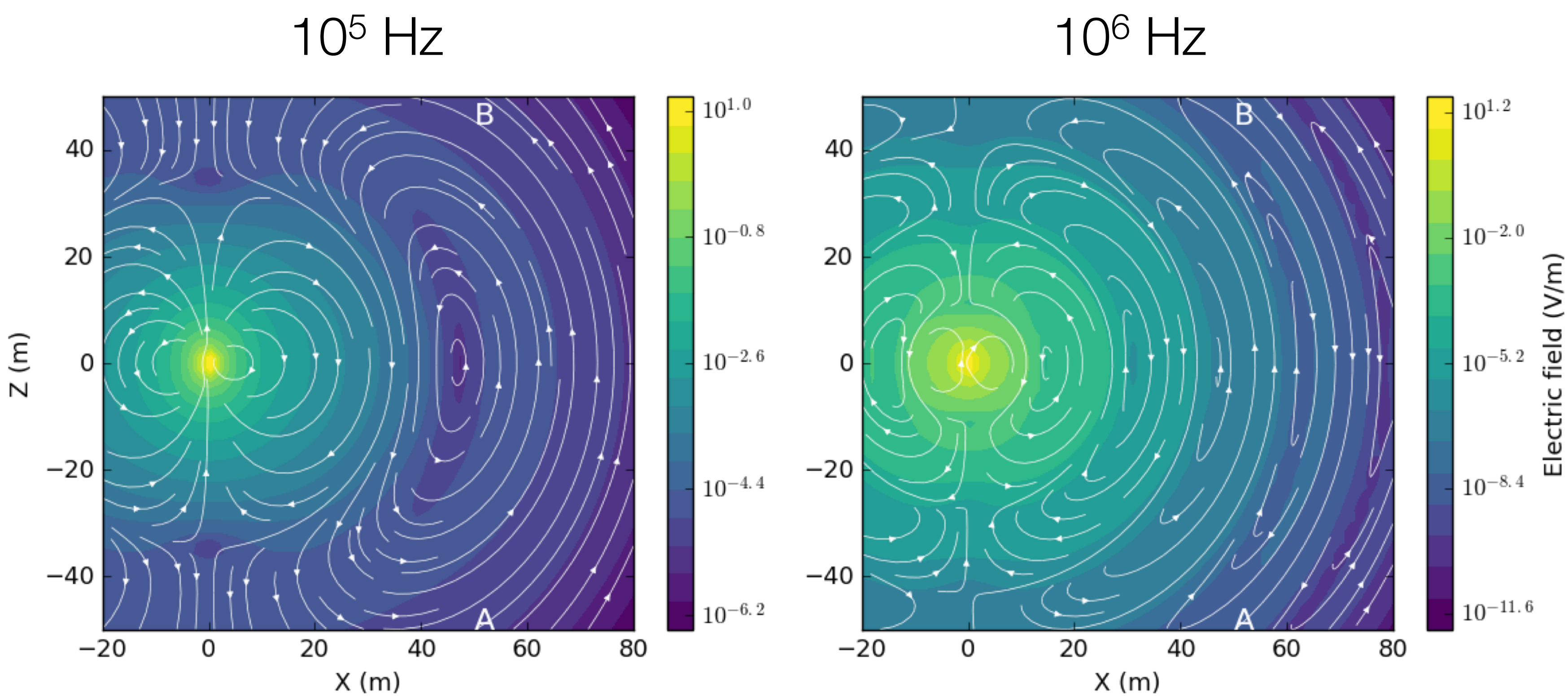
Attenuation: Skin Depth



δ : skin depth

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

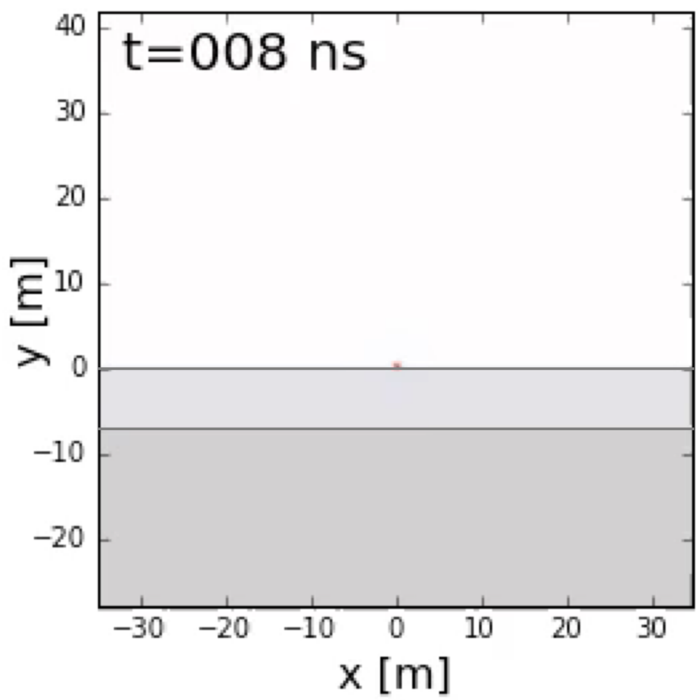
Electric Dipole in a Whole Space

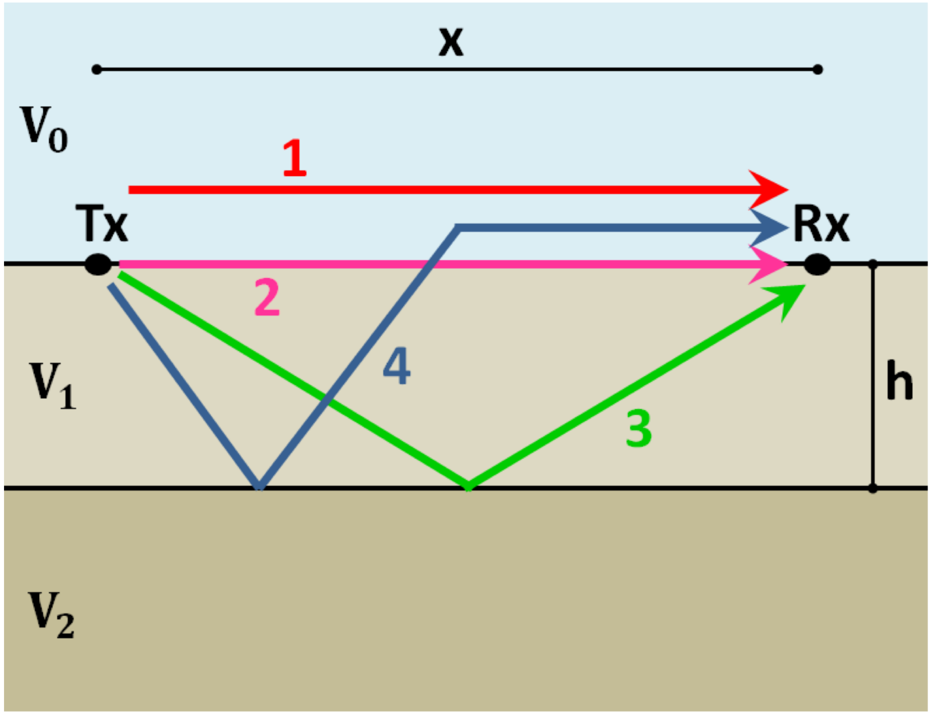


$$\lambda = \frac{v}{f}$$

Waves and Rays

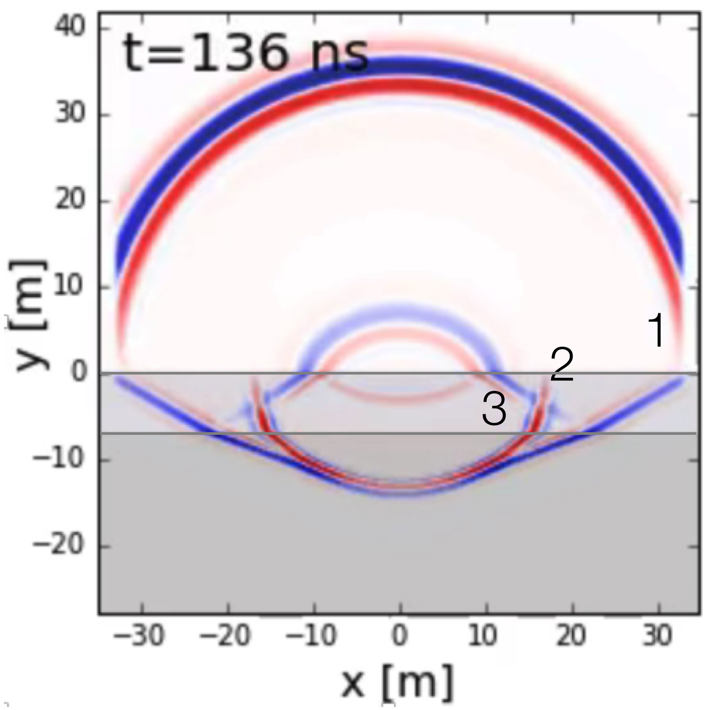
$$v = \frac{c}{\sqrt{\varepsilon}}$$

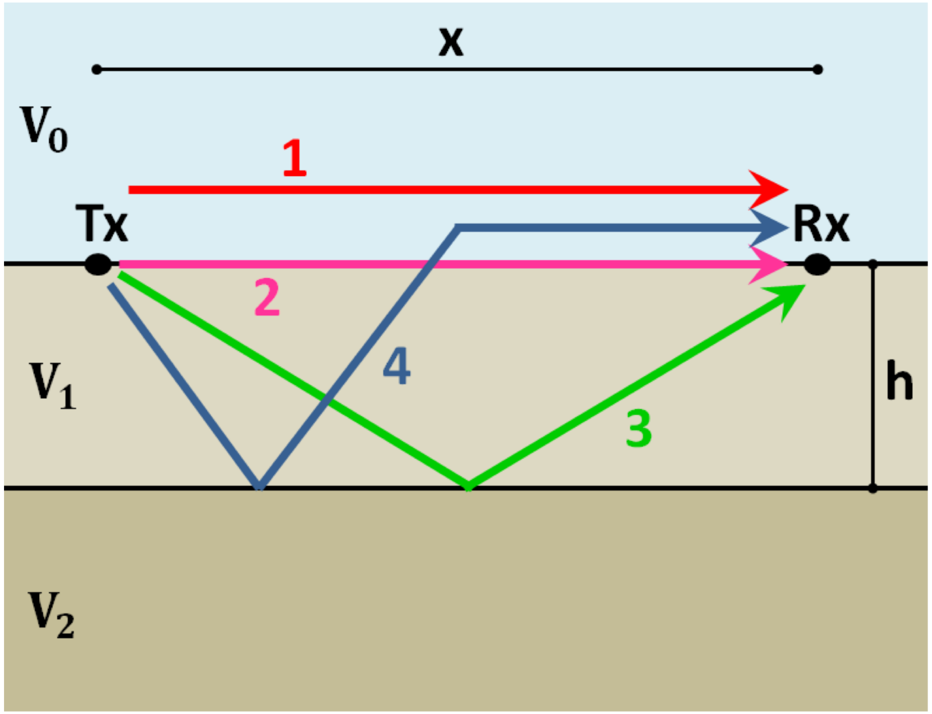




Waves and Rays

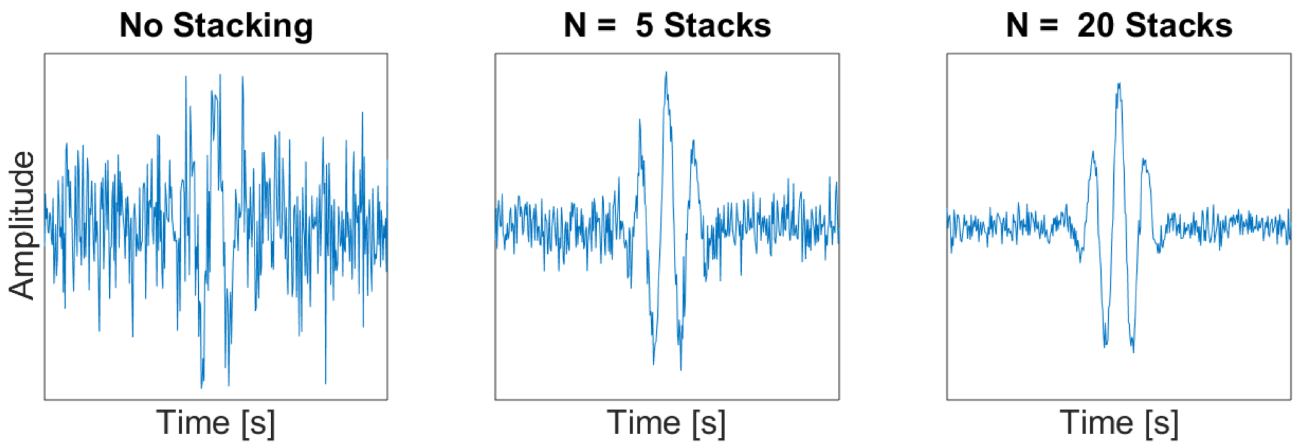
$$v = \frac{c}{\sqrt{\varepsilon}}$$



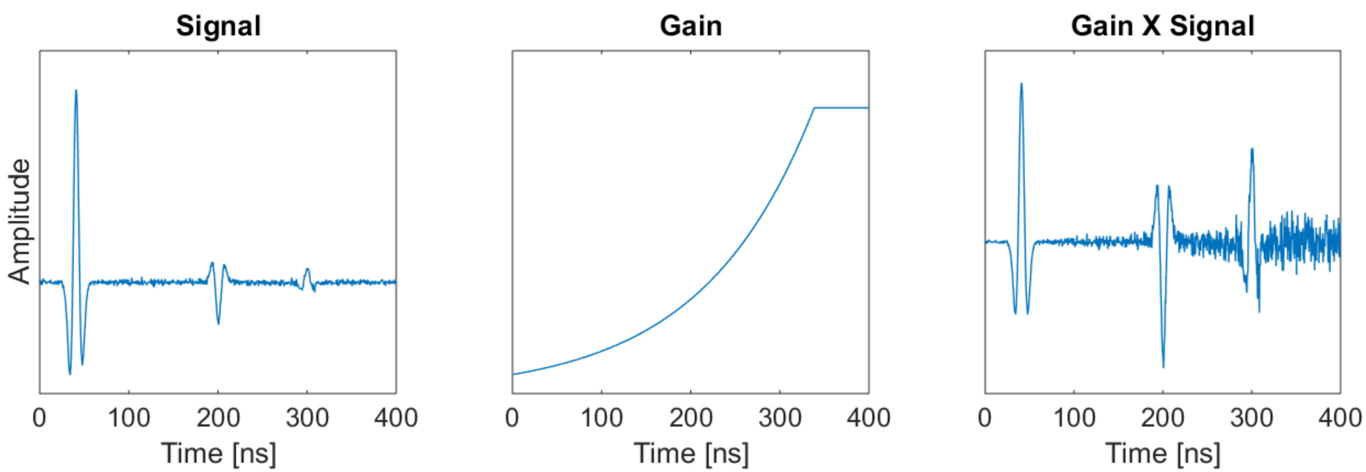


Processing

Stacking

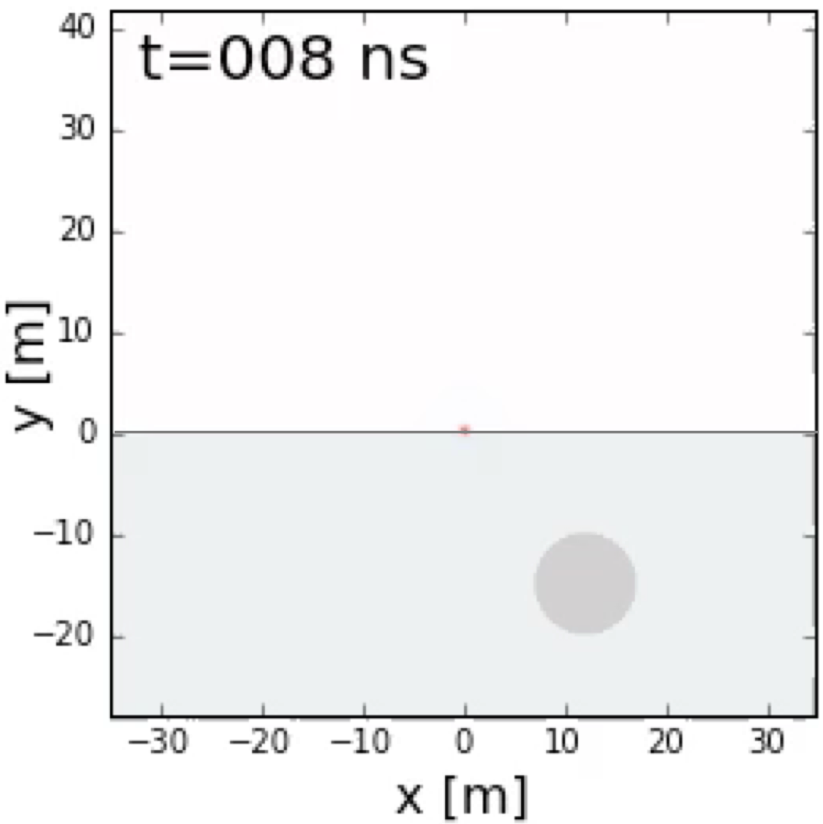


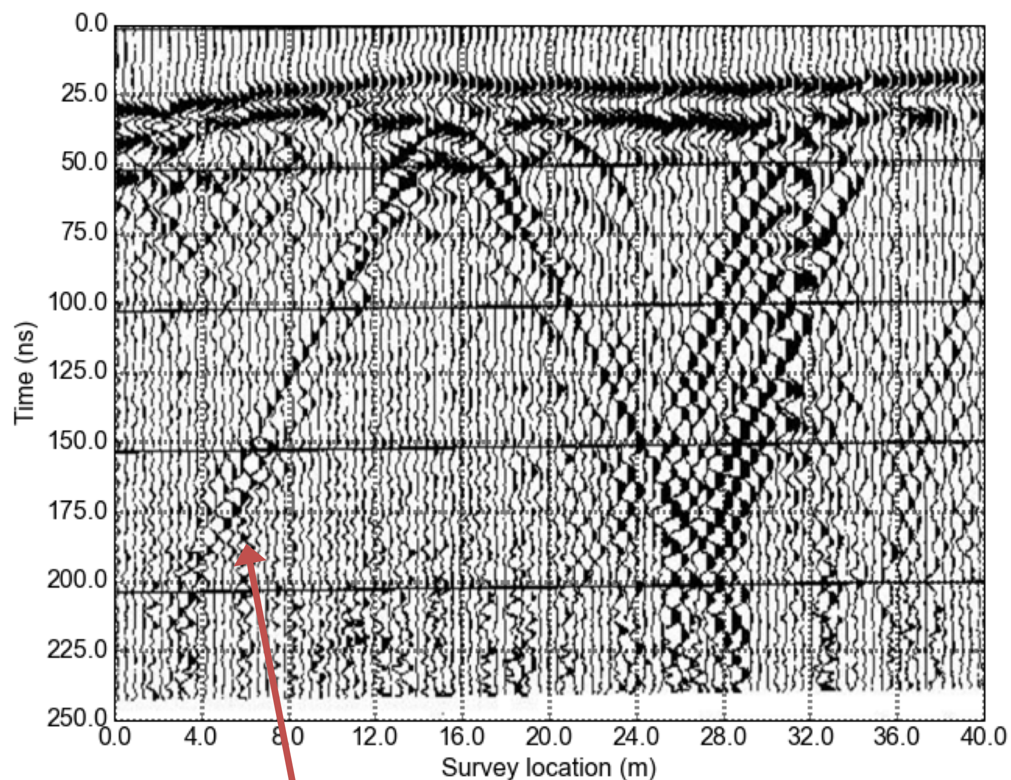
Gain Control



Radargrams

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

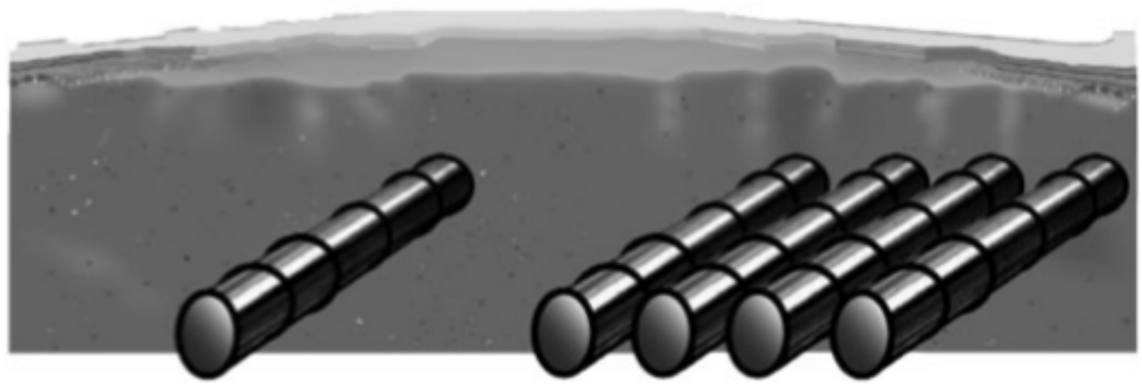


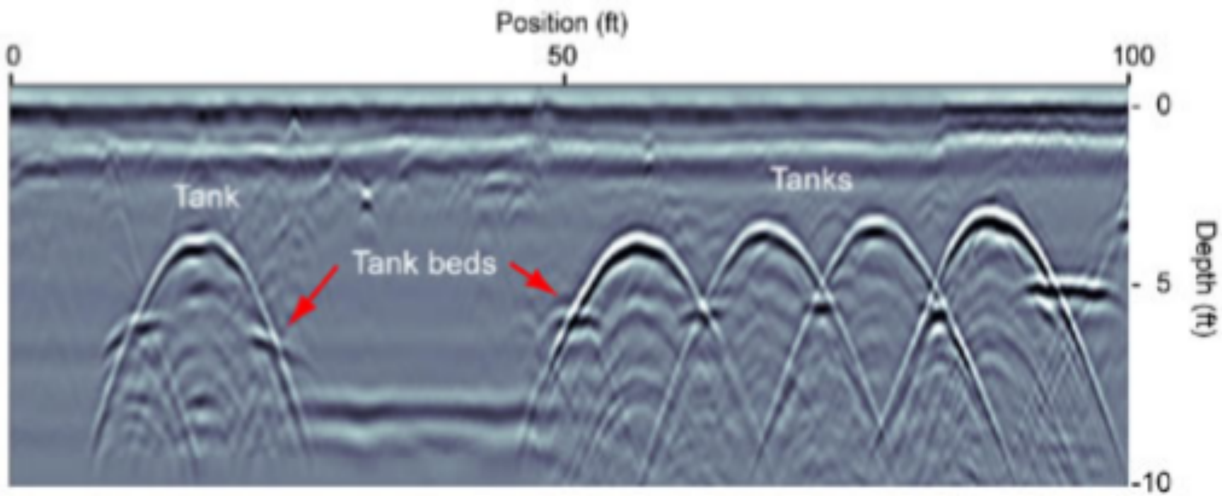


Hyperbola

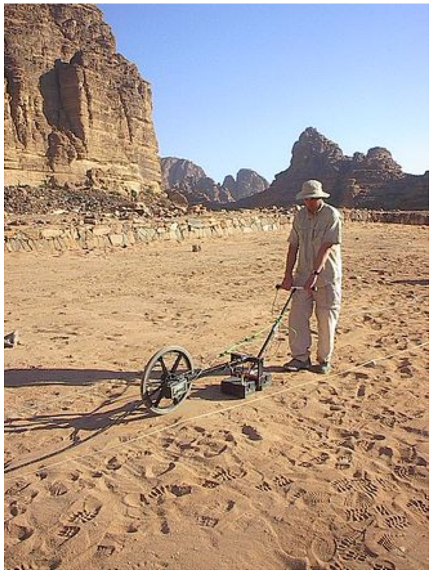
slope ~ 2/v

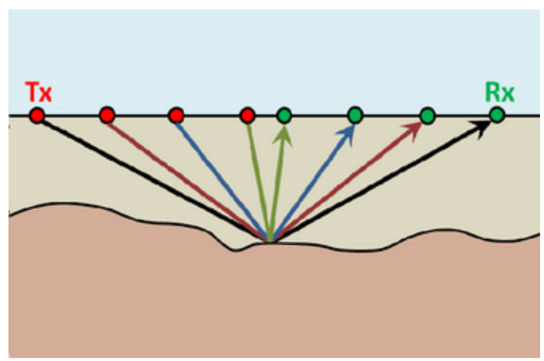
Radargrams



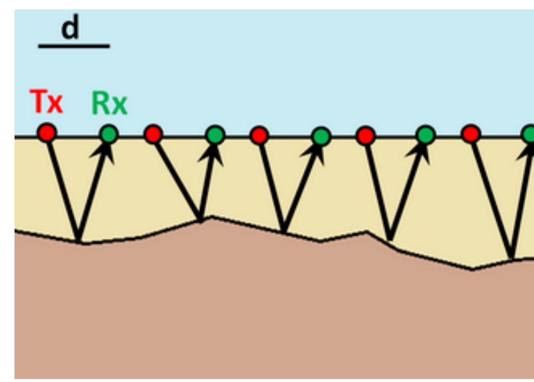


GPR systems





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?

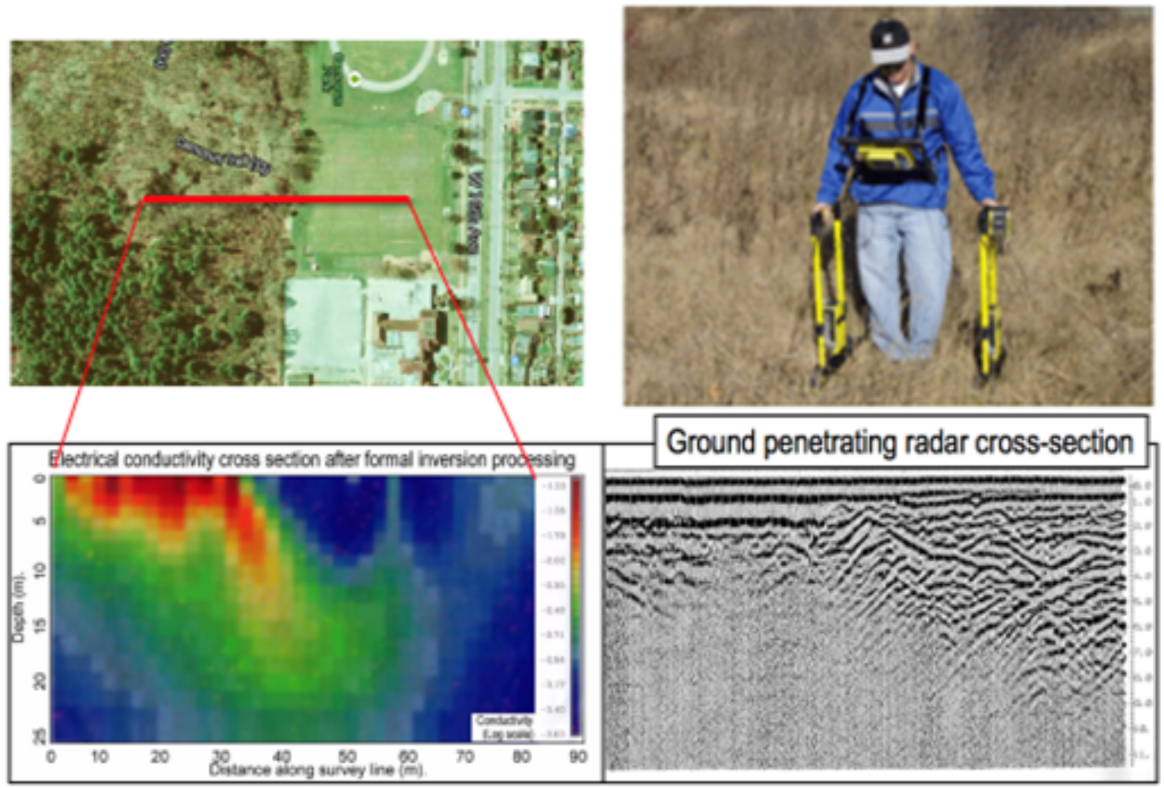
- Dielectric permittivity varies with
  - Water content
  - Lithologies

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

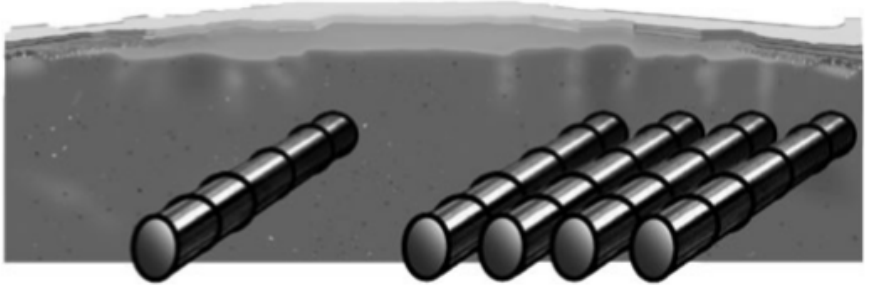


Fig. Geophysical problem

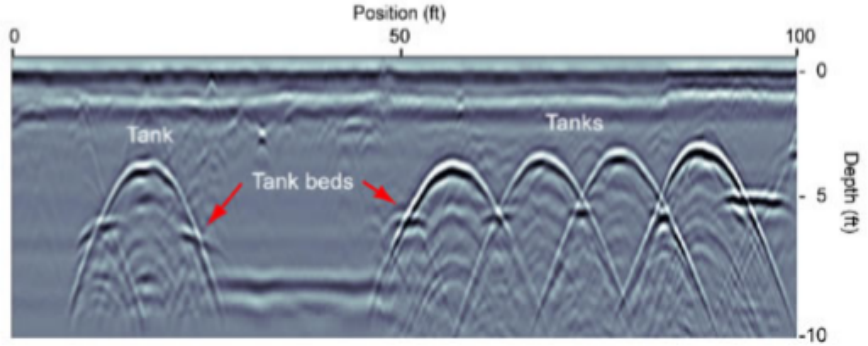


Fig. 2D Radargram profile perpendicular to storage tanks

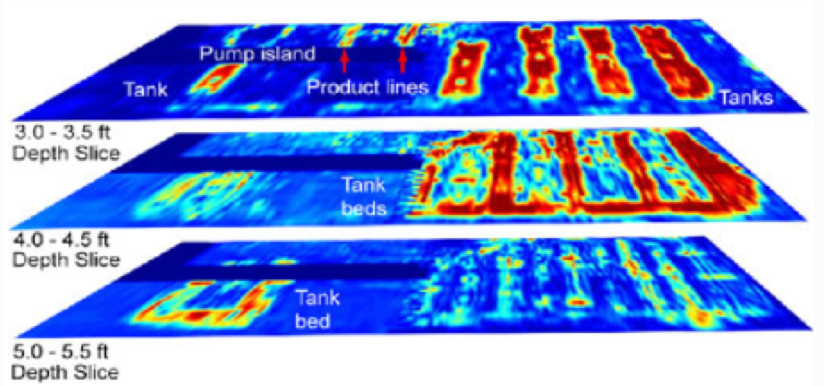


Fig. 129 3D interpolation from several GPR survey lines.

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

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

Mapping Peat Thickness

Problem

- Estimate peat thickness

Why use GPR?

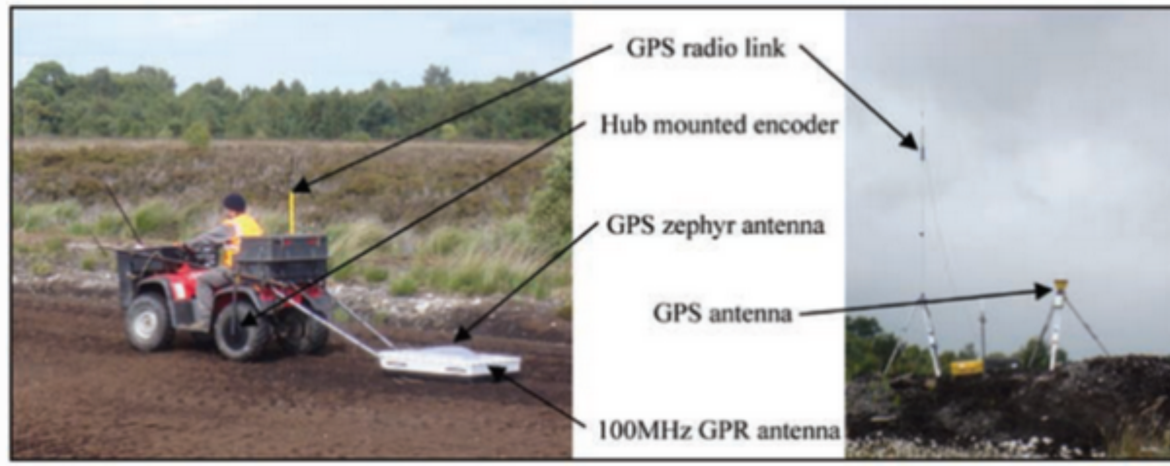
- Strong reflector at base of the peat

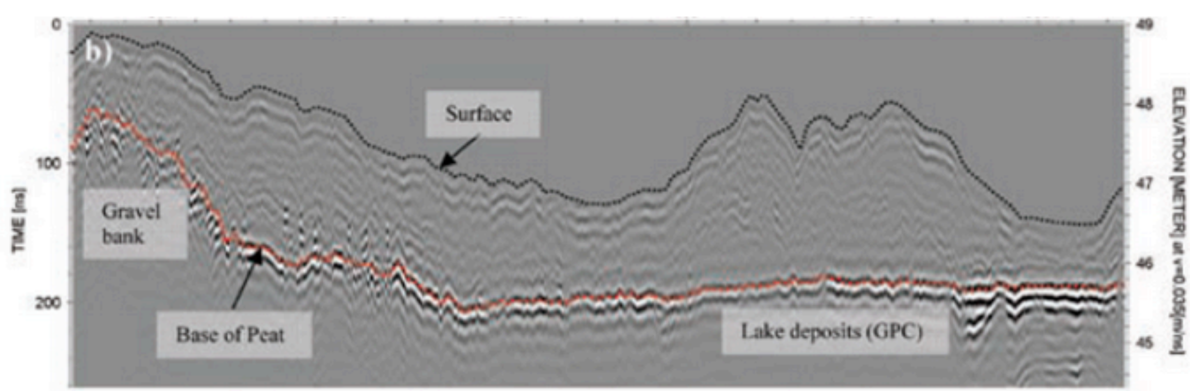
Survey and Data

- 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?

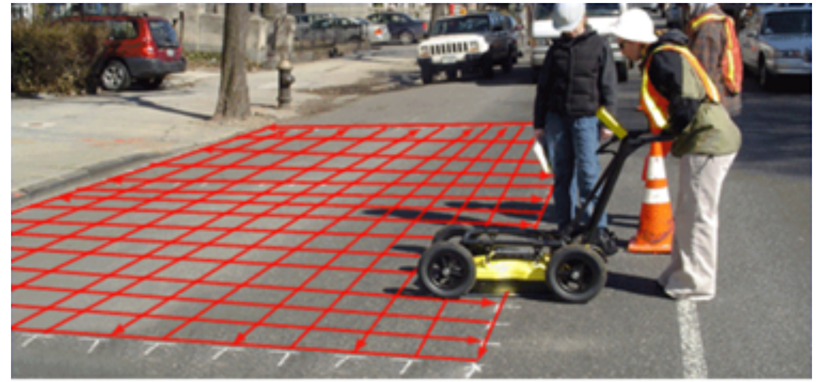
- Iron pipes very conductive → strong GPR reflector
- PVC v. low dielectric permittivity → GPR reflector

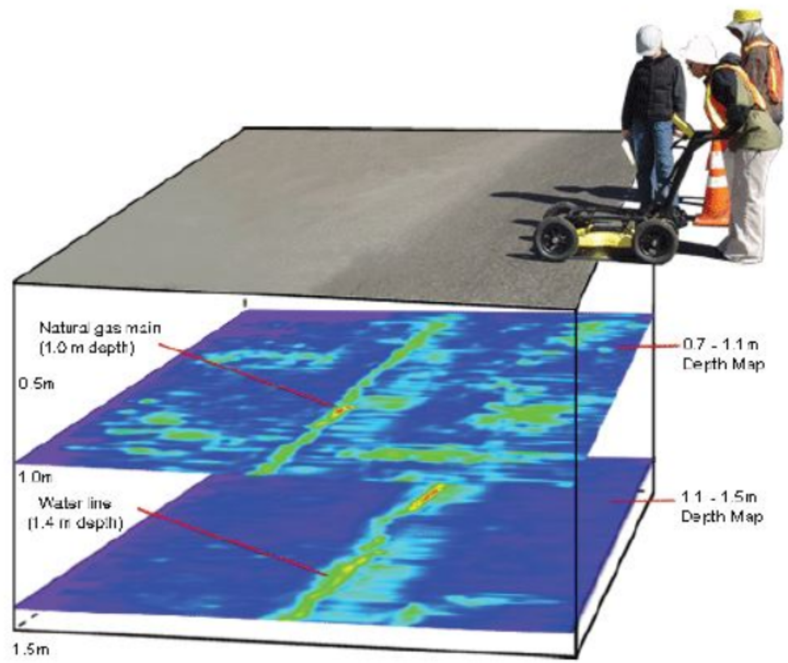
Survey and Data

- 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

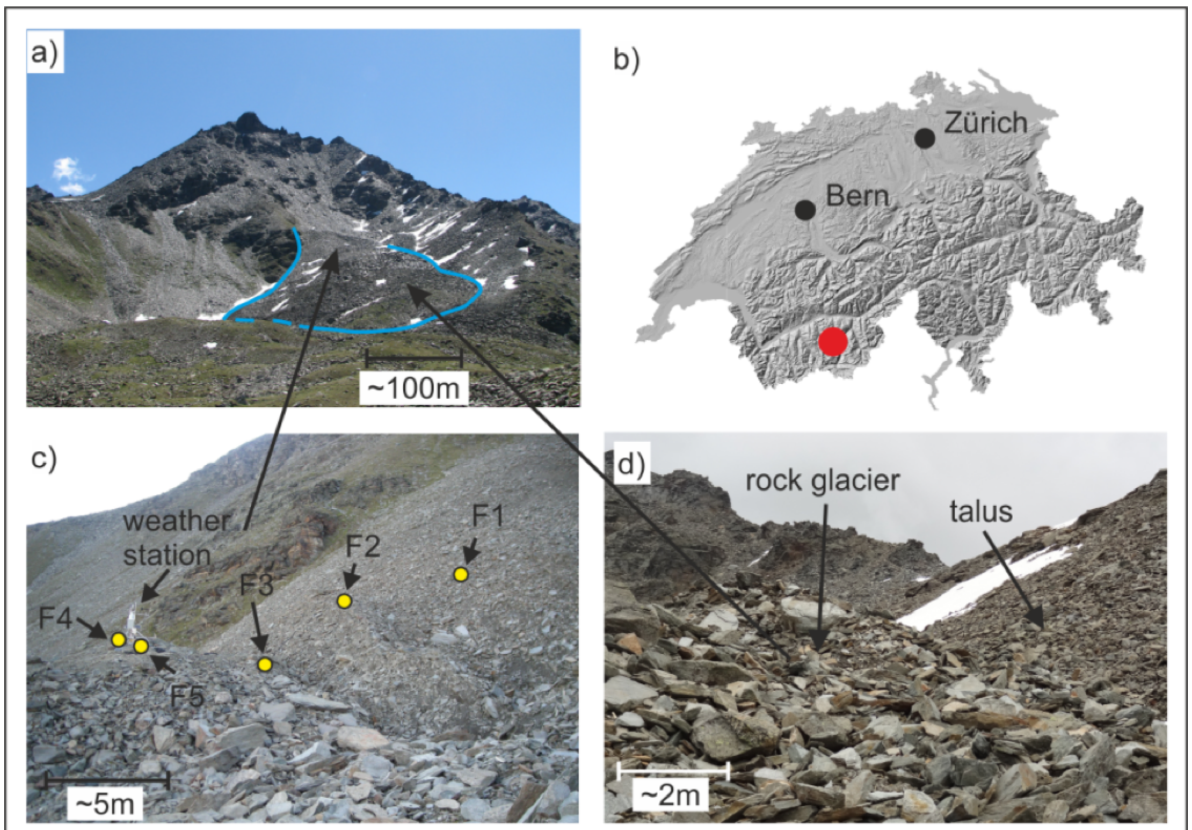
- Arrival time to depth conversion using velocity of 0.13 m/ns for anhydrites

Fig. Inflow problems in a mine

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

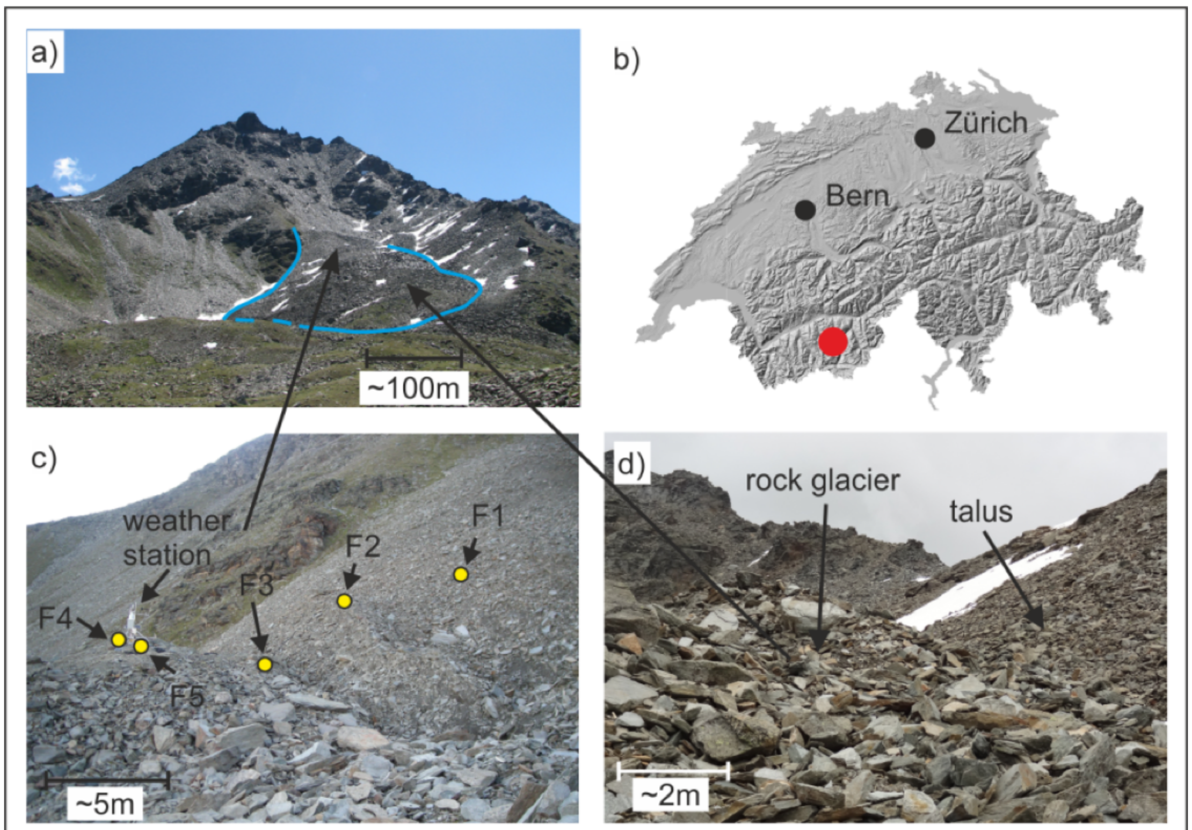
Case History: Furggwanghorn

Merz et al, 2015



Setup

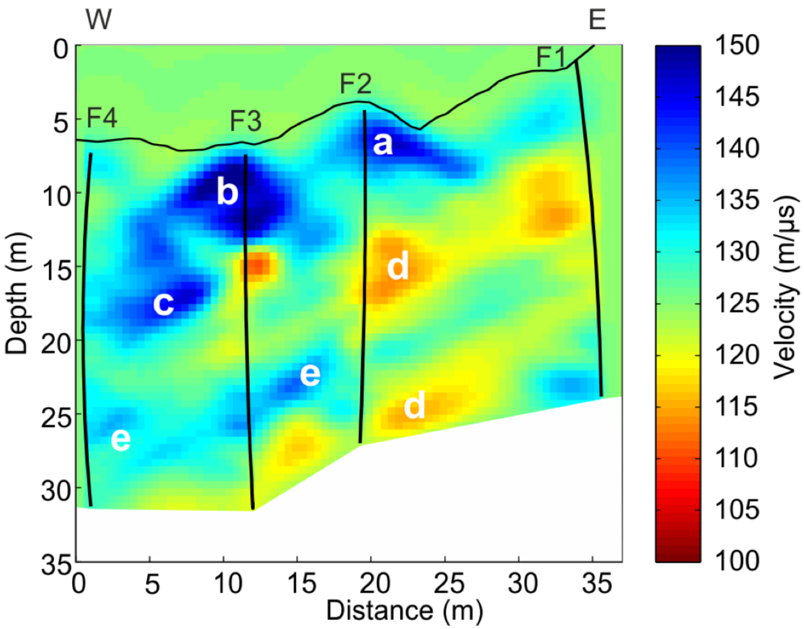
- Downslope movement shown to increase from 1.5 m/yr to 4.0 m/yr.
- Aim: characterize rock units and evolution of glacier
- Surface GPR: unsuccessful (too close to scatterers)
- Helicopter GPR used



Properties

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

Velocity from cross well GPR

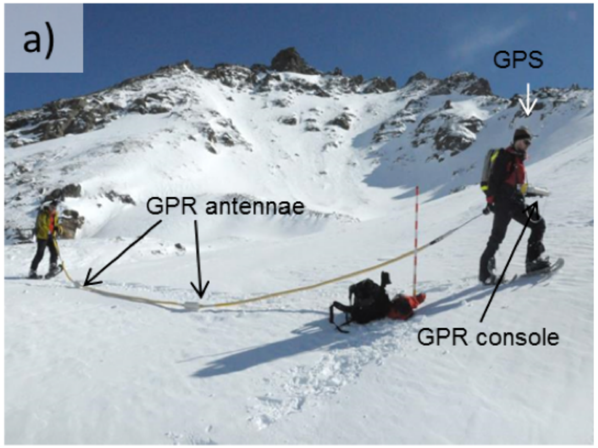


Material	Velocity ($\mathbf{m/\mu s}$)
(a & b) Unconsolidated sediments	> 140
(c) Ice	> 140
(d) Ice + partial melt	110 - 130
(e) Compact debris	130 – 140
Saturated sediments	80 -100
Bedrock	110 -130

Survey

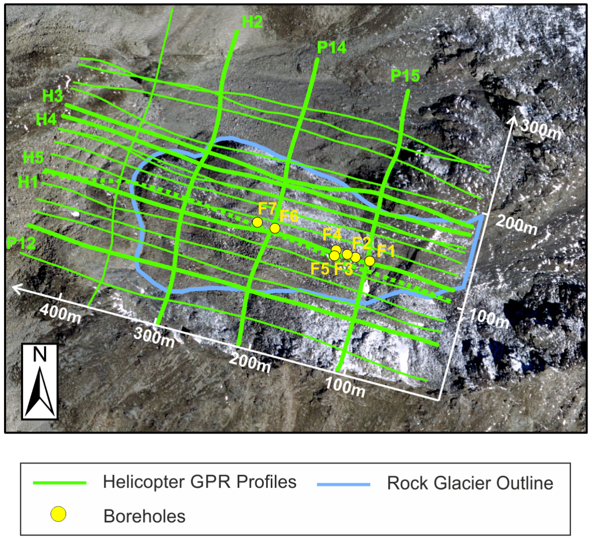
- Initial Ground-Based Survey
  - 2 systems
  - Frequencies: 25 MHz and 50 MHz
- Heli-GPR
  - Frequency: 60 MHz
  - Flight height: 15-20 m
  - Line separation ~15 m

Ground-GPR

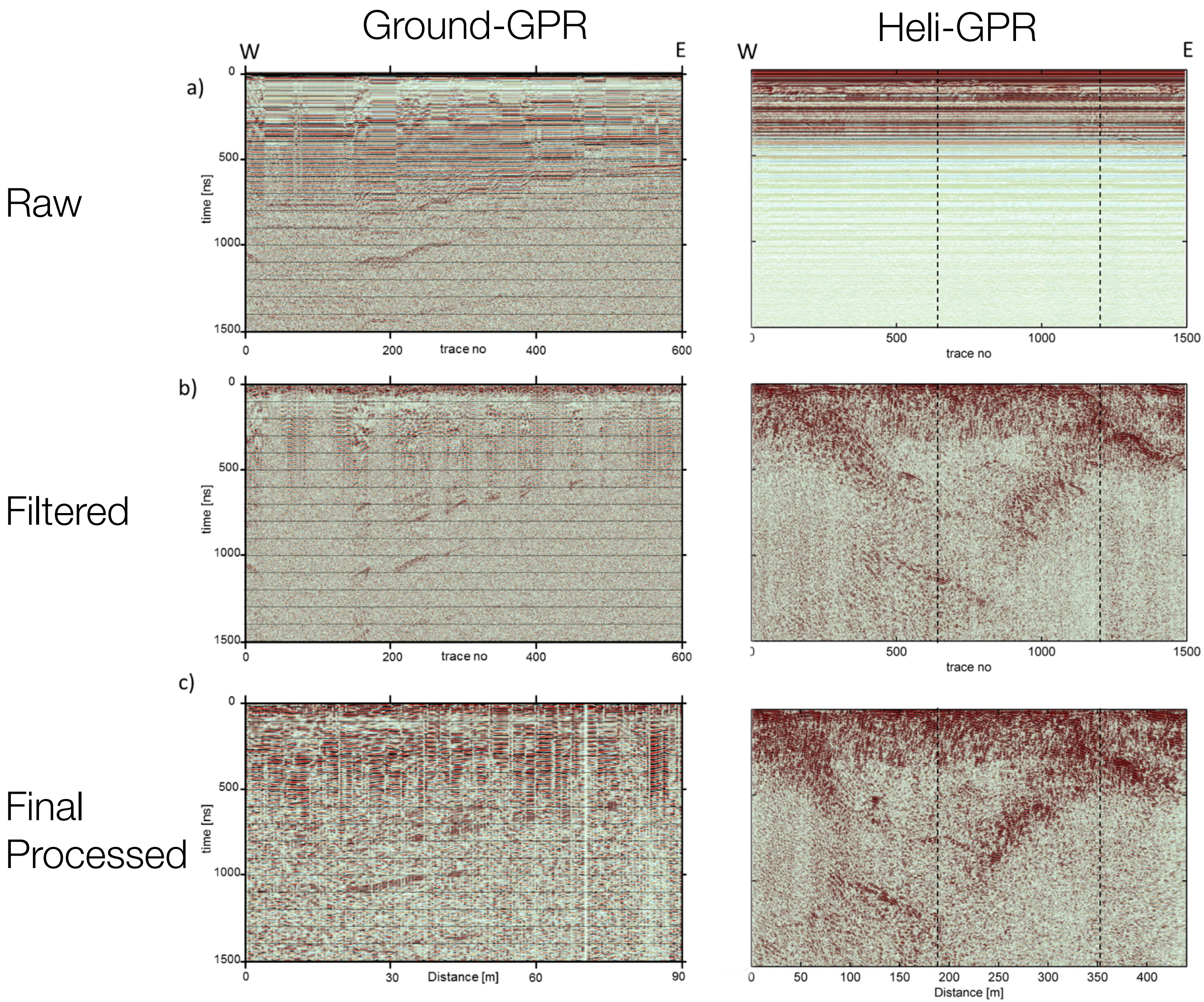


Heli-GPR

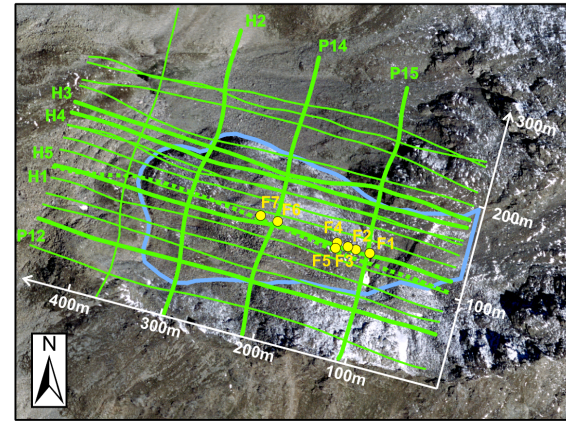
Survey lines



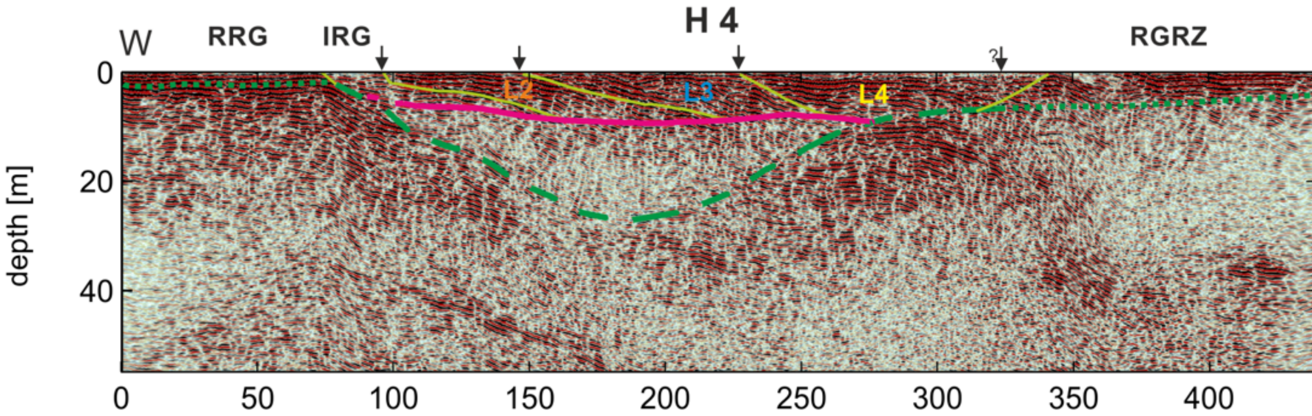
Data and Processing



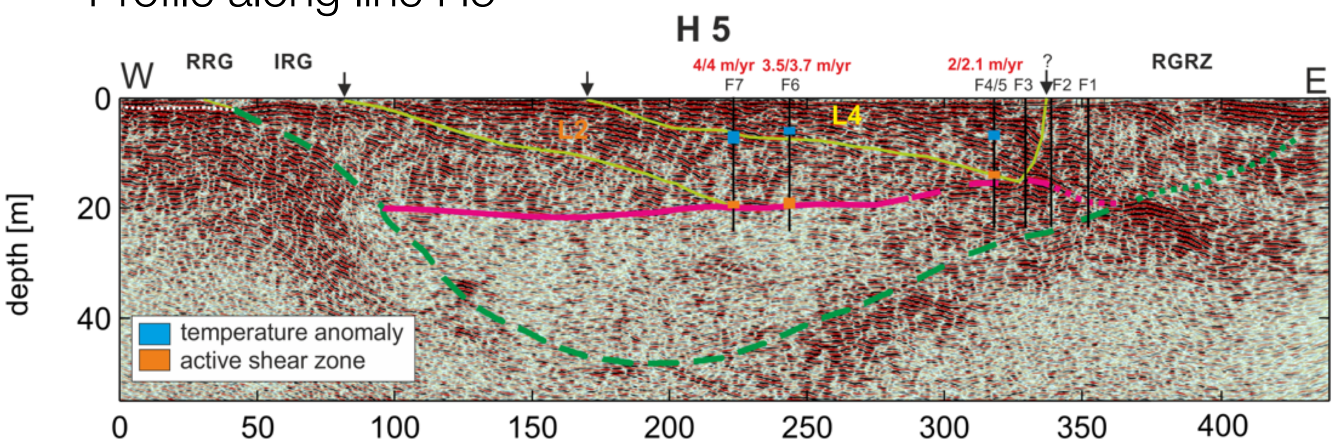
Interpretation



Profile along line H4



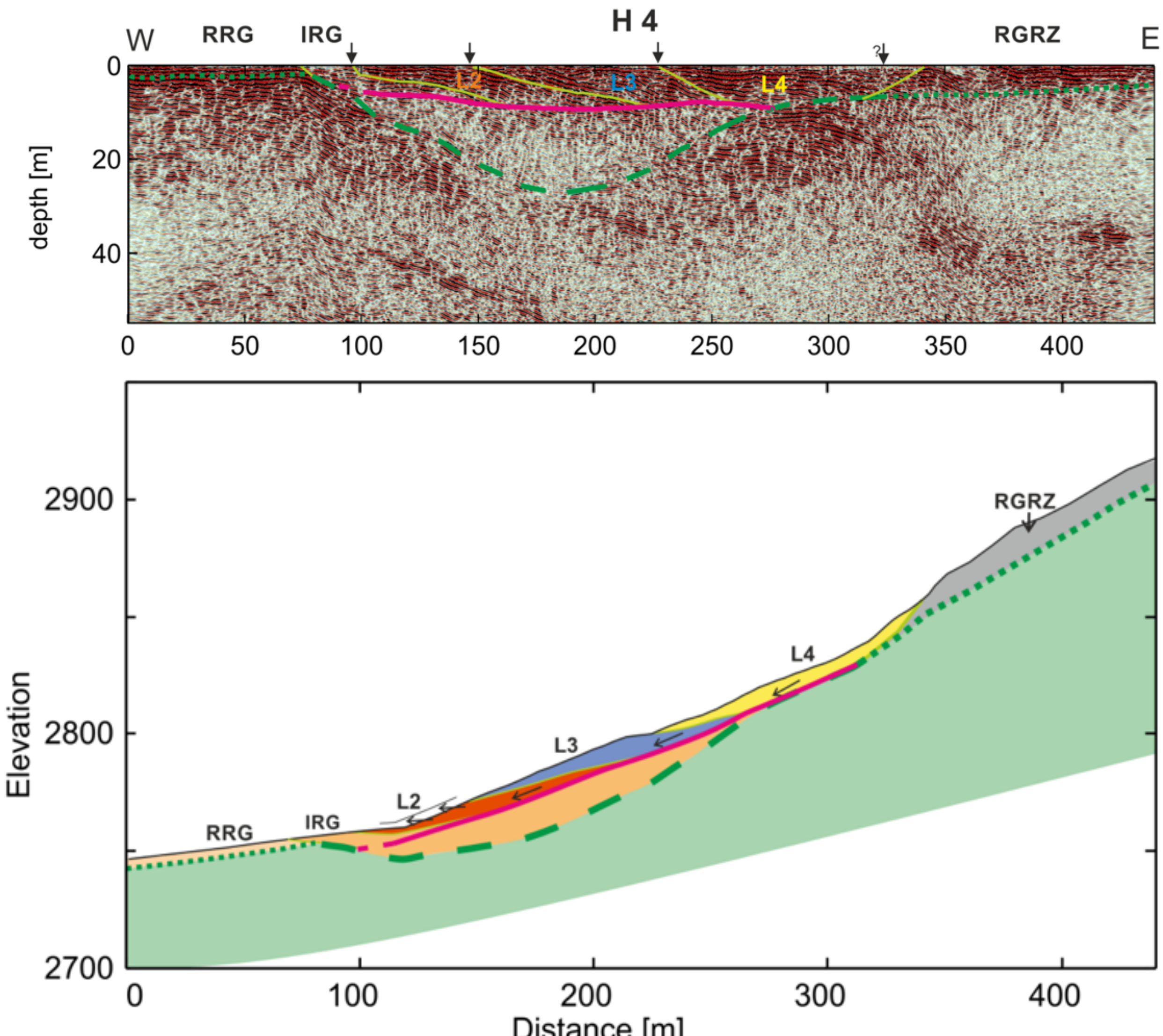
Profile along line H5



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

Synthesis

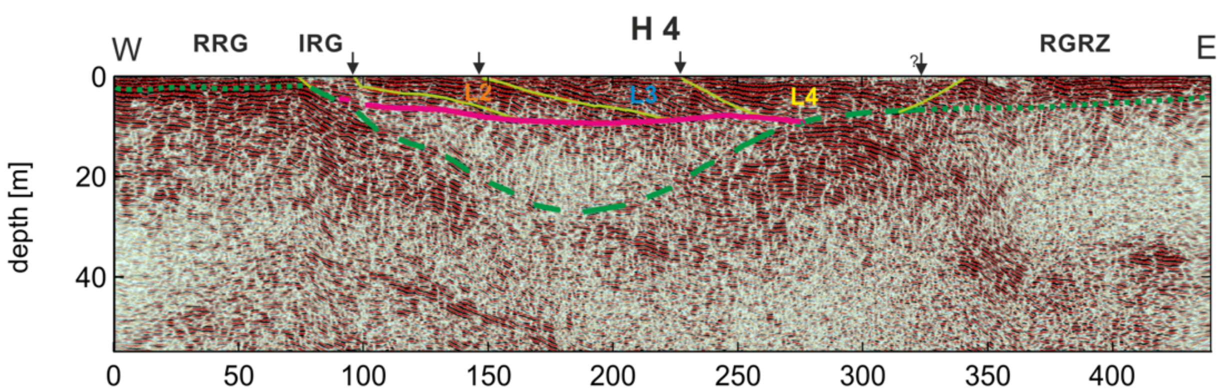
Final Structural and Kinematic Model



- 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

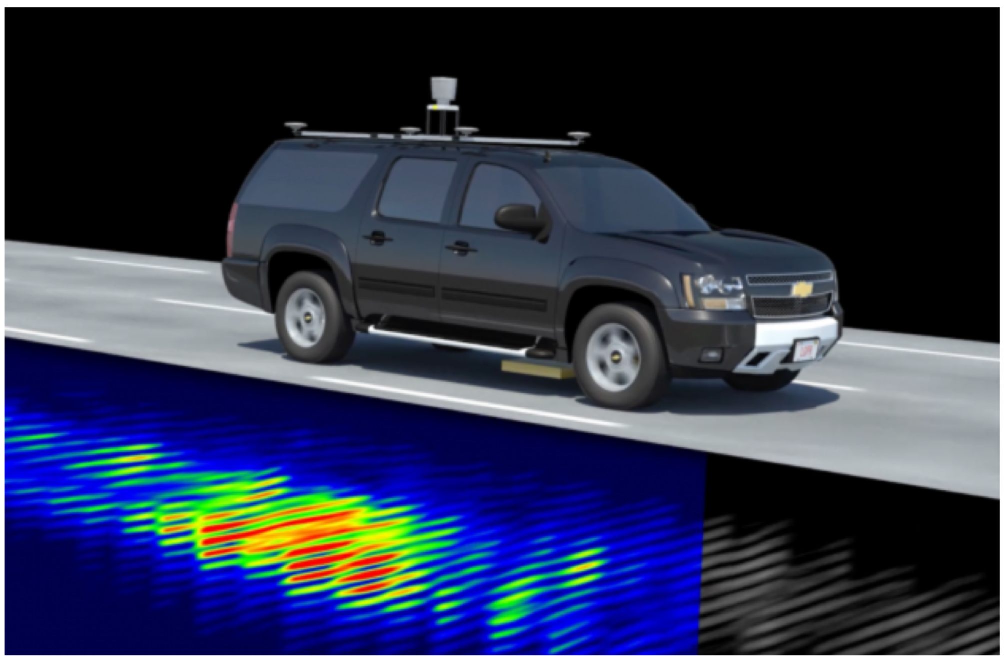
Summary

- 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, 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

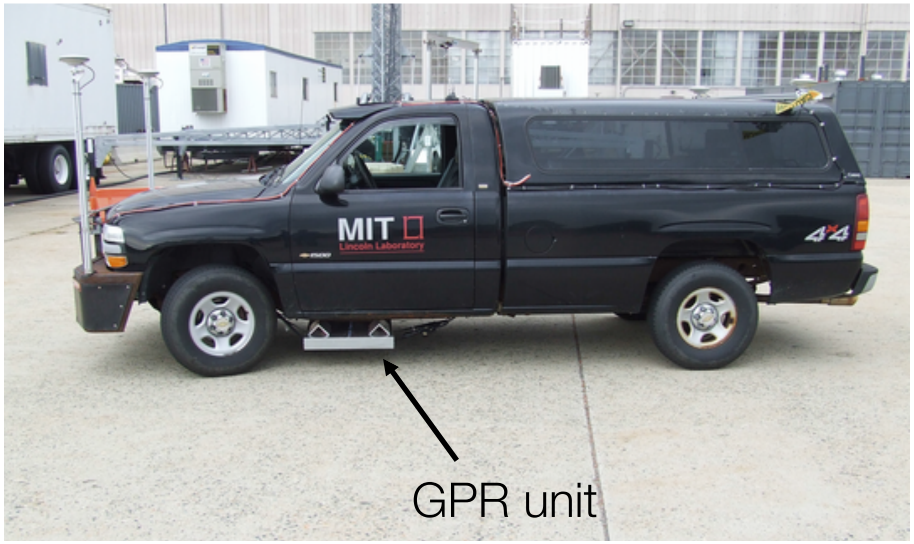
• Work fine in good weather

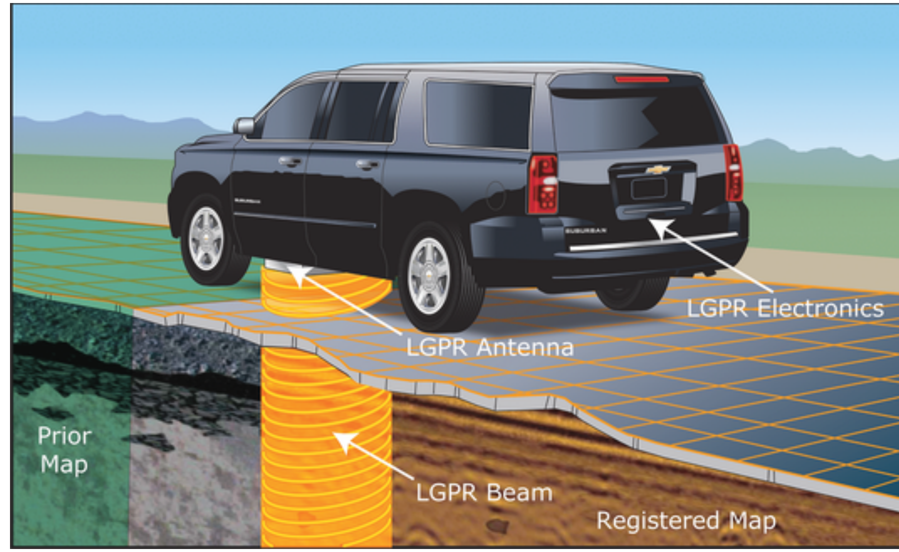
What happens when

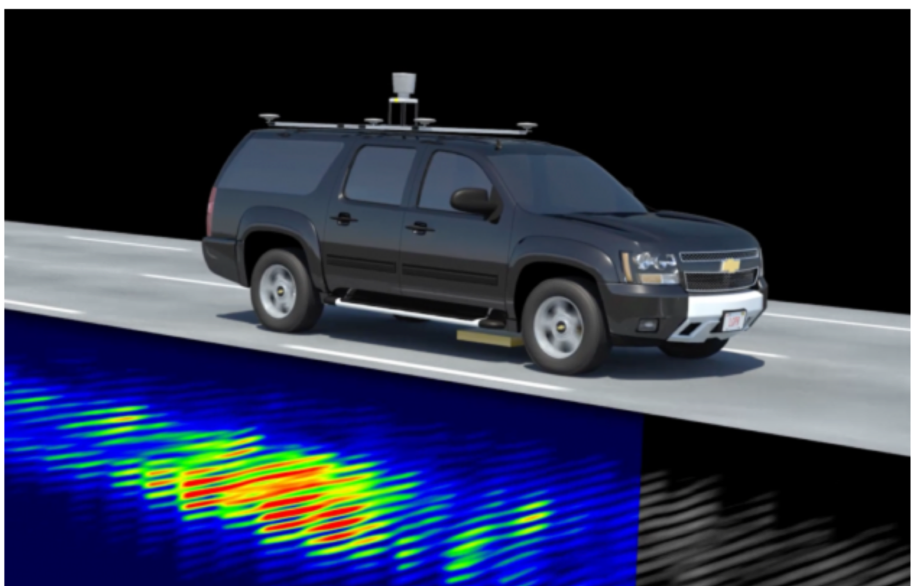
• Bad weather
  - rain, snow, sleet, fog, …
• Changes
  - signs, road stripes, vegetation, …

Need additional sensor data

Localizing Ground Penetrating Radar

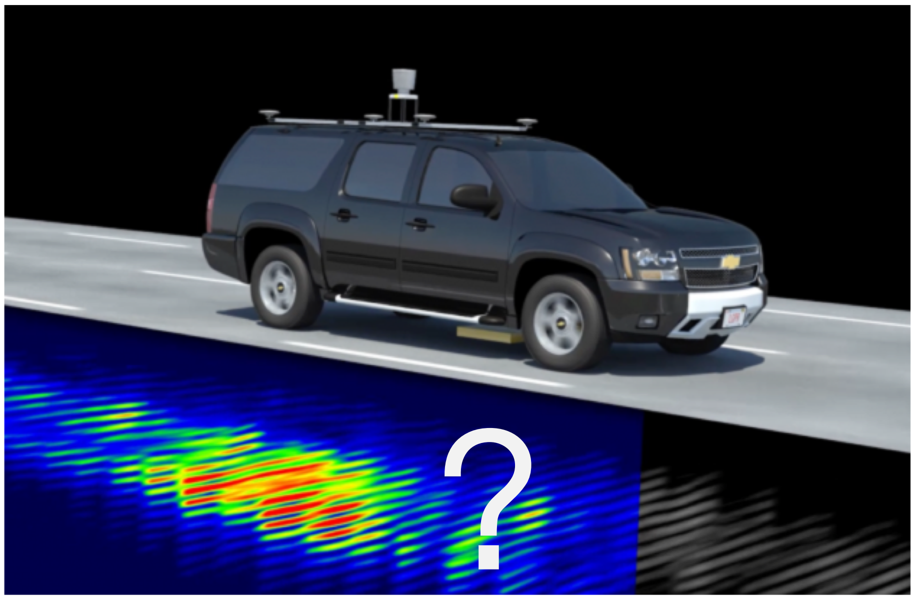


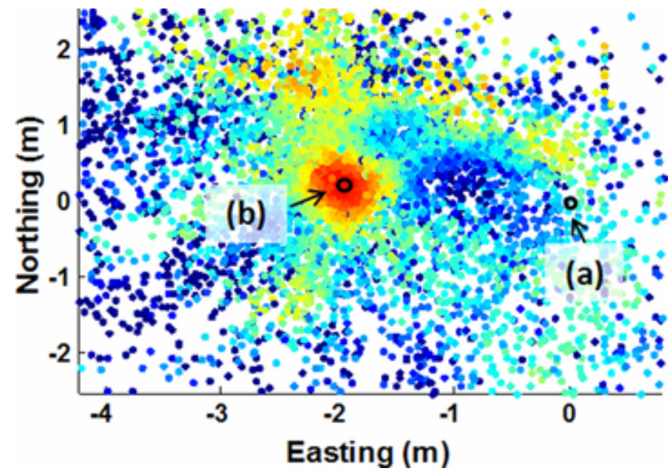




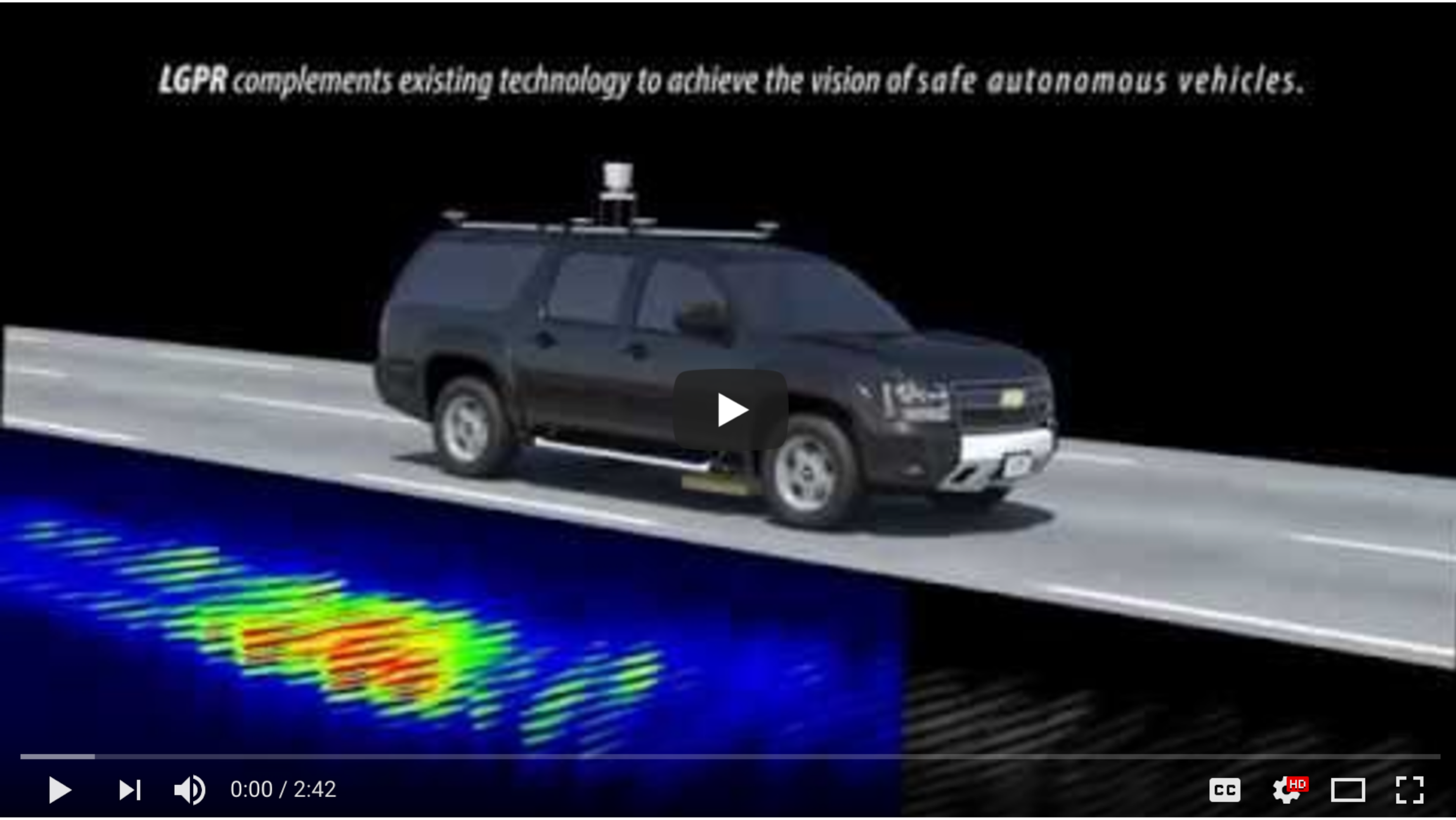
- Collect reference GPR data on clear day
- Store reference data set

Localizing Ground Penetrating Radar



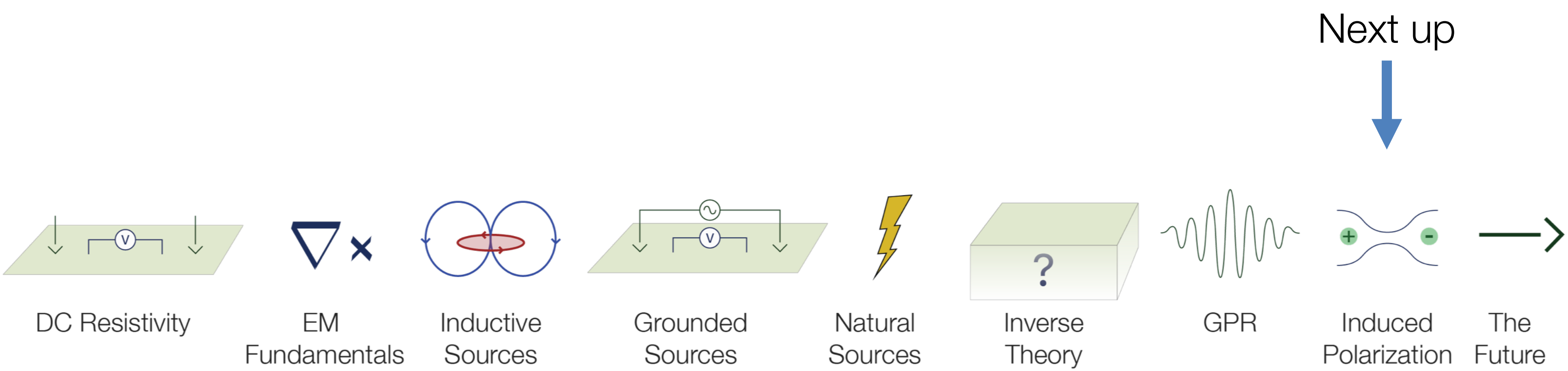


Cross correlate real-time data with reference data to find location



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

End of GPR



Next up
DC Resistivity
EM Fundamentals
Inductive Sources
Grounded Sources
Natural Sources
?
Inverse Theory
GPR
Induced Polarization
The Future